

The Heavy Oil-productive Lower Cretaceous Mannville Sandstones of the Unity-Biggar District, West-central Saskatchewan

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Abstract

The Unity-Biggar district is one of several localities south of the Lloydminster heavy oil fields with significant potential for commercial heavy oil production. Forty-eight of the 241 wells drilled in the area have prospective reservoirs in the sandstone bodies of the Pense (McLaren) and Cantuar formations of the Mannville Group. The sandstones bodies are generally curvilinear and are developed as tidal and estuarine channel fills and upper shore beaches anchored to draped topographic valleys, scarps, and prominences on the underlying Devonian carbonates. The commanding structure is the draped form of the sub-Cantuar Wilkie Dome, now tilted to the south by the Laramide Orogeny and delineated by post-Cretaceous salt-dissolution tectonics. Lineaments, both north-south and Laramide northwest and northeast, served as conduits for passage of oil from parent sources in the underlying Devonian strata. Oil reservoirs rise stratigraphically from basal Cantuar (Dina, Cummings, and Lloydminster) in the south to dominantly Upper Cantuar (Waseca W5 and W6) and McLaren in the north.

Keywords: Unity-Biggar, heavy oil, channel sandstones, beach sandstones, drape structure, salt-dissolution tectonics, lineaments.

1. Introduction

Petroleum exploration in the Unity-Biggar district, west-central Saskatchewan, has targeted Mannville and Viking hydrocarbons. In this region, some 241 wells have been drilled, resulting in the discovery of several Viking gas pools and about 48 Mannville heavy oil sites with production potential (Figure 1). About 30 of these wells are petroliferous in the upper part of the Mannville Group, and are concentrated in a northern sector around the village of Wilkie. The lower part of the Mannville Group is oil-saturated in a southern belt of wells that trends 54° northeast between the towns of Kerrobert and Biggar. The petroleum reservoirs lie at depths ranging from 620 m in the north to 780 m in the south. They are hosted in 20 m thick bodies of poorly consolidated quartzose sandstones that are distinct from the regionally more typical semiconsolidated, argillaceous, litharenitic quartzose sandstones and siltstones of the Mannville Group. The area of study lies within Ranges 14W3 and 23W3, and Townships 32 and 42 inclusive. It is dissected by longitude 109° and latitude 52°. Its main topographic feature is the 90 km long Tramping Lake along Ranges 19W3 and 20W3 (Figure 1).

2. Stratigraphic Nomenclature

Mannville terminology in the Lloydminster region was first developed by Nauss (1945) at the type Northwest Mannville No. 1 well (1-15-50-8W4) in east-central Alberta. It was subsequently adapted by Wickenden (1948), Ambler (1951), Kent (1959), Fuglem (1970), Vigrass (1977), and Putnam (1980). The Mannville members of current usage are (oldest to youngest): Dina, Cummings, Lloydminster, Rex, General Petroleum, Sparky, Waseca, McLaren, and Colony. This paper follows the stratigraphic nomenclature of Christopher (in press) which integrates Lloydminster terminology with that utilized in southern Saskatchewan (Price, 1963; Maycock, 1967; Christopher, 1974). Here, the Pense Formation of southern Saskatchewan, by geophysical log and core correlation, includes the McLaren and Colony members. The underlying Mannville units from the Dina to the Waseca (oldest to youngest) are members of the Cantuar Formation.

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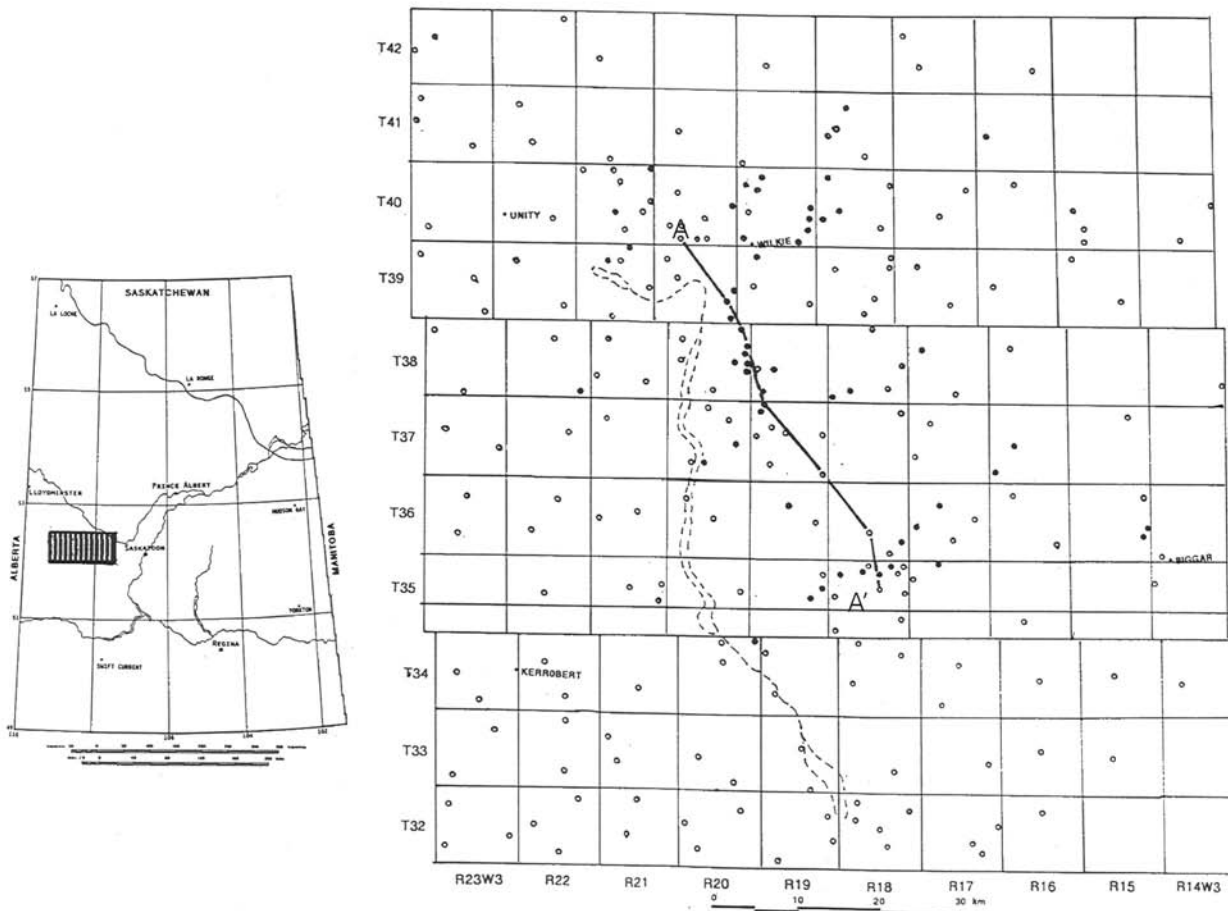


Figure 1 - Location map of study area showing north-south stratigraphic cross section, A-A' of Figure 2.

3. Stratigraphic Setting

The overall setting of the Mannville appears to be transgressive from the northwest with countering progradations from the southeast in the Lower Mannville and from the southwest and northeast in the Upper Mannville. Each Mannville member, in its simplest form, is mapped as beginning with a transgressive facies and ending with a regressive facies. Cyclic bedding typically includes coal-capped, upward-coarsening units that grade from basal shale through sandy mudstone to sandstone, and upward-fining units that grade from basal sandstone to mudstone and shale. Up to 34 bedding cycles have been recorded in a complete Mannville section (Christopher, in press). The basic lithologic category used in the description of cored Mannville sections in the regional Mannville report is the tripartite (and reversible) bedding cycle of shale (a), mixed shale and sandstone (b), and sandstone (c). In the deeper parts of the Mannville Basin, these may represent cyclic sedimentation of the order a, b, c, c, b, a. Over most of Saskatchewan outside the northwestern region, however, the hemicycle on an erosional contact prevails as the dominant upward-coarsening (a, b, c) and the subordinate upward-fining (c, b, a) bedding facies. The bedding cycle appears to be nomenclaturally equivalent to the term parasequence used by Pemberton *et al.* (1994) in the Lloydminster district of east-central Alberta. However, because of the lenticular geometry of the Mannville beds in the study area, no persistent attempt has been made to use the bedding cycle as a correlation tool. The basic lithostratigraphic entity adopted here is a "unit", which typically includes one or more bedding cycles. It more or less corresponds to a parasequence set (Waggoner *et al.*, 1987) in a coastal to shelf setting, and, perhaps, to a transgressive sequence (Embry, 1993), in that reliance is placed on the trace of subaerial pavements and overlying transgressive beds to define its upper surface. A Mannville member includes one or more units. Maximum bedding-cycle thickness in cores of the offshore and shoreline deposits of the Mannville is about 20 m. This is a measure of the amount of sea-level rise and fall, and quantifies the upper limit of base-level change permissible in the correlation framework.

4. Methodology

Mapping the Mannville assemblage of lenticular quartzose sandstone and siltstone, mudstone, and sub-bituminous coal is predicated on the validity of: 1) correlating marine shale beds, 2) distinguishing provenances of different mineral suites, and 3) extrapolating correlative horizons (made possible by extremely low depositional gradients). Stratigraphic difficulties exist in dealing with the Mannville units because marine shelf deposits commonly grade into alluvial deposits inset with fluvial and estuarine channel bodies. Each member includes truncated bedding sequences, erosion channels, and corresponding erosion and exposure surfaces as products of an oscillatory strand. Detailed mapping in the Lloydminster oilfield district to the north of the study area by many workers has been used to delineate the geometry of individual marine and continental bodies, ranging from offshore sand sheets to shoreline beach and tidal channel deposits to onshore deltaic and marsh sediments. These individual forms are simply included between member contacts as relicts and palimpsests (Swift *et al.*, 1971) in the overall transgression and regression.

Regional correlation of Mannville members is based on control lines initiated in the northwestern part of the province where marine shales are most pronounced. A Lower Colorado stratigraphic marker is taken as datum. Recognition of the sub-Mannville contact as a topographic or tectonic datum determines whether the overlying stratigraphic contact is one of onlap or structural warp. Sub-Mannville topographic control results in loss of Mannville units by onlap against highs. Intra-Mannville tectonic control is indicated by the general conformity of member contacts with the basal unconformity, and by loss of stratigraphic units through internal overlap and through erosional truncation against the basal contact of the Pense Formation.

5. Bedding Cycles

Immediately northwest of the study area at Shell Manito 6-7-43-24W3, the fully cored Mannville Group is in erosional contact with the superjacent Joli Fou Formation and the underlying Duperow Formation. The section includes 31 bedding cycles, of which 28 are upward coarsening and three upward fining. They are arranged within the Pense and Cantuar members (youngest at top) as follows:

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

The thickest cyclic beds are in the Dina and Lloydminster members. In the Waseca Member, the ten cycles are condensed by attenuation of bioturbated beds to thin, black, carbonaceous shale overlain by thicker sandstones on erosional bases. The Mannville stratigraphic format at this location closely approximates the rhythmic model of the hemicycle cycle that coarsens upward from offshore black shale, through subtidal, bioturbated, argillaceous sandstone, to wave-dominated shoal sandstone. A capping paleosol and carbonaceous to coaly bed is commonly present. Shoal sandstones above the Lloydminster Member generally display basal rusted, calcite- and siderite-cemented zones in erosional contact with the subjacent bioturbated beds.

Within the study area, glauconite occurs as an accessory mineral in burrow fills and coprolites, and as grains in the medial shale of the Cummings Member and the sandstone and shale of the Lloydminster and Rex members. It is also present in the lower part (McLaren) of the Pense Formation. Capping coal beds commonly terminate the Cummings, Rex, and Sparky members, the W2 and W4 units of the Waseca, and the first unit of the Pense Formation (see 8-11-39-20W3, Figure 2). Thin carbonaceous shale characterizes most of the Waseca cycles. The rootlet zones, oxidized surfaces, and calcite-cemented pavements that appear in all the General Petroleums and Sparky bedding cycles, probably reflect penecontemporaneous, perched groundwater tables. At the Shell Manito well, the two upward-fining beds of the Dina and the first bedding cycle of the Cummings combine to resemble a massive 37 m thick body in which sandstones grade from coarse grained at the base, through medium grained to fine grained at the top. However, regional considerations indicate stacking of two or more depositional bodies, the lowermost representing an initial fluvial setting, the uppermost an estuarine to marine environment. Thick sandstones, best developed in the Waseca Member, are present across the area of study (see Figure 2). The general parallelism of the sub-Waseca members indicates progressive, though episodic, progradation of the Unity Paleoplatform. Local thickening of Waseca units may reflect accommodation of sandstone deposits at sites of active salt dissolution sinks originating in the Middle Devonian Prairie Evaporite (e.g. at 7-5-40-20W3) and/or compaction in sub-Mannville topographic depressions.

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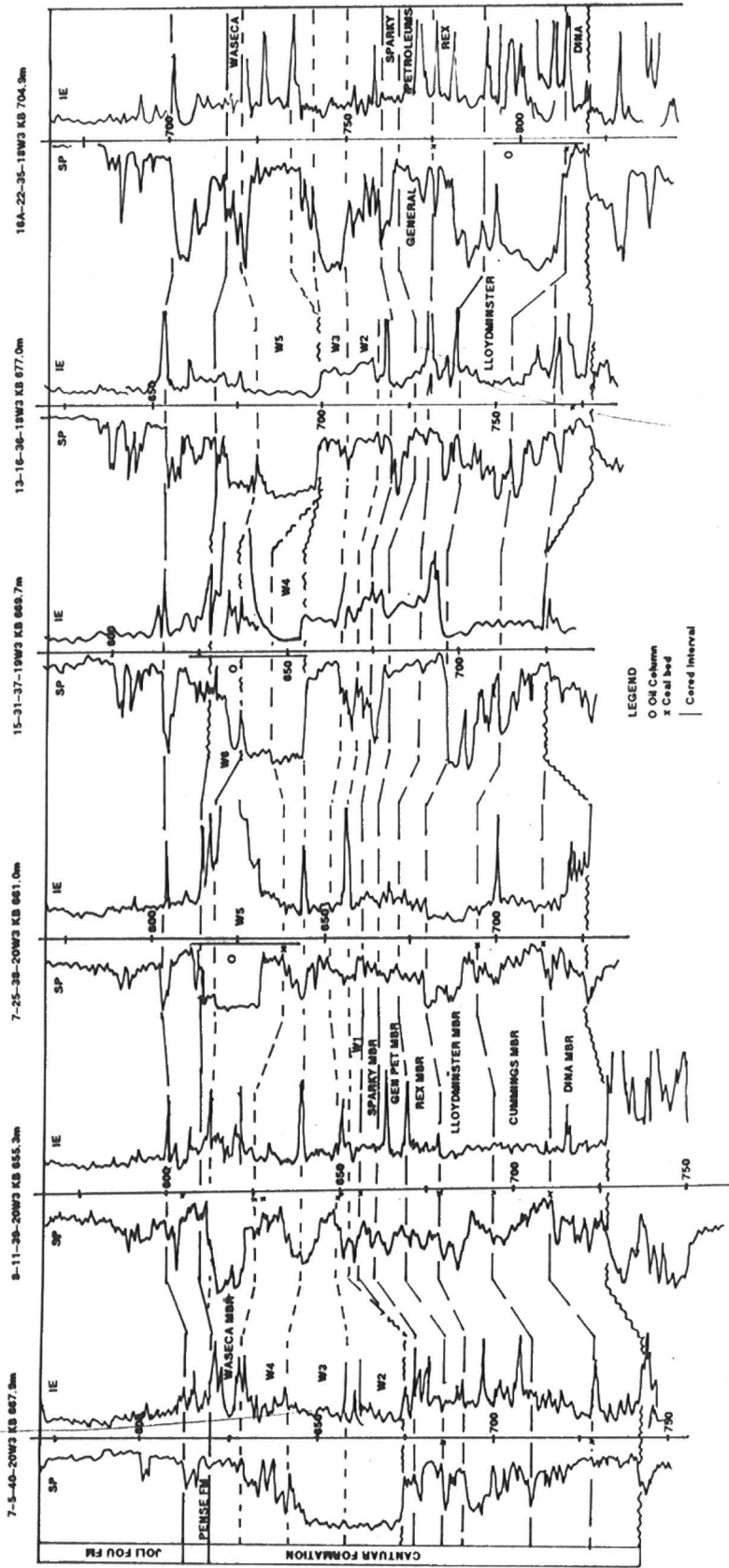


Figure 2 - Stratigraphic cross section of the Mannville Group from 7-5-40-20W3 southward to 16A-22-35-18W3.

6. Morphology of the Local Depositional Basin

The isopach map of the combined Dina and Cummings members of the Cantuar Formation (Figure 3) mirrors the morphology of the pre-Cantuar depositional surface (Christopher, 1980). The study area is situated in the eastern region of the Unity Paleo-upland where it slopes eastward toward the Govan Paleo-lowland basin. The zero isopach of the combined Dina and Cummings members delineates the edge of the Unity Paleo-upland. This region was dominated by the easterly and northerly thalwegs of the Unity and McGee tributaries of the Assiniboia Paleovalley system, here entrenched 30 m deep into Upper Devonian Torquay and Birdbear carbonates. The locale is developed as a broad, shallow amphitheatre that opens to the northeast and slopes from the escarpment of Mississippian Madison limestone situated 16 km south and southwest of the study area. The Wilkie Mesa, central to the study area, forms a low-relief, flat divide below the upland surface and between the north-trending paleovalleys. As elsewhere in Saskatchewan, the sub-Mannville paleovalleys are linked in their courses by salt-dissolution sinks that originate at depth in the Middle Devonian Prairie Evaporite. After initial infill by the Dina, the amphitheatre served as an embayed, shallow, coastal shelf across which agents of deposition and erosion competed during the remainder of Cantuar time.

7. Waseca Sandstones

The thickened Waseca sandstone bodies depicted in Figure 2 reflect a mixed genesis from pre-existent beds in the basin. Compositionally, they are quartz dominant and low in heavy mineral and other rock components. Waseca units W4, W5, and W6 are present in core at Baytex Wilkie 7-25-38-20W3.

Unit W4 consists of 2 m thick bedding couplets of ripple- and current-bedded, quartzose sandstone and subordinate laminae of carbonaceous shale. The lower couplet grades upward into carbonaceous shale, whereas the upper grades into bioturbated sandstone and shale and ends in 2.6 m thick, regionally developed coaly shale.

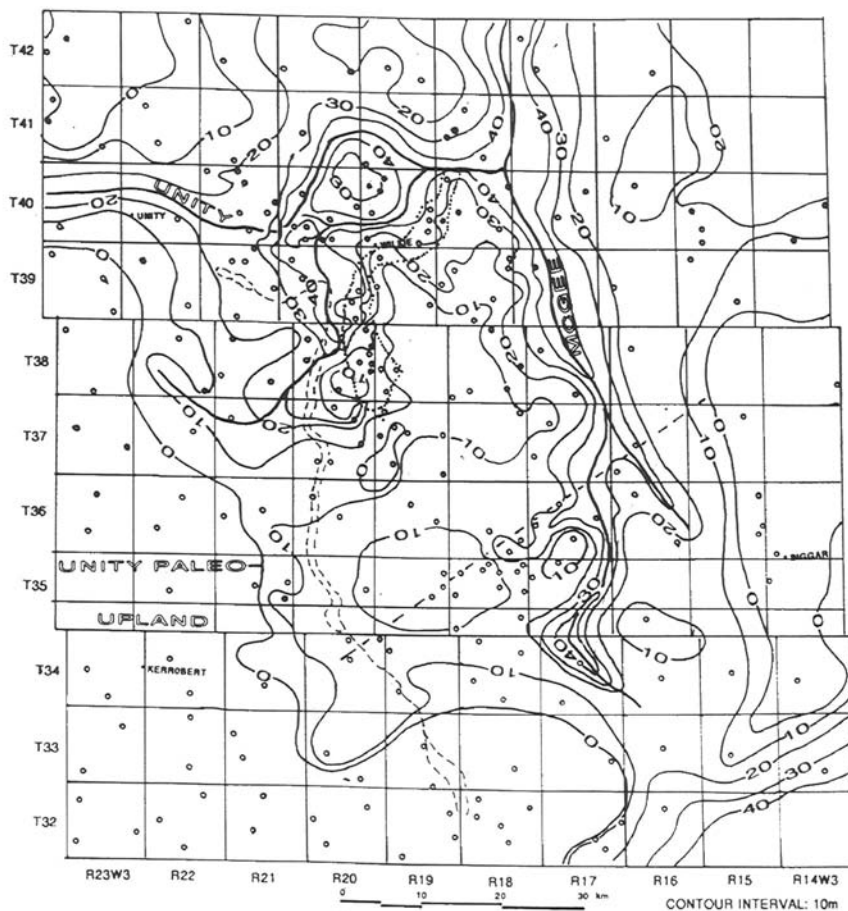


Figure 3 - Isopach map of the combined Dina and Cummings members of the Cantuar Formation.

The overlying 4.73 m thick shale of W5 is similarly widespread and incorporates a flooding surface (Waggoner *et al.*, 1987) that separates a “lower Waseca” from an “upper” (Christopher, in press). The overlying 12.38 m thick, weakly indurated, heavy oil-permeated quartzose sandstone is fine and medium grained, contains accessory kaolinite grains, and displays tabular (set dips are about 20°) and trough cross-sets throughout. Overall grain size increases downward. Rare cherty pebbles are present in the lower half of the bed and clay infilling in the basal 0.5 m. The underlying contact zone is silica cemented and sharply irregular. A channel-fill body is indicated.

The 3.84 m thick W6 heavy oil-permeated quartzose sandstone rests abruptly on W5. It is made up of fine, well sorted, subangular grains, and displays subsets of low-angle, tangential, opposing cross-beds (herringbone) interlayered with subordinate brown concretionary, laminated and herringbone cross-bedded, medium brownish grey, very fine-grained quartzose sandstone and shale. The herringbone cross-stratification

reflects systematic current reversals and, therefore, probable microtidal conditions. Unit W6 is interpreted to represent deposition in progradational tidal conditions, completing infill of a depression that had been initiated at the end of W4 times. Downwarp rather than erosional truncation attributable to sea-level fall is indicated by the presence of underlying W4 coal beds at both 8-11-39-20W3 and 7-25-38-20W3 as well as by thickening of the basal W5 shale at 7-25-38-20W3. At Baytex Cathkin 15-31-37-19W3, sandstones characterize W4, W5, and W6.

The 10 m thick W4 medium greyish brown, permeable, lightly oil-stained sandstone is made up of fine, subangular, well-sorted quartz grains and accessory white kaolinite and black chert. It is tabular cross-bedded (sets dip at about 20°) in its upper half, flat bedded and massive in its lower half. Lags of ironstone pebbles occur 2.5 m above the base and at the basal, sharp, irregular contact. In facies and fabric, the unit is similar to W5 at Baysel Wilkie 7-55-39-20W3, but significant kaolinite and chert content indicates closer proximity to a fluvial source.

The W5 unit at the Cathkin site consists of a 5 m thick lower bed of heavy oil-permeated quartzose sandstone that grades upward from fine grained with 10 per cent clay-draped laminae to fine and medium grained, and from flat bedded to low-angle crossbedded. The upper 3 m of W5 is made up of heavy oil-permeated, fine-grained quartzose sandstone that grades upward into a cap of very fine-grained quartzose sandstone interbedded with subordinate shale. The compound cyclic changes indicated at this site apparently reflect initial shoaling and bar buildup succeeded by shallow subsidence and transgressive infill.

The 3 m thick basal bed of W6 overlies W5 in sharp contact. It is a heavy oil-permeated quartzose sandstone marked by tabular, truncational cross-sets, 0.15 to 0.30 m thick, with set dips ranging from low angle to 25°. Overlying the basal bed are: i) 4.3 m of fine-grained quartzose sandstone that is strewn with boulder and pebble mudstone clasts and that contains minor carbonaceous and coaly shale laminae, ii) sideritic, nodular shale, and iii) a 1.7 m thick bed of argillaceous sandstone. Unit W6 represents channel-fill deposits that include collapse material from undercut banks. In view of the distinctive tidal signature in W6 at Baytex Wilkie 7-25-38-20W3, the presence of a tidal course at Baytex Cathkin 15-31-37-19W3 is suggested.

At 13-16-36-18W3, the base of the W5 surface appears to incise W4 (Figure 2). Earlier, thick W2 and W3 quartzose sandstones (e.g. in 7-5-40-20W3 and 16A-22-35-18W3, Figure 2) are also observed at some localities.

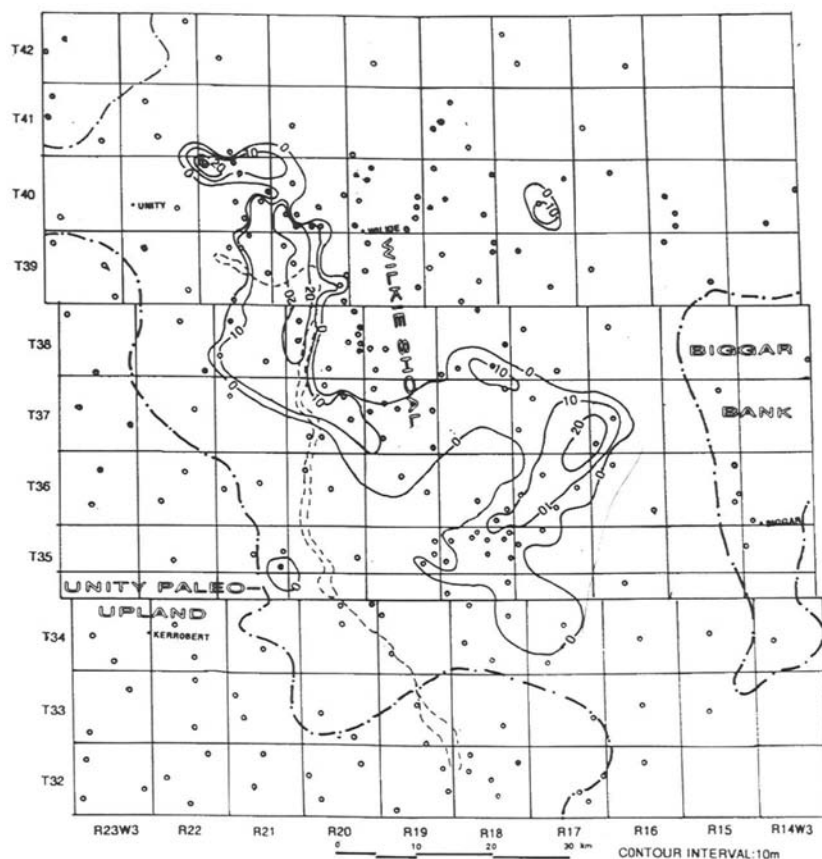


Figure 4 - Isolith map of combined W2 and W3 sandstones.

Although not cored, these sandstones, where present, are conspicuous in well-cuttings samples. The last-cited wells are apparently situated in structural depressions associated with dissolution of salt beds in the Middle Devonian Prairie Evaporite. Subsidence at 16A-22 appears to have been contemporaneous with deposition of Lloydminster and Rex sediments.

8. Sandstone Geometry

Sandstone isolith maps (Figures 4, 5, and 6) show that all Waseca sandstones are contained within the central embayment, and are parallel to, but not necessarily coincident with, the buried zero edges of the underlying combined Dina and Cummings members (equivalent to the edges of the Unity Paleo-upland and the Biggar Bank). The sandstone isoliths of the combined units W2 and W3 (Figure 4) form a 10 km wide linear band oriented west-east and north-south over its 34 km long northern section, and, in five reticulate segments, southeast, northeast, southeast,

southwest and southeast over its 87 km long southern section. They follow a pattern which, in the north, lies along dominant, basement-controlled, north-south and east-west lineament sets, and, in the south, conforms to Laramide northwest and northeast lineament sets (Gough and Bell, 1981). The isoliths thicken to more than 30 m in the north, and 20 m in the south. The northern maxima appear to be related to accommodation in salt-dissolution sinks active during deposition of the sand and probably represent channel fills. The buildup along the southern southwesterly segments apparently resulted from wave motion and shore accretionary currents acting on the channel influx from the north. In this context the southern sand bodies draped the flanks of the buried Wilkie Mesa.

In general, Waseca W4 sandstone bodies flank W2 and W3 sandstones to the east and west of the combination's northern area of distribution and, except for scattered pockets, to the south of its southern section. The W4 pattern is that of a 15 m thick, broad rectangular sheet, that may have once covered the Wilkie shelf, although only remnants have survived pre-W5 marine planation. W4 sandstones are terminated to the north and east by depressions or troughs related to compaction or incomplete infill of the Unity and McGee paleovalleys. To the west and south, they encroach the Unity Paleo-upland. Their distribution suggests a reworking of shoal sands in a marine basin undergoing mild progradation. Regression is also suggested by the widespread distribution of outlying terminal W4 coal beds, indicative of paralic marshes.

Combined Waseca W5 and W6 sandstones more or less drape the buried form of the Wilkie Mesa (Figure 6). The sandstone body is rectangular in plan and is aligned north-northwest with short spurs to the west in the northwest, to the north-northeast in the northeast, and to the south-southeast in the south. Thickness across the 17 km wide body is generally less than 10 m, and decreases internally to zero in Township 38, Range 18W3. Linear sandy belts, 1 to 2 km wide and 10 m to more than 30 m thick, flank the main body along its perimeter, except in the northwest. The combined W5 and W6 isolith map, when overlaid on the isopach map of the combined Dina and Cummings members (Figure 3), reveals alignment of the eastern and southeastern linear sandstone bodies with the underlying upper slope of the Wilkie Mesa. These linear bodies overlook the McGee Paleovalley and its upper tributary valley to the southwest in Township 36, Range 17W3 and 18W3. Core from Baytex Cathkin 15-31-37-19W3 shows these sandstones as having shoaling characteristics. The environment of deposition was, therefore, probably a barrier bar fronting the upper slope of a shallow interior shelf. The western linear body lies parallel to the eastern bar front but lacks an offshore trench. Rather, it appears to be anchored to draped topographic knolls, thereby forming an upper

stage strand of beach and short-length channel sandstones overlooking the Wilkie shelf to the east. Overall, the combined W5 and W6 sandstone body is located centrally within the embayment indicated by the zero contour of the combined Dina-Cummings isopach map, and impinges the Unity Paleo-upland only in the extreme south.

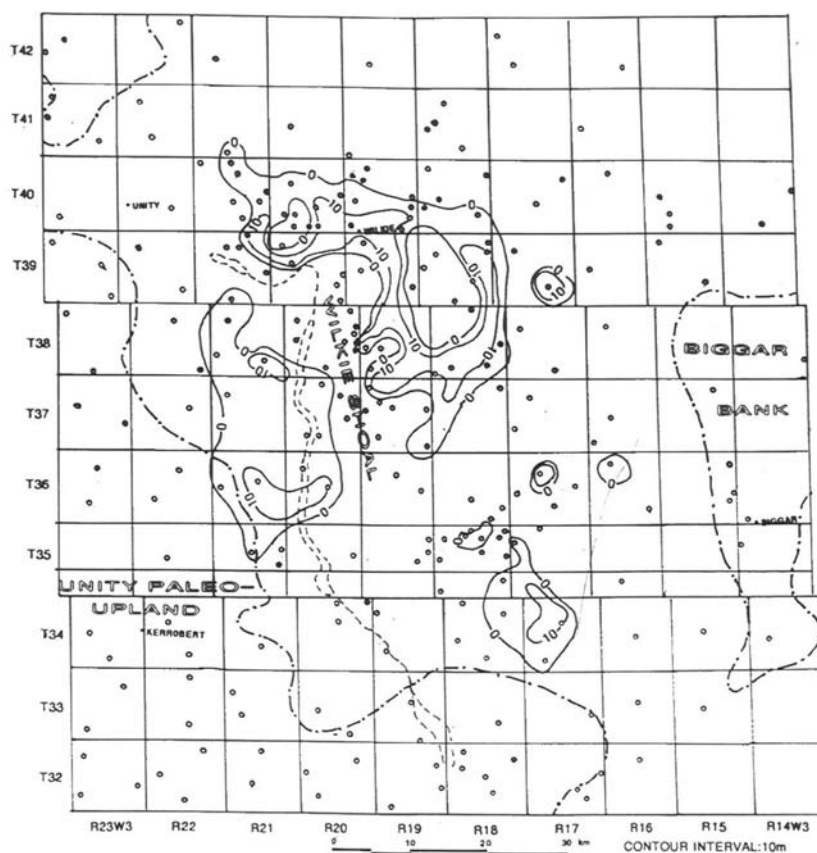


Figure 5 - Isolith map of W4 sandstones.

9. Depositional History

Like their predecessors, the original sediments forming the combined W5 and W6 sandstones probably entered the shoal basin by way of the depression linked to the buried Unity Paleovalley west of the village of Unity in Township 40, Range 23 W3. Waseca sands on the shelf were apparently distributed by fluvial and or estuarine drainage south-southeast across the Wilkie shoal onto a marine strand open to the southeast and northeast during W2 and W3 times. W4 transgression and succeeding progradation resulted in the widest spread of sands and attachment to the low-lying

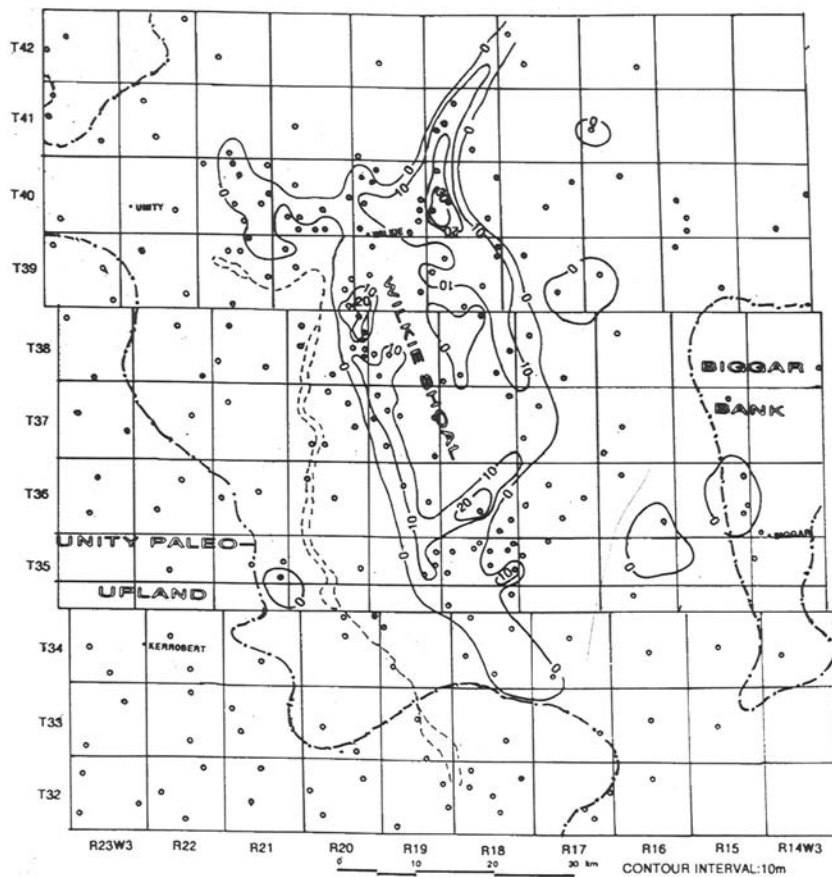


Figure 6 - Isolith map of combined W5 and W6 sandstones.

draped Unity Paleo-upland marshy coast to the southwest. The W4 terrain was mildly eroded by W5 marine transgression, resulting in the removal of W4 sands from the crown of the draped Wilkie Mesa, and from the southeastern flank by benching. The physical separation of the W4 body in Range 19W3 and 20W3 may reflect tidal channeling above the buried course of the W3-W2 fluvial-estuarine channel. Collectively the Waseca sandstone bodies formed an island made up of palimpsests (i.e. remnants of more extensive bodies) not unlike the stacking of bypass sandstones on the shelf of the Java Sea (Posamentier, 2001) or the North Atlantic shelf (Swift *et al.*, 1971). A comparable generation of these Waseca sandstones is described for the Swift Current Platform southwest of the City of Swift Current (Christopher, 1974, Figures 38 and 39, wherein they are equivalent to late Atlas sandstones). Fetch in the study area was apparently from the southeast and northeast.

10. Structural Control

The southward tilted Wilkie Dome, as depicted by contours on the top of the Cantuar Formation between Ranges 18W3 and 21W3 and Townships 34 and 40 inclusive, commands the structural surface from an elevation of 70 m (msl) in the north to -40 m (msl) in the south (Figure 7). A 16 km wide trough, 60 m deep overall, and 120 m deep locally, demarcates its eastern flank, and a series of shallow, southerly plunging re-entrants 10 km west of Tramping Lake delineates the western side. The dome is terminated to the north in Township 41 by a structural depression, and to the south by a series of lows in Township 33. Although the structural surface is largely defined by Laramide tilt, much of the pre-Cantuar configuration is retained. Of particular interest are: 1) the crest of the Wilkie Dome, which corresponds to the draped Wilkie Mesa that supports the Waseca sandstone sheets; 2) the narrow depression defining the eastern flank of the dome, which coincides with the course of the McGee Paleovalley but has twice the relief; and 3) the annular trough delineating the Wilkie Dome, which corresponds to the edge of the pre-Cantuar paleo-upland from Biggar in the east, to Kerrobert in the southwest, to Unity in the northwest. The last of these relationships accounts for the relative decrease of Waseca sandstones between the draped Wilkie Mesa and the Unity Paleo-upland, in that the extant littoral currents apparently lacked the energy to drive sands across depressions in the embayment. Deepening and widening the eastern structural compound trough is a consequence of post-Cantuar collapse due to renewed dissolution at depth of salt beds of the Middle Devonian Prairie Evaporite.

11. Setting of the Petroleum Reservoirs

The bulk of upper Mannville heavy oil prospects discovered to date in the study area centre on 20 wells drilled into the Waseca W5 unit (see Figure 7, enclosed by dotted line). These wells lie within a 2 to 3 km wide belt that, projected onto the top of the Cantuar Formation, rises from an elevation of 32 to 72 m on the crest of the Wilkie Dome. On the Dina-Cummings isopach map (Figure 3), it aligns with the western and northern flanks of the Wilkie Mesa and overlooks the Wilkie Paleovalley. The thickness of heavy oil columns ranges from a full-section 17 m at 3-7-38-19W3 northward to part-sections of 13 m and 8 m at 3-36-38-20W3 and 11-1-39-20W3, where the sandstone bodies thicken to 20 m and 13 m respectively. Farther north, at 5-18-40-18W3, the oil column involves

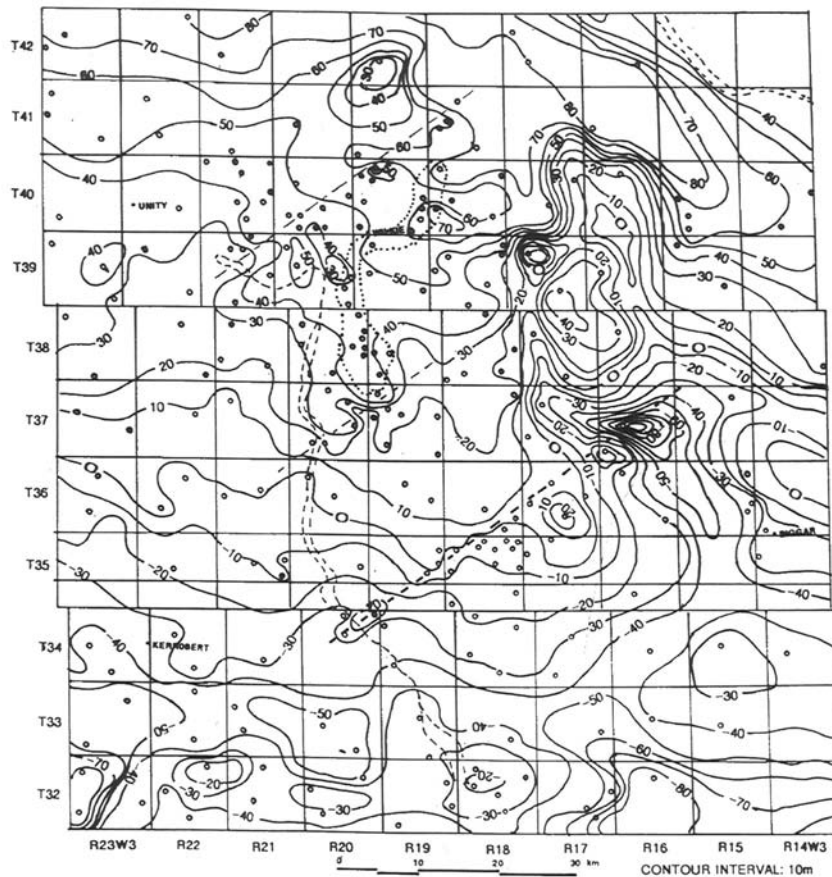


Figure 7 - Structure map on the Cantuar Formation. Outline of W5 petroliferous belt is dotted; short dashed line depicts linear belt of lower Cantuar heavy oil accumulations; long-dashed lines depict upper Cantuar and Pense petroliferous trends.

infill. Southward, post-Cantuar structural tilt of the dome is Laramide in age (i.e. Late Cretaceous), in keeping with renewed downwarp and expansion of the Williston Basin. Migration of petroleum into the Waseca W5 sandstone bodies would have been in post-Albian Cretaceous time, early enough for biodegradation and partial encapsulation prior to development of the southerly tilt. This structural incongruity of oilfield distribution has been described for the heavy oilfields in the Lloydminster district to the north (Haidl, 1984, 1986) and the medium-gravity oilfields in the Swift Current district to the south (Christopher, 1984). There is also a stratigraphic rise in position of the reservoirs in that, northward on the dome, W6 and Pense Formation sandstones become oil-bearing in Township 40, Range 19W3 and 21W3, (specifically in wells 10-16 and 9-36-40-21W3, and 10-30 and 8-32-40-19W3). This progression is consistent with the regional one wherein, to the south, W3 sandstones are petroliferous in Township 37, and farther south, Lloydminster, Cummings, and Dina sandstones are oil permeated.

A major belt of oil shows is also located on the southeastern lower flank of the Wilkie Dome. It is delineated by 12 wells aligned on a bearing of N54° from 13-36-34-20W3 in the southwest to 1-20-37-16W3 in the northeast (Figure 7). All reservoirs are lower Cantuar, involving one or other of the Dina, Cummings, and Lloydminster members. They may be further categorized as reservoirs in near or actual contact with underlying Paleozoic formations that serve as oil source beds. Two of the wells, 16-14-35-19W3 and A2-25-35-19W3, at the southwestern end of the belt penetrate oil-bearing Upper Devonian Birdbear strata. The bearing N54° is characteristic of regional lineaments in the Lloydminster district (Mollard, 1987; Gregor, 1997) and the Kindersley Platform immediately to the south (Christopher, 1999). The lineaments in the Kindersley district apparently facilitated cross-formation migration of oil from underlying Paleozoic strata into the Jura-Cretaceous Success Formation and the Lower Cretaceous Mannville Group. In the study area, oil columns in the Cantuar members on the lineament are 2 to 7 m thick. The lineament was apparently active during pre-Cantuar and Cantuar times as suggested by the coincident alignment of a tributary to the McGee Paleovalley (Figure 3), and the orientation of W2-W3 and W5 beach deposits (Figures 4 and 6). Late Cretaceous movement at 1-20-37-16W3 is suggested by oil-bearing sandstones of the Lloydminster Member found 100 m below datum in a salt-dissolution collapse site. The sandstone is heavy oil saturated and presumably

the upper 12 m of a total sandstone section of 32 m, the upper 8 m of the 25 m section at 1-31-40-18W3, and the upper 2.5 m of the 17 m section at 4-18-41-18W3. Thinner oil columns corresponding to thinner sandstone beds prevail in the intervening zone in Township 39, Range 19W3. The northward thinning of oil columns relative to the available reservoir section seems incongruous with the buoyancy forces consistent with a northward rise in elevation on the dome. Additionally, the trace of W5 reservoir sandstones on the Dina-Cummings isopach map (Figure 3) suggests a former northeasterly slope to the Wilkie Mesa. Both relationships indicate a reversal of elevation across the dome, which occurred after filling of the reservoirs and congealing of the oil in place. The draped configuration would have located the apex of the dome in Township 38 (i.e. at the site of the buried pre-Cantuar Wilkie Mesa). Thus compactional drape of pre-Cantuar paleotopographic elements by Waseca sediments provided a primary control for emplacement of oil in the reservoirs. The structural Wilkie Dome probably reflects the westward build-out of the Wilkie Mesa into the Wilkie Paleovalley by virtue of Waseca sandstone

biodegraded, and thereby indicates pre-collapse migration and fixation of oil into the reservoir. Strike-slip movement along the lineament may be indicated by the easterly offset of the zero structural contour on the broad nose of the dome, and a similar deflection to the northeast of contours outlining the northern flank of the inner trough east of the dome in Township 37. An indication of a similar lineament that crosses the dome farther north is given by a parallel alignment of W1 to W3 oil shows at 10-8-37-20W3 (completed as Sparky), 6-24-37-20W3 (6 m oil column) and 15-31-37-19W3 (cased as Sparky). This particular lineament may also have served as a conduit that fed oil into the W5 sandstone body immediately to the north. A third set of lineament-controlled oil shows, here in upper Waseca and Pense sandstone bodies, can be traced from Township 39, Range 21W3 to Township 41, Range 18W3.

12. References

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