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Mannville Group

and

Associated Lower Cretaceous Clastic Rocks in Southwestern Saskatchewan

by

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PREFACE

The data presented in this report was gathered over the years 1962-1964 and compiled in 1965.

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I

INTRODUCTION

The area considered within this report (Fig. 1) occupies some 16,200 square miles in southwestern Saskatchewan, extending from the Alberta border on the west to include Range 15 west of the Third Meridian on the east, with northern and southern boundaries including Townships 40 and 18 respectively.

Information obtained from 356 wells has been utilized during the course of this study. Geophysical logs, drill cuttings, and cores have been examined (Fig. 2). Samples from a total of 22,000 feet of well bores and 4,970 feet of cores were described, together with 115 thin sections of characteristic and atypical lithologies.

Surface sections of correlative sequences were visited, described, and sampled in the Crow's Nest Pass region, Alberta, and the Great Falls, Lewistown, and Sweetgrass Hills districts of Montana. Outcrops of the Cadomin and Cloverly Conglomerates were examined, the former near Coleman, Alberta, and the latter in the Boulder River Canyon, Montana.

The studied area was chosen in view of (a) its proximity to previously studied areas in Alberta, (b) the variable nature of the subject lithologies, and (c) the association of hydrocarbon accumulations of differing types within either Cretaceous or subjacent strata.

The author seeks to describe the significant Lower Cretaceous rock groups, to elucidate their stratigraphy and sedimentation, and to a lesser extent their structure; and where possible to relate these factors to known or geologically feasible hydrocarbon occurrences.

II

ACKNOWLEDGEMENTS

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III

PREVIOUS WORK

Published work on the Mannville Group of the Saskatchewan subsurface is limited. The most comprehensive account to date is that of Price (1963) which deals with the stratigraphy, sedimenta-

Fig. 1: Location of area of study.

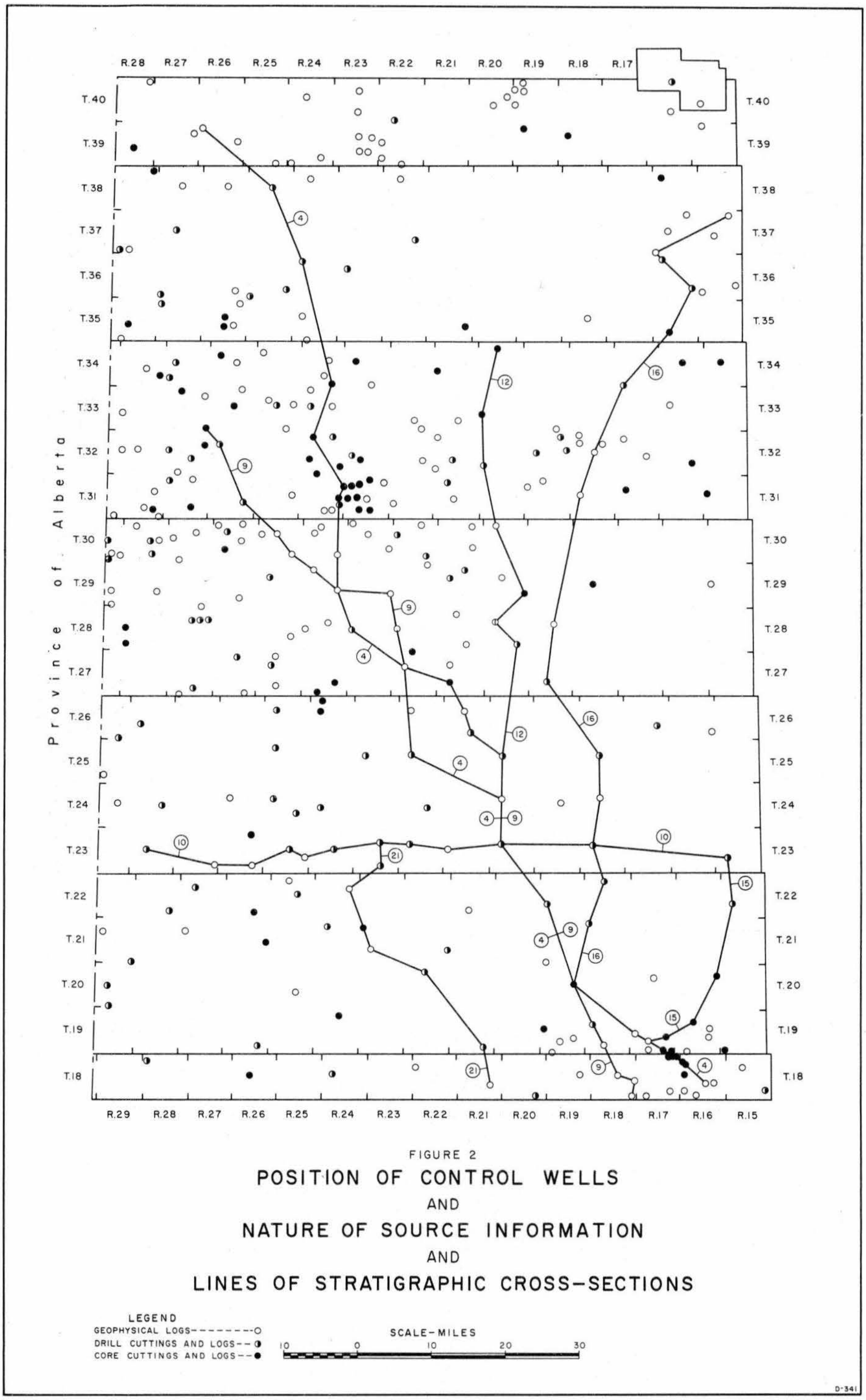

Fig. 2: Position of control wells, nature of source information and lines of stratigraphic cross-sections.

tion, and correlation of these sediments in the southeastern portion of the province. Earlier works consider either more limited areas (e.g. oil fields) or more limited aspects (e.g. correlation).

Reasoner and Hunt (1954) discussed the geology of the Coleville-Smiley oil field, and Elphinstone (1958) dealt with that of the Fosterton Field. Hadley and Milner (1953) outlined correlations of southwestern Saskatchewan rocks with those in Montana, whereas Price (1955) extended the term Mannville from Alberta. Milner and Blakslee (1958) illustrated electric log characteristics of Lower Cretaceous sediments in southwestern Saskatchewan; on the other hand, Cumming and Francis (1957) discussed the lithologic nature and probable origin of the "Cantuar Marker". Other restricted studies include that of Humphreys and Rogers (1954) on textural discrimination between Roseray and Cantuar sands, and that of Procter (1962, p. 269) on the clay mineral distributions within the Cretaceous and Jurassic shales of the Cantuar area. Maycock (1964) discussed the petrography, sedimentation, and provenance of lithic sandstones in western Saskatchewan. Beltz (1953) reviewed the nature of the pre-Cretaceous topography in western Saskatchewan and Alberta, and its probable relationship to an ancient drainage system, and Price (1964) outlined the pre-Cretaceous geology of the southern portion of the Province. A similar subcrop map of a more restricted area in the west was included in a report on the Devonian-Mississippian Bakken and Three Forks Formations by Kents (1959).

Unpublished works include those of Ambler (1951) and Kent (1959) on the Lloydminster area, and Roussell's (1956) review of the Mannville and correlative beds across the southern portion of the province. The last named work constitutes, in the writer's view, one of the better syntheses yet introduced. Using the concept of arbitrary cut-off (Wheeler and Mallory, 1953) Roussell delineated the various areas within Saskatchewan where terminology in common use in contiguous areas might reasonably be introduced.

Apart from the above-mentioned works dealing directly with aspects of Saskatchewan geology, various studies in neighbouring areas supply pertinent information. Among the more noteworthy of these are McLearn's (1944) account of the stratal distribution, palaeontology, and palaeogeography of the Lower Cretaceous in Western Canada; Glaister's (1959) discussion of the stratigraphy and sedimentation of the Lower Cretaceous of Southern Alberta and adjoining areas, and Nauss's (1945) account of the Mannville Formation of the Vermilion area. Other significant papers on neighbouring regions to the south include those of Hansen (1955) and Wulf (1962). Reference to works dealing primarily with regional correlation are made in the section dealing with age and correlation. (Ch.VII).

Summary of Conclusions reached in Previous Work

Heterogeneous clastic sediments overlie a topographically irregular and lithologically variable pre-Cretaceous erosion surface, thought to represent a relatively mature, river-dissected landscape. The clastics are overlain by a dark marine shale of the Colorado Group. The degree of diachronism of this upper contact is as yet unknown but its overall relief is of a very much lower order than that of the base. The clastic sequence has in general been correlated with part of the Blairmore Group of the Alberta Foothills. Although the term Mannville Group is used for these sediments within the Alberta plains, they are still popularly referred to as Blairmore within the Saskatchewan subsurface. Within the area studied during the present investigation the group is considered divisible into a lower, heterogeneous, probably continental, sequence and an upper, more lithologically regular succession, within which greater electric-log correlation is feasible and which may more reasonably be referred to a marine, or marginal marine, origin. Within the lower unit much of the clastic material is presumed to derive from the west although some contributions from the Canadian Shield have been considered as probable by several workers. No material alteration of these conclusions is offered in the present report, but the writer hopes that the fuller descriptions of the component lithologies and their interrelations, and more detailed evaluation of their probable depositional environments will benefit future workers on the Lower Cretaceous.

IV

GENERAL STRATIGRAPHY

NOMENCLATURE

As noted above, a twofold subdivision of the Mannville strata in western Saskatchewan has been proposed. Both the nomenclature and exact limits of these divisions have, however, varied. In the past these Mannville beds have been known in Saskatchewan as "Blairmore" in spite of the fact that these rocks are both geographically separated and lithologically distinct from those of the type-Blairmore of the Alberta foothills.

The Blairmore Group of the foothills has been in part correlated with the Mannville Group of the Alberta Plains by Glaister (1959), Mellon and Wall (1961), and Mellon *et al.* (1963). The term Mannville Formation was first applied by Nauss (1945) to those Lower Cretaceous sediments underlying the Lloydminster (Colorado) shale in the Vermilion area of east-central Alberta. Badgley (1952) raised the Mannville Formation to group status and included within it the McMurray Formation (McLearn, 1917) and the Clearwater and Grand Rapids Formations (McConnell, 1893) of the lower Athabasca River Valley. The correlations of these formations with the Blairmore and Mannville Groups of southern Alberta have been recently summarized by Williams (1963).

In western Saskatchewan the nomenclature proposed for beds occupying a similar stratigraphic position has varied considerably during the past decade. Hadley and Milner (1953, p. 85) noted the bipartite nature of the "Blairmore" in the southwest of the province and advocated that use of the term "Blairmore" be discontinued and Montana terminology be introduced. Roussell (1956) similarly correlated the Upper "Blairmore" of Hadley and Milner (*op. cit.* p. 85) with the First Cat Creek of Montana and their Lower "Blairmore" with all or part of the Kootenai Formation. Roussell (*op cit.*), appreciating the difficulty of correlation within these sediments throughout Saskatchewan, used the concept of arbitrary cut-off (Wheeler and Mallory, 1953) and equated the "Blairmore" sediments north of Township 32 with part of the type-Mannville Group. Kent (1959) similarly related the rocks of the Lloydminster district to the type-Mannville of Nauss (1945) but subdivided the sequence differently.

Cumming and Francis (1957) agreed with the basic two-fold division of the "Blairmore" in southwestern Saskatchewan. They, however, raised the contact between the Upper and Lower Blairmore to the upper shoulder of the "birdhead", or "Cantuar Marker" prominent on electric logs and used by previous authors (*e.g.* Hadley and Milner, 1953) as the basal sequence of the Upper "Blairmore". Milner and Blakslee (1958), in a discussion of Jurassic correlation use the base of the "Blairmore" as datum in all electric-log cross-sections (*op. cit.* Figs. 13-16). This "Blairmore", however, corresponds to the Upper "Blairmore" of Hadley and Milner (1953) while the previously designated Lower "Blairmore" or Kootenai Formation is shown on the same cross-sections as "Cantuar". The captions suggest that the "Blairmore" and "Cantuar" are considered to be formations although no formal appellation is proposed. This use of the term "Cantuar" differs from that of other writers (*e.g.* Humphreys and Rogers, 1954; Elphinstone, 1958) who refer to a producing sand within the Lower "Blairmore" of the Cantuar Field (T. 16N., R. 17 W3M) by that name.

Price (1963, p. 6) modified his previous (1955) view that the term Mannville should be used in southern Saskatchewan, and formally designated the Cantuar Formation which essentially resembles the "Cantuar" of Milner and Blakslee (1958). The electric-log pick for the top of this formation (Price, 1963, p. 7) differs slightly from that of Milner and Blakslee. Price (1963, p. 26) proposed the name Pense Formation for that part of the sequence between the Cantuar Formation and the overlying Joli Fou shale. The Pense and Cantuar Formations together comprise the informally designated "basal Cretaceous sandy group" of Price (1963, p. 5) in the southern part of the province. Price subsequently (1964, p. 135) referred to this sandy group as "Inyan Kara" after the Lower Cretaceous formation of the Black Hills, South Dakota (Waagé, 1959). This use of the name Inyan Kara is open to question in view of Waagé's (1959, p. 11) statement that "because of the strictly local nature of much of the Inyan Kara group neither its name nor the names Fall River and Lakota should be used outside of the Black Hills region". However, the writer agrees with Price, that the division of the southwestern Saskatchewan sequence into two lithogenetically distinct units, namely continental and marginal-marine, parallels very closely Waagé's (*op. cit.*) subdivision of the basal Lower Cretaceous beds of the Black Hills. The stress which Waagé (1959) put on this type of subdivision as a basis for the regional elucidation of such Lower Cretaceous sequences may be vindicated by the similarity of the breakdown of successions as distant as those of western Saskatchewan (reviewed here) and the Denver Basin (MacKenzie, 1963). Consideration of the regional significance of the apparent disconformity separating the two facies must await more detailed studies in the intervening areas.

The lower unit of this bipartite division is here referred to as the "Continental Facies" and is considered analogous to the type Cantuar Formation of Price (1963). This latter name is not accepted unreservedly by the writer in view of its use by Price for sediments in the southeast of the province within which quartzose sandstones are more volumetrically significant, and which were previously

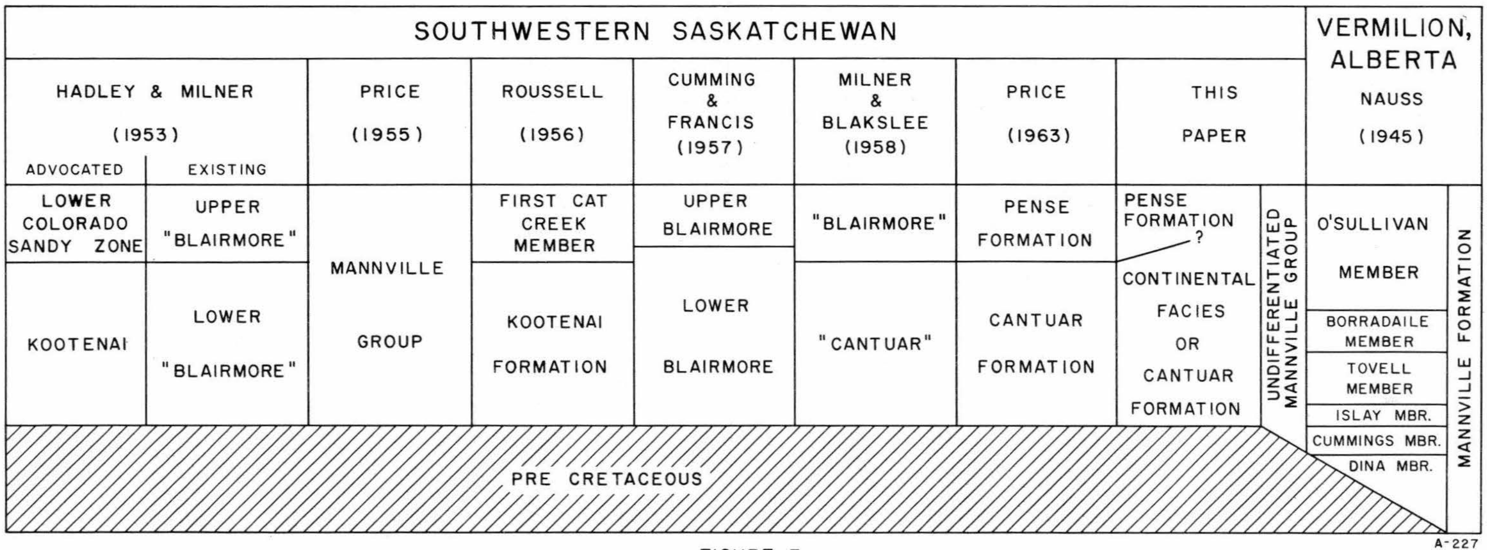

FIGURE 3

Fig. 3: Evolution of stratigraphic terminology for Mannville sediments in southwestern Saskatchewan.

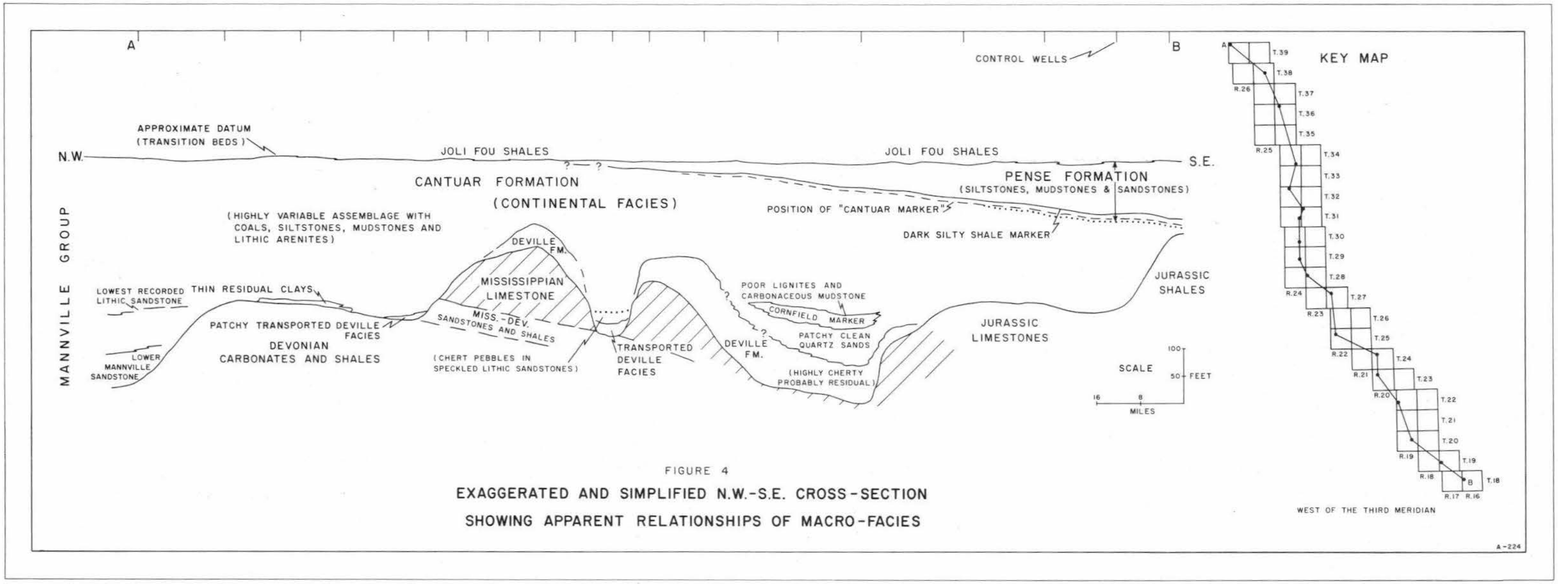

FIGURE 4

EXAGGERATED AND SIMPLIFIED N.W.-S.E. CROSS-SECTION SHOWING APPARENT RELATIONSHIPS OF MACRO-FACIES

Fig. 4: Exaggerated and simplified N.W.-S.E. Cross-section showing apparent relationships of macro-facies.

designated by Roussell (1956) as more closely correlative with rocks in North Dakota. However, the name would appear to be widely understood, and in the present study is considered as synonymous with, and will be used interchangeably with, the term "Continental Facies" in the southern portion of the studied area, *i.e.* that lying to the south of the Mississippian erosional edge (or south of Township 32). To the north of the Mississippian edge the Mannville sediments are best considered as undifferentiated. An attenuated or northward extension of the Pense Formation may exist (see "Pense Formation" below) but its exact extent cannot be accurately assessed. Similarly the basal sequence north of Township 32 shows increasing affinities with Lower Mannville sediments of the type area. As yet, the insufficiency of available core data renders the accurate evaluation of the boundary between Upper and Lower Mannville strata in the studied area questionable. Basal quartzose sands are herein tentatively referred to the Lower Mannville and are viewed as probably marginal marine in origin. The undifferentiated Mannville sediments to the north of the Mississippian subcrop edge appear more sandy than those to the south. The relations of the previously proposed terms and the operational subdivisions used in this paper are summarized in Figure 3, which also indicates their probable association with the Vermilion area to the north. Likewise, the diagrammatic cross-section (Fig. 4) illustrates the probable relationships as encountered in a northwest-southeast traverse across the studied area.

The Mannville Group grades upwards into the sandy Spinney Hill facies of the Joli Fou Formation (see Edwards, 1960, Fig. 2, p. 143), as a result of which the top of the Manville becomes very difficult to determine (both on logs and in core). Because this is particularly applicable to the northeastern part of the area, the structure contour and isopachous maps within that locality should be interpreted with caution.

Underlying the Mannville Group and overlying the Mississippian limestone and in places the Devonian, is the Deville Formation (Badgley, 1952) or Detrital, a chert-rich, sandy, often conglomeratic sediment of variable aspect. In the present study a subjecitve division has been made between The Deville Formation and Transported Deville facies. The former is presumed to be residual in origin and to exist essentially in place, whereas the latter, as the name suggests, is considered to have been transported a significant distance (*i.e.* several miles) from its original residual site.

The lithologic bodies considered in this descriptive account are (1) the Deville Formation and (2) the facies of the Mannville Group as follows: (a) Undifferentiated Mannville (b) Transported Deville facies (c) Lower Mannville sandstones (d) Cantuar Formation, or the Continental Facies of the Upper Mannville (e) Pense Formation and (3) the Joli Fou Formation (lower portion) with its Spinney Hill Member in the northeast and the Mannville - Joli Fou transition beds to the west and south.

An idealized conception of their relative positions is presented in Fig. 5. The variety of their mutual contact relationships is more fully discussed under "Descriptive Stratigraphy".

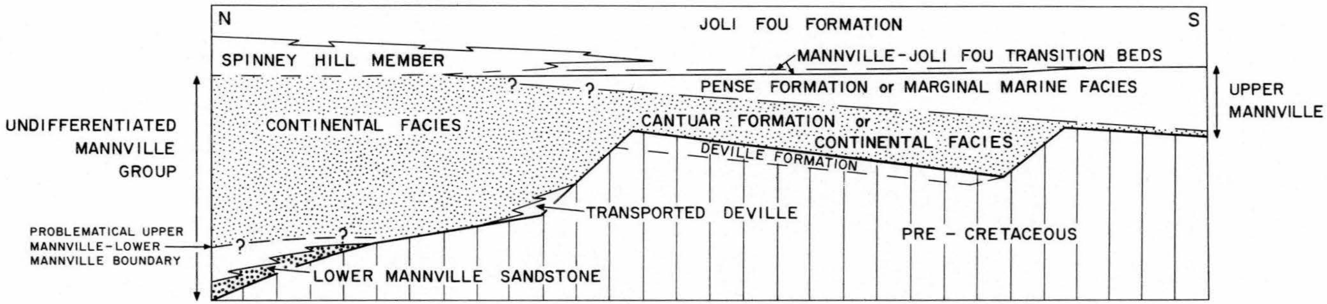

FIGURE 5

IDEALIZED DIAGRAM ILLUSTRATING RELATIVE STRATIGRAPHIC POSITIONS OF THE MANNVILLE AND JOLI FOU FACIES

A-228

Fig. 5: Idealized diagram illustrating relative stratigraphic positions of the Mannville and Joli Fou facies.

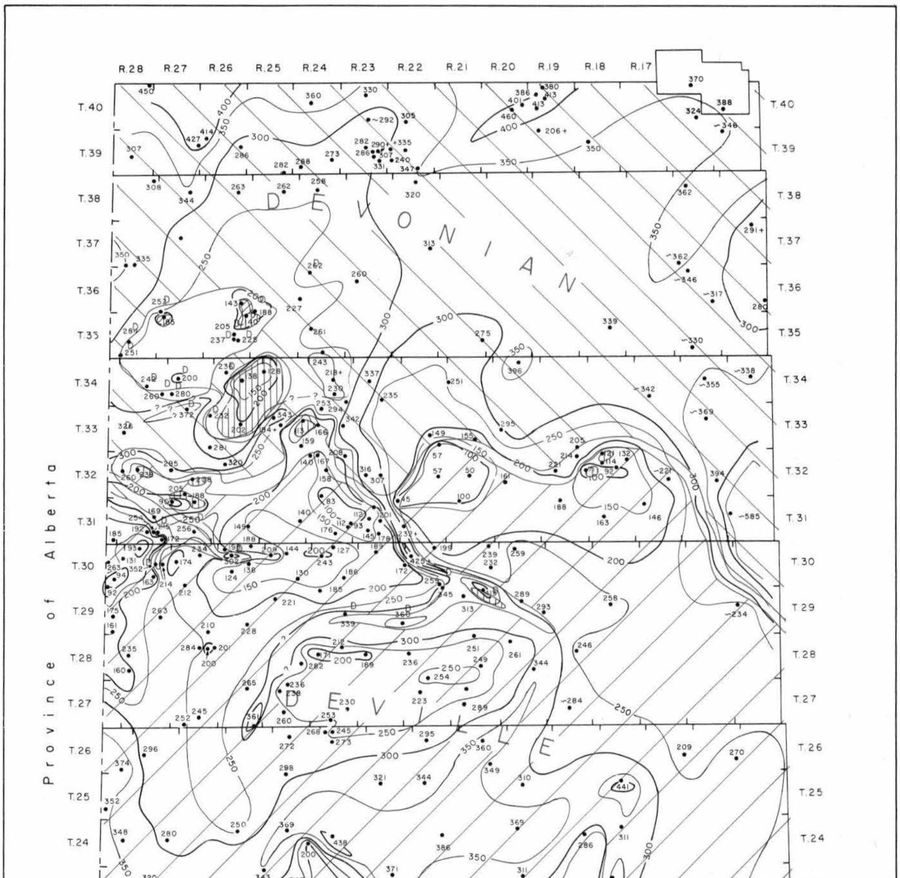

Fig. 6: Isopachous map of the Mannville Group and the transitional beds on map of the sub-Cretaceous palaeogeology.

Pre-Cretaceous Erosion Surface

The different ages of rocks underlying the Mannville Group (as indicated in the present study) are summarized in the isopachous map (Fig. 6). Due to their regional southerly dip these rocks become progressively younger to the south. Representatives of the following have been recognized: Duperow Formation, Birdbear Formation, Three Forks Group, Bakken Formation, Madison Group (undifferentiated), Deville Formation, Gravelbourg (?) Formation, the Lower and Upper Members of the Shaunavon Formation, and the Middle and Upper Members of the Vanguard Formation.

In the present study the basic tenet of Beltz's (1953) work is accepted, namely that an isopachous map of the Mannville deposits indicates in an approximate manner the pre-Cretaceous relief. Thus narrow, excessively-thickened deposits are considered as infilling pre-Cretaceous valleys, whereas areas of thin Mannville sediments are viewed as draped remnants of early uplands. The use of the total Mannville isopach as an indication of initial relief within the area covered by recognizable Pense sediments may well be questioned in view of the probable marine origin of these upper rocks. Unfortunately the indefinite limits of this formation preclude the construction of an isopachous map of the Continental Facies (Cantuar Formation) only, which could more reasonably be related to the exact pre-Cretaceous topography. Nevertheless, the combined isopachous and palaeogeologic map of Figure 6 has been prepared in accordance with this concept of negative relief. The writer realises that a different map would probably be constructed if another premise were followed, or a purely mathematical approach adopted.

Generalizing, the Mississippian and Jurassic rocks may be said to form embayed, northerly-facing escarpments with associated gently sloping, southerly dip slopes. To the north and west of the main Mississippian sub-crop edge within the studied area several outliers of these carbonates top a somewhat flattened Devonian nose. The outliers are (in the writer's opinion) relatively steep sided, and may possibly resemble subdued mesas. They are flanked, and their intervening valleys are in places floored, by aprons or flats of Middle Bakken sandstone or, less commonly, Bakken shales. These flanking rocks are overlain in many cases by cherty or sandy sediments here designated as Transported Deville facies, and are presumed to have accumulated during Lower Cretaceous time as alluvial fans or stream deposits (in part reworked by contemporaneous or later Mannville rivers) round the limestone hills. The main Mississippian escarpment appears to be breached by a deep valley in Township 31, Range 23 west of the 3rd Meridian, *i.e.*, immediately to the east of the Coleville-Smiley oil field (see Reasoner and Hunt, 1954). That this channel, herein called the Coleville-Smiley valley, continues through the Mississippian escarpment has not as yet been verified; but the excessive thicknesses of Mannville sediments to both the south and north, and corresponding underlying seismic "lows" (Sawatzky, 1959) suggest this. Seismic evidence cannot, however, be taken as an unequivocal indicator of the topography of the underlying Mississippian, as an apparently similar but shallower valley at the junction of townships 31 and 30, ranges 27 and 28 west of the 3rd Meridian is represented by a "high" on the same seismic map.

The Coleville-Smiley valley mentioned above apparently bifurcates to the south, the westerly arm trending almost due west and the easterly east-southeast. The easterly arm, which may be floored by Devonian sediments covered by apparently transported cherty detritus, is buried under as much as 413 feet of Mannville sediments as shown in the Pan American Netherhill No. 9-34 well (Lsd. 9-34-29-21W3). This excessive thickness contrasts sharply with that of the Mannville sequences overlying the flanking Deville-covered Mississippian limestone escarpment breached by the main valley to the north, where thicknesses of 45 feet and 70 feet are recorded from the Canpet Highwood Eureka No. 10-36 (Lsd. 10-36-31-23W3) and Royalite Albercan Coleville No. 22-30 (Lsd. 6-30-31-23W3) wells.

To the south a thickened Mannville sequence appears to occupy a depression (presumably a valley) against or near the Jurassic erosional edge. Presumably the erosive agents instrumental in deepening the valley were closely allied with those responsible for the removal of the Jurassic sediments farther north. The Jurassic upland to the south would appear to have varied in altitude (as indicated by present Mannville isopachs) and probably was channelled by rivers associated with the Continental Facies (examples are included in the section on sedimentation). Locally the Jurassic beds appear to be covered directly by rocks of the Pense Formation, e.g., in the SMPS 9-22-18-17 well (Lsd. 9-22-18-17W3) at 2936 feet, sandy marls or mudstones of the Roseray Sand (Middle Vanguard) are overlain by muddy, somewhat carbonaceous siltstones, here attributed to this Upper Mannville formation.

V

DESCRIPTIVE STRATIGRAPHY

Introduction

One of the aims of this report is to furnish workers on the Lower Cretaceous with adequate descriptions of the significant rock types occurring within the studied area. To this end a large number of photographs have been included. The great variety of lithologies encountered during the course of this work precludes the inclusion of descriptions of each. An attempt has been made, however, to summarize the features of both the volumetrically-important varieties and of those considered by the writer to be genetically significant. In writing lithological descriptions one is rarely entirely objective. Equally in the reading of a rock description subjectivity is commonly introduced. Descriptive terminology is frequently open to a variety of interpretations, and genetic terms such as ripple-lamination, loadcasts, burrows etc. are unlikely to evoke the same mental response in all readers. Reference to the photographs and their legends at the end of this report will, the writer hopes, give readers both an idea of the various rock types encountered and a visual appreciation of the significance of descriptive terms as used herein. In corollary, the accounts within the body of the text have been abbreviated where feasible.

Log responses of the various descriptive sub-units and their significant areal variations are summarized on Fig. 7.

Deville Formation

Rocks included within this formation (named by Badgley, 1951, for a rock unit previously known as the "Detrital zone" or "Residual zone" occurring in the Imperial Deville No. 1 well, (Lsd. 9-36-51-

20W4, Alberta), vary in thickness, distribution and lithology. In the present account the term "Deville Formation" is restricted to those commonly chert-rich sediments overlying Mississippian carbonates. The evidence of closely spaced wells suggests that the thickness of the Deville Formation changes rapidly (e.g. 90 feet in Husky Phillips Marengo No. 1 well, Lsd. 10-26-28-27W3, and zero or nearly so in Husky Phillips Marengo No. 2 well, Lsd. 10-27-28-27W3) and for this reason no attempt has been made to construct an isopachous map of the formation. Although the lithological heterogeneity of these rocks precludes the establishment of a characteristic well, the cherty breccio-conglomerates frequently encountered in cores are well developed in the Imperial Warrior 10-29-27-25 well (Lsd. 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 Plato Crown No. 1 well (Lsd. 9-22-24-19W3) between 2728 and 2813 feet. Generally no notable electric-log characteristics typify the Deville Formation, although the spontaneous potential usually assumes a high level throughout, a feature which may be accompanied by increased resistivity. In well cuttings the formation is identifiable by the presence of large quantities of hard white and gray chert fragments, frequently exhibiting porosity due to the apparent leaching of non-chertified organic fragments (*e.g.* crinoid ossicles). The chert fragments may or may not be accompanied by varying quantities of clear, angular and subangular quartz grains (sometimes aggregated by light brown siderite) and/or floods of isolated or aggregated brown siderite spherules (0.2 to 1 mm.). More rarely very pale greenish-gray, silty clay fragments, which swell or lose their coherence in water, are found. Occasional reddened clay-rich fragments also occur. In core the parent lithologies of the above mentioned fragments have been observed and may for ease of description be subdivided into four main varieties, Viz:—

(1) Conglomerate and breccio-conglomerate,

(2) Sandstone,

(3) Waxy mud or claystone and

(4) Reddened (oxidised) equivalents of (2) and (3).

The pebbles and/or rare cobbles within the conglomerates always consist of chert, apparently in different stages of decomposition to a variable coherent, white floury material ('tripolite"?). The latter, where still in identifiable lumps shows good permeability and good, very fine porosity and is frequently oil stained (see Pl. 1). The chert itself may, as is frequently indicated in drill cuttings, exhibit porosity due to preferential leaching of non-chertified organic debris. In such examples the degree of staining suggests lower permeabilities than that of the "semi-rotted" product. The pebbles most commonly are supported by a white, off-white, pale yellowish gray or light gray, powdery, apparently argillaceous, fine to medium grained, poorly sorted sandstone consisting of angular quartz and chert detritus, exhibiting irregular lamination and speckled with scattered sphaerosiderite. In some specimens, however, for example that illustrated in Pl. 1, the host material is essentially a lithified, pale gray, argillaceous paste supporting scattered siliceous fragments from silt to pebble size.

The sandstones resemble the finer clastic fraction of the conglomerates although they appear somewhat better sorted. The detrital fraction consists of chert and quartz grains while the matrix is, as a rule, very light in colour, is plucked out very easily during the thin-sectioning process, and consists of many tiny, very poorly birefringent, elongate unidentified crystals. Lamination is generally indistinct in oxidised varieties although some specimens show aligned concentrations of brown siderite spherules (*e.g.* Tidewater Plato Crown No. 1 well, Lsd. 9-22-24-19W3, 2741 to 2767 feet). In other localities a brecciated aspect is imparted to the rock by the occurrence of irregular pebbles or cobble-sized, sand-rich masses within superficially similar but sand-poor sediment. (*e.g.* Coleville 13-29 well, Lsd. 3-29-31-23W3, 2445 to 2486 feet, Pl. 11a). Elsewhere fragments of the sand-poor sediment may be included within more sandy material (*e.g.* Phillips Husky Cathy No. 1 well, Lsd. 11-17-30-26W3, 2655 to 2665 feet). These fragments consisting of white clay, swell considerably on contact with water, and in this regard resemble many of the pale grayish-green, waxy mudstones which may be intermixed with the coarser cherty sediments or directly overlie pre-Cretaceous limestone (e.g. J. L. Graham Major No. 1 well, Lsd. 5-22-33-26W3, at approximately 2684 to 2691 feet).

The mudstones vary in colour, may be slightly reddened, but are usually pale green, yellowish-green or gray, contain a varying admixture of silt-grade siliceous material and scatterings of sphaerosiderite (e.g. Coleville Unit 5-30-31-23 well, Lsd. 5-30-31-23W3, 2495 feet).

Oxidised (*i.e.* reddened) examples of all the lithologies noted above, with the exception of the coarser conglomerates, have been seen. Poorly sorted, moderate reddish-brown, very argillaceous sandstone, with chert or weathered chert pebbles up to 1 cm. diameter and containing zones of siderite spherules ranging from 0.5 to 0.7 mm., occur in Phillips Husky Alsask No. 1 well, (Lsd. 10-7-27-28W3) at 2662 feet (Pl. 11b). Likewise, patchily reddened, fine-grained sandstone is seen at 2755 feet in Tidewater Plato Crown No. 1 well. Other stained occurrences within the same core reveal disturbed or even brecciated lamination (*e.g.* at 2767 feet). The irregular reddening of sandstone in the R.G.A.I. Coleville No. 63-19 well, Lsd. 13-19-31-23W3, between 2505 feet and 2524 feet, (Pl. III) delineates highly disturbed lamination, some of which resembles burrow structures and may be attributable to organic action. That associated small-scale arcuate lamination might represent some variety of diffusion banding (a possibility suggested to the author by D. E. McCubbin) cannot, however, be discounted. In Phillips Hoosier No. 1 well, (Lsd. 13-11-31-28W3) at 2854 feet, below conglomerates with floury chert and overlying dolomites and limestone, light medium-gray and light olive-gray mudstones containing sphaerosiderite alternate with dark reddish-brown mudstones. Similar oxidised sediments (a trifle sandier), pale reddish-brown in colour, occur at the base of the cored interval (2917 feet) in Husky Phillips Eatonia A No. 2 well (SW9-29-26-24W3, again beneath cherty conglomerate (white, floury chert), which in turn underlies fine-grained white sandstone.

Transported Deville Facies

As previously stated, sediments have been attributed to this sub-unit primarily on the basis of their position and lithology *i.e.* cherty rocks overlying pre-Mississippian strata proximal to known, relatively elevated, Mississippian subcrops. The evidence for the presence of the facies is based largely on drill cuttings from the wells plotted in Figure 6. In a core from Imperial Oil Enterprises McLeod Dodsland well (Lsd. 6-33-32-20W3) fine to medium quartzose sandstone with chert pebbles up to 3 cm. long overlies fossiliferous, greenish, calcareous mudstones of the Devonian Big Valley Formation (Three Forks Group). Cherty conglomerate (Pl. IVa) although resembling much of the Deville Formation, occurs at 2846 feet above a questionable, very thin, basal Mississippian sequence (one normally poor in chert) in the Imperial Netherhill 10-13-29-20 well (Lsd. 10-13-29-20W3). The conglomerate comprises large pebbles and small cobbles of chert containing partially silicified spiriferids and other brachiopods. The low stratigraphic position of this deposit, the valley-ward thickening of the Mannville sediments (Fig. 6) and the occurrence above this sequence (*viz.* at 2771 feet) of conglomeratic lithic sandstone, bearing carbonized wood fragments up to 1 cm. in diameter, and gray angular chert pebbles up to 2 cm. in diameter, indicate that this deposit represents Deville or other weathered Mississippian material supplied to a lowland area from nearby uplands. Although neither the degree of sorting nor the unstratified nature of the cored sediment suggest active fluvial reworking, its heterogeneous nature might be ascribed to an alluvial fan origin.

Other examples of presumably transported though locally-derived chert pebbles occur in fine-grained and carbonaceous lithologies; for example, cherty conglomerate in coaly, very fine sandstone and siltstone at 2834 feet in the Canadian Seaboard Canso Fusilier 10-33 well (Lsd. 10-33-33-27W3) (Pl. IVb), or chert pebbles underlying coal at 2778 feet in the Canso Pan Western Major No. 1-25 well, (Lsd. 1-25-33-27W3).

Undifferentiated Mannville Group-Lower Mannville sandstones

Those Mannville sediments here considered as undifferentiated occur within the studied area north of the Mississippian erosional edge and beyond the readily recognizable limits (on electric logs) of the Pense Formation. Essentially they consist of equivalents of the Continental Facies with or without a basal sequence of possibly marginal marine, possibly barrier bar and lagoonal sediments, herein called the Lower Mannville sandstones. In the northeast of the area where the Mannville Group underlies the Spinney Hill Member of the Joli Fou Formation, the overall sand content of the individual strata appears higher than positionally equivalent sequences to the south. This characteristic is made apparent on electric logs by a generally higher spontaneous potential response. In the extreme northwest of the area round Wilkie several shale breaks (as indicated by electric logs) throughout the Mannville succession may be correlated. Whether or not this indicates an approach to marine conditions is at present unknown. The available cores in that region illustrate lithologies closely allied to those of the Continental Facies as recognized to the south. Discussion of these sediments awaits further study; at present reference will be made only to the probably marginal marine Lower Mannville sandstones as developed in the basal 50 feet of the Mannville Group in the Dukesbury 13-18 well (Lsd. 13-18-34-21W3). The Mannville Group thickens to the north and the lower Mannville lithologies at this well may well be part of the diachronous basal sands, and hence might be expected to have facies equivalents (possibly of more argillaceous variety) farther north. The overall poor quality of drill cuttings precludes accurate evaluation of this possibility. The lower limit of the Continental Facies may be suggested by the lowest samples containing either speckled lithic sandstone or coal but such can be considered no more than a suggestion.

In view both of the similarity of the uppermost beds in the Dukesbury 13-18 well[1] to those in the Pense Formation and the rough resemblance of the appropriate resistivity curve to those of attenuated Pense sequences (cf. Figs. 8 or 9), and because of the equivalence of the lithologies immediately beneath with those of the Continental Facies, consideration of their respective lithologic characteristics will be deferred to the appropriate headings. Only the Lower Mannville sediments will be discussed under this heading. These, in view of the proximity of the unconformity, need not be viewed as typical, but their dissimilarity to those of the overlying continental sequence is significant. The character of these beds is summarized in plates V to VII.

In the Ceepee Dukesbury 13-18 well the contact between the Continental Facies and the Lower Mannville sandstones is viewed as between the depths of 2451 and 2454 feet, where argillaceous very fine sandstone, with sub-horizontal and small scale cross-lamination disturbed by tubules (rarely 4 mm. wide, commonly 2 mm.), grades downward, with increase in mud content, through finely laminated argillaceous siltstone, with a somewhat "clotted" appearance due to elongate, paler muddy bodies, to a finely laminated alternation of carbonaceous mud and siltstone with "rolled" siltstone bodies, small-scale bedding disturbances, and micro-pseudonodules (*cf.* Macar, 1948). This directly overlies fine-grained, poorly consolidated, densely oil-stained, quartzose sandstone. Below this horizon neither poorly laminated, pale greenish or grayish, rootlet-bearing claystones and mudstones (swelling in contact with water), nor the gray lithic sandstones, both lithologies characteristic of the Continental Facies, are seen. While, in contrast, the lower sandier sediments are generally cleaner and more quartzose, the mudstones are darker than those of the overlying sequence.

These sandstone deposits, of variable thickness (0 to 30 feet) and patchy distribution, occur also in the Partington, Unity, and Wilkie areas (T39-R26W3, T40-R23W3 and T40-R19W3 respectively). Characterised by good spontaneous potential-log expressions they exhibit different types of resistivity curves, depending on the presence or absence of oil, saline or fresh water. A good example of such log response is illustrated in the British American Eyehill Partington 2-31-39-26 well (Lsd. 2-31-39-26W3) between 2493 and 2557 feet (see Fig. 7).

A core of these sediments within the above-mentioned areas (*viz.* British American Eyehill Partington Ayrey 7-25-39-27 well, Lsd. 7-25-39-27W3, between 2484 and 2524 feet) was examined by the author. Heavily oil-stained, this core of quartzose sand shows some

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[1] In view of the long, 3½ inch diameter, core, with almost complete recovery through most of the Mannville sequence in the Dukesbury well, many lithologies, particularly those of the Continental Facies, are available for detailed study. This has resulted in the apparently disproportionate number of samples illustrated from this well.

sub-horizontal lamination, and in the upper portions, thin argillaceous breaks. Removal of the oil reveals that the sand resembles positionally equivalent sediments cored between 2250 and 2360 feet in the Superior Manito No. 2 well, (Lsd. 6-34-42-28W3), north of the studied area. These consist of unindurated, well sorted, fine-grained, angular and more rarely subangular quartz with very rare heavy minerals and equally scarce plagioclase clasts.

Continental Facies (Cantuar Formation)

This heterogeneous sequence of clastic sediments, which occurs throughout the area and whose variable thickness reflects the irregular pre-Cretaceous topography, is absent only in isolated localities where Pense sediments directly overlie the Jurassic, *e.g.* in the Battrum Field T.18 R.18W3. In thickness the sequence ranges from zero (as mentioned above) to over 350 feet, *e.g.*, 360 feet in the valley-filling sequence in the Imperial Netherhill 10-13-29-21 well (Lsd. 10-13-29-21W3). Except where underlain by the basal Mannville sandstones in the north, rocks of this facies appear to directly cover the subcropping pre-Cretaceous sequences throughout much of the area. In several localities a gradational contact with the underlying Deville Formation or Devonian strata renders the exact establishment of the lower boundary difficult. The facies is in turn overlain by Pense sediments throughout much of the area (see Figs. 8 and 9) although in the west, and more particularly the northwest, it appears to be covered by the Joli Fou Formation. In the northeast, if not blanketed by an attenuated Pense equivalent, it is succeeded by sands of the Spinney Hill Member of the Joli Fou Formation. The variable nature of the component lithologies and their erratic spatial distribution is reflected in the irregular and unpredictable nature of the resultant electric logs, with the expected consequences that such logs, even of neighbouring wells, are not useful for intra-facies correlation. The "Cornfield Marker", an informally designated bed in the south central portion of the area (see Fig. 7 for distribution) of variable thickness and characterized by low resistivity and spontaneous potential, is typically developed in the Imperial Cornfield well, (Lsd. 10-32-25-25W3) between 2900 and 2930 feet, (log reproduced in Fig. 7). Uncored, this unit apparently consists of mudstones, sometimes carbonaceous, and/or lignites as indicated by drill cuttings. In the Phillips Husky Coombe No. 1 well (Lsd. 16-21-23-28W3) lignitic fragments characterize the cuttings from the upper 20 feet of the unit.

The Continental facies is best described as an extremely heterogeneous assemblage containing scattered lithic sandstones in association with a preponderance of dominantly argillaceous siltstones, together with fine sandstones of variable clay content. Lignites, carbonaceous shales and mudstones, together with rarer rocks rich in carbon filaments (probable rootlet beds) make up the remainder of the assemblage. Other than lithic sandstones exhibiting calcitic replacement of the matrix, calcareous rocks are rare. However, finely-conglomeratic argillaceous limestone occurs at 2548 feet in the Tidewater Plato Crown No. 1 well, (Lsd. 9-22-24-19W3). As seen in core scattered sphaerosiderite occurs in certain mudstone lithologies. The misconception that sphaerosiderite typifies Mannville sediments apparently originated from the tendency of this mineral to be found concentrated in drill cuttings as an apparent result of the drilling process.

Description is facilitated by a somewhat arbitrary breakdown according to dominant grain size, degree of lamination, and apparent clay or carbon content, into the following groups:

(1) Lithic sandstones and associated conglomerates.
(2) Laminated, argillaceous, fine sandstones, siltstones and laminated mudstones.
(3) Argillaceous fine sandstones, siltstones, and mudstones with poorly preserved fragmented or severely disturbed lamination and carbon stringers.
(4) Lignites, carbonaceous mudstones and shales.
(5) Miscellaneous, e.g. siderite-rich, or calcareous sediments.

The characteristics and relationships of the various rock types are summarized in Figure 10, reproduced from Maycock (1964, Fig. 5) and the photographs of Plates VIII to XV.

(1) Lithic Sandstones

Elsewhere (Maycock, 1964) the writer has discussed the nature of the lithic sandstones, their sedimentary structures, petrography, associated sediments, sedimentation and probable provenance. Interested readers are referred to this paper for an account more detailed than the synopsis offered here.

The term lithic sandstone is based on the sandstone classification of Packham (1954) and its modification by Cook (1960). On the basis of the sedimentary structures and lithological associates the sandstones are ascribed to the "arkose-sandstone suite" of Packham (*op. cit.*) while the high percentage of included rock fragments allows them to be classified as "lithic sandstone" (Crook, *op. cit.* p. 25).

The sandstones exhibit calcareous, partially calcareous, and argillaceous matrices and, depending on the percentage of carbonate, comprise either high-recovery cores of hard, well-indurated, poorly porous rocks, or cores of lower recovery of comparatively unindurated sediment with variable intergranular porosity.

The rocks are light gray to light medium-gray in general appearance, and are very finely speckled with dark and light grains. The calcareous specimens may exhibit a faint bluish cast while the argillaceous varieties tend towards pale olive gray. Under the binocular microscope many colors of grains are visible, the most common being white, clear, varying shades of gray, and black. Minor quantities of green, red, brown, orange, and yellow grains occur, examples of any one of which may be concentrated in a single specimen. Grain size ranges from very fine to medium on the Wentworth scale. Angular and subangular varieties predominate, although in thin section some rock fragments and very rare quartz and feldspar grains appear subrounded or very occasionally rounded.

Rare conglomerates include both chert (often angular) and mudstone or silty mudstone (rounded and angular) pebbles (Pl. X). The non-pebbly fraction of these conglomerates is fine to medium-grained speckled sandstone. Carbon (Pl. IX) is one of the most conspicuous sandstone constituents and occurs as fragments ranging in size from that of sawdust to pieces of carbonized wood over 6 cm

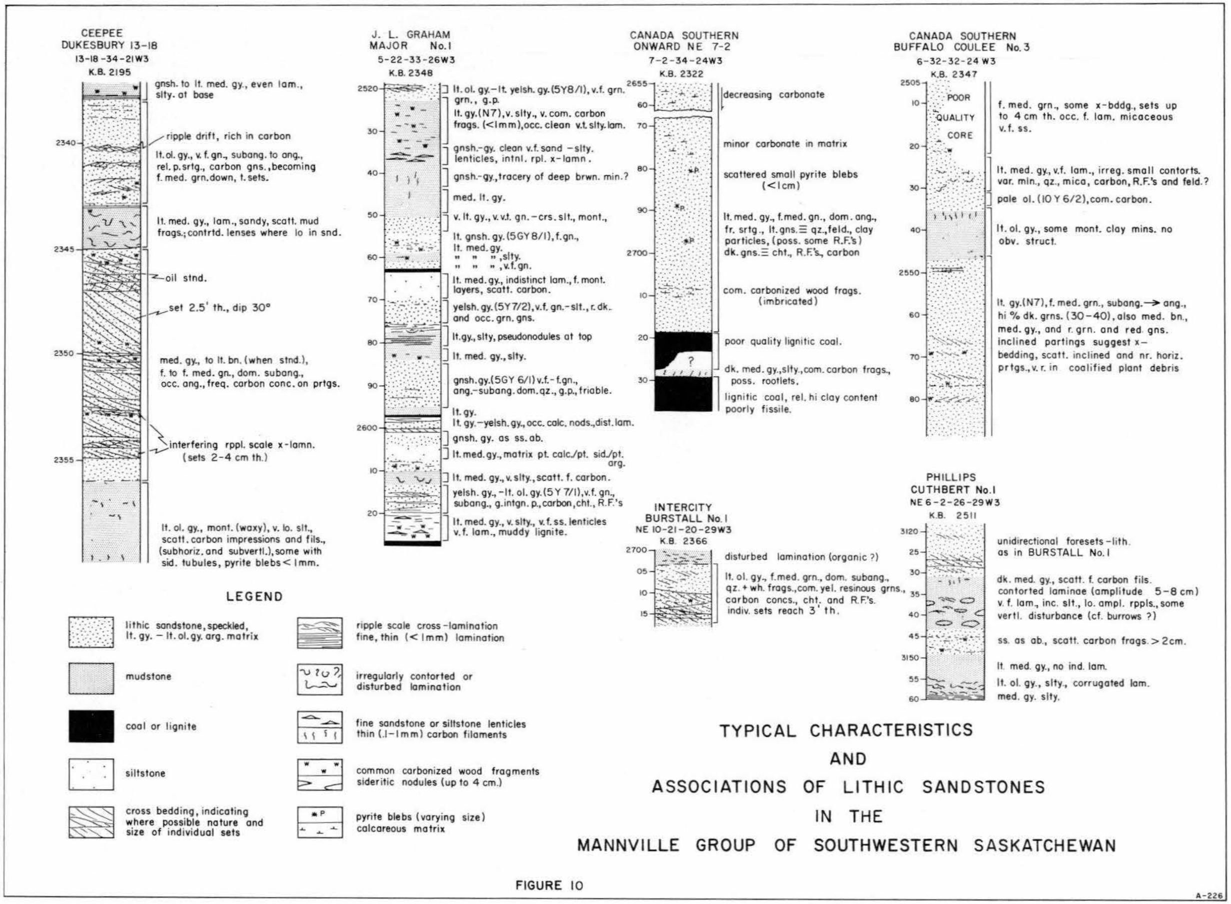

Fig. 10: Typical characteristics and associations of lithic sandstones in the Mannville Group of southwestern Saskatchewan.

long and 2 to 3 cm. thick which extend beyond the limits of the core. Small flattened fragments up to 1 cm. wide and less than 0.1 mm. thick are frequently concentrated along partings and help to emphasize the sedimentary structures. Other constituents enriched along individual laminae are unidentified yellow to deep orange-brown, soft, rather resinous grains, often exceeding 1 mm. in diameter. Often they appear to have been preferentially replaced by very finely crystalline carbonate.

Cross-stratification varies in scale from progressive rippling or ripple-drift bedding (Sorby 1908) to the medium to high-angle, medium-scale cross-lamination of McKee and Weir (1953), with rarer examples of irregularly superimposed ripple scale cross-laminae. Studies of dip directions of cross-lamination indicated (Maycock, 1964, Fig. 4) preferential orientation in two sequences 10 and 13 feet thick from Husky Phillips Cuthbert No. 1 well (NE-3-2-26-29W3) and Ceepee Dukesbury 13-18 well (Lsd. 13-18-34-21W3) respectively.

Average grain size varies between adjacent laminae (Pl. XI) but superimposed general trends of downward coarsening may be seen in several sequences (Maycock 1964, p. 157). Ripple and small-scale cross-lamination is generally finer in grain (and often enriched in carbon dust) than thicker sets where granule-grade detritus and larger carbonised wood fragments may be concentrated.

The sandstone mineralogy is relatively simple. The predominant minerals in order of volumetric importance are quartz, feldspar (plagioclase microcline microperthite orthoclase), chlorite and/or biotite, and muscovite. Opaque minerals occur in very minor quantities, and detrital carbonate is probably present. Scattered heavy minerals (zircon, tourmaline, garnet, epidote) are not volumetrically significant. Glauconite grains are rare.

Sedimentary, igneous, and very fine-grained metamorphic rock fragments were recognised. The majority of the igneous fragments are fine-grained (with occasional phenocrysts) and are presumed volcanic. The fine-grained nature of the sediment precludes the easy recognition of plutonic fragments, which presumably would have been reduced to their component grains prior to incorporation.

(2) Laminated fine-grained sediments

These rocks occur in varying shades and hues of gray; light olive gray and medium light gray are among the most common. The various sedimentary structures are rendered visible by the difference of grain size between successive layers and by concentrations of carbon dust and/or micromica. The structures are attributable to current origin and may consist of connected, semi-isolated or isolated low amplitude (1 cm.) ripple lenticles showing internal low angle cross-stratification, of both a simple (unidirectional) or more complex type. Low amplitude ripple-drift bedding is usually restricted to the sandier zones as are irregularly-choppy, superimposed ripple structures, although the former may occur on a very small scale within thin siltstone bands (1 to 2 cm. thick).

Small discontinuities and truncations of minor laminae between successive ripples are characteristic, while irregular truncation surfaces (presumably erosional) may occur within otherwise finely, and

and evenly laminated, argillaceous silts. Structures attributable to penecontemporaneous deformation are not uncommon, and as a rule take the form of irregular corrugations varying in amplitude from a few millimetres to several centimetres. When well developed they resemble the convolute bedding of ten Haaf (1956, p. 190). Smaller and more restricted types are load casts (occasionally of individual ripple lenticles) and pseudonodules (Macar, 1948). This deformation may be so far advanced that original sets of laminae are fragmented and appear as small rolled ellipsoids or sometimes as irregular or angular lumps. In extreme examples such sediments resemble those of the third descriptive category.

Narrow zones of vertical disturbance are not ubiquitous but where seen appear to be related to either a floral or a faunal origin. Varieties attributable to the former are more irregular and are usually associated with carbon stringers, whereas the latter consist of narrow vertical or near-vertical zones in which the original lamination has been destroyed and replaced by either a relatively homogeneous mass of similar clastic material or a series of superimposed, subparallel, gently arcuated, fine laminae. In Pl. XI a typical finely laminated sediment has undergone some "burrowing".

(3) "Homogenized" fine-grained sediments

These mudstones and muddy siltstones include a higher percentage of clay which expands when wet than do their laminated counterparts. Usually lighter in colour, often of a greenish hue, (pale greenish gray and light gray or pale olive, are common) they are usually finely mottled with irregularly intermixed, lighter and darker argillaceous material. Rare examples contain sufficient carbon to achieve an overall dark gray appearance.

This characteristic may or may not be associated with thin carbon filaments, seldom thicker than 1 mm. and seldom longer than 2 cm. Some filaments are surrounded by a siderite tubule. Sometimes only the tubule remains. Both large sideritic concretions (up to 10 cm. thick) and tiny spherules (0.2 to 2 mm.) occur within these sediments. Elsewhere (*e.g.* Albercan Crown 35-26, Lsd. 4-22-35-26W3, 2420 to 2425 feet; and Royalite Druid 60-18 well Lsd. NW 15-18-33-20W3, 2356 to 2357 feet) brown translucent fibres, as yet unidentified, irregularly traverse light gray and light olive-gray, silty, waxy mudstones containing swelling clay.

In view of the difficulty involved in describing these modifed sediments, several illustrations (Pls. XI to XV) have been included. These illustrate the varying degrees of distortion and the scattered fragmentation of the presumably original lamination, and the distribution of carbon filaments and their relationship (where visible) to coal or lignite horizons.

(4) Lignites, carbonaceous mudstone and shales

None of these lithologies has been studied in detail during the course of this work. Argillaceous lignitic coals, lignites, and occasional low-medium rank harder coals are found. The lignites are more widespread and thicker, reaching 12 to 20 feet, (Canada Southern Onward NE 7-2 well, (Lsd. 7-2-34-24W3), 2719 to 2739 feet), than the sub-bituminous coals which appear to be restricted to a thickness of 2 or 3 feet or less. The columnar sections in Fig. 10

typify the generally observed relationships of the more carbonaceous lithologies. In Plate XIIa the remnant of a thin coal seam overlies mottled, pale, argillaceous silts (*cf.* type (3) lithology above) with carbon stringers, presumably coalified rootlets. Similar fine carbon filaments occur beneath a two foot thick coal at 2730 feet, in the Canso Summit 7-29-well (Lsd. 7-29-34-26W3). A large rootlet (over 20 cm. long) underlies a silty carbonaceous zone at 2444 feet in the Dukesbury 13-18 well (Lsd. 13-18-34-21W3).

(5) Miscellaneous lithologies

The heterogeneity of the Continental Facies precludes complete documentation of component lithologies. During the course of the study, however, several rock types other than those grouped above were encountered. Though volumetrically insignificant these merit brief description.

(i) Limestone conglomerate: Rounded calcitic bodies up to 1 cm. diameter, together with minor quantities of coal and carbonized wood fragments, scattered quartz, feldspar and occasional quartzose rock fragments, occur at depths of 2455.5 feet and between those of 2548 to 2549 feet in the Tidewater Plato Crown No. 1 well (Lsd. 9-22 24-19W3). The contact relationships of many of the calcareous components suggest some degree of plasticity at the time of sedimentation. The grains now consist of radiating masses of fibrous calcite (cf. Orme and Brown, 1963, Figs. 3 and 4) which in places appears to be replacing carbonaceous debris. Superficial examination suggests that, although the individual fibrous masses appear restricted to separate clasts, the crystallinity may have developed subsequent to their incorporation in the present detrital fabric.

(ii) Calcareous silty mudstones and argillaceous limestones: At 2560 feet in the Woods Paramount Tramping Lake 29-36 well (Road Allowance South Boundary 29-36-23W3) medium gray, calcareous, muddy siltstone with wisps and flecks of carbon overlies a thin bed of calcareous lithic sandstone. Limestone, light or medium brown, fine, of relatively fine crystallinity, with minor clay content, many fine carbon stringers, and rare pyrite characterises the drill cuttings between 2863 and 2875 feet from the Pan American Netherhill 9-34 (Lsd. 9-34-29-21W3) well. In the Husky Phillips Marengo No. 2 well (Lsd. 10-27-28-27W3) light gray argillaceous ostracod-bearing limestone fragments were recovered from the 2760 to 2770 feet interval. The included ostracods were ornamented but unfortunately were lost during an attempted identification. Study of cuttings from adjacent wells revealed no similar calcareous lithologies.

(iii) Siderite mudstones: Although sphaerosiderite may be enriched within certain mudstones of the Continental Facies, it occasionally constitutes a large portion of the visible specimen surface. Such an example occurs between 2571 and 2572 feet in the Tidewater Plato Crown No. 1 well (Lsd. 9-22-24-19W3) where approximately 90 per cent of the rock consists of medium olive-gray darkrimmed siderite spherules between 0.2 to 0.5 mm. diameter. Fine quartz grains and small quantities of clay compose the remainder.

(iv) Conglomerates: In the Battrum area rare polymictic conglomerates occur in a thickened Cantuar Formation or Continental Facies developed at the expense of the underlying Middle Vanguard Roseray sand. These exhibit a variety of sedimentary rock pebbles (mudstones, fine sandstones, rare quartzites and cherts) together with rarer organic debris (*e.g.* bone fragments, see Pl. XXVIII). The occurrence of these and associated rock types is discussed under the heading Sedimentation-Battrum locale.

Pense Formation

Price (1963, p. 26) proposed the name Pense Formation for the upper 105 feet of his "basal Cretaceous sand group" from the Sohio Canadian Devonian Pense No. 1 well (Lsd. 14-6-17-22W2). At this locality the sequence consists essentially of rapid alternations of thin units and laminae of fine-grained sand of varying clay content, siltstone, shale and irregular intermixtures of the three; (for a detailed lithological description see Price, *op. cit.* p. 27 to 30). These sediments, according to Price, contain variable quantities of comminuted plant debris, and show indications of organic reworking together with other forms of laminae brecciation. Comparison of the type Pense sequence with sediments here referred to by the same name suggests that, although the type core is now very badly fragmented and in places severely mixed, the overall lithological similarity is great. In the type well, however, both a higher percentage of undisturbed primary lamination and a greater overall content of dark gray clay are apparent.

In the present study area neither the top nor the base of the Pense Formation can be picked with ease on geophysical logs. The nature of the top is complicated by the development of sandy transitional beds between typical Pense sediments beneath and typical Joli Fou above. The regional log variations are shown in Figs. 8, 9, and 11. The lithological characteristics of this transition (based on scarce core evidence) are summarized under the next heading. The base of the Pense Formation as defined by Price (1963) occurs beneath the Cantuar Marker horizon (see Cumming and Francis, 1957) but is not typified by a specific log characteristic. On the basis of lithologic criteria the base is picked at the bottom of the lowermost "disturbed", often slightly carbonaceous, bed overlying variable silty, sandy or muddy rocks (generally of a lighter colour) of the Continental Facies. This lower horizon corresponds to the "lower plant-bearing bed" of Cumming and Francis (*op. cit.*, p. 24). The nature of these sediments is more fully discussed below.

The index horizon above the Cantuar Marker bed, the base of which was proposed as the Upper Blairmore/Lower Blairmore boundary by Cumming and Francis is visible in a modifed form on logs over approximately half of the studied region. In view of the paucity of core through the Upper Mannville Group the presence or absence of the index has been used by the writer as an indicator of the presence or absence of Pense sediments. In view of the difficulty experienced in picking the base, the isopachous map (Fig. 12) relating to the Pense Formation has been prepared using only the beds overlying the index horizon above the Cantuar Marker bed. On the basis of this index horizon the Pense Formation is here informally divided into an Upper Member (above it) and a Lower Member (below it). Indications are that the Lower Member thins in a manner similar to that of the Upper Member; thus the isopachous map of the Upper Member is considered a true indicator of the trends of variation.

The Pense Formation reaches its thickest development in the southeastern portion of the studied area, thinning towards both the north and east. Cross-sections based on resistivity logs (Figs. 8 and 9) illustrate this tendency. Good cores through the Pense are rare. However, certain cores within the north-central and western portions of the area suggest lateral extension of Pense lithologies farther than might be expected from the illustrated log characteristics.

For example highly disturbed, fine sandstone/siltstone/mudstone sequences occur in the upper portions of the Mannville Group in the Phillips Husky Alsask No. 1 well, (Lsd. 10-7-28-28W3) between 2480 and 2485 feet, in the Phillips Husky Saskal No. 1 well (Lsd. 7-2-29-29W3) between 2549 and 2554 feet, and as previously mentioned in the Ceepee Dukesbury 13-18-well (Lsd. 13-18-34-21W3) between 2270 and 2292 feet (Pl. XIXa). On the other hand, Pense lithologies are absent in the J. L. Graham Major No. 1 well (Lsd. 5-22-33-26W3) where at 2488 feet dark medium gray, silty shales of the Joli Fou Formation directly overlie the Continental Facies of speckled, fine-grained, lithic sandstones, which in turn cover greenish-gray unlaminated mudstones containing carbon fragments.

Within the studied area cores from three wells, namely Tidewater Cabri Crown No. 1 (Lsd. 1-23-20-19W3), Tidewater North Battrum Crown No. 1 (Lsd. 9-34-19-24W3), illustrate the various lithologies constituting the Pense Formation. In township 18, range 14W3, *i.e.*, that adjacent to the most southeasterly township studied, an excellent core through the basal portion of the Pense Formation, the Cantuar Marker bed, and the underlying Continental Facies has been recovered from the Tidewater Atlas Crown No. 1 well (Lsd. 8-20-18-14W3) between the depths of 3043 and 3234 feet.

These cores, together with other shorter, examples, allow a fairly accurate assessment of the constituent lithologies, which may be summarized and grouped as follows:—

(1) Fine and very fine-grained sandstone, pale olive gray to pale, poor to medium sorting, angular and subangular grains (dominantly quartzose), scattered micromica, scattered small carbon or other dark grains, (very rare polycrystalline quartzose material in thin section); argillaceous, calcareous, or negligible amount of matrix (fair to good intergranular porosity if latter); finely laminated: small-scale, low angle and occasionally low-medium angle cross-stratification with slightly arcuate foresets; occasional brecciation of lamination, very rare arcuate burrow-like structures.

(2) Alternating laminae of argillaceous fine sandstone, and siltstone with or without mudstone; generally discrete very fine lamination; silt or fine sand lenticles common, with internal micro-cross-stratification; frequent small-scale deformation of lamination, loadcastings, fragmentation, and flowage-type deformation of silt-filled cracks.

This type grades into (3) below.

(3) Irregularly intermixed, argillaceous, fine sandstone/siltstone/mudstone assemblages—a partially homogenized rock with incipient boudinage, wisps and pods of silt, micro-contortions, micro-pseudonodules (*cf.*

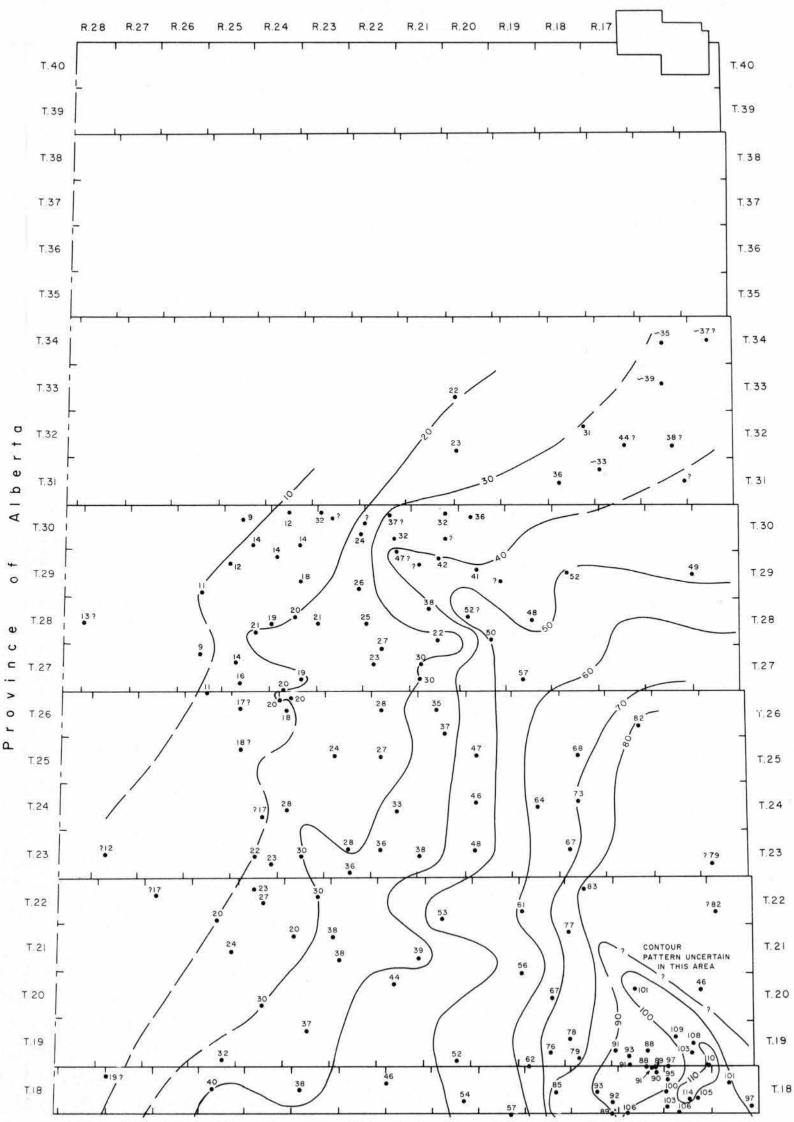

FIGURE 12

ISOPACHOUS MAP OF UPPER PORTION
OF
PENSE FORMATION

SCALE-MILES

10 0 10 20 30

LEGEND

CONTROL POINT - - - - - - - - • 35

CONTOUR INTERVAL 10 FEET

E-215

Fig. 12: Isopachous map of upper portion of Pense Formation.

Macar 1948), fragments (angular to subrounded), subhorizontal and subvertical silt-filled tubules.

(4) Mudstones or shales; medium or dark medium gray, silty, finely laminated, with occasional very thin (1-3 mm.) lenticles of pale olive silt, often with hieroglyphs, or questionable very fine tracks on their bases; lamination occasionally fragmented, sometimes in an apparently fluid manner.

Figure 13 illustrates several of the above-mentioned lithologies and the associated electric log responses from the Tidewater North Battrum Crown 4-4 well (Lsd. 4-4-19-17W3), in which, unfortunately, few well preserved examples of very finely laminated silt or mudstone alternations occur. Plates XVI and XVII exemplify the badly micro-contorted and fragmented muddy siltstone lithology so characteristic of the formation. With the exception of group (1) sediment, varying quantities of carbonaceous material occur throughout. Many of the darker gray mudstones contain carbon detritus although the occurrence, on parting planes, of flattened vegetal remains is comparatively rare. Although the Cantuar Marker bed and its associated "lower plant bearing bed" contain a carbonaceous mud fraction, together with recognizable wisps of plant debris in many localities, they do not appear to be significantly richer in such organic material than similar disturbed or "bioturbated" sequences above (Pl. XIXb).

Thin silt laminae or lenticles occur within the index horizon above the Cantuar Marker bed, and their presence in some wells may be a factor contributing to the development of the small resistive "kick" within the otherwise poorly-resistive electric log zone. The undersides of such lenticles are commonly covered with tiny, preferentially-orientated, elongate, raised mounds, resembling the "prod" and "bounce-casts" of Wood and Smith (1959) or the "toolmarks" or "hieroglyphs" of Dzulynski and Sanders (1962) (see Pl. XIX). Other, faintly bulbous, raised areas, may represent small scale load or flute casts, while narrow silt-filled cracks also stand out on certain of the parting planes. Hairlike, irregular, often sinuous, raised lineaments (see Pl. XIX) traverse some surfaces. These may represent the tracks or grazing marks of small organisms.

With the exception of scattered small fish teeth and occasional fish vertebrae (*e.g.* in Tidewater Cabri Crown No. 1 well, Lsd. 1-23 20-19W3, 2380 to 2384 feet), no faunal relics were found.

Mannville-Joli Fou Transition Beds

The contact between the Mannville Group and the overlying Joli Fou Formation cannot usually be picked with ease within the studied area. Figures 8, 9, 11, 14 and 15 indicate some of the variety of electric log characteristics. In the south-central portion of the area, *i.e.* between the Jurassic and Mississippian erosional subcropping edges, the electric log signature of the beds where one might place the upper contact of the Mannville group is distinguished by two resistivity noses (see Figs. 8 and 9) either of which might be picked as the Mannville Group top. Elsewhere, irregularly distributed calcareous sandstones within this sequence result in the development of scattered resistivity peaks. In some wells, *e.g.*, Tidewater Sanctuary Crown No. 1 (Lsd. 16-17-23-15W3), sandstones of this type thicken into the Mannville sequence thereby obscuring the contact relationship. Along the eastern margin of the area the horizon appears to be laterally correlative with a basal Spinney Hill sandstone (see Fig. 16), and may represent a thinning southerly extension of this lithology. The rare cores through these beds suggest interfingering of Mannville and Joli Fou lithologies, hence the informal term "Transition Beds". With the exception of those localities where sandier sequences occur these beds rarely exceed 20 feet in thickness.

The Transition beds, as indicated by cores, may be conveniently summarized as consisting of four main sediment types *viz*:—

(1) Dark gray mudstone, finely laminated, with or without pale olive gray very fine sandstone or siltstone lenticles (*cf*. Joli Fou).

(2) Light gray to pale olive gray, intimately mixed, disturbed or "bioturbated" sequences of very fine sandstone, siltstone, and mudstone (*cf*. Pense).

(3) Light gray sandstone, medium to very coarse grain, either unindurated or cemented by sparry calcite, pyrite, or more rarely exhibiting a silty mud matrix, with or without phosphatic debris.

(4) Phospate concentrations.

These sediment-types are summarized in Fig. 16.

Types (1) and (2) above need no elucidation here as their characteristics are more fully discussed under the headings of the Joli Fou and Pense Formations respectively. A transition between types (3) and (4) might be argued, the end members being phosphate-free quartz sand on the one hand and quartz-free pebbly phosphate concentrations on the other. Various intermediate mixtures exist.

The coarse quartz clasts (which may reach granule dimensions) are often seen in drill cuttings as isolated, well-rounded, highly polished, clear, or rarely greenish grains of low sphericity. When aggregated in cuttings they are most frequently bound by pyrite and/or white calcite. In the latter case the grains are rarely so highly polished, apparently as a result of marginal replacement by calcite (a feature readily visible in thin sections of similar calcareous sandstones from core).

In cores these coarse sandstones (Pl. XX) range from isolated lenticles rarely thicker than 2 cm. to beds of over 4 feet in thickness which may or may not exhibit narrow internal clay laminae (*cf*. Imperial Netherhill 10-13-29-20 well, Lsd. 10-13-29-20W3, 2527 to 2531 feet). Frequently, as in the example quoted above, erosive forms such as small flute casts are visible on the bases of these sandy layers (Fig. 11). Rare examples of these coarse sandstones are characterized by a silty argillaceous partly glauconitic matrix (*e.g.* Ceepee Broadacres 13-13, Lsd. 13-13-35-21W3, 2303 feet). Such examples appear to be made up of two dominant grain-size populations *viz*. a very coarse and a very fine. Binocular microscope examination indicates the absence of clastic particles within the intermediate size range. The thicker developments of these sand-

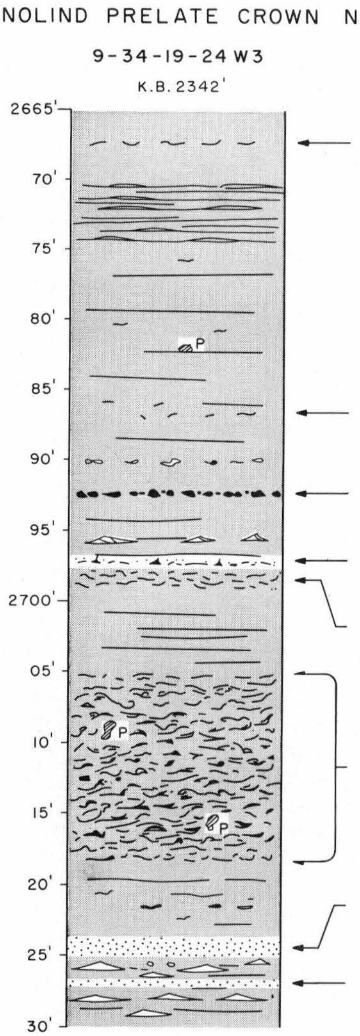

FIGURE 16

Pelecypod fragments, *Inoceramus* prisms.

Scattered pelecypod fragments, often lustrous; occasional phosphate; apparent fish scales.

Phosphatic pebbles, up to 15 mm. long, smooth, often polished, associated pyritic masses.

Phosphatic teeth and bone fragments, concentrated in zone 2-3 mm. thick; occasional quartz grains up to 2 mm. in diameter.

Disturbed mudstone zone, frequent small irregularly contorted siltstone masses.

Disturbed, "bioturbated", coarse and fine muddy siltstone/mudstone attenuations; resemble typical Pense Formation disturbed sediment.

Sandstone, light medium-grey to light brownish-grey, fine medium grain, friable, dominantly quartz, subangular, occasional dark grains, some mica, part argillaceous matrix; indistinct structure.

Fine sand and silt lenticles, up to 2 cm. thick, internally cross-laminated, hieroglyphs on bases, set in dark grey silty mudstone; thin layer of medium quartz grains; occasional silt-filled horizontal tubules.

DOMINANT LITHOLOGY

Mudstone, dark medium-grey, finely laminated with varying silt content, partly micromicaceous, swelling clay minerals common; different degrees of loading apparent on included silt laminae and lenticles.

Fig. 16: Lithologic characteristics of lower portion of Joli Fou Formation and included Transition Beds in Stanolind Prelate Crown No. 1 well, Lsd. 9-34-19-24W3.

stones characteristically consist almost entirely of quartz, with minor quantities of other detritus, notably small, brown, shiny, phosphate bodies some of which may be recognized as fragments of small teeth. However, more typical of the thinner (6 inches to 1 foot thick) sandstone beds, scattered larger rounded compound phosphatic bodies, up to 15 mm. in length, occur. These consist of aggregates of small rounded phosphate lumps as well as bone or tooth fragments. Many of these sandstone beds are cemented with spar-calcite. Small spherulitic developments associated with opaque, possibly vegetal, matter occur within the spar (*e.g.* Wilkie No. 1 well, Lsd. 10-32-39-19W3, 1965 feet). This is true of the examples where the coarse sand grains frequently (but not always) make up a greater percentage of the sediment (up to 15 percent) (Pl. XXIa).

The true phosphate concentrations occur in two forms:—

(a) Aggregates of rounded, polished, dark brown or black bodies (2 to 15 mm. in diameter), associated with pyritic replacement of adjacent silty shale, and rare sand grade quartz (Pl. XXIc).

(b) Thin enriched zones consisting almost entirely of fish teeth, vertebrae, scale and other tiny bone fragments (Pl. XXIb).

Although these lithologies have not been recognized in all cores across the boundary, phosphatic sands or phosphate enriched lenticles appear to occur at or near the Mannville/Joli Fou contact over a wide area. Good examples are found from wells as widely separated as Community Petroleums Battleford No. 1 (Lsd. 3-2-46-16W3, 1401-1406 feet), Wilkie No. 2 (SE 11-6-40-19W3, 1980 feet) and Imperial McCarthy Coleman Masefield No. 1 (Lsd. 15-31-2-14W3, 3176 feet). Similarly two thin lenticles (2 cm. thick) of quartz sand occur between laminated argillaceous sediments (typical Joli Fou Formation) and irregularly contorted or disturbed siltstones (typical Pense Formation) at approximately 2325 feet in the Tidewater Cabri Crown No. 1 well (Lsd. 1-23-20-19W3).

Drill cuttings indicate that in two wells, namely Phillips Pete Noremac No. 1 (Lsd. 6-29-25-22W3) at approximately 2585 feet and Sohio Peter Wartime No. 1 (Lsd. 2-14-26-17W3) between 2300 and 2310 feet, iron-rich oolitic bodies occur at or near the Mannville/Joli Fou contact. The individual ooliths, often with quartz cores, are set in a clear sparry calcite matrix, and appear to consist of siderite in places altered to limonite or, more rarely, to pyrite.

Joli Fou Shale (Lower Part)

Although the underlying Mannville rocks form the basis for this study, adequate consideration of their nature and relationships presupposes an understanding of those sediments immediately above. Consequently a very brief summary of the characteristics of the lower portion of the Joli Fou Shale is included.

Fine-grained representatives of the Joli Fou formation cover the Mannville throughout the area with the exception of the north-eastern corner where sandstones of the Spinney Hill Member intervene. The formation is marked by overall low resistivity and spontaneous potential response, while included silty or sandy bands are generally recognizable on electric logs as small shoulders or occasionally as pronounced kicks.

Lithological variation is adequately summarized in the upper portion of figure 16. The dominant constituent of the formation is a dark medium gray to dark gray, very finely laminated, swelling clay, containing varying quantities of silt grade quartz and mica, with occasional fine to medium sand-grade glauconite. No clay mineral identifications were attempted during the course of the study. However, Chakravorty *et al.* (1964) in a discussion of the overlying Viking Formation in the Eureka Sand Pool (Township 31, Ranges 22 and 23W3) show that the 2 micron fraction of these sediments contains a substantial quantity of mixed-layered illite-montmorillonite minerals together with montmorillonite and minor illite, kaolinite and chlorite. In view of the great physical resemblance (swelling properties when wet, and so on) of these and the Joli Fou clays the constitution of the latter is probably similar.

Sedimentary structures typical of the Joli Fou Formation are illustrated in Fig. 17. The granular clastic constituents are generally separated into very thin laminae, or low amplitude cross-laminated lenticles. The bases of the latter often exhibit well-preserved hieroglyphs resembling those previously described from the Pense Formation. In some examples a form of microflute casts is apparent. Low-amplitude, irregular, erosion surfaces are frequent *cf.* that of the silt lenticle in Fig. 17E. Occasional micro-faulting of lenticles (*cf.* Fig. 17G) without deformation of successive clay laminae suggests some degree of early cohesion of the fine silt.

Fine, crenulated, sandstone dikelets (Fig. 17B, D) are seen in bedding plane section (*cf.* Pl. XIXd) as irregular or sinuous cracks in clay, resembling closely the syneresis cracks of White (1961). Shelton (1962) figures very similar dikelets from the Lower Cretaceous of North Dakota. Occasional downward-tapering thicker cracks, up to 1 cm. wide, *e.g.*, Fig. 17A, resemble more typical mud or suncracks and may more reasonably be related to temporary desiccation.

Faunal activity is reflected by the frequent shell debris (often concentrated in thin coquinitic lenses, 2 to 3 cm. thick), *Inoceramus* fragments and prisms, a recognizable microfauna (of the *Haplophragmoides gigas* zone), scattered fish teeth, vertebrae and scales, and the frequent hieroglyphs which seem most probably attributable to the impact of shell or bone fragments on the cohesive clay substrate (see Pl. XXII). Horizontal or sub-horizontal silt- or fine sand-filled tubules (*cf.* Fig. 17F) occur within the lower portions of the formation, particularly near the Mannville-Joli Fou Transition Beds.

Spinney Hill Member

The distribution, thickness, and lithology of this member have been adequately summarized by Edwards (1960). Typical log characteristics are illustrated in Figs. 7 and 15. In the rocks here attributed to this member, fine to coarse light gray sandstones, with or without calcite cement and with variable quantities of shell fragments, rare small phosphatic bodies, green quartz, and scattered glauconite appear to be more characteristic than is suggested by Edwards. The other important lithologies are glauconitic siltstone,

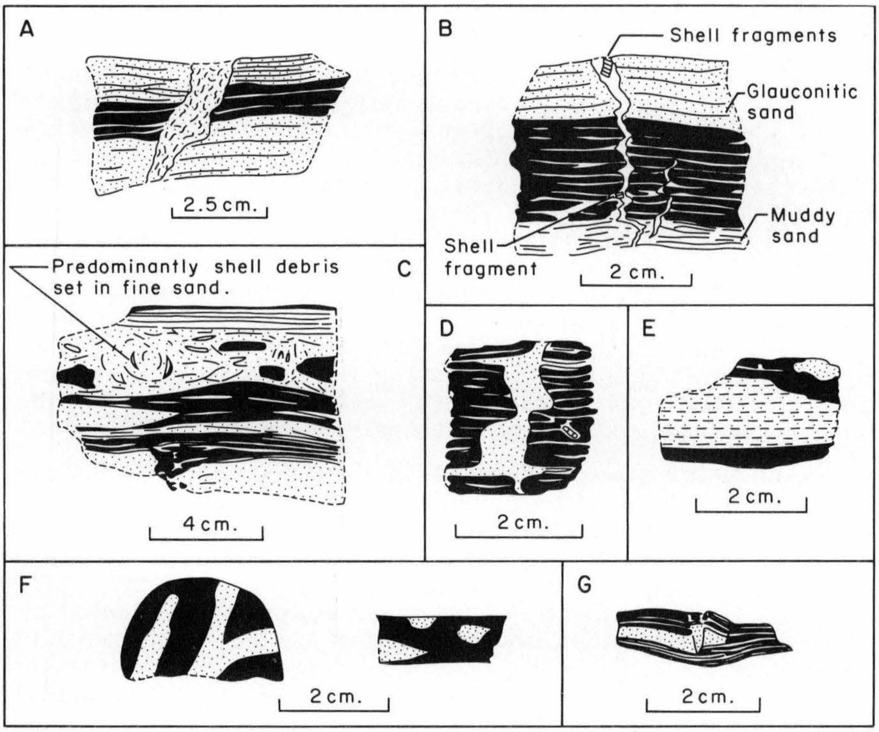

FIGURE 17

Fig: 17: Sedimentary Structures from the Lower Portion of the Joli Fou Formation within southwestern Saskatchewan.

A: Tapering sand-filled crack in laminated dark gray mudstone or shale and pale olive gray fine sand and/or siltstone; Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2217 feet.

B: Crenulated glauconitic fine sandstone dikelets with included shell fragments, in mudstone and glauconitic sandstone; Ceepee Dukesbury 13-18 well, 2222.5 feet.

C: Fine sandstone, shell debris, and mudstone fragments between finely laminated and occasionally disturbed mud and fine sandstone; Ceepee Dukesbury 13-18 well, 2235 feet.

D: Irregular, apparently thickened, sandstone dikelet associated with thin fine sand lenticles and scattered shell fragments—irregular boundaries suggest flowage; Tidewater Cabri Crown No. 1 well, Lsd. 1-23-20-19W3, approximately 2268 to 2270 feet.

E: Fine sandstone lenticles with internal low-angle cross-lamination. Irregular base due to filling of small erosional grooves, and uneven top resulting from subsequent erosion. Small horizontal sand-filled tubule in upper right; Tidewater Cabri Crown No. 1 well, 2280 feet.

F: Fine, sandstone-filled, sub-horizontal tubules, both bedding plane and vertical sections, Tidewater Cabri Crown No. 1 well, 2310 feet.

G: Fine sandstone lenticle, showing micro-faulting: Tidewater Cabri Crown No. 1 well, 3312 feet.

glauconite-bearing mudstones, and laminated siltstones and mudstone (*cf.* the characteristic Joli Fou lithology). Scattered faunal debris (for description see Edwards, 1960) occurs within the member.

The top of the Mannville group, where overlain by Spinney Hill sediments, is difficult to pick in core. Occasionally disturbed, originally finely-laminated, sediments resembling those of the Pense Formation occur, but more commonly mixed lithologies similar to those of the Continental Facies appear to underlie the cleaner or more glauconitic sands here considered to be Spinney Hill. In cores the contact can rarely be placed more precisely than within two or three feet, while on logs accuracy of greater than plus or minus 10 feet is unlikely.

VI

SEDIMENTATION

INTRODUCTION

In the preceding sections a complex sequence of lithologies has been described. An accurate assessment of their development presupposes a detailed knowledge of the structural history of the area. However, the lack of adequate markers (lithologic or faunal) precludes any discussion with such a basis. Hence in the following review, the factors considered environmentally significant for each descriptive sub-unit are listed where possible, and an appropriate sedimentologic model is constructed. On the basis of the observed macro-relationships a sedimentational history is summarized below.

Summary

An erosional period (presumably post-Jurassic) was followed by a period of intense weathering during which time a residual mantle developed on the exhumed Mississippian landscape (the original Jurassic subcrop is unlikely to have extended beyond the present Mississippian edge in this portion of Saskatchewan). The development of a drainage system on this pre-Mannville land surface was coupled with the redistribution and reworking of part of the mantle, the formation of which probably continued through Mannville times until local ground water fluctuations ceased: *i.e.*, until active Mannville sedimentation reached any particular area. To the north of the main Mississippian escarpment as now seen, thin fans or sheets of reworked residual material accumulated prior to Mannville time, while smaller quantities were supplied subsequently.

The pre-Cretaceous land surface appears to have been lowest to the north and in early Mannville times marine sedimentation commenced to the north of the studied area. Depending on the sediment supply, prevailing currents, and the irregular topography on the Devonian outcrops; shore sands, bars, and probably associated lagoonal deposits accumulated along the margins of this sea. As the sea transgressed southward, diachronous basal sands were deposited. Whether or not similar sandy sediments accumulated in the lower lying parts of the region between the Jurassic and Mississippian edges is at present unknown. However, the lack of well-developed demonstrably marine sediments in the Lower Mannville beds of southern Alberta (*cf.* Glaister, 1959) suggests that this is unlikely, although the homotaxial quartz sands of both the latter area and northern Montana may possibly have originated in a manner analagous to that suggested here.

There followed a period of active, continental, dominantly fluvial sedimentation, during the course of which, deposits of channels and associated flood plains completed the filling of the irregularities in the pre-Mannville landscape. Local streams helped to distribute fractions of the residual cover and other pre-existing lithologies, but the major effect was one of filling and mantling. The mineralogy of the constituent sands indicates an ultimate source to the west in the site of the present-day Rocky Mountains.

Shallow-water, probably marginal marine, sedimentation followed, but was apparently active over only that part of the area within the generally accepted limits of the Williston Basin. The nature of the contact between these shallow water sediments (Pense Formation) apparently deposited on a very broad shelf of low local relief, and the underlying continental sediments is obscure. However, the lack of recognisable deltaic features or exotic detritus such as that seen in the sediments below suggests that Pense development possibly coincided with, or immediately followed the cessation of active Cordilleran upwarping and sediment supply, or that some form of transgressive disconformity exists at this contact (*cf.* Fall River/Lakota relationships in the Black Hills, Waagé, 1959). At present the lithologic evidence is inconclusive.

A subsequent regional raising of sea-level resulted in the covering of these comparatively arenaceous sequences with clay-rich sediments of the Joli Fou Formation - beds relatively rich in faunal remains and probably of shallow marine origin. Although the detailed contact relationships of these and the underlying lithologies are uncertain, localized phosphatic and quartzose concentrations may represent lag deposits, indicating a sedimentation break.

The origin of quartzose sands of the Spinney Hill Member is still questionable, but possibly they represent some type of gigantic spit, with associated shallow water marine sediments.

Deville Formation

The salient features of the Deville Formation (described previously) which must be explained in any evaluation of its sedimentation or development are summarized below:

(a) position overlying Mississippian carbonates,

(b) breccio-conglomeratic and/or argillaceous sandy character,

(c) variable condition of included chert pebbles and cobbles,

(d) common occurrence of sphaerosiderite, and

(e) patchy development of red coloration.

The many occurrences of silicified Mississippian fossils within the included chert, the variable condition of this latter constituent, the overall lack of rounding of the clastic particles, and their extreme size range within a single core specimen indicates neither prolonged transport nor extensive sorting. Where extensively altered to a floury product (tripolite?), chert pebbles may be streaked or attenuated, suggesting that the movement responsible was not extreme and took place subsequent to the incorporation of the pebbles or cobbles. Clays similar to the greenish, swelling, argillaceous fraction of certain of these sediments have been seen as apparent weathering alteration products of dark gray Lower Bakken shales at the pre-Cretaceous unconformity beneath Transported Deville Facies in the Imperial Oil Enterprises McLeod Dodsland 6-33 well (Lsd. 6-33-32-20W3). The red coloration is apparently due to the presence of oxidised ferric constituents, the development of which has been attributed by many writers (*e.g.* Krynine 1949, 1950) to soil formation on well drained tropical uplands subject to alternating wet and dry seasons (for comprehensive summary see Van Houten 1961).

Weathered limestone terrains typically develop irregular karst topography characterized by deep solution cracks along joint planes, underground water courses, sink holes etc. In association with the development of such a topography residual material tends to concentrate both on flat surfaces between the enlarged joints and other depressions, and within the latter. The prolonged development of such a residuum, in association with the collapse of the underground caverns and the filling of "clints" and "grikes" within an originally cherty limestone, might be expected to result in a poorly sorted breccio-conglomeratic deposit with chert pebbles in various stages of decomposition (hence their variable permeability and coherence under stress) and rare terra rossa horizons. The origin of the sphaerosiderite cannot be enlarged upon at this point but is considered as a response to local conditions of groundwater chemistry, Eh and pH, coupled with the existence of nuclei favourable to the aggregation of secondary siderite.

The sandier Deville deposits are thought to have resulted from the prolonged weathering of limestone with a higher initial sand content. Thin section study indicates many chert grains within these sandstones, possibly suggesting greater contemporaneous or subsequent reworking than do the conglomerates discussed above.

Transported Deville Facies

The use of the term "transported" as previously mentioned, is based on the presence of these cherty sediments on chert-free Bakken or older rocks. The amount of primary residual material which developed on Devonian rocks is not known, but the occurrence of small crinoid ossicles similar to those within certain Big Valley sediments suggests that some of the pale green silty clays did accumulate in such a manner (*cf.* Fig. 4). Conversely, the presence of chert fragments of pebble and larger grades (occasionally containing recognizable Mississippian faunal relicts) indicates provenance from topographically higher sediments. The exact process of accumulation of these cherty lithologies can only be guessed, but the writer thinks it likely that they developed either as alluvial fans and stream deposits, or as rock slides proximal to steeper Mississippian slopes, *e.g.* the escarpment, outliers, or within the Coleville-Smiley valley. The majority of described modern fanglomerates occur in desert environments, although many, *e.g.*, those of the southwestern United States of America, may have developed under more pluvial Pleistocene conditions. However, the Transported Deville facies resembles the recent flood and slide deposits of the

White Mountains of California and Nevada as described and illustrated by Kesseli and Beaty (1959), or those of Arroyo Seco, California (Krumbein, 1942).

Woody material presumably would have been incorporated in the load of any stream flowing off the relatively steep Mississippian slopes. Hence the absence of carbonaceous detritus is puzzling, unless such light constituents were transported farther and concentrated to give thin coaly seams, presumably indistinguishable the load of any stream flowing off the relatively steep Mississippian residual debris was presumably transported both prior to and during the deposition of the main mass of continental sediments. Evidence for the latter statement is afforded by the chert pebbles in coaly sequences and lithic sandstones.

Lower Mannville Sandstones

The lack of indurated core, and hence of preserved sedimentary structures, precludes the ready establishment of the depositional environment of these sands. Their mineralogically-mature nature, good sorting, position marginal to the sub-cropping Devonian rocks and apparent diachronism suggest a shoreline or beach origin. If Friedman's (1962) techniques for the establishment of environment may be used on sediments irrespective of the source of the detritus (*i.e.*, irrespective of the nature of the initial grain population) then a mathematical consideration of the grain size distribution of these sediments may afford corroboration or otherwise of the hypothesis advanced here.

If the basal calcite-cemented sands in the Ceepee Dukesbury 13-18 well (Lsd. 13-18-34-21W3) are genetically related to the unindurated sediments farther north, then the occurrence in the former of low-angle cross-stratification strongly resembling that of beach sediments described by Thompson (1937), McKee (1957) and van Straaten (1959) may be significant. Without detailed knowledge of these basal sands their origin is tentatively assigned to a combination of barrier beach, bar or spit, or beach-dune environments. The preponderance of sediments from any one of these would presumably depend on conditions of local geography, sediment supply, prevailing currents and degree of preservation. The overall lack of calcareous detritus, such as shell fragments, emphasizes the hypothetical nature of such an environmental reconstruction.

Farther south, in the zone of relatively thick Mannville sediments to the north of the Jurassic edge, drill cuttings suggest that poorly indurated quartzose sands, sometimes containing sphaerosiderite, occur above the Deville Formation and beneath the "Cornfield Marker". Whether or not these represent Deville material reworked in a manner analagous to that suggested here is unknown.

If the section in the Ceepee Dukesbury No. 13-18 well be used as a criterion, these relatively pure quartzose sandstones grade upward into more argillaceous and carbonaceous sequences as summarized below:

(a) Fine grained quartzose sandstones with well preserved low-angle cross-lamination (often emphasized by carbon dust), rare contortions and occasional indications of burrowing and/or springpit activity.

(b) Fine and very fine grained quartzose sandstones exhibiting both accretionary ripple and scour-filling structures, together with frequent indications of organic reworking (Pls. V and VI).

(c) Finely laminated alternations of thin mud and silt lenses with internal structures attributable to erosion, accretion, shrinkage, compaction, and organic disturbance — varying quantities of very fine carbonaceous detritus (Pl. VII).

(d) Rare very thin coals or carbonaceous shales.

In each of the above groupings certain physical mechanisms are indicated. Similarly the observed characteristics resemble those described from environmentally-restricted Recent sediments. Those of group (a) suggest repetitive accretion and erosion of fine sand on low gradient slopes, with some movement of entrained water, together with some faunal activity. The carbon dust suggests a readily available source of carbonaceous detritus, but does not necessarily indicate repeated desiccation with subsequent carbon concentration on the sediment surface. Small carbonaceous grains when waterlogged rarely float, and, although their low specific gravity enables them to be easily moved by wave activity, they behave in manner very similar to that of other heavier clastic particles. The low-angle cross-lamination and shallowly-inclined erosion planes resemble those described from modern beach sediments by Thompson (1937) and McKee (1957). Many recent studies have verified the findings of these workers and examples of high angle cross-strata from beach or bar environments such as described by Hoyt (1962) are generally recognized to be atypical. Contorted bedding of various types, particularly pseudonodular has been described by several writers from modern beaches, *e.g.* Macar (1951), Stewart (1956).

The original accretionary structures within group (b) sediments were apparently subject to penecontemporaneous mechanical and organic disturbance. On the basis of comparison with published descriptions these internal structures cannot be said to typify any particular environment.

Sediments resembling in many respects those of group (c) have been figured in studies of Recent tidal flats (*e.g.* Hantzschel, 1936; van Straaten 1954, 1959; Reineck 1961) while similar features have also been seen from material accumulating in a variety of shallow water environments such as delta bays, and lagoons (van Straaten, 1959) or lakes (*e.g.* Blackwelder, 1930). The main inferences drawn are that the sediments (1) accumulated in relatively shallow wave-affected water which achieved some separation of hydrodynamically different constituents, (2) may have been subject to desiccation, and (3) were reworked to some extent by burrowing organisms, the degree presumably dependent on the local rate of sediment accumulation. Again, very finely divided carbonaceous material appears to have been readily available, a fact emphasised by the sporadic occurrence of the thin coals and carbonaceous shales.

In the writer's opinion the synthesis which most reasonably explains the association of these various lithologies is that of beach or bar (group (a) and associated lagoon, (groups (b), (c) and possibly (d), with or without asociated tidal flats (groups (b) and (c)). The unusual feature is the lack of recognisable shelly detritus or visible microfauna. (No microfaunal separations were, however, attempted on this material). The general lack of secondary cement (calcite occasionally occurs) may indicate leaching of any comparatively soluble initial constituents. If in fact these sediments do represent beach, bar and lagoon environments then their lateral equivalents to the north might be expected to be more argillaceous and possibly fossiliferous. The marine Cummings Member of the Vermilion and Lloydminster areas may represent such an equivalent.

Continental Facies

The reasons for considering the constituent lithologies of this facies as having accumulated in a broad, flat-lying, warm temperate to subtropical, alluvial plain have been summarized (Maycock, 1964, pp. 163-66), a synopsis of which treatment is included here. An account of the origin of these sediments should explain:

(a) With regard to the dominantly argillaceous lithologies:

- (i) Heterogeneity of the succession as indicated by core studies and by lack of easy correlation between adjacent wells.
- (ii) Lignites, and carbonaceous shales or mudstones.
- (iii) Carbonaceous rootlets within a variety of lithologies.
- (iv) Frequent detrital carbon, often as large fragments.
- (v) Existence of both well-laminated and unlaminated ("homogenized") fine-grained sediments.
- (vi) Lack of identified marine macro- and microfauna.

(b) With regard to the lithic sandstones:

- (i) Lack of lateral continuity.
- (ii) Scale, form, and orientation of cross-lamination.
- (iii) Frequent detrital carbon, often as large fragments.
- (iv) Occasional conglomerates.
- (v) Textural and mineralogical immaturity.

The reasons for discounting wooded coastal areas with chenier ridges and/or fringing barrier islands or delta tops as being the possible parent environments have been summarized previously (Maycock 1964, p. 164). Stated briefly, the lack of identifiable marine or brackish water macro- or microfauna within the fine sediments, coupled with the textural and mineralogical immaturity of the sands, and their overall dissimilarity to sediments described from modern low-relief coasts (see *e.g.* Bryne *et. al.*, 1959; Miller 1953, 1962; Scruton, 1960) form the basis of the argument. On the other hand the nature of the sequence corresponds well with that of described alluvial or flood plain sediments, a comprehensive summary of which has been recently published by Allen (1964).

Allen (*op. cit.* p. 166) after Happ *et al.* (1940, p. 22) considers a heterogeneous assemblage of alluvial sediments as classifiable amongst five genetic types *viz*:

(1) Vertical accretion deposits (levee and backswamp).
(2) Channel-fill deposits.
(3) Crevasse-splay deposits.
(4) Lateral accretion deposits (point bar and channel bar).
(5) Channel-lag deposits.

Allen (*op. cit.* Fig. 4 and Table 1) illustrates the idealised spatial relationships of these various groups, and summarizes their lithologic character, geometry, and typical sedimentary structure associations. The characteristics of these groups and their origins, as postulated by Allen with reference to Devonian sequences in the United Kingdom, accord closely with those described for the Mannville Group (Maycock, 1964, pp. 164). The fine-grained lithologies are seen as vertical accretion deposits derived from suspended load sediment during overbank flooding of main channels. Dependent on the degree of subsequent colonization by plants the original fine lamination is either preserved or destroyed. The sideritic concretions resemble the calcareous and ferruginous nodules recently formed in the laminated and poorly-stratified sandy clays and silts with numerous soil-zones of the flood plain of the Brazos River, Texas (Bernard and Major, 1963). The thin interbeds of fine-grained lithic sandstone, often rippled and usually rich in "sawdust"-grade carbon, probably represent crevasse-splay or levee deposits (*cf.* Coleman *et al.* 1963).

The thicker lithic sandstone sequences, frequently cross-stratified, are readily referable to a lateral accretion origin, presumably due to bed-load accumulation as point and channel bars. Such features as the nature of the cross-stratification (set size, set contacts, etc.) its preferred orientation (where studied), the general tendency for sequences to increase in grain size downwards, and the entrained carbon fragments, resemble those described and illustrated from modern point-bar sediments (*e.g.* Frazier and Osanik 1961; Lane 1962, and Marms *et al.* 1963). The generally accepted view that much bed load in rivers is transported as ripples and/or dunes of different dimensions (see Kindle 1917, Sundborg, 1956; Simons and Richardson, 1960, 1961, 1962 for typical accounts and summaries), and that the resulting accretionary deposits are cross-bedded (see *e.g.* McDowell, 1960; Jopling 1962; Allen 1963; Potter and Pettijohn, 1963 Chap. 4) accords well with the relationships observed.

Certain of the conglomerates consisting of sedimentary pebbles (*e.g.* Pl. VIII) may represent channel lag deposits, as may some of the polymictic varieties from the Battrum area.

The mineralogic and textural immaturity of those sediments has been explained (Maycock, 1964, p. 166) on the basis of relatively rapid transport with little or no reworking, together with "matrix" formation by the flowage and coalescence of fine-grained clastic aggregates (*e.g.* very fine-grained rock fragments) in the manner suggested in 1959 by Mellon for Blairmore sediments in the foothills of Alberta (*cf.* Krynine, 1951; Cummins, 1962).

Comparison with previous petrographic work indicates that the ultimate source of much of the lithic sandstone lay in the region of the present day Rocky Mountains (*cf.* Glaister, 1959; Williams *et al.*, 1962, Rapson, 1962, 1964).

Within the framework outlined certain localities include sequences of apparently unusual nature as discussed below.

(1) Eatonia Locale (T25, R25W3)

The Cornfield marker bed (Fig. 7) acquires stratigraphic character here. On the basis of the fine-grained argillaceous and carbonaceous drill cuttings recovered from this poorly-resistive bed of low spontaneous potential a vertical accretionary origin is suggested. The sediments most probably accumulated in a large, long-lived lake associated with shallow swampy areas. Presumably the local relationships of lake and swamps varied considerably through time.

(2) Lemsford Locale

In several wells in this district thick, poorly indurated, quartz sands, as indicated by poor quality drill cuttings, appear to be banked against the Jurassic escarpment. The sands (see Fig. 18) are apparently laterally equivalent to typical sediments of the Continental Facies. Quartz grains are frequently bound together by subspherical siderite aggregates, covered by thin films of limonitic, haematitic and possible goethitic material and/or have apparently undergone secondary enlargement (development of crystal faces etc.).

The uncomplicated mineralogy of these sediments distinguishes them from the lithic sandstones of the Continental Facies, and while they more closely resemble the Roseray sands (Middle Vanguard) as developed in the Battrum area, their greater thickness and apparent lack of any immediate correlation with lithologies to the south indicate otherwise. The origin of these sands is unknown; possibly they represent products of the pre-Mannville post-Jurassic erosional period. If so, they might have been partially reworked by meandering rivers and reconcentrated against the Jurassic edge by lateral accretionary processes.

(3) Battrum Locale

Although no detailed study of field areas was attempted during the course of this work, representative wells from the constituent fields were examined and their lithologic characteristics noted. In the course of the examination of several cores within the Battrum Area one fact became apparent, namely that it is virtually impossible to distinguish Roseray sands from overlying Mannville sediments on the basis of electric logs alone. This is most notable in areas where the sequence is heavily oil stained. Hence, the validity of any detailed structure contour map on the top of the Roseray, unless based on abundant core evidence, is open to question.

The brief study indicates that within this area at least, sediments of the Cantuar Formation or Continental Facies are lithologically distinguishable from the Roseray sand, and that a variety of mutual relations exist. These characteristics are summarized below (see also Figs. 14 and 19).

Roseray sand: As used here and by the majority of geologists working in the Battrum area, the term denotes a sand-body, of probable Middle Vanguard age, underlying the Cantuar Formation or Continental Facies, and which is frequently separated from the subjacent Vanguard shales by a thin oxidised layer. The lower contact is readily observable on electric logs due to the marked drop in both resistivity and spontaneous potential, but the upper boundary (see Fig. 19) is more obscure. Lithologically the unit is divisible into three types *viz*:

(a) Quartzose sandstone with white floury matrix.

(b) Very pale olive-gray or yellowish to cream silty claystone, with or without fine sand.

(c) A basal calcareous and/or argillaceous sandstone, intimately associated with pale green mudstone.

Within the basal calcareous or argillaceous sediments calcite is irregularly distributed either as small spherules (up to 5 mm. diameter) or as larger irregular masses (up to 4 cm. diameter) over which the clay-rich fraction appears to have draped (see Pl. XXIII). Ripple structures and disturbed lamination, comparable with that of the Pense lithology, are occasionally encountered (*e.g.* in the Mobil Woodley Sinclair Battrum 21-14B well, Lsd. 14-21-18-17W3 at 2940 feet). The pale green clay, which swells when wet, frequently includes sand-filled tubules (presumably burrows) in association with very narrow sinuous track-like lineaments (see Pl. XXIVb). As in the other argillaceous members of the Roseray, sphaerosiderite is common.

The white quartzose sands (often stained dark brown by oil) are usually fine to fine-medium grained, although thin pebble or granule-rich horizons occur. The sands commonly exhibit fine, horizontal to very low angle laminations. The clay-rich rocks of type (b) are irregularly distributed within the white sands either as thin (1 to 3 cm.) lenticles or lenses, thin beds (rarely over 2 feet thick), or disaggregated angular fragments reaching several centimetres in length. Relatively impermeable, and as a result rarely stained, they are particularly noticeable in oil-impregnated sequences. Finely laminated, they in places show segregation of the siltier grades into very low amplitude, internally cross-stratified lenticles (see Pl. XXV). Sphaerosiderite is common (Pls. XXIVa and XXVI) and may be altered to pyrite.

The overlying Cretaceous sediments most frequently belong to the Continental Facies although basal Pense sediments directly overlie the Roseray. The lower Cretaceous rocks are always easily distinguishable from the Roseray sand in the absence of heavy oil-staining. Characteristically continental sediments here consist of greenish-gray, cross-stratified, lithic, often carbonaceous sandstones of channel or lateral accretionary origin, together with gently rippled or finely laminated, occasionally sandy, fine-grained lithologies probably from levees and/or backswamps. More argillaceous sequences (commonly dark greenish-gray with varying detrital carbon content) probably represent accretionary deposits in cut-off channels, while basal conglomerates are likely to be lag-concentrates. Various features of these conglomerates are illustrated by Pls. XXVIII and XXIX. Teeth, bone fragments, pyritised wood, and relatively soft sedimentary pebbles are associated with rarer rounded chert pebbles. While the former are probably of local derivation the latter are presumably multicyclic in origin, and possibly derive from the underlying Roseray sand, and ultimately from the Mississippian limestone.

Where Cretaceous channels into the Roseray sand are filled by sand the oil-staining most frequently affects rocks of both ages, in some areas effectively increasing the thickness of the pay zone (Pl. XXVII). Where filled by argillaceous sediments, however, staining rarely extends beyond the originally-white Roseray sand body.

In summary, the porous and permeable Roseray sand, typified by very high quartz content and white floury matrix, with associated pale-coloured, poorly-permeable, argillaceous lithologies often bearing sphaerosiderite, lies immediately beneath the Continental Facies (or rarely the Pense Formation) in the Battrum area. In places it has been either partially or completely removed by channelling. These channels are filled with lithologically distinct, darker sands and clays of the Continental Facies. Whereas the Roseray is laterally extensive and exhibits good porosity and permeability, the continental sediments are much more varied in both lithology and physical properties. Neither the presence of sand-filled channels nor the exact top of the Roseray sand is readily discernible on electric logs. The base, however, with irregular calcite bodies, green clay, abundant sand-filled burrow structures and typified by high resistivity can apparently be traced throughout the Battrum area.

Pense Formation

The Pense Formation and its probable lithogenetic equivalents (the Fall River Formation of North Dakota, the First Cat Creek sandstone of Montana) have generally been ascribed to a marine, probably transgressive origin (see *e.g.* Roussell, 1956; Wulf, 1962; and Price, 1963). A similar environment is favoured here, although the evidence for such a hypothesis is by no means conclusive. In any reconstruction of the depositional environment the following features must be explained:

(a) Overall fine grain.
(b) Wide extent of certain beds, particularly shales or mudstones, as indicated by electric logs.
(c) Initial finely laminated nature of much of the sediment.
(d) Destruction of initial structure in the majority of fine-grained rocks.
(e) Scattered laminated fine-grained sandstones.
(f) Lack of faunal remains, other than scattered fish debris.
(g) Presence of tiny borings and hieroglyphs.
(h) Scattered carbon, apparently enriched towards the base.
(i) Nature of base (both abrupt and gradational).
(j) Nature of top (interdigitation with Joli Fou Formation and/or phosphatic sand concentrations).

The overall fineness of grain suggests that either the currents responsible for distribution or deposition of the sediments were not unduly strong or that coarse material was unavailable. The initial delicate lamination of the more argillaceous members probably reflects hydrodynamic separation by repetitive currents (wave action). A sequence 4 cm. thick, containing four superimposed siltstone lenticles set in mud from 2390 feet in the Tidewater Cabri Crown No. 1 well (Lsd. 1-23-20-19W3) shows cross-lamination within the lenticles inclined alternately in opposing directions, suggesting currents of variable direction as responsible for their development. Higher in the well, at 2384 feet undisturbed ripple structures are capped conformably by fine clay laminae, suggesting gentle current-affected settling of the finest constituents onto earlier accretionary structures. Such features characterise many modern tidal sediments, in which structures formed by relatively strong currents during intermediate tidal stages are capped by clays settling from slack water at high tide.

The most noticeable overall aspect of the fine sediments is their mixed, "disturbed", nature. This appears to be referable to the interaction of several processes *viz*:

(i) Penecontemporaneous erosion and occasional fragmentation.

(ii) Load casting of silts and fine sands within clays.

(iii) Mixture by a variety of burrowing organisms.

(iv) Possible thixotropic effects (*cf*. Boswell, 1961) aggravated by the burrowing action.

The fine sandstones, characterised by low angle cross-lamination, may represent small beaches on bars, or the internal structures of low bars. Their fine lamination is reminiscent of that caused by repetitive breaking-wave action on fine sands today (*cf*. McKee, 1957). Miller (1962) on the basis of a comparison with Recent sediments of the Atlantic coast of the United States has postulated the existence of barrier bars in the Fall River Formation of Wyoming, a unit lithologically similar to the Pense Formation. The relative absence of "burrows" in the Pense Formation is not readily explained unless the organisms responsible preferred to feed in the more argillaceous material.

The lack of fauna is also striking. One might expect fossil remains from such a widely distributed, organically reworked, postulated shallow-marine, sequence. Presumably the reworking helped to destroy the tests of microfauna and larger shells. Some of the fine sandstones are cemented by calcite indicating the availability of calcium carbonate at some time during their lithification. Many of the small hieroglyphs marking the bases of well preserved, fine sandstone lenticles (*e.g*. Pl. XIX) were probably formed by the impact of tiny, hard, possibly angular fragments on the cohesive clay substratum. Woody particles might be capable of this but shell fragments because of their harder edges, are thought more likely to be the agents responsible. Similar features occur within the Joli Fou Formation where well preserved shell material is common. In the writer's opinion the lack of fossil debris is explained by a combination of its comminution by burrowing organisms within the finer sediments and its penecontemporaneous or subsequent leaching. Solution of carbonate by organic acids forming *in situ* is reported as occurring in modern intertidal sediments of coastal Holland by van Straaten (1954, p. 55). The original porosity of the sandstones presumably facilitated the solution of any primary carbonate.

With respect to the basal contact, highly disturbed, sometimes carbonaceous, argillaceous silts and/or fine sands may grade downwards into the Continental Facies. Else the contact may be sharp with the Pense Formation overlying the Continental Facies (Pl. XXX) or in the Battrum locale the Roseray sands (Pl. XXXI). Sphaerosiderite may occur immediately beneath the contact but is not conspicuous in the cores available. In this characteristic the boundary differs from that of the Fall River/Lakota Formations in the Black Hills (Waagé, 1959, p. 55), the South Platte Formation Lytle/sandstone in the Colorado Front Range (Waagé, 1958, p. 75), the Rusty Beds/Cloverly Formation in the Bighorn Mountains (MacClintock, 1957, p. 45) and the Fall River/Lakota sandstones of North Dakota (Wulf, 1962, p. 1379). In all the above examples the formations bear a lithogenetic similarity to the Pense and Continental Facies respectively. For instance, in a discussion of the possible regional significance of spherulites occurring beneath the Rusty Beds/Cloverly Formation contact on the eastern flank of the Bighorn Mountains, Eicher (1962, p. 77) states "the spherulites in all these areas formed in like environments, proximal to the transgressing Lower Cretaceous Sea. Thus they are believed to mark a contact of regional extent, upon which lie rocks deposited during or after the marine transgression."

If this contact is of regional extent, then the suggestion of Cumming and Francis (1957) that the "lower plant-bearing bed" represents a widespread soil may be valid. However, the present work suggests that, in general, the beds of this horizon are less carbonaceous than the example they described. Where the contact is very sharp the resemblance to a soil is also lost (*cf.* rootlet-bearing beds in the underlying Continental Facies within which carbon filaments extend downwards to disturb initial lamination beneath). The exact nature of this boundary merits more detailed investigation. In view of the dissimilarity of the sediments below and above, and the lack of exotic lithic detritus or the development of recognizable deltaic deposits within the Pense, no sedimentologic connection between the two stratal types can be readily postulated. Hence, in accordance with the view generally held, the contact is here considered a low-angle transgressive disconformity.

Joli Fou Formation

Mannville—Joli Fou Transition Beds

The lack of good core precludes any detailed discussion of the Mannville—Joli Fou Transition beds. The interdigitation of typical Pense and Joli Fou lithologies suggests continuous sedimentation and fluctuating conditions. Conversely the coarse quartz grains and phosphatic bodies may have been locally concentrated during a hiatus.

This paradox may represent different developmental phases of a low-relief surface during a period of comparative stillstand. Although definitive evidence of emergence is lacking, parts of a gently undulating offshore or wide tidal flat area may have been partially uncovered. If so, organic activity (burrowing, boring etc.) may have characterised submerged areas, while shoreline processes (beach and/or bar formation, local erosion, development of lag phosphate concentrates) may have affected irregularly distributed emergent portions. The ultimate origin of the sand is unknown but is possibly derived from a northeasterly source similar to that indicated by the geometry of the Spinney Hill member (Edwards, 1960). Some planation may have taken place on the contact in view of the overstep of the Pense Formation. Conclusions regarding this topic must await further detailed core study. Modern analogues of such apparently widespread shallow marine sequences are difficult to find and the scale of the sedimentological processes involved is not easily grasped.

Spinney Hill Member

The lower beds of the Joli Fou Formation appear to have been deposited in a shallow sea, fairly distant from any major source of detritus. The overall fine-grained nature of the formation, the thin, internally rippled, fine sand or silt lenticles, often with tiny erosive toolmarks on their lower surfaces, low amplitude erosion surfaces, and thin coquinitic lenses consisting of shell fragments of the comparatively thick-shelled *Inoceramus*, suggest repetitive current action or periodic agitation, probably in a silt- or sand-deficient environment. Allen (1959, p. 292) attributes comparable features to such a mechanism in reference to the lithologically very similar Hastings Beds of southeastern England. The narrow compacted siltstone dikelets (*cf.* Shelton 1962) need not necessarily indicate desiccation, as dewatering and partial shrinkage of clays may take place underwater (White 1961). Examples such as this are described and illustrated from the modern intertidal sediments of coastal Holland by van Straaten (1954). Glaister (1959, p. 637) suggests that correlative Lower Colorado sediments in Southern Alberta were laid down in a shallow sea, "probably never more than 120 feet deep". Eicher (1960), on the other hand, considers that the *Haplophragmoides gigas* fauna in Northern Wyoming was probably deposited in relatively deep water, on the basis of the purity of the clay-sized fraction of the Thermopolis shale there. Moberly (1962, p. 100) suggests that distance from shoreline and the accumulation and weathering of pyroclastic ash or dust in a shallow sea of abnormal (*i.e.* reduced) salinity are equally plausible explanation. Curry (1962, p. 120) likewise considers the Skull Creek sea in central Wyoming as shallow, and indicates possible ecologic similarities with the present day Baltic.

The origin of the Spinney Hill Member cannot be discussed in detail here. On the basis of the elongate nature of this essentially sandy sequence, Edwards (1960) has considered it possibly deltaic. The member might equally well have developed as a very large spit in the shallow Joli Fou sea, the main body of the spit being close to or above wave base, while the fringing, finer, more glauconitic beds may have formed in deeper water, possibly under slightly reducing conditions (*cf.* Cloud, 1955).

VII

AGE AND CORRELATION

The problem of dating the Mannville Group in southwestern Saskatchewan is intimately bound up with that of its correlation, as with the exception of a lone unidentified ostracod, no faunal remains were collected, nor was the nature of the floral debris examined. In this account an attempt is made to establish correlation with similar lithogenetic units outside the studied area where their age has been estimated. The problem is however compounded by disagreement of results from microfloral studies on the one hand and faunal studies on the other.

An approximation of a minimum age for these sediments may be reached *via* a study of the overlying Joli Fou shales. The *Haplophragmoides gigas* Cushman fauna recognized throughout Saskatchewan by Wickenden (1941) has been considered coextensive with the Joli Fou Formation (Stelck *et al.* 1956, p. 17) and has been correlated with the Upper Shale Member of the Thermopolis Shale in Wyoming (Eicher 1960; 1962, p. 79) where, as in Alberta, it is associated with *Inoceramus comancheanus* Cragin, a form which is also noted from the lower Thermopolis shale near Cloverly, Wyoming (Moberly, 1960, p. 1150). Cobban *et al.* placed both the Kiowa Shale of Kansas and the Skull Creek Shale of the Black Hills in the *Inoceramus comancheanus* zone. Similarly Curry (1962, p. 120) has correlated the Skull Creek shale Member of the Thermopolis formation in Wyoming with the Duck Creek Formation of the basal Washita Group of the Gulf coast, and, on the basis of the association there of *I. comancheanus* with *Pervinquieria kiliani* (Lasswitz) (Adkins, 1928, p. 17), equates it with subzone 12 of the Gault of England (considered basal Upper Albian).

Stelck *et al.* (1956) and Stelck (1958) on the other hand consider the *Haplophragmoides gigas* zone in the Joli Fou Formation of Alberta as Upper Middle Albian whereas Cobban and Reeside (1960, Fig. 3) indicate a basal Upper Albian age (*cf.* Curry, 1962, p. 120). *Inoceramus comancheanus* in Alberta occurs in the Joli Fou Formation above the Cadotte sandstone in which Stelck *et al.* (1956)) note the presence of *Gastroplites* cf. *cantianus* Spath and equate it (*op. cit.*, p. 17) with a similar species from subzone 11 of the English Gault. Reeside and Cobban (1960, p. 28) state that "there seems little doubt that *Gastroplites* is to be placed no higher than the top of the Middle Albian". However, on p. 31, Table 3, the same authors indicate that the overlying *I. comancheanus* zone (suggested by them as basal Upper Albian on Fig. 3) is Middle Albian, probably equivalent to the *Gastroplites* zone in northeastern British Columbia. Thus the uppermost Mannville sediments cannot be considered any younger than upper Middle Albian.

The work of Glaister (1959), Mellon and Wall (1961, 1963), and Williams (1963) would appear to have established distinct petrologic zones within the Alberta Blairmore/Mannville sediments. The Middle Blairmore of the Foothills is petrographically similar to the Upper Mannville of the southern Alberta Plains (Glaister *op. cit.* p. 633) and, in turn to the Grand Rapids Formation of central Alberta (Williams *op. cit.* p. 360). Within these sequences the sandstones are rich in feldspar, volcanic and other fine grained rock fragments, and chert. They contain minor quantities of metamorphic and questionably granophyric detritus. The Lower Mannville of the southern plains (Glaister, 1959) resembles the Lower Blairmore of the southern Foothills (Mellon and Wall, 1961, 1963) and the Ellerslie Member of the McMurray Formation of the Edmonton area in being richer in siliceous detritus, and poorer in volcanic rock fragments and feldspar. Maycock (1964, pp. 159-163, 166) demonstrates the petrographic similarity of the sandstones of the Continental Facies in southwestern Saskatchewan with those of the Middle Blairmore/Upper Mannville/Grand Rapids association, and suggests (following Rapson, 1962) that they derive from essentially the same source to the west. The petrographic work appears to bear out the regional conclusions reached by Mellon and Wall (1961, 1963, p. 408) who, in common with Glaister and Williams (*cf.* also McLearn, 1944; Rudkin, 1961) visualize "the Middle Blairmore — Upper Mannville succession as a single sedimentary complex that can be divided into several laterally interfingering facies reflecting a progressive change from a non-marine fluviatile depositional environment in the south to shoreline and marine environment in the north". This lithogenetic correlation is summarized diagrammatically in Fig. 20.

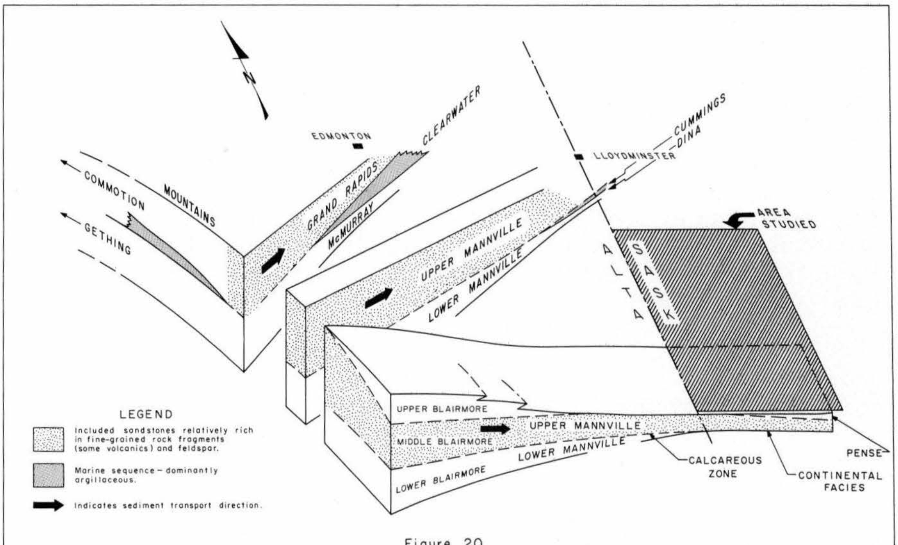

Figure 20

Fig. 20: Diagrammatic cross-sections of the Blairmore-Mannville sediments in western Canada.

Thus, the age of the Continental Facies may be approximated by correlation with the Grand Rapids Formation which overlies, and is in part transitional with, the Clearwater Formation in the Edmonton district. Mellon and Wall (1956) correlate the Clearwater fauna of the Lower Athabasca district with the upper portion of that in the Cummings Shale of the Vermilion area (see Nauss, 1947), recognising in both *Haplophragmoides gigas minor*. This fauna is dated Middle Albian, because it overlies the *Trochammina mcmurrayensis* zone at the top of the McMurray Formation in the Athabasca area. The latter zone is considered approximately equivalent to *Lemuroceras* cf. *indicum* thought to represent the *mamillatum* zone at the base of the Middle Albian of the Gault of England (an equation apparently based on the occurrence of the genus *Lemuroceras* in the *mamillatum* subzone of Madagascar). Mellon, Wall, and Stelck (1963), add the association of the Clearwater fauna with pelecypods characteristic of the *Subarcthoplites mcconnelli* zone in the Belcourt Ridge area of northeastern British Columbia as further corroboration of a Middle Albian age.

As indicated above, the McMurray Formation (a lower Mannville correlative) is considered Albian in age by Mellon and Wall (1956). Loranger (1951) views the Calcareous zone (Glaister's (1959) lithologic member separating the Upper and Lower Mannville) as Aptian. Pocock (1962) on the basis of the microflora considers the Lower Blairmore-McMurray sequence as Neocomian. The most recent microfloral work (Singh, 1964) terms the Grand Rapids Formation Middle Albian and the Calcareous Member as early Middle Albian. The same author thinks that the basal beds of the Mannville Group in east-central Alberta are probably no older than Barremian and that the overlying Ellerslie Member is probably Aptian, an age which agrees with the dating of the basal Lower Mannville of southern Alberta by Glaister (1959, Fig. 3) and that of the Kootenai of Montana (Cobban *et al.* 1959, Fig. 3). Until microfloral or faunal work is carried into western Saskatchewan the lowest beds in the "Undifferentiated Mannville" group are viewed as most probably Aptian and/or Lower Albian in age, and the Continental Facies and Pense Formation Middle Albian.

Previous mention has been made of the existence of units within the Lower Cretaceous of the northern United States, lithogenetically similar to the Pense Formation and Continental Facies respectively. The table below (essentially based on MacKenzie and Ryan, 1962, Fig. 2) summarizes some of these occurrences, and the local nomenclature.

TABLE 1

Area	Variable Continental Sequence	Marginal Marine, Coastal, or Tidal Flat Sequence	Author
Central Montana	Kootenai Formation	First Cat Creek Sandstone	Based on Lammers (1939)
North Dakota	Lakota Formation	Fall River Formation	Wulf (1962)
Beartooth Mountains	Kootenai Formation	Greybull Sandstone	Richards (1957)
Bighorn Basin	Cloverly Formation	Rusty Beds	Eicher (1960)
Bighorn Basin	Cloverly Formation	Sykes Mountain Formation	Moberly (1960)
Central Wyoming	Lakota Formation	Fall River Formation	Curry (1960)
Black Hills	Lakota Formation	Fall River Formation	Waagé (1959)
Northern Front Range Colorado Foothills	Lytle	Plainview	MacKenzie (1963)

That these various comparable sequences may be dissimilar in age has been stressed by many previous writers (*e.g.* MacKenzie and Ryan, 1962; Moberly, 1960, 1962). The occurrence of *Protelliptio douglassi* in the basal foot of the Fall River Formation in the northwestern Black Hills (Waagé 1959, p. 63) suggests an Aptian age for these sediments (cf. Stanton, 1903, p. 195), as compared with the Middle Albian age here favoured for the Pense Formation.

VIII
STRUCTURE

In view of the lack of a good structural datum within the Mannville throughout the studied area the top of the Transition Beds was used in the construction of a contour map even although this top is not easily picked throughout the area and is likely to be confused with sandstone tongues of the Spinney Hill Member in the northeast. The nature of this datum thus precludes accurate structural evaluation of the area, hence the adoption of a 25 foot contour interval in Fig. 21. The structure on the Mannville Group essentially reflects that of the underlying pre-Cretaceous erosion surface, a characteristic also true of the overlying Viking Formation (Jones, 1961, Figs. 5, 6, and 7) in the south-central portion of the area studied in this report. The overall southerly dip is complicated by irregularly trending amoeboid folds (Twenhofel, 1939, p. 533, *cf*. Jones, 1961, p. 22) and within the southeast and east of the area by steepened dips. The dominant structural features, as understood by the writer, are summarized in Figs. 21 and 22.

The nature of the source information precludes detailed evaluation of the structural history. On the basis of Christopher's (1964) exacting consideration of the structure of the Jurassic to the south, a complex series of relatively minor structural events may have occurred during Mannville time. However, a brief resumé of the major events is appended below. Prior to Mannville deposition a gentle southerly tilt, exposure and subaerial erosion, resulted in the younging of the subcropping strata in that direction. Filling and mantling of the irregular pre-Cretaceous landscape followed. In the southeast of the area somewhat accelerated sinking aided in the deposition of the Pense Formation. Compaction of the Mannville sequence, presumably during and after its deposition, produced a duplication of pre-Cretaceous structure. Accelerated sinking of certain portions of the area, *e.g.*, the Rosetown "Low", probably took place both during and after Mannville time, whereas in other areas, for example the southeast, the dips appear to have steepened during post-Cretaceous time.

The regional southerly tilt (Laramide) represents the last major event. Minor warping and uplifting may have taken place but if so are inconspicuous on the structural maps of the Bakken (Kents, 1959). Whether or not the low areas can readily be related to the removal of salt from the Middle Devonian Prairie Evaporite by solution processes has not been investigated in this study. However, the location of the Rosetown "Low" with respect to a "channel" in said salt beds strongly suggests that such salt removal has been an important factor (*cf*. Christopher, 1961).

IX
ECONOMIC CONSIDERATIONS

The origin of the oil within the Mannville Group or those sequences subcropping beneath is at present unknown. In the

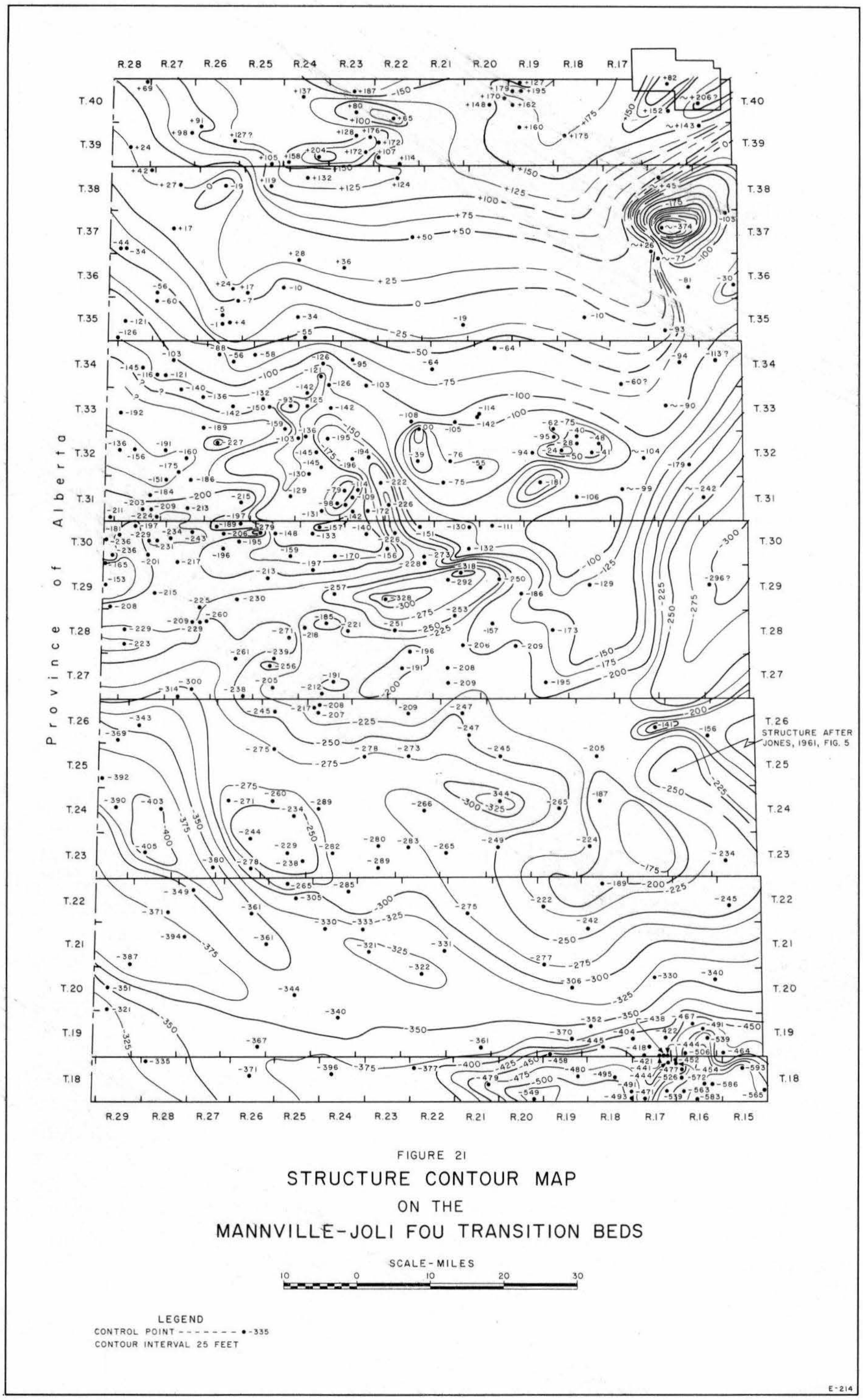

Fig. 21: Structure contour map on the Mannville-Joli Fou Transition beds.

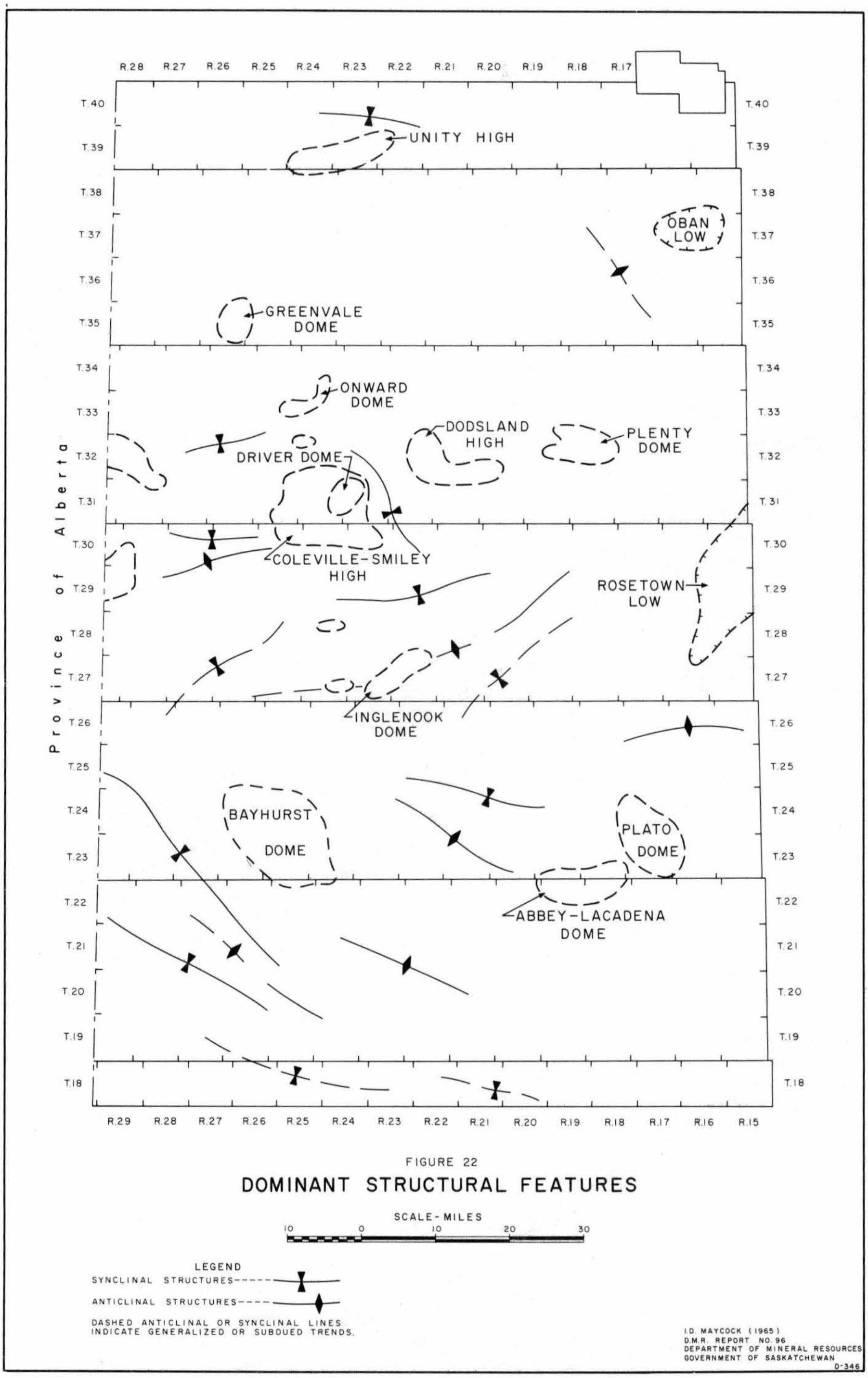

Fig. 22: Dominant structural features.

Lloydminster area to the north heavy oil is produced in quantity from sands within the Mannville Group, whereas in the studied area production is obtained from subcropping Bakken and Roseray sandstones of Mississippian-Devonian and Jurassic ages respectively. In both localities the oil is produced from the sands very close to their subcrop limits, suggesting that if it originated within the host sequences the age of up-dip migration must have been relatively late, otherwise the hydrocarbons would have been lost by surface seeps in the post-Mississippian, pre-Cretaceous hiatuses. The possibility of a regional hydrodynamic gradient forcing oil downdip to concentrate in favourable subcropping reservoirs (both of the occurrences described are on or within northward facing subcrop escarpments) may provide an explanation, although the regional mechanism responsible for such a situation is not readily understood. The basal sands abutting against Devonian carbonates within the northern portion of the area present rather similar oil traps, and are frequently heavily stained (as in the subcropping Devonian in places, D. Kent, pers. comm.). On the other hand, significant oilshows have not been found in the Lower Cretaceous sands associated with the Jurassic subcrop in the Lemsford and related areas. Adequate cores are unavailable and increased exploration to determine the extent, structure and local stratigraphy of these sands seems warranted, especially in view of the productive Battrum Field farther east along the subcrop margin. The occurrence of "indigenous" oil within fresh water sedimentary suites has been reviewed by Hedberg (1964) who cites several examples from the literature. Thus although the unconformity appears at present to effectively govern the limits of subcropping fields an ultimately Cretaceous origin for these hydrocarbons cannot be ruled out.

The uncertainty about the origin of Mannville or associated oil, together with the patchy occurrence of oil-staining in the cores studied, prompt a brief discussion of the various types of sand reservoirs likely to be found within the respective sub-units recognized herein.

Spinney Hill Member: In the extreme northeast of the area, where the sand content of the Spinney Hill Member exceeds 50 per cent (Fig. 7), the sand bodies appear laterally continuous and dominantly consist of coarse sand, locally poorly indurated, with good porosity and permeability. Both the latter characteristics are lost where the sands are cemented by calcite, a characteristic which is easily recognized by high resistivity response. Some well-developed structures for example the Oban "Low" (fig. 22), occur within this locality, and in view of the reservoir possibilities afforded by the sands the region may repay more active investigation.

Pense Formation: Although the majority of the sand bodies within the Pense Formation in the southeastern portion of the area are thin and exhibit different degrees of cementation, their probable genesis as some type of bar suggests a degree of lateral extension, and linearity, together with a comparatively simple electric log correlation. As the northern and western limits of the Pense Formation are approached these sand bodies attenuate, hence exploration for likely reservoirs within the Pense Formation should preferably be concentrated in areas where the unit is relatively thick, *i.e.,* over 40 feet.

Continental Facies: The lithic sandstones within this facies have been ascribed to a fluvial, probably lateral accretionary origin as point or channel bars. Hence, they are likely to be of variable thickness, sinuous, and in all probability discontinuous. Where cemented by calcite, the extensive replacement of both matrix and detrital constituents generally reduces the porosity to near zero, whereas in the calcite-poor specimens the swelling nature of the interstitial clay minerals might be expected to effectively limit the permeability. In the northeastern portion of the area the greater overall sand content of the facies suggests that laterally more widespread sand bodies occur (possibly reflecting change to a more deltaic or coastal environment). The existence of apparently extensive shale horizons in the Wilkie area facilitates intra-facies correlation, and thereby evaluation of the local structure. In the south-central part of the area the Cornfield Marker bed affords similar local control. The argillaceous and/or carbonaceous nature of the marker as indicated by cuttings suggest that it might form an effective local seal. Several well-developed sands occur between depths of 2870 and 2930 feet in Phillips Husky Dankin No. 1 well (Lsd. 11-20-24-24W3). Although when tested this particular sand body gave only salt water, the possibility exists that the interval was tested low. Basal Mannville sands possibly related to structure and/or topography on the pre-Cretaceous surface in this area may repay increased efforts at evaluation.

Basal Sands: In the northern portion of the area, well developed, if patchy basal sands overlie the Devonian. These sediments constitute the best of the Lower Cretaceous reservoirs, producing heavy oil in the Eyehill area. With respect to similar sands from the Bellshill district of east-central Alberta, Rudolph (1959) maintains that such sands may be recognized by seismic methods. They exceed other Mannville sandy bodies in both thickness and lateral extent; are permeable and porous, and occur near the basal unconformity, a contact associated with much of the heavy oil occurrences. These sands are distributed throughout the northern part of the area and further exploration to find such thick beach, beach-dune, or associated bar sediments would seem warranted. A probably associated bar-lagoon sequence has been described from the Dukesbury 13-18 well (Lsd. 13-18-35-21W3) and here again some of the sands are heavily oil stained.

Deville Formation and Transported Deville Facies: The thickness, lithology, and distribution of both deposits are extremely variable, hence accurate prospecting for hydrocarbons within these sediments presupposes considerable local control. Marginal producers from reservoirs in the Transported Deville Facies are to be expected in areas proximal to known oil fields in pre-Cretaceous strata, *e.g.*, the Coleville-Smiley Bakken accumulations. Others may occur round or in association with the irregular Mississippian scarp or its associated outliers in the northwest. Here questionable Cretaceous sands obscure the relationships between the Mannville, Bakken and Transported Deville sediments, and unless Mississippian limestone outliers can be located with certainty from seismic evidence palaeogeographic controls will be difficult to obtain.

Patchy distribution of favourable porosity and permeability coupled with irregular heavy oil-staining within the Deville Formation suggest the existence of small economic hydrocarbon concentrations. The location of such, or consideration of their possible relationship with unweathered Mississippian "highs" is, however, beyond the scope of this paper.

In summary, emphasis must be placed on the existence of heavy oil close to the sub-Cretaceous unconformity, some favourable sand accumulations, and the recent advances in recovery techniques, all of which suggest that further exploration of the Mannville or immediately contiguous strata may prove economically advantageous.

X

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APPENDIX

Well Data

1. Sections (1 square mile) in the western provinces of Canada are numbered 1 to 36 beginning in the southeastern corner of a given township (36 square miles). Legal subdivisions (L.s.d.) are numbered 1 to 16 starting from the southeastern corner of a section. Range-lines in the area of this paper are numbered to the west from the third medidian.

2. K.B. means kelly bushing or a datum on the drilling rig about 12 feet above the ground from which depths in the well are measured on electric and gamma ray-neutron logs as correlated with sample and core data.

			Depth in feet below K.B.					
Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
B.A. Wickham 7-12	7-12-18-15W3	2472	3037	3271				
Tidewater Pennant Crown No. 4-28	4-28-18-15W3	2446	3039	3300 ?				
Tidewater Battrum Crown No. 1	2- 6-19-15W3	2426	2890	3035				
Tidewater Tuberose Crown No. 1	16-17-22-15W3	2039	2284					
Tidewater Sanctuary Crown No. 1	16-17-23-15W3	1977	2211	2451				
Socony Sohio Ridpath 19-11	11-19-29-15W3	2117	2413 ?		2647			
Imperial Tidewater Rosetown 12-19-31-15	12-19-31-15W3	2098	2340 ?				2925 ?	
Tidewater Triumph Crown No. 1	8-21-34-15W3	2356	2436 ?				2774	
Eldoran Christie Biggar No. 2	7-12-36-15W3	2174	2204/2216				2484	
Allenbee Peak & Assoc. Canso Curtshill No. 1	4-35-37-15W3	2222	2325					
Red Pheasant No. 1	NW 5-32-39-15W3	2325	2182 ?				2528 ?	
Red Pheasant No. 2	11-17-40-15W3	2383	2177/2202				2565 ?	
Socony Vacuum Pennant 4-6	6- 4-18-16W3	2470	3053	3234				
Socony Vacuum Pennant 7-12	12- 7-18-16W3	2353	2916	3050				
Imperial Pennant No. 1	4-14-18-16W3	2459	3045	3326 ?				
Socony Vacuum Pennant 15-2	2-15-18-16W3	2460	3032	3185				
Francana E. Battrum 6-19-18-16	6-19-18-16W3	2342	2868					
Francana E. Battrum 4-30-18-16	4-30-18-16W3	2337	2828					
Francana Super Battrum 12-30-18-16	12-30-18-16W3	2321	2798	2966				
Tidewater N Battrum Crown 1B-5	SW1B-5-19-16W3	2296	2802	2970				
Tidewater N Battrum Crown 12B-14	12-14-19-16W3	2302	2841	2998				
B. A. Zeller 13-23-19-16	13-23-19-16W3	2228	2719	2872				
Tidewater North Battrum Crown 1B-28	1-28-19-16W3	2261	2728	2867 ?				
Tidewater Matador Crown #1	4-25-20-16W3	2247	2587	2830				
Sohio Standard Elrose #1	14-12-26-16W3	2059	2215 ?		2485			
Tidewater Herschel #2	15-11-32-16W3	2209	2388/2404				2782	
Tidewater Goldburg Crown #1	13-22-33-16W3	2391	2481				2850 ?	
Tidewater Duperow Crown #2	4-22-34-16W3	2360	2454-61				2809 ?	
Tidewater Duperow Crown #1	SW 4- 9-35-16W3	2291	2300 ?				2630 ?	
Albercan Crown Castlewood #1	4-12-36-16W3	2135	2216/2233				2542	
Liberal Canada Southern #3	2-32-36-16W3	2080	2157				2503 ?	
Liberal Canada Southern New Devon Skyline #2	SW 3- 6-37-16W3	2104	2078 ?				2440 ?	
Liberal Canada Southern New Devon Skyline #1	1-20-37-16W3	2131	2503					
Allenby Peak & Assoc. Canada Southern Salter #1	1-29-38-16W3	2185	2140				2503	
Eagle Hills #1	8-10-40-16W3	2398	2246/2264				2570	
Woodley Sinclair Battrum X-6-5	6- 5-18-17W3	2299	2770/2778	2916				
SMPS Battrum 2-35-18-17	2-35-18-17W3	2304	2748	2858				Roseray present
Francana E. Battrum 6-36-18-17	6-36-18-17W3	2306	2756	2888				Roseray present
Francana E. Battrum 2-36-18-17	2-36-18-17W3	2306	2760	2895				Roseray present
Altair et al Battrum 10-36-18-17	10-36-18-17W3	2298	2750	2927				
Tidewater N Battrum Crown #1B-1	1- 1-19-17W3	2290	2737	2903				Questionable Roseray not picked

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
			Depth in feet below K.B.					
Pure Battrum 3-1-19-17	3- 1-19-17W3	2286	2730	2840				Roseray present
Pure Battrum 1-2-19-17	1- 2-19-17W3	2311	2749	2900				Probable Roseray
Tidewater N Battrum Crown 4-2	4- 2-19-17W3	2400	2832	3018				Probably no Roseray
Tidewater North Battrum Crown 4-4	4- 4-19-17W3	2270	2691	2942				
Amax et al. Cabri 8-9	8- 9-19-17W3	2237	2655	2940				
Socony Mobil N Battrum 10-14-19-17	10-14-19-17W3	2360	2782	2897				Roseray present
Tidewater Cabri Crown #2	8-18-19-17W3	2164	2568	2840				
Socony Mobil Cabri 4-27-20-17	4-27-20-17W3	2108	2438/2457					
Sohio Wartime #1	SW 2-14-26-17W3	2071	2212		2421	2474		
Tidewater Herschel Crown #1	13-29-31-17W3	2021	2120 ?		2266-72	2310		
Royalite Glenellen 4-14	4-14-32-17W3	2206	2310		2531	2560		
Royalite Ruthilda #1	15- 5-34-17W3	2410	2470				2812	
McColl Frontenac Mosquito 6-34	6-34-40-16W3	2372	2290				2660	
Mobil Oil Woodley Sinclair Cabri X-7-1	7- 1-18-18W3	2329	2822	3016 ?				
A.P. Conn Tenn Battrum 3-13-18-18	3-13-18-18W3	2321	2812	3074				
Socony Woodley Southern Cabri No. 22-1	1-22-18-18W3	2347	2842	3117				
Ceepee Cabri 1-30	1-30-19-18W3	2152	2504	2790				
Tidewater Abbey Crown #2	1-31-21-18W3	1920	2162/2178		2583	2644		
Tidewater Lacadena Crown #1	16-33-22-18W3	1931	2120/2136	2408				Mannville top very diffuse
Tidewater Tyner #1	4-29-23-18W3	2008	2232/2253		2590 ?	2616		
Tidewater Imperial Plato Crown #5	16-28-24-18W3	2005	2192/2220		2503	2563		
Tidewater Imperial Plato Crown #4	10-28-25-18W3	2171	2376/2400		2817 ?	2922		
Sohio Standard Fiske #1	14-21-29-18W3	2383	2522/2550		2780	2848		
Royalite Stranrair #1	7-20-31-18W3	2408	2514		2677	2710		
Royalite Plenty #4	6-22-32-18W3	2093	2134		2226	2253		
Royalite Glenellen 9-26	9-26-32-18W3	2052	2100		2232	2248		
Royalite Plenty 3-29	3-29-32-18W3	2023	2051		2165	2177		
Royalite Plenty #3	7-32-32-18W3	2020	2060		?	2181 ?		
Hudson's Bay Whiteshore Lake #1	16-22-35-18W3	2303	2313 ?				2652 ?	Mannville top Very diffuse. Basal sand 2595-2652.
C.A.G.A. Canada Southern Moose Park No. 1	2-29-39-18W3	2195	2020 ± 15				2370	
Mobil Oil Woodley Southern Sanford 23-15	15-23-18-19W3	2222	2702	2960				
Tidewater South Shackleton Crown #1	1- 5-19-19W3	2312	2770	2995				
Seaboard Tidewater Cabri Crown 3-9	3- 9-19-18W3	2158.5	2604	2868				
Seaboard Tidewater Cabri Crown 14-14	14-14-19-19W3	2252	2622/2633	2900 ?				
Tidewater Cabri Crown #1	1-23-20-19W3	2021	2327	2502				Mannville top becoming irregular
Imperial Miry Creek 3-6-21-19	3- 6-21-19W3	2191	2468/2481	2696				Jurassic top very doubtful
Tidewater Abbey Crown #1	3-18-22-19W3	2096	2317/2332	2594 ?				

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
		Depth in feet below K.B.						
Tidewater Plato Crown #1	9-22-24-19W3	2071	2336	2622				
Mobil Oil Penkill X1-16	1-16-27-19W3	2245	2440 ?		2724	2830	2858	Upper portion Devill very rich in sphaerosiderite
Sohio Standard D'Arcy #1	NE¼-22-28-19W3	2354	2527		2773	2868		
Royalite Plenty #1	11-33-31-19W3	2101	2208		2396	2416		
Royalite Plenty 12-20	12-20-32-19W3	2047	2141				2362	Coal immediately overlying Middle Bakken
Royalite Plenty #2	7-24-32-19W3	1965	1989		2060 ?	2093		
Royalite Plenty 4-35	4-35-32-19W3	1993	2088				2302	Middle Bakken sanc with a basal Mannville sand?
Royalite Plenty 4-2	4-2-33-19W3	1998	2060				2265	Devonian probably Lower Bakken shale
Lloyd Petroleum Drillers Wilkie #1	SW10-32-39-19W3	2170	2010 ?					Probably bottoms ir basal Manville sand
Campana Wilkie 16-18	16-18-40-19W3	2214	2052 ± 15				2465	Basal sand 2450-65.
Calvan Charter Sapphire Wilkie No. 1	1-29-40-19W3	2215	2020 ?				2433	
Campana Wilkie #8-30	8-30-40-19W3	2197	2018 ?				2404	
Campana Wilkie #8-32	8-32-40-19W3	2217	2090				2470	
Homestead Mobil Roadene 10-2	10- 2-18-20W3	2313	2862	3090				Lithic sandstone at 3060.
Phillips Husky Fairdale #1	8-29-23-20W3	2128	2378/2392		2689	2718		Possible thin cornfield marker 2614-2620.
Phillips Husky Guth #1	11-29-24-20W3	2117	2461/2475		2830	2918 ?		Possible cornfield marker 2759-2795.
Phillips Husky Eston #1	7-29-25-20W3	2242	2487/2503		2797	2856		Cornfield marker 2778-2792
Phillips Husky McMorran #1	6-11-28-20W3	2377	2586/2600		2930	2950		Mississippian only 20 to 30′ thick
Husky Phillips Brock No. 1	13-29-28-20W3	2351	2508/		2769	2853		Lower pick of Tran sition Zone absent
Imperial Netherhill 10-13-29-20	10-13-29-20W3	2364	2550		2843	2865 ?		
Phillips Netherhill #1	7-28-29-20W3	2291	2541/2553				2830	Probably Middle Bak ken sand at 2830.
Phillips Braeburn #1	2-32-30-20W3	2298	2409/2424		2646	2668		
Fina et al Dodsland 11-7-32-20	11- 7-32-20W3	2279	2334/2352		2486	2495		
Royalite Druid #1	9-18-33-20W3	2136	2278				2622	
Royalite Druid 60-18	15-18-33-20W3	2139	2236/2253				2548	
Royalite Kelfield #1	8-33-34-20W3	2036	2100	2495			2428 ?	
Calvan Cateter Sapphire Wilkie 8-15	8-15-40-20W3	2198	2050 ?				2510	

Well Name	Location	K.B.	Depth in feet below K.B. Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
Campana Wilkie 8-24	8-24-40-20W3	2201	2031				2432	
Socony Woodley Southern West Roadene 14-7	7-14-18-21W3	2390	2869/2880	3057				
Shell Federated Baxterville A2-11	2-11-19-21W3	2281	2642/2654	2760				
Dome Provo Lancer 10-9	10- 9-22-21W3	2218	2493/2510	2723-33				Samples at base of Mannville poor
Phillips Husky Owen A#1	6-19-23-21W3	2253	2518/2535		2740 ?	2787		Samples very poor
Imperial Centrefield 13-10-26-21	13-10-26-21W3	2258	2505/2519		2854	2988		Cornfield marker 2773-2800
Phillips Husky Dome Snipe #1	7-28-26-21W3	2283	2530/2547		2890/2925	2987		Cornfield marker 2818-2840
Imperial Netherhill 11-17	11-17-27-21W3	2318	2527/2543		2816	2952		Mississippian approx. 14' thick
Phillips Husky Mylrea #1	10-29-27-21W3	2366	2574/2587		2818	2900 ?		
Husky Phillips Newburg #2	10-11-28-21W3	2331	2537/2551		2786	2860/2905		Samples indicate Miss. at 2905, while log indicates 2860
Imperial Netherhill 10-33-28-21	10-33-28-21W3	2391	2644/2660		2895 ?	2974		Mississippian 12-14' thick
Phillips Husky Sage #1	11-29-29-21W3	2283	2575		2888	2913		No good Transition development
Pan American Netherhill 9-34	9-34-29-21W3	2250	2568-2578				2981 ?	Possibly Transported Deville at 2923.
Phillips Husky Denehurst #1	1-14-30-21W3	2236	2368/2378		2600 ?	2663 ?		
Canpet Sarcee Kiyiu Lake 10-35	10-35-30-21W3	2214	2344/2358		2583	2598		
Canada Southern New Superior et al Cook Lake 11-32	11-32-31-21W3	2285	2360		2460	2503		
Superior Dodsland #1	9-16-32-21W3	2312	2387		2438	2476		
Royalite Millerdale 6-10	6-10-33-21W3	2230	2335				2490	Probably overlying Middle Bakken sand
Ceepee Dukesbury 13-18	13-18-34-21W3	2195	2259				2504/2510	
Ceepee Broadacres 13-13	13-13-35-21W3	2219	2238				2513	
Socony Vacuum North Bestville 30-3	3-30-18-22W3	2382	2759	2992				Mannville base difficult to establish
Shell Federated Lancer A1-33	1-33-20-22W3	2350	2672/2684	2830 ?				
Socony Sohio Lancer 13-8	8-13-21-22W3	2259	2590/2603	2730 ?				
Phillips Husky Riverfront #1	1-29-23-22W3	2397	2680/2692		3000	3047		
Imperial Athenian 16-22-24-22	16-22-24-22W3	2385	2651/2667		3037	3219		Cornfield Marker 2930-53. Mississippian very thin
Phillips Husky Noremac #1	6-29-25-22W3	2253	2526/2543		2870	2957		Cornfield Marker 2797-2831
Husky Phillips Madison #1	4-29-26-22W3	2278	2487/2504		2782	2878		Basal Mannville sand 2744-2782

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Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
			Depth in feet below K.B.					
Phillips Sandgren #1	7-29-27-22W3	2336	2527/2540		2750	2873		
Phillips Inglenook #1	1- 4-28-22W3	2406	2602/2613		2856	2918		
Phillips Husky Turvin #1	6-19-28-22W3	2310	2561/2573		2797	2845		
Pan American Netherhill Crown 4-2	4- 2-30-22W3	2304	2532				2877	Probably underlain by Middle Bakken sand
Husky Phillips Kiyiu #1	13-11-30-22W3	2302	2525		2860		2884	Chert and coal in samples above chert-rock sequence over probable Middle Bakken
Phillips Husky Beaufield #1	6-30-30-22W3	2314	2540				Not penetrated	
Canpet Sarcee Avon Hill 6-34	6-34-30-22W3	2240	2391		None obvious	2590		
Superior et al Coleville #1	6-18-31-22W3	2262	2488 ?				Not penetrated	
Canada Southern et al Beaufield 10-14	10-14-32-22W3	2276	2315 ?		2372	2440		
Canada Southern et al Ermine 9-2	9- 2-33-22W3	2243	2243		2300	2321		
Superior Dodsland #4	16-10-33-22W3	2245	2353				2502	
Zenith Crown #1	8-14-37-22W3	2100	2050 ?				2363	
Bata No. 14	14-28-38-22W3	1884	1760				2080	
Bata No. 13	10- 3-39-22W3	1874	1760				2107/2137	
Imperial Muddy Lake No. 1	11- 7-39-22W3	1897	1790				2130	
Bata No. 11	4-19-39-22W3	2063	1891				2226	Basal sand at 2212
Bata Petroleum D1-20	1-20-39-22W3	2083	1955				2272	
Prairie Salt #1	13- 4-40-22W3	2060	1990 ?				2300	
Rio Prado Lemsford 4-17	4-17-21-23W3	2299	2620/2630	2793				Basal Mannville sand 2694-2793 according to log
Shell Sceptre #1	14-31-21-23W3	2262	2595/2607	2760				If Jurassic coal then Jurassic top at 2700
Phillips Lemsford No. 1	8-10-23-23W3	2281	2570/2593		2970	3034		Clean quartz sands in basal Mannville
Phillips Husky River "A" #1	11-27-23-23W3	2379	2659/2672		3030			Cornfield Marker 2899-2937
Phillips Husky Dome Tuscola #1	7-29-25-23W3	2254	2532/2548		2853	2990		Cornfield Marker 2785-2827
Phillips Husky Verendrye #1	1-19-28-23W3	2250	2471/2482		2660			
Kewanee Kindersley 6-12	6-12-29-23W3	2273	2601/2610		2950	2700	2961	Cherty sediments overlie Middle Bakken

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
		Depth in feet below K.B.						
Imperial St. Eloi 16-13-30-23W3	16-13-30-23W3	2312	2468		2640	2682		
Phillips St. Eloi #1	13-28-30-23W3	2293	2433		2622	2680		
Royalite Coleville Unit 10-8-31-23	10- 8-31-23W3	2290	2432		2577	2634		
Canada Southern Eureka 4-10	4-10-31-23W3	2260	2432		2610	2630		
Royalite C.S.C. 18-20	8-20-31-23W3	2300	2409		2521	2581		
Canada Southern Eureka No. 1	SW¼ 22-31-23W3	2282.7	2406/2414		2548	2607		
Royalite Canada Southern Coleville 54-28	14-28-31-23W3	2306	2420		2549	2562		
Royalite Coleville Unit 5-30-31-23	5-30-31-23W3	2350	2426		2460/70	2520		
Royalite Albercan Coleville 22-30	6-30-31-23W3	2350	2428		2498	2557		
Canpet Highwood Eureka 10-36	10-36-31-23W3	2283	2505		2550	2598		
Stanolind Imperial Beaufield "A" #1	14-17-32-23W3	2317	2514				2830/2840	
Canada Southern Imperial Kerrobert 11-3	11-3 34-23W3	2358	2461		2696	2738		
Albercan Crown 1-20-34-23	SE 1-20-34-23W3	2226	2321				2658	
Woods Paramount Tramping Lake Road Allowance S. Bdry 29-36-23	29-36-23W3	2337	2300				2560	
Bata #27	16-11-39-23W3	1989	1839				2170	
SPC Unity 5-14-39-23	5-14-39-23W3	1980	1820				2124	
SPC Unity 13-14	13-14-39-23W3	1944	1786				2075	
SPC Unity 15-14-39-23	15-14-39-23W3	1942	1770				2077	
Bata B5-22	5-22-39-23W3	2022	1882				2168	
Bata B3-24	3-24-39-23W3	1980	1804				Not penetrated	
Bata #21	2-27-39-23W3	2182	2054				2336	Basal Mannville sand at 2330
Bata #3	3-10-40-23W3	2130	2050				2342	No log available company picks
Superior Bata #1	5-27-40-23W3	2039	2054				2183	
Socony Woodley Southern Sandhills 20-4	4-20-18-24W3	2295	2691/2702	2840				
Stanolind Prelate Crown #1	9-34-19-24W3	2342	2683/2692	2809				
Shell Rio Tinto Sceptre #2	5-32-21-24W3	2297	2627/2640	2733				
Rio Prado Scenture 9-26	9-26-22-24W3	2231	2516/2530	2620				
Phillips Sceptre #1	1-22-23-24W3	2229	2511/2523		2717	2746 ?		
Phillips Husky Dankia #1	11-20-24-24W3	2283	2572/2586		3010	3077		
Husky Phillips Eatonia #A-1	4-29-26-24W3	2407	2614/2626		2878	None seen		
Husky Phillips Eatonia #A-2	9-29-26-24W3	2385	2592/2604				2865	
Husky Imperial Pinkham #1	1-31-26-24W3	2445	2662/2675		2930	3075		If present Mississippian very thin
Husky Phillips Eatonia #1	4-32-26-24W3	2444	2652/2675		2897	3065 ?		If present Mississippian very thin
Husky Phillips Eatonia B#1	2- 4-27-24W3	2402	2611/2624		2856	None seen		Possibly transported Deville
Husky Phillips Eatonia B-2	14- 4-27-24W3	2385	2597/2608		2850	None seen		

			Depth in feet below K.B.					
Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
Phillips Husky Glidden #1	7-14-27-24W3	2274	2463/2478		2695	2758		
Husky Phillips Fairmount No. 1	8-19-28-24W3	2282	2500/2515		2671	2712		
Phillips Husky Lynnhurst #1	9-27-28-24W3	2198	2383/2397		2595	2642		
Kewanee Kindersley 6-14	6-14-29-24W3	2256	2513/2524		2816	2846		Transported Deville on Middle Bakken sand
Phillips Husky Clover #1	13-32-29-24W3	2206	2403/2414		2588	2624		
Husky Phillips Awde #1	4-11-30-24W3	2260	2430		2616	2649		
Phillips Coleville Unit 12-29-30-24	12-29-30-24W3	2264	2397			2640		
Coleville Unit 10-33-30-24	10-33-30-24W3	2326	2483		2610	2718		
Royalite Canada Southern Coleville #6	7-10-31-24W3	2301	2432		2608	2643		
Royalite R.C.S.I.C. 27-13	NE 7-13-31-24W3	2342	2435		2546	2603		
Royalite General American Imperial Coleville 43-10	NE 10-13-31-24W3	2355	2453		2546 ?	2600		
Royalite General American Imperial Coleville 36-13	SW10-13-31-24W3	2347	2445		2557	2602		
Altair Harr-Marsh Buffalo 2-5	2- 5-32-24W3	2223	2353		2436	2482		
Canada Southern Buffalo Coulee 11-21	11-21-32-24W3	2288	2433					
Buffalo Coulee NE 3-31	NE 3-31-32-24W3	2370	2473		2613	2644	2591	
Canada Southern Buffalo Coulee #3	6-32-32-24W3	2347	2483				2650	
Stanolind Beaufield B-1	1-35-32-24W3	2327	2522				2925-30	
Pan American Onward 4-20	4-20-33-24W3	2319	2444				2610	
Canada Southern Imperial Ashford 6-23	6-23-33-24W3	2298	2440/2450				2788	
Spooner Street Lake 10-32	10-32-33-24W3	2275	2417				2667	
Canada Southern Onward NE 7-2	7- 2-34-24W3	2322	2448				2742	
Canada Southern Onward 7-10	7-10-34-24W3	2307	2420				2650	Samples not very helpful, indicate Mannville to 2700′
Royalite Onward 4-22	4-22-34-24W3	2246	2372				Not penetrated	
Strain, Atkinson and Woods Onward 16-4	16- 4-35-24W3	2232	2287				2530	Possibly Mannville sands overlying Middle Bakken sand
Woods Paramount Shallow Lake Rd. Allow North bdy 20-35-24W3	4-20-35-24W3	2219	2253				2514	
Woods Paramount Luseland Rd Allow West bdy 32-36-24W3	13-32-36-24W3	2286	2258				2520	Chert-rock interval with white soft sand stone 2430-2520
Ceepee Reward 4-28	4-28-38-24W3	2282	2150				2408	
Hudson's Bay Bata Denzil #4	16- 6-39-24W3	2268	2157				2445	
Wilrich Pete Trans Era #1	NE 16-11-39-24W3	2250	2097				2370	
Bata #12	5-21-40-24W3	1908	1771				2131	
Saskoil Leader #1	9-15-20-25W3	2287	2631/2643	2796				
Hudson's Bay Prelate 16-22-22-25	16-22-22-25W3	2184	2489/2502	2615				

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
			Depth in feet below K.B.					
Hudson's Bay Prelate 13-33-22-25	13-33-22-25W3	2207	2472/2486	2602				
Phillips Prelate #1	4-13-23-25W3	2237	2475/2489	2649				Apparent thick sandy sequence 2550-2649.
Phillips Husky Prelate #2	2-22-23-25W3	2184	2413/2425		2660	2700 ?		
Phillips Husky Lestwyn #1	11-14-24-25W3	2262	2496/2510		2696	2790		
Phillips Husky Quinney #1	7-29-24-25W3	2227	2487/2498		2856	2957		Thick sand 2755-2853
Imperial Cornfield 10-32-25-25	10-32-25-25W3	2387	2662/2675		2960	3100		Cornfield Marker 2894-2932
Phillips Kindersley LaPorte #1	16-29-26-25W3	2467	2712/2726		2984	3130-40		Cornfield Marker 2950-2984
Phillips Husky Warrier #1	11- 9-27-25W3	2538	2743/2754		3003	3140		Mississippian if present probably only 2' thick
Imperial Warrier 10-29-27-25	10-29-27-25W3	2526	2782/2794		3020/3030	3139		
Phillips Husky Pinkham #1	10-33-27-25W3	2520	2759/2770		2995	3108		
Phillips Husky Dome Fairmount #1	7-14-28-25W3	2289	2560/2572		2842	2861		
Kewanee Kindersley 11-29-29-25	11-29-29-25W3	2361	2574/2586		2795	2857		
Phillips Husky Ryerson #1	4-11-30-25W3	2353	2512/2521		2642	2702		
Phillips Husky Teo #1	2-28-30-25W3	2269.5	2418/2432		2562	2658		
Cabeen Exploration Whiteside 7-30	7-30-30-25W3	2330	2609/2619		2813 ?	2900 ?		
Albercan Coleville Unit #4-24-31-25	4-24-31-25W3	2261	2390		2530	2584		
Canada Southern Superb 10-2	10- 2-33-25W3	2351	2493				2652 ?	Upper Bakken possibly in Mannville at 2700.
Stanolind Imperial Beaufield C-1	1-21-33-25W3	2366	2516					
Stanolind Canso Superb #A-1	13-24-33-25W3	2327	2420		None seen	2533		Upper Bakken Shale at 2558.
Canso Superb 16-29	16-29-33-25W3	2394.5	2527				2870	Deville contains Crinoid fragments off-white sand, etc.
Canso Patrick 3-30	3-30-34-25W3	2434	2492			2620		
Merrill Shell West Luseland 4-6	4- 6-36-25W3	2299	2282		2392		2470	Transported or collapsed Deville? on Middle Bakken sand.
Wood Paramount Luseland Rd Allow East bdy 12-36-25W3	16-12-36-25W3	2263	2273				2480	
Hudson's Bay Canada Southern Denzil #3	16-22-38-25W3	2274	2155				2417	
Hudson's Bay Canada Southern Denzil #5	2- 2-39-25W3	2255	2150				2432	
Imperial Fox Valley 5-21-18-26	5-21-18-26W3	2404	2775/2784	2986				
Canadian Export Gas Fox Valley 13-11	13-11-19-26W3	2423	2790/2800	3045				
Saskoil Leader #2	7-24-21-26W3	2247	2608?/2619	2804 ?				

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
		Depth in feet below K.B.						
Saskoil Leader #3	5-10-22-26W3	2206	2567/2576	2740				
Phillips Husky Leader #1	13-11-23-26W3	2112	2390/2400	2520				
Phillips Husky Dungloe #1	8-35-23-26W3	2266	2510/2520		2765	2853		
Phillips Husky Gorefield #1	7-29-24-26W3	2304	2575/2586		2825	2886		
Phillips Husky Bailey #1	7- 2-27-26W3	2442	2680/2692		3041	3084		
Provo Pinkham #1-34	1-34-27-26W3	2374	2635/2646		2900	2945		
Phillips Husky Flaxcombe #1	8-10-29-26W3	2468	2698/2708		2926	2951		
Phillips Husky Cathy #1	11-17-30-26W3	2325	2521		2645	2715		
Husky Phillips Whiteside 11-22	11-22-30-26W3	2375	2570		2708	2751		
Phillips Husky Dewar #1	8-29-30-26W3	2304	2528		2760		2789	Middle Bakken sand beneath Mannville
Sturgeon and Assocs. Smiley #3	11-31-30-26W3	2386	2573		2771	2852		
Husky Phillips Dewar #15-34	15-34-30-26W3	2355	2552		2740	2784		
Canada Southern Dewar 6-14	6-14-31-26W3	2327	2542		2691	2740		
Canso Canadian Seaboard #6-29	6-29-32-26W3	2333	2560				2880	
J. L. Graham Major #1	5-22-33-26W3	2348	2490		None in core	2692 ?		
Stanolind Oil and Gas Canso Superb #B-1	16-22-34-26W3	2419	2475		None seen	2613		
Canada Southern Summit 7-29	7-29-34-26W3	2460	2548				2784	Apparently transported Deville 2778-92.
Albercan Calvan Greenvale #1	5-14-35-26W3	2436	2432				2657 ?	Possibly Transported Deville with oil stain 2632-52
Calvan Canada Southern et al 8-15	8-15-35-26W3	2440	2441				2678 ?	Thin Transported Deville overlying Middle Bakken?
Albercan Cr. #35-26 well #1	SW 2-22-35-26W3	2399	2404				2609	Deville lithology 2580-2609 over Middle Bakken sand
Calvan et al Hearshill 13-36	13-36-35-26W3	2353	2360		2500			
Mosbacher CHCTV Cactus Lake 10-11	10-11-36-26W3	2310.8	2287	2430	2463			
Hudson's Bay Canada Southern Denzil #2	16-22-38-26W3	2296	2315				2578	
Hudson's Bay Canada Southern Denzil #6	13-24-39-26W3	2211	2084				2370	
B. A. Eyehill Partington 2-31-39-26	2-31-39-26W3	2234	2143				2557	Basal sand 2492-2557
Baysel Mobil Okalta Canpet Leader 7-30	7-30-21-27W3	2339.5	2734		3053	3110		White sandstone sideritic cement, euhedral grains 3030-3042
Baysel Mobil Okalta Canpet Leader 11-29	11-29-22-27W3	2309	2658/2665	2923 ?				
Phillips Husky Westerham #1	4-12-23-27W3	2156	2536/2541		2758	2807		
Phillips Husky Mantario #1	1- 5-27-27W3	2281	2595		2847	2900		

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
			Depth in feet below K.B.					
Phillips Husky Eyre #1	6-10-27-27W3	2245	2545		2790	2845		
Husky Phillips Marengo #3	10-25-28-27W3	2499	2759		2960 ?	3040		
Phillips Husky Marengo #1	10-26-28-27W3	2461	2690		2890 ?	2980		
Husky Phillips Marengo #2	10-27-28-27W3	2354	2563			2847		Ostracod bearing argillaceous limestone at 2770
Phillips Husky Marengo 12-2	12- 2-29-27W3	2335	2560		2770 ?	2866		
Alminex Crystal #14-5	14- 5-30-27W3	2316	2533		2745	2828		Possibly repetitive sequence chert and sphaerosideritic sandstone at 2870
Alminex Crystal 7-19	7-19-30-27W3	2284	2518		2692	2708		
Alminex Crystal Smiley 6-27	6-27-30-27W3	2325	2568		2802	2846		
Canso Natural Gas Hoosier 1-10	1-10-31-27W3	2385	2598		2854		2924 ?	Conglomeratic Deville
Canso Natural Gas Hoosier 6-31	6-31-31-27W3	2371	2522		2612	2660		
Altair Harrington Marsh Antelope 10-34	10-34-31-27W3	2296	2480		None seen	2668		
Altair et al Antelope 7-4-32-27	7- 4-32-27W3	2327	2502		None seen	2707		
Canso P. W. Hilldale 13-15	13-15-32-27W3	2392	2552		2760 ?	2812 ?		Log suggests Mississippian at 2760, samples at 2812.
Canso Hilldale 7-19	7-19-32-27W3	2304	2495				2790/2800	Upper Bakken shale or Middle Bakken sand?
Canadian Seaboard Canso Oil Fusilier 7-1	7- 1-33-27W3	2403	2592				2873	Mississippian and carbon contributions to conglomerate on contact
Canso P. W. Major 1-25	1-25-33-27W3	2416	2552				2784	Some Mississippian chert fragments between 2760 and 82′
Canadian Seaboard Canso Oil Fusilier 10-33	10-33-33-27W3	2350	2490				2863	Coal and Chert fragments 2835-55
Canadian Seaboard Canso Fusilier 10-27	10- 7-34-27W3	2412	2533				2823	Basal Mannville sand with some chert 2783-2823.
Canadian Seaboard Canso Fusilier 10-20	10-20-34-27W3	2369	2472				2713 ?	Transported Deville 2672-80? Basal Mannville sand?
Sarcee Barryville 7-31	7-31-35-27W3	2570	2630		2815	2870		
Merrill-Shell Cactus Lake 4-6	4- 6-36-27W3	2441.6	2498		2716		2750	Presumably transported Deville

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
			Depth in feet below K.B.					
Royalite Albercan Denzil #1	15-21-37-27W3	2465	2448				2735	Green gray mudston and marls at base
Hudson Bay Canada Sthn Denzil #1	16-22-38-27W3	2452	2425				2769	Greenish marls an minor oxidised laye at base
B.A. Eyehill Ayrey 2-25-39-27W3	2-25-39-27W3	2247	2149				2576	Basal sand 2470-257
Mobil Oil North Richmond 31-1	1-31-18-28W3	2521	2856			3143		Chert above coal above Mississippian
Mobil Oil South Estuary 11-13	13-11-22-28W3	2318	2689		3030	Samples insuf- ficient		
Phillips Husky Coombe #1	16-21-23-28W3	2255	2660/2671		2980 ?	2990		
Phillips Husky Cabri #1	1-23-24-28W3	2317	2720		3000	3081		
Texaco Cuthbert 4-17	4-17-26-28W3	2437	2780/2791		3076	3165 ?		Cornfield Marker 2918-3000 Cornfield Marker 3046-3076
Phillips Husky Alsask #1	10- 7-28-28W3	2253	2476		2636	2674		
Phillips Husky Merid #1	4-19-28-28W3	2214	2443/2455		2678	2683		
Phillips Husky Roslyn #1	3-14-29-28W3	2222	2437		2700	2736		
Whitehall Milton 10-10	10-10-30-28W3	2257	2438		2621 ?	2698		
Altair Milton 10-22	10-22-30-28W3	2291	2520		2797 ?		2872	Presumably partly Transported Deville good samples
Phillips Husky Greene #1	13-23-30-28W3	2292	2523		2737	2800		
Husky Phillips Greene #10-32	10-32-30-28W3	2310	2507		2600	2668		
Husky Phillips Hoosier 6-1	6- 1-31-28W3	2296	2520		2692 ?	2735		
Husky Phillips Hoosier #3	NW16-10-31-28W3	2397	2600		2792	2850		
Phillips Hoosier #1	13-11-31-28W3	2437	2641		2800	2856		
Husky Phillips Hoosier #2	14-11-31-28W3	2426	2635			2825	2889 ?	Possibly Upper Bak ken shale beneath Mannville
Husky Phillips Hoosier 11-23	11-23-31-28W3	2302	2486		2655	2688 ?		
Phillips Husky Antelope 2-19	2-19-32-28W3	2359	2495		2655	2695		
Phillips Husky Antelope #1	9-21-32-28W3	2359	2515		?	2753		
Phillips Husky Compeer #1	13-18-33-28W3	2340	2532				2858	Probably Trans- ported Deville 2840
Canso Fusilier 7-12	7-12-34-28W3	2404	2520		2780		2788	Middle Bakken san beneath Mannville
Canso Fusilier 11-15	11-15-34-28W3	2498	2643		2866 ?		2885	
Bata Provost #1	4- 5-35-28W3	2313	2439		2660 ?		2690	Middle Bakken san below possible Transported Deville

Well Name	Location	K.B.	Top Mann.	Top Jur.	Top Deville	Top Miss.	Top Dev.	Remarks
			Depth in feet below K.B.					
Petromine Exploration Bata Superior #1	4-16-35-28W3	2290	2411				2695	Presumably Transported Deville
Bata Superior #2	8- 4-37-28W3	2186	2220				2555 ?	
Zapata Cactus Lake 7-5-37-28	7- 5-37-28W3	2191	2235				2585	
Superior Dempsey Macklin #2	4-36-38-28W3	2242	2200				2508	
Superior Dempsey Macklin #1	5-15-39-28W3	2252	2228				2535	
B.A. Senlac Houser 14-36-40-28	14-36-40-28W3	2206.4	2137				2587	Diffuse Mannville Top
Intercity Burstall #5	7- 4-20-29W3	2399	2720	2812 ?				
Intercity Burstall #1	10-21-20-29W3	2366	2717/2731	2952				
Intercity Burstall #2	1- 1-21-29W3	2388	2775		3129	3192		Oxidised zone at top of Deville
Phillips Husky Josephine #1	1-23-24-29W3	2220	2610/2619		2958	3043		Cornfield Marker 2875-2910
Phillips Husky Border #1	7- 9-25-29W3	2452	2844/2856		3196	3305		Cornfield Marker 3125-3175
Phillips Cathbert #1	6- 2-26-29W3	2512	2881/2893		3255	3321		Cornfield Marker 3158-3218
Phillips Husky Saskal #1	7- 2-29-29W3	2339	2547		2708	2754		
Phillips Husky Eastside #1	13-14-29-29W3	2454	2607		2782	2796		
Husky Phillips Grattle 16-3	16- 3-30-29W3	2371	2536		2628	2675		
Phillips Husky Grattle #1	13-11-30-29W3	2326	2486		2580	2662		
Whitehall Milton 11-12	11-12-30-29W3	2260	2496		2616	2740		
Husky Phillips Grattle 7-22	7-22-30-29W3	2356	2592		2855	2918		
Husky Phillips Grattle 6-25	6-25-30-29W3	2213	2394		2525	2560		
Husky South Loverna 10-1	10- 1-31-29W3	2306	2517		2702	2753		

PLATE I

Specimen typical of conglomeratic sediments of the Deville Formation or the Transported Deville facies. White areas are partially altered chert pebbles in various stages of disaggregation. Varying permeability of the altered chert is emphasized by the patchy oil staining (black). The matrix consists of pale greenish-gray clay which swells and becomes sticky when wetted, while the small included dots represent siderite spherules. Some secondary void-filling silica is visible within the stained altered chert in the lower left. Canso Hoosier No. 1-10, Lsd. 1-10-31-27W3, 2880 feet.

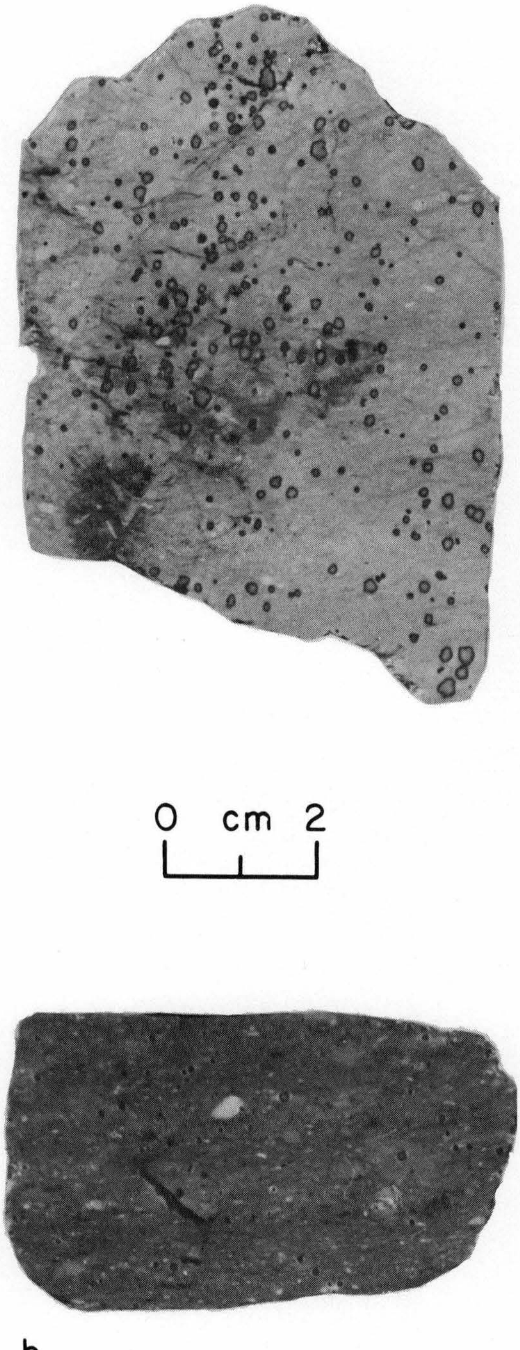


PLATE II b

a) Argillaceous quartzose rock, rich in relatively large siderite pellets showing darkened rims. Clastic constituents consist dominantly of micropolycrystalline quartz. Monocrystalline grains relatively minor. Irregular darker clay stringers with minor carbon dust. Deville Formation or basal Continental Facies. Royalite Coleville 13-29, Lsd. 3-29-31-23W3, approximately 2480 feet.

b) Moderate reddish brown fine conglomerate, with quartz, chert, weathered chert, and claystone pebbles or fragments. Siderite spherules, commonly with darkened rims are surrounded by narrow bleached zones. Deville Formation. Phillips Husky Alsask No. 1, Lsd. 10-7-27-28W3, 2662 feet.

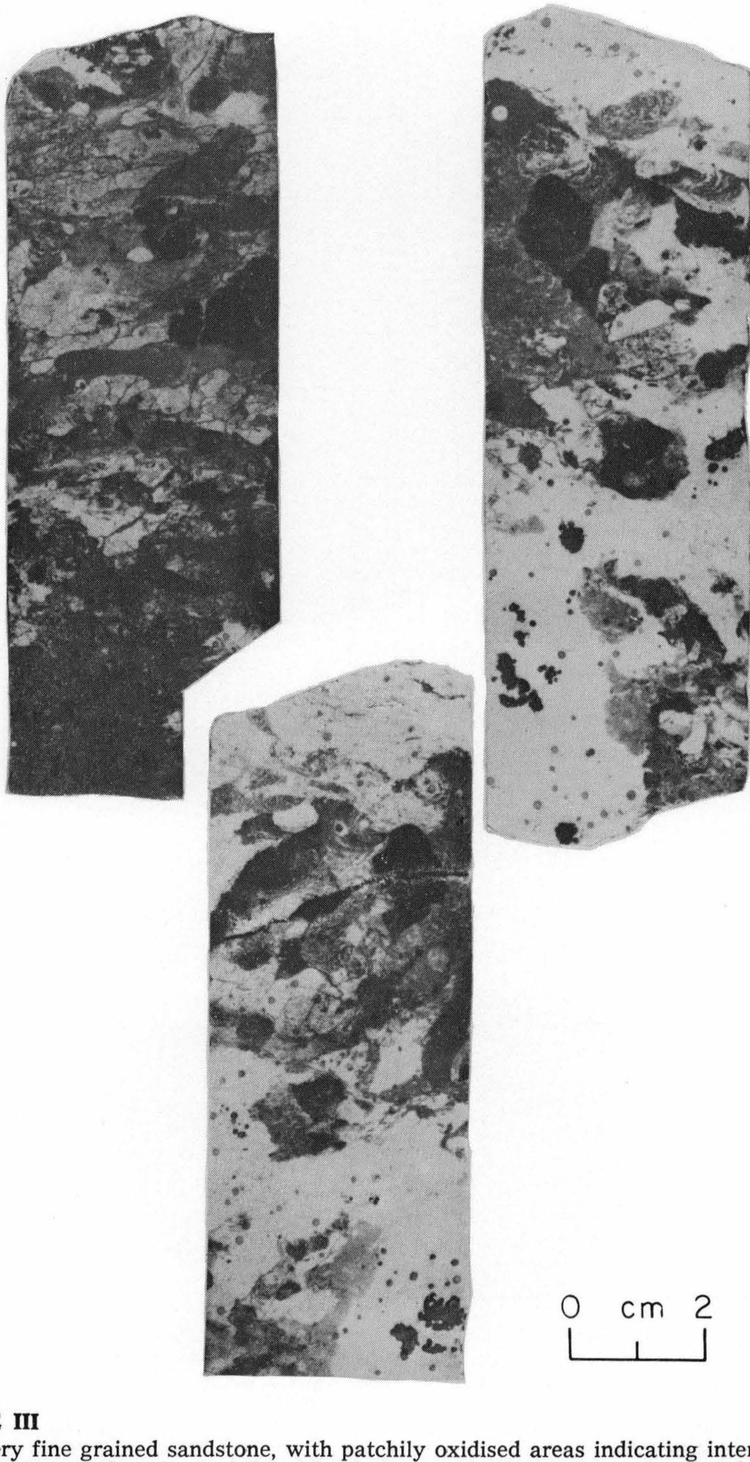
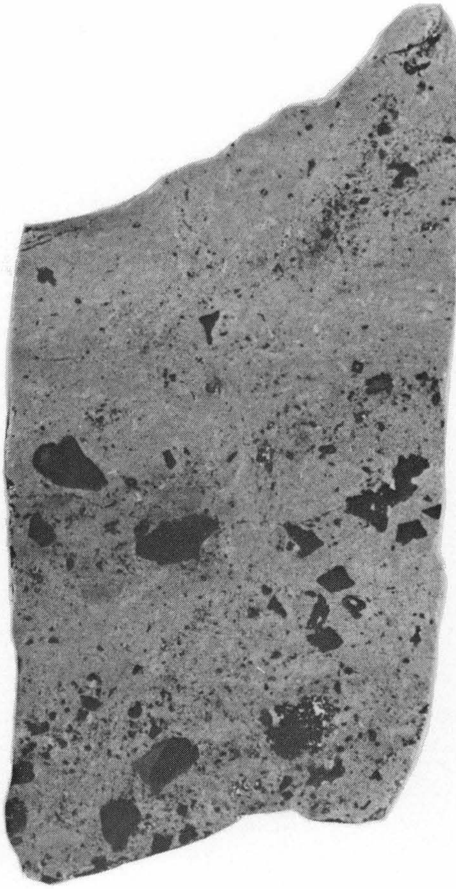


PLATE III

Very fine grained sandstone, with patchily oxidised areas indicating internal structures otherwise invisible. The dark areas in the photograph are reddish brown in hand specimen apparently due to the presence of finely divided ferric oxide minerals. In some places the lamination resembles that formed by burrowing organisms. The spots within the pale sandstone are small siderite spherules some of which have been reddened, presumably by oxidation. Deville Formation. R.G.A.I. Coleville No. 63-19, Lsd. 13-19-31-23W3, 2518 feet.



a

b

PLATE IV

a) Pale gray cherty conglomeratic sandstone (chert fragments appear dark), probably Transported Deville facies lying within the southeasterly extension of the Coleville-Smiley valley. Some of the included fragments are recognizable silicified crinoid ossicles, while in neighbouring portions of the core silicified spiriferids are conspicuous. The poor sorting and lack of rounding of constituents are characteristic. Imperial Netherhill 10-13-29-30, Lsd. 10-13-29-20W3, 2846 feet.

b) Partially altered and slightly rounded chert pebbles (white and mottled, due to patchy oil stain) in carbonaceous siltstones (presumably Continental Facies). Carbonized wood fragments, one of which is faintly visible in the right centre of the photograph, occur intimately mixed with chert pebbles in this zone. This type of chert pebble occurrence suggests local derivation from partially weathered Mississippian uplands Canadian Seaboard Canso Fusilier 10-33, Lsd. 10-33-33-27W3, 2384 feet

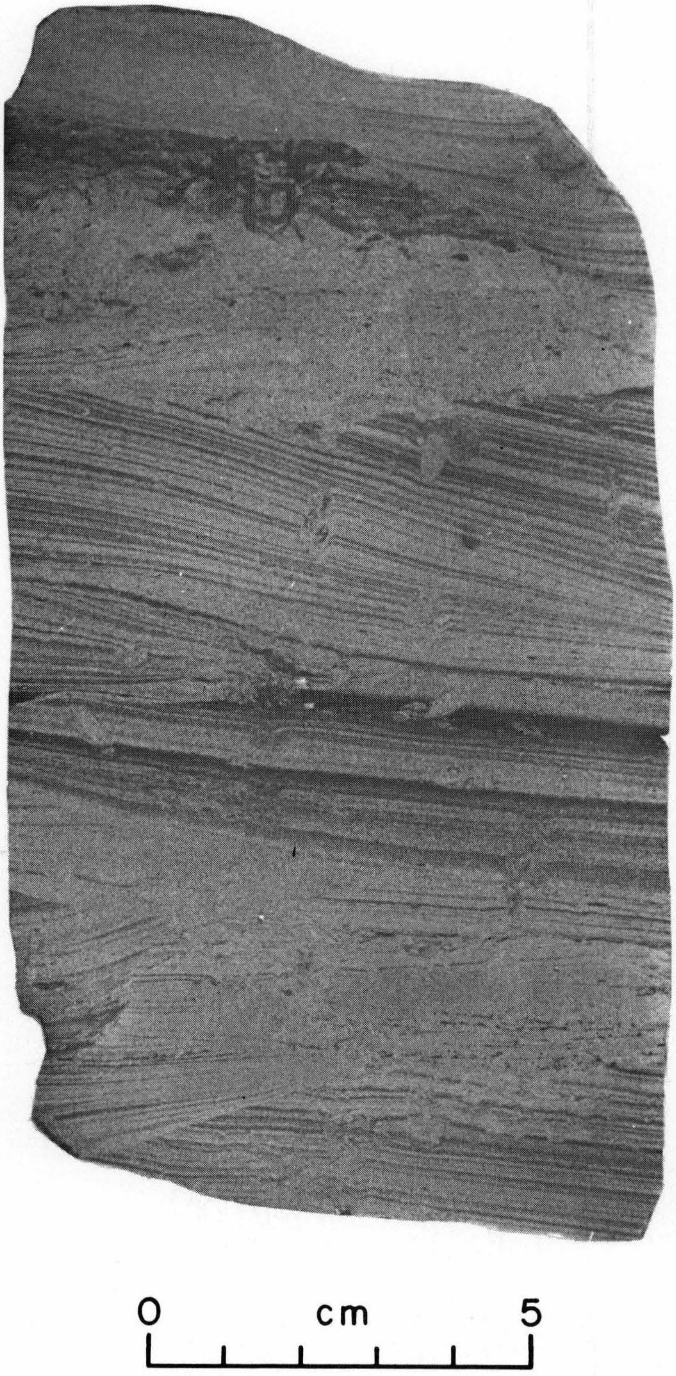


PLATE V

Siltstone to very fine sandstone, laminae accentuated by fine carbon dust. Frequent small scour-and-fill structures, together with low to medium angle small scale cross-stratification, and bedding disturbances presumably attributable to organic burrowing. Some of the sediment in the upper portion of the illustrated specimen has been thoroughly mixed in this manner. Observe the many truncations of disturbed sequences by small-scale erosion planes. Lower Mannville sandstones. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2467 feet.

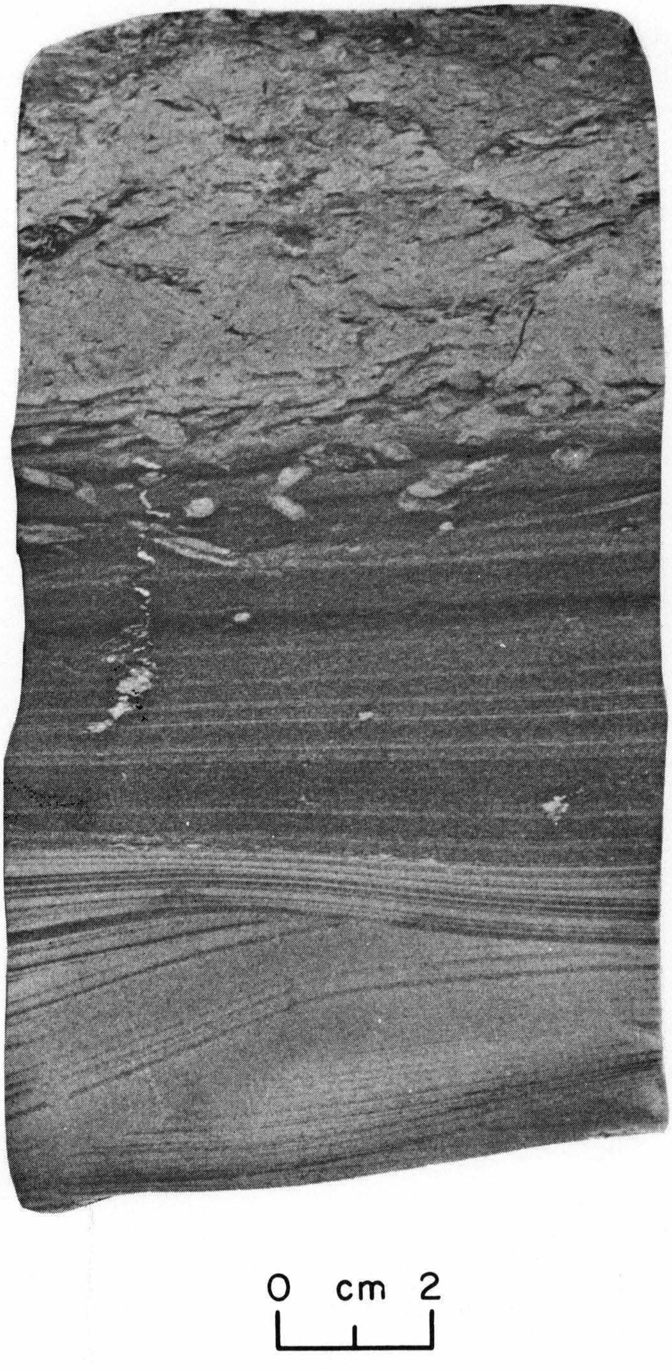
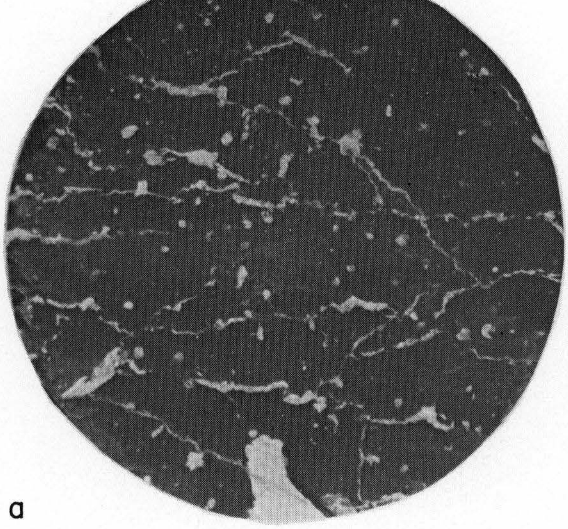


PLATE VI

Lithology similar to that illustrated in Plate V showing initially finely laminated sediments, apparently rippled at the base, in both partially disturbed, and, in the uppermost portions of the specimens, severely mixed condition. In the left centre of the specimen a discontinuous dikelet suggests the compaction of some type of irregular vertical structure. Organic activity is presumed the most probable cause of mixing. Lower Mannville sandstones. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2469 feet.



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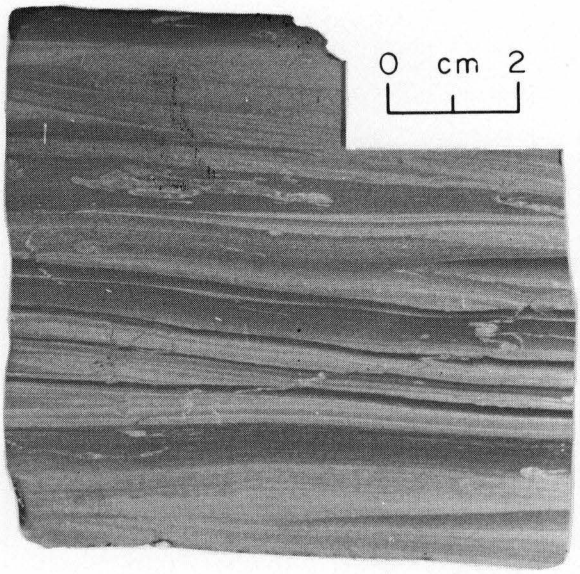


b

PLATE VII

a) Bedding plane section of finely laminated carbonaceous mudstone and light gray siltstone sequence within lower portion of Undifferentiated Mannville. Irregular, sinuous, lighter markings represent sections of compacted dikelets (see (b) below), and also intersection of slightly rough surface of specimen with thin, light silt laminae. The small oval or sub-circular spots are most probably narrow silt-filled burrows, or infilled hollow plant stems. Carbon filaments are, however, absent. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2497 feet.

b) Vertical section of finely laminated siltstone/mudstone similar to that illustrated above. Very delicate lamination and low angle cross-stratification are conspicuous. The irregularly corrugated silt zones are here considered to be compacted dikelets, possibly initially formed during dewatering of the clay (Not necessarily by subaerial desiccation — *cf.* White, 1961). Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2468 feet.

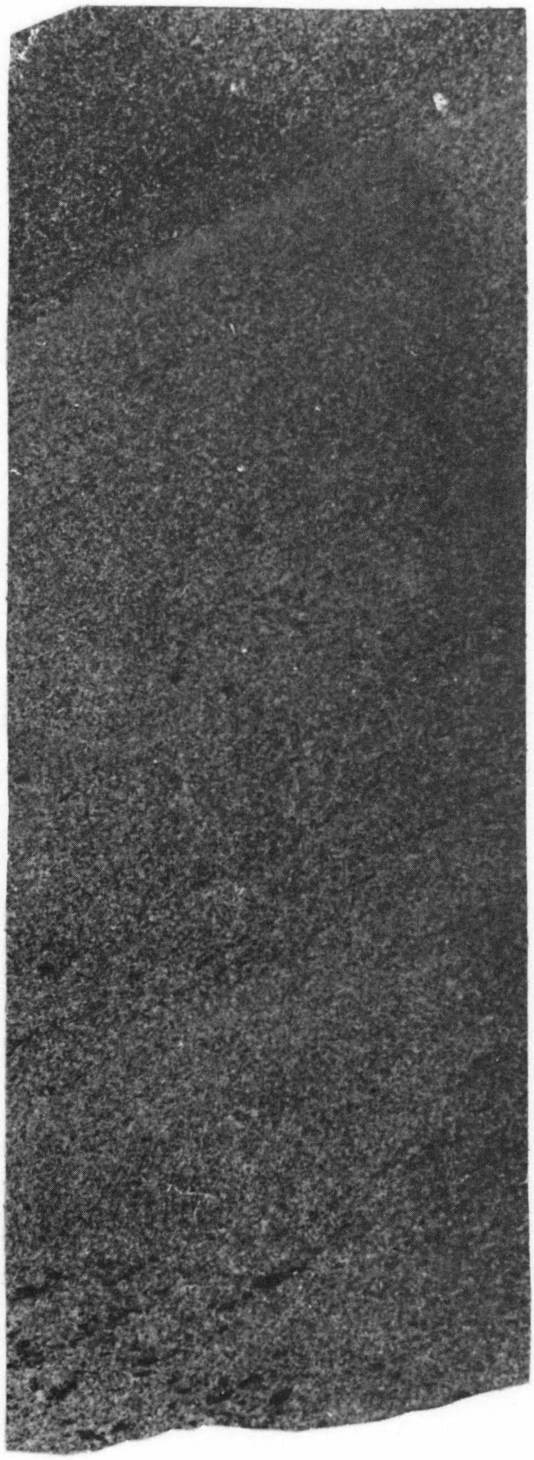


PLATE VIII

Portion of cross-stratified set of lithic sandstone with matrix replaced by carbonate. Dark particles in lower part are carbon fragments oriented subparallel to the stratification. Rock is light gray, not dark as suggested by photograph. Continental Facies. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2348 feet.

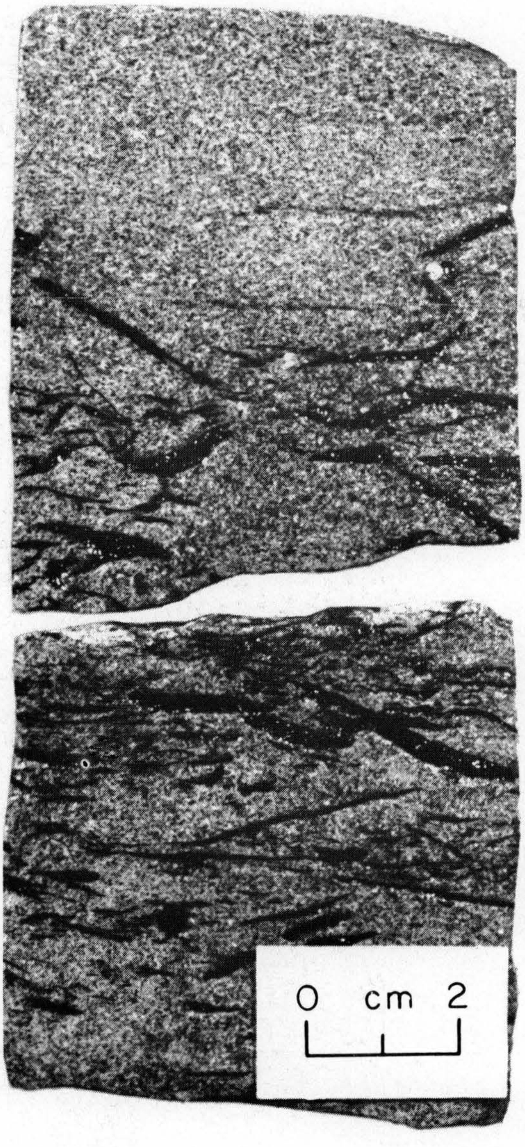


PLATE IX

Lithic sandstone rich in flattened, poorly imbricated carbonized wood fragments. Specimen from lower portion of a cross-stratified sequence. Continental Facies. Phillips Husky Glidden No. 1 well, Lsd. 7-14-27-24W3, 2685 feet.

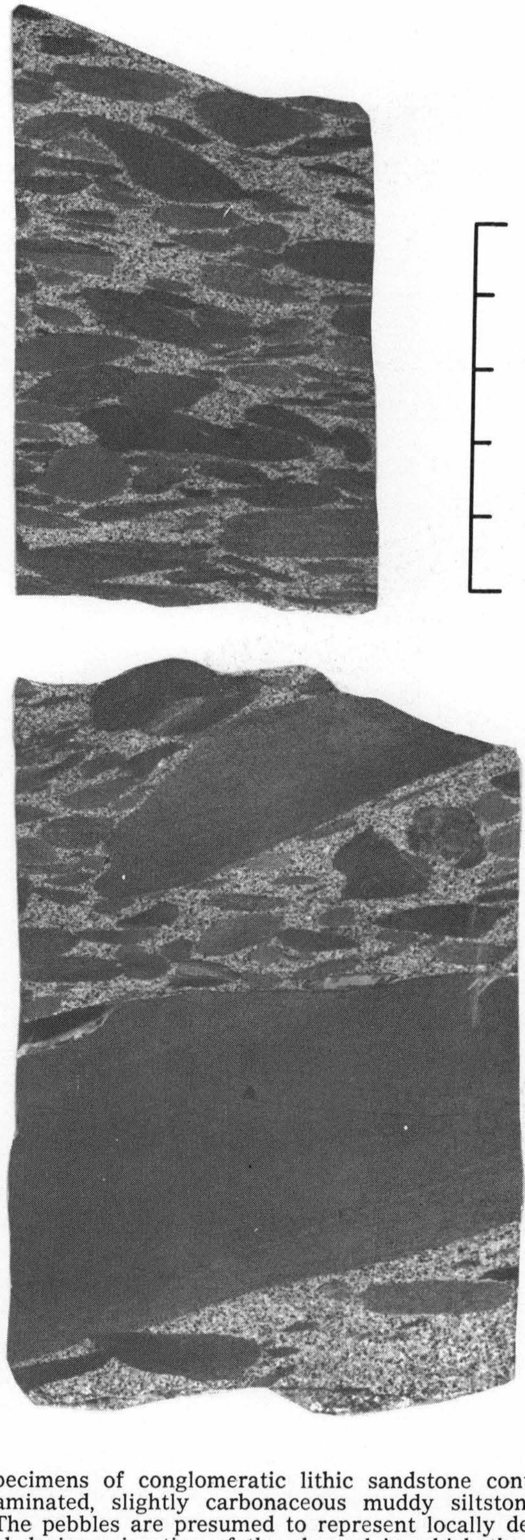


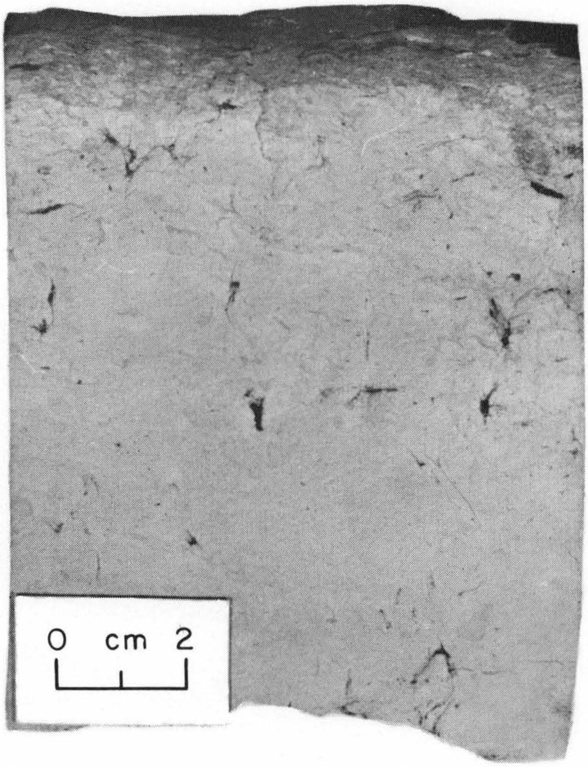
PLATE X

Adjacent specimens of conglomeratic lithic sandstone containing pebbles of finely laminated, slightly carbonaceous muddy siltstone and/or silty mudstone. The pebbles are presumed to represent locally derived sediment concentrated during migration of the channel in which the cross-stratified lithic sandstones developed. Scale divisions represent centimetres. Continental Facies. Husky Imperial Pinkham No. 1 well, Lsd. 1-31-26-24W3, 2939 feet.

PLATE XI

Finely laminated muddy siltstones and silty mudstones. Very finely divided "dust" grade carbon helps accentuate laminae. Scattered ripple structures, such as, the small accretionary lenticle immediately below top of specimen. Evidence of organic disturbance of lamination is abundant. Pale zone in the upper half of specimen is orange-brown due to preferential replacement of matrix by very finely crystalline siderite. Scale in centimetres. Continental Facies. Husky Phillips Cuthbert No. 1 well, Lsd. NE6-2-26-29W3, between 3135 and 3140 feet.

a



b

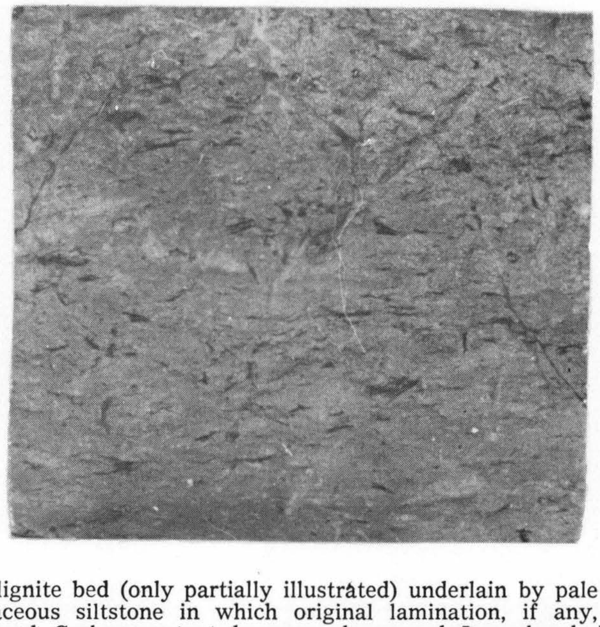


PLATE XII

a) Thin lignite bed (only partially illustrated) underlain by pale olive-gray argillaceous siltstone in which original lamination, if any, has been destroyed. Carbon content decreases downward. Irregular dark stringers and small spots represent carbonized rootlets. Although not obvious on photograph some in lower portion of specimen are now infilled with silt. Irregular pyritic concretions occur elsewhere in the specimen. Continental Facies. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2403 feet.

b) Olive-gray siltstone to fine sandstone, rich in irregularly distributed carbonaceous fragments, some of which are probably rootlets. Initial lamination has apparently been destroyed. Continental Facies. Fusilier 10-33 well, Lsd. 10-33-33-27W3, 2801 feet.

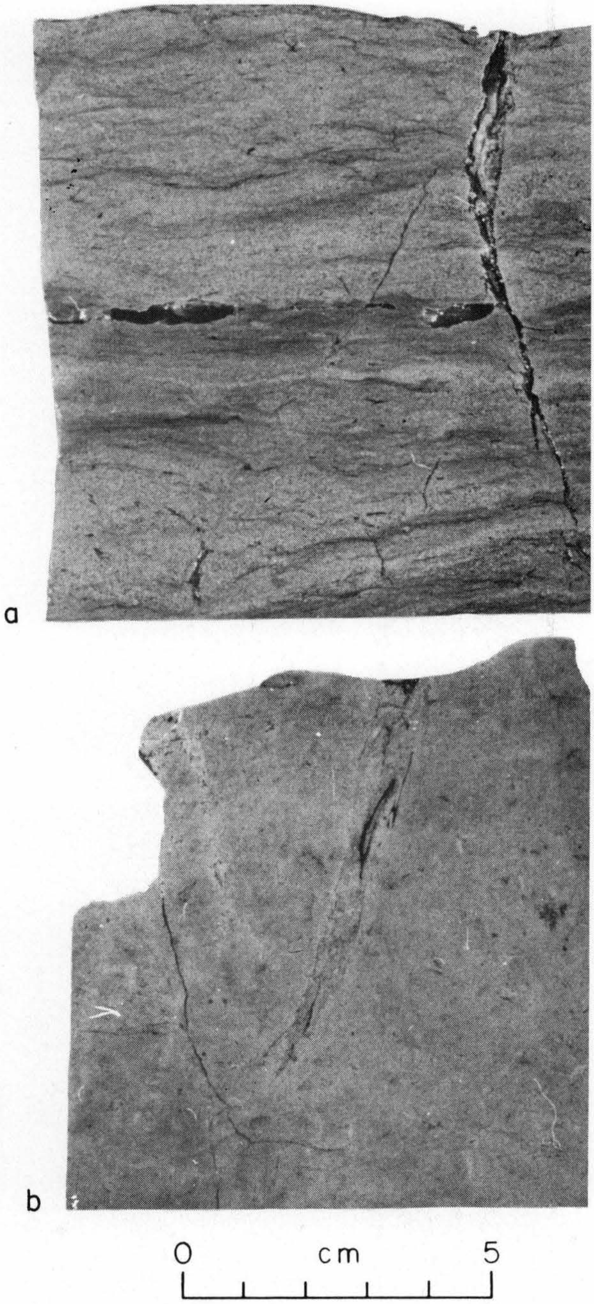


PLATE XIII

a) Large and small rootlets in laminated carbonaceous sandy and muddy siltstone. Large rootlet has been partly removed during the preparation of the rock surface. Many small carbon grains are oriented subparallel to the bedding suggesting a detrital origin prior to the intrusion of the root. Continental Facies. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2431 feet.

b) Pale olive-gray, "homogenized" rootlet-bearing zone, in which much of the original carbon appears to have been removed. Several large roots are visible on the un-illustrated portion of specimen. The clay fraction swells when wet and probably contains montmorillonite and/or mixed layer montmorillonite-illite minerals. Continental Facies. Canadian Seaboard Canso Fusilier 10-33 well, Lsd. 10-33-33-27W3, 2791 feet.

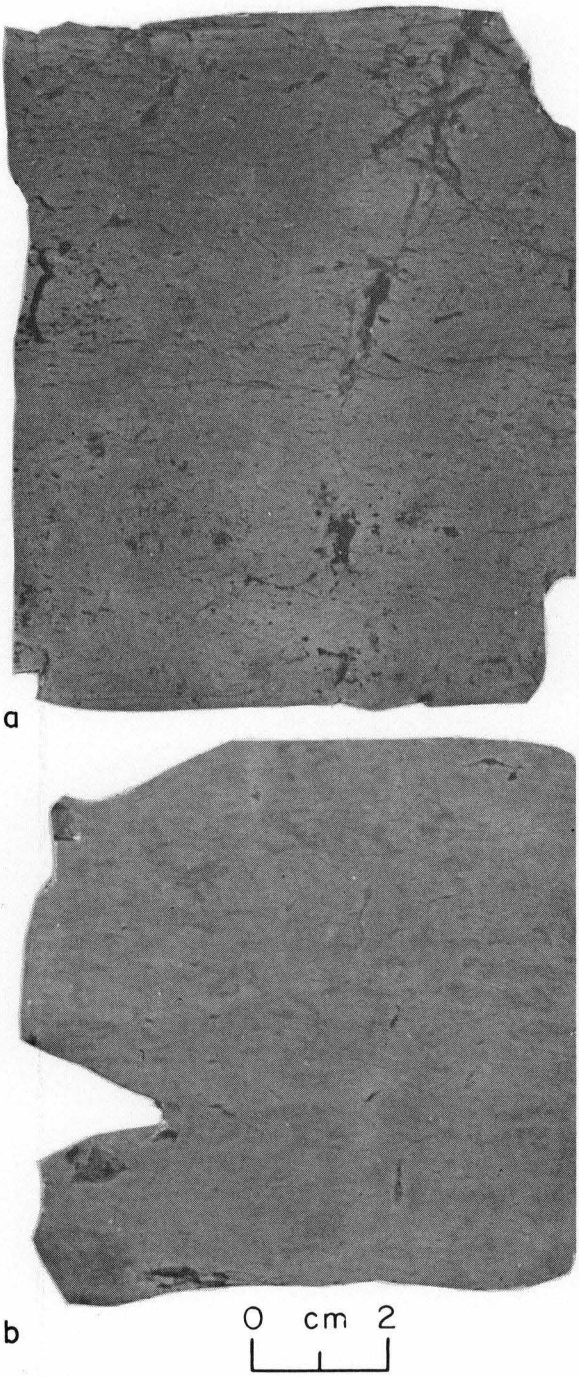


PLATE XIV (a) and (b)

Pale greenish gray, "homogenized", rootlet beds, rich in clay minerals which swell when wetted. In (a) carbonaceous stringers and irregular masses are conspicuous, while in (b) only thin films, and in some cases tubules are visible. These specimens are presumed to represent fossil soils formed on the flood plains of the Continental Facies. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, (a) 2303 feet, (b) 2228 feet.

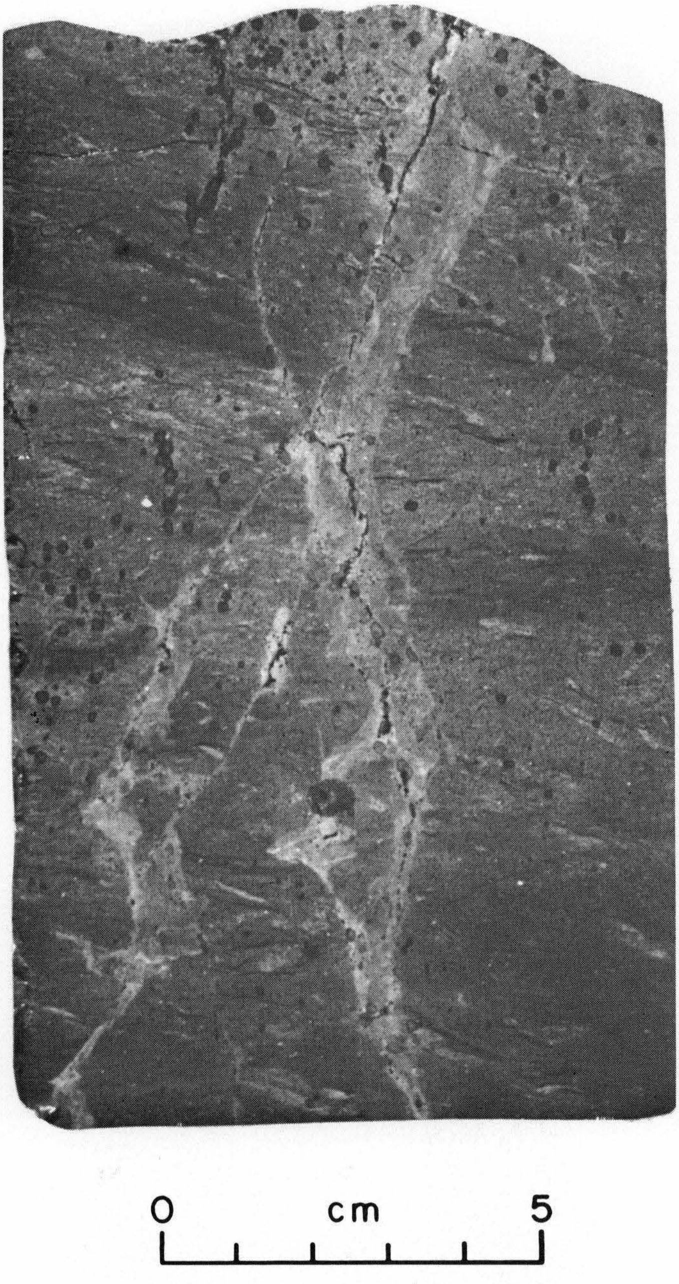


PLATE XV

Unusual development of sphaerosiderite in irregularly laminated and apparently slightly brecciated pale brown silty mudstone. Some of siderite (dark zones circular on sub-circular masses in photograph) appear to have developed along fractures while other enriched areas are tubular or filamentous in cross-section. The lithology is thought to represent an accretionary floodplain deposit in which iron compounds, concentrated around rootlets and within small fracture planes, have been subsequently altered to siderite. Zoning of the siderite is caused both by the expulsion of impurities during the recrystallization process, and apparently by slight oxidation on the spherulite margins. Continental Facies. Stanolind Prelate Crown No. 1 well, Lsd. 9-34-19-24W3, 2757 feet.

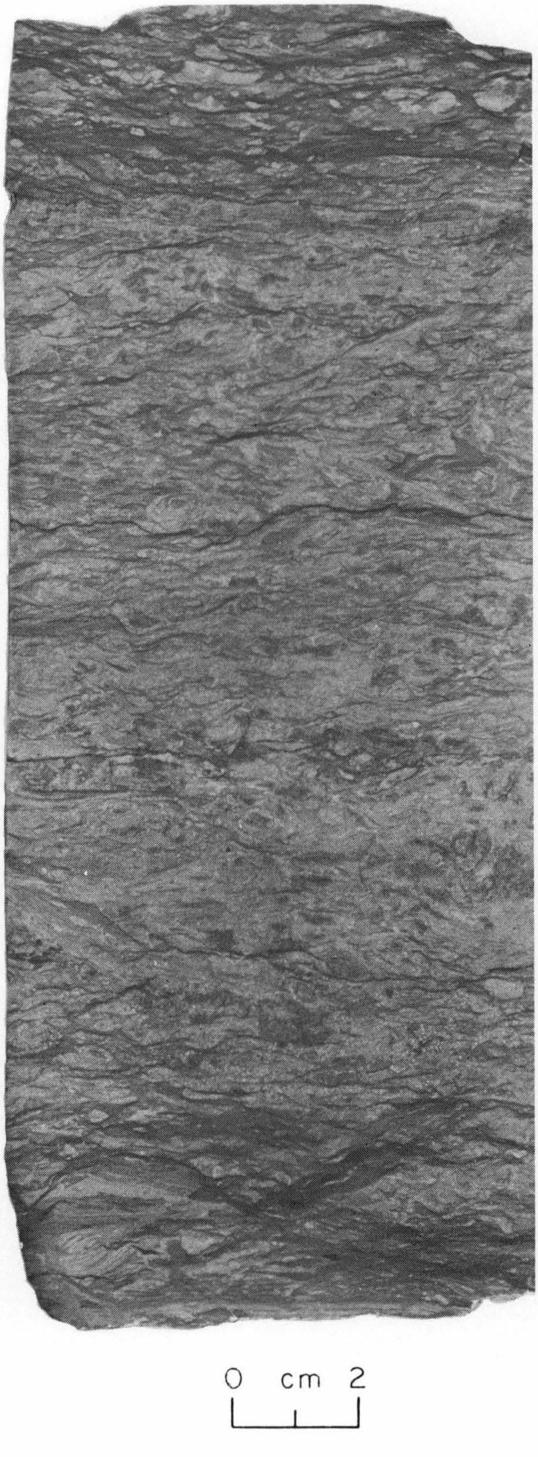


PLATE XVI

Typical specimen of disturbed, "bioturbated" or microcontorted mudstone/siltstone/very fine sandstone which characterizes the Pense Formation in many cores. Brecciation and flowage phenomena seem conspicuous near the base. Many of the small "rolled" or ellipsoidal bodies are elongated subparallel to the bedding. Pense Formation. Stanolind Prelate Crown No. 1 well, Lsd. 9-34-19-25W3, 2710 feet.

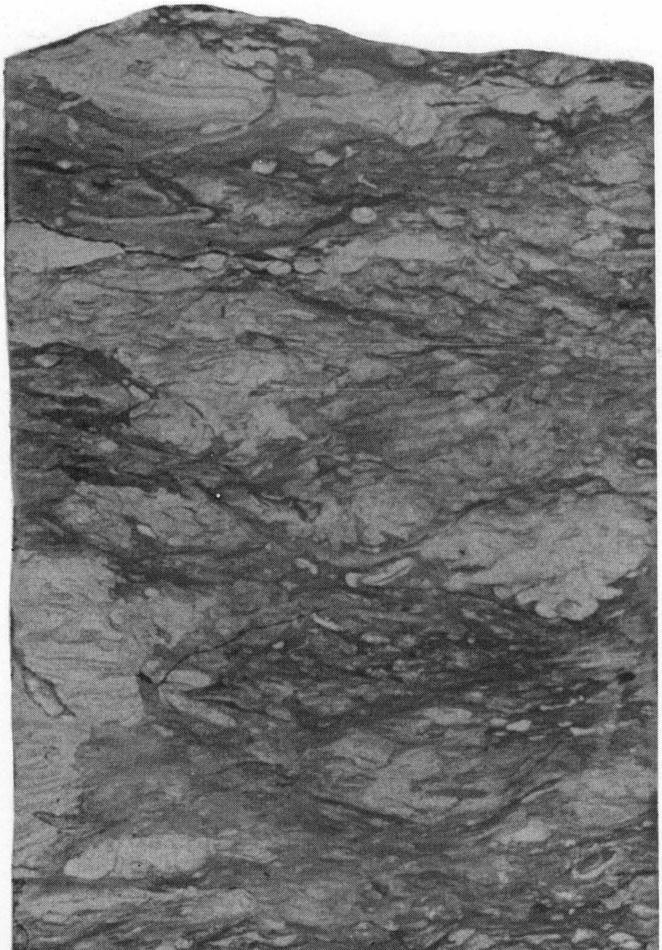
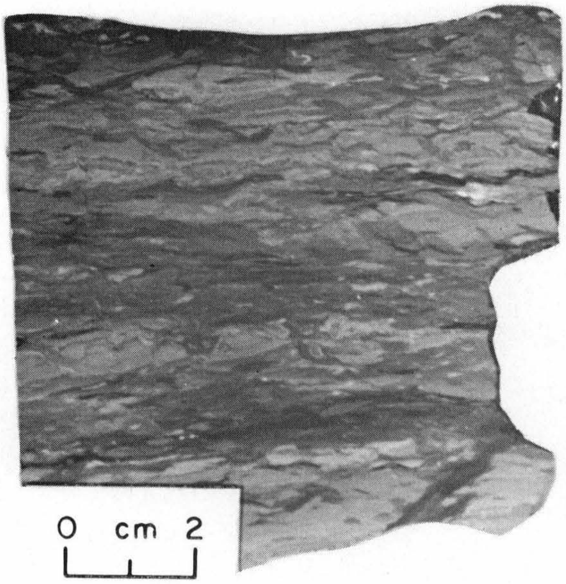


PLATE XVII

Specimen with higher silt content below that illustrated in Plate XXV. Severe mixing, loading, flowage, and minor micro-brecciation are well illustrated. Pense Formation. Stanolind Prelate Crown No. 1 well, Lsd. 9-34-19-24W3, 2711 feet.



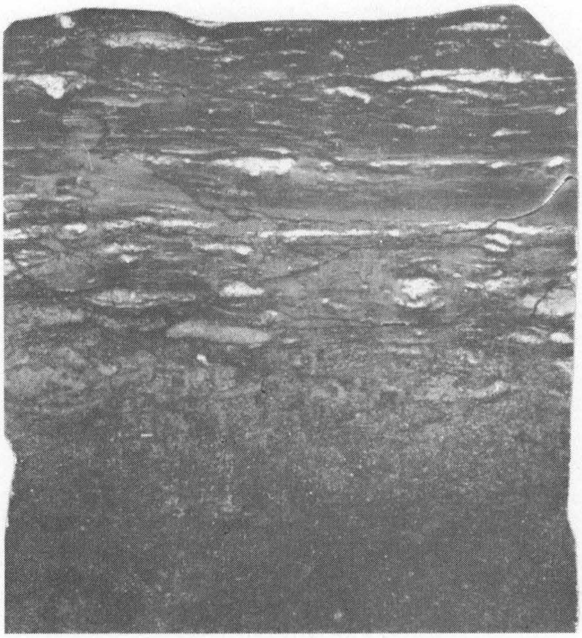


PLATE XVIII

a) Disturbed and microbrecciated mudstone/siltstone mixture. Apparent intrusion and flowage of muddy material along small fractures within the finely laminated siltier constituents. Positionally equivalent to the Pense Formation farther south. Ceepee Dukesbury 13-18 well, Lsd. 13-18-34-21W3, 2271 feet.

b) Dark mudstone at top with irregular siltstone and fine sandstone pods; belong to lower part of the shale or mudstone immediately beneath the Cantuar Marker. The faintly mottled dark area constituting the lower third is a light medium gray, relatively poorly sorted silty and argillaceous sandstone, stratigraphically equivalent to the "lower plant-bearing bed" of Cumming and Francis (1957). In the illustrated specimen the darkness of this lower area was caused by impregnation of the clear plastic used during the preparation of the rock surfaces. Pense Formation. Altair *et al.* Battrum 10-36-18-17W3, 2857 feet.

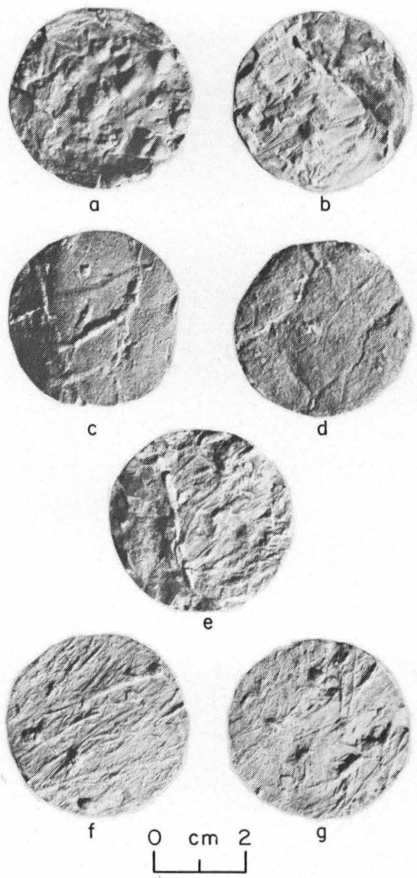


PLATE XIX

Small-scale bedding plane structures from siltstone lenticles within mudstone or shale in or adjacent to strata here termed the "Index horizon above the Cantuar Marker".

a) Possibly small load casts on underside of thin (1 to 2 mm.) fine silt lenticle. The very small protuberances between the larger are probably of organic origin and may represent silt-filled hollows or holes formed within the clay during feeding.

b) Cast of bottom structures illustrating, in lower left, small grooves in clay which when filled with silt are seen as the bottom structures, or hieroglyphs, of (e) below. Lineament across upper right side of the specimen is considered to be a silt-filled syneresis crack.

c) Similar cracks on undersurface of siltstone lenticle. Very fine irregular lineaments are thought to represent the tracks or grazing marks of tiny organisms.

d) Specimen similar to (c) above but with greater number of markings; probably attributable to the filling of small shallow borings.

e) Surface complementary to that of (b) above. Very fine branching mounds are in places (*e.g.* upper centre) visible on top of elongate hieroglyphs. This relationship suggests that the former developed probably organically on the mudstone after the erosion responsible for the hieroglyphs but prior to their mantling by silt.

f) Well-developed preferentially oriented hieroglyphs similar to the "toolmarks" of Dzulinski and Sanders (1962) or the "prod" and "bounce-casts" of Wood and Smith (1959). They are presumed to have resulted from the impact of small detrital fragments (shells, twigs) on the mud surface. The criss-crossing of the lineaments suggests differing current directions and separate erosive periods. The bulbous projections (three in lower left) are probably infilled shallow borings.

g) Similar surface hieroglyphs as in (f), again with varied orientation. Elongate lump in lower right considered to be silt-filled burrow. Pense Formation. Tidewater Atlas Crown No. 3 well, Lsd. 8-20-18-14W3, depth 3059 to 3061 feet.

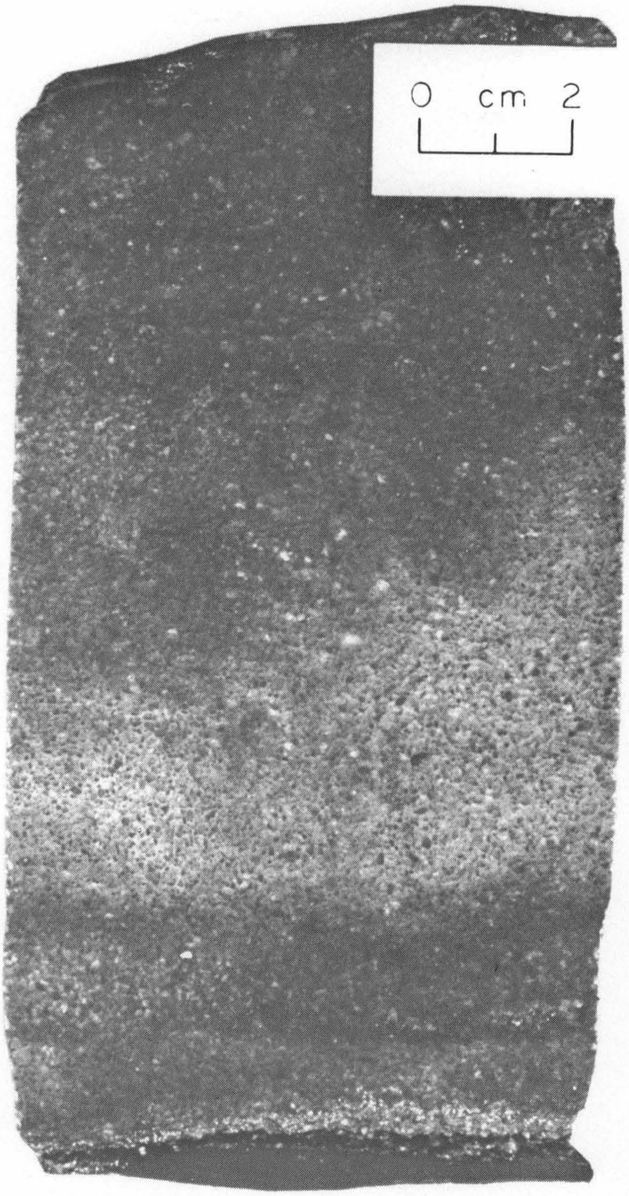


PLATE XX

Very coarse grained quartzose sandstone from basal Joli Fou Formation, probably part of the Spinney Hill Sand Member. The components belong to two grain-size populations *viz.* (a) very coarse sand and rarer granule grades, and (b) clay and silt grades. Colour variation in the central portion of the specimens is due to alteration of the gray matrix to rusty brown. The contact with the dark gray mudstone at the base is slightly irregular possibly due to erosion. Ceepee Broadacres 13-13 well, Lsd. 13-13-35-21W3, between 2179 and 2193 feet, (recovery very poor, due to unconsolidated nature of sand).

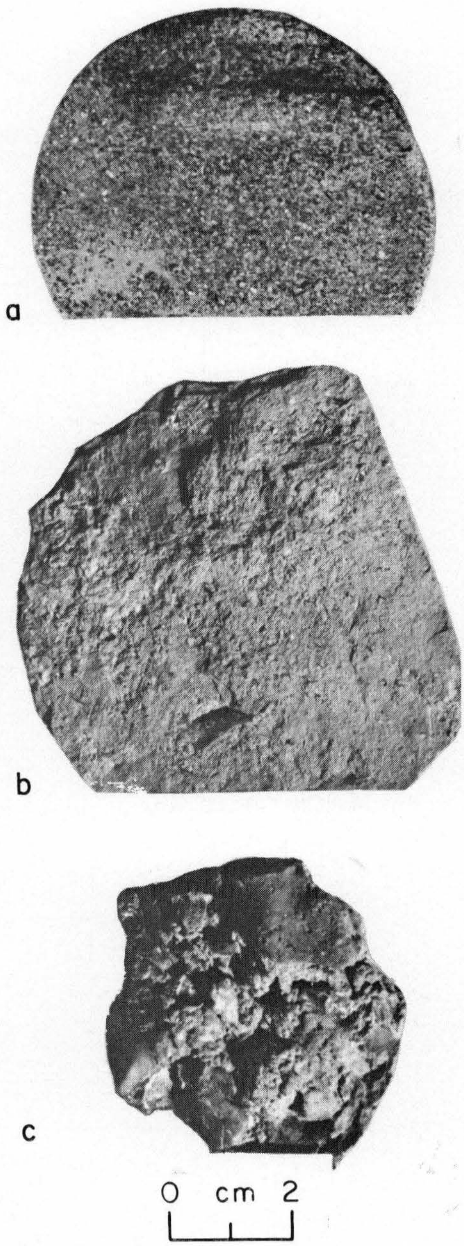


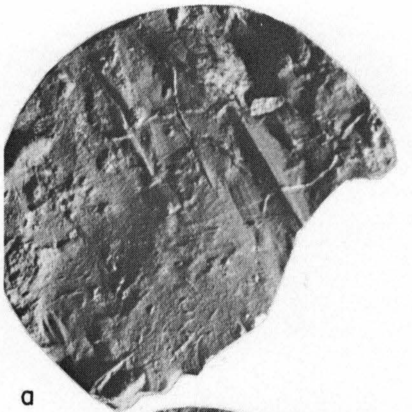
PLATE XXI

Phosphate concentrations.

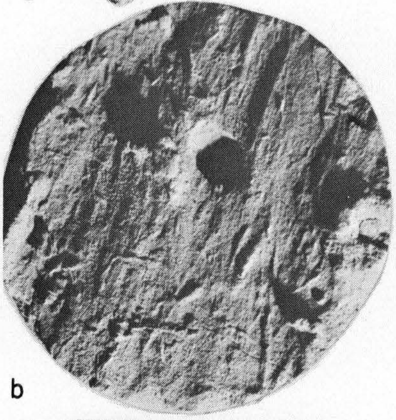
a) Underside of lenticle (maximum thickness 15 mm.) consisting of coarse-grained quartz sand and phosphate fragments. Many of the small darker particles are dark brown shiny phosphatic bodies (fish teeth or bone fragments are common). The lenticle with an irregular, apparently erosive base as illustrated, is the lower of two sets in pale gray argillaceous siltstone. The upper is cross-laminated at a low angle. Joli Fou-Mannville Transition Beds, Imperial Netherhill 11-17 well, Lsd. 11-17-27-21W3, 2527 feet.

b) Bedding plane rich in phosphate fragments (majority probably fish remains) within basal portion of Joli Fou Formation. Stanolind Prelate Crown No. 1 well, Lsd. 9-34-19-24W3, approximately 2697 feet.

c) Part of thin bed (2 to 3 cm. thick) rich in comparatively large phosphatic bodies, including teeth up to 15 mm. long. Matrix consists dominantly of pyritised silty mudstone. Lower part of Joli Fou Formation, Stanolind Prelate Crown No. 1 well, Lsd. 9-34-19-24W3, approximately 2692 feet.



a



b

c

PLATE XXII

Bottom structures within siltstone sequences in Joli Fou sediments or possibly silty Spinney Hill equivalents.

a) Tracks? and hieroglyphs on the base of a thin (1 to 4 mm.) finely cross-laminated silt lenticle. Some of the smaller irregularities may represent infilled burrows or grazing marks. Imperial Netherhill 11-17 well, Lsd. 11-17-27-21W3, approximately 2501 feet.

b) Hieroglyphs and possibly infilled burrows on underside of cross-stratified siltstone and fine sandstone bed, 3 cm. thick, containing scattered mud-pellets and shell fragments. Dark hole in surface represents the position of an original mud-pellet washed out during preparation of the specimen. Imperial Netherhill 11-17 well, Lsd. 11-17-27-21W3, approximately 2510 feet.

c) Bottom structures on ripple-scale cross-laminated siltstone. Structure in lower part of specimen may have been formed by the dragging or bouncing of a pelecypod or similar shell acros the original mud surface. Some adjacent laminae are rich in shell debris. Imperial Netherhill 11-17 well, approximately 2502 feet.

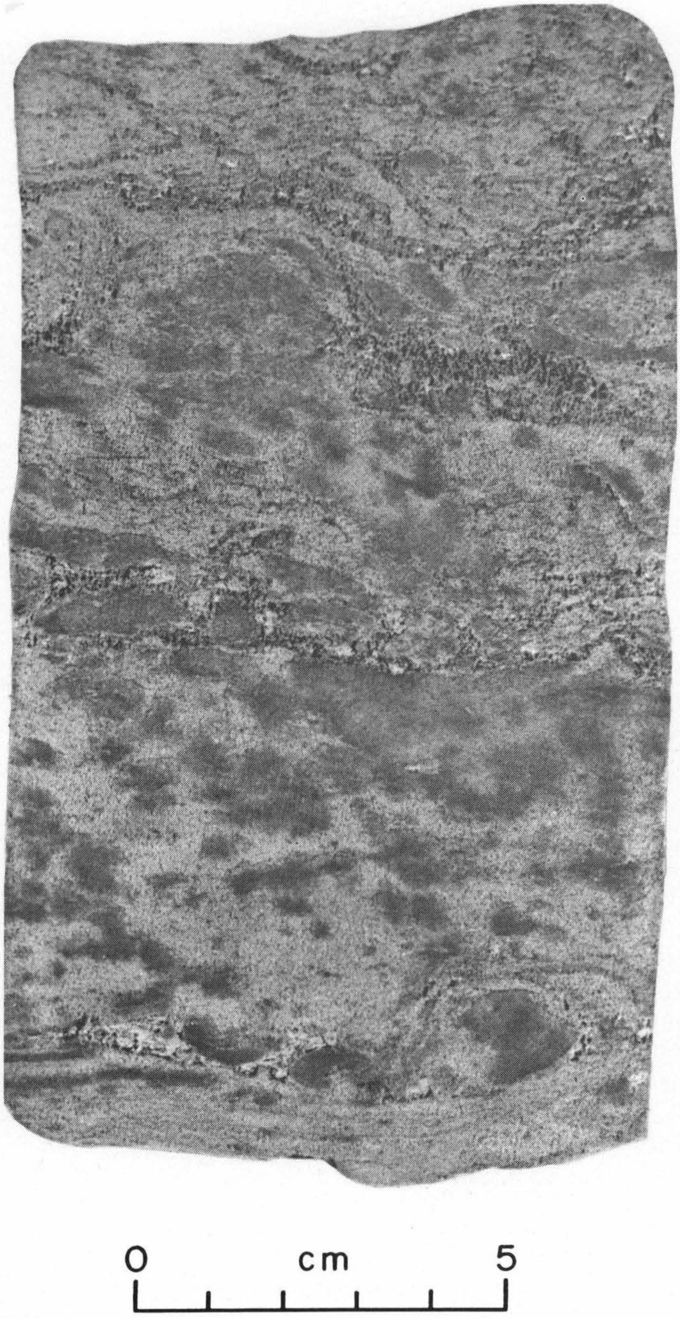
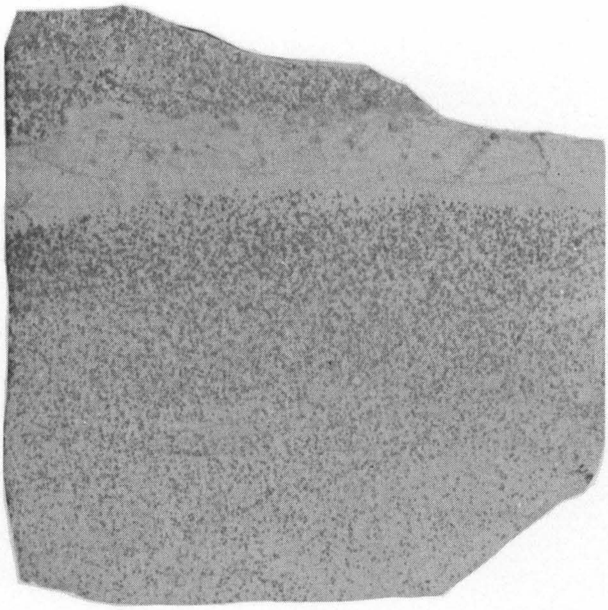
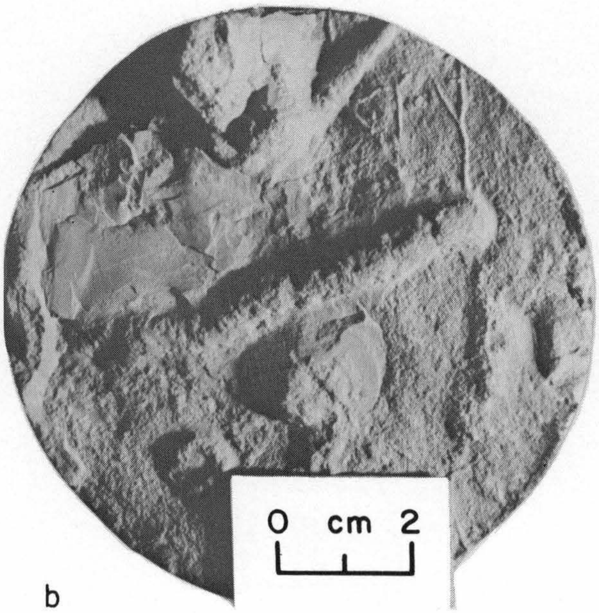


PLATE XXIII

Calcareous fine-grained sandstone with intermixed pale green to pale greenish-gray mudstone, characteristic of the base of the Roseray sand in the Battrum area. The irregular distribution of the calcite cement has been accentuated by staining with Alizarin Red-S. The dark spots represent small holes developed by the swelling and subsequent loss of the green clay during the smoothing of the surface by a water-based abrasive. In many cases the spots are shadows created by protruding siderite spherules, which are very numerous within the upper half of the specimen. Supertest CDP Battrum 1-11-18-17 well, Lsd. 1-11-18-17W3, 3094 feet.





b

PLATE XXIV

a) Pale greenish to pale olive gray argillaceous siltstone and fine sandstone very rich in sphaerosiderite. Basal Roseray sand. Supertest CDP 1-11-18-17 well, Lsd. 1-11-18-17W3, 3094 feet.

b) Bottom or bedding plane structures of a type frequently found in the partially calcareous sandstones associated with pale greenish clays at the base of the Roseray. The structures, here considered organic in origin are formed within the fine, white to pale gray, sandstone which overlies clay. The larger feature resembles a horizontal burrow, while the smaller may be tracks or infilled very narrow burrows. Mobil Woodley Sinclair Battrum 21-14B well, Lsd. 14-21-18-17W3, 2940 feet.

PLATE XXV

Very pale olive-gray silty claystone typical of the finest grained lithologies of the Roseray Sand. Silt lenticles are faintly cross-laminated and presumably resulted from concentration by the action of gentle repetitive currents, possibly in a silt- or sand-deficient local environment. The fine dots are dark brown sphaerosiderite, while the occasional darkening within the silty lenticles is caused by patchy oil staining. Pure Battrum 3-1-19-17 well, Lsd. 3-1-19-17W3, 2856 feet.

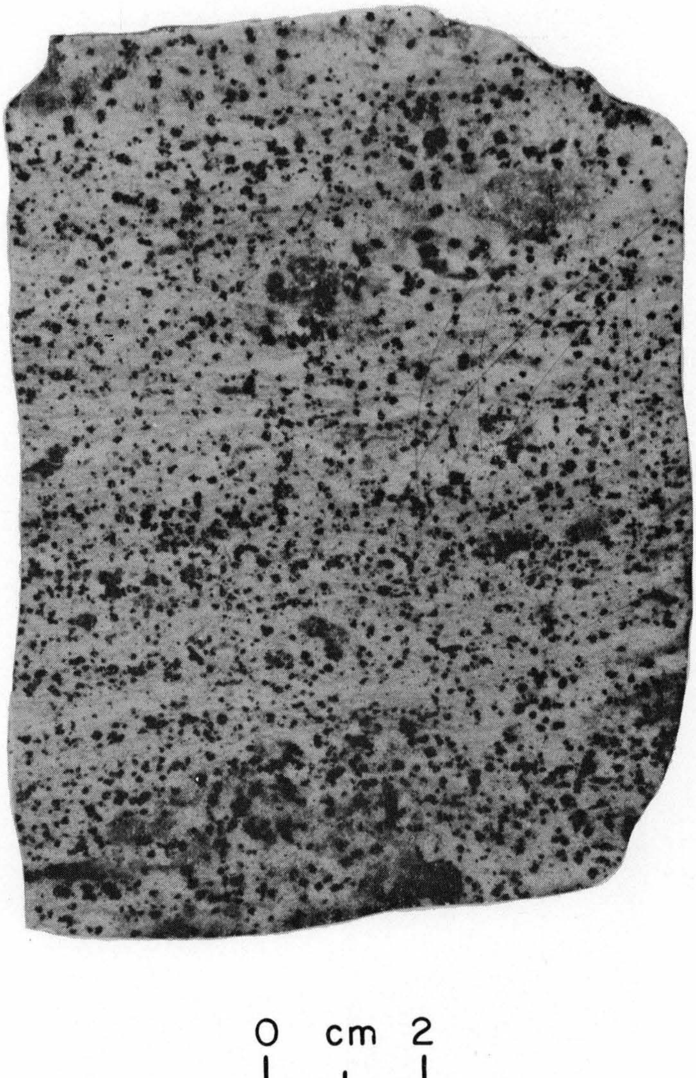


PLATE XXVI

Fine-grained disturbed? argillaceous Roseray sandstone rich in partially pyritised sphaerosiderite. Supertest East Battrum 12-36-18-17 well, Lsd. 12-36-18-17W3, 2866 feet.

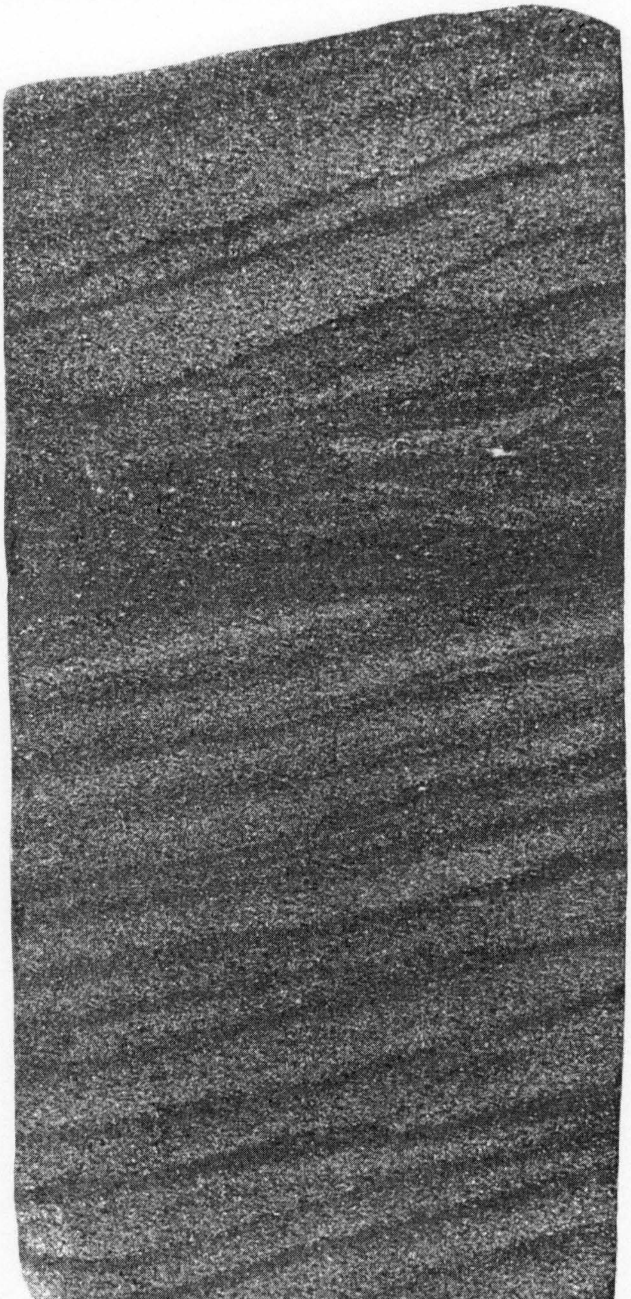


PLATE XXVII

Heavily oil stained, relatively quartzose sandstone from a channel or point bar sequence of the Continental Facies (Cantuar Formation) apparently in a valley eroded into the Roseray sand. These deposits have increased the productive sand thickness at this locality. The high quartz content of the sandstone suggests that subjacent Roseray detritus was reworked by the Cretaceous rivers. SMPS Battrum 9-9-18-17 well, Lsd. 9-9-18-17W3, 2900 feet.

PLATE XXVIII

Conglomerate, apparently of channel-base or lag-concentrate origin. The majority of the pebbles are of fine-grained, dominantly argillaceous, sedimentary rocks. Some similar to those at the base of the Roseray. Bone fragments are common, (three exhibiting cellular texture may be seen in the uppermost parts of the specimen), and chert and orthoquartzitic pebbles less so. Francana Supertest Battrum 12-30-18-16 well, Lsd. 12-30-18-16W3, 2695 feet.

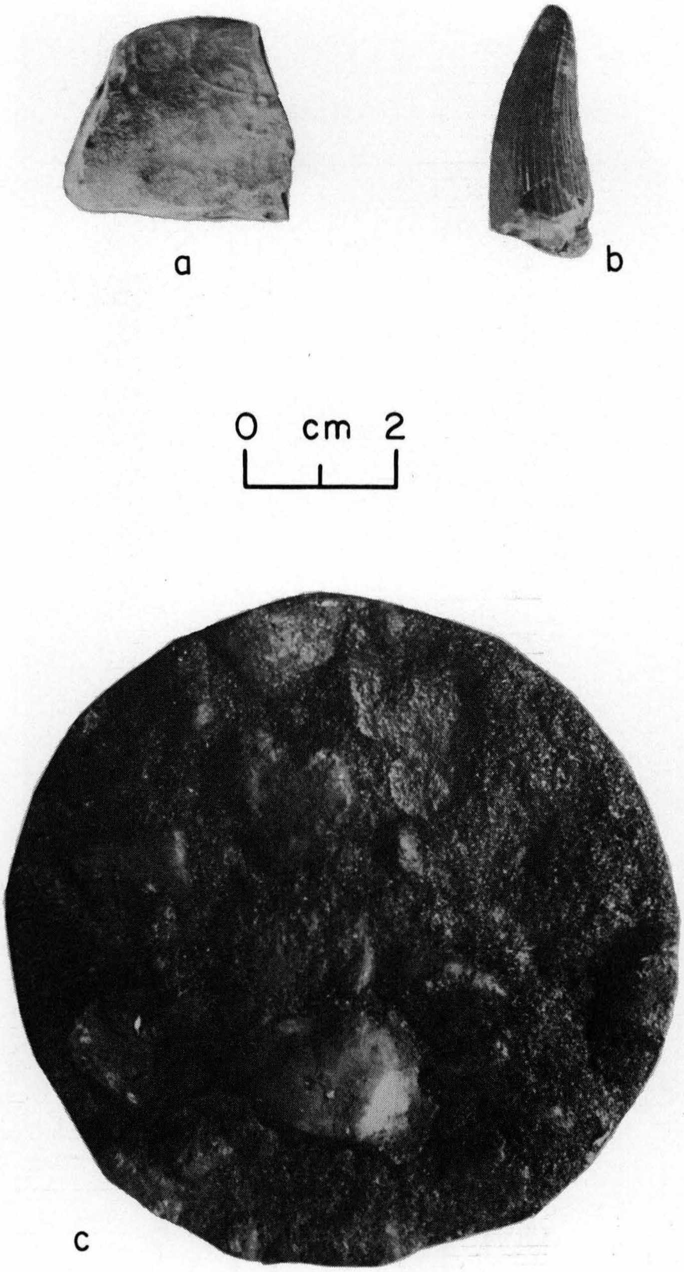


PLATE XXIX

a) Chert pebble, and (b) tooth, possibly crocodilian, from conglomerate illustrated in Pl. XXVIII. Francana Supertest Battrum 12-30-18-16 well, Lsd. 12-30-18-16W3, 2695 feet.

c) Oil-stained conglomerate containing chert pebbles at the base of sand sequence from which the cross-stratified specimen illustrated in Pl. XXVII was taken. Pyritised wood fragments and softer sedimentary rock particles also occur. SMPS Battrum 9-9-18-17 well, Lsd. 9-9-18-17W3, 2910 feet.

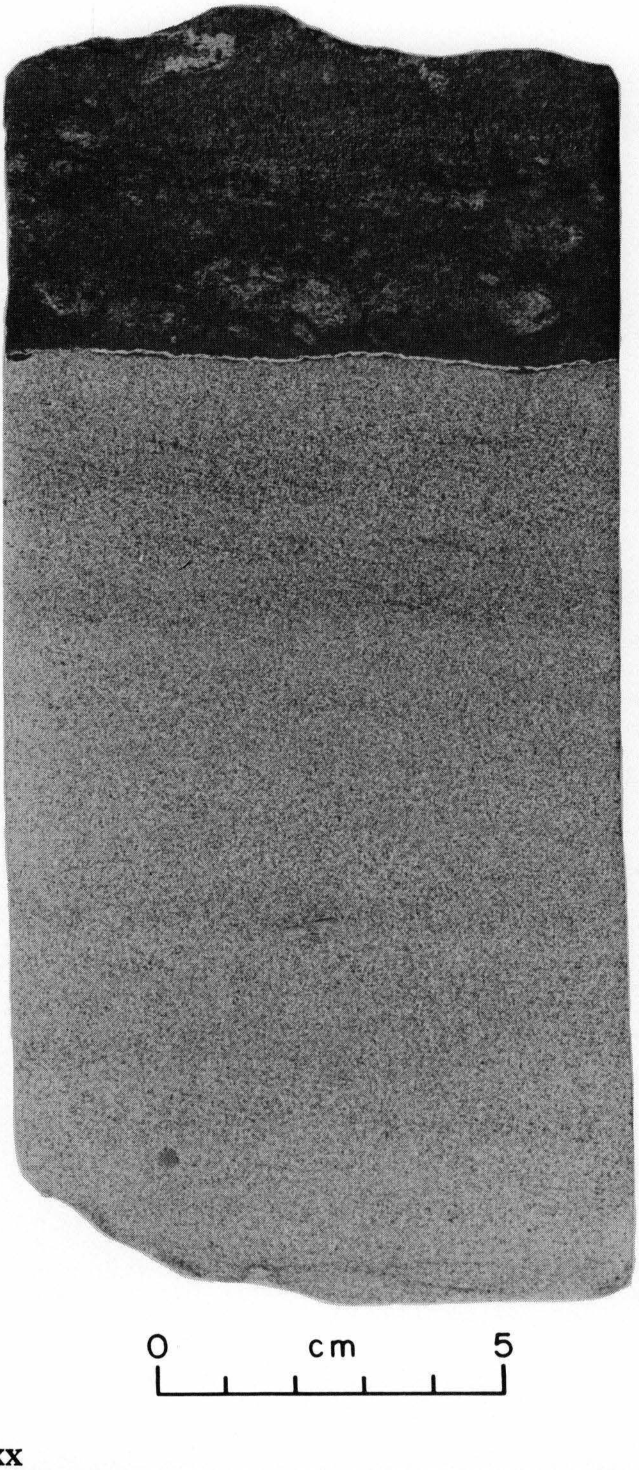


PLATE XXX

Pense sediments (dark) overlying lithic sandstones of the Continental Facies. The disturbed nature of the Pense has been obscured by impregnation of the plastic coating used in preparing the rock-surface for photography. The crenulate white line at the contact is glue used to hold the specimen together during sawing. Altair *et al* Battrum 10-36-18-17 well, Lsd. 10-36-18-17W3, 2861 to 2862 feet.

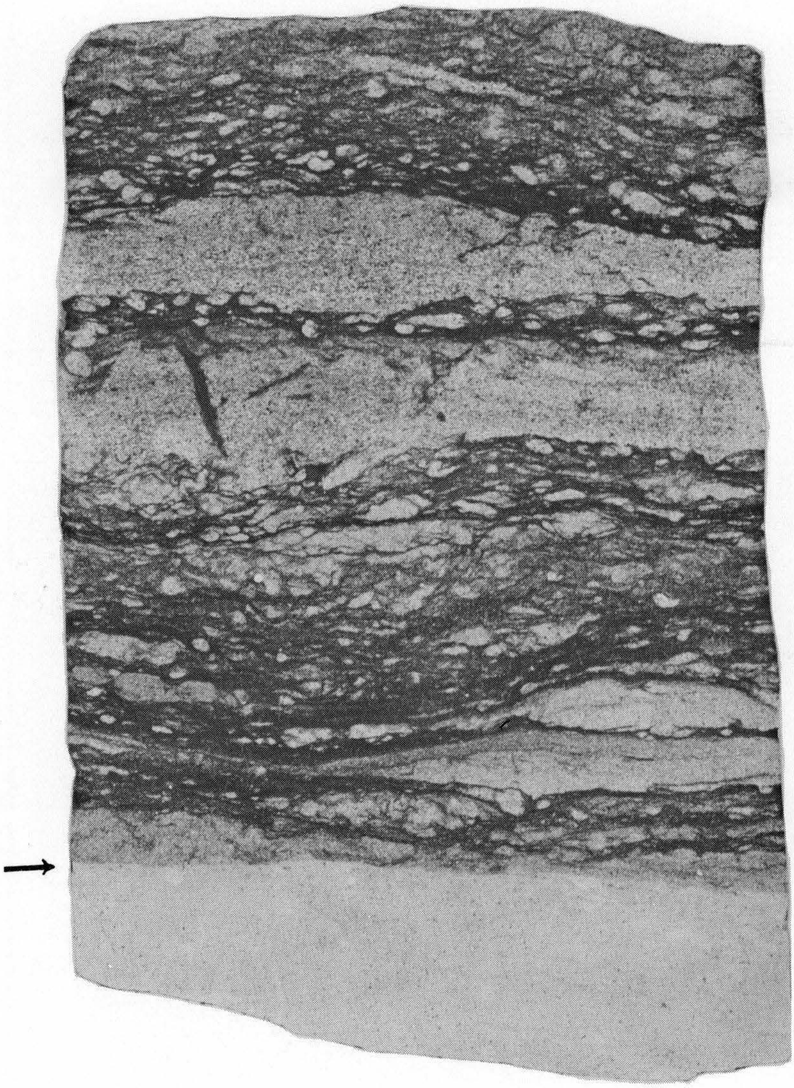


PLATE XXXI

Contact (arrowed) of basal Pense sediments, here positionally equivalent to the "lower plant-bearing bed" of Cumming and Francis (1957), and a relatively tight very pale olive-gray argillaceous Roseray lithology. The Continental Facies is not represented in this well. SMPS Battrum 9-22-18-17 well, Lsd. 9-22-18-17W3, 2935 feet.