Comments on the Mannville (Lower Cretaceous) Aquifer in Saskatchewan

by J. E. Christopher

Introduction

The formation waters of the Lower Cretaceous Mannville Formation in Saskatchewan are in a hydrodynamic state that largely reflects the major structural elements of the formation, as well as the existence of a regional recharge area in the central Montana uplift and a discharge region in central western Manitoba. Large scale distortions of the regional potentiometric surface reflect (1) local cells of high pressure water influxing through fractures from the underlying Paleozoic limestones and (2) regional saddles or flattened cones of depression at locales of discharge into the present-day ground and surface drainage system.

Mannville Tectonic Elements

(Ref. Christopher, J.E., 1980)

Just as the surface topography reflects many of the regional tectonic elements, so also do the paleo-topographic surfaces of the Early Cretaceous. The paleo-topographic surface underlying the Cantuar Formation of the Mannville Group can be reconstructed by drawing an isopach map of its basal member, the Dina (Fig. 1). This sandy unit partially blankets the old land surface. Terrain rising above the Dina cover is designated uplands; the form of the lowlands is indicated by the isopachs of the Dina. This surface is divided into five main regions representing independent structural blocks (Fig. 1).

The southwestern uplands (i.e. Swift Current, Kindersley and Unity) correspond to the eastern extension of the Sweetgrass Arch of Alberta, and are dominated by the Swift Current platform (Fig. 2); subsidiary elements of which are the Shaunavon monocline to the west and the Kindersley block or North Battleford Arch (Kent, 1968, Fig. 27) to the northwest.

The Swift Current platform, which is terminated by the northwesterly-trending Shaunavon-Elbow troughs, has moved up and down throughout the Mesozoic against these linears (Christopher, 1974, p. 105).

The Shaunavon monocline and the Kindersley block appear to have moved along the northerly and easterly trending linears depicted. These linears which appear to be subsets of the dominant northeasterly and northwesterly conjugate set, apparently also controlled the location of the northerly trending Jurassic and Cretaceous oil fields from Rapdan to Success, and the easterly-trending oilfields of the Kindersley region.

The Middle Devonian 180-m thick Prairie Evaporite has had a widespread and continuous influence on the Mannville basin. The halite forms two bodies joined by a neck north of the Elbow trough (Fig. 2). The eastern body forms a rectanguloid mass trending northwest and bounded to the south by the Elbow-Weyburn linear, conforming areally to the Lower Cretaceous pre-Pense Punnichy Arch. The arch apparently resulted by downwarp of the Williston Basin to the south and the Alberta Basin to the northwest, and flexing of the post-Prairie Evaporite beds, including the Mannville Cantuar Formation, over the halite body. The eastern body also conforms areally to the pre-Dina Govan lowland.

The western body of salt underlies the Shaunavon monocline and the Kindersley, Unity and Lloydminster blocks, but is largely absent from under the pre-Dina Meadow Lake lowlands.

This absence is mainly attributable to salt solution and retreat early but mainly after Mannville times. The absence of salt from under the Swift Current platform reflects long term solution of depositionally thinner beds (75 to 105 m) during the Paleozoic, but especially during uplift of the platform in the early Mannville (Aptian), and later in the Cretaceous.

The Present Structural Surface

The sub-Dina structural surface (Fig. 3) outcrops (subcrops) in the north and slopes southward from an elevation of 348 m in the north to minus 612 m in the southeast where it plunges into the Williston Basin. Northeasterly and northwesterly trending linears criss-cross the surface. The most important of these are the Elbow-Weyburn along the minus 276 m contour east of Longitude 107 degrees, and to the north of Latitude 52 degrees a similar linear, offset 80 km to the northeast, fronting the Unity-Lloydminster terraces. The Kindersley block, furrowed by the easterly trough associated with the pre-Dina drainage

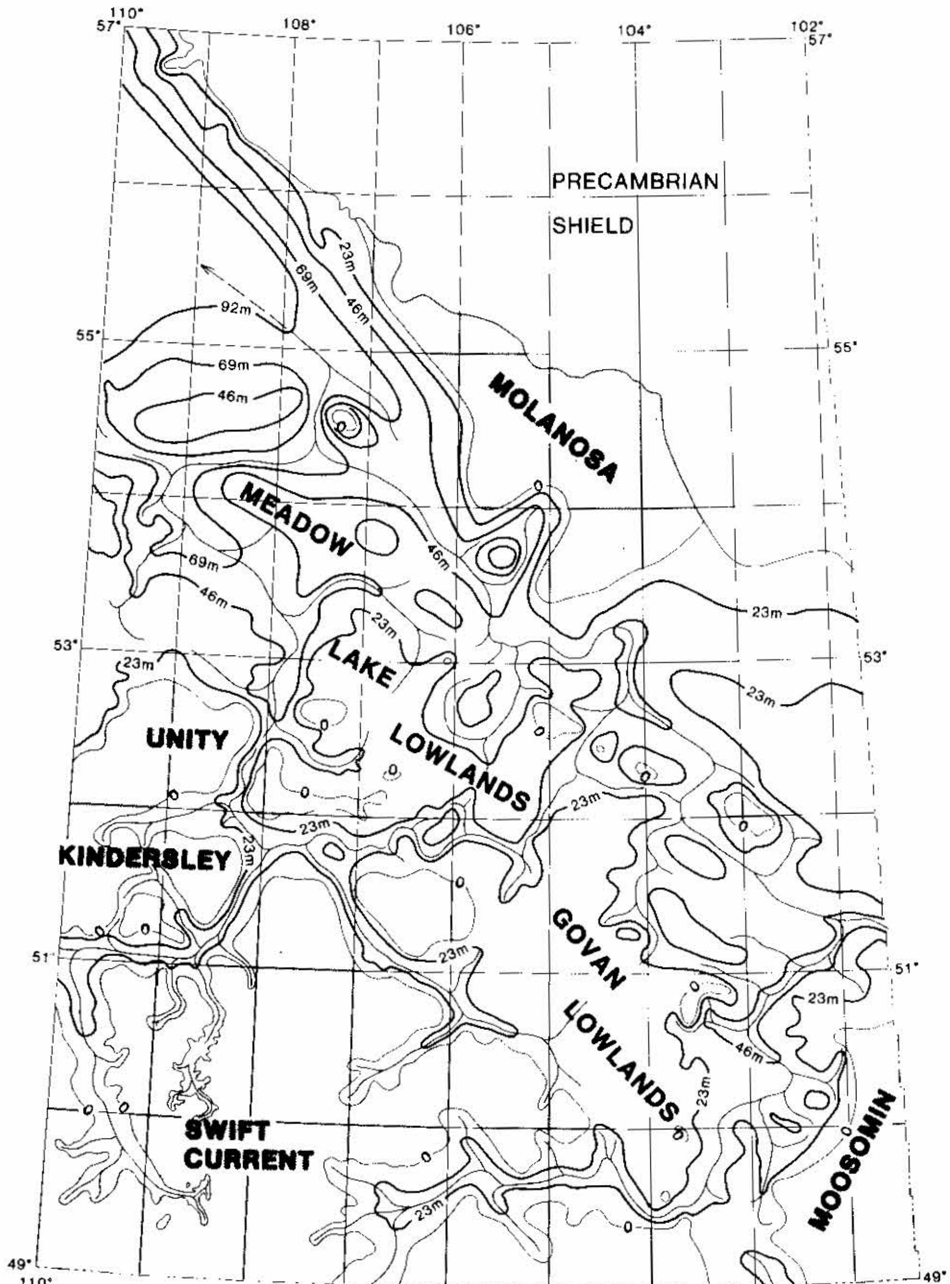

Fig. 1 - Elements of Sub-Cantuar Paleotopography and Dina Isopach map, Saskatchewan.

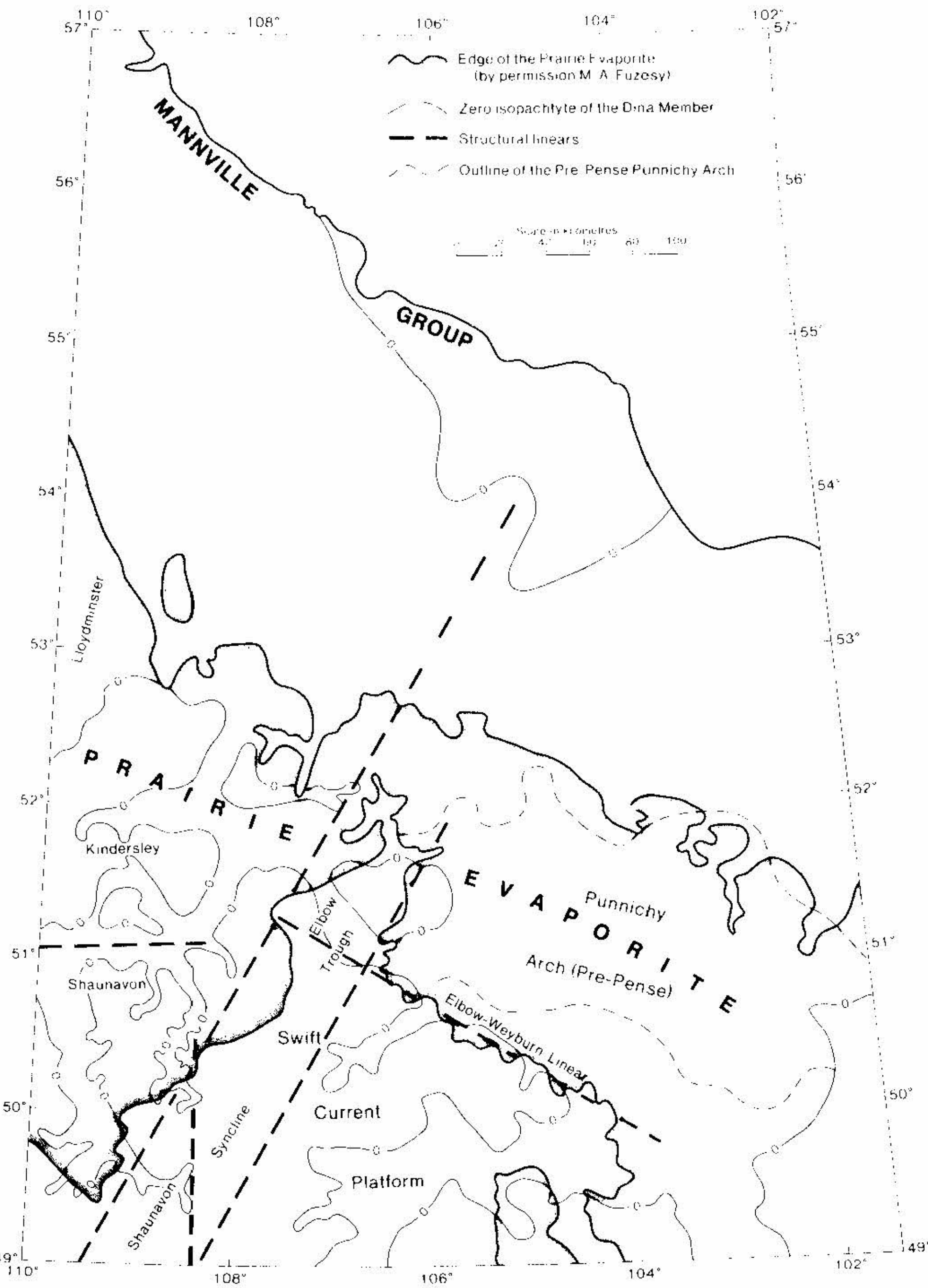

Fig. 2 - Structural-topographic elements of the pre-Dina and pre-Pense erosional surfaces, structural linears and the Prairie Evaporite.

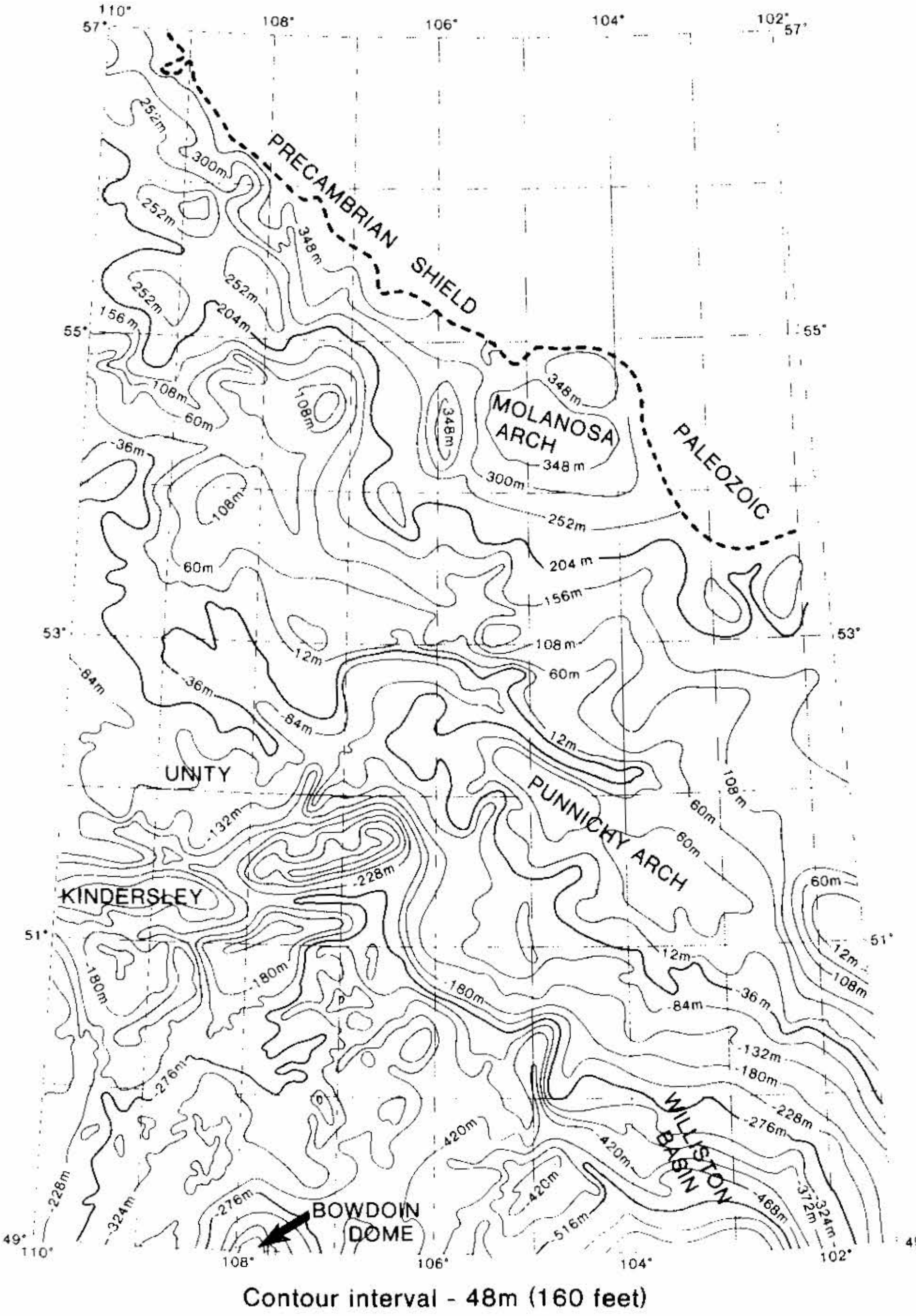

Fig. 3 - Structure contours of the Pre-Dina erosion, Saskatchewan.

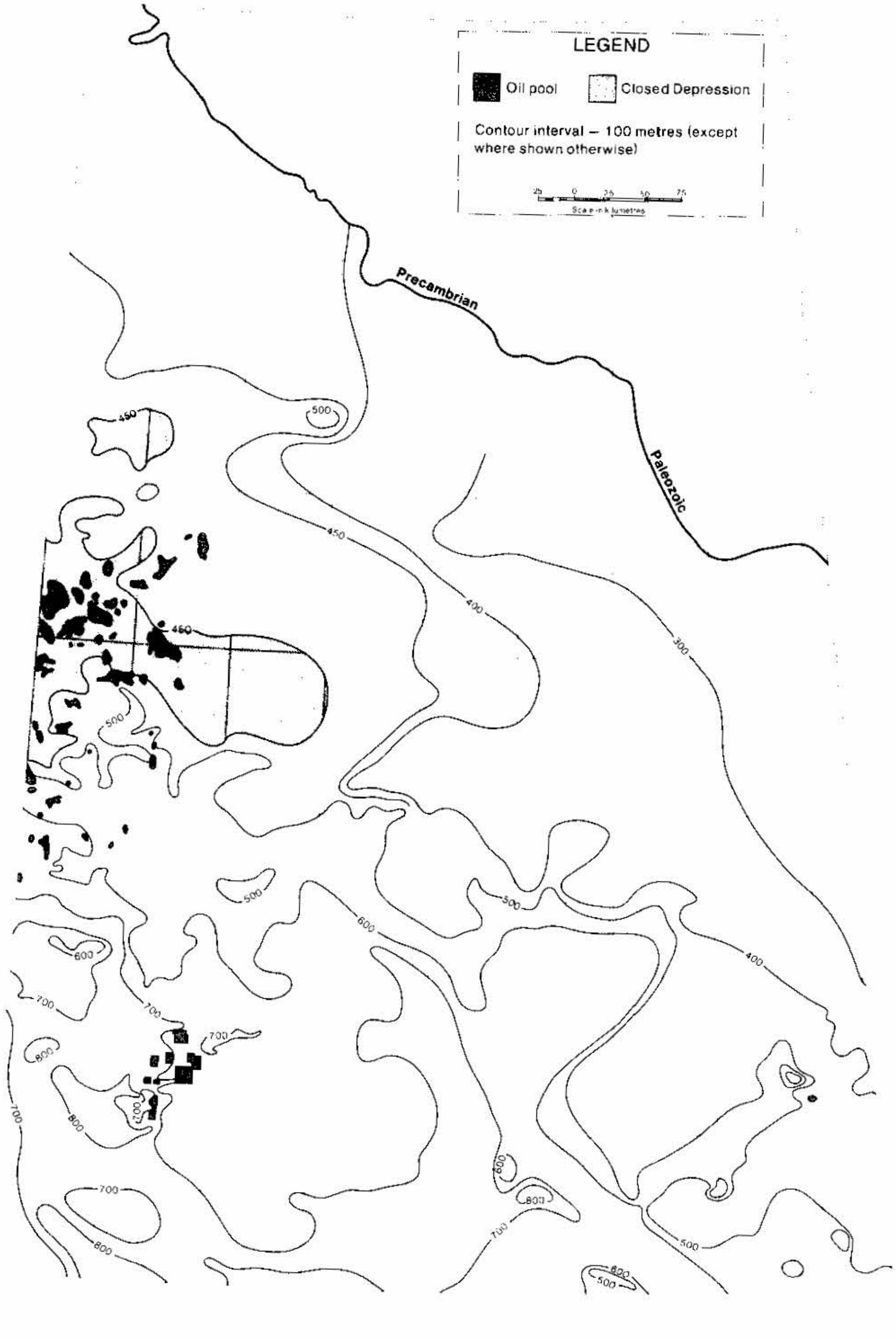

Fig. 4 - Formation water potentiometric map of the Mannville Group, Saskatchewan. Datum sealevel (values calculated from shut-in bottom hole pressures converted to meters of fresh water rise).

is prominent, as is the Punnichy Arch.

The structural surface records not only features of the pre-Dina topography but also the modifications since that time. Thus most of the pre-Dina troughs and linears are modified by extensions and reversals typical of salt solution phenomena. The most striking of the differences however, is the tectonic reversal of the regional gradient; for the Swift Current platform which in early Mannville times commanded the heights of the region now lies near the base of the regional dip. Its elevation is 620 m below the Peter Pond Lake area at Latitude 56 degrees near the border with Alberta. This, when contrasted with the pre-Dina elevation of 590 m above the said reference area, indicates that the Swift Current platform has been lowered 1210 m. Most of this movement reflects the Laramide orogeny and its negative effect on the Williston Basin.

The Potentiometric Surface

A regional potentiometric map for water in the Mannville formation (Fig. 4), as computed from the drill stem tests, reveals a potentiometric surface which declines from above 800 m in the southwest to a regional low below 300 m in the northeast. Moreover, the regional trends are northwesterly and northeasterly and are delineated by sharpened gradients and broader flats. More specifically the potentiometric surface map shows that:

1. values exceeding 800 m occur as closed contours or potentiometric cells (Christopher, 1974, ch. v) in the southwest near Maple Creek and in the south near Ogema, east of the Third Meridian (106 degrees);

2. these potentiometric cells are nuclei of regional ridges (delineated by the 700 m contour) oriented toward the northwest along the eastern and western flanks of the Swift Current platform i.e., along the major linears of the southwest;

3. potentiometric values across the Swift Current platform lie within a spread of 100 m between the 700 and 600 m contours, thereby indicating a region of quasi-stability within an overall surface declining toward the northwest;

4. in the regional decline toward the northeast, elevations fall below those of the outcrops in the Wapawekka (389 m), Pasquia and Porcupine (380 m) Hills;

5. in the northwest (north of Latitude 54 degrees and west of Longitude 107 degrees), the potentiometric elevations coincide with those of the large lakes such as the Peter Pond-Churchill-Ile a la Crosse system (420 m) and Dore (458 m);

6. there are four regional lows or saddles in the west, the largest of which is in the Lloydminster heavy oil district between Latitudes 54^{o} and 52^{o} where values, as contoured on a 50-m interval, form a depression (400-450 m) encompassing most of the heavy oil pools. Three of the lows are crossed by large river systems - the Beaver (north of Latitude 54 degrees), the North Saskatchewan at Lloydminster and the South Saskatchewan at Latitude 51 degrees (700 m closed contour); and

7. in the Kindersley region the pressure ridge (700 m) from the south flanks the southern edge of the oilfield district at Latitude 51 degrees.

In the Swift Current region, formation waters in the Jurassic and Mannville sandstones are pressurized by cross-formational flow from the underlying Paleozoic limestones (Christopher, op. cit.). This flow occurs through vertical fractures that act as conduits or cells from which the water spread down-dip and eastward to 1) trap the Jurassic Shaunavon oil against permeability wedgeouts of sandstone into shale and 2) trap the Upper Jurassic Roseray and Cretaceous Success oils at the up-dip unconformity-truncation of these sands against the less permeable Cantuar infill. Here the reservoirs occur in mesas, buttes and promontories of the pre-Dina topography. The meteoric source of this formation water has been shown to be Paleozoic limestones in the central Montana uplift (op. cit.). The alignment of the Jura-Cretaceous oilfields against the western pressure ridge is a result of the southwesterly dip and buoyancy forces acting to lift the oil up-dip.

In the Lloydminster region where the Mannville lies 500 to 600 m below ground, the formation flow from the south is countered by meteoric water intake from a broad belt to the north of the North Saskatchewan River. The coincidence of the east-west potentiometric trough with the course of the river indicates that the river is tapping the Mannville Formation through its associated glacial and pre-glacial valley gravels. This is more than merely suggested by the fact that the potentiometric levels are within 100 m of the average ground height and well within reach of the pre-glacial valley bottom. The distribution of the heavy oils throughout this potentiometric trough indicates that oil migrating from the south and southwest under the hydrodynamic drive was halted across the shallow dip of the Lloydminster shelf by the inflow from the north. This being a fresh water influx, it also biodegraded the oil as documented by Evans et al., (1971). Likewise to the north and south, the Beaver and South Saskatchewan River systems intercept the Mannville potentiometric surface. Influx to these rivers would be through fractures and faults in the overlying Cretaceous shales.

The Mannville heavy oils of the Kindersley district are hardly distinguishable from like oils in the Coleville sandstones of the Mississippian Bakken Formation (thus both are plotted on the map). These reservoirs are located at and in the vicinity of the up-dip truncation of the Bakken beds on the sub-Mannville unconformity. Oil leaking from these beds is also trapped in the "Detrital" (Success) and other Mannville sandstones.

In southeastern Saskatchewan a pressure ridge trends northeast from Weyburn to Broadview where it ends in a potentiometric cell. This pressure ridge corresponds areally to the Rocanville-Torquay trend (Christopher, 1961, Fig. 29), a structural belt marked by salt solution sinks, fractures and oil shows. The Mannville Wapella oil pool lies immediately to the southeast of the 700 m cell as shown. The inability to offset this pool by subsequent drilling, the presence of the cell, and the location of the pool on a nose within a U-shaped trough suggestive of a salt solution feature, all indicate that the pool is a vertical off-shoot of the Mississippian oil fields. The driving mechanism appears to be the potentiometric cell.

An argument has been made for the migration of oil into the reservoirs of the southwestern oilfields (Rapdan to Battrum) from Paleozoic source rocks (Christopher, 1974, p. 121). The evidence is based on the flow of formation waters, tectonics, as well as on the absence of source rocks. The following conclusions are tentatively made:

1. the source rocks are Paleozoic carbonates;

2. the oil migrated into the Mannville of Saskatchewan by formation water flowing from the deeper part of the basin through fracture conduits in the Paleozoic;

3. the latest phase of this migration coincides with the build up of pressure from the hydraulic head provided by uplift of the central Montana region during the Laramide (Late Cretaceous-Miocene) orogeny.

Another observation is that the potentiometric surface lies at or above bedrock artesian levels in most of the province west of the 400 m contour, with the exception of the Tertiary uplands in the southwest. This may account for much of the salinity in the Late Tertiary and Early Quaternary aquifers of the region.

Acknowledgments

The author is obligated to D.M. Kent of the University of Regina, and his colleagues, P. Guliov, J.A. Lorsong, D.F. Paterson and P. Ramaekers for the interchange of ideas necessary to this work.

References

Christopher, J.E. (1961): Transitional Devonian, Mississippian Formations of Southern Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. No. 61, 63 p.

____________ (1974): The Upper Jurassic Vanguard and Lower Cretaceous Mannville Groups of Southwestern Saskatchewan: Dept. Mineral Resources Rept. No. 15, 349 p.

____________ (1980): The Lower Cretaceous Mannville Group of Saskatchewan - A Tectonic Overview in Beck, L.S., Christopher, J.E., and Kent, D.M., eds., Lloydminster and Beyond: Geology of Mannville Hydrocarbon Reservoirs; Saskatchewan Geological Society Spec. Pub. No. 5, p. 3-32.

Evans, C.R., Rogers, M.A., Bailey, N.J.L. (1971): Evolution and alteration of Petroleum in Western Canada: Chem. Geology, v. 8, p. 147-170.

Kent, D.M. (1968): The Geology of the Upper Devonian Saskatchewan Group and Equivalent Rocks in Western Saskatchewan and Adjacent Areas: Saskatchewan Dept. Mineral Resources Rept. No. 96, 108 p.