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Report 223

Jura-Cretaceous Success Formation and Lower Cretaceous Mannville Group of Saskatchewan

J.E. Christopher

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Cover:

Clearwater River Valley at Contact Rapids (1.5 km south of latitude 56°45'; latitude 109°30'), Saskatchewan. View towards the north. Scarp of Middle Devonian Methy dolomite at right. Dolomite underlies the Lower Cretaceous McMurray Formation outcrops recessed in the valley walls.

Photo by J.E. Christopher.

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Recommended Citation:

Christopher, J.E. (2003): Jura-Cretaceous Success Formation and Lower Cretaceous Mannville Group of Saskatchewan; Sask. Industry and Resources, Report 223, CD-ROM.

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Foreword

This report, the first on CD to be released by the Petroleum Geology Branch, describes the geology of the Success Formation and the Mannville Group wherever these units are present in Saskatchewan. It combines the results of more than thirty years of detailed and meticulous research with insightful interpretations based on lengthy experience with, and deep understanding, of Saskatchewan's Mesozoic stratigraphy and sedimentology. Its author, Dr. Jim Christopher, started his career with this department (then named Mineral Resources) in 1959, when he worked on the Upper Devonian Three Forks Group. Jim first focused his attention on problems of the Success and the Mannville in the late 1960s, his work culminating in the 1974 publication of "The Upper Jurassic Vanguard and Lower Cretaceous Mannville Groups of Southwestern Saskatchewan". In 1975, Jim was promoted to Directorship of the Saskatchewan Geological Survey. Upon his retirement in 1987, he returned to full-time studies of the Success and Mannville, largely in an emeritus capacity.

Completion of this long-awaited report has been complicated by the changeover from printing reports in conventional paper format to reproducing them as CDs in electronic form. As such, it is a pilot project, and we look forward to feedback from users telling us what works well and what problems require our attention. It is my particular expectation that this report, with its numerous maps, cross-sections, core descriptions, and related databases, will prove to be of great value to companies which are exploring for or developing oil and/or natural gas accumulations in the Success and the Mannville, or plan to do so. It also sets a high standard for other geoscientists working on Saskatchewan's Phanerozoic strata to follow. In closing, I congratulate Dr. Christopher and the report's production team for making this superb work so readily available to anyone who wishes to use it.

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April 2003*

Abstract

The unconformity-bounded Success Formation and its homologues are found in five non-contiguous regions in southern and central Saskatchewan, and are remnants of widespread kaolinitic and sideritic quartzose sandstone deposits, up to 120 m thick, that blanketed much of the Prairie Provinces in the Late Jurassic and Neocomian. They are survivors of the succeeding Aptian pre-Mannville erosion, to which the relief of the sub-Cretaceous erosion surface is generally attributed. These sandstone deposits include a significant chert component close to the Mississippian limestone exposures, and coal beds in the subsiding localities of southeastern Saskatchewan. The dominantly fluvial genesis of the Success sandstone yields to marine facies on the approaches to the Williston Basin.

The Mannville Group (restricted) comprises the Cantuar and Pense formations. The Cantuar Formation infills and covers a topography of valleys and terraces, the morphology of which is controlled by major structural blocks. These valleys were deepest across the Swift Current Platform of southwestern Saskatchewan, from where they radiated into major drainage systems west into Alberta, and east and northwest across central Saskatchewan into the McMurray basin of east-central Alberta. The formation forms a regional wedge, up to 240 m thick in the northwest, and comprises seven members (Dina, Cummings, Lloydminster, Rex, General Petroleum, Sparky, and Waseca). Quartzose sandstone, siltstone and mudstone, and subbituminous coal form broad lenticular and narrow linear bodies separated by hiatuses and erosional discontinuities. Hemicyclic sequences of grey-black shale, bioturbated shale and sandstone, and flasered and cross-bedded sandstone are widespread. The Cantuar basin underwent oscillatory marine transgressions, from the Clearwater–Grand Rapids basin of central Alberta into the Williston Basin, that were offset by progradations from the southwestern Rocky Mountain region. A significant regression culminated in deposition of the Sparky coal beds.

The generally marine Pense Formation overlies the Cantuar Formation on a planar disconformity, under which the latter is truncated to its base across the Punnichy Arch in east-central Saskatchewan. It represents a change of depocentre to one controlled by the Big Horn Basin of Wyoming and its extension north to a subsiding Swift Current Platform. In southwestern Saskatchewan, the formation comprises as many as four lithological units of black shale, bioturbated and flasered black shale, and quartzose sandstone, with capping, well-sorted, flat-bedded and cross-bedded quartzose sandstone. The upper units grade southeastward into shale, and are incorporated into the Joli Fou Formation of the Williston Basin. In central Saskatchewan, the marine-deltaic McLaren and Colony members are regarded as equivalents. Westward from the Swift Current Platform, the Pense is partially truncated under the shale of the Joli Fou Formation of the Colorado Group.

The Success-Mannville structural setting is delineated by the major Precambrian basement blocks, which changed the configuration of the depositional basin by vertical motion in opposition to and in conjunction with one another. Lineaments, comprising a north- and east-trending set and a northwest- and northeast-trending set, exercised subsidiary control.

There are some 65 Mannville oil pools distributed across the Lloydminster and Kindersley districts. The major ones occupy the floor of a northeasterly rising amphitheatre, but vary in elevation and are warped onto highs and into lows. These discordances are attributed to irregular downsets of the structural datum by sporadic removal of salt from the Middle Devonian Elk Point evaporite beds, and to congealing of the oil in place by biodegradation. In southwestern Saskatchewan, the less permeable Mannville rocks act as a reservoir seal to Success and Upper Jurassic Roseray pools at the updip ends of strata terminated at the sub-Cantuar unconformity. In southeastern Saskatchewan, Mannville oil is pooled in channel sandstone updip against the unconformity with the Jurassic. The northern natural-gas fields of west-central Saskatchewan extend north from Twp. 52 to 68 in a narrow belt between the Saskatchewan-Alberta boundary and Rge. 21, W 3rd Mer., and are mostly in upper Mannville (Waseca, McLaren, and Colony) progradational sandstone built out from the west into offshore, more argillaceous facies. They are enclosed on small structural terraces and anticlines and across narrow troughs, above the eastern, partially dissolved mass of the Lower Elk Point evaporite beds that overlie the topographic relief of the Precambrian basement. The more than 25 pools constitute the second largest gas-producing district of the province.

Contents

Foreword	iii
Abstract	iv
Contents	v
Figures	vii
Tables	ix
Introduction	1
Geological Setting	1
Rationale of Study	2
Petroleum Industry	2
Mining Industry	2
Scope of Study	3
Acknowledgments	3
Stratigraphy	4
Nomenclature	4
Age and Correlation	4
Success Formation and its Homologues	6
Southwestern Saskatchewan	6
Southeastern Saskatchewan	7
Kindersley District	7
Punnichy Arch District	8
Meadow Lake District	12
Depositional Pattern	12
Mannville Group (Restricted)	14
Distribution	14
Lithology of the Mannville Group	15
Shell Husky Paradise Hill A13-19-52-23W3 Reference Section	17
Relationship to Other Fully Cored Mannville Sections	23
North to South Stratigraphic Cross-section A1-A1'	23
Northwest to Southeast Stratigraphic Cross-section A2-A2'	26
Southwest to Northeast Stratigraphic Cross-section A3-A3'	30
Stratigraphic Transects of the Northern Basin	34
Regional Stratigraphic Cross-section A-A'	34
Regional Stratigraphic Cross-section V-V'	35
Regional Stratigraphic Cross-section U-U'	36
Stratigraphic Transects of the Southern Basin	37
Regional Stratigraphic Cross-section B-B'	37
Regional Stratigraphic Cross-section C-C'	38
Regional Stratigraphic Cross-section D-D'	39
Regional Stratigraphic Cross-sections Z-Z', Y-Y', and Y1-Y1'	40
Stratigraphic Transects of the Kindersley–Punnichy Arch Region	43
Regional Stratigraphic Cross-section W-W'	43
Regional Stratigraphic Cross-section X-X'	43
Mannville Depositional Basin	45
Pre-Cantuar Drainage System	45
Lower Cantuar (Dina-Cummings) Depositional Pattern	46
Govan Paleolowland	46
Meadow Lake Paleolowland	51
Middle Cantuar (Lloydminster-Rex) Depositional Pattern	53
Upper Cantuar Depositional Pattern	62
General Petroleums and Sparky Members	63
Waseca Member	69
Sub-Pense Unconformity Surface	77
Pense (McLaren-Colony) Depositional Pattern	77

Tectonic Setting	83
Sub-Cantuar Jura-Cretaceous Erosion Surface	83
Geomorphic Elements	83
Upper Jurassic Masfield and Rierdon Subcrops	83
Middle Jurassic Shaunavon and Gravelbourg Subcrops.....	84
Jura-Triassic Watrous Subcrop.....	85
Mississippian Madison Subcrop	85
Upper Devonian Torquay and Birdbear Subcrops.....	85
Upper Devonian Duperow and Older Subcrops	85
Evolution of the Structural Regions.....	86
Pre-Laramide Structural Setting	86
Watrous Dome	86
Wynyard Dome.....	87
Laramide Structural Setting.....	88
Structure Related to Salt Dissolution	89
Mannville Linear Elements	92
Precambrian Basement-sourced Tectonic Elements.....	94
Interaction of Structural Components in the Meadow Lake Basin.....	95
Relationship of the Paleozoic Erosion Surface to the Holocene Land Surface	95
Relationship to Predecessor Basins	95
Relationship to the Precambrian Basement	96
Jura-Cretaceous Success Basin.....	97
Laramide Overprint.....	97
Mannville Hydrological Setting	98
General	98
Preglacial Bedrock Drainage System	98
Potentiometric Surface	99
Cross-formational Relationships	100
Characteristics and Origin of the Hydrocarbon Reservoirs	104
Southeastern Saskatchewan.....	104
Swift Current District	104
Kindersley District	106
Lloydminster District.....	107
Northern Natural Gas Fields.....	109
Hydrocarbon Reservoirs in the Post-Mannville Setting	109
Hydrocarbon Prospects	112
Swift Current–Maple Creek District	112
Kindersley District.....	112
Lloydminster District.....	113
Eastern and Central Saskatchewan	113
Coal Deposits	114
References	116
Appendix A – Core Descriptions	A-1
Appendix B – Wells Used in the Study.....	B-1
Appendix C – Elevations of Mannville Formation Waters in Drill-stem Tests.....	C-1

Figures (all occur as separate .pdf files)

Figure 1 – Location of study area and tectonic basins of the Western Interior Basin, Canada and the United States

Figure 2 - Structure contours on the Devonian Birdbear Formation of the Sweetgrass Arch–Williston Basin region, Canada and the United States

Figure 3 – Isopach map of the Mannville and equivalent strata in the contiguous regions of Saskatchewan, Alberta, Montana and North Dakota

Figure 4 – Oilfield locations, outcrops and lines of labelled regional stratigraphic cross-sections, Saskatchewan

Figure 5 – Correlation chart of Mannville units in the Alberta and Williston basins

Figure 6 – Isopach map of the Success and homologous formations of Saskatchewan

Figure 7 – West-east stratigraphic cross-section illustrating Jura-Cretaceous relationships across Saskatchewan south of latitude 50°N

Figure 8 – Structure map on the Mississippian erosion surface and isopach map of the Success Formation, Kindersley district, west-central Saskatchewan

Figure 9 – Isopach map of the Success Formation and sub-Success paleogeology, Punnichy Arch district, east-central Saskatchewan

Figure 10 – North-northwest to south-southeast stratigraphic cross-section showing interrelationship of the Pense, Cantuar and Success formations, southeastern Saskatchewan

Figure 11 – North to south stratigraphic cross-section W'-Y1', depicting stratigraphic relationship of the Success ('Insinger beds') Formation to adjacent strata east of longitude 102°W, southeastern Saskatchewan

Figure 12 – Isopach map of the Cantuar Formation and the edges of the Middle Devonian Prairie Evaporite salt fronts, southern Saskatchewan

Figure 13 – North to south stratigraphic cross-section A1-A1', west-central Saskatchewan

Figure 14 – Northwest to southeast stratigraphic cross-section A2-A2', central Saskatchewan

Figure 15 – Southwest to northeast stratigraphic cross-section A3-A3', central Saskatchewan

Figure 16 – North to south regional stratigraphic cross-section A-A' of the Mannville Group, western Saskatchewan

Figure 17 – West to east regional stratigraphic cross-section V-V' of the Mannville Group, central Saskatchewan

Figure 18 – West to east regional stratigraphic cross-section U-U' of the Mannville Group north of latitude 54°N, northern Saskatchewan

Figure 19 – North to south regional stratigraphic cross-section B-B' of the Mannville Group, Saskatchewan

Figure 20 – North to south regional stratigraphic cross-section C-C' of the Mannville Group, eastern Saskatchewan

Figure 21 – North to south regional stratigraphic cross-section D-D' of the Mannville Group, eastern Saskatchewan

Figure 22 – West to east regional stratigraphic cross-section Z-Z' of the Mannville Group, southernmost Saskatchewan

Figure 23 – West to east regional stratigraphic cross-section Y-Y' of the Mannville Group, southern Saskatchewan

Figure 24 – West to east subsidiary stratigraphic cross-section Y1-Y1' of the Mannville Group, southeastern Saskatchewan

Figure 25 – West to east regional stratigraphic cross-section W-W' of the Mannville Group, southern Saskatchewan

Figure 26 – West to east regional stratigraphic cross-section X-X' of the Mannville Group, southern Saskatchewan

Figure 27 – Isopach map of the McCloud (Dina-Cummings) Member of the Cantuar Formation, and elements of the sub-Cantuar paleotopography, Saskatchewan

Figure 28 – Early Mannville (Aptian) drainage systems of the northern Western Interior Basin, Canada and the United States

Figure 29 – Dina Member 'Silica Sands' in the bluffs of the Red Deer River, Sec. 21, Twp. 46, Rge. 30, W 1st Mer., east-central Saskatchewan

- Figure 30 – Metre-thick, tabular truncation sets in sandstone of the Dina Member, in a quarry near the Red Deer River, Sec. 21, Twp. 46, Rge. 30, W 1st Mer., east-central Saskatchewan
- Figure 31 – McMurray sandstone in the walls of a northwest-trending tributary valley of the Clearwater River, Sec. 29, Twp. 89, Rge. 23, W 3rd Mer., northern west-central Saskatchewan
- Figure 32 – Isopach map of the Dimmock Creek Member of the Cantuar Formation, Saskatchewan
- Figure 33 – North to south stratigraphic cross-section $\alpha\text{-}\alpha'$ of the Mannville Group up the Delta Paleovalley from the Kindersley Paleo-upland, southwestern Saskatchewan
- Figure 34 – Dominant facies in the Dimmock Creek Member, Cantuar Formation, Saskatchewan
- Figure 35 – Isopach map of the Atlas (General Petroleums, Sparky, and Waseca) Member, Cantuar Formation, Saskatchewan
- Figure 36 – Physiographic setting of shorefront sand deposits on the south shore of Lake Erie between Ashtabula and Fairport, Ohio
- Figure 37 – West to east stratigraphic cross-section $\gamma\text{-}\gamma'$ of the Cantuar Formation, illustrating the relationship of the Atlas, Dimmock Creek, and McCloud members across the Swift Current Platform, Saskatchewan
- Figure 38 – Dominant facies in the Lower Atlas, General Petroleums, and Sparky members of the Cantuar Formation, Saskatchewan.
- Figure 39 – Stratigraphic cross-sections of the Mannville Group, indicating disposition of intramember units across the Unity Paleo-upland of west-central Saskatchewan
- Figure 40 – Dominant facies in the Waseca Member of the Cantuar Formation, Saskatchewan
- Figure 41 – Waseca fluvatile sandstone on the Nipekamew River, east of La Ronge, northern Saskatchewan
- Figure 42 – Grand Rapids Formation on the Clearwater River, Twp. 89 at the Saskatchewan-Alberta boundary, west-central Saskatchewan
- Figure 43 – Geology of the sub-Pense unconformity surface, Saskatchewan
- Figure 44 – Bioturbated sandstone in Unit 1 of the Pense Formation at Mobil S Grassdale 10-32-6-15W2, southeastern Saskatchewan
- Figure 45 – Isopach map of the Lower Colorado Subgroup, Saskatchewan and the contiguous region of Canada and the United States
- Figure 46 – Geological map of the contoured sub-Cantuar erosion surface, Saskatchewan
- Figure 47 – Structural elements of the Punichy Arch district, southeastern Saskatchewan
- Figure 48 – Structure map on the Cantuar Formation and locations of Mannville natural-gas fields and oilfields, Saskatchewan
- Figure 49 – North-south stratigraphic cross-section, Punichy Arch district, southeastern Saskatchewan
- Figure 50 – Major Phanerozoic lineaments and related structural and sedimentary features, Saskatchewan
- Figure 51 – Three-dimensional seismic time slice of the Cantuar Formation, bordering halves of Twp. 35 and 36, Rge. 8, W 3rd Mer., Saskatchewan
- Figure 52 – Cantuar and other Phanerozoic structural and topographic elements on a background of Precambrian basement aeromagnetic patterns, Saskatchewan
- Figure 53 – Structure contour map on the Upper Devonian Souris River Formation in the southwestern portion of the Mannville-Success Meadow Lake Basin, west-central Saskatchewan
- Figure 54 – Overlay of Precambrian basement aeromagnetic patterns on structure contour map of the Upper Devonian Souris River Formation in the southwestern part of the Mannville-Success Meadow Lake Basin, west-central Saskatchewan
- Figure 55 – Formation-water potentiometric map of the Mannville Group and elements of the subglacial aquifer system, Saskatchewan
- Figure 56 – Rise of formation water in drill-stem tests of the Mannville and Devonian strata
- Figure 57 – Potentiometric heads versus depth, and salinity versus depth

Figure 58 – Distribution of oil shows in the Success and Mannville formations on the Kindersley structural terrace, Saskatchewan

Figure 59 – Location of Mannville heavy-oil fields, Lloydminster area of Alberta and Saskatchewan

Tables

Table 1 – Petroleum reserves ($\times 10^6 \text{ m}^3$) of the Jura-Cretaceous oilfields, southwestern Saskatchewan.....	105
Table 2 – Heavy-oil reserves ($\times 10^6 \text{ m}^3$) Lloydminster district, west-central Saskatchewan	108
Table 3 – Natural gas reserves, west-central Saskatchewan.....	110

Introduction

Geological Setting

The Mannville Group of Saskatchewan is situated in the northeastern part of a vast sheet of Early Cretaceous sandstone, siltstone, and mudstone that fronts the inner Rocky Mountains from New Mexico to the Arctic (Figure 1). From the Canada–United States border, where the Mannville Group lies in the subsurface of the Williston Basin at a depth of 1200 m, the succession rises northward to scattered outcrops across central Saskatchewan, in a belt trending northwest from the Pasquia Hills at the Saskatchewan-Manitoba boundary, through the Wapawekka Hills, to the Clearwater River at the Saskatchewan-Alberta boundary. Total thickness is as little as 15 m in isolated localities, but generally ranges from 75 m in the south to 240 m in the northwest.

In the context of the Western Interior Basin of the northern United States and western Canada, the post-Laramide Mannville structural surface rises onto the Sweetgrass Arch of northwestern Montana and southeastern Alberta, immediately west of the Williston Basin and southwest of the depressed Swift Current Platform (Figure 2). The Sweetgrass Arch occupies a 38 000 km² region that forms a northward plunging compound antiform consisting of the South Arch at Great Falls, Montana and the Kevin-Sunburst Dome at the Alberta-Montana border. Farther north, the arch elongates into a nose that closes at the Bow River, where it flattens into a broad saddle. To the northeast, the saddle rises onto the southwesterly plunging Battleford Arch and enters Saskatchewan at latitude 52°N. As mapped on the Upper Devonian Birdbear Formation by Kent (1968), the Sweetgrass Arch abuts the steeply dipping and thrust beds of the Rocky Mountain geosyncline to the west. Its eastern flank dips gently across southwestern Saskatchewan, around subsidiary domes and troughs, toward the Williston Basin some 500 km away.

In Montana, the structural surface is warped into complex domal forms towering up to four times the height of the arch. These are Late Cretaceous and Cenozoic Laramide uplifts, genetically associated with the laccoliths of the Sweetgrass Hills, the Bears Paw, Highwood and Little Rocky mountains, and the structural Bowdoin Dome. South of this region, the easterly trending central Montana uplift comprises the Little Belt and Big Snowy mountains (Figure 2). From a stratigraphic perspective, both the central Montana Platform and the adjacent Swift Current Platform of southwestern Saskatchewan have alternated, by uplift and downwarp, as extensions of the Sweetgrass Arch and the Williston Basin. Thus, at its maximum, the Sweetgrass Arch–Swift Current Platform region represented a structural complex, some 100 000 km² in area, consisting of a number of incongruent basement blocks. The complex formed a broad divide between an expanding Rocky Mountain foreland basin to the west and an episodically active Williston Basin to the east.

Major elements of the Mannville structural setting in Saskatchewan and the contiguous region are (Figure 2):

- the eastern flank of Sweetgrass Arch, which slopes into southwestern Saskatchewan as the Shaunavon Monocline and terminates against the Shaunavon Graben, along longitude 108°W;
- the South Dome of the Sweetgrass Arch and its extension eastward from Great Falls to, and including, the region of the Bowdoin Dome at longitude 107°W; named ‘Belt Island’ by Imlay (1945), it is otherwise known as the central Montana Platform;
- the Swift Current Platform (Baillie, 1955; Kent and Haidl, 1993), a basement-controlled structural block flanked by the northeasterly trending Shaunavon shelf in the west; the northwesterly trending Elbow-Weyburn Lineament in the northeast; the northeasterly trending flank of the Williston Basin between the Big Snowy trough and Weyburn in the southeast; and the Central Montana Platform in the south;
- the Battleford Arch segment of the Sweetgrass Arch (Kent, 1968) and its eastern flank, which consists of the Kindersley and Unity structural terraces that are now structurally inverted with respect to the Middle Cambrian Deadwood depositional basin (Van Hees, 1964; Paterson, 1989; Kreis and Haidl, 2000);
- the Punichy Arch (Christopher, 1980), a flattened basement-controlled compound antiform, comprising the Watrous and Wynyard domes, extending east-southeasterly from the Third Meridian (longitude 106°W) to the Second (longitude 102°W) between latitudes 51° and 52°N, and representing the northern rim of the Williston Basin;

- the Precambrian Kiseeynew Domain, as projected southward under the Phanerozoic strata between the western front of the Precambrian Churchill Province (as indicated by the Nelson River–Moosomin gravity trend; Hajnal and McClure, 1977) and the Trans-Hudson Orogen of Lewry and Sibbald (1977);
- the Lower Devonian Lower Elk Point sub-basin to the northwest of the Meadow Lake Escarpment, at latitude 55°N in west-central Saskatchewan; and
- the basement-controlled Molanosa Dome of east-central Saskatchewan.

These structural elements exercised a profound control on the erosional and depositional agents responsible for the distribution of Mannville sedimentary rocks. Their cumulative effects served to differentiate the Mannville deposits into: 1) a wedge thinning southeasterly from central Alberta into central Saskatchewan; and 2) a comparable wedge thinning northeasterly into the Williston Basin region of southeastern Saskatchewan from the Little Belt–Big Snowy aulacogen of central Montana (Figure 3). Both wedges are easterly extensions of the north-south Rocky Mountain foreland deposits.

The Mannville and coeval strata crop out in the mountains of the Central Montana Platform and the South Dome of the Sweetgrass Arch, and in the Little Rocky, Bears Paw, Sweetgrass, Little Belt, and Big Snowy mountains. Outcrops also occur in the banks of the Swan River of southwestern Manitoba, and in the Red Deer, Nipekamew, and Clearwater rivers of east-central, central, and northwestern Saskatchewan, respectively (Figure 4).

Rationale of Study

The importance of the Mannville Formation to the mineral and industrial environment of Saskatchewan is difficult to understate. Its impacts in these sectors are summarized below.

Petroleum Industry

The major economic and potential energy resources are the heavy-oil and natural-gas deposits of west-central Saskatchewan between the Air Weapons Range (Twp. 68) and the South Saskatchewan River along Twp. 24; and the medium-gravity oil deposits in the Swift Current region in southwestern Saskatchewan and the Wapella region in southeastern Saskatchewan. The report reviews these reserves and their geological setting in order to facilitate additional exploration and management.

Mining Industry

Potash: Because it is the major middle-depth aquifer underlying the plains of southern Saskatchewan, and the one in contact at one place or another with all of the Paleozoic formations, the Mannville Formation serves as a major transmitter of the subsurface hydrodynamic system. It incorporates a large-capacity, high-pressure flow system and is thus an ever-present threat to the integrity of potash mining galleries. On the other hand, its generally brackish water and high storage capacity present an eventual opportunity as a water source for dissolution of waste salt and storage of brine from the mining operations.

Petroleum: Currently, the Mannville Formation serves as the water source for some secondary recovery operations in the Mississippian oilfield district of southeastern Saskatchewan. Its many channel sandstone reservoirs are amenable to such developments.

Diamond: Occurrences of diamonds in the Fort à la Corne district, if contemporaneous with Mannville deposition, imply some redistribution from igneous sources by sedimentary and erosional agents acting in the basin.

Coal: Mannville sub-bituminous coal and lignite are widely distributed throughout central Saskatchewan. These are not currently utilized because of high extraction costs associated with their relatively deep burial. However, the prospect of exploitation by *in situ* gasification remains, and these deposits are therefore a resource for the future.

Potable and Industrial Water: Across central Saskatchewan to a distance of about 100 km inward from the erosional edge of the Western Canada Sedimentary Basin between Peter Pond Lake and Hudson Bay, the Mannville Formation is Saskatchewan's largest potable water reservoir. It interacts with the major waterways and lakes of the central region. Thus, its importance to the provincial economy may become vital as the Holocene climate continues to dry out.

This Mannville study is designed to provide a baseline for any investigative work required with respect to major environmental impacts of the above.

Scope of Study

The objective of the present work is to provide a synthesis of the three regional studies (Price, 1963; Maycock, 1967; Christopher, 1974) in the southwest and southeast with the many site- and unit-specific studies in west-central Saskatchewan, and an extrapolation of these to the unstudied outlying regions of central and eastern Saskatchewan. Emphasis has been placed on rationalization of the various stratigraphic schemes and correlations, reconstruction of the regional sedimentation and tectonic history, delineation of the hydrogeological setting, and determination of economic prospects. Thus, the study is an update of a regional overview by Rudkin (1964) and the base of a similar overview by Poulton *et al.* (1994). A database of 6,421 wells, selected from the more than 30,000 on hand, was standardized for the study. All cores from outside the main producing west-central regions, and representative ones from within, were utilized (Figure 4).

Appendix A contains lithological descriptions of relevant core sections from 79 selected wells. Appendix B, which was generated from the Saskatchewan Industry and Resources *Well Information Database*, is a listing of all 6,421 wells used in the study; it includes complete location information and all relevant well-log picks. Appendix C contains elevations of Mannville Formation waters in drill-stem tests.

In view of the large scale of the study, summary papers synthesizing aspects of the sedimentary, structural, and economic geology of the several sub-basins and arches have been released and are listed in the 'References' section.

Acknowledgments

The author is indebted to his colleagues for their stimulating discussion of many of the ideas presented in this report and for their constructive advice. In this regard, L.S. Beck, P. Guliov, F. Haidl, D.M. Kent, K. Kreis, W.G.E. Caldwell, D. Leckie, D. James, and E. Albrechtsons are particularly worthy of mention. He thanks P. Weir, E. Nickel, M. Opseth, J. Coolican, and other staff for their work on the final drafting of the maps and figures; L. Sutyla, J. Bilkhu, and R. Troyer for their dedication to the input of the some 35,000 well-log picks to the computerized format; L. Cruikshank for computer input on the core descriptions; and the staff of the Subsurface Geological Laboratory for logistical support in data gathering. He is deeply indebted to: C.F. Gilboy, C.T. Harper, and D.F. Paterson for critical review; to R. Davie of RnD Technical and C. Brown for final editing; and to Saskatchewan Industry and Resources for funding.

Stratigraphy

Nomenclature

The Mannville Group of Saskatchewan can be correlated with the Mannville Formation of western Alberta. As summarized by Christopher (1974), the name ‘Blairmore’ was earlier applied to these beds, but was replaced by ‘Mannville’ (Maycock, 1967). ‘Swan River’ (Wickenden, 1945) is restricted to the equivalent strata in Manitoba. The history of the development of Mannville nomenclature is extensively detailed in the *Lexicon of Canadian Stratigraphy, Volume 4* (Glass, 1990), and also in the publications mentioned below. Thus, it will be elaborated upon in the text of this report only as required by the context.

Historically, the term ‘Mannville’ has signified:

- in the southeast, ‘Unit A’ (Price, 1964) and the Cantuar and Pense formations (Price, 1963);
- in the southwest, the Success, Cantuar, and Pense formations of Christopher (1974);
- in the Kindersley region of west-central Saskatchewan, the Deville, Cantuar, and Pense formations of Maycock (1967); and
- in the Lloydminster region of west-central Saskatchewan, the terminology of Nauss (1945), which evolved through academic (the late Prof. F.H. Edmunds and students) and industry (Vigrass, 1968; Fuglem, 1970; Orr *et al.*, 1977) usage to result in the variously defined Dina, Cummings, Lloydminster, Rex, General Petroleums, Sparky, Waseca, McLaren, and Colony (oldest to youngest) members.

This report returns to a restricted usage of the term ‘Mannville Group’, and thereby excludes the Success Formation and its equivalents (Figure 5). Thus, the ‘Mannville’ comprises the Cantuar and Pense formations (Aptian to Albian). The Cantuar includes most of the members of the Lloydminster oilfield district: the Dina, Cummings, Lloydminster, Rex, General Petroleums, Sparky, and Waseca members. The Pense includes the McLaren and Colony members. The Jura-Cretaceous type Success Formation stands alone, separate from the Oxfordian Vanguard Group below and the Aptian to Albian Mannville Group above. This is an arrangement of convenience, designed to bring the nomenclature into alignment with the Jura-Cretaceous Kootenay and Lower Cretaceous Blairmore groups of Alberta and the similarly paired Morrison and Kootenai formations of Montana, and with usage in the *Geological Atlas of the Western Canada Sedimentary Basin* (Mossop and Shetsen, 1994) and the *Geological Atlas of the Rocky Mountain Region* (Mallory, 1972) of the United States.

The Success and Cantuar formations are bounded by basal unconformities on erosional surfaces with relief of up to 75 and 100 m, respectively. In places, the sub-Cantuar surface intersects the sub-Success surface. A low-relief sub-Pense unconformity represents marine planation, which in south-central Saskatchewan has transected underlying units as old as the Middle Jurassic. Mapping of these unconformities is as important to an understanding of Mannville depositional formats as mapping of the component rock types. By virtue of its vast extent and the basal unconformity, the Mannville Group of Saskatchewan is in contact, at one place or another, with every pre-Cretaceous Phanerozoic formation of the province. This includes inliers of Upper Mississippian strata, which are generally overlapped by the Jura-Triassic and by the Early and Middle Devonian Elk Point evaporite beds, which are set back from their erosional edges by meteoric-sourced formation-water sapping. These stratigraphic relationships are shown in the correlation chart of Figure 5.

Age and Correlation

Age of the Success, Cantuar, and Pense formations is constrained by the macrofauna of the subjacent marine Upper Jurassic strata of the Williston and Rocky Mountain basins, the Middle Albian of the equivalent Clearwater Formation in eastern Alberta, and the overlying Colorado shale. Macrofauna in the Success and Mannville strata are scarce in Saskatchewan. The marine tongues of the Clearwater facies form a dominant component of the Cantuar Formation, and include a widely distributed foraminiferal population of largely generalized endemic species that do not permit more than a general assignment of age.

Faunal histories and age correlation for the Jurassic of the Williston Basin are reviewed by Christopher (1974), based on the work of Imlay (1945, 1947), Peterson (1957), Wall (1960), Pocock (1962), and Brooke and Braun (1972); and for the Jurassic of the Western Canada Sedimentary Basin by Poulton (1984). The youngest of the

marine Jurassic formations is the S1 Member of the Success Formation, which is dated in southwestern Saskatchewan as Upper Jurassic by Hayes (1983) and, in southeastern Saskatchewan, more specifically as Oxfordian (this report).

Age relationships and correlations of the Cantuar and Pense formations are discussed in Christopher (1974), and reviewed by Caldwell (1984a, 1984b). Caldwell included an extensive treatment of the faunal correlations in the Western Canada Sedimentary Basin, as derived from Nauss (1945), Badgley (1951), Fuglem (1970), Playford (1971), North and Caldwell (1975), Caldwell *et al.* (1978), and Atkin (1986). According to Caldwell (1984b), the foraminifera of the Cantuar Formation clearly belong to the *Marginulinopsis collinsi*–*Verneuilinoides cummingensis* assemblage, which distinguishes the principal zone of the Early Albian Clearwater Formation. *Haplophragmoides gigas* appears in the basal Joli Fou Formation of the Colorado Group above the Pense Formation, and is representative of the Late Albian. Thus, the deduced age of the Pense Formation is Middle Albian, which is similar to that given the equivalent Fall River Formation of Montana and the southern Williston Basin region of North and South Dakota (Dyman *et al.*, 1995).

Success Formation and its Homologues

Six major non-contiguous regions of Jura-Cretaceous sandstone and mudstone are depicted in [Figure 6](#). The southern deposits are located in southwestern (area I) and southeastern Saskatchewan (area III), where they represent northward extensions of the Upper Jurassic Swift and Lower Cretaceous Lakota sandstone units of Montana and North Dakota, and in general overlie the Upper Jurassic Vanguard Group. The Success sedimentary rocks of central Saskatchewan are distributed on the Kindersley structural terrace (area II) and the Punnichy Arch (area IV). They are inlaid topographically on the Madison, Bakken, Torquay, and Birdbear formations. Both of these occurrences are part of an extensive sheet that reaches west to near Calgary and Red Deer in Alberta, and east into Manitoba (Poulton *et al.*, 1994, Figure 18.25). Farther north, Success sandstone blankets and infills topographic and salt-dissolution collapse depressions in the Upper Devonian Duperow Formation (area V) and, in the northwest (area VI), in the Upper Devonian Souris River Formation. Scattered outliers on the Lower Paleozoic are also present east of longitude 106°W in central Saskatchewan.

The Success sandstone is in disconformity with all subjacent strata and with the overlying Mannville Group. It is the remnant of a once widespread sheet that blanketed southern Saskatchewan and Alberta during the Late Jurassic and the Neocomian, and is the survivor of the succeeding pre-Cantuar erosional cycle, to which the relief of the sub-Cretaceous erosion surface is generally attributed. However, many of the sub-Cantuar landforms between the Success homologous bodies were shaped in pre-Success and Success times. The exception to this is in southwestern Saskatchewan, where the Success Formation caps the post-Success-pre-Cantuar dissected mass of the Swift Current Platform (Christopher, 1974).

Southwestern Saskatchewan

The type Success sandstone (detailed in Christopher, 1974; Leckie *et al.*, 1997b) lies between longitudes 107° and 109°W, and extends from Montana as far north as latitude 51°40'N. The thickness ranges up to 49 m in the deeper pre-Success valleys, but is a more uniform 12 to 18 m over wide areas east of the serrated western sub-Cantuar front. Overstep of the subjacent Jurassic formations is such that the Success Formation overlies the Masefield Shale as far north as latitude 50°N and the Oxfordian-Callovian Roseray Formation beyond.

By reference to the micropaleontological correlation of the Vanguard units by Brooke and Braun (1972), and by geophysical-log correlation from the Tidewater Frontier Crown No. 1 well (L.S. 12-21-3-20W3) to the Fergus Basin of central Montana, the S1 member is equated with the Kimmeridgian Morrison Formation and the S2 member with the Neocomian to Aptian Lakota Formation sandstone (Christopher, 1974, Figure 16). Similarly, Hayes (1983) traced the member to the Swift sandstone of the Sweetgrass Arch of southern Alberta by correlation from the same well, where the S1 was dated palynologically as Upper Jurassic.

The type section of the Success Formation is described for southwestern Saskatchewan from the well MUS E Cantuar 6-20-16-16W3, at depths of 637 m (2090 ft) to 967 m (3173 ft) (Christopher, 1974, p22). The formation consists of white and light greenish grey, kaolinite-indurated quartzose sandstone and siltstone, with abundant to minor feldspar, coarse-grained sphaerosiderite, chert, and carbonaceous fragments, and is subdivided into three informal units.

The basal S1 Member is characterized by beds 0.3 to 6 m thick, consisting of quartzose, very fine grained, subangular, grey-white to light grey, kaolinite-indurated sandstone intermixed and interlaminated with quartzose, coarse-grained, slightly to heavily carbonaceous, lavender-grey to black siltstone with abundant to sparse layers of sphaerosiderite. Locally, the carbonaceous beds are weakly bioturbated, contorted, brecciated, and faulted on a small scale. Accessory glauconite occurs in thicker deposits associated with valleys of the subjacent paleotopography. Laminae in S1 coarsen upward internally, as does the unit as a whole, with the exception of an irregular, local, conglomeratic basal bed. Ripple-drift and small-scale festoon cross-beds are seen where S1 is thickly bedded. The member thickens to a maximum of 33 m in the topographic lows of the pre-Success erosion surface.

The S2 Member features upward fining of grain size and large-scale trough and tabular cross-beds (Harms and Fahnestock, 1965). Grain sizes are bimodal: dominated by fine- and medium-grained quartzose sand, but including cobble and silt as end members. The large-scale cross-beds, as seen in core, are nearly tabular, dip 15 to 20°, form sets 0.3 to 0.6 m thick, and grade upward into low-angle trough cross-beds or nearly horizontal tabular layers. Small-scale festoons and ripple laminae appear higher in the section. The large-scale, upward-fining bodies are lenticular, as much as 13.5 to 15 m thick, although 4.5 to 12 m are more usual, and about a square kilometre in area.

These bodies are invariably floored by erosional contacts and terminated at many localities by sharp contacts on kaolin-indurated siltstone or mudstone.

The S3 Member is fine grained like S1, but is less carbonaceous. The absence of a cored section leaves the lithology poorly defined, and its distribution is limited to small areas in southwestern Saskatchewan near the border with Montana by virtue of the superjacent sub-Cantuar erosional unconformity.

Southeastern Saskatchewan

The Success Formation of southeastern Saskatchewan (Christopher, 1988), initially mentioned by Francis (1956), was later defined by Price (1963), who called it 'Unit A', dated it as post-Vanguard and pre-Inyan Kara (Late Jurassic and Early Cretaceous, respectively), and correlated it with the subsequently named Success Formation of southwestern Saskatchewan in the Tidewater Frontier Crown 13-21-3-20W3 well.

These sandstone units range up to 51 m in thickness, but are more typically 20 to 40 m. They lie between longitude 105°W (Rge. 24W2) and the Saskatchewan-Manitoba boundary, generally south of Twp. 11, and are separated from the western body by a 96 km wide corridor. Unlike its western counterpart, the Success Formation in southeastern Saskatchewan is represented mostly by the S1 Member. The capping S2 Member is eroded to a thin unit, barely distinguishable on geophysical logs from the overlying Cantuar Formation. Again, the Success Formation of the southeast overlies the Masefield Shale, truncating it to a depth of 75 m between the Canada–United States border and Twp. 6 along longitude 104°W; north of this, it oversteps the Masefield onto the Rierdon Formation. The relationships between the eastern and western bodies are depicted in [Figure 7](#) (see also stratigraphic cross-section Z-Z', [Figure 22](#)).

The formation is completely cored from 1340.2 m (4397 ft) to 1374.0 m (4508 ft) below KB in the CDR Flat Lake Water Source Well (L.S. C3-3-1-16W2). The core, stored at the Subsurface Geological Laboratory in Regina, is described in Christopher (1988) and in [Appendix A](#) of this report. As shown in the description, the S1 section is developed as six upward-coarsening transitions from basal dark grey shale, through laminated and interbedded, current bedded, flasered, bioturbated, podded, shale-draped, green glauconitic siltstone, to very fine grained, glauconitic quartzose sandstone. Thicknesses of the cycles are 1.9, 2.0, 8.3, 3.2, 11.4, and 4.4 m. An unconformity separates S1 from the overlying S2. The latter resumes the cyclic format, but in this case from variegated mudstone, through flasered, glauconitic, green siltstone, to white kaolinitic and sphaerosideritic siltstone laminated with argillaceous partings. A poorly sorted, very fine to medium-grained, cream-coloured, kaolinite-indurated quartzose sandstone, with abundant brown sphaerosiderite grains of coarse sand size, and a basal conglomerate of siliceous kaolinite constitute the uppermost unit. Palynomorphs (dinocysts), collected from the S1 member at the reference well, were dated as Late Middle to Late Oxfordian (courtesy of T. Poulton, pers. comm. in Christopher, 1988). The S2 member is not dated.

Kindersley District

The pre-Cantuar deposits of the Kindersley district were formally described by Maycock (1967), who introduced Badgley's (1951) term 'Deville Formation', after the Imperial Deville No. 1 well (L.S. 9-36-51-24W4) in eastern Alberta, for similar lithological bodies there; and by White (1969) for the Hoosier oilfield. Maycock (1967, p18) noted the presence of two facies: "cherty breccio-conglomerates frequently encountered in cores, are well developed in the Imperial Warrior 10-29-27-25 well (L.S. 10-29-27-25W3) between 3030 and 3080 feet, whereas whitish sandstones (unlike those of the overlying Mannville and here referred to the Deville) are cored in Tidewater Imperial Plato Crown No. 1 well (L.S. 9-22-24-19W3) between 2728 and 2813 feet." The two rock types are genetically unrelated, the first having been derived from the country rock and the other from outside of the district.

Core data from the Success Formation are relatively sparse, but representative well cuttings are available from most wells in the district. These samples are distinguished by the predominance of white porcelanite, oolitic and crinoidal bioclasts replaced by silica, and tan to red-brown, coarse-grained, sideritic spheroids consisting of very fine grained quartzose sand. It is apparent that considerable white, siliceous, kaolinitic, matrix-forming clay was washed out of the samples in the cleaning. Quartzose sandstone and coal, where present, were also recovered. In some localities, as at Imperial Centrefield 13-10-26-21W3, indurated, white, magenta and yellow claystone interbeds in quartzose sandstone and cherty facies are indicated. Low-API° oil staining in the samples is widely distributed throughout the Kindersley district, but mostly in the cherty, moldic pore deposits, thereby indicating a preferential permeability.

Whereas incorporation by reworking of one rock type during the formation of another is common, each can be fairly individual and thick. In places, the basal contact of the cherty beds may be difficult to distinguish from

underlying karsted Madison limestone. For instance, at the Hoosier Unit 1-10-31-27W3 well, the cored section of the Residual Zone of White (1969, p36) comprises 6.7 m of white to light grey chert breccia in a grey and pale green sphaerosideritic claystone and siltstone matrix, and an underlying 32.9 m of interbedded brecciated limestone and limestone breccia in grey-green calcareous shale and quartz particles. Placement of the formation boundary beneath the insoluble residues of chert and clay, concentrated *in situ* by chemical weathering of the Madison limestone, is blurred by joint- and cave-detrital infill. Whether the brecciated limestone bed of the foregoing section should be considered corroded aggregate (*i.e.*, part of the 'Residual Zone') or an altered Madison Formation is moot.

The quartzose sandstone, as typified by the 17.1 m core from Consumers Hartog Whiteside 11-9-30-26W3 (Appendix A), is white splashed with red, kaolinite indurated, and fine and very fine grained. It includes subordinate quartzose silt and clay, and abundant angular cherty pebbles and brown, coarse-grained, siderite-cemented aggregates of fine-grained quartzose sand. Bedding is fragmentary, and the fabric is so distorted by differential compaction that the rock breaks down under manual stress into rubble. Vertical siderite veins, mud-filled fractures, and plant detritus are displayed at the unconformity with the Cantuar Formation. In general, as determined from the well cuttings in the district, the quartzose sand postdates the chert and tripoli facies, although locally interbedded with the latter in the upper third of the section. Elsewhere, it may occupy nearly all of the Success section to lie directly on, or within a metre or so of, the contact with the Madison Formation.

Thus, at the Tidewater Plato Crown No. 1 well, 31 m of fine-grained, red-splashed, white-kaolinite-indurated quartzose sandstone with abundant sphaerosiderite of coarse sand grade characterizes the pre-Cantuar beds. Here, however, the contact between this body and the locally derived sediments of the overlying McCloud Member of the Cantuar Formation is not apparent. Therefore, the distinction, though stratigraphically important, may not be definitive. Christopher (1974, p347) placed these beds in the valley-filling McCloud Member of the Cantuar Formation. However, the relatively dense fabric of the quartz-kaolinite in the lower half of the section is more consistent with that of the pre-Cantuar deposits. Accordingly, the criteria for separation of the Success from the McCloud, as used in this report, are more nearly in accord with Maycock (1967); specifically, this sandstone is pre-Cantuar.

Because of the great irregularity in thickness of the Success Formation from well to well, neither Maycock (1967) nor White (1969) mapped the unit. Nonetheless, a structural map drawn on the subjacent Mississippian erosion surface (Figure 8a) displays a southerly tilted terrace rimmed by domes above the -140 m (msl)¹ contour in the northwest, north and east, and overlooking a central, southwesterly trending trough some 200 m below. The counterpart isopach map of the Success sediments (Figure 8b) depicts a general thickening to 79 m in the central trough, versus a thinning to less than 10 m on the topographic highs. In contrast to the northern and eastern rims, where the Success sediments end against Mississippian limestone scarps, they are terminated in the south, between longitudes 108° and 110°W, against the Jurassic of the Swift Current Platform. Deeper southerly penetrations by Success sediments onto the platform occur as pediment veneers and valley fill onlapping cuestas of the Gravelbourg, Shaunavon and Rierdon formations in Rge. 29, 27, 26, 25, and 18, W 3rd Mer. (*e.g.*, Saskoil Leader 9-15-20-25W3 and Saskoil Speyer 7-36-21-26W3). Thin Success isopachs trending east from the town of Kindersley reflect pre-Cantuar erosion under the Kindersley Paleovalley, and the Success body near Rosetown is an outlier.

Thus, the Success Formation of the Kindersley district lies mostly within an upland topographic basin, excavated from the general mass of Madison limestone, where the latter flattens in regional dip across the Kindersley region from out of the Williston Basin to the south (Christopher, 1974, Figures 17 and 45). The region evidently was arched along an east-west axis, weathered and erosionally breached as infilling progressed. The purely chert-clay detrital suite represents the earlier phase of a depositional event that included a penecontemporaneous influx of kaolinitic, quartzose clastic sediments. Northern outliers of this body are encountered on the Upper Devonian Three Forks Group.

Punnichy Arch District

The Success sediments of this district between Saskatoon and Yorkton in east-central Saskatchewan (Figure 9) overlie an irregular surface on southerly dipping formations that range in age from Paleozoic (upper Devonian Duperow and Birdbear, Devonian-Mississippian Three Forks, and Mississippian Madison formations) to Mesozoic (Jura-Triassic Watrous, Middle Jurassic Gravelbourg and Shaunavon, and Upper Jurassic Rierdon formations).

¹ The elevations on the structure maps are calculated from the well kelly bushings, as surveyed on the geodetic datum relative to mean sea level (msl).

Thickness of the Success Formation varies drastically (0 to 122 m) from locality to locality, a state that is attributable not only to sub-Success erosional valleys and Prairie Evaporite salt-dissolution sinks, but also to the subjacent Cantuar valleys intersecting it. Where the Success Formation overlies the Watrous Formation, thickness is less, ranging up to 25 m, although it reaches 70 m at a locality south of Lanigan. These variations in thickness imply a complicated geological history (Christopher, 2000).

Price (1963, 1964), in his study of the Lower Cretaceous in southeastern Saskatchewan, introduced the formation names Pense and Cantuar (younger to older) for the strata below the Albian Joli Fou Formation and above the Jurassic and older formations beneath the basal unconformity. As implemented, the regional Cantuar Formation also included the beds of this region. However, as indicated in his texts, he was aware that the Jura-Cretaceous beds were all or partly pre-Cantuar, and he described informally, though in some detail, the included chert deposits of the Yorkton district.

In the absence of fully cored sections from wells in the Jura-Cretaceous of this region, recognition of distinguishing rock types is dependent on geophysical log correlation from beyond the district and rock cuttings from wells within. Thickness of the sub-Joli Fou clastic rocks ranges from 61 to 213 m. In that most wells are located on structural anomalies, all sections are apt to be anomalous. The Sohio Western Pet Insinger 9-16-29-7(W2) well (Figure 10), selected as a reference for the Success-equivalent strata of this area (Christopher, 1987), may be extreme in this regard. However, the log expression is fairly precise, the quality of well cuttings is better than most in the vicinity, and the stratigraphy is wholly representative. Typically, sample representation is biased toward the cemented and indurated rocks, lignite and hard mineral species such as siderite and pyrite. Soft claystone tends to disappear in the drilling mud and the washing process, whereas shale, unless sufficiently conspicuous, is camouflaged by cavings from the Colorado Group.

The sub-Joli Fou Formation of Price (1963, Figure 13) in the Insinger well lies between 1305 ft (398 m) and 2000 ft (609.6 m), between the Albian Joli Fou and Upper Devonian Torquay formations. Price divided them into the Pense and Cantuar formations at 1343 ft (409.6 m). In this report, the Pense-Cantuar contact is lowered to the base of the sandstone at 1370 ft (417.6 m) and the base of the Cantuar is placed at 1600 ft (487.7 m), specifically at the base of the Dina Member by correlation from the Lloydminster district of west-central Saskatchewan. The remainder of Price's section, the strata between 487.7 and 609.6 m, is here taken as the stratigraphic equivalent or homologue of the Jura-Cretaceous Success Formation, and is here informally referred to as the 'Insinger beds'. As can be deduced from Figure 10, considerable structural displacement of the Success Formation exists with respect to its position in the Insinger No. 1 well and that in its neighbours. Additionally, stratigraphic discordance with the overlying Cantuar and Pense formations is conspicuous.

Three units, each terminating in coal beds, are apparent in the Insinger No. 1 well. These are designated A, B, and C (oldest to youngest) in the lithological description. Overall, the formation is dominated by quartz ranging in grade size from very fine to coarse sand, grit and conglomerate, with subordinate amounts of grain-aggregate and cement of chert and chalcedony, black shale and red-brown dolomite. Calcareous cement has a minor presence in Unit C, but a white siliceous kaolinitic matrix is pervasive in all units.

Unit A comprises coarse-grained sandstone and grit interbedded with a smaller proportion of poorly sorted, fine- to medium-grained sandstone. Overall grade size decreases upward. Pyrite-cemented sandstone is conspicuous beneath the coaly and carbonaceous uppermost beds and above black shale that is basal to the unit. Lithic grains are abundant in the lower two-thirds of the unit and reflect basal Mississippian and Upper Devonian rock sources.

Fragments of white chert, both porcelaneous and chalcedonic, dominate the lower two-thirds of Unit B to a thickness of 27 m. As observed by Price (1963), chert fragments are all broken cleanly by the drill bit, as if derived from slabs larger than the 9-inch diameter of the well bore. Scarce remains of crinoid ossicles suggest an ultimate Mississippian limestone source. The upper portion of Unit B features the more typical, fine- to medium-grained, kaolinite-indurated, sphaerosideritic quartzose sandstone with subordinate beds of black coaly shale. The unit includes lignite in the upper 6 m.

Unit C samples indicate a rather uniform suite of white kaolinite- and silica-cemented, fine-grained quartzose sandstone with some calcareous and marly interbeds, as well as brown siderite- and brassy pyrite-cemented beds. A coal bed, capped by a shale that has been oxidized red, marks the unconformity with the Cantuar Formation.

In contrast, the overlying Cantuar Formation at the Insinger No. 1 well is dominated by fine-grained quartzose sandstone, siltstone, and mudstone variably cemented with calcium carbonate and/or kaolinite. The argillaceous matrix ranges from white through green, grey, and dark grey. Brown sphaerosiderite of coarse sand grade, made up of siderite-cemented aggregates of fine-grained quartzose sand, is well represented at intervals of 12 to 18 m.

Likewise, depositional sequences show a tendency to coarsen upward from calcareous mudstone to very fine grained quartzose sandstone. Accessory minerals include green biotite, muscovite, finely disseminated pyrite, and white kaolinitized feldspar.

Detailed sample descriptions are as follows:

Sohio Western Pet Insinger 1 9-16-29-7(W2), KB 519.7 m (1705 feet)

Unit C

491.0 m	Shale: hematite red.
494.0 m	Coal: black, shiny.
497.2 m	Sandstone: quartzose, medium and coarse grained, abundant white and pink feldspar, iron-stained quartz-biotite aggregates.
500.2 m	Sandstone: quartzose, fine grained, well sorted, white, siliceous, kaolinite indurated, microvuggy, noncalcareous.
503.3 m	Mudstone: white, siliceous, kaolinitic, brittle, earthy.
506.3 m	Mudstone: finely speckled with brown siderite. Also sphaerosiderite, dark brown, coarse grained; some grains are magnetic.
509.4 m	Sandstone: quartzose, fine grained, white, well sorted; grain contact calcite cemented.
512.4 m	Sandstone as 509.4 m.
518.5 m	Marlstone: grey-white, well indurated, hackly fracture.
521.6 m	Sandstone: quartzose, fine grained, well sorted, pyrite cemented; also white, fine-grained quartzose sandstone speckled with siderite, and coarse-grained, spheroidal, siderite-cemented aggregates of fine-grained quartzose sand.
524.6 m	Sandstone as 521.6 m.

Unit B

527.7 m	Lignite: mostly durain with minor vitrain and carbonaceous shale.
530.7 m	Lignite as 527.7 m.
533.8 m	Sandstone: quartzose, fine to medium grained, partially pyrite cemented.
536.8 m	Sandstone: quartzose, fine to medium grained, white, kaolinite indurated, noncalcareous; also coarse-grained, sphaerosiderite-cemented aggregates of fine-grained quartzose sand.
539.9 m	Coal and carbonaceous shale: also medium grey, micaceous shale.
542.9 m	Sand: coarse-grained quartz, white and pink feldspar, black chert, quartz-biotite clusters and green lithic fragments; some quartz shows crystal faces (cavings?).
546.0 m	Sand as 542.9 m.
549.0 to 562.2 m	Chert fragments: porcelaneous, milky white, aphanitic; trace of silicified crinoidal columns, compound pisolites, silica druse; sharply angular; some pyrite-infilled fractures; also chert, white, earthy, porous, which may also rim porcelanite. Some black shale.
562.2 to 576.5 m	Chert fragments: chalcedonic, translucent, light grey, abundant platy shards; also about 30% porcelanite and black, bituminous shale. Limonite-infilled (rust) fracture and interstitial filling at 573.4 m.

Unit A

579.5 m	Coal: black carbonaceous shale and medium grey shale. Also sandstone, quartzose, fine grained, pyrite cemented.
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582.6 m	Sandstone: quartzose, fine to medium grained, pyrite cemented, black and gold flecked; also coarse grained and grit size; unfractured grains are rounded.
585.6 m	Sandstone: quartzose, fine to medium grained, poorly sorted; abundant black chert; larger grains are rounded, well cemented in microcrystalline quartz; some grains sutured to pyrite-cemented sandstone.
588.7 to 607.0 m	Grit: quartzose, subrounded; clear and frosted quartz grading in size to medium; abundant black chert, red and buff dolomitic mudstone and argillaceous dolomite disappearing below 588.7 m. Pyrite-cemented, fine-grained quartzose sandstone, iron-rusted in part and at base; abundant white chert.
610.0 m	Shale: black, waxy, and hard. Contact on tan, microcrystalline dolomite of the Torquay Formation.

Unit A occupies the lows of the pre-Success topography, and is therefore apt to be present on the Devonian Three Forks flatlands fronting the Mississippian escarpment, as well as in the structural depressions of the Duperow and Souris River formations. A cored portion of the unit at Northern Gas Kamsack 16-28-29-32(W1) (Figure 11; Appendix A) revealed, at 381.0 to 382.8 m, a very fine and fine-grained quartzose sandstone with a grey-white, siliceous, kaolinitic matrix and calcite cementation toward the base, overlying a karst breccia of variegated red, yellow and grey mudstone at 382.8 to 396.2 m. Coaly beds and basal coarse- and/or medium-grained quartzose sandstone appear to be consistent components across the northern region. The unit has been traced 120 km northwest from the reference well to, for instance, the Pheas Homestead Yellow Ck 16-9-43-21(W2) well, where it forms the bulk of the Insinger beds below the Dina.

Unit B, as traced by its conspicuous porcelaneous chert beds, apparently overlaps Unit A southward onto the Mississippian limestone-capped Punnichy uplands where it forms the basal unit in the many deep karst valleys. The chert beds are readily recognizable in the samples from many wells in the region: Dome Naco Tantallon No. 14-1 (Figure 11) and SWP Bredenburg 9-14-23-33W1, 150 and 85 km, respectively, to the southeast of the reference well; Husky Phillips Fitzmaurice No. 1 (16-18-27-8W2) and Transgas Brewer 12-15-23-6(W2), 16 and 32 km, respectively, to the south; and KR Pheas et al Punnichy DD 7-29-28-16(W2), 90 km to the west. Likewise, its coal beds are widespread throughout the region, although their thickness is unknown because of imprecise data and the general lack of density logs.

At Tidewater Wishart Crown No. 1 (13-21-30-13W2), where the Success lies on the Bakken Formation, at depth below KB of 492.3 to 522.4 m, Unit B comprises two mudstone-sandstone successions. The lower sequence, at 510.5 to 521.2 m, is dominated by a fine-grained quartzose sandstone with a white and light greenish grey, partially silica-cemented kaolinitic matrix, and an abundance of white siliceous pebbles and nodules over its lower third. It overlies a 1 m thick rubble bed of variegated red, green and white mudstone, claystone, and argillaceous, very fine grained quartzose sandstone. The 10 m thick mudstone of the upper succession, at 500.5 to 510.5 m, is ochreous red, earthy, and massive. The overlying sandstone, at 492.3 to 500.5 m, is quartzose, bimodally very fine and medium grained, and grey-white but speckled with about 7% red-brown sphaerosiderite of coarse sand grade, ochreous red from 493.8 to 499.9 m, and includes black shale cobbles near the base. Both sandstone units appear to have originated as fluvial channel deposits in an alluvial plain. In some wells, such as Sohio Baysel Foam Lake No. 2 (8-14-31-10W2) and Sohio Baysel Foam Lake 1-34-31-9(W2), the Success Formation includes variegated sideritic shale, black shale, and thin coal.

At Tidewater Beaver Hills Crown No. 1-5-26-9(W2), Unit B features: 1) a basal, 10.7 m thick rubble of white kaolinitic and tripoli mudstone and sandstone in white porcelaneous chert debris; 2) a medial, 4.6 m thick zone of glauconitic, argillaceous, fine-grained quartzose sandstone with pebble-size, black, pyrite-cemented nodules; which grades up into 3) a green- and cream-coloured kaolinitic shale with abundant glauconitic spherules and burrow fill. The shale is typical of the Success S1 Member, and thus may represent the most northerly expression of this marine unit. At Tidewater Ituna No. 2 (4-32-25-11W2), where the Success rests on the Middle Jurassic Gravelbourg Formation, upward-coarsening from mudstone to sandstone is indicated in three successions, of which the lowest is 3.7 m thick. The medial succession is 10.1 m thick and dominated by kaolinite-indurated sandstone that includes well-sorted, permeable, oil-stained beds. The section is completed by carbonaceous shale, 3.9 m thick, with capping lignite under argillaceous, kaolinite-indurated sandstone interbedded with shale and partially cemented with limonitic ironstone. Carbonaceous and calcareous shale in upward-coarsening sequences suggests progradation in a lagoon or coastal re-entrant such as a deltaic embayment. Thus, this section and that at Tidewater Beaver Hills Crown No. 1-5-26-9(W2) indicate the former existence of a Success coastal setting, which had encroached upon a subsiding Punnichy Arch.

Unit C, away from the local Success thicks, is erratically distributed on the upper terraces of the pre-Success erosional surface and by onlap is the most widespread of the Success units. Thus, in the core from California Standard Ratner 1-15 (1-15-48-17W2), the remnant Success body, over the depth interval of 322.8 to 334.8 m, is taken to be Unit C of the Insinger beds. It consists of well-indurated, variegated in Liesegang, calcareous and kaolinitic, very fine grained quartzose sandstone and coarse siltstone that were originally interbedded and cross-laminated, but are now broken, stretched, and microdeformed. The contact on the Souris River Formation is marked by a conglomerate that includes clasts of the underlying limestone.

Meadow Lake District

The most northwesterly body of the Success beds lies between Twp. 59 and 68, Rge. 8W3 and 23W3 of west-central Saskatchewan (Figure 6). There, it overlies the Upper Devonian Souris River Formation in the former Middle Devonian Lower Elk Point evaporite basin (*i.e.*, that region north of the Meadow Lake Escarpment). The abrupt thickening of both the Success beds and the overlying Mannville Formation is attributed to lowering of the depositional floor by dissolution of the underlying Devonian salt beds (Fuzesy, 1980). A Success section, comparable in lithological characteristics and thickness to that in the reference Sohio Western Pet Insinger 9-16-29-7(W2) well, is present at Cdn Seaboard Meadow Lake 3-21-63-15(W3). It is 145.4 m thick, lies between the Cantuar and Upper Devonian Souris River formations at a depth of 381.3 to 526.7 m, and consists of three units, as described below from the well cuttings.

Unit C

381.3 to 422 m	Sandstone: quartzose, medium grained, buff, partially kaolinite indurated; lower part of unit includes thin pebbly layers of quartzose grit. Beds coarsen upward from shale to capping, cemented, fine- and medium-grained quartzose sandstone in the upper part. Thin coaly layers occur at 396 to 402 m. Unit underlies coarse-grained, quartzose, weakly cemented sandstone of the Dina Member of the Cantuar Formation.
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Unit B

422 to 467 m	Sandstone: quartzose, fine to medium grained; interbedded with coaly shale and buff, kaolinitic mudstone; abundant chert over the lower half (439 to 457 m).
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Unit A

467 to 527 m	Sandstone: quartzose, coarse and medium grained; subordinate grit, light grey; kaolinite and pyrite cemented.
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Depositional Pattern

Although not restricted to the Success Formation, the quartz-kaolinite suite is universal to all of the homologous bodies. However, concentrated weathered chert is common in the Success Formation only for those deposits of central Saskatchewan immediately overlying and north of Mississippian limestone paleo-exposures. As in the Kindersley region, tripoli is a product of weathering, whereby the 200 m thick mass of cherty limestone was partially reduced, by dissolution, brecciation, compaction, and redistribution, to rubble. Thus, provenance of the cherty facies is local and directly traceable.

As for the quartz-kaolinite suite, the widespread distribution of kaolinite, both as allochthonous matrix and as an *in situ* product of feldspar decomposition, reflects intense weathering in a climate marked by high rainfall. The provenance of this suite is traceable to a granite-syenite terrain on the Precambrian Shield of Saskatchewan, Manitoba, and Minnesota. In addition to the Success Formation, the quartz-kaolinite facies is present in the entire section of the Mannville in east-central Saskatchewan and adjacent Manitoba, and in the continental facies of the Oxfordian Roseray Formation in southern Saskatchewan (Christopher, 1974, 1984b). Similarly, in the Moose River Basin of northwestern Ontario, a quartz-kaolinite facies occurs continuously from the Middle Jurassic Mistuskwia beds into the overlying Albian Mattagami Formation (Telford and Verma, 1982; Try *et al.*, 1984). The major upland contributing quartz and kaolinite to the basins west and east was the Severn Arch of north-central Manitoba (Porter *et al.*, 1982, Figure 16).

The Success Formation of southern Saskatchewan represents a northward transition from a marine to continental setting. This is evident in the S1 member in the southwest and in the S2 member in the southeast. The true nature of the transition is revealed by the underlying Roseray Formation, which displays a northerly facies shift from

glauconitic offshore sand and shale to shoreface quartzose sandstone and continental quartzose, kaolinite matrix-rich sandstone and mudstone, as well as a point-source shift from west to east (Christopher, 1974). The dense spacing of cores in the S2 member of southwestern Saskatchewan also permits the detailing of a distinctive fluvial deposit laid down in a meandering and braided stream system (Leckie *et al.*, 1997b), the flood plain of which prograded south onto the central Montana platform. In southeastern Saskatchewan, the extant section indicates a delta front overlooking a large embayment of the marine Williston Basin.

With respect to the Kindersley district, the sedimentary fabric of the Success Formation lacks the characteristics of organized sedimentation, such as regular grade-size distribution and bedding textures. Rather, the rocks are characterized by slump and collapse deposits, and fabrics are distorted by differential compaction and molding, and intense leaching, which at some localities have replaced more than 100 m of limestone. The foregoing reflects partial chert and mud detrital infill of a terrain of karst valleys and sinks. The widespread abundance of spherosiderite in these sediments likely indicates overbank flood conditions (*i.e.*, a depositional floor that was alternately flooded and desiccated). Restoration of the pre-karsted Mississippian limestone surface would, in effect, restore the topographic surface on which the quartzose kaolinite deposits were introduced to the district from sources to the northeast, as by-products of a Precambrian Shield-sourced fluvial system flowing southward onto the Swift Current Platform. Slow collapse of the underlying limestone bedrock in the dome of the upwarped Kindersley structural terrace eventually choked off the southerly drainage and created incipient lacustrine conditions, chaotic drainage, and sedimentary bypass.

The Success sediments on the Punichy Arch are inlaid in a westerly trending valley system entrenched along the axis of the arch, in which detrital chert is the characteristic rock fragment in the lower two-thirds of Unit B. Chalcedonic chert is detectable in these quartzose sandstone units as far to the northwest as the Seaboard Meadow Lake well in Twp. 63, Rge. 15W3. All units feature beds fining upward from kaolin-rich, quartzose gritstone and coarse-grained sandstone to fine-grained quartzose sandstone, mudstone and coal. Sphaerosiderite is ubiquitous. These criteria indicate an aggradational environment of river channel, overbank and, finally, lacustrine swamp deposits, either infill of subsiding regional basins or the abandoned channels of migrating rivers. The obvious source of chert was the Mississippian limestone-armoured uplands to the southeast, which overlooked the Insinger lowlands. In this context, Unit B is the eastern counterpart of the detrital chert facies in the Kindersley district.

Influx of the quartz-kaolinite suite was apparently controlled by a subsequent river system flowing northwest from Manitoba toward northern Alberta along the fronts of the Devonian cuestas. The Punichy Arch, during Success S1 and S2 times, would have been a water divide between that drainage system and others to the south of the arch, emptying into the Late Jurassic (Swift, Success S1) depositional sites peripheral to the Williston Basin of southeastern Saskatchewan. Although the drainage directions would have been counter to the Rocky Mountain-sourced streams of today, the paleotopography would have been similar; wherein the northern drainage was aligned with the present-day course of the Saskatchewan River in the east and with that of the North Saskatchewan River to the northwest of Saskatoon.

By the latter half of Unit B and into Unit C time, the Punichy Arch and Kindersley structural terrace were all but buried under the progradation of Success S2 quartzose kaolinite sediments onto the Swift Current Platform in the southwest. In the east, incipient subsidence of the Punichy Arch is indicated by the encroachment of calcareous facies from the Williston Basin.

Mannville Group (Restricted)

Distribution

The Cantuar Formation is separated from the Success Formation by an erosional surface that not only truncates the Success but oversteps it to become the sub-Mannville unconformity on all of the Paleozoic formations. It is separated from the Pense Formation by a flat erosional disconformity. In contrast, the sub-Cantuar erosion surface, especially in southern Saskatchewan, is deeply incised to depths of 100 m. Much of this dissection is conditioned by the larger structural elements of the basin and is deepest across the Swift Current Platform in the southwest, where a valley system radiates from off its crest to the northwest, north, and east. These valleys may enclose the entire section of Cantuar strata, such that the basal units of the Cantuar lie in physical contact with Middle Jurassic formations in the walls of the valleys, and the youngest Cantuar units at the top of the valley fill are laterally juxtaposed with the Success Formation that caps the divides (Christopher, 1974).

Similar deep valleys are entrenched on the Kindersley structural terrace. These are easterly, east-northeasterly, and westerly trending axial valleys in which the Cantuar deposits fill in erosional cuts through Success strata into the Paleozoic formations. On the crest of the Punnichy Arch, these valleys are entrenched on Success and Upper Paleozoic strata as part of a subsequent paleodrainage system tributary to a northerly consequent valley across the arch near the western front of the Moosomin–Hudson Bay escarpment along longitude 102°W. Elsewhere, because of tectonic downwarp of the erosion surface, the Cantuar Formation is a regional blanket, the basal units of which overwhelm the underlying relief. Accordingly, the thickness of the Cantuar is highly variable (Figure 12). The 100 m isopach along latitude 52°N differentiates regional values, which increase to 240 m in the extreme northwest from lesser values to the south. The northern region, from a 250 km width at the Saskatchewan–Manitoba boundary, opens westward to a 500 km front extending north from Unity to the Clearwater River at the Saskatchewan–Alberta boundary. Although a significant number of thins, representative of draped sub-Mannville highs, occur, the northern region is largely flat floored. Thinning across the broad northern flank reflects either a monocline or low density of data, whereas the detailed relief along the southern flank is related to onlap of dissected uplands and to proximity of the Middle Devonian Prairie Evaporite salt edge.

In the major topographic regions of the west and southwest (*i.e.*, the Kindersley and Swift Current pre-Cantuar paleo-uplands), thinning occurs by onlap of Mannville units onto southerly dipping strata that crop out on a southerly rising topographic surface. Much of the height of the Swift Current Paleo-upland therefore remained above the Cantuar depositional base and is devoid of Cantuar strata. In contrast, thinning over the Punnichy Arch east of the Third Meridian (longitude 106°W) and the Moosomin Paleo-upland is erosional, both intraformationally and pre-Pense (*i.e.*, Early Albian in age). As a consequence, the Cantuar is truncated through to underlying formations. On the Kindersley Paleo-upland, isolated zero points on the isopach map also reflect pre-Pense planation, but of Mississippian horsts on draped salt-dissolution structures (*e.g.*, at CS New Superior et al Ermine 9-2-33-22W3).

The Cantuar isopachs delineate many of the major underlying paleovalleys, although more broadly than those of the basal McCloud Member. The most conspicuous paleovalley is the integrated system of the Assiniboia, which is traceable from its headwaters in the Swift Current uplands and the Central Montana Platform (Christopher, 1984b), along the southern edge of the province, and north and northwest past Broadview, Yorkton and Prince Albert to north of Lloydminster. Valleys south of the Punnichy Arch are entrenched below broad flats, 100 to 200 km² in area, on which relief varies by less than the contour interval of 20 m. General thickness of the Cantuar ranges between 20 and 60 m but increases south of latitude 50°N to 100 m between Broadview and Estevan. Lack of increase in regional thickness toward the Canada–United States border indicates dormancy of the Williston Basin at that time.

A number of closed isopach thicks are present, mostly west of the Third Meridian. Those in the east are concentrated on the Watrous Dome east of Saskatoon. They are amoeboid in shape and, with one exception, enclose about 20 m of thickening. All of the large ones in the west occur in the vicinity of, or straddle, the northeastern and southwestern salt-dissolution fronts of the western body of the Prairie Evaporite (Figure 12). From south to north, these are:

- 1) a southeasterly trending, 25 to 35 m incremental thick corresponding to the Eastend–Maple Creek trough (Christopher, 1974), which here is linked across the salt-dissolution edge with the sub-Jurassic easterly depression (Adams Creek Trough; Christopher, 1966) along the Frenchman River;

- 2) a shallow (10 m or so) amoeboid thick with northeasterly fingers and general east-west distribution in the region between Rosetown and the South Saskatchewan River;
- 3) a string of thicks, ranging in incremental thickening from 20 to 75 m and associated with the north-northeasterly trending sub-Cantuar Kindersley valley; the most northerly of these thicks doubles in width and turns north toward the re-entrant in the salt-dissolution front at Rge. 10W3, under the bend of the North Saskatchewan River; and
- 4) a series of curvilinear depressions, 30 to 80 m deep, coincident with the salt-dissolution front of the Middle Devonian Prairie Evaporite from east of Lloydminster to the Beaver River.

The foregoing anomalies indicate that: a) although salt-dissolution activity was not a dominant factor in the Cantuar depositional basin, it was locally significant west of the Third Meridian; and b) the present edge of the Prairie Evaporite has not shifted much beyond the edge of the anomalies. The largest displacement appears to have been about 50 km westward in the case of (4) above.

Lithology of the Mannville Group

The evolution of Mannville terminology in the Lloydminster region can be traced from its origin with Nauss (1945) at the type Northwest Mannville No. 1 well (L.S. 1-15-50-8W4) in east-central Alberta, through its adaptation by Wickenden (1948) at the cored reference Community Services No. 29 well (L.S. 5-10-50-26W3) and the contributions of Ambler (1951) and Kent (1959), to the currently used nomenclature subdivisions by Fuglem (1970) and Vigrass (1977). Vigrass (1977) designated the geophysical log from the Aberfeldy Unit SWD A11-31-49-26W well as the type for the Lloydminster petroleum district and, in the absence of core from this well, presented a generalized description of the Mannville members. The history of Mannville nomenclature in southern Saskatchewan, based on Price (1963) and Maycock (1967), is presented in Christopher (1974).

The Mannville members of current usage are (oldest to youngest): Dina, Cummings, Lloydminster, Rex, General Petroleum (GP), Sparky, Waseca, McLaren, and Colony. Vigrass (1977) combined them into three formations: Lower Mannville (Dina, Cummings), Middle Mannville (Lloydminster, Rex, GP, and Sparky), and Upper Mannville (undifferentiated Colony-McLaren-Waseca). Generalization of the Upper Mannville units reflects, in part, the original definitions of Nauss (1945) and Wickenden (1948). Putnam (1980) also extended the range of the Waseca upward at the expense of the McLaren and Colony members because he found that the geophysical logs did not provide an effective basis for discriminating between these units. This report retains the nomenclature of Vigrass (1977). The Colony is regarded by some as a basal Joli Fou unit by virtue of its marine aspect and an underlying unconformity, and thus a correlative of Stelck's (1958) St. Edouard Member. In this report, the Pense Formation of southern Saskatchewan, based on geophysical log and core correlation, is deemed inclusive of the Colony and McLaren members. The remaining Mannville units from the Waseca to the Dina are members of the Cantuar Formation.

Much of what is known about the Mannville setting in the Lloydminster region came from studies conducted by the staff of Husky Oil Ltd. during the 1950s and 1960s, and published by Fuglem (1970). Marine and restricted marine fauna, in particular foraminifera, are present in each of the Mannville members from the Cummings to the Waseca, inclusive. At the Blackfoot Devonian Test Syndicate No. 1 well (L.S. 12-15-50-2W4) of Alberta, recoveries were as follows:

Cummings shale - *Marginulinopsis* cf. *M. collinsi* *Miliammina sproulei*, *Miliammina* n. sp.?, *Arenobulimina tortula*, and *Ammobaculites* sp.;

Lloydminster shale - *Spiroplectinata* cf. *S. battenstaedei*, *Verneulinoides cummingensis*, *Quinqueloculina* sp., and *Miliammina* n. sp.;

Rex shale - *Gaudryina* cf. *stattei*, *Bathysiphon* sp., *Hippocrepina* n. sp., and *Miliammina* sp.;

Sparky shale - *Hippocrepina*, *Bathysiphon*, and *Saccamina*; and

Waseca shale - *Hippocrepina*, *Microcarpolites*, and *Reophax*.

In Saskatchewan, foraminifera were collected from all units above the Dina in the Northern Development C.S. No. 29 well (L.S. 5-10-50-26W3).

Atkin (1986) presented a detailed listing and description of foraminifera in the Mannville as far southeast in western Saskatchewan as Duval Saskatoon 6-18-36-6W3. The Cummings shale in the Maple Creek area of southwestern Saskatchewan is also reported to contain foraminifera (Christopher, 1974).

Many of the conceptual stratigraphic difficulties that arise in dealing with the Mannville units are caused by facies changes within them. Specifically, marine character and stratigraphic consistency tend to dissipate into alluvial lithologies inset with fluvial and estuarine channel bodies at some point upslope beyond the shallows and strands of the depositional sea floor. The facies also include four main mineral suites: 1) white quartz–kaolinite–black chert in the northwest and west; 2) white quartz–kaolinite–muscovite in the east and south; 3) green biotite–chlorite–kaolinite in the southwest and northwest; and 4) in the central region of the basin, a mixed facies dominated by medium and dark grey mudstone and shale, bioturbated mudstone and shale, and fine-grained quartzose sandstone, with accessory glauconite and pyrite, and subsidiary coal. Eastern and northern facies reflect sources on the Precambrian Shield, such as sandstone of the Athabasca Group and a weathered granitoid terrain, whereas western facies indicate input from chert-rich Rocky Mountain Paleozoic rocks and Mesozoic volcanic sources (Christopher, 1974, 1984b; Putnam, 1980).

Mapping of the Mannville assemblage of lenticular quartzose sandstone, siltstone, mudstone, and sub-bituminous coal is based on the premises that: 1) the marine shale units can be used as correlation horizons; 2) provenances of the mineral suites are distinguishable; and 3) the extremely low depositional gradients make possible the extrapolation of correlation horizons from one locality to another. Cyclic bedding, of which as many as 34 are recorded in a complete Mannville section, ranges from basal shale through sandy mudstone to sandstone with capping coal, as well as the reverse, from basal sandstone to mudstone and shale. Where wells are closely spaced, as in the Lloydminster oilfields, and the economic focus is on the sandstone bodies of a particular member, any lithological entity can be a correlation criterion over short distances, although coal and shale are favoured. Differences from worker to worker in the extrapolation of a given member top occurs inevitably within a township or two; however, these are not dwelt upon in this report.

Regional correlation of the Mannville members is based on control lines initiated in the northwestern part of the province, where marine shale units are most pronounced, and traced to the southeastern border region of Saskatchewan along the track of their farthest persistence. A Lower Colorado stratigraphic marker is taken as datum. Recognition of the sub-Mannville contact as a topographic or a tectonic base determines whether or not the overlying stratigraphic contact is one of onlap or structural warp. Sub-Mannville topographic control results in the loss of Mannville units by basal onlap against highs. Intra-Mannville tectonic control is reflected in the generalized conformity of member contacts with the basal unconformity, and loss of stratigraphic units by internal overlap and/or by erosional truncation against the basal contact of the Pense Formation. Each member of the Mannville includes transgressive and regressive facies and, in its simplest form, is mapped as beginning with one of the former and ending with one of the latter. The overall setting of the Mannville appears to be transgressional from the northwest against a countering progradation from the southeast in the Lower Mannville and southwest and northeast in the Upper Mannville.

Practically all members include truncated bedding sequences, erosion channels, and corresponding erosion and exposure surfaces as products of an oscillatory strand. Detailed mapping in the Lloydminster oilfield district has been used to delineate the geometry of individual marine and continental bodies, ranging from offshore sand sheets to shoreline beach and tidal-channel deposits to onshore deltaic and marsh sediments. Detailing of these individual forms lies beyond the scope of regional mapping, so they are simply included between member contacts as relicts and palimpsests (Swift *et al.*, 1971) in the overall transgression and regression. The measurement of bedding cycle thickness in cores of the offshore and shoreline deposits of the Mannville indicates an upper limit of about 20 m. This is a measure of the amount of sea-level rise and fall, and therefore a control on the amount of base-level change permissible in the correlation framework.

The basic lithological category used in the description of cored Mannville sections in this report is the tripartite reversible-bedding cycle of shale, mixed shale and sandstone, and sandstone. In the deeper parts of the Mannville basin, these may represent cyclic sedimentation of the order a, b, c, b, a, where a is shale, b is mixed sandstone and shale, and c is sandstone. However, over most of Saskatchewan outside of the northwestern region, the hemicycle on an erosional contact prevails as the dominant upward-coarsening and the subordinate upward-fining bedding facies. The bedding cycle is an apparent nomenclature equivalent of the term ‘parasequence’, as used by Pemberton and Wightman (1994) in the Lloydminster district of east-central Alberta. Because of the regional nature of this study, however, no persistent attempt has been made to use the bedding cycle as a correlation tool. The basic lithological correlation entity used in this report is the ‘unit’, which generally includes one or more bedding cycles. It corresponds, more or less, to a parasequence set (Waggoner *et al.*, 1987) in a coastal to shelf setting or, perhaps, to a transgressive sequence in the usage of Embry (1993), in that reliance is placed on the trace of subaerial pavements and overlying transgressive beds. A Mannville member includes one or more units.

Shell Husky Paradise Hill A13-19-52-23W3 Reference Section

Fourteen full-section cores of the Mannville are correlated in the stratigraphic cross-sections A1-A1' (Figure 13), A2-A2' (Figure 14), and A3-A3' (Figure 15). These are tied into the Paradise Hills reference section and serve as stratigraphic reference-control points for this study. Except for the reference section described below, the detailed descriptions of the other cores are included with those of selected partial sections in Appendix A, but are annotated in the text.

Fuglem (1970) gave a general account of the depositional setting and a list of the foraminifera from the Northern Development CS No. 29 well (L.S. 5-10-50-26W3). However, a lithological log of the section was not issued, and the core has suffered from the wear of three decades of inspection. Thus the section at the Shell Husky Paradise Hill A13-19-52-23W3 well is here designated a standard reference section for the Mannville Group of Saskatchewan. The section is tied into the Husky Aberfeldy Unit SWD A11-31-49-26W3 reference well of Vigrass (1977), via the north to south regional stratigraphic cross-section A-A' (Figure 16).

Shell Husky Paradise Hill A13-19-52-23W3, KB 613.3 m

Joli Fou Formation

443.75 to 452.75 m Shale: dark grey, fissile; at 445.25 to 446.40 m, minor interbeds of sandstone; quartzose, very fine grained, thin, current bedded, fragmented, medium grey-green; grey-black with scattered beds of rusted, current-scoured, fine-grained quartzose sandstone with coquina and glauconitic pods below 448.25 m.

Pense Formation - Colony Member *Bedding Cycle 6 (3.7 m)*

452.75 to 453.91 m Sandstone: quartzose, very fine grained, strongly intermixed with dark grey mudstone; podded and generally bioturbated; oxidized brown over upper 0.18 m; becomes shaly downward; sharp contact.

453.91 to 454.68 m Claystone: light green-grey, soft to splintery; sharp contact.

454.68 to 456.45 m Sandstone: quartzose, very fine grained; dark grey argillaceous matrix; speckled with black carbon dust; current bedded, platy on shaly partings, some distortion; abundant, pebble-size, brown, round and bedding-elongated siderite concretions; includes a 15 cm thick claystone bed similar to that at 453.91 to 454.68 m, 8 cm above base; sharp contact.

Bedding Cycle 5 (2.69 m)

456.45 to 457.62 m Mudstone: clayey, dark grey, crumbly, abundant carbonized plant fragments; black and coaly over lower half; gradational contact.

457.62 to 458.12 m Sandstone: quartzose, fine grained, dark grey, argillaceous, oil stained; about 10% carbonaceous, shale-draped, current-bedded laminae and partings; microfaulted at base.

458.12 to 458.62 m Sandstone: quartzose, fine grained, argillaceous and loamy (*i.e.*, homogenized but includes vertical fractures and burrowed, oil-stained sandstone); grades over lower half into black carbonaceous mudstone with blebs of coal.

458.62 to 459.14 m Sandstone: quartzose, fine grained, argillaceous, medium grey, burrowed, mottled with oil stain; argillaceous content increases downward and becomes carbonaceous and grey black; sharp, irregular contact.

Pense Formation - McLaren Member *Bedding Cycle 4 (1.71 m)*

459.14 to 460.42 m Sandstone: quartzose, very fine grained, well sorted, low-angle current bedded; weakly indurated, permeated with heavy oil; subordinate shaly laminae over basal 0.2 m.

460.42 to 460.85 m Mudstone: dark grey, subordinate sandy layers down to 460.53 m at coaly layer, 4 cm thick; below, platy with grey-black shale partings ending in fissile black shale.

Bedding Cycle 3 (2.45 m)

- 460.85 to 461.97 m Sandstone: quartzose, very fine grained, well sorted, weakly indurated, heavy-oil permeated; scattered layers of dark grey shale with some contortion; contact sharp.
- 461.97 to 462.50 m Mudstone: dark grey, platy; abundant carbonized plant fragments; minor oil-stained sandy rolls; grades into
- 462.50 to 463.30 m Shale: dark grey, fissile to platy; scattered lenticular laminae of light grey, very fine grained quartzose sandstone; grey-black, argillaceous and carbonaceous sandstone, 5 cm thick at base.

Bedding Cycle 2 (7.52 m)

- 463.30 to 464.05 m Shale: black, carbonaceous and coaly; medial quartzose, very fine grained, oil-stained sandstone at 463.36 to 463.55 m.
- 464.05 to 466.00 m Siltstone: quartzose, medium grey, argillaceous; contorted at top; subordinate interbeds of very fine grained, heavy-oil-permeated sandstone, ranging in thickness from 3 to 15 cm; abundant sand-filled, randomly oriented cylindrical burrows.
- 466.00 to 470.82 m Sandstone: quartzose, bimodal; fine grained with subordinate very fine grained; moderately indurated; heavy-oil-permeated thicker beds at 466.13 to 466.50 m, 466.85 to 467.08 m, 467.33 to 467.55 m, and 467.81 to 467.97 m; remainder is thin, medium grey, very fine grained, quartzose sandstone intermixed with silty mudstone; moderately indurated, earthy; sharp basal contact.

Bedding Cycle 1 (1.78 m)

- 470.82 to 472.18 m Siltstone: medium grey, quartzose, argillaceous, platy; abundant lenticular layers of light grey, quartzose sandstone and oblique and criss-crossed burrow casts; ironstone concretionary bed, 12 cm thick, at 471.32 m.
- 472.18 to 472.60 m Shale: dark grey; subordinate very fine grained sandy laminae and pods; intensively bioturbated, medium grey argillaceous sandstone at base; sharp contact.

Cantuar Formation - Waseca Member

Bedding Cycle 7 (3.19 m)

- 472.60 to 473.50 m Mudstone: dark green-grey, platy, moderately indurated.
- 473.50 to 475.00 m Siltstone: quartzose, argillaceous, medium green grey; irregularly bedded with discontinuous, graded laminae of light grey, very fine grained quartzose sandstone; sharp basal contact beneath ironstone layer.
- 475.00 to 475.79 m Shale: olive, with patches of light green; waxy, coarsely fissile; basal 4 cm of black, carbonaceous, argillaceous sandstone.

Bedding Cycle 6 (3.26 m)

- 475.79 to 476.05 m Coal: fusain and vitrain rich; abundant argillaceous partings.
- 476.05 to 476.80 m Sandstone: quartzose, fine grained, current bedded, oil stained; laminated with black carbonized plant detrital shale; rootlet patterned over upper 2 cm; abundant coalified plant stems in basal 27 cm.
- 476.80 to 478.75 m Sandstone: quartzose, very fine grained, well sorted; variable argillaceous component; heavy-oil permeated.
- 478.75 to 479.05 m Shale: dark grey, fissile; abundant pyritic spherulites, muscovite; sharp irregular contact.

Bedding Cycle 5 (6.9 m)

- 479.05 to 481.33 m Sandstone: quartzose, very fine grained; speckled with black carbonaceous specks; medium green-grey, kaolinitic matrix; strongly bioturbated over upper 48 cm; current and ripple bedded with black carbonaceous mudstone drapes; argillaceous content increases over lower half, along with brown ironstone nodules; grades into

481.33 to 485.95 m Mudstone: silty, platy, medium grey; subordinate to minor lenticular laminae and pods of light grey, very fine grained, quartzose sandstone; abundant ironstone nodules; sharp basal contact.

Bedding Cycle 4 (1.7 m)

485.95 to 486.92 m Sandstone: quartzose, very fine grained, well sorted, finely bedded, weakly indurated, heavy-oil permeated; mudstone bed as above at 486.62 to 486.72 m.

486.92 to 487.65 m Mudstone: as 481.33 to 485.95 m, but more bioturbated.

Bedding Cycle 3 (2.35 m)

487.65 to 489.25 m Sandstone: quartzose, very fine grained; argillaceous to silty matrix; tan and grey; laminated and current bedded; subordinate beds of fine-grained, well-sorted, heavy-oil-permeated sandstone, 3 to 15 cm thick.

489.25 to 490.00 m Mudstone: dark grey, minor quartzose sandstone component; bioturbated throughout; moderately indurated, earthy; sharp contact.

Bedding Cycle 2 (12.6 m)

490.00 to 497.50 m Sandstone: quartzose, very fine grained, subordinate fine; silty matrix, grey white, cross-bedded with low-angle truncation sets; weakly indurated, very permeable; heavy-oil permeated over upper 8 cm.

497.50 to 502.60 m Mudstone: dark grey; subordinate light grey, very fine grained quartzose sandstone; bioturbated and podded; sharp contact.

Bedding Cycle 1 (2.9 m)

502.60 to 505.50 Sandstone: quartzose, medium grained, speckled white, black, and brown; tabular cross-bedded; subordinate black chert, carbonaceous grains, feldspar (including plagioclase), chlorite, and brown sphaerosiderite; moderately cemented in white kaolinitic, calcareous matrix; grades upward over upper 26 cm through fine-grained sandstone with minor dark grey, shaly lenticles into terminal, yellow-brown, cemented mudstone.

Cantuar Formation - Sparky Member

Bedding Cycle 3 (7.18 m)

505.50 to 507.00 m Mudstone: dark grey, minor light grey, very fine grained, lenticular quartzose sandstone (poor core recovery).

507.00 to 507.30 m Shale: pale green grading downward to dark grey green.

507.30 to 509.25 m Sandstone: quartzose, very fine grained, argillaceous matrix, moderately indurated, strongly bioturbated, rare U-shaped feeding burrows.

509.25 to 510.56 m Sandstone: quartzose, fine-grained, light grey, subordinate minerals as in 502.60 to 505.50 m; low-angle, current-bedded units interbedded with ripple-drift beds draped with carbonized plant detritus.

510.56 to 512.68 m Sandstone: quartzose, fine grained grading downward to medium; speckled with black and brown; subordinate black chert, carbonaceous grains, brown siderite, feldspar, and kaolinite after feldspar; white kaolinite matrix, earthy, well indurated; low-angle ripple and current bedded; black shaly partings at intervals of 15 cm; sharp contact.

Bedding Cycle 2 (3.32 m)

512.68 to 513.34 m Shale: dark grey, scattered current laminae of light grey, very fine grained quartzose sandstone.

513.34 to 516.00 m Sandstone: quartzose, very fine grained, light grey, bimodal with coarse-grained quartzose silt; moderately indurated, very permeable, faintly bedded; laminated with carbonized plant fragments at 513.84 to 513.96 m, scattered partings below.

Bedding Cycle 1 (1.75 m)

516.00 to 516.85 m	Shale: dark grey, waxy (most of core lost).
516.85 to 517.75 m	Sandstone: quartzose, very fine grained, medium grey, strongly intermixed and bioturbated with minor dark grey mudstone; massive, moderately indurated, earthy.

Cantuar Formation - General Petroleums Member

Bedding Cycle 4 (4.52 m)

517.75 to 517.92 m	Mudstone: dark grey, abundant reedy stalks; capped by coal bed 3 cm thick; sharp contact.
517.92 to 522.27 m	Sandstone: quartzose, very fine and fine grained, argillaceous, medium grey grading over lower half into buff and light grey; columnar fabric, rootlet traces as delineated by iron mineralization and argillaceous matter; alternating beds feature truncational cross-sets on tangential cross-beds; sharp basal contact.

Bedding Cycle 3 (3.23 m)

522.27 to 522.77 m	Shale: dark grey, fissile, waxy; grades into
522.77 to 523.00 m	Sandstone: quartzose, very fine grained, argillaceous, bioturbated; moderately indurated, earthy; sharp basal contact.
523.00 to 525.50 m	Sandstone: quartzose, medium grained, subordinate fine and very fine; subordinate kaolinite after feldspar, black chert, brown sphaerosiderite, and muscovite; moderately indurated in white kaolinite; cross-beds are current, ripple, and low-angle tangential sets; bedding outlined at intervals of 3 to 5 cm by sphaerosideritic concretions; sharp contact.

Bedding Cycle 2 (2.24 m)

525.50 to 527.74 m	Shale: grey black, silty, fissile to platy; thinly bedded with coarse laminae of very fine grained, medium grey, quartzose sandstone forming starved ripples, crenulated lenticles, dewatered compactional bodies; interbedded at 525.90 to 526.36 m with sandstone: quartzose, medium grey, fine grained, well indurated, massive and lenticular; sharp basal contact.
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Bedding Cycle 1 (10.76 m)

527.74 to 534.10 m	Sandstone: quartzose, fine grained, bimodal with silt; grey, low-angle planar cross-bedded over upper 3 cm; massive below; moderately to weakly indurated, very permeable; accessory black chert, plagioclase, kaolinite, and jasperoid quartz; irregular black carbonaceous shale laminae and vertical stringers over lower 2 m; grades sharply into
534.10 to 535.50 m	Sandstone: quartzose, very fine grained, light brown grey, current bedded with small-scale troughs, lenticular; subordinate dark brown-grey silty mudstone; moderately bioturbated with repetitive vertical resting burrows, small oblique feeding burrows; bedding integrity retained throughout; grades sharply into
535.50 to 536.82 m	Siltstone: very argillaceous, dark grey mottled with light grey; bioturbated but bedding aligned.
536.82 to 538.50 m	Shale: dark grey, fissile; 9 cm thick basal layer, sharply interlaminated with underlying sandstone.

Cantuar Formation - Rex Member

Bedding Cycle 4 (3.75 m)

538.50 to 542.25 m	Sandstone: quartzose, very fine grained, abundant black chert; light grey kaolinitic matrix; calcite cemented over upper 1.5 m; faintly flat bedded with scattered burrow casts, earthy; scattered grey-black shaly partings below cemented zone; minor shaly component integrated into sandstone as balls, irregular flowage forms at 541.05 to 541.95 m; basal 35 cm feature light grey, moderately indurated quartzose siltstone, bedded and balled with shrinkage cracks.
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Bedding Cycle 3 (6.3 m)

- 542.25 to 544.30 m Coal and coaly mudstone: black and grey black, 12 cm thick; on claystone, light green-grey, waxy, abundant carbonized reedy fragments; sandy over basal 12 cm.
- 544.30 to 548.55 m Sandstone: quartzose, fine grained, well sorted, weakly indurated, very permeable, light grey; abundant carbonaceous grains; faintly bedded, scattered laminae of carbonized plant dust; below 545.80 m is current, ripple, and ripple-drift laminated; minor light grey and medium grey shale laminae; sharp basal contact.

Bedding Cycle 2 (0.95 m)

- 548.55 to 549.32 m Sandstone: massive, as at 544.30 to 545.80 m; sharp contact.
- 549.32 to 549.50 m Sandstone: as at 545.80 to 548.55 m.

Bedding Cycle 1 (6.84 m)

- 549.50 to 552.00 m (1.0 m recovery) Sandstone: quartzose, fine grained, argillaceous matrix, light grey speckled with black; abundant black chert and kaolinite; current bedded in part with oblique and branching feeding burrow casts over upper 30 cm; strongly bioturbated below with remnants of lenticular, dark grey, mudstone-draped sandstone.
- 552.00 to 556.20 m Sandstone: quartzose, fine grained, abundant black chert; white kaolinite matrix speckled with black; calcite cemented below 553.5 m; faint current bedding, scattered trough truncation sets; scattered branching mudstone-filled *Teichichnus* burrows; dark grey, shaly, crenulated laminae at intervals of 10 to 15 cm, generally at top of burrowed sandstone beds; sharp basal contact.
- 556.20 to 556.34 m Shale: dark grey, splintery; sharp contact.

Cantuar Formation - Lloydminster Member

Bedding Cycle 4 (8.64 m)

- 556.34 to 563.38 m Sandstone: quartzose, fine grained, abundant black chert; medium grey kaolinitic matrix; earthy, well indurated; massive beds interbedded with subordinate beds, 3 to 8 cm thick, of thinly interbedded, wavy and current-bedded sandstone and dark grey shale drapes above 558.22 m and below 559.43 m; low-angle, tabular cross-sets at 562.25 to 562.50 m; *Teichichnus* burrows near top.
- 563.38 to 564.98 m Shale: dark grey, fissile; minor lenticular and wavy laminae and thin layers of light grey, very fine grained quartzose sandstone.

Bedding Cycle 3 (2.72 m)

- 564.98 to 567.70 m Sandstone: quartzose, very fine grained, well sorted, moderately indurated, grey white; wavy cross-bedded with minor thin, dark grey shale drapes; thin dark grey shale beds, 20 to 40 cm thick, at intervals of 20 to 50 cm; massive, well-sorted sandstone over basal 45 cm; sharp contact.

Bedding Cycle 2 (11.2 m)

- 567.70 to 578.90 m Sandstone: quartzose, very fine grained, weakly argillaceous, medium grey; thin bedding marked by ripple- and current-bedded forms with subordinate dark grey shale drape laminae; calcite cemented at 568.0 to 568.35 m; sandy layer becomes graded with increasing shale content downward; grades into shale at 570.13 m; grey black, fissile to papery; ironstone concretionary beds at 573.0 and 578.18 m; sharp basal contact.

Bedding Cycle 1 (13.92 m)

- 578.90 to 592.82 m Sandstone: quartzose, fine grained, light grey speckled with green argillaceous matrix; irregularly interbedded with thin black shale laminae and partings; abundant carbonaceous specks and lesser glauconite; bioturbated and boudinaged by differential

compaction throughout; calcite-cemented layers throughout; sharp irregular contact on oxidized sandstone.

Cantuar Formation - Cummings Member

Bedding Cycle 3 (1.93 m)

592.82 to 594.75 m Sandstone: quartzose, very fine grained, silica cemented and oxidized over upper half; grain-contact cemented, light grey and permeable below; cross-bedded as marked by medium-scale truncational trough cross-sets; also small-scale, black shale-draped trough cuts; basal contact marked by pyritic masses in massive sandstone.

Bedding Cycle 2 (5.63 m)

594.75 to 600.00 m Shale: grey black, silty, fissile to platy; abundant carbonized plant fragments; several thin coaly layers are present; brown ironstone and pyrite concretions over basal 15 cm.

600.00 to 600.38 m Sandstone: quartzose, fine grained, well sorted, poorly cemented, very permeable, medium grey; basal contact marked by boulder-sized ironstone concretion.

Bedding Cycle 1 (10.47 m)

600.38 to 600.41 m Coal: brittle, woody, black, fusain rich.

600.41 to 602.25 m Mudstone: dark grey, clayey; interbedded with argillaceous, very fine grained, medium grey and grey-white quartzose sandstone and rootlet-casted sandstone; large ironstone forms in basal 1 m.

602.25 to 610.85 m Sandstone: quartzose, very fine grained, argillaceous; tends to fracture along vertical columns; weakly indurated, permeable; interbedded with dark grey and green mottled, weakly bioturbated, sandy mudstone with accessory pyrite; shaly, dark purplish grey over basal 85 cm; sharp, irregular contact.

Cantuar Formation - Dina Member

Bedding Cycle 3 (14.15 m)

610.85 to 619.00 m Sandstone: quartzose, very fine grained, current laminated with dark grey shale; 12 cm of vermillion, oxidized sandy loam at top, and 20 cm of hematite-red-weathering rubble of grit in a clayey matrix at 612.25 m; massive sandstone with columnar fractures and abundant brown ironstone nodules below 615.50 m; grades by intercalation of splintery, dark purplish grey, carbonaceous mudstone laminae into

619.00 to 625.00 m Mudstone: medium grey, subordinate very fine grained quartzose sandstone interbedded with shale; dark grey, splintery; abundant green, lenticular, pyritic sandy bodies.

Bedding Cycle 2 (3.0 m)

625.00 to 628.00 m Sandstone: quartzose, very fine grained, light grey; laminated with dark grey shale; current bedded in part; penetrated at intervals of 20 to 30 cm by vertical carbon-filled tubules about 7 cm long and 1 mm in diameter.

Bedding Cycle 1 (22.0 m)

628.00 to 650.00 m Sandstone: quartzose, poorly sorted, medium grained, with minor fine and abundant rounded coarse; argillaceous, very fine pyrite crystals in interstices, as well as abundant coarse-grained, white kaolinite after feldspar; dark grey, permeable; basal 10 m includes coarse laminae of coaly and carbonaceous shale; sharp, irregular contact.

Duperow Formation

650.00 to 651.27 m Limestone: cryptocrystalline, grey white, mottled with brown-red calcareous mudstone; solution brecciated with mudstone infill; dense, interrupted by irregular oblique fractures.

651.27 to 655.77 m Calcilutite: argillaceous to silty, laminated with scoured basal contacts; light grey.

655.77 to 657.25 m Limestone: cryptocrystalline, grey white, solution brecciated; infilled with pinkish red to light grey argillaceous micritic limestone.

The Mannville section at the reference Paradise Hill well is 197.25 m thick. It features 34 cycles, 26 of which are upward-coarsening bedding cycles that range in thickness from a few metres to more than 14 m and are transitional from black shale, through bioturbated black shale and fine-grained quartzose sandstone, to a terminal quartzose, fine-grained, well-sorted sandstone (Figure 13). Eight cycles fine upward from fine-grained quartzose and/or lithic sandstone, generally cross-bedded and cross-laminated, into dark grey shale and mudstone. These cycles are up to 22 m thick. Bedding cycles of both types overlie diastemic breaks, marked by erosional contacts, weathering pavements, paleosols, and coals. Bedding cycles and their thicknesses are as follows (bottom to top):

Dina: 3 cycles (22.0, 3.0, and 14.15 m);
Cummings: 3 cycles (10.47, 5.63, and 1.93 m);
Lloydminster: 4 cycles (13.92, 11.2, 2.72, and 8.64 m);
Rex: 4 cycles (6.84, 0.95, 6.3, and 3.75 m);
General Petroleums: 4 cycles (10.76, 2.24, 3.23, and 4.52 m);
Sparky: 3 cycles (1.75, 3.32, and 7.18 m);
Waseca: 7 cycles (2.9, 12.6, 2.35, 1.7, 6.9, 3.26, and 3.19 m); and
Pense Formation: 6 cycles (1.78, 7.52, 2.45, 1.71, 2.69, and 3.7 m).

The uppermost 3.7 m of the Pense is composed of three thin-bedded units, each on erosional contacts, that have been treated as one upward-coarsening unit.

Virtually all of the shale units are foraminiferal, changing from marine to brackish marine upward in the section (Atkin, 1986). The succession from feeding-burrowed sandstone and grey-black shale, through laminated sandstone-shale containing escape burrows, to cross-bedded and well-sorted sandstone indicates a build-up of sediments into the surf zone from a deeper water base. Subaerial exposure is indicated by capping soils, weathering zones, and/or thin coal beds. Each upward-coarsening cycle represents a relatively abrupt marine incursion of a deepened depositional floor, followed by progradational infill and shoaling.

Above the 22 m thick basal unit of the Dina Member, which consists of poorly sorted, medium- and coarse-grained massive sandstone, the upward-fining bedding cycles are thinner and finer grained. These are bedding cycles 3 and 4 (3.23 and 4.52 m) of the General Petroleums Member, all cycles (1.75, 3.32, and 7.18 m) of the Sparky Member, and cycles 1 and 7 (2.9 m and 3.19 m) of the Waseca Member. In an overall setting above the Dina of fine- and very fine grained sandstone, the basal bed (523.0 to 525.5 m) of cycle 3 in the General Petroleums Member features bimodal, low-angle trough- and ripple-cross-bedded, medium- and fine-grained quartzose sandstone, with a subordinate suite of feldspar, black chert, brown sphaerosiderite and muscovite in a matrix of white kaolinite. Argillaceous, bioturbated, very fine grained quartzose sandstone, overlain by dark grey shale, completes the cycle. The feldspar-kaolinite matrix and overall fabric of the basal bed indicate proximity of a point source, probably a river. Avulsion and drowning of the channel by marine advance ensued. Bedding cycle 4 apparently reflects a return to alluvial and marshy conditions (*i.e.*, a weak progradation at the site).

Succeeding upward-fining cycles of the Sparky (516.0 to 517.75 m and 512.68 to 516.0 m) reveal a repetition of the drowning episodes. The third cycle (505.5 to 512.68 m) includes a basal sandstone (510.56 to 512.68 m) that displays the same fluvial channel suite and fabric as cycle 3 of the General Petroleums Member. However, the upper part (509.25 to 510.56 m) of the deposit, by its gradation to finer grained, bioturbated sandstone and shale, completes the profile of a point bar. Thus, drowning of a channel is indicated. Regression is defined by the capping, pale green (*i.e.*, iron-leached) shale. The most pronounced of the fluvial channel deposits is the relatively thin (2.9 m), tabular-cross-bedded sandstone at the base (502.6 to 505.5 m) of the Waseca Member. The cycle is completed and oxidized prior to the marine transgression and progradation represented by the succeeding upward-coarsening cycle. Apparently, the upward-fining sequences are also progradational deposits competing and losing against transgressing strands. The true strand-regressive events are depicted by the weathering horizons (*e.g.*, oxidation and plant-rootlet-bored surfaces) and by coal beds.

Relationship to Other Fully Cored Mannville Sections

North to South Stratigraphic Cross-section A1-A1'

The stratigraphic relationship of the reference Shell Husky Paradise Hill A13-19-52-23(W3) well to the other cored wells of stratigraphic cross-sections A1-A1', A2-A2', and A3-A3' is traced through Figure 13, Figure 14, and Figure

15. The sections are tied into the north to south cross-section A-A' (Figure 16), from Gulf Peter Pond 1-17-88-25W3 to BW Five Star Kerrobert 4-22-33-23(W3) in western Saskatchewan. Stratigraphic cross-section A1-A1' is a loop of A-A'. Lithological descriptions of the cored sections are recorded in Appendix A of this report.

The Mannville section at Shell Dee Valley A11-18-48-21(W3) (Figure 13) is 154.1 m thick, 43.25 m less than at the reference Paradise Hill section. Of this difference, 31 m are attributable to attenuation of the Dina and Lloydminster members, with most of the remainder reflecting the rise in sub-Dina relief. Thus, the overlying parts of the sections are directly comparable. The bedding cycles are lithologically similar but are 35 in total, apportioned as follows:

Dina: 3 cycles (9.0, 6.17, and 4.33 m);
Cummings: 4 cycles (4.0, 10.75, 7.58, and 2.42 m);
Lloydminster: 4 cycles (7.58, 0.94, 14.48, and 1.63 m);
Rex: 5 cycles (1.33, 1.04, 2.25, 8.8, and 3.35 m);
General Petroleum: 5 cycles (3.03, 2.73, 1.9, 3.93, and 5.56 m);
Sparky: 3 cycles (2.69, 1.13, and 4.26 m);
Waseca: 8 cycles (2.83, 4.23, 4.13, 3.92, 6.51, 3.37, 5.63, and 3.25 m); and
Pense Formation: 3 cycles (2.05, 6.82, and 3.48 m).

The Dina, Cummings, and Lloydminster members at Dee Valley feature thicker cycles than those at Paradise Hill and, together with the Rex, constitute more than half of the section. Additionally, the thickest of the cycles tend to be the penultimate unit of the member rather than the first. Because most of the thickness of a cycle is in the coarser clastic component, and this component reflects shallower depositional bottoms and/or greater proximity to source than do the marine shale units, the upward migration of the centre of mass indicates infill of a site shoreward of the Paradise Hill section. Support for this deduction is seen in the greater number and relative thinness of the units above the Lloydminster, even though the order of thickness is roughly the same as at Paradise Hill.

The eight upward-fining cycles at Dee Valley first appear in the Cummings Member, rather than in the General Petroleum as at the Paradise Hill section. They are present in the Lloydminster, Rex, and General Petroleum members, and in the Waseca, which has four. However, they are absent from the Sparky, which features three upward-coarsening cycles, and from the Pense Formation, here composed of upward-coarsening cycles rather than the upward-fining ones seen at Paradise Hill. Most of the upward-fining cycles include bioturbated sandstone and shale. The General Petroleum Member also includes graded beds of very fine grained quartzose sandstone and shale with abundant thin pelecypods, possibly deposited in tidal estuarine settings. Argillaceous, trough cross-bedded sandstone, containing quartz, black chert, sphaerosiderite, feldspar, and kaolinite, appears in bedding cycles 1 and 3 (Appendix A) of the Waseca and is indicative of a fluvial provenance. The lower of these sandstone units is a correlative of the similar sandstone of the Waseca bedding cycle 1 at the Paradise Hill section. At both Paradise Hill and Dee Valley, the stratigraphically lowest recovery of foraminifera by Atkin (1986) came from the base of the medial sandstone of the Dina Member, and the highest recovery at Dee Valley came from cycle 2 of the Waseca.

At Shell Manito 6-7-43-24(W3), the Mannville is in erosional contact with superjacent black shale and glauconitic, lenticular, very fine grained sandstone of the Joli Fou Formation at 604.3 m below KB, and it overlies the Duperow Formation at 740 m. It is thinned to 135.7 m from the 197.25 m of the Paradise Hill section, even though all members are present. Also, the number of cycles decreases to 31, of which 28 are upward coarsening and three are upward fining, apportioned as follows:

Dina: 2 cycles (13.0 and 19.0 m);
Cummings: 3 cycles (5.0, 3.0, and 3.0 m);
Lloydminster: 2 cycles (11.55 and 5.6 m);
Rex: 4 cycles (2.35, 1.64, 1.51, and 5.55 m);
General Petroleum: 2 cycles (4.2 and 6.43 m);
Sparky: 4 cycles (2.47, 2.68, 3.5, and 0.85 m);
Waseca: 10 cycles (2.05, 4.52, 1.24, 6.72, 2.45, 2.66, 1.05, 5.0, 3.15, and 3.65 m); and
Pense Formation: 4 cycles (2.9, 6.15, 4.7, and 8.1 m).

Although the thickest cycles constitute the Dina and initiate the Cummings and Lloydminster members, the centre of stratigraphic mass has shifted to beds above the Rex by attenuation of the Cummings Member and loss of the lower two Lloydminster units to southerly overlap by the upper Lloydminster units. The Waseca cycles are condensed, however, by attenuation of bioturbated units to thin, black, carbonaceous shale overlain by thicker sandstone on erosional bases.

The Mannville stratigraphic format at Shell Manito 6-7-43-24(W3) closely approximates the rhythmic model of the single Mannville cycle, coarsening upward from subtidal black shale through subtidal and tidal bioturbated argillaceous sandstone to wave-dominated shoal sand, commonly with capping paleosols and carbonaceous to coaly beds. Shoal sand units above the Lloydminster Member are generally floored by calcite-cemented and rusted, siderite-cemented zones in erosional contact with the subjacent bioturbated beds.

Glauconite, in burrow fill and coprolites and as grains, is an accessory in the medial shale of the Cummings Member and the sandstone and shale of the Lloydminster and Rex members. It is also present in the lower part (McLaren) of the Pense Formation. Capping coal beds terminate the Cummings and Rex members, the second cycle of the Waseca Member, and the first cycle of the Pense Formation, and thin carbonaceous shale is common in most of the Waseca cycles. The rootlet zones, oxidized surfaces, and calcrete pavements that appear in all sequences of the General Petroleums and Sparky members probably reflect penecontemporaneously perched groundwater tables. The two upward-fining beds of the Dina and the first cycle of the Cummings resemble a massive body, 29.3 m thick, in terms of grade-size gradation of the sandstone, ranging from a basal coarse, through a medial medium to a capping fine. However, regional considerations indicate two or more depositional episodes by which an initial fluvial setting was replaced by one that was estuarine to marine.

At Shell Zaller Lake 10-7-39-25(W3) on the Kindersley upland, the Cantuar Formation onlaps the Success Formation. The cored interval begins at 638 m below KB at the top of the Waseca Member, and intersects the Success Formation at 709.7 m and the Birdbear Formation at 717.3 m. The Mannville is thinned to 84 m and 20 bedding cycles by overlap of the Dina and Cummings Members and the lower Lloydminster against the southerly rising paleo-upland slopes. Nonetheless, the upward-coarsening cycle, of which 18 are recognized, remains a constant. The 20 cycles are allocated as follows (bottom to top):

Lloydminster: 2 cycles (4.2 and 3.29 m);
Rex: 2 cycles (3.17 and 2.87 m);
General Petroleums: 2 cycles (4.09 and 4.75 m);
Sparky: 4 cycles (2.73, 2.86, 4.53, and 1.95 m); and
Waseca: 10 cycles (2.18, 6.94, 2.86, 10.00, 3.3, 2.44, 3.69, 0.97, 3.2, and 1.6 m).

Black shale, with a basal reworked coaly component, underlies argillaceous sandstone that incorporates a variable but minor bioturbated component of black shale and sandstone. Bioturbation is most strongly exhibited in the Sparky and in the lower part of the Waseca Member.

Three upward-fining cycles are apparent; cycle 2 (2.87 m) of the Rex and cycles 2 (6.94 m) and 10 (1.6 m) of the Waseca. Bioturbated, trough-cross-bedded quartzose sandstone capped by carbonaceous shale distinguishes the Rex and may represent an estuarine channel fill. Both of the Waseca cycles feature kaolinite-indurated quartzose sandstone with accessory black chert. These two are interpreted as belonging to fluvial progradational bodies transitional to estuarine and tidal-channel fill, as indicated by slumped blocks of laminated, flasered, ripple-drift and festoon cross-bedded sandstone and shale. Coal is conspicuous only in the upper part of the Sparky Member. Elsewhere in the section, such coal beds as were present have been largely stripped off by marine transgression associated with shale of the succeeding cycle. Capping beds of fluvial, feldspathic quartzose sandstone occur in lieu of coal beds in the upward-coarsening cycle 2 of the General Petroleums, cycles 1 and 4 of the Sparky, and cycle 3 of the Waseca. Rootlet zones in mudstone and in the underlying sandstone are also found at the coal-prone horizons.

At Shell Cactus Lk 2-16-36-28(W3), the Mannville lies between 740.0 and 825.5 m below KB, but the cored interval begins at top of the Waseca at 748 m. The Mannville section is abbreviated by its location on an eminence of the Kindersley upland, as demonstrated by the uncored but full Mannville section in the nearby valley at BA Eyehill Partington 2-31-39-26W3 (Figure 16). Thus, the Cactus Lake section, like Zaller Lake, begins with the capping bed of the Lloydminster Member and continues with the Rex, General Petroleums, Sparky, and Waseca members, and the uncored Pense Formation. The Lloydminster Member rests on an erosional remnant of the Success Formation, here made up of a 3.3 m thick rubble of green calcareous shale and nodular limestone derived from the Upper Devonian Big Valley Formation.

There are 20 bedding cycles, of which 13 coarsen upward. Cycles are apportioned as follows (bottom to top):

Lloydminster: 2 cycles (2.3 and 1.13 m);
Rex: 2 cycles (8.47 and 5.1 m);
General Petroleums: 4 cycles (3.03, 2.42, 2.45, and 1.23 m);
Sparky: 3 cycles (1.8, 2.67, and 4.41); and

Waseca: 9 cycles (1.64, 5.3, 5.4, 6.6, 10.1, 4.3, 3.6, 0.83, and 2.17 m).

All cycles are characterized by carbon-speckled, fine- and very fine grained, flat- and current-bedded quartzose sandstone in a kaolinitic matrix with abundant chert. These sandstone units are laminated and intermixed with bioturbated, dark grey and green-grey, chloritic mudstone and shale with a few glauconitic nodules. Thin (<1 m) coal and associated mudstone terminate cycle 2 of the Rex, cycle 3 of the Sparky, and cycle 5 of the Waseca. The seven upward-fining cycles are: cycle 1 (2.3 m) of the Lloydminster, cycle 1 (8.47 m) of the Rex, cycle 3 (4.41 m) of the Sparky, and cycles 2 (5.3 m), 5 (10.1 m), 7 (3.6 m), and 8 (0.83 m) of the Waseca. Green chloritic shale, of Rocky Mountain andesitic provenance and characteristic of the Swift Current Paleo-upland depositional sites, appears as background sediment in cycle 4 (1.23 m) of the General Petroleum, cycle 3 (4.41 m) of the Sparky, and cycles 2 (5.3 m), 5 (10.1 m), and 7 (3.6 m) of the Waseca. The relatively great thickness of cycle 5 of the Waseca and its sandstone-shale couplets indicate infill at a site that had initially subsided to form a drowned estuary or lagoon.

Northwest to Southeast Stratigraphic Cross-section A2-A2'

The southeasterly oriented line of cored wells A2-A2' (Figure 14) links the Shell Husky Paradise Hill reference section and Shell Dee Valley with four cored Mannville sections in south-central Saskatchewan: Shell Meota C13-17-46-17W3, C.M.&S. Vanscoy 11-16-35-8(W3), Goldfield GRT CDN Dundurn 10-7-32-5(W3), and SWP Boulder Lake DD 1C 16-18-30-23(W2). All members show an increase southward of facies and components associated with shoreline proximity and continental deposition.

At Shell Meota C13-17-46-17(W3), the Mannville is 175.73 m thick and lies between the Spinney Hill Member of the Joli Fou Formation and the Duperow Formation, at depths below KB of 405.27 and 581 m respectively. The 33 bedding cycles are apportioned as follows (from bottom to top):

Dina: 3 cycles (26, 8.3, and 5.8 m);
Cummings: 4 cycles (6.4, 3.5, 7.0, and 2.5 m);
Lloydminster: 6 cycles (7.7, 5.3, 4.06, 1.9, 1.83, and 4.58 m);
Rex: 5 cycles (2.65, 3.18, 4.69, 2.4, and 2.81 m);
General Petroleum: 3 cycles (3.25, 12.15, and 3.0 m);
Sparky: 1 cycle (10.3 m);
Waseca: 7 cycles (3.6, 3.6, 5.5, 4.3, 3.7, 2.0, and 10.8 m); and
Pense Formation: 4 cycles (0.7, 1.4, 10.2, and 0.63 m).

There are 17 upward-fining cycles, more than the 9 and 10 at Paradise Hill and Dee Valley, respectively. Their places in the section are Dina cycles 1 (26 m) and 2 (8.3 m); Cummings cycles 2 (3.5 m), 3 (7.0 m), and 4 (2.5 m); Lloydminster cycles 3 (4.06 m), 4 (1.9 m), and 6 (4.58 m); Rex cycles 4 (2.4 m) and 5 (2.81 m); General Petroleum cycle 2 (12.15 m); Waseca cycles 1 (3.6 m), 2 (3.6), 3 (5.5 m), and 7 (10.8 m); and Pense cycles 1 (0.7 m) and 3 (10.2 m).

At Paradise Hill, the fluvial, kaolinitic, bimodal, medium- to fine-grained quartzose sandstone with the quartz-black chert-kaolinitized feldspar suite forms the basal unit of cycles 2 and 3 of the General Petroleum Member, cycle 3 of the Sparky, and cycle 1 of the Waseca. In contrast, this facies at Meota is restricted to cycle 1 of the Waseca. Here, it is 3.6 m thick, bipartite, white, kaolinitic, fine-grained quartzose sandstone, speckled with black chert, brown sphaerosiderite, and green chlorite. Bedding includes a medial, thin, carbon-flecked and carbonaceous, rootlet-casted mudstone. Beds in the lower half of the cycle are penetrated by nearly vertical, 15 cm thick calcite veins, which bifurcate and contort near the upper contact like compacted, infilled, shrinkage fractures. The Sparky section differs also in that it reflects a single event, either a 10.3 m shale infill of a channel or a site that was locally subsiding under progradation.

The Dina sandstone, at 34.1 m, is thickest in the Meota section. It is quartzose, fine grained, well sorted, silica grain-contact cemented, very permeable and distinguished on the geophysical log by its blocky spontaneous potential signature. The general low-angle cross- and flat-bedding, conspicuous disseminated carbonaceous aggregates, and pyrite cementation over the upper 2 m are characteristics closer to marine than continental in origin. They are probably those of a bay-mouth or lower estuary mouth to backshore deposit.

Coal beds, generally less than 30 cm in thickness, are present in the three localities. At Paradise Hill, four beds are recorded: one below the marine shale in the upper Cummings, one each in the Rex and General Petroleum, and one in the upper Waseca. There are also four at Dee Valley, but three are in the Sparky Member and one lies in the

upper Waseca. However, there are seven at Meota: a vestigial bed in the Cummings Member, four in the upper part of the Rex, and two in the upper Waseca. In general, the greater number of coal beds and channel deposits at Meota indicate a site that underwent more repetitive episodic subsidence than the others.

At CM & S Vanscoy 11-16-35-8(W3), the Mannville section is 112.8 m thick and lies between 519.1 and 631.9 m below KB, and on the Jura-Cretaceous Success Formation. All members are present, but the overall thinning of the Cantuar Formation is taken up by condensation of the Cummings and Dina Members in overlap on the rise of the Success-capped, Upper Devonian Birdbear topographic surface. The Mannville displays 15 upward-coarsening and nine upward-fining cycles, for a total of 24 cycles (from bottom to top):

Dina: 1 cycle (5.2 m);
Cummings: 1 cycle (9.8 m);
Lloydminster: 6 cycles (2.7, 7.6, 4.9, 1.7, 11.4, and 1.4 m);
Rex: 4 cycles (2.3, 3.3, 5.5, and 3.4 m);
General Petroleum: 3 cycles (3.9, 1.1, and 1.8 m);
Sparky: 1 cycle (8.9 m);
Waseca: 4 cycles (2.7, 9.3, 7.9, and 6.0 m); and
Pense Formation: 4 cycles (3.5, 6.4, 0.3, and 1.8 m).

Glaucinite and bioturbation are characteristic of the General Petroleum, Rex, and Lloydminster members. There are two major channel fills in the Waseca, the lower one truncating the Sparky Member. Coaly layers cap the Cummings Member, as well as bedding cycles 3 and 4 of the Lloydminster, cycle 4 of the Rex, and cycle 1 of the Waseca. Additionally, coaly fragments are part of the conglomerate at the base of the Waseca.

The Dina overlies a metre-thick erosional remnant of the Success Formation, here a polymict conglomerate of boulders and pebbles in a well-indurated matrix of poorly sorted, argillaceous, calcareous sandstone. Pebbles comprise well-cemented sandstone; tripoli chert; flat rectangular, angular, and pebble-sized fragments of laminated chert; and rounded, green, glauconitic siliceous mudstone. The conglomerate overlies the Birdbear Formation in erosional unconformity. The Dina consists of 5.2 m (only 2.5 m present in core) of an indurated, differentially compacted, fine- to very fine grained quartzose sandstone, with a dark grey argillaceous matrix and abundant carbonized plant fragments near the base.

The Cummings Member is a single upward-coarsening cycle, comprising 6.3 m of basal black shale and silty shale, and 1.8 m of very fine grained, well-sorted, silica grain-contact cemented, current-bedded quartzose sandstone with about 15% black shale partings. Black coaly shale, 1.7 m thick, caps the member.

Two bedding groups constitute the Lloydminster Member. The one at 601.7 to 616.9 m below KB incorporates bedding cycles 1 (2.7 m), 2 (7.6 m), and 3 (4.9 m), each of which coarsens upward from dark grey shale, through transitional, lenticular and podded silty shale that is partly bioturbated, to indurated, weakly argillaceous, fine-grained quartzose sandstone with rootlet casts near the top. Thin coal and coaly shale beds cap cycles 2 and 3, respectively. The second group, at 587.2 to 601.7 m, consists of cycles 4 (1.7 m), 5 (11.4 m), and 6 (1.4 m), all of them upward-fining. Cycle 4 is a poorly indurated, fine-grained to silty, glauconitic quartzose sandstone that grades into rootlet-casted, carbonaceous mudstone capped with lignitic shale; the thick cycle 5 displays trough-cross-bedded, fine-grained quartzose sandstone interbedded with thin black shale; and cycle 6 is a dark lavender grey mudstone with abundant plant fragments. Overall, the multiple units here contrast sharply with the relatively thick, deeper water shale and sandstone at the northern sites (*e.g.*, Paradise Hills and Dee Valley) and are a consequence of shallower bottoms and their greater sensitivity to strand oscillations. Cycle 5 indicates a sea-level fall of at least 12.8 m prior to infill.

The Rex Member comprises: 1) a basal cycle, 2.3 m thick, that fines upward from flattened mudstone pebbles in trough cut-and-fill, low-angle current-bedded, fine-grained quartzose sandstone into a calcite-cemented, argillaceous quartzose sandstone, laminated with carbonaceous black shale; and 2) three upward-fining shallow cycles (3.3, 5.5, and 3.4 m) featuring basal grey, glauconitic, silty shale and very fine grained quartzose sandstone, medial bioturbated sandstone and grey-black shale, and capping coaly shale and coal.

Cycle 1 (3.9 m) of the General Petroleum Member grades upward from a sharp irregular contact under 15 cm of kaolinitic, bimodal, fine- and medium-grained quartzose sandstone, through glauconitic, medium grey, argillaceous, very fine grained sandstone laminated with grey black shale, into fine-grained, quartzose, ripple-drift (with plant placers), trough-cross-bedded sandstone. The thin overlying beds are essentially shale-sandstone couplets. As for the Sparky Member, a thin (15 cm) dark grey shale with abundant, dark green, nodular glauconitic masses and a sharp, irregular basal contact lies at its base. This bed is overlain disconformably by a single upward-coarsening

deposit, 8.85 m thick, of carbonaceous burrowed mudstone and current-bedded, flasered, black-shale–draped, very fine grained quartzose sandstone, with abundant escape burrows and scattered glauconitic infilled burrows.

The Waseca fines upward overall through four upward-fining cycles (from bottom to top): a 2.7 m thick conglomerate on an erosional base; 9.3 m of grit, transitional to medium-grained quartzose sandstone, trough cross-bedded to ripple cross-bedded; 7.9 m of medium- to fine-grained quartzose sandstone; and 6.0 m of massive mudstone and claystone.

Upward-coarsening bedding cycles 1 (3.5 m) and 2 (6.4 m) characterize the lower part of the Pense Formation. The first consists of bioturbated sandstone and shale. The second grades upward from: 1) a well-indurated black shale with a scatter of grey siltstone lenticles; through 2) a lower black shale interbedded with lenticular, very fine grained quartzose sandstone with scoured basal contacts and an upper, current-bedded, medium grey, very fine grained quartzose sandstone with minor laminae of shale containing sand-filled burrows; into 3) a thin, medium grey, calcite-cemented, low-angle cross-bedded, coarse-grained quartzose sandstone speckled with white feldspar and brown siderite. Bedding cycles 3 (0.3 m) and 4 (1.8 m) are erosional, unconformity-bounded remnants of quartzose, very fine grained, lenticular and boudinaged, calcite-cemented, dark blue-grey quartzose sandstone with finely disseminated pyrite and subordinate black shale.

The Mannville thins abruptly between Vanscoy and Goldfield GRT CDN Dundurn 10-7-32-5(W3), where it overlies the Upper Devonian Big Valley Formation (Figure 14). The Big Valley and the underlying Torquay Formation form a lithological rampart overlooking the northwestern and western rim of the Watrous topographic basin. The stratigraphic horizons between the Vanscoy and Dundurn wells are depicted as conformable with the sub-Mannville erosion surface and, to a lesser degree, with the sub-Mannville stratigraphic horizons, rather than with the overlying Colorado stratigraphic datum. This is an empirical approach to the correlation between the sites, as based on the south to north regional stratigraphic cross-sections B-B' (Figure 19), C-C' (Figure 20), and D-D' (Figure 21), and west to east cross-sections W-W' (Figure 25) and X-X' (Figure 26) along the Punichy Arch. Most of the loss of Mannville section at the Dundurn site is therefore attributed to pre-Pense planation, by which the Waseca is severely truncated. Southward thinning of the Mannville has also occurred by basal onlap of the sub-Dina topography and by attenuation of units at the expense of their shale components. In fact, conspicuous transgressive shale units are present only in the Lloydminster Member, where they are a metre or so in thickness. Cycles are apportioned as follows (bottom to top):

Dina: 2 cycles (5.0 and 4.2 m);
Cummings: 1 cycle (3.5 m);
Lloydminster: 2 cycles (6.1 and 2.3 m);
Rex: 4 cycles (2.6, 1.5, 1.0, and 2.7 m);
General Petroleums: 2 cycles (7.5 and 1.2 m);
Sparky: 1 cycle (1.5 m);
Waseca: 1 cycle (9.5 m); and
Pense Formation: 4 cycles (3.3, 6.4, 0.3, and 3.1 m).

Of the 17 recorded cycles, six are upward fining. The condensed beds of the Dina fine upward from fine-grained, medium grey quartzose sandstone to grey-black carbonaceous shale with included plant detritus. The Cummings, however, is an upward-coarsening, very fine grained, ripple-drift, cross-laminated quartzose sandstone that is capped by carbonaceous mudstone with abundant plant films and rootlets and scattered coaly fragments. The coaly material appears to be incipient forms or remnants of the widespread coal beds on the Cummings Member in the Kindersley Paleo-upland to the west.

The Lloydminster (588.9 to 597.3 m) cycles are typical transitions from bioturbated, dark grey shale, laminated with subordinate, very fine grained quartzose sandstone, to fine-grained quartzose sandstone. They are thinly bedded with low-angle cross-laminae in shale-draped sets in the lower sequence and strongly contorted sandstone, cross-bedded with fine opposing sets capped by an oxidized mudstone bed, in the upper. The last bed indicates a hiatus with respect to the Rex Member. Bedding cycles 1 and 3 of the Rex apparently represent the sandy portions of upward-coarsening cycles. Like the Lloydminster, they are bioturbated, current bedded with small-scale troughs, and thinly interbedded with lenticular shale. Bedding cycle 2, at 584.8 to 586.3 m below KB, is kaolinitic, fine-grained quartzose sandstone, speckled with brown sphaerosiderite, black chert, accessory muscovite, and rare green glauconite. This cycle fines upward over its upper half into a well-indurated, kaolinitic, very fine grained quartzose sandstone, current-laminated with minor carbonaceous detritus. Bedding cycle 2 is likely progradational in a transgressive setting with respect to cycle 1. Likewise, bedding cycle 4, which is a medium- to fine-grained repetition of cycle 2, is progradational with respect to cycle 3.

A dramatic increase in mudstone thickness appears in the General Petroleum and Waseca members. Bedding cycle 1 of the General Petroleum (581.1 to 573.6 m) coarsens from a 6 m thick mudstone bed into a laminated, argillaceous quartzose siltstone and very fine grained quartzose sandstone with abundant plant detritus. A 1.2 m thick, bimodal, medium- and fine-grained quartzose sandstone, with low-angle trough-cross-bedding lined with carbonized plant detritus, makes up the second cycle. These sediments probably represent infill of an estuary behind a coastal barrier beach drowned by marine transgression, a setting analogous to that interpreted for the upward-fining cycles of this member at Paradise Hill. The 9.5 m thick mudstone bed representing the Waseca portrays a continuation of backshore infill after a brief marine incursion indicated by the ripple-laminated but generally flat-bedded, fine-grained, friable, quartzose sandstone of the Sparky. Overall, the site appears to have been part of a delta front.

In the general region of the Vanscoy and Dundurn sections, the Pense Formation has undergone a transition from facies mixed with respect to shore and onshore characteristics to the more stylized, repetitive, upward-coarsening cycles typical of the southern Mannville basin. Although four upward-coarsening sets are indicated at Dundurn, only bedding cycle 2 features the complete facies transition from a basal black shale, through bioturbated shale and sandstone, into a capping well-sorted sandstone that is calcite cemented to form a pavement. Bedding cycles 1 and 4 include bioturbated facies, and cycle 3 contains a sandstone remnant. They indicate lower shoreface environments that periodically became emergent.

The Mannville formation at the SWP Boulder Lk DD 1C 16-18-30-23(W2) well lies far inside the Watrous topographic basin and thus overlies a nearly complete section of the redbed-evaporite Jura-Triassic Watrous Formation. As at Dundurn, the Cantuar Formation is partially truncated under the Pense Formation, resulting in the Waseca being mostly absent. Whereas upward-coarsening and upward-fining cycles remain characteristic, wacke-type sandstone and mudstone take up a greater proportion of the section. However, the distribution of accessory glauconite in the stratal column has the same range as to the northwest (*i.e.*, Lloydminster to basal Waseca). There is an intimate association of green glauconite with the abundant coalified plant detritus. The Pense Formation, with its four, classical, upward-coarsening black shale, bioturbated shale and sandstone, and terminal sandstone cycles, above a basal black shale and sandstone on an erosional surface, is a faithful replica of Price's (1963) type Pense Formation at the Sohio Canadian Devonian Pense 14 6-17-22W2 well, 50 km to the south-southeast.

Of the 19 bedding cycles in the Mannville of the Boulder Lake section, seven coarsen upward and 12 fine upward. Their distribution is (bottom to top):

Dina: 3 cycles (4.2, 3.2, and 5.7 m);
Cummings: 2 cycles (8.8 and 2.5 m);
Lloydminster: 4 cycles (4.2, 2.8, 0.3, and 3.3 m);
Rex: 2 cycles (6.7 and 3.7 m);
General Petroleum: 2 cycles (9.1 and 3.2 m);
Sparky: 1 cycle (2.3); and
Pense Formation: 5 cycles (3.1, 5.5, 1.8, 1.8, and 2.1 m).

Bedding cycles 1 and 2 of the Dina Member (515.7 to 508.3 m below KB) are upward fining. The first grades from a basal conglomerate of olive green sideritic mudstone, tan dolomite, dark grey shale and cemented layers of coarse rhombohedral and trapezohedral quartz, tripoli chert, kaolinite, and carbonaceous plant debris, into argillaceous, bimodal, fine- and very fine grained, quartzose sandstone, irregularly interbedded with carbonaceous and coaly plant fragments. Bedding cycle 2 is a kaolinitic, tan to white, quartzose sandstone that grades upward from poorly sorted and coarse grained, with abundant kaolinite blebs and black carbonaceous grains, to very fine grained with abundant coarse-grained sphaerosiderite. These facies appear to be fluvial in origin. Bedding cycle 3 (508.3 to 502.6 m) is upward coarsening overall but includes a 1.2 m thick, bimodal, medium- and fine-grained, tabular-cross-bedded sandstone beneath an upper, 2.8 m thick, well-sorted, fine-grained sandstone bed. The relationship indicates stream avulsion and channel diversion across a local strand.

The Cummings Member consists of bedding cycle 1 (502.6 to 493.8 m), which fines upward from low-angle cross- and ripple-bedded, fine-grained quartzose sandstone, laminated and interbedded with shale and dark grey mudstone, and bedding cycle 2 (493.8 to 491.3 m) of interbedded sandstone and grey-black shale, variably calcite cemented and pyritic, and here taken to be upward coarsening.

Thin bedding and sandy mudstone dominate the Lloydminster Member (491.3 to 480.7 m below KB). Bedding cycle 1 (4.2 m) grades upward from medium green-grey and olive green mudstone with minor, very fine grained, quartzose, sandy lenticles and a glauconitic layer near the base, through laminated mudstone and flamed, boudinaged, argillaceous, fine-grained, quartzose sandstone, into a metre-thick cap of contorted and sheared

claystone. Bedding cycles 2 and 3 feature thinly interbedded couplets of argillaceous, very fine grained sandstone and claystone. The former is 2.8 m thick and incorporates three of the couplets; the latter is only 0.3 m thick but is separated from bedding cycle 2 by an irregular contact lined with nodules of pyrite and is therefore interpreted as an eroded third cycle. Thus, the fourth cycle rests on an erosional contact (3.3 m). It is a very fine grained, medium grey to light grey, quartzose sandstone, flat-bedded to low-angle current bedded with small-scale troughs and ripples. Some laminae are draped with black carbonaceous shale. The bed is calcite, silica, and nodular-pyrite cemented at the top.

The first cycle (480.7 to 474.0 m below KB) of the Rex, like the Lloydminster, is dominated by olive green, waxy, broken and slickensided claystone with scattered coalified twigs lying in the bedding. Abundant glauconitic and pyritic masses, 2.5 to 5 cm in length and up to 12 cm thick, occur in the metre-thick bed above the sharp basal contact. Argillaceous, medium grey, fine-grained quartzose sandstone, irregularly bedded with intensively bioturbated argillaceous layers containing scattered glauconitic and pyritic patches, makes up the second cycle. Distortion and plastic flowage are evident throughout and shear is evident at the basal contact.

Cycles 1 (9.1 m) and 2 (3.2 m) of the General Petroleum Member (470.3 to 458.0 m below KB) are nondescript with respect to cyclic pattern but are here referred to as upward fining, largely because of their marshy to alluvial characteristics. The lower cycle consists of a medium grey, argillaceous, very fine grained, massive quartzose sandstone with abundant sphaerosiderite that contributes to patchy red oxidation colours, and subordinate clayey mudstone with coalified tree fragments. Rootlet and animal burrows are apparent in sandier layers. The upper cycle (461.2 to 458.0 m) is represented by a dark lavender grey, waxy claystone that is criss-crossed by slickensided faults and grades upward through a lavender grey, red-mottled, massive sandy mudstone into a 1 m thick, sphaerosideritic, dark lavender grey, microfaulted claystone.

A medium grey, argillaceous, fine- to very fine grained quartzose sandstone with subordinate siltstone layers constitutes the condensed Sparky section (458.0 to 455.7 m). Abundant medium-grained, red-brown sphaerosiderite grains occur in bedding at 457.2 m and as grit-size aggregates with glauconitic shaly partings near the sharp basal contact. An ironstone-cemented rubble, 8 cm thick, consisting of mudstone and sandstone cobbles and coalified tree fragments, caps the section.

The Pense Formation overlies the Sparky Member of the Cantuar Formation with a sharp, irregular contact. Its basal, upward-fining unit shows a transition from trough cut-and-fill, dark grey and grey-black, bioturbated, very fine grained, quartzose sandstone and shale to a grey-black shale and is terminated by a partially calcite-cemented, dark grey, montmorillonitic shale with white, cone-in-cone calcitic veins, 2.5 cm thick. The overlying upward-coarsening sets, though relatively thin, feature the shale, bioturbated sandstone and shale, and sandstone hemicycle.

Southwest to Northeast Stratigraphic Cross-section A3-A3'

The line of representative cored wells depicted in [Figure 15](#) trends northeast from the Vanscoy and Cory mining district west of Saskatoon along the course of the South Saskatchewan River to the Choiceland No. 1 Choice DD 13-3-50-18(W2) west of Nipawin. Although offset some 250 km to the east of section A1-A1', it also transects the axis of the Mannville depositional basin but along the dip of the pre-Mannville formations. At C.M.&S. Vanscoy 11-16-35-8(W3), the sub-Cantuar erosional surface lies near the base of the Upper Devonian Torquay Formation and, at Duval Saskatoon 6-18-36-6(W3), it lies on the Birdbear Formation. However, at Transgas Prud Homme 11-12-38-28(W2), the erosion surface rises stratigraphically onto the Jura-Triassic Watrous Formation in the Watrous topographic basin. At Grey Owl Syndicate No. 1 (16-10-44-27W2), the Mannville basal contact steps down to the lower part of the Duperow Formation and, at Choiceland No. 1 Choice DD 13-3-50-18(W2), it laps onto the Souris River Formation on the southern flank of the Molanosa paleotopographic high. Again, the Mannville internal correlation lines tend to reflect the sense of the sub-Mannville erosion surface, so that members of the Cantuar Formation, as mapped, tend to fall and rise and thicken and thin accordingly. The Transgas Prud Homme 11-12-38-28(W2) and Grey Owl Syndicate No. 1 (16-10-44-27W2) wells are at intersections with stratigraphic cross-section B-B' ([Figure 19](#)), and the Choiceland No. 1 Choice DD 13-3-50-18(W2) well is at the intersection with stratigraphic cross-section C-C' ([Figure 20](#)).

Although Duval Saskatoon 6-18-36-6(W3) lies about 20 km northeast of C.M.&S. Vanscoy 11-16-35-8(W3), significant differences in the stratigraphic layout of the Mannville sequences are indicated. From Vanscoy to Saskatoon, the sub-Mannville erosion surface rises with respect to the Joli Fou stratigraphic datum, as does the underlying Birdbear-Duperow contact, although at twice the rate. Loss of Mannville section occurs in the Cantuar at the base of the Pense Formation. In that the sub-Mannville unconformity downsteps toward the north, the reverse should have occurred (*i.e.*, the Cantuar Formation should have thickened toward the Saskatoon site from Vanscoy). The implication is that, relative to Vanscoy, post-Cantuar-pre-Pense structural uplift occurred at the Saskatoon site,

as in the case of the Boulder Lake site to the southeast (Figure 14). The Saskatoon Mannville section resembles that at Transgas Prud Homme 11-12-38-28(W2) to the east in lithological organization and in thickness, but the Mannville overlies the Watrous Formation at the latter site. Sub-Mannville relief is absent between the Devonian and the Watrous Formation, and the Saskatoon, Prud Homme and Boulder Lake sites occupy the same topographic plain, one that is uplifted relative to Vanscoy and the region to the west and northwest (cf. H B Donavon 5-20-32-7(W3) and Great Canadian Dundurn 5-35-31-5(W3) on stratigraphic cross-section W-W'; Figure 25). These eastern sites are situated on the western part of the Punichy Arch (Christopher, 1980).

Of the 22 cycles in the Mannville Duval Saskatoon 6-18-36-6(W3) section, 14 are upward coarsening and eight are upward fining. The cycles are allocated as follows (oldest to youngest):

Dina: 1 cycle (7.0 m);
 Cummings: 2 cycles (7.4 and 3.6 m);
 Lloydminster: 4 cycles (2.0, 1.7, 2.1, and 9.8 m);
 Rex: 4 cycles (3.3, 3.1, 3.0, and 6.1 m);
 General Petroleum: 2 cycles (4.0 and 3.3 m);
 Sparky: 1 cycle (9.9 m);
 Waseca: 4 cycles (1.4, 3.3, 8.3, and 3.0 m); and
 Pense Formation: 4 cycles (2.5, 2.4, 3.4, and 6.5 m).

The eight upward-fining cycles are the Dina (7.0 m), cycle 4 of the Lloydminster (9.8 m), cycles 2 and 4 of the Rex (3.1 and 6.1 m), cycles 1, 3, and 4 of the Waseca (1.4, 8.3, and 3.0 m), and cycle 1 of the Pense Formation (2.5 m). Upward-coarsening cycles are dominated by thinly interbedded, bioturbated, fine- and very fine grained, quartzose sandstone and grey-black shale. Capping sandstone, where well sorted, bedded, and permeable, is topped by rootlet-mud infilled, loamy sandstone and/or sandy mudstone infilled with rootlet mud, or is infiltrated by mud and contains rootlet casts with scattered coaly laminae. Also present are terminal coal in the Dina and Cummings members and bedding cycle 1 of the Rex; glauconite in cycle 1 of the General Petroleum; and foraminifera in cycle 1 of the Rex (Atkin, 1986).

Fluvial characteristics are displayed in the upward-fining cycle 4 of the Lloydminster. The 9.8 m thick unit (552.3 to 542.5 m below KB) displays: 1) an indurated, kaolinitic, basal sandstone, 6.7 m thick, that is quartzose, bimodal, grading upward from medium to fine grained, low-angle trough cross-bedded with laminae of carbonaceous plant material, and rests on a sharp, irregular contact; grading over a 30 cm interval into 2) a medial, 1 m thick, very fine grained, quartzose sandstone laminated with subordinate dark grey shale; and 3) a dark grey, hard, platy mudstone with scattered coalified plant fragments.

A compound channel set constitutes the upward-fining fourth cycle of the Rex. The lower bed, 4.6 m thick, consists of a basal, flat-bedded, permeable, very fine grained sandstone featuring laminar truncations and carbonaceous plant detritus, that grades up into laminated and bioturbated, ripple-marked sandstone and shale. The upper 1.5 m is a transition from medium-grained sandstone to poorly sorted, argillaceous, very fine grained, quartzose sandstone with abundant coaly placers, and a terminal, thin (30 cm) grey-white sandy paleosol. These relationships indicate initial drowning of a chenier and overlap by foreshore deposits, then infill of the embayment by fringing marsh deposits.

The 8.3 m thick bedding cycle 3 of the Waseca consists of 7.7 m of lavender grey, carbonaceous, interbedded sandy mudstone and claystone under a 0.6 m thick cap of grey-white, clayey paleosol, speckled with coarse-grained, red-brown, sphaerosiderite. The unit resembles an alluvium. From its erosional base, the first cycle of the Pense grades from a medium-grained, quartzose, trough-cross-bedded, permeable sandstone, through light blue-grey, calcite-cemented, fine-grained quartzose sandstone with ironstone Liesegang and scattered, black-shale-draped, starved ripple lenticles, into bioturbated, dark grey and grey-black, very fine grained sandstone and shale. It is an apparent transgressive marine facies.

At Transgas Prud Homme 11-12-38-28W2, the core begins in the basal 5 m of the Waseca, (Figure 15). Here, also, the Waseca is partially truncated under the Pense Formation, so that only about a quarter of its original thickness remains. Of the 22 cycles recorded in core to the top of the Sparky, 13 coarsen upward and nine fine upward. This total contrasts with 15 at the Saskatoon site for the same interval and reflects multiple thin sequences in the Lloydminster and General Petroleum members. The Transgas Prud Homme distribution of cycles is as follows (oldest to youngest):

Dina: 3 cycles (3.0, 1.6, and 2.7 m);
 Cummings: 3 cycles (1.8, 1.3, and 3.0 m);

Lloydminster: 5 cycles (2.7, 6.1, 2.2, 1.2, and 1.2 m);
Rex: 4 cycles (5.5, 2.7, 4.9, and 3.4 m);
General Petroleums: 4 cycles (2.1, 1.1, 3.8, and 6.8 m);
Sparky: 3 cycles (1.7, 0.3, and 4.0 m); and
Waseca: 2 cycles (1.4 and 1.6 m).

The upward-fining cycles are cycles 1 and 2 (3.0 and 1.6 m) of the Dina; cycle 2 (6.1 m) of the Lloydminster; cycles 1, 2, and 4 (5.5, 2.7, and 3.4 m) of the Rex; cycles 1 and 4 (2.1 and 6.8 m) of the General Petroleums; and cycle 1 (1.7 m) of the Sparky. As at the other cored sections, bioturbated, ripple-bedded and flasered sandstone and shale, with associated overlying, flat-bedded sandstone, are the dominant components of the upward-coarsening cycles in the Cummings, Lloydminster, Rex, and Sparky Members. The facies is also present in the upward-fining cycles of the Lloydminster, cycle 1 of the Rex, and cycle 1 of the General Petroleums. Evidence of emergence appears at the top of the cycles as incipient coaly layers, rootlet-casted and oxidized sideritic sandstone, and calcite-, silica-, and iron-cemented sandstone.

Only the Dina cycles and cycle 4 (6.8 m) of the General Petroleums resemble fluvial-channel deposits. The Dina, at its base, consists of poorly sorted, coarse- and medium-grained sandstone, grading upward into fine-grained, carbonaceous sandstone and shale with coalified plant fragments. The second cycle comprises basal, argillaceous, blocky to massive, iron-concretionary, very fine grained sandstone, transitional to sandy mudstone with minor irregular beds of argillaceous, very fine grained quartzose sandstone containing scattered coalified plant fragments. The General Petroleums cycle displays a sharp, irregular, basal contact under a rubble of oxidized ironstone pebbles.

The apparently estuarine cycle 2 of the Lloydminster is floored by a sharp, irregular contact with a basal conglomerate of dark brown sideritic mudstone and dark grey mudstone pebbles on the calcite-cemented sandstone of the first cycle. It consists of severely microfaulted blocks of laminated and bioturbated, very fine grained quartzose sandstone and dark grey shale, reminiscent of large-scale slumping. The overlying, upward-coarsening cycles 3, 4, and 5 of the Lloydminster are similarly affected over 10.7 m of section. Apparently, these sediments had acquired enough strength through penecontemporaneous consolidation (in the sense of soil mechanics) that faulting, rather than plastic flow, became the expression of differential movement. Accordingly, the phenomenon implies emergence of these strata, consolidation by groundwater drawdown and desiccation, and slope failure, probably by stream undercut, prior to deposition of the Rex Member. Thus, a hiatus separates these members, and nearby is to be found an 11 m (or more) deep entrenched channel section.

The Mannville at Grey Owl Syndicate No. 1 (16-10-44-27W2) lies between 455.4 and 615.4 m below KB. Its thickness of 160.0 m reflects its location in the axial portion of the northern depositional basin. The core is wireline, somewhat disarticulated and incomplete in the General Petroleums, Rex, Lloydminster, and Cummings members (Figure 15). However, the combination of core data and an expressive electrical log signature indicate a depositional facies dominated by sandstone. The core from the upper half of the General Petroleums reveals upward fining, from well-sorted, fine-grained, subrounded and subangular, weakly cemented quartzose sandstone, 6.4 m thick, through 0.7 m of bioturbated, thinly interbedded, medium and dark grey, very fine grained quartzose sandstone and shale, to a vestigial grey-black claystone with abundant plant fragments.

The Sparky has four upward-coarsening cycles (3.2, 0.7, 7.6, and 5.2 m). Bioturbated, ripple drift, scour cut-and-fill, shale-draped, thin-bedded sandstone and subordinate shale are their dominant components. Initial shale and terminal coal beds are vestigial. Cycle 2 is calcite cemented, partly iron stained, and includes carbonized reed-like stalks on some bedding surfaces and a subjacent sharp contact. It probably reflects a lowered strand setting and a succeeding hiatus. The Waseca has eight cycles (2.8, 2.7, 3.4, 4.1, 0.7, 4.6, 5.2, and 5.5 m), of which cycles 1, 2, 3, and 6 coarsen upward (2.8, 2.7, 3.4, and 4.6 m). Well-sorted, flat-bedded, fine-grained quartzose sandstone, with kaolinite matrix varying from minor to trace, form the dominant component. Cycle 6 includes a capping claystone and a cemented red-brown clay ironstone penetrated by calcitic septarian veins. Sandstone of the upward-fining cycles is fine grained, highly argillaceous and, in cycle 8, bioturbated. The lower cycles grade into black shale, whereas cycles 6 and 7 yield to claystone beds, which may reflect a brackish water depositional environment.

The Pense Formation is dominated by upward-fining sandstone and mudstone. Moreover, the basal, typically bioturbated, sandy mudstone is replaced by a 1.4 m thick, flasered sandstone. The overlying unit, at 7.7 m, is thickest and fines upward from a medium grey, muscovitic, very fine grained, quartzose sandstone with accessory siderite and pyrite, into a 4.6 m thick mudstone with abundant plant fragments. The upper Pense units are rootlet penetrated, argillaceous, very fine grained, quartzose sandstone, and are 4.6 and 1.8 m thick. They include abundant aggregates of red-brown, coarse-grained sphaerosiderite in cycle 3 and bioturbation pods in cycle 4, and are bounded by sharp, irregular contacts, the topmost being at the Joli Fou Formation.

The Choiceland No. 1 Choice DD 13-3-50-18W2 section is located over a Precambrian monadnock, and the effects of draping were transmitted through the Devonian carbonate rocks into the Mannville. It lies between the Joli Fou Formation at 157.9 m and the Upper Devonian Souris River Formation at 266.1 m below KB. Thus, the formation is condensed to about 115 m. Additionally, the section is sited on the southern flank of the Molanosa Paleo-upland where the Mannville is thinned overall. The lithological units are fine grained throughout, thin bedded (strata ranging in thickness from 10 cm to 3 m), and diastemic, in that depositional cycles are separated by at least 18 erosional breaks at an average interval of about 3.6 m. Black mudstone, grey-black mudstone, and very fine grained, flasered, microlenticular and carbon-flecked sandstone are pervasive. Apart from the rare carbonaceous paleosol and the subordinate upward-fining facies, the stratigraphic pattern is a repetition of upward-coarsening cycles, in full or in part, in all members of the Mannville. However, only the Cummings and Lloydminster are glauconitic. The 29 recognized bedding cycles are allocated as follows:

Dina: 3 cycles (6.4, 14.9, and 5.2 m);
 Cummings: 1 cycle (3.8 m);
 Lloydminster: 5 cycles (4.6, 1.2, 6.0, 0.4, and 0.5 m);
 Rex: 4 cycles (8.1, 1.0, 1.6, and 1.3 m);
 General Petroleums: 3 cycles (2.6, 1.7, and 2.1 m);
 Sparky: 3 cycles (1.9, 4.7, and 3.5 m);
 Waseca: 7 cycles (1.4, 3.0, 1.8, 2.6, 7.6, 2.5, and 6.7 m); and
 Pense Formation: 3 cycles (4.0, 1.6, and 0.5 m).

Upward-fining cycles total 12, comprising all three cycles of the Dina; cycles 1 (4.6 m) and 2 (1.2 m) of the Lloydminster; cycle 1 (8.1 m) of the Rex; cycle 3 (3.5 m) of the Sparky; cycles 1, 2, 4, and 7 (1.4, 3.0, 2.6, and 6.7 m) of the Waseca; and cycle 1 (4.0 m) of the Pense.

Most of the Dina samples were lost in the process of coring. A basal conglomerate of chalcedonic pebbles, white Madison chert, coaly mudstone, siliceous concretions, coal, and pyrite-encrusted quartz rests on an erosion surface. It is overlain by 60 cm of medium blue-grey, planar-cross-bedded, calcite-cemented, fine- to medium-grained quartzose sandstone, dominated by subrounded and rounded quartz particles, with abundant pyrite crystals and kaolinite and sparse black chert, and including scattered beds laminated with carbonaceous detritus. At 259.0 to 260.2 m is an apparent fault gouge of dark grey, well-indurated, sandy mudstone with abundant distorted claystone pebbles and boulders. Sandstone higher in the unit is quartzose, fine grained and well sorted, and includes accessory lithic grains, black chert, and rose quartz.

The Cummings Member coarsens upward from an unconformity-bounded, 40 cm thick, bedding-aligned, bioturbation-podded, dark and light grey sandy mudstone, into a 3.3 m thick, light grey, fine-grained, calcite-cemented quartzose sandstone, with abundant pebbles and boulders of medium grey mudstone and glauconitic and pyritic ironstone.

The Lloydminster lies disconformably on the Cummings, and its first cycle (4.6 m) fines from sandstone, through bioturbated sandstone and shale, into mudstone. The succeeding cycles 2 through 4 are truncated and truncational. Cycle 2 (1.2 m) is a largely bioturbated, glauconitic, and foraminiferal (Atkin, 1986) mudstone. Cycle 3 (6.0 m) is quartzose sandstone that grades upward from very fine grained to medium grained, flat-bedded and massive. Quartz grains are well sorted and subrounded, coal flakes increase upward from accessory amounts to about 10%, and siderite occurs as brown nodules. Cycles 4 and 5 (0.4 and 0.5 m) are thinner repetitions of cycle 3.

At 8.1 m, the upward-fining cycle 1 of the Rex is the thickest in the section above the Dina. It presents an upward transition from a 1.5 m thick, calcite-cemented, medium- and coarse-grained quartzose sandstone with abundant black carbonaceous grains and scattered lenticles of carbonaceous detritus, to a very fine grained quartzose sandstone laminated with dark grey shale. The capping mudstone is mottled with iron stains, and the sand body is microfaulted near the base and top, probably in response to a shearing couple. The upward-coarsening cycles 2, 3, and 4 (1.0, 1.6, and 1.3 m) are thin, although internally transitional and similar in facies. As in cycle 1, bioturbated sediments are absent.

The three bedding cycles in the General Petroleums Member coarsen upward from basal mudstone with subordinate sandy layers into fine-grained, argillaceous, brown iron-stained quartzose sandstone. Cycles 1 and 3 (2.6 and 2.1 m) lie on erosional surfaces, but cycle 2 (1.7 m) is transitional to cycle 3. Sparky cycles 1 and 2 (1.9 and 4.7 m) are similar in facies to the General Petroleums, both coarsening upward from sharp basal contacts. However, cycle 3 (3.5 m) fines upward into clayey mudstone from laminated, very fine grained sandstone. Sideritic nodules are scattered throughout, and abundant coaly plant fragments are concentrated at the top.

The fluvialite, quartz–kaolinite–black-chert sandstone facies, as seen in the basal beds of the Waseca at the Paradise Hill and Dee Valley sections (Figure 13 and Figure 14), is also present here in the upward-fining cycle 1 of the Waseca, as a 1.4 m thick, calcite-cemented, medium-grained, quartzose sandstone with abundant black chert and kaolinite. It rests on the Sparky with a sharp, erosional contact and is in erosional contact with the 3 m thick, upward-fining cycle 2 of argillaceous, fine-grained quartzose sandstone and dark grey, clayey mudstone, with scattered cut-and-fill bedding, coaly blebs, lenticles and compressed tree fragments. Cycle 2 (3.0 m) is apparently a drowned-channel fill successor of cycle 1. The sandstone of cycle 3 (1.8 m) transgresses an ironstone conglomerate-strewn erosion surface, and grades from medium grey, argillaceous, muscovitic siltstone, through bioturbated, mixed sandstone-mudstone, into medium-grained, calcite-cemented, low-angle cross-bedded sandstone with subrounded and rounded grains and coaly placers. A bioturbated sandstone–carbonaceous shale–paleosol succession constitutes cycle 4 (2.6 m), whereas cycle 5 (7.6 m) is fine-grained, well-sorted, quartzose sandstone interbedded with thin, ripple-drift siltstone and sandstone, above a basal bioturbated and flasered mudstone-sandstone bed. Cycle 6 (2.5 m) starts from an erosional contact but continues through flasered mudstone and sandstone into cross-bedded, very fine and fine-grained, quartzose sandstone with abundant oxidized, brown sphaerosiderite. Cycle 7 (6.7 m) fines upward from mostly fine-grained quartzose sandstone, with subrounded and subangular grains and abundant carbonaceous grains, through a 1 m thick, laminated, argillaceous, obliquely burrowed, very fine grained quartzose sandstone and shale, into a thin, foraminiferal black shale. It ends with thin (0.70 m), very fine grained, quartzose sandstone under capping red and yellow sideritic claystone.

Bedding cycle 1 of the Pense Formation is clayey, massive mudstone, 4 m thick, on an erosional contact zone that includes scattered, irregular, coaly partings. There is also a medial bed, 0.10 m thick, of yellow-grey, siderite-cemented, fine-grained, quartzose to lithic sandstone with subordinate mudstone grit and quartz-nucleated clay oolites. Cycles 2 and 3 (1.6 and 0.5 m) are condensed and probably truncated. Each consists of bioturbated, argillaceous sandstone and subordinate shale, and each rests on sharp, irregular contacts. Vestigial Pense sequences continue into the overlying Joli Fou Formation. These are thin, calcite-cemented, cherty, glauconitic and pyritic sandy beds, with scattered coaly tree fragments and multiple erosional contacts.

Stratigraphic Transects of the Northern Basin

Because of the variability of Mannville facies and the uncertainty associated with the picking and definition of Mannville members, this study leans heavily on the use of geophysical-log stratigraphic cross-sections for correlation control. The grid of north to south stratigraphic cross-sections A-A' to D-D' and west to east cross-sections U-U' to Z-Z' (see Figure 4) serves this purpose. The cross-sections are vertical slices of the depositional basin, and thus provide means for the physical description of the basin and for the interpretation of morphological and tectonic factors active in its make-up. As a generality, the correlations are dependent on recognition of shale associated with the multiple marine transgressions from the northwest.

Southward in the western half of the Mannville basin, overlap of older strata by younger against the sub-Cantuar topography is recognized and correlation is done accordingly. The widespread distribution, across southeastern Saskatchewan, of the regional glauconitic and foraminiferal Cummings shale, which is the apparent equivalent of the calcareous shale and Ostracode zone of southern Alberta, indicates that the sub-Cantuar topography is not a significant obstacle to continuity of correlation. All correlation lines in the north to south cross-sections east of the Third Meridian (longitude 106°W) rise and fall in sympathy with the sub-Cantuar erosion surface. However, dislocations attributable to the dissolution of salt from Middle and Upper Devonian strata, and truncation of the Cantuar from the top downward under the Pense Formation, especially in east-central Saskatchewan, need to be taken into account.

Regional Stratigraphic Cross-section A-A'

Regional stratigraphic cross-section A-A' (Figure 16) is a north to south transect of the Mannville basin from the Clearwater River region of northern Saskatchewan at Gulf Peter Pond 1-17-88-25(W3) onto the Kindersley Paleoupland of west-central Saskatchewan at BW Five Starr Kerrobert 4-22-33-23(W3). It more or less follows the boundary with Alberta from the type region of the McMurray, Clearwater, and Grand Rapids formations, incompletely exposed in the Clearwater River valley of Saskatchewan (Paterson *et al.*, 1978) and picked at Gulf Peter Pond 1-17-88-25(W3). The correlation indicates that the top of the Cummings Member coincides with that of the Wabiskaw Member, basal to the Clearwater Formation (Carrigy, 1973, Figure 3). Thus, the Dina and most of the Cummings equate with the McMurray, the Lloydminster and Rex equate with the Clearwater, and the General Petroleum, Sparky, and Waseca equate with the Grand Rapids Formation. Cenozoic erosion has removed the Pense Formation (McLaren and Colony members) and the upper part of the Waseca in the northwestern region.

Section A-A' depicts the rhythmic array and general thinning of the Mannville southward across the Meadow Lake Paleolowland to where it onlaps: 1) the structural front presented by the drape of the Meadow Lake Escarpment and the northern edge of the Middle Devonian Prairie Evaporite, and 2) the sub-Cantuar topography. Further thinning is caused by attenuation of individual units, especially of the multicyclic members below the General Petroleum Member, in the wedge of the stratigraphic cross-section that tapers against the Kindersley Paleo-upland. Depositional gradients in the Mannville basin were apparently low, and broad lenticular sandstone units dominate the stratigraphic morphology. This cross-section is the northern extension of the line from the Swift Current Paleo-upland to the Kindersley Paleo-upland (Maycock, 1967) and is depicted in Christopher (1974, Figure 17).

The Mannville is thickest (up to 275 m) north of Twp. 55 in the Meadow Lake Basin, and virtually all of the thinning to the south occurs in the Dina, Cummings, and Lloydminster members. Calcite-cemented, marine sandstone pavements, indicated by their spiky resistivity signatures, coincide with emergent surfaces. They are conspicuous in the Rex and Lloydminster members across the basin, and increase in number southward to include the General Petroleum, Sparky, and Waseca members. These increases are sporadic south of Twp. 57, beginning at Imperial Sidney Lake 3-16-55-25(W3), but intensify south of Tenn Tangleflags 2-36-52-25(W3), where the Mannville overlies the broad terraces of the Unity shelf. The pavements are apparently products of lowstand seas. A particularly prominent Lloydminster shoreface sand body is displayed at Imperial Beacon Hill 8-16-62-25(W3), Bonavista Whelan 11-14-59-25(W3), and SPC HB Peck 8-32-57-26(W3) in transgressive overlap of a low sea-stand, lower Lloydminster surface. The sand body appears to be a barrier beach built up on a subsiding base, as indicated by the structural downwarp of the underlying units and the sub-Mannville erosion surface. That the depositional base was also structurally active across the basin is indicated by the sympathetic relationship of the lower Mannville correlation lines with the erosional surface, despite the topographic relief.

Whereas the members of the Mannville at a given site are divisible into units comprising bedding cycles, no persistent attempt has been made to correlate the cycles from one locality to another, other than to provide insight into the Mannville depositional format. Regional continuity of intramember units can be demonstrated for the Dina, Cummings, Lloydminster, and Waseca. The four numbered units of the Cummings and Lloydminster members in the Meadow Lake Paleolowland basin show a progressive onlap, from north to south, onto the upper slopes of the Unity and Kindersley paleo-uplands. Unit 1 of the Cummings (*i.e.*, the 'lower Cummings') is equal in thickness to the combined Units 2, 3, and 4 of the 'upper Cummings' in the Meadow Lake Paleolowland basin, but is overstepped southward by Unit 2 at a terrace of the Unity Paleo-upland. Units 3 and 4 constitute the Cummings south of Twp. 43. The units of the Lloydminster are similarly distributed. Unit 1 (*i.e.*, the 'lower Lloydminster') is also the thickest of the units in the Meadow Lake Paleolowland basin, but abuts the Unity terrace at Twp. 52. Its upper contact is also marked by a pronounced cemented zone or pavement indicative of regional regression and emergence. Units 3 and 4 represent transgressive units marked by lowstand strand deposits in the Meadow Lake Paleolowland basin and transgressive beds across the Unity and Kindersley terraces. The local attenuation of Unit 4 indicates that the Lloydminster is in erosional contact with the Rex Member.

The Rex, General Petroleum, and Sparky members are less amenable than the Lloydminster to the process of unit correlation because the bedding sequences and facies distribution are short ranging and intersected by erosional channels. Thus, the potential for erroneous correlation of units is relatively high. The approach is, however, applicable to the Waseca. As in the Cummings and Lloydminster members, a southerly onlap of the Unity and Kindersley paleo-uplands is indicated by the overlap of the Waseca Unit 1 at the Unity terrace front. An apparent widespread flooding surface at the top of Unit 4, marked by thin marine shale above a planed surface, effectively divides the Waseca into upper and lower parasequences. Regional truncation under the Pense Formation variously terminates the Waseca.

Regional Stratigraphic Cross-section V-V'

The east-trending keel of the northern Mannville depositional basin is axial to the broad erosional terraces fronting the cuestas on the Souris River and Duperow formations. In the absence of local salt-dissolution effects, the members of the Mannville are laid down largely as flat-lying strata made up of macrolenticular units (Figure 17). The mild sub-Cantuar relief between Husky N. Aberfeldy A8-22-50-27(W3) in the west and Brady No. 1 (16-28-44-3W2) in the east is obliterated by Dina sandstone. Stratigraphically higher correlation lines, with few exceptions, rise and fall with the basal unconformity. Conspicuous departures from this pattern indicate stratigraphic discordances related to local warp and erosion associated with episodes of subaerial emergence. At Britalta Brightholme No. 1 (5-29-47-3W3) and Britalta North Cabin No. 1 (16-26-47-2W3), the Cantuar Formation infills a partially exhumed Success-inlaid valley sink which, as indicated by downwarp of Cantuar correlation lines, was reactivated penecontemporaneously. Farther to the east, as at B.A. Sorby 13 (13-16-47-22W2), such downwarp occurred late in the Waseca.

All members of the Cantuar below the Waseca are multicyclic in the region west of the Third Meridian; that is, they are dominated by upward-coarsening and upward-fining facies and by sandstone, with shale forming only one-third or less of the succession. Their lithological characteristics can be extrapolated from the core descriptions of the wells in cross-sections A1-A1' and A2-A2', particularly Shell Husky Paradise Hill A13-19-52-23(W3), Shell Dee Valley A11-18-48-21(W3), and Shell Meota C13-17-46-17(W3). The Dina sandstone is the most consistently developed, although interrupted locally (*e.g.*, in HB Pikes Peak A6-12-50-24(W3)) by lateral shale-mudstone facies. The Lloydminster and Rex members, although having marine characteristics, are strongly lenticular. Bedding sequences swell and thin, appearing and disappearing along the line of section. These effects are dramatically expressed in the wells between HB Westhazel A7-32-50-22(W3) and Husky Daysville 7-30-50-19(W3), where the Lloydminster thickens to 46 m at Sceptre et al Turtleford 16-4-51-20(W3) from the 30 m in the adjacent wells. Here, only the stacked capping sandstone units of the four upward-coarsening cycles constitute the Lloydminster, and the bulk of these is taken up by cycle 3. In that thickening is accommodated by downwarp of the underlying datum levels in the Cummings and Dina, the Lloydminster sandstone probably accumulated in a local basin rather than in an erosional channel. Thinning of the Rex over the sand body is apparently compactional.

Truncational relationships between the Sparky, General Petroleum, and Rex members are depicted at Husky N. Alberfeldy A8-22-50-27(W3), HB Pikes Peak A6-12-50-24(W3), and Sceptre et al Turtleford 16-4-51-20(W3), and are apparently coincident with local penecontemporaneous downwarp. The sub-Waseca contact also displays erosional relationships, especially at Husky DH Turtleford 6-5-51-20(W3) and Husky Daysville 7-30-50-19(W3), where truncation of the Sparky and General Petroleum members has occurred. The erosional cuts are associated with the overlying mudstone facies of the Waseca and probably represent channel forms related to the Waseca Pikes Peak channel to the west (Van Hulten, 1984; MacEachern, 1986). The mudstone facies is also present at H.B. Pikes Peak A6-12-50-24(W3). Eastward toward the Third Meridian, the Waseca progressively thickens from 35 to 50 m, with sandy mudstone up to 30 m thick being prominent (Western Warner Shell Lake 2-6-49-8(W3), UOHL Parkside 8-5-47-4(W3), and Britalta Brightholme No. 1 (5-29-47-3W3). The sandy mudstone is conformable with the underlying Sparky.

The Mannville thins, east of the Third Meridian, largely by attenuation of the middle units by numerous diastems, and, east of Husky Phillips Speddington No. 1 (7-35-44-12W2), by regional uplift and truncation under the sub-Pense unconformity. The correlation surfaces conform to the Cantuar basal unconformity with the Devonian Duperow and Souris River formations. At Grey Owl Syndicate No. 1 (16-10-44-27W2) and Choiceland No. 1 Choice DD 13-3-50-18(W2) (stratigraphic cross-section A3-A3', [Figure 15](#)), upward-coarsening and upward-fining, bioturbated shale-sandstone facies and associated paleosols and alluvial beds are characteristic of the Cantuar Formation.

The Pense Formation is continuous across the province, varying no more than 3 m in thickness from regional values of about 12 m west of the Third Meridian and 10 m east of it. Although mildly truncational into the underlying Waseca, the basal contact is planar across the region with respect to the overlying Colorado datum. The Pense, like the Cantuar, features a range of rock types, such as upward-coarsening bioturbated facies, alluvial mudstone, patchy coal lenses near the base, and glauconitic beds near the top. Upper sandstone beds between Rge. 22W3 and 28W2, commonly called the 'Colony' (as distinguished from lower beds, named the 'McLaren'), attenuate across the region as truncated lenses below the Joli Fou Formation. Planation through the Waseca east of Husky Phillips Speddington No. 1 (7-35-44-12W2) reflects pre-Pense uplift of the region east of the north-south basement-controlled Tabernor Lineament Belt.

Regional Stratigraphic Cross-section U-U'

In northern west-central Saskatchewan, the axis of the Mannville depositional basin turns northwest toward the Cold Lake and Athabasca oil-sands region of east-central Alberta. Thus, the west to east regional stratigraphic cross-section U-U' ([Figure 18](#)) is a transect of the Meadow Lake Paleolowland re-entrant of those basins along Twp. 59 and 61, from the Alberta-Saskatchewan boundary to the Molanosa Dome of central Saskatchewan. It also crosses the underlying Middle Devonian Lower Elk Point Basin. The floor of the Meadow Lake Paleolowland basin is largely flat and, with values up to 240 m, the Mannville is at its thickest in Saskatchewan. The Mannville is also at its most marine overall, so member-correlation lines across the region are relatively uniform. The lithological description of the Mannville section at the Shell Husky Paradise Hill A13-19-52-23(W3) reference well is applicable to the wells of this region, and the intramember units delineated on the cross-section are extrapolated from the north-south regional stratigraphic cross-section A-A' ([Figure 16](#)).

Marine shale units are present in the Dina. The associated sandstone units, their geophysical-log signatures indicating massive bedforms to interbedded sandstone and shale, are presumed to be deposits of marine shoal and estuarine-bay environments. On the other hand, the basal coarse-grained sandstone is characteristically fluvial where seen in well cuttings and core. Lithological consistency is apparent between Imp Worthington 8-28-58-

27(W3) and Tidewater Meadow Lake Crown No. 4-34 (4-34-58-21W3); the Mannville thins east of the latter. Unit 3 of the Cummings is truncated under the Lloydminster Member at Cigol Amerada Watson Lake 10-5-60-22(W3), and Unit 2, which overlaps Unit 1 at Tidewater Meadow Lake No. 4-34 (4-34-58-21W3), continues eastward as the principal unit of the Cummings.

The four units of the Lloydminster Member display an easterly transgressive onlap, although Units 1 and 3 feather out under Unit 4 at MLO No. 1 (16-36-58-17W3). Farther east, Unit 4 overlaps Unit 2 onto the Molanosa Paleoup-land at Fina Montreal Lake No. 3-4 (3-4-59-25W2). Unit 2 returns to the line of section where it turns south at Union McPhee Lake No. 4-15 (4-15-56-27W2). The Rex and General Petroleums members are each thinner but behave similarly to the Lloydminster. The Sparky thickens slightly to the west (though with local deviations). The log signatures of the Waseca indicate consistent bedding groups of sandstone separated by shaly breaks and traceable to Seaboard Meadow Lake Crown No. 4 (10-20-61-12W3). Depositional slopes are eastward in an irregular downlap toward the base of the member.

From east of Choqua et al Meadow Lake 5-1-59-16(W3) to Great Plains McDermott Home Hay 3-18-63-1(W3), the sub-Cantuar floor changes its flat-lying aspect to one featuring strong structural displacement and topographic relief. Underlying Devonian strata are displaced by as much as 100 m. Most of this relief is transmitted directly to the erosion surface on the Devonian, where low areas are partially infilled by the Success Formation. Although punctuated by knobs of Devonian rock penetrating 42 m through the Dina, the sub-Cantuar erosion surface is essentially flat but rises gently eastward with respect to the sub-Pense unconformity. Thick sandstone beds are featured in all members, though more sporadically in the Rex, General Petroleums, and Sparky. Large-scale, fluvialite-channel cross-bedded grit and coarse-grained quartzose kaolinitic sandstone beds, 18 to 20 m thick, appear in the Waseca at Seaboard Meadow Lake Crown No. 5 (4-5-65-12W3) and are traceable eastward to outcrops on the Nipekamew River southeast of La Ronge. The Cantuar encounters the Meadow Lake Escarpment at Great Plains McDermott Home Hay 3-18-63-1(W3) and rises onto the Molanosa Dome from out of the Meadow Lake Basin, the middle members being draped and attenuated, and the Waseca partially truncated under the sub-Pense unconformity.

Stratigraphic Transects of the Southern Basin

Regional Stratigraphic Cross-section B-B'

As a generality, Cantuar sediments are constrained to valley systems within the mass of the Kindersley and Swift Current paleo-uplands west of the Third Meridian (longitude 106°W) and south of latitude 51°N. East of the Third Meridian, the Cantuar Formation maintains lithological continuity from northern to southern Saskatchewan. The north to south stratigraphic cross-section B-B' (Figure 19), along Rge. 28W2, exemplifies this and some of the stratigraphic problems associated with north to south (or vice-versa) correlations. The line of section, from its northern tie-in with the west to east cross-section V-V' (Figure 17) at Britalta Macdowall No. 1 (2-1-46-28W2), crosses the western flank of the Punichy Arch (specifically, the Watrous structural dome) and the eastern front of the Swift Current Platform, and ends at Socony Sohio Coronach 11-15-1-28(W2) on the west to east stratigraphic cross-section Z-Z' (Figure 22).

The Cantuar Formation at the northern wells, Britalta Macdowall No. 1 2-1-46-28(W2) and Grey Owl Syndicate No. 1 (16-10-44-27W2), is in contact with the Duperow Formation in the northern basin. It is about 120 m thick and includes all members, but the Waseca is about 6 m thinner at the latter well. Southward, the Cantuar thins mostly at the expense of the Waseca Member under the Pense contact. At Britalta Carpenter No. 1 (5-30-41-27W2), where the formation encounters the underlying Jura-Triassic Watrous Formation, thickness is 76 m. This stratigraphic relationship and general order of thickness are maintained to Davidson Crown No. 1 (13-4-27-28W2), some 145 km farther to the south, except for abrupt increases in thickness to 107 m at Duval Potash Co. Colonsay No. 1 (12-11-35-28W2) and to 88 m at Pheas BOAH Watrous 15-32-31-27(W2) and the adjacent HB Watrous 6-24-30-28(W2). The extra thickness of the Cantuar Formation at these wells is attributable to preservation of Waseca strata in structural downwarps of the underlying Watrous and Duperow contacts. The Dina remains the basal member of the Cantuar, but is overlain by a condensed Cummings Member, which is called the Cummings Shale in southern Saskatchewan. Combined, they constitute the McCloud Member of the Cantuar Formation in southwestern Saskatchewan, and are traceable across the broad, low-relief flats of the erosion surface. The pre-Cantuar flats bear only a slight resemblance to present structure, in that the elevations in the wells between the Macdowall and Watrous sites are now +33, -90, -102, -27, -37, -11, -103, -71, -35, -38, -49, and -63 m with respect to mean sea level (msl). Most of this structural relief is attributable to Late Cretaceous tectonics acting on the salt beds and the basement.

South from Davidson Crown No. 1 (13-4-27-28W2), the sub-Cantuar erosion surface rises stratigraphically onto the Middle Jurassic Upper Watrous, Gravelbourg, and Shaunavon formations. Also at this point, the sub-Watrous erosional surface crosses onto the Birdbear Formation but without topographic relief, although the dip of the Devonian strata increases southward into the Williston Basin. This lowered topographic level of the Birdbear Formation reflects pre-Watrous downwarp. Continuity of the McCloud Member onto and over the Middle Jurassic indicates a repetition of downwarp, but in pre-Pense time. Nevertheless, local pre-Dina topographic relief is indicated, as at United Comstock Craik 13-18-25-27(W2), where the Dina drapes a butte.

The northern front of the Williston Basin is encountered at CEGO Findlater 2-29-21-27(W2), where the southern limb of the breached anticlinal dome underlying the Watrous topographic basin coincides with the front of downdropped, thick, Mississippian Madison limestone. The back-stripped Madison scarp of the Watrous topographic basin lies some 18 km to the south at Socony Sohio West Marquis No. 1 (12-28-19-28W2). The sub-Cantuar erosion surface, which is perched on the resistant Shaunavon Formation, descends toward the south in conformity with the Middle Jurassic. Just north of Francana Marquis 4-12-19-27(W2), it intersects the Upper Jurassic Rierdon Formation, and is apparently uplifted on a horst attributable to multistage dissolution of the Prairie Evaporite salt (Smith and Pullen, 1967; Christopher, 1974, p113).

South of the Marquis site, the erosion surface crosses the vertical projection of the northeastern front of the southern dissolution edge of the Middle Devonian Prairie Evaporite salt beds, to the south of which the Upper Jurassic and underlying formations are downdropped on the salt-free Swift Current Platform. Consequently, the sub-Cantuar erosion surface rises stratigraphically but not topographically, to the Roseray horizon of the Rierdon Formation, remaining thereon to the paleotopographic front of the Masefield Shale at Worldwide LL E Old Wives L 5-23-7-27(W2), which the Cantuar onlaps. The Masefield Shale thickens to the south under the nearly flat sub-Cantuar unconformity, but its erosional front forms a locally breached scarp in the Mannville basin across the extreme southern part of Saskatchewan near latitude 49°N. Only the upper part of the Dina, the attenuated Cummings, and the Lloydminster extend over the Punichy Arch into the Williston Basin along cross-section B-B' (Figure 19). The younger members are truncated under the Pense Formation, but emerge from beneath it sequentially toward the south. This descent of the sub-Cantuar erosion surface results in a thickening of the Cantuar Formation to some 100 m in valleys entrenched in the Swift Current Paleo-upland (e.g., at Socony Sohio Readlyn 11-10-8-28(W2)) but only 64 m on the highs. Correspondingly, the Pense Formation not only thickens progressively southward to over 45 m from the 9 m on the crest of the arch, but also becomes differentiated into four, defined, upward-coarsening units.

Regional Stratigraphic Cross-section C-C'

North of Twp. 56, Rge. 27W2 (Figure 20), the Cantuar Formation onlaps the western flank of the Molanosa Dome, so that the Dina, Cummings, Lloydminster, and Rex members are progressively overlapped onto the basal unconformity by the General Petroleum and younger members. Additionally, the Cantuar is in erosional onlap with respect to the Middle Devonian Winnipegosis and Ashern, Silurian Interlake, Ordovician Stony Mountain and Red River, and Cambrian Deadwood formations. South to Choiceland No. 1 Choice DD 13-3-50-18(W2) and beyond it to Sun Kinistino 3-20-45-21W2, the Cantuar erosional floor flattens with respect to the Pense datum, primarily because the deep relief on the Souris River Formation is taken up by structural and erosional inliers of the Success Insinger beds, as at Hudsons Bay Torch Lake No. 2 (1-10-53-23W2), Gronlid No. 1 (15-32-47-17W2), and Pheas Jeff Lake Melfort 5-34-45-18W2. Thus, the 120 m thickness of the Cantuar Formation along the line of section is fairly consistent and correlation lines are nearly parallel.

Of all the units of the Cantuar Formation, the McCloud Member, comprising the sandy Dina Member and the shale facies of the Cummings Member, is by far the most lithologically consistent of the Cantuar units. The Dina sandstone in the well cuttings is invariably quartzose, fine, medium, and coarse grained, and generally poorly to moderately cemented. Its presence at virtually all of the full-sectioned Mannville sites implies a sheet-like distribution beyond the limits of individual channels, and thus considerable reworking in broad bodies of water.

The cored section at Choiceland No. 1 Choice DD 13-3-50-18W2, described in stratigraphic cross-section A3-A3' (Figure 15), is typical for the region around it. However, fronting the Molanosa Paleo-upland from Hudsons Bay Torch Lake No. 1 (13-14-52-23W2) and north onto its heights, conspicuous fluvatile-channel quartzose sandstone and grit form part of the Waseca. These are exposed in the cliffs of the Holocene Nipekamew River east of La Ronge (Christopher *et al.*, 1973). The basal Dina-Cummings sandstone constitutes as much as half of the Mannville section north of Choiceland because of thinning in the medial members by multiple diastems. The Pense (McLaren Member) Formation lies in general conformity across the region, only mildly truncating the Waseca. Younger Spinney Hill beds of the Joli Fou Formation form a southward-thinning tongue from the Tertiary erosional edge.

At Woodley Signal Yellow Creek 12-16-44-22W2, the Cantuar Formation abruptly thickens to 207 m in an apparent penecontemporaneous salt-dissolution sink. Deepening of the depositional site is also indicated by the presence of glauconite in the cemented quartzose sandstone of the upper part of the Dina. Regional Cantuar thickness returns to the section on the vast terrace of Success beds in the Insinger district. However, the Dina thins to between 10 and 20 m, thereby reflecting the higher elevation of the terrace, and is traceable to U.S.P. Wynyrd No. 11 (13-29-32-15W2), about 135 km to the south-southeast. In the Quill Lakes district, between Sohio Baysel Quill Lake No. 11 (13-36-38-15W2) and Sohio et al Quill Lake 12-10-37-14(W2), the Cantuar members are thickened into depressions created by penecontemporaneous downwarp of the underlying Duperow Formation, in a manner consistent with salt-dissolution phenomena. Blocky SP (spontaneous potential) and positive, low resistivity signatures, 10 to 15 m thick and suggestive of poorly cemented, water-saturated sandstone beds, occur at random throughout the member horizons of the Cantuar Formation, most of them resting on calcite-cemented pavements associated with emergent conditions. As deduced from the cored sections, they probably reflect shoreface beach, barrier-bar, and estuarine tidal-channel sandstone. Thinner, upward-fining sandstone-mudstone bodies, located at random in the sections and suggestive of fluvial- and tidal-channel sandstone units, are also indicated. On the whole, sandstone forms 30 to 50% of the formation. The Pense Formation is seen in the well cuttings to be variably glauconitic and maintains a uniform stratigraphic consistency throughout, ranging in thickness from 6 to 14 m and averaging 10 m.

At Tidewater Rushville Crown No. 1 (9-23-31-16W2), the Cantuar encounters the northern front of the Punniichy Arch. At that well and at St Mary Touchwood 16-6-30-18(W2), the Upper Devonian Three Forks Group is arched under the Success-blanketed terrain, and forms part of the structural framework on which the Dina and Cummings have been elevated. Thinning of the Cantuar Formation to half of its regional value occurs by truncation of the upper members under the Pense Formation, so that the General Petroleum Member forms the topmost unit. On the crest of the arch in the three Punniichy wells (KR Pheas et al Punniichy DD 7-29-28-16(W2), Pheas KR Punniichy 6-13-28-17(W2), and KR Punniichy DD 7B7-29-3B7 (7-29-27-17W2)), the Dina and Cummings are at the top of the Cantuar section, surrounding but not covering a butte of the Success Formation that is in contact with the Middle Jurassic-capped, Mississippian limestone-supported escarpment at Pheas KR Punniichy 6-13-28-17(W2). The descent of the Arch into the Williston Basin begins at KR Punniichy DD 7B7-29-3B7 (7-29-27-17W2), and the sub-Cantuar erosion surface crosses the bevelled Success Formation and the Middle Jurassic stratal onlap of the Mississippian at Tide Water Cupar Crown No. 4-28 (4-28-24-16W2). The southern boundary of the Punniichy Arch is taken to be at BA Qu'Appelle Hornung 2-4-22-15(W2), where the wedge of Jura-Triassic Watrous Formation opens southward at the unconformity on the Mississippian. The steepening of the regional dip into the Williston Basin is further marked at TW Imp Avonhurst Cr. 1-29-19-16(W2) by the rather abrupt appearance of the Upper Jurassic Rierdon Formation beneath the Dina. From the foregoing, it is deduced that: 1) uplift of the Punniichy Arch, as indicated by truncation of the Cantuar under the Pense Formation, was the last in the sequence of similar events initiated in the periods pertaining to the post-Mississippian-pre-Triassic and the Middle Jurassic; 2) a great deal of the structural relief on the arch was blanketed by the earlier events; and 3) the sub-Pense upwarp was extremely low, on the order of 60 m over a distance of 90 km, as taken between U.S.P. Wynyrd No. 1 (13-29-32-15W2) and Tide Water Cupar Crown No. 4-28 (4-28-24-16W2).

Extending south for 185 km from Avonhurst to CDR et al Ratcliffe 7-27-1-15(W2), near the border with North Dakota, the Cantuar forms a relatively thin (60 m) blanket draped across low terraces of the underlying terrain, and generally overlies the Upper Jurassic formations. The Dina is represented by bipartite sandstone, 5 to 12 m thick, under the thin Cummings shale marker, and features a southward transition from estuarine to fluvial bodies. The medial members, Lloydminster to General Petroleum, include glauconitic sandstone, and thus retain marine characteristics into the centre of the Williston Basin. Likewise, the Waseca, which returns from under the sub-Pense unconformity to the line of section at Agro Hurd 10-9-17-15W2, maintains a variable facies of sandy mudstone, ranging from continental to estuarine. The Dina in the line of section is terminated against the escarpment of the southern Success Formation at Central Del Rio Goodwater 10-35-5-13(W2). Thickening of the Dina to the north of escarpment, as at Central Del Rio Weyburn No. 6-14 (6-14-7-14W2), represents a location in the easterly course of the sub-Dina Assiniboia Paleovalley from off the Swift Current Paleo-upland to the west.

Regional Stratigraphic Cross-section D-D'

From the intersection with cross-section V-V' at California Standard Bannock 15-5-46-9W2 (Figure 4 and Figure 17), stratigraphic cross-section D-D' (Figure 21) is aligned southerly between Rge. 12W2 and 6W2 to its junction with Z-Z' at Dome Provo Co-op Pinto 16-14MZ-1-5 (16-14-1-5W2) near the Canada-United States border (Figure 22). Between Shell Chelan A7-11 (7-11-42-11W2) and H.B. Kuroki 12-6-35-10(W2), the sub-Cantuar erosional surface shows little stratigraphic relief. Contact is with the Duperow Formation, except at Miami HB No. 3 Nut Mtn 4-1-39-11(W2) and H.B. Kuroki 12-6-35-10(W2), where Success inliers are preserved in structural downwarps. The capping Waseca Member is gently planed southward under the Pense Formation. Member contacts in the Cantuar generally conform to the sub-Cantuar erosion surface, and the Dina and Cummings members maintain a

combined thickness of about 30 m. Uplift of the Cantuar Formation on the Devonian with respect to the Pense contact is indicated at Imperial Kuroki No. 7 (7-30-34-10W2) and Texas Pacific Pig Lake 12-18-34-9(W2) by loss of the Waseca Member. Southward onto the crest of the Punichy Arch, the Cantuar Formation is inlaid on a dissected Success Formation. At Imperial Kuroki No. 7 (7-30-34-10W2), the Cantuar Formation has risen about 30 m onto the terraced apex of the Punichy Arch.

The stratigraphic layout of the region to the north is retained southward for 125 km to Socony Sohio Killaly 14-11-21-6(W2), to where the stratigraphic datum on the Bakken Formation relative to the Pense Formation steepens into the Williston Basin. Sub-Pense truncation of the Cantuar Formation, as exemplified by loss of the Waseca and Sparky members at Imperial Kuroki No. 7 (7-30-34-10W2), and loss of the General Petroleum Member at Sohio Invermay No. 1 (4-6-33-8W2), leaves the Rex as the capping member of the Cantuar Formation. Severe pre-Cantuar erosion of the Success Formation and vertical downdrop of the Upper Devonian Birdbear and Three Forks strata are also indicated between Sohio Invermay No. 1 (4-6-33-8W2) and Seaboard Devils Lake Crown No. 16-11 (16-11-28-6W2). The Success butte at Sohio Baysel Foam Lake No. 1 (1-34-31-9W2) is apparently supported by an underlying Devonian horst, and contrasts with preservation of the Success Formation in the adjacent grabens, particularly that dramatized by the 115 m downfaulting of the Birdbear Formation at the Sohio Western Pet Insinger 9-16-29-7(W2) reference well for the Success Formation. Structural-stratigraphic combinations involving dislocations of this type typify salt-dissolution tectonics.

Stacked cyclic sandstone characterizes the Lloydminster Member, but sandy shale dominates the Rex, indicating a deepening of the basin. A similar progradational to transgressive relationship is repeated for the General Petroleum and Sparky members. The Sparky also appears to be erosionally thinned. The Waseca retains its multicyclic character southward, and its increasing sandstone content is suggestive of shoaling on the approaches to a submerged Punichy Arch. South of Sohio Allenbee Lintlaw 4-15-35-10(W2), this sandstone yields to shale-dominated facies. All sandstone bodies, including the Dina, are multipartite, as suggested by resistivity spikes indicative of cemented pavements and repeated exposure of the depositional bottom.

Gentle domes and sags are featured on the southern side of the Punichy Arch from UOHL Crescent Creek 6-16-24-7(W2) to BA Husky Phillips Colmer 5-28-22-7(W2). The shallow sinusoidal warp of the Bakken datum and its correspondence to the erosion surface indicate a pre-Cantuar dome at UOHL East Crescent Creek 13-21-23-6(W2), flanked by lows to the north and south. This is confirmed by pre-Jurassic thinning of the Mississippian, and thinning of the Dina over the dome. Discordance between the Bakken datum and Mannville correlation surface is present also at BA Husky Phillips Colmer 5-28-22-7(W2), where the Cantuar is domed and truncated at the pre-Pense contact but the Bakken is downwarped. Stacked sand bodies in the Dina, Lloydminster, and Rex members, in the southern part of the section between Socony Sohio Killaly 14-11-21-6(W2) and Imperial Warmley 6-23-10-6(W2), dominate the Cantuar lithology and overwhelm the sub-Cantuar topographic relief on the Middle and Upper Jurassic. They reflect fluvial and estuarine infill of the Broadview structural basin that lies athwart the course of the Assiniboia Paleovalley complex, entering from the paleo-uplands of the Swift Current district, and its confluence with the tributary system from the Williston Basin region of North Dakota (Figure 28).

Regional Stratigraphic Cross-sections Z-Z', Y-Y', and Y1-Y1'

The southern Mannville basin is flanked to the north by the Punichy Arch and to the south, along the Canada–United States border, by the breached escarpment of the Upper Jurassic Masfield Formation and the Jura-Cretaceous Success Formation. As illustrated in cross-section Z-Z' (Figure 22), the Cantuar Formation is in erosional onlap with the Success Formation on the Swift Current Paleo-upland west of Shell Wood Mountain No. 7 (12-20-3-10W3), where the General Petroleum forms the basal member. To the east, between Shell Wood Mountain No. 9 (14-19-1-8W3) and Sohio Standard Shell Wood Mountain No. 1 (16-10-4-4W3), where the Cantuar Formation is incised through the Success Formation into the Masfield Formation, the basal members are the Dina and Cummings. Beyond, to C.F.P. Torquay No. 2 (12-20-2-11W2), the Lloydminster is at the base of the Cantuar, whereas the Dina Member forms the basal Cantuar fill eastward to the Saskatchewan-Manitoba boundary.

The Cantuar depositional floor rises westward on broad pediments and valley straths to the heights of the Swift Current Paleo-upland; however, in the east along the Second Meridian (longitude 102°W), it is delimited by the escarpment of Upper Jurassic strata supporting the deeply dissected Moosomin Paleo-upland. Overall, the central Cantuar basin is in a structural depression on the partially eroded Upper Jurassic Rierdon Formation. Regional stratigraphic cross-section Y-Y' (Figure 23) is a west to east central transect of this basin, from Alberta to Manitoba, between Twp. 11 and 15. Nomenclature (*i.e.*, Cantuar and Pense formations) used is that defined by Price (1963), and the members of the Cantuar (*i.e.*, Atlas, Dimmock Creek, and McCloud) are after Christopher (1974, p26-32). The members of the Cantuar are equated with the Lloydminster units, on the basis of the north-south correlations as tied into cross-section Y-Y', as follows: McCloud (Dina-Cummings), Dimmock Creek (Lloydminster-Rex), and Atlas (General Petroleum–Sparky and Waseca).

The Amurex Albercan McCloud No. 1-15 (15-12-10-27W3) type well of the McCloud Member (Christopher, 1974, p18) and the Barhar Zamora BA Cardell 6-9-12-25(W3) well are located in the Eastend Paleovalley that trends northwest from the Swift Current Paleo-upland into Alberta (Christopher, 1974, Figure 10A) and thus features full Cantuar and Pense sections. In core of the McCloud Member, the Dina sandstone is separated from the Cummings shale by a 0.6 m thick, pyrite-cemented pavement. The sandstone is fine grained, weakly cemented with calcite over the upper half, and includes about 15% kaolinite below. It is flat bedded to low-angle trough-cross-bedded over the basal 1 m and is floored with green claystone boulders and cobbles. The superjacent Cummings shale comprises: 1) a lower, 3.9 m thick, unconformity-bounded, calcareous and sandy foraminiferal shale; and 2) an upper, 9 m thick, coal-veneered, calcareous mudstone-shale unit that includes subsidiary bedded and burrowed, quartzose sandstone with accessory chert. The base of the member is marked by 0.5 m of angular mudstone pebbles and granules. The overlying Lloydminster basal sandstone of the Dimmock Creek Member is quartzose, weakly cemented, fine grained, and well sorted, and includes abundant organic and pyritic specks.

The type well for the Dimmock Creek Member, Seaboard Cdn Dev Dimmock Ck 9-24-11-21(W3) (Christopher, 1974, p30), located in a shallow valley on the crown of the Swift Current Platform, comprises: 1) a basal 1.4 m of thin-bedded, medium-grained quartzose sandstone, consisting of rounded grains with quartz overgrowths and about 7% rose quartz, sphaerosiderite, and black chert in a white kaolinitic and green chloritic matrix; 2) a medial mudstone, 14 m thick, which grades upward from layered, black, coaly shale into dark green, massive mudstone; and 3) an upper mudstone, 10.6 m thick, with abundant (5%) coaly laminae and carbonized stalks, and scattered irregular layers of fine-grained, quartzose sandstone with about 15% coaly carbonaceous grains, kaolinite grains, and biotite flakes. The high mudstone content of the Dimmock Creek is a characteristic of the high-upland valley deposits. Because of the relative eastward increase in elevation of the Swift Current upland, the Dimmock Creek forms the basal onlapping unit of the Cantuar Formation at this site.

The type section for the Atlas Member is in the Tidewater Atlas Crown No. 3 (8-20-18-14W3) well, at 981.5 to 951.4 m below KB (Christopher, 1974, p31), and is located to the north of cross-section Y-Y'. It features: 1) a lower part, comprising five upward-fining cycles (4.2, 2.7, 1.2, 1.2, and 4.2 m thick), generally trough (high- and low-angle), festooned, and steep planar cross-bedded, consisting of green, chloritic mud-indurated, fine- and medium-grained quartzose sandstone with up to 30% dark grey chert, kaolinite pseudomorphic after feldspar, amorphous green chlorite, grey-green mudstone fragments, black chert, white feldspar, red-brown siderite, and carbonaceous grains; 2) a medial bed that coarsens upward from a basal, dark grey mudstone (3.7 m thick) through a green-grey shale-siltstone bed (9.2 m thick); and 3) a top bed (2.7 m thick) that fines upward from a thin, medium-grained quartzose sandstone, with mineralogy as above, into slightly contorted, light grey, graded, sandstone-shale couplets. The basal unit (*i.e.*, the 'Lower Atlas sandstone') is fluvial in character and is taken as the continental equivalent of the General Petroleum and Sparky members. The sandstone and shale of the medial unit are marine tongues from the east, and the 'Upper Atlas sandstone' (Chokecherry Member of Leckie *et al.*, 1997b) represents an estuarine channel. Both are equated with the Waseca Member.

With respect to cross-section Y-Y' (Figure 23), from Seaboard et al Carmichael 6-14-12-20W3 east to Tidewater Parkbeg Crown No. 2 (13-8-15-3W3), only the Atlas Member, in whole or in part, represents the Cantuar Formation, by virtue of onlap of the 67 m high western escarpment of the Success-capped Swift Current Paleo-upland, and by erosion under the Pense Formation. To the east, the basal contact descends the 45 m high east-facing wall of the pre-Cantuar Assiniboia Paleovalley complex, wherein the Cantuar Formation is developed to the extent permitted by the underlying relief. Between Shell Old Wives A (16-11-14-30W2) and Richfield et al Bechard 11-22-13-16(W2), the Dimmock Creek and Atlas thicken from 52 to 79 m, but thin to a more regional 56 m beyond the latter well. These members of the Cantuar include thick sand bodies in one or other of their units.

At Old Wives Lake, the Dimmock Creek Member reveals in core an upward gradation in the Rex, from dark green-grey shale to 8 m of kaolinite-indurated quartzose sandstone with a volcanic suite featuring biotite and chlorite, and a fluvial affinity. The General Petroleum is 15.5 m thick, massive, fine-grained, well-sorted, subrounded, weakly cemented, very permeable, quartzose sandstone with abundant muscovite, rose quartz, and carbonaceous specks. Its texture and mineralogy show no relationship to the underlying fluvial sandstone, and its sorting, rounding, and lack of cementation indicate multicyclic reworking. It is probably a beach or estuary mouth bar. The medial unit of the Atlas is a dark grey, flasered and bioturbated, very fine grained, quartzose sandstone and mudstone, which fines upward into dark grey and green-grey shaly mudstone. It apparently signifies a marine transgression typical of the member in the region. Stratigraphically equivalent sandstone bodies, about 24 m thick and resting on cemented pavements, appear also at HB et al Wilcox 13-14-13-21W2 and Socony Sohio East Corrine 9-20-13-19W2. The blocky spontaneous potential and flat, low, resistivity signatures at Wilcox suggest a water-saturated channel deposit, whereas those at Corrine indicate an upward-shoaling shale to sandstone transition. The Rex Member between Wilcox and Old Wives Lake includes two interbedded argillaceous sandstone beds in a thickened section. This sandstone consists of stacked tabular bodies.

The incline of the sub-Cantuar contact onto the Govan Paleolowland (Christopher, 1980, Figure 4) is marked by continuity of the Lloydminster and Cummings-Dina members. However, the eastward slope is not wholly topographic, in that these members are also downwarped toward the east, as indicated by their relative elevations with respect to the Colorado datum, at Socony Mobil Droxford 12-22-16-6(W3), Socony Sohio South Avonlea 4-9 (9-4-12-23W2), and Socony Sohio East Corrine No. 20-9 (9-20-13-19W2). Westward downwarp of the Swift Current Paleo-upland between Socony Mobil Droxford and Seaboard et al Carmichael 6-14-12-20W3 is also indicated by similar downwarp of Jurassic and Cantuar strata with respect to the Colorado. The space created is taken up by thickening of the Pense Formation to 45 m from the regional 30 m, and by an increase from five to eight in the number of cycles coarsening upward from black shale, through flasered, current-bedded, bioturbated black shale, siltstone, and sandstone, to capping, light grey, calcareous and glauconitic, cross-bedded, fine-grained quartzose sandstone.

East of Socony Sohio East Corrine No. 20-9 (9-20-13-19W2), the most definitive of the Cantuar units is the McCloud Member. Its thick Dina sandstone is spread as multiple sheets. Between Triton TW Windthorst Cr. 2-28-13-7(W2) and Central Del Rio Red Jacket No. 6-19-13-32(W1), the line of section intersects the northerly course of the pre-Cantuar Assiniboia Paleovalley, in which the Dina thickens from 18 to 30 m in the west to more than 40 m. At TW Imp Bender Cr. 13-11-12-5(W2), the Dina (depth 944.9 to 973.2 m) consists of the following three units (bottom to top):

Unit 1

973.2 to 965.0 m Sandstone: quartzose, very friable and permeable, bimodal, fine grained with subordinate medium increasing to dominant, interbedded with subordinate fine above 969.6 m.

Unit 2

965.0 to 964.7 m Shale: dark grey; minor green glauconite, very fine grained, quartzose sandstone lenticles.

964.7 to 954.3 m Sandstone: quartzose, bimodal, medium grained with subordinate fine; abundant jasper, white feldspar, black chert, and white kaolinite; weakly cemented and very permeable.

Unit 3

954.3 to 951.3 m Mudstone: medium grey, siliceous; scattered carbonaceous fragments and brown ironstone concretionary nodules.

951.3 to 944.9 m Shale: silty, fining upward into waxy, olive grey; scattered lenticles of white, quartzose, argillaceous siltstone; scattered glauconitic burrow-fill; abundant sideritic concretions.

By simple inspection, the argillaceous beds of Unit 3 would appear to be the Cummings shale; however, geophysical log correlations show them to be part of the upper Dina, and the Cummings shale marker to be an overlying unit. The bimodal sandstone of the Dina reflects fluvial transportation and deposition, but the intervening shale and the capping shale of Unit 3 are glauconitic and the shale units, burrowed as well, are evocative of marine deposition. An estuarine environment of competing fluvial and marine influences, or a prevailing fluvial environment punctuated by marine invasion, are probable interpretations. The Dina sandstone is further detailed in the chapter dealing with the Mannville depositional basin (*see* 'Lower Cantuar (Dina-Cummings) Depositional Pattern' section).

Upper Jurassic shale, flanking the pre-Cantuar Assiniboia Paleovalley, forms a ridge overlooking the Moosomin Paleo-upland, which extends north from beyond the Canada–United States border to about Twp. 20 and eastward into Manitoba. The Assiniboia Paleovalley in the vicinity of TW Imp Bender Cr. 13-11-12-5(W2) is 80 km wide and flat floored, compared to the more detailed and complex portion of the valley farther to the south. Here also, overlying members of the Cantuar feature large-scale, upward-coarsening and upward-fining sandstone bodies. This is the Broadview structural basin, the southern portion of which is crossed by cross-section Y-Y' and the northern portion by Y1-Y1' (Figure 24). As can be seen in the two cross-sections, the depression was also active in the Middle Jurassic as a depositional site for widespread sandstone sheets.

The transect of the Pense Formation by cross-section Y-Y' (Figure 23) reveals a large lens-like amplification in thickness of the formation to 45 m, from the regional average of 15 m, between Seaboard et al Carmichael 6-14-12-20W3 and Socony Sohio East Corrine No. 20-9 (9-20-13-19W2). This region corresponds to the sub-Cantuar Swift Current Paleo-upland, and the underlying tectonic Swift Current Platform (Christopher, 1974). Late Mannville settling of the platform enabled a buildup of the Pense sediments on it. East of Triton TW Windthorst Cr 2-28-13-

7(W2), concomitant uplift of the Punnichy Arch and the Moosomin–Hudson Bay structural belt resulted in the pre-Pense removal of the Waseca.

Stratigraphic Transects of the Kindersley–Punnichy Arch Region

The Kindersley structural region in the west and the Punnichy Arch in the east are both located between latitudes 52° and 51°N but are separated by a north-south structural zone near longitude 107°W. Their historical relationship is discussed in the ‘Tectonic Setting’ section. At the beginning of the Mesozoic, both elements were at the same relative structural elevation and were topographically capped by Mississippian limestone. This limestone was erosionally breached during several episodes of uplift and filled in with Jura-Triassic Watrous red beds in the central part of the area and with Jura-Cretaceous Success quartz-kaolinite and chert-rich sandstone in the west and the east. Differential structural movement of the Kindersley region relative to the Punnichy Arch accompanied these events so that, at the beginning of Cantuar time, the Kindersley region presented a significant topographic front to the north, whereas the Punnichy Arch had subsided to below the Cantuar initial depositional base. This relationship and its control on regional correlation are demonstrated in the north-south regional stratigraphic cross-sections A-A', B-B', C-C', and D-D'. Stratigraphic cross-sections W-W' and X-X' are drawn west to east, the first along the northern front of the structural forms, just south of latitude 52°N, and the second on their dip slope, farther south along latitude 51°N.

Regional Stratigraphic Cross-section W-W'

On the Kindersley Paleo-upland, full Mannville sections are found in the paleovalleys penetrating the Mississippian escarpment immediately to the south of cross-section W-W' (Figure 25) at Cdn Seaboard Fusilier 7-7-33-26(W3), BW Five Starr Kerrobert 4-22-33-23(W3), and Gulf Druid 10-17-33-20(W3). Eastward to H B Donavon 5-20-32-7(W3), the section lies on the Devonian north of the escarpment and along the regional paleostrike. Westward thinning of the Mannville is partially a result of onlap of the escarpment, which turns toward the north there, and partially because the terrain was undergoing an easterly downtilt during early Mannville time, as indicated by the westerly rise of the Dina, Cummings, and Lloydminster contacts. Overall, flat layering of Mannville members is very much in evidence across the Kindersley Paleo-upland.

At Great Canadian Dundurn 5-35-31-5(W3), the line of section encounters the western front of the Punnichy Arch at the Jura-Triassic Watrous topographic basin and by rise of the Waseca into the sub-Pense unconformity. Most of the Early Mesozoic relief along the axis of the Punnichy Arch is taken up by the infill of Watrous and Success sediments. The Punnichy Arch reaches its highest point on the line of section at N.P.C. Touchwood 16-12-31-18(W2), where the Dina is lifted to the sub-Pense unconformity and remnants of the Cantuar Formation onlap the Success-capped relief on the Wynyard Dome. At B.A. Invermay 1-29-31-7(W2), the Cantuar members below the Waseca return to the line of section by downwarp of the Success and Duperow formations. The 40 m thick Dina sandstone in this region is part of the Assiniboia Paleovalley deposits, and the 75 m thick, kaolin-indurated Success strata are in the Insinger Basin.

Regional Stratigraphic Cross-section X-X'

Stratigraphic cross-section X-X' (Figure 26), from Compadre Cuthbert 11-23-25-29W3 east to Husky Wartime 7-29-25-16W3, follows the axis of the Success-infilled, strike-aligned karst basin on the southerly dipping Mississippian limestone that supports the Kindersley Paleo-upland. The Success detrital chert and kaolinitic, quartzose sandstone fills the basin to a depth of 65 m. Full Cantuar sections, in which the Dina completes infill of the lows, overlie the Success Formation. The westward slope of Lloydminster and Cummings implies pre-Rex westerly tilt of the Kindersley depositional basin, from Alberta to the North Cdn Oil Eatonia 10-11-25-25W3 well. Pre-Cummings movements are similarly indicated by warp of the Dina and Success contacts.

A 76 m topographic scarp on the Mississippian Madison Formation terminates the Success Basin at Husky Wartime 7-29-25-16W3. The sub-Cantuar topographic surface rises gently eastward, with respect to the sub-Pense unconformity, onto the Middle Jurassic Shaunavon Formation at Tide Water Beechy Crown No. 1 (1-29-23-11W3), and beyond to the Watrous Basin at Imp TW Strongfield 12-16-26-4W3. The segment shows a pre-Jurassic structural downwarp in which the Mississippian limestone thickens to 155 m from the 0 to 60 m thickness range in the west. The horst-like uplift of the Madison Formation at I.N.C. Husky Wiseton 10-16-25-13W3 is also a site of an Early Mannville topographic breach, as shown by thickening of the Cantuar therein. The sub-Cantuar topographic surface across the Swift Current Platform was uplifted higher than the Kindersley Paleo-upland and tilt of the platform and planation of the Cantuar occurred at the end of Cantuar time, as evidenced by the presence of: 1) only thin Dina and Cummings members across the region, which also represents the northern extremity of the Swift Current Platform; 2) the westerly tilt of the Cantuar correlation surfaces toward the Success (Kindersley)

Basin; and 3) westerly erosional offlap of the Cantuar members against the Pense contact. Thickening of the Pense Formation over the platform suggests a subsequent settling with respect to the Kindersley block.

Between Imp TW Strongfield 12-16-26-4W3 and Tide Water Arbury Crown 13-11-25-18W2, the line of section crosses the deeply incised post-Mississippian topographic Watrous Basin that is infilled with Jura-Triassic Watrous red beds and evaporite. The western wall of the basin between Imp TW Strongfield and Tide Water Craik Crown No. 2 (4-29-25-1W3) is an escarpment, 61 m high, supported by the Madison and Bakken formations. At and east of Goldfield GRT CDN Liberty 4-28-25-26W2, a decline of 67 m is attributable to post-Middle Jurassic, pre-Dina downwarp. The truncated Cantuar Formation, with the Dina as basal and the Lloydminster as capping members, inlays the Watrous Basin on a planed surface supported by the Middle Jurassic.

The eastern Success strata (*i.e.*, those of the Insinger Basin) lap onto the Watrous Formation at Tide Water Bryce Lake Crown No. 1 (1-14-25-16W2) and underlie the Dina at most locations eastward to S.W.P. Yorkton 12-9-25-4W2. Unlike in the west, the sandstone in this segment is an extension of the Success Formation south of the Mississippian subcrop onto the Middle Jurassic, and represents deposits in a topographic basin excavated on an uplifted Wynyard Dome. However, by Dina time, much of the relief on this dome with respect to the Watrous Dome had been dissipated and both the Watrous and Wynyard domes presented a uniform and continuous surface on the Punnichy Arch across the eastern part of Saskatchewan. The Pense Formation, though half as thin on the arch as it is on the Swift Current Platform, retains its stratigraphic integrity. East of S.W.P. Yorkton 12-9-25-4W2 as far as Socony Sohio Kessock No. 1 (8-11-25-33W1), stratigraphic dislocations in the Madison and Cantuar strata are attributable to salt-dissolution tectonics arising from the Prairie Evaporite, and basement tectonics related to the north-south Hudson Bay–Moosomin structural belt.

Mannville Depositional Basin

Pre-Cantuar Drainage System

The isopach map of the McCloud Member (Figure 27) mirrors the morphology of the lower lying regions of the pre-Cantuar depositional surface (Christopher, 1980, 1997). The zero isopach of the McCloud delineates re-entrants into outlying regions above the general Mannville base in southwestern, southeastern, and northeastern Saskatchewan, and the member blankets most of the intervening southern region between longitudes 102° and 104°W, and east-central Saskatchewan south of the present-day Wapawekka Hills. Regions rising above the McCloud Member are designated paleo-uplands: Swift Current, Kindersley, and Unity in the southwest; Willowbunch and Moosomin in the south and southeast; and Molanosa in the northeast. These are physiographic forms overlapped by the younger Cantuar units. The intervening regions are the paleolowlands: Govan to the southeast of Prince Albert and Meadow Lake to the northwest.

The linear thickets define integrated valley systems that radiate from off the Swift Current, Kindersley, and Unity paleo-uplands. With respect to the former, the Assiniboia Paleovalley and its major tributaries (the Chaplin Lake and Elbow paleovalleys) are directed eastward, northeastward and northward onto the Govan Paleolowland, whereas the Delta and Eastend paleovalleys open northward and northwestward into the westward-draining Plato Paleovalley system along the edge of the Kindersley Paleo-upland. The Kindersley Paleovalley, which opens northeasterly onto the terrace of the Unity Paleo-upland, is a tributary of the Assiniboia Paleovalley.

In the headwater regions of the Assiniboia, Delta, and Eastend paleovalleys in the Swift Current and Kindersley paleo-uplands (Figure 27), the valleys are narrowly (less than 1 km width) and deeply (up to 100 m) incised, through the Jura–Cretaceous Success Formation and Jurassic Shaunavon and Gravelbourg formations (Christopher, 1974) of the Swift Current Paleo-upland, and the Success and Mississippian strata of Kindersley Paleo-upland. The Assiniboia Paleovalley widens into a collecting basin, 60 km across beneath the town of Assiniboia. Tributary valleys open into this basin from off the southeastern side of the Success-capped Swift Current divide to the northwest, the Central Montana Platform to the southwest, and the Willowbunch Paleo-upland to the south. The valley continues east on the Rierdon Formation shale, through a narrow gap to Weyburn and into the 120 km wide Broadview structural basin on the western flank of the Moosomin Paleo-upland at the Second Meridian (latitude 102°W). The Broadview basin forms a confluence for tributary systems comprising the Northgate, Estevan, and Weyburn paleovalleys, draining the eastern Williston Basin paleo-uplands of North Dakota, the Moosomin Paleo-upland of Saskatchewan and Manitoba, and the Willowbunch Paleo-upland, respectively. To the west of the Broadview basin rise low terraces of the Govan Paleolowland that separate it from the Chaplin Lake Paleovalley. The Assiniboia system continues north toward Melville and Yorkton along the front of the Moosomin Paleo-upland. In this district, delineation of the paleovalley is complicated by displacement of intra-Cantuar stratigraphic datum levels, attributable to salt-dissolution effects emanating from the underlying Prairie Evaporite, and by post-Cantuar, pre-Pense erosion of the McCloud Member. North of the Punnichy Arch, the Assiniboia bears west to Melfort, where it is joined by the Kamsack Paleovalley from paleo-uplands in Manitoba, and then to Prince Albert, where it enters the Meadow Lake Paleolowland.

The Chaplin Lake Paleovalley, which originates on the Swift Current Paleo-upland about 30 km north of the Assiniboia, follows a northeasterly course beneath Holocene Chaplin Lake and Quill Lakes to join the Assiniboia Paleovalley just south of Melfort. From the western side of the Swift Current paleodivide, the Eastend Paleovalley bears northwest to enter the Kindersley Paleo-upland. Similarly, the Delta Paleovalley, east of the Eastend, heads north in the Shaunavon Graben along Rge. 19W3. Both paleovalleys join the westerly opening Plato Paleovalley on the Kindersley Paleo-upland, and leave Saskatchewan at latitude 51°N, eventually to join the Edmonton Channel of Alberta (Smith, 1994). Northward from the Kindersley paleodivide, the Kindersley Paleovalley, which bisects the upland, bears northeasterly to join the Assiniboia. The Kerrobert Paleovalley opens northwest to the St. Paul Channel of Alberta (Williams, 1963). The Unity Paleo-upland, downstepped to the north of the Kindersley Paleo-upland, also features a number of re-entrants opening northward to the Assiniboia system. The most prominent of these is the Unity Paleovalley, which trends east from beneath the town of Unity to join the north-trending McGee tributary paleovalley of the Assiniboia on the Meadow Lake Paleolowland.

On the Meadow Lake Paleolowland, the Assiniboia Paleovalley bears west-northwest to beyond Meadow Lake, *en route* to the Cold Lake region of Alberta at about latitude 54°30'N. An earlier interpretation had the Assiniboia linked to a more northerly valley system, here named the Choiceland, that comes off the Molanosa Upland and heads northwest toward the McMurray basin, leaving Saskatchewan at latitude 57°N (Christopher, 1980, 1984b, 1997). These systems (Figure 28) are the most easterly of a series of pre-Cantuar streams that flowed north from off the Sweetgrass Arch–Swift Current Platform region of Alberta and Saskatchewan, the Precambrian Shield of

Manitoba, and the Continental Divide of Minnesota and North Dakota, into an Early Mannville marine basin in northern Alberta and British Columbia. The Williston Basin drainage system of central North Dakota, except for the headwater tributaries of the Assiniboia, seems to have been directed westward across Montana toward the rising Rocky Mountain front, probably as tributaries of the mountain-front Spirit River Channel (McLean, 1977).

Whereas thickness of the McCloud Member does not exceed 25 m in the southwestern and southeastern uplands of Saskatchewan, the valley forms are entrenched to a stratigraphic depth of 75 to 90 m. Thus, the McCloud lies in thalwegs below the later Cantuar fill. On the Govan Paleolowland, the McCloud buries the Assiniboia Paleovalley system to a depth of 70 m, and to 127 m on the Meadow Lake Paleolowland; however, large surfaces of the lowlands are veneered with less than 20 m of McCloud clastic rocks, through which knobs of the underlying rock protrude. The paleo-uplands are calculated to have been 120 to 150 m above the general floor of the Govan Paleolowland and 150 to 180 m above that of the Meadow Lake Paleolowland. An estimate of the total relief between the Swift Current headwater region and the northwestern area of departure from Saskatchewan can be made by assuming an average valley gradient of 0.37 m/km (2 ft/mi). The measured length of the Assiniboia taken through the system to Peter Pond Lake in northwestern Saskatchewan is 1390 km. The calculated elevation difference is therefore about 515 m; when added to the 75 m of local relief above the valley floor in the Swift Current Paleo-upland, this indicates that the paleo-upland rose 590 m above the region in the northwest. This elevation is roughly two-thirds that of the Holocene land surface between the Cypress Hills in the southwest and Peter Pond Lake in the northwest. The estimate is an extreme value, reflecting initial uplift. Apparently, early subsidence of the uplands in the southwest permitted sufficient decay of gradients to allow deposition of the initial fluvial sediments and the entry of the pursuant marine invasion that penetrated the inner re-entrants of the uplands during late Dina and Cummings time.

Lower Cantuar (Dina-Cummings) Depositional Pattern

Govan Paleolowland

The McCloud Member (*see* cross-section Y-Y', [Figure 23](#)) in the valleys of the Swift Current Paleo-upland comprises two thin units of poorly sorted, kaolinite-indurated quartzose sandstone (4 to 8 m thick), representative of the Dina, and up to 13 m of overlying foraminiferal and glauconitic shaly mudstone, commonly coaly at the top, that corresponds to an attenuated Cummings Member, or Cummings Shale in the McCloud. The sandstone is attributed to sheet wash, debris flow, and slump from sources in the quartz- and kaolinite-rich Success and Roseray formations that capped the hills. The overlying shale represents drowning of the valley basins by marine incursion. In contrast with the relatively high relief and gradients associated with the erosional phase of the valley system, the upland valleys had lost much of their axial slopes. From a broader perspective, the Swift Current Platform had begun to subside with respect to the central part of the province. Whereas some sections of the paleovalley basins (*e.g.*, Chaplin and Delta) were less than 8 km wide, other sections of the Plato and Assiniboia paleovalleys were on the order of 40 and 80 km in width, respectively, and more than 125 km long between constrictions. At these locales, the Cummings Shale of the McCloud is generally carbonaceous and can equal and even exceed the thickness of the Dina sandstone, thereby indicating that these sites were vast lagoons or restricted settling deeps astride the drowned valleys. In re-entrants of the Kindersley Paleo-upland to the north, the shale beds are capped with or feather into coal, the product of low-salinity marshy and swampy environments, as described by Groeneveld (1990) for the Winter-Senlac oilfield area of west-central Saskatchewan and east-central Alberta (Twp. 39 to 52, Rge. 21W3 to 7W4).

Blanketing of topographic relief on the Govan Paleolowland by the Dina sandstone is attributable to the ready erodibility of the flanking Upper Jurassic strata, but more effectively to tectonic downwarp. This is evidenced by the southeasterly stratigraphic downwarp of the Rierdon Formation beneath the lowland. The top of the Rierdon in the hills rises nearly 100 m above the base of the McCloud, but underlies it in the paleolowland near Estevan in southeastern Saskatchewan. Likewise, to the east, the Jurassic datum rises abruptly from the lowland onto the Moosomin Paleo-upland, as shown in stratigraphic cross-sections Y-Y' and Y1-Y1' ([Figure 23](#) and [Figure 24](#)).

Farther north in the lowland basin, the McCloud sandstone acquires the more transported and reworked aspect associated with the classic 'Dina' section, as typified in the cores from the CNRES Steelman 4U 1-6-5-5(W2) and Sceptre 3 Steelman Unit 11-28-4-6(W2) wells ([Appendix A](#)) of southeastern Saskatchewan. In this region, the Dina is 16 to 26 m thick and consists of cyclic beds of bimodal quartzose sandstone, featuring decimetre-thick tabular and trough cross-beds, and upward fining from basal coarse grained with grit and pebbles to fine grained. The unit is dominated by clear quartz, with subsidiary kaolinite, red-brown coarse-grained sphaerosiderite cementing fine-grained quartz, red jasper, black chert, and pink and white feldspar. Bedding cycles (oldest to youngest) are 6.5, 7.8, and 11.8 m thick at the first well and 3.0, 6.3, and 7.1 m at the second. The third cycle includes bioturbated, fine-grained sandstone, mudstone, and shale. The fabric of the sandstone corresponds to those of channel cut-and-fill

deposits. Bimodality of grain sizes and the accessory feldspar and jasper indicate an upper-flow fluvial regime (Harms and Fahnestock, 1965), with sources on a granitic terrain, presumably the Precambrian Shield to the southeast. The uppermost cycle, by its abrupt gradation to a calcareous and bioturbated facies, indicates a rapid marine invasion of the site.

The fabric of the sandstone in the Steelman cores indicates settling velocities considerably higher than those in the diamictic, clay-occluded, McCloud channel sandstone in the region of the western upland divides. The Dina sandstone in the Steelman 11-28-4-6W2 well also includes boulders and cobbles of the Success Formation, representative of undercut bank deposits and, by extension, stream entrenchment and lateral migration in a terrain capped by that formation, most likely the nearby Success-capped Willowbunch and Moosomin paleo-uplands. Differences in grain-size distribution and bedding thicknesses between the Steelman sites indicate that the Dina channel deposits comprise a complex of interlinked forms. The most southeasterly of the Dina fluvial sandstone cores is from Placid Antler WSW 3-1-1-31(W1), where a facies similar in mineral suite and grain-size transition (*i.e.*, from grit, through medium-grained quartzose sandstone, to coaly shale) is seen in the 8.8 m cored section. The Antler and Steelman sites are located in the northerly trending tributary Northgate and Estevan paleovalleys.

Dina sandstone facies are traceable northward. At BA Cdn Devonian 11-22-4-5(W2), a single, upward-fining bedding cycle, 19.5 m thick, is made up of bimodal coarse- and medium-grained, channel cut-and-fill, quartzose sandstone. It includes chunks of coalified plant material over the lower 12 m, which grades upward into grey-black carbonaceous mudstone interbedded at 1.5 m intervals with trough truncation sets, and laminated beds of fine-grained, quartzose sandstone with abundant, bedded, coalified plant stems. This single cycle is assigned to Unit 2. However, at Shell Midale 7-18-6-10W2, 50 km to the west, and Imperial TW Carlyle 16-23-7-3W2, 50 km to the northeast, the Dina is 36 and 43 m thick, respectively, and comprises two upward-fining fluvial facies and, at the top, a third facies transitional to marine shale. In general, the indications are that the three bedding cycles logged from the Dina cored sections of the southern Govan Lowland basin correspond to mappable units. This is not true farther north, where low sea-stand sequences are interpolated within the horizon of the larger southern forms, and the mapping units therefore may incorporate more than one cycle. Whether or not all three of the mapping units are present at a given locale appears to be a function of: 1) the sub-Dina relief (*i.e.*, the degree to which the sandstone units onlap the topography); 2) stacking on a subsiding floor; 3) erosional truncation of antecedent sand bodies and lateral accretion (Hopkins, 1984); and (4) coincidence of the well site with location of stacked sequences.

Except for the transitional capping bed, mudstone facies in the Dina are scarce in this part of the basin. In fact, at the 18 locations on cross-section D-D' (Figure 21) in the thalweg of the Assiniboia Paleovalley between Twp. 1 and 12, the lower fluvial sandstone yields to mudstone, up to 12 m thick, at only four wells. On a more limited basis, inspection of Dina sections from 98 wells in Twp. 4, Rge. 5W2 revealed only nine sites with a significant shaly component. Northward along the eastern flank of the Assiniboia Paleovalley of eastern Saskatchewan, however, finer grade sizes with interbedded shale and mudstone are conspicuous, and the overall facies become varied and thinner bedded, although without a general decrease in thickness of the McCloud Member. Thus, at Tide Water Imperial Bender Cr. 13-11-12-5W2 (Figure 23), the Dina remains tripartite, comprising an 8.2 m thick, bimodal fine- and medium-grained quartzose sandstone as Unit 1, separated from Unit 2 (10.7 m thick) by a thin pyritic shale. This shale is taken to be a transgressive marine tongue or flooding horizon, at which was initiated an upward-coarsening cycle that subsequently terminated under the regressive sandstone of the unit. Unit 3 (9.4 m) grades from a basal, pyritic, quartzose, silty, sideritic mudstone into a shale containing scattered lenticles of quartzose sandstone with accessory jasperoid quartz, white feldspar, black chert, and white kaolinite.

Some 45 km to the northeast, at Tidewater Earlswood 1-36-14-1W2, Unit 1 (7 m) grades upward from medium-grained quartzose sandstone into interbeds with dark grey mudstone that include carbonized reedy fragments. Unit 2 (16.1 m) likewise grades upward from a bimodal medium- and fine-grained quartzose sandstone, into a fine-grained, ripple-drift cross-bedded sandstone laminated with subordinate partings of coaly flakes, whereas Unit 3 is a weakly cemented, well-sorted, medium-grained quartzose sandstone (7.7 m thick) with quartz overgrowths on subrounded grains. Thus, the Dina at this locale shows a progressive, though episodic, shift of environment from upper estuarine to lower estuarine or inner shoreface to shoreface. At TW Sohio W. Wapella 16-33-14-2W2 (13 km to the west), Imp TW Oakshella 13-25-16-6W2 (37 km beyond that to the northwest), and TW Imp Gotham Cr 1-2-19-4W2 (another 33 km to the northeast), Unit 3 yields to an initially deeper water facies. This is indicated in a 12 m thick bedding cycle, which fines upward from fine-grained, weakly argillaceous, low-angle current-bedded sandstone, laminated with grey shale containing glauconite-infilled burrows, through bioturbated, glauconitic, very fine grained, lenticular, quartzose sandstone and shale, into a mudstone and carbonaceous black shale. The Cummings Shale at the three sites displays upward coarsening from dark grey mudstone with scattered carbonaceous flecks and abundant ironstone nodules and lenticles, to a lignitic mudstone interbedded with quartzose, very fine grained sandstone.

Northward in the Govan Paleolowland basin, bioturbated sediments are intrinsic components of Unit 3 of the Dina and all of the Cummings. The facies also appear as thin shaly beds between Units 1 and 2, coincident with the decline in prominence of more fluvial characteristics in Unit 2. Thus, thick beds of coarse-grained sandstone yield to thinner lenticular beds and to fine-grained sandstone. On the local rises of the Govan Paleolowland, the younger units are more widespread by onlap, and fine-grained, weakly cemented, quartzose sandstone therefore dominates the Dina. Unit 1 occurs in the lower elevations where the McCloud is relatively thick. It also tends to retain its coarse-grained texture and poor sorting, and to incorporate minerals of country rock that are indicative of provenance and larger plant fragments. Coarse-grained sandstone generally occurs sporadically as lenticular sheets that decrease volumetrically outward from the southeastern margins of the basin and upward in the section. This is fluvial sandstone, and it appears to be the product of waning floods, probably resulting from a decline in the topographic gradient. The Dina sediments were laid down on aggradational straths controlled by distant base-levels, resulting in their regional persistence as stratigraphic units to an extent beyond that predictable by variation in overall thickness.

Significant hiatuses separate the units. The evidence for hiatus appears in these facies, otherwise indicative of marine incursions, as calcite-cemented sandstone pavements at the base of bioturbated and/or glauconitic transgressive shaly tongues, or as coal beds at the top of upward-fining cycles. Two bedding cycles are recorded in the core from Tide Water Southey Crown No. 1 (4-29-22-18W2). The first coarsens upward over 15.2 m, from a basal, dark grey, interbedded and laminated, fine- and very fine grained, quartzose sandstone and dark grey shale, through a zone with crenulated coaly laminae and iron oxidation, into a 1.2 m thick, calcite-cemented, fine-grained, grey, mudstone-indurated quartzose sandstone, with abundant pink quartz, grey and black chert, white kaolinite, and brassy green pyrite-cemented sandstone nodules. It is an apparent progradational body in a deep of the Dina embayment. The second cycle is an upward-fining, 10.7 m thick transition of: 1) medium- and fine-grained quartzose sandstone with rounded grains, accessory minerals and coaly laminae as in bedding cycle 1, but basally kaolinite indurated and iron stained; and 2) very fine grained, uncemented, well-sorted quartzose sandstone capped by a 0.3 m thick sandy mudstone. Cycle 1 is a component of Unit 2. Cycle 2 is in Unit 3 and is traceable to Tidewater Earlwood 1-36-14-1W2 and similar bars on the eastern side of the Assiniboia Paleovalley. The pavement that caps Unit 2 (*i.e.*, bedding cycle 1 in the Southey well) is a product of subaerial cementation, iron oxidation of the rocks, and water table decline resulting from a fall in sea level. The white kaolinite matrix at the base of bedding cycle 1 reflects sources from up the Chaplin Lake Paleovalley in the Swift Current Paleo-upland (Figure 27).

On the eastern side of the Assiniboia embayment from Tide Water Southey Crown No. 1 (4-29-22-18W2), the Dina at Transgas Brewer 12-15-23-6(W2) is 10 m thinner but displays a similar depositional facies. Bedding cycle 1, of which only the upper 2.7 m is cored, is upward coarsening and ends in an ironstone-cemented, argillaceous, coarse-grained, quartzose sandstone pavement, with abundant white kaolinite and large coalified woody fragments, that caps a medium-grained, well-sorted sandstone suggestive of a sandbar or beach. It is placed in the upper part of Unit 2. Bedding cycle 2 (4.3 m) fines upward to very fine grained quartzose sandstone from a conglomeratic, fine-grained, quartzose sandstone laminated with shale. Cycle 3 (1.5 m) also fines upward from conglomeratic, bimodal medium- and fine-grained, kaolinite-indurated quartzose sandstone, to fine-grained sandstone with accessory kaolinite grains and glauconite. Cycles 2 and 3 are components of Unit 3. Transgas Brewer and TW Southey are comparable in depositional setting. The upward-fining cycles are attributable to stream influx, channel abandonment, and renewed influx in a marsh-fringed shore setting. The cored lower half of the Cummings marker bed reveals upward coarsening across 5.5 m of glauconitic shale and fine-grained, well-sorted, flat-bedded, quartzose sandstone laminated with dark grey shale.

At Alwinal Lanigan 3-28-33-23W2, 113 km north-northwest of Tide Water Southey Crown No. 1 (4-29-22-18W2), the Dina sandstone is quartzose, poorly cemented, well sorted, and upward fining overall, but by increments of beds with sharp contacts. Accessory minerals include red jasper, white kaolinite, and muscovite. Over the basal 2 m, pyrite cementing fine-grained quartzose sand occurs as coarse-grained spheroidal aggregates and as massive cement at the basal unconformity. Bedding cycle 1, medium-grained and 18.5 m thick, displays a fabric that coarsens upward from low- to high-angle planar cross-beds, and is terminated by a 0.1 m thick, red and green shale. Bedding cycle 2 is a 3.9 m thick repetition, and is terminated by similar shale, 0.2 m thick. Both cycles are assigned to Unit 2. Unit 3 consists of: 1) a 4.3 m thick cycle consisting of a 3.4 m thick, fine-grained, quartzose sandstone, avalanche cross-bedded on 20° slopes, that grades upward into ripple drift and is capped sharply by a 0.1 m thick, grey-black muscovitic shale; and 2) a flat-bedded, fine-grained, friable quartzose sandstone, 0.8 m thick. A pyrite-encrusted, irregular contact separates the Dina from the Cummings Member. Like at Southey, the main body of sandstone here (cycle 1) represents progradational longitudinal bars infilling the thalwegs. The later, thinner, sandstone-shale couplets were deposited in the broad upper levels of the flooded Assiniboia embayment. The repeated hiatuses, indicated by the oxidized and pyritic contacts, reflect corresponding subaerial emergences of the depositional floor resulting from channel abandonment and/or lowered base levels.

At Transgas Prud Homme B11-12-38-28W2, 150 km northwest of Tide Water Southey Crown No. 1 (4-29-22-18W2), the Dina forms a 7.3 m veneer on a terrace of the Govan Paleolowland. Unit 2 comprises:

Bedding Cycle 1 (3.0 m thick), sandstone: quartzose, upward fining from medium grained with subordinate fine, and abundant feldspar and dark grey chert, through fine grained with minor laminae and thin wavy beds of black, carbonaceous shale and carbonaceous shale with plant fragments, into coal and black shale; and

Bedding Cycle 2 (1.6 m thick), sandstone: quartzose, poorly sorted, medium and coarse grained, weakly cemented, with abundant carbonized plant fragments; capped by a carbonaceous mudstone.

Both cycles represent fluvial deposits, with the second laid down by avulsion of the main channel into off-channel marshes. The 2.7 m thick Unit 3 consists of well-sorted, fine-grained, quartzose sandstone, transitional from underlying interbedded bioturbated mudstone and sandstone. It is the lithologically consistent bedding cycle 3, as traced from the south.

Although, at 6.1 m, the thickness of the Cummings Member at Transgas Prud Homme does not differ significantly from that at other sites to the south, the Cummings features three upward-coarsening bedding cycles (1.8, 1.3, and 3.0 m) dominated by very fine grained, quartzose sandstone. The first grades from carbonaceous shale through bioturbated, flasered, and glauconitic shale into very fine grained, quartzose sandstone; the second from massive mudstone into bioturbated and laminated, very fine grained, quartzose sandstone and shale; and the third from low-angle, cross-bedded and laminated, very fine grained, quartzose sandstone and black shale into microfaulted, massive sandstone with abundant carbonized plant fragments and rootlet filaments. In this respect, the Cummings Shale here acquires the multiple cyclic format of the Cummings Member of the Meadow Lake Paleolowland basin. Thus, the regional attenuation of the Cummings Member from north to south is, to a certain extent, reflected by thinning of its stratigraphic components, although southerly overlap of the basal unit is indicated in cross-section A-A' ([Figure 16](#)) south of Aberfeldy Unit SWD A11-31-49-26(W3), where the ascent onto the Unity Paleo-upland begins.

At the Choiceland No.1 Choice DD 13-3-50-18(W2) well, 170 km northwest of Transgas Prud Homme, the three bedding cycles described correspond to Units 1, 2, and 3, respectively. However, interpretation of the Dina depositional environment from core is hampered by incomplete recovery of the friable sandstone; thus, demarcation of the three bedding cycles (6.4, 14.9, and 5.2 m) and the one-to-one relationship with Units 1, 2, and 3 are inferred from the geophysical log. Cycle 1 (of which only 2 m were recovered) is a calcite-cemented, medium-grained, tabular-cross-bedded, quartzose sandstone featuring rounded and subrounded grains, scattered black chert, and thin beds laminated with carbonaceous detritus. It includes a basal conglomerate containing clasts of white, chalcedonic chert from the Mississippian limestone escarpments to the south, and of coaly mudstone, siliceous concretions, and coal derived from the Success Formation of the Insinger Basin. Cycle 2 is also quartzose sandstone, but is fine-grained and well sorted, contains abundant lithic grains, black chert, and rose quartz, and is floored by a metre-thick mudstone, with incorporated, distorted, claystone pebbles and boulders attributable to streambank undercut erosion. The sand was apparently reworked and deposited as infill within the lower part of an estuarine or tidal channel. Only the calcite-cemented cap of fine-grained, well-sorted, quartzose sandstone of bedding cycle 3 was recovered, and the presence of a bioturbated facies is not indicated on the log. Thus, the implication is that the unit represents shoreline sand that backfilled the channel of cycle 2. The 3.8 m thick Cummings Member consists of a basal, bioturbated mudstone bed on an erosional contact and an overlying, light grey, calcite-cemented, fine-grained quartzose sandstone with abundant pebbles and boulders of medium grey mudstone and pyritic ironstone, also on an erosional base. The site appears to have been sediment starved along a wave-swept shoreface.

North of Choiceland No. 1 Choice (cross-section C-C', [Figure 20](#)), the Cantuar onlap of the Molanosa Paleo-upland results in pinchout of the Dina and Cummings members. To the northeast and northwest, however, these members flank the upland to crop out on the Precambrian Shield at Wapawekka Lake (Langford, 1973) and at the Mannville erosional edge in Manitoba. As shown in the west to east cross-section V-V' ([Figure 17](#)), the Cummings is severely attenuated across the northeastern shelf of the Govan Paleolowland, and only the Dina remains clearly defined. The latter crops out in the valley of the Red Deer River (Twp. 48, Rge. 30, W 1st Mer.), east of the town of Hudson Bay (Beck, 1974), as the so-called 'Silica Sands' ([Figure 29](#)). The section is truncated under the pre-Quaternary unconformity, with Units 1 and 2 being exposed. Unit 1 consists of 4 m of buff, iron-stained, medium-grained, cross-bedded, quartzose sandstone. Unit 2 consists of 11 m of grey-white, partially cemented, ledge-forming, medium-grained, cross-bedded, quartzose sandstone, grading upward to fine grained and containing minor clay and sericite, and scattered carbonaceous fragments. Both units are channel sandstone, probably fluvial, and the scarcity of argillaceous beds implies extensive reworking by lateral accretionary processes. As seen in a quarry cut south of the Red Deer River section ([Figure 30](#)), bedding of Unit 2 consists of metre-thick, tabular, unidirectional, high-angle cross-beds in truncational sets that form lenticular bodies 30 m or so in length. The bodies taper into trough cross-beds lined with carbonized plant detritus. Similar plant-detrital, tangentially cross-bedded sandstone

bodies, but occurring in thin wavy sheets, appear in an upward transition at the top of the section. The Red Deer River section apparently has the same characteristics (*i.e.*, they represent braided sandy stream deposits) as those in the Steelman area of southeastern Saskatchewan (*see* Cant, 1982). In the subsurface, the combined Dina and Cummings strata are 23 to 37 m thick, twice the thickness seen in the outcrops.

At Shell Husky Paradise Hill A13-19-52-23(W3) (Figure 13), the 22 m thick Unit 1 of the Dina equates with bedding cycle 1, which consists of weakly indurated, argillaceous, poorly sorted, coarse- and medium-grained quartzose sandstone with basal coaly lenticles. An attenuated Unit 2 (cycle 2) displays a current-bedded, fine-grained quartzose sandstone, laminated with dark grey shale and banded with carbon-infilled, rootlet-casted zones at intervals of 20 to 30 cm, laid down as an apparent backshore lagoonal or deltaic-plain sandy flat that was alternately flooded and exposed. The Cummings Member, at 18.03 m thick, is relatively thin. Its three bedding cycles are upward fining and are equated with Units 2, 3, and 4 respectively. Unit 1 seems to be missing due to erosion by a Unit 2 channel cut-and-fill. The thinness of the Cummings is probably the result of deposition on a relatively elevated depositional floor. Unit 2 (bedding cycle 1) is thickest, at 10.47 m, and in erosional contact with the weathered and oxidized surface of Unit 3 of the Dina. Although typically a bioturbated, very fine grained, quartzose sandstone and shale, the unit shows signs of prolonged subaerial exposure by virtue of its blocky soil-like structure, a 2 m thick zone of root casts, and a capping coal bed. Likewise, Unit 3 (5.63 m) fines upward from sandstone into black shale with thin coaly layers. Unit 4 (1.93) is an oxidized, trough-cross-bedded channel sandstone on a pyritized basal erosional contact. Accordingly, the Cummings here has a greater onshore overprint than at Meota and indicates a backshore progradation of marshes and channels.

The Dina Member at Shell Meota C13-17-46-17W3 (Figure 14) occupies a site on the southern side of the Assiniboia Paleovalley, in a re-entrant along the northwesterly front of the Unity Paleo-upland. It features 34.1 m of weakly cemented, well-sorted, fine-grained quartzose sandstone, containing abundant carbonized plant fragments, some of which are concentrated on low-angle tabular cross-beds. The three units of the Dina are interpreted to be present from the geophysical logs, and they correspond to the bedding cycles described in the 'Regional Stratigraphic Cross-section A-A' section. A metre-thick, mammillary, calcite-cemented sandstone pavement caps the 26 m thick Unit 1 and separates it from Unit 2, represented by bedding cycle 2 (8.3 m). The hiatus indicated by the cemented pavement marks the absence of the foraminiferal shale present at Dee Valley and Paradise Hill at the base of Unit 2. As indicated earlier, the sand bodies represent stacked baymouth or lower estuary shoreface bars. The lithological makeup of Unit 3 (5.8 m), marked by upward coarsening from bioturbated, glauconitic, sandy mudstone with abundant plant fragments including tree limbs, to wavy bedded, dark grey, shale-draped quartzose sandstone, is characteristic of the upper Dina transition from an embayed shoreline to upper shoreface depositional environment.

The four units of the Cummings Member at Shell Meota correspond to the four bedding cycles (6.4, 3.5, 7.0, and 2.5 m; Appendix A) shown in stratigraphic cross-section A2-A2' (Figure 14). At 19.4 m, the Cummings is considerably thicker than the 6.3 m at the Transgasp Prud Homme site in the Govan Paleolowland.

Unit 1 comprises: 1) a thin (0.3 m) basal couplet of partially eroded black shale with glauconitic nodules and an overlying sandstone; 2) a medial, very fine grained, well-sorted, massive quartzose sandstone with carbonized plant stringers; and 3) a capping, fine-grained, argillaceous quartzose sandstone with subordinate burrow casts, glauconitic sandy laminae, and lenticles of black shale, alternating with bioturbated and flow-structured sandstone.

Unit 2 is largely a bioturbated, fine-grained quartzose sandstone and grey shale that fines upward into a coaly mudstone. An overlying 30 cm thick, very fine grained, flasered, burrowed quartzose sandstone, irregularly intermixed with black shale and bounded by erosional contacts, may be the truncated remnant of a nearby upward-coarsening cycle. Thus, the estuary-shore setting of the Dina yields to one suggestive of a tide-influenced back barrier and bay.

Unit 3 of the Cummings is a moderately indurated, argillaceous, very fine grained quartzose sandstone with irregular laminae of black shale and abundant carbonaceous specks that grades upward into black shale. Unit 4 is also upward fining: from a fine-scale trough-cross-bedded, fine-grained quartzose sandstone into a fabric of ripple cross-beds, bioturbation pods, and black shale drapes reflective of tidal effects. Unit 4 indicates a stronger marine pulse than Unit 3 and thereby pulsational transgressive conditions for the Cummings at this site.

Shell Dee Valley A11-18-48-21W3 (Figure 14) is on the south wall of the Assiniboia Paleovalley, 48 km downvalley of the Meota site (Figure 24). Here, also, the cycles of the Dina equate with its correlative units. Unit 1, a 9.0 m thick, soft-sediment-microfaulted, interbedded fine-grained quartzose sandstone and mudstone is an apparent slump, induced by stream undercut. Unit 2 (6.17 m) consists of well-sorted, weakly cemented, fine-grained, trough-cross-bedded quartzose sandstone with minor carbonaceous placers, and a thin capping sandstone

laminated with coaly flakes. It, too, is soft-sediment microfaulted and an upward-fining channel deposit. At the top of Unit 1, a grey-black, foraminiferal glauconitic shale (Atkin, 1986) indicates a marine incursion and that the channel sandstone of Unit 2 is inserted in a progradational facies. Unit 3 grades upward over 4.33 m from a massive, well-sorted, fine-grained quartzose sandstone, through a contorted and microfaulted, bioturbated sandstone and dark grey, argillaceous sandstone laminated with coaly placers, into calcite-cemented, grey-white, fine-grained quartzose sandstone that is ripple laminated with dark grey shale. The basal sandstone rests on a sharp contact, and is probably a beach or shoal body that was buried by deeper water, nearshore sediments represented by the bioturbated beds. A 40 cm thick, vestigial, pyritic sandy mudstone, here combined with Unit 3, rests with erosional contact on Unit 2. It may be the bed missing at Shell Meota, in the hiatus implied by the cemented pavement on Unit 2 there. At Shell Dee Valley, the unstable substrate, indicated by the disturbed sediments of Units 1 and 2, does not extend into Unit 3; it may therefore reflect, in addition to channel bank undercutting, either compactional disequilibrium, perhaps induced by tidal or eustatic loading, or consolidation by drawdown of the water table during an emergence at the end of Unit 2 time.

The four bedding cycles (4.0, 10.75, 7.58, and 2.42 m) of the Cummings Member at Shell Dee Valley correspond to the four units traceable along the Assiniboia Paleovalley system. Units 1 and 2 are upward coarsening, the first dominated by dark grey glauconitic shale and bioturbated shale and sandstone, and the second by sandy glauconitic mudstone with a 3 m thick capping of small-scale current-bedded, fine-grained quartzose sandstone. Unit 3 is mainly flat-bedded and cross-bedded, fine-grained quartzose sandstone, the fabric of which alternates between paleosols and carbonized plant detrital layers, and ends with bioturbation near the top. Unit 4 coarsens upward from black shale to wavy bedded and glauconitic sandstone, and ends with a paleosol.

Lower shoreface deposition in a sand-deficient environment during Unit 1 time, and progradation by shoal sand during Unit 2 time, are indicated. Initial emergence of the site in Unit 3 time is depicted by the paleosol at 543.64 to 542.69 m below KB in the lower third of the unit, which is followed by deepening and progradation by shore sand and terminal marsh. Unit 4 indicates a shallowing marine embayment with wave reworking of sand and shale and, finally, anchoring of sediments in a marshy setting. Thus, the Cummings depositional setting at Dee Valley is comparable to that at Meota.

About 88 km to the south, at Shell Manito 6-7-43-24W3, Unit 1 of the Dina is pinched out by erosion under Unit 2 and by onlap against the Unity Paleo-upland (Figure 13). Units 2 and 3 are upward-fining sandstone, separated by a calcite-cemented pavement and ranging from coarse to fine in Unit 2 and from medium to fine in Unit 3. However, southward from Shell Frenchman Butte A7-3-54-25W3 to B.A. Senlac 11-15-41-26W3 (*i.e.*, up into the lower elevations and valleys of the Unity and Kindersley paleo-uplands), the three units, though attenuating, retain their stratigraphic coherency.

The thinly developed (11 m) Cummings Member comprises three cycles (5.0, 3.0, and 3.0 m) that correspond to Units 2, 3, and 4, respectively. Unit 2 fines upward from a basal, interbedded, argillaceous, very fine and fine-grained quartzose sandstone into dark grey shale. Unit 3 coarsens upward from basal glauconitic shale to bedded, fine-grained argillaceous sandstone, capped with lignite and carbonaceous mudstone. Unit 4 is faintly bedded, argillaceous, fine-grained quartzose sandstone with scattered crenulated black-shale partings. A general, low-gradient, shore-embayment setting of sandy flats and marsh is postulated as the depositional environment.

Meadow Lake Paleolowland

The depositional basin on the Meadow Lake Paleolowland (Figure 27) opens westward into wide re-entrants of the Cold Lake and McMurray basins in east-central Alberta. It is also the region dissected by thalwegs of the Assiniboia Paleovalley from the southeast and the Choiceland Paleovalley from off the Molanosa Paleo-upland to the east. As traced along section A-A', the Dina and Cummings members equate with the McMurray Formation but also include the thin, basal Wabiskaw Member of the Clearwater Formation as a correlative of the uppermost unit of the Cummings.

Carrigy (1973) subdivided the sandstone units of the McMurray basin into:

- 1) (?)Pre-McMurray sandstone (0 to 6 m thick): quartzose, coarse grained, kaolinite and silica indurated, cross-bedded and contorted, abundant potassium feldspar, pollen grains and spores; unconformity bounded.
- 2) Lower McMurray sandstone (0 to 15 m thick): quartzose, coarse grained, poorly sorted, siderite cemented, abundant spherosiderite and lenticular beds of gravel, grit, and autochthonous coal beds.

- 3) Middle McMurray (18 to 27 m thick): a) lower, unconformity-bounded subunit of poorly cemented, medium-grained quartzose sandstone with abundant potassium feldspar and muscovite, a weak kaolinitic matrix, and lenticular beds (20 to 30 cm thick) of high-angle cross-beds, and high concentrations of mummified logs up to 15 cm in diameter, pyritic nodules, lignite beds and carbon dust; and b) upper subunit of fine-grained, quartzose sandstone with abundant potassium feldspar; marked by large-scale, low-angle foresets (10 to 15 cm thick) and minor small-scale cross-beds with abundant burrows, spores, and pollen grains.
- 4) Upper McMurray (4.5 to 9.1 m thick): laminated and burrowed, broadly lenticular quartzose siltstone and very fine grained sandstone, partially calcite and siderite cemented, kaolinitic; carbonaceous, and fossiliferous with molluscs, agglutinated Foraminifera, fish teeth, spores and pollen grains, and a disconformable basal contact.
- 5) Wabiskaw Member of the Clearwater Formation (1.8 to 9.1 m thick): lenticular, fine-grained quartzose sandstone, kaolinite and chlorite indurated, with abundant chert and glauconite.

In Saskatchewan, the Middle Unit of the McMurray crops out in cliff faces, 22 m high, in the tributary valleys of the Clearwater River in Twp. 89, Rge. 25 and 24, W 3rd Mer. (Norris, 1963, 1973; Paterson *et al.*, 1978). The lower subunit is readily identified by the presence of tar-impregnated, mummified tree trunks in the channelled and large-scale trough- and low-angle tabular-cross-bedded, white quartzose grit and medium- and fine-grained, interbedded quartzose sandstone with abundant feldspar and muscovite (Figure 31). These stacked, channel sandstone units are recognizable by their thick, blocky, and upward-tapering spontaneous potential–resistivity and gamma ray–neutron log signatures from Seaboard Meadow Lake Crown No. 6 (16-36-59-14W3) to Grt Plns et al Smoothstone 1-36-63-5(W3) on cross-section U-U' (Figure 18), and in the upper reaches of the Choiceland Paleovalley, where they correspond to Units 2 and 3 of the Dina. These are the classic McMurray sandstone facies of the Athabasca River, and have been described as products of lateral accretion in sinuous, migrating stream channels prograding into an open body of water (Flach and Mossop, 1985); as estuarine-channel deposits (Yuill *et al.*, 1994); and as incised valley fills, fluvial or estuarine (Cant and Abrahamson, 1996). The Lower Unit of the McMurray is equivalent to Unit 1 of the Dina, and the 'pre-McMurray sandstone' corresponds to the Success Formation, as depicted in Seaboard Meadow Lake Crown No. 4 (10-20-61-12W3) and B.A. Dore Lake 13-18-65-11(W3), and as far west as SDXC Cigol Makwa Lake 7-19-59-23(W3) of U-U' (Figure 18). The Upper Unit of the McMurray and the glauconitic Wabiskaw Member of the Clearwater Formation are correlatives of the Cummings Member of the Mannville in Saskatchewan.

Transitional marine facies are also interpreted to be present in the McMurray Formation of the southern part of the Athabasca tar-sand basin by Nelson and Glaister (1978), for the locale incorporating Twp. 83 and 84, Rge. 10 to 12, W 4th Mer., where they mapped a distributary system prograding southwestward into shorefront sandstone and marine shale for each of the three units of the McMurray. Thus, from the Athabasca and Cold Lake basins southeastward up the Assiniboia Paleovalley system, the overall Dina depositional pattern is one of episodic but progressive onlap from the northwest to the southeast, and from the keel of the basin outward to the flanks and re-entrants of the uplands.

The large concentrations of fluvialite, kaolinite-matrix, quartzose sandstone along the northern and eastern flanks of the paleolowlands from the McMurray basin to the Williston Basin are deposits of streams originating on the Precambrian Shield. These streams occupied the Choiceland-McMurray system, unnamed entry points northeast of the town of Hudson Bay (Figure 27) and east of Yorkton, and the southeastern tributary complex of the Assiniboia Paleovalley, which involved the Northgate, Estevan, and Weyburn paleovalleys that drained the eastern Williston Basin bordering region of North Dakota. They represent bajadas (*i.e.*, coalesced alluvial fans built out by distributaries into and along the main channels of the Assiniboia paleodrainage). Quartzose sandstone predominates (>90%), indicating principal contributions from such major sandstone formations as the Precambrian Athabasca Group of northern Saskatchewan, the Cambro-Ordovician Deadwood and Winnipeg formations, the Jura–Cretaceous Success Formation of the paleo-uplands, and the granitic terrain of the Severn Arch of Manitoba. A southeastern source would have been the Precambrian Shield and the Cambrian and Ordovician sandstone units of the Sioux Arch in eastern Minnesota. Sediments from the southwest would have been derived primarily from country rock, particularly Upper Jurassic shale and the Success Formation.

The marine invasions of the valley intercepted, from time to time, the fluvialite influx, reworking it into river-mouth bars and fringing beaches, and into sheet sands in the structural sags as the Broadview, the Lloydminster arm of the Meadow Lake Paleolowland and the Meadow Lake structural basin. Along the western flank of the Govan Paleolowland, the higher elevations precluded the sea, but low gradients in the valley bottoms and finer grained source beds in the uplands made for starved depositional sites with relatively thin, poorly sorted, clay-infilled, fine-grained quartzose sandstone and carbonaceous and sideritic mudstone in the re-entrants of the Swift Current and Kindersley paleo-uplands. These uplands are fronted to the east by shoreface, better sorted, reworked sandstone sheets of Units 2 and 3 across the Govan terraces. During deposition of the latter units, the Govan Paleolowland had

become a nearly flat-floored shelf across which wide-ranging movements of the strand were possible. Such movements would have been aided by tidal forces and extensive wind fetch from the northwest or southeast. In this regard, argillaceous content of the Dina increases somewhat in the central part of the basin, between the Molanosa and Kindersley paleo-uplands, and indicates a null region for currents generated by opposing vectors along the axis of the basin.

The Cummings Member displays a relatively thin layer of foraminiferal, glauconitic, and bioturbated sandstone and shale across the Govan Paleolowland, and carbonaceous mudstone in the valley basins of the paleo-uplands. Upward-coarsening progradational facies and, to a lesser extent, upward-fining transgressive beds, as well as a northwesterly thickening across the Meadow Lake Paleolowland, indicate a deepening of the paleolowland by northwesterly downwarp. The relatively steep eastward rise of the Dina, and coincident thinning of the Cummings on the western flank of the Molanosa Paleo-upland, indicate a reactivation of the Molanosa Dome.

The cyclic format of the Cummings Member is punctuated by hiatuses, as indicated by the cemented pavements. Shoreline deposits, such as barrier beaches, baymouth and lower estuary bars, fringe the highs and spurs of the Unity Paleo-upland throughout the Lloydminster oilfield district and along the eastern flank of the Meadow Lake Paleolowland toward the Third Meridian (latitude 106°W). The setting was generally shallow coastal, and thus bioturbated, with seemingly widespread glauconite-forming, current-scoured bottoms on the one side and marshes giving rise to coal on the other. Lagoons and tidal inlets in the re-entrants of the Swift Current Paleo-upland and the Kindersley and Unity paleo-uplands extended for scores of kilometres into the hinterland. They were sites of estuarine mud deposition in the former, and fluvial sand and mud with widespread terminal coal-forming marsh conditions in the latter. Coal beds, 1 to 5 m thick, attest to these conditions on the northwestern part of the Unity Paleo-upland, and were mapped by Groeneveld and Stasiuk (1984) over an area of 280 km². Deposition of thin, bioturbated mud and sand was widespread across the Govan Paleolowland, and indicates a shallow seafloor with a virtual absence of gradient.

Middle Cantuar (Lloydminster-Rex) Depositional Pattern

The Lloydminster and Rex members are eastern expressions of the open marine shale in the lower part of the Clearwater Formation of central Alberta (McLean and Wall, 1981). As traced into southern and southwestern Saskatchewan, they overlap the Lower Mannville onto the flanks of the Swift Current Paleo-upland as the Dimmock Creek Member of the Cantuar Formation (Christopher, 1974). This overlap is also present on the upper slopes of the adjacent Kindersley Paleo-upland and, in southeastern Saskatchewan, against the Moosomin Paleo-upland. In that much of the erosional relief on the depositional floor had by then been subdued, the combined Lloydminster and Rex members are spread as a sheet, up to 40 m thick, over vast expanses of the Govan Paleolowland basin (Figure 32) and on the lower slopes of the Swift Current Paleo-upland. The closed zero isopachs (hachured) between the present-day Quill Lakes and the Qu'Appelle River (surrounding Yorkton) represent post-Cantuar, pre-Pense truncation, whereas, in the northeastern part of the Mannville basin, they represent Tertiary and Quaternary truncation.

The greater isopach values are in the southeast (up to 60 m), north of Estevan, and in the northwest (up to 71 m, west of Meadow Lake), over the Meadow Lake Paleolowland. With respect to the latter region, a narrow belt of thickening lies parallel to the northern dissolution front of the Middle Devonian Prairie Evaporite along the present-day North Saskatchewan River. Likewise, wider curvilinear belts of thickening and thinning occupy an implied depression trending northeast toward and around Doré Lake. Both locales are believed to represent sites of penecontemporaneous salt-dissolution tectonics associated with, respectively, the Prairie Evaporite (Orr *et al.*, 1977) and the Lower Devonian Lower Elk Point evaporite beds (Fuzesy, 1980). The north-south alignment of the 40 m contour from Primrose Lake to the Clearwater River represents the eastern flank of the Cold Lake and Athabasca heavy-oil and tar-sand basins centred in Alberta. South of Melville, thickening occurs over a topographic basin in the partially infilled Assiniboia Paleovalley system.

The Cummings-Lloydminster contact is defined by an erosion surface in the reference section at Shell Husky Paradise Hill A13-19-52-23(W3). The top bed of the Cummings is a 1.93 m thick, very fine grained, quartzose, trough-cross-bedded sandstone, with small-scale black shale drapes, that caps a coaly black shale and sandstone sequence. The sandstone is silica cemented and oxidized over its upper half, and its base is pyrite cemented. These are regarded as diagenetic effects under emergent conditions terminating the Cummings episode of deposition. This contact is depicted in the cored wells of cross-sections A1-A1' (Figure 13), A2-A2' (Figure 14), and A3-A3' (Figure 15), as calcite-, siderite- and silica-cemented pavements, coal beds and soil-rootlet zones, all of which imply a widespread withdrawal of the sea (*i.e.*, a 'forced regression'; Posamentier *et al.*, 1992) prior to resumption of marine deposition in Lloydminster time.

The Lloydminster Member is described in its type area as a single cycle that coarsens upward from marine shale through bioturbated sandstone and shale into a capping sandstone laid down in a shoal or strand environment. This is a generalization, because cross-section A-A' (Figure 16) shows that the capping sandstone at the Husky Aberfeldy A11-31-49-26(W3) type well is overlain by a thinly interbedded sandstone-shale bed that represents the offshore deposits of higher strand sands to the south. The single-stage lowstand sequence is compounded at BA Hillsdale Poppleton 12-29-43-25(W3) and farther south with an overlying highstand sequence. In this context, therefore, reference to an 'upper and lower Lloydminster' in the Winter-Senlac oilfield district of Groeneveld (1990) corresponds, in this study, to a bipartite Upper Lloydminster comprising Units 3 and 4.

At Shell Husky Paradise Hill A13-19-52-23(W3), the Lloydminster consists of four upward-coarsening bedding cycles. At 13.92 m, cycle 1 is thickest and typical of the Lloydminster. It features a capping, fine-grained quartzose sandstone above an irregular transition of interbedded and interlaminated, bioturbated and glauconitic sandstone and shale. Five calcite-cemented pavements are indicated from the geophysical log, so the cycle may represent five depositional episodes. Cycle 2 (11.2 m) grades upward from grey-black, fissile shale into very fine grained quartzose sandstone, thinly bedded and marked by ripple- and current bedding with subordinate black-shale-draped laminae. Cycle 3 (2.72 m) is mostly wavy cross-bedded, very fine grained quartzose sandstone with minor thin, dark grey shale beds and shale-draped laminae. Cycle 4 (8.64 m) is similar to cycle 3 but thicker. A sharp contact separates all bedding cycles except 3 and 4, and the Lloydminster rests on the erosional and oxidized surface of the Cummings Member.

The bedding cycles of the Lloydminster at Paradise Hill equate with the mapping units as follows: Cycles 1 and 2 correspond to Units 1 and 3, respectively; and cycles 3 and 4 represent an apparent full-cycle deposit, and therefore combine make up Unit 4. As traced from the north on cross-section A-A' (Figure 16), Unit 2 is overstepped by Unit 3 against the draped topographic front of the Middle Devonian Prairie Evaporite lying at depth, at Imp Sidney Lake 3-16-55-25W3. This relationship extends west and south onto the draped surface of the Unity Paleo-upland. However, to the east and southeast of the Paradise Hill section (*i.e.*, toward and along the axis of the Govan Paleolowland basin), Unit 2 remains an integral part of the Lloydminster (cross-section A2-A2', Figure 14). Eastward in the Meadow Lake Paleolowland basin toward the Molanosa Paleo-upland, overlap of Unit 1 by Units 2 and 3 takes place at about Seaboard Meadow Lake Crown No. 6 (16-36-59-14W3) of cross-section U-U' (Figure 18). In general, all four units are present in the northern part of the Govan Paleolowland basin (SWP Boulder Lake DD 1C 16-18-30-23(W2) of cross-section A2-A2', Figure 14; Transgas Prud Homme 11-12-38-28(W2), Grey Owl Syndicate No. 1 (16-10-44-27W2), and Choiceland No. 1 Choice DD 13-3-50-18(W2) of cross-section A3-A3', Figure 15). Unit 4 tends to be severely attenuated under the Rex Member, and Unit 1 thins southward to vestigial across the Punnichy Arch. Thus Units 2 and 3 become prominent southward, although variable in thickness (cross-section B-B', Figure 19).

Lloydminster and Rex sandstone in the western part of the Meadow Lake Paleolowland basin, by virtue of their mineral suite, represent multiple progradational influxes from the Rocky Mountain system. Their mineral suite is characterized by medium- and fine-grained quartz, combined with up to 15% black and dark grey chert, white kaolinite and feldspar, green glauconite and brown siderite, and widespread calcite and pyrite cements. In the nearby Cold Lake Basin of Alberta, where this mineral suite is more proximal, the equivalent Clearwater sandstone units are litharenite dominated by rock fragments (28 to 49%), consisting of volcanic rocks (3 to 15%), chert (7 to 15%), sedimentary rocks (4 to 13%), dolomite (9%), igneous-metamorphic rocks (3 to 11%), quartz (13 to 25%), plagioclase (5 to 10%), and K-feldspar (4 to 11%); accessory components include amphibole, biotite, muscovite, tourmaline, zircon, and opaque minerals (McKay and Longstaffe, 1977). A comparable suite is found in the Dimmock Creek and Atlas members on the Swift Current Platform in southwestern Saskatchewan (Christopher, 1974) and in the Grand Rapids Formation of the Athabasca River basin and the Wabasca Basin (Keeler, 1980). Here, in the Meadow Lake Basin, the volcanic mineral species are less in evidence, but hard black chert is abundant and readily identified in the well cuttings across the region. At the Shell Frenchman Butte A7-3-53-23(W3) well (stratigraphic cross-section A1-A1', Figure 13; Appendix A), the suite is conspicuous in the lowstand deposits characterizing the Lloydminster Member. Bedding cycles 1 and 2 (3.0 and 2.5 m thick, respectively) are unconformity-bounded sequences that coarsen upward from dark shale, wavy and ripple-laminated with fine-grained quartzose sand, into oxidized and calcite-cemented, fine-grained quartzose sandstone. The 9.02 m thick bedding cycle 3 is also a quartzose sandstone that coarsens upward from fine to medium grained and displays a subordinate mineral suite of 10 to 15% black and dark grey chert, white kaolinite (after feldspar), glauconite, chloritic mudstone, pyritic nodules, and calcitic cement; it is generally bioturbated and indurated throughout. The basal contact is sharp and irregular. Bedding cycle 4, at 5.43 m, is half the thickness of cycle 3 but shares all of the characteristics. It is also unconformity bounded, as indicated by the sharp and irregular basal contact and deep, yellow and brown oxidation at the top. This four-fold episode of emergence, weathering, deposition, and emergence reflects sea-level changes equivalent to the thickest of the cycles, in that Mannville beds are lenticular. The high sea-stand, upper Lloydminster strata are dominated by a medial, 8.7 m thick cycle 6, consisting of very fine and fine-grained quartzose sandstone, which is current and low-angle wavy bedded with shale-draped sandy lenses,

laminae, and bioturbation toward the top, and a 1.5 m thick, dark grey, fissile shale at the base. The subjacent cycle 5, at 3.4 m, is half as thick but likewise displays an upward transition from shale to sandstone. Cycle 7, 0.4 m thick, is oxidized and cemented, and represents an eroded remnant of a speckled sandstone body with about 5% coaly grains.

Unit 1 of the Lloydminster appears to be a lowstand sea deposit across the Meadow Lake Paleolowland basin in the northwest and as far south as Tenn Tangleflags 2-36-52-25(W3), beyond which the unit is overlapped (Figure 16). The dominant depositional forms in any of the units across the Meadow Lake Paleolowland basin, particularly between the towns of Meadow Lake and Lloydminster, appear to have been lithic arenite laid down as large-scale submarine fan deposits sourced by rivers to the west, and juxtaposed with calcareous, quartzose sand sheets, worked into compound sand bars and ridges up to 40 m thick. The latter are depicted at Sceptre et al Turtleford 16-4-51-20(W3) on cross-section V-V' (Figure 17) and Imperial Beacon Hill 8-16-62-25(W3), Bonavista Whelan 11-14-59-25(W3), and Banff Aquitaine HB Peck 8-32-57-26(W3) on cross-section A-A' (Figure 16). Associated shale units are typically dark grey, foraminiferal, glauconitic, and pyritic, and intermixed with bioturbated, locally calcareous, very fine grained quartzose sandstone and shale. However, to the south, northeastward opening tidal-channel regimes are indicated (e.g., A1-14-50-25(W3) and A14-15-52-25(W3) of the Tangleflags oilfield), where slumped shale blocks and imbricated shale clasts are present in massive sandstone of a thickened Lloydminster section (Wilson, 1984).

At Shell Dee Valley A11-18-48-21(W3) (Figure 14), the four upward-coarsening bedding cycles in the Lloydminster are equated to stratigraphic units with the same numbers. Bedding cycle 1 (7.58 m), on an erosional contact on the Cummings Member, grades from black shale with subordinate current-bedded, fine-grained quartzose sandstone, through thinly interbedded, shale-draped lenticular sandstone, into massive, medium-grained quartzose sandstone. Bedding cycle 2 (0.94 m) is vestigial, but marked by a gradation of black shale, with about 20% argillaceous, fine-grained quartzose sandstone exhibiting starved ripples and scoured and graded layering, into light blue-grey, medium-grained, calcite-cemented quartzose sandstone with abundant coarse-grained glauconite. Bedding cycle 3 (14.48 m) is essentially calcite-cemented, fine-grained quartzose sandstone with minor black shale partings near the base, and cycle 4 (1.63 m) consists of sandstone with hummocky and opposing cross-stratified layers. The abundant wavy cross-laminated sandstone, black shale and glauconite, and the herringbone fabric all provide evidence of offshore, tidal conditions (Weimer *et al.*, 1982). Bedding cycle 3 is fully gradational, except for the sharp contact underlying its 1.05 m thick, capping, calcite-cemented sandstone. Thus, its 14.48 m thickness gives an indication of the amount of sea-level rise at this site, and is comparable to the 11.2 m of the full cycle 2 at Shell Husky Paradise Hill.

At Shell Meota C13-17-46-17(W3) (Figure 14), six bedding cycles in the Lloydminster are exhibited. Cycle 1 (7.7 m) is an upward transition from black glauconitic shale, through bioturbated, glauconitic quartzose sandstone and shale, into a fine-grained quartzose sandstone that is well sorted and flat bedded with subordinate low-angle, tabular cross-beds, diastemic breaks, and thin laminae of coal. It is similar to bedding cycle 1 at Shell Dee Valley in lithology and thickness, and is equated with Unit 1. Bedding cycle 2 (5.3 m) coarsens upward from an erosional base through a succession of black shale, bioturbated sandstone and shale, and well-sorted, tabular-cross-bedded, fine-grained quartzose sandstone, and corresponds to Unit 2. The upward-fining cycles 3 (4.06 m), 4 (1.9 m), and 5 (1.83 m) apparently represent a three-stage channel fill: tabular- and trough-cross-bedded sandstone with thin, capping, laminated sandstone and shale in the first stage; tangentially cross-bedded, calcareous, fine-grained, quartzose sandstone, laminated at the top with white kaolinite, in the second stage; and very fine grained, permeable, massive quartzose sandstone under current-scoured sandstone and mudstone, with capping loam, in the third stage. Cycles 3, 4, and 5 are components of a 7.79 m thick Unit 3, and the terminal soil indicates infill of the local depositional site. Bedding cycle 6 (4.58 m) also fines upward from an erosional contact, but displays tangentially and herringbone-cross-bedded, fine- and very fine grained quartzose sandstone under a thin, bioturbated, interbedded sandstone and dark grey shale. It appears to be a tidal-channel deposit in Unit 4.

At C.M.&S. Vanscoy 11-16-35-8W3 (Figure 14 and Figure 15), bedding cycles 1 (2.7 m) and 2 (7.6 m) of the Lloydminster both coarsen upward from grey-black shale through a bioturbated facies into wavy-cross-bedded quartzose sandstone, which ends in a calcite-cemented pavement. Both are included in Unit 1 and represent an offshore marine section, 10.3 m thick, and a depositional environment similar to that at Shell Husky Paradise Hill A13-19-52-23W3, 225 km to the northwest. Bedding cycles 3 (4.9 m) and 4 (1.7 m) end in carbonaceous shale and lignite, cycle 3 grading upward from black shale and bioturbated sandstone into very fine and fine-grained quartzose sandstone with wavy cross-bedding and shale drapes, and cycle 4 into carbonaceous and coaly sandstone on an erosional contact. Cycle 4 is an apparent infilled tidal channel cut into cycle 3. Both cycles are components of Unit 2. Bedding cycle 5 (11.4 m) is equated with Unit 3 and is a trough-cross-bedded and channelled, very fine grained, weakly indurated quartzose sandstone, with minor laminated sets of carbonaceous sandstone and shale, and scattered glauconite. Cycle 6 (1.4 m) represents Unit 4. Above a sharp basal contact, thin, fine-grained quartzose sandstone grades into oxidized mudstone with abundant plant fragments indicative of a marshy setting. Thus, the

depositional history of the site began with an offshore marine depositional floor (Unit 1), which shallowed by progradation into a tidal basin (Unit 2). Then followed strand retreat and valley cut, strand re-advance and estuarine infill (Unit 3), ending in a marsh (Unit 4).

On the Kindersley Paleo-upland, Lloydminster Units 3 and 4 are basal to the member in the paleovalley re-entrants, where they overlie relatively thick coal beds of the Cummings Member. At the Senlac and Winter oilfields (Twp. 37 to 43, Rge. 24 to 28, W 3rd Mer.), the Lloydminster sediments are interpreted to have been deposited in tidal estuaries (Zaitlin and Schultz, 1984; Groeneveld, 1990). The Senlac sandstone body is described as linear, flanked by shale and axial over a buried valley on the sub-Dina erosion surface. A similar depositional control is exercised by the Plato Paleovalley to the south. Thus, at Tidewater Imperial Plato Crown No. 1 (9-22-24-19W3), the Lloydminster (796.4 to 787.0 m below KB) is an upward-coarsening, single-cycled Unit 3 that comprises: 1) a basal 3.4 m of dark grey mudstone, and 2) an overlying 6 m of fine-grained quartzose sandstone, with abundant black and grey chert, kaolinite grains, interbeds of silty and argillaceous sandstone, and scattered layers of flat mudstone pebbles under a fine-grained, kaolinite- and calcite-cemented quartzose sandstone featuring frosted grains, dark grey chert and scattered green biotite. The Lloydminster succession is an apparent progradation into an embayment and buildup into a beach environment.

Vigrass' (1977) description of the Rex as a 15 to 24 m thick succession of grey shale, siltstone, quartzose sandstone and chert-rich sandstone summarizes all that has been published on the member. At Shell Husky Paradise Hill A13-19-52-23W3, the Rex consists of four upward-coarsening bedding cycles, each transitional from basal shale or laminated shale and sandstone into quartzose sandstone. These are taken to represent Units 1 to 4. Unit 1 (6.84 m) includes extensive feeding- and escape-burrow forms. Units 2 (0.95 m) and 3 (6.3 m) feature basal current-rippled and ripple-drift, fine-grained quartzose sandstone with minor laminae of concentrated plant detrital grains, and an overlying well-sorted sandstone that, in Unit 3, is capped by green-grey and black, carbonaceous and coaly mudstone. Unit 4 (3.75 m) is also sandstone dominated, with a minor grey-black carbonaceous shale as laminae, balls, and irregular flow forms, and is calcite cemented over the upper 1.5 m. In that foraminifera have been recovered from the shale, the member retains the overall oscillatory coastal marine characteristics of the Lloydminster, but in the context of a renewed transgression.

Northward in the Meadow Lake Paleolowland, the speckled sandstone seen in the Lloydminster Member also appears in the Rex, as exemplified at the Frenchman Butte A7-3-54-25(W3) well. It reappears in bedding cycle 1 of the Rex Member as an unconformity-bounded, 8.8 m thick sequence that coarsens upward from dark grey shale, through laminated and intensively burrowed (*Teichichnus*) sandstone and shale, into quartzose, bimodally fine- and medium-grained sandstone, with about 12% black and dark grey chert, sphaerosiderite, and feldspar, that is moderately cemented with calcite and kaolinite. Bedding cycle 2, similar in thickness (9.15 m), is apparently compounded, in that the basal metre-thick bed, though a dark grey, bioturbated shale on an erosion-pitted contact, grades upward to include subordinate, starved rippled sandstone lenticles with minerals as in bedding cycle 1. The major body of cycle 2, by virtue of its sharp contact, apparently truncates the basal bed and grades upward through swaley, cross-bedded, very fine grained quartzose sandstone into low-angle, planar-cross-bedded and flat-bedded, fine-grained quartzose sandstone. Mudstone and coaly seat earth caps the cycle. Thus, cycle 2 may represent a buildup of a shoal into barrier beach and lagoon. Bedding cycle 3, though thin at 2.12 m, sees a return of the upward transition to the speckled sandstone of cycle 1, whereas cycle 4, similarly thin at 3.38 m, returns to the facies of bedding cycle 2. The speckled sandstone, by virtue of its mineral suite, represents direct input or nearby sourcing by fluvial channel systems, which shift their location over time because of shoreline retreat or advance. The intervening, current-bedded, well-sorted quartzose sandstone represents *in situ* shoreline reworking of sand into barrier beaches and shoals on former offshore depositional floors. In general, the Rex depositional forms appear to be shallower water repetitions of the Lloydminster.

Southward from Shell Paradise Hill, the four units of the Rex continue through Shell Dee Valley A11-18-48-21(W3). At Shell Manito 6-7-43 24(W3), however, Unit 1 pinches out against the Lloydminster contact and Unit 4 pinches out against the overlying General Petroleum Member. Thus, at Shell Zaller Lake 10-7-39-25(W3) and southward to Shell Cactus Lake 2-16-36-28(W3), Units 2 and 3 represent the Rex (cross-section A1-A1', [Figure 13](#)). Of the five bedding cycles at Shell Dee Valley, cycles 1 (1.33 m) and 2 (1.04 m) are components of Unit 1. The first is a medium grey, calcite-cemented, flat-bedded, very fine grained quartzose sandstone, speckled with black pyritic carbonaceous grains. The second coarsens upward from dark grey, bioturbated shale with sandy beds to hummocky, cross-stratified, calcite-cemented, very fine grained quartzose sandstone, speckled with pyritic carbonaceous grains and abundant plant fragments. Cycle 3 (*i.e.*, Unit 2, 2.25 m) is a glauconitic version of cycle 2. Cycle 4 (8.8 m) is a tabular and trough-cross-bedded, kaolinite-indurated, very fine grained quartzose sandstone with medial laminated bands of siderite grains and a basal carbonaceous shale lamina. It is a facies suggestive of a nearby fluvial source, progradation from which is implied by the similar sandstone in cycle 5 (*i.e.*, Unit 4, 3.35 m). This latter sandstone, however, is medium grained and interbedded with kaolinite-rich, indurated layers and plant

detritus concentrated on bedding surfaces. Thus, deposition of the Rex at Shell Dee Valley, like that in the Lloydminster, was initiated in a tidal offshore and completed onshore.

The overall progradation expressed by the Rex units is also seen at Shell Meota C13-17-46-17(W3) (Figure 14), where cycles (Units) 1 (2.65 m), 2 (3.35 m), and 3 (4.69 m) retain the upward-coarsening, current-scoured, bioturbated, glauconitic, and therefore marine character to the rootlet-casted, coaly underclay at the top of cycle 3. Bedding cycles 4 (2.4 m) and 5 (2.81 m) are upward-fining components of Unit 4. The former is terminated by a thin coal, suggestive of a marsh environment, and the latter is a completion of the progradation by its four-part alternation of claystone and coal.

At Shell Manito 6-7-43-24(W3) (Figure 13), bedding cycles 1 (2.35 m) and 2 (1.64 m) represent condensed and truncated Units 1 and 2. Cycle 1 retains the current-bedded, shale-draped, glauconitic, very fine grained quartzose sandstone, but cycle 2 is calcite cemented, flat and current bedded, well sorted, and fine grained, with abundant, partially leached and oxidized, coarse-grained sphaerosiderite throughout and thin beds of black shale toward the base. Cycle 2 is an apparent erosional remnant with a subaerial exposure surface. The overlying thin (1.51 m) cycle 3 (Unit 3) of bioturbated and glauconitic black shale, with subordinate argillaceous sandstone, implies a renewed transgression. It, too, appears to be a remnant preserved under an erosional contact. Bedding cycle 4 (*i.e.*, Unit 4, 5.55 m) is coal-capped quartzose sandstone containing rip-up clasts of indigenous sandstone and interbeds of black shale, with lateral sandy burrow-casts and shale layers draping wavy, sandy beds. It apparently originated in a tide-scoured lower estuary, which was encroached upon by marshes.

The two cycles (3.17 and 2.87 m) of the Rex at Shell Zaller Lake 10-7-39-25(W3) (Figure 13) are representative of Units 2 and 3 respectively. Unit 2 is kaolinite-infilled, current-bedded, fine-grained quartzose sandstone with abundant coaly fragments. Unit 3 fines upward from fine-grained, massive, patchily bioturbated, kaolinite-indurated quartzose sandstone with minor black chert and scattered chlorite, into bioturbated, argillaceous quartzose siltstone with black shale stringers capped by lignitic shale. Thus, all five sites on the Unity Paleolowland, late in the Rex, share a regressive facies representative of a tidal embayment in the lowland, with headward distributaries penetrating broad saline marshes. Terminal coal beds are characteristic of the Rex across much of the Unity terrace, reaching thicknesses of 6 m (*e.g.*, at Precambrian Cosine 8-6-35-28(W3)).

At C.M.&S. Vanscoy 11-16-35-8(W3) (Figure 14), the Rex bedding cycles are equated with the units. Upward-coarsening, glauconitic, bioturbated shale-sandstone beds, capped with thin coal, characterize Units 2 (3.4 m), 3 (5.5 m), and 4 (3.3 m), but Unit 1 (2.3 m) represents a channel sandstone, which grades upward from low-angle trough-cross-bedded fabric with basal mudstone conglomerate, through coaly interlamination, into calcite-cemented, current-bedded sandstone. This sequence may be indicative of an abandoned distributary that was eventually transgressed by shoreface sand deposits. At nearby Duval Saskatoon 6-18-36-6(W3) (Figure 15), Units 1, 2, and 3 (3.3, 3.1, and 3.0 m, respectively) correspond to three upward-coarsening, shale to sandstone cycles 1 to 3, but Unit 4 (6.1 m) is compounded of flat-bedded quartzose sandstone that grades through bioturbated shale into a medium-grained quartzose sandstone terminated by a paleosol. It appears that the unit should be regarded as a beach site that was drowned and later prograded.

Cycles 1 (5.5 m), 2 (2.7 m), and 4 (3.4 m) at Transgas Prud Homme 11-12-38-28W2 are sandstone with upward fining and upward increasing burrowed-podded and bioturbated fabric, but cycle 3 (4.9 m) is upward coarsening from thinly cross-bedded, very fine grained quartzose sandstone to fine-grained. Pulsational transgressive conditions are indicated. Units 1 and 2, by their fine texture, the absence of current bedding and the presence of pyritic nodules and laminae of carbonized reeds and palmate leaves, reflect an inshore, poorly oxygenated settling basin. Unit 3, though upward coarsening, is sandstone dominated, trough and current bedded, and calcite cemented, and thereby indicates a shoreface barrier beach or bar. The transition to bioturbated black shale in Unit 4 time reflects a late Rex deepening of the site. Relative increase of the shale component eastward in the Govan Paleolowland basin appears to be a function of increasing distance from western sources.

At Tidewater Imperial Plato Crown No. 1 (9-22-24-19W3) (Figure 33) on the Kindersley Paleo-upland, the Rex (787.0 to 777.2 m below KB) fines upward from 3.3 m of indurated, very fine grained, kaolinitic quartzose sandstone into 9.7 m of carbonaceous and plant-detrital mudstone, siderite cemented near the top. These sediments were probably deposited as an initial channel deposit that built up into lagoonal behind shoreface barrier deposits. Whereas the kaolinite component may have been derived from local interfluvial, green biotite in the Lloydminster implies fluvial influx from a Rocky Mountain source.

The Lloydminster and Rex constitute the Dimmock Creek Member of the Cantuar Formation across the middle flats of the Swift Current Paleo-upland (Figure 33). The Dimmock Creek in the western part of the upland records the introduction of green chloritic and biotitic quartzose sandstone from southwestern volcanic sources. This influx

encountered the north-south ridge of the Roseray-Success escarpment along Rge. 19W3, against which the deposits were partially dammed and funnelled through water gaps to the eastern slopes of the Swift Current Paleo-upland (Figure 32). The volcanic facies is typical in the core of the Dimmock Creek Member from Pan Am A-1 Roseray 7-13-17-19W3 (Christopher, 1974, p80), in which the member is subdivided into six units. Units 1 to 3 of the Dimmock Creek are correlated with Lloydminster Units 2, 3, and 4, and Dimmock Creek Units 4 to 6 with Rex Units 1, 2, and 3. The Lloydminster, in its sandstone component beds, coarsens upward overall, but through the following upward-fining cycles:

Unit 2

967.8 to 964.7 m Sandstone: quartzose, argillaceous (inferred from geophysical log); coal and capping carbonaceous mudstone and claystone.

Unit 3

964.7 to 961.0 m Sandstone: quartzose, very fine grained, very argillaceous, dark grey, irregular basal contact marked by pyritic concretionary bodies; succeeded by flat-laminated alternating with ripple-drift cross-laminated sandstone; overlain by 2.4 m of dark grey to grey-black, silty mudstone with scattered coaly lenticles.

Unit 4

961.0 to 950.9 m Sandstone: quartzose, fine grained, well sorted, subrounded, about 15% green amorphous chlorite, green and dark brown biotite, red-brown sphaerosiderite, grey muscovite, and black hydrated schist; well indurated in white kaolinite and microgranular and acicular silica; minor argillaceous partings and laminae of coal flakes; ripple cross-laminae separated by irregular, dark grey, shaly partings yielding downward to scoured lenticular sandstone with shale drapes; grades upward through 3.0 m of argillaceous, flat-laminated and ripple-cross-bedded siltstone, with abundant biotite, chlorite, and coarse sand size carbonaceous grains, into carbonaceous mudstone and thin terminal coal.

Thus, the depositional setting at this site during the Lloydminster was progradational. An interdistributary bay site was increasingly encroached upon by influx of fluvial sediments from southwestern volcanic sources. Similar facies are seen in the outcrops of the Little Rocky and Bears Paw mountains and the Sweetgrass Hills of northern Montana, and the middle part of the Blairmore Group of southwestern Alberta. The progradational setting is consistent with that described for Units 3 and 4 at Shell Meota C13-17-46-17W3 and C.M.&S. Vanscoy 11-16-35-8(W3) (Figure 14).

The Dimmock Creek Units 4, 5, and 6 at Pan Am A1 Roseray 7-13-17-19(W3) (Figure 33) are similarly related to upward-fining bedding cycles, and are assigned to the Rex as Units 1, 2, and 3.

Unit 1

950.9 to 944.4 m Sandstone: quartzose, fine grained, mineralogy as Unit 3 of the Lloydminster; medial, flasered, very fine grained quartzose sandstone and siltstone; capped by olive mudstone.

Unit 2

944.4 to 940.6 m Sandstone: quartzose, fine grained, blue-grey to dark grey-green, ripple cross-laminated, silica cemented in green chlorite, and includes scattered black chert, oxidized sphaerosiderite, and laminae of montmorillonite; overlain by thin grey-black to green, plant-detrital-rich claystone.

Unit 3

940.6 to 938.8 m Sandstone: quartzose, fine grained; abundant carbonaceous grains, glauconite and pyrite; faintly burrowed and intermixed with montmorillonite; well-indurated carbonaceous mudstone at top.

The flasered bedding of Rex Unit 1 and the burrowed glauconitic sandstone of Unit 3 indicate a shallow, lower shoreface setting. Decrease of the allochthonous mineral input accompanied a waning fluvial contribution, either by marine transgression or, more likely, by avulsion and relocation of the stream mouth elsewhere along the strand.

The shale components of the Dimmock Creek are vestigial at Chevron Spring Creek 12-21-22-19(W3), where virtually all of the units coalesce into a 21 m thick sandstone body (Figure 33). However, the indurated pavements indicated on the log deflections suggest that the member consists of sandstone units as delineated. The condensed Dimmock Creek body, as traced throughout the locality, is ellipsoidal, with dimensions of 19 km east-west and 9 km north-south, and anchored against a scarp on the calcilutite of the Lower Member of the Jurassic Shaunavon Formation. Narrow channel sandstone is also recorded, above the Middle Jurassic Delta oil field (Christopher, 1974, p83, Figure 37), where Dimmock Creek sandstone replicates underlying channel facies of the Upper Shaunavon Member. It attains a thickness of 24 m, but is only 2.5 km long and 1 km wide. Apparently, this is a southeasterly trending valley-in-valley deposit, which was controlled by penecontemporaneous downwarp of the pre-Cantuar Delta trough. Farther east, as at Tide Water Leinan Crown No. 2 (2-20-18-13W3) (Figure 37), the units tend to coarsen upward and one or other of them becomes glauconitic. Elsewhere, glauconitic channel sandstone, as at Shell Tidewater Beaver Flat 2-16-19-12(W3) (Figure 37), replaces a substantial portion of earlier shale and mudstone.

With respect to depositional setting, the Dimmock Creek facies of the Swift Current Paleo-upland, by virtue of their lenticular shape, high content of vegetable detritus, upward-fining channel parameters, and poorly developed bedding forms, indicate an association with distributary-channel-marsh-swamp facies, such as that described for the Rockdale delta system of the Eocene Wilcox Group of Texas (Fisher and McGowan, 1969). The stratiform character of the member and the terminal lignite beds imply an aggrading system, modified periodically by a weakening of the sedimentary influx and a consequent spread of marsh-forming conditions. The order of thickness, 6 to 8 m for each rhythm, approximates the averages recorded in northern wells, such as Shell Paradise Hill A13-19-52-23(W3), and also appears to be on the order of base-level control, as expressed by sea-level rise or sinking of the depositional floor.

On the eastern flank of the Swift Current Paleo-upland (*i.e.*, the upper terraces of the Govan Paleolowland), the Dimmock Creek thins, and shale and mudstone may be the dominant rock types. This factor, in addition to the 20 m thick Lloydminster-Rex channel cut-and-fill bodies and/or loss of the Lloydminster by onlap against the sub-Cantuar erosion surface, may thwart subdivision of the Dimmock Creek into Lloydminster and Rex units. At Tidewater Parkbeg Crown No.1 (10-32-18-3W3) (Christopher, 1974, p319), such a channel deposit is seen at 1032.0 to 1008.9 m below KB. The section comprises: 1) a basal 2.7 m thick, indurated, very fine to medium-grained, poorly sorted, kaolinite-infilled quartzose sandstone; grading upward into 2) a 17.2 m thick, black coaly shale; 3) a thin (45 cm), calcite- and siderite-cemented, fine- to medium-grained, poorly sorted quartzose sandstone, with about 10% sphaerosiderite, black and dark grey chert, green chlorite, large tree fragments, and glauconite; grading upward into 4) a 2.4 m thick, medium grey, muscovitic mudstone.

Sandstones (1) and (3) above, by virtue of their wackestone texture and poor sorting, appear to be channel hosted, the former by fluvial channels and the glauconitic latter one probably by estuarine channels. They are considered to have been products of distributaries intersecting a persistent marsh. Similar marsh conditions are also postulated for the region around the type Seaboard et al Dimmock Creek 9-24-11-21W3 well (Christopher, 1974, p30) to the southwest, along the western side of the Swift Current divide, where the Lloydminster unit is overlapped by the Rex and the section consists of interbedded coaly mudstone and subsidiary quartzose sandstone.

Eastward to and beyond the Third Meridian (longitude 106°W), the Dimmock Creek is characterized by widely distributed, stacked sandstone sheets. The core at Shell Old Wives Lake A16-11-14-30W2 (Christopher, 1974, p317), which penetrates the Rex and most of the Atlas Member (General Petroleum and Lower Waseca) over the intervals 1066.8 to 1050 m and 1050 to 1018.6 m, respectively, reveals the Rex as a progradational succession grading upward from: 1) a 4.6 m thick, olive shale with abundant carbonaceous specks; through 2) a 2 m thick, well-indurated, argillaceous quartzose siltstone, with subordinate very fine grained quartzose sandstone; into 3) an 8 m thick, fine-grained, white-kaolinite-infilled quartzose sandstone with subordinate black chert, biotite, chlorite, red-brown siderite, carbonaceous specks, and white feldspar; and 4) a 1.8 m thick, grey-black shale with minor light grey, coarse-grained, quartzose silt forming graded laminar couplets on scoured contacts. The kaolinite matrix and mixed provenance are suggestive of a nearby fluvial source accessing kaolinitic Success sediments in the hills and distant volcanic rocks to the southwest. The absence of bioturbation in (4) may indicate deposition in a lagoon or a relatively deepwater embayment.

On the western side of the Govan Paleolowland basin, other examples of the Dimmock Creek sandstone are mostly upward-fining transgressive facies incorporating coalesced channel, bar, and beach deposits. High permeability, as indicated by a reduced clay matrix and good sorting, is characteristic. Thus, at Shell Mossbank A10-33-12-29W2 (Appendix A), the upper part of the Lloydminster (1067.4 to 1064.1 m) displays a single unit that fines upward from a medium-grained, weakly indurated, well-sorted, tabular-cross-bedded (0 to 15°), medium grey-brown quartzose sandstone, with scattered lenses of green and white, siliceous, kaolinitic mudstone pebbles, into olive green shale intermixed with fine-grained quartzose sandstone. The overlying Rex (1064.1 to 1055.1 m) is kaolinite-infilled, calcite-cemented, fine-grained, low-angle cross-bedded quartzose sandstone, with subordinate black chert, white

kaolinite, pink feldspar, green chlorite, and grey chert, and interbedded with quartzose sandstone that is laminated with carbonized plant detritus. The basal contact is erosional.

Fabrics are reversed at Shell Dahinda No. 1 (6-2-9-23W2), where the cored section of the Rex (1117.4 to 1083.6 m) is composed of full-section sandstone units and the Lloydminster, as determined from samples, comprises interbedded glauconitic, chloritic, and green biotitic sandstone and shale. At HB Shell Avonlea 11-7-11-21W2, the upper part of the Lloydminster features lenticular beds of trough-cross-bedded, fine-grained, silica-cemented quartzose sandstone, with subordinate pebbles and cobbles of sandstone, siliceous mudstone, and brown ironstone. These constitute the basal portion of a cycle that fines upward through laminated, small-scale current-bedded, very fine grained sandstone and green-grey shale, into a green shale that is some 10 m thick. Geophysical-log signatures reveal the Rex to consist of two upward-coarsening successions of shale and sandstone. However, at neighbouring HB et al Avonlea 13-29-11-21W2, the lower Lloydminster is represented by three cycles (7.3, 1.2, and 9.2 m) of shale that grade upward from black and carbonaceous at the base into green in the first, green and silty in the second, and 4 m of very fine grained, argillaceous quartzose sandstone in the third. The log signatures indicate that this facies extends upward through the Lloydminster and Rex, with only a damped indication of increased sandstone content in the lower part of the Rex. The overlying massive sandstone of the General Petroleum is consistent from one site to the other; however, the McCloud is missing from Avonlea 13-29 and more of the Rierdon is present, thereby indicating a mudstone-blanketed topographic high at the site. Apparently, mudstone is the prevailing regional sediment, and sandstone of the upward-fining sequences represents fan deposits at lowstand extensions of fluvial channels that were drowned by the succeeding marine transgressions (Figure 34). Sandstone at the top of thick shale represents highstand shoreface progradational tongues.

The Lloydminster is in contact with the Upper Jurassic on the dip slope of the monocline forming the northern flank of the ancestral Williston Basin south of Twp. 10. From a thin veneer along the southern edge of the Swift Current Paleo-upland, it thickens to regional values above the buried Assiniboia tributary paleovalley complex (Weyburn, Estevan, and Northgate) from the Williston Basin at Rge. 9, W 2nd Mer. (cross-section Z-Z', Figure 22). Cored sections of the Lloydminster are scarce south of Twp. 7, but the Rex shares similar depositional characteristics. Thus, the Socony et al W Ratcliffe 13-22-1-16W2 core and the geophysical logs indicate that burrowed, dark grey, sandy mudstone and shale form the dominant lithological type for not only the Rex but also the Lloydminster. At Imperial Steelman 11-17M-4-5(W2), a partial core of the Rex (1045.2 to 1034.5 m) displays two bedding cycles fining upward from metre-thick, very fine grained quartzose sandstone, marked by current beds, ripple-drift, wavy laminae that become muscovitic and carbonaceous at the base of avalanche slopes, and vertical burrow-fills. The overlying bed on the first cycle is a 2 m thick, burrow-mottled claystone with minor laminae and thin beds of very fine grained sandstone. The overlying bed on the second cycle is 6.8 m of greenish grey and dark grey mudstone, with burrow pods and rolls of very fine grained quartzose sandstone that contains abundant pyritic nodules over its lower half and coaly blebs, rootlet casts, and ironstone concretions over its upper half. An upper-shore mudflat or lagoonal embayment is indicated.

Sandstone-dominant facies are prominent along the approaches to the Moosomin Paleo-upland of southeastern Saskatchewan (Figure 32). At Imperial Carnduff Unit Source 14-28-2-34(W1), compound channel-fill deposits make up the Lloydminster. The 12.9 m thick lower body (at 952.8 to 939.9 m) is a medium-grained, well-sorted, flat-bedded quartzose sandstone composed of faceted quartz grains whose contacts are silica cemented. It is very permeable but has abundant patches of coarse-sand-size, kaolinite- and calcite-cemented quartz-sand aggregates. A conglomerate bed made up of boulders and cobbles of medium grey, argillaceous, fine-grained, cross-bedded, calcite- and pyrite-cemented sandstone and coalified tree limbs occupies the upper 2 m, and underlies a brown sideritic pavement, penetrated by calcite-infilled, irregular vertical joints. The basal contact zone is 30 cm thick; features coarse-grained quartzose sandstone with abundant fragments of coaly tree limbs and pebbles of cemented, medium grey, fine-grained sandstone and medium green-grey, siliceous mudstone; and is floored on a sharp, irregular contact. The upper body (at 939.9 to 936.5 m) is 3.4 m thick, coal-capped, medium grey, current-bedded, fine-grained quartzose sandstone, interbedded and interlaminated with dark grey mudstone and entirely microfaulted, brecciated, and flow contorted. The basal contact zone (30 cm) is siderite and calcite cemented, includes a breccia of dark grey siliceous mudstone and pyritic nodules, and rests on a contact that slopes at 20° on a granular layer of white, quartzose sandstone and light green-grey claystone.

The cored lower part of the Rex Member (929.6 to 936.5 m) comprises: 1) dark grey, blocky to platy mudstone with basal attenuated lenses of current-bedded, very fine grained quartzose sandstone and, at its base, a sharp irregular contact; and 2) dark grey, clayey mudstone with scattered lenses of quartzose silty sandstone and also a sharp irregular basal contact. Overall, the section fines upward from the base of the Lloydminster to the base of a progradational sandstone capping the Rex; in that sense, it marks a major transgression. However, the pavements and erosional surfaces terminating each of the above units reveal interruptions of sedimentation and subaerial exposure. The penecontemporaneous slump deposits may also be associated with groundwater drawdown and resultant differential compaction, which preceded the next phase of drowning.

The bedding cycles described apparently correspond to Units 3 and 4 of the Lloydminster in that, this far up the Govan Paleolowland basin, Unit 2 is likely eroded out under the channel cuts of Unit 3. The channel sandstone and conglomerate indicate a strong initial fluvial influx and, perhaps, a return of the river that laid down the underlying Dina sandstone. The general absence of glauconite in the overlying mudstone is consistent with freshwater dilution and therefore mixing environments in the distributaries of lower deltas or estuaries. The region lay beyond the main front of the western-sourced biotite-chlorite facies, although the presence of green biotite flakes in the thin beds of well-sorted, very fine grained quartzose sandstone that caps upward-fining kaolinitic sequences in the upper part of the Rex (818.7 to 816.3 m) at Imperial Hastings 1-35-4-33(W1) suggests that minerals of the western provenance were reworked to the eastern side of the Govan Paleolowland basin by longshore currents.

In the Broadview topographic depression of southeastern Saskatchewan (Figure 32), where both Lloydminster and Rex isopach values are at regional highs, sandstone components of these members predominate, as in the underlying McCloud. In that none of the pertinent wells are cored in the Dimmock Creek Member, geophysical logs are the only source of information about the depositional fabric of the sandstone. The basin is transected from west to east by cross-section Y-Y' (Figure 23) between Pan Am B1 Fillmore Crown 13-4-14-10(W2) and the Moosomin Paleoup-land at TW Central Earlswood 1-19-14-33(W1); from west to east by cross-section Y1-Y1' (Figure 24) between Sohio Grenfell 13-14-17-7(W2) and CPOG Kahkawistahaw 5-18-18-4(W2); and from north to south by cross-section D-D' (Figure 21) between Soc Sohio Killaly 14-11-21-6(W2) and Imperial Warmley 6-23-10-6(W2). Both Rex and Lloydminster units appear to consist of as many as three broadly lenticular beds (township width or so), each of which lenses into shale and generally coarsens upward. Away from the nuclear mass, as delineated by the 40 m contour south of Yorkton on the isopach map (Figure 32), the sandstone spreads west to southwest from Broadview to the eastern front of the Swift Current Paleoup-land. To the north and south of its eastern distribution, the sandstone yields to sandy mudstone as the major component of upward-coarsening sequences (Figure 34). In the marine setting of the Lloydminster and Rex, the sandstone bodies appear to have originated as coalesced lowstand alluvial fan deposits that were reworked by longshore currents into strand deposits as sea level rose. The sand body was expanded into an offshore sand sheet by continued influxes and reworking by the tidal and storm-activated currents of an overall transgressive sea.

Northward, in the Govan Paleolowland basin, the Lloydminster and Rex members retain the dominantly fine-grained facies of thin-bedded, burrowed, green and dark grey, glauconitic, argillaceous quartzose sandstone and thin, black carbonaceous shale (*e.g.*, at Penzance Crown No. 1 [3-30-24-25W2], where the upper two cycles of the Rex Member are exhibited in core). The lower cycle (611.7 to 607.5 m) is a gradation from very fine grained quartzose sandstone, laminated with sandy mudstone, into mixed argillaceous, current-bedded, burrowed, microcontorted, calcite-cemented, oxidized sandstone. Likewise, the upper cycle (607.5 to 603.0 m), from basal medium grey mudstone, passes through argillaceous, very fine grained quartzose sandstone with dark green, glauconitic burrow-fillings, to 0.5 m thick coal and carbonaceous shale. At Community Service Watrous No. 1 (4-2-32-25W2), the Lloydminster (at 697.5 to 681.7 m) exhibits three bedding cycles (5.3, 6.4, and 4.1 m), belonging to Units 2, 3, and 4, respectively. They grade upward from green shale into laminated, very fine grained quartzose sandstone and shale that are cemented by calcite and capped by carbonaceous shale in the first cycle, uncemented in the second, and argillaceous with scattered rootlet casts in the third. The Rex (at 681.7 to 673.3 m) is predominantly grey-green shale, divided into three (1.1, 4.6, and 2.7 m) upward-coarsening cycles. The first is truncated in the sandy component; the second grades upward into argillaceous, very fine grained quartzose sandstone; and the third (incompletely cored in its upper part) is waxy claystone with abundant glauconite and pyrite.

To the east, at SWP Boulder Lake DD 1C 16-18-30-23(W2), sandstone is prominent but only in the topmost beds, specifically bedding cycle 4 (3.3 m) of the Lloydminster and cycle 2 (3.7 m) of the Rex. As described previously for cross-section A2-A2' (Figure 14), the mudstone is glauconitic and pyritic, contorted and sheared, and, in the Lloydminster, is interbedded with subordinate thin sandstone. The Lloydminster sandstone rests on an erosional contact and displays flat beds, low-angle current beds with small-scale troughs and ripples, and laminae draped with black shale. The Rex sandstone is irregularly bedded and intensively bioturbated with scattered glauconitic and pyritic patches. The upward transition in the Lloydminster, from nonbioturbated glauconitic mudstone to cross-bedded sandstone, probably corresponds to a shift from offshore to lower shoreface conditions. The similar transition in the Rex, by presence of extensive bioturbation, suggests a renewed buildup, but into an upper shoreface setting. On the whole, the relatively thin bedding, pyrite-cemented layers, erosional contacts and truncated bedding all indicate a sediment-deficient site that was subjected to repeated exposure by lowering of sea level.

The northeastward increase, in the Govan Paleolowland basin, of glauconite and bioturbation complements the sparsely bioturbated mudstone that blankets the approaches to the paleo-uplands in the southwest. It reflects a basinward transition from more brackish water conditions inshore to the more marine conditions offshore. The sandstone, by presence of mud-draped cross-beds, also indicates an intermittent type of current-driven depositional event, probably lower tidal to subtidal. Here and elsewhere in the Govan Paleolowland basin, soft-sediment

deformation is suggestive of a meteoric-marine mixing environment (*i.e.*, peripheral slumps associated with distributary mouth bars in the immediate vicinity; Coleman and Pryor, 1982). From similar glauconitic mudstone-sandstone relationships in the Lloydminster core at Imperial Kuroki No. 7-30-34-10(W2), this depositional facies can be extrapolated across the width of the basin (Figure 34).

As shown in the north to south cross-section D-D' (Figure 21), the Lloydminster and Rex in the Govan Paleolowland basin east of the Second Meridian (longitude 102°W) are distinguished by massive sandstone beds. Although none of these beds is cored, inspection of the well cuttings indicated that the members consist of stacked fine-, medium-, and coarse-grained sandstone. The sandstone bodies alternate with sites where mudstone dominates. A similar distribution is indicated in the west to east cross-sections W-W' (Figure 25) along Twp. 33 and X-X' (Figure 26) along Twp. 25. The sandstone bodies are apparently concentrated in depressions over the thalweg of the partially buried Assiniboia Paleovalley, and are similar in fabric to those spread across the Broadview topographic basin. Like the latter, they probably represent low-tide shoal or storm deposits that filled in the lows of the basin. Apparently, this eastern sandstone facies also rims the basin to the north, through the district of Hudson Bay and the approaches to the Molanosa Paleo-upland. Similar stacked sandstone beds, generally upward coarsening and including abundant plant detritus and nodular siderite bodies, also constitute the Rex and the Lloydminster at Choiceland No. 1 Choice DD 13-3-50-18(W2). The absence of glauconite implies a lessening of offshore marine influences and, therefore, depositional conditions on the onshore side of the average strand position.

The overall depositional patterns of the Lloydminster and Rex Members are depicted by dominant facies in Figure 34. In the northwest, across the Meadow Lake Paleolowland and the northern flank of the Unity Paleo-upland, lowstand marine beaches and bars and their accompanying dark grey, glauconitic and pyritic deeper water shale units were deposited early in each transgressive cycle. These sediments were built up into progradational shoals and reefal islands toward the end of each cycle. The sea progressively penetrated the Govan Paleolowland basin and the valley re-entrants of the Kindersley, Swift Current, Moosomin, and Molanosa paleo-uplands. The basin, by virtue of its southward topographic rise, remained shallow and its heights are therefore flanked by tidal and supratidal mudstone with subordinate channel sandstone. Sandy mudstone, which spreads across the area of a nascent Punnichy Arch, is relatively structureless below but grades upward into intensively bioturbated forms, and probably reflects offshore to shoreface settings. Upper shoreface and tidal deposits are marked by cross-beds ranging from herringbone to ripple to wavy forms draped by mudstone, trough-cross-bedded sandstone bars, and tabular-cross-bedded beach sandstone.

All units display signs of emergence, such as weathering horizons, soils and coals, especially on the upper tidal flats and fringing onshore region. Linked submarine-fan sheets and upslope fluvial-channel deposits flank and infill the eastern front of the Moosomin Paleo-upland. Fluvial deposits predominate on the lower and middle slopes and terraces of the Swift Current Paleo-upland and the bordering region of the Kindersley Paleo-upland. Most of the sand sheets of the Govan Paleolowland basin digitate along northwesterly trends after the fashion of strand beaches and bars, and thereby indicate a similar orientation for Lloydminster-Rex shorelines. Linear sandstone bodies with orientations that intercept these shoreline trends reflect short stream and tidal-channel deposits. The geomorphic layout of the Lloydminster-Rex depositional basin in Saskatchewan resembles that of the Yellow Sea embayment between Korea and the northeastern coast of China (Alexander *et al.*, 1991). The Yellow Sea embayment is similar in areal dimensions, but has considerably greater relief in the flanking uplands and larger rivers entering the sea. It is essentially unbarred, and features a comparable distribution of broad (30 km) tidal mudflats fringing the coast and even broader (100 km) basin-axial, subtidal sand sheets. The tendency for sand to concentrate at subtidal levels is apparent even in the macrotidal embayments of the Yellow Sea (*e.g.*, at Inchon) and reflects the increased wave and tidal energy available on the side of the flats exposed to marine fetch.

Upper Cantuar Depositional Pattern

Upper Cantuar isopach gradients are extremely low (Figure 35). Maxima are 53 m in the southern part of the Govan Paleolowland basin and 87 m in the Meadow Lake Paleolowland. The ratio of these maxima is 1:1.6, which is not significantly different from the 1:1.4 of the middle Cantuar. Thus, the Early Cantuar ratio of 1:2.5 represents infill of the Mannville lowland basins after an initial downwarp from the northwest. Subsequent sedimentary influxes apparently kept pace with the net sea-level rise. Relief on the Kindersley Paleo-upland is fairly detailed, ranging from minimal to 55 m, and reflects drape over the Mississippian Madison limestone escarpment. The upper heights of the Swift Current and Moosomin paleo-uplands form large inselbergs that protrude through the upper Mannville blanket, of which the Waseca accounts for less than 40 m. As a result of post-Cantuar, pre-Pense stripping, the upper Cantuar is severely truncated across the 53 000 km² central region of the Govan Paleolowland basin, between the present-day Quill Lakes and Qu'Appelle River and between Saskatoon and the Saskatchewan-Manitoba boundary. The stripped region is the Punnichy Arch, as delineated by the 20 m contour in the north and west and the zero contour in the south and east. Such stripping also applies to the region in east-central Saskatchewan, north of the town of Hudson Bay. Thinning across the Moosomin Paleo-upland in the extreme southeast is a function of both

Mannville onlap and pre-Pense planing. In terms of the depositional setting, southerly attenuation of the Upper Cantuar is gently progressive, as shown by the closed isopach thicknesses: 80 m in the Meadow Lake Paleolowland, 60 m on the Unity Paleo-upland, and 40 m in the southern part of the Govan Paleolowland.

General Petroleums and Sparky Members

Because of their economic importance as petroleum reservoirs, the General Petroleums and Sparky members are individually mapped in the Lloydminster heavy-oil district. Difficulty exists in differentiating them even within reservoir boundaries, because of variable thicknesses and similar lithologies (Haidl, 1980). Wilson (1984, p121) observed that “whilst the Sparky and G. P. are individually quite variable in thickness, their combined thickness is relatively consistent (about 30 m) throughout the Tangleflags area; this suggests that these units would be better combined into one for correlation purposes.” Vigrass (1977, p1,014), in his summation of the General Petroleums and Sparky members of the Lloydminster district, described the former as 9 to 15 m thick, thin grey shale and overlying, sorted, very fine grained quartzose sandstone; and the latter as “one, two, or three submembers composed of grey shale at the base, overlain by sorted, very fine to fine-grained, very glauconitic, quartzose sandstone.” The Sparky section ranges between 9 and 18 m and, where complete, the uppermost sandstone is overlain by marine, fissile grey shale with interlaminated sandstone or siltstone. With respect to regional stratigraphic setting, the General Petroleums and Sparky in this report are correlated with the lower part of the Grand Rapids Formation of east-central Alberta, as depicted in cross-section A-A' (Figure 16). In southwestern Saskatchewan, they are equated with the lower part of the Atlas Member of the Cantuar Formation.

Along the line of cross-section A-A', from Gulf Peter Pond 1-17-88-25(W3) to B.A. Hillsdale Poppleton 12-29-43-25(W3), the combined thickness of the General Petroleums and Sparky members ranges between 27 and 30 m. Farther to the south, regional thinning across the Unity Paleo-upland decreases this to about 15 m at Husky Cactus Lake 13-6-37-27(W3). Maximum values and lithological differentiation are displayed at the Aberfeldy oilfield in Twp. 49, Rge. 26 and 27, W 3rd Mer., where as many as five sandstone beds in the Sparky have been designated (Maccagno and Watson, 1980). Upward-coarsening cycles are characteristic of these units. The lower part of the General Petroleums ranges between 9 and 14 m in thickness and coarsens upward from bioturbated mudstone into interbedded mudstone, siltstone and sandstone that display wavy bedding, wavy ripples, bioturbation, and parallel flat laminated sandstone (Smith, 1984). The upper part consists of bioturbated, carbonaceous silty mudstone, which grades upward into cross-laminated shaly siltstone.

Smith (1984) divided the Sparky at the Aberfeldy oilfield into four parts:

- 1) A bipartite ‘basal Sparky’, 0.8 to 2.5 m thick, comprises a lower unit of silty mudstone laminated with light grey and carbon-rich siltstone, giving the rock a ‘pin-stripe’ appearance, and an upper, bioturbated unit that yields locally to a carbonaceous mudstone capped with thin coal. This basal Sparky, where recognized, is placed at the top of the General Petroleums in this report.
- 2) The ‘lower Sparky’ is in erosional contact with the basal Sparky and ranges in thickness from 8 and 11.5 m. It coarsens upward overall, through three thinner, upward-coarsening sequences (D, C, and B) that comprise interbedded carbonaceous mudstone and flat- and current-laminated siltstone, and fine-grained, better sorted, glauconitic sandstone that forms sheet-like bodies, 3 to 6 m thick.
- 3) An ‘upper Sparky’ is in erosional contact with the lower. This is also upward coarsening, comprising the A/B and A subsequences: the A/B is a highly bioturbated, carbonaceous, poorly sorted, silty mudstone, whereas the A is a flat- and wavy-laminated, bioturbated, moderately to well-sorted, silty to very fine grained, quartzose sandstone.
- 4) The Sparky coal unit comprises three upward-fining beds of carbonaceous mudstone and coal for a maximum thickness of 6 m.

Strata not conforming to the foregoing are considered to be intersecting intra-Sparky channel deposits (Van Hulten and Smith, 1984). Both Sparky and General Petroleums of the Aberfeldy oilfield district are interpreted as shoreface to offshore deposits, in agreement with Putnam (1982a), but laid down under initially restricted marine, probably lagoonal conditions that yielded to shoreface conditions of a wave-dominated delta. Accordingly, channel deposits are components of a distributary system, rather than the purely fluvial system suggested by Putnam (1982b). Robson (1980), in his study of the Dulwich-Silverdale field immediately to the southwest, opted for a tidal-estuary setting for the channel deposits.

The General Petroleum and Sparky members of the Celtic, Westhazel, and Standard Hill oilfields in the northern part of the Lloydminster heavy-oil district are described by Lorscheider (1979, 1980, 1984) and Haidl (1984, 1986). In the central part of the Celtic oilfield (Twp. 51, Rge. 23, W 3rd Mer.), low-angle planar-cross-bedded, rippled and trough-cross-laminated quartzose sandstone, 4 to 7 m thick, typifies upward-coarsening sequences. It is intersected by stacked channel sandstone, up to 18 m thick, as at Mobil Celtic A15-8-52-23(W3). The channel sandstone is very fine to fine grained, well sorted, generally high-angle planar cross-bedded or massive, and at some sites fines upward through shale interbeds. It yields laterally to bioturbated silty shale, with minor interbeds of well-sorted sandstone along the eastern edge of its distribution. In the southeastern part of the Celtic oilfield, the sandstone is thinner (*i.e.*, less than 4 m thick), generally upward coarsening through bioturbated beds into small-scale cross-laminated sandstone, with abundant plant fragments disseminated and draping ripple-laminae, that is carbonate cemented near the top. The general depositional pattern appears to have been one of wave-generated sand bodies in a shoreface environment, which yielded southward to lower energy backshore tidal flats intersected by tidal channels. The western side of the field features a broad channel fill of uncertain origin, but probably estuarine or tidal. An apparent network of such deposits characterizes the Westhazel oilfield to the south of the Celtic, and resembles distributary channels of a wave-dominated delta. At Standard Hill oil field (Twp. 50, Rge. 22, W 3rd Mer.), the General Petroleum comprises thin quartzose sandstone and thick shale and coal, indicative of intertidal and marshy conditions.

Sparky sandstone in the Lloydminster region is more regionally consistent than that of the General Petroleum. Haidl (1986) defined a Lower Sparky, which is primarily shale; a dominant Middle Sparky, consisting of two sandstone units; and an Upper Sparky of shale, silt, and coal. At the Celtic and Westhazel oilfields, the Middle Sparky includes a basal sandy bed (MS1), typically less than 10 m thick, and an overlying thin shale with 'pin stripe lamination', topped by thin cemented sandstone (MS2). Unit MS1 is typically bioturbated, locally contorted, variably sorted, and gradational from silty to fine grained. It is capped by a 2 to 6 m thick, low-angle, tabular-cross-laminated argillaceous sandstone, with interbeds of bioturbated and horizontally laminated siltstone containing comminuted plant fragments. Unit MS2 consists of interbedded bioturbated sandstone and shale featuring ripple laminae, flasers, and lenticles, and irregular concentrations of plant fragments. Cementation and root traces are widespread toward the top of the unit. At Standard Hill, the Middle Sparky consists of three sandstone beds, each less than 3 m in thickness, separated by bioturbated shale. The Upper Sparky coal beds range widely in thickness, from less than 1 m to 3.5 m, and are sub-bituminous and huminite rich. Shale beds in the Sparky also vary in thickness and, at localities such as A16-14-51-23(W3), thicken the Sparky at the expense of the General Petroleum (Haidl, 1986).

Depositional conditions in the Sparky were similar to those in the General Petroleum, although the reduced thickness of the sandstone and the more widespread distribution of paleosols and coal indicate somewhat shallower marine transgressions. At some localities, finely laminated sandstone and shale of the Lower Sparky, featuring small-scale oscillation and truncated ripples, indicate high intertidal or supratidal flats, and intense bioturbation reflects subtidal conditions at others (*e.g.*, the Celtic oilfield). A complex of longshore bars, tidal flats, and lagoonal deposits appears to be the genetic framework of the lower part of the Middle Sparky. The general transition from sand to shaly to coaly deposits reflects regressive conditions ranging from low intertidal to supratidal and swamp. Haidl (1986) also observed that Lower Sparky supratidal deposits overlie paleosols in the uppermost General Petroleum and underlie Sparky coals. Similarly, Lower Sparky subtidal deposits are superjacent to longshore bars of the General Petroleum, and subjacent to wave-generated basal Middle Sparky sandstone. Finally, the widespread distribution of the Sparky coal, which serves as a correlation horizon in the Lloydminster region, signifies a regional sedimentation break, terminating the informal 'Middle Mannville' of some authors.

At the reference Husky Shell Paradise Hill A13-19-52-23(W3) (Figure 13) well section, the General Petroleum (at 538.50 to 517.75 m) displays four bedding cycles:

Cycle 1 (10.76 m) grades upward from: 1) grey shale; through 2) bioturbated shale and quartzose siltstone, and lenticular current- and thin trough cross-bedded, fine-grained quartzose sandstone and dark grey silty mudstone; to 3) fine-grained quartzose sandstone, bimodal with silt, that includes accessory black chert, plagioclase, kaolinite, and jasperoid quartz, plus vertical carbonaceous stringers over the basal 2 m and low-angle tabular cross-bedding at the top. The overall poor sorting of the sandstone and presence of the accessory minerals indicate a lack of winnowing, particularly by wave action, until near the end of the depositional episode. The cycle indicates a change from a lower shoreface to a prograding channel bar in an upper shoreface or beach setting.

Cycle 2 (2.24 m) is grey-black shale that is coarsely laminated with very fine grained quartzose sandstone, in the form of starved ripples, crenulated lenticles, and dewatered compactional forms. It is apparently a truncated, upward-coarsening bed under an erosional contact laid down in an estuary or interdistributary bay.

Cycle 3 (3.23 m) is a quartzose sandstone, kaolinite indurated, bimodal, medium grained with subordinate fine and very fine, low-angle cross-bedding, current bedding with tangential sets, and about 15% kaolinite pseudomorphic after feldspar, black chert, brown sphaerosiderite, and muscovite. It fines upward into bioturbated sandstone that grades into shale.

Cycle 4 (4.5 m) is coal-capped, rootlet-casted argillaceous sandstone with truncational sets of tangential cross-beds, and rests on a sharp contact.

On the basis of their fabric and texture, cycles 3 and 4 appear to be onshore deposits: the former a thin, fluvial channel fill and the latter an alluvium and marshy soil. The compactional phenomena in cycle 2 are most likely related to groundwater drawdown implied by the change of environment in cycle 4.

Likewise, the Sparky is progradational, across its three upward-fining cycles, from lower and upper shoreface to interdistributary channel bar. Bedding cycle 1 (1.75 m) is a very fine grained, bioturbated quartzose sandstone that is transitional to a grey, waxy shale. Likewise, cycle 2 (3.32 m), a faintly bedded, bimodal, very fine grained quartzose sandstone with subordinate siltstone and laminae of carbonized plant detritus, grades into a dark grey shale with scattered laminae of current-bedded quartzose sandstone. Cycle 3 (7.18 m) features a basal, medium- to fine-grained, bimodal quartzose sandstone, with subordinate black chert, carbonaceous particles, brown siderite, kaolinite after feldspar, and a white kaolinite matrix, and an overlying, low-angle ripple- and current-bedded, very fine grained quartzose sandstone with black shale drapes and plant detritus, which grades upward through a bioturbated zone into dark grey shale.

To the southeast, at Shell Meota C13-17-46-17(W3) (Figure 14), the General Petroleum cycle 1 (3.25 m) is primarily flat-bedded, very fine and fine-grained quartzose sandstone, laminated with subordinate black carbonaceous siltstone and dark grey shale. It displays bioturbation in the upper 40 cm and an oxidized surficial zone. Cycle 2 (12.15 m) is predominantly light grey, well-sorted, fine-grained quartzose sandstone with low-angle cross-beds. It is capped with 80 cm thick, dark grey shale with bedding-aligned worm trails. Cycle 3 (3.0 m) comprises a basal, medium grey claystone with scattered coaly pods under a microfaulted and brecciated, argillaceous, very fine grained quartzose sandstone, thinly interbedded with dark grey mudstone. The well-sorted sandstone of cycle 2 probably represents either a late-generation beach sand that infilled a channel or a lower-estuary reworked channel deposit. Cycles 1 and 2 are interpreted as brackish-water bay deposits. A single cycle (10.3 m thick) represents the Sparky. It is predominantly dark grey shale (9.1 m thick) beneath a thin, bioturbated, shale-draped, small-scale tangentially cross-bedded, very fine grained quartzose sandstone. Its depositional environment appears to be a repeat of the General Petroleum cycle 2 (*i.e.*, an estuarine interdistributary bay without the sand infill).

Both upward-fining and upward-coarsening facies of the General Petroleum and Sparky correspond in overall depositional style (*i.e.*, both types are episodically progradational in a transgressive setting). The differences are: 1) the presence of a drowned point source nearby, in the upward-fining situation, that initially provided entry for sediments from outside of the district, versus local line sources of reworked sediments in the case of the cycle coarsening upward into shore and offshore sands; and 2) the timing of sand deposition. Regression and subaerial exposure made possible the entry of fluvial channel deposits in the case of (1), and terminal weathering horizons, pavements, and coal deposits in both (1) and (2). Withdrawal of the strand across broad shelving surfaces extended stream courses through soft sediments, with a consequent choking of channels by oversupply of sediment and reduction of gradients. Deposition of bimodal sandstone followed in re-entrants of the former strands shoreward of lowstand active-shoreline sandstone and mudstone.

Where sandstone is well sorted, it is likely compounded from shoreline and channel sources. Specifically, sand in longshore transport by littoral currents and/or under tidal influences, where intercepted by the hydraulic barrier created by channel flow, is combined with the channel load and reworked into flanking beaches and offshore bars that encroach upon subaqueous fans. All channel deposits are susceptible to buildup, and are spread into offshore sand sheets by the action of storm-generated littoral currents, as well as to landward accretion by the longer-term oscillatory advance of the strand. Well-sorted channel sandstone may also be a derivative of higher stage shoreline deposits that were remobilized by headward advance and meander sweep of short streams and tidal channels responding to a fall in sea level. Bioturbated facies are associated with both types of deposits and, in a succeeding transgression and by tidal pulsations, would have overlapped the well-sorted sandstone farther in the re-entrants. The low gradients would have facilitated tidal- and stream-channel avulsion and diversion to other localities. At some point, all channel deposits terminate headward under erosional overlap by the succeeding cycle.

General Petroleum and Sparky lithological distributions in the Lloydminster heavy-oil district are not unlike those of the Holocene deposits mapped along the coast of Lake Erie between Fairport and Cleveland, Ohio (Hartley,

1960) and depicted in [Figure 36](#) of this report. The Lake Erie offshore sand bodies are irregular, macrolenticular, variable in facies and thickness, and being encroached upon by deeper water mud deposits. The Grand, Chagrin, and Cuyahoga rivers, which are separated by 16 and 32 km, respectively, exercise hydraulic control on the littoral drift, both by interception of sediment transport after the fashion of jetties and by lakeward deflection and transport to offshore sites. As a result, large sandy lacustrine fans, extending 8 to 12 km offshore into water depths exceeding 15 m, front their mouths. The fans are lakeward of, and linked by, low-stage linear beaches and longshore bars, and are themselves modified by wave action and littoral drift, which have sculptured on them ridged bars extending outward like pseudopods to the northeast and southwest, parallel to the shore. In detail ([Figure 36b](#)), the Fairport subaqueous fan is more than 14 m thick, and its morphology has been modified so that the body is not only terraced shoreward, but forms a large bar elongated away from, and to the west-northwest of, the mouth of the Grand River. The present-day beach at lake-level datum also lies to the west of the Grand River. The linear buildouts are counter to the predominant littoral drift, and caused by deceleration of the shore-sourced littoral drift at the hydraulic barrier created by the stream outflow.

Other observations worth noting include the following:

- 1) Although the Chagrin River is aligned perpendicular to the shore, the other two streams follow more meandering and temporary courses. Thus, the Grand River, which currently enters the lake at Fairport, is related to a marsh-filled abandoned channel that lies parallel to and south of the shore, and reaches the lake at a point 8 km to the southwest.
- 2) Along the present shoreline, smaller streams, no more than a few kilometres long and irregular in orientation, and which entered the lake at its earlier, lower stages, have channels that are clogged at the present shore with beach sand and marshy material. Drainage to the lake is generally by seepage through river-mouth bars, though these may be breached during the rainy season.
- 3) As the shoreline retreats by erosion (*i.e.*, the lake transgresses), the marshes are destroyed by shoreline processes and the surviving deposits are severely compressed by the weight of the shore sands that bury them.
- 4) Because of inadequate sand supply, present-day beaches are nourished by line sources; these are the exposed bluffs of the present shoreline, complemented by the small stream influxes derived from upper-stage shore deposits.
- 5) A substantial portion of the sediments contributed to the beaches is lost to offshore deposits by storm waves and currents associated with augmented littoral drift.

South of the Lloydminster heavy-oil district, the General Petroleum and Sparky retain their rhythmic depositional format well into the front of the Kindersley Paleo-upland. At Shell Zaller Lake 10-7-39-25(W3) ([Figure 13](#)), upward-coarsening cycles through bioturbated sandstone and shale remain characteristic, particularly of the Sparky. However, fluvialite, feldspathic quartzose sandstone is conspicuous, not only in the basal portion of upward-fining cycles, but also at the top of upward-coarsening cycles. The lower cycle of the General Petroleum ends in a bioturbated shaly sandstone that is capped by carbonaceous seat earth, but the upper cycle is terminated by calcite-cemented, poorly sorted, medium- to fine-grained quartzose sandstone with abundant coarse-grained brown sphaerosiderite, black chert, white feldspar, and rare biotite. This facies is similar to the first cycle of the Sparky. The second Sparky cycle is strongly bioturbated, but the third is a 4.53 m thick, rootlet-penetrated, homogenized, very fine grained quartzose sandstone with an argillaceous matrix, and is probably a backshore deposit. The fourth cycle is a coal-capped fluvialite sandstone with mineralogy of a volcanic provenance (*i.e.*, kaolinitized feldspar, black chert, brown siderite, and chloritic green amphibole). Thus the overall depositional facies of both members is progradational, probably deltaic interdistributary bay to fluvialite channel and marsh.

At Shell Cactus Lake 2-16-36-28(W3) ([Figure 13](#)), some 60 km to the southwest and well into the partially buried Kindersley Paleo-upland, the proportion of volcanic-provenance indicators increases, but the depositional environment remains predominantly estuarine. Bedding cycles 1 (3.03 m), 2 (2.42 m), and 4 (1.23 m) of the General Petroleum feature vertical and oblique burrows and glauconitic nodules and burrow fills. Cycle 1 also includes starved ripple beds, graded bedding with dark grey shale, and siltstone-infilled syneresis cracks. Cycle 2 is dominated by a kaolinite-indurated, plant-detritus-laminated, ripple-drift- and flat-bedded, very fine grained quartzose sandstone, and cycle 4 sandstone is low-angle cross-bedded and laminated with green chloritic shale. As at Zaller Lake, cycle 3 (2.45 m) is upward fining and includes a volcanic suite; however, it is current laminated with carbonized plant detritus, convoluted, and rests on a sharp, irregular contact. A channel deposit is indicated, but one more likely to have been tidal or in a lower estuary. Cycle 3 of the Sparky (4.41 m) displays fluvialite, fine-grained quartzose sandstone cemented with silica and kaolinite, and a subordinate suite of angular black chert, dark grey

chert, carbonaceous grains, white feldspar, pyrite, and green chlorite. It grades upward through weakly bioturbated, glauconitic quartzose sandstone, interbedded with dark grey, silty mudstone with abundant plant fragments, into a thin, medium grey shale. A coal, almost 2 m thick, caps the sequence on an erosional contact.

The spatial distribution of the Sparky terminal coal provides a clue to the orientation of the general shoreline. As mapped by Smith *et al.* (1984) for the transboundary Lloydminster heavy-oil district, the coal bed is by far the most widespread of the Mannville coal units in western Saskatchewan. As shown in this report (Figure 50), it extends from Alberta to longitude 108°30'W in western Saskatchewan, and lies between latitudes 51° and 55°N. If the coal beds are interpreted as shore-fringing marshes, as reconstructed by Groeneveld and Stasiuk (1984) for those of the Lloydminster Member, then the general orientation of the shore was likewise north-south but facing east toward the sea. The north-facing scarp of the Swift Current Paleo-upland, south of latitude 51°N, would have formed an east-west headland to the embayment that was breached in the west at the pre-Cantuar Eastend Paleovalley re-entrant near the Saskatchewan-Alberta boundary, and open in the east to the Govan Paleolowland basin. At latitude 53°N, the northern front of the coal beds is aligned northwesterly, coincident with the course of the present-day North Saskatchewan River. Presumably, the Middle Cantuar shoreline had a similar orientation. The channels, sourced from the southwest or south, traversed the broad strand flats on courses toward the east, northeast, and north. The coal beds also imply a widespread prolonged quasi-stability and flatness of the nearly infilled Unity and Kindersley paleo-uplands with respect to sea level, during which small increments of base-level rise permitted the accumulation of peat.

In the Swift Current Paleo-upland, the General Petroleum and Sparky beds are not readily distinguishable from each other, and are therefore combined as the 'Early Sandstone' of the Atlas Member. These, the most unequivocal of the regional fluvial facies in the Cantuar Formation, formed an anastomosing network of fluvial sandstone deposits in the thalwegs of the subdued topography. They grade laterally into flanking mudstone units that encroach upon the upper reaches of the pre-Cantuar interfluves (Christopher, 1974).

At Williamson W. Cantuar 10-7-16-17(W3) (Figure 37), the Atlas Early Sandstone comprises (oldest to youngest):

- 1) Gritstone: 2.7 m thick; dominated by rounded, green, chloritic mudstone fragments and about 15% coarse-grained quartzose sand with subordinate feldspar, black chert, and biotite; well indurated in olive green chloritic mud and white sandy kaolinite; tabular cross-bedded with dips of 25° in truncation sets 0.10 m thick, and interbedded with thin black shale bounded by sharp contacts.
- 2) Sandstone: 5.2 m thick; quartzose, medium grained, with overgrowths on subangular and subrounded grains, and subordinate black chert, pyroxene, biotite, chlorite, and white and pink feldspar; trough cross-beds dipping up to 15° and scattered black shale laminae; grades downward into dark grey-green chloritic mudstone with a sharp contact on an underlying 1 m thick grey-black shale.
- 3) Sandstone: 9.8 m thick; quartzose, fine grained, subordinate chlorite, biotite, muscovite, coarse carbonized plant flakes, and aggregated carbonaceous matter; laminated and cross-laminated; well indurated in dark grey-green chloritic mudstone, and interbedded with sandstone laminated with black shale.

Although texture fines upward through the section, the depositional sequence incorporates separate events, of which only five remain recorded at this site. The gritstone bed not only postdates the subjacent dark grey shale, but is itself partially constituted of pre-lithified olive-green Cantuar mudstone. The contacts with the bounding and included carbonaceous shale are sharp, and therefore indicate abrupt changes in the sedimentary regime, in spite of the apparent interdigital relation between sandstone and shale. For its part, the uppermost bed also reveals a dual sedimentation framework, marked by alternation of green chloritic mudstone and laminated black shale and sandstone. Along the western flank of the Cantuar oilfield, the black shale represents the background autochthonous sediments, whereas the green mudstone and sandstone represent the channel-controlled allochthonous influxes.

The Lower Atlas sandstone mapped in the Swift Current Paleo-upland (Christopher, 1974, Figure 39) represents an easterly to northeasterly trending fluvial network dominated by anastomosing, ephemeral, upper flow regime streams in valleys choked by overbank mudstone and lacustrine to estuarine, laminated, and current-bedded deposits fronting a marine wedge. The marine tongue penetrates the fluvial facies on the eastern flank of the Swift Current Paleo-upland (Figure 38). At the type Tidewater Atlas 8-20-18-14(W3) (Figure 37) section, the 'Early Atlas sandstone' consists of two bedding cycles, each of which fines upward in grain size and texture, and includes abundant carbonized plant fragments, but is calcite cemented, especially in the high-angle cross-bedded layers.

Some 46 km to the east, at Tidewater Leinan Crown No. 2 (2-29-18-13W3) the 'Lower Sandstone' of the Early Atlas sandstone displays three bedding cycles:

- 1) 1033.9 to 1032.4 m: quartzose, fine-grained, glauconitic and chloritic, calcite- and concretionary-siderite-cemented sandstone; thin conglomeratic layers at top and bottom.
- 2) 1032.4 to 1025.7 m: conglomerate (3.1 m thick), composed of cream-coloured calcilutite (from the Lower Member of the Shaunavon Formation), medium green-grey sandy mudstone and grey-brown sideritic ironstone in a matrix of dark brown ferroan sparry calcite, containing kaolinite grains and calcite-spar-infilled pelecypod molds; grades upward through quartzose, calcite-veined and calcite-cemented, bimodally coarse- and fine-grained sandstone (1.2 m thick), with about 10% kaolinite grains and coarse-grained carbonized plant fragments; into quartzose, medium-grained, well-sorted, friable, and calcareous sandstone (2.4 m thick).
- 3) 1025.7 to 1024.7 m: dark grey, silty to sandy mudstone ('Medial shale'), with scattered ironstone nodules, underlies the 'Upper sandstone' (at 1024.7 to 1019.1 m), which is well sorted, flat bedded, weakly cemented, medium grained, and quartzose; reminiscent of a beach deposit.

The sandstone units, as at Shell Tidewater Beaver Flat 2-16-19-12(W3) (Figure 37), 10 km to the northeast, are apparently offshore shoal sand separated by 12 m thick shale. There, the cored 'Lower sandstone' (976.6 to 968.0 m) displays a basal bed (5.9 m thick) of pyrite-speckled, very fine grained to silty, mudstone-indurated, light blue-grey, cross-laminated and laminated, quartzose sandstone on a sharp basal contact, and an upper bed (2.7 m thick) of fine-grained, well-sorted, weakly indurated, very permeable quartzose sandstone. Likewise, at CDR North Aquadell 13-12-20-6(W3), about 64 km to the east (Christopher, 1974, p95), the Lower sandstone (963.1 to 958.9 m) fines upward from medium-grained, subrounded, well-sorted, thinly trough-cross-bedded (dips up to 15°) quartzose sandstone, with minor kaolinite grains and abundant kaolinitic mudstone and sandstone boulders typical of the Success Formation, into medium grey, very fine grained quartzose sandstone, moderately indurated in silty mudstone. The Medial shale (958.9 to 954.6 m) comprises 1 to 2 m thick, interbedded quartzose sandstone and claystone, argillaceous siltstone, and mudstone transitional beds separated by erosional contacts, and displays rootlet zones, coaly lenses, and fragments along with pyrite- and marcasite-encrusted plant fragments. The Upper sandstone (954.6 to 948.5 m) is upward coarsening and essentially well sorted, fine grained, calcite cemented and quartzose, with abundant coalified plant fragments throughout; in the lower half, it is thinly trough-cross-bedded and interbedded with laminated sandstone and pyritic, burrowed black shale.

The widespread autochthonous pebbles and boulders of the General Petroleums–Sparky (Early Atlas sandstone) are traceable to their source beds on the Swift Current Paleo-upland. The boulders from the Success Formation at CDR North Aquadell 13-12-20-6(W3) were probably derived from outcrops of that formation immediately to the southwest, and the Shaunavon boulders at Tidewater Leinan Crown No. 2 (2-29-18-13W3; Figure 37) were probably derived from outcrops to the northwest in the area of the Batrum oilfield. The conglomerate beds represent flood deposits and/or increased stream gradients following mild uplifts of the Swift Current region. The Leinan conglomeratic bed is entrenched in well-sorted glauconitic sandstone suggestive of marine lower-shoreface deposits (McCubbin, 1983). This sandstone appears without the conglomeratic beds in the section at Shell Tidewater Beaver Flat 2-16-19-12W3, where it is well sorted and flat bedded above pyrite-speckled, finely cross-laminated and laminated sandstone and shale, and at CDR North Aquadell where it is thinly cross-bedded. The three sections apparently sample a relatively narrow coastal environment that, on the shore side, impinges the low-lying hills and their re-entrants and, on the shoreface, yields to shelving offshore.

Southward, and east of the Third Meridian (longitude 106°W), the sandstone units that are equivalent to the General Petroleums–Sparky, though thin and argillaceous overall, abruptly thicken at certain localities by stacking of sandstone bodies similar to that described for the Lloydminster and Rex members. A 30 m thick body at Shell Old Wives A16-11-14-30(W2) (cross-section Y-Y', Figure 23), features 15.5 m of flat-bedded, well-sorted, fine-grained, subrounded, poorly bonded quartzose sandstone, with accessory rose quartz and carbonaceous specks, overlain by 14 m of thinly interbedded, dark grey silty mudstone and light grey, very fine grained, well-sorted, flasered, truncationally cross-bedded, bioturbated quartzose sandstone. The combined beds apparently represent a transgressive facies ranging from onshore beach for the lower bed to subtidal for the upper.

Poor core control and loss of section by pre-Pense erosion of Cantuar strata across the Punnichy Arch make reconstruction of the General Petroleums–Sparky depositional basin in the east-central part of the Govan Paleolowland dependent on a reduced number of data points. The General Petroleums–Sparky strata retain their marine aspects at C.M.&S. Vanscoy 11-16-35-8(W3) (Figure 14) and Duval Saskatoon 6-18-36-6(W3) (Figure 15) (cross-section A2-A2', Figure 14), as indicated by glauconite at the former and bioturbated facies at the latter. The facies appear to be more continental at SWP Boulder Lake DD 1C 16-18-30-23(W2), where General Petroleums sandstone is argillaceous and sphaerosideritic, and includes subordinate mudstone with coalified tree fragments, and the Sparky is dominated by lavender grey, sphaerosideritic, partially oxidized, microfaulted, slickensided mudstone. This alluvial mudstone is an apparent correlative of the terminal coal beds in the west, and is indicative of widespread emergent conditions at the end of Sparky time.

At Transgas Prud Homme 11-12-38-28(W2) (Figure 15), most of the facies coarsen upward through basal or medial bioturbated and flasered sandstone and shale into very fine grained sandstone, and are apparently marine. Only the upward-fining third cycle of the General Petroleum indicates onshore conditions, in that the 4.2 m thick, fine-grained quartzose sandstone is argillaceous and blocky to massive, and contains coalified plant remains. A correlative upward-fining unit is present at Grey Owl Syndicate No. 1 (16-10-44-27W2) (Figure 15), but the basal sandstone there is well sorted and the shale is bioturbated. All four cycles of the Sparky are classical upward-coarsening marine types. At the Choiceland No. 1 Choice DD 13-3-50-18(W2) (Figure 15) site, marine indicators diminish, although the upward-coarsening cycle retains its dominance of the cyclic format.

Thus, in the basin overall, the progradational expansion of the volcanic-sourced, fluvial-deltaic, biotite- and chlorite-rich feldspathic sandstone eastward and northeastward, across the Swift Current and Kindersley paleo-uplands, reached a climax during General Petroleum time (Figure 38). This facies is transitional eastward to a mudstone-dominated region, some 150 km wide, in the southern Govan Paleolowland basin that apparently served as a low-gradient interdistributary bay, prograded from time to time with deltaic fan deposits and traversed during low seastands by alluvial channels from the south. Deeper parts of the bay, such as the depressions associated with the buried Assiniboia Paleovalley system, formed tongues of the sea in which upward-coarsening facies expanded. Likewise, in the east, similar embayments extended southward from Yorkton to Moosomin and from the Quill Lakes region to Indian Head, in the troughs between the Wynyard Dome and the Moosomin Paleo-upland on the one hand and the submerged Watrous and Wynyard domes of the Punnichy Arch on the other.

North of latitude 52°N, the seaway widened to include the entire width of the Cantuar basin. Typically, most of the marine sequences indicate upward shoaling and emergence of the depositional bottom, in keeping with the oscillatory character of the Mannville depositional format. Although these are thinner than the cycles of the earlier members, they are best developed in the northwestern part of the Meadow Lake Paleolowland basin. From the core at the Shell Frenchman Butte A7-3-54-25(W3) well (Appendix A), loss of basin accommodation is indicated by the two ~6 m thick bedding cycles of the General Petroleum Member. The first coarsens upward from dark grey shale through bioturbated mudstone and sandstone into very fine and fine-grained, current- and cross-bedded quartzose sandstone. The second grades upward from very fine grained, bioturbated, cross-bedded argillaceous sandstone into flat-laminated and swaley cross-bedded, fine-grained quartzose sandstone, with centimetre-thick truncating cross-sets. In the Sparky Member, bedding cycle 1 is 4.4 m thick and bipartite, in that the lower half is a black shale with subordinate layers of ripple beds, graded beds and trough cut-and-fill quartzose sandstone, and the upper half is the speckled black chert and white-kaolinite-rich, fine-grained quartzose sandstone. The 5.95 m thick sandstone of the second bedding cycle is quartzose, fine grained, massive, weakly indurated, conglomeratic at the base, and siderite cemented at the top. It is interpreted to be an estuarine-channel deposit common to the Sparky Member in the Lloydminster heavy oilfield district. The Sparky is terminated by a regional coal, here less than 0.4 m thick, in a 3.4 m thick, upward-coarsening third cycle that includes shale and very fine grained quartzose sandstone.

Channel deposits form a subordinate but important facies component, especially on the mixed flats of the Unity Upland and the Meadow Lake Basin, and are generally attributed to tidal and estuarine depositional control. The waning sedimentary influx ended with widespread emergence and the spread of marshes on flats of the Unity and Kindersley paleo-uplands and the northwestern lowland basin, as indicated by the surviving coal beds (Figure 38).

Waseca Member

At the reference Shell Husky Paradise Hill A13-19-52-23(W3) (Figure 13) section, seven bedding cycles make up the Waseca and all of them, except for the first and seventh, coarsen upward. Cycle 1 (2.0 m) is a kaolinite-indurated, white speckled with black and brown, tabular-cross-bedded, medium-grained quartzose sandstone with subordinate black chert, carbonaceous grains, green chlorite, and brown sphaerosiderite. It grades near the top into fine-grained quartzose sandstone with minor, dark grey, shaly lenticles and a capping, yellow-brown, cemented mudstone. The facies is interpreted as fluvial and is typical of its type in the western Mannville region of Saskatchewan. It has been traced to Shell Dee Valley A11-18-48-21(W3) (Figure 13), Shell Meota C13-17-46-17(W3) (Figure 14), Shell Zaller Lake 10-7-39-25(W3) (Figure 13), and Choiceland No. 1 Choice DD 13-3-50-18(W2) (Figure 15), but is absent at Shell Manito 6-7-43-24(W3) (Figure 13). Bedding cycles 2 to 5 feature - and ripple-bedded sandstone, black-shale-draped sandstone lenticles, bioturbation, and foraminiferal shale, and are thus taken to be marine with tidal overprint. Cycle 6 is a transgressive, pyritic black shale overlain by a well-sorted, fine-grained quartzose sandstone, which grades into coal and a thin, capping, light green, waxy shale. Cycle 7 incorporates green-grey, argillaceous quartzose siltstone with subordinate graded laminae of fine-grained quartzose sandstone. Thus, the Waseca depositional setting at Paradise Hill appears to have been shoreface, in which progradation ensued episodically. Following the regression indicated by cycle 1, the first progradation, as indicated by the 12.6 m thickness of cycle 2, was apparently the strongest. The progradational episodes ended with the coal-forming marshes of cycle 6, and with what appears to be a thin, avulsed channel deposit in cycle 7.

The Waseca section at Shell Meota C13-17-46-17W3, which does not differ significantly in lithology from that at Shell Paradise Hill, is as follows:

Bedding Cycle 1 (3.6 m) is similar in thickness to its Paradise Hill correlative and in erosional contact with the Sparky. It is a quartzose, very fine grained, bipartite sandstone. The upper third includes a grey-white kaolinitic matrix speckled with black chert, white kaolinite grains, brown sphaerosiderite, and pale green chlorite. The lower two-thirds are calcite cemented at the top, fine bedded with low-angle tangential cross-sets, and feature crenulated argillaceous partings, oblique fractures, and downward-converging, calcite-cemented, vertical to oblique veins that end in a 0.10 m oxidized basal zone.

Bedding Cycle 2 (3.6 m) is a quartzose, very fine grained, bioturbated sandstone, with pods and rolls of dark mudstone and sandstone and a sharp basal contact. Subordinate laminae of wavy, dark grey-black silty shale are present medially and at the top, where the shale is podded, crenulated, and wrapped around sandstone pillows and balls. Thin, medium grey shale (0.1 m) and capping coal (0.25 m) terminate the cycle. Bedding cycle 2 at both sites coarsens upward through bioturbated beds. The compensatory thickness (12.16 m at Paradise Hill, 3.6 m at Meota) probably reflects corresponding subsidence of the local depositional floor and sediment supply, rather than the amount of regional sea-level rise. Cycle 2 is the only one at the Meota site that is bioturbated and therefore on the open shoreface.

Bedding Cycle 3 (5.5 m) is a medium grey claystone, overlying 0.8 m of black coaly shale on a thin (0.5 m), basal, very fine grained quartzose sandstone.

Bedding cycles 4 (4.3 m), **5** (3.7 m), and **6** (2 m) are upward-coarsening transitions from a medium grey siliceous shale and claystone, through laminated beds, into well-sorted, weakly cemented, fine-grained quartzose sandstone with abundant kaolinitic grains.

Bedding Cycle 7 (10.8 m) is a silty, medium grey, massive mudstone with abundant brown, iron-stained clayey concretions and scattered carbonized reedy fragments; it has a sharp basal contact and an upper erosional contact with the Pense Formation. This mudstone may either be indicative of a channel fill like that depicted by cycle 7 (3.17 m) at Paradise Hill, or be infill of a penecontemporaneously subsiding depression.

The Waseca, in the literature of the Lloydminster heavy-oil district, is described as consisting of two facies types: “a regional and an areally restricted channel facies” (Van Hulten, 1984). The regional beds are relatively widespread units, correlated on the basis of markers that more or less conform to the sequences of the Shell Paradise Hill A13-19-52-23(W3) (Figure 13) section of this report. His regional Waseca comprises a “basal unit (15 to 20 m) thick, of interbedded siltstone and shale, overlain by two thin (3 to 6 m) correlatable sands which are separated by a thin (1 m) shale” (Van Hulten, 1984, p445). This shale grades into a coal in some areas. An ironstone marker bed forms the top of the upper thin shale unit. The two sand beds are informally named the ‘Upper and Lower Waseca.’ Thus, Van Hulten’s Basal unit corresponds to bedding cycles 1 to 5 of the Shell Paradise Hill section, and his ‘Lower Waseca’ and ‘Upper Waseca’ to bedding cycles 6 and 7, respectively. This unbalanced subdivision of the Waseca is probably attributable to the emphasis given to the heavy-oil reservoir properties of the ‘Lower Waseca’. It also reflects the general practice, in the Lloydminster heavy-oil district, of not correlating individual units beyond the immediate requirement of mapping in a given field.

For the Waseca in the Celtic field (Twp. 51 and 52, Rge. 23, W 3rd Mer.), Lorsong (1979, 1980) emphasized the lithological and areal definition of sandstone bodies with respect to sedimentary fabric as seen in core. He described the depositional fabric of the Waseca as consisting of seven lithofacies, each designated by the first letter of the word describing its type: L, low-angle cross-laminated sand; T, trough cross-laminated sand; M, massive sand; B, bioturbated sand and shale; S1, massive shale; S2, laminated shale; and C, coal. Most sand bodies thicker than 1 m extend throughout the area, although many are internally heterogeneous. More than half of all sand lithofacies units change facies or pinch out in less than 370 m. Facies L is the most consistently uniform and generally the thickest, and M tends to be thin and discontinuous. On the basis of these sandstone types and their intervening B facies, he divided the Waseca into Units W1 to W6, of which Units W1, W3, W4, and W6 consist of laterally extensive sand bodies dominated by facies L. By the presence of these low-angle, flat-laminated sandstone units, the deduction was made that the regional Waseca in the Celtic field was laid down in a wave-dominated marine shorefront environment. These strand deposits are present at Tangleflags and Westhazel oilfields but, according to MacEachern (1986), diminish southward through the Pikes Peak field with an increase in prominence of bioturbated mudstone and thin, lenticular, wave-rippled sandstone, more typical of a mixed, estuarine, backshore region (*i.e.*, inner coastal plain with abundant tidal channels). The strand, in keeping with those of the Sparky and General Petroleums of the northern part of the Lloydminster heavy-oil district, trended northeasterly (Haidl, 1986).

Waseca channel facies are akin to the section at Shell Meota C13-17-46-17(W3) (Figure 14), which includes relatively thick clay-mudstone units classified as 'anomalous' and coeval with thick sandstone elsewhere in the channel environment. The precise relationship of channel sequences to the regional facies of the Waseca and other members of the Mannville Formation is topical to most papers on the Mannville, and the interpretations concerning their origin, morphology, and spatial dimensions vary widely. These include deep fluvialite-valley cut-and-fill (Vigrass, 1977), vertical accretionary fluvialite-valley fill (Putnam, 1980, 1982b), lateral accretionary estuarine-valley fill (Van Hulten, 1984), and vertical accretionary estuarine-channel fill (MacEachern, 1986). The most celebrated of the Waseca channel deposits is that named after the Pikes Peak oilfield, sitting astride the four corners of Twp. 49 and 50, Rge. 23 and 24, W 3rd Mer., a description of which is summarized below from Van Hulten (1984), MacEachern (1986), and Haidl (1986).

The Pikes Peak channel facies is recognized as an anomalously thick, laterally shale flanked, northerly trending curvilinear sand body, 0.8 to 2.7 km wide, that extends more than 60 km from south of Twp. 48 to beyond Twp. 52 along Rge. 24 and 22, W 3rd Mer. At the Pikes Peak oilfield, it ranges in thickness from 22.5 to 36.8 m. Overall, the basal sandstone fines upward and is up to 32.4 m thick, massive, medium to fine grained and quartzose, with scattered pebble- to cobble-sized mudstone clasts, woody plant fragments, pyritic and sideritic nodules, and traces of laminae and cross-beds toward the top. It grades into bioturbated, mixed sandstone and interbedded sandstone-shale beds featuring wavy, lenticular, and pin-striped bedding, and then into a capping shale. South of Pikes Peak, at Golden Lake Birling A2-5-48-22(W3), the section consists of 34 m of well-sorted, upward-fining quartzose sandstone, with prominent, high-angle, planar cross-beds and, at the top, very thin ripple forms with clay drapes under a 1.5 m thick capping unit of mixed sandstone and shale. At Lashburn B13-6-49-23(W3), there is a stack of two massive sandstone units, each fining upward into wavy, lenticular, pin-striped, bedded and bioturbated, laminated sandstone and shale.

Thus, the depositional setting of the Pikes Peak channel is interpreted as estuarine tidal. Van Hulten (1984) emphasized an incised channel, wherein the sandstone was built up in a laterally accreting system as point bars, and the flanking mudstone as deposits in the abandoned thalweg of a migrating system. MacEachern's (1986) reconstruction called for a shallow channel cut, followed by an up-channel, accretionary, estuarine to fluvialite phase and a down-channel, dominantly transgressive depositional system accreting vertically with a minimum of incision. In this context, the channel deposits are coeval with the regional facies, which are also products of vertical accretion in a transgressive setting. The channel has not been traced south of the northern limits of Twp. 47 nor any great distance northward into Twp. 53. Thus, the length of the channel deposit is equivalent to the width of the traversed supratidal and tidal shelf (*i.e.*, 60 to 80 km). To the northeast lay subtidal depths and, to the south, an onshore region erosionally overlapped by the succeeding transgressive regional Waseca.

Bioturbated facies, indicative of lower shoreface deposition, persists southward and is a component of the 10 upward-coarsening cycles of the Waseca at Shell Zaller Lake 10-7-39-25(W3) (Figure 13). Only cycle 2 (6.94 m) fines upward, and its sandstone shares the quartz-kaolinite suite with cycle 1 (2.18 m), as well as with the basal cycles of the Waseca in the wells to the north and northeast. At Zaller Lake, the sandstone is medium grained and quartzose; indurated in white kaolinite; speckled with abundant kaolinitized feldspar, black chert, grey chert, green chlorite and hornblende, and brown sphaerosiderite; and textured with low-angle trough cross-beds, partially lined with carbonized plant detritus. It is the most ubiquitous of the individual beds and stratigraphically the most consistent, being present at all of the cored wells in section A1-A1' (Figure 13). At Zaller Lake, however, the facies, though typically fluvialite, has undergone a subtle southward transition from a quartz-kaolinite-feldspar-chert suite to one that has expanded to include the green chlorite and amphibole of an andesitic provenance.

Nine bedding cycles form the Waseca at Shell Cactus Lake 2-16-36-28(W3) (Figure 13; Appendix A):

Cycle 1 (1.64 m): upward-coarsening sequence of dark grey glauconitic and bioturbated shale; mudstone with abundant carbonaceous plant fragments; and fine-grained quartzose sandstone with a light green-grey and white kaolinitic matrix, abundant carbonaceous grains and pyrite crystals.

Cycle 2 (5.3 m): olive, massive mudstone with scattered carbonized plant fragments and brown ironstone nodules; appears to be an alluvium equivalent to the fluvialite cycle 2 facies of the Waseca at Shell Zaller Lake 10-7-39-25(W3) (Figure 13).

Cycles 3 (5.4 m) and **4** (6.6 m): quartzose sandstone, both upward coarsening; the lower cycle is current bedded and laminated with grey shale, and the upper is well sorted and oil permeated but includes medium grey interbeds in its lower half.

Cycle 5 (10.1 m): quartzose sandstone, upward fining from fine to very fine grained; coal capped; basal 4 m include graded siltstone-shale couplets and the remainder is oil permeated and well sorted but interbedded with subordinate shale.

Cycle 6 (4.3 m): dark green-grey, carbonaceous mudstone, which coarsens upward into argillaceous, quartzose sandstone with rootlet casts.

Cycles 7 (3.6 m) and **8** (0.83 m): green-grey and dark grey mudstone, respectively.

Cycle 9 (2.17 m): shale to sandstone transition.

The Cactus Lake site, in Waseca time, underwent initial episodic marine inundation and accompanying progradation; as indicated by the great thickness and graded bedding of cycle 5 (10.1 m), it had become semi-isolated in a barred estuary. Cycle 6 (4.3 m) indicates a renewed transgression, but one terminated under soil-forming conditions, as indicated by the ramose network of siderite-infilled rootlet molds. With respect to regional correlations on the Kindersley-Unity depositional floor (Figure 39), each of bedding cycles 1 to 5 equates with Waseca stratigraphic units of like number. Cycles 6 to 9 are components of Waseca Unit 6.

East of Shell Cactus Lake 2-16-36-28(W3) (Figure 13), the Unity Paleolowland basin supported wide strands and tidal flats, as well as backshore marshes and lagoons and their intersecting tidal creeks and estuaries, similar to the Lloydminster heavy-oil district 100 km to the north. This is illustrated in the north to south geophysical log stratigraphic cross-section (Figure 39a) of the Mannville along the eastern flank of the Unity Paleo-upland between Shell Dee Valley A11-18-48-21(W3) and Tidewater Imperial Plato Crown No. 4 (10-28-25-18W3), wherein the Waseca is informally subdivided into six units on the basis of its transgressive marine shale units and cemented pavements indicative of surfaces of emergence. Units 1 to 4 constitute a 'Lower Waseca', made up of macrolenticular beds several kilometres in area. Units 5 and 6 constitute an 'Upper Waseca' regional bedding group that overlies a flooding surface (Waggoner *et al.*, 1987) above Unit 4, and south of Twp. 25 are progressively truncated under the sub-Pense unconformity. Northward from Arco Handle 6-22-36-20(W3), the cross-section intersects the Unity Paleo-upland basin, a region across which oscillated marine eustatic and tidal strands under a fetch from the north and east. Southward from Arco Handle to Tidewater Plato, the cross-section depicts re-entrants into the Kindersley Paleo-upland from the Govan Paleolowland basin to the east, and accordingly reflects more valley-controlled estuarine and alluvial conditions.

The lensing character of the lower Waseca units are more apparent on the Unity Paleo-upland terrace, where the section lies along the depositional strike, than on the Kindersley Paleo-upland basin, where the strands are turned east-west along the axis of the ancestral paleovalley system and the Mississippian escarpment. The thin shale of Units 1 and 2 represents relatively rapid transgressions, followed by slower progradations in a depositional cycle that was overall transgressive. Units 3 and 4, however, are offlapping and overall regressive. In this context, Unit 4 on the section features the highest number of upward-fining, and ostensibly channel fill, beds. Unit 3, by correlation with the neighbouring cored Tidewater Imperial Plato Crown No. 1 (9-22-24-19W3) section, is an alluvial red bed that is traceable to the south but apparently replaced by upward-coarsening sequences to the north. The general parallelism of the Waseca units in the cross-sections indicates progressive, though episodic, base-level rises across the Unity Paleo-upland basin. Local thickening, with or without Waseca channel cut-and-infill, may reflect location on active sinks generated by salt dissolution in the Middle Devonian Prairie Evaporite.

Many upward-fining cycles in Unit 4 along the eastern flank of the Unity Paleo-upland basin are intercepted by the north-south alignment of the cross-section along Rge. 20, W 3rd Mer. (Figure 39a). However, the west to east line of section (Figure 39b), which lies parallel to the general drainage directions, intercepts very few. Thus, the westerly directed channel body of Unit 5 (10.1 m) at Shell Cactus Lake 2-16-36-28(W3) is independent of those in the east, such as at Baytex Wilkie 11-25-38-20(W3) and CS Saskoil Cathkin 15-31-37-19(W3).

At Baytex Wilkie 7-25-38-20(W3) (Appendix A), the partially cored Unit 1, a bimodal fine- and medium-grained, kaolinitic quartzose sandstone, represents the terminal part of an upward-fining sequence, presumably the widespread fluvial strata that occur near the base of the Waseca across the Kindersley and northern Govan paleobasins, from Shell Cactus Lake 2-16-36-28(W3) to Choiceland Choice No. 1 DD 13-3-50-18(W2). Unit 2, which includes the lower upward-fining cycle 2 (1.51 m) of sandstone and shale and the overlying upward-coarsening cycle 3 (0.80 m) of shale to bioturbated shale and current-laminated shale-sandstone, was probably deposited in an upper shoreface to shoal-bottom environment that was episodically prograded by mixed bay and marshy mudflat deposits, represented by Units 3 and 4 (bedding cycles 4 [0.52 m], 5 [2.12 m], and 6 [4.73 m]). The highly permeable sandstone body of Unit 5 (cycle 7 [12.38 m]), by virtue of its fabric and upward fining, is taken as

estuarine distributary point bar. The herringbone cross-bedded fabric of bedding cycle 8 (3.84 m) reflects a tidal setting.

The distinctive channel deposit of the Wilkie section is probably aligned easterly, as indicated by its presence at CS Saskoil Cathkin 15-31-37-19(W3) (Appendix A), where Waseca Units 3 to 6 are also cored. Here is found the probably estuarine, 10 m thick Unit 4 of highly permeable, well-sorted, fine-grained quartzose sandstone with accessory kaolinite and black chert. Unit 5 (8 m), however, is represented by flat-bedded and shale-draped sandstone over its lower two-thirds and tabular-cross-bedded sandstone above, thereby implying a transition from tidal flat to channel bar and barrier. The estuarine channel cycle (7.27 m) of Unit 6 is lithologically equivalent at both sites, but the overlying cycle 7 (1.73 m), though consisting of similarly interbedded sandstone and shale, is of uncertain origin. The extra sand bodies at Cathkin were accommodated by syndepositional subsidence of the site, as indicated by downwarp of the underlying member contacts (Figure 39a). The geology of these sandstone units is further examined in Christopher (2002).

The Waseca, at 557.0 to 531.1 m below KB in C.M.&S. Vanscoy 11-16-35-8(W3) (Figure 15; Appendix A), fines upward overall through four bedding cycles, each of which is upward fining. The absence of cycles 5 to 7 is attributed to erosion prior to Pense deposition. Cycle 1 (2.7 m) rests on an erosional contact with relief exceeding 3 m over the 4 cm diameter of the core. It is coarse-grained, kaolinite-indurated quartzose sandstone with basal layers of flat mudstone pebbles and grit and, at the top, thin coaly shale. The large clasts comprise kaolinite, sideritic concretions, and tree limbs. Cycle 2 (9.3 m) is transitional from coarse- and medium-grained, trough-cross-bedded, calcareous, kaolinite-indurated quartzose sandstone with accessory grey chert and brown siderite, into ripple- and current-bedded sandstone with black-shale-draped laminae. Cycle 3 (7.9 m) grades upward from medium-grained, white-kaolinite-indurated quartzose sandstone with subordinate dark grey and black chert, carbonaceous grains, and a basal mudstone pebble conglomerate, through a very fine grained, argillaceous quartzose sandstone, into a terminal 2.7 m of dark purplish grey, waxy to brittle claystone. Cycle 4 (6.0 m) is massive, medium grey mudstone with alternate silty and clayey beds at intervals of 0.6 to 1.5 m, and scattered layered concentrations of coarse-grained sphaerosiderite. The Waseca reflects a fluvial depositional environment punctuated by estuarine in the second cycle and, in general, displays classical point-bar deposits that are terminated with abandoned-channel alluvial infill.

At neighbouring Duval Saskatoon 6-18-36-6(W3), lithology of the Waseca reflects proximity of the coast. Of the four cycles, an overall transgressive relationship is apparent across the upward-coarsening first and second cycles. Bedding cycle 1 (1.4 m) is an attenuated, current- and wavy-bedded, lenticular, very fine grained quartzose sandstone with upward-decreasing black shale interbeds and capped by a metre-thick, lavender grey oxidized shale. Cycle 2 (3.3 m) is a repeat of the first, but includes bioturbation pods, rounded ripple crests, and shale drapes of sandy lenticles over the lower portion. The upper two-thirds of the Waseca are dominated by cycle 3 (8.3 m), consisting of interbedded lavender grey mudstone and claystone with minor beds of clay-indurated quartzose sandstone and siltstone that are transitional to a thin bed of grey-white claystone containing subordinate coarse-grained sphaerosiderite. Cycle 4 (3 m) is poorly bedded to massive, argillaceous, medium-grained grading upward to fine, quartzose sandstone, which is sphaerosideritic near the base. Apparently, the earlier upward-coarsening units were deposited in oscillatory fashion on an upper shoreface or, more likely, in a tidal basin that was later prograded by fluviodeltaic deposits.

The tidal basin to the west of the Vanscoy site fronted the nearly buried, north-facing escarpment of Mississippian limestone and Jura-Cretaceous sandstone that formed the upper levels of the Kindersley and Swift Current paleo-uplands. These upper levels also supported the flood plains and straths of the 'Atlas' (continental facies of Maycock, 1967) outpouring of green, wacke-type sandstone, distinguished by its accessory biotite-chlorite-black-chert-kaolinite suite, from the Rocky Mountain uplifts of southern Alberta and northern Montana (Christopher, 1974; Putnam, 1980). The progradational 'Early Atlas sandstone' of the Swift Current uplands (*i.e.*, the beds that are equivalent to the General Petroleum-Sparky), spread out to the northern and eastern front of the hills as coalescent alluvial fans originating in the upland interfluvies. The transgressive 'Middle Atlas shale' and progradational 'Late Atlas sandstone' are Waseca correlatives. These correlations are depicted in the stratigraphic cross-sections of Figure 33 and Figure 38. A portion of the Waseca, particularly the Upper Atlas sandstone, has been removed from the northern crown of the Swift Current Paleo-upland by pre-Pense erosion, especially east of the Roseray escarpment along the western side of the Shaunavon Graben, north of Twp. 15, Rge. 18, W 3rd Mer. (Figure 38). More of the Waseca emerges from under the Pense contact farther south, in the paleovalleys of Twp. 13 and 14 (cross-section Y-Y', Figure 23).

In Twp. 15, Rge. 18 to 20, W 3rd Mer. and to the southwest, Late Atlas sandstone (Christopher, 1974), renamed the 'Chokecherry Creek' (Leckie *et al.*, 1997b), forms a general easterly trending, sheet-like body, more than 22 km long, 10 km wide, and up to 18 m thick, that includes as many as four erosionally delimited units. The basal unit sweeps out a 6 m deep trough, from the underlying Middle Atlas Shale, in which younger beds overlap older beds

outward from the thalweg. West of the Delta Paleovalley, the sandstone body widens to 10 km, mostly in the uppermost unit, and correspondingly thins to less than 6 m. The body narrows to the east, then broadens into a fist-like pattern at its maximum thickness along a stacked front that coincides with a structural depression. There, it changes abruptly to the regional Middle shale along an apparent deltaic front (Christopher, 1974, Figure 39).

Other Waseca sandstone bodies also reach into the locality from the southwest as remnant tongues of fluvial channel deposits. These sand bodies are lenticular, 3 to 10 m thick and less than 1 km in length, and imbricate and alternate with mudstone in their stratigraphic areal disposition. They thicken and thin in accordance with the inverse distribution of the General Petroleum (Early Atlas) sandstone, and grade laterally into mudstone (Christopher, 1974, Figure 38), but overall appear to be misfit stream deposits in a broad valley from which about 11 m of the underlying Early Atlas (General Petroleum) sandstone has been eroded.

The parent stream for each aggradational deposit initially followed the depressions created by compaction of the argillaceous sediments around antecedent sandstone bodies. Such compaction probably resulted from falling base levels and dewatering of the substratum. Some meandering of the streams is indicated by the geometry of the channel forms, and the mudstone facies therefore also include overbank deposits. The several episodes of channelling and deposition partially redistributed sediments laid down during the weak transgressions southward up the paleovalley. Location of the delta-front-stacked sandstone at the Jurassic North Premier oilfield and under present-day Antelope Lake was apparently an effect of episodic structural subsidence. The relatively high permeability of the Late Atlas sandstone probably reflects wave reworking into distributary mouth bars after the model of Coleman and Gagliano (1965, Figure 9).

On the eastern slopes of the Swift Current Paleo-upland, the Waseca includes thin limestone, calcite-cemented sandstone, and accessory glauconite, indicating the presence of marine transgressive deposits in the depositional setting. These components are seen in the 'Middle shale' of the Atlas Member at CDR North Aquadell 13-12-20-6W3 (Figure 37), where the section at 948.5 to 941.8 m comprises three bedding cycles, assigned to the lower part of the Waseca. The remaining beds are apparently lost to the sub-Pense erosion surface. Cycle 1 corresponds to shallow marine, progradational buildup into wave base, probably a sand shoal; cycle 2, a back-barrier microtidal embayment; and cycle 3, lagoonal mud that closed off the embayment. The descriptions of these cycles are as follows:

CDR North Aquadell 13-12-20-6(W3), KB 643.7 m

Bedding Cycle 1 (3.3 m)

948.5 to 945.2 m	Sandstone: quartzose, very fine grained, interbedded at 0.6 m intervals with dark grey, carbonaceous to coaly mudstone; coarsens upward into fine-grained, low-angle trough-cross-bedded, calcareous sandstone laminated with shale.
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Bedding Cycle 2 (1.4 m)

945.2 to 943.8 m	Sandstone: quartzose, light blue-grey, fine bedded, well sorted, with about 10% muscovite, chlorite, black and dark grey chert, carbonaceous grains, and kaolinite; dark blue-grey spherulitic limestone at the base and, at the top, a transition into metre-thick, poorly sorted, kaolinite-indurated, flat-laminated sandstone that includes scattered glauconite, bioturbation pods, and abundant mud-infilled and pyritic rootlet casts.
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Bedding Cycle 3 (2.0 m)

943.8 to 941.8 m	Mudstone: sharp basal contact, medium grey; subordinate irregular and contorted thin laminae of very fine grained quartzose sandstone; burrowed at the top.
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Sand-deficient shore conditions are indicated to the southeast, in the Lower Waseca core from Shell Mossbank A10-33. There, the basal unit (4.3 m), at 1040.9 to 1036.6 m (adjusted), consists of four beds, two of which, each 1.5 m thick, are quartzose, coarse-grained, massive, microfaulted, and mottled siltstone, with attenuated, randomly oriented stringers of red-brown mudstone and black coal, suggestive of a lagoonal to marshy setting. Each siltstone bed is succeeded by 0.8 and 0.5 m, respectively, of sandstone and mudstone pebbles that probably represent lag deposits of sandy beaches swept away by littoral drift associated with episodic strand encroachment. The upper unit, at 1036.6 to 1033.3 m (adjusted), is very fine grained, well-sorted, fine-bedded quartzose sandstone, with a trace of carbonaceous laminae, and is bioturbated (vertical and lateral burrows) and irregularly interbedded with

argillaceous siltstone with brown ironstone stringers. The unit reflects an oscillatory buildup of beach sand and upper shoreface sediments, and thus marine transgressive conditions.

In the Williston Basin, the lower and upper parts of the Waseca were sampled in 3 m cored intervals at Mobil CDR Flat Lake 15-15-1-15(W2) and Penn West et al Hoffer 12-30-1-15(W2), respectively. Both horizons are represented by light and medium grey, bioturbated, small-scale current-bedded siltstone and mudstone. Similarly, to the north at Mobil Oil S. Grassdale 10-32-6-15(W2), the upper part of the Waseca displays very fine grained, well-sorted quartzose sandstone with abundant accessory kaolinite, scattered carbonaceous grains, and glauconite, and interbeds and laminae with lenticles and bioturbation pods of coarse-grained siltstone. These sites are located in the extreme south of the Mannville depositional basin in Saskatchewan, and the sediments indicate that the Govan Paleolowland basin remained part of a marine to estuarine environment to the end of Waseca time. Also, geophysical log interpretation suggests that more than half of the area of the Govan depositional basin is occupied by blanket sandstone dissected by channel sandstone. Mudstone deposits are extant throughout the region but are dominant only at isolated sites.

Little is known of the Waseca depositional format above the buried Moosomin Paleo-upland, because of lack of core and loss of section due to pre-Pense truncation. The Waseca is absent across the 120 km wide Punnichy Arch between latitudes 50° and 51°N. However, the sedimentary facies on the southern and northern sides of the Punnichy Arch are similar, and the northern facies are easily traceable over the blanketed Kindersley and Swift Current paleo-uplands around the western front of the arch. Facies continuity across the arch in the pre-Waseca members of the Cantuar increases with stratigraphic depth. Thus, extrapolation of the Waseca facies across the central part of the Punnichy Arch, along the length of the Govan Paleolowland basin, appears to be a logical extension of the approach used for the lower members of the Cantuar Formation.

Two belts of upward-coarsening quartzose sandstone, about 3 m thick and comprising as many as six stacked units (*e.g.*, BA Buxall 1-10-46-15(W2); cross-section V-V', [Figure 17](#)), trend north-northwesterly from the Punnichy Arch to about the trace of the present Saskatchewan River. The eastern belt, between Nipawin and Wadena ([Figure 40](#)), fringes a domal region, approximately centred at the town of Hudson Bay, from which the Waseca has been removed by pre-Pense erosion. These sandstone units, probably derived from northeastern sources, are shoal deposits that grade westward to deeper water shale in a narrow belt that includes the town of Melfort and the area north of the Quill Lakes, and overlies the axial region of the pre-Dina Assiniboia Paleovalley. Quartzose sandstone of the western belt, between Prince Albert and the Quill Lakes, coarsens upward more conspicuously from basal shale and bioturbated mudstone, and is interpreted to consist of lowstand, offshore deposits that pass westward into the broad belt of mudstone between the buried topographic Watrous Dome to the east of Saskatoon and the eastern front of the Kindersley Paleo-upland. The mudstone facies apparently represents tidal mud aprons that flanked the southwestern and eastern paleo-uplands.

The Waseca displays seven cycles at Choiceland No. 1 Choice DD 13-3-50-18(W2), described under stratigraphic cross-section A3-A3' ([Figure 15](#)). Cycle 1 is a 1.4 m thick, fluvialite, upward-fining, medium-grained, calcite-cemented quartzose sandstone on an erosional base, and includes abundant black chert and kaolinite grains. From here, the most northeasterly extent of its known distribution, the cycle extends: 1) as far west as Shell Paradise Hill A13-19-52-23(W3); 2) as far southwest as Shell Zaller Lake 10-7-39-25(W3) and Shell Cactus Lake 2-16-36-28(W3), where accessory biotite, chlorite, and amphibole of the andesitic fluvialite suite of the Kindersley and Swift Current uplands are incorporated; and 3) as far south as Transgas Prud Homme B11-12-38-28(W2), where thin fluvialite channel sandstone represents the cycle. At C.M.&S. Vanscoy 11-16-35-8(W3), the four lower sequences of the Waseca feature this facies. However, at Duval Saskatoon 6-18-36-6(W3), 20 km to the east-northeast, and at CDR North Aquadell 13-12-20-6(W3) ([Figure 38](#)), in the southern part of the basin, these fluvialite facies yield to progradational shorefront deposits. Thus, a vast early Waseca fluvialite progradation from southwest of Swift Current across an infilled northern Govan Paleolowland basin is indicated. Although the bed is generally less than 3 m thick on the depositional floor of the Unity and Govan paleolowlands, the geomorphic character of the region below the Kindersley Paleo-upland appears to have been, at that time, a constructional plain. However, estuarine to marine conditions persisted to the south into the Williston Basin, therefore indicating a southerly downwarp of a precursor to the Pense Basin.

Above Unit 1 at Choiceland No. 1 Choice, Unit 2 (3.0 m) reflects marine transgressive conditions by its drowned channel deposits of mudstone with cut-and-fill bedding, coaly blebs, and fossil tree trunks. Progradational pulses are indicated by the upward-coarsening, bioturbated sandy mudstone and fine-grained quartzose sandstone of bedding cycles 3 (1.8 m) and 4 (2.6 m) of Unit 3. The first is terminated by a rootlet-penetrated and rootlet-casted sandy paleosol, implying emergence. Subtidal bioturbated mudstone also initiated the progradational quartzose sandstone bedding cycle 5 (7.6 m) of Unit 4. Its ripple-current beds are suggestive of a protected shoal. Bedding cycle 6 (2.5 m) of Unit 5 is a flasered shale-sandstone transition into cross-bedded, calcite-cemented, very fine grained, kaolinitic sandstone with abundant oxidized sphaerosiderite. Atkin (1986) recovered an impoverished foraminiferal

fauna from the shale of Units 4 and 5. Bedding cycle 7 (6.7 m) of Unit 6 fines upward from a 3.5 m thick, fine-grained quartzose sandstone, interbedded with argillaceous, sandy mudstone and bioturbated at the top; through a 70 cm thick, very fine grained, contorted, highly argillaceous quartzose sandstone; into a 2 m thick, medium to light grey (mottled with red and yellow), sideritic mudstone; and, at the top, a 50 cm thick, argillaceous, very fine grained quartzose sandstone. The facies indicate chenier encroachment and infill of a river-mouth channel, followed by alluvial infill and renewed beach encroachment.

On the Molanosa Paleo-upland to the north, fluvial sandstone dominates the upper Waseca. This crops out most spectacularly in 22 m high cliffs in the east wall of the Nipekamew River, in Twp. 64, Rge. 18, W 2nd Mer., about 1.6 km south of Highway 165 (Christopher *et al.*, 1973, p261; Leckie *et al.*, 1998). The outcropping section (Figure 41) comprises two units in ascending order:

- 1) Sandstone: quartzose, fine to very fine grained, well sorted, trough-cross-bedded in truncation sets 0.3 to 1.0 m thick; light grey to white, with buff limonitic stains where kaolinite (up to 5% by weight) is present; basal portion is scree covered down into the river; exposed thickness ranges up to 3 m.
- 2) Gritstone: pebbly, subordinate coarse sand; quartzose, bimodal, white-kaolinite bonded, abundant metamorphic strained quartz, kaolinitic pebbles, and carbonaceous balls; intensively channelled and cross-bedded, with cuts tens of metres across; contact rises and falls on underlying, medium- to fine-grained quartzose sandstone, with large-scale tabular foresets dipping 15 to 20° across 3 to 4.5 m; thickness of individual beds ranges from 3 to 15 m.

A correlative coarse-grained quartzose sand and grit unit, 18 to 20 m thick, is recognizable in well cuttings as far south as Torch Lake No. 1 (13-14-52-23W2, cross-section C-C', Figure 20), and as far west as Seaboard Meadow Lake Crown No. 6 (16-36-59-14W3) (cross-section U-U', Figure 18). Its areal expression is that of an alluvial fan, intertongued with marine sediments on a radius of 40 to 80 km. The coarse grade sizes and large trough and tabular cross-sets of the Nipekamew River section imply a late Cantuar uplift of the nearby Precambrian Shield and consequent high-volume and rapid fluvial discharge into the Waseca marine basin. In texture and fabric, this sandstone bears a striking resemblance to the lower McMurray sandstone of the Athabasca River in east-central Alberta (Carrigy, 1971; Mossop and Flach, 1983), and may therefore represent a late Mannville rejuvenation and diversion to central Saskatchewan of the early Mannville river system that fed the McMurray basin of Alberta.

Extending west and northwest of the Nipekamew fan into the Meadow Lake Paleolowland basin, the marine Waseca, as traced through cross-sections V-V' (Figure 17) and A-A' (Figure 16), grades into the upper part of the Grand Rapids Formation of east-central Alberta. The type section of the latter is 90 m thick at Grand Rapids on the Athabasca River and was described in 1893 by McConnell (in Carrigy, 1959) as a 'salt and pepper' concretionary sandstone with a heterogeneous mineral composition that includes quartz, feldspar, glauconite, chert, muscovite, and biotite. On the Clearwater River of northwestern Saskatchewan (Figure 42), near the Saskatchewan-Alberta boundary, the outcrops are of brownish green bedded sandstone with trough truncation cross-sets, planar foresets and festooned cross-sets, thin carbonaceous lenses, and large concretions, up to 0.6 m across, that have been built up around woody to lignitic bodies (Paterson *et al.*, 1978, p13). This lithology is similar to the Atlas facies of the Waseca on the Swift Current and Kindersley uplands, 700 km to the south, and represents a deltaic-marine northern tongue of the Rocky Mountain influx. To the southwest, at Shell Frenchman Butte A7-3-54-25(W3) (Figure 13), the Waseca is composed of eight bedding cycles that range in thickness from 2.0 to 5.7 m. This relatively narrow range is atypical of the Waseca, in that 10 m thick channel and shoal sandstone units are present in many of the wells in the region. Waseca units are highly variable and, in the Meadow Lake Paleolowland basin to the northeast, acquire strong fluvial inputs from the Precambrian Shield. All cycles shoal upward, except for the 2.8 m thick, dual sandstone-mudstone couplets of cycle 2. All sandstone at the top of the upward-coarsening cycles is current and cross-bedded, swaley and trough cross-bedded, and ripple bedded. The sandstone of the 3 m thick cycle 4 displays opposing cross-sets suggestive of a tidal setting. Mudstone and shale are bioturbated, and the sandstone of cycles 1 to 3 is fine grained, and that of cycles 4 to 7 very fine grained, thereby reflecting a waning depositional gradient. The speckled black chert and kaolinite-rich quartzose sandstone appear only in cycles 3 and 7 as distal components of a western influx. The 3.5 m thick, bioturbated, argillaceous quartzose sandstone of bedding cycle 8 ends in a 0.6 m thick coal bed.

Thus, the Waseca depositional basin in Saskatchewan (Figure 40) formed a broad axial region, which more or less conformed to the Govan and Meadow Lake paleolowlands, and the adjoining flats of the Unity Paleo-upland. Across this region, the Waseca is dominated by bedding cycles, whole and truncated, that coarsen upward from marine shale through bioturbated mudstone and sandstone into well-sorted, fine-grained sandstone, locally capped with loamy, carbonaceous, and rootlet-penetrated sandstone. Also widely distributed are subordinate upward-fining beds, representative of channels infilled during the transgressive stages, and emergent surfaces, indicated by calcite- and siderite-cemented pavements, erosional contacts, and oxidation colours suggestive of falling sea levels.

Channel-sediment units are typically short (tens of kilometres), similar to the widths of the relatively narrow adjoining strand belts. The marine basin, contrary to earlier impressions of a late Mannville continental obliteration, remained essentially that defined by the Late Dina and Cummings transgressive episodes. Unlike the Lloydminster-Rex basin, where broad mudstone-dominated sheets flanked the major topographic eminences such as tidal flats, those of the Waseca spread farther into the Govan and Meadow Lake Paleolowland basin, probably because of lower depositional gradients. Upward-coarsening shale-sandstone sheet-like deposits were oriented axially to the depositional basin. They also blanketed the Unity and Kindersley paleo-uplands, which were apparently tilting southward at that time, thereby creating an embayment against the northern edge of the subsiding Swift Current Platform. Deep marine penetration of the southwestern paleo-uplands also accompanied this subsidence, as indicated by the Middle shale (Lower Waseca) of the Atlas Member.

The facies map (Figure 40) generalizes the basin progradational limits of the Waseca fluvial influx, where these sediments form more than half of the section. Fluvio-marine deltaic deposits prograded the Swift Current and Kindersley paleo-uplands from the southwest, the Govan Paleolowland basin from the southeast and the Molanosa Paleo-upland from the northeast. The degree to which the Moosomin Paleo-upland was blanketed by such sediments is obscured by pre-Pense truncation of the Waseca. The eastern limit of the Grand Rapids deltaic-marine influx from the northwest cannot be determined from the available data, but these deposits intertongue, in the northern part of the Meadow Lake Paleolowland basin, with those originating on the Molanosa Paleo-upland.

Sub-Pense Unconformity Surface

The Cantuar Formation is variably truncated at the contact with the Pense Formation, on an unconformity that is most pronounced on the regional topographic and structural highs of the Cantuar basin. Examples of these relationships are detailed on cross-sections B-B' (Figure 19), C-C' (Figure 20), and D-D' (Figure 21) across the Punichy Arch. The regional pattern of this pre-Pense stripping of the Cantuar is illustrated by the geology of the sub-Pense unconformity surface (Figure 43), in which strata as old as the Mississippian Bakken Formation and as young as the Waseca display annular subcrop patterns of outward younging, from highs on the arch and from the main body of the arch itself. On the paleo-uplands to the west and southeast, much of the sub-Pense planing is at the expense of the Waseca Member. Sub-Pense erosion of the Cantuar is also apparent in the northeast, around the town of Hudson Bay and toward the Molanosa Dome. By the early Late Albian (Caldwell, 1984b), the Pense-Cantuar relationship reflected changes in the Mannville depositional basin that forecasted rejuvenation of the structural Williston Basin. As the Swift Current Platform subsided, the Punichy Arch rose and the weakly indurated Cantuar sediments on the latter were partially stripped and probably recycled into the Upper Waseca of the Mannville basin to the northwest. The Pense transgression, marked by Unit 1, followed and, though regional in extent, built up sediments to twice regional thickness on the subsiding Swift Current Platform. Sedimentary sources may have been the upper Mannville on the Sweetgrass Arch to the west and the Precambrian Shield in Manitoba.

Pense (McLaren-Colony) Depositional Pattern

Price (1963) selected the name 'Pense Formation' for those strata between the Cantuar and Joli Fou formations in southeastern Saskatchewan, and designated as type section the core from the Sohio Canadian Devonian Pense No. 1 (L.S. 14-6-17-22W2) well, at depth below KB of 2,657 to 2,758 ft (809.9 to 840.6 m). It is considered to be the equivalent of the 'Upper Blairmore' of southern Saskatchewan (Roussel, 1956) and of southwestern Saskatchewan (Cumming and Francis, 1957). Price traced the formation east to the Third Meridian (longitude 106°W) and north beyond latitude 52°N (*i.e.*, to near the Red Deer River in eastern Saskatchewan). Maycock (1967) and Christopher (1974) mapped the formation in southwestern Saskatchewan, from the Canada-United States border to as far north as the town of Kindersley (at latitude 51°N). This report extends the Pense nomenclature north into the heavy-oil region of west-central Saskatchewan by means of the regional stratigraphic cross-sections. The Pense Formation thins to about 15 m across the Punichy Arch and Kindersley region of south-central Saskatchewan. In west-central Saskatchewan, the Pense includes the McLaren and Colony members of the Mannville at the Vigrass (1977) reference well, Husky Aberfeldy Unit A11-31-49-26(W3). The formation thickens to about 25 m in the vicinity of the Meadow Lake Basin.

In southwestern Saskatchewan, as many as four multicyclic informal units were delineated and mapped by Christopher (1974, p98). These are readily recognized on the geophysical logs by the upward-expanding positive deflections of the spontaneous potential and resistivity curves. This characteristic reflects the upward-coarsening nature of the bedding cycles: from basal shale through mixed (bioturbated) shale, siltstone, and sandstone to capping, relatively well sorted, calcite-cemented sandstone. The formation coarsens upward as a whole, but not all individual cycles do so and upward-fining bodies also contribute a minor but significant aspect. In this regard, the Pense Formation is typically 'Mannville' in character. What distinguishes it from members of the Cantuar Formation is its far ranging lithological and thickness consistency, its physical integrity over the geographic extent

of the Mannville in the province, and its basal contact against which the Cantuar and older formations are in erosional disconformity, especially in the region south of latitude 53°N. The boundary relationship with the Joli Fou Formation is lithological rather than marker defined (Simpson, 1982, p6), in that the sandstone at the top of the Pense is lenticular and invariably includes a component of black shale indistinguishable from that of the Joli Fou. This sandstone is also erosional attenuated, and features scoured surfaces with accumulations of grit and local pebbles that are commonly attributed to a widespread hiatus with respect to the 'Colorado' Joli Fou Formation. Most of the arguments regarding the biostratigraphic status of the Pense and its equivalents, the McLaren and Colony, are extensively reviewed by Caldwell (1984a, 1984b); *see also* Mattison and Wall (1993).

Shale, basal to a given cycle of the Pense Formation in southwestern Saskatchewan, is black, hard, and fissile, and includes 5% (increasing upward to 15 and 20%) medium grey, sandy flasers that rest on tool-marked (Dzulynski and Sanders, 1962) contacts, criss-crossed by randomly oriented trace fossils (Maycock, 1967). Locally, as in the core from Unit 1 at CDR H.B. Aquadell 1-26-19-6(W3), thin beds of dark grey, argillaceous, spherulitic limestone or dense, darker grey, argillaceous limestone are also included. The medial sandy mudstone is by far the most widespread of the Pense rock types, and is generally dark grey and greyish black, and thinly interbedded and laminated with flasers and lenticles of very fine grained quartzose sandstone. It is generally burrowed in the bedding layers, and considerable disruption of depositional fabric is partially attributable to compactional effects. The sandstone layers rest on sharp, erosional contacts and load-casted shaly partings, and they may yield abruptly or grade into superjacent shale. Where preserved, the terminal sandstone is fine grained and well sorted, weakly silica-to densely calcite-cemented, generally flat, lamellar and locally festoon bedded and quartzose, with abundant rose quartz, black chert, muscovite, biotite, and glauconite. Scattered, crenulated, carbonaceous, black shaly partings with rare sand-filled mudcracks relieve the overall uniformity. The sand body may dominate half to two-thirds of a 13 m or so thickness of a complete cycle.

The Pense Formation thickens to a maximum 45 m on the crown of the Cantuar-infilled Swift Current Uplands, as shown in cross-section Y-Y' (Figure 23), where thick sandstone caps the cycles. The four units, which include seven bedding cycles, some of them truncated and upward fining, are described below:

CDR Calderbank 13-28-19-7(W3), KB 741.6 m

Pense Formation

Unit 1 *Bedding Cycle 1 (4.9 m)*

1022.3 to 1017.4 m Sandstone: quartzose, argillaceous, very fine grained; scattered calcite-cemented, trough-cross-bedded lenticles; fines upward through a grey-black argillaceous siltstone into black shale.

Bedding Cycle 2 (5.0 m)

1017.4 to 1012.4 m Shale: black, coarsens upward by increase in lenticular, podded and flasered, very fine grained, calcite-cemented, fine-bedded quartzose sandstone into sandstone, which is 2.9 m thick, quartzose, very fine grained, well sorted, and calcite cemented, and contains abundant black and grey chert.

Bedding Cycle 3 (0.8 m)

1012.4 to 1011.6 m Sandstone: quartzose, bipartite, very fine grained, well sorted and calcite cemented, erosional basal contact, minor black shale laminae in the lower bed.

Unit 2 *Bedding Cycle 4 (7.4 m)*

1011.6 to 1004.2 m Shale: black; subordinate, light grey, fine-bedded, very fine grained, quartzose sandstone laminae on scoured contacts; grades into argillaceous, fine-bedded, flasered, and strongly bioturbated, very fine grained, quartzose sandstone.

Bedding Cycle 5 (0.2 m)

1004.2 to 1004.0 m Sandstone: quartzose, very fine grained, well sorted, oil stained; alternately thin, flat bedded and trough cross-bedded; erosional basal contact; fines upward into a capping, dark grey, argillaceous sandstone.

Unit 3 *Bedding Cycle 6 (4.3 m)*

1004.0 to 999.7 m Sandstone: quartzose, very fine grained, flasered, lenticular, podded, bioturbated, matrix of grey and grey-black shale, well indurated; overlies a 0.6 m thick alternation of trough-cross-bedded and flat-bedded, argillaceous, very fine grained, quartzose sandstone on an erosional contact; silica and pyrite cemented on a truncated layer of well-sorted, muscovitic, very fine grained, quartzose sandstone.

Unit 4 *Bedding Cycle 7 (1.5 m)*

999.7 to 998.2 m Shale: black, abundant burrow pods and lenticles of light grey, very fine grained, quartzose sandstone; scattered pyrite-cemented layers; sharp, irregular basal contact.

Units of the Pense Formation are separated by erosional contacts, as are a number of the bedding cycles. These are either truncated remnants of fuller bodies or the lensing tongues of bodies more complete beyond the particular borehole. For instance, all of the sandstone bodies in CDR Calderbank 13-28-19-7(W3) are composites of two beds, the lower separated from the upper by erosional contacts. They reflect the lenticular morphology and probable migratory tendency of sheet-like sandstone bodies formed as bars and shoals by strong, shifting currents. Additionally, all of the shale and bioturbated facies have yielded fish remains and the foraminifera *Hippocrepina barkdalei* sp. (Atkin, 1986), thereby indicating marine depositional conditions. Unit 4 is regionally the most discontinuous of the units in that, away from the Swift Current Platform, it yields to a black-shale-dominated facies, and is therefore apt to be included with the Joli Fou. In the extreme southeast corner of the province, Unit 3 passes into the Joli Fou shale lithotope, as demonstrated on cross-section Z-Z' east of Socony et al Tribune 12-31-3-14(W2) (Figure 22). In the Kindersley-Unity region, Units 3 and 4 attenuate to form either the 'Transitional Beds' of Maycock (1967) or condensed phosphatic sandstone beds and lenticles at the base of the Joli Fou shale, enriched with fish remains (e.g., teeth, vertebrae, scales, and other skeletal fragments). Examples of these are found at Community Petroleum Battleford 3-2-46-16(W3) and at Wilkie No. 2 (11-6-40-19W3) (Maycock, 1967). Elsewhere, as at Mobil Celtic A10-4-52-23(W3) (Haidl, 1986, Figure 2.4), conglomerate lies at this contact.

The four units can be traced into the Sohio Canadian Devonian Pense 14-6-17-22W2 type section in southeastern Saskatchewan and can be categorized, based on Price's (1963) description of the core, as follows:

Sohio Canadian Devonian Pense 14-6-17-22(W2)

Pense Formation

Unit 1 *Bedding Cycles 1 and 2 (16.2 m)*

841.9 to 825.7 m Shale: dark grey, 12.8 m thick, bioturbated near the base and the top; includes a minor but variable component of thin, medium and light grey siltstone and very fine grained, quartzose sandstone as partings and thin interbeds; underlies sandstone, which is 3.4 m thick, quartzose, light grey, kaolinitic, friable, and very fine and fine grained, and contains accessory kaolinite after feldspar, spheroidal glauconite, and grey chert.

Unit 2 *Bedding Cycle 3 (7.5 m)*

825.7 to 818.2 m Siltstone: quartzose; interbeds of fine-grained, sideritic, quartzose sandstone, and gritstone of rounded black and grey chert; fines upward into shaly siltstone with shale-draped ripple cross-beds and abundant carbonized vegetal matter.

Bedding Cycle 4 (0.6 m)

818.2 to 817.6 m Siltstone: quartzose, argillaceous, chloritic; coarsens upward into shale-laminated, burrowed, fine-grained quartzose sandstone with accessory green chlorite, green glauconite, and white kaolinite.

Unit 3 *Bedding Cycle 5 (4.1 m)*

817.6 to 813.5 m Shale: dark grey, grades into bioturbated siltstone.

Unit 4 Bedding Cycle 6 (5.5 m)

813.5 to 808.0 m

Shale: dark grey, abundant fish bones and glauconite; grades through interbedded quartzose siltstone and shale into burrowed, very fine grained, quartzose sandstone.

The shale component of the Pense Formation increases in all units toward the Williston Basin (*i.e.*, southward through the Govan Paleolowland region) to the extent that, at Mobil South Grassdale 32-10 (10-32-6-15W2) (Appendix A), the sandstones are but tongues in black shale. As seen in core, sandstone is quartzose, well sorted, fine grained, strongly current and trough cross-bedded, and features scoured contacts. Bioturbation is general throughout the sand-shale laminated components, and is conspicuous by virtue of relatively large (0.06 to 0.12 m) diameter, closely packed, cylindrical burrows (Figure 44). From the geophysical logs, all bedding cycles coarsen upward, but the sandstone component is least in Units 2 and 4, and most in Units 1 and 3; black shale occupies 16 m of the 29.6 m interval. The Pense maintains a general 30 m thickness into the Williston Basin.

At S.W.P. Bredenbury 11-36-22-1(W2), to the northeast of the type section, only Units 1 and 2 are present in the Pense Formation. The basal transgressive shale of Unit 1 lies on a conglomeratic lag deposit in erosional contact with the Cantuar Formation at a depth of 404.5 m. It coarsens upward over 7.7 m from dark grey, argillaceous, lenticular and flasered, quartzose siltstone, thinly interbedded with grey-black silty shale, into a flat and low-angle cross-bedded, very fine grained, quartzose sandstone with minor carbonaceous and pyritic bedding traces. The 5 m thick Unit 2 comprises lower beds of bioturbated, very argillaceous, very fine grained quartzose sandstone, transitional to well-sorted, fine-grained sandstone, and an upper, bioturbated, argillaceous, very fine grained quartzose sandstone that is interbedded with well-sorted sandstone like that capping the underlying bedding cycle. Units 3 and 4 are condensed into thin, calcite-cemented, glauconitic, lenticular, very fine grained quartzose sandstone with sharp, erosional, lower and upper contacts. They are interspersed with black shale typical of the Joli Fou at 391.7 to 385.9 m, beneath the bright green, glauconitic, and fossiliferous beds of the Spinney Hill interval in southwestern Saskatchewan. Functionally, Pense Units 3 and 4 at this locality are marker beds in the Joli Fou Formation.

At C.M.&S. Vanscoy 11-16-35-8(W3), west of Saskatoon (cross-section A2-A2', Figure 14), all four units are included in the Pense Formation, but Units 1 and 2 are predominant. Unit 1 loses its multicyclic character, consisting only of 3.5 m of bioturbated sandstone and shale. From an erosional contact, Unit 2 coarsens upward over an interval of 6.4 m from black shale, through medial, burrowed interbedded sandstone and shale, into thin, calcite-cemented, low-angle cross-bedded, coarse-grained quartzose sandstone with subordinate white feldspar and brown siderite. Units 3 and 4, with thicknesses of 0.3 m and 1.8 m, respectively, are vestigial, calcite-cemented, lenticular and boudinaged, dark blue-grey pyritic sandstone with subordinate black shale. However, at SWP Boulder Lake DD 1C 16-18-30-23(W2), due north of the type section in the axial region of the former Govan Paleolowland basin, Units 3 and 4, like Unit 2, are upward-coarsening bedding cycles dominated by transitions from black shale to bioturbated sandstone. This location is on the Punichy Arch across which the Cantuar is severely truncated. From its erosional base, the 3.1 m thick Unit 1 (bedding cycle 1) fines upward from trough cut-and-fill, dark grey and grey-black, very fine grained quartzose sandstone and shale into a grey-black shale. Throughout the Govan Paleolowland and the downwarped Swift Current Platform region, bedding cycle 1 of Unit 1, where distinguishable, fines upward from a thin, basal, argillaceous, calcite-cemented sandstone on an erosional contact, and is therefore transgressive. The unit is fully displayed in the core from Duval Saskatoon 6-18-36-6(W3) (Appendix A).

Westward from the Swift Current region to the Sweetgrass Arch of Alberta, the Pense Formation thins by attenuation of Units 4 and 3, leaving only Units 2 and 1 (Christopher, 1974, Plate II). Likewise, in the Kindersley region, Units 1 and 2 are predominant and Units 3 and 4 thin into erosionally attenuated beds (*i.e.*, the 'Transitional Beds' of Maycock [1967]) at about Twp. 30. Farther north, Units 3 and 4 thicken and become the Colony Member (cross-section A-A', Figure 16). Correspondingly, the Pense Formation increases in thickness and undergoes a facies shift, across the Meadow Lake Paleolowland region, to more complex bodies that include mudstone, coal, and channel deposits. At the Vigrass (1977) reference well, Husky Aberfeldy Unit A11-31-49-26(W3) (Figure 16), Units 1 and 2 are correlated with the McLaren Member, and Units 3 and 4 with the Colony Member of the Mannville. The lithological succession at this reference well is displayed in the cored section at neighbouring South Aberfeldy Unit C7-13-49-27(W3) (Appendix A), where the Pense lies in erosional contact with the Cantuar formation at a depth of 506.9 m.

At South Aberfeldy Unit C7-13-49-27(W3), Units 1 and 2, comprising bedding cycles 1 and 2 and bedding cycles 3 and 4, respectively, are assigned to the McLaren Member. Units 3 and 4, incorporating bedding cycles 5 and 6, and bedding cycle 7, respectively, constitute the Colony Member. The 4 m thick Unit 1 is dominated by the 3.2 m thick, upward-fining bedding cycle 2 of trough-cross-bedded, medium- to fine-grained quartzose sandstone. Its

subordinate suite of white kaolinite, brown siderite, green chlorite and glauconite, black chert, and carbonaceous grains, indicates lack of reworking and thus nearby fluvial input. The thin (0.8 m) bedding cycle 1 of argillaceous, very fine grained quartzose sandstone, laminated and bioturbated with grey-black shale, appears to be a remnant of an upward-coarsening, lower-shoreface section. Likewise, the 3.6 m thick bedding cycle 3 coarsens upward. Its impoverished accessory mineral suite of black chert and kaolinite, and its very fine grained and fine-grained, quartzose sandstone transition marked by small-scale flasers, ripple and trough cross-bedding, and grey-black shaly laminae both indicate a lower-shoreface setting. The succeeding carbonaceous mudstone, claystone, and coal of the 3.7 m thick bedding cycle 4 reflect infill of a barred embayment.

The four McLaren bedding cycles at South Aberfeldy Unit C7-13-49-27(W3) are directly comparable to those at Shell Husky Paradise Hill A13-19-52-23(W3), 40 km to the northeast. However, the Shell Husky Paradise Hill truncational bedding cycle 2, at 7.52 m, is twice as thick and the exotic minerals are absent. The quartzose sand is bimodal, fine and very fine grained (rather than fine and medium), and grades upward into burrowed, argillaceous quartzose siltstone. The underlying truncated bedding cycle 1, at 1.78 m, is nonetheless also twice as thick, but consists of laminated shale and siltstone. One can therefore conclude that both beds at Paradise Hill are deeper water equivalents of those at Aberfeldy. The reverse appears to be true for bedding cycles 3 and 4. Bedding cycle 3 coarsens upward at both sites, but at Aberfeldy is thicker (3.6 m), dominated by quartzose sandstone, and grades from very fine to fine grained and from black shale laminated, through ripple and small-scale trough cross-bedded, to flat bedded, flasered and wavy bedded. Cycle 3 at Paradise Hill is 2.45 m thick, and dominated by shale and mudstone under a capping of very fine grained quartzose sandstone. Bedding cycle 4 at both sites is carbonaceous, coaly mudstone and claystone topped by very fine grained quartzose sandstone, and is again thicker at Aberfeldy (3.7 m) than at Paradise Hill (1.71 m). The sandstone is well sorted and current bedded at Aberfeldy, but bioturbated, boudinaged, and argillaceous at Paradise Hill. Thus, the facies of cycles 3 and 4 at the latter site appears to represent deeper water conditions. The total McLaren thickness of 19.8 m at Paradise Hill, versus 11.3 m at Aberfeldy, reflects the increment of subsidence taken up by Unit 1.

The Colony Member at Aberfeldy is only 3.5 m thick, and overlies the McLaren Member on an erosional contact. Its three bedding cycles coarsen upward, individually and overall, from a basal mudstone to fine-grained quartzose sandstone. Sorting is poor and coaly laminae are abundant. Thus, infill of a nearly flat, episodically subsiding shallow embayment is indicated here as well. The Colony Member (bedding cycles 5 to 7 inclusive) at both sites is therefore in erosional contact with the McLaren. Bedding cycles are 1 m thick and mostly loamy interdistributary sands at Aberfeldy, but are 2 m thick at Paradise Hill, except for the 1.7 m thick cycle 7. At both locations, they feature upward-fining sandstone-claystone transitions reflective of deposition in shallow channels.

In the Meadow Lake Basin, the McLaren beds are highly lenticular and variable in thickness, ranging between decimetre values and a metre or two. At the Shell Frenchman Butte A7-3-54-25(W3) well, they are grouped into three bedding cycles. Quartzose sandstone predominates as stacked, friable, well-sorted, current-bedded, very fine grained bodies, separated by thinner, bioturbated shale. As shown on the northern cross-sections, 3 to 5 m thick sand bodies are present locally and represent channel inlet and beach sands. The sandstone of bedding cycle 3 at the Shell Frenchman butte well is 6.3 m thick, and an apparent stacked channel succession. A coal bed on a loamy paleosol caps the McLaren Member, and a basal shale lies at its contact with the Waseca. The Colony Member is a shallower water repetition of the McLaren, and includes bedding cycles 4, 5, and 6 of the Pense Formation. A black shale, 1.6 m thick, initiates bedding cycle 4, and the three bedding cycles are terminated by loamy mudstone suggestive of paleosols and/or marsh deposits and, in cycle 4, by a decimetre-thick coal. Sandstone is very fine grained, quartzose, and variably argillaceous.

To the south-southeast at Canterra et al Prince 1-8-46-16(W3) ([Appendix A](#)), Units 1 (422.2 to 419.14 m) and 2 (419.14 to 415.02 m) are mostly very fine grained quartzose sandstone (heavy-oil permeated), laminated with quartzose siltstone and shale. They are interpreted as channel-fill deposits. Unit 1, which is microfaulted and includes intraformational blocks, 0.13 m in size, and beds, 0.60 m thick and tilted 20°, that overlie a basal plastically deformed bed, appears to be a slumped mass. In that the overlying Spinney Hill Formation is not so affected, deformation probably occurred by warping of the depositional floor, or by groundwater drawdown after initial emergence and consolidation of the sediments. Unit 2 displays numerous broken and distorted pods and lenticles of sandstone, probably indicative of compactional shear in the plastic clay laminae as the result of uneven draping over the slumped mass of Unit 1. Unit 3 (415.02 to 413.0 m) coarsens upward from thin black shale into bioturbated, argillaceous, very fine grained quartzose sandstone, with scattered lenticles and flasers of oil-stained, fine-grained quartzose sandstone. Its fabric is overprinted by compactional partings indicative of lateral slippage. Unit 4 is not cored. Elsewhere, massive sand deposits, 20 to 25 m thick, are indicated at a number of other sites, such as Francana et al Livelong 9-16-52-19(W3), Kissinger Horsehead Creek 7-30-57-20(W3), Wascana Makwa 13-34-57-20(W3), Wascana et al Brightsand 11-13-56-21(W3), NCO et al Poundmaker 6-18-45-21(W3), JCIP et al Unity 10-16-40-21(W3), and NCO et al Poundmaker A5-16-45-22(W3). As well, coal beds capping Unit 2 occur throughout the region.

The Pense Formation overlies the eroded and oxidized surface of the Cantuar Formation at a depth of 162.9 to 169 m in Choiceland No. 1 Choice DD 13-3-50-18(W2) (cross-section A3-A3', [Figure 15](#)). Apparently, only two units are present, of which Unit 1 is well developed. It is a 4 m thick, massive, clayey, medium grey mudstone, with abundant sideritic concretions in the upper half and a black, carbonaceous, basal layer in erosional contact with the Cantuar Formation. The mudstone is split by a medial, thin, quartzose to lithic, fine-grained sandstone with subordinate mudstone grit and quartz-nucleated claystone oolites. The vestigial bedding cycles 2 (1.6 m) and 3 (0.5 m) are foraminiferal (Atkin, 1986), bounded by sharp irregular contacts, and assigned to Unit 2. Bedding cycle 2 fines upward to grey-black mudstone from a bioturbated, irregularly bedded, very fine grained quartzose sandstone, with a medial, thin, sideritic mudstone. Bedding cycle 3 displays a similar sandstone, but with a basal grey-black shale. The erosional contact on the Cantuar Formation indicates a hiatus. The mudstone of Unit 1 appears to be alluvium. Marine incursion occurred during Unit 2 time, as indicated by the foraminiferal beds. Significant gaps in the depositional record are indicated by the erosional contacts.

Roussel (1956), Price (1963), Maycock (1967), Christopher (1974), and Leckie *et al.* (1997b) all concurred that the Pense Formation is marine in character. For southern Saskatchewan, despite the absence of shelly debris, the units of the Pense resemble, in their bedding and bioturbational fabric, the *faciessequenz* of Reineck *et al.* (1968, p300), a depositional model based on marine sediments off the North Sea coast of the inner German Bay, south of Heligoland. In this tidal setting, three depositional facies are distinguished: shelf-mud, transitional, and coastal, which are associated with water depths of 40 to 15 m, 15 to 10 m, and 10 to 0 m, respectively. The graded rhythmites or laminated beds of the North Sea transitional facies are attributed to seasonal storms. Compared to this setting, the units of the Pense can be viewed as prograding marine, in which the terminal sandstone of the sequences represents surf-distributed shore sand; the mudstone-indurated, bioturbated and laminated sandy mudstone represents the intertidal and subtidal zones; and the black shale represents the deeper offshore. Thus, the total thickness of a sequence approximates the depth below sea level at its initiation (*i.e.*, 13.7 to 15 m). The formation is thickest, about 45 m, over the Swift Current Platform in the southwest, thus indicating a relative downset of the depositional floor of that magnitude in that area.

A renewed series of marine transgressions from the northwest (Caldwell, 1984a) accompanied the expanded setting for the Pense Basin. The pervasive dark grey and black mud indicates a poorly oxygenated bottom, and the bioturbated sediments represent subtidal conditions. Both types of deposits are characteristic of the rejuvenated Govan Paleolowland basin and the downwarped former Swift Current Paleo-upland. Great shoal sands, with accompanying shore-fringing marshes and alluvium in the northwest, prograded vast stretches of southwestern Saskatchewan at the end of each of the events associated with episodic downset of the Swift Current Platform.

Eastern sandstone tongues are highly muscovitic, indicative of their derivation from the bordering Precambrian Shield. Similar sandstone flanks the southeastern portions of the Williston Basin in the Dakotas to form the Fall River Formation (Hooper, 1961). The First Cat Creek sandstone of central Montana is part of the Pense body of the Swift Current Platform. 'Colony' sandstone of the northwest is more typically 'Mannville' in character, in that it includes a variety of lithological types representative of intersecting and interbedded coastal palimpsests, such as channel sandstone, beach sandstone, tidal and offshore mudstone, and marsh deposits. The deeper marine part of the Pense Basin appears to have been in the south of the province, where the Pense Formation not only thickens into the Williston Basin but also loses much of its sandstone component, becoming shale-dominated in the transition. This basin morphology was created by a southerly downwarp that deepened the Williston Basin and lowered the Swift Current Platform to form a shelving embayment. As a precursor of the Joli Fou expansion of the marine basin, deepening of the Pense Basin was initiated in the Big Horn Basin of Wyoming (Vuke, 1984), as evidenced by the pattern of thickening of the Lower Colorado Subgroup ([Figure 45](#)). A counterpart uplift of the Sweetgrass Arch of southeastern Alberta is also indicated by westward attenuation of the Pense Formation.

Tectonic Setting

Sub-Cantuar Jura-Cretaceous Erosion Surface

Geomorphic Elements

The sub-Cantuar erosion surface cuts across rocks ranging from the Precambrian basement and the Cambrian Deadwood Formation at Pinehouse and Wapawekka lakes in northern Saskatchewan to the Upper Jurassic Vanguard and Jura-Cretaceous Success strata at the Canada–United States border (Figure 46). This erosion surface is a composite created by several cycles of uplift and denudation associated with the post-Mississippian–pre-Triassic Alleghanian epeirogeny and the Oxfordian to pre-Aptian Columbian orogenic pulses (Stott, 1984). The oldest of the erosion surfaces underlies the Triassic Watrous Formation, where the Watrous is in contact with the Upper Mississippian Big Snowy and Charles groups in the southern part of the province and the Upper Devonian Duperow Formation in the south-central part. Southerly younging of the formations across easterly trending subcrops is a feature of this erosion surface, and the layout of the subcrops to the north of the Watrous edge is apparently of this age. A regional dip toward the Williston Basin during the hiatus is indicated by the annuli of Late Paleozoic subcrops centripetal on the Williston Basin, and by the subsequent southward facies transition in Saskatchewan from continental to marine in the superjacent Triassic and Jurassic strata (Christopher, 1984a).

The later unconformities underlie the Success and Cantuar formations. Relatively large parts of the sub-Cantuar surface feature inliers of the Success Formation on beds ranging from the Late Jurassic in the southern part of the province to Mississippian and Upper Devonian in the south-central part. Sub-Success relief, as measured by the incision of underlying strata, is significant. It is on the order of 75 and 33 m on the Oxfordian Masfield Formation in southeastern and southwestern Saskatchewan, respectively, and about 100 m on the Mississippian limestone of the Kindersley Paleo-upland (Maycock, 1967; Christopher, 1974, Figure 16). On the Punnichy Arch and in the Meadow Lake Basin, as much as 122 and 137 m, respectively, of the Success Insinger beds are preserved in pre-Cantuar structural depressions attributed to salt-dissolution sinks.

The topographic expression of the Punnichy Arch and Kindersley structural terrace is deduced to have been episodically continuous from one to the other and positive enough to have diverted, from time to time, the influx of Success sediments from the northeast to the west and northwest. The broad subcrop widths of the subjacent formations, relative to their thicknesses, suggest a low regional dip and a lower topographic gradient overall. In general, bodies of Success strata, wherever found, are preserved in sub-Success thalwegs and in structural lows. Their preservation north of the Punnichy Arch is attributed to subsidence of the subjacent Upper Devonian surface into sinks created by the dissolution of salt from underlying Devonian formations. On the Kindersley structural terrace and the crest of the Punnichy Arch, these deposits lay protected in interior topographic basins. In southeastern Saskatchewan, preservation was made possible by southerly tilt into an expanded Williston Basin. Success sediments survived uplift of the Swift Current Platform, where they protected the erodible, Upper Jurassic strata on the plateau, probably because erosional processes were short-lived and focussed on downcutting of deep valleys rather than lateral stripping of sediments.

The conspicuous landforms on the sub-Triassic erosion surface are relatively closely spaced annular cuestas with a southward drainage (Martin, 1966), whereas those on the Jurassic, as shown by the isopach maps of the Success and Cantuar formations, feature-entrenched drainage systems controlled by structural blocks and also, in the southwestern and southeastern parts of the province, badlands carved into the Jurassic strata.

Upper Jurassic Masfield and Rierdon Subcrops

Topographically, the Oxfordian Masfield Shale forms broad terraces, generally north of and downstepped with respect to the more resistant Success Formation that caps the Willowbunch Paleo-upland. The Masfield subcrop trends north-northwesterly on the northwestern flank of the Williston Basin and, west of the Third Meridian (longitude 106°W), is distributed as a broad, outlying, serrated belt to the Success Formation of the Swift Current Paleo-upland. From Rge. 19, W 3rd Mer. to the Saskatchewan-Alberta boundary, it forms a vast 'V' re-entrant south of Maple Creek. Southeasterly trending rectilinear re-entrants, the major one of which is the fault-controlled, sub-Cantuar, Eastend Paleovalley (Figure 27), apparently conform to regional lineaments. Along with the overlying Success strata, Masfield beds are stripped back to an escarpment along Rge. 18 and 19, W 3rd Mer., on a front overlooking the Shaunavon Graben.

The 180 km wide subcrop of the Rierdon Formation trends largely west from Manitoba to Alberta, and the truncational slope across the exposure belt averages about 1.75 m/km. However, between longitudes 106° and 104°20'W, the truncation is greatest between Twp. 19 and 21, and reflects pre-Success erosion across the Rierdon Formation, uplifted by the southern flank of the Punnichy Arch. Southward, the exposed surface of the Rierdon Formation conforms more closely to the stratigraphic top, and thereby indicates southward backstripping on a regional dip. North-facing embayments of the Rierdon toe, between Rge. 34, W 1st Mer. and Rge. 11, W 2nd Mer., and between Rge. 15 and 21, W 2nd Mer., accentuate two domes from which the Rierdon was stripped in pre-Success time. Structural sags, formed by subsidence of the domes, accommodate thickened Cantuar deposits. The more easterly sag is the Broadview structural basin, through which the early Cantuar Assiniboia drainage system was directed northward across the eastern part of a similarly depressed Punnichy Arch. The northern expression of this subsidence, but in post-Success, pre-Cantuar time, is seen north of Yorkton in the counterpart northward arc of the Upper Devonian Birdbear subcrop edge, and a concomitant preservation of thick Success strata. Truncation of the Rierdon in the Broadview structural basin is roughly 61 m between Twp. 15 and 12, W 2nd Mer, but only 31 m between Twp. 12 and 3, W 2nd Mer.

Northerly projections of the Rierdon subcrop at Last Mountain Lake and the town of Fort Qu'Appelle correspond to former synforms that have been inverted to present-day antiforms. At Last Mountain Lake, between Rge. 20, W 2nd Mer. and the 3rd Mer., the subcrop projects into the southern flank of the breached structural dome underlying the Jura-Triassic Watrous-infilled topographic basin. Other re-entrants include one that lies below the northwesterly course of the Qu'Appelle River, north of Moose Jaw, and another, 19 km west of Moosomin, that trends southwest from Twp. 17, Rge. 30, W 1st Mer. to Twp. 14, Rge. 1, W 2nd Mer. at Wapella. Both features are sub-Cantuar erosional expressions of structural troughs.

From the Third Meridian, the Rierdon subcrop trends westerly beneath the present South Saskatchewan River to longitude 108°W, where pre-Cantuar erosion has carved a re-entrant into the Shaunavon Graben. At Rge. 25, W 3rd Mer., the erosional edge trends south for about 170 km to the town of Maple Creek before turning northwest into Alberta at Twp. 15 along the northerly and northwesterly trending Eastend–Maple Creek lineament. The strike on the Rierdon subcrop at Rge. 25, W 3rd Mer. is the same as that of the Masefield outlying it to the south, so the projected trace from one to the other may signify the presence of a controlling lineament. Dissection of the Vanguard and Success formations is greatest on the Swift Current Paleo-upland, being about 130 m. It serrated the western scarp, overlooking the northern part of the Shaunavon Graben, into mesas and buttes separated by steep-walled valleys. As shown on the isopach map of the McCloud Member (Figure 27), the valley systems trended east and west from off the crest of the hills. The northwesterly opening Eastend Paleovalley is aligned with the Eastend–Maple Creek lineament and extends into Alberta. The Assiniboia Paleovalley system is entrenched in the Jurassic shale along the front of the Masefield- and Success-capped Willowbunch Paleo-escarpment to the south. In southeastern Saskatchewan, the Weyburn, Estevan, and Northgate tributaries dissect to the south the paleo-upland region of the Williston Basin that is capped by the Jura-Cretaceous and Upper Jurassic.

Middle Jurassic Shaunavon and Gravelbourg Subcrops

The combined subcrop of the Shaunavon and Gravelbourg formations ranges from 5 to 50 km in width, but is generally 30 to 40 km, the combined thickness of the two formations ranging between 76 and 85 m. The widest subcrop expression occurs in the east, on the southern flank of the Punnichy Arch, where it trends northwesterly but sweeps out a southerly arc into the Broadview structural basin, in conformity with that of the Rierdon Formation to the south. Most of the exposure represents a backstripping of Rierdon shale from the Shaunavon Formation cuesta of resistant, cemented sandstone and limestone. To the west, across the southern part of the Watrous topographic basin, the subcrop turns gently to the southwest along an irregular front facing the southern margin of the Kindersley Paleo-upland.

Overall, the Middle Jurassic subcrop belt coincides with the course of the present-day South Saskatchewan River, from the Saskatchewan-Alberta boundary to Elbow (Twp. 24, Rge. 5, W 3rd Mer.), and with that of the present-day Qu'Appelle River, east of the Watrous topographic basin. A departure occurs where the Qu'Appelle River sweeps out a north-opening arc around the plunge of the Watrous structural dome, in contrast to the south-opening arc of Middle Jurassic strata on the counterpart Watrous topographic basin. The southeasterly course of the Qu'Appelle, as an extension of the South Saskatchewan River from the town of Elbow, also coincides with a similarly trending valley re-entrant of the Shaunavon subcrop. The coincidence may indicate that both features are structurally controlled. On the southern flank of the Kindersley Paleo-upland, the southward displacement of the Middle Jurassic subcrop belt reflects pre-Success relative uplift of the region with respect to the Swift Current Platform to the south (Christopher, 1974) and the Punnichy Arch to the east.

Jura-Triassic Watrous Subcrop

The Watrous Formation is overlapped by the Middle Jurassic Gravelbourg Formation, except in the region between Saskatoon and the Quill Lakes (Rge. 2, W 3rd Mer. and Rge. 19, W 2nd Mer.), where it extends northward beyond the Middle Jurassic edge to Twp. 42 as a 60 m thick, red sandy mudstone and anhydrite infill of the Watrous topographic basin. The basin is developed on a breached structural dome, as delineated by the southward bending cuestas of the Upper Devonian Birdbear and Torquay formations, and the Mississippian Bakken and Madison formations. Centrally, the Watrous Formation overlies the Upper Devonian Duperow Formation. Along the western flank of the basin, the Watrous subcrop continues south under the Middle Jurassic Gravelbourg Formation. Watrous strata infill sub-Triassic topographic relief on the Swift Current Platform, and pinch out westward onto the Shaunavon Monocline due to a Middle Jurassic onlap of the Sweetgrass Arch (Christopher, 1984a, Figure 3).

Mississippian Madison Subcrop

The Madison limestone is the predominant ridge builder on the pre-Mannville erosion surface. Along the Punnichy Arch east of the Quill Lakes, the subcrop width is 10 to 64 km. The formation is dissected longitudinally along the crest of the arch like a breached anticline, as indicated by Bakken, Big Valley, and Torquay inliers. The Mississippian topographic front becomes sub-Watrous west of the present-day Quill Lakes. It sweeps out an arc, convex southward around the southern side of the Watrous Dome, that is as spectacular as the counterpart, northward-convex front of the Watrous Formation. West of the Punnichy Arch, the Madison edge is shifted southward on the Unity-Kindersley structural terraces for about 48 km from the projected line of the Punnichy Arch and the subcrops of the Torquay and Birdbear formations, but converges to within 9 km of the Birdbear Formation at the Saskatchewan-Alberta boundary. The exposure width of the Madison ranges from 26 km against the Watrous Dome in the east to 170 km in the west. With the outliers included, the overall exposure width is 106 km. In contrast to the Punnichy Arch, this expansion of subcrop width corresponds to a monoclinical base across which, in the Late Jurassic, the Madison was broadly flexed, karsted to depths exceeding 100 m, and partially stripped, especially toward the east. Karsting of the exposed limestone stopped at its base, on the siliciclastic Bakken Formation. However, backstripping proceeded across the less soluble dolomitic Torquay Formation but on a very low gradient, as indicated by the 1.4 m/km topographic transect of its 67 m thickness.

Upper Devonian Torquay and Birdbear Subcrops

The subcrops of the Upper and Middle Devonian formations strike northwesterly, thereby implying a southwesterly pre-Cantuar dip and a paleo-subsequent drainage gradient to either the northwest or the southeast. The Torquay Formation has an outcrop width that is considerably out of proportion to its thinness of 67 m and its readily erodible dissolution-brecciated carbonate and clastic rocks. The Birdbear Formation, of similar thickness but an integrated carbonate, presents only a narrow (5 km wide) exposure along the Punnichy Arch. In the Kindersley and Unity paleo-uplands, the combined subcrop width of the two formations is a nearly uniform 90 to 100 km, but relative widths of the individual exposures are inverse one to the other. Also, the trace of the Birdbear subcrop is east-west and nearly parallel with that of the Middle Jurassic. The southeasterly recession of the Torquay subcrop reflects a Jura-Cretaceous, pre-Success, antiformal uplift of the Kindersley structural terrace that was greater toward the southeast. On the structural Watrous Dome, both Torquay and Birdbear subcrops can be traced southward around the axis of the dome, in conformity with the trace of the Madison Formation. The expanded Birdbear exposure is a consequence of Triassic, pre-Watrous doming and consequent flattening of the dip. To the east, the Birdbear subcrop forms a north-facing escarpment along the crest of the Punnichy Arch. Outliers to the north are apparent downsets into Early Cretaceous, pre-Cantuar salt-dissolution sinks associated with the northern front of the Middle Devonian Prairie Evaporite.

Upper Devonian Duperow and Older Subcrops

The Duperow paleo-exposure belt is 100 km wide, and trends west to northwest across central Saskatchewan. This great width is due to the 220 m thickness of the formation, as well as to flattening and downwarping of the erosion surface north of the Punnichy Arch. Irregularity of the erosional front is generally related to differential subsidence of the terrain into structural sinks in the Middle Devonian Prairie Evaporite and/or movements of Precambrian structural elements.

East of the Stanley Fault (Padgham, 1967), as projected southwest from the eastern side of Lac La Ronge, the pre-Cantuar erosion surface transects the Souris River Formation across a subcrop width of 40 to 88 km. The erosion surface extends northward across the Middle Devonian Dawson Bay, and Winnipegosis formations onto the Lower Paleozoic Interlake, Red River, Winnipeg, and Deadwood formations. West of the projected Stanley Fault, Souris

River exposures widen to 145 km and the underlying erosional offlap of the Precambrian Shield involves only the Middle Devonian Winnipegosis and Meadow Lake formations. This region is the site of the Middle Devonian Lower Elk Point evaporite basin (Fuzesy, 1980; Meijer Drees, 1986), the southern flank of which lies against the Meadow Lake Escarpment of Ordovician limestone, as delineated by Haidl (1989). Offset and widening of the subcrop belt of the Souris River and Winnipegosis formations against the Stanley Fault can be largely attributed to dissolution of the approximately 180 m thick Lower Elk Point evaporite beds and preservation from erosion of the younger formations by downset into the Lower Elk Point Basin (eastern half of cross-section V-V', [Figure 17](#)). As shown on the sub-Cantuar structure map ([Figure 46](#)), this subsidence was greatest north of Meadow Lake, where a broad, southwesterly plunging synform extends to beyond the Saskatchewan-Alberta boundary. Structural relief is up to 200 m (*i.e.*, equivalent to the structural downset of the Middle Devonian Ashern Formation). The trough includes a large body of the Success Formation, 70 to 145 m thick. East of the Stanley Fault, pre-Success backstripping of the Paleozoic formations occurred across steepened dips created by upwarp of the Molanosa Dome ([Figure 48](#)). West of the fault, the wide subcrop belt of the Elk Point and Souris River formations reflects erosion on the flattened dip of the pre-Success Meadow Lake Basin (*i.e.*, the Lower Cretaceous successor to the Lower Devonian Lower Elk Point Basin).

Evolution of the Structural Regions

Pre-Laramide Structural Setting

Large structural blocks exercised significant control on the erosional fabric of the paleolandscape. The southwestern paleo-uplands were supported by the structural Swift Current Platform (Baillie, 1955; Christopher, 1974) and by upwarp of the Kindersley structural terrace. Similarly, the southeastern Moosomin Paleo-upland (Christopher, 1980) was based on the northerly trending monocline over which the Upper Devonian Torquay and Birdbear formations are truncated toward the east (Christopher, 1961) onto the Birdtail-Waskada Axis of Manitoba (McCabe, 1967). The western front of this structural region in eastern Saskatchewan corresponds to the linear 'Nelson River Gravity Anomaly' in the Precambrian Basement (Hajnal and McClure, 1977), and the Moosomin-Hudson Bay Structural Belt in this report.

The **Kindersley-Unity structural terraces** are oriented east-west along Twp. 24 from the Saskatchewan-Alberta boundary to about Rge. 8, W 3rd Mer. From there, the structural surface, as expressed on the Bakken Formation, dips steeply to the south onto the Swift Current Platform (Christopher, 1974, Figures 17 and 45). The region represents the eastern portion of an infilled Paleozoic Lloydminster Basin, which was active in the Cambrian (Paterson, 1989) and Upper Devonian (Kent, 1968, 1987). It is now mildly antiformal on a northeasterly axis between the towns of Kindersley and the Battlefords, forming the North Battleford component of the Sweetgrass Arch in Alberta (Kent, 1968). The Kindersley structural terrace is delimited in the north by the Upper Devonian Birdbear subcrop, in the east (near the Third Meridian) by the south-southwesterly trace of the Jura-Triassic Watrous Formation, and in the south by the erosional edge of the Upper Jurassic Rierdon Formation. The western limit lies beyond the Saskatchewan-Alberta boundary and is not mapped. A north-south structural zone, between Rge. 10 and 1, W 3rd Mer., separates the Kindersley-Unity terraces from the Punnichy Arch to the east. This is the Saskatoon Trough, and it includes the north-aligned escarpments of the Madison, Watrous, and Birdbear formations, as well as a downset outlier of the Madison Formation.

The **Punnichy Arch** (Christopher, 1980, 2000) is located in southeastern Saskatchewan between latitudes 50° and 52°N. On the present topographic surface, it supports the broad interfluvial and Quill Lakes internal drainage basin between the Qu'Appelle and Saskatchewan rivers. On the sub-Jurassic erosion surface ([Figure 47](#)), the main components are the yoked Watrous and Wynyard domes (west to east). The Punnichy Arch is delimited laterally by north-south elements: to the west, by the Saskatoon Trough along longitude 106°W and, to the east, by the Insinger Trough of the Tabernor Lineament Belt along longitude 103°W. The northern flank overlooks the 150 m deep Humboldt Trough, a collapse sink caused by salt dissolution from the Prairie Evaporite, and the southern limb slopes southwesterly to the 40 m (msl) contour. The arch adjoins the westerly projecting Yorkton salient of the north-south Moosomin-Hudson Bay structural belt. Crest elevations increase southeasterly from 20 m (msl) on the Watrous Dome, to 120 m (msl) on the Wynyard Dome and 140 m (msl) on the Yorkton salient.

Watrous Dome

The striking discordance of outcrop trends in the Punnichy Arch district ([Figure 46](#)) is a product of the three major unconformities. Striking northwesterly with relatively high relief from Manitoba to the Quill Lakes, the Upper Paleozoic subcrops display, beneath the Watrous Formation, a southward bending annulus that delineates the southern flank of the Watrous Dome and, at about 10 km west of longitude 106°W, trends northward and then westward. The Watrous Formation is broadly distributed west of the Quill Lakes, north to Twp. 36 and northwest to

Twp. 42, and is inlaid on a basin floor that transects formations ranging from the Duperow in the north to the Madison in the south, where the Watrous dips beneath the erosional edge of the Middle Jurassic Gravelbourg Formation. The area of the Watrous Basin so defined is approximately 22 000 km². The thickness of the Watrous Formation in this region, which ranges up to 75 m, and its stratigraphy of calcareous, red, argillaceous, quartzose sandstone and siltstone, anhydritic mudstone, and anhydrite, are exhibited in the fully cored section at Alwinsal Lanigan 3-28-33-23(W2) ([Appendix A](#)).

East of the Watrous Dome, the Watrous subcrop trends southeasterly to the Saskatchewan-Manitoba boundary beneath an overlap of the Middle Jurassic Gravelbourg and Shaunavon formations. Little evidence exists of a more northerly extent for the Watrous Formation in this region; from this edge, it thickens southward into the Williston Basin. Thus, during the Jura-Triassic, the Watrous Dome was a depositional arm of the Williston Basin and, to the east, the Wynyard Dome–Yorkton salient presented a significant upland barrier to the Jura-Triassic marine transgression. The combined Shaunavon-Gravelbourg exposure belt conforms to the southern slope of the Punnichy Arch; it therefore trends southeasterly but sweeps out a narrow southerly arc in the Tabernor Lineament Belt at Melville, in conformity with the overlying Rierdon subcrop to the south. Most of the exposure represents backstripping of Rierdon shale from the Shaunavon-Gravelbourg cuesta of resistant, cemented limestone, dolostone, and sandstone. Across the southern part of the topographic Watrous Basin, the subcrop turns gently southwesterly along an irregular front. However, outliers capping Watrous strata to the north, as at Alwinsal Lanigan 3-28-33-23(W2), indicate a deep Middle Jurassic marine penetration of the Watrous Basin. In view of the general Gravelbourg-Shaunavon overlap of the Watrous, this advance likely extended beyond the Watrous edge at Twp. 42.

Wynyard Dome

Vestiges of Middle Jurassic transgression of the Wynyard Dome are either absent or not recognized, perhaps because of a facies change from marine to nonfossiliferous continental. Moreover, the overlap of the Watrous Formation on the relatively steep flank of the dome indicates proximity of a former shoreline, the sediments of which are very much in evidence to the east, extending southward from Twp. 22 along longitude 102°W (Kreis, 1991). Thus, erosional backstripping of Middle Jurassic strata from the Wynyard Dome is implied.

The Madison subcrop east of the Quill Lakes is 10 to 24 km wide, and the exposure is dissected lengthwise along the crest of the arch in the pattern of a breached anticline. Rising 40 to 50 m above this inner valley, the Madison ridge to the north is 3 to 5 km wide and 120 km long, whereas the valley floor is 10 to 20 km wide and originates in the southeast against the Madison escarpment between Yorkton and Melville. There, at the entry to the Broadview structural basin, the Madison exposure widens to 64 km over the Tabernor Lineament Belt, and the valley steps up to an amphitheatre controlled by the re-entrant in the Middle Jurassic escarpment west of Esterhazy. At the northwestern end, on the flattened top of the Wynyard Dome, the valley broadens into a circular, 56 km wide, flat floored by Bakken sandstone. The Mississippian escarpment immediately to the west becomes sub-Watrous as it turns southward along the Watrous Dome. Middle Jurassic onlap of the southern flank of the Wynyard Dome coincided with a northward planation of the Madison Formation, from a thickness of about 60 m to less than 25 m. Thus, the strike valley on the Madison escarpment was probably initiated in the Middle Jurassic as a backshore, flanking basin that was subsequently deepened and flushed of sediments by pre-Success erosion. If the northern outliers are included, then the width of the exposure belt of the combined Torquay and Birdbear formations exceeds 60 km, and the erosion surface is cut across 140 m of strata on a northward slope of 2.3 m/km (*i.e.*, the post-Triassic terrain would have been nearly flat). If the 75 m thickness of the Watrous Formation to the west indicates infill of the topographic Watrous Basin, then the Wynyard Dome, as taken on the sub-Triassic surface, would have been at least that high above the Watrous Dome.

Late Jurassic uplift of the Wynyard Dome made possible deep weathering of the Mississippian carbonate rocks and the accumulation of detrital chert on the dome. This event coincided with karsting of the Madison limestone on the upwarped Kindersley structural terrace. Correspondingly, uplift and weathering of Precambrian granite on the Severn Arch of Manitoba resulted in an outpouring of fluvialite, kaolinitic, quartzose sandstone of the Success Formation, which at one time blanketed all of southern and central Saskatchewan. By the end of Success deposition, the Wynyard Dome, which had been tilted eastward by subsidence in the Tabernor Lineament Belt against uplift of the Precambrian Superior Province, was buried to a depth of 122 m and the crown of the Watrous Dome had become the apex of the Punnichy Arch.

In a regional context, the structural blocks ([Figure 2](#)), by their apparent tendency to rise and fall in opposition to neighbouring elements, reorganized the depositional floor from one geological stage to the next. Thus, in the Middle Jurassic, when the Williston Basin was the regional depocentre, the Swift Current Platform was largely downset with respect to the northern rim of the basin as defined by the Shaunavon Monocline to the west, the Kindersley structural terrace to the northwest, and the Punnichy Arch to the northeast. Gravelbourg, Shaunavon, and Vanguard

sedimentary patterns are therefore centripetal to the Williston Basin (Christopher, 1984a). By the Late Callovian and into the Oxfordian, the Swift Current Platform became positive enough to shape the shoreline patterns of the Rierdon clinoforms, as defined by the Roseray Formation. The platform formed the lower slope of an uplifted Kindersley structural terrace and Punnichy Arch, both of which were breached by drainage systems responsible for Roseray and Success sedimentary influxes to the Williston Basin. East of the Second Meridian (longitude 102°W), the southerly plunging promontory, named the 'Birdtail-Waskada Axis' (Kreis, 1991 *after* McCabe, 1967), partitioned the Jurassic basin along the Saskatchewan-Manitoba boundary.

Uplift of the Swift Current Platform, with concurrent downset of the Punnichy Arch, resumed in the Early Cretaceous. By the Late Neocomian, the platform became the highest region in the Williston Basin, as indicated by the 100 m deep, entrenched, pre-Cantuar valley systems that radiated off of it (Figure 27). Likewise, a northward regional gradient across the Punnichy Arch from the Williston Basin into central Saskatchewan is indicated by the Assiniboia Paleovalley system, controlled by the Tabernor Lineament Belt, that opened into the Cold Lake–Athabasca basins. Apparently, downset of the Punnichy Arch had also tilted the Kindersley structural terrace eastward. Overall regional subsidence began in the Aptian and continued into the Early Albian, as indicated by marine waters that flooded in from the northwest and penetrated the depositional basin well into North Dakota, and by the progressive burial of the Swift Current and Kindersley paleo-uplands in the southwest and the Willowbunch and Moosomin paleo-uplands in the south and southeast. Late Cantuar (Albian) uplift of the region to the north of the Molanosa Dome is indicated by spread of the 'Nipekamew' grit across the dome and development of an associated deltaic fan (Figure 18 and Figure 41). This uplift may have coincided with, or been a result of, intrusions accompanying emplacement of the diamondiferous kimberlite field on the flanks of the dome. As described in Leckie *et al.* (1997a), known occurrences of kimberlite are recorded from the Cantuar, Pense, and Joli Fou formations.

Laramide Structural Setting

The present regional tilt of the sub-Cantuar erosional surface (Figure 46) was initiated in the Late Albian by tectonic events that created the Pense Basin and facilitated its marine invasion. Uplift of the Punnichy Arch restored the southerly regional dip into the Williston Basin, and foundering of the Swift Current Platform accompanied an expansion of that basin to dimensions that included the Powder River Basin of Wyoming. This negative state remained throughout the Lower Cretaceous, so that the Williston Basin proper and the adjacent Central Montana Platform served as depocentre for the succession of Colorado strata (Koziol, 1988). Further tilt of the platforms hinged on subsidence of the Williston Basin, which continued into the Paleocene and whereby the influx of sediments from the Rocky Mountain belt to the west and southwest was accommodated.

Accordingly, the contemporary Saskatchewan monocline downsteps to the south and southwest on the southerly tilted terraces of its major structural components: from an elevation of 375 m (msl) at La Ronge to –726.7 m (msl) on the Canada–United States border south of Estevan. With respect to the pre-Cantuar topographic surface, the most striking difference in the structural surface is the reversal of the former regional gradients: the Swift Current Platform, which commanded the heights of the region in early Mannville time, now lies at the base. Elevations of –400 m (msl) or so, on the southern flank of the Swift Current Platform at the Third Meridian (longitude 106°W), are now some 580 m below the elevation of 180 m (msl) in the district between Primrose and Churchill lakes, on the course of the Assiniboia Paleovalley as plotted in this report. The difference represents a post–Early Cretaceous southerly downwarp at least as great. It was likely twice as great, if the pre-Cantuar regional topographic elevation difference of 590 m, as calculated from the Assiniboia paleothalweg on the basis of a course gradient of 0.38 m/km, is added. The sum of these differences indicates a total downset of 1110 m. In spite of the structural reversal of the pre-Cantuar topographic slope, the forms of the structural blocks themselves, along with much of the relief of valleys, interfluvies, and large and small mesas and domes, are retained on the structural surface, especially in the former paleo-uplands of western Saskatchewan. The lowered Swift Current Platform, between longitudes 109° and 105°W, is characterized by northwesterly and northeasterly lineaments and elevations between –240 and –300 m (msl) on the higher surfaces. To the west, the north-aligned Shaunavon Monocline rises onto the eastern flank of the Sweetgrass Arch of Alberta. As shown on in Figure 46, the Success Formation caps many of the highs on the Swift Current Platform, and the 'V' trace of older Jurassic formations is present in the troughs.

Straddling the Canada–United States border at longitude 108°W, the northern third of the Laramide Bowdoin Dome projects into Saskatchewan from Montana. Its relief of 240 m makes it the highest of the domes in the province. An ancestral predecessor appears to have been the Middle Jurassic Shaunavon Climax Apron (Christopher, 1966). To the west of the Bowdoin Dome lies the Shaunavon Graben, a shallow, northerly trending trough between the Shaunavon Monocline to the west and the Swift Current Platform to the east. The graben has acted as a hinge for opposing vertical movements between the Sweetgrass Arch and the Swift Current Platform (Christopher, 1984b).

The Kindersley structural terrace, between the Saskatchewan-Alberta boundary and the Third Meridian, is elevated about 120 m above the Swift Current Platform along Twp. 20. It rises to the north, but over an irregular surface of subsidiary knobs and depressions, representative of post-Mississippian karst and Devonian salt-dissolution sinks. The narrow, easterly trending, ridge-like highs between the boundary at Twp. 32 and Rosetown (Twp. 30, Rge. 14, W 3rd Mer.) reflect the Mississippian limestone northern escarpment overlooking the Success (detrital) basin to the south. At Twp. 42, the higher flats of the Unity structural terrace, cut on the Duperow Formation, strike northwesterly.

The Punnichy Arch trends southeasterly in the 290 km wide region between Saskatoon and Yorkton, and between latitudes 51° and 52°N. Elevations (relative to mean sea level, msl) on the arch rise toward the southeast, from –80 m to 63 m on the Watrous Dome to between 40 and 100 m on the Wynyard Dome. The Watrous Dome is sharply delineated and penetrated by narrow troughs, about 250 m deep. These are structural depressions caused by dissolution of underlying Devonian salt beds. However, a similar depression, 30 to 50 m deep, on the nearly flat Wynyard Dome along Twp. 27 west of Yorkton, represents a pre-Cantuar valley carved into the Mississippian limestone. As demarcated by the subcrop edges of the Birdbear and Watrous formations, the Punnichy Arch overlooks, to the north, the northwesterly trending, 150 m deep Humboldt Trough. Beyond lies the rectangular, bi-terraced Melfort Amphitheatre, which rises northeastward to elevations similar to those of the Wynyard Dome. To the east, both the amphitheatre and the Punnichy Arch end against the northerly trending, easterly rising Moosomin–Hudson Bay structural belt.

The Moosomin Paleo-upland of southeastern Saskatchewan was a Jura-Cretaceous, dissected high plain much like the Kindersley, except that its structural elements are northerly aligned and it extends eastward into western Manitoba as the Birdtail-Waskada Axis and southward into North Dakota. On the sub-Cantuar structure map of Saskatchewan (Figure 46), the structural belt extends north to the town of Hudson Bay; in this report, it is therefore designated the ‘Moosomin–Hudson Bay structural belt’. At Twp. 6, the structural belt swings southeastward into Manitoba. North to Twp. 16 it is relieved by erosion-accentuated, northeasterly trending, synclinal re-entrants and anticlines. From Moosomin to Esterhazy, the eastern limb of the Broadview structural basin coincides with the structural belt and, at Yorkton (Twp. 26), a westerly projection of the belt, crosscut by narrow depressions, joins the Punnichy Arch. The structural belt here, at 140 to 160 m (msl), overlooks the Wynyard Dome by 20 to 40 m and rises northward as a large antiform, trending north-northeast, some 190 km to Hudson Bay (Twp. 45) and Manitoba.

The Molanosa Dome lies north of latitude 54°N. It rises northward along Rge. 23, W 2nd Mer., from 269 to 392 m (msl) on the sub-Cantuar surface, and commands the structural region north of the Melfort Amphitheatre. Its northern and eastern fronts are encroached upon by the Tertiary erosional edge and the dome is terminated in the west by the southwesterly trending projection of the Stanley Fault. Though extant in the Cantuar depositional basin, its high structural relief indicates substantial post-Cantuar uplift (which, by inference, is Late Cretaceous to Tertiary). A southwestern spur of the dome terminates against the Unity structural terrace along the northwesterly trending Battleford Trough. From the trough, the surface climbs northeastward at a rate of 1 m/km, the steepest in the northern region.

In the northwest lies the Meadow Lake Basin, which is, in effect, a Cantuar derivation of the predecessor Lower Devonian evaporite basin of that name (Grayston *et al.*, 1964). It is the eastern portion of a trough extending from central Alberta, and is delimited to the north by the Cenozoic erosional edge, to the northeast by the Molanosa Dome and to the south by the Meadow Lake Escarpment. The Meadow Lake Basin is tilted toward the south, and consists of southwesterly plunging re-entrant troughs and intervening irregular domes. The most prominent of the re-entrants is the Doré Lake Trough, the floor of which is flanked by sub-Cantuar heights of 140 to 200 m in the south, 260 m on the Beauval Dome 115 km to the north, and less than 70 m in the west. From elevations exceeding 350 m (msl) in the east, the trough plunges irregularly along its 220 km long axis to –10 m (msl) at the Saskatchewan-Alberta boundary. The southern half of the trough is terraced 100 m below the top, from Doré Lake to the town of Meadow Lake, and grooved by a westward widening inner trough that links lows under Primrose Lake to the north and the northwesterly trending Battleford Trough to the south. Likewise, the Beauval Dome, between Doré Lake and Peter Pond Lake, appears to be a compound form that, near Alberta, overlooks the Primrose Lake arm of the Doré Lake Trough. The 160 m deep re-entrants fronting Peter Pond Lake and La Loche to the west are upper level extensions of the Athabasca tar-sand basin at its southeastern end.

Structure Related to Salt Dissolution

The sub-Cantuar structure map (Figure 46) depicts a network of narrow depressions that corresponds to the drainage system of the pre-Cantuar erosion surface (Figure 12 and Figure 27). However, an overlay of the McCloud (Dina-Cummings) isopach map or the Cantuar isopach map (both of which mirror pre-Cantuar relief) reveals significant departures of structure from isopach. A study of this phenomenon carried out for the Mannville of the Swift Current Platform (Christopher, 1974, Chap. IV) and for the Punnichy Arch (Christopher, 2000) shows these differences to

be of three types: 1) structural relief between two points that are well in excess of the Mannville isopach difference; 2) structural extension and diversion of isopach elements; and 3) structural highs created by drape of non-reef, thickened sedimentary masses. Changes of these types are attributed to dislocation of strata by the episodic removal of salt from sites in the underlying Middle Devonian Prairie Evaporite (Bishop, 1956; Sawatzky *et al.*, 1959; Christopher, 1961; Wilson *et al.*, 1963; Smith and Pullen, 1967; Kent, 1968) prior to, during, and after deposition of the Cantuar Formation. Whereas pre-Cantuar relief and penecontemporaneous structural changes are recorded as anomalous thicks and thins in the isopach maps of the members, post-Cantuar anomalies are recorded in the structure map on the Cantuar Formation, except for those localities where inliers in the Cantuar blanket occur (Figure 48).

Pronounced scarps terrace the northwestern and northeastern flanks of the downset Swift Current Platform. These slopes are also coincident with the southwestern solution edge of the 200 m thick salt beds of the Prairie Evaporite (Figure 48; Lahey, 1964; Holter, 1969; Fuzesy, 1982), and this region of the Swift Current Platform is often referred to as the 'No Salt Area'. Because of the platform's relatively positive elevation in the Devonian, evaporite beds thinned southwesterly across it to about 65 m. This amount of elevation loss at the base of the Cantuar Formation can therefore be attributed to settling of the post-Prairie Evaporite formations into space vacated by the salt beds (Christopher, 1961). Off the northern edge of the platform into the northeasterly trending Elbow depression, elevation difference across the flanking scarp is about 260 m. This is also true along the eastern flank of the platform, marked by the Elbow-Weyburn Lineament (Christopher, 1980). These values correspond to the greater thickness of salt beds that was present in those regions of the platform and removed in post-Cantuar time.

Across central Saskatchewan, the northern front of the Prairie Evaporite salt mass generally coincides with the northern flank of the Punnichy Arch and Unity structural terrace. East of longitude 104°W, it is deeply recessed on the Wynyard Dome and into the Tabbernor Lineament Belt. To the west, the salt front follows and is delineated to a great extent by the northwesterly trending Humboldt Trough; however, beyond the Third Meridian, it shifts to the southwest where it coincides with the southeasterly alignment of the North Saskatchewan River. Beyond that as far as the Saskatchewan-Alberta boundary, it is northwesterly aligned along the Battleford Trough. The erosional scarps of the Birdbear and Watrous formations along the northern front of the Punnichy Arch overlook the Humboldt Trough, and thereby suggest a common structural control. Also, the western flank of the Watrous Dome impinges on the Saskatoon Trough. This trough, though predominantly post-Cantuar in development, indicates a genesis as old as the Jurassic by its coincidence with pre-Cantuar topographic elements. Likewise, the Battleford Trough is associated with Cantuar thicks and therefore with an Albian precursor. The troughs represent linear salt-dissolution sinks, but their episodic persistence through time implies basement control.

On the Punnichy Arch, not much of the Success strata would have survived the succeeding pre-Cantuar erosional episode, but for the drastic modification of the Success terrain by site-specific collapse of the underlying Devonian carbonate into caverns created by the dissolution and removal of the Devonian salt beds. The northern front of the Punnichy Arch is modified by these irregularities, and the Insinger Trough (in Twp. 27 to 29 Rge. 7, W 2nd Mer., inclusive) is an archetypical compound salt-dissolution sink. Located over the Cussed Creek embayment in the Prairie Evaporite salt beds (Li *et al.*, 1998), the Success and Cantuar strata in the trough (Figure 49) show large-scale displacements and truncations. Along the 15 km line of section that extends south from Sohio Western Pet Insinger 9-16-29-7(W2) to Winsal Jedburgh No. 12-11-27-7W2, the major unconformities depicted are at the base of: 1) the Jura-Cretaceous Success Formation, 2) the Aptian-Albian Cantuar Formation, and 3) the marine Albian Pense Formation.

The Success section at the Insinger well is downset 122 m with respect to that at the neighbouring Sohio Theodore No. 1 (4-22-28-7W2) well, as indicated by their common contact on the Upper Devonian Torquay Formation. This Theodore well is taken as a benchmark, because it also shares a common sub-Success stratigraphic base on the Torquay Formation with B.A. et al Pine Hill 8-29-27-7W2, located near the southern end of the trough. Just beyond, at Winsal Jedburgh No. 12-11 (12-11-27-7W2), the Success Formation rises onto the Mississippian Madison limestone. Accordingly, the Success sections at Chel TRC Teck Theodore 16-9-28-7W2 and Winsal Theodore 12-11-28-7W2 are also downset. However, the sub-Success erosion surface at these sites lies within 10 m of the Duperow-Souris River contact, and some 229 m of Upper Devonian strata, involving the Duperow, Birdbear, and Torquay formations, are missing from the sections. Insertion of this stratal thickness below the sub-Success erosion surface at Winsal Theodore 12-11-28-7W2 would raise the erosion surface to the stratigraphic horizon of the sub-Pense unconformity. Although the combined thickness of the Success formation (110 m) and the Cantuar Formation (121 m) approximates the thickness of the missing Devonian strata, the loss of the latter does not equate to simple erosional removal. The Success Formation is present, in its entirety, in all of the wells, from B.A. et al Pine Hill 8-29-28-7(W2) in the south, where it onlaps the Torquay Formation, to Sohio Theodore No. 1 (4-22-28-7W2) and Sohio Western Pet Insinger 9-16-29-7(W2) in the north, where it also overlies the Torquay Formation. Thus, it is likely that the pre-Success erosion surface at Winsal Theodore 12-11-28-7(W2) and Chel TRC Teck Theodore 16-9-28-7(W2) lay above the sub-Pense unconformity, on an uplifted block that was eroded to within 10 to 17 m of the

Duperow–Souris River contact. This contact at Winsal Theodore 12-11-28-7(W2) has a sub-Pense stratigraphic relief of 52 m above that at B.A. et al Pine Hill 8-29-27-7W2. Episodic settling of the uplifted block accompanied Success and Cantuar infill to depths of 110 and 121 m respectively. The pre-Pense stratigraphic relief on the Souris River Formation, with respect to the B.A. et al Pine Hill 8-29-27-7W2 site, indicates a 52 m erosional loss of the Cantuar to pre-Pense truncation.

The present –205 m (msl) structural elevation of the Souris River Formation at Winsal Theodore 12-11-28-7(W2), versus the –150 m (msl) at Chel TRC Teck Theodore 16-9-28-7(W2), indicates a relative post-Mannville lowering of the former site by 55 m. A measurement of subsidence at the Sohio Western Pet Insinger 9-16-29-7(W2) site, where movement was apparently unidirectional, is obtained by adding the Cantuar thickness of 70 m to the 122 m of Success strata, for a total of 192 m. This value is not unlike the pre-Pense net subsidence of 177 m at the Winsal Theodore 12-11-28-7W2 well. The projected elevation of the Souris River contact in the Insinger well, at –301 m (msl), is the deepest in the line of section, and the Prairie Evaporite salt beds are assumed to be entirely gone. At the Chel TRC Teck Theodore 16-9-28-7W2 well, this contact, at –150 m (msl), is above 150 m of Prairie Evaporite salt beds which, if removed, would lower the Souris River contact to –300 m (msl), the same elevation as in the Insinger well.

The elevations of the stratigraphic datum on the Pense Formation in the Sohio Western Pet Insinger 9-16-29-7(W2), Sohio Theodore No. 1 (4-22-28-7W2), and Chel TRC Teck Theodore 16-9-28-7W2 wells are within a range of 8 m. The lowest elevation is at Winsal Theodore 12-11-28-7W2, which, at 52 m (msl), is 129 m below the adjacent well to the south, B.A. et al Pine Hill 8-29-27-7W2. Thus, early Albian collapse at the Insinger site is succeeded by post-Pense collapse at Winsal Theodore 12-11-28-7W2. Apparently, the wells to the north also shared in the latter movement, but only by half as much. With respect to Winsal Theodore 12-11-28-7W2, the 129 m downset probably reflects loss of Prairie Evaporite salt beds from the section; by comparison with the 150 m salt section at Chel TRC Teck Theodore 16-9-28-7W2, only 21 m remain at Winsal Theodore. It is noteworthy that the pre-Pense section at Sohio Theodore 4-22-28-7W2 displays a stratigraphic uplift similar to that postulated for the Chel TRC Teck Theodore and Winsal Theodore wells, but shows a projected loss of only 70 to 122 m of Cantuar section. Both structural and stratigraphic displacements on the Souris River Formation and the B bed of the Success Formation, with respect to Sohio Western Pet Insinger 9-16-29-7(W2), are similar (*i.e.*, 137 and 122 m, respectively). These differences indicate that a thickness of about 130 m of Prairie Evaporite salt beds is present at Sohio Theodore No. 1 (4-22-28-7W2). Because Chel TRC Teck Theodore 16-9-28-7W2 also retains a similar thickness of Prairie Evaporite salt, pre-Pense uplift and erosion of the Devonian strata at this well and at Winsal Theodore 12-11-28-7W2 are assumed to be a function of tectonic forces. These two wells are located about 1.5 km apart on a structure astride the Insinger Trough that, in turn, is located on a seismically detected basement graben in the Tabernor Lineament Belt (Li *et al.*, 1998).

Collapsed Souris River strata and the sub-Cantuar topographic low at the Choiceland No. 1 Choice DD 13-3-50-18(W2) well indicate the former presence of the Prairie Evaporite salt in that region and pre-Cantuar removal. The coincidence of these features with an underlying Precambrian monadnock strengthens the postulation of Gendzwil (1978) for the region to the south, that initiation of salt-dissolution collapse phenomena at a given site is caused by the presence of a sub-Prairie Evaporite topographic high, namely a Winnipegosis reef. The relative lows on the post-Cantuar terrace at Choiceland and Hudson Bay, and on the terrace above the Melfort Amphitheatre, indicate post-Cantuar salt removal in the region. Pre-Cantuar sapping of Prairie Evaporite salt to form the Melfort Amphitheatre also accounts for the preservation of Success (Insinger) beds from pre-Cantuar erosion by downset below local base levels, as in the reference Socony Western Pet Insinger 9-16-29-7(W2) well to the southeast, where these beds are preserved in sinks along the northern front of the Punichy Arch.

A spectacular displacement of pre-Cantuar stratigraphic datum levels, which can largely be attributed to loss of salt section at depth, is apparent in the former Lower Elk Point Basin, north of the Meadow Lake Escarpment (Fuzesy, 1980; Meijer Drees, 1986). As shown in cross-section U-U' (Figure 18), Devonian stratigraphic datum levels as a group, beginning with the Ashern Formation in the region between the Saskatchewan-Alberta boundary and the Meadow Lake Escarpment at Great Plains McDermott Home Hay 3-18-63-1(W3), display discordances of some 200 m with respect to the sub-Cantuar erosion surface. Displacement of the Ashern Formation, for instance, is greatest against the Stanley Fault (projected) and about equal to the thickness of the missing Lower Elk Point evaporite beds. A major portion of this displacement is pre-Success, and the remnant Success beds have taken up 20 to 140 m of this relief, so that the sub-Cantuar surface, as shown on the isopach map of the Cantuar Formation (Figure 12), was essentially planar, except for the local horsts and troughs controlling the course of the early Cantuar drainage. The structural gradients in the western part of the basin reflect post-Cantuar subsidence and, by extension, the current phase of salt dissolution. Thus, the Doré Lake Trough in the southern part of the Lower Elk Point Basin retains a post-Cantuar presence as a southwesterly opening, compound depression that becomes more irregular toward the west and southwest, close to the Lower and Upper Elk Point salt fronts.

Mannville Linear Elements

Regional and local linears recorded on structure and isopach maps of the Paleozoic and Mesozoic formations and the present topographic surface, and the subject of lineaments in general, are extensively reviewed in Mollard (1987, 1988), Penner and Mollard (1991), and Gregor (1997). Mollard concluded that lineaments in southern Saskatchewan form two major suborthogonal sets: 305° to 310° and 035° to 040°, and 320° to 325° and 050° to 055°. However, in subsurface mapping, these bearings may vary by up to 15°, depending on how the lineament trends are measured from map to map. Likewise, a similar variation can occur between those readings taken on isopach maps versus those from structural counterparts. Discrepancies arise from the imprecision in subsurface mapping of dispersed data points, as well as from the nature of lineaments themselves. Subsurface linear map forms can be discernible for many kilometres, but they represent extrapolations based on aligned structural and isopach anomalies that, over a distance, may well include offsets within a zone of lineaments. Major linears apparently originate in the basement, and are propagated through the sedimentary section episodically over geological time, as faults, flexures, fracture zones, and master joint sets.

Pervasive northeasterly and northwesterly stress directions, as determined from breakouts in well bores distributed across the Western Canada Sedimentary Basin (Gough and Bell, 1981; Bell and Babcock, 1986; Bell *et al.* 1994), are attributed to an origin in the lithosphere. The above authors determined that the horizontal stress was greatest toward the northeast and least toward the northwest, and that this phenomenon reflects strain in the lithosphere created by drag effects from continental plate motion toward the south-southwest relative to the mantle. This asymmetry corresponds to northeasterly trends of enhanced permeability in reservoirs of some of the larger oilfields, such as Pembina and Cold Lake in Alberta. Stauffer and Gendzwill (1987), from their survey of surface fractures in the Precambrian Shield of Saskatchewan, stream drainage directions, and published subsurface sedimentary patterns, agreed with the sense of plate motion. Northeast would be the direction of maximum stress for a dominant set and northwest for a subordinate set, but both sets of fractures are likely extensional in origin, formed by uplift of the crust within the continental stress field. The subordinate set would have originated as early as the Late Jurassic.

Fracture patterns in southeastern Saskatchewan were examined in a case history of the waterflood and CO₂ flood of the Mississippian Midale oilfield by Beliveau *et al.* (1993), who found that the fractures are vertical to nearly vertical and, depending on the lithology, have height and spacing ranging from a centimetre to 1.2 m. The effect of these fractures on enhancing permeability produced a strong anisotropy toward the northeast (48°, as measured on their map). Control on the geometry of the Lloydminster heavy oilfields by northwesterly and northeasterly lineaments was also examined in Klován *et al.* (1986), Mollard (1987), and Gregor (1997). They observed that Lloydminster oil pools tend to be aligned northwesterly and cut off by northeasterly trending linears. They attributed the local structural relief in the district to small-scale movements induced along the linears by episodic basement activity. Slip along northeasterly trending lineaments opened northwesterly oriented fractures, which were accessed by formation waters dissolving salt beds of the Prairie Evaporite. Thus, northwesterly oriented subsidence structures in the Mannville were created. Wilmot (1985) also attributed irregularities of sedimentary isopach patterns in the Edam oilfield to this phenomenon.

The major linears in the regional Mannville setting are depicted in [Figure 50](#). Conceptually, they are relatively broad zones that incorporate multiple fractures and minor faults over structurally controlled depositional forms in the Paleozoic and Mesozoic. Linears appear to belong to three families: the two defined above and a third set oriented north-south and east-west. The most prominent is the Elbow-Weyburn Lineament, aligned 307°. It coincides with the Middle Devonian Winnipegosis reef trend, but is duplicated to the east by the southeastern dissolution front of the Middle Devonian Prairie Evaporite and the Upper Devonian Davidson Evaporite (Lane, 1964), and, at ground surface 68 km to the west, by the erosional front of The Missouri Coteau. The Elbow-Weyburn Lineament also appears to be the most persistent of the Phanerozoic lineaments, in that it is recorded as early as the Silurian by an isopach axis of southeasterly thickening (Paterson, 1973; Kreis and Haidl, 1995). The lineament appears on the sub-Cantuar geological map ([Figure 46](#)) as a re-entrant into the Rierdon erosional front, under the present-day Qu'Appelle Valley, southeast of the town of Elbow. It also coincides with the southeasterly trending erosional front of the Jura-Cretaceous Success Formation, between the cities of Weyburn and Estevan.

Linear forms throughout southwestern Saskatchewan, though rotated to 313°, echo the Elbow-Weyburn Lineament: 1) in the isopach patterns of the Mannville units; 2) in both structure contours and isopachs of the Middle Jurassic Shaunavon Formation on the Shaunavon Shelf; and 3) in miniature, on three-dimensional seismic time slices in the Vanscoy potash mining district, west of Saskatoon ([Figure 51](#)). The complementary bearing, 034°, is picked up by the regional strike of the Shaunavon Monocline as delineated by the 1400 ft (427 m) contour (Christopher, 1966) and the southwestern front of the Prairie Evaporite south of latitude 51°N. In southeastern Saskatchewan, the bearing 053° is fairly well defined by the Mannville expression of the Torquay-Rocanville Trend (Christopher, 1961), as depicted by the alignment of the formation-water high-pressure zone in the Mannville and by the

northeasterly aligned arm of the Lower Colorado Newcastle sandstone channel complex (Figure 50; Koziol, 1988). Structural downset related to the Newcastle is observable on the sub-Cantuar erosion surface (Figure 46). On the Bakken Formation, however, the alignment of the Rocanville-Torquay Trend is 044° and is apparently an extension of the Weldon-Brockton-Froid Fault of Montana and North Dakota (Lefever and Crashell, 1991).

The significance of north-south and east-west sets has been underemphasized in the literature, possibly because of overprint by the northwest and northeast sets. The Shaunavon Graben in southwestern Saskatchewan is an example. Its flanks are serrated by northwesterly and northeasterly elements that outline similarly oriented troughs and terraces, respectively, but the graben itself trends north from the Canada–United States border to latitude 51°N. On the sub-Cantuar erosion surface, the western flank of the graben is expressed as the western escarpment of the Success Formation along Rge. 18 and 19, W 3rd Mer. North-south multiples are displayed to the west of longitude 109°W by similar alignments of the Middle and Upper Jurassic erosional edges between the South Saskatchewan River and the Canada–United States border.

In west-central Saskatchewan, the best expression of the north-south trend is topographic, specifically the alignment of the Mudjatik River, Lac Ile-à-la-Crosse, the Beaver River, and Green Lake. South of latitude 54°N, the trend is displaced 30 km to the east of the Shaunavon Graben at latitude 51°N, but multiples are seen on the Kindersley-Unity structural terraces in the north strike of the Three Forks and Birdbear erosional fronts between Twp. 32 and 38, Rge. 24, W 3rd Mer. Some of the major Phanerozoic sedimentary trends of west-central Saskatchewan suggest, by their north-south alignments, a relationship to this belt of linears. Thus, the eastern front of the western body of the Middle Devonian Prairie Evaporite lies along it at Rge. 10, W 3rd Mer. There was also Early Colorado activity, as indicated by the spatial coincidence of the western edge of the Spinney Hill Sandstone with the linear belt (Koziol, 1988). These apparent multiples of the Ile-à-la-Crosse Lineament are more easterly analogues of those along the Shaunavon Graben. In the Mannville, the eastern front of the Sparky coal beds on the Kindersley-Unity terraces, as extrapolated to the south, coincides with the western flank of the Shaunavon Graben.

East and west of longitude 106°W in central Saskatchewan, a similar belt of north-south linears can be delineated on the topographic surface by the Foster and Montreal rivers, Montreal Lake, and tributaries of the Saskatchewan River. In the subsurface, it coincides with: 1) re-entrants in the northern front of the Prairie Evaporite and the western flank of the Punnichy Arch (Figure 48) at latitudes 53° and 52°N; 2) re-entrants on the southern flank of the Punnichy Arch and the toe of the Rierdon subcrop at latitude 51°N; and 3) the flanking troughs of the Roncott Prairie Evaporite salt outlier at the Canada–United States border.

The Tabbernor Lineament Belt is an eastern counterpart of the Lac Ile-à-la-Crosse Lineament. It is well displayed in the Precambrian Shield and is traceable southward well into the Phanerozoic sedimentary basin, where it appears to be a western parallel of the Moosomin–Hudson Bay structural belt. The intervening region includes the pre-Cantuar Assiniboia Paleovalley, so faulting was apparently reactivated in the Jura-Cretaceous. The Early Albian southerly elongation of the Waseca erosional edge along Rge. 10, W 2nd Mer. reflects pre-Pense downset, and the Late Albian north-south alignment of the Newcastle barrier-beach sandstone between latitudes 50° and 53°N (Koziol, 1988) indicates mild uplift (Figure 50).

The Kindersley structural region features a high concentration of east-west and north-south short lineaments. These probably record episodes of flexuring between the Swift Current Platform to the south, the Punnichy Arch to the east, and the Unity structural terrace to the north. In the Meadow Lake Basin, the east-west trend is seen in the alignment of the Holocene Beaver and Waterhen Rivers in Twp. 62. In southwestern Saskatchewan, the sub-Jurassic Adams Creek re-entrant (Christopher, 1966) along Twp. 6, as well as the present-day Frenchman River valley west of Eastend, are similarly aligned. Overall, north-south and east-west lineaments appear to be genetically associated with the major structural elements of the Phanerozoic basin outside the Swift Current Platform. They shape the overall configuration of the Punnichy Arch, the Moosomin–Hudson Bay structural belt, and the Shaunavon Graben, and seem to represent hinge zones for regional vertical movement between the large structural blocks. The age of the north-south linear sets may well be Early Proterozoic, in that the Trans-Hudson structural bodies displayed on the aeromagnetic map of the Precambrian basement show significant north-south elongations (Figure 52). The north-south linears may also have served to accommodate post-Laramide epeirogenic uplift, downstepping eastward from the Rocky Mountain region. They are therefore likely to be tensional in character, although the southeasterly offsets of the erosional edges of the Phanerozoic formations may indicate dextral slip. They may also have controlled the depositional setting of some of the petroleum reservoirs, as indicated by the north-south alignment of the Mannville Aberfeldy and Tangleflags fields, as well as the general north-south distribution of the Jurassic oilfields in southwestern Saskatchewan, the oilfields at the western edge of the Mississippian oilfield district in southeastern Saskatchewan, and the Mannville Wapella and Jurassic Red Jacket oilfields in southeastern Saskatchewan.

Precambrian Basement-sourced Tectonic Elements

A summary account the Archean and Proterozoic Precambrian Shield in Saskatchewan is given in Macdonald (1991). The Shield is areally divided into 'domains' (Lewry and Sibbald, 1977): lithotectonic belts that trend south-southeasterly in three geological regions, namely (from west to east) the Western Craton, the Cree Lake Zone, and the Reindeer Zone (Figure 52). The predominantly Archean Western Craton is the southward extension of the Keewatin Zone of the Northwest Territories, and comprises granulite, granite, and anorthosite. The Cree Lake Zone represents a remobilized ensialic miogeoclinal belt on the western flank of the Trans-Hudson Orogen and is divided, from west to east, into the Virgin River, Mudjatik, and Wollaston domains. The Mudjatik Domain is primarily Archean granitoid gneiss, with subordinate supracrustal metapelite, amphibolite, and iron formation, whereas the Wollaston Domain is an Aphebian (2400 to 2200 Ma) metasedimentary belt of mostly meta-arkose and pelite.

The Early Proterozoic (1880 to 1800 Ma) Reindeer Zone (Lewry and Sibbald, 1980; Stauffer, 1984) comprises eugeoclinal volcanic arc, plutonic and interarc greywacke-shale assemblages that were generated between convergent continental plates. It includes, among others, the Rottenstone, La Ronge, Glennie, Kiseynew, and Flin Flon domains. The plutonic Wathaman monzonitic to quartz dioritic batholith characterizes the western two-thirds of the Rottenstone Domain, and interfingering tonalite-trondhjemite intrusions and psammitic to psammopelitic metagreywacke occupy the remainder. Low-potassium tholeiitic to calc-alkalic metavolcanic rocks, attributed to an island-arc origin, typify the La Ronge belt, and granitoid gneiss with infolded metavolcanic and metasedimentary rocks distinguish the Glennie Domain. The Kiseynew Domain comprises extremely deformed granulite, psammopelitic garnet-biotite gneiss, and metagreywacke. Rocks to the east of the Needle Falls Shear Zone involve material of the deep crust, whereas those to the west are ancient sediments. The Tabernor Fault separates the block-like Glennie Domain from the Kiseynew Domain. The domains are extrapolated southward beneath the Phanerozoic by correlating basement aeromagnetic patterns after Camfield and Gough (1977), Green *et al.* (1985), Collerson *et al.* (1988), Jones and Craven (1990), Ross *et al.* (1991), and Burwash *et al.* (1993). For alternative and updated interpretations of these patterns, the reader is referred to Miles *et al.* (1997) and Kreis *et al.* (2000).

The La Ronge Domain is linked to the belt of magnetic lows that extends along longitude 106°20'W as far south as latitude 51°30'N. Here, it is apparently terminated against a northwesterly trending belt of medium highs of uncertain rock affinity but corresponding to the Phanerozoic Elbow-Weyburn Lineament, which in turn intercepts the extrapolated Tabernor Lineament Belt. Apparently, in so doing, it cuts off the sub-Phanerozoic extension of the Glennie Domain (Green *et al.*, 1985). The Tabernor Belt is more or less aligned with longitude 103°W, is apparently deep seated in the crust, and maintains its role as the partition between the extended Glennie and Kiseynew domains (Burwash *et al.*, 1993). South of latitude 52°N, the Kiseynew Domain incorporates the 'Nelson River Gravity Anomaly' (Hajnal and McClure, 1977), a complex of anomalies with a 25 mGal major high, flanked by minor lows, that is coincident with the area of magnetic highs east of Yorkton. West of longitude 106°W, the Rottenstone Domain apparently coincides with the narrow belt of magnetic lows, which expands south of Saskatoon into the region between Last Mountain Lake and Rosetown. The Wollaston Domain trends south-southwest into Alberta along a 50 to 75 km wide belt of magnetic highs. Along longitude 108°W between latitudes 53° and 52°N, the western edge of the Wollaston magnetic high is aligned with the Ile-à-la-Crosse Lineament.

The large region of magnetic highs south of latitude 51°N in the southwest corner of the province represents the quasi-stable, 1.8 Ga Swift Current Anorogen (Collerson *et al.*, 1988), around which the folded Wollaston and Rottenstone domains are deflected to the southwest and southeast respectively. To the east of the Swift Current Anorogen lies the curvilinear belt of anomalous electromagnetic induction, called the North American Central Plains Conductor (NACP). This feature has been traced into Saskatchewan from the Black Hills region of Wyoming by Camfield and Gough (1977) to align with the Needle Falls Shear Zone, as projected from the Precambrian Shield.

An overlay of major Mannville structural, sedimentary, and topographic elements on the aeromagnetic anomalies map reveals significant spatial coincidence with major features of the underlying basement. The paired Watrous and Wynyard domes, forming the body of the Punnichy Arch and delineated by the erosional edges of the Birdbear (Db), Watrous (Jw), Souris Valley (Mm), and Rierdon (Jr) formations, correspond to three aeromagnetic highs that trend southeast from longitude 106°W to 103°W. The Molanosa Dome, to the north, is represented by a similar aeromagnetic high immediately south of the exposed Glennie Domain. The region to the south displays a spatial pattern of irregular elliptical forms with a general northerly bias that may imply a common structural heritage. Thus, if the subsurface La Ronge Domain is interpreted as having been compressed into the Rottenstone Domain, then the region east to the Tabernor Belt is part of the Glennie Domain and the Punnichy Arch is its southern front. Early Cretaceous mild downwarp and uplift of the Kiseynew Domain is indicated by overlying Mannville sedimentary infill, pre-Pense erosion, and Newcastle beach-sand buildup (Figure 52).

In southwestern Saskatchewan, the Swift Current Platform is the Phanerozoic counterpart of the Swift Current Anorogen. The northeastern front of the former is taken to be the Elbow-Weyburn Lineament and that of the latter is taken to be the North American Central Plains Conductor (NACP). The Middle Jurassic Shaunavon Monocline ends along the western aeromagnetic highs. Movement of the Swift Current Anorogen appears to have been mostly vertical, repetitive, and mildly positive throughout the Paleozoic, until the Mississippian when it subsided deeply. Uplift to a pronounced height occurred in the Late Jurassic. The succeeding post-Albian subsidence made a total change in elevation of 700 m. The Middle Devonian Prairie Evaporite salt beds that covered the Swift Current Platform have been dissolved away, but most of this sapping was done in the Cenozoic, especially in the northern apical region.

Structural forms in the Kindersley and Unity structural regions, conspicuously easterly in the former and northwesterly in the latter, are incongruent with the predominant northeasterly alignment of the Wollaston and Mudjatik domains. The Phanerozoic behaviour of this western region is generally: 1) downwarp toward the west, as shown by westward thickening of the Cambrian Earlie Formation (Paterson, 1989); 2) eastward and northeastward tilt toward the Elk Point Basin during the Middle Devonian; 3) westward downwarp again in the Upper Devonian Duperow basin (Kent, 1968; Kreis, 2000); 4) eastward and northeastward tilt in the Cantuar basin; and finally 5) southward and southeastward tilt in the post-Cantuar Cretaceous basin.

Deep re-entrants of the Prairie Evaporite salt front occur east and west of Saskatoon at the aeromagnetic highs on the western flank of the Watrous Dome, and where the Prairie salt body lies astride the trace of the eastern flank of the Wollaston Domain and the Tabernor and Moosomin–Hudson Bay structural belts. All may reflect basement-controlled movements that fractured the Phanerozoic strata and permitted access of brackish formation waters to the Prairie Evaporite.

Interaction of Structural Components in the Meadow Lake Basin (extracted from Christopher, 2001)

Relationship of the Paleozoic Erosion Surface to the Holocene Land Surface

In the southwestern part of the Meadow Lake Basin (Figure 53), the sub-Cretaceous unconformity surface cuts across the south-dipping Upper Devonian Souris River Formation and displays a gross morphological congruence with the Holocene land surface. Accordingly, the Mostoos Hills in the west-central part of the basin, as delineated by the northern surficial topographic 610 m contour, correspond to an underlying, large structural dome on the Souris River Formation. The monocline on the Paleozoic surface created by drape of Dawson Bay, Winnipegosis, and Souris River strata across the Lower Paleozoic Meadow Lake Escarpment (Van Hees, 1964; Kreis and Haidl, 1995) is defined by the closely spaced contours extending from Twp. 55 in the extreme southwest, through Meadow Lake, to beyond Twp. 63 at the northeastern boundary of the district (Figure 53). The drainage pattern reveals a Holocene surface expression of the Meadow Lake Escarpment by (from west to east): 1) the eastward closing U-shaped jog in the course of the easternmost, northward flowing tributary of the Makwa River; 2) the eastward elongation and alignment of Meadow Lake and its incoming streams, such as the Chitek River; 3) the eastward closing U-shaped bends in the courses of the Green and Cowan rivers; and 4) the westward loop in the course of the river entering Sled Lake. The southern 610 m (msl) contour bends to the south from alignment with the escarpment by glacial stripping. On the Devonian erosion surface, the escarpment rises 160 m onto a mesa that is buttressed by the Beaverhill Member of the Souris River Formation, and above which a northwesterly topographic grain is projected along the Chitek River and Cowan and De La Ronde lakes. Below the Souris River Formation, the Meadow Lake Escarpment physically terminates the Lower Paleozoic Big Horn and Deadwood formations from the south (Kreis and Haidl, 1995, 2000). It thereby forms the southern wall of the Lower Devonian Elk Point Basin (Fuzesy, 1980; Meijer Drees, 1986), the deposits of which comprise the evaporite, carbonate, and red bed units of the Lower Devonian Lower Elk Point Group.

Relationship to Predecessor Basins

The Mannville Meadow Lake Basin, as a pre-Success and pre-Cantuar derivation of the predecessor basin, is tilted to the southwest and shaped by southwesterly plunging re-entrant troughs and irregular domes that reflect the irregular dissolution of the underlying Devonian Elk Point evaporite beds by formation and meteoric water. The more durable carbonate and red bed strata, though locally brecciated, constitute the dominant components, but evaporitic beds are present as far east as the La Ronge district. There, a 180 m downdrop of the Middle Devonian Ashern Formation across the Meadow Lake escarpment indicates a comparable loss of salt section (cross-section U-U', Figure 18). Apparently the dissolution front retreated from east to west, so that the Lotsberg and Cold Lake salt masses are encountered west of longitude 109°W. Thus, the irregular, depressed central region on the Paleozoic

surface from Doré Lake to Ministikwan Lake is attributable to episodic dissolution of the salt beds, which was especially pronounced in the Jura-Cretaceous (Success) and less so in the Cretaceous (Cantuar and Colorado). In that the amoeboid large and smaller lake complexes of the Holocene occupy sites corresponding to depressions on the Paleozoic erosion surface, extensive Holocene salt dissolution and collapse of the overlying strata are indicated. This genetic connection between surficial drainage patterns and the Paleozoic erosion surface is used to accentuate structural forms, especially where well points are widely spaced in the eastern half of the region (Figure 53).

Relationship to the Precambrian Basement

The structural framework of the Mannville Meadow Lake Basin apparently reflects the geological configuration and topography of the Precambrian basement. One element of this control is shown by north-south and east-west linear sets. The Precambrian aeromagnetic overlay of the southwestern part of the basin (Miles *et al.*, 1997; Kreis *et al.*, 2000), superimposed on the structure map of the Paleozoic surface (Figure 54), shows the central part of the basin, between longitudes 109° and 108°W, to be marked by linear highs and lows that trend north-south and flank a central core of curvilinear, 10 to 12 km wide, closed highs and lows. The eastern boundary coincides with the eastern flank of the structural trough on the Paleozoic surface, and the northerly aligned course of the Holocene Green River–Beaver River (this alignment continues north beyond the district to Lac Ile-à-la-Crosse and into the course of the Mudjatik River on the Precambrian Shield). The western boundary underlies the western limb of the structural depression on the Paleozoic, and continues south-southwest under the Makwa River and its north-flowing tributary across the Paleozoic Meadow Lake Escarpment. The broad axial keel of the structural trough from beneath Keeley Lake to Waterhen Lake corresponds to a compound aeromagnetic low of similar dimension. This low is partitioned by a pair of curvilinear aeromagnetic highs, which amalgamate south of the Waterhen structural depression on the Paleozoic and enclose most of the triangular area that closes to an apex at Meadow Lake. The general aeromagnetic pattern continues on the Meadow Lake Escarpment, but the order reverses abruptly, with highs yielding to lows and vice versa.

The linked alternation of magnetic highs and lows, broad across the central part of the basin and narrow along the flanks, probably reflects the domal layout of complexly folded metasedimentary rocks. Low magnetic flux emanates from rocks that are low in iron-based minerals, presumed to be erosion-resistant quartzofeldspathic gneiss, and therefore form paleotopographic highs. The magnetic highs probably represent iron-rich rocks, such as amphibolite and mafic volcanic rocks, that were likely more prone to Precambrian weathering and erosion and therefore generally occupy paleotopographic lows. The Precambrian topography appears to have been genetically controlled by an antiform that was breached axially along the erosion-prone rocks from Waterhen Lake north to Keeley Lake. This antiform was less breached south to the Meadow Lake Escarpment, where the resistant rocks appear to have provided better cover on the plunge to the south. The narrow flanking magnetic belts represent ridges and valleys of folded rocks outlying the axial region. The northerly alignment of the Beaver River and its tributary, the Green River, coincides with a strip of magnetically high Precambrian rocks, more prone to erosion and therefore forming depressions that exercise linear control on present-day surficial streams. The aeromagnetic zone to the east angles off toward the northeast, in keeping with the regional trend of the Precambrian Wollaston Fold Belt, and displays relatively wide (20 to 60 km) bands of lows and highs. The magnetic pattern is much flatter than in the central part of the basin. Thus, the entire area around Doré and Sled lakes and south to Chitek Lake is characterized by a belt of magnetic lows, and is adjacent to a comparable band of magnetic highs extending from Beaupré Lake to Cowan and De La Ronde lakes. Assuming that the basement rocks are tightly folded, and that the magnetic properties are caused by thick, steeply dipping Wollaston Group metasedimentary rocks, the lower lying belts of iron-rich gneiss and schist (stippled areas in Figure 54) subcrop to the east of a more resistant belt of quartzofeldspathic meta-arkose. The Doré Lake structural low, like the central trough, may be situated over a Precambrian dome and/or antiform, and both have acquired their trough-like character by dissolution of the Lower Elk Point evaporite beds that was initiated above the highs.

The eastward shift of aeromagnetic patterns on the north side of the Paleozoic Meadow Lake Escarpment, with respect to patterns on the south side, indicates that the escarpment originated by faulting. The northeastward increase in the lateral displacements of the aeromagnetic patterns suggests a right-lateral wrench fault with increasing northeasterly tilt of the northern block. Most streams on the northern block west of Meadow Lake flow eastward along the general front of the escarpment and, east of Meadow Lake, north-aligned streams such as Green, Cowan, De La Ronde, and Sled are offset eastward in the vicinity of the escarpment.

West of the central part of the basin and south of the west-flowing Ustookumin River, the area from longitude 109°W to the Saskatchewan-Alberta boundary is characterized by low magnetic flux, in keeping with the interpretation that it is underlain by a granitoid terrain. However, between Twp. 64 and 61 (inclusive), the magnetic low encloses a compound, easterly opening, U-shaped magnetic high, 800 km² in area, that partially encloses a central low. Analogues of this magnetic feature on the Paleozoic erosion surface, though partially masked by the

Lower Elk Point evaporite beds, are: 1) the northwesterly striking trough, controlled by salt dissolution, that fronts the magnetic body to the east; 2) a similar trough that plunges southwesterly along the southeastern flank of the magnetic body; and 3) structural highs and lows on the Paleozoic surface that correspond to the arms and central low of the magnetic high. This magnetic feature appears to translate into Precambrian igneous-metamorphic topographic forms analogous to those of the overlying Paleozoic erosion surface, and may represent a complex mafic, igneous or gneissoid dome. To the south, along latitude 54°N, an elliptical, east-trending zone of extremely low magnetic values occurs beneath the Ministikwan Lake basin. The Makwa Lake trough on the Paleozoic surface rises northeasterly from this site onto the central structural depression beneath Waterhen Lake.

Jura-Cretaceous Success Basin

The Success Formation, as mapped in [Figure 6](#) and outlined in [Figure 53](#), occupies the structural depression on the Souris River erosion surface between the northerly course of the Beaver River in the east, the Mostoos Hills in the west, and the Meadow Lake Escarpment. The locale is the most northwesterly of the six major homologous bodies of this formation in the province, and all are pre-Cantuar eroded remnants of a Jura-Cretaceous depositional basin that once extended throughout western Canada (Poulton *et al.*, 1994). The kaolinitic quartzose sandstone of the Success Formation is distributed throughout the central trough but is thickest in an annulus on the central core between Keeley and Waterhen lakes, reaching a maximum 137.3 m at the Cdn Seaboard Meadow L 3-21-63-15(W3) reference well for the Success Meadow Lake Basin. Although pre-Success in age, as they are all capped with Success sediments, domes in the structural trough share little else in common, and are:

- buttes fronting the Paleozoic Meadow Lake Escarpment (*i.e.*, erosional outliers of the Beaverhill Member that forms the upper third of the Souris River Formation, as at Imperial Barnes 1-33-61-17(W3) and Seaboard Meadow Lake Cr. No. 7 [12-31-61-14W3]);
- drapes on 90 m high Winnipegosis mounds, as at Clark Flotten L 4-5-66-16(W3) and Seaboard Meadow Lake Cr. No. 3 (8-30-64-14W3) on the flank of the central dome in the depression and on the north-south Precambrian aeromagnetic high that bisects it; and
- post-Souris River, pre-Cantuar uplifts, as at Texcan Sled Lake 5-19-64-9(W3), as shown by the comparable positions of the Paleozoic erosion surface on the Souris River Formation with respect to the Dawson Bay structural datum at Seaboard Meadow Lake Crown No. 5 (4-5-65-12W3) and Seaboard Meadow Lake Crown No. 2 (9-21-63-8W3).

Outliers of the Success Formation to the west confirm a wider distribution to beyond the Saskatchewan-Alberta boundary. Early Cretaceous erosion appears to have stripped the Jura-Cretaceous Success strata from the Paleozoic surface immediately south of the Meadow Lake Escarpment. Success sedimentary rocks in the trough escaped, because regional sapping of the Elk Point evaporite beds in the structural trough had lowered these sediments below the pre-Cantuar erosional base.

Laramide Overprint

Tectonic overprint is also apparent. A Laramide stress field is indicated by: 1) the northeasterly (048°) alignment of lakes and rivers from off the Holocene Meadow Lake upland in the southeast; 2) the northeasterly alignment of the drainage across the Mostoos Hills of the northwest; 3) the southeasterly drainage into Flotten Lake and the Waterhen River of the central region; and 4) the northwesterly alignment of the major upper Mannville gas fields. On the Paleozoic surface, the complementary northeasterly vector is exemplified by the southwesterly plunge of the Makwa Lake trough.

Mannville Hydrological Setting

General

“A hydrogeological unit is a lithostratigraphic unit or reservoir through which water may flow with varying degrees of ease under the impetus of hydraulic gradients or potentials ... Special attention must be paid to leakage ... , which is the flow of water from one aquifer to the next through an intervening hydrogeological unit of low permeability. A hydrogeological unit composed of alternating layers of pervious and semi-pervious formations is known as a multi-layered aquifer ... Water moves between aquifers not only by leakage but along stratigraphic and tectonic discontinuities. Thus ... each sedimentary or hydrogeological basin ... represents a unique hydrodynamic and hydrochemical complex.” (Castany, 1981, p18).

The foregoing quotation more or less frames the hydrogeological environment of the Mannville Group in Saskatchewan. Because of the sub-Success and sub-Cantuar unconformities, the Mannville forms a hydrological continuum with subjacent formations across the province wherever its contact transects underlying aquicludes. The shale of the superjacent Joli Fou Formation acts as the overlying seal, except where broken at fault and fracture sites and where stripped back into erosional offlap of the Mannville by Cenozoic and Holocene agents. In keeping with the overall pattern of formation waters in the basin, the Mannville potentiometric surface slopes from the southwestern part of the province to the northeast. In the general context of the Western Canada Sedimentary Basin, this slope is seen as compatible with the overall post-Laramide topographic decline in elevation from west to east, and is attributed to meteoric cross-formational infiltration from the present-day topography (Hitchon, 1984). However, the Sweetgrass-Battleford Arch acts as a divide that diverts much of this easterly flow, from the Rocky Mountain meteoric intake of the southwest, northward to discharge points in east-central Alberta.

The relatively small area of the Cypress Hills is generally taken as the major meteoric-water recharge site for the Phanerozoic of Saskatchewan. However, the classic pattern for artesian flow across the basin to the north is provided by: 1) the thick Cretaceous shale, which restricts general access to the Mannville; and 2) the presence of Mannville outcrops in the mountains of central Montana at elevations some 2500 m higher than in the subsurface of Saskatchewan (Porter and Fuller, 1959). Low salinities in formation water of all formations are widespread in central Montana and are attributable to meteoric dilution (Downey *et al.*, 1987). This characteristic extends to and across the Swift Current Platform. A similar zone of reduced salinity forms a broad belt along the northern edge of the Mannville in Saskatchewan and Manitoba. The distribution of salinities in Phanerozoic formation waters for Saskatchewan and Manitoba was published by Simpson and Dennison (1975), and for the sub-Mississippian formations of Saskatchewan by Kreis *et al.* (1991). These authors revealed that regions of highly saline water in the Lower Paleozoic and Middle Devonian strata conform to the distribution of the Devonian salt beds, especially the Prairie Evaporite, and that the salinity-reduced areas correspond to regions where such salt beds have been leached away. The regions of reduced salinity in strata younger than the Upper Devonian Souris River Formation expand in area upward into the Mesozoic. Total dissolved solids (tds), apart from some strong positive and negative anomalies, range between 275 000 and 175 000 mg/l in the Cambrian, Ordovician, Silurian, and Middle Devonian formations, over and under the broad back of the Prairie Evaporite of southeastern and west-central Saskatchewan. In the younger formations, values of 80 000 mg/l tds or less are widespread, except for the Mississippian of southeastern Saskatchewan, where values greater than 130 000 mg/l persist.

The major aquifers above the Mannville are the Viking in the southwest, the Newcastle in the southeast, the Judith River of western Saskatchewan south of the North Saskatchewan River, and the linear Late Cenozoic to Holocene Empress Formation gravel that partially infills the preglacial valley system (Figure 55) ancestral to the present drainage system. All of these aquifers, including the Mannville, are in intercommunication at scattered localities across the province, especially near Manitoba.

Preglacial Bedrock Drainage System

The Missouri Coteau (Richards, 1969), at the 732 m contour, marks the eastern edge of the Great Plains Province. To the east lies the Central Lowlands Province. However, for purposes of this study, the 550 m bedrock contour (Figure 55) delineates a general upland of the south and southwest, and its outliers to the north, that forms a third of southern Saskatchewan. Late Cretaceous strata and, within the 915 m contour in the extreme south, Paleocene Ravenscrag Formation and Oligocene Cypress Hills–Wood Mountain gravels constitute the dominant landforms. The lowlands, and especially their valley straths, descend northeast toward the 305 m contour near the Manitoba border. They also descend through the stratigraphic section so that, in east-central Saskatchewan, the Lower Cretaceous Mannville and Paleozoic strata crop out in escarpments below the glacial drift (Whitaker and Pearson,

1972). The major bedrock aquifers, as defined and described by Christiansen *et al.* (1970), belong to the Tyner, Hatfield, and Swift Current systems.

The Tyner valley system refers to the hydraulic continuum created by linkage of the Tyner bedrock valley sandstone with the sandstone of the Battleford bedrock valley group, the sandstone of the Judith River Formation, and the intertill aquifers, as well as the South and North Saskatchewan rivers. The system is vast and undersaturated, in view of the 148 000 km² expanse of the Judith River Formation and its overall thickness of 30 to 45 m. The Judith River aquifer is replenished by meteoric infiltration through the overlying drift (Christiansen *et al.*, 1970). The Tyner bedrock valley follows a 383 km course that extends from Alberta at latitude 51°N (Twp. 23) under the South Saskatchewan River to longitude 109°W, before cutting a northeasterly chord across the bow of the river at Saskatchewan Landing and Outlook, 50 km south-southwest of Saskatoon, to join the Hatfield valley aquifer about 20 km north of the city. Between longitudes 110° and 108°W, the Tyner bedrock valley serves as a central basin for collecting groundwater that is up to 50 km wide and axial to the South Saskatchewan River. Tributaries reach north past Kindersley to latitude 52°N and south to Maple Creek at latitude 50°N. Water is funnelled northeast toward Saskatoon.

The Battleford group represents a complex of near-parallel bifurcating valleys entering the province from Alberta between latitudes 52°40' and 54°N. The 130 km wide network trends southeast, with its general axis passing through Lloydminster and the Battlefords to join the Tyner Valley at Warman, 18 km northeast of Saskatoon. The portion of the complex south of the North Saskatchewan River taps the northern erosional front of the Judith River Formation, and the combined output discharges into the South Saskatchewan River.

The Hatfield bedrock valley extends from the Beaver and Waterhen rivers in the northwest, southeastward along the Cowan River, De La Ronde Creek, and Shell Brook to underlie the Saskatchewan River at Prince Albert, and then southward to Last Mountain Lake, where it turns eastward under the Qu'Appelle River to enter Manitoba. The Empress Formation, which is the aquifer in the valley, consists of fine- to coarse-grained sand, 0 to 36 m thick. Along its 782 km length, the valley floor intersects all Cretaceous outcrops, from the Mannville in the north to the Bearpaw in the southeast. Although mapped as a single valley form, the Hatfield bedrock valley lacks an overall gradient, in the sense that the 430 m contour satisfies its general elevation across the province. It appears to be a bipolar system with a northern and a southeastern arm. The northern leg, extending from the Waterhen River to Lanigan at latitude 52°N, falls to an elevation of 365 m (msl), thereby funneling water from the Tyner system east into the Saskatchewan River system. The southeastern arm is apparently pressurized by the flux of the ancestral Swift Current valley aquifer, under its head of 670 m.

The Swift Current ancestral valley is a subtile extension of Swift Current Creek, which is supplied by the Ravenscrag Formation in the Cypress Hills near Eastend, 100 km southwest of Swift Current. About 18 km east of Swift Current, the creek turns north to the South Saskatchewan River. The ancestral valley, its 3 to 43 m thick basal sand forming the aquifer, continues eastward under the northern flank of the Old Wives Lake basin at Chaplin Lake. There, the Swift Current aquifer is linked with the Gravelbourg buried valley that enters from the south, where it tapped the influx from Notokeu Creek and the Wood River headwaters in the Ravenscrag Formation. At The Missouri Coteau, the Swift Current aquifer trends east-northeast under Last Mountain Lake to join the Hatfield bedrock valley, 56 km north of Regina. The system sustains water bodies, such as The Fishing Lakes in the Qu'Appelle River valley (Christiansen *et al.*, 1972, p15).

Potentiometric Surface

The regional gravitational flow of formation water across Saskatchewan can be mapped by computation of its potentiometric surface: the elevation to which water would rise in well-bore drill stems when the formation is opened to the atmosphere (Wilson *et al.*, 1963; Christopher, 1980; Hannon, 1987; Bachu *et al.*, 1987). Potentiometric heads in this study are calculated to freshwater equivalent heads, with the density of freshwater being 1 g/cm³.

Thus, potentiometric surface elevation (E) is given by the equation

$$E \text{ (imperial)} = (KB - D) + 2.31P$$

where P is the formation-water pressure (in pounds per square inch, psi); KB is the Kelly bushing elevation (in feet); D is gauge depth (in feet); and the coefficient 2.31 or 0.704 is the height per unit of pressure of the freshwater column (in feet or metres, respectively). Alternatively, if P is given in kilopascals (kPa) and the depths are in metres, the coefficient becomes 0.704/6.89 kPa and the equation becomes:

$$E \text{ (metric)} = (KB - D) + 0.102P$$

Density of water increases with increasing concentration of salt. Thus, salinity reduces the height to which water would rise in the drill-stem test and, in only a few of the tests, does formation water actually rise to the calculated freshwater head. In the potash mining district west of Saskatoon, where Mannville formation water salinities are in the range 46 500 to 53 800 mg/l tds, density varies between 1.028 and 1.038 g/cm³, and the calculated potentiometric head falls by 15.2 and 20.6 m, respectively (*i.e.*, to 518.8 and 513.4 m from 534 m). For the higher salinities, such as 162 876 and 286 211 mg/l in water from the Upper Devonian Souris River Formation, the densities are 1.104 and 1.186 g/cm³ and the respective calculated potentiometric heads are 471.5 and 436.5 m. These are decreases in elevation of 52.7 and 88.1 m, respectively. The relationship between potentiometric elevations and salinity is discussed by Bachu *et al.* (1987), who observed that water density increases above that of freshwater at atmospheric pressure, and is also related to the depth at which the formation lies. The potentiometric map of the relatively brackish Mannville formation waters (Figure 55) is drawn at 100 m contour intervals in order to mask qualitatively the lesser variations attributable to the foregoing relationships. Actual (A) rise of formation water in the drill stem is also recorded, but not contoured.

The Mannville potentiometric surface declines from highs exceeding 1000 m in the southwestern part of the province to a regional low of less than 300 m in the northeast (*i.e.*, below the 389 m elevation of Mannville outcrops at the foot of the Wapawekka Hills but just above their 260 m elevation at the base of the Pasquia Hills). In the northwest, potentiometric elevations decline to the levels of large lakes, such as those of the Peter Pond–Churchill–Ile-à-la-Crosse system (420 m) and Doré Lake (458 m), which occupy topographic lows of the region. As in the northeast, the potentiometric surface lies well below the heights of the region, such as the Mostoos Hills (770 m). These northern hills can thus be regarded as meteoric intake sites for the Mannville, as described by Toth (1979) for the Red Earth region of central Alberta. Thus, in the absence of strong drill-stem test control in the northern part of the province, the potentiometric pattern is shaped to conform to the 450 m topographic contour.

Cross-formational Relationships

Two types of major anomaly on the potentiometric surface are closed highs and lows (*i.e.*, potentiometric cells; Christopher, 1974). These cells are generally associated with fracture zones and faults in the underlying Mississippian and Devonian limestone, the effects of which are amplified in southwestern Saskatchewan through transection of the Jurassic and Mississippian strata by Cantuar-infilled valleys. The cells feature high-pressure centres on the one hand and cones of depression on the other, and appear to represent localities and regions where the Mannville formation-water system is in communication with subjacent and superjacent formations. Linkage with subjacent formations is indicated by: 1) similarity of the potentiometric pattern of the Middle Devonian Dawson Bay Formation in the Saskatoon potash district with the overlying Mannville (Dunn, 1982); 2) artesian elevations in the Silurian Interlake of the Willowbunch area of extreme south-central Saskatchewan (Wilson *et al.*, 1963), equivalent to those of the Mannville highs in southwestern Saskatchewan; 3) artesian conditions in wells drilled to the Madison and Dawson Bay formations in Twp. 11 and 14, respectively, of Rge. 28, W 2nd Mer.; and 4) northerly convergence, in southwestern Saskatchewan, of the regionally higher Mississippian Madison values with those of the Mannville potentiometric highs.

Feltis (1980) showed that the Madison potentiometric surface slopes northward from elevations of 1800 m on the central Montana uplift to 1090 m in southwestern Saskatchewan at longitude 108°W. Also, carbonate rocks of the Mississippian Madison and Upper Devonian Jefferson formations are recognized as the primary aquifers for meteoric water in the Northern Great Plains of the United States and, by cross-formational flow, the Inyan-Kara, Dakota and Kootenai formations their subsystems (Swenson, 1968; Schoon, 1969; Downey *et al.*, 1987). The stratigraphically equivalent Mannville system in southwestern Saskatchewan is charged by cross-formational flow from the Madison via the faults and fractures of the Eastend–Maple Creek lineament (Christopher, 1974). In southeastern Saskatchewan, potentiometric highs are associated with collapsed sites attributed to salt-dissolution in the Middle Devonian Prairie Evaporite. For instance, in the Torquay–Rocanville Trend, the cells indicated are near Kisbey and Wapella, and at the collapse and fault site near Ogema on the Elbow–Weyburn Lineament.

The integrated character of cross-formational waterflow relationships is examined by plots of: 1) formation-water rise in the drill-stem tests of Mannville and Devonian strata at C.M.&S. Vanscoy 11-16-35-8W3 and Duval Saskatoon 6-18-36-6W3 (Figure 56); and 2) calculated potentiometric heads in the same wells (Figure 57). At the Vanscoy site, all units of the Mannville (DSTs 5, 6, 9, and 10), and the Seward and Wymark members of the Duperow Formation (DSTs 12 and 23), have potentiometric elevations between 518 and 549 m. This relationship indicates hydraulic continuity between these strata. Distinct increases in potentiometric elevation occur in the Birdbear Formation (DSTs 22 and 25), the Saskatoon Member of the Duperow (DST 26), and the lower half of the Souris River Formation (DST 17). A secondary trend is also indicated by the empirical slope or isograd drawn through the region of DSTs 6, 9, 5, 10, 22, 25, and 17. This line represents the potentiometric loss from the lower

formations to the higher (Powley, 1990). The gradient is determined as $0.33d$, where 'd' represents the incremental increase in depth. Projection of this line to the Dawson Bay Formation would indicate a head of 683 m. However, a parallel line drawn through the area of DSTs 12, 23, 18, 26, 14, and 15 (*i.e.*, the lower part of the Duperow Formation and the Souris River Formation) shows a negative displacement of 44.2 m. The mass of Souris River carbonate and evaporite rocks is apparently acting as a semipermeable barrier to vertical fluid exchange. This is reflected in the salinity plots, which show that the total dissolved solids range from 37 700 mg/l in the upper Mannville to 103 500 mg/l in the Duperow, in contrast to the more than 252 000 mg/l in the Souris River Formation.

The potentiometric head of the Waseca Member (DST 5), though lying in the isopotentiometric field, plots well above the isograd. The displacement may indicate relict pressures due to the nature of the Waseca, which consists at Vanscoy of clay-encapsulated, argillaceous, fluvial-channel sandstone, limited in permeability and storage capacity. However, Price and Ball (1973) reported that, in the adjacent shaft hole, the member is microfaulted and jointed. The over-pressure may therefore be a consequence of water influx from underlying units. The other unit described as microfaulted is the more permeable Lloydminster Member, which records the same head (DST 10). In the Birdbear Formation, DST 22 plots on the isograd but well above the isopotentiometric field. Here, the upper part of the formation is composed of a microcrystalline dolomite featuring vugs and cavities that are partially clay filled and coated with calcite druse, as well as calcite-filled joints and fractures. The karsting represented by the cavities relates to pre-Cantuar weathering, and the calcite inlay relates to a post-karst formation-water system. Porosity is high but permeability is a function of the microporous matrix and the karst fractures. Therefore, the 366 m of water released in the drill-stem test may have been a trapped high-pressure reservoir that was sealed by late diagenetic mineralization.

At Duval Saskatoon 6-18-36-6W3, the isopotentiometric field is narrower than at C.M.&S. Vanscoy 11-16-35-8W3, being only 22.9 m wide. It includes all drill-stem test values for the Pense, Cantuar, and Birdbear formations, as well as the Seward and Wymark members of the Duperow Formation. Likewise, the $0.33d$ isograd satisfies all potentiometric elevations from the Mannville Formation (DSTs 8, 9, 10, 11, and 12), with the exception of DST 7. As at Vanscoy, departure from the isograd occurs below the Wymark Member. The negative shift is 102 m (*i.e.*, some 61 m greater than at Vanscoy). Similarly, the salinities of formation water from all units above the Souris River Formation lie between 46 000 and 53 800 mg/l tds. In the Souris River Formation, these values increase abruptly to 256 000 and 393 000 mg/l. Although DST 7 of the Pense Formation lies along the isograd at an elevation of 491 m, it plots at 15 m below the isopotentiometric field, whereas DST 8 of the same interval came in at 516.9 m, well within the isopotentiometric field. Both tests seem valid; the local body of Pense sandstone, though underpressured at the time of DST 7, may have been disturbed sufficiently to open communication with underlying units by the time of DST 8.

Of all the formations above the Prairie Evaporite at Vanscoy, only the Cantuar and Birdbear recorded a significant (*i.e.*, 300 to 800 m) rise of water in the drill-stem tests (Figure 56). At the Saskatoon well, they are the Pense and Cantuar formations and Wymark Member of the Duperow Formation. The highest of the water columns rose to within 30 to 60 m of the ground-surface elevation of 506 m. Although the plots of water columns between the two localities indicate a common hydraulic system, lateral and vertical lithological variability restricts or amplifies volumetric capacity and flow rates. The marine sandstone units of the Cummings, Lloydminster, Rex, and General Petroleum members tend to be spatially consistent in terms of productive capacity (Vanscoy DSTs 9 and 10, and Saskatoon DSTs 9, 10, and 11). However, these sandstone units are transected by low-permeability channel-fill deposits, which create flow barriers at one site or another. The more fluviodeltaic Waseca Member is variable in water productivity (DSTs 5, 6, and 6, 8 respectively) because of the greater lenticularity of its sandstone bodies. Many of the better permeabilities in the Birdbear Formation and upper Duperow Formation are dependent upon enhanced pore volume by vuggy and moldic porosity in what is otherwise mudstone-occluded bioclastic limestone. Water recoveries are variable, ranging from insignificant to 600 m.

The potentiometric difference in elevation from C.M.&S. Vanscoy to Duval Saskatoon, 19.2 km to the northeast, is -29 m in the Wymark Member versus -21 m in the Lloydminster Member. Thus, the gradients are 1.5 and 1.1 m/km, respectively, to the northeast, although the salinities of both units are similar. The difference in potentiometric elevation increases to -95 m in the upper part of the Souris River Formation and to -79 m in the lower part. This steepening of the average hydraulic gradient to 4.9 m/km and the overall negative shift of the pressure gradient line through the Souris River Formation to 46.7 m at Vanscoy and 102 m at Saskatoon indicate a drainage of these lower units toward a potentiometric low, here deduced to be the fractured and faulted Saskatoon Trough or its subsidiary in the region of Rge. 6, W 3rd Mer.

Regionally, the Mannville potentiometric surface broadly corresponds to the general subglacial topographic slope; however, the potentiometric surface is downstepped by belts of steepened gradients that coincide with the major bedrock Tertiary to Quaternary valley aquifers, such as the Tyner and the Hatfield. Minimum elevations in these

valley systems lie below the local Mannville potentiometric elevations over much of southern Saskatchewan, and thereby indicate that the Mannville formation-water system is in potential communication with (*i.e.*, leaking into) the surficial groundwater system. In southwestern Saskatchewan, the northwesterly trend of the potentiometric contour south of the South Saskatchewan River delineates the eastern front of the Middle Jurassic Shaunavon Monocline, and is apparently developed in response to the northwesterly component of the joint set conspicuous to the region. Likewise, the north-south faults responsible for the Shaunavon Graben along Rge. 18 and 19, W 3rd Mer. coincide with the similarly aligned eastern front of the high-potential region bounded by the 800 m contour.

The Maple Creek potentiometric high is also an expression of intersecting northwesterly and northerly oriented faults. This complex has been repeatedly reactivated, as indicated by the overprinted Cenozoic Johns Borough (David and Whitaker, 1973) arm of the Tyner bedrock valley along Rge. 25, W 3rd Mer., which lies at an elevation of 660 to 610 m (*i.e.*, some 200 m below the Maple Creek potentiometric elevation). The relationship indicates communication of the Johns Borough bedrock valley with the Maple Creek potentiometric cell. On the other hand, the stratigraphically intervening giant natural-gas fields in the Cretaceous Medicine Hat and Milk River formations overlie the Maple Creek potentiometric cell, like a vast cloud on a rising hydraulic plume, and their very presence would intuitively deny the effectiveness of cross-formational water communication in the district. However, it can be argued that these low-permeability natural-gas reserves are retained down dip on the Medicine Hat dome of adjacent Alberta, by virtue of the easterly drive of formation water from the Maple Creek potentiometric cell. Another factor for consideration may be that movement along the lineaments is intermittent, and that cross-formational waterflow behaves likewise, occurring when the region undergoes extension.

The Mannville potentiometric gradient flattens abruptly east of the Shaunavon Graben onto the Swift Current Platform, across which the potentiometric surface lies between 650 and 680 m, against a slightly raised annular 700 m belt in the south and east. An easterly aligned depression, delineated by the 680 m contour, indicates tapping of the Mannville aquifer by the bedrock-valley system associated with Chaplin Lake, Notokeu Creek, and the Wood River at 610 m. In contrast, the potentiometric rise enclosed by the 700 m contour may reflect input from Mississippian strata at depth. The eastern front of the Swift Current Platform corresponds to the 600 m potentiometric contour, here depicted by the irregular trace of re-entrants around potentiometric lows that can be attributed to multistage salt-dissolution collapse phenomena originating in the Middle Devonian Prairie Evaporite. This is the region of the Elbow-Weyburn Lineament and, in the south, the draped Roncott Prairie Evaporite salt outlier. Potentiometric anomalies in this region (Figure 55) coincide with Cantuar structural forms (Figure 46).

In Twp. 21, Rge. 27, W 2nd Mer., elevation within the 700 m potentiometric belt rises to 759 m, some 260 m above the general elevation of the preglacial bedrock valley between Chaplin Lake, Moose Jaw Creek, and the Qu'Appelle River, thereby indicating artesian conditions. The westward recession of the 600 m potentiometric contour east of Regina probably reflects drawdown of Mannville Formation water into Moose Jaw and Wascana Creeks, and the Qu'Appelle River valley segment between them. Southwestward, to between Weyburn and Assiniboia, the rise of the bedrock topography from 550 m to more than 670 m is accompanied by a decrease in Mannville potentiometric elevations, so that the potentiometric elevations lie more than 170 m below the topographic elevations. East of the 500 m potentiometric contour, the potentiometric surface flattens to the elevation of the Empress Formation gravel in the Hatfield bedrock valley (south) complex at 450 m. This complex apparently intercepts enough of the Mannville northeasterly flux to reduce the potentiometric field north of the 400 m contour to quasi-stability, balanced against meteoric inflow from Nut Mountain and the Porcupine Hills.

In the Broadview structural basin, the Hatfield bedrock valley (south) is infiltrated by formation water rising from Mississippian strata through a potentiometric cell at 600 m. This cell lies at the northeastern terminus of the potentiometric ridge between Broadview and Weyburn, which corresponds to the Torquay-Rocanville Trend (Christopher, 1961) of northeast-trending lineaments and faults. The trend also transects north-trending faults and salt-dissolution sinks propagated by basement elements of the Precambrian Tabernor Lineament Belt. Upwelling of water through the Torquay-Rocanville Trend also contributes to the formation-water system on the eastern flank of the north-trending belt of Newcastle barrier-beach and shoal sandstone (Koziol, 1988). As indicated by values of corresponding potentiometric elevations in the Newcastle Formation that are somewhat lower than those in the Mannville (Hannon, 1987), similar influx into the Newcastle Formation is also apparent along its western flank on the Elbow-Weyburn Lineament. This relationship is also indicated in the Mannville by the westward retreat of the 600 m potentiometric contour from a line along the Souris River to its irregular placement along longitude 105°W, south of Regina.

A vast depression of the Mannville formation-water potentiometric field across the Kindersley region of west-central Saskatchewan is delineated by the southward embayment of the 600 m contour to a position along the South Saskatchewan River. It corresponds spatially to the extensive network of the Tyner bedrock-valley system. The regional potentiometric decline reaches northward into a depression delineated by the 450 m contour at latitude 53°N and encloses the Unity terrace and most of the Lloydminster heavy-oil district (Figure 55). The hydraulic low

is elongated easterly, more or less along the course of the North Saskatchewan River and its antecedent glacial and preglacial channels, and thus indicates a shallow cone of depression associated with drawdown by the river system. As such, it indicates influx from the south, from the west around the northern apex of the Sweetgrass Arch of Alberta (Hitchon, 1984), and from the subcrop intake region to the north. An indication of influx from a northern recharge area into the depression is also provided by Haidl's (1986, Figure 7-7) plot of salinity values of Mannville Formation waters in the Lloydminster district, which shows an increase from less than 10 000 mg/l tds in Twp. 58 to 50 000 mg/l in Twp. 48 along the North Saskatchewan River. Likewise, Haidl (1984) noted that, in the Celtic and Westhazel fields, oil-water contacts in Waseca, Sparky, and General Petroleums sandstone on the western side of the anticline bordering the Battleford Trough are at elevations consistently higher than those on the eastern side of the trough.

One of the author's explanations of this phenomenon is based on the probability that it represents a potentiometric slope toward the trough. With respect to the potentiometric map (Figure 55), elevations in the thalweg of the North Saskatchewan River lie below 480 m in the Lloydminster-Battleford region (*i.e.*, within 30 m of the calculated potentiometric low). Bedrock elevations in the preglacial valleys, such as the Battleford and Lloydminster, are considerably lower, on the order of 390 m (Christiansen, 1967a, 1967b; Christiansen and Whitaker, 1973), and therefore well below the Mannville potentiometric surface. Apparently, most of the drawdown occurs by transit of formation water through the preglacial-valley gravel trains into the modern drainage system east of the Third Meridian (longitude 106°W; Christopher and Koziol, 1990).

Farther to the north, a similar depression is associated with the upper streams of the Churchill drainage: the Makwa, Beaver, Waterhen, and Cowan Rivers in the lowland between the Meadow Lake and Mostoos uplands. Likewise, south of Kindersley at latitude 51°N, potentiometric lows are present at the South Saskatchewan River and, south of latitude 51°N, along the Frenchman River at Eastend. This relationship between drawdown sites and the major rivers is consistent with that described by Hitchon (1969a, 1969b). The isopach (Figure 12) and structure (Figure 48) maps of the Cantuar Formation show that these sites have been and still are in a state of significant structural dislocation as a result of local tectonics, in part due to salt-dissolution collapse. The associated fault-fracture systems largely control the course of these rivers, and also apparently facilitate the cross-formational flow of water out of the Mannville. However, unlike its counterparts in the north, where the Mannville potentiometric surface is at or above ground level, the 700 m elevation of the cell at the Frenchman River is more than 200 m below the river-valley floor. The site is at the intersection of the north-northwest-trending Eastend-Maple Creek lineament, the western flank of the north-south Shaunavon Graben, and the east-west Adams Creek erosional paleovalley on the Mississippian erosion surface. Thus, the cone of depression probably indicates a conduit for Mannville waters, but probably through the Joli Fou shale into the Viking Formation.

The rate of flow in the lenticular Cantuar sandstone of the Mannville Group is likely controlled by bottlenecks, created through thinning and termination of high-permeability beds within areas of a few to a few hundreds of square kilometres. On a larger scale, the potentiometric map displays broad regions where the relief is nearly flat. On the Swift Current Platform, for instance, the regional flow from the Maple Creek potentiometric cell registers a pressure drop at the Shaunavon Graben. There, water funnelling through narrow Cantuar channel sandstone in the overall low-permeability, fluvial facies to the west floods into widespread, permeable, Cantuar estuarine and Upper Jurassic Roseray marine sandstone to the east (Christopher, 1974). Nonetheless, from the Maple Creek potentiometric cell northeastward across Saskatchewan to near the town of Hudson Bay, the regional gradient is about 1 m/km. Permeabilities of individual units in the Mannville are extremely variable, ranging from a few tens of millidarcies in mudstone and shale to more than 10 darcies in marine and estuarine sandstone, as exemplified by the Waseca and General Petroleums members of the Celtic and Westhazel oilfields east of Lloydminster (Haidl, 1986).

A nominal estimate of flow rate across the province in the Mannville can be determined from the formula:

$$V = (K/U) (g\rho_w) (dh/ds)$$

where V is rate of flow per unit cross-sectional area (in cm/sec); K is permeability (in darcies, converted to cm^2 using the factor 9.869×10^{-9}); U is viscosity (in centipoise, cP), which is 1 g/cm-sec for water; g is the gravitational acceleration constant (9.80×10^2 cm/sec); ρ_w is the density of water (g/cm^3); and dh/ds is the potentiometric gradient.

Therefore, the local rate of flow, with the proper combination of permeability and gradient, is a variable that can range through two orders of magnitude. For instance, using values for K of 0.1D, D, and 10D in the equation generates values for V of 1.1×10^{-9} cm/sec, 1.1×10^{-8} cm/sec, and 1.1×10^{-7} cm/sec, respectively.

In southeastern Alberta, the flow rate for the Mannville is given as 4×10^{-7} m/sec (*i.e.*, 4×10^{-5} cm/sec; Toth and Corbet, 1986). In the Cold Lake region of east-central Alberta, it is computed as 5 mm/yr (*i.e.*, 1.58×10^{-8} cm/sec) for the Lower Mannville and 1 mm/yr (*i.e.*, 3.1×10^{-9} cm/sec) for the Upper Mannville (Bachu *et al.*, 1987). Because of the relatively high proportion of sandstone with porosity of 20 to 25%, the storage capacity of the formation is relatively high.

Characteristics and Origin of the Hydrocarbon Reservoirs

The four hydrocarbon-producing regions in the Mannville of Saskatchewan are located at Wapella in southeastern Saskatchewan, just west of longitude 102°W and at latitude 50°20'N; around Swift Current in southwestern Saskatchewan; and in the Kindersley and Lloydminster districts in the west-central part of the province, east of longitude 108°W between latitudes 51° and 54°N (Figure 48 and Figure 55). The districts differ markedly with respect to reservoir geometry and stratigraphic relationships.

Southeastern Saskatchewan

The Wapella oil pool, located in Twp. 14 and 15, Rge. 1, W 2nd Mer., is the sole Mannville producer in eastern Saskatchewan. It is a Dina reservoir located on an anticlinal nose, in a cul-de-sac of an eastern tributary of the Assiniboia Paleovalley. According to Putnam (1989), the field is intersected and flanked to the east and west by several northeasterly trending antiforms spaced about 1.6 km apart, and is flanked to the north by a northwesterly striking monoclinal flexure. The floor of the cul-de-sac is believed to represent a sink caused by salt-dissolution. Discovered in 1952, the field has yielded 1.605×10^6 m³ of oil from initial oil-in-place reserves of 14.481×10^6 m³ and recoverable reserves of 2.520×10^6 m³. The parameters of the pool are: area, 1278 ha; net pay, 5.86 m; average porosity, 27.9%; and oil density, 906 kg/m³.

The reservoir is contained in channel sandstone bodies at the eastern updip edge, where they abut an outer shaly envelope against the Middle Jurassic escarpment of the Moosomin Paleo-upland. Its structural-stratigraphic setting is similar to that of the Middle Jurassic Red Jacket oilfields immediately to the south (Kreis, 1991): a downdip location in a northeasterly trending, lineament-controlled, salt-dissolution trench filled with multiple channel sandstone units. According to Van Delinder (1984), similarity in the C₁₃/C₁₂ plots of saturates versus aromatics suggests that oils produced from the Wapella and from the Mississippian Alida and Parkman fields are derived from the same source beds. The migration path is taken to be cross-formational along lineament-controlled faults and fractures of the Torquay-Rocanville Trend, especially where they intersect northerly oriented lineaments related to the basement (Figure 52).

Swift Current District

The Upper Jurassic and Jura-Cretaceous Roseray-Success oilfields of southwestern Saskatchewan occupy the northern half of the general oilfield district, which includes, over its southern half, the Middle Jurassic Shaunavon oilfields from Rapdan to Delta (Christopher, 1966, 1974, 1984a). The linear belt of oilfields rises structurally and stratigraphically from south to north and is distributed along the western limb and northeastern portion of the Shaunavon Graben, on terraces partitioned by northwesterly and northeasterly trending linears that intersect the north-south axis of the graben. The northern oilfields range in area from less than 1 km² to 60 km², and are defined by the pre-Cantuar relief, particularly the valley system. Because it is filled with sediments of relatively low permeability, the valley system seals the permeable flanks of the Roseray-Success buttes and mesas, and the overall productive peninsular body that projects northwest beyond the general line of the Roseray-Success erosional front (Figure 46). Post-Mannville subsidence has tilted the region to the southeast, and the oil-water contact therefore falls toward the southeast but at a lower rate than that of the regional dip, so that oil accumulations tend to be concentrated in the stratigraphically higher beds toward the southeast. Thus, the Fosterton, Verlo and Batrum fields in the northwest yield oil primarily from the Roseray Formation, and the Cantuar, Beverley, and Gull Lake fields produce primarily from the Success Formation, although all fields are, to some extent, dual producers. The gradient on the oil-water contact toward the southeast is not uniform, but is segmented and 'perched' by transecting permeability barriers of the Cantuar valley infill. These barriers and the easterly hydrodynamic gradient cause a distribution of oil pools over a structural elevation range of 60 m (*i.e.*, from -237 m in the southeast to -177 m in the northwest). They also negate the buoyancy that would tend to lift the oil out through the updip argillaceous sandstone and sandy mudstone of the Cantuar Formation.

The reservoirs of the Success and Roseray formations are generally contiguous, except for the western portion of the Cantuar and Beverley fields where the Masefield Shale intervenes. They are, however, sedimentologically dissimilar, in that the Success reservoirs originated as complex, fluvial point-bar, clay-bound quartzose sandstone, and the Roseray reservoirs as offlapping, shorefront, marine quartzose sandstone, greater in permeability

and area. However, all dual reservoirs are separated by beds of low permeability (*i.e.*, by marine Roseray shale and Roseray and Success sideritic, silty, argillaceous pavements). The reservoirs, including scattered small ones in permeable pockets of the Cantuar Formation, had initial oil-in-place (IOIP) reserves of $246.179 \times 10^6 \text{ m}^3$ of medium API° gravity oil (Table 1). At an average recovery factor (Rec%) of 31.3%, the initial recoverable reserves (IR) were $77.047 \times 10^6 \text{ m}^3$. As of the end of 1999, cumulative production (Prod) was $59.958 \times 10^6 \text{ m}^3$ and the remaining recoverable reserves (Rem) were $17.089 \times 10^6 \text{ m}^3$ (Saskatchewan Energy and Mines, 1999). Five fields (Battrum, Cantuar, Fosterton, Success, and Suffield) that produce primarily from the Success and Roseray formations had remaining recoverable reserves of $12.174 \times 10^6 \text{ m}^3$ or 71.2% of the total for the oilfield district.

The hydrocarbon reserves of the Success Formation in southwestern Saskatchewan, together with those of the Upper Jurassic Roseray and Middle Jurassic Shaunavon formations, apparently originated in the Paleozoic strata of the Williston and Fergus–Great Falls basins of North Dakota and Montana (Christopher *et al.*, 1971). According to Osadetz *et al.* (1991), they have boiling points greater than 210°C, and are characterized by pristane/phytane ratios greater than 1, a predominance of even/odd n-alkanes, high (C_{23} tricyclic)/(C_{30} pentacyclic) terpanes, a C_{35} hopane prominence, and diasterane/(regular sterane) ratios greater than 1. They concluded that these oils are compositionally similar to Family C oils of the Madison in southeastern Saskatchewan, and therefore originated in the Lodgepole Formation.

Associated natural gas is produced from the East Cantuar oilfield (Twp. 15, Rge. 16, W 3rd Mer.). The reserves at the end of 1999 are estimated as follows: $915.8 \times 10^6 \text{ m}^3$ initial gas-in-place (IGP), $799.5 \times 10^6 \text{ m}^3$ initial recoverable reserves (IER), $569.3 \times 10^6 \text{ m}^3$ cumulative production (Cum Prod), and $230.8 \times 10^6 \text{ m}^3$ remaining reserves (Rem Res; Saskatchewan Energy and Mines, 1999). The location of the gas field downdip of the petroleum reservoirs is an anomaly contrary to the updip position required by buoyancy forces. It may indicate an early introduction to, and entrapment on, the crown of the Swift Current Platform prior to the reversal of dip created by the Late Cretaceous tilt into the Williston Basin.

Table 1 – Petroleum reserves ($\times 10^6 \text{ m}^3$) of the Jura-Cretaceous oilfields, southwestern Saskatchewan (Saskatchewan Energy and Mines, 1999).

Field	IOIP	Rec%	IR	Cum Prod	Rem Res
Battrum	53.312	36.8	19.607	14.079	5.528
Beverley	22.414	20.2	4.524	3.702	0.822
Cantuar	49.516	25.6	12.605	9.317	3.288
Fosterton	27.548	43.4	11.920	10.810	1.140
Gull Lake	7.791	10.6	0.824	0.724	0.100
Hazlet	1.985	39.9	0.793	0.694	0.099
Java	7.429	12.9	0.967	0.214	0.743
Success	20.396	45.9	9.362	8.505	0.857
North Premier	9.384	51.8	4.859	4.466	0.395
Ross Lake	1.326	3.8	0.050	0.003	0.048
Seward	3.236	2.9	0.090	0.038	0.54
Suffield	17.255	27.6	4.771	3.410	1.361
Verlo	9.787	46.05	4.507	3.140	1.367
Webb	14.859	14.6	2.148	0.856	1.292
Total	246.179	31.3	77.047	59.958	17.089

Abbreviations: IOIP, initial oil in place; Rec%, recovery factor; IR, initial recoverable reserves; Cum Prod, cumulative production; and Rem Res, remaining recoverable reserves.

Kindersley District (extracted from Christopher, 1991)

Between the Saskatchewan River and Kindersley, most of the oil shows occur in the Success Formation, the quartzose and cherty wackestone of which fills in the breached crown of Mississippian limestone on the antiform of the Kindersley structural terrace (Figure 58). The Success Formation is spatially separated into a larger southern and a smaller northwestern region by the east- to northeast-trending, sub-Cantuar Kindersley Paleovalley. Oil shows are similarly concentrated, but limited to the western half of the terrace, and are generally low in API° gravity.

The southern region represents Success fill, up to 80 m thick, in an eroded valley complex, more than 100 m deep, that trends east-west from Rge. 16, W 3rd Mer. to beyond the Saskatchewan-Alberta boundary and flattens southwesterly into the regional dip on the Middle Jurassic Gravelbourg and Shaunavon formations. The 22 mapped hydrocarbon shows are distributed about a trend bearing 050° across the thalweg of the valley. A parallel subset of five wells to the west does likewise. Three wells in Twp. 25, Rge. 25, W 3rd Mer. plot along the complementary bearing of 320°. Thus, joint-fracture control of permeability appears to be related to the distribution of the oil shows.

The cluster of northern shows can be grouped into western and eastern areas, both terminated to the north by the sinuous pre-Cantuar erosional edge. The western area, against the Saskatchewan-Alberta boundary, includes 29 hydrocarbon shows and the Alsask and Loverna oil pools. It is a trapezohedral trough that plunges southeasterly into the tributary heads of the pre-Cantuar Assiniboia Paleovalley, and is flanked in the east by post-Mannville scarps and narrow depressions aligned at 320°. The eastern area includes the remaining oil shows and a small pool in the Coleville Bakken oilfield district. It trends north in Twp. 30 to 32 (inclusive), Rge. 23, W 3rd Mer.

In the southern region, where the hydrocarbons are retained in the Success sandstone by walls of relatively dense Mississippian limestone, the oil shows may reflect a lateral migration train from the Shaunavon shelf to the south. There, Mississippian oil has migrated cross-formationally into the Shaunavon and Cantuar formations in the Maple Creek–Eastend trough (Figure 46) and at the defunct Fox Valley pool, respectively. The carrier beds would have been the irregularly permeable Success Formation, and the migration would have been facilitated by the joint system and the northeasterly hydrodynamic gradient. However, this extrapolation of the petroleum system to the south is not supported by the northern oil shows. For the western area, migration from Alberta is indicated, with the influx terminated at the eastern trough lineament. The oil shows of the eastern area are relatively isolated by pre-Cantuar incision.

The petroleum deposits could have been introduced directly from the underlying Paleozoic strata rather than by long lateral migration in the formation. Although the sparsely stained Mississippian limestone and the potentially oil-rich Bakken Formation are possible candidates, the widely distributed bituminous and petroliferous beds of the Birdbear Formation seem to be the most likely. Evidence of vertical migration is seen in the multizonal oil shows involving the Bakken, Madison, Success, and Cantuar formations at Norvanian Hi NOR Eatonia 11-6-25-24(W3), G&W Glidden S 10-4-26-23(W3), G&W Glidden S 3-31-24-23(W3), Phillips Husky Dome Tuscola No. 1 (7-29-25-23W3), Husky Phillips Madison No. 1 (4-29-26-22W3), Imperial Centrefield 13-10-26-21(W3), and INC Husky Richlea 7-34-25-20(W3). The high density of Success oil shows indicates widespread oil saturation, induced by an intense fracture field arising from tectonic warp of the Kindersley structural terrace. The upwarp not only focussed pre-Success erosion on the apex of the antiform and the pre-Cantuar location of the Kindersley Paleovalley, but also facilitated Late Cretaceous salt-dissolution collapse structures along extensions of the precursor paleovalleys. Thus, the pre-Success erosional valley of Twp. 24 extends eastward into Late Cretaceous structural sinks, with relief seven times greater than that caused by erosion, as determined from a comparison of isopach differences versus structural differences between adjacent wells in the depression.

The 18 Cantuar heavy-oil shows, although widely scattered, tend to occur where the Success sediments are thinned or removed entirely by Cantuar cut-and-fill, and by drape of Mississippian limestone hills, especially along the northern perimeter. The relationship of the Cantuar to the underlying topography is one of onlap, and the better sorted quartzose sandstone is in the lower members against the interfluvial: the Dina-Lloydminster, as at Marengo-Mantario in Twp. 27 and 28, Rge. 26 and 27, W 3rd Mer.; and the General Petroleums–Sparky at Cactus Lake in Twp. 35, Rge. 28, W 3rd Mer. The pools along the northern edge of the Madison Formation are generally contiguous with pools in the Middle Bakken sandstone (Reasoner and Hunt, 1958; White, 1974; Ducharme and Murray, 1980).

In their analysis of Mannville oil samples from the neighbouring Provost oilfield in Alberta, Riediger *et al.* (1999) distinguished two families, EQ and D, on the basis of their biomarker characteristics. Family EQ shares common characteristics with other Lower Cretaceous conventional and heavy oils in Alberta, and with some of those in southwestern Saskatchewan, and suggests mixing of oil from the Devonian-Mississippian Exshaw Formation and the Lower Mannville Ostracode zone. The single sample of Family D oil is similar to Upper Devonian Leduc oil sourced from the Duvernay Formation. Both families were interpreted to have migrated 150 to 200 km from more mature sources west and southwest of the Provost oilfield. Their conclusion, that the Family D oil escaped the

relatively closed Upper Devonian petroleum system through breaches in the Devonian aquitards, is consistent with the postulated vertical migration from the Birdbear Formation. Likewise, the obvious Bakken-Mannville oilfield contact relationship along the subcrop, such as in the Coleville oilfield of Saskatchewan, indicates Exshaw sources. However, the possibility that the Mannville Formation, particularly the Ostracode zone (*i.e.*, the equivalent of the Cummings shale marker), is also a source bed in the Saskatchewan context may warrant further investigation.

Lloydminster District

By far the largest of the Mannville petroleum-producing regions, the Lloydminster and Kindersley districts include more than 125 Mannville heavy-oil pools and fields between Twp. 30 and 52 and Rge. 17, W 3rd Mer. and the Fourth Meridian (Figure 48 and Figure 55). The northern oilfields of the Lloydminster district, along with outlying oil shows and subeconomic pools, are concentrated on a southwesterly dipping, sub-Cantuar monocline. From a northwesterly trending scarp overlooking the western flank of the North Battleford syncline, the monocline flattens onto a dome, north of the town of Unity in Twp. 43, at the northeastern end of the North Battleford Arch of Kent (1968). The major fields occupy the northern part of the monocline and constitute the larger portion of an oil-producing region that extends west to Rge. 6, W 4th Mer. in eastern Alberta. The oil pools are constrained on their updip sides by narrow synclines, attributed to subsidence of underlying strata into salt-dissolution channels in the Middle Devonian Prairie Evaporite (Figure 46 and Figure 48). Apart from the foregoing relationship, the fields are incongruently positioned with respect to structural morphology. They vary from each other in elevation, and occur in lows and over highs. Many of these discordances relate to salt-dissolution tectonics before and after petroleum migration into the reservoirs (Haidl, 1986). South of Twp. 45, scattered small pools occur in sandstone drapes of sub-Cantuar topographic and structural knobs (*e.g.*, Winter oil pool) and as mudstone-encapsulated channel sandstone bodies controlled by subsidence induced by erosional valleys and salt dissolution (*e.g.*, Senlac oil pool; Groeneveld, 1990).

The reservoirs of the Lloydminster district lie in compound, large-scale lenticular bodies associated with shoreline environments, ranging from beach to tidal flat, marshy backshore, and marine offshore, that are intersected by tidal and estuarine inlets and generally anchored by underlying topographic highs (Haidl, 1984; Smith *et al.*, 1984). They are aligned northwesterly in three major belts:

- a northeasterly belt, overlooking the Battleford Trough and comprising, from north to south, the Celtic, Westhazel, Standard Hill, and Edam fields;
- a medial belt, represented by the Tangleflags, Big Gully, Lashburn, and Golden Lake fields; and
- a compound western belt, comprising the Northminster, Aberfeldy, and Lashburn fields on the eastern side and the Silverdale and Epping fields of Saskatchewan and the Devonia Lake, Blackfoot, and Kitscoty fields of Alberta on the western side (Figure 59).

The oilfields are internally compartmented and terminated by linear mudstone units that form low-permeability barriers to oil migration, by facies changes, and by steep structural gradients. Depths of the main fields range between 450 and 720 m. Oil-in-place for the region has been variously estimated, and ranges from the Saskatchewan Industry and Resources regulatory estimates, limited by the oil-pool boundaries, to the more wide-ranging calculations of Wilson and Bennett (1985) that incorporate oil shows in wells of outlying and inlying undeveloped localities. Their conclusion, that the region contains $2.55 \times 10^9 \text{ m}^3$ of oil-in-place, contrasts sharply with the official estimate of $1.79 \times 10^9 \text{ m}^3$. They assigned the oil-in-place to formation members as follows: Sparky, $812.76 \times 10^6 \text{ m}^3$; Waseca, $638.11 \times 10^6 \text{ m}^3$; General Petroleum, $347.82 \times 10^6 \text{ m}^3$; Lloydminster, $236.02 \times 10^6 \text{ m}^3$; Cummings-Dina, $231.52 \times 10^6 \text{ m}^3$; McLaren, $191.48 \times 10^6 \text{ m}^3$; Colony, $68.02 \times 10^6 \text{ m}^3$; and Rex, $25.78 \times 10^3 \text{ m}^3$. Most of the reserves are within the larger fields in the region, bounded by the North Saskatchewan and Battle rivers, that extend westward into Alberta. According to published data (Saskatchewan Energy and Mines, 1999) seven of the fields (Tangleflags, Celtic, Aberfeldy, Golden Lake, Epping, Edam, and Lashburn; Table 2), contain 48% ($857.482 \times 10^6 \text{ m}^3$) of the $1\,792.764 \times 10^6 \text{ m}^3$ initial oil-in-place and 45.9% ($67.356 \times 10^6 \text{ m}^3$) of the total recoverable reserves of $146.733 \times 10^6 \text{ m}^3$. Their cumulative production of $45.456 \times 10^6 \text{ m}^3$ is 48.2% of the total production of $94.141 \times 10^6 \text{ m}^3$, and remaining reserves of $21.919 \times 10^6 \text{ m}^3$ represent 23% of the total remaining ($94.141 \times 10^6 \text{ m}^3$), thus indicating a good potential for many of the smaller pools in the district. In 1993, the seven pools accounted for 43% of the remaining reserves. Despite the increase in cumulative production during the intervening six years, remaining reserves have increased by $7.766 \times 10^6 \text{ m}^3$ (a 35% increase).

Table 2 – Heavy-oil reserves ($\times 10^6 \text{ m}^3$) Lloydminster district, west-central Saskatchewan (Saskatchewan Energy and Mines, 1999).

Field	Member	IOIP	Rec Res	Cum Prod	Rem Res	Area (ha)
Tangleflags	LL	102.597	8.344	5.747	3.081	8416
	GP	74.646	6.518	3.240	3.279	5965
	Sy	39.791	4.162	1.528	2.640	4999
	McL	18.743	2.515	0.926	1.590	2379
		235.777	21.539	10.968	10.590	21,759
Celtic	GP	24.845	2.492	1.227	1.265	1682
	Sy	42.162	2.909	1.076	1.833	2884
	Was	110.876	4.839	2.616	2.223	5252
		177.836	7.711	7.603	4.919	9818
Aberfeldy	Sy	96.836	7.711	7.603	0.107	6589
Epping	GP	19.209	1.046	0.970	0.970	3238
	Sy	88.105	6.887	6.028	0.859	7187
		107.314	7.933	6.988	0.935	10,425
Golden Lake	Sy	52.311	1.690	1.378	0.311	3860
	Was	50.951	5.205	4.887	0.314	4711
		102.902	6.895	6.265	0.625	8572
Edam	Sy	21.069	2.308	2.053	0.255	1879
	Was	56.770	6.481	3.978	2.503	6401
	Ll	0.811	0.060	0.050	0.011	130
		78.650	8.849	6.081	2.769	8500
Lashburn	Sy	14.576	1.511	0.513	1.002	1882
	Was	43.544	2.678	2.109	0.571	2477
		58.120	4.189	2.622	1.572	4359
		857.482	67.356	48.456	21.919	70,022

Abbreviations:

IOIP, initial oil in place; Rec Res, recoverable reserves; Cum Prod, cumulative production; Rem Res, remaining reserves; McL, McLaren Member; Was, Waseca Member; Sy, Sparky Member; GP, General Petroleum Member; and Ll, Lloydminster Member.

Each major pool includes one to eight lenses of stacked, oil-permeated sandstone (Wenneckers *et al.*, 1979). Duplicates of the main oil lens appear in the overlying and underlying sandstone strata, but are separated by less permeable siltstone and mudstone. Vertical spacing is about 10 to 20 m and the oil-permeated sandstone bodies, though only 9 to 10 m thick, are extensive, ranging from 3388 to 17 447 ha in area. Differences of a few API° in the fields correlate with gravity separation of lighter crude from the heavier by a process that is accelerated by increasing permeability and decelerated by increasing viscosity. Oil of API° exceeding 10 (*i.e.*, 1000 kg/m³) rises to the top of the reservoir because it is lighter than the brackish reservoir water (of density 1005 kg/m³). This separation is enhanced where denser, more saline water is encountered, such as the 1037 kg/m³ water at the Winter oilfield (Groeneveld, 1990). Heavier oil sinks toward the bottom of the reservoir. Fields that show gravity separation in the Sparky, for instance, are Northminster, Silverdale, Dulwich, Aberfeldy, Epping, and Lone Rock; density increases are seen at intervals of 1.5 to 3 m. In a number of pools, the heavy oil segregated at the base of a reservoir is of a viscosity high enough to be a tar (Wenneckers *et al.*, 1979). Density of produced oil from the region ranges from 991 kg/m³ at Lashburn West to 946 kg/m³ at Marsden (*i.e.*, API° 11 to 18); however, the bulk of the production consists of oil in the range 964 to 968 kg/m³ (*i.e.*, API° 15).

The Mannville heavy-oil and tar-sand deposits are genetically related across eastern Alberta and western Saskatchewan. These deposits range from the Peace River, Wabasca, and Athabasca tar sands in the north, through the Cold Lake–Lloydminster heavy-oil fields, to the Bellshill Lake medium-gravity pools in the south (Vigrass, 1968; Deroo *et al.*, 1980; Montgomery *et al.*, 1974). These authors concurred that the heavy-oil and bitumen reserves represent a Laramide (*i.e.*, Late Cretaceous to Cenozoic) updip migration from Mannville sources in western Alberta. Disparate arguments for Devonian source beds and an Early Cretaceous emplacement of the

hydrocarbons are also extant and were reviewed in Conybeare (1966). A definitive work by Allan and Creaney (1991) on genetic sources of Mannville oil looked at the oil families of the Western Canada Sedimentary Basin. On the basis of gas-chromatography and mass-spectrometry, all Mannville oils, including the tar sands, were typed as belonging to a mixed family from the transitional Devonian-Mississippian Exshaw and the Lower Jurassic Nordegg formations of the Rocky Mountain geosyncline. The spread of indicated source beds, from the Upper Devonian Duvernay to the Mannville Ostracode bed itself, reflects the wide-ranging stratigraphic architecture of the Mannville, in that its basal contact intersects virtually all of the pertinent oil-source formations.

Northern Natural Gas Fields

Most of the natural-gas fields lie at elevations above the heavy-oil-producing region, though not updip from the latter. From an overlap with the Lloydminster heavy-oil fields, they extend north from Twp. 52 to Twp. 68 in a narrow belt between the Saskatchewan-Alberta boundary and Rge. 21, W 3rd Mer., and rise from south to north in elevation, as taken on the Cantuar Formation, from 160 to 220 m (Figure 48). The gas pools are mainly in upper Mannville (Waseca, McLaren, and Colony members) progradational shoreline facies built out from the west into offshore, more argillaceous, sandy mudstone. They are enclosed on draped Precambrian domes (Figure 54), small structural terraces, and anticlinal noses, and across narrow re-entrant troughs by easterly shale-out, but set in a large amphitheatre in the western part of the Doré Lake synform (*i.e.*, above the eastern, partially dissolved flanks of the Early Devonian Lower Elk Point evaporite beds). With more than 32 established gas pools (Figure 53), this is the second largest natural-gas-producing district in the province. Initial gas-in-place at the end of 1999, in both established and miscellaneous pools, was estimated at $51\,435.8 \times 10^6 \text{ m}^3$, with initial established reserves estimated at $39\,613.5 \times 10^6 \text{ m}^3$ and cumulative production at $25\,892.2 \times 10^6 \text{ m}^3$ (Table 3; Saskatchewan Energy and Mines, 1999). The Beacon Hill fields enclose the largest IGP ($7157.2 \times 10^6 \text{ m}^3$) and have provided 14% of the total recoverable reserves. However, their cumulative production ($4888.7 \times 10^6 \text{ m}^3$) indicates that 87.4% of the reserves has been consumed. At Tangleflags and at Pierceland, the runners-up in reserves and cumulative production, this percentage is 68.9% and 97%, respectively. The recoverable reserves in the 'miscellaneous' pools exceed those in the established pools ($21\,408.4 \times 10^6 \text{ m}^3$ versus $18\,205.1 \times 10^6 \text{ m}^3$, respectively), but only 52.8% of the gas in the miscellaneous pools ($18\,205.1 \times 10^6 \text{ m}^3$) has been produced.

Hydrocarbon Reservoirs in the Post-Mannville Setting

Anomalies in formation-water pressure have been routinely noted in the study of oilfield districts and, in the case of Alberta, extensively investigated by Hitchon (1984), who noted a relationship of such features with local variations in the geothermal gradient. These anomalies have been used to account for the local distribution, displacement, and/or absence of petroleum reserves. Large anomalies also have regional significance in the location and absence of the oilfield districts. As shown on the potentiometric map (Figure 55), these are associated with three of the four oil-producing districts in Saskatchewan. The exception is the basal Mannville pools of the Kindersley district, which, together with the larger Middle Bakken pools (*e.g.*, Cactus Lake), are close to the sub-Cantuar unconformity at the updip end of Mississippian Lodgepole and Bakken carrier beds.

In southwestern Saskatchewan, upwelling water from the Maple Creek potentiometric high, depicted by the 800 m contour, is contiguous with the Gull Lake oilfield at the southeastern end of the Roseray-Success oilfield belt. Also, the eastern front of the broader region, encompassed by the 700 m contour, passes through the fields along the axis of the Shaunavon Graben. The relationship indicates easterly and northeasterly flow across the fields, and an associated pressure drop where the system encounters the edge of the highly permeable Roseray Formation. A similar high-pressure belt lies west of the Middle Jurassic Shaunavon fields to the south (Christopher *et al.*, 1971). Shaunavon oil reservoirs are situated at the downdip eastern edge of widespread sandstone that terminates as lowstand shoreline deposits along the Shaunavon Graben (Christopher, 1966). Jura-Cretaceous Roseray-Success oilfields are stratigraphically separated from the Shaunavon Formation by 45 m of Rierdon Shale and are located at the updip edge of those formations in buttes and mesas along the sub-Cantuar erosional edge in the northern part of the Shaunavon Graben. Petroleum is produced simultaneously from both reservoir systems where they vertically overlap. Thus, it appears (Christopher, 1974) that formation water moving east down the regional dip is: 1) holding Shaunavon oil in downdip feather-edge reservoirs against an updip argillaceous and calcite-cemented barrier; and 2) increasing the effectiveness of the semipermeable seal of Cantuar valley fill in trapping both Roseray and Success oil in their updip sites against the sub-Cantuar unconformity.

Shaunavon oil shows are widely distributed west of the oilfield trend, and may indicate oil that escaped downdip traps on its passage out of the fracture system in the Shaunavon Graben. Alternatively, they may reflect an incomplete sweep of oil derived from the fracture system related to the Maple Creek potentiometric cell by the downdip-moving formation-water drive. The latter setting would require that the oil be forced into the reservoirs through the updip seals that now retain it. Roseray-Success oil shows are distributed immediately to the east of the graben (Figure 46). By far the largest of these is on a dome immediately south of Swift Current, about 10 m below

Table 3 - Natural gas reserves ($\times 10^6 m^3$), west-central Saskatchewan (Saskatchewan Energy and Mines, 1999).

Pool	Formation	IGP	IER	Cum Prod	Rem Res
Beacon Hill	Mn	7,157.2	5,595.4	4,888.7	706.75
Bronson Lake	Col	1,033.6	873.7	710.0	163.7
Carruthers	Col	458.4	348.4	134.1	exhtd
Cold Lake	Col	382.9	291.0	178.6	112.4
Flat Valley	Col	382.9	70.8	37.8	exhtd
Fort Pitt	Col	1,565.4	1,155.4	952.3	203.1
Frenchman Butte	Col	1,157.4	672.2	413.5	259.7
Lloydminster	Col	333.1	252.1	244.8	7.3
Makwa	Mn	464.1	330.7	274.5	356.2
Mudie Lake	Col	1,259.1	956.9	679.3	277.6
Paradise Hill	Col	368.8	289.3	179.5	100.8
Peck Lake	Col	1,963.2	1,583.3	1,348.5	235.8
Pierceland	Mn	1,804.5	1,553.4	1,509.4	44.1
Primate	Mn	140.8	106.4	101.2	5.2
Primrose Lake	Col	1,964.2	1,586.1	1,018.3	567.8
Salvador	Mn	335.1	254.7	90.8	163.9
Senlac	McL, Sy	715.8	566.5	433.1	133.4
Spruce Lake	Col	97.7	69.1	58.8	10.3
Tangleflags	Col	2,169.4	1,648.8	902.0	746.8
Unity	Mn	366.2	313.5	300.6	exhtd
Miscellaneous	Cumg	329.7	248.2	143.9	104.3
	Ll	1,032.0	816.1	524.2	291.9
	Rex	656.8	493.0	300.0	192.1
	GP	224.5	173.1	112.5	60.6
	Sy	1,347.1	1,016.2	680.4	335.8
	Was	1,191.9	898.8	400.8	498.0
	McL	3,241.1	2,455.8	1,902.2	553.6
	Col	11,214.5	8,446.5	4,887.4	3,559.1
	Mn	9,039.1	6,854.7	2,343.0	4,517.7
Misc. total		28,276.7	21,408.4	11,295.3	10,113.1
Estimated pool total		23,159.1	18,205.1	14,596.9	3,610.5
Grand total		51,435.8	39,613.5	25,892.2	13,723.6

Abbreviations:

IGP, initial gas-in-place; IER, initial established reserves; Cum Prod, cumulative production; Rem Res, remaining reserves; exhtd, exhausted; Mn, Mannville Formation; Col, Colony Member; McL, McLaren Member; Was, Waseca Member; Sy, Sparky Member; GP, General Petroleum Member; Rex, Rex Member; Ll, Lloydminster Member; and Cumg, Cummings Member.

the elevation of the fields. Outlying shows occur to the northeast in Twp. 19, Rge. 13, W 3rd Mer., Twp. 17, Rge. 12, W 3rd Mer., and Twp. 18, Rge. 11, W 3rd Mer. Northwestward updip migration from cross-formational conduits in the faulted, high-pressure region southeast of Assiniboia, as augmented by buoyancy forces against the eastward formation-water flow, could explain the hydrocarbon filling of the sub-Cantuar unconformity traps. However, the tarry nature of the oil shows on the twin domes of the Swift Current high indicate the former existence of entrapped oil on the crest of the platform. A second event, such as the Laramide easterly tilt of the platform toward a renewed Williston Basin, would be required for the oil to spill out of the structures along the crests and move to its present location at the Shaunavon Graben.

Thus, the Shaunavon graben is physically central to the oil district. It was the great water divide, between the Assiniboia paleodrainage to the east and the Edmonton paleochannel system to the west, at the height of the Swift Current uplift during Aptian and Early Albian time. The uplift was probably a corollary of the Jura-Cretaceous Columbian-Sevier Orogeny in the Rocky Mountains region of southeastern British Columbia and western Montana and Idaho. The pre-Upper Jurassic easterly slope on the Shaunavon shelf was reversed to the west at that time, and the easterly dip of the Swift Current Platform was steepened by downwarp of the pre-Aptian Govan Paleolowland basin. Petroleum migrating up the faults and fractures associated with the graben would have spilled into the flanking sandstone. The collapse of the platform in the Late Albian restored the Middle Jurassic structural dip of the Shaunavon Formation, thereby causing an updip migration of excess oil and, in the case of the Roseray-Success

deposits, an eastward spread. The succeeding Late Cretaceous Laramide structural changes not only increased the eastward dip toward the Williston Basin, but also elevated the central Montana mountain system and introduced the present hydrodynamic gradients. Roseray-Success oil that had migrated into the western extremities of these formations is held there against Cantuar low-permeability argillaceous sandstone and mudstone by the downdip formation-water flow. Shaunavon oil west of the oilfield belt was rearranged into high-relief structural traps, driven into permeable Mannville sandstone (*e.g.*, the Fox Valley pool in the Eastend–Maple Creek lineament) and, in the oilfield district, forced into synclinal pools on the lower terraces of the Shaunavon Monocline and added to the northern pools of the Roseray and Success formations via the fracture system of the Shaunavon Graben (Van Delinder, 1984).

In the heavy-oil district of west-central Saskatchewan, evidence for a two-stage filling of the Mannville pools, with the first as early as the Albian, is partly based on the preservation of thousands of oil-impregnated logs in the fluvial sandstone of the McMurray Formation of Alberta (Sproule, 1938). The aptly named ‘mummified’ logs of Carrigy (1973) are also found along the Clearwater River of west-central Saskatchewan (Figure 31), where they are embedded in outcrops of cross-bedded, channel cut-and-fill sandstone of the McMurray Formation (Paterson *et al.*, 1978). In the Clearwater River area, the logs are 15 cm in compressed diameter, and one of them bridged a cave with a span exceeding 3 m. The logs are pulpy, being easily separated along the fibres by hand. The sandstone is poorly cemented, and the absence of petrification in the logs suggests that an early oil infiltration preserved them from complete decay and/or preservation by silicification. Thus, the first oil-infill stage implies nearby source beds and/or reservoirs.

A post-Mannville stage would require sufficient depth of burial and increase in temperature for hydrocarbon generation and therefore migration from Mannville depths greater than that in the current reservoirs. Although the proponents of long-distance hydrocarbon migration tend to regard the Mannville strata as a vast open system that rises on the Laramide dip from the Rocky Mountain geosyncline to the outcrop belt, the present study indicates that, at least in Saskatchewan, sedimentological, paleotopographic, and structural inhomogeneities tend to compartmentalize the formation, both vertically and laterally. Thus, it can be argued that an earlier Albian episode of oil migration was overprinted and accentuated by the Late Cretaceous–Cenozoic Laramide orogeny (Christopher, 1980, 1984b). The earlier event saw the spread of oil to the northeast, beyond the barrier now posed by the Late Cretaceous, northwesterly trending Battleford Trough. The Lloydminster heavy-oil deposits are enclosed by a shallow but large potentiometric depression in the Mannville formation-water surface, where meteoric inflows from northern, southwestern, and southern intakes meet (Figure 53). An outflow into the North Saskatchewan preglacial valley system is indicated. Petroleum from southwestern source beds in the Jurassic and Mississippian of the Rocky Mountain foreland basin accompanied the Cenozoic Laramide influx. Hydrocarbon biodegradation ensued, as documented by Evans *et al.* (1971) and Bailey *et al.* (1973, 1974). Exit of water and some oil through the preglacial Saskatchewan River drainage system, as well as local reorganization of structure by salt-dissolution processes, maintained the system until the remaining oil became too viscous to pass out of the present reservoirs.

The Wapella oilfield of southeastern Saskatchewan lies immediately to the southeast along the regional strike, but somewhat downdip from, the Broadview potentiometric cell (in Twp. 16, Rge. 2, W 2nd Mer.), which is, in turn, located at the updip end of a ridge of higher pressure formation water that corresponds with the Torquay-Rocanville Trend. As in southwestern Saskatchewan, both ridge and cell represent cross-formational water flow from the Paleozoic system. The lateral juxtaposition of not only the Wapella, but also the Middle Jurassic Red Jacket pools (Kreis, 1991), to this cell indicates that they also are related in the same manner, and that updip petroleum seals of the reservoirs are being enhanced by a downdip component of radial outflow from the cell. Additionally, the northeasterly alignment of the northern perimeter of the Mississippian oilfield district along the southeastern flank of the Torquay-Rocanville Trend, between Twp. 6 and 14, W 2nd Mer. (Figure 55), may have been predetermined by this phenomenon of cross-formational outflow through the fracture system to the overlying Mesozoic strata.

The northern natural-gas reservoirs of the Mannville crowd the western perimeters of the potentiometric drawdown by the Beaver, Waterhen, and Makwa rivers (Figure 53 and Figure 55) between Twp. 67 and 60 in the north, and the potentiometric drawdown associated with the North Saskatchewan River between Twp. 56 and 52 in the south. At the potentiometric divide in Twp. 58 and 57, the natural-gas district extends farthest east to include Loon Lake in Rge. 21 and 20, W 3rd Mer. The bulk of the reserves in the south are trapped on east-facing structural scarps overlooking narrow, salt-dissolution, strike-aligned synforms originating in the Prairie Evaporite. The fields to the north are extremely shallow (274 to 310 m), and are situated on structural knobs and against west-facing scarps related to dissolution of Lower Elk Point evaporite beds in the floor of the Doré Lake synform. Buoyancy forces on the regional dip are from the southwest in Alberta. The location of the gas fields at the western perimeter of the major potentiometric lows indicates that the pools are survivors of a process that would tend to deplete them of natural gas. Perhaps:

- convergent inflow of meteoric water from the uplands to the northeast and southeast is countering the updip passage of natural gas to the rivers and the erosional edge of the Lower Colorado shale; and
- input of natural gas from western source beds is greater than loss to meteoric outflow.

Although the natural-gas fields lie at elevations above the Lloydminster oil pools, they are not updip of them. Rather, they appear to be components of another hydrocarbon field downdip to the west, probably the Cold lake deposits of Alberta. The gas reserves intrinsic to the Lloydminster heavy-oil fields, if they still exist, lie to the east and northeast of the Battleford Trough.

Hydrocarbon Prospects

Swift Current–Maple Creek District

The major oil shows in the Success and Cantuar formations west of the oilfield belt occur beyond the north-south erosional edge of the Rierdon Shale (*e.g.*, in the lineament-controlled Maple Creek Paleovalley and the adjacent area to the north), where those formations are in erosional proximity to the Shaunavon, Gravelbourg, and Madison formations. Oil prospects are better where permeable, lenticular sandstone units of the Dimmock Creek Member pinch out against topographic knobs (*e.g.*, the exhausted Fox Valley pool in Twp. 17, Rge. 26, W 3rd Mer.). Others are found in channel sandstone units of the basal McCloud Member of the Cantuar Formation, or in estuarine sandstone units of the Atlas Member close to the pools of the oilfield trend (Leckie *et al.*, 1997b). South of the Maple Creek fracture belt, Cantuar and Success facies tend to be wackestone and therefore low in permeability. Thus, away from the major lineaments, Cantuar prospecting should also include the Shaunavon, Gravelbourg, and Madison formations.

Sandstone of the Pense Formation caps sequences that coarsen upward from black shale. At Rge. 20, W 3rd Mer., these sandstone units attenuate westward, updip on the Shaunavon Monocline, into argillaceous facies. Accordingly, there is a setting for hydrocarbon reservoirs, defined by updip permeability pinchouts against the easterly, downdip, formation-water flow. Offsetting factors in these prospects would be the generally indurated character of the southwestern Pense sandstone and scarcity of oil shows. However, their permeabilities are probably similar to those of the stratigraphically higher, natural-gas-producing Milk River and Medicine Hat sandstone of the district. Pense sandstone thickens eastward to a maximum across the Swift Current oilfield trend, where prospective traps would be contingent on faulting or doming. To the south, Pense sandstone rising onto the Bowdoin Dome offers good prospects for production.

Kindersley District

The Success Formation of the Kindersley district, in spite of its widespread oil shows, is poorly productive because of high interstitial kaolinite and tripoli in the context of low API° oil. On the other hand, the well-developed fracture system increases gross permeability, as well as access to cross-formational flow (Christopher, 1999). In the southern part of the district, the oil shows are multizonal, appearing also in the Middle Bakken sandstone and the Cantuar Formation along the northeasterly aligned lineaments (Figure 58). Thus, further exploration along the trend may be warranted.

In the northern part of the district, the high density of Success oil shows in the western area suggests that there has been an adequate amount of exploration for commercial production from the Success Formation. The potential for oil discovery may be greater in the Cantuar Formation farther north, beyond the erosional edge of the Success Formation and around topographic highs to the south. Targets in the Bakken Formation are also a major incentive

for exploration. Isopach trends in the Middle Bakken Member are controlled by the northwesterly and northeasterly lineaments, and the Bakken fields are the largest producers in the district except for those of the Viking Formation (White, 1974). Elevations on the Mississippian surface rise eastward to knobs, south and east of Rosetown, and to highs along the northern perimeter of the Kindersley structural terrace. The highs serve as drape anticlines in Viking oil and gas reservoirs (Jones, 1961), and may well have a potential for Cantuar and Success hydrocarbon discoveries.

Lloydminster District

The oil shows of the Lloydminster district, comprising both point and subeconomic deposits up to a township in area, form a wide ring around the core of producing oil fields concentrated in the northern half of the region. Some subeconomic deposits, such as one near the village of Wilkie (Twp. 38, Rge. 19, W 3rd Mer.), await higher oil prices and improved extraction techniques based on horizontal drilling and tertiary-recovery processes. Additional prospects lie in Waseca and Sparky sandstone bodies east and southeast of the Lloydminster oil fields on the terraces flanking the western side of the Battleford Trough, where retention of oil in potential reservoirs is reinforced by the potentiometric depression (Figure 46 and Figure 55). Beyond the fields to the northeast, the structural rise increases, causing an increase in the northeasterly vector of the buoyancy forces. Trapping of oil may well be dependent on the presence of dip reversals, and therefore on structural and sedimentological linear elements similar to those present in the oilfield district. The most easterly of the known oil shows occurs at Sohio Red Creek Arelee 13-11-40-12(W3), along the southern flank of the potentiometric depression associated with the Battleford Trough and the North Saskatchewan River.

Eastern and Central Saskatchewan

South of latitude 51°N, up to 320 m of Jurassic shale and mudstone separate the Mannville from potential Mississippian petroleum sources. Thus, the presence of regional intersecting lineaments and potentiometric cells for inflow of formation water from below is as important a prerequisite for oil accumulation in the Mannville as is the presence of suitable reservoirs. This combination of geological elements exists at the Mannville Wapella and Middle Jurassic Moosomin oilfields. This region differs from the southwestern oilfield belt only in the lesser variety of reservoir configurations. A recurrence of the Wapella play is patently dependent on the discovery of other northeasterly trending Mannville and Jurassic channel sandstone units along updip re-entrants in the Moosomin–Hudson Bay structural front. An oil show at Imp TW Broadview 14-17-15-4(W2) in the Rocanville-Torquay potentiometric high may indicate the presence of pools to the west, along intersections of the north-south Tabernor Lineament Belt with those aligned northeasterly. Farther west, the region is largely barren of oil shows except for one in the Middle Jurassic Gravelbourg Formation at Tide Water Ituna Crown No. 4 (1-29-25-12W2). This show occurs at the northeastern front of a broad, Mannville, high-pressure potentiometric ridge trending 048° from the Elbow-Weyburn Lineament–controlled potentiometric high near Moose Jaw. This high appears to be controlled by the same family of lineaments as the Rocanville-Torquay Trend, and corresponds to a southwesterly plunging structural trough at the base of the Cantuar Formation.

Of the formations between the Mississippian Madison Group and the Colorado shale on the southern flank of the Punnichy Arch, both Mannville and Middle Jurassic sandstone units are available as hydrocarbon reservoir rock, but the Lower Watrous tends to be occluded by anhydrite. The southern limb of the arch, by virtue of the sub-Pense unconformity, might have formed an effective barrier to updip migration of oil but for the permeable nature of the Pense sandstone. Thus, the presence of reservoir seals in the Mannville of this region is dependent on permeable sand bodies sealed off by mudstone. North of the Punnichy Arch, the Mississippian limestone forms an escarpment against variable Success rock types, including impermeable chert pavements acting as probable caprock. The potential exists for oil reservoirs in the Success Formation, as it does for the same formation in the Kindersley district. Likewise, Mannville facies are similar to those on the Unity Terrace, being variable and including shore-, shoal- and channel-sandstone units. The Humboldt Trough, like the Battleford Trough, presents an updip impediment to northward migration of oil.

Scattered oil shows across central Saskatchewan were reported by Simpson (1970) in the Upper and Middle Devonian (Figure 55) at Western Petroleum No. 1 (12-23-29-32W1), Northern Royalties 6-35-29-32(W1), Trail Blazer 1-31-44-2(W2), and Husky Phillips Fitzmaurice No. 1 (16-18-27-8W2), raising the prospecting potential of the region as an alternate and extant oil source for Mannville reservoirs. Three of these shows, which are spatially associated with the Moosomin–Hudson Bay structural belt and therefore with the similarly located southern Mesozoic fields, may be an indication of tectonic activity and an elevated geothermal environment. In fact, enhanced thermal maturities in the Ordovician have been mapped along the Tabernor Lineament Belt, from the Nesson Anticline of North Dakota as far north as the Punnichy Arch; along the Punnichy Arch at Broadview and Jedburgh; and on the Watrous Dome (Osadetz *et al.*, 1989; Li *et al.*, 1998). To the eastern shows can be added those

in west-central Saskatchewan, from the Souris River and Meadow Lake formations at Seaboard Meadow Lake No. 4 (10-20-61-12W3) and from the Winnipegosis Formation at Seaboard Meadow Lake Crown No. 5 (4-5-65-12W3). Perhaps the oil-generating potential of central Saskatchewan should also be viewed in the context of Early Cretaceous Colorado tectonic activity, which saw uplift of the Punnichy Arch, deep downset of the Swift Current Platform, and the intrusion of kimberlitic bodies (Lehnert-Thiel *et al.*, 1992; Leckie *et al.*, 1997a) along the southern base of the Molanosa Dome from Sturgeon Lake to Fort-à-la-Corne, just north of the Saskatchewan River. Baker (1992), who projected the passage of the Farallon Plate beneath the lithosphere of Saskatchewan toward Hudson Bay, observed that the Eocene outpouring of mantle-derived material of the central Montana alkalic province was accompanied by a large increase in the geothermal gradient of that region. A similar, if milder, temperature increase may have occurred during the Early Cretaceous in central Saskatchewan, although none has been detected to date.

Natural gas shows in the Mannville of southeastern Saskatchewan are recorded from wells associated with potentiometric anomalies, such as:

- the down-dip intersection of the northeasterly oriented Rocanville-Torquay and northwesterly oriented Weyburn-Elbow potentiometric highs at Central Del Rio H.B. Ralph 10-8-7-13(W2), Plymouth Sun Talmage No. 1 (9-22-9-13W2), and Bennett Burns Young Bell 11-19-5-14(W2);
- a potentiometric low at the Mobil CDR Flat Lake wells 15-5 and 5-30-1-15(W2);
- downdip from an adjacent potentiometric high, in Twp. 8, Rge. 21, W 2nd Mer., at Norcanols Ogema No. 1 (4-24-7-23W2) and Socony Sohio Channel Lake No. 1 (9-3-7-24W2); and
- a potentiometric low at Shell Dahinda No. 1 (6-2-9-23W2) and Dahinda No. 1 (10-23-10-23W2).

As indicated by the sub-Cantuar structure map (Figure 46), all sites are located on the flanks of short structural re-entrants attributable to collapse over salt-dissolution sinks in the Prairie Evaporite. Accordingly, these shows are probably sourced from underlying Mississippian oil reservoirs, which are still degassing across the formations through fractures created by the intersection of active regional joint and fault sets. However, gas migrating northeastward from the Mississippian oilfields (*i.e.*, up the dip with the regional hydrodynamic flow) may have escaped from the Mannville strata, unless trapped in channel sandstone enclosed in updip shale. Perhaps coincidentally, the gas shows (Simpson, 1970) in the Colorado Group north of the Punnichy Arch and the Devonian oil shows occur in two structural belts, the Tabernor and the Moosomin-Hudson Bay.

Basement to Holocene land-surface structural forms, including faults, are widespread in the Meadow Lake Basin. The effects of basement forms are transmitted by the process of salt dissolution in the evaporites of the Devonian Elk Point formations and by repetitive drape effects accentuated and locally inverted by agents of erosion during the several major hiatuses of the Late Paleozoic, Mesozoic, and Cenozoic. The Precambrian igneous-metamorphic domain west of longitude 109°W exhibits less structural differentiation than that to the east, but probably more effective and larger structural-topographic closures in the context of natural-gas entrapment and storage. Leakage of natural gas to the surface is also inhibited by a full coverage of Colorado shale. Thus, the regions north and south of the present gas fields provide the most promise of success in the search for new reserves. The region to the east of longitude 109°15'W appears to have been tectonically active, with many reactivated faults, especially those aligned with the Meadow Lake Escarpment and the northward course of the Green and Beaver rivers system. Drape structures on erosional, depositional, and collapse forms are widespread, as are the paths for migratory fluids. Heavy-oil shows are known to be present along the western portion of the Meadow Lake Escarpment, as well as on the flank of the dome southeast of Primrose Lake. Natural-gas prospects decrease northeastward of longitude 108°W, with the irregular thinning of the overlying Colorado shale by Cenozoic and Holocene erosion.

Coal Deposits

According to Falini (1965), the transformation from peat carrying about 95% water to brown coal with 50% water entails a reduction in thickness of 90%. He defined paralic peat deposits as those formed in depressed coastal belts, so near the coast that the water level is practically at the same height as that of the sea, from which the marsh is separated by a more or less permeable diaphragm (usually a dune ridge). Because of the hydraulic connection with the sea, a rise of water level in the marsh can only occur as a result of eustatic rise in sea level, which, however, cannot continue indefinitely. Peat accumulated during a rising phase would be destroyed during the subsequent falling phase because, under paralic conditions, the preservation and diagenesis of peat are controlled by subsidence of the basin. Where local subsidence is episodic, each eustatic rise causes seawater to invade the site prior to renewal of peat growth. The maximum thickness of a single bed of peat rarely exceeds the maximum eustatic

variation in sea level between two successive episodes of subsidence. Thus, paralic coal beds show numerous repetitions of seams, all of relatively modest thickness.

On the other hand, lacustrine peat is developed in basins that have no communication with the open sea. The basin may originate wherever a hydrologically closed depression occurs, and be the result of various geological causes, among which are tectonic activity, erosive or glacial activity, and solution of subsurface rocks. A peat accumulation cannot develop into a workable deposit except in the presence of shallow water, the surface of which rises (with respect to the bottom on which the peat rests) at a rate that can be followed by the development of the vegetation. Thus, there does not seem to be a lower limit for the rate of growth of a bog, provided the water level keeps rising (Falini, 1965, p1,320).

The foregoing encapsulates the environmental framework of the Mannville coal deposits. Coal beds are found at the tops of bedding cycles in several of the members, at one place or another, north of the Punichy Arch and on the Kindersley and Unity paleo-uplands to the west. Most are less than a metre thick. Coal beds are also intrinsic to the Success Formation of the inland Insinger and Meadow Lake basins. However, except for those deposits along the northern outcrop belt south of Lac la Ronge and Wapawekka Lake, the coal-bearing strata descend southward on the regional dip to depths of 850 m, beyond the limit for strip-mining.

The most widespread of the coal beds is the one that caps the Sparky Member on the Kindersley and Unity paleo-uplands (Figure 38). It represents deposits developed on broad depositional flats over a 20 000 km² area, when peat growth was equilibrated with sea-level rise for an extended period. These flats appear to have supported coastal plains inlaid with lagoons, fluvial and tidal channels, and interdistributary mounds and islets. Accordingly, the coal deposits thicken (up to 2 m) and thin (to less than 0.1 m) from one locality to another and are spatially intersected by channel-fill deposits and changes of facies. At the Aberfeldy oilfield (Smith, 1984), for instance, there are as many as three seams. Of these, the lower two are restricted to channels of deltaic distributaries and are therefore bedded and infiltrated with muddy sand and clay, but range in thickness up to 4.5 m. The regional capping coal is 0.5 to 1.5 m thick. Another of the major Mannville coal beds is found in the Cummings Member of the Senlac and Winter oilfields (Twp. 37 to 43, Rge. 28 to 24, W 3rd Mer.). The characterization of these coals by Groeneveld and Stasiuk (1984) and Groeneveld (1990) as paralic deposits linked to lacustrine depocentres is entirely compatible with Falini's (1965) parameters.

The thin, regional coal beds make good stratigraphic markers but have less resource potential than the site-specific (over a township or two in area), thickened coal bodies. These latter sites are attributable to subsidence in salt-dissolution sinks; therefore, being more lacustrine than paralic in character, their accumulation of peat escaped the limitation on thickness imposed by simple fluctuations in sea level. Thus, lacustrine coal beds are up to 5.5 m thick, as at Senlac, and may be present in any of the Mannville members. For instance, the Lloydminster coal is recorded as 5.4 m thick, exclusive of argillaceous splits, at Pacific Smiley 13-30-30-25(W3) (P. Gulio, Saskatchewan Energy and Mines, internal report, 1974); it is 3.0 m thick at Husky N. Hoosier 14-14-32-27(W3) and 2.6 m thick at Cigol Oliphant Kerrobert 4-10-34-24(W3). The Rex coal bed is 3 m thick at Precambrian Cosine 8-6-35-28(W3) and 2.0 m thick at Gulf Shop et al Druid 16-13-34-22(W3). Immediately south of Lac La Ronge, in Twp. 67 to 70, Rge. 22 to 19, W 2nd Mer., coal beds lie beneath a relatively thin (6 to 24 m) Pleistocene drift in the western part of a compound, southerly plunging trough flanked by a low anticline at Rge. 21, W 2nd Mer. (Christopher, 1996). The coal forms most of the Cummings Member at the basal unconformity with the Devonian Winnipegosis and Meadow Lake formations. The seams, between one and three in number, are 0.3 to 2 m thick and include interbeds of carbonaceous shale and poorly indurated, argillaceous quartzose sandstone (Assessment File 731-14-0014, Saskatchewan Industry and Resources, Regina). All of the aforementioned Mannville coal beds are recorded in the literature as subbituminous in grade, based on their proximate analyses and reflectance values.

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Appendix A – Core Descriptions

Lithological descriptions of selected Mannville, Success, and contiguous formations from the following wells:

Name of Well	Location	Page
Northern Gas Kamsack 16-28-29-32W1	16-28-29-32W1	A-3
International Yarbo 17S	1-24-20-33W1	A-4
Imp Royalite HB Auburnton 1-2-5-1(W2)	1-2-5-1W2	A-4
Tidewater Earlswood 1-36-14-1(W2)	1-36-14-1W2	A-5
SWP Bredenbury 11-36-21-1(W2)	11-36-22-1W2	A-5
Imp Royalite HB Northgate 4-36-1-2(W2)	4-36-1-2W2	A-6
TW Sohio W Wapella 16-33-14-2(W2)	16-33-14-2W2	A-7
Imp TW Carlyle 16-23-7-3(W2)	16-23-7-3W2	A-8
Sohio St Hubert No. 14-1	14-1-15-3W2	A-9
Imp TW Broadview 14-17-15-4(W2)	14-17-15-4W2	A-9
TW Imp Gotham Cr. 1-2-19-4(W2)	1-2-19-4W2	A-10
St Unit 6 Plant 1 Source Well 5-36-3-5(W2)	5-36-3-5W2	A-11
Imperial Steelman 11 17M 4 5	11-17-4-5W2	A-12
Sceptre Stlmm 1A Unit 11-22-4-5(W2)	11-22-4-5W2	A-13
CNRES Steelman 4U 1-6-5-5(W2)	1-6-5-5W2	A-14
TW Imp Bender 13 11 12 5(W2)	13-11-12-5W2	A-14
St. Unit 3 Plant 2, Source Well 16-26-4-6(W2)	16-26-4-6W2	A-15
Sceptre 3 Stlmm Unit 11-28-4-6(W2)	11-28-4-6W2	A-16
Imp TW Oakshella 13 25 16 6(W2)	13-25-16-6W2	A-16
Sohio Grenfell No. 8-4	8-4-17-6W2	A-17
Sohio Grenfell No. 9-24	9-24-17-6W2	A-18
Transgas Brewer 12-15-23-6(W2)	12-15-23-6W2	A-19
Shell Estevan No. 1	6-24-8-9W2	A-20
Tidewater Beaver Hills Crown No. 1-5	1-5-26-9W2	A-20
Shell Midale A7-18	A7-18-6-10W2	A-21
Tidewater Bon Accord Crown No. 1-29	1-29-25-10W2	A-21
Sohio Baysel Foam Lake No. 2	8-14-31-10W2	A-23
Imperial Kuroki No. 7-30-34-10(W2)	7-30-34-10W2	A-23
Gulfmin Mistatim 5A-17-45-10(W2)	5A-17-45-10W2	A-24
Tidewater Ituna Crown No. 2	4-32-25-11W2	A-25
Tidewater Ituna Crown No. 1	16-11-25-12W2	A-27
Tidewater Ituna Crown No. 4	1-29-25-12W2	A-28
Tidewater Wishart Crown No. 1	13-21-30-13W2	A-29
Tidewater Headlands Crown No. 4-34	4-34-24-14W2	A-30
Mobil South Grassdale 32-10	10-32-6-15W2	A-31
Whitefox No. 1	5-14-52-15W2	A-32
CDR Flat Lake WSW C3-3-1-16(W2)	C3-3-1-16W2	A-33
Socony et al W Ratcliffe 13-22-1-16(W2)	13-22-1-16W2	A-35
TW Imp Avonhurst Cr. 1-29-19-16(W2)	1-29-19-16W2	A-35
Tidewater Cupar Crown No. 4-28	4-28-24-16W2	A-38
Tide Water Bryce Lake Crown No. 1	1-14-25-16W2	A-40

California Standard Ratner 1-15	1-15-48-17W2	A-41
Tide Water Southey Cr. No. 1	4-29-22-18W2	A-41
Choiceland No. 1 Choice DD 13-3-50-18(W2)	13-3-50-18W2	A-44
H B Shell Avonlea 11-7-11-21(W2)	11-7-11-21W2	A-48
H B et al Avonlea 13-29	13-29-11-21W2	A-49
Shell Dahinda No. 1	6-2-9-23W2	A-49
SWP Boulder Lake DD 1C16-18-1C16-18-30-23(W2)	16-18-30-23W2	A-51
Alwinal Lanigan 3-28	3-28-33-23W2	A-54
Imp Findlater Disposal 16-10-21-25(W2)	16-10-21-25W2	A-61
Imperial Penzance Crown No. 1	3-30-24-25W2	A-62
Community Services Watrous No. 1	4-2-32-25W2	A-64
Grey Owl Syndicate No. 1	16-10-44-27W2	A-65
TW Davidson Crown No. 1	13-4-27-28W2	A-69
Transgas Prud Homme B2 11-12-38-28(W2)	11-12-38-28W2	A-70
Shell Mossbank A10-33	10-33-12-29W2	A-74
Goldfield GRT CDN Dundurn 10-7-32-5(W3)	10-7-32-5W3	A-75
Duval Saskatoon 6-18-36-6(W3)	6-18-36-6W3	A-77
C.M.&S. Vanscoy 11-16-35-8(W3)	11-16-35-8W3	A-81
Imp TW Rosetown 12-19-31-15(W3)	12-19-31-15W3	A-86
Canterra et al Prince 1-8-46-16(W3)	1-8-46-16W3	A-87
Shell Meota C13-17-46-17(W3)	13-17-46-17W3	A-90
Saskoil Cathkin 15-31-37-19(W3)	15-31-37-19W3	A-96
Saskoil Wilkie 7-25-38-20(W3)	7-25-38-20W3	A-98
Sceptre et al Turtleford A16-4-51-20(W3)	A16-4-51-20W3	A-99
Shell Dee Valley A11-18-48-21(W3)	11-18-48-21W3	A-101
Shell St. Walburg 6-28-53-22(W3)	6-28-53-22W3	A-108
Westburne et al Coleville 16-10-31-23(W3)	16-10-31-23W3	A-109
Shell Manito 6-7-43-24(W3)	6-7-43-24W3	A-109
Shell Zaller Lake 10-7-39-25(W3)	10-7-39-25W3	A-114
Shell Frenchman Butte A7-3-54-25(W3)	7-3-54-25W3	A-119
Consumers Hartog Whiteside 11-9-30-26(W3)	11-9-30-26W3	A-125
Saskoil Plover Lake 15-5-35-26(W3)	15-5-35-26W3	A-126
SPC Luseland 7-7-35-26W3	7-7-35-26W3	A-126
KPL Macklin 11-32-38-26(W3)	11-32-38-26W3	A-127
CS Fort Pitt 11-26-55-26(W3)	11-26-55-26W3	A-130
South Aberfeldy Unit C7-13-49-27(W3)	C7-13-49-27W3	A-132
Wascana Marengo S A15-36-27-28(W3)	15-36-27-28W3	A-136
Shell Cactus Lake 2-16-36-28(W3)	2-16-36-28W3	A-138

Depth in feet (m)	JOLI FORMATION
735.0 to 749.0 (224.0 to 228.3)	Shale: dark grey, clayey; scattered pyritic burrows, lignitic grains; brown iron-infiltrated quartzose silt layers at 227.8 to 228.1 m; sharp contact.
	PENSE FORMATION
749.0 to 783.5 (228.3 to 238.8)	Siltstone: quartzose, argillaceous, medium grey, friable, thinly bedded with subordinate dark grey silty shale; lenticular and flaser bedded, and bioturbated (wireline core mud-coated and infiltrated, as well as distorted, though continuous).
	CANTUAR FORMATION
	Waseca Member
783.5 to 823.0 (238.8 to 250.9)	Mudstone: silty, dark grey, subordinate thin layers of medium grey argillaceous siltstone; earthy, moderately indurated.
	General Petroleums Member
823.0 to 830.0 (250.9 to 253.0)	Sandstone: quartzose, very fine grained, very argillaceous, dark grey, minor laminae of grey-black carbonaceous mudstone, moderately indurated, earthy; scattered thin (0.08 m) interbeds of sandstone, quartzose, fine-grained, light grey, weak argillaceous matrix, and abundant carbonized plant fragments and muscovite.
830.0 to 864.0 (253.0 to 263.3)	Sandstone: quartzose, fine grained, friable, well sorted, permeable, abundant black carbonaceous specks; subordinate black, carbonaceous interbeds at 259.7 to 260.3 m.
	Rex Member
864.0 to 874.0 (263.3 to 266.4)	Sandstone, quartzose, fine-grained, poorly sorted, grey-white kaolinitic matrix, friable (0.46 m present).
	Lloydminster Member
874.0 to 894.0 (266.4 to 272.5)	No core.
894.0 to 915.0 (272.5 to 278.9)	Sandstone: quartzose, very fine and fine grained, low-angle cross-laminated and flat bedded, friable, moderately cemented; interbedded with subordinate medium-grained grey shale; scattered glauconitic sandy bodies.
915.0 to 928.0 (278.9 to 282.9)	Shale: medium grey, interbedded with subordinate argillaceous, very fine grained quartzose sandstone; minor trough cross-bedded, fine-grained quartzose sandstone.
	Cummings Member
928.0 to 941.0 (282.9 to 286.8)	Sandstone as at 272.5 m.
941.0 to 943.5 (286.9 to 287.6)	Shale as 272.5 to 278.9 m.
	Dina Member
943.5 to 965.0 (287.6 to 294.1)	Sandstone: quartzose, fine-grained, argillaceous, mottled yellow and red; interbed of medium grey shale; grades downward into sandstone, quartzose, fine- to medium-grained, weakly silica-cemented; scattered glauconitic sandy bodies.
965.0 to 1250.0 (294.1 to 381.0)	No core.

SUCCESS FORMATION

1250.0 to 1256.0 (381.0 to 382.8)	Sandstone: quartzose, very fine grained, minor very fine, grey-white siliceous matrix, calcite cemented toward base.
1256.0 to 1300.0 (382.8 to 396.2)	Claystone: rubble, medium grey variegated with red; below 390.1 m red variegated with yellow and grey; resembles a karst breccia.

International Yarbo 17S	(1-24-20-33W1)	KB 1690 feet (515.1 m)
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Depth in feet (m)	JOLI FOU FORMATION
1247.0 to 1256.0 (380.1 to 382.8)	Shale: dark grey, platy, scattered ironstone concretions, trace of green, glauconitic, silty laminae.
	PENSE FORMATION (log pick 381.3 m)
1256.0 to 1265.0 (382.8 to 385.6)	Siltstone: dark grey, argillaceous, laminated with shale, grey black, scattered layers of coarse muscovite; some lenticles of coarse-grained, light grey siltstone.
1265.0 to 1268.0 (385.6 to 386.5)	Shale: black, carbonaceous, platy, abundant pyrite-encrusted, rounded grains and filaments.
1268.0 to 1276.0 (386.5 to 388.9)	Sandstone: very fine grained, quartzose, medium grey (mostly lost), grades into fine-grained, and silica grain-contact cemented, well sorted, and permeable at base.
1276.0 to 1279.0 (388.9 to 389.8)	No core.
	SUCCESS FORMATION
	S2 Member
1279.0 to 1281.0 (389.8 to 390.4)	Lignite: black, very argillaceous and mudstone, coaly.
1281.0 to 1299.0 (390.4 to 395.9)	Claystone: medium grey (seat earth) with rootlet casts; grading below 0.15 m into cream (0.6 m), then medium grey with increasing quartzose silt content.
1299.0 to 1316.0 (395.9 to 401.1)	Sandstone: quartzose, poorly sorted, very fine and fine-grained with abundant medium; sphaerosiderite aggregates scattered throughout; cream coloured kaolinite matrix (wackestone). Erosional contact on red and yellow variegated, Upper Jurassic Rierdon Shale.

Imp Royalite HB Auburnton 1-2-5-1(W2)	KB 1861 feet (567.2 m)
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Depth in feet (m)	PENSE FORMATION
2730.0 to 2754.0 (832.1 to 839.4)	Mudstone: dark grey; subordinate to minor (15%) bioturbated, light grey, calcite-cemented, quartzose siltstone irregular bodies, lenticles, bedding aligned pods, flasers and lenticles. Sharp contact.
2754.0 to 2754.5 (839.4 to 839.6)	Coal: shaly, black, hard.
2754.5 to 2756.0 (839.6 to 840.0)	Mudstone: grey black, abundant carbonized fragments of stalks; hard, platy.

Tidewater Earlswood 1-36-14-1(W2)**KB 1945 feet (592.8 m)**

Depth in feet (m)	CANTUAR FORMATION Cummings Member
2163.0 to 2179.0 (659.3 to 664.2)	Mudstone: silty; subordinate siltstone beds, very argillaceous; dark grey with scattered lignitic flakes and abundant brown ironstone nodules; grades into
2179.0 to 2196.0 (664.2 to 669.3)	Mudstone: clayey; minor silty mudstone, dark grey, scattered carbonaceous material and abundant ironstone nodules and lenticles.
	Dina Member Unit 3
2196.0 to 2213.0 (669.3 to 674.5)	Sandstone: quartzose, medium grained, well sorted; subrounded with quartz overgrowths, very friable to unconsolidated, very permeable.
2213.0 to 2221.0 (674.5 to 677.0)	No core.
	Unit 2
2221.0 to 2241.0 (677.0 to 683.1)	Sandstone: quartzose, fine grained, well sorted; laminated with subordinate partings of lignitic flakes; grey white, calcite cemented at 677, 680, and 682 m; low-angle ripple drift beds at 680 m.
2241.0 to 2274.0 (683.1 to 693.1)	Sandstone: quartzose, bimodal, fine grained with subordinate medium, light grey, very friable, very permeable.
	Unit 1
2274.0 to 2282.0* (693.1 to 695.6)	Mudstone: dark grey, well indurated; scattered carbonized reed-like fragments; interbedded with sandstone, quartzose, medium grained, very friable, very permeable.
(695.6 to 700.1)	Sandstone: quartzose, medium-grained, very friable, very permeable, scattered white kaolinite grains.
	RED JACKET FORMATION
	Shale: medium grey green, noncalcareous. Core continues to 728.5 m.

* E log reading

SWP Bredenbury 11-36-22-1(W2)**KB 1760 feet (336.5 m)**

Depth in feet (m)	JOLI FOU FORMATION
1249.0 to 1261.0 (380.7 to 384.4)	Shale: dark grey, blocky; abundant lenticular laminae of medium grey, muscovitic, quartzose siltstone.
	Spinney Hill Horizon
1261.0 to 1266.0 (384.4 to 385.9)	Sandstone: quartzose, fine grained, glauconitic, medium green, abundant fragments of pearly pelecypod shells, dark brown fish scales; lenticles, pods and irregular bodies of dark grey shale.
1266.0 to 1285.0 (385.9 to 391.7)	Shale: as at 380.7 m; scattered irregular laminae of glauconitic siltstone; calcite cemented, dark blue-grey, tool marked, fine-bedded, podded, argillaceous quartzose siltstone at 391.2 to 391.4 m; sharp and irregular contacts; basal contact sharp and undulatory.

PENSE FORMATION

Unit 2

1285.0 to 1293.0 (391.7 to 394.1)	Sandstone: quartzose fine grained, argillaceous, dark grey and grey black, strongly bioturbated (mostly vertical burrow fillings); interbedded with sandstone, quartzose, fine grained, well sorted, muscovitic at 392.58 to 392.89 m and 393.34 to 393.8 m.
1293.0 to 1298.0 (394.1 to 395.6)	Sandstone: quartzose, very fine grained, abundant medium; well sorted, muscovitic, medium grey; traces of white kaolinite.
1298.0 to 1301.5 (395.6 to 396.7)	Sandstone: quartzose, very fine grained, very argillaceous, dark and medium grey, strongly bioturbated, traces of bedding throughout, platy.

Unit 1

1301.5 to 1323.25 (396.7 to 403.4)	Sandstone: as at 394.1 m; scattered carbonaceous laminae sets 0.005 to 0.01 m thick; flat and low-angle cross-bedding traced by carbonaceous layers and thin, pyritic cementation at 402.03 to 402.79 m.
1323.25 to 1327.0 (403.4 to 404.5)	Siltstone: quartzose, dark grey, subordinate very fine grained sand; thinly bedded with grey black mudstone; lenticular and flaser bedded throughout with argillaceous content increasing downward; sharp irregular contact under medium grey sandstone and mudstone conglomerate.

CANTUAR FORMATION

General Petroleums Member

1327.0 to 1348.5 (404.5 to 411.2)	Mudstone: silty, massive, cream; abundant to minor (15%) coarse sand size sphaerosiderites; scattered quartzose sandy beds with iron-cemented stringers and green and white clay (kaolinite); weakly carbonaceous at 406.4 m.
1348.5 to 1351.25 (411.2 to 411.9)	Mudstone: medium to dark grey, massive, silty; interbedded with siltstone, quartzose, argillaceous.
1351.25 to 1354.5 (411.9 to 412.7)	Sandstone: quartzose, very fine grained, very argillaceous, medium grey, well sorted, earthy, permeable, abundant muscovite, carbonaceous grains, white kaolinite grains; rare pale green biotite and oxidized sphaerosiderite.

Rex Member

1354.5 to 1395.75 (412.7 to 422.15)	Mudstone: grading below 413.3 m into claystone, dark grey, massive, waxy, hematite-red, ironstone septarian sideritic layer near base; basal contact sharp and irregular.
1395.75 to 1396.5 (422.2 to 425.7)	Sandstone: quartzose, fine grained, abundant to minor rounded medium, moderately sorted; abundant oxidized orange-brown sphaerosiderite and carbonaceous grains; complete siderite cementation at 425.2 m, decreasing below by layers to uncemented at 425.5 m; basal conglomerate, 0.15 m thick, of coal fragments in sandstone; sharp, irregular contact.

SHAUNAVON FORMATION

1396.5 to 1399.0 (425.7 to 426.4)	Sandstone: quartzose, very fine grained, interbedded with green calcareous shale.
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Imp Royalite HB Northgate 4-36-1-2(W2)

KB 1902 feet (579.7 m)

Depth in feet (m)	CANTUAR FORMATION General Petroleums Member
3376.0 to 3384.0 (1029.0 to 1031.4)	Sandstone: quartzose, very fine grained, argillaceous matrix; well indurated, medium grey; abundant to scattered thin black carbonaceous partings and carbonaceous specks,

	faint irregular bedding; scattered pyritic nodules; minor interbeds of mudstone, dark to medium grey.
3384.0 to 3438.0 (1031.4 to 1047.9)	No core.
Rex Member	
3438.0 to 3455.0 (1047.9 to 1053.1)	Mudstone: dark grey, abundant carbonaceous plant fragments (stalks) and flecks; hackly to platy downward; at 1050.3 m medium to light grey, cemented, argillaceous, very fine grained quartzose sandstone, 0.15 m thick; bioturbated, abundant carbonaceous slivers. Over basal 0.6 m mudstone becomes platy, hard, siliceous and clayey; grades into
3455.0 to 3458.0 (1053.1 to 1054.0)	Siltstone: quartzose, argillaceous, bioturbation podded, finely lenticular and laminated with subordinate dark grey shale; grades into
(1054.0 to 1054.5)	Sandstone: quartzose, very fine grained, silty, light grey, argillaceous, abundant calcareous grains intermixed and concentrated in scattered lenticles; well indurated, varied brown iron-stain, scattered pyritic nodules; basal contact marked by 0.025 m layer of grey black shale and light grey siltstone on crenulated pyrite-cemented surface of underlying unit.
Lloydminster Member	
3459.5 to 3462.0 (1054.5 to 1055.2)	Sandstone: quartzose, fine grained, well sorted, subangular in quartz overgrowths; poorly indurated, permeable; scattered white kaolin grains, muscovite, black and dark grey chert, jasperoid quartz.
3462.0 to 3567.0 (1055.2 to 1087.2)	No core.
Dina Member	
3567.0 to 3573.0 (1087.2 to 1089.1)	Sandstone: quartzose, medium grained, well sorted, subrounded, minerals as at 1054.5 m; moderately indurated, permeable, friable.

TW Sohio W Wapella 16-33-14-2(W2)
KB 2012 feet (613.3 m)

Depth in feet (m)	CANTUAR FORMATION Cummings Member
2220.0 to 2223.0 (676.7 to 677.6)	Shale: clayey, medium green grey, scattered carbonized plant fragments; grey black toward base.
2223.0 to 2224.5 (677.6 to 678.0)	Mudstone: dark grey, massive, well indurated, earthy.
2224.5 to 2227.5 (678.0 to 678.9)	Claystone: light green grey, grading into medium and dark green grey with increasing carbonaceous content; 5 to 10% coarse sphaerosiderite.
2227.5 to 2241.5 (678.9 to 683.2)	Shale: medium grey green, laminated with flasers and lenticles of grey white, very fine grained quartzose sandstone; glauconitic nodules above 680.0 m; variegated with red-brown sideritic ironstones at 0.3 to 0.6 m intervals below; likewise sand component increases to thin interbeds; sandy mudstone over basal 0.3 m.
2241.5 to 2243.0 (683.2 to 683.7)	Shale: black, carbonaceous.
2243.0 to 2246.5 (683.7 to 684.7)	Mudstone: medium grey, massive, moderately indurated.

Dina Member

2246.5 to 2257.0 (684.7 to 687.9)	Sandstone: quartzose, very fine grained, argillaceous; grading downward into fine grained, medium grey; weak, crenulated and discontinuous laminae, lateral bioturbation forms and scattered oblique, green, glauconite-infilled burrows.
2257.0 to 2282.0 (687.9 to 695.6)	Sandstone: quartzose, fine grained, weak argillaceous matrix, light grey, low-angle current bedded in part; scattered beds laminated with dark grey shale; scattered white kaolinite grains, carbonaceous specks; sphaerosiderite- and glauconite-infilled, oblique burrow-forms.
2282.0 to 2284.0+ (695.6 to 696.2)	Mudstone: medium grey, well indurated, massive; interbedded light grey, argillaceous, very fine grained sandstone downwards.
2284.0 to 2295.0 (696.2 to 699.5)	Sandstone: quartzose, fine grained, medium grey; interbedded sandy and shaly mudstone; basal septarian ironstone nodule.
2295.0 to 2310.0 (699.5 to 704.1)	Sandstone: quartzose, fine and medium grained, moderately sorted, very friable, abundant coaly blebs, medium grey; subordinate carbonaceous shale laminae and thin coaly beds.

VANGUARD FORMATION

2311 to 2357 (704.4 to 718.4)	Shale: grey green, calcareous, abundant <i>Gryphaea nebrascensis</i> . At base, quartzose sandy microcrystalline, light grey limestone with abundant pelecypods, especially <i>G. nebrascensis</i> .
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Imp TW Carlyle 16-23-7-3(W2)

KB 1941 feet (591.6 m)

Depth in feet (m)	CANTUAR FORMATION Cummings Member
2897.0 to 2898.0 (883.0 to 883.3)	Mudstone: medium green grey, subordinate, very fine grained, quartzose, sandstone; grades into
2898.0 to 2900.0 (883.3 to 883.9)	Sandstone: quartzose, light grey and grey white, very fine grained, well sorted, scattered carbonaceous grains, weakly cemented with white, siliceous kaolinite (1%), very permeable; abundant kaolinite-cemented grit of sandstone and siltstone, chert and clay balls.
2900.0 to 2908.0 (883.9 to 886.4)	Shale: dark grey, papery, traces of carbonaceous specks (thickness unknown); also sandstone: quartzose, fine to medium grained, well sorted, weak grain-contact cemented, abundant white kaolinite grains, black carbonaceous grains, very permeable, light grey.
2908.0 to 2911.0 (886.4 to 887.3)	Shale: dark grey; partings of carbonaceous plant fragments and white, kaolinite-indurated quartzose sandstone.
2911.0 to 2917.0 (887.3 to 889.1)	No core.
Dina Member	
2917.0 to 2953.0 (889.1 to 900.1)	Sandstone: quartzose, very fine and fine grained, well sorted, weakly cemented, very permeable, quartz overgrowths in general.
2953.0 to 2993.0 (900.1 to 912.3)	Sandstone: quartzose, fine grained, well sorted, light grey; subangular and subrounded, silica and kaolinite cemented along thin layers alternating with thicker uncemented beds; very permeable throughout; cemented portions nucleated as pea-size nodules; abundant jasperoid quartz, black and grey chert, white kaolinite.
2993.0 to 3011.0 (912.3 to 917.8)	Sandstone: quartzose, coarse grained and grit; subrounded; thin layers of conglomerate (toward base?); includes minor grains of kaolinite-cemented, quartzose silt

and very fine grained quartzose sand, black chert, brown jasperoid chert(?), carbonaceous grains; variably indurated in white kaolinite.

3011.0 to 3020.0
(917.8 to 920.5)

No core.

3020.0 to 3024.0
(920.5 to 921.7)

Grit and conglomerate as 912.3 m (0.15 m recovered).

Sohio St Hubert No. 14-1	(14-1-15-3W2)	KB 2045 feet (623.3 m)
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Depth in feet (m)	CANTUAR FORMATION Cummings Member
2280.0 to 2290.0 (694.9 to 698.0)	Shale: grey black to carbonaceous downward, clayey; interbedded with medium grey argillaceous siltstone at 695.2 to 695.6 m and 697.7 to 698 m.
	Dina Member
2290.0 to 2294.0 (698.0 to 699.2)	Claystone: medium green grey, scattered coaly fragments toward base.
2294.0 to 2296.0 (699.2 to 699.8)	Claystone: laminated with downward increasing grey-white quartzose sandstone; earthy.
2296.0 to 2298.0 (699.8 to 700.4)	Sandstone: quartzose, very fine grained, subordinate fine, light grey, weakly indurated, flaggy with minor shaly partings.
2298.0 to 2304.0 (700.4 to 702.3)	Shale: medium green grey, subordinate lenticles and laminae of grey-white and brown variegated, very fine grained sandstone.
2304.0 to 2311.0 (702.3 to 704.4)	Siltstone: quartzose, argillaceous matrix; medium grey, sandy downward; massive with traces of plant rootlets.
2311.0 to 2315.0 (704.4 to 705.6)	Sandstone: quartzose, very fine grained, argillaceous, grading downward into fine, light grey, friable, low-angle current bedded.
2315.0 to 2320.0 (705.6 to 707.1)	Shale: medium grey, subordinate light grey, argillaceous very fine grained sand; grades below 706.3 m into mudstone, medium grey, massive; abundant coarse-grained, straw-coloured sphaerosiderite.

Imp TW Broadview 14-17-15-4(W2)		KB 2026 feet (617.5 m)
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Depth in feet (m)	JOLI FOU FORMATION
2077.0 to 2099.0 (633.1 to 639.8)	Shale: dark grey, platy, scattered blebs and pods of very fine grained, quartzose sandstone, indurated in light grey glauconitic mudstone; dark brown fish scales increasing downward to abundant; nodular glauconite associated with a sliver of coal.
2099.0 to 2100.5 (639.8 to 640.2)	Siderostone: brown, dense; interbedded below 639.9 m with shale, dark grey, abundant silty lenticles and pods.
	PENSE FORMATION
2100.5 to 2106.0 (640.2 to 641.9)	Sandstone: quartzose, very fine grained to silty, well sorted, abundant black and dark grey lithic grains, moderately indurated and permeable, friable, light grey; thin, flat and wavy bedded with some ripple lamination and cross-lamination; minor dark grey shaly laminae draping and truncating sandy cross-sets; grades into

2106.0 to 2117.0 (641.9 to 645.3)	Sandstone: quartzose, light grey, laminated with shale, dark grey; moderately to weakly indurated, high percentage of carbonaceous dust and abundant muscovite; interbedded downward with laminated shale and sandstone.
2117.0 to 2319.0 (645.3 to 706.8)	No core.
CANTUAR FORMATION Cummings Member	
2319.0 to 2322.0 (706.8 to 707.7)	Sandstone: quartzose, very fine grained, argillaceous, moderately indurated; interbedded with mudstone, silty, platy, medium grey; scattered nodular and tabular bodies encrusted with yellowish green glauconitic druse and grain coatings.
2322.0 to 2330.0 (707.7 to 710.2)	Sandstone: quartzose, light grey, well sorted; scattered muscovite, chert, and white kaolinite; weak grain-contact cemented, very permeable, faint fine bedding; minor laminated sets of dark grey micaceous shale, abundant grains (pore fillings) of adamantine pitch (pyrobitumen).
2330.0 to 2330.5 (710.2 to 710.3)	Shale: dark grey, micaceous, abundant calcareous flecks, hard (15 cm present in box).
Dina Member (picks adjusted)	
2339.0 to 2342.0 (712.9 to 713.8)	Sandstone: quartzose, light grey, fine grained, well sorted; accessory carbonaceous grains, white kaolinite, grey chert, books of muscovite, rare tourmaline, black chert; moderately to weakly grain-contact cemented.
2342.0 to 2348.0 (713.8 to 715.7)	Sandstone: quartzose, fine grained, grey white to light blue grey, well sorted, well cemented with calcite; accessory black chert, grey chert, bright green glauconitic patches in uncemented white kaolinite and as individual mica-like grains.
2348.0 to 2353.0 (715.7 to 717.2)	Shale: medium grey and dark grey, patches of fine-grained, glauconitic, quartzose sandstone. Apparently grades into
2353.0 to 2360.0 (717.2 to 719.3)	Sandstone: quartzose, medium-grained, well sorted, subrounded; accessory kaolinite grains, dark grey chert, black chert, oxidized (red) grains; weakly cemented, very permeable.
2360.0 to 2418.0 (719.3 to 737.0)	No core.
2418.0 to 2454.0 (737.0 to 748.0)	Sandstone: quartzose, very fine grained to medium, subrounded to rounded, unconsolidated (in the box), grey white, accessory white kaolinite <1%.
2454.0 to 2461.0 (748.0 to 750.1)	Mudstone: dark grey, hard, platy, some contortion toward base; scattered nodular pyrite; claystone downward.
2461.0 to 2463.0 (750.1 to 750.7)	Sandstone: quartzose, mudstone indurated, medium grey, poorly sorted, very fine grained to grit; accessory white kaolinite grains, coaly flakes; grades into
2463 to 2466 (750.7 to 751.6)	Mudstone, dark grey; clayey downward; grades into Rierdon shale. Contact at 751.6 m.

TW Imp Gotham Cr. 1-2-19-4(W2)
KB 1846 feet (562.7 m)

Depth in feet (m)	CANTUAR FORMATION Dina Member
1824.0 to 1840.0 (556.0 to 560.8)	Shale: medium grey, laminated with siltstone, quartzose, friable, light grey, argillaceous; grades to siltstone with shaly partings.

1840.0 to 1856.0 (560.8 to 565.7)	Sandstone: quartzose, very fine grained, medium grey, silica grain-contact cemented, friable, thin bedded (0.5 cm), flaggy on shaly partings, grade size decreasing downward; calcite-cemented layers below 563.3 m reveal low-dipping tabular truncation sets across steeply dipping foresets.
1856.0 to 1870.0 (565.7 to 570.0)	Shale: medium grey, hard; platy; interbedded quartzose siltstone and very fine grained sandstone, argillaceous, light grey; scattered glauconitic nodules.
1870.0 to 1882.0+ (570.0 to 573.6)	Shale: medium grey, hard, chippy, minor laminae of very fine grained, argillaceous quartzose sandstone.
1882.0+-1890.0 (573.6 to 576.1)	Sandstone: quartzose, fine grained, light grey, well sorted, weak grain-contact silica cemented, very permeable, scattered white kaolinite grains.
1890.0 to 1896.0 (576.1 to 577.9)	Shale: as at 570.0 m; interbedded with sandstone as at 573.6 m.
1896.0 to 1970.0 (577.9 to 600.5)	Sandstone: quartzose, medium grained, subordinate fine, moderately sorted; abundant grains of white kaolinite, silica grain-contact cemented, very permeable, medium grey.
1970.0 to 1982.0 (600.5 to 604.1)	Shale: medium grey, light grey, minor very fine grained quartzose sandy beds (ratio unknown).
1982.0 to 1987.0 (604.1 to 605.6)	Sandstone: as at 577.9 m.

GRAVELBOURG FORMATION

1987.0 to 1990.0 (605.6 to 606.6)	Shale: medium grey green grading into bright yellow green and light grey.
1990.0 to 1995.5 (606.6 to 608.1)	Sandstone: quartzose, fine grained, well sorted, argillaceous matrix, very permeable.
Core continues to 2076 feet (632.8 m).	

St Unit 6 Plant 1 Source Well 5-36-3-5(W2)	KB 1942 feet (591.9 m)
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Depth in feet (m)	CANTUAR FORMATION Cummings Member
3571.0 to 3587.0 (1088.4 to 1093.3)	Mudstone: silty, dark grey, platy, well indurated; minor increasing to subordinate crenulated, contorted lenses and bioturbation pods of cross-laminated, well cemented, light grey siltstone; abundant pebble size pods and burrow-fills of dark grey-green glauconitic-pyritic masses.
3587.0 to 3594.5 (1093.3 to 1095.6)	Shale: dark grey, laminated with siltstone, quartzose, light grey, well cemented, reverse graded, thin current and ripple bedding; scattered glauconite-infilled lenticular pods, bioturbated; channelled very fine grained sandstone with climbing ripple and drift laminae at 1093.9 to 1094.0 m; sharp basal contact.
	Dina Member
3594.5 to 3606.0+ (1095.6 to 1099.1)	Sandstone: quartzose, very fine grained, light grey; well sorted, silica grain-contact cemented, very permeable; cross-bedded (tabular and low-angle trough) with dark grey mud drapes. Basal conglomeratic beds incorporating dark grey shale clasts.
3606.0+ to 3610.0+ (1099.1 to 1100.3)	Sandstone: quartzose, fine grained, subrounded, well sorted, high-angle truncation sets; silica grain-contact cemented, permeable, medium grey; scattered lenticles of carbonaceous detritus.

3610.0 ⁺ to 3613.5 (1100.3 to 1101.4)	Shale: dark grey, siliceous, abundant carbonaceous dust; at 1100.9 m boudinaged, light grey, very fine grained, cross-bedded, quartzose sandstone, in sharp basal contact on 0.025 m thick ripple-drift, glauconitic, very fine grained quartzose sandstone; underlain by dark brown grey sideritic nodules.
3613.5 to 3623.0 (1101.4 to 1104.3)	Sandstone: quartzose, fine grained; subordinate medium and silt; poorly sorted, moderately indurated, light grey; truncational contact with 0.15 m thick interbed of sandstone as at 1099.1 m.
3623.0 to 3630.0 (1104.3 to 1106.4)	Grit, quartzose, bimodal with medium; interstitial fine-grained sand and silt; abundant grains of oxidized ironstone.
⁺ approximate	

Imperial Steelman 11 17M 4 5	(11-17-4-5W2)	KB 1940 feet (591.3 m)
Depth in feet (m)	CANTUAR FORMATION	
	Waseca Member	
3293.0 to 3312.0 (1003.7 to 1009.5)	Siltstone: argillaceous; medium grey; laminated with fine- and very fine grained, quartzose, light grey sandstone; muscovitic, grey black shaly partings throughout; light grey, massive sandstone beds with coaly rootlets 0.06 m long, also present; scattered to abundant pebble-size brown ironstone.	
3312.0 to 3394.0 (1009.5 to 1034.5)	No core.	
	Rex Member	
3394.0 to 3411.0 (1034.5 to 1039.7)	Mudstone: dark grey with greenish tint, massive; abundant coaly slivers, brown concretionary pebble to cobble sized bodies; massive layers 0.10 to 0.15 m thick interbedded with laminated, light grey, current-bedded quartzose siltstone and dark grey mudstone; abundant mudstone rootlet casts.	
3411.0 to 3416.5 (1039.7 to 1041.3)	Mudstone: dark greenish grey, hard; minor lenticular laminae, burrow pods and rolls of light grey, very fine grained, quartzose, sandstone; graded laminae on scour surfaces; scattered pyritic and abundant brown nodules; irregular stains, and microfaults over lower 0.08 m; grades into	
3416.5 to 3419.0 (1041.3 to 1042.1)	Sandstone: quartzose, very fine grained, light grey mottled with brown, minor fine brown specks; fine bedded with ripple drift and hummocky cross-laminae falling into muscovitic, carbonaceous layers at base of avalanche slopes; bedding crenulated; many vertical burrow fills; well indurated.	
3419.0 to 3426.0 (1042.1 to 1044.2)	Claystone: grades downward into mudstone, dark grey, platy, micro-faulted; abundant to minor laminae and thin beds of fine bedded sandstone with scattered oblique burrows; large boulder-size brown ironstone near base; grades into	
3426.0 to 3429.0 (1044.2 to 1045.2)	Sandstone: quartzose, very fine grained, light grey, fine-bedded and cross-bedded as at 1041.3 m; microfaulted.	
3429.0 to 3504.0 (1045.2 to 1068.0)	No core.	
	Cummings Member	
3504.0 to 3512.0 (1068.0 to 1070.5)	Mudstone: dark green grey, platy, hard.	
3512.0 to 3514.0 (1070.5 to 1071.1)	Mudstone: dark grey, scattered oblique burrows, infilled by carbonaceous, pyritic-glauconitic(?) matter over basal 0.3 m.	

3514.0 to 3515.0 (1071.1 to 1071.4)	Claystone: dark grey, banded with light green grey to cream; scattered carbonaceous films.
3515.0 to 3523.0 (1071.4 to 1073.8)	Mudstone: dark grey, platy, hard; 15% to 25% hematitic sphaerosiderite; fine-grained sandstone at about 1071.7 m and 1072.6 to 1072.8 m.
3523.0 to 3523.5 (1073.8 to 1074.0)	Claystone: dark grey, weakly carbonaceous, abundant plant flakes, aggregates of pyrite and dark green glauconite; sharp irregular contact.
Dina Member	
3523.5 to 3525.0 (1074.0 to 1074.4)	Sandstone: quartzose, very fine grained, laminated with abundant fine; well sorted, light grey and black,; abundant grains of white kaolinite (5%), microfaulted; silica-kaolinite cemented; upwardly gradational from a basal (0.15 m) carbonaceous bed with coaly and crenulated plant fragments to muscovitic; grades into
3525.0 to 3528.0 (1074.4 to 1075.3)	Sandstone: quartzose, very fine grained and argillaceous, medium grey, well indurated; bedding broken and attenuated (penecontemporaneous flowage and micro-faulting); originally finely interbedded with (dark grey) mudstone; sharp irregular contact.
3528.0 to 3529.5 (1075.3 to 1075.8)	Sandstone: quartzose, medium- and coarse- grained, subrounded with faceted overgrowths, friable; grain-contact cemented with high porosity; accessory kaolinite and pyrite (very fine), hematite-stained grains; interbedded with sandstone, fine grained, dense silica-cemented to calcite cemented; irregular partings of lenticular woody coal; some nodular pyrite; grades into
3529.5 to 3547.0 (1075.8 to 1081.1)	Sandstone: quartzose, fine grained, light grey, well cemented; abundant irregular crenulated coaly partings, well indurated; calcite cemented at 1080.2 to 1080.5 m, including a coarse-grained, kaolinite-infilled, quartzose sandstone lens with basal accessory black chert and carbonaceous grains. Irregular interbeds of dark grey mudstone below 1080.7 m.
3547.0 to 3552.0 (1081.1 to 1082.6)	No core.
3552.0 to 3584.0 (1082.6 to 1092.4)	Sandstone: quartzose, medium grained, subrounded and faceted, well sorted, about 5% kaolinite grains; tabular cross-beds sloping 10° and trough truncated; scattered coaly partings on cross-beds; generally well sorted and permeable; kaolinite content increases downward by laminae frequency.
3584.0 to 3594.0 (1092.4 to 1095.5)	Gritstone: quartzose, moderately sorted with coarse and medium; minor white kaolinite in interstices increasing downward into grit-size blebs; moderately indurated, friable; permeable but decreasing downward with increase of dark green-grey clay matrix; pebble-size fragments of pyritic and coaly wood become abundant downward; subordinate beds of quartzose sandstone as 1082.6 to 1092.4 m.

Sceptre Stlmn 1A Unit 11-22-4-5(W2)
KB 1942 feet (591.9 m)

Depth in feet (m)	CANTUAR FORMATION Dina Member
3480.0 to 3505.0 (1060.7 to 1068.3)	Mudstone: grey black, carbonaceous and dark grey; interbedded at 1.5 m intervals with cross-bedded and laminated, argillaceous, medium grey, fine-grained, quartzose sandstone and dark grey shale; rolled and contorted beds and plastic faulting throughout; coaly wood on bedding; grades by interbedding over basal 1 m into
3505.0 to 3544.0 (1068.3 to 1080.2)	Sandstone: quartzose, coarse-grained, interbedded with medium; dominantly medium below 1069.2 m; channel trough truncations displayed throughout; large (5 cm) chunks of coaly material from 1068.3 to 1072.9 m; silica grain-contact cemented, permeable; sharp, wavy, contact.

RIERDON FORMATION

3544.0 to 3579.0
(1080.2 to 1090.9)

Shale: dark grey green and green grey, calcareous; subordinate interbedded sandstone, 0.05 to 0.3 m thick, quartzose, very fine grained, argillaceous; wavy cross-bedded, light blue grey, calcite cemented; laminated with shaly partings; scattered glauconitic layers over upper half.

CNRES Steelman 4U 1-6-5-5(W2)	(1-6-5-5W2)	KB 1954 feet (595.6 m)
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Depth in feet (m)

Dina Member
Unit 3 Bedding Cycle 3 (11.8 m)

3385.0 to 3390.0
(1031.7 to 1033.3)

Sandstone: quartzose, very fine grained, argillaceous, calcite cemented at top; minor light green crenulated shaly partings; low-angle cross-bedded with scattered vertical burrows; grades into

3390.0 to 3423.5
(1033.3 to 1043.5)

Sandstone: quartzose, fine grained, well sorted, faceted; abundant coarse-grained sphaerosiderite and pyrite; scattered white kaolinite and black chert; weak silica grain-contact cemented, very permeable; slightly argillaceous, some layers silica-cemented at top; high-angle tabular cross-sets and channel cut-and-fill bedded throughout; basal contact inferred on carbonaceous layer.

Unit 2 Bedding Cycle 2 (7.8 m)

3423.5 to 3449.0
(1043.5 to 1051.3)

Sandstone: quartzose, fine grained, grading at 1047.0 m into medium and at 1048.5 m into coarse with grit; accessory white kaolinite, red jasper, black chert, pink feldspar, white feldspar; moderately silica-cemented, very permeable; tabular truncational cross-sets throughout.

Unit 1

Bedding Cycle 1 (6.5+ m)

3449.0 to 3464.0
(1051.3 to 1055.8)

Sandstone: quartzose, fine grained, grading into medium at 1055 m; tabular cross-beds alternate with very fine grained, flat-bedded sandstone; silica grain-contact cemented, very permeable; thin plant detrital layer at 1053.7 m.

TW Imp Bender 13 11 12 5(W2)	(13-11-12-5W2)	KB 2498 feet (761.4 m)
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Depth in feet (m)

CANTUAR FORMATION
Dina Member
Unit 3

3100.0 to 3121.0
(944.9 to 951.3)

Shale: waxy, olive, scattered lenticles of white, argillaceous, quartzose siltstone; scattered glauconitic burrows, abundant brown ironstone concretions; silty downward.

3121.0 to 3131.0
(951.3 to 954.3)

Mudstone: medium grey, siliceous, scattered carbonaceous fragments; brown ironstone concretionary layers.

Unit 2

3131.0 to 3165.0
(954.3 to 964.7)

Sandstone: quartzose, bimodal, medium grained and subordinate fine, subrounded; abundant jasper, white feldspar, black chert, white kaolinite, weakly cemented, very permeable.

3165.0 to 3166.0+
(964.7 to 965.0)

Shale: dark grey, abundant glauconitic very fine grained, quartzose sandstone lenticles.

Unit 1

3166.0 to 3181.0
(965.0 to 969.6)

Sandstone: quartzose, medium grained as at 954.3 m; interbedded with fine-grained, quartzose sandstone, weakly cemented, very permeable.

3181.0 to 3193.0+
(969.6 to 973.2) Sandstone: quartzose, fine grained, subordinate medium, friable and permeable.

RIERDON FORMATION

3193.0 to 3201.0
(973.2 to 975.7) Mudstone: platy, medium grey green.

3201.0 to 3202.0
(975.7 to 976.0) Sandstone: quartzose, very fine grained, well sorted, light grey, weakly cemented, very permeable, abundant black carbonaceous specks.

3202.0 to 3381.0
(976.0 to 1030.5) No core.

SHAUNAVON FORMATION **Lower Member**

3381.0 to 3387.0
(1030.5 to 1032.4) Sandstone: quartzose, fine grained, well cemented with calcite except for weakly indurated beds at 1030.5 m; abundant pelecypod molds, minor crenulated shaly partings; abundant oolites at 1031 m; dark grey, argillaceous and bituminous at 1032 m.

3387.0 to 3396.0
(1032.4 to 1035.1) Shale: dark grey, calcareous, platy, minor lenticular laminae of light grey siltstone.

3396.0 to 3399.0
(1035.1 to 1036.0) Sandstone: quartzose, very fine grained, calcite cemented, fine bedded with some wavy lenses, moderately bioturbated; subordinate laminae of dark grey calcareous shale; grades into

3399.0 to 3418.0
(1036.0 to 1041.8) Shale: as at 1032.4 m.

3418.0 to 3427.0
(1041.8 to 1044.5) Sandstone: quartzose, very fine grained, argillaceous, medium green grey; lenticular bedding, calcite cemented, abundant muscovite; subordinate black carbonaceous shale interbeds.

3427.0 to 3428.0+
(1044.5 to 1044.9) Sandstone: quartzose, medium-grained, well sorted, silica grain-contact cemented, very permeable, trough cross-bedded.

St. Unit 3 Plant 2, Source Well 16-26-4-6(W2)

KB 1951 feet (594.7 m)

Depth in feet (m)

CANTUAR FORMATION **Dina Member**

3426.0 to 3445.0
(1044.2 to 1050.0) Sandstone: quartzose, fine grained, well sorted, subrounded with quartz overgrowths, grain-contact silica cemented, very permeable; scattered accessory kaolinite grains, black chert; trough cross-bedded; includes light green-grey mudstone boulders, flat cobbles and tabular pebble layers at 1044.2 to 1045.3 m; calcite cemented at 1047.9 to 1048.2 m; sharp irregular basal contact.

3445.0 to 3460.0
(1050.0 to 1054.6) Sandstone: quartzose, fine grained, light grey, well sorted, quartz overgrowths, weak silica cemented, very permeable; scattered pods of concentrated carbonized plant fragments; faint flat bedding; carbonaceous bed at 1054.5 m.

Sceptre 3 Stlmn Unit 11-28-4-6(W2)**KB 1953 feet (595.3 m)**

Depth in feet (m)	CANTUAR FORMATION Dina Member Unit 3 Bedding Cycle 3 (7.1 m)
3494.0 to 3499.0 (1065.0 to 1066.5)	Sandstone: quartzose, fine grained, well sorted, light grey argillaceous matrix; silica grain-contact cemented; current laminated with subordinate carbon speckled argillaceous drapes, permeable; microfaulted with plastic deformation; thin lateral fault slice in dark lavender-grey mudstone at 1065.7 m.
3499.0 to 3508.0 (1066.5 to 1069.2)	Mudstone: dark lavender grey, platy; interbedded with siltstone, argillaceous; abundant pods and lenticles of very fine grained, quartzose, light grey sandstone; scattered pyritic burrows; mottled and banded with purplish red ironstone liesegang; some microfaulting.
3508.0 to 3517.5 (1069.2 to 1072.1)	Sandstone: quartzose, fine grained, well sorted, medium grey, slightly argillaceous, silica grain-contact cemented, current bedded, boudinaged, rolled and podded, some bioturbation; laminated and interbedded with subordinate dark lavender-grey mudstone conglomerate; brown ironstone nodules below 1069.8 m; basal zone, 0.015 m thick, of dark grey mudstone with deformed conglomerate of white, quartzose, kaolinitic sandstone (presumably from the Success Formation) and dark grey mudstone. Unit 2 Bedding Cycle 2 (6.3 m)
3517.5 to 3524.0 (1072.1 to 1074.1)	Sandstone: quartzose, medium grained, medium grey, grain-contact cemented, scattered white kaolinite grains; very permeable; low-angle cross-bedded as delineated by laminae with concentrated carbonaceous plant detritus; laminated and coaly with abundant pyritic nodules over basal 0.65 m.
3524.0 to 3528.0 (1074.1 to 1075.3)	Sandstone: quartzose, medium grained, medium grey, silica grain-contact cemented; scattered white kaolinite grains, low-angle cross-bedded; interbedded with boulders and cobbles of white, medium grained, quartzose, kaolinitic sandstone and dark grey mudstone.
3528.0 to 3534.0 (1075.3 to 1077.2)	Sandstone: quartzose, coarse grained; scattered white kaolinite grains; silica grain-contact cemented; very permeable; planar high angle (25°) cross-bedded; sharp contact.
3534.0 to 3538.0+ (1077.2 to 1078.4+)	Gritstone: quartzose, poorly sorted, subordinate coarse-, medium-, and fine-grained sand; abundant white and cream feldspar, dark grey chert, white kaolinite; scattered pink orthoclase and black chert; thinly bedded with deformed coal; sharp basal contact. Unit 1 Bedding Cycle 1 (3.0 m)
3538.0 to 3548.0 (1078.4 to 1081.4)	Sandstone as at 1075.3 m.

Imp TW Oakshella 13 25 16 6(W2) (13-25-16-6W2)**KB 1965 feet (598.9 m)**

Depth in feet (m)	CANTUAR FORMATION Cummings Member
2221.0 to 2269.0 (677.0 to 691.6)	Mudstone: medium grey; subordinate very fine grained, quartzose sandstone intergradational with beds of very fine grained quartzose, argillaceous sandstone, and dark grey shale; faintly bedded and bioturbated (mostly laterally); scattered glauconite-infilled burrows (679.7 to 680.5 m); abundant disseminated carbonaceous plant flakes increasing downward; brown siderostone and yellow-green, sulphurous, iron stains in calcite-cemented sandstone near base.
2269.0 to 2273.0 (691.6 to 692.8)	Shale: dark grey, carbon-flecked, abundant muscovite; grades into shaly, calcareous sandstone; sharp irregular contact.

Dina Member

2273.0 to 2285.5 (692.8 to 696.6)	Sandstone: quartzose, light grey, fine grained, well sorted, subangular; scattered white kaolinite and muscovite, well cemented with calcite, light blue grey at top; remainder weakly indurated, very permeable.
2285.5 to 2287.0 (696.6 to 697.1)	Shale: dark grey, carbon flecked, abundant muscovite; interbedded sandstone as at 692.8 m; sharp contact.
2287.0 to 2292.0 (697.1 to 698.6)	Mudstone: waxy, dark grey, upper 0.1 m cemented and oxidized limonite yellow.
2292.0 to 2341.0 (698.6 to 713.5)	Sandstone: quartzose, light grey, fine grained, well sorted, weakly indurated, very permeable, scattered carbonaceous grains and white kaolinite; thin, flaggy bedding; sharp(?) contact.

SHAUNAVON FORMATION**Upper Member**

2341.0 to 2343.0 (713.5 to 714.1)	Shale: dark grey, glauconitic, limonite yellow over lower half.
2343.0 to 2351.0 (714.1 to 716.6)	Sandstone: quartzose, very fine grained, light green grey, calcareous, argillaceous; interbedded with medium grey-green sandy marlstone and calcareous mudstone; flasered and fine current bedded throughout; sharp contact.
2351 to 2353 (716.6 to 717.2)	Limestone: microcrystalline, subordinate very fine grained, quartzose sand, oolite, pelecypod shells; microcrystalline, black pyrite encrustations of shells and marlstone grains; dense, tan speckled with dark grey.

Sohio Grenfell No. 8-4	(8-4-17-6W2)	KB 1912 feet (582.8 m)
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Depth in feet (m)	CANTUAR FORMATION Dina Member
2265.0 to 2268.0 (690.4 to 691.3)	Siltstone: quartzose, argillaceous, very friable; interbedded medium grey mudstone.
2268.0 to 2270.0 (691.3 to 691.9)	Ironstone: dense, red brown and yellow, septarian, white calcite veined.
2270.0 to 2282.0 (691.9 to 695.6)	Sandstone: quartzose, very fine grained, permeable, light grey laminated with black, carbonaceous detritus, weakly indurated; interbedded at 0.3 m intervals with dark grey and medium grey shale.
2282.0 to 2301.0 (695.6 to 701.3)	Shale: medium grey, hard, platy; interbedded sandstone: quartzose, very fine grained, light grey, unindurated.
2301.0 to 2303.0 (701.3 to 702.0)	No core.
2303.0 to 2317.0 (702.0 to 706.2)	Sandstone: quartzose, fine grained, well sorted, subrounded; abundant rose quartz, iron-coated grains and white kaolinite grains; very friable, very permeable.
2317.0 to 2319.0 (706.2 to 706.8)	Mudstone: medium grey, abundant carbonized leaves and twigs.
2319.0 to 2342.0 (706.8 to 713.8)	Sandstone: quartzose, medium grained, well sorted, scattered iron-stained quartz, jasper, white kaolinite, black chert, white feldspar; basal grit.
2342.0 to 2349.0 (713.8 to 716.0)	Sandstone: quartzose, very fine grained, grading downward into fine-grained, well sorted, weakly indurated, very permeable; capping and basal argillaceous siltstones.

VANGUARD FORMATION

2349.0 to 2353.0 (716.0 to 717.2)	Shale: medium grey green, noncalcareous.
2353.0 to 2360.0 (717.2 to 719.3)	Mudstone: dolomitic-sideritic, buff, dense; calcareous near base (0.3 m present).
2360.0 to 2362.0 (719.3 to 719.9)	Shale: medium green grey, calcareous, soft.
2362.0 to 2372.0 (719.9 to 723.0)	Mudstone: medium grey green, minor silt lenticles, moderately indurated, platy, scattered patches of red.

SHAUNAVON FORMATION Upper Member

2372.0 to 2377.0 (723.0 to 724.5)	Sandstone: quartzose, very fine grained, weakly indurated, grey white, well sorted.
2377.0 to 2387.0 (724.5 to 727.6)	Sandstone: quartzose, very fine grained, very argillaceous, moderately indurated, medium green grey; interbedded with grey-green silty mudstone, dark grey downward.
2387.0 to 2395.0 (727.6 to 730.0)	Sandstone: quartzose, very fine grained, calcite cemented, irregular cross-bedding; minor layers of grey-green mudstone; abundant ostracods.

Sohio Grenfell No. 9-24	9-24-17-6W2	KB 1919 feet (584.9 m)
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Depth in feet (m)	CANTUAR FORMATION Dina Member
2250.0 to 2270.0 (685.8 to 691.9)	Sandstone: quartzose, fine grained, abundant medium, subrounded and faceted, weakly cemented, very permeable; abundant pyrite crystals, scattered to abundant muscovite.
2270.0 to 2293.0 (691.9 to 698.9)	Sandstone: as above; thin black carbonaceous shale beds and partings coated with coarse-grained muscovite toward base.
	SHAUNAVON FORMATION Lower Member
2293.0 to 2296.0 (698.9 to 699.8)	Limestone: cryptocrystalline, buff, abundant pelecypod fragments replaced with clear calcite spar; abundant oolite and pisolite.
2296.0 to 2318.0 (699.8 to 706.5)	Shale: dark grey, siliceous; minor laminae of siltstone: quartzose, light grey, lenticular; abundant green glauconitic nodules.
2318.0 to 2341.0 (706.5 to 713.5)	Sandstone: quartzose, fine grained, subrounded, well sorted, argillaceous, very permeable, scattered pyrite crystals.
2341.0 to 2350.0 (713.5 to 716.3)	Shale: dark grey, clayey, subordinate quartzose very fine grained sandstone laminae, some with concentration of carbonized plant fragments; olive green toward base.
2350.0 to 2378.0 (716.3 to 724.8)	Sandstone: quartzose, medium-grained, well sorted, rounded, argillaceous matrix, very permeable, abundant muscovite; minor black carbonaceous laminae on low-angle cross-beds below 721.8 m.
	GRAVELBOURG FORMATION
2378.0 to 2379.0 (724.8 to 725.1)	Mudstone: platy, siliceous, medium grey.

2379.0 to 2383.0 (725.1 to 726.3)	Siltstone: quartzose, unindurated, light grey.
2383.0 to 2384.5 (726.3 to 726.8)	Shale: platy, siliceous, medium grey.
2384.5 to 2386.0 (726.8 to 727.3)	Limestone: crystalline, grey white, speckled with dark blue grey, oolite and pisolite nucleated with disseminated pyrite; hard, dense, solution brecciated and re-cemented at top.

Transgas Brewer 12-15-23-6(W2)	KB 1846 feet (562.7 m)
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Depth in feet (m)	PENSE FORMATION
1443.0 to 1444.0 (439.8 to 440.1)	Mudstone: olive green, silty, abundant pyritic rootlets (badly mangled).
1444.0 to 1448.0 (440.1 to 441.4)	Sandstone: quartzose, medium grey to grey white, fine grained, well sorted; massive, but laminated and low-angle cross-laminated over lower half; bedding surfaces coated with carbonized plant fragments.
1448.0 to 1449.0 (441.4 to 441.7)	Shale: olive green and dark grey (badly mangled).
1449.0 to 1466.0 (441.7 to 446.8)	Sandstone: quartzose, fine grained, light grey intermixed with black carbonaceous mudstone, strongly bioturbated; upper 0.6 m laminated, but thinly bedded below; sharp contact.
1466.0 to 1469.0 (446.8 to 447.8)	Shale: black, laminated with subordinate sandstone, quartzose, very fine grained, well sorted; flat-bedding interrupted by scour-and-fill glauconitic bed, 4 cm thick at 447.1 m.
1469.0 to 1625.0 (447.8 to 495.3)	No core.
	CANTUAR FORMATION
	Cummings Member
1625.0 to 1640.0 (495.3 to 499.9)	Sandstone: quartzose, fine grained, well sorted, light grey, permeable, current bedded; laminated with subordinate dark grey shale; upper 1.5 m feature flame structures, boudins, rolls and microfaulted beds denoting penecontemporaneous deformation; glauconitic bodies scattered below 498.3 m.
1640.0 to 1643.0 (499.9 to 500.8)	Shale: dark grey (badly broken up).
	Dina Member
	Bedding Cycle 3 (1.5 m)
1643.0 to 1646.0 (500.8 to 501.7)	Sandstone: quartzose, fine grained with subordinate very fine; abundant black chert; scattered white kaolinite grains and green glauconite; flat-bedded, friable, very permeable, light grey.
	Bedding Cycle 2 (4.3 m)
1646.0 to 1648.0 (501.7 to 502.3)	Sandstone: quartzose, fine grained with subordinate very fine, abundant medium; grade size increases downward to medium, with increase in kaolinitic matrix and cobbles of dark grey mudstones.
1648.0 to 1652.0 (502.3 to 503.5)	Sandstone: quartzose, very fine grained, increasing downward to fine grained; laminated with subordinate dark grey shale; contorted iron-stained concretionary and fracture-filled forms; shale decreases downward.

1652.0 to 1655.0 (503.5 to 504.4)	Sandstone: quartzose, fine grained with subordinate very fine, light grey; sharply interbedded with dark grey shale, 0.05 to 0.08 m thick at 503.5 m; thin shale partings above and massive, friable and very permeable below.
1655.0 to 1662.0 (504.4 to 506.6)	Sandstone: as 503.5 to 504.4 m, but includes clasts of dark green-grey mudstone, iron-cemented brown sandstone and brown ironstone.
Bedding Cycle 1 (2.7 m)	
1662.0 to 1664.0 (506.6 to 507.2)	Sandstone: quartzose, argillaceous, coarse grained, ironstone cemented, abundant white kaolinite grains and large carbonized woody fragments.
1664.0 to 1671.0 (507.2 to 509.3)	Sandstone: quartzose, medium grained, light grey, friable, very permeable, massive.

Shell Estevan No. 1	(6-24-8-9W2)	KB 2023 feet (616.6 m)
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Depth in feet (m)	CANTUAR FORMATION Cummings Member
3210.0 to 3228.0 (978.4 to 983.9)	Sandstone: quartzose, medium grained, faceted, well sorted, grain-contact silica-cemented, very permeable, scattered pyrite crystals, rare glauconite; dark grey shale interbeds below 982.7 m.
3228.0 to 3240.0 (983.9 to 987.6)	Shale: fissile and platy, dark grey, abundant carbonized reedy films on bedding surfaces; scattered pyritic nodules; glauconitic layer at 986.3 to 987.2 m.
Dina Member	
3240.0 to 3276.0 (987.6 to 998.5)	Sandstone: quartzose, medium grained, well sorted, subrounded with quartz overgrowths, weak silica grain-contact cemented, very permeable; abundant white kaolinite grains and carbonaceous specks; coal balls at 989.7 m.
3276.0 to 3308.0 (998.5 to 1008.3)	Shale: dark grey, fissile, abundant carbonaceous specks, scattered yellow-green glauconitic nodules; subordinate thin beds of argillaceous sandstone in middle of interval.
3308.0 to 3339.0 (1008.3 to 1017.7)	Sandstone: quartzose, fine grained grading downward to medium, light grey, weak silica grain-contact cemented, very permeable; abundant white kaolinite grains.

Tidewater Beaver Hills Crown No. 1-5 (1-5-26-9W2)	KB 2207 feet (672.7 m)
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Depth in feet (m)	CANTUAR FORMATION Lloydminster Member
1943.0 to 1959.0 (592.2 to 597.1)	Sandstone: quartzose, very fine grained, medium grey argillaceous matrix decreasing downward from 35% to about 20%; cross-bedded at about 20° but below 594.7 m alternates with massive beds; abundant coaly and brown ironstone concretionary nodules; calcite cemented and light blue grey, speckled with brown siderite at 596.8 to 597.1 m.
1959.0 to 1969.0 (597.1 to 600.2)	Sandstone: quartzose, very fine grained and argillaceous; moderately indurated, earthy; fine-bedded with plastic deformation, traces of iron-stained fractures and burrow-pods.
1969.0 to 1971.0+ (600.2 to 600.8+)	Sandstone: quartzose, fine grained, argillaceous, moderately indurated, fine bedded, glauconitic especially in burrow fill.
Cummings Member	
1971.0 to 2002.0 (600.8 to 610.2)	Mudstone: grades downward into clayey shale, dark grey; scattered layers of carbonized plant fragments; dark green glauconitic mass infilling an irregular cavity(?) at 604.1 m.

Dina Member

2002.0 to 2015.0
(610.2 to 614.2) Sandstone: quartzose, fine grained, well sorted, poorly indurated, very permeable, subrounded, scattered white grains of kaolinite, abundant carbonaceous grains.

2015.0 to 2025.0
(614.2 to 617.2) No core.

SUCCESS FORMATION - S1 Member

2025.0 to 2041.0
(617.2 to 622.1) Mudstone, medium grey, kaolinitic, earthy; grading downward into cream, with thin partings of bright green glauconitic shale; abundant sphaero-glaucanites after pyrite and glauconitic burrow-fill.

2041.0 to 2047.0
(622.1 to 623.9) Shale: medium grey, thinly interbedded with grey green; soft earthy.

2047.0 to 2062.0
(623.9 to 628.5) Sandstone: quartzose, fine grained, argillaceous, light grey, indurated, earthy, permeable; glauconitic toward base with pebble-sized black nodules studded with pyrite crystals.

2062.0 to 2097.0
(628.5 to 639.2) Rubble: white kaolinitic and tripolitic mudstone and sandstone; micro-conglomeratic in part, white porcelainous chert toward base (core is badly broken and distorted).

Shell Midale A7-18	(A7-18-6-10W2)	KB 2000 feet (609.6 m)
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Depth in feet (m)

CANTUAR FORMATION
Dina Member

3425.0 to 3475.0
(1043.9 to 1059.2) Sandstone: quartzose, medium and fine grained, bimodal, abundant kaolinite grains and blebs and black carbonaceous specks; well indurated with kaolinite, permeable, brown and white speckled; large-scale trough cross-bedded with truncation sets, 0.3 m or so thick, dipping about 10°; minor carbonaceous plant detrital partings toward base (Rec. 4 m).

3475.0 to 3525.0
(1059.2 to 1074.4) Sandstone: quartzose, medium grained with interstitial fine; grain-contact silica cemented, very permeable; abundant white kaolinite grains (Rec. 0.6 m).

3525.0 to 3528.0
(1074.4 to 1075.3) Sandstone: quartzose, coarse-grained with subordinate grit; abundant dark grey chert, brown sphaerosiderite; calcite cemented at top; conglomerate of shale, mudstone and ironstone at base.

SUCCESS FORMATION - S2 Member

3528.0 to 3540.0
(1075.3 to 1079.0) Mudstone: medium green grey, massive; solution pitted and brecciated, includes green glauconitic masses at 1075.3 to 1076.2 m; oxidized purplish iron-stained patches below, includes massive 0.2 m thick layer of mudstone supported coarse-grained sphaerosiderite at 1078.7 m.

Tidewater Bon Accord Crown No. 1-29	(1-29-25-10W2)	KB 2218 feet (676.0 m)
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Depth in feet (m)

CANTUAR FORMATION
Lloydminster Member

1950.0 to 1955.0
(594.4 to 595.9) Sandstone: quartzose, very fine grained, well sorted, argillaceous matrix, medium grey, minor carbonaceous flakes, abundant muscovite; grades downward into shale, platy, carbonaceous, dark grey; sharp contact.

SUCCESS FORMATION

1955.0 to 1968.0 (595.9 to 599.8)	Sandstone: quartzose, very fine grained; argillaceous matrix; light grey, earthy, friable, permeable.
1968.0 to 1971.0 (599.8 to 600.8)	Sandstone: as above, interbedded green grey, waxy shale.
1971.0 to 1973.0 (600.8 to 601.4)	Shale: platy, medium green grey, hard.
1973.0 to 1982.0 (601.4 to 604.1)	Sandstone: as 599.8 to 600.8 m.
1982.0 to 1985.0 (604.1 to 605.0)	No core.

SHAUNAVON FORMATION **Upper Member**

1985.0 to 1988.0 (605.0 to 606.1)	Shale: dark grey grading through green into limonite yellow; pelecypods abundant toward oxidized, sphaerosideritic base.
1988.5 to 1990.5 (606.1 to 606.7)	Marlstone: grades into sandy argillaceous limestone, cream, well cemented, abundant ostracods.

Lower Member

1990.5 to 1992.0 (606.7 to 607.2)	Calcilutite: hard, cream.
1992.0 to 1996.0 (607.2 to 608.4)	Shale: dark, green grey, waxy (distorted).
1996.0 to 2000.0 (608.4 to 609.6)	Shale: dark green grey, thinly interbedded cross-laminated, white, very fine grained marly sandstone over upper half; sharp basal contact on a thin sandy bed.
2000.0 to 2011.0 (609.6 to 613.0)	Calcilutite: tan, abundant pelecypods, hard; minor thin interbedded dark grey shale and argillaceous sandstone.
2011.0 to 2015.0 (613.0 to 614.2)	Sandstone: quartzose, very fine grained, marly, thinly interbedded calcilutite, marlstone, and calcareous shale; light grey and dark green grey.
2015.0 to 2017.5 (614.2 to 614.9)	Limestone: cryptocrystalline, cream coloured; irregular, finely disseminated pyrite-rich, bituminous layers.
2017.5 to 2021.0 (614.9 to 616.0)	No core.
2021.0 to 2027.0 (616.0 to 617.8)	Sandstone: quartzose, very fine grained, argillaceous, light grey; subordinate laminae and thin beds of dark grey shale.
2027.0 to 2029.0 (617.8 to 618.4)	Limestone: cryptocrystalline; subordinate quartzose siltstone, cream, abundant carbonaceous and pyritic specks; faint crenulated bedding.
2029.0 to 2043.0 (618.4 - 622.7)	Sandstone: quartzose, very fine grained, argillaceous, weakly indurated; light grey; medium grey downward into argillaceous siltstone and dark grey into shale; accessory muscovite, trace of glauconite.

GRAVELBOURG FORMATION

2043.0 to 2047.0 (622.7 to 623.9)	Sandstone: quartzose, fine grained, medium grey, well sorted, subrounded, weakly cemented, very permeable, abundant white kaolinite and carbonaceous blebs and grains, scattered round glauconite.
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2047.0 to 2057.0 (623.9 to 627.0)	Shale: bright green, glauconitic, platy; silty downward (mostly lost); includes 0.3 m of cream, cryptocrystalline limestone.
2057.0 to 2078.0 (627.0 to 633.4)	Sandstone: as at 622.7 m, increasing to medium grained downward; thin, green, noncalcareous shale at 632.2 m.
2078.0 to 2090.0 (633.4 to 637.0)	Sandstone: quartzose, light grey, very fine grained, well sorted, subrounded, weakly indurated; traces of thin cross-beds, abundant kaolinite grains.
2090.0 to 2106.0 (637.0 to 641.9)	Sandstone: quartzose, medium grey and white speckled, medium grained and coarse; abundant kaolinite grains; weakly indurated.
2106.0 to 2142.0 (641.9 to 652.9)	Sandstone: quartzose, medium grained, interbedded with fine (irregular rec.), glauconitic (yellow-green) nodule at base.
2142.0 to 2143.0+ (652.9 to 653.2)	Shale: waxy, green; yellow-green glauconitic laminae.
2143.0+ (653.2)	Siliceous pelletoid and oolitic rock (probably from Madison karst).
2146 to 2148 (654.1 to 654.7)	Sandstone: quartzose, fine grained, well sorted, fine bedded; calcite cemented at top, disaggregated and oil stained below; basal limestone rubble on the Mississippian Souris Valley Formation.

Sohio Baysel Foam Lake No. 2	(8-14-31-10W2)	KB 1820 feet (554.7 m)
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Depth in feet (m)	SUCCESS FORMATION
1440.0 to 1445.0 (438.9 to 440.4)	Shale: light green grey, minor white, quartzose, silty partings at 438.9 to 439.5 m; grades into
1445.0 to 1446.0 (440.4 to 440.9)	Claystone: medium grey green variegated with red; dark grey and weakly carbonaceous downward.
1446.0 to 1448.0 (440.9 to 441.4)	Sandstone: quartzose, very fine grained, light grey, laminated and intermixed with light green-grey claystone.
1448.0 to 1515.0 (441.4 to 461.8)	No core.
1515.0 to 1529.0 (461.8 to 466.0)	Shale: medium grey, platy, scattered red-brown ironstone nodules and carbonaceous partings.
1529.0 to 1536.0 (466.0 to 468.2)	Sandstone: quartzose, very fine grained, argillaceous matrix, minor shaly partings lined with carbonized plant fragments; dark grey variegated with red.

Imperial Kuroki No. 7-30-34-10(W2)	KB 1882 feet (573.6 m)
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Depth in feet (m)	JOLI FOU FORMATION
1310.0 to 1315.0 (399.3 to 400.8)	Sandstone: quartzose, very fine grained, argillaceous, calcareous, glauconitic, yellow green, laminated with dark grey shale; strongly burrowed and microfaulted; grades into
1315.0 to 1345.0 (400.8 to 410.0)	Shale: grey black, scattered thin beds of glauconitic, very fine grained, quartzose sandstone; abundant load casts, current scours, tool markings and glauconitic burrow fill. Interbedded with silica-cemented, fine-grained, argillaceous, quartzose, bioturbated, sandstone toward base.

PENSE FORMATION

1345.0 to 1355.0
(410.0 to 413.0) Sandstone: quartzose, very fine grained, well sorted, weak silica grain-contact cemented; massive with trace of crenulated bedding.

1355.0 to 1480.0
(413.0 to 451.1) No core.

CANTUAR FORMATION

Lloydminster Member

Bedding Cycle 3 (6.1 m)

1480.0 to 1487.0
(451.1 to 453.2) Sandstone: quartzose, very fine grained, argillaceous, medium grey; laminated with mudstone, dark grey; faint, low-angle current bedding and scour surfaces; brown iron-stained nodular layers, 0.02 m or so thick, occur at 0.6 m decreasing downward to 0.15 m intervals; mudstone interbeds, 0.05 to 0.1 m thick, below 452.6 m.

*1487.0 to 1494.0
(453.2 to 455.4)
(* E-log adjusted) Shale: dark green grey, crumbly; abundant pyritic, sulphurous nodules, intermixed with medium grey-green, glauconitic claystone.

1494.0 to 1500.0
(455.4 to 457.2) Sandstone: quartzose, medium-grained, well sorted, weak silica grain-contact cemented, scattered white kaolinite grains, (mostly lost). Basal 0.07 m is brown iron stained, and irregularly cemented with pyrite; sharp irregular contact.

Bedding Cycle 2 (7.0 m)

1500.0 to 1523.0
(457.2 to 464.2) Mudstone: interbedded at 0.06 m intervals with subordinate argillaceous, quartzose very fine grained sandstone; medium grey, earthy, moderately indurated; faintly bedded with some contortion, brown iron-stained bands with scattered pyritic-sulphurous nodules; dark grey and carbonaceous towards base.

Bedding Cycle 1 (7.3 m)

1523.0 to 1526.0
(464.2 to 465.1) Sandstone: quartzose, fine grained, well sorted; weak grain-contact silica cemented, medium grey, abundant muscovite, scattered carbonaceous shaly partings.

1526.0 to 1531.0
(465.1 to 466.6) Mudstone: silty, dark grey, interbedded laminated argillaceous siltstone and grey black shale; generally bioturbated; abundant brown ironstone and green glauconitic concretionary layers; black, coaly, carbonaceous shale below 466.3 m.

Cummings Member

1531.0 to 1547.0
(466.6 to 471.5) Mudstone: light grey, earthy, blocky; abundant fine-grained pyrite-encrusted plant filaments; scattered glauconitic burrow fills and black carbonaceous partings.

Gulfmin Mistatim 5A-17-45-10(W2)

KB 1840 feet (560.8 m)

Depth in feet (m)

JOLI FOU FORMATION

808.0 to 820.0
(246.3 to 249.9) Shale: grey black, fissile to platy, abundant very fine carbonaceous grains; scattered very fine pyrites, blebs and pelecypodal shell impressions; sharp, irregular contact.

PENSE FORMATION

820.0 to 822.0
(249.9 to 250.5) Sandstone: quartzose, fine grained, well sorted, abundant, black carbonaceous grains, calcite cemented, dark blue and medium blue grey speckled with black; uppermost 0.08 m pyrite cemented and infilled; scattered fragments of dark brown goethite, traces of bioturbation; sharp, irregular contact.

822.0 to 833.0 (250.5 to 253.9)	Sandstone: quartzose, very fine grained, argillaceous, medium grey, weakly indurated, abundant muscovite, carbonaceous grains; partially interbedded with dark grey shale; traces of low-angle cross-beds; sharp basal contact.
833.0 to 844.0 (253.9 to 257.3)	Sandstone: quartzose, light grey, fine grained, well sorted, subangular with overgrowths, medium grey, poorly indurated; scattered carbonaceous grains and muscovite; very permeable, faint bedding; grades into
844.0 to 850.0 (257.3 to 259.1)	Sandstone: quartzose, very fine grained, grey white, subrounded with overgrowths, scattered black carbonaceous grains, abundant muscovite, poorly indurated, flat bedded where coherent; sharp irregular contact.
CANTUAR FORMATION	
Waseca Member	
850.0 to 856.0 (259.1 to 260.9)	Siltstone: sandy, quartzose, abundant fine-grained muscovite, massive, moderately indurated, earthy, medium to light grey; bedded (0.07 to 0.1 m thick) downward with traces of trough cross-beds; grades into
856.0 to 865.0 (260.9 to 263.7)	Siltstone: sandy, medium grey; laminated with crenulated dark grey silty shale; weakly indurated; traces of low-angle trough cross-beds and bioturbation below 262.1 m; sharp contact.
865.0 to 869.0 (263.7 to 265.0)	Mudstone: clayey, dark grey, carbonaceous; scattered coaly laminae at 263.6 to 264.3 m, silt content increases downward; grades into a very fine grained sandstone, 0.6 m thick; sharp contact.
869.5 to 873.0 (265.0 to 266.1)	Sandstone: quartzose, very fine grained, abundant muscovite, well sorted, light grey; thin, low-angle cross-beds (ripple drift) and trough sets outlined by dark grey argillaceous laminae; moderately indurated.
873.0 to 881.0 (266.1 to 268.5)	Sandstone: quartzose, fine grained, abundant muscovite, well sorted, flat-bedded with traces of tabular cross-beds (10° to 15°), grey white; scattered medium grey shale laminae over the upper half and rarer coaly lenticular partings below.

Tidewater Ituna Crown No. 2		(4-32-25-11W2)	KB 2225 feet (678.2 m)
Depth in feet (m)	CANTUAR FORMATION		
	Dina Member		
1993.0 to 1996.0 (607.5 to 608.4)	Sandstone: quartzose, very fine grained, subordinate fine and medium; white and grey white, poorly sorted; larger grains, frosted, pitted, subrounded; smaller sizes subangular and vitreous; scarce accessories of muscovite, carbonaceous specks, pyrite, kaolinite, jasperoid quartz; thinly interbedded with kaolinitic mudstone.		
1996.0 to 2000.0 (608.4 to 609.6)	Sandstone: quartzose, fine grained, well sorted, matrix of quartzose silt and white kaolinite; subordinate laminae of grey-white silty claystone; accessories as at 607.5 m, also includes white feldspar.		
2000.0 to 2015.0 (609.6 to 614.2)	Sandstone: quartzose, fine grained, well sorted; interbedded with sandstone, quartzose, medium-grained, well sorted; subrounded, weakly indurated, about 5% interstitial white kaolinite; accessories as at 607.5 m.		
2015.0 to 2022.0 (614.2 to 616.3)	Sandstone: quartzose, medium-grained, well sorted, rounded, friable, medium grey; about 5% matrix of silty kaolinite; scarce accessories include white feldspar and minerals as at 607.5 m; some layers include interstitial, brown, granular siderite.		
2022.0 to 2025.0 (616.3 to 617.2)	Shale: medium grey, waxy, scattered pyrite-infilled burrow.		

2025.0 to 2030.0 (617.2 to 618.7)	Sandstone: quartzose, very fine grained, well sorted, light grey, poorly cemented; abundant white kaolinized feldspar, grey chert; scattered muscovite, pyrite, carbonaceous grains; subangular and subrounded with quartz overgrowths; some silica grain-contact cementation, including jasperoid, quartz; very permeable.
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SUCCESS FORMATION

2030.0 to 2036.0 (618.7 to 620.6)	Shale: medium grey, clayey; laminated in part with white, kaolinitic, quartzose siltstone.
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2036.0 to 2040.0 (620.6 to 621.8)	Sandstone: quartzose, very fine grained, minerals as 617.2 to 618.7 m; partially cemented with limonitic siderite and white kaolinite.
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2040.0 to 2047.0 (621.8 to 623.9)	Sandstone: quartzose, very fine grained, argillaceous, medium grey grading downward into finely interbedded mudstone and claystone.
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2047.0 to 2057.0 (623.9 to 627.0)	Sandstone: quartzose, very fine grained, very argillaceous, medium greenish grey, well indurated; abundant iron-stained blebs, muscovite; grades into silty claystone, waxy.
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2057.0 to 2059.0 (627.0 to 627.6)	Shale: carbonaceous; overlies coal.
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2059.0 to 2063.0 (627.6 to 628.8)	Claystone: carbonaceous, 0.3 m thick; grades into dark grey mudstone and argillaceous, medium grey siltstone.
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2063.0 to 2067.0 (628.8 to 630.0)	Mudstone: carbonaceous, grey black grading onto black carbonaceous shale.
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2067.0 to 2070.0 (630.0 to 630.9)	Mudstone: dark grey, hard, platy, carbonaceous.
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2070.0 to 2081.0 (630.9 to 634.3)	Sandstone: quartzose, grey white, well sorted, weakly cemented, abundant rounded medium, white kaolinite in interstices; medium grey downward with increase in argillaceous content.
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2081.0 to 2084.0 (634.3 to 635.2)	Sandstone: quartzose, very fine grained, well sorted, weakly cemented, calcareous, disseminated fine carbon, grey black.
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2084.0 to 2089.0 (635.2 to 636.7)	Sandstone: quartzose, fine grained, well sorted, weakly cemented, very permeable, brown grading downward to light brown grey, oil stained.
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2089.0 to 2094.0 (636.7 to 638.3)	Sandstone: quartzose, very fine grained, well sorted, light grey, moderately indurated with downward increasing white kaolinite.
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2094.0 to 2097.0 (638.3 to 639.2)	Siltstone: quartzose, coarse grained, well indurated with white kaolinite; interbedded with sandstone as at 636.7 m.
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2097.0 to 2103.0 (639.2 to 641.0)	Mudstone: very calcareous, black; grades below 639.8 m into claystone, waxy, calcareous, grey black and below 640.4 m to mudstone, silty, grey black.
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2103.0 to 2106.0 (641.0 to 641.9)	Sandstone: quartzose, very fine grained, very argillaceous, dark green grey; abundant carbonized plant fragments; fine grained, light green grey over lower half.
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2106.0 to 2115.0 (641.9 to 644.7)	Mudstone: medium green grey, subordinate quartzose sand, platy; interbedded with claystone, waxy, dark green grey, brown ironstone concretionary cementation over basal 0.3 m.
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GRAVELBOURG FORMATION

2115.0 to 2120.0 (644.7 to 646.2)	Sandstone: quartzose, fine grained, light greenish grey, argillaceous matrix, calcite cemented (densely so at top); abundant white kaolinite, glauconite, carbonaceous specks, oxidized siderites, jasperoid quartz; poorly sorted, grade size ranging from very fine to medium; larger grains include calcite rimmed fragments of green mudstone and black carbonaceous mudstone; grey green and marly toward the base.
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2120.0 to 2130.0 (646.2 to 649.2)	Sandstone: quartzose, grey white, very fine grained, well sorted, abundant jasperoid quartz, subrounded; weakly indurated with white kaolinite, very permeable.
2130.0 to 2142.0 (649.2 to 652.9)	Sandstone: as at 646.2 m, but light to medium grey; interbeds of medium grey mudstone indicated (loss high).
2142.0 to 2146.0 (652.9 to 654.1)	Sandstone: quartzose, very fine grained, subrounded, well sorted, abundant muscovite; laminated with dark grey mudstone; includes fragments of coal and olive to grassy green glauconitic bodies; sideritic brown layer (0.02 m thick) at 653.5 m.
2146.0 to 2148.0 (654.1 to 654.9)	Sandstone: quartzose, very fine grained, argillaceous, grading downward into silty mudstone; dark grey; abundant carbonaceous plant fragments downward, highly muscovitic.
2148.0 to 2152.0 (654.9 to 655.9)	Shale: grey black, platy, hard.
2152.0 to 2181.0 (655.9 to 664.8)	Sandstone: quartzose, very fine grained, grading downward into fine grained, fine bedded, well cemented with calcite. Below 659.6 m up to 10% calcareous peloids, ooids, shell fragments, pyritic fragments and glauconitic grains.
2181.0 to 2188.0 (664.8 to 666.9)	Shale: medium grey green and dark green grey, abundant glauconite; resinous fish scales(?); interbeds of argillaceous siltstone.
2188.0 to 2202.0 (666.9 to 671.2)	Sandstone: quartzose, very fine grained with abundant fine, marlstone matrix, light greenish grey, well indurated; scattered green grey shale; calcite-cemented below 668.4 m and includes abundant calcareous peloids, ooids and shell fragments.
MADISON FORMATION	
2202.0 to 2204.0 (671.2 to 671.8)	Limestone: dense, cryptocrystalline, minor white tripolitic clay.

Tidewater Ituna Crown No. 1		(16-11-25-12W2)	KB 2267 feet (691.0 m)
Depth in feet (m)	CANTUAR FORMATION		
2100.0 to 2102.0 (649.1 to 640.7)	Shale: dark grey and olive, crumbly; scattered black carbonaceous(?) films.		
2102.0 to 2103.0 (640.7 to 641.0)	Sandstone: quartzose, very fine grained, argillaceous, moderately indurated, earthy, mottled medium grey and brown (iron-stain).		
2103.0 to 2117.0 (641.0 to 645.3)	Mudstone: medium grey and brown mottled, moderately indurated; subordinate interbedded argillaceous quartzose sandstone; scattered reed-like carbonaceous films; basal 0.015 m dark brown ironstone.		
	SHAUNAVON FORMATION		
	Lower Member		
2117.0 to 2119.0 (645.3 to 645.9)	Sandstone: quartzose, fine grained, argillaceous, very calcareous, dark grey; abundant pelecypod shells; upper 0.15 m includes tan, sandy limestone; cross-bedded with truncational sets 0.3 m thick.		
	GRAVELBOURG FORMATION		
	Upper Member		
2119.0 to 2134.0 (645.9 to 650.4)	Siltstone: quartzose, argillaceous, noncalcareous, light green grey, abundant muscovite, earthy, moderately indurated; minor increasing to subordinate dark green-grey shale partings and interbeds; glauconitic near base.		

2134.0 to 2140.0 (650.4 to 652.3)	Shale: dark green grey, fissile to platy, noncalcareous.
Lower Member	
2140.0 to 2144.0 (652.3 to 653.5)	Mudstone: dolomitic, hard, platy, medium grey green grading into buff at 653.2 m; grades into
2144.0 to 2147.0 (653.5 to 654.4)	Sandstone: quartzose, fine grained, subordinate very fine, dolomitic, well indurated, current and ripple bedded; buff with grey thin banding; mudstone below 654.1 m grades into
2147.0 to 2157.0+ (654.4 to 657.5)	Shale: dark grey, noncalcareous, platy.
2157.0 to 2166.0 (657.5 to 660.2)	Sandstone: quartzose, fine grained, well sorted, light grey, unindurated (loss very high).
2166.0 to 2175.0 (660.2 to 662.9)	Sandstone: quartzose, very fine grained, argillaceous, indurated, light grey, minor mudstone interbeds; permeable.
2175.0 to 2177.0 (662.9 to 663.5)	Sandstone: quartzose, medium grained, well sorted, scattered grey chert, weakly indurated, very permeable, medium grey.
2177.0 to 2179.0 (663.5 to 664.2)	Shale: dark grey, fissile, noncalcareous.

Tidewater Ituna Crown No. 4	(1-29-25-12W2)	KB 2244 feet (684.0 m)
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Depth in feet (m)	SUCCESS FORMATION
2074.0 to 2078.0 (632.2 to 633.4)	Sandstone: quartzose, very fine grained, subordinate siltstone; scattered black carbonized plant fragments, sideritic red speckled at top; unindurated, light grey, very permeable. Rubbly and iron cemented at base.
SHAUNAVON FORMATION	
Lower Member	
2078.0 to 2084.0 (633.4 to 635.2)	Calclutite: tan, cryptocrystalline, abundant corals, pelecypods; marly below 634.9 m.
GRAVELBOURG FORMATION	
Upper Member	
2084.0 to 2087.0 (635.2 to 636.1)	Shale: grey black, calcareous, fissile, abundant thin pelecypod shells; interbedded with dark green grey mudstone, platy, noncalcareous.
2087.0 to 2089.5 (636.1 to 636.9)	Sandstone: quartzose, very fine grained, well sorted, abundant muscovite, light grey; minor dark grey shale laminae and partings; glauconitic patches downward.
2089.5 to 2091.5 (636.9 to 637.5)	Shale: grey black, noncalcareous, fissile; minor quartzose siltstone; abundant carbonized plant fragments; silty glauconitic mudstone toward base.
2091.5 to 2115.0 (637.5 to 644.7)	Sandstone: quartzose, very fine grained, argillaceous, light grey and green grey, moderately indurated, earthy, permeable; scattered green glauconitic layers at 627.9 to 640 m and clayey partings below 642.5 m; grades with increasing argillaceous content into
2115.0 to 2131.0 (644.7 to 649.5)	Shale: limonite yellow, green and red; interbedded argillaceous sandstone as 637.5 to 644.7 m.

2131.0 to 2149.0 (649.5 to 655.0)	Sandstone: quartzose, very fine grained, well indurated, argillaceous matrix, dark grey speckled with black carbonaceous grains and muscovite; bedded with some bioturbation; scattered glauconitic lenticles; basal contact marked by 0.08 to 0.1 m of black carbonaceous shale.
2149.0 to 2162.0 (655.0 to 659.0)	Sandstone: quartzose, fine grained, ca. 6% angular and subangular medium; moderately angular and subangular medium; moderately sorted, abundant muscovite, dark grey argillaceous matrix, slightly friable, permeable; scattered nodules of pyrite, kaolinite grains, small carbonized plant fragments and glauconite.
2162.0 to 2164.0 (659.0 to 659.6)	Mudstone: platy, dark grey, interbedded with siltstone, light grey.
GRAVELBOURG FORMATION	
Lower Member	
2164.0 to 2173.0 (669.6 to 662.3)	Limestone: cryptocrystalline, hard, dense, tan, minor very fine grained quartzose sand, interbedded with laminated fine-grained quartzose sandstone with oxidized bitumen grains in calcilutite and dark grey bituminous shale.
2173.0 to 2182.0 (662.3 to 665.1)	Shale: dark grey, coquinoïd at 662.3 to 663.2 m; abundant pelecypods below.
2182.0 to 2190.0+ (665.1 to 667.5)	Sandstone: quartzose, fine grained, minor fine and medium-grained pyrite-infilled oolites, coarse lithic, bitumenized and pyritized fragments; well cemented with medium blue-grey calcite; pronounced cross-bedding dips up to 15° and in truncation sets up to 0.05 m thick.
2190.0 to 2193.0 (667.5 to 668.4)	Sandstone: quartzose, very fine grained, well sorted, well-cemented in calcite, light blue grey; abundant dark green-grey marly partings, some load deformation; downward increasing argillaceous content.

Tidewater Wishart Crown No. 1	(13-21-30-13W2)	KB 1961 feet (597.7 m)
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Depth in feet (m)	CANTUAR FORMATION Cummings Member
1590.0 to 1592.0 (484.6 to 485.2)	Sandstone: quartzose, very fine grained, well sorted, argillaceous, abundant carbonaceous grains, weakly indurated, medium grey.
1592.0 to 1615.0 (485.2 to 492.3)	Claystone: dark grey, waxy, scattered carbonized plant fragments; silty and platy toward base; sharp irregular contact.
SUCCESS FORMATION	
1615.0 to 1642.0 (492.3 to 500.5)	Sandstone: quartzose, fine grained, abundant medium; kaolinitic matrix; about 7% coarse-grained, red brown sphaerosiderites; grey white speckled with red brown and variegated with ochreous red between 493.8 to 499.9 m; cobbles of black shale below 500 m.
1642.0 to 1675.0 (500.5 to 510.5)	Mudstone: ochreous red, earthy, massive.
1675.0 to 1710.0 (510.5 to 521.2)	Sandstone: quartzose, very fine grained, white and light green, argillaceous matrix partially silica cemented; abundant white chert pebbles and nodules over lower third.
1710.0 to 1714.0 (521.2 to 522.4)	Rubble: variegated red, green and white mudstone, claystone, and argillaceous sandstone (about 0.45 m present of 1.2 m cored interval).

BAKKEN FORMATION

1714.0 to 1720.0 (522.4 to 524.3)	Shale: dark purplish grey, hard, platy.
1720.0 to 1737.0 (524.3 to 529.4)	Sandstone: quartzose, very fine grained, calcite cemented, cross-laminated, light green-grey shaly partings, some oxidized red.

(Core continues through the Lower Bakken, and Big Valley and Torquay formations).

Tidewater Headlands Crown No. 4-34 (4-34-24-14W2) KB 2123 feet (647.1 m)

Depth in feet (m)	CANTUAR FORMATION Dina Member
2191.0 to 2193.5 (667.8 to 668.6)	Shale: black, carbonaceous, some coal.
2193.5 to 2202.0 (668.6 to 671.2)	Mudstone: grey black, hard, platy to shaly, abundant carbonaceous plant film.
2202.0 to 2202.0 (671.2 to 671.2)	Sandstone: quartzose, fine grained, weakly argillaceous, medium grey, poorly indurated, abundant carbonized plant fragments; less than 0.08 m thick.
2202.0 to 2205.0 (671.2 to 672.1)	Mudstone: grey black, hard, platy, abundant carbonaceous plant film; minor layers 0.03 to 0.5 m thick of medium grey, argillaceous, quartzose siltstone with abundant carbonized plant fragments; grades into
2205.0 to 2211.0 (672.1 to 673.9)	Sandstone: quartzose, very fine grained, light grey, argillaceous, moderately indurated; laminated, massive and bioturbated in part.
2211.0 to 2214.0 (673.9 to 674.8)	Mudstone: as at 671.2 m.
2214.0 to 2228.0 (674.8 to 679.1)	Mudstone: dark grey; grey black and black downward, clayey layers alternate with silty; grades into
2228.0 to 2236.0 (679.1 to 681.5)	Coal: woody and shaly, black.
2236.0 to 2240.5 (681.5 to 682.9)	Mudstone: clayey, dark grey; abundant carbonized twigs, and other plant fragments; scattered rootlet castings.
2240.5 to 2241.5 (682.9 to 683.2)	Mudstone: black, carbonaceous, platy, abundant carbonized plant fragments; grades into
2241.5 to 2243.0 (683.2 to 683.7)	Coal: black, crumbly; shaly toward base.
2243.0 to 2262.0 (683.7 to 689.5)	Sandstone: quartzose, fine grained with subordinate very fine and medium, indurated, very permeable; abundant white kaolinized feldspar, dark brown grey chert, carbonaceous grains and lithic fragments, muscovite; interbedded with medium-grained quartzose sandstone with similar components and texture.
2262.0 to 2265.0 (689.5 to 690.4)	Sandstone: as above, but calcite-cemented, light grey, dense; minor interbeds of sandstone, medium-grained, cross-bedded, bounded by irregular contacts.
SUCCESS FORMATION	
2265.0 to 2274.5 (690.4 to 693.3)	Sandstone: quartzose, fine grained, well sorted, weakly indurated, low argillaceous content, medium grey; scattered to abundant white kaolinitic and black carbonaceous grains.

2274.5 to 2280.0 (693.3 to 694.9)	Sandstone: quartzose, fine grained, well sorted, well cemented with calcite, light blue grey, abundant white kaolinite grains, scattered carbonaceous grains; conglomerate, 0.3 m thick, with abundant carbonized woody fragments at 694.0 m, below which argillaceous content increases as matrix and partings.
2280.0 to 2298.0 (694.9 to 700.4)	Sandstone: quartzose, fine grained, grading downward to 697 m with increasing argillaceous and decreasing calcareous content to very fine; abundant white kaolinite grains; some scattered carbonaceous laminae and partings over lower half, as well as fine-grained sandstone layers.
2298.0 to 2299.0 (700.4 to 700.7)	Shale: dark grey green, waxy, fissile; interbedded with weakly indurated medium and coarse grained, quartzose, sandstone, with abundant medium grey green, argillaceous siltstone pebbles, white kaolinite grains and carbonaceous grains.
2299.0 to 2307.0 (700.7 to 703.2)	Sandstone: quartzose, medium grained, interbedded with fine, weakly indurated, argillaceous, medium grey speckled with white kaolinite grains; minor coaly laminae and lenticles.
2307.0 to 2313.0+ (703.2 to 705.0)	Shale: dark grey, muscovitic, grading below 703.5 m into sandstone, quartzose, very fine grained, argillaceous, medium grey; laminated and thinly interbedded with shale; scattered coaly partings; minor plastic deformation in clayey beds.
2313.0+-2315.0 (705.0 to 705.6)	Sandstone: quartzose, very fine grained, argillaceous, medium grey, laminated with dark grey shale, grades into
2315.0 to 2320.0 (705.6 to 707.1)	Sandstone: quartzose, very fine grained, grading through fine and medium into coarse; medium grey, abundant white kaolinite grains, weakly indurated; basal mudstone conglomerate and shingles; sharp contact.
GRAVELBOURG FORMATION	
2320.0 to 2332.0 (707.1 to 710.8)	Shale: dark grey green and dark grey, waxy, fissile (0.8 m present).
2332.0 to 2344.0 (710.8 to 714.5)	Conglomerate: sandstone, mudstone and limestone from the Souris Valley Formation; dark grey shale matrix.

Mobil South Grassdale 32-10	(10-32-6-15W2)	KB 1949 feet (594.1 m)
Depth in feet (m)	PENSE FORMATION	
3145.5 to 3148.5 (958.6 to 959.7)	Sandstone: quartzose, fine grained, well sorted, grain-contact cemented, friable, light grey to grey white, abundant dark grey chert, small amount of interstitial white clay, permeable; quartzose grains faceted; balled and bioturbated into cylindrical forms 0.006 to 0.012 m in diameter, and intermixed with subordinate dark grey mudstone. Bioturbated beds interbedded with coarse laminae of dark grey mudstone. Thicker layers of sandstone are finely cross-bedded and in scoured contact with mudstone. Latter includes sand-filled, lateral burrows.	
3148.5 to 3153.0 (959.7 to 961.0)	Sandstone: quartzose, very fine grained, subordinate fine, argillaceous, dark grey; laminated and thinly interbedded with light grey, fine grained, quartzose sandstone with scattered low-angle, planar truncation sets and thin (0.012 m) trough sets with scoured contacts; scattered iron-rusted bands (siderite?).	
3153.0 to 3155.0 (961.0 to 961.6)	Sandstone: quartzose, bioturbated as 959.7 m; large, oblique burrows transect lateral burrows.	
3155.0 to 3159.5 (961.6 to 963.0)	Sandstone: quartzose, fine grained, well sorted, greyish white, grain-contact cemented, low-angle cross-bedded on scoured contacts, thin bedded; subordinate grey black shale with scattered sand-filled burrows, and burrowed sandstone as at 958.6 m; sharp basal contact.	

3159.5 to 3160.0 (963.0 to 963.2)	Sandstone: quartzose, very fine grained, well cemented; dark brown siderite-cemented pavement at top and light grey calcite-cemented zone at base; sharp contact.
3160.0 to 3160.0 (963.2 to 963.3)	Shale: dark grey, chippy.
3160.0 to 3161.5 (963.3 to 963.6)	Sandstone: quartzose, light grey, very fine grained; laminated with grey-black shale; scoured contacts and scattered sandy burrows; overlies 0.1 m layer of bioturbated sandstone as at 958.6 m; sharp contact.
3161.5 to 3162.5 (963.6 to 963.9)	Shale: grey black, splintery, hard; sharp contact.
3162.5 to 3168.0 (963.9 to 965.6)	Sandstone: quartzose, very fine grained, medium grey, low-angle cross-bedded; current scoured contacts; laminated with subrounded dark grey mudstone; scattered balls and rolls; sandstone increases downward; sharp contact.
CANTUAR FORMATION	
Waseca Member	
3168.0 to 3170.5 (965.6 to 966.4)	Sandstone: quartzose, fine grained, well sorted, light grey, moderately silica cemented, abundant kaolinite grains; rare coaly grains and glauconite; upper 0.3 m densely silica cemented; interbedded with
3170.5 to 3178.0 (966.4 to 968.7)	Sandstone: quartzose, very fine grained, argillaceous, dark grey with scattered light grey laminae, lenticles and rolls of fine grained quartzose sandstone.
3178.0 to 3188.0 (968.7 to 971.7)	Sandstone: quartzose very fine grained, argillaceous, accessories and fabric as at 965.6 m; interbedded with subordinate sandstone as at 966.4 m.
3188.0 to 3275.0 (971.7 to 998.2)	No core.
General Petroleums Member	
3275.0 to 3283.0 (998.2 to 1000.7)	Claystone: hard, grey with brownish cast, montmorillonitic, popcorn texture; grades into
3283.0 to 3285.0 (1000.7 to 1001.3)	Sandstone: quartzose, fine grained, argillaceous, medium to dark grey; oblique rootlet casts; sharp erosional contact.
SUCCESS FORMATION	
3285.0 to 3289.0 (1001.3 to 1002.5)	Sandstone: quartzose, fine grained, well sorted, abundant muscovite and kaolinite; light grey to white, interbedded with medium grey (drilling mud?); crenulated partings; sharp contact.
3289.0 to 3297.0 (1002.5 to 1004.9)	Sandstone: quartzose, medium grey, hard; iron stained at top; trace of intraformational deformation; dark grey argillaceous content increases downward.

Whitefox No. 1	(5-14-52-15W2)	KB 1215 feet (370.3 m)
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(Recovery poor throughout)

Depth in feet (m)	CANTUAR FORMATION Sparky Member
364.0 to 366.0 (110.9 to 111.6)	Mudstone: subordinate, very fine grained quartzose sandstone, medium green grey; weakly indurated.
366.0 to 376.0 (111.6 to 114.6)	(0.08 m recovery); brown ironstone.

376.0 to 386.0 (114.6 to 117.7)	Siltstone: quartzose, well cemented with calcite, light grey, brown iron staining (about 0.45 m present); mudstone as above.
386.0 to 403.0 (117.7 to 122.8)	Mudstone: grey black, carbonaceous; interbedded mudstone, platy, medium grey; scattered carbonized plant fragments.
General Petroleums Member	
403.0 to 436.0 (122.8 to 132.9)	Mudstone: light grey interbedded with medium grey; laminated with argillaceous, quartzose very fine grained sandstone; weakly indurated.
Rex Member	
436.0 to 456.0 (132.9 to 139.0)	No core.
456.0 to 496.0 (139.0 to 151.2)	Mudstone: clayey, medium green grey, mottled with red; thin interbeds of argillaceous, very fine grained quartzose sandstone below 150.6 m.
Lloydminster Member	
496.0 to 506.0 (151.2 to 154.2)	Sandstone: quartzose, very fine grained, argillaceous, medium grey; laminated with dark grey shale; subordinate thin current-bedded, well sorted, sandstone; some bedding aligned bioturbation.
506.0 to 515.0 (154.2 to 157.0)	Claystone: waxy, dark grey, weakly indurated (0.15 m rec.).
Cummings Member	
515.0 to 524.0 (157.0 to 159.7)	Claystone: as at 154.2 m; interbeds of dark grey, argillaceous, very fine grained quartzose sandstone with trace of bioturbation.
Dina Member	
524.0 to 665.0 (159.7 to 202.7)	(Recovery too poor for logging). Below 178.3 m core fragments consist of white, kaolinitic, poorly indurated, very fine grained, quartzose sandstone and sandy mudstone.

CDR Flat Lake WSW C3-3-1-16(W2)
KB 2261 feet (689.6 m)

Reference section for the Success Formation, southeastern Saskatchewan, see main text

Depth in feet (m)	CANTUAR FORMATION Lloydminster Member
4385.0 to 4389.0 (1336.5 to 1337.8)	Mudstone: olive, subordinate argillaceous siltstone, abundant carbonized plant fragments; bedding disrupted by plastic deformation; claystone below 4388 feet (1337.5 m); sharp, irregular contact.
4389.0 to 4396.0 (1337.8 to 1339.9)	Siltstone: dark grey, massive; includes dark grey, clay-filled anastomosed rootlet burrows; interbedded with argillaceous, poorly sorted, fine to medium-grained, quartzose sandstone at 4394.0 to 4395.0 feet (1339.3 to 1339.6 m) and 4395.5 to 4396.0 feet (1339.7 to 1339.9 m); sandstone includes granules and blebs of coarse-grained pyrite.
4396.0 to 4397.0 (1339.9 to 1340.2)	Conglomerate: pebbles of quartzose, fine-grained, silica-cemented sandstone; light grey; hard, dense.

Success Formation

S2 Member

- 4397.0 to 4399.5
(1340.2 to 1341.0) Sandstone: quartzose, very fine grained to medium, poorly sorted, larger grains are rounded; white; well indurated in earthy, kaolinitic and quartzose silt; large, mudstone-infilled, oblique fracture-joints; also white, siliceous, kaolinitic, irregular pebbles; abundant coarse-grained sphaerosiderite; irregular contact on apparent soft sediment.
- 4399.5 to 4401.5
(1341.0 to 1341.6) Siltstone: quartzose, white, well indurated in siliceous kaolinite; minor, increasing to subordinate, light grey green argillaceous partings; crenulated bedding with traces of current lamination and deformational attenuation.
- 4401.5 to 4405.5
(1341.6 to 1342.8) Mudstone: glauconitic, olive variegated with yellow and red; interbedded with subordinate flasers, lenticles and thin beds of indurated, cross-bedded, white, kaolinitic, quartzose, siltstone; abundant reddish brown sphaerosiderite and muscovite; sharp, irregular contact.

S1 Member

Bedding Cycle 6 (4.4 m)

- 4405.5 to 4419.0
(1342.8 to 1346.9) Siltstone: quartzose, grey white grading to medium grey green with increasing glauconite; kaolinitic matrix; current beds marked by small-scale ripples, cut-and-fill lenses, 0.06 to 0.75 m thick, bifurcating and terminating in black shale; burrow pods, tool markings and flame structures in evidence; shale increases to 20% downward.
- 4419.0 to 4420.0
(1346.9 to 1347.2) Shale: dark grey laminated with green.

Bedding Cycle 5 (11.4 m)

- 4420.0 to 4434.4
(1347.2 to 1351.6) Sandstone: quartzose, very fine grained, well sorted, glauconitic, medium grey green, silty to argillaceous matrix, moderately indurated; generally current bedded with minor green and black shaly partings, some burrow casted and trail marked; low-angle, cut-and-fill at 1350.9 m.
- 4434.4 to 4443.9
(1351.6 to 1354.5) Sandstone: quartzose, very fine grained, green, glauconitic; black shale-draped cross-bedded, scour-and-fill lensoid sandstone; interbedded with trough cross-bedded sandstone, 0.05 to 0.08 m thick; abundant bedding-aligned sandy burrow casts, trails and concentrations of small pelecypod molds.
- 4443.9 to 4452.0
(1354.5 to 1357.0) Siltstone: quartzose, coarse-grained, glauconitic, medium grey green; trough truncation sets and ripple-drift beds 0.02 to 0.05 m thick; calcareous argillaceous matrix; thinly interbedded with dark grey, bioturbated, and sand-podded mudstone and shale.
- 4452.0 to 4457.3
(1357.0 to 1358.6) Siltstone: quartzose, coarse-grained, glauconitic, medium grey green, argillaceous; thin cut-and-fill-bedding; podded, bioturbated, and compaction attenuated; thinly interbedded and draped with bioturbated shale.

Bedding Cycle 4 (3.2 m)

- 4457.3 to 4460.1
(1358.6 to 1357.4) Sandstone: quartzose, very fine grained, argillaceous; glauconitic, medium grey green; current scour-and-fill; some black shale drapes and sandy burrow pods; calcite cemented at 1359.1 to 1359.4 m.
- 4460.1 to 4465.9
(1357.4 to 1361.2) Shale: olive, glauconitic; laminated with mudstone, light green grey; minor boudinage.
- 4465.9 to 4467.8
(1361.2 to 1361.8) Siltstone: argillaceous, glauconitic, green; laminated with black shale; minor shale-draped sandy flasers.

Bedding Cycle 3 (8.3 m)

- 4467.8 to 4472.8
(1361.8 to 1363.3) Sandstone: quartzose, very fine grained, glauconitic; argillaceous, medium green; low-angle cross-bedded and flat bedded; minor black shale partings.

4472.8 to 4480.0 (1363.3 to 1365.5)	Siltstone: quartzose, glauconitic, argillaceous; calcite cemented at 1363.5 to 1364.1 m; cut-and-fill, thin cross-bedding; minor black shale wavy laminae; graded mudstone, 0.04 m thick, at 1364.0 m.
4480.0 to 4495.0 (1365.5 to 1370.1)	Siltstone: green, glauconitic, argillaceous; laminated with black shale; abundant feeding burrows and compactional attenuation of shale on silty flasers and lenticles.
Bedding Cycle 2 (2.0 m)	
4495.0 to 4496.4 (1370.1 to 1370.5)	Sandstone: quartzose, very fine grained, argillaceous, glauconitic, medium grey green; massive, well indurated, faintly cross-bedded.
4496.4 to 4499.0 (1370.5 to 1371.3)	Shale: grey black, and dark grey mudstone; on interbedded green silty mudstone and dark grey shale; strongly glauconitic at base.
4490.0 to 4500.3 (1371.3 to 1372.1)	Shale: dark grey, noncalcareous.
Bedding Cycle 1 (1.9 m)	
4500.3 to 4506.5 (1372.1 to 1373.6)	Mudstone: silty, and siltstone: quartzose, argillaceous, medium green grey, well indurated; laminated and thinly interbedded with dark grey shale; faint current bedding with scoured contacts and shale drapes; vertical escape burrows at 1372.7 m.
4506.5 to 4507.8 (1373.6 to 1374.0)	Shale: dark grey; minor 0.05 to 0.10 m thick mudstone beds in upper portion; noncalcareous (end of core).

Socony et al W Ratcliffe 13-22-1-16(W2)
KB 2337 feet (712.3 m)

Depth in feet (m)	CANTUAR FORMATION Rex Member
4305.0 to 4316.0 (1312.2 to 1315.5)	Mudstone: dark grey, intermixed with subordinate medium grey, very fine grained, quartzose sandstone; small randomly oriented burrow casts; dark red thin bands and streaks; weak plastic deformation.
4316.0 to 4320.0 (1315.5 to 1316.7)	Sandstone: quartzose, argillaceous, medium grey; moderately distorted clayey flame structures; scattered brown ironstone nodules; interbedded at 0.3 to 0.6 m intervals with mudstone as at 1312.2 m.
4320.0 to 4336.0 (1316.7 to 1321.6)	Mudstone: as at 1312.2 m.
4336.0 to 4341.0 (1321.6 to 1323.1)	Mudstone: dark grey, flat-bedded, platy, medium grey downward; minor bioturbated layers 0.02 to 0.05 m thick over upper half.

TW Imp Avonhurst Cr. 1-29-19-16(W2)
KB 2188 feet (666.9 m)

Depth in feet (m)	CANTUAR FORMATION Cummings Member
2470.0 to 2474.4 (752.9 to 754.2)	Claystone: light grey, waxy, mottled with limonite (yellow) and dark brown filaments (plant?); grades into
2474.4 to 2477.4 (754.2 to 755.1)	Mudstone: medium grey, platy; subordinate thin, argillaceous, very fine grained, quartzose sandstone.

Dina Member

2477.4 to 2487.0 (755.1 to 758.0)	Sandstone: quartzose, very fine grained, argillaceous, medium grey, grades into fine grained, friable and light grey; abundant muscovite, adamantine carbonaceous specks; well sorted.
2487.0 to 2493.0 (758.0 to 759.9)	No recovery (presumably of sandstone above); but 0.15 m of limonite yellow mudstone present in box.
2493.0 to 2503.0 (759.9 to 762.9)	Shale: dark grey, crumbly (poor recovery).
2503.0 to 2505.0 (762.9 to 763.5)	Mudstone: dark grey, subordinate very fine grained, quartzose sandstone (poor recovery).
2505.0 to 2507.0 (763.5 to 764.1)	Shale: dark grey.
2507.0 to 2510.0 (764.1 to 765.0)	No core.
2510.0 to 2525.0 (765.0 to 769.6)	Sandstone, quartzose, medium grained, subrounded and rounded, moderately sorted, bimodal, matrix of very fine grained quartzose sand; decreases to fine grained, and well sorted below 766.6 m; generally grey white, very permeable, nearly unindurated.

RIERDON FORMATION

2525.0 to 2530.0 (769.6 to 771.1)	Shale: clayey, dark green grey, very calcareous.
2530.0 to 2553.0 (771.1 to 778.2)	Mudstone: platy, medium green grey, very calcareous.
2553.0 to 2562.0 (778.2 to 780.9)	Shale: dark green grey, abundant pyritic, bedding aligned, crisscrossing filaments; very calcareous.
2562.0 to 2562.5 (780.9 to 781.1)	Sandstone: quartzose, poorly sorted, fine to coarse grained, abundant limonitic ironstone grains and pellets, belemnite guards, and <i>Gryphaea</i> ; well cemented with calcite; speckled dark blue grey and light grey.

SHAUNAVON FORMATION

Upper Member Unit 3

2562.5 to 2572.0 (781.1 to 783.9)	Mostly lost. About 15 cm of limonite-stained marlstone incorporating shell debris.
2572.0 to 2578.0 (783.9 to 785.8)	Sandstone: quartzose, fine grained, calcite cemented, light grey, argillaceous; strongly bioturbated as indicated by calcite-lined burrows, escape burrows and severe disruption of bedding.
2578.0 to 2592.0 (785.8 to 790.0)	Sandstone: quartzose, very fine grained, calcite-cemented layers laminated with green shale partings and argillaceous, weakly cemented sandstones; grades into a laminated, medium green grey, calcareous, argillaceous siltstone over basal 0.3 m.
2592.0 to 2593.0 (790.0 to 790.3)	Sandstone: quartzose, very fine grained, well cemented with calcite, grey white; crenulated and contorted fine bedding and shaly partings; abundant pelecypod shells and oncolites; sharp irregular contact.

Unit 2c

2593.0 to 2599.0 ⁺ (790.3 to 792.2)	Marlstone: green, dolomitic, intermixed with a vertical lace of tan dolomitic siltstone (caliche profile?).
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2599.0 to 2603.0 (792.2 to 793.4)	Sandstone: quartzose, very fine grained, well sorted, calcite cemented, grey white; interbedded with medium green grey, dolomitic, platy, mudstone (loss 50%).
2603.0 to 2605.5 (793.4 to 794.2)	Sandstone: quartzose, marly matrix, medium grey green.
2605.5 to 2625.0 (794.2 to 800.1)	Shale: dolomitic to calcareous downward; dark grey variegated with green and purple; minor thin beds of calcareous, quartzose siltstone over basal 0.1 m.
Unit 1	
2625.0 to 2628.5 (800.1 to 801.2)	Calclutite: light green grey tinted with yellow; abundant small pelecypod molds; grades into mudstone, marly, yellowish grey; and mudstone, dolomitic, platy, grey and red variegated.
2628.5 to 2632.0 (801.2 to 802.2)	Sandstone: quartzose, very fine grained, argillaceous, dark grey, calcite cemented, grey white, ripple and truncational cross-sets; subordinate laminae of dark grey shale; grades into
2632.0 to 2644.0 (802.2 to 805.9)	Sandstone: quartzose, very fine grained, faintly current laminated with minute truncational sets; grades below 803.5 m into grey black shale with scattered silty laminae.
2644.0 to 2655.0 (805.9 to 809.2)	Sandstone: marly matrix, medium grey green, weakly indurated; interbedded with dark grey, noncalcareous shale; sharp contact.
Lower Member	
2655.0 to 2659.0 (809.2 to 810.5)	Calclutite: tan, hard, cream coloured, abundant pelecypod shell fragments.
2659.0 to 2668.0 (810.5 to 813.2)	Sandstone: quartzose, very fine grained, very argillaceous, medium grey, finely bedded, and current bedded; thinly interbedded with grey-black shale; scattered carbonaceous films.
2668.0 to 2671.0 (813.2 to 814.1)	Calclutite: as at 809.2 m.
2671.0 to 2674.0 (814.1 to 815.0)	Sandstone: quartzose, very fine grained, well sorted, weakly indurated, light grey, thin bedded; argillaceous at top; sharp contact.
2674.0 to 2682.0 (815.0 to 817.5)	Sandstone: quartzose, very fine grained, argillaceous matrix, dark grey, well indurated; thinly interbedded with dark grey shale; abundant muscovite, bedding aligned carbonized plant fragments.
2682.0 to 2693.0 (817.5 to 820.8)	Limestone: cream, cryptocrystalline; finely comminuted bioclastic stringers; abundant horn corals, scattered pelecypods, bituminous; basal 0.3 m includes subordinate very fine grained quartzose sand and quartz-cored oolites.
2693.0 to 2695.0 (820.8 to 821.4)	Sandstone: quartzose, fine grained, argillaceous, calcareous; dark grey, thin truncational cross-laminated sets; sandy mudstone increase downward with laminae of grey black shale.
2695.0 to 2698.5 (821.4 to 822.5)	Oolite: quartz nucleated, medium grained; calcite cemented; dense, grey buff, bituminous; grade by dark grey, argillaceous increase into
2698.5 to 2710.0 (822.5 to 826.0)	Sandstone: quartzose, fine grained; grading downward into very fine, argillaceous, silica cemented, dark grey; abundant carbonized plant fragments; minor to subordinate grey-black shaly partings, noncalcareous.
2710.0 to 2711.0 (826.0 to 826.3)	Calclutite: cream, cryptocrystalline; abundant verti-spiral gastropods; subordinate very fine grained quartzose sand, carbonaceous specks, calclutite fragments.
2711.0 to 2713.0 (826.3 to 826.9)	Sandstone: quartzose, fine grained, dark grey, argillaceous grading into

2713.0 to 2713.0 (826.9 to 826.9)	Shale: (0.05 m) dark grey, calcareous, laminated with cream calcilutite.
2713.0 to 2719.0 (826.9 to 828.8)	Calcilutite: cream, grading downward through tan, pyrite-infiltrated, pseudo-oolitic and pelletal limestone into quartzose, calcarenitic sandstone.
2719.0 to 2719.5 (828.8 to 828.9)	Shale: dark grey, noncalcareous, fossiliferous.
2719.5 to 2721.0 (828.9 to 829.4)	Mudstone: dolomitic, medium green grey, abundant carbonized plant films; grades into
2721.0 to 2731.0 (829.4 to 832.4)	Sandstone: quartzose, very fine grained, argillaceous, well indurated, medium grey, finely cross-laminated; thin bedded with dark grey argillaceous partings; abundant muscovite.
2731.0 to 2732.0 (832.4 to 832.7)	Calcilutite: cream, hard, abundant pelecypods; sharp irregular contact.
2732.0 to 2732.5 (832.7 to 832.9)	Shale: dark grey, mottled with green glauconitic patches, very calcareous.
2732.5 to 2735.0 (832.9 to 833.6)	Calcilutite: tan, argillaceous, hard; solution pitted holes infilled with green mudstone.
2735.0 to 2740.0 (833.6 to 835.2)	Sandstone: quartzose, fine and very fine grained, bimodal, light grey, friable, permeable, abundant rose quartz, subangular to subrounded, low argillaceous content, scattered black carbonaceous specks.
2740.0 to 2745.0 (835.2 to 836.7)	Sandstone: quartzose, fine grained, grading downward to very fine; argillaceous matrix, medium grey downward to dark grey, faintly bedded.
2745.0 to 2748.0 (836.7 to 837.6)	Shale: dark green grey, calcareous, glauconitic.
2748.0 to 2753.0 (837.6 to 839.1)	Sandstone, quartzose, fine grained, subordinate very fine, white kaolinite matrix, moderately indurated, earthy.
GRAVELBOURG FORMATION	
Upper Member	
2753.0 to 2755.0 (839.1 to 839.7)	Mudstone: dark grey, dolomitic, subordinate quartzose silty beds, light grey.
2755.0 to 2760.0 (839.7 to 841.2)	Mudstone: variegated red and yellow on dark grey, dolomitic, platy.

+ estimate

Tidewater Cupar Crown No. 4-28	(4-28-24-16W2)	KB 2074 feet (632.2 m)
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Depth in feet (m)	MANNVILLE GROUP Dina Member
2189.0 to 2191.0 (667.2 to 667.8)	Sandstone: quartzose, light blue grey, well cemented with calcite, fine grained; abundant white kaolinite, black carbonaceous grains, muscovite, biotite, black and grey chert; scattered pebble sized coaly plant fragments; sharp irregular contact on grey black shale.
2191.0 to 2193.0 (667.8 to 668.4)	Sandstone: quartzose, white, medium grained with facets, and fine grained; variably but weakly cemented with white kaolinite; finely bedded, very permeable; ca. 10% dark grey crenulated shale laminae.

2193.0 to 2194.0 (668.4 to 668.7)	Shale: waxy, dark grey, limonite yellow at top.
2194.0 to 2197.0 (668.7 to 669.6)	Sandstone: quartzose, fine grained, well sorted, subangular to subrounded, faceted, weakly indurated, very permeable; abundant black carbonaceous specks, rose quartz, kaolinite as grain coating; light grey to white.
2197.0 to 2221.0 (669.6 to 677.0)	Sandstone: quartzose, medium grained; metre-thick interbeds of fine-grained; well sorted, subrounded to rounded, weakly indurated, very permeable; scattered grains of black and grey chert and white kaolinite; coaly pebble-conglomerate toward base.
2221.0 to 2223.5 (677.0 to 677.7)	Shale: dark grey, platy; faintly interbedded with argillaceous siltstone laminated with mudstone; scattered carbonaceous plant fragments; coaly partings near base; traces of green glauconitic or chloritic colouration in a few silty layers midway in the section.
2223.5 to 2229.0 (677.7 to 680.0)	Sandstone: quartzose, very fine to fine grained, well sorted; weakly indurated with white kaolinite; thinly interbedded with black coaly laminae (green alteration colour in certain laminae is associated with the coaly layers and may be derived from breakdown of pyrite and marcasite).
2229.0 to 2240.0 (680.0 to 682.8)	Shale: dark grey, platy, scattered carbonaceous plant impressions.
SHAUNAVON FORMATION	
Lower Member	
2240.0 to 2246.0 (682.8 to 684.6)	Calclutite: tan, hard, slightly argillaceous (0.25 m present).
2246.0 to 2248.0 (684.6 to 685.2)	Shale: medium green grey and grey green, variably calcareous; sharp contact.
2248.0 to 2250.0 (685.2 to 685.8)	Limestone: tan, microcrystalline, subordinate very fine grained, quartzose sand; scattered light grey oolites; some layers include abundant pelecypod shells; joint in upper half is pyrite infilled.
GRAVELBOURG FORMATION	
Upper Member	
2250.0 to 2251.0 (685.8 to 686.1)	Shale: dark grey and green grey.
2251.0 to 2260.0 (686.1 to 688.8)	Sandstone: quartzose, very fine grained, well sorted, well cemented with calcite at top, light grey, argillaceous below; interbedded with calcareous, argillaceous siltstone and silty shale, green grey and dark grey.
2260.0 to 2266.5 (688.8 to 690.8)	Shale: dark green grey, noncalcareous, waxy; some layers include abundant carbonaceous plant fragments.
2266.5 to 2270.0 (690.8 to 691.9)	Mudstone: dolomitic, light green grey, hard, platy.
2270.0 to 2295.0 (691.9 to 699.5)	Sandstone: quartzose, light grey, weakly; indurated, fine grained, well sorted, cross-bedded; scattered carbonaceous laminae, abundant muscovite, scattered glauconite; interbedded with grit of quartz, plant fragments, green mudstone and green shale below 677.7 m.
2295.0 to 2298.0 (699.5 to 700.4)	Sandstone: quartzose, fine grained, well sorted, grey white, calcite cemented; scattered partings of light green shale.
2298.0 to 2325.0 (700.4 to 708.7)	Shale: silty and argillaceous sandstone, grey black, platy, hard; subordinate lenticles and pods of dark grey, very fine grained, quartzose sandstone; minor laminae aggregates of coaly detritus; medium-grained quartzose sandstone, argillaceous, scattered black

carbonaceous shale partings and abundant coarse grains of muscovite at 706.8 to 708.1 m; sharp contact.

Lower Member

2325.0 to 2328.0 (708.7 to 709.6)	Oolite: medium grained, quartz nucleated; grades downward into sandstone, quartzose, fine-grained and thin siltstone; calcite cemented throughout, fine-bedded over lower half, medium grey tan; scattered thin beds (3 cm) of laminated, bituminous, calcareous shale and siltstone; dense, dark brown cryptocrystalline dolomite bed, 0.07 m thick, at base.
2328.0 to 2336.5 (709.6 to 712.2)	Shale: grey black, bituminous; laminated with subordinate light grey silt; interbedded with tan-grey argillaceous dolomite laminated with subordinate shale.
2336.5 to 2342.0 (712.2 to 713.8)	Shale: dark grey, calcareous, abundant papery thin pelecypod shell fragments; beds about 0.3 m thick of cryptocrystalline limestone at 712.3 m.
2342.0 to 2344.5 (713.8 to 714.6)	Dolomite: argillaceous, grey tan, massive, hard.
2344.5 to 2354.0 (714.6 to 717.5)	Shale: as at 712.2 to 713.8 m; interbedded with limestone, calcilitic, argillaceous, grey tan, 0.3 m thick, at intervals of 0.6 m.
2354.0 to 2359.0 (717.5 to 719.0)	Shale: dark grey and olive, glauconitic, calcareous, abundant thin pelecypod shell fragments. Thin basal green, glauconitic, fine-grained, quartzose sandstone at base.

WATROUS FORMATION

Upper Member

2359.0 to 2365.0 (719.0 to 720.9)	Dolomite: microcrystalline, light grey, dense, minor vugs filled with green and red claystone and white anhydrite.
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Tide Water Bryce Lake Crown No. 1 (1-14-25-16W2)

KB 2169 feet (661.1 m)

Depth in feet (m)	SUCCESS FORMATION (sequenced as follows, thickness uncertain, rec. 2.3 m)
2240.0 to 2268.0 (682.8 to 691.3)	a) Sandstone: quartzose, fine grained, well sorted; abundant white kaolinite grains, black carbonaceous grains, scattered green glauconite and red sphaerosiderite; permeable, weakly indurated with white kaolinite; speckled black and white. b) Shale: medium grey, platy, hard, muscovite-flecked, noncalcareous. c) Sandstone: as at (a), includes layers of medium-grained sandstone. d) Shale as at (b).
2268.0 to 2295.0 (691.3 to 699.5)	a) Sandstone: quartzose, medium grained, subrounded and subangular; minor iron-rusted grains (siderites), abundant green glauconite; moderately indurated in rust-stained kaolinite. (Rock may be basal portion of a finer grained unit; only a few inches are present.) b) Shale: medium grey, platy, noncalcareous. c) Sandstone: quartzose, medium grained, well sorted; subordinate dark grey and black chert, white kaolinized feldspar and kaolinite grains; weak cementation, very permeable; truncational cross-sets 0.07 m thick at angles of 15° or so. d) Shale: as at (b). e) Sandstone: quartzose, fine grained, (mangled into shale at base of section).
	GRAVELBOURG FORMATION
2295.0 to 2297.0 (699.5 to 700.1)	Mudstone: dense, anhydritic and siliceous; dark grey variegated with red.

California Standard Ratner 1-15	(1-15-48-17W2)	KB 1425 feet (434.3 m)
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Depth in feet (m)	SUCCESS FORMATION
1059.0 to 1098.5 (322.8 to 334.8)	Sandstone: quartzose, very fine and fine grained, argillaceous, calcareous, variegated light grey green and red; bedding is broken, stretched and microdeformed, but originally interbedded with ripple drift, cross-laminated and perhaps flasered beds; lenticles of medium- and coarse-grained quartzose sand grains at 330.4 to 331.0 m; includes rare kaolinite grains; matrix highly kaolinitic; colouration appears to be liesegang, although deeper reds are associated with mudstone, cream colour with calcareous cemented sandstone and green with calcareous mudstone; scattered burrows, some pyritic basal conglomerate includes fragments of the underlying formation.
	SOURIS RIVER FORMATION
1098.5 to 1129.0 (334.8 to 344.1)	Limestone: dense, cryptocrystalline, light grey and cream; lateral solution joints, oblique fractures, and breccia partially cemented with calcite druse.

Tide Water Southey Cr. No. 1	(4-29-22-18W2)	KB 1842 feet (561.4 m)
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Depth in feet (m)	CANTUAR FORMATION Cummings Member
2070.0 to 2084.0 (630.9 to 635.2)	Shale: dark grey, blocky, scattered carbonaceous flakes and brown ironstone nodules, abundant muscovite; at top pebble-size nodule of very fine grained quartzose sandstone with dark emerald green, resinous glauconitic matrix. Traces of green glauconitic clayey bodies below; also in burrow at 630.9 m (3 m of core recovered, but mangled).
	Dina Member Unit 3 Bedding Cycle 2 (10.7 m)
2084.0 to 2085.0 (635.2 to 635.5)	Mudstone: dark grey, silty to sandy, moderately indurated, many brown sideritic nodular and streaky bands.
2085.0 to 2105.0 (635.5 to 641.6)	Sandstone: quartzose, very fine grained, well sorted, weakly indurated, very permeable, light grey to white, subrounded to subangular; abundant chalcedonic quartz, black carbonaceous grains, patchy iron stains; scattered crenulated fine bedding with coaly laminae.
2105.0 to 2119.0 (641.6 to 645.9)	Sandstone: quartzose, fine to medium grained, variably sorted, kaolinite indurated, brown iron stained; scattered cemented aggregates with minor white kaolinite grains.
2119.0 to 2123.0 (645.9 to 647.1)	Sandstone: quartzose, medium grey and brown speckled, well cemented with calcite; subordinate coarse-grained sphaerosiderite, fine, white kaolinite grains, very fine grained black chert, black carbonaceous grains and coarse flakes; scattered black carbonaceous-argillaceous partings.
2123.0 to 2140.0 (647.1 to 652.3)	Sandstone: quartzose, medium grained, well sorted, weakly indurated, slightly argillaceous; subordinate kaolinite, black chert and coal grains; speckled white and light grey; scattered medium grey argillaceous laminae; patches of yellow-brown iron stains at 649.2 to 650.4 m, and crenulated coaly laminae.
2140.0 to 2149.0 (652.3 to 655.0)	Sandstone: quartzose, fine grained, well sorted, subrounded and rounded; weakly indurated to moderately indurated in red-grey argillaceous matrix; abundant pink quartz, grey chert, black chert, white kaolinite, green clay, pyrite-cemented sandy bodies. Interbedded with laminated very fine grained sandstone and dark grey shale.
2149.0 to 2169.0 (655.0 to 661.1)	Shale: dark grey, hard, platy; minor thin white, fine- and very fine grained quartzose sandstone, and sandstone laminated with dark grey shale; scattered pyrite-cemented sandy nodules.

SHAUNAVON FORMATION

Upper Member

2169.0 to 2171.0 (661.1 to 661.7)	Sandstone: quartzose, very fine grained, argillaceous, calcareous, well indurated; abundant muscovite, medium grey, abundant large pelecypod shells, strongly bioturbated.
2171.0 to 2178.0 (661.7 to 663.9)	Sandstone: quartzose, very fine grained, argillaceous, moderately indurated; variably laminated with dark grey shale, scattered glauconite-filled burrows; sharp contact.
2178.0 to 2179.0 (663.9 to 664.2)	Sandstone: quartzose, very fine grained, silty, very calcareous, well indurated, very fossiliferous (pelecypod), subordinate oolite; interbedded with oolitic-bioclastic, quartzose sandy lenticles; red grey.
2179.0 to 2179.5 (664.2 to 664.3)	Limestone: calcilititic to microcrystalline tan, hard, abundant pelecypods.
2179.5 to 2185.0 (664.3 to 666.0)	Sandstone: quartzose, very fine grained to silty, argillaceous, calcareous; abundant large vertical burrows (2 to 7 cm deep), dark grey; abundant muscovite.
2185.0 to 2187.0 (666.0 to 666.6)	Limestone: microcrystalline, argillaceous, medium blue grey, dense, abundant pelecypods.
2187.0 to 2200.0 (666.6 to 670.6)	Calcilutite: tan, hard, abundant, small pelecypods.
2200.0 to 2220.0 (670.6 to 676.7)	Sandstone: quartzose, fine grained, very argillaceous, medium grey, friable, abundant muscovite; interbedded with laminated medium grey, quartzose very fine grained sandstone and dark grey shale; latter includes layers of crushed pelecypods and brown bitumen; grades into
2220.0 to 2221.0 (676.7 to 677.0)	Shale: grey black, waxy; subordinate, silty laminae.
2221.0 to 2227.0 (677.0 to 678.8)	Limestone: tan grey, argillaceous to silty, hard, platy; grades into well cemented, marly, very fine grained, quartzose sandstone, with irregular partings lined with coaly blebs, fish teeth, grey green claystone fragments, and crenulated coarse laminae of sandstone.
2227.0 to 2231.0 (678.8 to 680.0)	Shale: noncalcareous, hard, platy, medium green grey.
2231.0 to 2234.0 (680.0 to 680.9)	Sandstone: quartzose, very fine grained, well sorted, subangular and subrounded; scattered black and grey chert, rare rose quartz and muscovite; light grey, weakly indurated, very permeable, argillaceous content increases downward.
2234.0 to 2235.0 (680.9 to 681.2)	Shale: medium green grey, blocky, noncalcareous; grades into
2235.0 to 2236.0 (681.2 to 681.5)	Sandstone: quartzose, very fine grained to silty, tan grey, hard, argillaceous dolomitic matrix; contorted bedding marked by argillaceous laminae.

GRAVELBOURG FORMATION

Upper Member

2236.0 to 2245.0 (681.5 to 684.3)	Shale: dark grey, waxy, very calcareous, limonite yellow; grades into argillaceous sandstone downward.
2245.0 to 2257.0 (684.3 to 687.9)	Sandstone: quartzose, fine grained, well sorted, weak argillaceous matrix, light grey, permeable, abundant muscovite.
2257.0 to 2259.0 (687.9 to 688.5)	Sandstone: quartzose, very fine grained, dark grey and grey black argillaceous matrix; carbonaceous with abundant plant detritus on bedding; weak current-laminae, moderately indurated.

2259.0 to 2272.0
(688.5 to 692.5) Sandstone: quartzose, fine grained, well sorted, weak argillaceous matrix, medium grey, abundant muscovite; minor laminae and thin interbeds of dark grey, argillaceous and carbonaceous sandy mudstone.

2272.0 to 2279.0*
(692.5 to 694.6) Shale: grey black, silty, abundant muscovite, abundant laminae of light grey siltstone.

Lower Member

2279.0 to 2291.0
(694.6 to 698.3) Limestone: coquinoid, well cemented, light blue grey; thinly bedded with subordinate tan, cryptocrystalline limestone; thin interbeds of argillaceous glauconitic limestone near base.

2291.0 to 2309.0
(698.3 to 703.8) Calcilutite: argillaceous, medium tan grey, platy, hard.

2309.0 to 2315.0
(703.8 to 705.6) Shale: marly to very calcareous, medium yellowish grey grading downward to dark green grey mottled with grey black; abundant thin shelled pelecypods over upper half.

2315.0 to 2317.0
(705.6 to 706.2) Dolomite: argillaceous, light greenish tan, hard, blocky; veined with grey black pyrite infiltrated dolomite at top.

2317.0 to 2322.0
(706.2 to 707.7) Shale: grey black, interbedded with shale, glauconitic, olive and waxy, noncalcareous.

2322.0 to 2326.0
(707.7 to 709.0) Dolomite: tan, cryptocrystalline, minor stylolitic parting of bright green glauconitic shale.

WATROUS FORMATION

Upper Member

2326.0 to 2357.0
(709.0 to 718.4) Anhydrite: dense, microcrystalline, medium translucent grey; minor thin beds (0.02 to 0.05 m) of tan, cryptocrystalline dolomite; white powdery gypsum at 712.6 and 716.3 m.

2357.0 to 2360.5
(718.4 to 719.5) Shale: dark grey, noncalcareous, waxy, subordinate nodules, grains and stringers of white gypsum.

2360.5 to 2371.5
(719.5 to 722.8) Anhydrite: medium translucent grey, dense; chicken wire texture with incipient nodular; stylolitic; minor clay partings and stringers; thin (0.02 to 0.03 m) beds of tan, cryptocrystalline bituminous dolomite below 721.9 m at intervals of 0.30 m.

2371.5 to 2393.5
(722.8 to 729.4) Dolomite: tan, cryptocrystalline bituminous; irregular laminae of dark brown bituminous dolomitic shale; scattered layers of nodular anhydrite; mostly anhydrite at 724.2 to 725.2 m.

2393.5 to 2401.0
(729.4 to 731.8) Gypsum: white, powdery, interbedded and intermixed with dark grey shale, noncalcareous.

2401.0 to 2413.0
(731.8 to 735.5) Mudstone: dark grey, dolomitic, hard, platy; scattered layers of dissolution breccia; minor nodular anhydrite beds over lower half.

2413.0 to 2428.5
(735.5 to 740.2) Anhydrite: medium translucent grey, dense, chicken wire texture, also dissolution brecciated; dark red grey anhydritic shale bed at 739.1 to 739.7 m.

Lower Member

2428.5 to 2448.0
(740.2 to 746.2) Mudstone: brown red, minor very fine grained quartzose sandstone; well indurated, faintly bedded; scattered anhydrite nodules and veins.

2448.0 to 2453.0
(746.2 to 747.7) Anhydrite: as at 735.5 m; basal dissolution breccia of white siliceous dolomite and grey-green shale.

MADISON FORMATION

2453.0 to 2500.0
(747.7 to 762.0)

Dolostone: white, dense, microcrystalline, siliceous; irregularly distributed chert nodules, and veinlets of coarse, crystalline anhydrite.

* E log reading

Choceland No. 1 Choice DD 13-3-50-18(W2)

KB 1381 feet (420.9 m)

Depth in feet (m)

JOLI FOU FORMATION

495.0 to 511.5
(150.9 to 155.9)

Mudstone: dark grey, platy, hard; abundant flasers and bedding trails of fine-grained, glauconitic, green quartzose, sandstone.

511.5 to 518.0
(155.9 to 157.9)

Mudstone: grey black, platy, hard; traces of bedding-aligned, green, glauconitic sand-filled burrows.

Spinney Hill Sandstone

518.0 to 534.5
(157.9 to 162.9)

Mudstone: as at 155.9 m; interbedded with green glauconitic, cherty, quartzose sandy beds, and diastemic, white, calcite-cemented, argillaceous, pyritic, fine-grained, quartzose sandstones, 0.16 to 0.33 m thick at 0.6 m intervals; coaly tree fragment at 157.94 m; phosphatic conglomerates at 162.1 m; sharp irregular contact.

PENSE FORMATION

Unit 2 *Bedding Cycle 3 (0.5 m)*

534.5 to 536.0
(162.9 to 163.4)

Sandstone: quartzose, very fine grained, subordinate siltstone, dark grey argillaceous matrix, earthy, bioturbated; sharp, irregular contact.

Bedding Cycle 2 (1.6 m)

536.0 to 537.5
(163.4 to 163.8)

Mudstone: grey black, hard.

537.5 to 541.5
(163.8 to 165.0)

Sandstone: as at 162.9 m; brown sideritic mudstone bed at 164.0 m; sharp irregular contact.

Unit 1 *Bedding Cycle 1 (4.0 m)*

541.5 to 547.5
(165.0 to 166.9)

Mudstone: massive, earthy, medium grey; abundant sideritic pebble size, brown concretionary nodules; quartzose sandstone increases downward; abundant muscovite.

547.5 to 548.0
(166.9 to 167.0)

Sandstone: quartzose to lithic; subordinate mudstone grit; weakly cemented with siderite (yellow grey) and mudstone; matrix includes partially leached quartz-nucleated clay oolite; very permeable and friable.

548.0 to 554.5
(167.0 to 169.0)

Mudstone: clayey, massive, medium grey; abundant near vertical fractures; scattered irregular, carbonaceous partings, black carbonaceous bed, 0.1 m thick, at base; sharp, irregular contact.

CANTUAR FORMATION

Waseca Member

Bedding Cycle 7 (6.7 m)

554.5 to 556.0
(169.0 to 169.5)

Sandstone: quartzose, very fine grained, argillaceous, weakly indurated, brownish grey (Rec. 30%).

556.0 to 562.5
(169.5 to 171.5)

Mudstone: clayey, massive, medium to light grey mottled with hematitic red and limonitic yellow; speckled with sphaerosiderite and sphaerolimonite at the top; abundant crenulated carbonaceous films throughout; grades into

- 562.5 to 565.0
(171.5 to 172.2) Sandstone: quartzose, very fine grained, argillaceous, light grey, earthy, abundant to minor (15%) broken, contorted bodies of fine-grained, argillaceous, quartzose, friable, brownish grey, fine-bedded sandstone.
- 565.0 to 576.5
(172.2 to 175.7) Sandstone: quartzose, fine grained, subangular and subrounded, well sorted; abundant carbonaceous grains, moderately indurated; laminated with argillaceous very fine grained quartzose sandstone at 172.8 m, bioturbated with oblique burrow casts at 173.4 m; thick bedded below as delineated by darker argillaceous layers; sharp contact marked by grey black mudstone laminae.

Unit 6 Bedding Cycle 6 (2.5 m)

- 576.5 to 580.0
(175.7 to 176.8) Sandstone: quartzose, fine grained, decreased downward to very fine, ca. 15% black, carbonaceous grains, medium-grained brown sphaerosiderite and white kaolinite; calcite cemented, light grey; weakly cross-bedded; over upper 0.15 m, siderites are oxidized to brown-yellow limonites; grades into
- 580.0 to 583.5
(176.8 to 177.9) Sandstone: quartzose, very fine grained, argillaceous, laminated on low-angle cross-bedding with carbonaceous mudstones; argillaceous component increases downward, along with colour change from medium grey to dark grey.
- 583.5 to 584.5
(177.9 to 178.2) Mudstone: grey black, subordinate flasers of light grey, very fine grained, quartzose sandstone; sharp irregular contact.

Unit 4 Bedding Cycle 5 (7.6 m)

- 584.5 to 600.0
(178.2 to 182.9) Sandstone: quartzose, fine grained, well sorted, weakly indurated, very permeable; accessory black carbonaceous specks; minor thin, ripple-drift laminated beds of sandstone and siltstone; grades into
- 600.0 to 609.5
(182.9 to 185.8) Mudstone: dark grey; subordinate medium grey, very fine grained quartzose sandy flasers, bioturbation pods and trails; argillaceous content increases downward; sharp contact.

Unit 3 Bedding Cycle 4 (2.6 m)

- 609.5 to 613.0
(185.8 to 186.8) Sandstone: quartzose, fine grained to silty, poorly sorted, argillaceous matrix, light grey, earthy, massive; abundant vertical root casts and molds and ramose filaments.
- 613.0 to 615.0
(186.8 to 187.5) Shale: black, carbonaceous, abundant irregular coaly laminae.
- 615.0 to 618.0
(187.5 to 188.4) Sandstone: quartzose, fine grained, moderately indurated with argillaceous quartzose silt, bioturbated; interbedded irregular laminae of sand and coal dust; earthy, permeable.

Bedding Cycle 3 (1.8 m)

- 618.0 to 619.0
(188.4 to 188.7) Sandstone: quartzose, medium grained, well sorted, subrounded and rounded; calcite cemented at grain contacts, moderately permeable; faint low-angle cross-bedding outlined by thin coaly placers and carbonaceous dust.
- 619.0 to 621.5
(188.7 to 189.4) Sandstone: quartzose, very fine grained, light grey; intermixed with mudstone, quartzose, silty, medium grey, strongly bioturbated.
- 621.5 to 624.0
(189.4 to 190.2) Siltstone: argillaceous, medium grey, faintly bedded; scattered coaly lenticles, abundant muscovite; sharp, undulatory contact under conglomerate of brown sideritic concretions.

Unit 2 Bedding Cycle 2 (3.0 m)

- 624.0 to 634.0
(190.2 to 193.2) Mudstone: dark grey, clayey; faintly bedded as indicated by brown siderite bands and coal lenticles and compressed tree fragments; scattered cut-and-fill bedding; sharp irregular contact.

Unit 1 *Bedding Cycle 1 (1.4 m)*

634.0 to 638.5
(193.2 to 194.6) Sandstone: quartzose, medium grained, well sorted, faceted on subrounded grains; abundant black chert and kaolinite grains; calcite cemented, medium grey, moderately friable and permeable; sharp erosional contact.

**Sparky Member
*Bedding Cycle 3 (3.5 m)***

638.5 to 650.0
(194.6 to 198.1) Mudstone: dark grey, faintly bedded, contorted; massive beds alternate with laminated mudstones and quartzose siltstones; abundant coaly fragments above 195.1 m; sideritic concretionary nodules and iron stains scattered throughout; sharp contact.

Bedding Cycle 2 (4.7 m)

650.0 to 655.5
(198.1 to 199.8) Sandstone: quartzose, fine grained, subordinate fine; medium grey; laminated with dark grey, silty mudstone; abundant muscovite; mildly contorted; grades into

655.5 to 665.5
(199.8 to 202.8) Mudstone: dark grey, silty, carbonaceous laminae traces, mildly contorted; interbedded with laminated, quartzose sandstone, fine grained, carbonaceous, medium grey and black; weak bedding flexures; sharp contact.

Bedding Cycle 1 (1.9 m)

665.5 to 669.0
(202.8 to 203.9) Sandstone: as at 198.1 m

669.0 to 671.5
(203.9 to 204.7) Mudstone: as at 199.8 m; sharp, irregular contact sloping 15°.

**General Petroleums Member
*Bedding Cycle 3 (2.1 m)***

671.5 to 672.5
(204.7 to 205.0) Sandstone: quartzose, fine grained, very argillaceous, dark grey, abundant brown, sideritic concretionary nodules; strongly contorted with flame and diapiric fabric; sharp contact.

672.5 to 677.0
(205.0 to 206.3) Sandstone: as at 198.1 m; grades into

677.0 to 678.5
(206.3 to 206.8) Mudstone: as at 199.8 m; grades into

Bedding Cycle 2 (1.7 m)

678.5 to 684.0
(206.8 to 208.5) Sandstone: quartzose, fine grained, very argillaceous, abundant muscovite, dark grey; faint bedding outlined by brown limonitic-sideritic stains; interbedded with ca. 20% mudstone; argillaceous content increases downward; sharp erosional contact.

Bedding Cycle 1 (2.6 m)

684.0 to 688.0
(208.5 to 209.7) Sandstone: quartzose, fine grained, argillaceous, medium grey, abundant muscovite; laminated with dark grey sandy mudstone mottled by brown siderite and limonite; microfaulted at 209.4 m; grades into

688.0 to 692.5
(209.7 to 211.1) Mudstone: clayey to silty, dark grey, faintly laminated with light grey, very fine grained quartzose sandstone; bedding aligned fractures dip about 10° sharp irregular contact.

**Rex Member
*Bedding Cycle 4 (1.3 m)***

692.5 to 694.0
(211.1 to 211.5) Sandstone: quartzose, fine grained, medium grey, well sorted, abundant carbonaceous grains, friable, weakly cemented, trough cross-bedded; grades into

694.0 to 697.0 (211.5 to 212.4)	Sandstone: quartzose, very fine grained, very argillaceous, dark grey, scattered brown sideritic concretions, abundant carbonaceous specks.
	<i>Bedding Cycle 3 (1.5 m)</i>
697.0 to 699.5 (212.4 to 213.2)	Sandstone: quartzose, very fine grained, very argillaceous, grades into argillaceous sandstone as at 211.1 m.
669.5 to 702.0 (213.2 to 214.0)	Sandstone: as at 211.5 m.
	<i>Bedding Cycle 2 (1.0 m)</i>
702.0 to 705.5 (214.0 to 215.0)	Sandstone: quartzose, fine grained, grading into massive, silty dark grey mudstone; abundant blebs, stringers and lenticles of brown sideritic mudstone; weakly contorted; sheared and faulted at base.
	<i>Bedding Cycle 1 (8.1 m)</i>
705.5 to 710.0 (215.0 to 216.4)	Sandstone: quartzose, very fine grained, very argillaceous, faintly interbedded with mudstone; dark grey mottled with scattered brown limonitic-sideritic nodules.
710.0 to 727.0 (216.4 to 221.6)	Sandstone: quartzose, very fine grained, light grey, abundant muscovite; laminated with dark grey shale (mostly lost).
727.0 to 732.0 (221.6 to 223.1)	Sandstone: quartzose, fine grained, well sorted, subrounded; abundant rounded medium-grained quartz, and black, carbonaceous grains; scattered lenticles of carbonaceous detritus; well cemented with calcite; low to moderate permeability; microfaulted at 221.6 m; sharp irregular contact.
	Lloydminster Member
	<i>Bedding Cycle 5 (0.5 m)</i>
732.0 to 733.5 (223.1 to 223.6)	Sandstone: quartzose, very fine grained, argillaceous, medium grey; laminated with silty, dark grey mudstone and downward, grey-black mudstone; scattered brown siderite nodules; contorted and balled near base; sharp irregular contact.
	<i>Bedding Cycle 4 (0.4 m)</i>
733.5 to 735.0 (223.6 to 224.0)	Sandstone: quartzose, fine grained, light grey, well sorted, subrounded; ca. 10% coaly flakes decreasing to abundant downward; scattered brown sideritic nodules; flat-bedded to massive; well cemented with calcite; sharp irregular contact.
	<i>Bedding Cycle 3 (6.0 m)</i>
735.0 to 754.5 (224.0 to 230.0)	Sandstone: quartzose, fine grained to very fine downward, massive; sharp irregular contact.
	<i>Bedding Cycle 2 (1.2 m)</i>
754.5 to 758.5 (230.0 to 231.2)	Mudstone: clayey, dark grey, massive; glauconitic druse, haloes, nodules, blebs and stringers scattered throughout; sharp irregular contact.
	<i>Bedding Cycle 1 (4.6 m)</i>
758.5 to 773.5 (231.2 to 235.8)	Mudstone: as at 230.0 m; becomes quartzose, siltier and sandier downward by laminated layers and thin interbeds; sandstone at 233.0 m is bioturbated and microfaulted; sharp irregular contact.

Cummings Member
Bedding Cycle 1 (3.8 m)

773.5 to 784.5 (235.8 to 239.1)	Sandstone: quartzose, fine grained, well sorted, well cemented with calcite, light grey; moderately cemented and permeable below 236.7 m; abundant pebbles and boulders of medium grey mudstone and pyritic ironstones above 236.8 m; sharp irregular contact.
784.5 to 786.0 (239.1 to 239.6)	Mudstone: sandy, dark grey and light grey, bioturbated (mostly bedding aligned sandstone pods); sharp erosional contact.

Dina Member
Unit 3 Bedding Cycle 3 (5.2 m)

786.0 to 787.0 (239.6 to 239.9)	Sandstone: quartzose, fine grained, well sorted, cemented with calcite, light grey.
787.0 to 803.0 (239.9 to 244.8)	No recovery.

Unit 2 Bedding Cycle 2 (14.9 m)

803.0 to 836.0 (244.8 to 254.8)	Sand: quartzose, fine grained, well sorted (recovery mostly lost).
836.0 to 849.0 (254.8 to 258.8)	Sandstone: quartzose, fine grained, well sorted, abundant dark grey lithic grains, black chert, rose quartz; subrounded and rounded (0.8 m recovered).
849.0 to 852.0 (258.8 to 259.7)	No recovery.

Unit 1 Bedding Cycle 1 (6.4 m)

852.0 to 856.0 (259.7 to 260.9)	Mudstone: silty to sandy, well indurated, abundant distorted claystone pebbles and boulders, dark grey to grey black (recovery 0.5 m).
856.0 to 871.0 (260.9 to 265.5)	No recovery.
871.0 to 873.0 (265.5 to 266.1)	Sandstone: quartzose, fine to medium grained, well sorted, subrounded and rounded; abundant pyrite crystals and kaolinite; scattered black chert; fine bedded with scattered beds laminated with carbonaceous detritus, medium blue grey; well cemented with calcite; planar dips throughout; basal conglomerate of chalcedonic pebbles, white Madison chert, lignitic mudstone, silicified concretions and lignite, quartz grains coated with pyrite; contact sharp and erosional, slopes 20° on the upper Devonian Souris River Formation.

H B Shell Avonlea 11-7-11-21(W2)

KB 2058 feet (627.3 m)

Depth in feet (m)	CANTUAR FORMATION Lloydminster Member
2990.0 to 2992.0 (911.4 to 912.0)	Shale: medium green grey, clayey, waxy.
2992.0 to 2999.0 (912.0 to 914.1)	No core.
2999.0 to 3001.0 (914.1 to 914.7)	Siltstone: quartzose, ripple and small-scale current bedded, medium green grey laminated with dark green grey shale.

3001.0 to 3025.0 (914.7 to 922.0)	Sandstone: quartzose, very fine grained, well sorted, light grey to greyish white, silica grain-contact cemented, channelled and cross-bedded; subordinate pebble and cobble size conglomerates of dark grey sandstone, siliceous mudstone and brown ironstone.
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H B et al Avonlea 13-29	(13-29-11-21W2)	KB 2019 feet (615.4 m)
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Depth in feet (m)	CANTUAR FORMATION Lloydminster Member <i>Bedding Cycle 3 (9.2 m)</i>
2960.0 to 2974.0 (902.2 to 906.5)	Sandstone: quartzose, very fine grained, argillaceous matrix, medium grey, trough cross-bedded, well indurated, abundant carbonized plant fragments; grades into
2974.0 to 2984.0 (906.5 to 909.5)	Mudstone: medium green grey, platy, well indurated, abundant carbonaceous specks, muscovite; grades into
2984.0 to 2990.0 (909.5 to 911.4)	Shale: dark green gray intermixed with grey black, clayey.
	<i>Bedding Cycle 2 (1.2 m)</i>
2990.0 to 2991.0 (911.4 to 911.7)	Shale: light green grey grading downward into argillaceous siltstone, light green grey; grades into
2991.0 to 2994.0 ⁺ (911.7 to 912.6)	Shale: grey black, clayey, waxy, and black, carbonaceous.
	<i>Bedding Cycle 1 (7.3 m)</i>
2994.0 ⁺ to 3003.0 (912.6 to 915.3)	Shale: olive, waxy, weakly indurated.
3003.0 to 3018.0 (915.3 to 919.9)	Shale: black carbonaceous, grading into dark grey.
	RIERDON FORMATION
3018.0 to 3039.0 (919.9 to 926.3)	Shale: bright green grey, hard, chippy, grading below 920.8 m into medium grey; thin, grading below 920.8 m into medium grey; thin, calcite-cemented, finely cross-bedded light grey siltstone at 921.4 m.

⁺ approximate

Shell Dahinda No. 1	(6-2-9-23W2)	KB 2424 feet (738.8 m)
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Depth in feet (m)	PENSE FORMATION
3370.0 to 3375.0 (1027.2 to 1028.7)	Sandstone: quartzose, very fine grained, medium grey, very argillaceous; abundant muscovite, glauconite; subordinate crenulated partings of grey black, muscovite-flecked shale.
3375.0 to 3378.0 (1028.7 to 1029.6)	Sandstone: quartzose, very fine grained, light grey, calcite cemented, podded, rolled, and flasered; abundant muscovite; glauconite, carbonaceous specks; well indurated in subordinate grey black argillaceous, quartzose sandstone.
3378.0 to 3388.0 (1029.6 to 1032.7)	Sandstone: quartzose, very fine grained, argillaceous, grey black, well indurated; subordinate flasers of light grey, calcareous sandstone above.

3388.0 to 3398.6 (1032.7 to 1035.9)	Mudstone: black, carbonaceous; minor to subordinate lenticles, rolls, and flasers of light grey, calcite cemented, very fine grained, quartzose sandstone, with abundant, glauconite, muscovite and biotite (brown); abundant truncating sandstone laminae over basal 1 m.
3398.6 to 3400.0 (1035.9 to 1036.3)	Shale: black, carbonaceous; thin, green, silty, glauconitic lens below 1036 m.
3400.0 to 3403.0 (1036.3 to 1037.2)	Mudstone: grey black, silty; dark brown siderite indurated layer at top.
3403.0 to 3413.0 (1037.2 to 1040.3)	Mudstone: very silty, grey black, minor; very fine grained, quartzose sandstone laminae, lenticles and flasers; abundant vertical to oblique burrow forms and finely disseminated muscovite; induration weak in mudstone, good in sandy layers.
3413.0 to 3418.0 (1040.3 to 1041.8)	Mudstone: silty, grey black, fine bedded, platy.
3418.0 to 3433.0 (1041.8 to 1046.4)	Shale: black, carbonaceous, papery.
3433.0 to 3437.0 (1046.4 to 1047.6)	Mudstone: black and grey black; subordinate rolls, flasers, lenticles, pods, pygmatic laminae and burrow fillings of light grey, very fine grained, quartzose, calcite-cemented sandstone; abundant muscovite and black carbonaceous specks; moderately indurated.
3437.0 to 3444.0 (1047.6 to 1049.7)	Mudstone: grey black, silty and platy; about 7% silty lenticles.

CANTUAR FORMATION

Waseca Member

3444.0 to 3450.0 (1049.7 to 1051.6)	Sandstone: quartzose, fine grained, subrounded, well sorted, abundant carbonaceous particles, faint irregular bedding; indurated in grey white, siliceous kaolinite.
3450.0 to 3479.0 (1051.6 to 1060.4)	Sandstone: quartzose, fine grained, subrounded, moderately sorted, bimodal; well indurated in grey white siliceous kaolinite, generally massive; abundant coarse grained sphaerosiderite at 1060.1 m; sharp irregular contact.
3479.0 to 3484.0 (1060.4 to 1061.9)	Sandstone: quartzose, very fine to fine grained, poorly sorted, subangular to subrounded, faintly bedded and intermixed with calcareous beds containing abundant coaly fragments ranging from 0.003 m to >0.025 m (core diameter); kaolinite indurated, grey white and medium grey; upper 0.6 m faulted with bedding dips of about 50°.
3484.0 to 3498.0 (1061.9 to 1066.2)	Sandstone: quartzose, very fine grained, kaolinite cemented; minutely ripple laminated with dark lavender-grey, argillaceous siltstone; interbedded at intervals of 0.02 to 0.03 m with dark grey argillaceous siltstone with subordinate lenticles, rolls and flasers of white sandstone; contorted and micro-faulted above 1064 m.
3498.0 to 3555.0 (1066.2 to 1083.6)	No core.

Rex Member

3555.0 to 3607.0 (1083.6 to 1099.4)	Sandstone: quartzose, medium and fine grained, well sorted, subrounded and rounded; bonded with ca. 10% white kaolinite partially infilling voids; very friable and permeable; abundant rose quartz, jasper, black chert and scattered tourmaline; speckled white or light grey. Lower half interbedded with sandstone laminated with minor coal on low-angle truncation cross-beds.
3607.0 to 3666.0 (1099.4 to 1117.4)	Sandstone: as above but coarse grained (loss very high).

Depth in feet (m)	JOLI FOU FORMATION
1432.0 to 1435.0 (436.5 to 437.4)	Shale: dark grey, platy, scattered pelecypod shells.
1435.0 to 1442.0 (437.4 to 439.5)	Shale: grey black, interbedded at 0.3 m intervals with thin (0.05 to 0.07 m) layers of light grey, calcite-cemented, bioturbated, very fine grained, quartzose sandstone and comminuted shell fragments; basal contacts of sandstone beds sharp and irregular; minor lenticles and flasers of glauconitic sandstone; rust brown silty ironstone bed (0.1 m thick) in middle of section.
1442.0 to 1448.0 (439.5 to 441.4)	Shale: dark grey, scattered carbonaceous specks, poorly fossiliferous; silty and bioturbated; at 440.7 m (8 cm) sharp, irregular contact.
	PENSE FORMATION (log pick 1438 feet (438.3 m)) <i>Bedding Cycle 5 (2.1 m)</i>
1448.0 to 1449.5 (441.4 to 441.8)	Sandstone: quartzose, very fine grained, light grey, calcite cemented, accessory glauconite; bedded with scoured contacts, but strongly bioturbated, minor dark grey, silty mudstone layers; erosional contact at base.
1449.5 to 1455.0 (441.8 to 443.5)	Mudstone: silty, grey black, bioturbated; subordinate thin layers and lenticles of light grey, weakly calcareous, argillaceous sandstone; basal dark grey, bioturbated, massive, argillaceous sandstone with traces of bedding fragments at 443.2 m.
	<i>Bedding Cycle 4 (1.8 m)</i>
1455.0 to 1456.0 (443.5 to 443.8)	Sandstone: quartzose, fine grained, channel and trough cross-bedded, white, calcite-cemented, sideritic and brown at base; erosional contact.
1456.0 to 1461.0 (443.8 to 445.3)	Shale: grey black, platy; minor increasing to subordinate lenticles, flasers, stringers, and pods of light grey, quartzose, very fine grained sandstone; bioturbation and boudinage increase downward.
	<i>Bedding Cycle 3 (1.8 m)</i>
1461.0 to 1465.0 (445.3 to 446.5)	Sandstone: quartzose, fine grained, white and calcite cemented at 445.3 m; medium grey below; bedding strongly podded, bioturbated and boudinaged; laminated with graded silty mudstone and black shale, increasing below 445.9 m.
1465.0 to 1467.0 (446.5 to 447.1)	Shale: black laminated with graded, grey white, calcite-cemented, quartzose sandstone and dark grey mudstone; bedding crenulated with weak boudinage; sharp contact.
	<i>Bedding Cycle 2 (5.5 m)</i>
1467.0 to 1468.5 (447.1 to 447.6)	Sandstone: quartzose, fine grained, argillaceous matrix, medium grey, moderately indurated, abundant carbonaceous specks; interbedded with thin argillaceous siltstone at intervals of 0.01 to 0.02 m; bedding contacts erosional; sharp basal contact.
1468.5 to 1476.0 (447.6 to 449.9)	Sandstone: quartzose, very fine grained, light grey intermixed with black mudstone; strongly bioturbated with retention of bedding alignments of sandstone lenticles and flasers; bedding is more pronounced with downward increase of black shale, and grading of sandstone laminae; abundant layers of glauconitic sandstone; some pyrite-cemented nodules.
1476.0 to 1485.0 (449.9 to 452.6)	Shale: black, hard, minor laminae of graded siltstone; scattered pyritic and glauconitic nodules near base; dark green grey, silty mudstone, 0.05 m thick at 452.3 m; sharp, irregular contact.

Bedding Cycle 1 (3.1 m)

1485.0 to 1486.0 (452.6 to 452.9)	Mudstone: montmorillonitic, calcite calcareous, dark grey, massive, pepper-corn exfoliation; at base white calcite-beef cone-in-cone structure, 0.03 m thick.
1486.0 to 1489.0 (452.9 to 453.8)	Shale: grey black, platy; minor fine laminae of graded, very fine grained, quartzose sandstone increasing downward.
1489.0 to 1495.0 (453.8 to 455.7)	Mudstone: silty, bioturbated, with some trough cut-and-fill sandy layering; dark grey and grey black; sharp, irregular contact.

CANTUAR FORMATION

Sparky Member

Bedding Cycle 1 (2.3 m)

1495.0 to 1496.0 (455.7 to 456.0)	Sandstone: quartzose, very fine grained, subordinate fine, grey-white clay matrix, abundant brown, coarse-grained sphaerosiderite, well indurated; massive or homogenized with traces of convolutions; upper 0.08 m rubble of siderite-cemented carbonized tree, mudstone and sandstone fragments.
1496.0 to 1500.5 (456.0 to 457.4)	Mudstone: intermixed with subordinate very fine grained, argillaceous, quartzose sandstone; lavender grey, massive, abundant medium-grained red-brown sphaerosiderites at 457.2 m; crisscrossed with slickensided microfaults; gradational contact.
1500.5 to 1502.5 (457.4 to 458.0)	Sandstone: quartzose, very fine grained, argillaceous, grey white; laminated with mudstone, lavender grey; bedding crenulated, attenuated and laterally distorted; abundant grit-size ironstone aggregates and green glauconitic partings at base; sharp contact.

General Petroleums Member

Bedding Cycle 2 (3.2 m)

1502.5 to 1509.0 (458.0 to 459.9)	Claystone: dark lavender grey, waxy, massive; microfaulted.
1509.0 to 1513.0 (459.9 to 461.2)	Mudstone: massive, lavender grey mottled with red; oblique microfaults; abundant red brown sphaerosiderite; large (>0.10 m long and 0.025 m wide) burrow fills at base; grades into

Bedding Cycle 1 (9.1 m)

1513.0 to 1516.0 (461.2 to 462.1)	Claystone: dark lavender grey, abundant coarse-grained sphaerosiderites; weakly carbonaceous at top.
1516.0 to 1543.0 (462.1 to 470.3)	Mudstone: medium grey, massive, mottled with red; well indurated, abundant coarse-grained, red brown sphaerosiderites. Below 464.5 m red mottling disappears through a yellow zone; intergradational clayey mudstone with coaly tree fragments at 466.3 and 467.9 m; though homogenized, evidence of burrowing (rootlet and animal) is visible in siltier beds; carbonized plant fragments and brown ironstones, 0.03 to 0.06 m thick, with sandy mudstone at 468.5 and 469.7 m; sharp contact.

Rex Member

Bedding Cycle 2 (3.7 m)

1543.0 to 1555.0 (470.3 to 474.0)	Sandstone: quartzose, very fine grained, subordinate siltstone and claystone, massive, well indurated, medium grey; irregularly bedded with siltstone, intensely bioturbated; abundant granules of carbonized plants, scattered glauconitic and pyritic patches. Plastically deformed throughout especially over basal 1 m; shear near base associated with injection of 0.01 m of underlying claystone.
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Bedding Cycle 1 (6.7 m)

1555.0 to 1577.0
(474.0 to 480.7)

Claystone: olive, waxy, broken and slickensided; scattered carbonized twigs on bedding surfaces; abundant glauconitic and pyritic masses (0.025 to 0.05 m by 0.015 m) in basal 1 m; claystone grades through mudstone into carbonaceous, dark grey claystone at 480.0 m; sharp contact on basal cemented siltstone.

Lloydminster Member

Bedding Cycle 4 (3.3 m)

1577.0 to 1588.0
(480.7 to 484.0)

Sandstone: quartzose, very fine grained, light grey, weakly cemented to unindurated; flat-bedded to low-angle current bedded, small-scale troughs and ripples; minor number of laminae are draped with black carbonaceous particles; upper, 0.3 m is silica and calcite cemented and includes nodular pyritic masses; basal contact sharp and irregular.

Bedding Cycle 3 (0.3 m)

1588.0 to 1598.0
(484.0 to 487.1)

Microfaulted interbedded black siltstone, and olivine claystone, as follows:
484.0 to 484.2 m: Claystone, black, carbonaceous, grading into carbonaceous mudstone.
484.2 to 484.3 m: Siltstone, quartzose, light grey, weakly indurated, massive; argillaceous and medium grey downwards; irregular basal contact under pyritic nodules.

Bedding Cycle 2 (2.8 m)

484.3 to 484.9 m: Claystone, black, well indurated, platy.
484.9 to 485.2 m: Siltstone, quartzose, dark grey, argillaceous, friable, moderately indurated.
485.2 to 486.3 m: Claystone, black, grading below 485.4 m into olive, laminated with reverse grading toward the base (silt and clay).
486.3 to 486.6 m: Siltstone as at 484.9 m.
486.6 to 487.1 m: Claystone, grey black and olive.

Bedding Cycle 1 (4.2 m)

1598.0 to 1602.5
(487.1 to 488.4)

Claystone: olive, scattered carbonized plant fragments, minor argillaceous siltstone stringers; contorted and sheared.

1602.5 to 1606.0
(488.4 to 489.5)

Mudstone: medium grey green, hard, platy; laminated with flamed and boudinaged quartzose sandstone, light grey, argillaceous, calcareous below 488.6 m; patches of red throughout; grades into

1606.0 to 1612.0
(489.5 to 491.3)

Mudstone: medium grey green and olive; red oxidation along siltstone laminae; glauconitic at 490.7 m; basal 0.15 m is black, carbonaceous to coaly.

Cummings Member

Bedding Cycle 2 (2.5 m)

1612.0 to 1620.0
(491.3 to 493.8)

Sandstone: quartzose, very fine grained, medium grey; flaggy with black shale partings at 491.6 m; some severe contortion and squeezing of sandy beds into more argillaceous beds; scattered pyrite cementation; calcite cemented, boudinaged laminae, 0.075 m thick, at 493.2 m.

Bedding Cycle 1 (8.8 m)

1620.0 to 1641.0
(493.8 to 500.2)

Mudstone: dark grey, hard, massive; microfaulted.

1641.0 to 1649.0
(500.2 to 502.6)

Mudstone: dark grey, massive; interbedded at 0.3 m intervals with sandstone: quartzose, very fine grained, low-angle and ripple cross-laminated, medium grey, argillaceous, sheared; sharp contact.

Dina Member
Bedding Cycle 3 (5.7 m)

1649.0 to 1658.0 (502.6 to 505.4)	Sandstone: quartzose, fine grained, well sorted, light grey, subrounded, abundant carbonaceous specks, kaolinite bonded grains; unindurated.
1658.0 to 1662.0 (505.4 to 506.6)	Sandstone: quartzose, grey white, medium grained with minor coarse and fine, moderately sorted, weak kaolinite matrix, abundant carbonaceous grains, muscovite; tabular cross-beds dip across the core at about 20°.
1662.0 to 1665.0 (506.6 to 507.5)	Sandstone: as at 502.6 m. Medial, thin (0.025 m) black, carbonaceous, argillaceous sandstone layer.
1665.0 to 1666.0 (507.5 to 507.8)	Sandstone: quartzose, very fine grained, argillaceous, tan, small-scale cross-laminated; subordinate black carbonaceous mudstone laminae increasing downward in thickness; lower half heavily burrowed.
1666.0 to 1667.5 (507.8 to 508.3)	Mudstone: silty, grey black strongly bioturbated.

Bedding Cycle 2 (3.2 m)

1667.5 to 1676.0 (508.3 to 510.8)	Sandstone: quartzose, very fine grained, subordinate very fine, increasing downward to sandstone, quartzose, fine grained, well sorted; kaolinite indurated with abundant coarse sphaerosiderite over 508.3 to 509.6 m; friable toward base.
1676.0 to 1678.0 (510.8 to 511.5)	Sandstone: quartzose, coarse grained, poorly sorted with medium and fine, buff; moderately indurated in argillaceous matrix, massive, friable; abundant kaolinite blebs and carbonaceous grains; sharp irregular contact.

Bedding Cycle 1 (4.2 m)

1678.0 to 1687.0 (511.5 to 514.2)	Sandstone: quartzose, fine grained, subordinate very fine; argillaceous matrix; abundant carbonized plant fragments aligned along bedding; coaly lenticles at 511.5 m; brownish dark grey with patches of black; irregularly bedded.
1687.0 to 1692.0 (514.2 to 515.7)	Conglomerate: olive sideritic mudstone, tan dolomite, dark grey shale in matrix, partially silica-cemented; include layers of coarse rhombohedral and trapezohedral quartz, white tripoli and kaolinite blooms, and carbonaceous plant debris toward base; sharp irregular contact.

WATROUS FORMATION

1692.0 to 1700.0 (515.7 to 518.2)	Dolomite: tan, cryptocrystalline, rubbly and stylolitic; green, clay lateral veins at 518.0 m.
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Alwinal Lanigan 3-28	(3-28-33-23W2)	KB 1765.6 feet
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Reference well for the Gravelbourg Formation and Lower Member of the Watrous Formation in central southern Saskatchewan.

Depth in feet (m)	JOLI FOU FORMATION (Spinney Hill equivalent)
1379.0 to 1396.0 (420.3 to 425.5)	Shale: olive to dark grey downward; about 15% medium olive grey, silty, current bedding; olive, calcite-cemented, coarse-grained, glauconitic, graded, quartzose siltstone at 0.6 m intervals; grades into
1396.0 to 1400.0 (425.5 to 426.7)	Mudstone: dark grey, platy; green, glauconitic, cross-bedded, very fine grained, quartzose sandstone over upper 0.6 m, grading below into olive green, glauconitic, silty lenticles in dark grey shale; grades into

1400.0 to 1411.0 (426.7 to 430.0)	Shale: as at 420.3 m (1379 feet); sharp contact.
1411.0 to 1411.7 (430.0 to 430.3)	Sandstone: quartzose, very fine grained, argillaceous, calcite cemented in part; abundant crenulated, calcitic, thin pelecypod shells; burrowed, green, glauconitic.
1411.7 to 1432.0 (430.3 to 436.5)	Shale: dark grey, splintery, scattered brown, aragonitic, small pelecypods shells; about 15% medium grey, silty lenticles decreasing downward to trace; sharp, irregular contact.
1432 to 1432.3 (436.5 to 436.6)	Siltstone: current bedded, siderite cemented, dense, brown.
1432.3 to 1433.0 (436.6 to 436.7)	Shale: grey black, fissile; silty and current bedded downward; sharp contact.
1433.0 to 1434.5 (436.7 to 437.2)	Sandstone: quartzose, very fine grained, calcite cemented, light grey, wavy bedded with dark grey shale draped laminae; abundant pyritic nodules; sharp, irregular contact.
1434.5 to 1436.0 (437.2 to 437.7)	Shale: grey black, fissile, sharp, irregular contact.

PENSE FORMATION

1436.0 to 1438.0 (437.7 to 438.3)	Mudstone: dark grey; subordinate light grey, fine grained, quartzose sand as component and thin lenticles; grades into
1438.0 to 1443.5 (438.3 to 440.0)	Sandstone: quartzose, fine grained, argillaceous, mottled light and dark grey, calcareous, moderate to well indurated, earthy, bioturbated (mostly feeding burrows, 1 to 4 mm diameter); sharp contact.
1443.5 to 1453.0 (440.0 to 442.9)	Sandstone: quartzose, fine grained, light grey, calcite-cemented centimetre-scale swaley cross-bedded with dark grey, argillaceous very fine grained sandstone below massive upper 0.05 m; abundant feeding burrows in the argillaceous beds; shale blackens downward, and below 1446 feet (440.7 m) sandstone features thin ripple laminae with shale drape; interbedded with decimetre-thick black shale below 1450 feet (442.0 m); sharp, irregular contact under basal black shale.
1453.0 to 1453.5 (442.9 to 443.0)	Sandstone: quartzose, very fine grained, dense, iron cemented, rusty brown, current bedded; sharp, basal contact.
1453.5 to 1457.8 (443.0 to 444.3)	Shale: black, minor ripple and current-bedded laminae and laminae (443.0 to 444.3 m) groups of light grey, very fine grained, quartzose sandstone; abundant feeding burrows; sharp, irregular contact.
1457.8 to 1458.3 (444.3 to 444.5)	Sandstone: as at 1453.0 feet (442.9 m).
1458.3 to 1463.5 (444.5 to 446.1)	Shale: as at 1453.5 feet (443.0 m); no bioturbation pods; sharp basal contact.
1463.5 to 1469.0 (446.1 to 447.8)	Siltstone: quartzose, argillaceous, medium grey; grades into black shaly mudstone laminated with subordinate current-bedded siltstone; below 1468 feet (447.4 m) siltstone is dense, argillaceous with trace of current bedding; sharp contact marked with pyritic nodules.

CANTUAR FORMATION SPARKY MEMBER

1469.0 to 1470.0 (447.8 to 448.1)	Sandstone: quartzose, fine grained, subordinate coarse-grained medium grey speckled with red brown siderite, silica cemented, irregularly bedded.
1470.0 to 1471.5 (448.1 to 448.5)	Mudstone: massive, medium grey; subordinate coarse-grained rusty brown sphaerosiderite increasing to 40% downward.

1471.5 to 1472.8 (448.5 to 448.9)	Claystone: platy, dark grey, sharp, irregular contact.
1472.8 to 1476.0 (448.9 to 450.0)	Sandstone: quartzose, very fine grained, medium grey, abundant muscovite; downward increasing dark grey shale laminae; strongly contorted decreasing downward to nearly flat bedded; sharp, irregular basal contact.
1476.0 to 1479.5 (450.0 to 451.0)	Sandstone: quartzose, very fine grained, well sorted, friable, abundant muscovite; about 7% sphaerosiderite over upper half; scattered concretionary nodular pyrite; sharp basal contact.
1479.5 to 1480.3 (451.0 to 451.2)	Sandstone: quartzose, very fine grained, well sorted, silica cemented, dense; about 20% coarse-grained sphaerosiderite; light grey speckled with brown, low-angle cross-bedded to flat current bedded; sharp, irregular basal contact.

General Petroleums Member

1480.3 to 1486.0 (451.2 to 452.9)	Claystone: waxy, dark grey mottled with red and yellow flaky plant partings over upper half; scattered carbonized filaments below.
1486.0 to 1487.9 (452.9 to 453.5)	Mudstone: massive, medium grey, moderately well indurated, scattered red-brown iron mottling downward.
1487.9 to 1499.5 (453.5 to 457.0)	Sandstone: quartzose, very fine grained, subordinate coarse-grained brown sphaerosiderite; very argillaceous, well indurated, medium grey mottled and speckled with iron stains; sharp(?) contact.

Rex Member

1499.5 to 1512.5 (457.0 to 460.9)	Mudstone: subordinate very fine grained quartzose sand, medium grey, massive; sandier and severely contorted over lower 0.3 m, and pebbly ironstone conglomeratic with carbonized woody fragments near base; base on slickensided shear dipping about 25°.
1512.5 to 1516.0 (460.9 to 462.0)	Mudstone: clayey, dark grey to medium grey downward, blocky to platy.
1516.0 to 1519.5 (462.0 to 463.1)	Siltstone: quartzose, argillaceous, medium grey, massive, hard; sharp, irregular contact.
1519.5 to 1521.5 (463.1 to 463.7)	Sandstone: quartzose, fine grained, light grey, internally brecciated; subordinate coarse-grained brown sphaerosiderite; calcite cemented over upper 0.3 m, well indurated below; grades into
1521.5 to 1527.5 (463.7 to 465.6)	Mudstone: light green grey to medium grey downward; faintly flasered with sandy laminae; abundant small burrows over basal 0.05 m; sharp, irregular contact.
1527.5 to 1529.5 (465.6 to 466.2)	Siltstone: argillaceous, light green grey, massive; abundant siderite-infilled vertical burrows; sharp, irregular contact.

Lloydminster Member Unit 4

1529.5 to 1531.0 (466.2 to 466.6)	Mudstone: platy, argillaceous, light green grey, platy, hard, shaly and clayey over lower half; abundant ironstone nodules and silty lenticles; sharp contact.
1531.0 to 1536.0 (466.6 to 468.2)	Mudstone: dark green grey, abundant; carbonaceous flecks and sulphurous coaly fragments and lenticles; sharp, irregular contact.

Unit 3

1536.0 to 1539.5 (468.2 to 469.2)	Sandstone: quartzose, fine grained, grey white, kaolinitic, moderately indurated, earthy in part; blocky structure with scattered coaly fragments and irregular pyritic masses at the top; and about 15% black shale ripple laminae below.
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1539.5 to 1541.0 (469.2 to 469.7)	Sandstone: quartzose, fine grained, light grey, current bedded, well sorted, densely calcite cemented; scattered black shale ripple laminae toward base.
1541.0 to 1543.5 (469.7 to 470.5)	Sandstone: quartzose, very fine grained, grey white, kaolinitic, massive, blocky structure, moderately indurated, bioturbated towards base.
1543.5 to 1544.0 (470.5 to 470.6)	Shale: black, subordinate graded laminae of white, very fine grained, quartzose sandstone and bedding aligned bioturbation pods; rare <i>Chondrites</i> ; well indurated; sharp, irregular contact on oxidized, vertically burrowed hardground of cemented sandstone.

Unit 2

1544.0 to 1546.0 (470.6 to 471.2)	Sandstone: quartzose, fine grained, kaolinitic, grey white, moderately indurated, about 15% coarse-grained, reddish brown sphaerosiderite; flow distorted bed and lenticular layering below with slight increase in dark grey argillaceous content; strongly bioturbated with <i>Teichichnus</i> conspicuous near base.
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Unit 1

1546.0 to 1548.7 (471.2 to 472.0)	Sandstone: quartzose, fine grained, kaolinitic, grey white, cross-bedded; thinly interbedded with ripple laminae of black shale; about 7% coarse-grained sphaerosiderite; grades into black shale over basal 0.25 m; sharp, irregular contact with coaly fragments on oxidized surface.
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Cummings Member

1548.7 to 1553.5 (472.0 to 473.5)	Mudstone: medium green grey, platy; interbedded with subordinate sandstone: quartzose, very fine grained, kaolinitic, grey white and laminated with light grey green shale; strongly contorted, scattered brown sideritic nodules; sharp, irregular contact lined with sideritic nodules and pyrite crystals.
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Dina Member

Unit 3 Bedding Cycle 3 (4.3 m)

1553.5 to 1556.2 (473.5 to 474.3)	Sandstone: quartzose, fine grained, abundant muscovite, light grey, well sorted, friable, permeable; flat bedded with trace of fine current beds; sharp contact.
1556.2 to 1556.5 (474.3 to 474.4)	Siltstone: quartzose, subordinate grey-black muscovitic shale; ironstone cemented in part; sharp contact.
1556.5 to 1567.5 (474.4 to 477.8)	Sandstone: as at 1553.5 feet (473.5 m); ripple drift bedded, increasing to 20° avalanche slopes over lower half; sharp contact on oxidized red and green laminated shale, 0.02 m thick.

Unit 2 Bedding Cycle 2 (3.9 m)

1567.5 to 1580.5 (477.8 to 481.7)	Sandstone: quartzose, fine grained to medium, well sorted, subangular with overgrowths; scattered red jasper, white kaolinite; abundant muscovite; medium grey, massive, with intervals marked by steep, planar cross-beds; basal contact on wavy, oxidized red and green mudstone, 0.01 m thick.
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Unit 1 Bedding Cycle 1 (18.5 m)

1580.5 to 1641.0 (481.7 to 500.2)	Sandstone: as at 1567.5 feet (477.8 m), but dominantly medium grained; interbedded with high-decreasing downward to low-angle planar cross-beds; below 1635 feet (498.3 m) occur decimetre-thick interbeds laminated with subordinate coarse-grained sphaeropyrites; sharp, irregular, pyrite-encrusted contact.
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SUCCESS FORMATION

1641.0 to 1646.0 (500.2 to 501.7)	Coal: black, fusain-rich, argillaceous, sulphurous.
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1646.0 to 1647.0 (501.7 to 502.0)	Sandstone: quartzose, fine grained, coaly, argillaceous, black, friable, massive downward; sharp contact.
1647.0 to 1648.0 (502.0 to 502.3)	Claystone: kaolinitic; tan, massive; abundant carbonized crisscrossed reeds; sharp(?) contact on dark brown, pyrobituminous layer.
SHAUNAVON FORMATION	
Lower Member	
1648.0 to 1650.0 (502.3 to 502.9)	Limestone: calcilutite (cream), dolomitic (tan); abundant coarse-grained oolites, coralline (<i>Actinastrea</i>) fossils; earthy to dense, jointed and brecciated, bitumen stained on partings and in joints.
GRAVELBOURG FORMATION	
Gbg 5	
1650.0 to 1650.5 (502.9 to 503.1)	Shale, dark grey, noncalcareous, blocky.
Gbg 4	
1650.5 to 1657.5 (503.1 to 505.2)	Dolomite: cryptocrystalline buff, faintly bedded; interbedded and intermixed with tan calcilutite and grey cryptocrystalline limestone, the latter as irregular nodules and the former as debris infilling solution joints and large cavities (Rec. 70%).
1657.5 to 1659.0 (505.2 to 505.7)	No recovery.
1659.0 to 1659.5 (505.7 to 505.8)	Dolomite: as at 503.1 m (1650.5 feet).
1659.5 to 1660.0 (505.8 to 506.0)	Limestone: cryptocrystalline, dense, dark grey, fractured; nodular, bitumen-coated bodies lined with dark grey claystone; overlies subordinate dark grey claystone; (Rec. 70%).
1660.0 to 1661.5 (506.0 to 506.4)	Limestone: microcrystalline, dense, oolitic and pelletal; buff mottled with dark grey (Rec. 70%).
1661.5 to 1662.5 (506.4 to 506.7)	Limestone: calcilutite, buff, silty; dark grey, argillaceous and quartzose sandy over lower half; crumbly and disaggregated.
1662.5 to 1663.5 (506.7 to 507.0)	Limestone: calcilutite, buff, earthy; interbedded with limestone: microcrystalline, medium grey, abundant bitumen-lined stylolites, bedding partings and large moldic cavities.
1663.5 to 1664.5 (507.0 to 507.2)	Limestone: calcilutite, tan, earthy, disaggregated.
Gbg 3	
1664.5 to 1665.5 (507.2 to 507.6)	Limestone: cryptocrystalline, dense, dark grey, marked by calcitic flame structures and irregular geodes; centimetre-scale interbed of calcilutite: tan, flow textured.
1665.5 to 1666.5 (507.6 to 507.9)	Limestone and shale: brecciated.
1666.5 to 1669.5 (507.9 to 508.9)	Limestone: microcrystalline, pelletal, dark grey, dense; calcilutite interbeds, tan, flamed injected, slope 20° across core.
1669.5 to 1672.0 (508.9 to 509.6)	Sandstone: quartzose, fine grained, dark grey, dolomitic, friable (Rec. 50%).

1672.0 to 1678.5 (509.6 to 511.6)	Mudstone: dolomitic, medium grey, massive, calcareous toward base; interbedded at 0.06 m intervals with limestone: mesocrystalline, dense, dark grey, pygmatic and distorted.
Gbg 2	
1678.5 to 1680.5 (511.6 to 512.2)	Limestone: microcrystalline, dense medium grey; abundant centimetre-diameter geodes; sharp, irregular contact.
1680.5 to 1681.0 (512.2 to 512.4)	Shale: dark grey, papery, calcareous; bedded, granular lithic aggregates over upper half; sharp, basal contact.

Gbg 1

1681.0 to 1688.0 (512.4 to 514.5)	Dolostone: cryptocrystalline, earthy, massive; 0.04 m thick, dark grey and grey black bituminous shaly interbeds at 0.08 m intervals; argillaceous over lower 0.06 m; sharp basal contact.
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WATROUS FORMATION

Upper Member

1688.0 to 1688.5 (514.5 to 514.7)	Limestone: cryptocrystalline, medium green grey, dense; subordinate stringers of tan calcilutite; sharp, basal contact.
1688.5 to 1690.0 (514.7 to 515.1)	Mudstone: dolomitic, medium green grey, platy to blocky; minor stringers and pygmatic lenses of coarsely crystalline white limestone.
1690.0 to 1696.0 (515.1 to 516.9)	Mudstone: red variegated with green, noncalcareous; abundant large pygmatic networked bodies, fracture fillings and nodules of white, coarsely crystalline calcite; scattered similar gypsiferous bodies toward base.

Lower Member

1696.0 to 1724.0 (516.9 to 525.5)	Mudstone: dolomitic, red variegated with green, massive; steep fractures dipping 60°, rare anhydrite bleb.
1724.0 to 1730.0 (525.5 to 527.3)	Mudstone: dolomitic, red, massive; enterolithic anhydrite nodules exceeding 0.1 m in thickness at 1724.0 feet (525.5 m); smaller nodules and scattered lateral millimetre-thick anhydrite veinlets below.
1730.0 to 1738.0 (527.3 to 529.7)	Mudstone: dolomitic, red; marked over upper half by 0.01 m thick, intersecting curved, lateral veinlets of fibrous gypsiferous anhydrite at intervals of 0.08 to 0.1 m; and over lower half by interbeds of lensoid, 0.03 to 0.06 m thick, coarsely crystalline, white anhydrite.
1738.0 to 1749.0 (529.7 to 533.1)	Mudstone: dolomitic, red variegated with green, compaction distorted texture; sharp-edged, post-compactional vertical veins >0.82 m long and up to 0.02 m thick, and subsidiary lateral, mildly distorted veinlets, up to 0.02 m thick, of white, coarsely crystalline anhydrite.
1749.0 to 1772.0 (533.1 to 540.1)	Mudstone: dolomitic, red and green variegated; compaction distorted texture; interbeds at 0.6 m intervals of coarsely crystalline, nodular enterolithic anhydrite, from which at 1759 feet (536.1 m) radiate lateral and vertical sharp-edged veins <0.3 m long and 0.03 m thick.
1772.0 to 1778.0 (540.1 to 541.9)	Mudstone: dolomitic, red and green variegated; trace of lamination, but mostly compaction distorted; lateral veins of fibrous anhydrite, 0.01 m thick at intervals of 0.3 to 0.6 m, microfaulted at 1775 feet (541.3 m).
1778.0 to 1780.0 (541.9 to 542.5)	Mudstone: dolomitic, red, subordinate enterolithic and coarse granoblastic anhydrite; lateral veins of fibrous anhydrite over lower half.

1780.0 to 1793.0 (542.5 to 546.5)	Mudstone: dolomitic; red, massive; lateral fibrous anhydrite veins at 1780 to 1781 feet (542.5 to 542.8 m) and at 1788 to 1793 feet (545.0 to 546.5 m); generally contorted and compaction distorted; minor green grey, argillaceous dolomitic nodules.
1793.0 to 1806.0 (546.5 to 550.5)	Mudstone: dolomitic, red, interbedded with current-bedded, dolomitic, quartzose siltstone; bedding crenulated and distorted around anhydrite nodules; fibrous anhydrite veins up to 0.06 m thick alternate at 0.3 m intervals with zones of abundant nodular anhydrite.
1806.0 to 1809.5 (550.5 to 551.5)	Mudstone: dolomitic, red, compaction distorted, massive, abundant nodular and granoblastic anhydrite.
1809.5 to 1831.0 (551.5 to 558.1)	Sandstone: quartzose, very fine grained, argillaceous, calcite cemented, reddish tan, current bedded with flasers, low-angle cut and fill; mildly distorted throughout, dense, well cemented.
1831.0 to 1851.0 (558.1 to 564.2)	Mudstone: calcareous, red, subordinate interbeds of reddish tan, argillaceous, calcite-cemented sandstone; abundant nodular, granoblastic anhydrite; scattered thin anhydrite veins over lower 1 m; strongly contorted over basal 0.6 m.
1851.0 to 1853.5 (564.2 to 564.9)	Sandstone: quartzose, very fine grained, argillaceous, calcite cemented, reddish tan, flow distorted and balled with minor interbeds of red, calcareous mudstone and rare fibrous anhydrite veins.
1853.5 to 1856.0 (564.9 to 565.7)	Sandstone: quartzose, very fine grained, massive, argillaceous, dolomitic, light reddish grey; abundant coarse grains and grits of quartzose sand, feldspar and ironstone; wavy veinlets of fibrous anhydrite toward base.
1856.0 to 1860.5 (565.7 to 567.0)	Mudstone: deep red, calcareous; subordinate detached laminae and lenticles of sandstone as at 1851 feet (564.2 m); sandstone as 1853.5 feet (564.9 m) becomes dominant downward.
1860.5 to 1862.0 (567.0 to 567.5)	Sandstone: as at 1809.5 feet (551.5 m).
1862.0 to 1869.0 (567.5 to 569.7)	Mudstone: deep red, calcareous; minor compaction distorted, reddish tan, argillaceous, very fine grained, quartzose sandstone flasers increases to subordinate downward; lateral fibrous anhydrite vein at 1864 feet (568.1 m).
1869.0 to 1884.0 (569.7 to 574.2)	Sandstone: quartzose, very argillaceous, calcareous; subordinate coarse-grained quartz, white feldspar, deep brown ironstone; dark grey and red variegated, current bedded; over lower 1 m interbedded at 0.6 m intervals with sandstone: quartzose, very fine grained, argillaceous, calcite cemented, current bedded with climbing ripples; reddish tan; current rip-up clasts conspicuous over basal 0.03 m.
1884.0 to 1888.5 (574.2 to 575.6)	Dolostone: argillaceous, light reddish grey, hard, dense, grading below upper 0.6 m into mudstone: dolomitic, red, hard, dense; fractured and veined with anhydrite over upper and basal 0.3 m; sharp, sloping basal contact.
DUPEROW FORMATION (Karst debris)	
1885.5 to 1889.5 (574.7 to 575.9)	Dolostone: cryptocrystalline, cream coloured, dense; annealed breccia of pebble-and boulder-size fragments, veined with minor crenulated veins of white fibrous anhydrite; irregular basal contact.
1889.5 to 1892.5 (575.9 to 576.8)	Mudstone: dolomitic, increasingly argillaceous and quartzose silty downward, red variegated with green, flow bedded along truncating annealed fractures.
1892.5 to 1893.8 (576.8 to 577.2)	Anhydrite: coarsely crystalline, dense, translucent light grey; subordinate stringers of mudstone; includes dolomite fragments over basal 0.03 m; faulted basal contact.
1893.8 to 1895.6 (577.2 to 577.8)	Rubble: dolomite, anhydrite, and red dolomitic mudstone; dipping to 30°, well indurated with partings along bedded mudstone.

1895.6 to 1902.1 (577.8 to 579.8)	Dolostone: as at 1885.5 feet (574.7 m), but veins are white, coarsely crystalline anhydrite with open intergranular pore network; interbreccia space infilled with anhydrite.
1902.1 to 1903.1 (579.8 to 580.1)	Sandstone: quartzose, very fine grained, finely cross-bedded, densely cemented with dolomite, cream coloured; coarsely laminated with red and green, dolomitic, argillaceous mudstone; predominantly red over upper 0.6 m and green below; sharp, dipping fracture controlled contact.
1903.1 to 1905.0 (580.1 to 580.6)	Dolostone: argillaceous, medium green grey to reddish grey downward; mostly an annealed cobble-size breccia; dense; sharp contact.
1905.0 to 1908.0 (580.6 to 581.6)	Mudstone: argillaceous, dolomitic, red, dense; medial, irregular, low-angle sloping veins of white anhydrite.
1908.0 to 1912.5 (581.6 to 582.9)	Breccia: green dolomitic mudstone and white, coarse crystalline anhydrite.
DUPEROW FORMATION (Proper)	
1912.5 to 1915.0 (582.9 to 583.7)	Anhydrite: massive, dark grey, coarsely crystalline; subordinate lenticles and stringers of medium grey, cryptocrystalline dolomite; sharp, basal contact.
1915.0 to 1917.0 (583.7 to 584.3)	Dolostone: cryptocrystalline, dense, faintly laminated; scattered, black, bituminous incipient stylolites.

Imp Findlater Disposal 16-10-21-25(W2)
KB 1845.5 feet (562.5 m)

Depth in feet (m)	CANTUAR FORMATION General Petroleums Member
2225.0 to 2245.0 (678.2 to 684.3)	Sandstone: quartzose, fine grained argillaceous, irregularly interbedded with silty mudstone; medium green grey, abundant brown, sideritic nodular rootlets and carbonized plant fragments.
2245.0 to 2252.0 (684.3 to 686.4)	Claystone: medium green grey, thin interbeds of laminated very fine grained sandstone and claystone; microfaulted and slickensided at oblique angles with brown ironstone lenticular slabs sloping at about 70°.
Rex Member	
2252.0 to 2255.0 (686.4 to 687.3)	Sandstone: quartzose, fine grained, well sorted, thin bedded, current bedded and microfaulted; interbedded at about 0.1 m intervals with laminated dark grey and rusty brown siltstone and shale.
2255.0 to 2500.0 (687.3 to 762.0)	No core.
SHAUNAVON FORMATION Lower Member	
2500.0 to 2503.0 (762.0 to 762.9)	Sandstone: quartzose, fine grained, well sorted, calcite cemented; sharply interbedded with fine-grained, marly, bioturbated, quartzose sandstone, light tan grey.
2503.0 to 2503.5 (762.9 to 763.1)	Dolomite: dense, cryptocrystalline, light reddish brown, subordinate fine-grained, quartzose sandstone; sharp irregular contact.
GRAVELBOURG FORMATION Gbg 5	
2503.5 to 2509.0 (763.1 to 764.7)	Sandstone: quartzose, fine to very fine grained, calcareous argillaceous matrix, contorted, variably cemented with medium blue grey calcite over upper 0.4 m; microfaulted; abundant brown, papery thin pelecypod shells near top and at base.

2509.0 to 2514.0 (764.7 to 766.3)	Mudstone: silty, dark grey, abundant carbonized plant fragments, some microfaulting and contortion; becomes clayey downward.
2514.0 to 2518.5 (766.3 to 767.6)	Shale: grey black to black downwards carbonaceous; trace of thin, black, pyrite-encrusted pelecypod shells; carbonized woody material; sharp, irregular contact.
Gbg 4	
2518.5 to 2520.0 (767.6 to 768.1)	Sandstone: quartzose, fine grained, well sorted, abundant muscovite, carbonized woody fragments, argillaceous matrix, faintly bedded and distorted.
2520.0 to 2523.0 (768.1 to 769.0)	Marlstone: medium grey green, hard, blocky; grades into
2523.0 to 2525.0 (769.0 to 769.6)	Shale: black, calcareous, abundant brown, thin pelecypod shells, some concentrated on bedding surfaces.
2525.0 to 2533.0 (769.6 to 772.1)	Sandstone: quartzose, very fine grained, well sorted, brown grey, laminated and cross-laminated in thin truncation sets with subordinate muscovitic black shale.
2533.0 to 2540.0 (772.1 to 774.2)	Siltstone: quartzose, medium grey; interbedded with laminated siltstone and black shale, and bioturbated grey-black sandy mudstone; noncalcareous.

Imperial Penzance Crown No. 1	(3-30-24-25W2)	KB 1946 feet (593.1 m)
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Depth in feet (m)	CANTUAR FORMATION General Petroleum Member
1962.0 to 1965.0 (598.0 to 598.9)	Sandstone: quartzose, very fine grained, argillaceous, light green grey; thinly interbedded with olive-green mudstone; oxidized red brown at 598.0 m.
1965.0 to 1973.0 (598.9 to 601.4)	Mudstone: olive, earthy; interbedded and laminated with dark grey claystone; weakly indurated.
1973.0 to 1978.5 (601.4 to 603.0)	Shale: dark grey, clayey; grey black downward; white calcite beef(?) lenticles at 602 m.
Rex Member	
1978.5 to 1980.0 (603.0 to 603.5)	Coal: black, and shale carbonaceous.
1980.0 to 1989.0 (603.5 to 606.2)	Sandstone: quartzose, very fine grained, argillaceous, grey white, grading downward to light grey, well indurated; dark green glauconite-infilled burrows at 605.3 m, fine-grained, quartzose, sandstone downward; laminated with argillaceous, very fine grained sandstone over lower 0.3 m.
1989.0 to 1993.0 (606.2 to 607.5)	Mudstone: medium grey, earthy, platy.
1993.0 to 1997.0 (607.5 to 608.7)	Sandstone: quartzose, very fine grained, current bedded, micro-contorted, burrowed, calcite cemented; rusty brown oxidation.
1997.0 to 2002.0 (608.7 to 610.2)	No core.
2002.0 to 2007.0 (610.2 to 611.7)	Sandstone: quartzose, very fine grained, laminated to interbedded downward with argillaceous, quartzose, very fine grained sandstone and mudstone; upper one-half rust-brown, medium grey below.
2007.0 to 2450.0 (611.7 to 746.8)	No core.

WATROUS FORMATION

Upper Member

2450.0 to 2453.0 (746.8 to 747.7)	Shale: medium grey, dolomitic; blebs and lenses of dark grey crystalline anhydrite and white, powdery gypsum.
2453.0 to 2456.0 (747.7 to 748.6)	Gypsum: white, powdery, and anhydrite, medium grey, crystalline, dense; interbedded with subordinate medium grey shale.
2456.0 to 2463.0 (748.6 to 750.7)	Shale: medium grey, noncalcareous, platy to fissile downward; scattered hematitic red streaks.
2463.0 to 2466.0 (750.7 to 751.6)	Shale: hematitic dark red, splintery; scattered anhydritic layers.
2466.0 to 2476.0 (751.6 to 754.7)	No core.
2476.0 to 2483.0 (754.7 to 756.8)	Anhydrite: dense, coarsely crystalline, light blue grey, translucent chickenwire fabric.
2483.0 to 2485.0 (756.8 to 757.4)	Dolomite: microcrystalline, hematitic red; interbedded with red and green mudstone and white powdery gypsum.
2485.0 to 2494.0 (757.4 to 760.2)	Mudstone: vermilion, platy; abundant blebs of white gypsum.
2494.0 to 2496.0 (760.2 to 760.6)	Anhydrite: crystalline, light blue grey, gypsiferous.

Lower Member

2496.0 to 2502.0 (760.6 to 762.6)	Shale: vermilion red, fissile to plastic; scattered flat-lying to dipping, millimetre-thick, gypsiferous veins.
2502.0 to 2510.0 (762.6 to 765.0)	Mudstone: red and green grey variegated, platy; subordinate shaly interbeds.
2510.0 to 2520.0 (765.0 to 768.1)	Siltstone: quartzose, very argillaceous, well indurated, variegated medium green grey and red, massive; variously crisscrossed at decimetre intervals with planar, white gypsum veins.
2520.0 to 2526.0 (768.1 to 769.9)	Anhydrite: white, chickenwire texture, nodular with red mudstone veins; interbedded with green grey and red siltstone and mudstone (Rec. 0.3 m).
2526.0 to 2534.0 (769.9 to 772.4)	Shale: red, noncalcareous, crumbly; grades downward into dolomitic and anhydritic mudstone with nodules of white, gypsiferous anhydrite.
2534.0 to 2556.0 (772.4 to 779.0)	Mudstone: quartzose, silty, variegated red splashed with green; interbedded at 0.3 m intervals with shale.
2556.0 to 2564.0 (779.0 to 781.2)	Siltstone: quartzose, argillaceous, well indurated, earthy, variegated red and green; minor thin layers of nodular gypsum and rare oblique gypsum veins.
2564.0 to 2580.0 (781.2 to 786.4)	Mudstone: quartzose silty, red and green variegated; interbedded with subordinate shale.
2580.0 to 2603.0 (786.4 to 793.4)	No recovery.
2603.0 to 2608.0 (793.4 to 794.9)	Shale: red, crumbly (Rec. 20%).

2608.0 to 2623.0 (794.9 to 799.5)	Sandstone: quartzose, argillaceous, very fine grained, current bedded, slightly calcareous, well indurated, interbedded with mudstone; medium brownish red, coarse-grained, sphaerosideritic bed at 2620 to 2621 feet (798.6 to 798.9 m), interbed of platy, red mudstone below.
2623.0 to 2638.0 (799.5 to 804.1)	Sandstone: quartzose, very fine grained, argillaceous, very calcareous, medium reddish brown, bedded, flaggy (Rec. 50%).

Community Services Watrous No.1	(4-2-32-25W2)	KB 1774 feet (540.7 m)
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Depth in feet (m)	CANTUAR FORMATION Rex Member <i>Bedding Cycle 3 (2.7 m)</i>
2209.0 to 2218.0 (673.3 to 676.0)	Claystone: waxy, dark grey, scattered glauconitic pyritic nodules, occasional layer with concentrated carbonized plant fragments. <i>Bedding Cycle 2 (4.6 m)</i>
2218.0 to 2220.0 (676.0 to 676.7)	Claystone: waxy, medium grey green; beds of rust brown coarse-grained sphaerosiderite.
2220.0 to 2227.0 (676.7 to 678.8)	Sandstone: quartzose, very fine grained, argillaceous, light grey, moderately indurated, dense, earthy, friable, massive; scattered black ironstone nodules with surficial green glauconite; traces of ironstone rootlet casts.
2227.0 to 2233.0 (678.8 to 680.6)	Shale: clayey, dark grey to grey black, waxy; sharp, irregular contact. <i>Bedding Cycle 1 (1.1 m)</i>
2233.0 to 2236.5 (680.6 to 681.7)	Shale: clayey, waxy, medium grey grading below 680.9 m into light green grey; abundant dark grey carbonized plant fragments; sharp irregular contact. Lloydminster Member Unit 4 <i>Bedding Cycle 3 (4.1 m)</i>
2236.5 to 2239.0 (681.7 to 682.4)	Sandstone: quartzose, very fine grained, argillaceous matrix, light grey, moderately indurated, earthy; occasional carbonized rootlet.
2239.0 to 2250.0 (682.4 to 685.8)	Shale: medium grey green, waxy; patchy brown iron stains; interbeds of calcite-cemented, brown, iron mottled quartzose, very fine grained sandstone at 682.4 and 684.3 m. Unit 3 <i>Bedding Cycle 2 (6.4 m)</i>
2250.0 to 2260.0 (685.8 to 688.8)	Sandstone: quartzose, fine grained, well sorted, light grey, weakly indurated, very permeable.
2260.0 to 2264.0 (688.8 to 690.1)	Shale: grey black, carbonaceous, abundant plant fragments; laminated with sandstone as at 685.8 m; sandstone interbed at 689.8 m.
2264.0 to 2268.0 (690.1 to 691.3)	Shale: clayey, medium grey green, waxy, sharp contact.
2268.0 to 2271.0 (691.3 to 692.2)	Shale: black, carbonaceous, grading below 691.6 m into dark grey; sharp contact. Unit 2 <i>Bedding Cycle 1 (5.3 m)</i>
2271.0 to 2280.0 (692.2 to 694.9)	Sandstone: quartzose, very fine grained, calcite cemented, flat bedded; grades below 693.1 m into unindurated, noncalcareous sandstone laminated with light grey green shale.

2280.0 to 2288.0
(694.9 to 697.4) Shale: medium grey green, noncalcareous; scattered brown sphaerosiderite, variegated.

2288.0 to 2288.5
(697.4 to 697.5) Shale: black, calcareous; sharp basal contact on 0.05 m of light grey, argillaceous, very fine-grained quartzose sandstone.

Cummings Member

2288.5 to 2292.0
(697.5 to 698.6) Shale: dark green grey, scattered glauconitic-pyritic nodules.

Dina Member

2292.0 to 2342.0
(698.6 to 713.8) Sandstone: quartzose, very fine grained, weakly bonded to unconsolidated, light grey; interbedded with black shale laminated with subordinate sandstone lenticles, pods and burrow traces; calcite-cemented sandstone below 710.8 m.

2342.0 to 2348.0
(713.8 to 715.7) Shale: greenish grey black, abundant glauconitic burrows; silty interbeds towards base.

WATROUS FORMATION

Upper Member

2348.0 to 2356.5
(715.7 to 718.3) Dolostone: microcrystalline; weakly argillaceous, dense light grey; rubbly with interstices filled with calcite and siliceous cream-coloured kaolinite.

2356.5 to 2369.0
(718.3 to 722.1) No core.

2369.0 to 2370.0
(722.1 to 722.4) Mudstone: red, dolomitic.

Grey Owl Syndicate No. 1	(16-10-44-27W2)	KB 1740 feet (530.4 m)
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Depth in feet (m)	PENSE FORMATION <i>Bedding Cycle 4 (1.8 m)</i>
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1494.0 to 1500.0 (455.4 to 457.2)	Shale: grey-black, hard, platy; minor lenticles and pods of laminated light grey to grey-black, argillaceous, fine-grained, quartzose sandstone, abundant muscovite; sharp irregular contact.
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Bedding Cycle 3 (4.6 m)

1500.0 to 1515.0 (457.2 to 461.8)	Sandstone: quartzose, very fine grained, very argillaceous and midstone, silty to clayey; earthy, moderately indurated, light grey; abundant to minor coarse, red-brown sphaerosiderites; traces of carbonized rootlets; sharp irregular contact.
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Bedding Cycle 2 (7.7 m)

1515.0 to 1518.5 (461.8 to 462.8)	Siltstone: quartzose, light grey, argillaceous matrix, traces of carbonized rootlets; sphaerosiderite aggregates concentrated near top. Upper 0.15 m siderite cemented, red brown, hard, dense.
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1518.5 to 1533.0 (462.8 to 467.4)	Claystone: grading into mudstone, medium grey; carbonaceous with plant fragments at top and traces throughout; moderately indurated, platy to blocky, earthy; grades into
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1533.0 to 1540.5 (467.4 to 469.5)	Sandstone: quartzose, very fine grained, argillaceous, light grey, weakly indurated; abundant carbonaceous specks, muscovite; scattered grey black, argillaceous, coarse laminae associated with patches of bright green and yellow sulphur blooms; cemented with brown siderite at base.
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Bedding Cycle 1 (1.4 m)

1540.5 to 1545.0
(469.5 to 470.9) Sandstone: quartzose, very fine grained, light grey, friable, abundant muscovite, carbonaceous specks; irregularly laminated and flasered with dark grey mudstone and shale; sharp contact.

CANTUAR FORMATION

Waseca Member

Bedding Cycle 8 (5.5 m)

1545.0 to 1562.0
(470.9 to 476.1) Mudstone: dark grey, clayey, platy; abundant carbonized plant fragments and films; scattered iron-stained patches.

1562.0 to 1563.0
(476.1 to 476.4) Sandstone: quartzose, very fine grained, grey white, argillaceous matrix, moderately indurated; grey black over lower half, with pods and slivers of grey-white sandstone outlining flowage forms.

Bedding Cycle 7 (5.2 m)

1563.0 to 1571.0
(476.4 to 478.8) Claystone: medium grey, waxy, black and carbonaceous.

1571.0 to 1580.0
(478.8 to 481.6) Sandstone: quartzose, fine and very fine grained, light grey argillaceous matrix, generally massive; moderately indurated, earthy; minor interbeds of platy mudstone.

Bedding Cycle 6 (4.6 m)

1580.0 to 1581.0
(481.6 to 481.9) Clay ironstone: red brown, hard, well cemented, septarian calcite veins.

1581.0 to 1591.0
(481.9 to 484.9) Sandstone: quartzose, fine grained, subordinate very fine; minor red-brown siderite, black carbonaceous grains, white kaolinite aggregates, muscovite; weakly indurated in white kaolinitic clay (Rec. 30%).

1591.0 to 1595.0
(484.9 to 486.2) Sandstone: quartzose, very fine grained, medium grey; boudinaged and irregularly laminated with dark grey mudstone and at base, black shale.

Bedding Cycle 5 (0.7 m)

1595.0 to 1596.0
(486.2 to 486.5) Mudstone: medium grey, clayey, black; grades into

1596.0 to 1597.5
(486.5 to 486.9) Sandstone: as at 481.9 m; sharp contact.

Bedding Cycle 4 (4.1 m)

1597.5 to 1598.5
(486.9 to 487.2) Shale: black, carbonaceous.

1598.5 to 1600.0
(487.2 to 487.7) Shale: dark grey, clayey; scattered laminae of light grey silt; grades into

1600.0 to 1611.0
(487.7 to 491.0) Sandstone: quartzose, very fine grained, very argillaceous; subordinate beds of mudstone; grey white, earthy, weak to moderately indurated.

1611.0 to 1612.0
(491.0 to 491.3) No recovery.

Bedding Cycle 3 (3.4 m)

1612.0 to 1620.0
(491.3 to 493.8) Sandstone: quartzose, fine grained, well sorted; scattered white kaolinite and carbonaceous grains; silica and kaolinite cemented, permeable; creamy white, flat bedded; grain size decreases downward to very fine, and wavy laminae partings increase.

1620.0 to 1623.0 (493.8 to 494.7)	Shale: siliceous, medium grey, laminated with thin flasers and lenticles of white, very fine-grained, quartzose sandstone.
<i>Bedding Cycle 2 (2.7 m)</i>	
1623.0 to 1631.0 (494.7 to 497.1)	Sandstone: quartzose, very fine grained, argillaceous matrix, medium grey, well indurated, earthy; weakly cemented and clay-free below 496.5 m with minor partings of grey-black shale.
1631.0 to 1632.0 (497.1 to 497.4)	Shale: black, carbonaceous, fissile.
<i>Bedding Cycle 1 (2.8 m)</i>	
1632.0 to 1637.0 (497.4 to 499.9)	Claystone: dark grey, waxy; grey white downward with increasing sand content.
1637.0 to 1640.0 (499.9 to 500.2)	Sandstone: very fine grained, argillaceous, quartzose, grey white, moderately indurated.
1640.0 to 1641.0 (500.2 to 500.4)	No recovery.
Sparky Member	
<i>Bedding Cycle 4 (5.3 m)</i>	
1641.0 to 1643.0 (500.4 to 500.8)	Mudstone: medium grey, abundant films of carbonized plant fragments.
1643.0 to 1658.0 (500.8 to 505.4)	Sandstone: quartzose, fine grained, well sorted, scattered muscovite, weakly cemented, very permeable, grey white, kaolinite content less than 5%; dark grey at 502 m, with increasing argillaceous laminae, pods, lenticles and bioturbation.
1658.0 to 1659.0+ (505.4 to 505.7)	Shale: grey black, platy, hard, abundant muscovite and carbonized plant fragments.
<i>Bedding Cycle 3 (7.6 m)</i>	
1659.0 to 1684.0 (505.7 to 513.3)	Sandstone: as at 500.8 m.
<i>Bedding Cycle 2 (0.7 m)</i>	
1684.0 to 1686.0 (513.3 to 513.9)	Sandstone: quartzose, fine grained, well sorted, thinly cross-bedded, low-angle truncation sets, ripple drift and scour surfaces; light grey, calcite cemented, hard, dense; podded and burrowed in part; more permeable layers are iron stained; reed-like carbonized stalks on some bedding partings; sharp contact.
1686.0 to 1686.5 (513.9 to 514.0)	Sandstone: quartzose, fine grained, laminated with dark grey argillaceous, very fine grained sandstone and siltstone; thin (0.006 m) coal at base.
<i>Bedding Cycle 1 (3.2 m)</i>	
1686.5 to 1697.0 (514.0 to 517.2)	Sandstone: quartzose, very fine grained, argillaceous matrix, dark grey; fine bedded but strongly lenticular with ripples and flasers; buff, with reduced argillaceous content below 516.3 m; sharp contact.
General Petroleums Member	
1697.0 to 1698.5 (517.2 to 517.7)	Shale: black, carbonaceous, thin slivers of pyritic coaly fragments.
1698.5 to 1699.0 (517.7 to 517.9)	Claystone: grey black, abundant carbonized plant fragments; very fine grained, quartzose sandstone lenticles increasing downward.

1699.0 to 1701.5 (517.9 to 518.6)	Sandstone: quartzose, very fine grained, argillaceous, medium grey, thinly interbedded with dark grey silty shale; bedding lenticular, flasered and bioturbated (severe core distortion).
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1701.5 to 1722.5 (518.6 to 525.0)	Sandstone: quartzose, fine grained, well sorted, subrounded and subangular, low argillaceous content, virtually uncemented; light grey; scattered thin layers of medium grey mudstone.
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1722.5 to 1786.0 (525.0 to 544.4)	No recovery.
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Rex Member

1786.0 to 1801.0 (544.4 to 548.9)	Sandstone: as at 518.6 m.
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1801.0 to 1806.0 (548.9 to 550.0)	No recovery.
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1806.0+ (550.0)	Sandstone: as at 518.6 m; also shale: dark grey, waxy, minor fine-grained, quartzose sandstone: scattered chitinous spheroids or discoids.
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Lloydminster Member

1806.0+ to 1826.0 (550.0 to 556.6)	Sandstone: quartzose, fine grained, well sorted, subrounded, weakly cemented, light grey, scarce black chert; scattered dark grey shaly partings.
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1826.0 to 1884.0 (556.6 to 574.2)	No recovery.
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1884.0 to 1888.0 (574.2 to 575.5)	Sandstone: quartzose, fine grained, well sorted, calcite cemented, grey white, contorted (slumped).
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1888.0 to 1934.0 (575.5 to 589.5)	No recovery.
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Cummings Member

1934.0 to 1939.0 (589.5 to 591.0)	Shale: black, carbonaceous, scattered light grey sandstone lenticles.
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1939.0 to 1974.0 (591.0 to 601.7)	No recovery.
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Dina Member

1974.0 to 1981.0 (601.7 to 603.8)	Mudstone: medium grey, blocky, interbedded with argillaceous, very fine grained, quartzose sandstone (0.6 m pres.).
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1981.0 to 2010.0 (603.8 to 612.6)	Sandstone: quartzose, very fine grained, well sorted, massive, light grey; silica cemented, permeable and slightly friable; minor interbeds of well indurated, medium grey mudstone (2 m pres.).
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2010.0 to 2019.0 (612.6 to 615.4)	No recovery.
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DUPEROW FORMATION

Limestone, grey white, microcrystalline, saccharoidal, featuring abundant molds of fossils, leached and dedolomitized(?).

Depth in feet (m)	CANTUAR FORMATION Rex Member
2289.0 to 2295.0 (697.7 to 699.5)	Mudstone: silty, medium grey, moderately indurated; abundant muscovite, trace of carbonaceous plant films, and red ironstone nodules; sharp irregular contact.
	Lloydminster Member
2295.0 to 2296.5 (699.5 to 700.0)	Sandstone: quartzose, very fine grained, bedded and cross-bedded, calcite cemented, stained hematite red on light grey, trace of burrows; microfaulted.
2296.5 to 2317.0 (700.0 to 706.2)	Mudstone: sandy, weakly indurated (apparently an interbedded mudstone and argillaceous, quartzose, very fine grained sandstone), medium grey.
2317.0 to 2324.0 (706.2 to 708.4)	Sandstone: quartzose, very argillaceous, earthy, moderately indurated, abundant red ironstone nodules, faintly trough cross-bedded.
2324.0 to 2427.0 (708.4 to 739.7)	No recovery.
	GRAVELBOURG FORMATION Lower Member
2427.0 to 2432.0 (739.7 to 741.3)	Shale: calcareous, silty, dark grey, laminated with sandstone: quartzose, very fine grained, argillaceous, dark green grey; abundant muscovite, pelecypod shell fragments.
2432.0 to 2437.0 (741.3 to 742.8)	Limestone: subordinate quartzose silt, pseudo-oolites and shell fragments, well cemented; buff grey speckled with black, finely disseminated pyrite.
2437.0 to 2439.0 (742.8 to 743.4)	Shale: dark grey, calcareous, abundant pelecypod shells.
2439.0 to 2454.0 (743.4 to 748.0)	Calclutite: tan, hard (cryptocrystalline), faintly bedded, abundant impressions of small pelecypods.
2454.0 to 2459.0 (748.0 to 749.5)	Shale, grey black, calcareous, glauconitic, and pyritic in patches.
	WATROUS FORMATION Upper Member
2459.0 to 2470.0 (749.5 to 752.9)	Dolomite: cryptocrystalline, tan, dense.
2470.0 to 2555.0 (752.9 to 778.8)	Dolomite: cryptocrystalline, subordinate anhydritic nodules, tan, dense; interbedded with subordinate dense, white, crystalline anhydrite.
2555.0 to 2563.0 (778.8 to 781.2)	Mudstone: dolomitic, red brown, minor blebs of white gypsiferous anhydrite.
2563.0 to 2572.0 (781.2 to 783.9)	Anhydrite: crystalline, dense, thinly interbedded with subordinate red shale.

Depth in feet (m)	CANTUAR FORMATION Waseca Member
1784.0 (543.8)	Mudstone: concretionary; yellow brown, hard; sharp, irregular basal contact (0.04 m thick). <i>Bedding Cycle 2 (1.6 m)</i>
1784.0 to 1789.5 (543.8 to 545.4)	Shale: dark grey, silty; laminated with subordinate argillaceous, very fine grained, quartzose sandstone, medium grey, bioturbated; sharp irregular contact sloping about 20°. <i>Bedding Cycle 1 (1.4 m)</i>
1789.5 to 1794.0 (545.4 to 546.8)	Sandstone: quartzose, fine grained, subangular; abundant carbonaceous grains; scattered oxidized sphaerosiderite; argillaceous to silty matrix, calcite cemented, somewhat friable, medium grey but oxidized yellow brown at 545.6 to 546.2 m; reduced to medium grey at top; strongly but variably trough cross-bedded; abundant coaly tree fragments and reeds nestled in channel cuts; sharp flat basal contact. Sparky Member <i>Bedding Cycle 3 (4.0 m)</i>
1794.0 to 1796.0 (546.8 to 547.4)	Mudstone: earthy, massive, medium grey, moderately indurated, scattered carbonaceous flakes.
1796.0 to 1806.0 (547.4 to 550.5)	Sandstone: quartzose, fine grained, subangular; laminated with subordinate medium grey, burrowed (skolithos) shale; thin low-angle truncation sets throughout.
1806.0 to 1807.0 (550.5 to 550.8)	Shale: medium grey, grading into mudstone, massive; some quartzose sandstone laminae in upper half; sharp irregular contact sloping 30°. <i>Bedding Cycle 2 (0.3 m)</i>
1807.0 to 1808.0 (550.8 to 551.1)	Sandstone: quartzose, fine grained, well sorted, light grey, grain-contact silica cemented, friable, abundant muscovite; flat-bedded and ripple cross-laminated; ripples coated with grey black carbonaceous detritus; sharp contact. <i>Bedding Cycle 1 (1.7 m)</i>
1808.0 to 1811.0 (551.1 to 552.0)	Shale: dark grey, hackly (bentonitic), interbedded with medium grey mudstone, massive.
1811.0 to 1813.5 (552.0 to 552.8)	Sandstone: quartzose, fine grained, medium grey, current bedded; bedding lined with dark grey argillaceous siltstone; silica and iron cement; laminated with dark grey shale and abundant carbonaceous specks and flakes; argillaceous content increases to dominant downward as sandstone becomes flasers, lenticles and bioturbation pods; sharp contact. General Petroleums Member <i>Bedding Cycle 4 (6.8 m)</i>
1813.5 to 1814.5 (552.8 to 553.1)	Claystone: dark grey, blocky; abundant carbonized plant fragments; sharp contact.
1814.5 to 1819.0 (553.1 to 554.4)	Mudstone: sandy, medium greenish grey, well indurated, blocky; subordinate lenoid channel infill of argillaceous, fine-grained, quartzose sandstone; subordinate laminae of ripple-bedded sandstone at base.
1819.0 to 1822.0 (554.4 to 555.3)	Mudstone: clayey, dark grey; subordinate laminae of fine-grained, light grey, quartzose sandstone; crenulated and distorted in part.

1822.0 to 1830.5 (555.3 to 557.9)	Mudstone: medium grey, silty, blocky to massive; irregular beds of very argillaceous, fine-grained, quartzose sandstone; scattered iron-stained lenticles, nodules and carbonized plant fragments.
1830.5 to 1832.5 (557.9 to 558.5)	Sandstone: quartzose, very fine grained, argillaceous matrix, massive, concretionary, brown iron stained; medium grey.
1832.5 to 1836.0 (558.5 to 559.6)	Sandstone: quartzose, very fine grained, argillaceous, massive; minor partings of shale, dark grey; scattered iron-stained lenses; sharp irregular contact on brown iron-cemented layer and rubble of ironstone pebbles over basal 0.3 m; sharp irregular basal contact.
<i>Bedding Cycle 3 (3.8 m)</i>	
1836.0 to 1837.0 (559.6 to 560.0)	Sandstone: quartzose, fine grained, very argillaceous, well indurated, medium grey; becomes brown iron stained and cemented with decrease in grain size as bed grades into
1837.0 to 1848.5 (560.0 to 563.4)	Mudstone: clayey, massive, blocky, medium grey; scattered carbonized plant fragments and hematite red ironstone nodules; sharp contact.
<i>Bedding Cycle 2 (1.1 m)</i>	
1848.5 to 1850.0 (563.4 to 563.9)	Sandstone: quartzose, very fine grained, medium grey, current and ripple bedded, friable, lenticular; laminated with dark grey shale; mostly cemented with brown siderite in massive beds and along silty laminae.
1850.0 to 1852.0 (563.9 to 564.5)	Sandstone: quartzose, very fine grained, laminated with shale; grades into shale, dark grey, laminated with and draping lenticles, pods, and rolls of light grey sandstone.
<i>Bedding Cycle 1 (2.1 m)</i>	
1852.0 to 1859.0 (564.5 to 566.6)	Sandstone: quartzose, very fine grained, light grey; abundant carbonaceous specks; trough cross-bedded with channel cut-and-fill and truncation sets; laminated beds draping lenses; channel-fill sandy bodies 0.1 to 0.45 m thick, alternate with black shale thinly interbedded (0.06 m spacing) with laminated silt and black shale; burrowed, bioturbated, and thixotropically deformed; sharp basal contact.
Rex Member	
<i>Bedding Cycle 4 (3.4 m)</i>	
1859.0 to 1868.0 (566.6 to 569.4)	Mudstone: medium green grey, massive, blocky, well indurated; grades by sandstone laminae to
1868.0 to 1870.0 (569.4 to 570.0)	Sandstone: quartzose, very fine grained, grey white, laminated with green-grey mudstone; grades into sandstone, argillaceous, grey black; abundant oblique burrows over basal 0.15 m.
<i>Bedding Cycle 3 (4.9 m)</i>	
1870.0 to 1872.0 (570.0 to 570.6)	Mudstone: medium green grey, massive, blocky, scattered ironstone nodules.
1872.0 to 1882.0 (570.6 to 573.6)	Sandstone: quartzose, fine grained, well sorted, ripple drift, finely cross-bedded, interrupted by subordinate small-scale trough cross-beds; calcite cemented, rusted buff. Laminated siltstone and shale, light and dark grey at 571.5 m; some carbonaceous debris on laminae at 573.0 m.
1882.0 to 1886.0 (573.6 to 574.9)	No recovery.
1886.0 (574.9)	Sandstone: as at 570.6 m, sharp contact (0.076 m thick).

Bedding Cycle 2 (2.7 m)

1886.0 to 1895.0
(574.9 to 577.6) Mudstone: dark grey, massive, platy, abundant carbonized plant fragment; scattered coaly twigs coated with green glauconite; scattered iron-stained bands.

Bedding Cycle 1 (5.5 m)

1895.0 to 1913.0
(577.6 to 583.1) Sandstone: quartzose, very fine grained, very argillaceous, dark grey; minor interbeds of mudstone above decreasing downward; subordinate medium grey, bedding-aligned pods of very fine grained quartzose sand over lower half; abundant partings of carbonized reeds and palmate leafs throughout; scattered pyritic nodular bodies up to 0.03 m across; brown iron-oxide cementation of sandy beds 0.03 to 0.15 m thick at intervals of 0.3 m to 0.6 m. Mudstone at 582.5 to 583.1 m; sharp contact; microfaulted at 580.9 m.

Lloydminster Member

Bedding Cycle 5 (1.2 m)

1913.0 to 1914.0
(583.1 to 583.4) Sandstone: quartzose, fine grained, medium grey, well sorted, subangular to subrounded; abundant black carbonaceous grains, scattered muscovite; weak cement, very permeable; oblique faulted contact.

1914.0 to 1917.0
(583.4 to 584.3) Mudstone: dark grey, massive, platy, abundant carbonized plant fragments; bed of argillaceous, very fine grained, quartzose sandstone, laminated with dark grey mudstone, bioturbated, lenticular and podded at 583.7 m; microfaulted and slickensided; sharp basal contact.

Bedding Cycle 4 (1.2 m)

1917.0 to 1921.0
(584.3 to 585.5) Sandstone: quartzose, fine grained, moderately sorted, silica and iron cemented; reddish brown below 584.9 m, light grey and weakly indurated above; abundant carbonized plant fragments, rootlet-turbated bedding, yellow sulphur coating pyrite-rich layer, sphaeropyrite and brown siderite. Basal 0.15 m is bioturbated, fluted and tool-marked on dark grey argillaceous partings; sharp contact.

Bedding Cycle 3 (2.2 m)

1921.0 to 1922.0
(585.5 to 585.8) Mudstone: dark grey, platy, well indurated; scattered brown ironstone nodules and reed-like carbonized plant fragments; sharp(?) contact.

1922.0 to 1928.0
(585.8 to 587.7) Sandstone: quartzose, fine grained, moderately sorted, light grey, friable, very permeable; minor dark grey shale laminae; evidence of bioturbation, shearing and faulting (50% lost); iron stained at base; sharp contact.

Bedding Cycle 2 (6.1 m)

1928.0 to 1948.0
(587.7 to 593.8) Mudstone: dark grey, blocky, scattered iron-stained nodules; interbedded with sandstone, quartzose, very fine grained and argillaceous, medium grey; severely microfaulted with offsets of obliquely dipping blocks of laminated and podded siltstone and mudstone. In that the mudstone is thoroughly fragmented by coring, entire unit may be microfaulted. Basal conglomerate, 0.025 to 0.05 m thick, of dark brown sideritic mudstone and dark grey mudstone embedded and cemented in subjacent sandstone.

Bedding Cycle 1 (2.7 m)

1948.0 to 1952.0
(593.8 to 595.0) Sandstone: quartzose, medium grained, well sorted, microfaulted, abundant white kaolinite grains, feldspar; dark grey, iron stained rust brown and calcite cemented over upper 0.6 m; uncemented and mostly lost, below.

1952.0 to 1957.0
(595.0 to 596.5) Shale: dark grey, platy, well indurated, flat streaks of brown iron stain; sharp undulatory contact.

Cummings Member
Bedding Cycle 3 (3.0 m)

- 1957.0 to 1959.5
(596.5 to 597.3) Sandstone: quartzose, very fine grained, argillaceous, dark grey; laminated with subordinate black shale; strongly contorted; coaly shale beds at top (0.08 m) and base (0.15 m); sharp contact.
- 1959.5 to 1967.0
(597.3 to 599.5) Sandstone: quartzose, very fine grained, well sorted, grey white, friable; massive beds with abundant carbonaceous plant fragments, stalks, root filaments; microfaulted; below 598.0 m sandstone is laminated and low-angled cross-laminated with subordinate black carbonaceous shale; massive, argillaceous and grey black below 599.2 m as unit grades into dark grey mudstone; sharp(?) contact.

Bedding Cycle 2 (1.9 m)

- 1967.0 to 1971.0
(599.5 to 600.8) Sandstone: quartzose, fine grained, subordinate very fine, light grey, friable, massive; grades below 600.0 m into laminated siltstone and dark grey shale, podded and bioturbated; grades into
- 1971.0 to 1973.0
(600.8 to 601.4) Mudstone: dark grey, massive, well indurated.

Bedding Cycle 1 (1.8 m)

- 1973.0 to 1979.0
(601.4 to 603.2) Sandstone: quartzose, very fine grained, medium grey, bioturbated; laminated with dark grey shale; bioturbation decreases downward to flasers and lenticles as rock grades through a dark grey mudstone, then black carbonaceous shale; abundant brown ironstone nodules and glauconitic pods downward over upper half.

Dina Member
Unit 3 *Bedding Cycle 3 (2.7 m)*

- 1979.0 to 1982.0
(603.2 to 604.1) Sandstone: quartzose, very fine grained, well sorted, friable; minor laminae of black calcareous shale.
- 1982.0 to 1988.0
(604.1 to 605.9) Sandstone: very fine grained, argillaceous, grey black, intermixed with black mudstone; podded and bioturbated, moderately indurated; subordinate shaly beds, dominantly a dark grey mudstone over basal 0.6 m.

Unit 2 *Bedding Cycle 2 (1.6 m)*

- 1988.0 to 1993.0
(605.9 to 607.5) Sandstone: quartzose, fine grained, dark grey, poorly sorted with abundant medium grains; abundant plant fragments, friable, weakly indurated; upper 0.30 m is carbonaceous and silty, well indurated (high loss of friable portion).

Bedding Cycle 1 (3.0 m)

- 1993.0 to 1996.0
(607.5 to 608.4) Shale: black, carbonaceous, with partings of carbonized plant fragments; grades into sub-bituminous coal at 607.9 to 608.2 m; conspicuous pyritic bodies; grades into
- 1996.0 to 1996.5
(608.4 to 608.5) Mudstone: massive, grey black, abundant carbonized plant fragments, massive; grades into
- 1996.5 to 2002.0
(608.5 to 610.2) Sandstone: quartzose, very fine grained, medium grey; minor laminae and thin crenulated and wavy beds of black carbonaceous shale; grade size increase downward to
- 2002.0 to 2003.0
(610.2 to 610.5) Sandstone: quartzose, dark grey, fine grained to medium, well sorted, faceted, friable, abundant white kaolinite after feldspar and dark grey chert; sharp contact.

WATROUS FORMATION

- 2003.0 to 2007.0
(610.5 to 611.7) Dolomite: argillaceous, light grey with pink and tan overtones, microcrystalline in part.

Depth in feet (m)	CANTUAR FORMATION Waseca Member
3390.0 to 3401.0 (1033.3 to 1036.6)	Sandstone: quartzose, fine grained, well sorted; scattered white kaolinite grains, muscovite; medium brown grey, fine bedded, some carbonaceous laminae; traces of vertical and lateral burrows; irregularly interbedded with very fine grained, quartzose, argillaceous sandstone, abundant carbonaceous specks, brown ironstone stringers; permeable and friable.
3401.0 to 3402.5 (1036.6 to 1037.1)	Conglomerate: flat sandstone pebble and mudstone rip-up clasts; weakly indurated, medium grey brown.
3402.5 to 3407.5 (1037.1 to 1038.6)	Sandstone: quartzose, very fine grained, with subordinate interbeds of fine as at 1033.3 m.
3407.5 to 3410.0 (1038.6 to 1039.4)	Conglomerate: as at 1036.6 m.
3410.0 to 3415.0 (1039.4 to 1040.9)	Sandstone: quartzose, very fine grained, weakly argillaceous, medium grey brown; strongly contorted and microfaulted (penecontemporaneous); mottled with alternating randomly oriented stringers of red-brown mudstone and black coal; moderately indurated; earthy.
General Petroleums Member	
3415.0 to 3423.0 (1040.9 to 1043.3)	Sandstone: quartzose, fine grained, well sorted, subrounded; medium grey brown; traces of white kaolinite, red siderite, muscovite; moderately indurated, very permeable; trough cross-bedded at intervals of 0.05 to 0.08 m; minor buff clay laminae over lower half.
3423.0 to 3426.5 (1043.3 to 1044.4)	Sandstone: quartzose, very fine grained, medium grey brown, weakly argillaceous; laminated with dark grey silty shale; abundant carbonaceous plant fragments.
3426.5 to 3437.5 (1044.4 to 1047.8)	Sandstone: as at 1040.9 m; includes green-grey claystone pebbles, coaly tree fragments and coal balls; sharp(?) basal contact.
Rex Member Bedding Cycle (6.9 m)	
3437.5 to 3461.5 (1047.8 to 1055.1)	Sandstone: fine grained with subordinate medium and very fine, quartzose, subordinate black chert, white kaolinite, pink feldspar, green chlorite, white feldspar, brown siderite, medium grey translucent chert; well indurated in white siliceous kaolinite reinforced with calcite, speckled white and black; generally massive with a suggestion of steep cross-bedding.
3461.5 to 3491.0 (1055.1 to 1064.1)	Sandstone: as at 1047.8 m; interbedded at 0.3 m intervals with sandstone: coarsely laminated with transported carbonized plant debris; cross-bedding ranges from moderately dipping (12°) to low-angle, current rippled; sharp irregular contact.
Lloydminster Member	
3491.0 to 3496.5 (1064.1 to 1065.7)	Shale: olive, concretionary, intermixed with fragments of fine-grained, quartzose sandstone (presumably from underlying unit).
3496.5 to 3502.0 (1065.7 to 1067.4)	Sandstone: quartzose, medium grained, scattered grains of white kaolinite, well sorted, weakly indurated, very permeable, medium grey brown; tabular cross-beds dipping at low angle to 15°; scattered conglomeratic lenses of siliceous, green-grey, mudstone pebbles and woody fragments; blebs of kaolinitic, buff mudstone over lower half.

Depth in feet (m)	Core 1700 to 2060 feet (518.2 to 627.9 m)
	JOLI SHALE
1779.0 to 1791.0 (542.2 to 545.0)	Shale: dark grey, hard, platy; abundant flasers of light grey, calcite-cemented, very fine-grained, quartzose sandstone; grey brown, iron-cemented (siderite and finely disseminated pyrite) mudstone beds 0.05 to 0.1 m thick, with sharp irregular contacts at 544.5 and 544.8 m; include traces of spherulites, pelecypod shells and hystrichospheres.
1791.0 to 1799.0 (545.9 to 548.3)	Shale: dark grey; irregularly laminated and thinly interbedded with light grey, silica-cemented, bioturbated, current-bedded and flasered, quartzose sandstone; scattered lensoid pyritic nodules; grades into
	PENSE FORMATION
	<i>Bedding Cycle 4 (3.1 m)</i>
1799.0 to 1809.0 (548.3 to 551.4)	Sandstone: quartzose, fine grained; medium yellowish grey argillaceous matrix; lenticular, flasered, scoured contacts, bioturbated (mostly bedding aligned pods); black shaly partings downward from 550.8 m; sharp, basal contact on current scoured surface.
	<i>Bedding Cycle 3 (0.3 m)</i>
1809.0 to 1810.0 (551.4 to 551.7)	Sandstone: quartzose, fine grained; moderately indurated with about 10% clay; friable, permeable; sharp irregular contact.
	<i>Bedding Cycle 2 (6.4 m)</i>
1810.0 to 1813.0 (551.7 to 552.6)	Sandstone, quartzose, fine grained, well sorted, calcite cemented, medium blue grey; scattered stylolitic argillaceous laminae and partings.
1813.0 to 1816.0 (552.6 to 553.5)	Sandstone: quartzose, fine grained, argillaceous; medium grey, very fine grained over lower 0.15 m; subordinate partings of crenulated black shale; abundant bedding-aligned burrow pods; grades into
1816.0 to 1831.0 (553.5 to 558.1)	Shale: black; subordinate lenticular laminae of medium grey, stretched and boudinaged sandstone between 553.5 to 554.1 m, decreasing to traces below; brown, iron-cemented bed at 557.0 to 557.2 m; contact not seen.
	<i>Bedding Cycle 1 (3.3 m)</i>
1831.0 to 1842.0 (558.1 to 561.4)	Sandstone: quartzose, fine grained argillaceous, medium grey; faintly bedded and bioturbated; basal contact sharp and underlies large pyrite nodule.
	CANTUAR FORMATION
	Waseca Member
	<i>Bedding Cycle 1 (9.5 m)</i>
1842.0 to 1873.0 (561.4 to 570.9)	Mudstone: medium grey, massive, platy, siliceous at 565.1 to 566.6 m; yellow-brown iron-stained nodular mottling at 566.6 to 568.1 m; dark grey claystone with carbonaceous plant material and pyritic masses over basal 0.3 m.
	Sparky Member
	<i>Bedding Cycle (1.5 m)</i>
1873.0 to 1878.0 (570.9 to 572.4)	Sandstone: quartzose, fine grained, friable, light grey; thinly interbedded with sandstone, very fine grained, quartzose, light grey, and subordinate mudstone, medium grey; generally flat-bedded with traces of ripple-laminae; sharp contact.

General Petroleum Member

Bedding Cycle 2 (1.2 m)

1878.0 to 1882.0
(572.4 to 573.6) Sandstone, quartzose, bimodal, medium and fine grained; moderately indurated, low argillaceous content, friable, permeable; low-angle trough cross-bedding indicated by slivers of carbonized plant fragments.

Bedding Cycle 1 (7.5 m)

1882.0 to 1886.5
(573.6 to 575.0) Sandstone: quartzose, very fine and fine grained, argillaceous; current bedded; minor laminated sandstone and grey black shale; abundant carbonized reeds, leaves and smaller plant fragments; patchy brown iron cementation.

1886.5 to 1906.5
(575.0 to 581.1) Mudstone: silty to clayey, generally massive, faintly mottled, medium to dark grey; scattered irregular partings of carbonized woody material; well indurated; basal 0.3 m sandy.

Rex Member

Bedding Cycle 4 (2.7 m)

1906.5 to 1915.5
(581.1 to 583.8) Sandstone: quartzose, fine grained, well sorted; grades downward by alternation to medium; well indurated in tan kaolinite; thin low-angle (<10°) truncation sets, ripple drifts and troughs, outlined by carbonized plant detrital and iron-stained sideritic laminae; carbonaceous detritus abundant throughout; sharp contact.

Bedding Cycle 3 (1.0 m)

1915.5 to 1918.5
(583.8 to 584.8) Sandstone: quartzose, very fine grained, medium grey; current laminated with dark grey shale; grey black and carbonaceous at 584.5 to 584.6 m; basal contact sharp and irregular.

Bedding Cycle 2 (1.5 m)

1918.5 to 1923.5
(584.8 to 586.3) Sandstone: quartzose, very fine grained, argillaceous (kaolinitic), tan, well indurated, current bedded; minor carbonized plant detrital layers; grades over lower half to sandstone, quartzose, fine grained, kaolinite indurated, speckled with brown siderite, glauconite and kaolinite pseudomorphic after feldspar; large (0.1 m long) pyrite-infilled vertical burrow near base; strongly bioturbated at top.

Bedding Cycle 1 (2.6 m)

1923.5 to 1928.0
(586.3 to 587.7) Sandstone: quartzose, very fine grained, argillaceous, tan; thinly interbedded with dark grey shale; sandstone is lenticular, current bedded with small-scale channel forms; shale includes small sandy burrow pods.

1928.0 to 1932.0
(587.7 to 588.9) Sandstone: quartzose, very fine grained, tan; fine-bedded with wavy forms and dark grey, shale drapes on truncation sets; grades into mudstone, silty, massive, light grey.

Lloydminster Member

Bedding Cycle 2 (2.3 m)

1932.0 to 1934.5
(588.9 to 589.9) Mudstone, dark grey, intermixed with contorted, light grey, argillaceous, quartzose, very fine grained sandstone; oxidized red brown at upper 0.2 m.

1934.5 to 1938.0
(589.9 to 590.7) Sandstone: quartzose, fine grained, well sorted, interbedded with very fine grained; herringbone cross-beds; friable, moderately indurated, with tan silty claystone; permeable as indicated by diesel oil infiltration; medial very fine grained strongly contorted sandstone bed (0.3 m thick); sharp contact.

1938.0 to 1939.5
(590.7 to 591.2) Shale: dark grey, abundant siltstone pods and lenticles; thinly interbedded with downward increasing very fine grained sandstones, quartzose, argillaceous, tan coloured.

Bedding Cycle 1 (6.1 m)

1939.5 to 1955.0 (591.2 to 595.9)	Sandstone: quartzose, very fine and fine grained, moderately indurated; thinly bedded with low-angle cross-laminae in shale draped sets, permeable.
1955.0 to 1959.5 (595.9 to 597.3)	Shale: dark grey; laminated with subordinate very fine grained quartzose sandstone; abundant vertical burrows; cross-laminated sandstone is massive and dominant over basal 0.1 m; sharp contact.

Cummings Member
Bedding Cycle 1 (3.5 m)

1959.5 to 1961.0 (597.3 to 597.7)	Mudstone: dark grey to black and coaly downward, abundant carbonaceous films and filaments.
1961.0 to 1971.0 (597.7 to 600.8)	Sandstone: quartzose, very fine and fine grained, well sorted, tan, ripple-drift bedded, weak to moderate induration, very permeable.

Dina Member
Bedding Cycle 2 (4.2 m)

1971.0 to 1972.0 (600.8 to 601.1)	Sandstone: quartzose, very fine grained, argillaceous, carbonaceous, grey mixed with black.
1972.0 to 1985.0 (601.1 to 605.0)	Sandstone: quartzose, fine grained, well sorted, tan, moderately indurated at 601.1 to 602.6 m, unindurated below; scattered laminae groups lined with plant detritus; very permeable.

Bedding Cycle 1 (5.0 m)

1985.0 to 1989.0 (605.0 to 606.2)	Mudstone: grey black; lenticular laminae of tan, quartzose sandstone at top; clayey down to 605.9 m.
1989.0 to 2001.0 (606.2 to 610.0)	Sandstone: quartzose, fine grained, medium grey, argillaceous; moderate to weakly indurated, massive, permeable; sharp, irregular contact.

BIG VALLEY FORMATION

2001.0 (610.0)	Shale: pale grey green, hard, platy, calcareous.
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Duval Saskatoon 6-18-36-6(W3)

KB 1659.1 feet (505.7 m)

Depth in feet (m)	JOLI FOU FORMATION
1569.0 to 1570.0 (478.2 to 478.5)	Shale: grey black, blocky; minor lenticles and partings of medium grey, very fine-grained, quartzose sandstone.
1570.0 to 1571.5 (478.5 to 479.0)	Mudstone: dark grey, massive, faint bioturbational stippling; sharp contact.
	PENSE FORMATION <i>Bedding Cycle 4 (6.5 m)</i>
1571.5 to 1573.5 (479.0 to 479.6)	Sandstone: quartzose, fine grained, wavy herringbone cross-lamination, medium grey, weakly indurated; permeable except for 0.13 m thick calcite-cemented bed at top; interbedded with subordinate laminated grey-black shale and very fine grained sandstone.
1573.5 to 1580.0 (479.6 to 481.5)	Sandstone: quartzose, bimodal, fine grained with subordinate medium, variable silt content; abundant finely disseminated pyrite and nodular pyrite aggregates; well

	indurated though permeable; traces of wavy cross-bedding; minor thin black shale draping wavy sandy forms and crisscrossed with tubular trails.
1580.0 to 1591.0 (481.5 to 484.9)	Sandstone: quartzose, fine and very fine grained; severely bioturbated with mostly lateral feeding burrows and minor vertical and oblique escape burrows; calcite cemented, medium blue grey; minor crenulated, thin, grey-black shale; argillaceous content increases downward.
1591.0 to 1593.0 (484.9 to 485.5)	Shale: grey black, minor laminae and lenticles of light grey, very fine grained quartzose sandstone.
	<i>Bedding Cycle 3 (3.4 m)</i>
1593.0 to 1600.0 (485.5 to 487.7)	Sandstone: quartzose, very fine grained, light grey; starved ripples and lenticles draped and laminated with grey-black shale; abundant bedding aligned burrows; permeable, well sorted, current-bedded sandstone, 0.08 m thick, at 486.0 m.
1600.0 to 1604.0 (487.7 to 488.9)	Shale: grey black, hard; ironstone beds, 0.09 and 0.1 m thick, at 488.0 and 488.7 m respectively.
	<i>Bedding Cycle 2 (2.4 m)</i>
1604.0 to 1612.0 (488.9 to 491.3)	Sandstone: quartzose, very fine grained, very argillaceous, dark grey and grey black; strongly bioturbated, massive and well indurated; sharp wavy contact marked by feeding burrow forms.
	<i>Bedding Cycle 1 (2.5 m)</i>
1612.0 to 1620.0 (491.3 to 493.8)	Sandstone: quartzose, very fine grained grading downward to medium, trough cross-bedded; ironstone lieegang and calcite cemented (light blue grey) at top and basal 0.3 m; otherwise, moderately indurated, porous and permeable; scattered wavy black shale drapes; sharp undulatory contact.
	CANTUAR FORMATION
	Waseca Member
	<i>Bedding Cycle 4 (3.0 m)</i>
1620.0 to 1630.0 (493.8 to 496.8)	Sandstone: quartzose, fine grained, increasing to medium downwards; well sorted, light grey clay matrix; moderately to weakly indurated, permeable, earthy; bedding poorly developed; bedded aggregates, 0.14 m thick, of coarse grained sphaerosiderites near base.
	<i>Bedding Cycle 3 (8.3 m)</i>
1630.0 to 1632.0 (496.8 to 497.4)	Claystone: grey white; subordinate coarse grained, dark red-brown sphaerosiderites; massive, moderately indurated.
1632.0 to 1657.0 (497.4 to 505.1)	Claystone interbedded with mudstone: light to dark lavender grey; minor beds of sandy mudstone, scattered layers of carbonized plant fragments.
	<i>Bedding Cycle 2 (3.3 m)</i>
1657.0 to 1668.0 (505.1 to 508.4)	Sandstone: quartzose, very fine grained, well sorted, moderately indurated, friable, permeable, light grey, current bedded; minor dark grey shale laminae; conspicuous, rounded ripple forms, shale drapes and bioturbation over lower half.
	<i>Bedding Cycle 1 (1.4 m)</i>
1668.0 to 1671.0 (508.4 to 509.3)	Mudstone: medium lavender grey, blocky to splintery.
1671.0 to 1672.5 (509.3 to 509.8)	Sandstone: quartzose, very fine grained, argillaceous, current bedded, with wavy lenticular sandstone in grey black shale increasing downward; contorted at top.

Sparky Member
Bedding Cycle 1 (9.9 m)

- 1672.5 to 1677.0
(509.8 to 511.1) Mudstone: as at 508.4 m (0.2 m present), scattered carbonized rootlets; sharp irregular contact(?).
- 1677.0 to 1690.0
(511.1 to 515.1) Sandstone: quartzose, very fine grained, argillaceous; current bedded in part but mostly bioturbated; contorted over upper 0.5 m; interbedded with grey black shale, 0.4 m thick, below 514.2 m.
- 1690.0 to 1705.0
(515.1 to 519.7) Shale: grey black; irregularly laminated and thinly interbedded with downward decreasing subordinate sandstone: quartzose, very fine grained, medium grey, lenticular, wavy topped, starved rippled and bioturbation podded; sharp irregular contact.

General Petroleums Member
Bedding Cycle 2 (3.3 m)

- 1705.0 to 1716.0
(519.7 to 523.0) Sandstone: quartzose, very fine grained, well sorted, light grey, moderately indurated, porous, permeable; scattered coaly laminae; dark grey, argillaceous sandy mudstone with abundant interlayered sandy *Chondrites* over lower half; lower part of sequence includes wavy bedded, well sorted, very fine grained, quartzose sandstone, 0.1 m thick.

Bedding Cycle 1 (4.0 m)

- 1716.0 to 1721.0
(523.0 to 524.6) Claystone: massive, medium green grey, root burrowed, caliche layered and calcite cemented toward base.
- 1721.0 to 1727.0
(524.6 to 526.4) Sandstone: quartzose, fine grained to very fine, moderately indurated, friable, light grey, massive, permeable, penecontemporaneous distortion delineated by calcite-cemented flare structures; thinly interbedded below 525.2 m with subordinate dark grey shale, ripple laminated with glauconitic sandstone; grades into
- 1727.0 to 1729.0
(526.4 to 527.0) Shale: dark grey, hard, siliceous; subordinate laminae, lenticles and pods of very fine grained, light grey, quartzose sandstone (0.10 m thick at base); irregular contact?

Rex Member
Bedding Cycle 4 (6.1 m)

- 1729.0 to 1730.0
(527.0 to 527.3) Sandstone: quartzose, fine to very fine grained, argillaceous, massive; moderately indurated, earthy, poorly sorted (resembles a sandy loam with blocky structure).
- 1730.0 to 1732.0
(527.3 to 527.9) Mudstone: irregular, thin, dark grey, flowage fabric; interbedded with sandstone: quartzose, very fine grained, medium grey, hard, silicious.
- 1732.0 to 1734.0
(527.9 to 528.5) Sandstone: quartzose, very fine grained, grading downward to medium; poorly sorted, massive, argillaceous, abundant bedding aligned carbonized plant fragments.
- 1734.0 to 1736.0
(528.5 to 529.1) Shale: grey black carbonaceous; laminated with very fine grained, light grey, ripple marked and podded, quartzose sandstone.
- 1736.0 to 1749.0
(529.1 to 533.1) Sandstone: quartzose, fine grained, well sorted, poorly indurated, very permeable; generally flat bedded, but with thin (1 cm) low-angle truncation sets lined with carbonized plant detritus over basal 0.6 m; sharp(?) contact.

Bedding Cycle 3 (3.0 m)

- 1749.0 to 1759.0
(533.1 to 536.1) Sandstone: quartzose, very fine grained, argillaceous, medium and dark grey; abundant carbonaceous plant detritus as laminae and rootlet casts; lower half laminated and bioturbated with dark grey shale.

Bedding Cycle 2 (3.1 m)

- 1759.0 to 1760.5
(536.1 to 536.6) Shale: grey black, hard, platy; faintly bedded; scattered carbonized plant fragments.

1760.5 to 1769.0 (536.6 to 539.2)	Sandstone: quartzose, very fine grained, subordinate fine; massive with traces of vertical roots over upper half; flowage and flame layering intergradational with thin interbeds of lenticular and podded sandstone and dark grey shale.
	<i>Bedding Cycle 1 (3.3 m)</i>
1769.0 to 1770.5 (539.2 to 539.6)	Coal: shaly grading into carbonaceous shale.
1770.5 to 1780.0 (539.6 to 542.5)	Sandstone: quartzose, very fine grained, subordinate fine, medium grey, massive; grades downward into mudstone, dark grey, bioturbated.
	Lloydminster Member
	<i>Bedding Cycle 4 (9.8 m)</i>
1780.0 to 1786.5 (542.5 to 544.5)	Mudstone: dark grey, massive, hard, platy; scattered carbonized plant fragments.
1786.5 to 1790.0 (544.5 to 545.6)	Sandstone: quartzose, very fine grained, light grey, current-laminated with subordinate dark grey shale; interbedded over basal 0.3 m with
1790.0 to 1812.0 (545.6 to 552.3)	Sandstone: quartzose, fine grained increasing downward to medium, bimodal; argillaceous, earthy, grey-white kaolinitic matrix; low-angle trough cross-bedded; streaked with bedded aggregates of carbonized plant fragments; sharp irregular contact.
	<i>Bedding Cycle 3 (2.1 m)</i>
1812.0 to 1819.0 (552.3 to 554.4)	Sandstone: quartzose, fine grained; argillaceous, medium grey intermixed with grey black carbonaceous mudstone; strongly bioturbated and disrupted; cavitated rootlet bed at 553.4 to 553.8 m; grades into basal, black carbonaceous mudstone at 554.1 m.
	<i>Bedding Cycle 2 (1.7 m)</i>
1819.0 to 1823.0 (554.4 to 555.7)	Sandstone: quartzose, very fine grained, argillaceous, medium grey, rootlet burrowed, earthy, moderately indurated.
1823.0 to 1824.5 (555.7 to 556.1)	Shale: grey black, carbonaceous; subordinate lenticles of grey-white, quartzose, very fine grained sandstone.
	<i>Bedding Cycle 1 (2.0 m)</i>
1824.5 to 1831.0 (556.1 to 558.1)	Sandstone: quartzose, very fine grained, well sorted, light grey, massive and rootlet burrowed over upper half; wavy, ripple cross-bedded with minor black shale laminae drapes below; moderately indurated, friable, very permeable.
	Cummings Member
	<i>Bedding Cycle 2 (3.6 m)</i>
1831.0 to 1831.5 (558.1 to 558.2)	Coal: blocky.
1831.5 to 1843.0 (558.2 to 561.7)	Shale: dark grey, minor current laminae of sandstone: quartzose, very fine grained, light grey; sharp irregular contact.
	<i>Bedding Cycle 1 (7.4 m)</i>
1843.0 to 1856.5 (561.7 to 565.9)	Sandstone: quartzose, fine to very fine grained, well sorted, medium grey, moderately indurated, earthy, permeable; massive and blocky at 561.7 to 562.2 m; minor argillaceous thin beds below.
1856.5 to 1867.0 (565.9 to 569.1)	Sandstone: quartzose, fine to very fine grained, well sorted, medium grey, moderately indurated, earthy; wavy cross-laminated with dark grey shale drapes; interbedded with denser, sandstone, quartzose, dark grey, intermixed with crenulated, bioturbated and fragmented layers of light grey sandstone.

Dina Member
Bedding Cycle 1 (7.0 m)

1867.0 to 1868.0 (569.1 to 569.4)	Coal: blocky.
1868.0 to 1890.0 (569.4 to 576.1)	Sandstone: quartzose, very fine and fine-grained, low-angle trough cross-laminae lined with black carbonaceous detritus; weakly indurated, very permeable.

BIRDBEAR FORMATION

1890.0 (576.1)	Limestone: dense cryptocrystalline, nodular with stylolitic partings, medium blue grey over upper 0.6 m; light grey below.
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C.M.&S. Vanscoy 11-16-35-8(W3)

KB 1675 feet (510.5 m)

Depth in feet (m)

JOLI FOU FORMATION

1699.0 to 1703.0 (517.9 to 519.1)	Shale: black, hard; scattered bedding-aligned stringers of white, very fine grained, quartzose, sandstone; abundant pyrite nodules.
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PENSE FORMATION
Bedding Cycle 4 (1.8 m)

1703.0 to 1709.0 (519.1 to 520.9)	Sandstone: quartzose, very fine grained, dark grey argillaceous matrix, well indurated; minor lenticular and boudinaged layers of grey white, very fine grained, quartzose sandstone; basal contact sharp and irregular, and marked by a 0.02 m thick bed of calcite-cemented, dark grey-blue, pyrite-infiltrated calcarenite.
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Bedding Cycle 3 (0.3 m)

1709.0 to 1710.0 (520.9 to 521.2)	Siltstone: quartzose, argillaceous, dark grey; irregularly interbedded with calcite-cemented, dark blue-grey, pyritic, quartzose sandstone; erosional basal contact with relief of 0.06 m.
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Bedding Cycle 2 (6.4 m)

1710.0 to 1711.0 (521.2 to 521.5)	Grit: quartzose, subordinate white feldspar, calcite and brown siderite cemented, medium to dark grey; low-angle cross-bedded over upper third.
1711.0 to 1712.0 (521.5 to 521.8)	Sandstone: quartzose, very fine grained, argillaceous matrix, medium grey, well indurated, thin bedded; current-laminated lenticles and burrows; minor black shale with silt-infilled burrows.

1712.0 to 1725.0 (521.8 to 525.8)	Sandstone: as at 521.5 m, sandy lenticles include basal scoured contacts and boudins.
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1725.0 to 1731.0 (525.8 to 527.6)	Shale: black, well indurated; minor light grey sandy lenticles and burrows.
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Bedding Cycle 1 (3.5 m)

1731.0 to 1741.5 (527.6 to 530.8)	Sandstone: quartzose, very fine grained, dark grey, intermixed with black, and downward with grey mudstone; strongly bioturbated, massive, well indurated.
1741.5 to 1742.5 (530.8 to 531.1)	Sandstone: quartzose, fine grained, subordinate very fine; argillaceous, medium grey, moderately indurated, strongly bioturbated.

CANTUAR FORMATION

Waseca Member

Bedding Cycle 4 (6.0 m)

1742.5 to 1762.0
(531.1 to 537.1)

Mudstone: medium grey, massive, silty alternating with clayey at intervals of 0.6 to 1.5 m; abundant disseminated, brown coarse-grained sphaerosiderites at 532.2 to 535.8 m.

Bedding Cycle 3 (7.9 m)

1762.0 to 1771.0
(537.1 to 539.8)

Claystone: dark purplish grey, waxy to brittle, massive.

1771.0 to 1778.0
(539.8 to 541.9)

Sandstone: quartzose, very fine grained, medium grey argillaceous matrix, earthy, well indurated, massive; grades over basal 0.1 m to

1778.0 to 1788.0
(541.9 to 545.0)

Sandstone: quartzose, fine grained, increasing downward by alternation to medium and coarse grained; white kaolinite matrix; subordinate black carbonaceous grains, dark grey chert, and straw-coloured and brown siderites; scattered thin, carbonaceous, current-bedded laminae; dark grey mudstone conglomerate at 544.3 to 544.7 m. Moderate to weak induration, earthy, especially at 543.5 to 544.7 m.

Bedding Cycle 2 (9.3 m)

1788.0 to 1801.0
(545.0 to 548.9)

Sandstone: quartzose, medium grained, minerals as above, medium grey; calcareous with increased density and less porosity.

1801.0 to 1810.0
(548.9 to 551.7)

Sandstone: as above but noncalcareous; low-angle cross-laminated bed lined with black, carbonaceous detritus at 549.5 and 550.9 m; faint trough cross-sets throughout.

1810.0 to 1818.5
(551.7 to 554.3)

Sandstone: quartzose, medium to coarse grained downwards; subordinate black carbonaceous grains, dark grey chert, brown siderite; well indurated in calcareous kaolinite; light grey speckled with brown and black; trough cross-sets delineated by accessory minerals; coarse grained over basal 0.15 m.

Bedding Cycle 1 (2.7 m)

1818.5 to 1819.0
(554.3 to 554.4)

Shale: coaly, black; laminated with subordinate sandstone.

1819.0 to 1820.5
(554.4 to 554.9)

Gritstone: subordinate coarse- and medium-grained sand, quartzose; subordinate black carbonaceous grains, dark grey chert and siderite in white kaolinite; abundant medium grey, flat, siliceous claystone pebbles; subordinate low-angle cross-beds; sharp contact.

1820.5 to 1821.5
(554.9 to 555.2)

Claystone: medium grey, hard, siliceous; subordinate light grey, sandy lenticles; sharp irregular contact.

1821.5 to 1827.5
(555.2 to 557.0)

Conglomerate: flat mudstone pebbles and grit in coarse-grained, kaolinite-indurated, quartzose sand. Pebbles are brown clay ironstone, white kaolinite, grey and black carbonaceous mudstone, and plant fragments inclusive of large stems transecting the 0.10 m diameter core; sharp contact with relief exceeding 0.03 m.

Sparky Member

Bedding Cycle 1 (8.9 m)

1827.5 to 1830.0
(557.0 to 557.8)

Sandstone: quartzose, very fine grained, argillaceous, medium grey, current bedded with ripple drift; laminated with dark grey mudstone; abundant oblique burrow traces.

1830.0 to 1843.0
(557.8 to 561.7)

Sandstone: quartzose, very fine grained, medium grey argillaceous matrix, well indurated; traces of current beds, low-angle scour fills and flasers; minor increasing to subordinate dark grey mudstone drapes, laminae and lenticles with escape burrows; glauconitic nodule in scour surface at 559.6 m; grades into

1843.0 to 1856.0

Mudstone: dark grey; subordinate siltstone lenticles and laminae; abundant

(561.7 to 565.7) carbonaceous specks, oblique burrow traces abundant at 562.3 to 562.7 m; contact sharp and irregular.

1856.0 to 1856.5
(565.7 to 565.9) Shale: abundant nodular, olive, glauconitic masses, dark grey; sharp irregular contact.

General Petroleums Member

Bedding Cycle 3 (1.8 m)

1856.5 to 1859.5
(565.9 to 566.8) Sandstone: quartzose, medium grained, well sorted, grain-contact silica cemented (microcrystalline quartz); trough cross-laminae delineated by carbonaceous detrital layers over upper half; flat laminated below.

1859.5 to 1861.5
(566.8 to 567.4) Shale: dark grey; laminated with subordinate medium grey, lenticular, very fine grained sandstone; strongly bioturbated over lower half.

1861.5 to 1862.5
(567.4 to 567.7) Sandstone: quartzose, very fine grained, dark grey, argillaceous, massive, bioturbated; sharp contact.

Bedding Cycle 2 (1.1 m)

1862.5 to 1865.5
(567.7 to 568.6) Sandstone: quartzose, very fine grained, medium grey; trace of carbonized rootlets; strongly contorted, weak to moderate induration, porous, permeable; sharp contact.

1865.5 to 1866.0
(568.6 to 568.8) Shale: dark grey, siliceous, abundant glauconitic bedding-aligned burrows, 0.03 m in length.

Bedding Cycle 1 (3.9 m)

1866.0 to 1869.0
(568.8 to 569.7) Sandstone: quartzose, medium grey, fine grained, well sorted, slightly argillaceous; moderate to weak induration; current bedded with ripple-drift and lenticular thin beds coated with carbonaceous detritus; permeable.

1869.0 to 1874.0
(569.7 to 571.2) Sandstone: quartzose, fine grained, slightly argillaceous, permeable, moderately indurated; interbedded at 0.03 to 0.06 m intervals with laminated sandstone and silty grey black shale; current bedded with truncations and scoured sets; massive below 570.3 m.

1874.0 to 1876.0
(571.2 to 571.8) Sandstone: quartzose, very fine grained, argillaceous, medium grey; glauconitic at 571.2 to 571.3 m; scattered sandstone trough cut-and-fill with pyritic nodules and interbeds of laminated carbonaceous shale and siltstone.

1876.0 to 1878.0
(571.8 to 572.4) Sandstone: quartzose, very fine grained, argillaceous, medium grey, massive; faint bioturbation; scattered glauconitic nodules fine- to medium-grained quartzose, kaolinitic sandstone over basal 0.15 m; sharp irregular contact.

1878.0 to 1879.0
(572.4 to 572.7) Mudstone: grey black, abundant flasers, lenticles and bioturbation pods of medium grey siltstone; sharp irregular contact.

Rex Member

Unit 4 *Bedding Cycle 4 (3.4 m)*

1879.0 to 1880.0
(572.7 to 573.0) Mudstone: black carbonaceous; 0.10 m of basal coal; sharp irregular contact.

1880.0 to 1890.0
(573.0 to 576.1) Sandstone: quartzose, fine grained, slightly argillaceous, medium grey; minor lenticles and drapes of carbonaceous detritus coating and filling scour channels and truncation sets; compactional distortion of beds below 574.5 m; well indurated but permeable; sharp contact.

Unit 3 *Bedding Cycle 3 (5.5 m)*

1890.0 to 1890.0
(576.1 to 576.1) Shale: black, carbonaceous to coaly, (0.08 m present); sharp basal contact.

1890.0 to 1895.0 (576.1 to 577.6)	Sandstone: quartzose, very fine grained, argillaceous, medium grey, bioturbated and contorted; subordinate, fine-grained, quartzose sandstone downwards; grades into
1895.0 to 1908.0 (577.6 to 581.6)	Sandstone: quartzose, very fine grained, argillaceous, medium grey, current bedded with thin scour and fill, strongly bioturbated; thinly interbedded and intermixed with grey black carbonaceous shale; glauconitic, pyritic nodule at 581.2 m; sharp contact.
Unit 2 Bedding Cycle 2 (3.3 m)	
1908.0 to 1909.0 (581.6 to 581.9)	Coal: brittle, blocky, 0.10 m thick; grades into mudstone black and grey black, carbonaceous.
1909.0 to 1917.5 (581.9 to 584.5)	Sandstone: quartzose, very fine grained, argillaceous; subordinate thin beds of laminated sandstone and black shale alternate with massive units above 582.6 m. Laminated beds show current scour fill in black shale, and sandstone infilled syneresis cracks at 582.6 to 582.9 m. Wavy shale-lined partings on current-bedded sandstone below 582.9 m, as well as contortion, bioturbation, glauconitic nodular bodies and downward increase in calcite cementation; grades into
1917.5 to 1919.0 (584.5 to 584.9)	Shale: medium grey, laminated with subordinate sandstone lenticles; hard, platy, minor glauconite.
Unit 1 Bedding Cycle 1 (2.3 m)	
1919.0 to 1926.5 (584.9 to 587.2)	Sandstone: quartzose, fine grained, argillaceous, low-angle current bedded, calcite cemented, light grey; laminated with black carbonaceous coal over 0.1 m interval at 585.5 m, below which low-angle trough cut-and-fill bedding appears. Abundant flat mudstone pebbles at 586.9 to 587.2 m; sharp basal contact.
Lloydminster Member	
Unit 4 Bedding Cycle 6 (1.4 m)	
1926.5 to 1931.0 (587.2 to 588.6)	Mudstone: dark lavender grey; laminated with lenticles of light grey, very fine grained quartzose sandstone; abundant carbonaceous plant fragments; dark grey sulphurous, carbonaceous shale, 0.09 m thick, at 587.3 m; argillaceous sandstone dominant at 588 to 588.3 m; sharp contact.
Unit 3 Bedding Cycle 5 (11.4 m)	
1931.0 to 1968.5 (588.6 to 600.0)	Sandstone: quartzose, very fine grained, subordinate fine, medium grey, weakly indurated to unindurated; low-angle trough cut-and-fill, with minor carbonaceous sandstone-shale-laminated truncation sets at intervals of 0.1 to 0.2 m; scattered glauconite at 588.9 m, carbonaceous mudstone bed at 595.3 m; highly porous and permeable; sharp contact.
Unit 2 Bedding Cycle 4 (1.7 m)	
1968.5 to 1969.0 (600.0 to 600.2)	Shale: black, carbonaceous, subordinate coaly lenticles, sulphurous.
1969.0 to 1970.0 (600.2 to 600.5)	Mudstone: sandy, medium grey, rootlet zone with abundant vertical carbonaceous filaments.
1970.0 to 1974.0 (600.5 to 601.7)	Sandstone: quartzose, fine grained, subordinate very fine, poorly indurated to unindurated, medium grey; thin crenulated, black, carbonaceous and coaly beds at 601.4 m; sharp sloping contact.
Bedding Cycle 3 (4.9 m)	
1974.0 to 1974.5 (601.7 to 601.8)	Shale: coaly, black, 0.06 m thick.

1974.5 to 1987.0 (601.8 to 605.6)	Sandstone: quartzose, very fine grained; subordinate fine, medium grey; thin wavy beds (0.02 m thick) with subordinate dark grey shale drapes (0.005 to 0.01 m thick); massive at 604.7 to 605.4 m; grades into
1987.0 to 1990.0 (605.6 to 606.6)	Shale: black, subordinate lenticles of light grey, graded, very fine grained, quartzose sandstone, well indurated, friable; pyritic nodule at 605.9 m; some bedding aligned bioturbation pods; sharp contact.
Unit 1 <i>Bedding Cycle 2 (7.6 m)</i>	
1990.0 to 1992.0 (606.6 to 607.2)	Sandstone: quartzose, very fine grained, subordinate fine; weak to moderate induration, wavy bedded, very permeable and porous; grades sharply into
1992.0 to 2004.0 (607.2 to 610.8)	Sandstone: quartzose, very fine grained, well cemented with calcite, medium blue grey; strong high-angle truncation cross-sets suggestive of dunes or upper regime flow; dark grey, bioturbated shale (0.05 m thick) at 609.9 to 610.8 m.
2004.0 to 2012.0 (610.8 to 613.3)	Shale: dark grey, silty, glauconitic, bioturbated; thinly interbedded with lenticles and flasers of very fine grained quartzose sandstone; grades into
2012.0 to 2015.0 (613.3 to 614.2)	Shale: grey black, minor lenticles and pods of grey-brown bioturbated sandstone; grades sharply into
<i>Bedding Cycle 1 (2.7 m)</i>	
2015.0 to 2021.0 (614.2 to 616.0)	Sandstone: quartzose, fine grained, medium yellowish grey; ripple and wavy bedded with subordinate black shale-draped beds; moderate induration and permeability.
2021.0 to 2023.0 (616.0 to 616.6)	Sandstone: quartzose, medium grey, fine grained, well sorted, low-angle current bedded, weakly indurated, very porous and permeable.
2023.0 to 2024.0 (616.6 to 616.9)	Shale: as at 613.3 m; sharp contact.
Cummings Member	
<i>Bedding Cycle 1 (9.8 m)</i>	
2024.0 to 2029.5 (616.9 to 618.6)	Shale: black carbonaceous, silty; interbedded with subordinate argillaceous coal and coaly shale, moderate to weak induration.
2029.5 to 2035.5 (618.6 to 620.4)	Sandstone: quartzose, fine grained, well sorted with grain contact-cemented, medium yellowish grey, wavy bedded; minor (15%) black shale partings and thin beds draping sand wave forms; scattered sigmoidal compactional forms in shale; sharp contact.
2035.5 to 2054.5 (620.4 to 626.2)	Shale: black, hard, blocky, siliceous; interbedded with subordinate grey-black argillaceous quartzose sandstone; abundant plant fragments at 623.9 m.
2054.5 to 2056.0 (626.2 to 626.7)	Shale: black, very fissile (loss high).
Dina Member	
<i>Bedding Cycle 1</i>	
2056.0 to 2065.0 (626.7 to 629.4)	No recovery.
2065.0 to 2073.0 (629.4 to 631.9)	Sandstone: quartzose, fine grained with subordinate very fine, dark grey, argillaceous matrix; massive, fabric strongly distorted by differential compaction; abundant plant fragments; grey black and carbonaceous at 631.5 m; sharp, irregular contact.

SUCCESS (DETRITAL) FORMATION

2073.0 to 2076.0
(631.9 to 632.8) Conglomerate: polymict; ranging from small boulders to pebbles in well indurated, poorly sorted argillaceous and carbonaceous sandstone; pebbles comprise well-cemented, fine-grained, quartzose sandstone, tripolitic chert, flat rectanguloid, angular pebbles of laminated chert, and rounded, green glauconitic, silica-indurated mudstone; sharp, irregular contact.

TORQUAY FORMATION

2076.0 to 2081.0
(632.8 to 634.3) Mudstone: dolomitic, medium grey green; subordinate lensoid aggregates of tan, argillaceous dolomite; solution pipe infilled calcite vein at 632.7 m; sharp irregular contact.

2081.0 to 2085.5
(634.3 to 635.7) Siltstone: calcite cemented, tan, current and ripple bedded; thinly interbedded with subordinate grey-green mudstone; lenticular, decreasing downwards to solution-brecciated silty laminae.

2085.5 to 2089.0
(635.7 to 636.7) No recovery.

2089.0 to 2091.0
(636.7 to 637.3) Mudstone: as at 632.7 m.

2091.0 to 2107.0
(637.3 to 642.2) Siltstone: quartzose, calcite cemented, calcareous; variably massive, dissolution generated forms ranging from nodular aggregates separated by thin green mudstone envelopes to tabular layers marked by crenulated and stylolitic green shaly partings.

BIRDBEAR FORMATION

2107.0 to 2113.0
(642.2 to 644.0) Limestone: argillaceous to calcilititic; thinly bedded on crenulated laminae; cream coloured, earthy; minor secondary calcite and intraformational conglomerate at 642.8 m; flaggy bedding separating along more calcilititic layers (algal laminite); shaly over basal 0.015 m; sharp irregular contact.

Imp TW Rosetown 12-19-31-15(W3)

KB 2098 feet (639.5 m)

Depth in feet (m)

CANTUAR FORMATION Waseca Member

2371.0 to 2374.5
(722.68 to 723.75) Sandstone: quartzose, medium grained, ca. 12% black chert, white and light grey feldspar; grey white kaolinite matrix, earthy, white speckled with black; moderately indurated, flat bedded; sharp contact.

2374.5 to 2378.0
(723.75 to 724.8) Mudstone: platy, medium to dark grey downwards, scattered carbonized plant fragments; sharp contact.

2378.0 to 2381.0
(724.8 to 725.7) Sandstone: fine grained, minerals and fabric as at 2371 feet (722.68 m); laminated with dark grey shale at 2380.5 to 2381 feet (725.66 to 725.73 m).

2381.0 to 2400.0
(725.7 to 731.52) No recovery.

2400.0 to 2450.0
(731.52 to 746.76) Sandstone: quartzose, fine grained, ca. 7% black chert, white kaolinitic after feldspar, coarse-grained, brown, concretionary siderite, kaolinitic matrix, calcareous at 2400 to 2406 feet (731.52 to 733.35 m); white speckled with black and brown; earthy, moderately indurated; siderite-lined low-angle cross-bedding; grade size increases to medium below 2435 feet (742.18 m); carbonized plant detrital laminae bedding groups at 2435 to 2438 feet (742.18 to 743.10 m) and 2446 feet (745.54 m); sharp contact.

2450.0 to 2454.0
(746.76 to 747.98) Mudstone: light grey, subordinate coarse laminae of quartzose siltstone increase downward; earthy, scattered carbonized, reedy fragments.

2454.0 to 2470.0 (747.98 to 752.86)	Siltstone: quartzose, subordinate very fine grained sand, muscovitic; weakly indurated, light grey, very permeable; thin flat beds; abundant <i>Chondrites</i> below 2463 feet (750.72 m).
2470.0 to 2472.0 (752.86 to 753.47)	Siltstone: quartzose, carbonaceous, grey, finely laminated, moderately indurated; scattered to abundant white, quartzose, silt-filled burrow casts.
2472.0 to 2504.0 (753.47 to 763.21)	Mudstone: medium green grey, platy to blocky; scattered plant filaments; sandstone as at 2400 feet (731.52 m) present at 2488 to 2489 feet (758.34 to 758.64 m).
2504.0 to 2520.0 (763.21 to 768.10)	Shale: dark grey, laminated with subordinate draped ripples of white, fine-grained, quartzose sandstone over upper two-thirds.
2520.0 to 2521.0 (768.10 to 768.40)	Sandstone: quartzose, medium grained, minerals as at 2400 feet (731.52 m).
2521.0 to 2525.0 (768.40 to 769.62)	Shale: dark grey, silty, faintly current bedded, minor clayey, carbonaceous partings; sharp contact.
2525.0 to 2527.0 (769.62 to 770.23)	Sandstone: quartzose, medium grained, minerals and texture as at 2400 feet (731.52 m); minor coaly layers with abundant stalks.
2527.0 to 2530.0 (770.23 to 771.14)	Shale: as at 2521 feet (768.40 m), carbonaceous toward base; sharp contact.
Sparky Member	
2530.0 to 2540.0 (771.14 to 774.19)	Sandstone: quartzose, medium grained as at 2525 feet (769.62 m adjusted), decreasing downward to fine grained; minor interbeds of shale as at 2521 feet (768.4 m).
2540.0 to 2543.0 (774.19 to 775.11)	Shale: dark grey, fissile, silty; quartzose sandy downward.
2543.0 to 2551.0 (775.11 to 777.54)	Sandstone: quartzose, very fine grained, kaolinitic, abundant carbonized plant fragments; ripple drift and current bedded, grey white, well indurated, sharp basal contact.
General Petroleums	
2551.0 to 2560.0 (777.54 to 780.29)	Shale: black, carbonaceous, coaly.

Canterra et al Prince 1-8-46-16(W3)
KB 537 m

(Reference well for the Spinney Formation)

Depth in metres	Spinney Hill Member
390.00 to 390.13	Sandstone: quartzose, fine grained, medium brownish grey, well sorted, weak grain-contact silica cemented, very permeable, abundant muscovite, flat bedded.
390.13 to 390.58	Shale: grey black; subordinate thin interbeds of sharp-based laminated sandstone: quartzose, very fine grained, dark green grey, glauconitic; some contortion of beds.
390.58 to 391.45	Sandstone: quartzose, very fine grained, dark grey green, glauconitic; laminated with subordinate grey black shale; moderately indurated, permeable; sharp contact.
391.45 to 392.54	Shale: grey black, fissile; about evenly interbedded at 0.02 to 0.03 m intervals with boudinaged and lenticular sandstone: quartzose, very fine grained, dark green grey, glauconitic, argillaceous; sharp irregular contact on basal grey-black shale bed 0.06 m thick.

392.54 to 394.00	Sandstone: quartzose, fine grained, massive well sorted, moderately indurated, permeable, medium greenish grey downward to dark grey with increase in argillaceous matrix; thin beds (0.05 m) of black, carbonaceous shale with scattered coaly lenticles at intervals of 0.15 to 0.30 m below upper 0.75 m; lowermost 0.20 m glauconitic and greenish brown.
394.00 to 398.00	No recovery.
398.00 to 399.60	Shale: grey black, papery; minor lenticles and flasers of green, very fine grained, glauconitic, quartzose sandstone; includes a sandstone: quartzose, fine-grained, green, glauconitic, current bedded, 0.08 to 0.12 m thick, sharp contacts.
399.60 to 401.10	Sandstone: quartzose, very fine grained, argillaceous, moderately indurated, medium grey green and grey; small-scale, low-angle tangential cross-bedding; interbedded irregularly with grey-black shale 0.4 to 0.17 m thick; sharp basal contact.
401.10 to 402.00	Shale: grey black, fissile; scattered sandy layers and thin beds; scoured sandy beds thinly interbedded with shale over lower 0.2 m; coquina near base.

PENSE FORMATION

402.00 to 413.00	No recovery.
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Unit 3 Bedding Cycle 4 (2.02 m)

413.0 to 415.02	Sandstone: quartzose, very fine grained, very argillaceous, medium grey, bioturbated, compactional flow-fabric throughout; scattered lenticles and flasers of oil-stained, very fine grained, quartzose sandstone; basal 0.3 m of grey-black shale with subordinate sandstone ripple laminae; sharp contact.
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Unit 2 Bedding Cycle 3 (4.12 m)

415.02 to 415.45	Sandstone: quartzose, very fine grained, very argillaceous, medium grey; subordinate lenticles and irregular bodies and thin beds of quartzose sandstone, heavy-oil permeated.
415.45 to 416.01	Sandstone: quartzose, fine grained, weakly indurated heavy-oil permeated; subordinate broken and distorted beds of sandstone as at 415.02 to 415.45 m
416.01 to 416.76	Sandstone: as at 413.0 m.
416.76 to 417.24	Sandstone: as at 415.02 m; graded over lower half into sandstone as at 415.45 m.

Unit 1 Bedding Cycle 2 (1.90 m)

417.24 to 419.14	Sandstone: quartzose, fine grained, well sorted, unindurated, heavy-oil permeated; scattered beds (0.08 m thick) of dark grey shale laminated with subordinate oil-permeated sandstone 0.8 to 1 m apart.
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Bedding Cycle 1 (3.06 m)

419.14 to 420.69	Sandstone: as at 417.24 m, but includes slumped debris consisting of large blocks (0.13 m) of laminated, dark grey, sandy argillaceous, quartzose and permeable oil-stained sandstone.
420.69 to 421.30	Sandstone: quartzose, very fine grained, silty argillaceous matrix, light and medium grey; laminated with medium grey shale, moderately indurated, shaly to platy, microfaulted throughout at 20°.
421.30 to 422.00	Sandstone: quartzose, very fine grained, weakly indurated, heavy-oil permeated; laminated with silty sandstone as at 420.69 m; medial portion exhibits plastic flowage.
422.00 to 422.20	Shale: medium grey, splintery, scattered carbonized reed-like fragments; sharp(?) contact.

CANTUAR FORMATION

Waseca Member

422.20 to 428.80	Mudstone: medium grey, massive, abundant brown ironstone nodules, scattered woody impressions and carbonized fragments; scattered sandy patches; sharp contact.
428.80 to 429.30	Sandstone: quartzose, fine grained, well sorted, tabular cross-bedded, heavy-oil permeated; sharp(?) irregular contact.
429.30 to 429.50	Mudstone: as at 422.2 m (fault breccia?)
429.50 to 429.95	Sandstone: as at 428.8 m; upper 0.17 m include angular fragments of overlying mudstone.
429.95 to 430.70	No recovery.
430.70 to 431.00	Sandstone: as at 428.8 m; basal 0.15 m is argillaceous, well indurated; sharp irregular contact.
431.00 to 433.00	Sandstone: quartzose, very fine grained, light grey; flat laminated with silty shale, medium grey; moderately well indurated, platy; scattered thin current beds.
433.00 to 460.00	No recovery.

Sparky Member

460.00 to 463.26	Sandstone: quartzose, fine grained, well sorted, weakly indurated, heavy-oil permeated; subordinate interbeds of medium grey shale and current bedded, light grey, very fine grained, quartzose sandstone; oil-saturated sandstone at 460.58 to 460.84 m, 461.28 to 461.41 m, and 463.01 to 463.25 m.
463.26 to 465.47	Sandstone: quartzose, fine grained, well sorted, calcite grain-contact cemented, heavy-oil permeated; includes breccia of cobble-sized, laminated light grey sandstone and medium grey silty shale.
465.47 to 465.50	Sandstone: quartzose, fine grained, well sorted, weakly indurated, heavy-oil permeated; minor beds of medium grey, glauconite-speckled silty shale at intervals of 0.10 to 0.5 m.
465.50 to 470.00	Sandstone: quartzose, very fine grained; massive with scattered traces of coaly laminae; medium grey brown, oil stained.
470.00 to 470.25	Sandstone: quartzose, fine grained, weak argillaceous matrix; laminated with coaly plant debris, very permeable.
470.25 to 474.00	Sandstone: quartzose, fine grained, weak argillaceous matrix, medium grey, very permeable; scattered coaly beds and beds laminated with coaly fragments.
474.00 to 475.45	Sandstone: quartzose, fine grained, grey white, well sorted, weak clay matrix towards base; sharp contact.
475.45 to 476.00	Sandstone: argillaceous, dark grey, strongly bioturbated; sharp contact.

General Petroleums Member

476.00 to 476.05	Coal: vitrain, blocky.
476.05 to 477.00	Siltstone: (loessite), medium grey, very permeable; abundant sphaerosiderite; upper 0.3 m current bedded and includes grey black shale.

Depth in metres	JOLI FOU FORMATION Spinney Hill Member
405.00 to 405.27	Sandstone: quartzose, very fine grained, well sorted, yellow green glauconitic; abundant muscovite; minor laminae of grey-black shale decreasing downward; some shale drape of ripple surfaces; sharp irregular contact.
	PENSE FORMATION <i>Bedding Cycle 4 (0.63 m)</i>
405.27 to 405.52	Sandstone: quartzose, fine grained, weakly argillaceous; well cemented with medium blue-grey calcite; some bioturbation and distortion; abundant thin shelled pelecypods, most shells resting convex side up; sharp contact.
405.52 to 405.90	Shale: grey black, fissile; subordinate beds of shaly, very fine grained, quartzose sandstone; 0.15 m thick sandstone as at 405.27 m on basal shale of similar thickness; sharp contact.
	<i>Bedding Cycle 3 (10.2 m)</i>
405.90 to 406.50	Sandstone: quartzose, fine grained, yellow green, glauconitic, moderately indurated, earthy; laminated to fine bedded; minor grey-blue shaly partings.
406.50 to 413.00	Shale: grey black; minor lenticular laminae of calcareous, very fine grained, quartzose sandstone, and white shale over a medial half metre interval which includes 0.10 m of light grey, calcite-cemented, fine-bedded, quartzose sandstone, truncated by trough cuts, and resting on an irregular contact; scattered calcareous sandstone lenses below; grades by interbedding over basal 0.3 m into
413.00 to 416.10	Sandstone: quartzose, very fine grained, argillaceous, medium grey, moderately indurated, earthy, muscovitic, faintly laminated; interbedded with minor thin beds of grey black shale laminated with podded, medium grey sandstone; sharp contact.
	<i>Bedding Cycle 2 (1.4 m)</i>
416.10 to 417.50	Sandstone: quartzose, fine grained, medium grey, argillaceous, attenuated and bioturbated with feeding and scattered oblique burrows; interbedded and intermixed with dark grey silty shale; basal 0.7 m includes lenticles of oil saturated quartzose sandstone; sharp contact.
	<i>Bedding Cycle 1 (0.7 m)</i>
417.50 to 417.90	Shale: grey black, fissile; minor lenticles of light grey, rippled, fine-grained, quartzose sandstone.
417.90 to 418.20	Sandstone: quartzose, fine grained; upper half intermixed and bioturbated with dark grey argillaceous sandstone; weakly cemented and heavy oil saturated over lower half; sharp, irregular contact.
	CANTUAR FORMATION Waseca Member <i>Bedding Cycle 7 (10.8 m)</i>
418.20 to 429.00	Claystone: silty, medium grey, blocky, massive; abundant brown iron-stained clay concretions over lower half; scattered carbonized reedy fragments; sharp contact.
	<i>Bedding Cycle 6 (2 m)</i>
429.00 to 430.00	Sandstone: quartzose, very fine grained, well sorted, faintly bedded, heavy-oil permeated.

430.00 to 431.00	Claystone: as at 418.2 m; brecciated and heavy oil-permeated sandstone at 429.0 to 430.0 m (slump?).
<i>Bedding Cycle 5 (3.7 m)</i>	
431.00 to 433.30	Sandstone: as at 429.0 m, low-angle cross-laminated; heavy-oil permeated.
433.30 to 434.70	Mudstone: downward increasing quartzose sandstone laminae, medium grey, irregularly bedded; brown iron claystone nodules and carbonaceous laminae near base; some oil staining of sandy laminae.
<i>Bedding Cycle 4 (4.3 m)</i>	
434.70 to 437.20	Sandstone: quartzose, fine grained, well sorted, weakly argillaceous, very permeable, poorly cemented, medium grey brown, abundant white kaolinite grains after feldspar, oily and tarry films in interstices; grades into very fine grained and argillaceous, medium grey sandstone; laminated with carbonaceous clay over lower half; dips 30 to 35° and grades into
437.20 to 439.00	Claystone: medium grey, waxy and shale, medium grey, chippy, hard, siliceous.
<i>Bedding Cycle 3 (5.5 m)</i>	
439.00 to 443.20	Claystone: waxy, medium grey, grades into silty mudstone with carbonized plant fragments and brown silty ironstone breccia; microfaulted.
443.20 to 444.00	Shale: black, coaly, fissile; 0.2 m thick claystone bed above basal 0.1 m thick coaly bed; sharp contact.
444.00 to 444.50	Sandstone: quartzose, very fine grained, finely bedded, silica grain-contact cemented, permeable, medium brown grey, lightly oil stained; sharp irregular contact.
<i>Bedding Cycle 2 (3.6 m)</i>	
444.50 to 444.75	Coal: vitrain and fusain, brittle.
444.75 to 444.85	Shale: medium grey, fissile.
444.85 to 446.85	Sandstone: quartzose, very fine grained, friable, silty matrix, light grey, very permeable; subordinate laminae of grey black shale; feeding burrows, crenulation and shale envelopes of sandstone pillows and balls increase downward.
446.85 to 447.10	Sandstone: quartzose, very fine grained, light grey; thinly interbedded with carbonaceous, grey black, argillaceous, wavy bedded sandstone.
447.10 to 448.10	Sandstone: quartzose, very fine grained, light grey; subordinate dark grey, bioturbation pods over upper 0.12 m; grades into mixed sandstone and mudstone (bioturbated); over lower half grades into dark grey argillaceous sandstone with minor sandier pods; sharp contact.
<i>Bedding Cycle 1 (3.6 m)</i>	
448.10 to 449.10	Sandstone: quartzose, fine grained, grey white, speckled with black chert, and white kaolinite as grains and matrix; scattered brown sphaerosiderite, pale green chlorite; bedding irregular, 0.02 to 0.1 m of sandstone, bounded by coarse crenulated laminae of carbonaceous mudstone; upper 0.035 m rootlet penetrated; 0.2 m of high-angle planar cross-beds at 449.6 m.
449.10 to 449.50	Sandstone: quartzose, very fine grained to silty, grey white; wavy dark grey carbonaceous silty laminae; some ripple-drift bedding.
449.50 to 451.70	Sandstone: as at 448.10 m; upper 0.5 m calcite cemented and with crenulated argillaceous partings and oblique fractures; fine-bedded, with low-angle tangential cross sets and laminae of brown sphaerosiderite and carbonized plant detritus; lower half is

dissected by vein 0.015 m wide, lined with coarse calcite crystals and cored with very fine grained quartzose sandstone as country rock. Vein is exposed over a metre, rising vertically from base of sandstone before crenulating and bifurcating at the top. Basal 0.1 m of sandstone is highly sideritic, cross-bedded and oxidized; sharp irregular contact.

Sparky Member

Bedding Cycle 1 (10.3 m)

- | | |
|------------------|--|
| 451.70 to 452.40 | Sandstone: quartzose, fine grained; small-scale, low-angle tangential cross-sets; medium grey argillaceous beds alternate with grey-black, carbonaceous laminae and thin shale drapes; brown and sideritic over basal 0.5 m; sharp curved contact. |
| 452.40 to 452.90 | Sandstone: quartzose, very fine grained, medium grey, interbedded at 0.01 to 0.02 m intervals with grey black shale; flasered, shale draped and bioturbated. |
| 452.90 to 462.00 | Shale: dark grey, splintery, hard, scattered pyritic nodules; sharp irregular contact. |

General Petroleum

Bedding Cycle 3 (3.0 m)

- | | |
|------------------|--|
| 462.00 to 464.00 | Sandstone: quartzose, very fine grained, argillaceous; buff grading downward into grey; microfaulted, brecciated and plastic flowage deformed; thinly interbedded with dark grey argillaceous siltstone. |
| 464.00 to 465.00 | Claystone: medium grey, splintery; scattered sulphurous coaly pods and lenses; basal brown sideritic bed, 0.2 m thick. |

Bedding Cycle 2 (12.15 m)

- | | |
|------------------|--|
| 465.00 to 465.80 | Shale: dark grey, fissile; abundant muscovite; pyritic burrow casts on bedding surfaces. |
| 465.80 to 475.00 | Sandstone: quartzose, fine grained, well sorted; very permeable, low-angle (10°) cross-bedded, light grey; some layers coated with carbonized plant fragments. |
| 475.00 to 477.15 | No recovery. |

Bedding Cycle 1 (3.25 m)

- | | |
|------------------|---|
| 477.15 to 477.55 | Sandstone: quartzose, very fine grained, argillaceous, dark grey, carbonaceous matrix mottled with medium grey; feeding burrows and flasered, well indurated; upper 0.01 m oxidized buff. |
| 477.55 to 478.35 | Sandstone: quartzose, fine grained, speckled with black chert, light grey kaolinitic matrix, abundant coaly fragments; massive alternating with laminated; evidence of flowage; lower half grey black, carbonaceous with thin coaly lenses. |
| 478.35 to 479.95 | Sandstone: as above; laminated with dark brown and black, carbonaceous matrix-rich layers, 0.4 m thick; overlies 0.3 m thick interbedded fine-grained sandstone and dark grey argillaceous very fine grained couplets on scoured contacts. |
| 479.95 to 480.40 | Sandstone: quartzose, very fine grained, argillaceous, dark grey; minor lenticles of light grey quartzose sandstone; traces of graded bedding; sharp basal contact. |

Rex Member

Unit 4 *Bedding Cycle 5 (2.81 m)*

- | | |
|------------------|--|
| 480.40 to 480.85 | Sandstone: quartzose, fine grained, argillaceous; bioturbated, well indurated; upper 0.18 m oxidized buff. |
| 480.85 to 481.15 | Claystone: medium grey, abundant bedded carbonized reeds; sharp contact. |
| 481.15 to 481.40 | Coal: fusain and vitrain, brittle, abundant sulphurous, pyritic lenticles; carbonaceous claystone at top. |

481.40 to 481.53	Claystone: black, carbonaceous, grading to grey white, kaolinitic; abundant carbonized reedy plant fragments (seat earth).
481.53 to 481.63	Coal: vitrain, glossy, brittle.
481.63 to 482.15	Claystone: grey black, carbonaceous, intermixed with medium grey; hackly.
482.15 to 482.43	Coal: vitrain, subordinate, shaly laminae, lenticular and nodular sulphurous pyrite.
482.43 to 482.93	Shale: grey black, fissile to platy, carbonaceous; grades near base into
482.93 to 483.21	Sandstone: quartzose, fine grained, medium grey, argillaceous; bioturbated, well indurated.

Bedding Cycle 4 (2.4 m)

483.21 to 483.33	Coal: durain, blocky, 0.08 m thick; capped by 0.04 m of dark grey shale.
483.33 to 484.51	Shale: fissile to platy, hard, dark grey; scattered to abundant carbonized plant fragments; grades into
484.51 to 485.41	Sandstone: quartzose, very fine grained, argillaceous; dark grey and buff banded; mildly contorted, bioturbated; grades by interbedding into
485.41 to 485.61	Sandstone: quartzose, fine grained, fine bedded, argillaceous matrix, contorted, some bioturbation, oil stained; buff and dark brown mottled; sharp irregular contact.

Unit 3 Bedding Cycle 3 (4.69 m)

485.61 to 486.43	Claystone: medium grey; upper 0.08 m is root casted and partially coalified; compaction-flattened, sideritic nodules toward base; sharp contact.
486.43 to 488.60	Sandstone: quartzose, very fine grained, argillaceous; laminated with black and grey-black shale; interbedded with black, silty shale incorporating light grey, sandstone flasers and bioturbation pods and bioturbated sandstone at intervals of 0.15 to 0.3 m; grades into
488.60 to 490.10	Shale: dark grey, platy; laminated with lenticles of quartzose, fine and very fine grained sandstone; thin beds of fine-grained, quartzose, heavy oil-saturated sandstone at intervals of 0.015 to 0.025 m.
490.10 to 490.30	Sandstone: quartzose, fine grained, well sorted, weakly indurated, heavy-oil permeated; irregular base.

Unit 2 Bedding Cycle 2 (3.18 m)

490.30 to 491.00	Sandstone: quartzose, very fine grained; medium grey, argillaceous, well indurated; laminated with subordinate dark grey shale; current bedded with reverse-graded laminae and scoured tops; interbedded with oil-permeated sandstone as 490.1 to 490.3 m.
491.00 to 491.37	Sandstone: as at 490.1 m, oil permeated.
491.37 to 491.59	Sandstone: interbedded as at 490.3 m.
491.59 to 492.27	Sandstone: as at 490.1 m, oil permeated.
492.27 to 492.93	Sandstone: interbedded with bioturbated podded shale as at 490.3 m.
492.93 to 493.17	Sandstone: as at 490.1 m; oil permeated at scoured basal contact.
493.17 to 493.48	Shale: dark grey, silty; minor sandy stringers; interbedded with oil-permeated, well sorted, fine-grained, quartzose, sandstone; sharp irregular contact.

Unit 1 *Bedding Cycle 1 (2.65 m)*

- 493.48 to 494.48 Sandstone: quartzose, very fine grained, very argillaceous, medium grey, strongly bioturbated, well indurated; sharp irregular contact.
- 494.48 to 496.13 Shale: grey black, fissile; minor lenticles of light grey; well indurated, quartzose sandstone bioturbation pods increase in abundance to subordinate over lower half; silicified at base on sharp contact.

Lloydminster Member

Unit 4 *Bedding Cycle 6 (4.58 m)*

- 496.13 to 498.00 Sandstone: quartzose, very fine grained; laminated with downward decreasing lenticles of dark grey shale; oil stained to permeated near base.
- 498.00 to 498.20 Sandstone: quartzose, fine grained, medium grey and dark grey, argillaceous, strongly bioturbated, well indurated; scattered lenses of heavy oil-permeated sandstone and black shale.
- 498.20 to 499.96 Sandstone: quartzose, fine and very fine grained, well sorted, permeable, cross-bedded with basal tangential opposing truncation sets 0.01 to 0.03 m thick; heavy-oil permeated; thin beds of argillaceous sandstone as 498.00 m at 498.87 to 499.17 m, 499.3 to 499.36 m and basal 0.27 m; sharp erosional contact.
- 499.96 to 500.71 Sandstone: as at 498.0 m.

Unit 3 *Bedding Cycle 5 (1.83 m)*

- 500.71 to 501.48 Mudstone: sandy (loam?), buff irregular columnar forms injected into underlying heavy oil-permeated, fine, well-sorted, quartzose, sandstone interbeds, 0.05 to 0.09 m thick; some bioturbation of mudstone (mostly 0.01 m long oblique cylindrical bodies, some penetrating subjacent sandstones).
- 501.48 to 501.88 Sandstone, quartzose, very fine grained, weakly indurated, heavy-oil permeated; subordinate thin interbeds of current-scoured buff sandy mudstone.
- 501.88 to 502.54 Sandstone: quartzose, very fine grained, weakly indurated, heavy-oil permeated; sharp, irregular basal contact.

Bedding Cycle 4 (1.9 m)

- 502.54 to 504.24 Sandstone: quartzose, very fine grained, medium grey, argillaceous; laminated with white clay matrix, giving rock a grey striped appearance; interbedded with subordinate beds, 0.01 to 0.05 m thick, of heavy oil-permeated, fine quartzose sandstone with current-scoured upper and lower contacts; brecciated over upper 0.3 m.
- 504.24 to 504.44 Sandstone: quartzose, fine grained, well sorted, weakly argillaceous, light blue grey, calcite cemented; finely bedded with carbonaceous dust, low-angle tangential cross-beds at base; minor medium grey marly layers; buff siderite-cemented concretion and scattered burrow pods; sharp contact.

Bedding Cycle 3 (4.06 m)

- 504.44 to 505.24 Shale: silty, medium grey; striped with subordinate laminae of grey-white, very fine grained, quartzose sandstone; platy to fissile, flaggy toward base with gradation to shaly sandstone.
- 505.24 to 508.50 Sandstone: quartzose, fine grained, tabular and trough truncation sets; upper 0.06 m churned and distorted; moderately indurated; oil stained from top to 507.0 m; calcite cemented and light grey with scattered bituminous shale partings below.

Unit 2 *Bedding Cycle 2 (5.3 m)*

- 508.50 to 510.75 Sandstone: quartzose, fine grained, well sorted, silica grain-contact cemented, permeable, medium grey, low-angle tabular cross-sets; interbedded with thinly interbedded, medium grey, very fine grained sandstone and dark grey shale with syneresis cracks; massive sandstone with scattered crenulated, dark grey shale partings below 510.0 m.
- 510.75 to 511.25 Sandstone: quartzose, fine grained, dark grey; intermixed with grey black shale; strongly bioturbated over upper half; below, glauconitic pods, and wavy bedded sandstone alternates with shale; grades into
- 511.25 to 513.80 Shale: grey black, coarsely laminated with bioturbation pods of medium grey, fine- and very fine grained quartzose sand; grades into strongly bioturbated, well-indurated, argillaceous, fine-grained, quartzose sandstone at base; sharp irregular contact.

Unit 1 *Bedding Cycle 1 (7.7 m)*

- 513.80 to 516.00 Sandstone: quartzose, very fine grained, well sorted, friable, very permeable; generally flat bedded with low-angle, tabular cross-beds; upper 0.5 m features diastemic breaks on truncation surfaces and scattered glauconitic burrow casts; below, beds are tabular with minor thin laminae of carbonaceous shale; at 0.3 m above base bed is glauconitic at top, light grey and calcite cemented.
- 516.00 to 517.50 Sandstone: quartzose, fine grained, well sorted, current bedded, buff on green; scattered green glauconitic burrow casts; subordinate medium brownish grey shale drape laminae at intervals of 0.03 to 0.04 m.
- 517.50 to 518.25 Shale: medium brownish grey, laminated with grey white, very fine grained, quartzose sandstone; abundant green glauconitic nodules; grades into
- 518.25 to 521.50 Shale: dark brownish grey, fissile, large green concretions.

Cummings Member

Unit 4 *Bedding Cycle 4 (2.5 m)*

- 521.50 to 522.40 Sandstone: quartzose, grey white, fine grained, lenticular, rippled cross-beds, subordinate grey-black shale drape; some vertical shale-filled burrows and lateral sandy feeding burrows; yield to laminated shale and sandstone over lower half (Rec. 50%).
- 522.40 to 524.00 Sandstone: quartzose, fine grained, well sorted, calcite cemented, light blue grey; thin (0.02 to 0.03 m) truncation sets of trough cross-bedding; scattered thin grey-black shale drapes; sharp sloping contact.

Unit 3 *Bedding Cycle 3 (7.0 m)*

- 524.00 to 525.00 Shale: grey black, fissile; minor lenticles and coarse laminae of grey white, fine grained, quartzose sandstone (mostly lost?).
- 525.00 to 531.00 Sandstone: quartzose, very fine grained, argillaceous, medium grey, abundant black, carbonaceous specks and muscovite, moderate induration; massive but for irregular beds of laminated, compaction distorted, black carbonaceous shale; sharp irregular contact.

Unit 2 *Bedding Cycle 2 (3.5 m)*

- 531.00 to 531.30 Sandstone: quartzose, very fine grained, argillaceous, well indurated; intermixed and irregularly bedded with grey-black shale; flasered, burrowed and compaction stretched; scattered pyritic nodules; sharp contact.
- 531.30 to 532.30 Mudstone: black, carbonaceous, platy, blebs of coal and pyrite; grades into
- 532.30 to 532.90 Sandstone: quartzose, very fine grained, very argillaceous, grey black; laminated with black silty shale, compaction distorted; scattered lenses of green glauconitic sandstone; grades into

532.90 to 533.75	Sandstone: quartzose, fine grained, medium grey, argillaceous; intermixed with grey black argillaceous sandstone and black sandy mudstone; generally attenuated, flasered, compaction-stretched, with evidence of bioturbation such as oblique, crisscrossed, short burrow forms.
533.75 to 534.50	Shale: medium grey green, splintery. Unit 1 Bedding Cycle 1 (6.4 m)
534.50 to 536.30	Sandstone: quartzose, fine grained, medium grey, argillaceous matrix, well indurated; beds of crenulated, glauconitic, sandy laminae and lenticles and black shale, alternate with beds, 0.1 m thick, of bioturbated and flow textured sandstone.
536.30 to 540.60	Sandstone: quartzose, very fine grained, well sorted, massive, friable; scattered lenticles of black carbonaceous plant material; green and glauconitic over upper half, medium grey below, very permeable; sharp irregular contact.
540.60 to 540.90	Shale: black, fissile, abundant glauconitic nodules, sharp contact. Dina Member Unit 3 Bedding Cycle 3 (5.8 m)
540.90 to 542.30	Sandstone: quartzose, very fine grained, white kaolinitic matrix, wavy cross-bedded; dark grey shale drapes at intervals of 0.05 to 0.15 m.
542.30 to 546.70	Mudstone: medium grey and dark grey, massive; abundant carbonized plant fragments, pods, nodules and lenses of green glauconitic sandstone and coprolites(?) and tree limbs. Unit 2 Bedding Cycle 2 (8.3 m)
546.70 to 555.00	Sandstone: quartzose, fine grained, well sorted, very friable, silica grain-contact cemented, very permeable; abundant carbonized fragments concentrated on low-angle cross-beds; pyrite-cemented nodular layers over upper 2 m; carbonaceous aggregates throughout; nearly flat cross-laminae over lower half. Unit 1 Bedding Cycle 1 (26 m)
555.00 to 561.00	Sandstone: as at 546.7 m; sharp sloping contact on calcite-cemented mammillary surface.
561.00 to 562.00	Sandstone: quartzose, fine grained, well sorted, calcite cemented, light blue grey, dense; split by coal parting; scattered traces of carbonaceous, bedding-aligned flakes.
562.00 to 581.00	Sandstone: as at 546.7 m; irregular contact. DUPEROW FORMATION
581.00 to 584.00	Limestone: dense, cryptocrystalline, medium grey, nodular; solution brecciated and veined with light greenish grey sandy mudstone.

Saskoil Cathkin 15-31-37-19(W3)
KB 669.7 m

Depth in metres (core adjusted downward 5 m)	PENSE FORMATION Bedding Cycle 5 (1.73 m)
622.00 to 623.73	Mudstone: dark grey; subordinate flasers and lenticles of medium grey quartzose siltstone, bioturbated; moderately indurated; sharp contact. Bedding Cycle 4 (0.62 m)
623.73 to 624.35	Shale: black, scattered lenticles (starved ripples) of light grey, argillaceous, fine-grained quartzose sandstone at top and very fine grained sandstone at base; large, medial, dark brown, ironstone concretionary bed 0.2 m thick; sharp irregular contact.

Bedding Cycle 3 (1.96 m)

- 624.35 to 624.47 Sandstone: gritty, argillaceous, quartzose, dark grey; carbonaceous and lenticular near base (resembles a sandy loam).
- 624.47 to 625.16 Sandstone: quartzose, very fine grained, argillaceous; hummocky cross-stratification ending on erosional contact over upper 0.06 m, argillaceous content increases downward to mudstone; bioturbation decreases downward; sharp contact on 0.07 m of medium grey, sandy mudstone.
- 625.16 to 626.31 Mudstone: dark grey; laminated with light grey siltstone; stretched and broken along bedding horizon; bioturbated and homogeneous over lower half; basal zone includes rip-up clasts of underlying sandstone.

Bedding Cycle 2 (0.36 m)

- 626.31 to 626.40 Sandstone: quartzose, fine grained, current bedded, medium grey, well sorted, weakly indurated, very permeable.
- 626.40 to 626.67 Shale: grey black; subordinate thin, lenticular, graded and current-bedded layers of shrinkage-cracked, medium grey, fine-grained quartzose sandstone; sharp irregular contact marked by pyritic concretionary pebbles.

Bedding Cycle 1 (1.33 m)

- 626.67 to 628.00 Sandstone: very fine grained, very argillaceous, moderately indurated; homogenized by bioturbation as indicated by sandy fragments intermixed with mudstone; grades into dark grey, hard, chippy mudstone over lower half; sharp irregular contact marked by pyritic pebbles.

CANTUAR FORMATION

Waseca Member

Unit 6 *Bedding Cycle (1.73 m)*

- 628.00 to 629.73 Sandstone: quartzose, fine grained, dark grey, argillaceous matrix; scattered siderite concretions, well indurated; minor to subordinate distorted layers of heavy oil-permeated sandstone.

Bedding Cycle (7.27 m)

- 629.73 to 630.53 Shale: splintery, medium grey, abundant sideritic, bedding aligned nodules; interbedded with sandstone below at 630.43 m.
- 630.53 to 634.00 Sandstone: quartzose, fine grained, well sorted, heavy-oil permeated and indurated; minor crenulated beds of laminated carbonaceous to coaly shale and sandstone 0.02 to 0.07 m thick; abundant to minor (15%) intraformational boulder to pebble size mudstone clasts over lower half; interbeds of medium grey sandy mudstone, 0.28 m thick at 631.53, 632.06, and 632.89 m.
- 634.00 to 637.00 Sandstone: quartzose, fine grained, subangular, well sorted; tabular cross-beds (low angle to 25°) in truncational sets 0.15 to 0.30 m thick, heavy-oil permeated; abundant pyritic pebbles over upper 0.5 m; sharp basal contact.

Unit 5 *Bedding Cycle (8 m)*

- 637.00 to 637.44 Sandstone: quartzose, very fine grained, light grey; laminated with medium grey, silty shale; includes two interbeds of overlying sandstone, each 0.7 m thick.
- 637.44 to 639.90 Sandstone: as at 634 m.
- 639.90 to 645.00 Sandstone: quartzose, fine grained, subangular, abundant medium, heavy-oil-permeated, low-angle trough cross-bedded; flat bedded over lower two thirds; clay-draped laminae increasing to 10% over lower half.

Unit 4 *Bedding Cycle (10 m)*

645.00 to 655.00 Sandstone: quartzose, medium grey brown, fine grained, subangular, well sorted, accessory white kaolinite grains, black chert; weakly indurated, very permeable, tabular cross-bedded (20°) yielding to flat bedded and massive over lower half, lightly oil stained; lag ironstone pebbles at 652.5 m; sharp; irregular contact with ironstone nodules.

Unit 3 *Bedding Cycle (incomplete)*

655.00 to 657.00 Sandstone: quartzose, very fine grained, argillaceous, platy, medium grey, well indurated, current bedded in part.

Saskoil Wilkie 7-25-38-20(W3)

KB 661.0 m

Depth in metres

PENSE FORMATION

610.00 to 610.71 Sandstone: quartzose, very fine grained, medium grey; intermixed with grey-black shale and bioturbated over upper half; thinly interbedded and laminated as graded couplets through siltstone into black shale over lower half; grades into

610.71 to 612.03 Shale: black, fissile, scattered rippled lenticles of grey sandstone near base; ironstone concretionary bed at 611.21 m; sharp contact.

Bedding Cycle 2 (0.47 m)

612.03 to 612.50 Siltstone: bioturbated with medium grey quartzose silt and dark grey mudstone, weakly indurated; sharp contact.

Bedding Cycle 1 (1.28 m)

612.50 to 613.00 Sandstone: quartzose, very fine grained, well sorted; abundant brown sideritic envelopes around quartz grains; well cemented with calcite, light blue grey; low-angle to nearly flat tabular bedding, thin (0.03 m) dark grey, argillaceous siltstone bed with sharp contacts at 612.68 m; basal contact not seen.

613.00 to 613.78 Mudstone: shaly, dark grey, minor pods and lenticles of medium grey argillaceous, very fine grained, quartzose sandstone and scattered lenticles of starved rippled, light grey sandstone; basal 0.13 m is of homogenized, oil-permeated, dark grey, very argillaceous, quartzose sandstone on dark grey shale; sharp contact.

CANTUAR FORMATION

Waseca Member

Unit 6 *Bedding Cycle 8 (3.84 m)*

613.78 to 617.62 Sandstone: quartzose, fine grained, well sorted, subangular, low-angle tangential cross-bedding with opposing sub-sets (herringbone), moderately indurated, heavy-oil permeated; interbedded with subordinate brown, concretionary, laminated and herringbone cross-bedded, medium brown grey siltstone and medium grey shale, 0.02 to 0.15 m thick; sharp contact on basal shale.

Unit 5 *Bedding Cycle 7 (12.38 m)*

617.62 to 630.00 Sandstone: quartzose, fine and medium grained, low kaolinite content; weakly indurated, heavy-oil permeated; tabular (20°) and trough cross sets throughout; overall grade size coarsens downward; rare chert pebbles in lower half and clay infilled over basal 0.5 m; silica-cemented base on sharp irregular contact.

Unit 4 *Bedding Cycle 6 (4.73 m)*

630.00 to 634.73 Shale: chippy to splintery, medium grey and light grey; coaly shale interbed at 631.25 to 631.43 m and dark grey, carbon-flecked shale at 631.43 to 631.7 m and 632.0 to

632.55 m; basal contact zone includes fragments of coal from underlying 0.35 m thick, lignitic bed.

Unit 3 Bedding Cycle 5 (2.12 m)

634.73 to 636.85 Shale: fissile to platy, grey black, faintly bedded; capped with coal; basal contact sharp under fragments of coal.

Bedding Cycle 4 (0.52 m)

636.85 to 637.37 Shale: medium grey, splintery to fissile, dark grey over basal 0.10 m; sharp contact.

Unit 2 Bedding Cycle 3 (0.80 m)

637.37 to 637.87 Sandstone: quartzose, fine grained, massive, weakly argillaceous and indurated, light grey; grades into current-laminated sandstone and medium grey silty shale and shale.

637.87 to 638.17 Sandstone: as above, grades into bioturbated sandstone and medium grey silty mudstone; sharp contact.

Unit 1 Bedding Cycle 2 (1.51 m)

638.17 to 638.47 Shale: grey black, fissile to splintery; subordinate coaly layers over lower half; sharp contact on dark grey silty mudstone.

638.47 to 639.68 Sandstone: quartzose, very fine grained to silty, light grey, weakly indurated; massive with traces of ripple cross-beds delineated by carbonaceous laminae, microfaulted; sharp irregular contact under grey-black chert nodules.

Bedding Cycle 1 (incomplete)

639.68 to 640.00 Sandstone: quartzose, fine grained intermixed with medium downward, abundant kaolinite blebs; weakly indurated and permeable except for upper dense, brown, sideritic, silica-cemented pavement, 0.14 m thick.

Sceptre et al Turtleford A16-4-51-20(W3)

KB 613.7 m

Depth in metres	CANTUAR FORMATION Waseca Member
449.00 to 450.20	Sandstone: quartzose, fine grained, bimodal with very fine grained quartzose sand, white kaolinite indurated, speckled with black chert, carbonaceous grains and brown siderite; tabular cross-bedded with partings of black carbonized plant fragments; lightly oil stained along bedding over lower half; sharp basal contact.
450.20 to 452.45	Sandstone: quartzose, very fine grained, argillaceous; current bedded at 450.20 to 450.35 m; interbedded with shale, medium grey, grading downward through bioturbated sandy shale into a fissile shale 0.55 m thick; sharp irregular contact.
452.45 to 453.81	Sandstone: quartzose, bimodal, fine grained with very fine, weakly argillaceous, cross-bedded with trough truncation sets, heavy-oil permeated; sharp irregular contact.
453.81 to 456.50	Shale: medium grey, fissile; minor downward decreasing, starved ripple lenticles and graded laminae of white, very fine grained, quartzose sandstone; sharp contact.
456.50 to 456.15	Sandstone: quartzose, fine grained, low argillaceous content, heavy-oil permeated; rests on 0.04 m of grey, fissile shale.
456.15 to 456.37	Mudstone: silty, medium grey; abundant blebs and lenticles of white, quartzose sandstone.

456.37 to 457.22	Sandstone: quartzose, very fine grained, minor fine; white kaolinitic matrix, medium grey; subordinate irregular interbeds of current-bedded, oil-permeated, fine-grained, quartzose sandstone; sharp contact.
457.22 to 457.60	Sandstone: quartzose, fine grained, well sorted, weakly indurated, heavy-oil permeated; sharp contact.
457.60 to 458.80	Sandstone: quartzose, fine grained, very argillaceous, medium grey, homogenized (sandy loam); small balls and irregular lenticles of fine-grained, light grey, quartzose sandstone; scattered thin beds of heavy oil-permeated, quartzose, fine-grained sandstone; sharp contact.
458.80 to 459.20	Sandstone: as at 457.22 m; sharp contact on basal sandstone-shale couplets interlined with coaly fragments.
459.20 to 459.50	Coal: abundant reed-like impressions; fusain and durain conspicuous.
459.50 to 465.66	Sandstone: quartzose, fine grained, well sorted, bedded, weakly indurated, heavy-oil permeated; scattered thin beds of medium grey, bioturbated, sandy mudstone and fissile shale; sharp irregular contact.
465.66 to 466.00	Sandstone: quartzose, fine grained, subordinate very fine, light grey; laminated with oil-stained, fine-grained, quartzose sandstone; decreasing downward over lower one-third; sharp contact.
466.00 to 466.82	Sandstone: (loamy) as at 457.6 m, current bedded and thinly interbedded with oil-permeated sandstone lenses and brown ironstone concretionary layers; heavy oil-permeated sandstone at 466.39 to 466.52 m; sharp contact.
466.82 to 467.50	Sandstone: as at 465.66 to 466.0 m.
467.50 to 479.00	No recovery.
479.00 to 480.13	Sandstone: quartzose, very fine grained, very argillaceous, well indurated; homogenized with minute anastomosed partings of light grey sandstone; grades into mudstone, medium grey, brittle, over lower half; sharp contact.
480.13 to 482.63	Sandstone: quartzose, fine grained; thinly bedded and bioturbated within bedding layers 0.01 m thick; minor dark grey shale as crenulated laminae and flared beds incorporating sandy pods and pellets; sharp irregular contact.
Sparky Member	
482.63 to 486.50	Sandstone: quartzose, fine grained, well sorted, heavy-oil permeated, indurated, massive; at 483.26 m includes brittle coal (vitrain) 0.02 m thick, interlayered with thin shale and overlying fragments of tree limbs more than 0.1 m long; minor thin, argillaceous beds interbedded with sandstone over basal 1 to 2 m.
486.50 to 487.25	Sandstone: as above; interbedded with subordinate very fine, quartzose, light grey, weakly argillaceous and 0.04 to 0.12 m thick; scattered laminated siltstone and medium grey shale.
487.25 to 489.55	Sandstone: quartzose, very fine grained, argillaceous, light grey, moderately indurated, earthy, water absorbent, medium yellow grey; minor thin layers and laminae of oil-permeated, fine-grained quartzose sandstone.
489.55 to 490.10	Sandstone: quartzose, fine grained, bedded and cross-bedded, moderately grain-contact cemented; permeable, heavy-oil permeated; includes pebble-size clasts of underlying bed near base; sharp contact.
490.10 to 490.43	Sandstone: quartzose, poorly sorted, fine grained to silty, argillaceous matrix, medium grey banded with buff, ironstone concretion near top (sandy loam?).

490.43 to 490.69	Sandstone: quartzose, fine grained, well sorted, heavy-oil permeated, about equally bedded at 0.05 to 0.10 m intervals with medium grey, laminated, argillaceous sandstone and shale.
490.69 to 491.00	Sandstone: quartzose, very fine grained, argillaceous, medium grey, moderately well indurated; subordinate bioturbated layers of heavy oil-permeated sandstone over upper half, massively bioturbated below.

Shell Dee Valley A11-18-48-21(W3)
KB 564.3 m

Depth in metres	JOLI FOU FORMATION Spinney Hill Member
425.0 to 425.40	Shale: dark grey, fissile, subordinate very fine grained quartzose sandstone, glauconitic, green, argillaceous matrix; sharp contact. PENSE FORMATION <i>Bedding Cycle 3 (3.48 m)</i>
425.40 to 425.76	Sandstone: quartzose, very fine grained, white kaolinitic matrix, well indurated; current bedded with flasers and ripples lined with carbonized plant fragments; abundant sphaerosiderite, brown sideritic cement; light oil staining, scattered carbonaceous shaly partings and laminae, especially at basal 0.03 m; sharp contact.
425.76 to 428.34	Sandstone: quartzose, fine grained, minor kaolinite grains, kaolinitic matrix, massive, moderately indurated, oil permeated; medial bed, 0.75 m thick, of sandstone as at 425.40 m.
428.34 to 428.88	Shale: dark grey; lenticles and current-scoured laminae of light grey, quartzose sandstone increasing downward from scattered to subordinate; basal bioturbated, black and grey mottled, very argillaceous sandstone; sharp irregular contact on underlying rootlet-burrowed bed. <i>Bedding Cycle 2 (6.82 m)</i>
428.88 to 434.00	Sandstone: quartzose, fine grained, very argillaceous (wackestone), well indurated; tabular cross-sets (15°) on truncational base; moderately oil permeated; abundant crenulated partings lined with carbonized plant fragments; thin (0.02 m) coal at 430.45 m; light grey speckled with black, carbonaceous grains, brown sphaerosiderite and white kaolinite, weakly carbonaceous at 429.30 to 429.89 m.
434.00 to 435.70	Shale: medium grey, fissile to splintery; grey black with sandy lenticles over basal 0.2 m; sharp contact. <i>Bedding Cycle 1 (2.05 m)</i>
435.70 to 436.64	Sandstone: quartzose, weakly indurated, variable argillaceous content, plastic deformation and microfaulted; oil stained to permeated according to argillaceous content.
436.64 to 436.86	Sandstone: quartzose, very fine grained, grey black, argillaceous matrix, well indurated, strongly deformed.
436.86 to 437.23	Sandstone: as at 435.70 m; sharp irregular contact (probably distorted).
437.23 to 437.75	Mudstone: grey black, minor very fine grained quartzose sandstone, platy to fissile; includes pods and rolls of contorted, light grey, oil-stained quartzose sandstone near base; scattered coaly lenticles and strongly carbonaceous at basal 0.6 m; sharp contact.

CANTUAR FORMATION

Waseca Member

Bedding Cycle 8 (3.25 m)

- 437.75 to 438.10 Sandstone: quartzose, fine grained, medium grey, argillaceous, well indurated; homogenized with carbonaceous argillaceous rootlet casts.
- 438.10 to 441.00 Sandstone: quartzose, fine grained, well sorted; moderately indurated with kaolinitic clay and oil permeated between 438.1 and 439.6 m; bedded with scattered partings of carbonized plant-coated partings, and small-scale trough cross-bedded, with carbonized plant fragments coating base of troughs; patchy oil stains at 439.6 to 439.68 m. Weak alternation of truncational cross-sets and horizontal laminated layers; scattered carbonaceous partings; generally light grey; densely silica-cemented beds alternate with brown sideritic laminae groups; scattered escape burrow forms from 439.86 to 441.00 m.

Bedding Cycle 7 (5.63 m)

- 441.00 to 443.00 Sandstone: quartzose, fine grained, well sorted, argillaceous, moderately oil stained; laminated with minor, increasing downward to subordinate, dark grey shale, and interbedded with sandy, dark grey bioturbated mudstones over lower third of unit; short vertical burrows and syneresis cracks are present throughout.
- 443.00 to 446.63 Shale: medium grey, fissile, minor lenticles, laminae and abundant thin beds (0.2 to 0.4 m) of grey white, quartzose sandstone; brown and pale green, ironstone-cemented sandstone beds at 445.0 to 445.6 m.

Bedding Cycle 6 (3.37 m)

- 446.63 to 447.56 Sandstone: quartzose, fine grained; weakly indurated, low argillaceous content; oil-permeated beds separated by dark grey shale; current laminated with oil-stained sand at 447.03 to 447.23 m.
- 447.56 to 448.40 Sandstone: as above; thinly interbedded with shale laminated with subordinate sandstone.
- 448.40 to 450.00 Shale: medium grey; laminated with tan-grey siltstone, platy; scattered lenses of oil-stained, fine-grained, quartzose sandstone; sulphurous coprolitic mass at 448.76 m; oil-permeated, fine-grained, quartzose sandstone at basal 0.16 m; sharp contact.

Bedding Cycle 5 (6.51 m)

- 450.00 to 450.90 Coal: brittle to crumbly.
- 450.90 to 450.47 Sandstone: quartzose; very argillaceous, dark grey, well indurated, rootlet burrowed; abundant coaly plant stems and pyritic nodules.
- 450.47 to 452.00 Sandstone: quartzose, fine grained, well sorted, heavy-oil permeated; interbedded with subordinate tan-grey, carbonized plant fragments, muscovitic, shaly, current laminated sandstone and dark grey shale.
- 452.0 to 452.98 Sandstone: quartzose, fine grained, well sorted, heavy-oil permeated.
- 452.98 to 454.30 Sandstone: quartzose, fine grained, weak argillaceous matrix, variable oil permeation; interbedded with subordinate mudstone; medium grey, with scattered laminated layers of black, carbonaceous shale and scattered pyritic nodules.
- 454.30 to 455.60 Sandstone: quartzose, fine grained, light grey, very argillaceous, well indurated; thinly interbedded with laminated and scattered cross-laminated sets of grey-black, coaly, sandy shale; scattered brown, ironstone nodules, cobble-size concretions and bioturbation pods; grades into
- 455.60 to 456.51 Sandstone: quartzose, medium grey, fine grained; variably argillaceous as indicated by oil mottling; heavily bioturbated though on the whole structureless; sharp irregular contact on basal dark grey shale.

Bedding Cycle 4 (3.92 m)

- 456.51 to 456.69 Sandstone: quartzose, fine grained, argillaceous, weakly indurated, moderately oil permeated; balled and intermixed with subordinate medium grey, powdery shale.
- 456.69 to 457.00 Sandstone: quartzose, fine grained, well sorted, oil permeated, fine bedded, weakly indurated.
- 457.00 to 459.73 Shale: medium grey; laminated and current laminated with carbonaceous, very fine grained quartzose sandstone; interbedded with subordinate thin beds (0.04 to 0.07 m) of oil-permeated, fine-grained quartzose sandstone; microfaulted.
- 459.73 to 460.43 Sandstone: as at 456.69 to 457.0 m; glauconitic burrow pods in medial, 0.05 m thick, medium grey mudstone; sharp contact.

Bedding Cycle 3 (4.13 m)

- 460.43 to 461.97 Sandstone: quartzose, medium grained; well indurated in white kaolinite; earthy, minor black, carbonaceous grains and brown sphaerosiderite; faint traces of low-angle current-bedded sets outlined by black carbonaceous detritus; lightly oil stained below 461.77 m; sharp sloping contact.
- 461.97 to 462.72 Sandstone: quartzose, fine grained, low argillaceous content, permeable, moderately oil permeated; lenticular, wavy layers, 0.02 to 0.06 m thick, alternate with subordinate dark grey, shaly, very fine grained, quartzose sandstone forming drapes and thin interbeds; numerous syneresis cracks and scattered oblique burrow pods.
- 462.72 to 464.56 Sandstone: quartzose, argillaceous, shaly, dark grey, bioturbated, well indurated; minor oil-stained, thin current- and wavy-bedded, fine-grained, quartzose sandstone between 462.73 to 463.72 m; sharp contact.

Bedding Cycle 2 (4.23 m)

- 464.56 to 465.13 Sandstone: quartzose, fine grained, grey white kaolinitic matrix, well indurated; generally flat bedded, ripple and finely cross-bedded with drapes of black carbonized plant detritus; some siderite-cemented laminae; laminated with argillaceous, dark grey, current-bedded, very fine grained, quartzose sandstone over upper 0.2 m.
- 465.13 to 466.28 Sandstone: quartzose, fine grained, grey white; thinly interbedded and laminated with dark grey, argillaceous, very fine grained, quartzose sandstone; current and wavy bedded throughout; grades into
- 466.28 to 468.50 Sandstone: quartzose, very fine grained, argillaceous, dark grey, shaly to platy, moderately indurated; abundant sideritic, concretionary nodules of brown ironstone over upper half; small glauconitic nodules below with increasing shale.
- 468.50 to 468.79 Sandstone: as at 464.56 m; sharp irregular contact.

Bedding Cycle 1 (2.83 m)

- 468.79 to 471.50 Sandstone: quartzose, fine grained, grading over lower third into coarse grained; induration decreases downward to weak; white, siliceous kaolinite matrix; minor medium-to coarse-grained, black carbonaceous grains; abundant medium brown sphaerosiderites, white kaolinite pseudomorphs after feldspar; tabular cross-beds (20°) in upper third, trough cross-beds over basal 0.4 m; sharp contact.
- 471.50 to 471.62 Shale: dark grey, platy; subordinate glauconitic, very fine grained, quartzose sandstone; sharp irregular contact.

Sparky Member

Bedding Cycle 3 (4.26 m)

- 471.62 to 471.69 Coal: brittle, vitrain, abundant pyritic nodules, grades into

471.69 to 471.86	Mudstone: hard, siliceous and carbonaceous, platy; irregular pyritic nodule.
471.86 to 474.76	Sandstone: quartzose, fine grained, well sorted; low-angle tabular bedding; weakly indurated, very permeable, oil permeated; sharp contact.
474.76 to 475.08	Sandstone: quartzose, fine grained, well sorted, oil permeated; lenticular and wavy horizontal beds alternate with sandstone, quartzose, very fine grained, well indurated dark grey argillaceous matrix increasing to dominant downward.
475.08 to 475.88	Sandstone: quartzose, very fine grained, dark grey, intermixed with grey-black mudstone, strongly bioturbated; oil-permeated layer near base includes coal (vitrain) bed, 0.01 m thick; undulatory basal contact.
<i>Bedding Cycle 2 (1.13 m)</i>	
475.88 to 475.93	Coal: vitrain and fusain, fissile; basal sulphurous partings; sharp undulatory contact.
475.93 to 476.68	Sandstone: as at 474.76 m; irregular contact.
476.68 to 477.01	Sandstone: quartzose, fine grained, argillaceous, medium and dark grey mottled, strongly bioturbated, moderately indurated.
<i>Bedding Cycle 1 (2.69 m)</i>	
477.01 to 477.02	Coal: vitrain (looks like a candle coal).
477.02 to 477.67	Sandstone: quartzose, fine grained; weakly argillaceous and indurated, oil permeated; medial bed, 0.14 m thick, of bioturbated, medium grey sandy mudstone.
477.67 to 478.87	Sandstone: as at 474.76 m.
478.87 to 479.00	Sandstone: quartzose, fine grained, well sorted, weakly indurated, oil permeated; interbedded with carbonized plant fragments laminated with silty mudstone.
479.00 to 479.70	Sandstone: quartzose, fine grained, well sorted, massive, oil permeated, unindurated; sharp contacts with interbedded mudstone, earthy, injected and intermixed with oil-permeated sandstone; medium brownish grey, bioturbated(?); sharp irregular contact.
General Petroleums Member	
<i>Bedding Cycle 5 (5.56 m)</i>	
479.70 to 480.85	Sandstone: quartzose, very fine grained; oxidized, siderite-cemented, bioturbated bed caps, well sorted, heavy oil-permeated, fine-grained, quartzose sandstone as three couplets in the ratio of 0.09/0.09, 0.07/0.14, 0.09/0.01 m; upper contacts sharp and irregular.
480.85 to 481.20	Mudstone: yellowish grey, blocky; mottled with irregular rolls and pods of quartzose, very fine grained, quartzose sandstone, moderately indurated, earthy.
481.20 to 485.26	Sandstone: quartzose, fine grained; flat bedded with low-angle, fine current bedding prominent at 481.20 to 481.55 m; well sorted, oil permeated; minor thin beds of dark grey carbonaceous shale; grades into sandstone, quartzose, medium-grained, white kaolinite matrix, minor to subordinate laminae with carbonized plant fragments; sharp contact.
<i>Bedding Cycle 4 (3.93 m)</i>	
485.26 to 489.19	Mudstone: dark grey, blocky; subordinate fine grained, quartzose sandstone interbedded as irregular distorted layers and lenses, 0.05 to 0.06 m thick and a bed, 0.14 m thick at 486.28 m; bioturbation intense over lower half with increase in argillaceous content and oxidized siderite-cemented layers; sharp contact.

Bedding Cycle 3 (1.9 m)

- 489.19 to 490.34 Sandstone: quartzose, fine grained, well sorted, weakly indurated, heavy-oil permeated; thin beds of dark grey, silty, carbonaceous shale at intervals of 0.13 to 0.3 m.
- 490.34 to 491.09 Mudstone: dark grey, sandy; subordinate oil-stained sandstone as above, but smaller scale cut-and-fill bodies over upper half; massive below; sharp irregular contact.

Bedding Cycle 2 (2.73 m)

- 491.09 to 493.34 Shale: dark grey; from 491.09 to 491.69 m thinly varved with light grey, very fine grained, quartzose sandstone; grey black, fissile and splintery below; brown sideritic concretions, one of which includes numerous thin pelecypod shells; pelecypod-rich bed at 492.95 m; grades into
- 493.34 to 493.82 Sandstone: quartzose, fine grained, medium grey, earthy, indurated, patchy oil stains; flasers and bioturbation pods in black shale decreasing downward; basal trough cross-bedded sandstone, 0.09 m thick, includes scattered glauconitic nodules; sharp, erosional contact.

Bedding Cycle 1 (3.03 m)

- 493.82 to 494.76 Sandstone: quartzose, fine grained, well sorted, weakly indurated, oil permeated; subordinate laminae of dark grey shale; grades into
- 494.76 to 495.45 Sandstone: quartzose, fine grained, well sorted, oil permeated; intermixed with dark grey shale by injection, balling and many microfractures; interbedded over lower 0.20 m.
- 495.45 to 496.85 Shale: dark grey; subordinate medium grey, very fine grained, quartzose sandstone beds; weak bioturbation with small-scale oblique burrows; lower half interbedded with light grey, wavy bedded, fine-grained, quartzose sandstone; sharp, irregular contact.

Rex Member

Unit 4 *Bedding Cycle 5 (3.35 m)*

- 496.85 to 497.66 Sandstone: quartzose, fine grained, well sorted, oil permeated; interbedded with yellow-grey kaolinitic mudstone; over lower half medium grained, buff, kaolinitic, current bedded with climbing ripples, laminae of carbonized plant fragments and fine quartzose sandstone.
- 497.66 to 499.25 Sandstone: quartzose, very fine grained, weakly argillaceous, oil permeated; irregular interbeds of tan, kaolinitic mudstone, increasing over lower third into argillaceous sandstone with oblique burrows.
- 499.25 to 500.20 Sandstone: quartzose, very fine grained, argillaceous, medium grey; laminated and bioturbated with dark grey shale over upper 0.45 m and basal 0.2 m; sharp contact.

Unit 3 *Bedding Cycle 4 (8.8 m)*

- 500.20 to 506.00 Sandstone: quartzose, very fine grained, well sorted, light grey, calcite cemented, medium-scale tabular and trough truncational cross-sets, kaolinitic matrix, abundant black, carbonaceous specks; brown sphaerosiderite concentrated in laminae packets or bands through middle of unit; minor carbonaceous shale laminae in lower 1 m.
- 506.00 to 509.00 No recovery; interval entered in Unit 3.

Unit 2 *Bedding Cycle 3 (2.25 m)*

- 509.00 to 510.50 Sandstone: as at 500.20 m; wavy cross-bedded with shale drapes; shale beds with sandstone pods and scattered glauconitic bedding increase to subordinate over lower half.
- 510.50 to 511.25 Shale: dark grey, fissile; minor current scoured layers of light grey, very fine grained, quartzose sandstone; glauconitic sandstone near top; sharp contact.

Unit 1 *Bedding Cycle 2 (1.04 m)*

511.25 to 511.86 Sandstone: quartzose, very fine grained, calcite cemented; medium grey speckled with black, carbonaceous grains, abundant carbonized blebs, pellets, and irregular coaly fragments, small-scale hummocky cross-stratification; subordinate thin drapes of grey black shale.

511.86 to 512.29 Shale: dark grey, splintery; interbedded with dark grey, very fine grained, argillaceous, bioturbated quartzose sandstone.

Bedding Cycle 1 (1.33 m)

512.29 to 513.62 Sandstone: quartzose, very fine grained, medium grey, well sorted, speckled with black carbonaceous grains, kaolinitic matrix, bedded, calcite cemented; irregular partings of grey-black shale; basal shale laminated with minor sandstone; sharp contact.

Lloydminster Member

Unit 4 *Bedding Cycle 4 (1.63 m)*

513.62 to 515.25 Sandstone: quartzose, fine grained, well sorted, weakly indurated, heavy-oil permeated; massive sandstone interbedded with buff, partially silica-cemented, hummocky, opposing cross-stratified beds over upper half; sharp irregular contact.

Unit 3 *Bedding Cycle 3 (14.48 m)*

512.25 to 513.30 Sandstone: quartzose, fine grained, well sorted, weakly argillaceous, dense, light blue grey, well cemented with calcite; minor laminae of black carbonized plant fragments over basal 0.05 m; sharp contact.

513.30 to 520.35 Sandstone: quartzose, fine grained, well sorted, silica grain-contact cemented, low argillaceous content, medium grey, wavy cross-laminated as well as flat; interbedded with subordinate dark grey fissile shale, laminae groups and beds; thin compaction broken and distorted sandstone layers; abundant syneresis veins, scattered green glauconitic patches; grades into

520.35 to 521.60 Sandstone: coarsely laminated with shale; shrinkage cracked, mildly distorted by differential compaction, scattered glauconitic, starved-ripple lenticles; grades into

521.60 to 526.73 Shale: dark grey, fissile, minor light grey, sandy lenticles; scattered glauconitic, sandy bodies the lower half; sharp contact.

Unit 2 *Bedding Cycle 2 (0.94 m)*

526.73 to 527.00 Sandstone: quartzose, medium grained, abundant coarse, well sorted, abundant black chert, black carbonaceous grains, green rounded glauconite; well cemented with light blue-grey calcite, dense.

527.00 to 527.67 Shale: black, fissile; about 20% medium grey, argillaceous, very fine grained, quartzose sandstone lenticles forming starved ripples, scoured and graded layers; sharp(?) contact.

Unit 1 *Bedding Cycle 1 (7.58 m)*

527.67 to 533.75 Sandstone: quartzose, medium grained, abundant coarse, weakly cemented, medium grey, very permeable, massive; scattered dark grey chert; sharp contact.

533.75 to 534.50 Sandstone: as at 527.67 m; interbedded at 0.15 m intervals with thinly interbedded sandstone and black shale draping lensoid sandstone; acquire about 10% kaolinite grains downward.

534.50 to 535.25 Shale: black; thinly interbedded with subordinate current-bedded sandstone above; contact sharp on 0.04 m green, sulphurous shale; sharp irregular contact.

Cummings Member

Unit 4 *Bedding Cycle 4 (2.42 m)*

- 535.25 to 537.50 Sandstone: quartzose, fine grained, dark grey, weakly argillaceous, very permeable; massive and black, carbonaceous, root casted; fine bedded below 537 m; wavy bedded, glauconitic and black shale draped below 537.30 m; grades into
- 537.50 to 537.67 Shale: black, minor laminae and wavy lens of sandstone above; sharp contact.

Unit 3 *Bedding Cycle 3 (7.58 m)*

- 537.67 to 538.72 Sandstone: quartzose, fine grained, very argillaceous, well indurated, earthy, bioturbated, dark grey and grey black; sulphurous upper contact zone (0.07 m) includes coal slivers in a breccia cap; sharp basal contact.
- 538.72 to 539.97 Sandstone: quartzose, fine grained, well sorted, friable, light grey, weak silica grain-contact cemented, very permeable; laminated over upper half with black, carbonized plant detritus; compaction distorted layering over lower half.
- 539.97 to 542.69 Sandstone: quartzose, fine grained, light grey, well sorted, weak silica grain-contact cemented, friable, very permeable; shallow trough cross-bedding becomes conspicuous below 540.8 m.
- 542.69 to 545.25 Sandstone: quartzose, fine grained, light grey, well sorted, weak silica grain-contact cemented, friable, very permeable; massive but vertically furrowed by rootlet molds at 542.69 to 543.64 m; faint, flat bedding marked by scattered carbonized plant fragments below; basal dark grey shale, 0.03 m thick.

Unit 2 *Bedding Cycle 2 (10.75 m)*

- 545.25 to 547.45 Sandstone: quartzose, fine grained, subordinate very fine, abundant coarse, light grey; weak silica cement, friable, very permeable; irregular traces of small-scale current bedding; scattered green streaks and lenses of more cemented, carbonaceous sandstone; grades over basal 0.30 m into
- 547.45 to 548.67 Sandstone: quartzose, very fine grained; intermixed with fine, weak argillaceous matrix; calcite cemented over upper half, very argillaceous and noncalcareous below; abundant burrows; glauconitic layer on sharp basal contact.
- 548.67 to 556.00 Mudstone: silty, dark grey, blocky to massive; scattered layers of laminated, argillaceous, very fine grained quartzose sandstone; abundant green, flat, glauconitic sandstone nodules.

Unit 1 *Bedding Cycle 1 (4.0 m)*

- 556.00 to 559.00 Shale: dark grey, interbedded with medium grey, argillaceous, fine grained, quartzose, sandstone at intervals of 0.04 to 0.2 m; bioturbation fragments of sandstone in shale increase downward along with sand content; abundant green glauconitic and black pyritic, sandy concretionary nodules; flat-bedded, fine-grained, friable, quartzose sandstone with thin carbonaceous partings over basal 0.3 m.
- 559.00 to 560.00 Shale: quartzose, silty, dark grey; minor bioturbation pods and blebs of medium grey, very fine grained, quartzose sandstone; scattered thin beds of green, glauconitic, pyritic sandstone; sharp contact.

Dina Member

Unit 3 *Bedding Cycle 3 (4.33 m)*

- 560.00 to 560.10 Sandstone: quartzose, fine grained, calcite cemented, grey white; ripple laminated with dark grey shale.
- 560.10 to 563.00 Sandstone: quartzose, fine grained, argillaceous, medium and dark grey; bioturbated and compaction distorted over upper half; carbonized laminated beds, microfaulted and contorted below; scattered pyritic nodules.

563.00 to 563.89	Sandstone: quartzose, medium grey, fine grained, well sorted, weak silica grain-contact cement, friable, very permeable, generally structureless; sharp contact.
563.89 to 564.33	Mudstone: sandy, quartzose, dark grey; solitary pyritic sandstone cobble; sharp irregular contact.

Unit 2 Bedding Cycle 2 (8.7 m)

564.33 to 564.68	Sandstone: quartzose, fine grained, accessory muscovite, weakly silica cemented, friable, very permeable; laminated with coaly flakes over lower half.
564.68 to 570.50	Sandstone: quartzose, fine grained, well sorted; weakly silica grain-contact cemented; friable, very permeable, medium grey, accessory kaolinite grains and muscovite, scattered white kaolinite blebs; microfaulted, blocks display trough cross-bedding, some lined with carbonized plant fragments.
570.50 to 573.03 ⁺	Shale: grey black, fissile, basal glauconitic masses.

Unit 1 Bedding Cycle 1 (5.47 m)

RUBBLE (Recovery 13%)

573.03 ⁺ to 578.50	Mudstone: medium grey; intermixed with sandstone, quartzose, fine grained.
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DUPEROW FORMATION

578.50	Limestone: dense, cryptocrystalline, medium grey; joint with some brecciation, decreases in width downward; infilled with medium grey, calcareous, fine-grained quartzose sandstone and sandy mudstone, current bedded with truncational cross-sets (cave fill is indicated).
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⁺ estimate from E log

Shell St. Walburg 6-28-53-22(W3)

KB 642.7 m

Depth in metres

JOLI FOU FORMATION	
431.00 to 440.40	Shale: dark grey, fissile with subordinate graded layers, lenses and lenticles of very fine grained to silty, medium green grey, quartzose sandstone; scattered trough cross-bedded, coquinoid, fine-grained calcite-cemented quartzose sandstone; abundant pelecypod fragments; at 436.0 m thin sandstone infilled, steeply plunging oblique vein, >0.30 m long; sharp basal contact.
PENSE FORMATION	
440.40 to 441.91	Mudstone: shaly, dark grey; subordinate medium grey, very argillaceous, very fine grained, quartzose sandstone; bioturbated, over upper half; sharp basal contact.
441.91 to 442.69	Mudstone: sandy, massive, light green grey; traces of ramose and vertically isolated carbonaceous filaments; grades into
442.69 to 443.82	Sandstone: quartzose, very fine grained, argillaceous matrix, medium green grey; minor dark grey shale layers; squeezed and boudinaged; traces of current bedding and burrows; truncational cross sets at base with grit-size mudstone flakes.
443.82 to 444.52	Mudstone: dark grey, platy, abundant cobble-sized, round and flat, brown ironstone concretions; grades into

444.52 to 446.18	Sandstone: quartzose, very fine grained, argillaceous matrix, medium grey; bioturbated and contorted, interbedded and intermixed with mudstone as above; basal bed, 0.17 m thick, carbonaceous and strongly bioturbated.
446.18 to 448.0	Sandstone: quartzose, fine grained; accessory white kaolinite, low argillaceous content, medium grey; weakly indurated, very permeable; scattered carbonized woody fragments.

Westburne et al Coleville 16-10-31-23(W3)
KB 694.10 m

Depth in metres

CANTUAR FORMATION
Waseca Member

755.00 to 755.42	Sandstone: quartzose, fine grained, well sorted, heavy-oil permeated and bonded; sharp contact.
755.42 to 756.15	Mudstone: medium grey; subordinate irregular laminae and partings of light grey, fine-grained, quartzose sand, weakly indurated, abundant carbonaceous grains and muscovite; faintly cross-bedded and plastically deformed below 0.10 m; heavy oil-permeated sandstone at 755.76 m; sharp contact.
756.15 to 763.55	Sandstone: as at 755.0 m
763.55 to 767.21	Claystone: medium grey, moderately indurated, hackly fractures to fissile.

Shell Manito 6-7-43-24(W3)
KB 688.4 m

Depth in metres

JOLI FOU FORMATION

600.00 to 604.30	Shale: grey black, fissile; scattered layers of sandstone, very fine grained, quartzose, glauconitic, medium green grey, lenticular, current bedded, oil stained; sharp irregular contact on a basal grit.
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PENSE FORMATION
Bedding Cycle 4 (8.1 m)

604.30 to 612.00	Sandstone: quartzose, fine to medium grained, cream coloured, oil-stained kaolinitic matrix, moderately indurated; speckled with subordinate, dark grey and grey black chert; scattered white feldspar; tabular (15° dip), truncational (near-horizontal) opposing cross-sets, 0.50 to 0.60 m thick; calcite cemented (light blue grey) interlayered with aggregates of brown, coarse-grained sphaerosiderite; cross-bedded (10 to 20°) at 611.33 to 611.72 m.
612.00 to 612.40	Sandstone: quartzose, fine to medium grained, well sorted, weak argillaceous matrix, oil stained; subordinate boulders and cobbles of medium grey mudstone. Bedding Cycle 3 (4.7 m)
612.40 to 616.70	Sandstone: quartzose, fine grained, minor dark grey and grey-black chert, scattered feldspar; moderately indurated with light grey clay matrix, moderately oil stained, decreasing downward; tabular cross-bedded (up to 15°) over lower half, opposing ripple-current beds over upper half; sharp contact.
616.70 to 617.10	Shale: medium grey, splintery.

Bedding Cycle 2 (6.15 m)

617.10 to 623.25 Sandstone: quartzose, fine grained, subordinate medium; minor black chert, abundant sphaerosiderite, feldspar, trace of green glauconite, white kaolinitic matrix, well indurated; light grey speckled with black; abundant laminae of brown sideritic aggregates; weakly current bedded, generally flat except for planar cross-beds 0.35 m thick at top; sharp basal contact.

Bedding Cycle 1 (2.9 m)

623.25 to 623.38 Coal: vitrain with fusain partings, brittle.

623.38 to 625.40 Sandstone: quartzose, very fine grained, subordinate silt, light grey banded with carbonaceous black, kaolinitic matrix; contorted, graded laminae and oblique burrows; fine-grained, oil-permeated quartzose sandstone in basal 0.25 m.

625.40 to 626.15 Shale: grey black, splintery; oil-permeated, fine-grained, quartzose sandstone at 625.5 to 625.58 m; abundant thin lenses below; sharp irregular contact.

CANTUAR FORMATION

Waseca Member

Bedding Cycle 10 (3.65 m)

626.15 to 626.50 Sandstone: quartzose, fine grained, argillaceous matrix, oil permeated, massive; sharp irregular contact.

626.50 to 627.00 Sandstone: quartzose, very fine grained, argillaceous component increasing downward; herringbone current bedded over upper half.

627.00 to 627.25 Sandstone: quartzose, fine grained, speckled light grey and black, minor black chert, moderately indurated in white kaolinite, massive; sharp contact.

627.25 to 628.83 Sandstone: quartzose, very fine grained, argillaceous matrix, flat bedded with minor ripple cross-bedding; subordinate laminae of black plant detritus.

628.83 to 629.80 Mudstone: shaly, medium grey, abundant plant fragments.

Bedding Cycle 9 (3.15 m)

629.80 to 630.40 Sandstone: as at 627.0 m, fine grained and oil permeated over lower half.

630.40 to 632.10 Sandstone: as at 627.25 m, laminated with black carbonaceous partings over lower half, sharp contact.

632.10 to 632.25 Shale: dark grey, fissile.

632.25 to 632.95 Shale: dark grey, subordinate silty lenticles, fissile to crumbly, carbonaceous near base; sharp contact.

Bedding Cycle 8 (5.0 m)

632.95 to 634.50 Shale: fissile, light green grey; interbedded with massive, light green grey, very fine grained sandy, brown, concretionary sideritic mudstone; carbonaceous at top.

634.50 to 635.60 Sandstone: quartzose, fine grained, current bedded, siderite cemented, reddish brown; subordinate laminae of medium green-grey mudstone; some reverse graded laminae over lower half; oxidized with shrinkage cracks and concretionary distortion of bedding; grades into

635.60 to 637.95 Shale: dark grey, splintery; sharp contact.

Bedding Cycle 7 (1.05 m)

637.95 to 638.88 Sandstone: quartzose, fine to medium grained decreasing downward to fine; black and grey speckled, argillaceous matrix, minor black chert; moderately indurated, poorly permeable; generally massive; sharp contact.

638.88 to 639.00 Shale: black, coaly; sharp contact.

Bedding Cycle 6 (2.66 m)

639.00 to 640.88 Sandstone: as at 637.95 m; scattered carbonaceous, coarse, deformed laminae and pyritic nodules; sharp(?) contact.

640.88 to 641.66 Mudstone: medium grey, hackly, abundant carbonized plant stems, leaves and small fragments; sharp contact.

Bedding Cycle 5 (2.46 m)

641.66 to 642.80 Sandstone: quartzose, medium to coarse grained, medium grey brown, abundant chert, kaolinite blebs; grain-contact cemented, friable, very permeable; traces of rippled beds; sharp sloping contact.

642.80 to 644.12 Shale: medium grey, splintery.

Bedding Cycle 4 (6.72 m)

644.12 to 646.30 Sandstone: quartzose, fine grained, thinly flat bedded and current bedded; minor argillaceous laminae and partings lined with carbonized plant fragments; abundant coaly blebs; medium grey, argillaceous matrix over upper one metre, calcite cemented and light grey below; grades into

646.30 to 650.40 Sandstone: quartzose, fine to very fine grained; strongly bioturbated and intermixed with dark grey argillaceous mudstone; generally flat bedded with lateral burrows; grades into

650.40 to 650.84 Shale: dark grey, splintery; sharp contact.

Bedding Cycle 3 (1.24 m)

650.84 to 652.08 Sandstone: quartzose, very fine grained, medium-scale starved ripple cut-and-fill; light grey sand in grey-black shale beds and drapes; sand infilled syneresis cracks increases to subordinate downward; sharp irregular contact.

Bedding Cycle 2 (4.52 m)

652.08 to 653.00 Claystone: waxy, brittle to crumbly; capped by layer of pyritic nodules; medium to dark grey downward with increase in carbonaceous content.

653.00 to 654.00 Coal: vitrain and fusain, brittle, minor black carbonaceous shale.

654.00 to 655.63 Sandstone: quartzose, fine grained, medium grey argillaceous matrix; includes laminae of black carbonized plant fragments and carbonaceous shale, weak ripple bedding; subordinate coarse-grained, brown sphaerosiderite over basal 0.15 m; sharp contact.

655.63 to 656.60 Sandstone: very fine grained, silty and argillaceous, medium grey, well indurated; abundant bedding-aligned yellow-brown sideritic concretionary nodules; weakly bedded with some distortion at top.

Bedding Cycle 1 (2.05 m)

656.60 to 657.60 Sandstone: quartzose, medium grained, well sorted minor carbonized plant fragments, coarse brown sphaerosiderite, calcite cemented; light blue-grey speckled with black and brown; massive with scattered shaly partings; sharp contact.

657.60 to 658.65	Shale: medium grey brown, ironstone concretionary, minor lenticular laminae of very fine grained, quartzose sandstone; dark grey and carbonaceous black below 658.0 m; sharp contact.
Sparky Member Bedding Cycle 4 (0.85 m)	
658.65 to 659.07	Sandstone: quartzose, fine grained, well sorted, light grey kaolinitic matrix, well indurated; minor brown, coarse-grained sphaerosiderite and black, carbonaceous grains, thin current-bedded laminae of black carbonized plant material; grades into
659.07 to 659.50	Shale: dark grey, fissile; sharp contact.
Bedding Cycle 3 (3.5 m)	
659.50 to 661.53	Sandstone: quartzose, fine grained, medium grey, well sorted, accessory dark grey chert, kaolinite grains; weak grain-contact cemented, very permeable, friable; subordinate interbeds of very fine grained, argillaceous sandstone; traces of rootlet casts and compactional fractures.
661.53 to 663.00	Sandstone: quartzose, fine grained, oblique burrows (crisscrossed over 1.5 m interval), brown, iron-cemented*, grading below 661.9 m through rootlet burrowed sandstone as at 659.5 m into a basal grey black carbonaceous shale.
Bedding Cycle 2 (2.68 m)	
663.00 to 665.68	Sandstone: quartzose, fine grained, well sorted, grain-contact cemented, friable, permeable; rootlet casts over upper 1 m, increasing argillaceous content below to minor, with bioturbation marked by balled and lateral tubular sand in dark grey, argillaceous matrix; brown ironstone cemented over basal 0.4 m*.
Bedding Cycle 1 (2.47 m)	
665.68 to 666.26	Sandstone: quartzose, bimodal, fine grained with subordinate medium in a matrix of very fine grained, quartzose sand; abundant black carbonaceous grains; light grey speckled with black, well indurated.
666.26 to 668.15	Sandstone: quartzose, very fine grained, argillaceous, grey black; thinly interbedded with subordinate lenticles and flasers of medium grey, fine-grained, quartzose sandstone; well indurated; grades into a basal 0.02 m of dark grey shale; sharp irregular contact.

* Brown ironstone cementation is apparently related to perched ground water tables at the end of each emergence.

General Petroleums Member
Bedding Cycle 2 (6.43 m)

668.15 to 670.15	Sandstone: quartzose, very fine grained, well sorted, moderately indurated, low argillaceous content, medium grey, permeable, rootlet-casted, blocky structure; increasingly argillaceous to subordinate over basal 0.5 m; sharp contact.
670.15 to 674.58	Sandstone: quartzose, very fine grained, light grey; intermixed with minor argillaceous sandstone; calcite cemented at 670.15 to 671.22 m and oxidized as indicated by brown sideritic concretionary bands; well indurated, bioturbated (mostly centimetre length, oblique and lateral burrows), and churned. Moderately indurated and medium grey to 672.58 m; bedded with subordinate grey-black shale drape laminae at 672.58 to 672.88 m; oxidized brown, siderite cemented and bioturbated to 674.28 m; medium grey, bioturbated and earthy to base; sharp undulatory contact under 0.02 m layer of fine and medium-grained, quartzose sandstone.
Bedding Cycle 1 (4.22 m)	
674.58 to 676.00	Sandstone: quartzose, fine grained, well sorted, abundant black chert, white kaolinite, brown siderite; well indurated in kaolinitic silty clay, medium green grey; minor laminae bands of carbonaceous shale; basal 0.6 m of hummocky cross-beds.

676.00 to 678.80	Shale: black; interbedded with subordinate starved ripple, sandstone beds with shale drapes; sharp irregular contact.
Rex Member Bedding Cycle 4 (5.55 m)	
678.80 to 679.10	Coal: fusain and vitrain, abundant bedded plant stems; sharp contact.
679.10 to 683.22	Sandstone: quartzose, very fine grained, well sorted, medium grey, friable, weak grain-contact cemented, very permeable; low-angle cross-bedded to flat bedded; laminae partings of thin carbonaceous black shale at intervals of 0.10 to 0.15 m; shale drape of sand swale in lower part of bed.
683.22 to 684.35	Sandstone: as above, but includes rip-up clasts of indigenous sandstone; centimetre-thick alternation of grey-black sandy shale and lateral burrows; scattered glauconitic nodules; red-brown siderite cemented over basal 0.3 m; sharp irregular contact.
Bedding Cycle 3 (1.51 m)	
684.35 to 685.86	Shale: dark grey to black downward, fissile; glauconitic nodules in upper 0.15 m; bioturbated, medium grey, argillaceous sandstone over basal 0.1 m; sharp irregular contact.
Bedding Cycle 2 (1.64 m)	
685.86 to 687.50	Sandstone: quartzose, light grey, very fine grained, well sorted; abundant partially leached, coarse-grained, orange-brown sphaerosiderite and black carbonaceous grains; argillaceous, well cemented with calcite; generally low-angle flat and current bedded; massive over upper 1 m, thinly bedded with black carbonized plant fragments and shale below; sharp contact.
Bedding Cycle 1 (2.35 m)	
687.50 to 689.85	Siltstone: argillaceous, medium grey; thinly interbedded with subordinate low-angle, current and ripple-bedded shale-draped siltstone; abundant glauconitic nodules; sharp irregular contact.
Lloydminster Member Bedding Cycle 2 (5.6 m)	
689.85 to 693.65	Sandstone: quartzose, fine grained, well sorted, permeable; about 7% black and grey chert, white kaolinite grains; weakly indurated in kaolinitic clay, grey and white speckled; balled and distorted in dark grey clayey coatings; pyritic nodular bodies over lower 0.5 m.
693.65 to 695.45	Shale: dark grey, fissile, minor current bedded and starved ripple layers of light grey, very fine grained, permeable, quartzose sandstone; pyritic and sulphurous shale becomes black over basal 0.6 m.
Bedding Cycle 1 (11.55 m)	
695.45 to 697.30	Sandstone: quartzose, very fine grained, medium grey, moderately indurated, earthy; wavy bedded with subordinate dark grey, argillaceous siltstone, permeable; grades into
697.30 to 698.50	Mudstone: dark grey, bedded to massive, earthy; scattered yellow-green glauconitic nodules; grades into grey-black shale over lower half.
698.50 to 699.40	Mudstone: dark grey, minor very fine grained sand, bedded to massive; scattered glauconitic nodules; grades into
699.40 to 706.30	Shale: dark grey, splintery, abundant glauconitic nodules; grades sharply into
706.30 to 706.65	Sandstone: quartzose, very fine grained, medium grey, flat to low-angle laminated with black shaly partings; scattered glauconitic, pyritic nodules.

706.65 to 707.00	Shale: grey black, clayey, silty downward; sharp irregular contact on cemented sandstone layer.
	Cummings Member Bedding Cycle 3 (3.0 m)
707.00 to 710.00	Sandstone: quartzose, fine grained, well sorted, weak argillaceous matrix, oil permeated, faintly bedded; scattered crenulated black shaly partings.
	Bedding Cycle 2 (3.0 m)
710.00 to 710.50	Coal: vitrain (mostly lost) and black carbonaceous mudstone.
710.50 to 712.00	Sandstone: quartzose, fine grained, argillaceous matrix, dark grey; scattered black shale, 0.1 m thick; subordinate sandstone as at 707.0 m.
712.00 to 713.00	Shale: black grading to medium grey green, glauconitic, splintery.
	Bedding Cycle 1 (5.0 m)
713.00 to 713.70	Sandstone: quartzose, fine grained, very argillaceous; subordinate 0.04 m thick beds of oil-permeated, distorted sandstone as at 707.0 m; sharp contact.
713.70 to 715.00	Shale: dark grey, splintery; grades into
715.00 to 718.00	Sandstone: quartzose, fine grained, very argillaceous; well sorted, heavy oil-permeated sandstone layers at 715.28 to 715.78 m.
	Dina Member Unit 3 Bedding Cycle 2 (9.0 m)
718.00 to 727.00	Sandstone: quartzose, fine grained to medium, well sorted, weakly cemented, very permeable; flat bedded to low-angle, tangential cross-bedded downward with overall increase in grade size to medium.
727.00 to 740.00	Sandstone: quartzose, medium to coarse grained, poorly cemented, very permeable (only 0.63 m present).
	Unit 2 Bedding Cycle 1 (13.0 m)
	DUPEROW FORMATION
740.00 to 741.50	Limestone: microcrystalline, white, dense, fractured.

Shell Zaller Lake 10-7-39-25(W3)
KB 663.0 m

Depth in metres

	CANTUAR FORMATION Waseca Member Bedding Cycle 10 (1.6 m)
638.00 to 639.60	Sandstone: quartzose, subordinate white kaolinite after feldspar; abundant grey black chert, green biotite; very fine to fine grained, well sorted; moderately indurated in medium grey mudstone, earthy; medium grained downward; weak trough cross-beds lined with coarse-grained brown sphaerosiderite and minor clay drape; carbonaceous laminae at basal 0.06 m; sharp irregular contact.

Bedding Cycle 9 (3.2 m)

- 639.60 to 639.90 Sandstone: quartzose, fine grained, minerals as above; moderately indurated in medium grey, kaolinitic mudstone; irregularly interbedded with dark grey argillaceous siltstone; scattered brown, ironstone nodules; bedding distorted with low-angle slippage.
- 639.90 to 640.35 Shale: dark grey, crumbly, abundant carbonaceous slivers; sharp contact.
- 640.35 to 641.20 Sandstone: as at 638.00 m, light grey and white speckled, earthy, moderately indurated; scattered scours and ripples coated with carbonized plant fragments; sharp contact.
- 641.20 to 641.35 Shale: dark grey, crumbly, abundant plant remains.
- 641.35 to 641.72 Sandstone: quartzose, very fine grained with minor fine, medium grey silty matrix, moderately sorted; abundant brown, coarse-grained sphaerosiderite and sideritic nodules, carbonaceous flakes; moderately indurated; plastically deformed fine bedding, (penecontemporaneous differential loading); brown iron-stained over basal 0.1 m.
- 641.72 to 642.80 Sandstone: quartzose, very fine grained, scattered fine; silty matrix, calcite cemented, medium grey; cross-laminated with climbing ripple-drift and iron-stained laminae under truncation surfaces, unidirectional and sloping about 15°; laminae tend toward horizontal and to disappear over basal 0.02 m; sharp irregular contact.

Bedding Cycle 8 (0.97 m)

- 642.80 to 643.54 Sandstone: quartzose, very fine grained, well sorted, variably argillaceous; very permeable; penecontemporaneous slumped pile comprising blocks with (1) unidirectional cross-laminae (20°) and near-horizontal truncation sets 0.02 m thick, (2) trough cross-beds (iron stained) 0.09 m thick, and (3) massive sandstone beds with vertical shrinkage fractures, which toward the base show lateral offsets of interbedded, cross-laminated, flasered sandstone and dark grey shale, alternating with well sorted sandstone.
- 643.54 to 643.77 Shale dark grey; thinly interbedded with subordinate sandstone as flasers, lenses and layers; ironstone nodular layer, 0.04 m thick; sharp contact.

Bedding Cycle 7 (3.69 m)

- 643.77 to 645.10 Sandstone: quartzose, fine grained, well sorted; low-angle parallel beds intercalated with minor thin, small-scale festoons, 0.02 to 0.03 m thick above 644 m; and below, dominant festooned trough cross-laminae; oil stained, moderately indurated.
- 645.10 to 647.00 Sandstone: quartzose, well sorted, weakly indurated; bedded fabric masked by heavy-oil saturation.
- 647.00 to 647.46 Shale: black, carbonaceous, fissile to papery; grades below 647.24 m into shale laminated with argillaceous sandstone; strongly bioturbated(?), variably oil saturated (core badly deformed).

Bedding Cycle 6 (2.44 m)

- 647.46 to 649.10 Sandstone: as at 645.1 m; sharp contact.
- 649.10 to 649.90 Shale: grey black, papery; minor thin flasers and isolated flasers of light grey, very fine grained to silty, quartzose sandstone; sharp irregular contact below 0.03 m thick basal oil-saturated sandstone.

Bedding Cycle 5 (3.3 m)

- 649.90 to 650.20 Sandstone: quartzose, fine grained, medium grey, massively bioturbated, moderately indurated, earthy; sharp irregular contact.
- 650.20 to 651.70 Sandstone: as at 645.1 m; irregular contact.

651.70 to 652.00	Sandstone: quartzose, fine grained, argillaceous, medium grey; bioturbated (mostly <i>Chondrites</i>); abundant vertical shrinkage fractures.
652.00 to 653.20	Sandstone: quartzose, well sorted, weakly indurated; bedded fabric masked by heavy-oil saturation; includes thin interbeds of argillaceous, medium grey sandstone below 652.5 to 652.76 m; sharp irregular contact with relief of 0.18 m.
<i>Bedding Cycle 4 (10.00 m)</i>	
652.20 to 655.76	Sandstone: quartzose, very fine grained, medium grey, well sorted, low-angle trough cross-bedded, friable, very permeable; many laminae lined with black carbonaceous detritus; microfaulted and jointed with sandstone veins.
655.76 to 656.32	Sandstone: quartzose, fine grained, medium grey, argillaceous matrix; laminated, cross-bedded, bioturbated, microfaulted and moderately indurated.
656.32 to 658.82	Mudstone: medium green grey, crumbly, limonitic concretionary beds at 0.4 to 0.6 m intervals; interbedded below 657.9 m with laminated shale, ripples, lenticles and flasers of tan, very fine grained, quartzose sandstone.
658.82 to 662.52	Shale: dark grey, splintery.
662.52 to 663.20	Mudstone: minor very fine grained, quartzose sandstone, dark grey with burrow fills and pods of medium grey sandstone; moderately indurated, earthy; sharp irregular contact.
<i>Bedding Cycle 3 (2.86 m)</i>	
663.20 to 663.90	Sandstone: quartzose, medium grained, speckled black and white, well indurated; subordinate kaolinized feldspar, black chert, grey chert, altered green amphibole and brown siderite; scattered coaly partings on dipping layers, otherwise massive; sharp contact.
663.90 to 665.76	Sandstone: quartzose, very fine grained, argillaceous, medium grey; minerals as at 663.20 m; current bedded with ripple beds and lenticles draped by dark grey shale; interspersed <i>Chondrites</i> and small-scale contorted beds; below 665.36 m sandstone is dark grey blue, calcite cemented, and cross-beds are draped with carbonaceous detritus; sharp contact.
665.76 to 666.06	Shale: grey black, splintery, sharp contact.
<i>Bedding Cycle 2 (6.94 m)</i>	
666.06 to 669.00	Mudstone: olive green and dark green grey; interbedded with sandy mudstone, generally massive; at 668.5 m ironstone concretionary layer, 0.13 m thick; scattered coal lenticles.
669.00 to 669.56	Sandstone: quartzose, fine grained, grey black, argillaceous carbonaceous matrix; rootlet burrowed and microfaulted; abundant carbonaceous films of leaves and stems.
669.56 to 671.64	Sandstone: quartzose, medium grained, kaolinite indurated, speckled black and white, earthy; subordinate kaolinized feldspar, black chert, grey chert, chloritic green amphibole and brown siderite; low-angle cross-bedded, with a number of laminae lined with carbonaceous debris; above 670.12 m grades through fine-grained sandstone into a capping sandy mudstone penetrated by carbonized rootlet casts; grades over basal 0.2 m into
671.64 to 673.00	Sandstone: quartzose, fine grained, silty argillaceous matrix, medium buff grey; laminated with grey black plant detrital mudstone; also current bedded with thin (0.01 m) calcite-cemented, laminated truncation sets, trough and ripple beds; some microfaults and contortion; interbedded with argillaceous very fine grained sandstone similarly laminated; sharp basal contact.

Bedding Cycle 1 (2.18 m)

- 673.00 to 673.54 Sandstone: quartzose, very fine grained, argillaceous; grades into sandstone: quartzose, fine grained, calcite cemented, dark blue grey, generally contorted, massive; scattered brown septarian bodies with coarse calcite veins.
- 673.54 to 674.10 Sandstone: quartzose, fine grained, argillaceous, minerals as at 669.56 m; dark blue grey speckled with white, earthy, moderately indurated; low-angle current bedded with minor carbonaceous laminae and thin beds; sharp basal contact.
- 674.10 to 675.18 Sandstone: quartzose, very fine grained, argillaceous; laminated with shale, medium grey and dark grey; bioturbated below 674.50 m, ironstone cemented medially; sharp contact.

Sparky Member
Bedding Cycle 4 (1.95 m)

- 675.18 to 675.45 Coal.
- 675.45 to 676.17 Shale: dark grey, crumbly; scattered coaly lenticles abundant below 676.0 m; sharp contact.
- 676.17 to 677.13 Sandstone: quartzose, fine grained; mineralogy and fabric as at 669.56 m; basal 0.1 m is a dark grey, coaly, grey black shale conglomerate; sharp contact.

Bedding Cycle 3 (4.53 m)

- 677.13 to 677.31 Shale: black, coaly; grades into coal over lower half.
- 677.31 to 681.66 Sandstone: quartzose, very fine grained, very argillaceous, medium grey, generally homogenized; abundant brown ironstone nodules; rootlet penetrated above 678.14 m, faintly bioturbated in places.

Bedding Cycle 2 (2.86 m)

- 681.66 to 684.52 Sandstone: quartzose, fine grained, argillaceous matrix, medium grey, bioturbated with feeding burrows, as delineated by lighter grey, less argillaceous pods and lenticles; grades below 683 m into very fine grained with mudstone interbeds.

Bedding Cycle 1 (2.73 m)

- 684.52 to 686.31 Sandstone: quartzose, medium grained decreasing downward to fine; subordinate fine-grained sandy and silty, argillaceous matrix, poorly sorted; abundant white feldspar and black chert, rare biotite; strongly bioturbated throughout; sharp(?) contact.
- 686.31 to 687.25 Sandstone: quartzose, fine grained, light grey and black, kaolinitic matrix; minerals as at 684.52 m; current bedded with tangential laminae within thin truncation sets (0.01 m); layers lined with carbonized plant detritus; abundant brown siderite; well indurated.

General Petroleums Member
Bedding Cycle 2 (4.75 m)

- 687.25 to 688.64 Sandstone: quartzose, medium grained, subordinate fine and very fine, poorly sorted, white kaolinite matrix; minerals as at 684.52 m; abundant increasing downward to minor (15%) coarse-grained, brown sphaerosiderite, calcite cemented; generally massive with trace of current beds; sharp basal contact.
- 688.64 to 689.61 Sandstone: as at 686.31 to 687.25 m; grades downward into argillaceous, very fine grained, quartzose, sandstone and silty mudstone, dark grey with traces of medium grey bioturbation sandy fill; sharp contact.
- 689.61 to 690.39 Shale: dark grey, fissile to crumbly; grades into an argillaceous, quartzose sandstone, 0.1 m thick, on a pyritic, irregular, basal contact.
- 690.39 to 692.00 Shale: black, carbonaceous; sharp contact.

Bedding Cycle 1 (4.09 m)

- 692.00 to 692.56 Shale: dark grey, fissile to crumbly, capped by medium brownish grey, silty mudstone (seat earth?), 0.18 m thick.
- 692.56 to 694.50 Sandstone: quartzose, very fine grained, argillaceous matrix; brown iron stained at 692.56 to 692.86 m; medium grey grading to dark grey with increasing argillaceous content; bioturbated throughout, with burrows mostly short (0.01 m) and oblique; grey black and carbonaceous over basal 0.15 m.
- 694.50 to 696.09 Shale: black, scattered lenticles of light grey argillaceous siltstone; grades into dark grey below 695.46 m with an increase of very fine grained, quartzose sandstone flasers and lenticles; sharp contact.

Rex Member

Bedding Cycle 2 (2.87 m)

- 696.09 to 696.60 Shale: black, carbonaceous; grades into a coal over basal 0.1 m.
- 696.60 to 697.23 Sandstone: quartzose, very fine grained, argillaceous, medium and dark grey, homogenized throughout by bioturbation, minor stringers of pelleted black shale; traces of channel cut-and-fill; coaly rootlet casts over upper 0.6 m; sharp contact.
- 697.23 to 698.96 Sandstone: quartzose, fine grained grading downward to very fine; minor black chert, scattered green glauconite; grey white kaolinite matrix; becomes very fine grained downward and medium grey with brown iron-stained patches; generally massive with grey-black shaly stringers along oblique fractures; bioturbated and laminated with dark grey shale at 698.09 to 698.42 m; sharp contact.

Bedding Cycle 1 (3.17 m)

- 698.96 to 702.13 Sandstone: quartzose, fine grained, well sorted, light grey, argillaceous (kaolinitic) matrix; low-angle current bedded (ripple-drift) with coaly fragments; well indurated, earthy, flaggy; boudinaged towards base; sharp contact.

Lloydminster Member

Bedding Cycle 2 (3.29 m)

- 702.13 to 705.05 Sandstone: quartzose, fine grained, well sorted; abundant black chert, dark grey chert, sphaerosiderite; well cemented with calcite, low argillaceous content, light blue grey; trough cross-bedded, some laminae lined with plant fragments.
- 705.05 to 705.42 Shale: medium grey, splintery; laminated with current-bedded, light grey, argillaceous, very fine grained, quartzose sandstone over basal 0.1 m.

Bedding Cycle 1 (4.24 m)

- 705.42 to 705.75 Sandstone: quartzose, fine grained, argillaceous, medium grey, yellow-brown iron cemented over basal 0.08 m; boudinaged and microfaulted with dark grey shale; sharp contact.
- 705.75 to 709.66 Shale: dark grey grading downward into black; subordinate decreasing to scattered, lenticles and flasers of argillaceous, quartzose, very fine grained sandstone; sharp irregular contact.

SUCCESS (DETRITAL) FORMATION

- 709.66 to 717.34 Melange of red and pale green, dolomitic mudstone of the Upper Devonian Big Valley and Torquay formations, capped by kaolinitic sandy mudstones and pebble-conglomerate of sandstone, mudstone and sideritic ironstone; faulted basal contact.

BIRDBEAR FORMATION

717.34 to 719.00 Dolomite: cryptocrystalline, argillaceous, medium brownish grey; faintly bedded, as delineated by lenticular stringers and bioturbation pods of vuggy, microcrystalline dolomite.

Shell Frenchman Butte A7-3-54-25(W3)

KB 630.7 m

Depth in metres

JOLI FOU FORMATION

433.25 to 438.40 Shale: grey black, very fissile, pelecypod shell hash in rust-brown siderite-cemented, cross-bedded sandstone lens at 435.5 m; sharp erosional contact with relief of 0.06 m.

PENSE FORMATION

Colony Member

Bedding Cycle 6 (6.1 m)

438.40 to 439.40 Mudstone: sandy, dark grey, minutely bioturbated as marked by millimetre-scale, medium grey, sandy bedding-aligned slivers; ironstone nodule at 438.85 m; sharp contact.

439.40 to 439.53 Coal: black, vitrain, fissile.

439.53 to 441.29 Mudstone: dark grey; subordinate medium grey, lenticular, current-bedded, very fine grained, quartzose sandstone; sharp contact marked by fragments of underlying bed.

441.29 to 443.60 Sandstone: quartzose, loamy, severely bioturbated and compacted; minor interbeds of sandstone, quartzose, fine grained, well sorted, heavy-oil permeated, weakly indurated, 0.02 to 0.03 m thick.

443.60 to 444.50 Sandstone: quartzose, very fine grained, argillaceous, massive, heavy-oil-permeated beds, 0.15 m thick; interbedded with loamy sandstone, medium grey, 0.02 to 0.03 m thick; sharp contact.

Bedding Cycle 5 (1.7 m)

444.50 to 445.80 Claystone: dark grey, coaly laminae toward base; minor quartzose sandy lenticular laminae throughout.

445.80 to 446.20 Sandstone: quartzose, very fine grained, weakly indurated; upward increase in argillaceous content; sharp basal contact.

Bedding Cycle 4 (2.6 m)

446.20 to 446.30 Mudstone: medium grey; subordinate very fine grained, quartzose sandy lenticles and bioturbation pods; sharp contact.

446.30 to 447.20 Sandstone: quartzose, very fine grained, weakly indurated, heavy-oil permeated; sharp basal contact.

447.20 to 448.80 Shale: grey black, fissile, scattered medium grey sandy lenticles; sharp basal contact.

McLaren Member

Bedding Cycle 3 (6.3 m)

448.80 to 448.96 Coal: black, argillaceous, fissile.

448.96 to 449.21 Loam: sandy, compaction distorted, medium grey (paleosol?); sharp contact.

449.21 to 450.27	Sandstone: quartzose, very argillaceous, medium grey; minor lenticles, lenses and balls of oil-saturated, very fine grained, quartzose sandstone; bioturbated and contorted throughout, earthy; sharp contact.
450.27 to 450.80	Sandstone: quartzose, very fine grained, well sorted, low argillaceous content, heavy oil saturated; scattered lenticles and pods of sandstone as at 449.21 m; sharp contact.
450.80 to 451.88	Sandstone: as at 449.21 m; sharp contact.
451.88 to 453.58	Sandstone: as at 450.27 m; sharp contact.
453.58 to 454.52	Sandstone: quartzose very fine grained, argillaceous, medium grey, finely bioturbated; thinly interbedded with oil saturated, centimetre-thick, current-bedded, very fine grained, quartzose sandstone, and rust-brown siderite-cemented, current-bedded, quartzose sandstone; basal oil-saturated sandstone, 0.35 m thick; sharp contact.
454.52 to 455.10	Mudstone: quartzose sandy, medium grey, bioturbated, minor oil-saturated lenticles of argillaceous, fine-grained, quartzose sandstone; sharp irregular contact.
<i>Bedding Cycle 2 (2.21 m)</i>	
455.10 to 456.10	Sandstone: quartzose, very fine grained, well sorted, weakly indurated, heavy-oil permeated; incorporated material from underlying bed at sharp basal contact.
456.10 to 456.20	Sandstone: quartzose, very fine grained, argillaceous, medium grey; quartzose sand-filled small-scale burrows near top; grades downward into ripple-drift bedded, oil-permeated, very fine grained, quartzose sandstone.
456.20 to 456.76	Sandstone: as at 455.10 m, sharp contact.
456.76 to 457.31	Sandstone: as at 456.10 m; ripple bedded with mudstone drapes throughout; brown siderite cemented in part; sharp, current scoured basal contact.
<i>Bedding Cycle 1 (2.17 m)</i>	
457.31 to 457.96	Sandstone: as at 455.10 m, sharp, erosive contact.
457.96 to 458.75	Sandstone: as at 456.76 m, sharp contact.
458.75 to 459.48	Shale: grey black, fissile, minor lenticles of oil-stained, current-bedded, quartzose sandstone near top; sharp basal contact.
<i>Waseca Member</i>	
<i>Bedding Cycle 8 (3.54 m)</i>	
459.48 to 460.12	Coal: argillaceous, fusain, hard, platy; sharp, basal contact.
460.12 to 463.02	Sandstone: quartzose, argillaceous, severely bioturbated, moderately indurated, earthy, medium and dark grey.
<i>Bedding Cycle 7 (5.67 m)</i>	
463.02 to 466.22	Sandstone: quartzose, very fine grained, subordinate coarse-grained silt, ca. 10% medium-grained black chert, carbonaceous grains and brown siderite; medium grey, current bedded with scattered truncational cross-bedded sets; minor grey-black shale and coaly laminae; very friable over basal 0.4 m.
466.22 to 467.52	Siltstone: quartzose, medium grey, argillaceous, laminated with shale, dark grey; subordinate current-bedded very fine grained, quartzose sandstone.
467.52 to 468.69	Shale: dark grey, fissile, subordinate lenticles and pods of silt; sharp, irregular contact.

Unit 5 *Bedding Cycle 6 (4.01 m)*

- 468.69 to 472.40 Sandstone: quartzose, very fine grained, well sorted, weakly indurated, very permeable, medium grey; current and ripple bedded with subordinate dark grey shale laminae over lower half; scattered rust-brown, siderite-cemented layers over lower half.
- 472.40 to 472.70 Mudstone: subordinate quartzose sand, medium grey to grey black downward; weakly bedded with minor quartzose sandstone lenticles; sharp basal contact.

Bedding Cycle 5 (2.12 m)

- 472.70 to 474.82 Sandstone: quartzose, very fine grained, well sorted, medium grey, weakly argillaceous, permeable, moderately indurated, fine bedded and current bedded; sharp, irregular basal contact on 0.05 m of grey-black bioturbated mudstone and sandstone.

Unit 4 *Bedding Cycle 4 (3.01 m)*

- 474.82 to 477.05 Sandstone: quartzose, very fine grained, well sorted, medium grey; swaley and trough cross-bedded with opposing truncation sets, permeable, moderately indurated, friable; scattered dark grey, bioturbated lenses; sharp contact on trough cut.
- 477.05 to 477.83 Sandstone: as above, but interbedded with dark grey, bioturbated shale; ripple and trough cross-bedded; basal 0.4 m includes cross-bedded medium-grained quartzose sandstone.

Unit 3 *Bedding Cycle 3 (1.97 m)*

- 477.83 to 479.80 Sandstone: quartzose, fine grained, argillaceous (kaolinitic), medium green grey; ca. 3% black chert, carbonaceous grains; permeable, moderately indurated, massive; minor centimetre-thick, dark grey, argillaceous, bioturbated layers at 478.35 to 478.4 m; fine-grained, low-angle planar laminated below; sharp, irregular contact.

Unit 2 *Bedding Cycle 2 (2.77 m)*

- 479.80 to 480.00 Mudstone: carbonaceous, dark grey, bioturbated with medium grey, very fine grained, quartzose sandstone pods.
- 480.00 to 480.43 Sandstone: quartzose, fine grained, medium green-grey kaolinitic matrix; ca. 5% brown siderite, black chert and carbonaceous grains, moderately indurated.
- 480.43 to 481.00 Mudstone: dark grey, ca. 7% brown sphaerosiderite, faint bioturbation traces, massive; grades into
- 481.00 to 482.57 Sandstone: quartzose, minerals and fabric as at 480.00 m, minor ripple interbeds; flowage contorted and oxidized red brown over lower 0.4 m.

Unit 1 *Bedding Cycle 1 (4.83 m)*

- 482.57 to 484.25 Sandstone: quartzose, fine grained grading downward to very fine, medium green grey; faintly trough and current bedded as delineated by brown, medium-grained siderite; calcite-cemented, kaolinitic matrix.
- 484.25 to 485.42 Mudstone: medium grey, laminated with ripple-bedded, very fine grained, medium grey, quartzose sandstone; alternating with burrowed mudstone.
- 485.42 to 485.92 Mudstone: medium grey, massive, scattered rust-brown sideritic nodules on basal 0.07 m thick, channel fill quartzose sandstone as at 482.57 m.
- 485.92 to 487.25 Mudstone: as at 485.42 m; sharp contact.
- 487.25 to 487.40 Shale, grey black, fissile; sharp contact.

Sparky Member
Bedding Cycle 3 (3.4 m)

- 487.40 to 487.80 Coal: black, shaly, vitrain; sharp contact.
- 487.80 to 488.50 Sandstone: quartzose; very fine grained, well sorted, light grey, massive, weakly indurated, very permeable.
- 488.50 to 490.10 Sandstone: quartzose, very fine grained, argillaceous, medium grey; swaley cross-bedded and loading deformed in part, bioturbated towards base; grades into
- 490.10 to 490.80 Mudstone: subordinate, very fine grained quartzose sand; traces of bioturbation,

Bedding Cycle 2 (5.95 m)

- 490.80 to 496.75 Sandstone: quartzose, fine grained, well sorted, massive, weakly indurated, very permeable, light grey, mottled with brown siderite cementation over upper 0.20 m; thin conglomeratic layers near base; sharp contact.

Bedding Cycle 1 (4.4 m)

- 496.75 to 499.20 Sandstone: quartzose, fine grained, ca. 12% black chert, white kaolinite after feldspar; kaolinitic matrix, weakly indurated, earthy; grades downward to very fine grained with swaley cross-beds and scattered thin grey-black shale; sharp contact.
- 499.20 to 501.15 Shale: grey black; subordinate thin, medium grey sandstone as ripple beds, graded beds and trough cut-and-fill; sharp basal contact.

General Petroleum
Bedding Cycle 2 (8.31 m)

- 501.15 to 501.65 Sandstone: quartzose as at 496.75 m; loading deformation delineated by irregular network of black carbonaceous shale; grades into
- 501.65 to 502.25 Sandstone: quartzose, very fine grained, light grey, well sorted, centimetre-scale current bedded with thin truncational sets, loading deformed over basal 0.15 m; scattered *Skolithus*.
- 502.25 to 503.70 Sandstone: quartzose, very fine grained, argillaceous, medium grey, flat laminated yielding to swaley cross-bedded, scattered vertical and oblique burrows.
- 503.70 to 508.90 Sandstone: quartzose, fine grained, light grey, well sorted, flat-bedded alternating with low-angle truncation sets, moderately indurated, permeable.
- 508.90 to 509.46 Sandstone: quartzose, very fine grained; light grey, argillaceous, cross-bedded, interbedded with bioturbated dark grey mudstone and sandstone; sharp contact.

Bedding Cycle 1 (6.09 m)

- 509.46 to 509.89 Sandstone: as at 503.70 m; sharp contact.
- 509.89 to 510.09 Sandstone: as at 508.90 m.
- 510.09 to 512.35 Sandstone: quartzose, very fine grained, well sorted, iron stained yellow brown, permeable; minor thin beds of laminated and cross-bedded sandstone, abundant oblique centimetre-deep burrows; shrinkage microfractures and micro-convoluted bedding over basal 0.7 m.
- 512.35 to 513.85 Mudstone: quartzose, sandy, medium grey, bioturbated, moderately indurated; grades into
- 513.85 to 515.55 Shale: grey black, fissile, basal 0.12 m include lenticles and fragments of underlying sandstone; sharp contact.

Rex Member
Bedding Cycle 4 (3.38 m)

- 515.55 to 517.00 Sandstone: quartzose, very fine grained, kaolinitic matrix, light grey, moderately indurated; abundant medium-grained, brown siderite and coaly fragments at upper 0.4 m; below current-bedded, ripple bedded and flasered; dark grey shale increases downward as mud drapes, laminae and thin beds; grades into
- 517.00 to 518.93 Shale: dark grey, minor starved ripples, lenticles and laminae of light grey, very fine grained, quartzose sand; moderately indurated; thin, limonite-cemented beds over basal 0.4 m; sharp basal contact.

Bedding Cycle 3 (2.12 m)

- 518.93 to 521.05 Sandstone: quartzose, very fine grained, light grey, kaolinitic, moderately indurated, earthy, permeable; ca. 7% black chert, massive; carbonaceous, argillaceous content increases downward; sharp contact on centimetre thick coaly layer.

Bedding Cycle 2 (9.15 m)

- 521.05 to 521.40 Mudstone: (seat earth), medium grey, abundant carbonized plant fragments, massive; grades into
- 521.40 to 522.80 Sandstone: quartzose, fine grained, kaolinitic matrix, medium grey, moderately indurated, permeable, bioturbated; minor thin, laminated bedding sets of sandstone and dark grey shale, abundant *Skolithus*.
- 522.80 to 529.20 Sandstone: quartzose, fine grained decreasing downward to very fine, flat- and low-angle planar cross-bedded, moderately indurated; swaley cross-bedded over basal 0.8 m, medium grey, iron-stained *Chondrites* mottling at 522.80 to 525.00 m; earthy, permeable; sharp basal contact.
- 529.20 to 530.20 Shale: dark grey, bioturbated; subordinate beds of sandstone, quartzose, fine-grained, kaolinitic matrix, ca. 15% black chert and coarse-grained sphaerosiderite in 0.3 m thick bed at 529.25 to 529.55 m, and in starved ripple sandy lenticles, decreasing downward to insignificant; sharp, irregular basal contact on cemented, pitted surface.

Bedding Cycle 1 (8.8 m)

- 530.20 to 537.87 Sandstone: quartzose, fine grained, ca. 5% medium; 12% black and dark grey chert, sphaerosiderite, feldspar; moderately indurated in kaolinite; calcareous, earthy, medium green grey; extensively burrowed (*Teichichnus*) at 529.30 to 529.95 m; minor crenulated, dark grey shale laminae sets below 536.30 m; otherwise massive, earthy; oil impregnated at 535.55 to 535.85 m; grades by thinly interbedded shale into
- 537.87 to 539.00 Shale: dark grey, fissile (ca. 0.18 m present); sharp basal contact (depth adjusted) on cemented pavement.

Lloydminster Member (Upper unit)
Bedding Cycle 7 (0.4 m)

- 539.00 to 539.40 Sandstone: quartzose, fine grained, minerals as at 530.20 m; ca. 5% coaly bedded flakes; calcite-cemented, kaolinitic matrix; oxidized reddish brown over upper third; sharp, irregular basal contact.

Bedding Cycle 6 (8.7 m)

- 539.40 to 540.10 Sandstone: quartzose, fine grained, argillaceous, weakly indurated, oil permeated; bioturbated over lower half; grades into
- 540.10 to 545.24 Sandstone: quartzose, very fine grained, well sorted, light grey, weakly indurated, low-angle planar cross-bedded truncational sets at 540.2 to 541.0 m; minor thin shaly interbeds at 542.50 to 543.24 m.

545.24 to 546.50	Sandstone: quartzose, very fine grained, current bedded, light grey: subordinate dark grey shale drape, laminae and thin interbeds increasing downward; scattered brown siderite-cemented layers.
546.50 to 548.10	Shale: dark grey, fissile, noncalcareous, sharp contact (depths adjusted to log). <i>Bedding Cycle 5 (3.70 m)</i>
548.10 to 549.25	Sandstone: as at 545.24 m.
549.25 to 551.80	Shale: dark green, fissile, silty; becomes dark grey brown downward; erosional contact on weathered surface (depths adjusted to log). Lloydminster Member (Lower unit) <i>Bedding Cycle 4 (5.83 m)</i>
551.80 to 557.63	Sandstone: quartzose, medium grained decreasing downward to fine; ca. 10% black chert, white kaolinite after feldspar; light green-grey kaolinite matrix, moderately indurated, massive; calcite cemented below 554.0 m; patterned by brown siderite-infiltrated burrow forms; upper 0.5 m severely oxidized dark yellow and brown; basal contact sharply angular with relief of 0.05 m across core on oxidized surface. <i>Bedding Cycle 3 (9.02 m)</i>
557.63 to 559.10	Sandstone: quartzose, medium grained, ca. 15% black and dark grey chert, green glauconite, white kaolinite after feldspar, weakly indurated kaolinitic matrix, earthy, permeable, dark green grey, massive with burrow traces.
559.10 to 566.65	Sandstone: quartzose, fine grained, ca. 10% black and dark grey chert, white kaolinite after feldspar, kaolinitic matrix, dark green grey, bioturbated throughout, moderately indurated; oxidized and calcareous at 559.1 to 561.7 m, abundant pyritic nodules; sharp, sloping basal contact with relief 0.01 m across core on oxidized surface. <i>Bedding Cycle 2 (2.52 m)</i>
566.65 to 569.17	Sandstone: quartzose, fine grained; minerals as at 559.1 m; ca. 5% crenulated black shale laminae and lenticles, increasing to 30% downwards; oxidized brown and calcite cemented over uppermost 0.03 m; sharp basal contact on oxidized surface. <i>Bedding Cycle 1 (3.0 m)</i>
569.17 to 572.17	Sandstone: quartzose, fine grained; minerals as at 559.1 m; uppermost 0.2 m oxidized rust brown and siderite cemented; ca. 30% increasing downward to 40% crenulated and wavy laminae and thin beds of black shale; scattered pyritic nodules; sharp irregular contact. Cummings Member <i>Bedding Cycle 3 (8.99 m)</i>
572.17 to 574.25	Sandstone: quartzose, very fine grained, well sorted; abundant carbonaceous specks, scattered muscovite, massive, weakly indurated, very permeable, medium grey; scattered coaly rootlets.
574.25 to 577.41	Sandstone: quartzose, very fine grained, strongly bioturbated with incorporated grey black shale; subordinate dark grey shale laminae downward.
577.41 to 581.16	Siltstone: quartzose, bioturbated, medium green-grey mudstone becoming grey black downward; moderately indurated, earthy, sharp basal contact. <i>Bedding Cycle 2 (2.09 m)</i>
581.16 to 583.25	Sandstone: quartzose, fine grained, medium grey and brown; grades downward to very fine; well sorted and massive over upper half, bioturbated with minor siltstone and shale

laminae below; siderite-cemented concretionary sandstone alternates at 0.3 m intervals; some plastic deformation.

Bedding Cycle 1 (18.00 m)

583.25 to 592.25 Sandstone: quartzose, fine grained, rusty grey and brown banded, well sorted, silica grain-contact cemented, weakly indurated, very permeable; flat bedded and current bedded (50% loss).

592.25 to 601.25 Sandstone: quartzose, fine grained, silica grain-contact cemented, weakly indurated, medium grey; interbedded with dark grey shale; pyritic sulphur bloom (60% loss).

Dina Member

601.25 to 610.25 Sandstone: as at 592.25 m (loss 90%).

610.25 to 619.25 Shale: dark grey, fissile (mostly mangled); lower 2/3 of core is a shale, dark grey, laminated with subordinate light grey siltstone; thin, green, pyritic lenticular beds also present (loss 50%).

619.25 to 637.25 Sandstone: quartzose, medium grained, well sorted, poorly indurated, massive, medium grey, very permeable (loss 33%).

637.25 to 643.25 Loss 100%.

643.25 to 645.25 Sandstone: quartzose, medium grained with subordinate coarse, subrounded, friable, very permeable (1.5 m rec.).

Consumers Hartog Whiteside 11-9-30-26(W3)

KB 2391 feet (728.8 m)

Depth in feet (m)

SUCCESS FORMATION (DETRITAL)

2710.0 to 2715.0
(826.0 to 827.5) Sandstone: quartzose, very fine grained with subordinate fine and medium, kaolinitic matrix, medium grey to buff grey, earthy, poorly sorted; siderite-lined and dark grey mudstone veins; some distortion of fabric; abundant carbonized plant detritus and rootlets; massive; minor, thin (0.02 to 0.06 m), dark grey, distorted claystone.

2715.0 to 2717.0
(827.5 to 828.1) Sandstone: quartzose, fine grained, well sorted, buff, kaolinitic matrix; distorted and intermixed with subordinate very fine grained quartzose sandstone; oil mottling delineated by sandier bodies; rock tends to break down into aggregates of pebble-size pods.

2717.0 to 2730.0
(828.1 to 832.1) Sandstone: quartzose, coarse-grained, variably sorted, subordinate to minor very fine-grained quartzose sandstone, cream-coloured, kaolinitic matrix, earthy, moderately indurated; about 10% coarse-grained sphaerosiderites concentrated at 828.1 to 829.7 m and in more scattered bands below; scattered clay, 0.02 to 0.06 m thick; traces of fine current beds but generally massive with abundant vertical fractures.

2730.0 to 2733.5
(832.1 to 833.2) Sandstone: as at 828.1 m but reduced to a rubble, oil stained; scattered sideritic clayey beds with distorted dips toward base; sharp slickensided contact.

2733.5 to 2735.0
(833.2 to 833.6) Claystone: medium green grey, abundant sphaerosiderite, scattered carbonaceous fragments, moderately indurated; conglomerate of white tripolitic angular chert at 833.3 to 833.6 m.

2735.0 to 2748.5
(833.6 to 837.7) Sandstone: quartzose, very fine grained, cream coloured, kaolinitic matrix; well-sorted sandstone nodules intermixed with more argillaceous and silty ones, traces of current beds; layered breccia and conglomerate alternate with silty sphaerosideritic claystone; becomes cherty conglomeratic downward.

2748.5 to 2751.0 (837.7 to 838.5)	Siltstone: quartzose, cream, kaolinitic matrix, massive, well indurated, abundant coarse sphaerosiderite.
2751.0 to 2756.0 (838.5 to 840.0)	Sandstone: quartzose, very fine grained, well sorted, slightly argillaceous, oil stained, weakly indurated to rubbly; abundant patchy silica-cemented chert in scattered bedding groups.
2756.0 to 2758.5 (840.0 to 840.6)	Claystone: silty, abundant tripolitic breccia and sphaerosiderite, grey white stained with red, massive, well indurated.
2758.5 to 2766.0 (840.6 to 843.1)	Siltstone: quartzose, minor very fine grained, quartzose sandstone, oil stained; interbedded with silty, grey-white claystone; abundant conglomerate and breccia of sandstone. Massive, tripolitic(?) and white below 842.2 m (2763 feet); Many vertical fractures.

Saskoil Plover Lake 15-5-35-26(W3)
KB 727.7 m

Depth in metres

SUCCESS FORMATION (DETRITAL)

805.0 to 810.5	Tripoli: earthy, white, massive, hackly, porous; grades into
810.5 to 811.5	Shale: mottled olive and limonite yellow; finely bedded with mudstone, crumbly.
811.5 to 815.0 ⁺	Conglomerate: grey chert nodules, siliceous limestone in matrix of light green-grey, sandy mudstone and argillaceous, oil stained sandstone.

BAKKEN FORMATION

815.0 to 827.0	Sandstone: quartzose, fine grained, well sorted, weakly cemented, finely bedded, heavy oil saturated; sharp contact.
827.0 to 832.0	Sandstone: quartzose, very fine grained, light grey, laminated with light green mudstone, cross-bedded with numerous small truncation sets; subordinate thin beds (0.08 to 0.3 m) of oil-stained sandstone as above.

⁺ adjusted to log

SPC Luseland 7-7-35-26W3
KB 2436 feet (742.5 m)

Depth in feet (m)

SUCCESS FORMATION (DETRITAL)

2710.0 to 2728.0 (826.0 to 831.5)	Conglomerate/breccia: siltstone and claystone: white, siliceous; light green-grey, medium-grey and grey-black claystone, and dark grey, argillaceous fine-grained sandstone; dolomitic over basal 1 m. Matrix dominated by kaolinitic and tripolitic mudstone, with abundant partially oxidized sphaerosiderite; heavily oil mottled over basal 2 m; sharp, irregular contact.
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MADISON FORMATION

2728.0 to 2733.0 (831.5 to 833.0)	Limestone: cryptocrystalline, dense, medium lavender and greenish grey, some solution pipes and pits, incipient stylolites along clayey envelopes of concretionary bodies; oxidized, obliquely to vertically splayed, argillaceous stringers annealed into the limestone.
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2733.0 to 2756.0 (833.0 to 840.0)	Limestone, cryptocrystalline, siliceous argillaceous downward; faint laminae delineated by light grey, limestone grading up or down into light grey-green siliceous claystone; laminated beds distorted around concretionary, brownish grey limestone; calcite syneresis veins and joints and microfaults lined with green marlstone; argillaceous content and green marlstone interbeds conspicuous over basal 1 m; sharp contact.
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KPL Macklin 11-32-38-26(W3)
KB 2261 feet (689.2 m)

Depth in feet (m)

CANTUAR FORMATION
Waseca Member

2310.0 to 2312.0 (704.0 to 704.7)	Mudstone: dark grey, silty, massive to platy; 5 to 10% sandstone: quartzose, very fine grained, argillaceous, medium to light green grey, abundant muscovite in minute flasers and lenticles; 5 to 10% plant detritus, both as sand size particles laminated with sandstone or as larger fragments in mudstone; grades (with reworking) into
2312.0 to 2312.3 (704.7 to 704.8)	Sandstone: quartzose, medium-grained, subangular; 5 to 10% black chert, black carbonaceous grains, white kaolinite, green biotite, green chlorite; argillaceous, dark grey and medium grey, well indurated; (recovery 0.05 m).
2312.3 to 2312.5 (704.8 to 704.9)	Shale: black, carbonaceous; thin (0.03 m), hard, brittle coaly interbed; yellow-green sulphurous parting; sharp contact.
Bedding Cycle 6 (1.3 m)	
2312.5 to 2313.5 (704.9 to 705.0)	Sandstone: quartzose, fine grained, well sorted, minerals as at 704.7 m; tangential current bedded, medium grey; laminated with mudstone: black, carbonaceous, abundant plant detritus and green biotite; bedding penetrated by sand-filled burrow; iron stained (siderite) at base.
2313.5 to 2315.0 (705.0 to 705.6)	Sandstone: quartzose, very fine grained, dark grey, massive, argillaceous, severely bioturbated and intermixed with grey-black mudstone; trace of bedding; basal 0.2 m comprises sandstone: argillaceous, fine-grained, quartzose, minerals as 704.7 m, bioturbated, and thin, grey black claystone with abundant reedy impressions at base.
2315.0 to 2317.0 (705.6 to 706.2)	Sandstone: quartzose, fine grained grading downward to very fine, argillaceous, dark grey; minerals as at 704.7 m, abundant coaly fragments; burrowed mostly along and at low angle to bedding.
Bedding Cycle 5 (2.0 m)	
2317.0 to 2318.0 (706.2 to 706.5)	Mudstone: dark grey, silty to clayey, abundant bedded, crisscrossed carbonized stalks; scattered sideritic nodules.
2318.0 to 2318.5 (706.5 to 706.7)	Coal: hard, brittle, fragments only, 0.08 m thick on mudstone; sharp irregular contact.
2318.5 to 2321.5 (706.7 to 707.6)	Mudstone: medium, green grey, massive, scattered carbonized rootlets and irregular silty partings; sharp erosional contact.
2321.5 to 2323.5 (707.6 to 708.2)	Sandstone: quartzose, fine grained, grading downward into medium with abundant coarse; abundant brown, fine to medium-grained sphaerosiderite, black chert, black carbonaceous grains, coaly slivers; ca. 30% detrital coal laminae at 707.9 m; reddish grey to light grey downward with decrease in argillaceous content and increase in calcite cementation; white, siliceous kaolinitic matrix; sharp irregular contact.

Bedding Cycle 4 (2.0 m)

2323.5 to 2330.0
(708.2 to 710.2) Mudstone: medium and dark grey; well indurated; ca. 15% lenticular laminae of light grey, very fine grained, quartzose sandstone; sandstone, 0.05 m thick, ripple cross-bedded, carbonaceous with abundant plant detritus at 708.4 m; brown ironstone (siderite or ankerite) cobble-size nodules at 708.8 and 709.7 m; dark grey with increasing carbonaceous content derived by reworking of basal coaly bed; contact sharp and irregular.

Bedding Cycle 3 (2.9 m)

2330.0 to 2335.5
(710.2 to 711.9) Sandstone: quartzose, fine grained, ca. 10% black chert, carbonaceous grains, white kaolinite (some pseudomorphic after feldspar), scattered green, earthy chlorite and greenish brown biotite; kaolinitic matrix, moderately to well indurated, grey; below 711.6 m occur scattered low-angle ripple and scoured cross-beds marked by detrital coal grains and carbonaceous siltstone; carbonaceous to coaly at top; sharp basal contact.

2335.5 to 2336.5
(711.9 to 712.2) Mudstone: hard, well indurated, dark brownish grey; grades into

2336.5 to 2338.0
(712.2 to 712.6) Sandstone: quartzose, very fine grained, calcareous, argillaceous, well indurated; subordinate, fine-grained, quartzose sandstone with minerals as at 710.2 m; medium brownish grey; annealed vertical fractures; grades into

2338.0 to 2339.5
(712.6 to 713.1) Sandstone: quartzose, fine grained, minerals as at 710.2 m; calcite cemented, dense, light blue grey, trace of small-scale tangential cross-beds with detrital coal; sharp contact.

Bedding Cycle 2 (2.1 m)

2339.5 to 2346.0
(713.1 to 715.1) Sandstone: quartzose, very fine grained; ca. 10% carbonaceous grains, kaolinite, black chert, biotite, green glauconite, sphaerosiderite; light grey kaolinitic matrix, friable, moderately indurated; thin tangential and ripple cross-beds; abundant obliquely cross-cutting sandy burrows; subordinate thin dark grey mudstone; bioturbation intense over basal 0.15 m; sharp load-casted contact.

2346.0 to 2346.5
(715.1 to 715.2) Mudstone: grey black, carbonaceous, faintly bedded and contorted; carbon content decreases downward; sharp contact.

Bedding Cycle 1 (2.9 m)

2346.5 to 2353.0
(715.2 to 717.2) Mudstone: dark grey, platy; thinly interbedded with light grey, sandstone; quartzose, very fine grained, shallow trough cut-and fill, flasered and lenticularly laminated; abundant nodules, lenses and beds of dark brown siderite (ankeritic); sharp, flat contact.

2353.0 to 2356.0
(717.2 to 718.1) Mudstone: medium green grey, blocky, abundant carbonized rootlets; dark grey and thinly bedded with lenticular coaly laminae over basal 0.3 m; sharp contact.

Sparky Member

2356.0 to 2357.5
(718.1 to 718.4) Coal: massive brittle.

2357.5 to 2358.5
(718.4 to 718.7) Claystone: waxy, dark grey, abundant coaly fragments and laminae; silty to sandy over lower half.

2358.5 to 2364.0
(718.7 to 720.5) Sandstone: quartzose, ca. 10% white kaolinite, fine and very fine grained, laminated; abundant black carbonaceous grains; friable, moderately indurated, light grey, generally low-angle current bedded; interbedded with dark grey, argillaceous, very fine grained, quartzose sandstone and contorted grey-black and dark grey mudstone; sharp, pitted contact.

2364.0 to 2365.5
(720.5 to 721.0) Sandstone: quartzose, grading downward into mudstone; upper 0.3 m cemented with siderite; carbonaceous over basal 0.15 m.

2365.5 to 2367.0 (721.0 to 721.5)	Shale: black carbonaceous; grades into
2367.0 to 2369.0 (721.5 to 722.0)	Mudstone: dark grey, massive, brown ironstone nodules at 721.8 m; some flowage around nodules; sharp erosional contact marked by black, carbonaceous layer.
2369.0 to 2370.0 (722.0 to 722.4)	Sandstone: quartzose, very fine grained, medium grey, well indurated, earthy; weakly penetrated by sand-filled tubules in dark grey, argillaceous matrix; basal contact surface is severely pitted and infilled with coarse grained, kaolinitic, quartzose sandstone, 0.05 m thick.
2370.0 to 2371.0 (722.4 to 722.7)	No recovery.
2371.0 to 2377.0 (722.7 to 724.5)	Sandstone: quartzose, medium grey, fine grained with quartz overgrowths, well sorted, weakly cemented, very permeable; interbedded at 0.3 m intervals with 0.15 m thick beds of laminated sandstone with subordinate, detrital carbonaceous grains and flakes; bedded and low-angle planar and small-scale trough cross-bedded throughout.
2377.0 to 2377.5 (724.5 to 724.7)	Sandstone: as above; interbedded and intermixed with dark grey, argillaceous siltstone; coaly detritus veneered ripple festoons, burrow forms, flowage forms and shrinkage cracks; abundant small concretions; truncational basal contact above vertical rootlet casts.
2377.5 to 2379.0 (724.7 to 725.2)	Sandstone: quartzose, reddish grey, fine grained with quartz overgrowths, well sorted, weakly cemented, very permeable; fine bedding marked by coaly flakes on shallow channel cuts; mottled by yellow-brown oxidation; pebble-size concretions and flowage forms at 725.0 m.
2379.0 to 2380.0 (725.2 to 725.4)	Sandstone: quartzose, dark grey, very fine grained, argillaceous, flowage distorted as indicated by thin rolls of light grey sandstone, contorted beds, truncations, blocks of laminated sandstone and detrital coal.
2380.0 to 2381.0 (725.4 to 725.7)	Sandstone: as at 722.7 m, grades over lower half into
2381.0 to 2385.5 (725.7 to 727.1)	Sandstone: quartzose, very fine grained, mottled medium grey and yellowish brown, strongly bioturbated, traces of coaly detritus on thin beds, laminae and ripple drift cross-beds; bedding tops penetrated by vertical silt-filled, burrows; flowage forms with lateral discontinuities marked by vertical truncations.
2385.5 to 2388.5 (727.1 to 728.0)	Sandstone: quartzose, very fine grained, subordinate fine, dark grey; abundant to ca. 10% black, carbonaceous grains and white kaolinite; intensively bioturbated; grades over lower half into sandstone: quartzose, fine grained, subordinate very fine; moderately to well indurated.
2388.5 to 2390.5 (728.0 to 728.6)	Mudstone: dark grey, well indurated; subordinate thin beds and flasers of sandstone; quartzose, fine grained, medium grey, and bedding rolls of quartzose sandstone with subordinate coaly detritus; sharp contact on 0.03 m thick, dark grey laminated shale and siltstone; sharp basal contact.
2390.5 to 2392.5 (728.6 to 729.2)	Sandstone: as at 727.1 m; sharp contact.
2392.5 to 2393.0 (729.2 to 729.4)	Shale: black, carbonaceous, abundant carbonized plant fragments.
General Petroleums Member	
2393.0 to 2394.5 (729.4 to 729.8)	Mudstone: silty, dark grey, abundant rootlet casts over upper 0.15 m, well indurated; traces of flowage forms; sharp basal contact.

2394.5 to 2404.0 (729.8 to 732.7)	Sandstone: quartzose, fine grained, well sorted, subangular to subrounded; ca. 10% white feldspar, black chert, carbonaceous grains, dark green biotite, coarse-grained sphaerosiderite (brown); black and brown speckled in white siliceous kaolinite, well indurated; planar cross-beds dipping 10 to 15°; some beds lined with carbonized plant detritus; sharp erosional contact.
2404.0 to 2406.0 (732.7 to 733.3)	Mudstone: dark grey, silty; ca. 10% to 25% thin beds, flasers and laminae of quartzose sandstone as at 729.8 m; black carbonaceous partings; flowage forms near top, large sideritic (ankeritic), concretionary nodules scattered throughout; sharp contact.
2406.0 to 2406.5 (733.3 to 733.5)	Sandstone: quartzose, very fine and fine grained, argillaceous, poorly sorted, dark grey, strongly bioturbated; minerals as at 729.8 m; scattered pebble-size coal balls; well indurated; sharp contact.
2406.5 to 2406.5 (733.5 to 733.5)	Sandstone: as at 729.9 m; laminated with dark grey, mudstone; 0.06 m thick, sharp contact.
2406.5 to 2409.5 (733.5 to 734.3)	Sandstone: quartzose, fine grained, well sorted, minerals and matrix as at 729.8 m, light grey; general shallow channel cut and low-angle fill bedding; channel lined with dark grey mudstone; thin, dark grey mudstone at 733.8 m; sharp contact.
2409.5 to 2411.5 (734.3 to 735.0)	Mudstone: dark grey, laminated with subordinate light grey, fine-grained, quartzose sandstone; sharp crenulated contact.
2411.5 to 2412.0 (735.0 to 735.2)	Sandstone: quartzose, fine grained, dark grey, carbonaceous, bioturbated; sharp contact.
2412.0 to 2415.5 (735.2 to 736.2)	Sandstone: quartzose, fine grained, well sorted; abundant black coaly grains; medium grey, silica cemented, friable, very permeable; abundant burrow pods, argillaceous content and induration increase downward.
2415.5 to 2423.0 (736.2 to 738.5)	Sandstone: quartzose, very fine grained, subordinate fine; medium grey, friable; interbedded with dark grey and grey-black, well indurated mudstone; bioturbated and disrupted by penecontemporaneous flowage and brecciation; hematitic red at base.

CS Fort Pitt 11-26-55-26(W3)
KB 2312 feet (704.7 m)

Depth in feet (m)

JOLI FOU FORMATION

1654.0 to 1687.0
(504.1 to 514.2)

(Core still in sleeves).

1687.0 to 1698.25
(514.2 to 517.6)

Shale: grey black, moderately fissile, minor thin, quartzose, very fine grained, glauconitic sandstone, dark grey-green over upper 0.3 m; sharp basal contact.

PENSE FORMATION
Colony Member
Unit 4 Bedding Cycle 6 (0.6 m)

1698.25 to 1700.0
(517.6 to 518.2)

Sandstone: quartzose, fine grained, very argillaceous, carbonaceous, well indurated; bioturbated, green grey mottled with grey black; sharp irregular contact.

Unit 3 Bedding Cycle 5 (1.1 m)

1700.0 to 1702.75
(518.2 to 519.0)

Sandstone: quartzose, very fine grained, medium grey, moderately indurated, glauconitic, bedding-aligned burrows; sharp contact under contorted layer.

1702.75 to 1703.25
(519.0 to 519.3)

Shale: grey black, hard, platy, with fine-grained, quartzose, argillaceous, glauconitic sand-filled burrows; sharp irregular contact.

McLaren Member
Unit 2 Bedding Cycle 4 (5.7 m)

1703.25 to 1712.5 (519.3 to 521.9)	Sandstone: quartzose, very fine grained, light grey, friable; irregularly bedded with subordinate medium grey silty shale; bedding lenticular, current scoured with some bioturbation; shaly over basal 0.06 m.
1712.5 to 1719.0 (521.9 to 524.0)	Sandstone: quartzose, fine grained, argillaceous, dark grey; low-angle current bedded with minor medium grey silty laminae and lenticles, poorly indurated,; carbonaceous over basal 0.15 m.
1719.0 to 1722.5 (524.0 to 525.0)	Sandstone: quartzose, fine grained, very friable, light grey, permeable; argillaceous and medium grey over basal 0.3 m; sharp contact.

Bedding Cycle 3 (3.3 m)

1722.5 to 1725.5 (525.0 to 526.0)	Sandstone: quartzose, fine grained, friable, carbonaceous and grey black over upper 0.15 m; below, medium grey and interbedded with thin (0.02 to 0.03 m), carbonaceous shale.
1725.5 to 1729.0 (526.0 to 527.0)	Sandstone: quartzose, fine grained, weak silica grain-contact cemented, faintly bedded, friable, light grey.
1729.0 to 1733.25 (527.0 to 528.3)	Sandstone: quartzose; interbedded with carbonaceous shale as at 525.0 m.

Bedding Cycle 2 (5.3 m)

1733.25 to 1735.5 (528.3 to 529.0)	Sandstone: quartzose, fine grained, well sorted, weakly indurated, light grey.
1735.5 to 1749.0 (529.0 to 533.1)	Sandstone: quartzose, fine grained, variable argillaceous matrix, medium grey; weakly indurated, fine bedded; thicker beds laminated with carbonized plant fragments at 530.0 and 530.8 m.
1749.0 to 1750.5 (533.1 to 533.6)	Shale: dark grey, clayey, platy.

Unit 1 Bedding Cycle 1 (4.7 m)

1750.5 to 1754.5 (533.6 to 534.8)	Sandstone: quartzose, fine to medium grained, well sorted, weak argillaceous matrix; faintly trough cross-bedded; very permeable.
1754.5 to 1759.5 (534.8 to 536.3)	Sandstone: as above, thin interbeds of medium grey, argillaceous, silty sandstone; very permeable.
1759.5 to 1764.5 (536.3 to 537.9)	Sandstone: quartzose, fine grained, medium grey; centimetre-scale cross-beds with shale-draped truncations under opposing sets; weakly indurated, very permeable; abundant grains of white kaolinite near base.
1764.5 to 1766.5 (537.9 to 538.3)	Claystone: olive black, grading downward to black, carbonaceous and coaly; sharp irregular contact.

CANTUAR FORMATION
Waseca Member

1766.5 to 1771.0 (538.3 to 539.9)	Sandstone: quartzose, fine grained, argillaceous, medium grey, moderately well indurated, scattered crenulated partings of carbonaceous grey-black shale (slumped bed).
1771.0 to 1779.0 (539.9 to 542.2)	Sandstone: quartzose, very fine grained, well sorted, indurated in olive silty clay, starved ripple-bedded in part, platy, abundant <i>Chondrites</i> .

Depth in feet (m)

PENSE FORMATION**Colony Member****Unit 4 *Bedding Cycle 7 (1.2 m)***

1615.0 to 1617.0
(492.3 to 492.9) Sandstone: quartzose, fine grained, well sorted, weakly cemented, very permeable, oil permeated, abundant muscovite, lithic grains, black chert, white feldspar (plagioclase) and others (sand mostly lost); indurated, interbedded fine- and very fine grained, argillaceous quartzose sandstone, 0.08 m thick, at base.

1617.0 to 1619.0
(492.9 to 493.5) Sandstone: quartzose, very fine grained, dark grey, argillaceous matrix, earthy, moderately indurated; subordinate beds laminated with coaly reedy stalks; includes dark brown ironstone concretionary body (0.05 m thick) near top.

Unit 3 *Bedding Cycle 6 (1.0 m)*

1619.0 to 1621.0
(493.5 to 494.1) Sandstone: as at 492.3 m (recovery about 0.025 m).

1621.0 to 1622.5
(494.1 to 494.5) Sandstone: as at 492.9 m; contorted (slump or differential loading); sandy layers marked by sharp contacts.

Bedding Cycle 5 (1.1 m)

1622.5 to 1624.0
(494.5 to 495.0) Sandstone: as at 492.3 m; grades into

1624.0 to 1625.0
(495.0 to 495.3) Sandstone: quartzose, fine grained, very argillaceous, oil stained, bioturbated, medium grey mottled with brown; grades into

1625.0 to 1626.0
(495.3 to 495.6) Mudstone: very sandy, dark grey, bioturbated; scattered coaly fragments near base; sharp irregular contact.

McLaren Member**Unit 2 *Bedding Cycle 4 (3.7 m)***

1626.0 to 1628.5
(495.6 to 496.2) Mudstone: grey black, subordinate decreasing downward to minor, laminae and thin layers of medium grey, argillaceous, quartzose, sandstone, boudinaged, flasered, and podded downward; basal 0.3 m is ironstone indurated, dark brown, and penetrated by rootlet cavities and carbonaceous fill; sharp contact.

1628.5 to 1636.5
(496.2 to 498.8) Claystone: medium grey, crumbly, abundant coaly fragments and iron-oxide stained beds.

1636.5 to 1637.0
(498.8 to 499.0) Coal: hard, brittle, 0.8 m thick, resting on 0.5 m of hard, sandstone with pyrite-infilled pebble size concretions.

1637.0 to 1638.0
(499.0 to 499.3) Mudstone: dark grey, abundant floating coaly plant fragments.

Bedding Cycle 3 (3.6 m)

1638.0 to 1639.0
(499.3 to 499.6) Sandstone: quartzose, fine grained, very argillaceous, well indurated, carbonaceous, black; stringers and lenticles of medium grey sandstone become conspicuous downward.

1639.0 to 1642.0
(499.6 to 500.5) No recovery.

1642.0 to 1649.0
(500.5 to 502.6) Sandstone, quartzose, fine grained, well sorted, subangular and subrounded, weakly cemented, moderately indurated, very permeable, oil stained; abundant black chert, white kaolinite, muscovite; faintly bedded with gentle trough cross-laminae; sharply interbedded at 500.8 and 502.2 m with grey-black shale laminated with flasers, lenticles and stringers of grey white, very fine grained, quartzose sand.

1649.0 to 1650.0
(502.6 to 502.9) Sandstone: quartzose, very fine grained, well sorted, subangular, light grey; grain-contact cemented, permeable; abundant black chert, muscovite; ripple drift and small-scale trough cut-and-fill highlighted with bedded carbonaceous plant fragments; minor thin layers and laminae of black shale and laminated black shale and sandstone; shale includes flasers and boudinaged sandstone pods.

Unit 1 *Bedding Cycle 2 (3.2 m)*

1650.0 to 1652.0
(502.9 to 503.5) Sandstone: quartzose, very fine grained, very argillaceous, grey black, carbonaceous; strongly bioturbated; subordinate thin shale as at 502.6 to 502.9 m.

1652.0 to 1660.5
(503.5 to 506.1) Sandstone: quartzose, fine grained, grading downward to medium, well sorted; subangular and subrounded, light grey; ca. 15% white kaolinite, brown sphaerosiderite, green chlorite, biotite and glauconite (probably after chlorite), black chert, carbonaceous grains; moderately indurated in kaolinite and microcrystalline silica; light oil stain outlines faint trough cross-bedding; sharp basal contact.

Bedding Cycle 1 (0.8 m)

1660.5 to 1663.0
(506.1 to 506.9) Sandstone: quartzose, very fine grained, argillaceous, grey black to dark grey, laminated and bioturbated; intermixed with light grey, fine-grained, quartzose sandstone; sharp undulatory contact.

CANTUAR FORMATION

Waseca Member

Bedding Cycle 8 (3.6 m)

1663.0 to 1667.5
(506.9 to 508.3) Sandstone: quartzose, very fine grained, well sorted, abundant muscovite, kaolinite, dark lithic grains, weakly to moderately grain-contact cemented; light grey, current, ripple and low-angle, small-scale trough cross-bedded; vertical burrows over basal 0.3 m; brown iron staining at base and top; sharp contact.

1667.5 to 1670.0
(508.3 to 509.0) Mudstone: sandy, dark grey and medium grey; sand component present as small-scale bioturbation pods.

1670.0 to 1675.0
(509.0 to 510.5) Mudstone: shaly, dark grey, scattered carbonized plant fragments, grey black and carbonaceous over basal 0.15 m; sharp contact.

Bedding Cycle 7 (3.5 m)

1675.0 to 1686.5
(510.5 to 514.0) Sandstone: quartzose, very fine grained, argillaceous, medium and dark grey; more massive, weakly bioturbated beds alternate with well sorted, trough cross-bedded units; abundant black carbonaceous grains, scattered kaolinite, green biotite; sharp contact.

Bedding Cycle 6 (2.9 m)

1686.5 to 1688.5
(514.0 to 514.7) Sandstone: quartzose, fine grained, moderate to poor sorting; subordinate black carbonaceous grains and white kaolinite; well cemented with brown siderite or ankerite; traces of low-angle cross-laminae over upper half, and bioturbation with abundant bedded plant fragments over lower half; grades into

1688.5 to 1691.5
(514.7 to 515.6) Mudstone: grey black, abundant rolls and pods of medium grey sandstone, moderately indurated; grades into

1691.5 to 1696.0
(515.6 to 516.9) Sandstone: quartzose, fine grained, medium grey, subrounded and subangular; ca. 15% kaolinitic and carbonaceous grains, green biotite, green chlorite, brown siderite, muscovite, weakly indurated in kaolinite; subordinate dark grey, very fine grained, quartzose sandstone in lower half; bioturbated, and podded; sharp irregular contact.

Bedding Cycle 5 (4.0 m)

1696.0 to 1702.5
(516.9 to 518.9) Sandstone: quartzose, very fine grained, minerals as at 515.6 m, medium grey, low-angle trough cross-bedded, interbedded with mudstone, grey black; microfaulted over lower half; grades into

1702.5 to 1709.0
(518.9 to 520.9) Sandstone: quartzose, very fine grained, argillaceous, dark grey; interbedded and laminated with sandstone as at 516.9 m, moderately indurated; minor vertical burrows, pods and rolls; thoroughly bioturbated near base; sharp contact.

Bedding Cycle 4 (0.5 m)

1709.0 to 1710.5
(520.9 to 521.4) Sandstone: quartzose, fine grained, well sorted, subrounded, subordinate white kaolinite, white feldspar, carbonaceous grains, rust-red siderite, black chert, green chlorite and biotite; kaolinite indurated, white speckled with brown; sharp contact.

Bedding Cycle 3 (3.3 m)

1710.5 to 1716.5
(521.4 to 523.2) Sandstone: quartzose, very fine grained, argillaceous, dark grey; laminated and thinly bedded with boudinaged and bioturbated, light grey, fine-grained, quartzose sandstone at 0.08 to 0.15 m intervals; moderately indurated.

1716.5 to 1721.5
(523.2 to 524.7) Sandstone: quartzose, fine and very fine grained, argillaceous, poorly sorted; ca. 10% white kaolinite, siderite, carbonaceous grains, coaly fragments, green chlorite, well indurated; dark grey, light grey and brown intermixed; variably bioturbated and low-angle current bedded; sharp undulatory contact.

Bedding Cycle 2 (6.0 m)

1721.5 to 1734.5
(524.7 to 528.7) Sandstone: quartzose, fine grained, well sorted; ca. 5% carbonaceous grains, white kaolinite, siderite; well indurated in kaolinite but with fair permeability; flat and low-angle planar and trough cross-beds with carbonized plant placers; scattered pyritic concretions.

1734.5 to 1737.0
(528.7 to 529.4) Sandstone: as at 524.7 m; strongly bioturbated and boudinaged; subordinate grey black shale; grades into

1737.0 to 1741.0
(529.4 to 530.7) Shale: silty, grey black; laminated with sandstone as above; low-angle current bedded, some flame and flow structure, abundant brown sandstone nodules; sharp contact.

Bedding Cycle 1 (5.1 m)

1741.0 to 1748.0
(530.7 to 532.8) Sandstone: quartzose, very fine grained, moderately sorted; subordinate, coarse-grained, brown sphaerosiderite, white kaolinite, fine- to medium-grained, black chert, carbonaceous grains; trace of green chlorite; well indurated in siliceous claystone; medium grey speckled with black and brown, faintly bedded to massive; upper half ripple-bedded, with flowage structure in more massive layers; some carbonaceous, bifurcated partings.

1748.0 to 1758.0
(532.8 to 535.8) Mudstone: dark grey; minor thin beds of argillaceous sandstone as above, also flasers; grades into grey-black shale.

Sparky Member

Bedding Cycle 4 (3.4 m)

1758.0 to 1760.0
(535.8 to 536.5) Coal: brittle, vitrain rich, interlayered with coaly shale.

1760.0 to 1769.0
(536.5 to 539.2) Sandstone: quartzose, fine grained, well sorted, heavy oil impregnated; flat-, thin-, and low-angle ripple bedded; weakly to moderately silica cemented; scattered argillaceous partings; sharp irregular contact on siderite-cemented pavement (duricrust).

Bedding Cycle 3 (1.5 m)

1769.0 to 1774.0
(539.2 to 540.7) Sandstone: quartzose, very fine grained, grey black, argillaceous; bioturbated with pods, rolls and stringers of oil-stained sandstone; minor laminae of coaly shale.

Bedding Cycle 2 (1.5 m)

1774.0 to 1778.0
(540.7 to 541.9) Sandstone: quartzose, fine grained, well sorted, oil impregnated.

1778.0 to 1779.0
(541.9 to 542.2) Sandstone: as at 539.2 m (thickness estimated).

Bedding Cycle 1 (6.6 m)

1779.0 to 1800.5
(542.2 to 548.8) Sandstone: quartzose, fine grained, well sorted, slightly argillaceous, heavy oil saturated; scattered coal lenses, massive; sharp contact on siderite-cemented pavement.

General Petroleums Member

Bedding Cycle 3 (5.0 m)

1800.5 to 1805.5
(548.8 to 550.2) Sandstone: quartzose, very fine grained, argillaceous, orange brown; grades downward into interbedded fine and very fine grained; heavy oil saturated; laminated and current bedded, with abundant cylindrical burrows infilled with mudstone.

1805.5 to 1813.0
(550.2 to 552.6) Shale: grey black, minor thin lenticles and laminae of light grey, graded siltstone; abundant tool markings; slump folded over basal 0.3 m.

1813.0 to 1815.0
(552.6 to 553.2) Mudstone: dark grey, bioturbated; laminated with subordinate, very fine grained, quartzose, oil-stained sandy lenticles, pods and layers; grades into

1815.0 to 1817.0
(553.2 to 553.8) Sandstone: quartzose, fine grained, argillaceous, heavily bioturbated, boudinaged and podded, oil stained; sharp irregular contact on pitted surface.

Bedding Cycle 2 (3.1 m)

1817.0 to 1818.0
(553.8 to 554.1) Sandstone: quartzose, very fine grained, argillaceous, hard, well indurated, severely bioturbated, red brown mottled with grey; sharp contact.

1818.0 to 1827.0
(554.1 to 556.9) Sandstone: quartzose, very fine grained, laminated with silt and black shale; crenulated, weakly indurated; oil stained (section largely deteriorated).

Bedding Cycle 1 (7.6 m)

1827.0 to 1839.0
(556.9 to 560.5) Sandstone: quartzose, very fine grained, well sorted, heavy-oil permeated over upper 1.5 m, moderately oil permeated below, weakly indurated; low-angle current beds below 558 m outlined by laminae of coaly placers; calcite cemented at 558.7 m(?).

1839.0 to 1843.0
(560.5 to 561.7) Mudstone: dark grey, sandy, severely bioturbated; orange brown iron stained; interbedded with oil-stained, very fine grained, low-angle current- and ripple-bedded, quartzose sandstone.

1843.0 to 1848.0
(561.7 to 563.3) Mudstone: dark grey, reworked with sandy traces of burrowing and bedding; grades into

1848.0 to 1852.0
(563.3 to 564.5) Shale: dark grey, hard, siliceous; trace of silty pods and lenticles.

Rex Member

1852.0 to 1853.0
(564.5 to 564.8) Sandstone: quartzose, fine grained, well sorted; subordinate black chert, carbonaceous grains, white kaolinite; scattered red sphaerosiderite; well indurated in pale green and white, chloritic kaolinite; planar and tangential cross-bedding terminated by truncation surfaces; minor thin beds of black shale with flasers and lenticles of sandstone.

1853.0 to 1854.0 (564.8 to 565.1)	Siltstone, quartzose, mineralogy as above; podded, boudinaged, flasered and microfaulted; interbedded thinly with dark grey mudstone.
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Wascana Marengo S A15-36-27-28(W3)
KB 685.85 m

Depth in metres

CANTUAR FORMATION
Rex Member

853.00 to 853.60 Sandstone: quartzose, fine grained, well sorted, centimetre-scale ripple drift bedded, laminated with black carbonaceous flakes; oil stained, moderately indurated; capped by 0.1 m of medium grey, compaction-distorted, sandy mudstone; sharp basal contact.

Bedding Cycle 3 (1.83 m)

853.60 to 853.74 Sandstone: quartzose, fine grained, light grey kaolinitic matrix; ca. 5% brown, fine-grained siderite, massive; sharp contact.

853.74 to 854.15 Sandstone: as above, but 0.03 m scale current bedded with truncational sets; carbonaceous laminae over basal 0.06 m; sharp contact.

854.15 to 854.73 Mudstone: dark grey, shaly; minor starved laminae and ripples of very fine grained, quartzose sandstone.

854.73 to 855.43 Mudstone: dark grey, massive; calcite cemented and sideritic over upper 0.2 m; below contorted with abundant brown sideritic nodules; sharp contact.

Bedding Cycle 2 (1.47 m)

855.43 to 856.38 Sandstone: quartzose, fine grained; ca. 15% white kaolinite after feldspar, black chert, coarse-grained brown siderite; grey white, well indurated; decimetre-scale low-angle, plant detritus-lined cross-beds fining upward into centimetre scale, with increased sorting and the rare thin, dark grey, vertically burrowed shale lamina; patchy oil stains.

856.38 to 856.90 Mudstone: medium grey to dark grey downward, shaly to blocky, faint silty laminae; erosional basal contact.

Bedding Cycle 1 (0.51 m)

856.90 to 857.18 Sandstone: quartzose, fine grained, well sorted and oil saturated over upper half, argillaceous and bioturbated below; sharp irregular contact.

857.18 to 857.41 Shale: dark grey, platy, stringers of fine-grained, argillaceous, bioturbated sandstone near base; sharp contact.

Lloydminster Member
Upper Unit *Bedding Cycle 5 (9.49 m)*

857.41 to 862.76 Sandstone: quartzose, fine grained, well sorted, weakly indurated, flat bedded with traces of low-angle scour and fill; oil permeated; grades over basal 0.5 m into

862.76 to 866.76 Sandstone: quartzose, fine grained, well sorted, silica grain contact, friable, moderately indurated, flat sets of low-angle cross-beds; truncational sets increase to dominant over basal 0.5 m; large oil-saturated burrows throughout, lightly oil stained; sharp contact.

866.76 to 866.90 Sandstone: quartzose, fine grained, argillaceous, medium grey and brown mottled with oil stain, bioturbated; sharp basal contact on grey black shale laminae.

Bedding Cycle 4 (1.0 m)

- 866.90 to 867.65 Sandstone: quartzose, fine grained, silica grain-contact cemented, decimetre scale, swaley cross-bedded, oil stained; variably interbedded with argillaceous, laminated sandstone; sharp contact.
- 867.65 to 867.90 Mudstone: dark grey, subordinate quartzose sand, well indurated; bioturbation featuring oil-filled sandstone burrow pods; sharp basal contact.

Lloydminster Member
Lower Unit *Bedding Cycle 3 (3.1 m)*

- 867.90 to 868.65 Shale: black, minor thin coal (vitrain), fissile; sharp basal contact.
- 868.65 to 868.85 Sandstone: quartzose, fine grained, friable, oil permeated, severely bioturbated and intermixed with minor, buff, argillaceous sandstone; black shale-draped rippled sandstone at base (contact not seen).
- 868.85 to 871.00 Conglomerate: chert, dark grey, pebble and cobble sized, rounded; well indurated, buff, argillaceous, quartzose sand matrix;.

Bedding Cycle 2 (1.4 m)

- 871.00 to 871.26 Sandstone: quartzose, fine grained, argillaceous, buff; grades downward into loamy mudstone, and paleosol: dark grey, carbonaceous, with abundant coaly fragments, sharp contact.
- 871.26 to 872.40 Sandstone: quartzose, fine grained, argillaceous, medium grey brown; intermixed with subordinate oil-saturated, bioturbation pods and irregular beds of fine-grained, well-sorted, friable sandstone; irregular basal contact.

Bedding Cycle 1 (0.85 m)

- 872.40 to 872.60 Sandstone: quartzose, fine grained, silica grain-contact cemented, light grey; bioturbated and laminated with grey black shale.
- 872.60 to 873.25 Shale: grey black, subordinate dark grey, bioturbated, argillaceous, quartzose siltstone.

Cummings Member

- 873.25 to 873.55 Sandstone: quartzose, fine grained, argillaceous, buff; silica-cemented pavement at top; distorted fabric.
- 873.55 to 873.80 Shale: black, carbonaceous, minor coaly laminae: sharp contact.
- 873.80 to 874.00 Shale: black, carbonaceous; comprises compacted, dark grey, dark green and tan mudstone granules and scattered pebbles.
- 874.00 to 880.00 Shale: black and dark grey; decimeter-thick, bioturbated, light grey and black, argillaceous sandstone and mudstone couplet at 876.8 m; medium grey mudstone with minor coaly laminae at 877.5 to 878.0 m.

Depth in metres

CANTUAR FORMATION**Waseca Member*****Bedding Cycle 9 (2.17 m)***

748.0 to 749.50 Sandstone: quartzose, very fine grained, argillaceous, dark grey; laminated and thinly interbedded with dark grey shale; abundant nodular and lenticular ironstone, yellow-brown concretionary bodies; grades into

749.50 to 750.17 Shale: dark grey, silty, platy; accessory carbonized plant detritus; sharp(?) contact.

Bedding Cycle 8 (0.83 m)

750.17 to 750.34 Shale: dark grey, very fissile, papery; abundant carbonized plant fragments.

750.34 to 751.00 Mudstone: clayey, dark green grey with carbonaceous tint.

Bedding Cycle 7 (3.6 m)

751.00 to 752.60 Shale: as at 749.50 to 750.17 m.

752.60 to 754.60 Mudstone: blocky to crumbly, dark green grey; abundant filaments of carbonized plant material; below 753.5 m interbedded at 0.2 m intervals with argillaceous, very fine grained, quartzose sandstone; dark grey speckled with brown sphaerosiderite; rusted on uppermost bed; sharp irregular basal contact.

Bedding Cycle 6 (4.3 m)

754.60 to 755.30 Sandstone: quartzose, very fine grained, argillaceous matrix, well indurated; medium grey mottled with brown siderite in a network of mostly vertical, irregular veins (appears to be a rootlet zone); sharp sloping contact.

755.30 to 758.90 Mudstone: blocky to crumbly, olive, dark grey and carbonaceous over lower half; underlain by 0.2 m of coal; sharp contacts on coal and at base of bed.

Unit 5 Bedding Cycle 5 (10.1 m)

758.90 to 764.20 Sandstone: quartzose, very fine grained, medium greenish grey, argillaceous; laminated with sandstone, quartzose, fine grained, moderately to weakly indurated, scattered brown ironstone nodules; calcite cemented at 759.5 m; interbedded at 0.3 m intervals with greenish grey silty shale.

764.20 to 765.70 Sandstone: quartzose, very fine grained, argillaceous, medium greenish grey, laminated with lenticles of fine-grained sandstone; interbedded with crumbly clayey shale at intervals of 0.05 to 0.10 m, and compaction-distorted sandstone: quartzose, fine grained, well sorted, permeable, heavy-oil permeated, 0.04 to 0.05 m thick.

765.70 to 769.00 Sandstone: quartzose, fine grained, well sorted, uncemented, heavy-oil permeated, beds 0.05 to 0.20 m thick, alternate with siltstone-shale couplets, 0.05 to 0.15 m thick and reminiscent of varves; varved sequences include and are compacted around flattened, boulder-size ironstone concretions and sandstone lenses.

Unit 4 Bedding Cycle 4 (6.6 m)

769.00 to 775.60 Sandstone: quartzose, fine grained, well sorted, unindurated, heavy-oil permeated; includes in lower portion two couplets, each 0.15 m thick, of sandstone, quartzose, fine-grained, white kaolinite matrix and medium grey, fissile shale.

Unit 3 *Bedding Cycle 3 (5.4 m)*

775.60 to 781.00 Sandstone as above; about 40% interbeds of laminated light grey, quartzose, very fine grained sandstone and grey shale, and scattered current-bedded lenticles of kaolinite-indurated sandstone.

Unit 2 *Bedding Cycle 2 (5.3 m)*

781.00 to 786.30 Mudstone: olive, massive to blocky; scattered carbonized plant fragments and brown ironstone nodules.

Unit 1 *Bedding Cycle 1 (1.64 m)*

786.30 to 787.20 Sandstone: quartzose, fine grained, light green grey and white, kaolinitic matrix; minor black, carbonaceous grains; abundant pyrite as crystals, and aggregated pea-size bodies; thinly interbedded with mudstone as at 781.0 m; glauconitic nodules and traces of bioturbation toward base.

787.20 to 787.94 Mudstone: dark grey, blocky, clayey; abundant carbonized plant fragments grading downward into shale, splintery; sharp(?) contact.

Sparky Member *Bedding Cycle 3 (4.41 m)*

787.94 to 789.80 Coal: vitrain and durain, platy to blocky; black with minor sooty beds in middle of unit; sharp irregular contact.

789.80 to 790.00 Shale: medium grey laminated with grey black; fissile, splintery.

790.00 to 790.75 Sandstone: quartzose, fine grained, medium grey, white kaolinite matrix; minor carbonaceous grains and black, chert; abundant pyrite as crystals and aggregated pea-size bodies, and glauconitic near base; some bioturbation; interbedded with dark grey silty mudstone with abundant carbonized plant fragments.

790.75 to 792.35 Sandstone: quartzose, fine grained; ca. 15% angular, black and dark grey chert; abundant carbonaceous grains, white feldspar, pyrite and green chlorite; well indurated in white siliceous kaolinite; minor thin beds of dark grey sandstone laminated with carbonized plant fragments near base.

Bedding Cycle 2 (2.67 m)

792.35 to 792.55 Siltstone: black, argillaceous and carbonaceous; flaggy on coaly shale partings.

792.55 to 795.02 Sandstone: quartzose, very fine grained, well sorted, medium grey; faint bedding and cross-laminae with truncation sets; some crenulated laminae marked by carbonized plant fragments especially over upper 0.3 m; sharp erosional contact.

Bedding Cycle 1 (1.08 m)

795.02 to 795.55 Sandstone: quartzose, fine grained, well sorted, grain-contact silica cemented; low argillaceous content, very permeable, medium grey; grades into

795.55 to 796.10 Sandstone: quartzose, very fine grained, medium grey, argillaceous; intermixed with mudstone, dark grey, strongly bioturbated; grades into basal dark grey shale; sharp(?) irregular contact.

General Petroleums Member *Bedding Cycle 4 (1.23 m)*

796.10 to 796.83 Sandstone: quartzose, very fine grained, medium green grey, argillaceous matrix, well indurated; faint bioturbation, boudinage and current bedding; laminae of dark green grey shale increasing downward into silty mudstone.

796.83 to 797.33	Sandstone: quartzose, very fine grained, subordinate fine, light green-grey argillaceous matrix, low-angle current bedded; subordinate olive shale; scattered vertical and oblique glauconite-infilled burrows; grades over lower third into dark green-grey shale; sharp irregular contact.
	<i>Bedding Cycle 3 (2.45 m)</i>
797.33 to 799.78	Sandstone: quartzose, fine grained, kaolinite matrix; speckled light greenish grey and black; minerals as at 790.75 m; current laminated with carbonized plant fragments; slumped at 797.33 to 798.0 m, calcite cemented below; sharp irregular contact.
	<i>Bedding Cycle 2 (2.42 m)</i>
799.78 to 802.20	Sandstone: quartzose, very fine grained, light grey kaolinitic matrix, well indurated; ripple-drift bedded with carbonized plant fragments at 800.04 to 800.34 m; below, thinly interbedded with dark grey shale drapes, wherein shallow burrows penetrate sandy layers across shale contacts; grades rapidly into a basal dark grey silty shale 0.25 m thick; sharp contact.
	<i>Bedding Cycle 1 (3.03 m)</i>
802.20 to 805.23	Sandstone: quartzose, very fine grained, subordinate silt, medium grey; about 15% starved ripple beds, graded beds with dark grey shale, bioturbated forms (vertical and oblique) and syneresis cracks; abundant glauconitic nodules; basal 0.3 m strongly bioturbated in dark grey, sandy mudstone; sharp contact.
	Rex Member
	<i>Bedding Cycle 2 (5.1 m)</i>
805.23 to 809.50	Sandstone: quartzose, very fine grained, dark grey, argillaceous; subordinate laminae and flasers of light grey, fine-grained, quartzose sandstone; scattered thin beds of green, glauconitic sandstone at top and over lower third of unit; at 808.2 m occurs a calcareous, sandy and argillaceous septarian nodule, 0.020 m in diameter, with annular calcite veins; sharp contact.
809.50 to 810.33	Mudstone: dark grey, carbonaceous, platy to hackly; abundant pyritic nodules near base; sharp contact.
	<i>Bedding Cycle 1 (8.47 m)</i>
810.33 to 811.00	Coal, fusain dominant, very argillaceous, sulphurous over basal 0.16 m; sharp contact.
811.00 to 811.58	Mudstone: clayey, crumbly, medium grey; abundant carbonized plant fragments; irregular contact.
811.58 to 813.75	Mudstone: medium grey; subordinate very fine grained, quartzose sandstone, moderately indurated, massive with compaction layering; below 812.33 m laminated with subordinate shale.
813.75 to 814.42	Sandstone: quartzose, very fine grained, finely laminated with traces of current bedding; green glauconitic patches at intervals of 0.20 to 0.30 m; grades over basal 0.5 m into sandstone, quartzose, fine grained, speckled black on white; subordinate black and grey chert, green chlorite; white kaolinite matrix; laminae and float of carbonized plant fragments over basal 0.20 m.
814.42 to 818.80	Sandstone: quartzose, fine grained, speckled black on white; subordinate black and grey chert; moderately indurated in white kaolinite; current bedded with low-angle detrital plant layers at intervals of 0.5 m; calcite cemented at 816.74 to 817.85 m.
	Lloydminster Member
	<i>Bedding Cycle 2 (1.13 m)</i>
818.80 to 819.93	Sandstone: quartzose, fine grained, moderately indurated; strongly bioturbated in matrix of dark grey mudstone; sharp irregular contact.

Bedding Cycle 1 (3.37 m)

- 819.93 to 821.00 Shale: black, carbonaceous, abundant thin coal increases downward to 0.2 m thick coal bed at base; sulphurous, pyretic, irregular basal contact.
- 821.00 to 823.30 Sandstone: quartzose, fine grained, grain-contact silica cemented, well sorted but bimodal with medium-grained rounded quartz and angular chert towards base, well indurated; variable permeability as marked by secondary quartz overgrowths and patchy oil permeation; subordinate irregular, thin clay-indurated sandstone beds; irregular contact.

SUCCESS FORMATION (DETRITAL)

- 823.30 to 826.60 Rubble: pale green, calcareous shale and nodular limestone from the Devonian Big Valley Formation.

TORQUAY FORMATION

- 826.60 Siltstone: quartzose, dolomitic, grey white; thin bedded with green grey shale partings, dissolution brecciated.