Hydrocarbon Potential of the Bakken and Torquay Formations, Southeastern Saskatchewan

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Abstract

Detailed examination of Bakken cores, geophysical logs, and production data in southeastern Saskatchewan indicates that significant potential exists for by-passed pay and finding additional oil in siltstones and sandstones of the Middle Member of the Bakken Formation. Weathered and brecciated dolostones of the Torquay Formation in southeastern Saskatchewan also exhibit high and relatively untested potential for oil production. The relatively low permeability of these rocks suggests that they might best be developed using horizontal-completion drilling programs. Recognition of structural and anomalous resistivity trends has implications for hydrocarbon exploration in this area.

Keywords: *Bakken, Torquay, Devonian, Mississippian, Williston Basin, source rock, by-passed pay, high-resistivity shales.*

1. Introduction

Shales of the Upper Devonian to Lower Mississippian Bakken Formation in the Williston Basin have generated and expelled at least 16 billion m^3 (100 billion barrels) of oil, of which only a small fraction has been identified in, or produced from, Williston Basin reservoirs. Recently, horizontal drilling and large sand-fracture completions have resulted in significant production of Bakken oil in Richland County, Montana. Detailed examination of Bakken cores, geophysical logs, and production data in southeastern Saskatchewan indicates that similar exploitation potential exists using horizontal completions, identifying by-passed pay, and finding additional oil in siltstones and sandstones of the Middle Member of the Bakken Formation. Weathered and brecciated dolostones of the Torquay Formation in southeastern Saskatchewan also exhibit high, relatively untested potential for oil production.

To date, most Bakken production in Saskatchewan has been from siltstones and sandstones of the Middle Member. During the late 1980s to early 1990s, however, additional production in North Dakota was obtained from overlying and underlying Bakken shale members. More recently in Richland County, eastern Montana, horizontal drilling has proved to be a successful method for producing Bakken oil from sandstones, siltstones, and limestones of the Middle Member. Common practice in this area is to drill one or two laterals that are subsequently subjected to sand-fracture completions using as much as 450 000 kg (1,000,000 lbs) of sand. The economic success of this play has spurred a renewed interest in land acquisition and exploration of the Bakken eastward and northward into North Dakota, and into the Estevan area of southeastern Saskatchewan. Over the past 19 months, Bakken oil production in southeastern Saskatchewan has jumped from approx. 3000 m^3/mo (July 2003) to approx. 5700 m^3/mo (February 2005), and the number of producing wells has risen from 62 to 87.

2. General Stratigraphy

The Bakken Formation is present over a large portion of southeastern Saskatchewan and generally ranges in thickness from zero to 30 m (Figure 1).It is, however, more than 70 m thick in places where salt collapse structures have formed. The formation is subdivided into three members characterized by a middle siltstone to sandstone unit sandwiched between black organic-rich shales. These organic-rich shales are considered to be source rocks (Dow, 1974; Williams, 1974; Meissner, 1978; Schmoker and Hester, 1983; Leenheer, 1984; Price *et al.*, 1984; Webster, 1984; Dembicki and Pirkle, 1985; Osadetz *et al.*, 1992; Osadetz *et al.*, 1994; Caplan and Bustin, 1996; Stasiuk and Fowler, 2004). The source-rock potential and thermal maturity of Bakken shales are discussed in Kreis *et al.* (2005).

In southeastern Saskatchewan, the Late Devonian to Early Mississippian Bakken Formation is conformably overlain by grey, fossiliferous limestones of the Souris Valley (Lodgepole) Formation of Mississippian (Kinderhookian) age. The Bakken Formation conformably overlies greenish grey shales of the Big Valley Formation in much of southeastern Saskatchewan. Where Bakken overlaps the Big Valley, it unconformably overlies interbedded

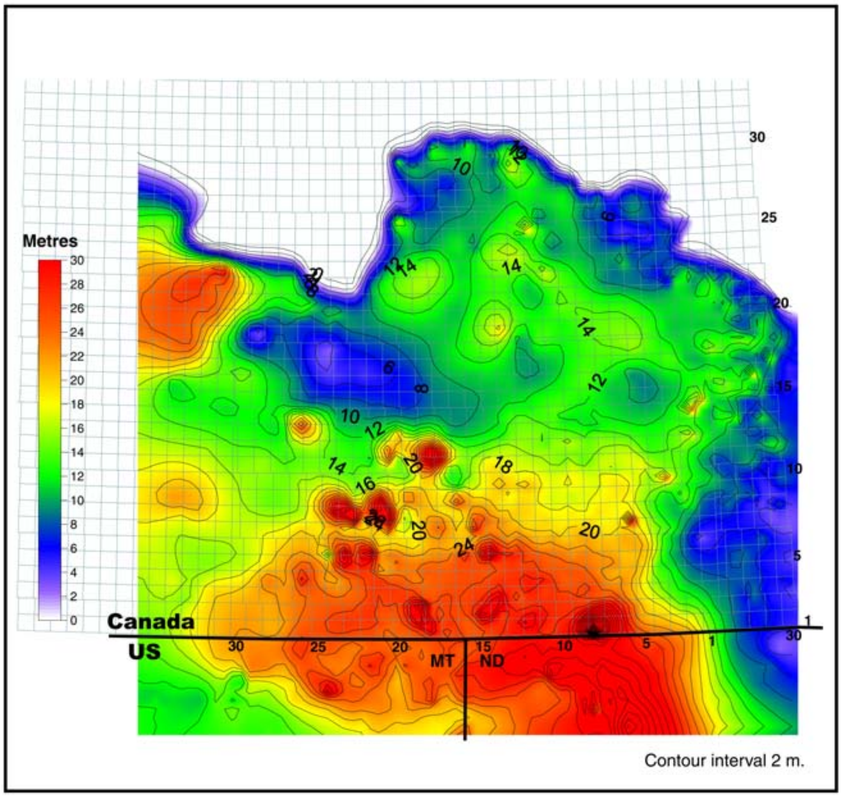

Figure 1 - Isopach map of the Bakken Formation in southeastern Saskatchewan.

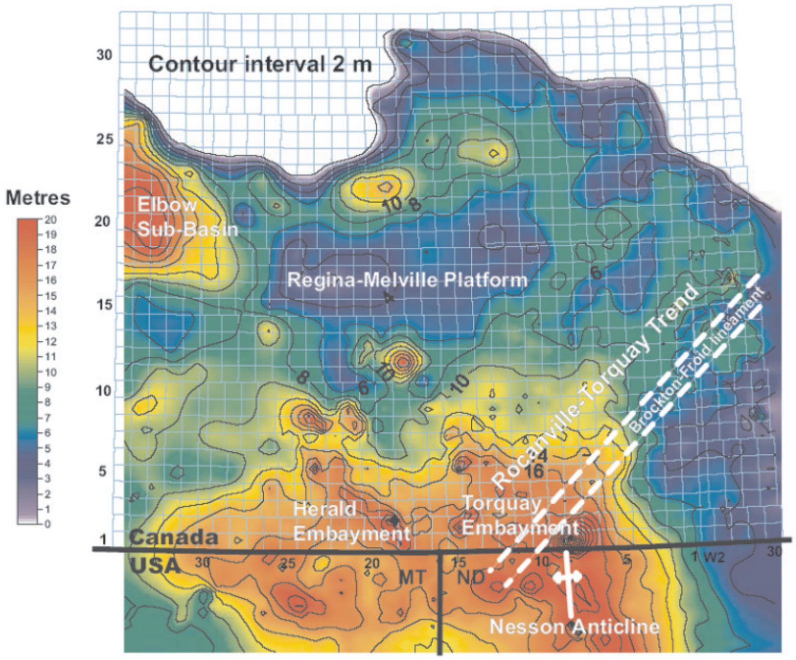

Figure 2 - Isopach map of the Middle Member of the Bakken Formation.

weathered dolostones, dolarenites, dolomitic mudstones, and minor anhydrites of the Upper Devonian Torquay Formation (Christopher, 1961).

A more detailed discussion of Bakken and Torquay formation stratigraphy can be found in Kreis *et al.* (2005).

3. Bakken Regional Geology

Sandstones and siltstones of the Middle Member of the Bakken Formation become increasingly thick towards the unit's depositional centre in northwestern North Dakota and northeastern Montana. In Saskatchewan, the Middle Member reaches a regional thickness of about 25 m, but, above areas of known salt dissolution, it attains thicknesses of up to 44 m. Anomalous thickening is also observed in shales of the Lower Member at these locales. Christopher (1961) recognized and named two areas of thick Bakken in the south the Torquay and Herald embayments (Figure 2), and a thick region along the western margin, the Elbow Sub-Basin, a feature related to contemporaneous dissolution of the underlying Prairie Evaporite Formation. Relatively thin Middle Bakken occurs in the vicinity of the Regina-Melville Platform (T18-R23W2) and in the extreme southeastern portion of the map, which is discussed later with respect to its significance to the Torquay Formation play. A noteworthy feature of the isopach map of the Middle Member is a relatively thick zone of Middle Bakken that extends southwest from the Rocanville Pool to the Torquay Embayment. This northeast-southeast trend is coincident with the Rocanville-Torquay trend (Figure 2), also named by Christopher (1961), about which he stated "…this trend consists of a band of northeasterly aligned furrows into which the study beds are downwarped" (p59). He noted that salt sinks in the Rocanville, Wapella, and Kisbey pools, as well as oil shows and oil production in Bakken and older strata, were aligned along this trend, which is parallel to, if not coincident with, the northeasterly projection of the Brockton-Froid-Fromberg Fault Zone in northeastern Montana and northwestern North Dakota. This trend has been considered a migration fairway in the U.S. part of the Williston Basin (Gerhard *et al.*, 1987). Recent examination of cores and geophysical logs suggests that sandstones developed along this northeasterly trend are potential migration conduits for Bakken-sourced oil into the Rocanville region.

In southeastern Saskatchewan, the Middle Member of the Bakken Formation was divided by Kreis *et al.* (2005) into the following sub units:

Unit A: Massive, medium grey to dark greenish grey, calcareous, argillaceous, pyritiferous, fossiliferous siltstone. Calcitic brachiopod shells are common. Unit A records the initial transgression of the Middle Member sea with deposition of silt and clay in a quiet-water environment that favoured preservation of abundant brachiopods. This unit shows little to no oil reservoir potential in all cores observed in this study. Unit A unconformably overlies the Lower Member Bakken Formation shale (Christopher, 1961). Unit A pinches out and is overlapped to the northeast by unit A1.

Unit A1: Unit A1 is in gradational contact with the underlying unit A. In southern portions of the study area, it is generally a light greenish grey to dark greenish grey argillaceous siltstone to silty, argillaceous, very fine grained quartzose sandstone. Sedimentary structures are diverse, but the unit is generally characterized by a sequence of moderately to highly bioturbated, wispy laminated siltstones interbedded with very silty and argillaceous very fine-grained sandstones. In some localities, the sandstones are less argillaceous and sedimentary structures such as flaser-bedding, current ripples and low-angle laminations suggest deposition in higher energy environments that may be found in a shallow-shelf or near-shore setting that was tidally influenced. Regionally, unit A1 appears to become increasingly less argillaceous to the north and east toward the Viewfield and Rocanville areas.

Unit B: Unit B disconformably overlies unit A1. In most cores the contact is sharp and erosive. Unit B is typically made up of light to medium grey, calcite-cemented, very fine- to fine-grained, clear quartz sandstone to oolitic calcarenite. Sedimentary structures are diverse. The lower portion of this unit is commonly massive, but in places shows cross-bedding with dips measuring up to 15°. The upper portion of this unit is generally overlain by thinly laminated, silty and argillaceous, very fine-grained sandstones that grade up into interbedded and bioturbated, argillaceous siltstones and silty, very fine-grained sandstones of unit C.

Unit C: The lower metre or two of unit C is characterized by a widespread marker bed made up of interbedded siltstones and sandstones. From log correlation, the marker bed appears to undergo a facies change into laminated sandstones in the Rocanville area where it is an effective reservoir rock in some wells. Unit C oversteps unit B towards the east-northeast. It is distinguished by bioturbated beds of light grey to tan (*i.e.*, cleaner), silty, very fine-grained sandstones and argillaceous siltstones in gradational contact with the underlying unit B and with overlying massive to wispy laminated medium grey to light grey calcareous and argillaceous siltstones of unit C.

a) Bakken Shale Resistivity Anomaly

In places, the Upper and Lower Member shales of the Bakken Formation show very high resistivity values (Figures 3 and 4) that are attributed to the presence of oil which has replaced conductive pore waters. With continued oil replacement, oil saturation increases to produce progressively higher formation resistivity values. Other rock characteristics such as mineralogy, porosity, tortuosity, and the salinity of water within pore volume also contribute to the resistivity-log response of the shale, but these parameters are apparently secondary to the presence of oil in the shales (Schmoker and Hester, 1990). Although resistivity values do not distinguish whether oil has been generated *in situ* within the shales at a given location or has migrated into or within the shales, extensive Bakken core research by Schmoker and Hester (1990) has indicated that a resistivity value of greater than 35 ohm-m coincides with the onset of observable oil generation within Bakken shale. Resistivity values for Upper and Lower Member shales were mapped in southeastern Saskatchewan (Figures 3 and 4) using only deep-reading laterologs and without applying borehole or environmental corrections. Areas having resistivity values in excess of 35 ohm-m in the Upper Member shale oversteps that of the Lower Member shale.

It is noteworthy that the area of highest resistivities for Upper and Lower Bakken shales is located immediately north and west of the Nesson Anticline, a feature associated with the region of enhanced hydrocarbon generation in the United States and spatially located within the Trans Hudson Orogen (Kreis and Kent, 2000). This region has been documented to have anomalously high heat flow, probably related to basement tectonics (Majorowicz *et al.*, 1986; Majorowicz *et al.*, 1988), and enhanced hydrocarbon generation (Osadetz and Snowdon, 1995). A northeast-southwest–striking trend of exceptionally high resistivities (*e.g.*, 8-13-1-10W2 reads over 25 000 ohm-m in the Upper Member shale) is recognized on the Upper Member shale resistivity map, and is parallel to, and possibly a northeasterly extension of, the Brockton-Froid-Fromberg Fault Zone (Figure 4). Also, the salt-free area known as the Hummingbird Trough, where tectonic stress concentrations might be expected, is coincident with a region of anomalous resistivity values in both Upper and Lower Bakken shales. Recognition of these structural and resistivity trends has implications for hydrocarbon exploration in this area.

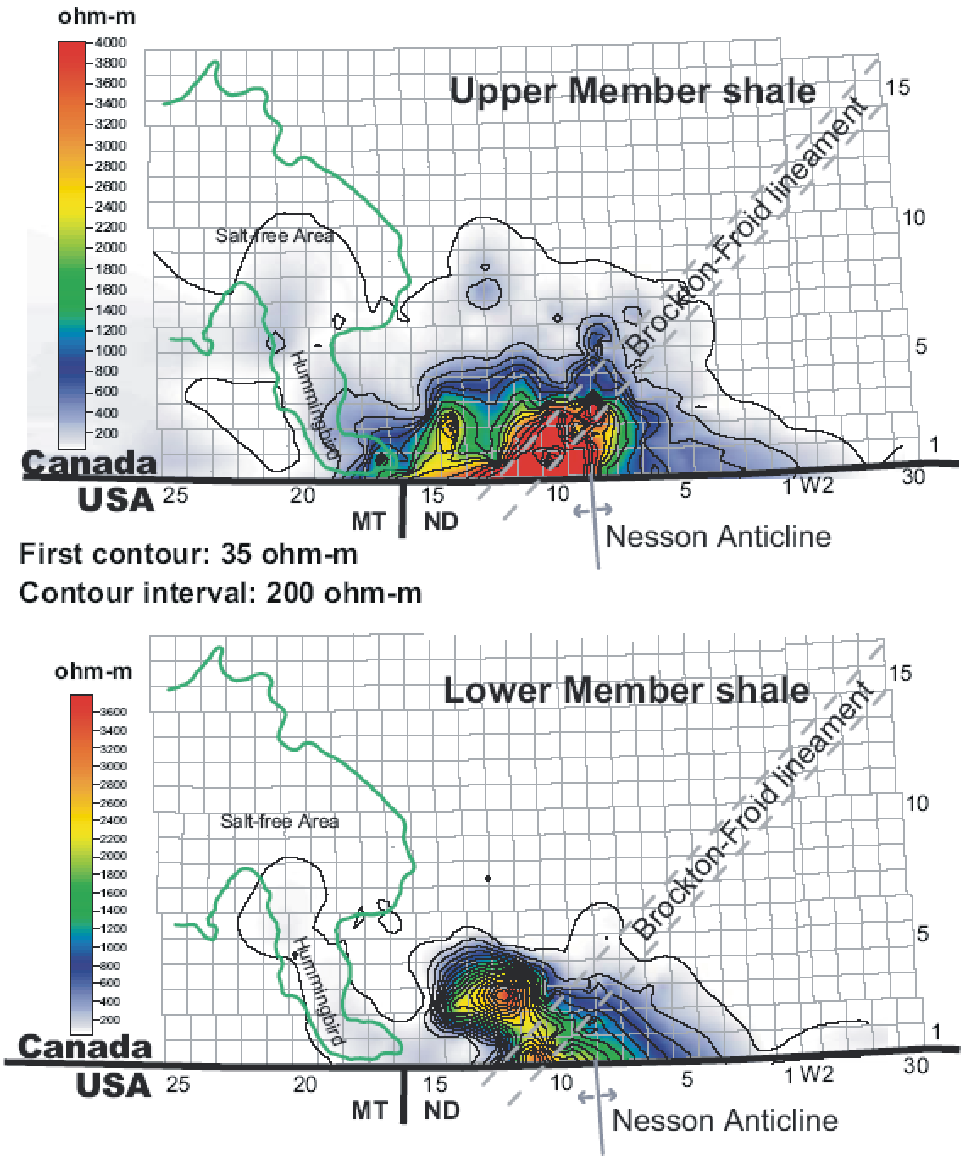

Figure 3 - Maps indicating distribution of anomalous resistivity values in the Upper (top) and Lower (bottom) Member shales of the Bakken Formation.

b) Low-Resistivity Pay

Reservoir quality in Middle Bakken sandstones and siltstones is generally fair to poor. Porosity usually ranges from 5 to 15%, but can reach over 20% in some locales such as in the Rocanville Pool in Tp 15 and 16, Rge 31W1. Permeabilities commonly range from 1 to 20 md. The relatively low permeability of these rocks suggests they might best be developed using horizontal completion programs.

Historically, exploration companies have targeted “clean” (*i.e.*, generally low argillaceous content) sandstones with relatively high geophysical log resistivities as their primary reservoir in southern areas near to the U.S. border. However, perforated intervals of high resistivity are commonly calcite-cemented sandstone with moderate to poor reservoir characteristics. Careful examination of numerous cores in this study has shown that, where present, the “dirtier” (*i.e.*, more silty and argillaceous) sandstone immediately overlying the calcite-cemented lower portion of unit B often shows a faint oil stain that produces a strong milk-white cut but gives a very low resistivity on geophysical logs (*i.e.*, 1.5 to 3 ohm-m). When completing the calcite-cemented portion of the Middle Bakken, companies have regularly fractured and sometimes acidized the interval in an effort to enhance production, but they have often ignored the immediately overlying non-calcite-cemented “dirty” sandstone (Kreis *et al.*, 2005). Resistivity values over this upper interval are only a few ohm-m but a faint oil stain and strong milk-white cuts were observed.

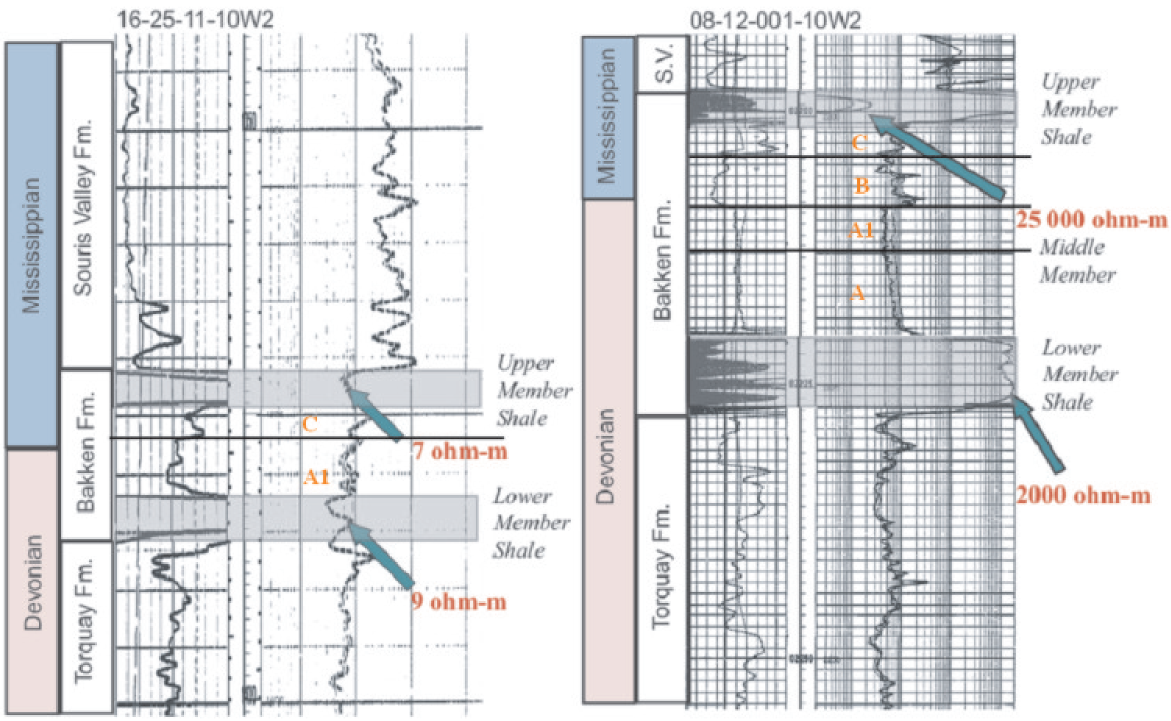

Figure 4 - Resistivity logs showing normal (left) and anomalous (right) readings in the Upper and Lower Member shales of the Bakken Formation. Units A1, B, and C are defined in the text.

Worthington (2000) discusses factors controlling low-resistivity pay zones citing numerous examples from around the world. He indicates that the low-resistivity pay problem is focused upon the inability to accurately evaluate water saturations from a resistivity log in certain circumstances. He suggests that this problem is most common in reservoirs displaying one or more of the following characteristics: laminated sandstones and shales, fresh waters, conductive minerals, fine-grained sandstones, and microporosity. Careful examination of core in this study suggests that Middle Member reservoirs often show many of these characteristics. The Middle Member sandstone is commonly silty, argillaceous, very fine grained, interlaminated, and abundantly pyritiferous. For these reasons, it appears that considerable potential exists for by-passed pay in the Bakken Formation, and that care must be taken in evaluating the prospectivity of a Middle Member reservoir from geophysical logs. It should be noted that, over the Middle Member producing intervals, low-resistivity readings (*i.e.*, <5 ohm-m) are often observed from rocks such as those described above. For example, a core from an oil-producing Middle Member sandstone in the 7-6-8-8W2 well of the Viewfield Pool shows a very silty, argillaceous, weakly interlaminated to massive, very fine-grained quartz sandstone with abundant pyrite over the perforated interval. Over most of this interval, a faint light brown oil stain is present, yet resistivity values range from only 3.4 to 4.7 ohm-m. Daily oil production reported from this vertical well is 3.03 m^3 (19.1 bls) in its first eight months. Another well at 2-6-8-8W2 reported a daily average production of 3.62 m^3 (22.75 bls) from an interval showing <4 ohm-m resistivity. This well has a cumulative fluid production of 965 m^3 (6,075 bls) oil and 824 m^3 (5,184 bls) water in its first nine months of production.

4. Bakken Production

The first Bakken discovery in southeastern Saskatchewan was in 1956 from the Middle Member sandstone in the Barnwell Roncott 09-34-005-25W2 well in the Roncott Pool. This well produced 33 907 m^3 (212,936 bls) of oil between 1956 and 1990. The second Bakken oil discovery in southeastern Saskatchewan was in 1957 from the Middle Member sandstone in the Riddle TW Rocanville 16-32-015-31W1 well in the Rocanville Pool. This well produced 1555 m^3 (9,765 bls) of oil between 1957 and 1966.

Figure 5 shows the location of past- and present-producing areas in southeastern Saskatchewan, DST oil shows, and oil shows recognized in cores examined in the present study. Production and shows are widespread throughout the Bakken Formation in southeastern Saskatchewan.

The table below shows the specific gravity of Bakken oils and the API equivalent values for some of the pools in southeastern Saskatchewan. Note that the Welwyn and Welwyn South pools and, to a lesser degree, the Rocanville Pool have slightly lower gravity oil. The variations in oil gravity are not understood, but biodegradation is a

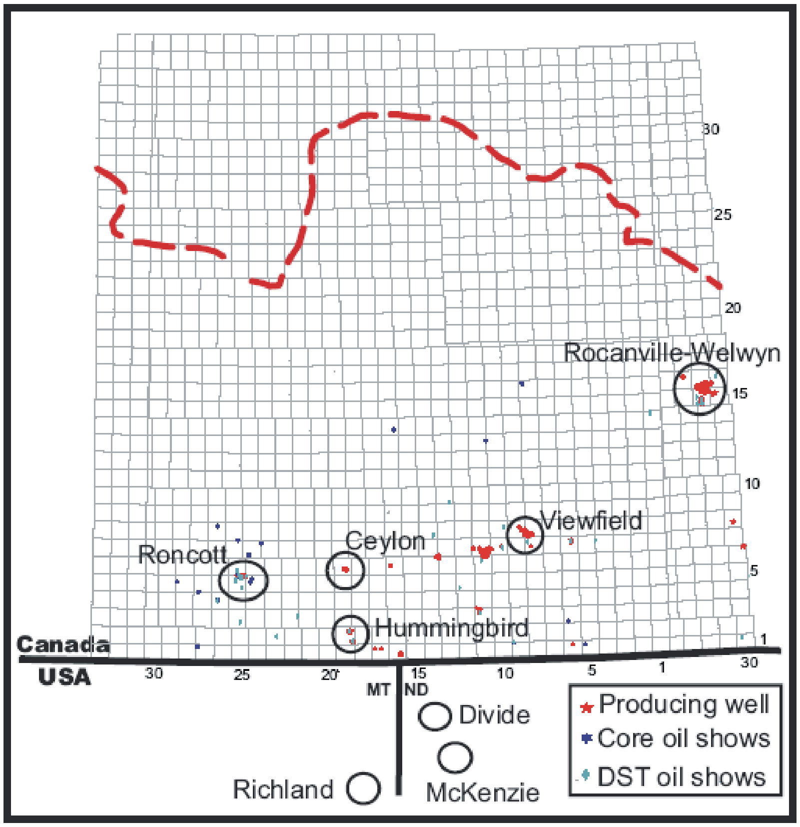

Figure 5 - Map showing location of present and past producing areas, DST oil shows, and oil shows recognized in selected cores examined in this study.

possible cause. Bakken oils do not, however, exhibit much internal variation in molecular composition (Pasadakis *et al.*, 2004) nor standard indicators of biodegradation (Osadetz *et al.*, 1992; Obermayer *et al.*, 2000).

Other pools and areas of miscellaneous Bakken production have been discovered since the Roncott and Roncanville pools. To date, the total oil production from the Middle Member in southeastern Saskatchewan is 1 289 910 m^3 (8,113,534 bls) from 167 wells of which 16 are horizontal. Some 123 379 m^3 (774,820 bls) oil have been produced from the Roncott Pool and 774 034 m^3 (4,860,940 bls) from the Rocanville Pool. Hummingbird Pool production is 183 194 m^3 (1,150,458 bls) oil. Together, these three pools account for more than 85% of the total Bakken production in southeastern Saskatchewan. The two most productive wells are: Transwest Rocanville 8-5-16-31W1 with 95 318 m^3 (599,000 bls) and Northrock Hummingbird 3-26-2-19W2 with 71 393 m^3 (448,350 bls). In 1992, a horizontal well was also drilled at 191/8-5-16-31W1 and has produced an additional 58 323 m^3 (366,200 bls) of oil. It is now the fourth most productive Bakken well in southeastern Saskatchewan. The third most prolific Bakken producer is the Transwest Rocanville 10-5-16-31W1 well drilled in 1960, which has yielded 68 828 m^3 (432,240 bls) and is still producing. Together, these four wells are responsible for 23% of the total Bakken Formation production in southeastern Saskatchewan.

In recent years, exploration activity for Bakken Formation production in southeastern Saskatchewan has focused upon regions between Tp 8, Rge 11W2 and Tp 6, Rge 6W2; and Tp 1 and 2 and Rge 9W2 and 10W2. Over the 14-month period from October 2003 to February 2005, the number of producing wells in the Bakken has risen from 8 to 35, increasing the monthly production from 232 m^3 (1,457 bls) to 3239 m^3 (20,373 bls). This recent upswing in Bakken drilling and production is readily visible on the line graph in Figure 6.

Table 1- Specific gravity for selected Bakken pools in southeastern Saskatchewan.

Pool	Specific Gravity (g/cm^3)	API
Ceylon	0.825	40.0
Hummingbird	0.825	40.0
Hummingbird South	0.825	40.0
Rocanville	0.843	36.3
Roncott	0.823	40.4
Welwyn	0.888	27.8
Welwyn South	0.841	36.7

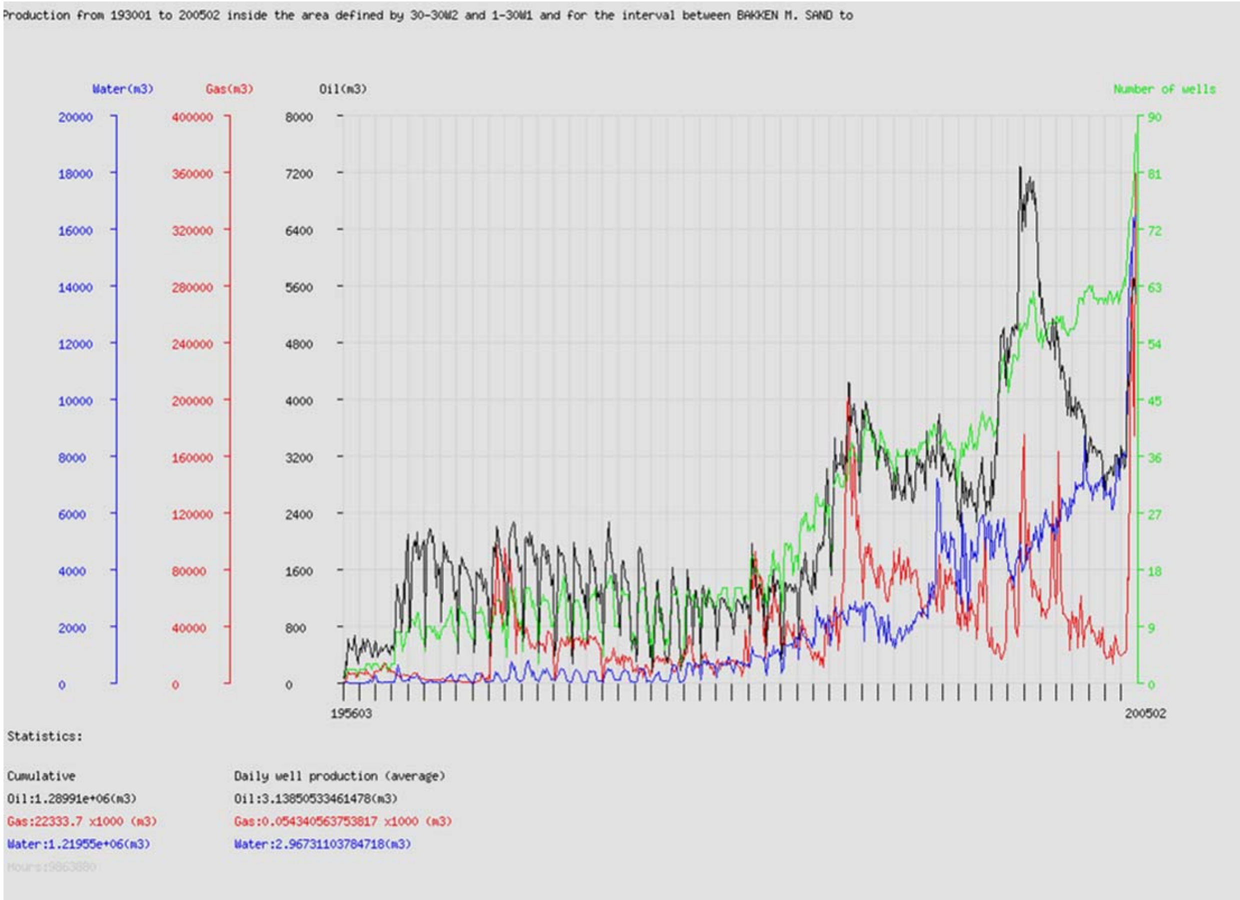

Figure 6 - Line graph of monthly Bakken oil production in southeastern Saskatchewan.

5. Torquay Regional Geology

The Torquay Formation, in the eastern portion of the study area along the Saskatchewan-Manitoba border (Figure 7), shows depositional and erosional thinning in a region interpreted to have been uplifted prior to deposition of the Bakken Formation. This general area is also indicated by anomalous thinning of the Middle Bakken as shown in Figure 2. Here, the Middle Bakken gradually onlapped a paleotopographic highland from west to east.

Significant to this play is the fact that weathering in the uplifted area prior to Bakken deposition appears to have enhanced reservoir characteristics of the Torquay Formation where it immediately underlies the regional unconformity. Reservoir conditions in this area also appear to have been favourably affected by the shallower depositional setting for the sediments that now host the oil. For example, well developed ripple-bedded dolarenite is common in Torquay Formation cores from the Rocanville Pool area (*e.g.*, 8-5-16-31W1). Also beneficial was the onlapping relationship of the overlying porous and permeable sandstones of the Middle Member of the Bakken Formation. Thinning and onlap of Bakken sediments are recognized throughout the eastern portion of Saskatchewan. The Lower Member shale is absent in this area resulting in direct contact between oil-saturated sandstones of the Middle Member with reservoir-quality rocks of the underlying Torquay Formation. The Torquay rocks are interpreted to have been charged with light Bakken-sourced oil that migrated from hydrocarbon kitchens to the south and west. The Torquay Formation in the inferred area of uplift exhibits reservoir-quality brecciated dolostones that show moderate to good porosity on sonic, density, and neutron logs. Streaming, milky white fluorescent cuts from dolostones have been observed in cores from 1-30W1 to 22-1W2. Resistivity logs also indicate the presence of hydrocarbons in wells from this area. Production has been attempted from three wells, 8-35-6-30W1, 12-36-6-30W1, and 13-10-8-30W1. Of these, the first two were vertical completions and have each produced approximately 3180 m^3 (20,000 bbls) of oil in three years. In this area, the Bakken Middle Member sandstone is generally less than 3 m thick, whereas geophysical logs and core from the Torquay Formation indicate that approximately 9 m thick porous intervals are oil-saturated from the unconformity down to the top of a well developed oxidized, reddish brown siltstone-mudstone.

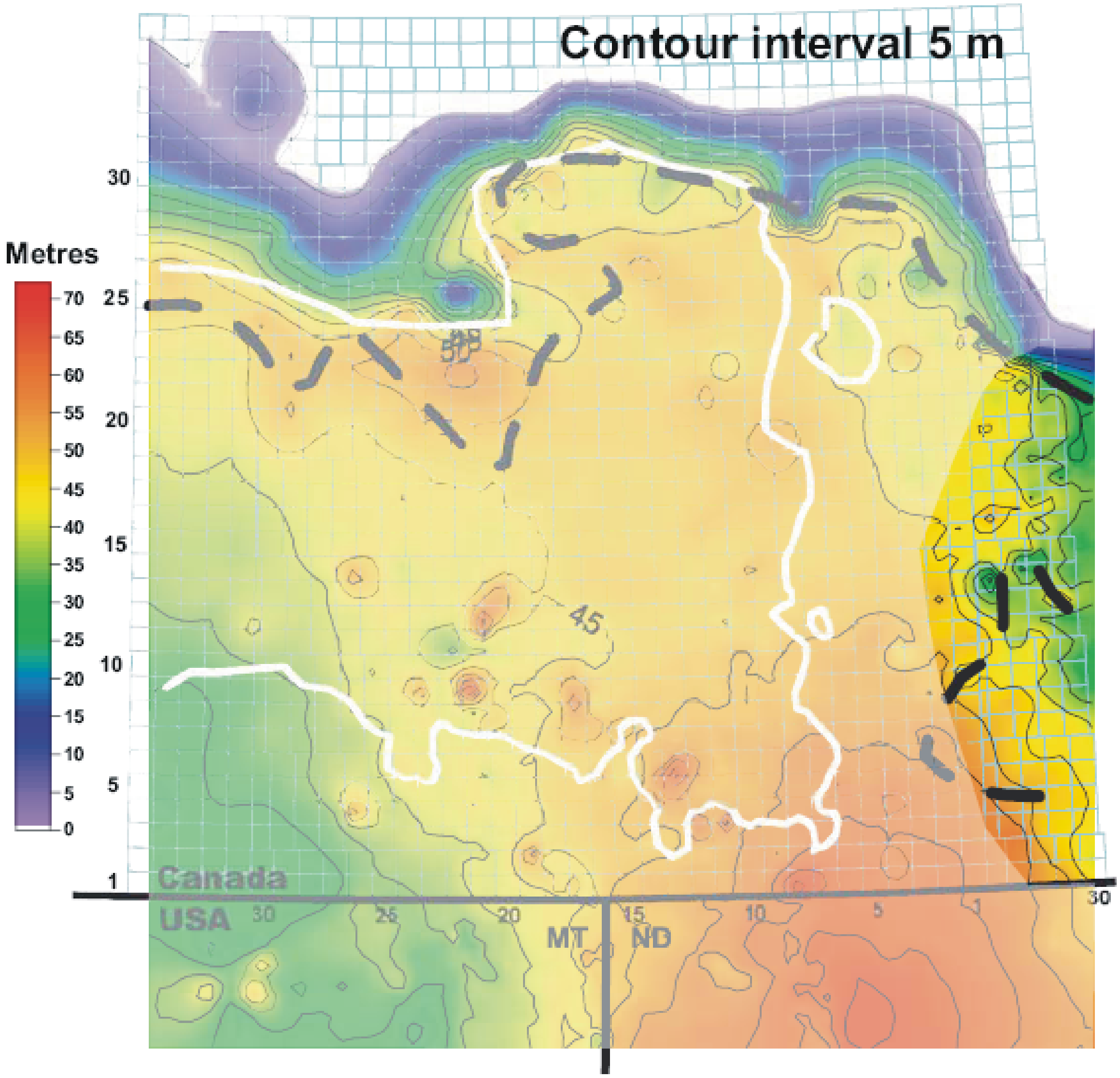

Figure 7- Isopach map of the Torquay Formation. Also shown are the Lower Bakken zero edge (dashed line), and the approximated Big Valley Formation zero edge (white line). The highlighted area along the eastern edge shows the region of depositional and erosional thinning in the Torquay and Bakken formations.

6. Conclusions

- Upper and Lower Bakken shales showing anomalously high resistivity values in southeastern Saskatchewan suggest that they are saturated with oil that has either been generated in place or has migrated into these locations.
- Basement structures, such as those associated with the Brockton-Froid lineament, and compactional features in regions of Middle Devonian salt dissolution may control fractures that serve as primary migration pathways for Bakken-sourced oils into possible plays in the Bakken and Torquay formations.
- The relatively low permeability of Bakken and Torquay reservoirs are likely best exploited through horizontal wells.
- A large untested and poorly evaluated rock volume remains in the Bakken and Torquay formations of southeastern Saskatchewan, within which there may be significant potential for finding new oil.

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