

Hydrocarbon Play Ranking and Production Trends in Southern Saskatchewan

Chao Yang

Yang, C. (2008): Hydrocarbon play ranking and production trends in southern Saskatchewan; in Summary of Investigations 2008, Volume 1, Saskatchewan Geological Survey, Saskatchewan Ministry of Energy and Resources, Misc. Rep. 2008-4.1, CD-ROM, Paper A-1, 21p.

Abstract

Hydrocarbon production from plays within Ordovician to Cretaceous strata in southern Saskatchewan (Tp 1 to 21, Rge 30W1 to 30W3) has been statistically assessed to evaluate average per-well production, cumulative production, and overall production trends.

The average per-well production is a parameter that reflects reservoir quality and actual drainage area of the reservoir and is a good measure of success. On the basis of average per-well production ranking, the Jurassic Roseray and Upper Shaunavon plays rank the topmost, followed by, respectively, the Mississippian Midale and Ratcliffe plays. The Devonian Winnipegosis ranks fifth, Mississippian Frobisher-Alida and Alida, sixth and seventh respectively, and Devonian Birdbear play, eighth.

Most oil and gas production in southern Saskatchewan has been from Madison Group (Mississippian) carbonates in southeastern Saskatchewan, cumulatively amounting to $339.0 \times 10^6 \text{ m}^3$ or about 70% of oil production. The Midale play alone has yielded about 36% of the total oil production from a total of 6,593 production wells.

Led by the Roseray and Upper Shaunavon plays, the total Jurassic crude oil production in southwestern Saskatchewan has amounted to $121.8 \times 10^6 \text{ m}^3$, about 25% of the overall production from southern Saskatchewan. It is interesting to note that Roseray and Upper Shaunavon production is from a total of only 3,019 producing wells, yielding the highest per-well average of 49.5×10^3 and $30.9 \times 10^3 \text{ m}^3$, respectively.

Although a total of only $3.9 \times 10^6 \text{ m}^3$ of oil has been produced from the Devonian Winnipegosis, Birdbear, and Duperow plays, the total well count of 275 in the Devonian plays is substantially lower than the total of 17,282 in the Mississippian. The comparable per-well average production between the Devonian and Mississippian plays highlights the hydrocarbon potential of Devonian reservoirs in southern Saskatchewan.

The major oil producer from Cretaceous reservoirs is the Mannville play in southern Saskatchewan, amounting to $17.0 \times 10^6 \text{ m}^3$ from 1,502 production wells. The Red River play is the major Ordovician oil producer, having a total production of $3.5 \times 10^6 \text{ m}^3$ of oil and a per-well average of $17.9 \times 10^3 \text{ m}^3$.

The Upper Cretaceous Milk River, Medicine Hat, and Second White Specks plays are the major shallow-gas producers in southwestern Saskatchewan, with a total production of $94.9 \times 10^6 \text{ m}^3$ and a per-well average of $4.5 \times 10^3 \text{ m}^3$.

Keywords: *statistical assessment, oil play, oil production, gas production, well count, ranking, trend, southern Saskatchewan.*

1. Introduction

Since the beginning of hydrocarbon production in southern Saskatchewan, monthly and yearly production data have been summarized by pool, unit, and area and published annually in the Saskatchewan Mineral Statistics Yearbook. However, overall statistical assessment of historical production data by play has not been done systematically. This study is a more geological approach to the historical oil and gas production data to rank the major plays in southern Saskatchewan. It compiles and evaluates all cumulative hydrocarbon production data (to the end of December 2007) from a database managed by the Petroleum Statistics Branch of Saskatchewan Ministry of Energy and Resources. The database covers Production and Disposition Areas III and IV as designated by the Saskatchewan Ministry of Energy and Resources (Figure 1). The study area of this paper encompasses Tp 1 to 21 and Rge 30W1 to 30W3 (Figure 1). Township 21 was chosen as the northern edge because it forms the northern limit of Area III and, in Area IV, little petroleum has been produced prior to the end of December 2007. The number of wells producing

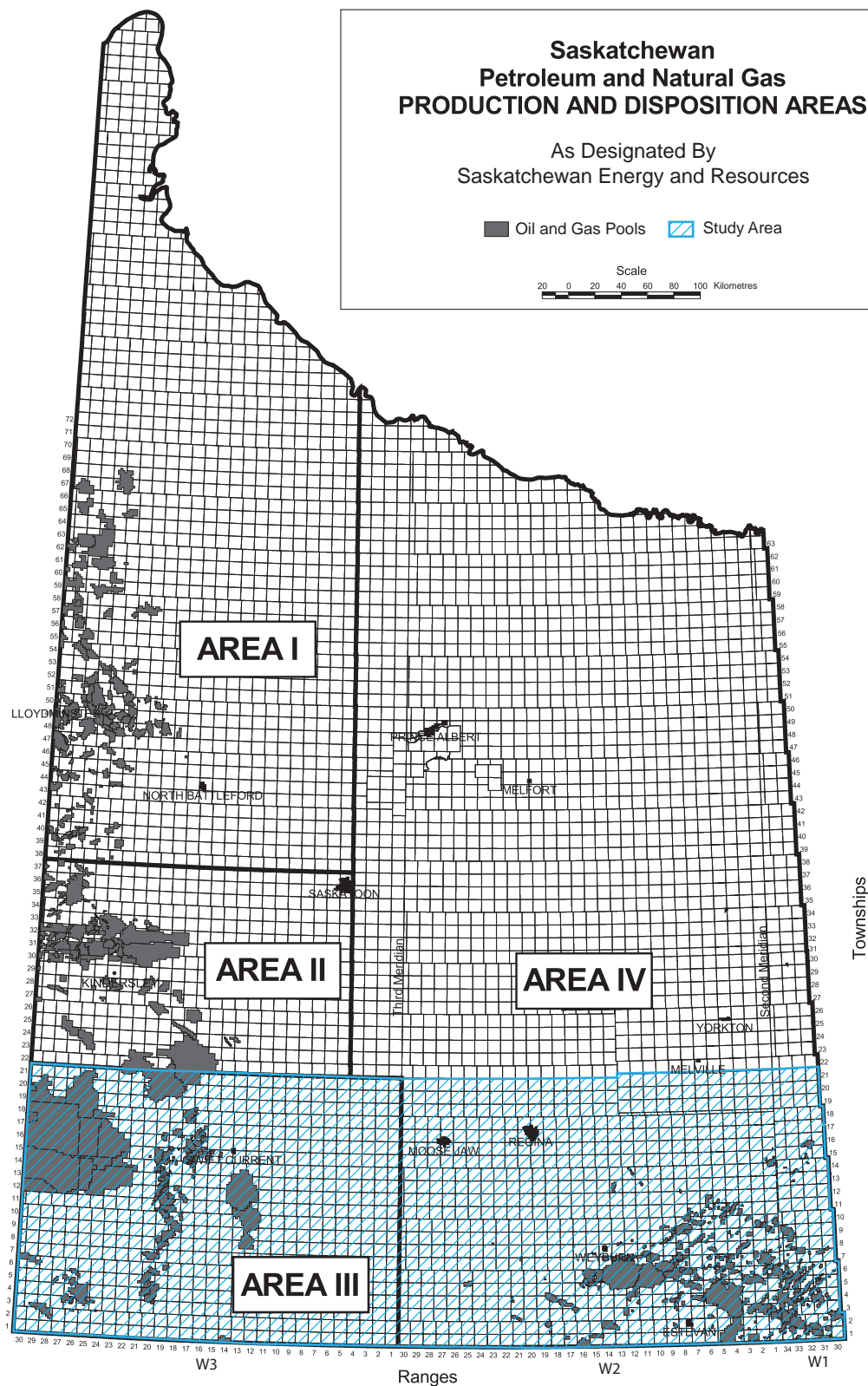


Figure 1 - Saskatchewan petroleum and natural gas production and disposition areas as designated by the Saskatchewan Ministry of Energy and Resources. The study area in southern Saskatchewan (Tp 1 to 21, Rge 30W1 to 30W3) is highlighted.

from a given play in the month of December each year is used for the well count for that year. The number of wells that have produced oil or gas from a given play from initial production to the end of December 2007 are used for the total production-well count. The total production-well count is a measure of industry drilling activity, but not a good measure for success. In this study, the average per-well production value is used as a measurement of success because it reflects reservoir quality and actual drainage area of the reservoir, and, therefore, points out the most prolific plays.

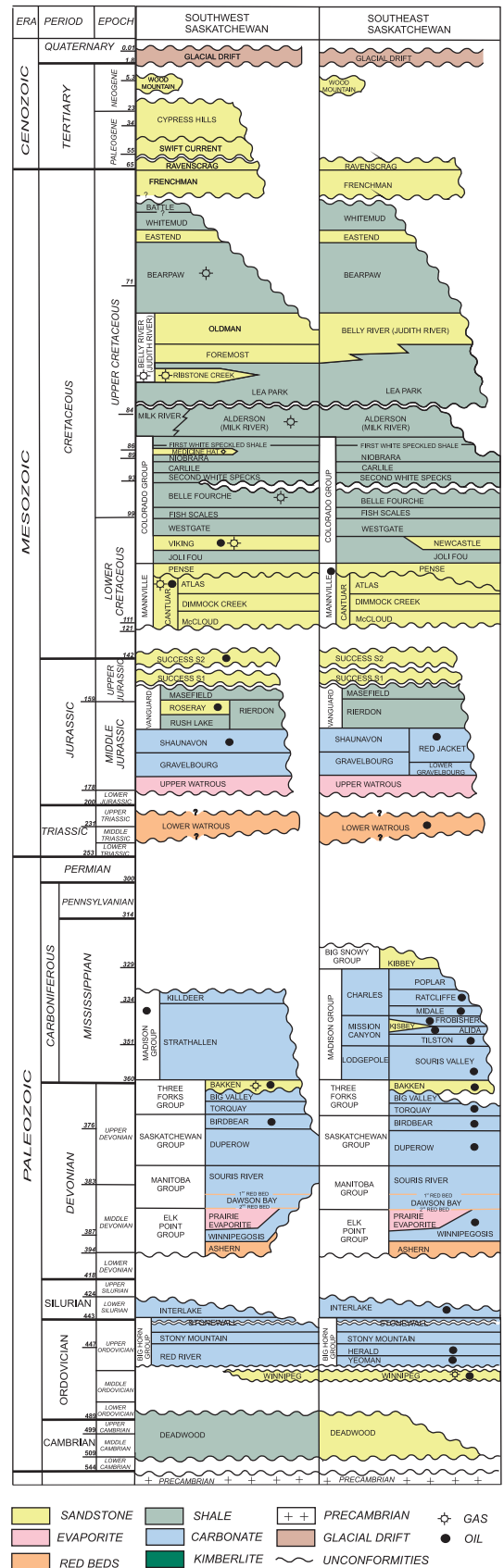
Most of the major hydrocarbon pools in southern Saskatchewan were discovered as a result of intensive exploration efforts in mid-1950s and early 1960s. Waterflood recovery was applied in many pools shortly after discovery since the first waterflood project in 1956 in the Upper Shaunavon in the Dollard Pool in southwestern Saskatchewan (Saskatchewan Geological Survey, 2003). An *in situ* combustion project was implemented in the Roseray reservoir at Batrum in 1965 and was commercially operated until 2001 (Saskatchewan Geological Survey, 2003). With development of advanced technology, horizontal well drilling has been used since 1987 and has increased oil production significantly from the mid-1990s in southern Saskatchewan (Saskatchewan Industry and Resources, 2007a). The first commercial CO₂ miscible flood project commenced operation in the Weyburn Midale Pool in 2000 and is expected to produce at least 20.8 x 10⁶ m³ of incremental oil (Saskatchewan Geological Survey, 2003). In this study, the impact on the oil-production trends of application of the above-mentioned recovery methods is assessed using historical production data.

The objectives of this study are to: i) monitor hydrocarbon production trends for the major plays using historical production data; ii) indicate the relationship between production and well count through the production history and pool development; iii) investigate the impact of water flooding, infill-drilling, horizontal well drilling, and enhanced oil recovery methods on the production trends; and iv) identify highly prolific plays in southern Saskatchewan. The results of this study will aid in the development of future petroleum exploration strategies in Saskatchewan.

2. General Geology

Phanerozoic sedimentary rocks in Saskatchewan can be divided into two major successions. The Paleozoic sedimentary succession is characterized by passive-continental marginal deposits of basal clastics, followed by a thick sequence of platform carbonates and evaporites (Figure 2). The Mesozoic succession is dominated by shale, siltstone, and sandstone. The two

Figure 2 - Stratigraphic chart for southeastern and southwestern Saskatchewan showing major lithostratigraphic and hydrocarbon-producing plays (from Saskatchewan Stratigraphic Correlation Chart, Saskatchewan Industry and Resources, 2004).



successions are separated by a basin-wide unconformity (Figure 2).

The major hydrocarbon-producing plays in southeastern Saskatchewan are in Paleozoic rocks and in southwestern Saskatchewan they are in Mesozoic strata. The major plays produce from the following stratigraphic units (in ascending stratigraphic order): Winnipeg, Red River (Yeoman and Herald), Interlake, Winnipegosis, Duperow, Birdbear, Torquay, Bakken, Souris Valley, Tilston, Alida, Frobisher, Midale, Ratcliffe, Lower Watrous, Gravelbourg, Red Jacket, Shaunavon, Roseray, Success, Mannville, Second White Specks (the Second White Specks Sandstone is now considered to be a unit within the Belle Fourche Formation), Medicine Hat, and Milk River (Alderson) (Figure 2). Their geological characteristics are summarized below.

a) Silurian-Ordovician Interval

The Middle Ordovician Winnipeg Formation consists entirely of clastic rocks and is differentiated into two units. The lower unit, composed of porous quartzose sandstone with minor amounts of siltstone and shale, forms a good reservoir for hydrocarbon accumulation in some areas. The upper unit is typically a green waxy shale with minor amounts of siltstone and shaly quartzose sandstone, providing excellent seals for hydrocarbon reservoirs (Paterson, 1971; Kreis, 2004).

The Upper Ordovician Red River strata (Yeoman and Herald formations) in southeastern Saskatchewan consists of three carbonate-evaporite sequences with burrowed, normal-marine carbonates at the base overlain by laminated carbonate mudstones which, in turn, are overlain by anhydrite (Kendall, 1976; Longman *et al.*, 1983; Kreis and Haidl, 2004; Nimegeers and Haidl, 2004; TGI Williston Basin Working Group, 2008). Oil production is restricted to upper Yeoman and lower Herald strata. Hydrocarbons are hosted in dolomitized reservoirs which commonly display burrowed textures, and variable amounts of vugs and fractures (Pu *et al.*, 2003).

The Silurian Interlake can be subdivided into: 1) a lower carbonate sequence with many argillaceous, commonly arenaceous, basin-wide marker beds which are interpreted to define transgressive/regressive cycles, some of which are capped by anhydrites; fossiliferous beds are common; 2) a middle carbonate succession that also has marine fauna in several beds; and 3) an upper unit in which vadose diagenetic features are common and no marine fauna has been identified (Kreis *et al.*, 2004; Haidl *et al.*, 2006). In 2002, the first Interlake oil producer was completed in the uppermost portion of the upper unit and subsequent Interlake wells have also produced from this same zone. Reservoir quality is primarily linked to fracture porosity (Larson *et al.*, 2003; Haidl *et al.*, 2006).

b) Devonian Interval

The Winnipegosis, Birdbear, and Duperow formations are the major Devonian hydrocarbon plays in southern Saskatchewan.

The Winnipegosis of southeastern Saskatchewan is subdivided into a lower unit of a non-porous, often organic-rich, lime mudstone and dolomudstone deposited in an open-marine platform setting, and an upper unit with carbonate build-ups (Jones, 1965). Oil production in southern Saskatchewan is from upper Winnipegosis carbonate reservoirs. East of about Rge 12W2, production is primarily from “pinnacle” reefs (Martindale *et al.*, 1991) with some production from a laminated dolostone (Ratner laminites) lying between the build-ups (Saskatchewan Industry and Resources, 2007b). In the Minton area (Tp 3, Rge 21W2), production is from shoal deposits (Potter and St. Onge, 1991).

The Duperow Formation in southeastern Saskatchewan displays shallowing-upward, rhythmic sedimentation patterns characterized by sequences of bioclast-rich, normal-marine, subtidal to intertidal lithofacies grading upward into more restricted lime- and dolo-mudstone and evaporite (Dunn, 1975; Cen and Hersi, 2006; TGI Williston Basin Working Group, 2008). Stromatoporoids and corals are common frame builders that form localized bank or mound structures (Kent, 1998). Kent (1998) emphasizes the importance of diagenetically altered stromatoporoid banks and potential stratigraphic traps in the Duperow Formation.

The Birdbear Formation is divided into lower carbonate and upper carbonate-anhydrite units in southeastern Saskatchewan (Nichols, 1970; Halabura, 1982). The lower Birdbear unit consists of a basal argillaceous dolomitic, open-marine and subtidal lime mudstone to wackestone overlain by subtidal limestone to dolostone wackestone to packstone probably deposited in a shoal environment. The upper unit is divided into a lagoonal anhydrite and intertidal to supratidal algal dolostones capped by supratidal anhydrite and anhydritic dolostones. Porosity is controlled primarily by its lithofacies type and depositional environment (Halabura, 1982) and the vuggy dolostones are good reservoirs for hydrocarbon accumulation (Smith, 1985). Identification of potential stratigraphic traps in the Birdbear Formation may be a future exploration strategy for petroleum companies (Halabura, 1982; Kent, 1998).

The Upper Devonian Torquay Formation consists of interbedded dolostone, dolarenite, dolomitic mudstones and siltstones, and lesser amounts of anhydrite (Kreis *et al.*, 2006). In recent years, dolostones and dolomitic siltstones

of the Torquay Formation have been proven to be productive in an area along the Saskatchewan-Manitoba border (Kreis *et al.*, 2005, 2006).

c) Mississippian Interval

The Upper Devonian to Lower Mississippian Bakken Formation is subdivided into three members with a Middle Member of siltstone to sandstone sandwiched between Lower and Upper members of black organic-rich shales (Kreis *et al.*, 2006). Oil has been produced from the porous and permeable sandstone of the Middle Member for many years in the Rocanville, Weyburn, Roncott, and Hummingbird areas in southeastern Saskatchewan. The recent application of advanced horizontal drilling and large sand-fracture completions in the less permeable silty, argillaceous and very fine-grained sandstone and lower siltstone of the Middle Member has resulted in significant new Bakken production in southeastern Saskatchewan (Kreis *et al.*, 2006; Kendall, 2008; G. Davies, pers. comm., 2008).

Strata of the Mississippian Madison Group are characterized by two styles of deposition – a lower progradational phase (Souris Valley, Tilston, and Alida beds), and an upper aggradational phase (Frobisher, Midale, Ratcliffe, and Poplar beds) (Kent and Kreis, 2001; Kent *et al.*, 2004). In southeastern Saskatchewan, strata deposited during the latter phase consists of a series of shallowing- or brining-upward cycles in which porous reservoir rocks are commonly overlain by dense anhydrite units (Kent *et al.*, 2004). Mississippian strata in the study area are progressively truncated to the north and west by the sub-Mesozoic unconformity (Fuzesy, 1983; Kent *et al.*, 2004; Marsh and Heinemann, 2005; Nickel and Yang, 2008; TGI Williston Basin Working Group, 2008). The repeated occurrences of porous and non-porous layers, and of porous layers truncated at the sub-Mesozoic unconformity, have formed multilayered hydrocarbon plays in these rocks (Kent *et al.*, 1988; Nimegeers *et al.*, 2006).

d) Triassic-Jurassic Interval

The Triassic-Jurassic Lower Watrous unconformably overlies Carboniferous strata in southern Saskatchewan. It consists of red argillaceous sandstone interbedded with quartzose to anhydritic mudstone of terrestrial origin (Edwards *et al.*, 1994; Saskatchewan Ministry of Energy and Resources, 2008). The fine-grained mudstone unit forms a regional and effective seal to hydrocarbon migration (Whittaker and Gilboy, 2003). Locally, dissolution of porosity-filling anhydrite has allowed oil to migrate into the Lower Watrous sandstone reservoirs that are capped by argillaceous mudstones (Bates and Kendall, 2008), and into the Gravelbourg, Shaunavon, and Mannville formations (Saskatchewan Ministry of Energy and Resources, 2008).

The Gravelbourg Formation has been informally subdivided into upper and lower members. The lower Gravelbourg is predominantly made up of carbonates, and the upper Gravelbourg mainly consists of siliciclastic deposits which grade into calcareous shales to the west (Blair and Bergman, 2002). Low-gravity oil in the Gravelbourg is the result of vertical seepage from the Mississippian reservoirs and has accumulated in fine quartz sandstone in the upper part of the lower member (Kent, 2001).

The Upper Shaunavon reservoir in southwestern Saskatchewan is predominantly made up of permeable, shallow-marine and shoreline, calcareous sandstones. Toward the east, lenticular quartzose sandstones, bioclastic arenites, dolostones, and shales are dominant. The Lower Shaunavon Formation is generally cream-coloured limestone in southwestern Saskatchewan and changes to interbeds of dark grey shales and sandstone eastwards (Christopher, 1964; Saskatchewan Ministry of Energy and Resources, 2008). Oil has been produced from a fossiliferous-oolitic, vuggy-mouldic, porous interval that commonly overlies more homogeneous carbonate mudstone in the Lower Shaunavon (Marsh and Yurkowski, 2008).

The Middle Jurassic Red Jacket Formation in southeastern Saskatchewan, stratigraphically equivalent to the Upper Gravelbourg and Shaunavon formations in southwestern Saskatchewan, is a play made up of a complex succession of sandstones, siltstones, mudstones, and minor carbonate (Kreis, 1991; Saskatchewan Ministry of Energy and Resources, 2008).

The Roseray Formation of southwestern Saskatchewan is composed primarily of sandstone clinothems lying between Rge 21W2 and 20W3, from the U.S. border to Tp 20. Ten clinobeds were identified by Christopher (1974). They offlap west to east and prograde eastward into the marlstones and shales of the Rierdon and Rush Lake formations (*ibid.*).

The Jura-Cretaceous Success Formation overlies rocks of Middle Devonian to Late Jurassic age on a low-relief erosion surface which sloped southward and southwestward off the Precambrian Shield. It is characterized by white and pale green kaolinitic quartzose sandstones and siltstones deposited in fluvial and lacustrine environments, with possible early marine conditions in the extreme south of the province (Christopher, 2003).

e) Cretaceous Interval

The Lower Cretaceous Mannville Group is a play for the oil sands and the majority of heavy oil deposits in the Western Canada Sedimentary Basin (WCSB) (Pemberton and James, 1997), and for light to medium oil in southeastern and southwestern Saskatchewan. The Mannville in Saskatchewan is a stratigraphically complex unit formed of fluvial to marine deposits (Christopher, 2003). The porous sandstones provide excellent reservoirs for hydrocarbon accumulation in southern Saskatchewan.

The Upper Cretaceous Milk River, Medicine Hat, and Belle Fourche formations (herein referred to as the Second White Specks, as commonly referred to by industry) are the major shallow-gas producers in southwestern Saskatchewan. These plays are characterized by their shallow depths, interbedded source and reservoir rocks, low-permeability muddy sandstones, and immature, locally generated biogenic gas (Pederson, 2004; Yurkowski, 2006). The trapping mechanisms for the shallow-gas pools are highly variable. The oldest of the three producers, the Second White Specks Sandstone (Belle Fourche Formation), is composed of very fine-grained, bioturbated muddy sandstones; it is unconformably overlain by offshore-marine mudstones that are characterized by coccoliths, fish debris, and shells. The gas-bearing Medicine Hat Formation consists of at least three upward-coarsening, very fine-grained sandstone and siltstone successions, 3 to 11 m thick, deposited in a shallow-marine shelf. The youngest producer, the Milk River Formation (also known as the Alderson Member of the Lea Park Formation), forms a shallowing-upward facies from offshore sandstones and shales to shoreline sandstones, and non-marine coastal-plain deposits (Gilboy, 1987, 1988; Pederson, 2004).

3. Oil-production Results

a) Silurian-Ordovician Oil Production

The Red River play is the major Ordovician oil producer in southern Saskatchewan. It ranks 11th in total oil production (Table 1) with production of $3.5 \times 10^6 \text{ m}^3$, 19th by well count (Figure 3), and 10th by the average per-well production of $17.9 \times 10^3 \text{ m}^3$ (Figure 4). Although oil was first produced from the Red River in 1958, the discovery by the Advantage et al Midale 111-04-02-007-11W2 well in December 1995 in the Midale Red River Pool sparked renewed interest in the Red River, resulting in a sharp increase of annual oil production to over $350 \times 10^3 \text{ m}^3$ from 1998 to 2000 (Figure 5A). To the end of December 2007, 196 wells have produced from the Red River play, of which 76 are directional and horizontal wells drilled after 1995. The horizontal well 91-11-26-003-21W2 drilled in 2003 has the highest production, $302.9 \times 10^3 \text{ m}^3$.

The Winnipeg and Interlake formations are additional Silurian-Ordovician plays. The Ordovician Winnipeg play has produced $95.4 \times 10^3 \text{ m}^3$ of oil (Table 1) from three wells in the Hartaven area (Tp 10, Rge 9W2), two wells in the Browning area (Tp 6, Rge 6W2), five wells from the Midale area (Tp 6, Rge 11W2), two wells from Huntoon area (Tp 7, Rge 10W2), and three other individual wells. The Silurian Interlake has produced $29.4 \times 10^3 \text{ m}^3$ (Table 1) from four wells in the Bryant area (Tp 5, Rge 7W2) and one well in the Browning area (Tp 6, Rge 5W2). The 216 wells producing from the three Silurian-Ordovician plays have a cumulative oil production of $3.6 \times 10^6 \text{ m}^3$ to the end of December 2007 (Figure 5B).

b) Devonian Oil Production

Among all the Devonian plays, the Winnipegosis play has the highest total oil production ($2.6 \times 10^6 \text{ m}^3$) and highest per-well average production ($23.3 \times 10^3 \text{ m}^3$), ranking this play 12th in southern Saskatchewan by total oil production (Table 1) and 5th by per-well average production (Figure 4). Oil has been produced from the Tableland Winnipegosis Pool since 1975 and from the Minton Winnipegosis Pool since 1976, but production levels increased with the drilling of new wells beginning in 1986. The Tableland 11-08-22-002-09W2 well, drilled in 1986, has a total production of $98.7 \times 10^3 \text{ m}^3$ of oil to the end of December 2007. A total of 111 wells produce from the Winnipegosis play, 27 of which are directional or horizontal wells. The highest per-well production is $142.0 \times 10^3 \text{ m}^3$ of oil from the Advantage Macoun 11-06-24-004-09W2 well. Winnipegosis oil production grew with increasing well count from 1986 to 1991 (Figure 6A). The overall production started to decline in 1992 even though the well count continued to increase. The high per-well average production and fast decline rate may be attributed to high reservoir permeability resulting from well developed vugs and fractures (Fu *et al.*, 2006).

A total of only nine wells produce from the Duperow play, eight of which are located in the Midale Duperow Pool (Tp 7, Rge 11W2), discovered in 1997, and one in the Kisbey South area (Tp 7, Rge 6W2). Total production is $145.2 \times 10^3 \text{ m}^3$, ranking the Duperow as 21st in total oil production in southern Saskatchewan (Table 1, Figure 6B). The Duperow average per-well production is $16.1 \times 10^3 \text{ m}^3$ placing it 11th in this parameter (Figure 4). The discovery well, Advantage et al Midale 13-02-007-11W2, has produced $21.2 \times 10^3 \text{ m}^3$ of oil to the end of December 2007. Three horizontal wells have been drilled in the Duperow play. The first horizontal well, Advantage et al

Table 1 - Cumulative oil production ranking by play to the end of December 2007 in southern Saskatchewan (data source is Saskatchewan Ministry of Energy and Resources, Petroleum Statistics Branch).

| Play | Cumulative Oil Production (to December 2007) | | Year to Start Production | Total Number of Production Wells | Average Per-well Oil Production (m ³) |
|-----------------------|---|------|-----------------------------|-------------------------------------|--|
| | (m ³) | Rank | | | |
| Midale | 176 987 991 | 1 | 1953 | 6,593 | 26 845 |
| Roseray | 62 627 843 | 2 | 1952 | 1,264 | 49 547 |
| Frobisher-Alida | 60 842 831 | 3 | 1953 | 2,839 | 21 431 |
| Upper Shaunavon | 54 205 316 | 4 | 1953 | 1,755 | 30 886 |
| Frobisher | 39 561 753 | 5 | 1954 | 3,386 | 11 684 |
| Alida | 21 731 211 | 6 | 1954 | 1,103 | 20 998 |
| Mannville | 16 990 051 | 7 | 1952 | 1,502 | 11 312 |
| Tilston | 15 829 798 | 8 | 1954 | 1,247 | 12 694 |
| Ratcliffe | 10 552 620 | 9 | 1953 | 426 | 24 771 |
| Tilston–Souris Valley | 8 504 172 | 10 | 1956 | 788 | 10 792 |
| Red River | 3 503 170 | 11 | 1958 | 196 | 17 873 |
| Winnipegosis | 2 584 121 | 12 | 1976 | 111 | 23 280 |
| Bakken | 2 444 324 | 13 | 1956 | 604 | 4 047 |
| Shaunavon | 2 240 019 | 14 | 1953 | 308 | 7 273 |
| Red Jacket | 1 636 495 | 15 | 1954 | 116 | 14 108 |
| Birdbear | 1 079 578 | 16 | 1966 | 55 | 19 629 |
| Alida-Tilston | 1 045 084 | 17 | 1980 | 56 | 18 662 |
| Souris Valley | 908 062 | 18 | 1957 | 190 | 4 779 |
| Madison | 538 245 | 19 | 1966 | 68 | 7 915 |
| Lower Shaunavon | 235 318 | 20 | 1953 | 48 | 4 902 |
| Duperow | 145 232 | 21 | 1997 | 9 | 14 523 |
| Lower Watrous | 145 183 | 22 | 1971 | 40 | 3 630 |
| Success | 143 854 | 23 | 1996 | 31 | 4 640 |
| Winnipeg | 95 433 | 24 | 1998 | 15 | 6 362 |
| Bakken-Torquay | 63 009 | 25 | 2001 | 45 | 1 400 |
| Torquay | 47 991 | 26 | 2005 | 54 | 889 |
| Gravelbourg | 41 560 | 27 | 1971 | 8 | 3 463 |
| Interlake | 29 388 | 28 | 2002 | 5 | 5 878 |

Note: Production smaller than $10 \times 10^3 \text{ m}^3$ from a play are not included in this table.

Midale 91-04-02-007-11W2, drilled in 1998, is the top producer; it has produced $36.6 \times 10^3 \text{ m}^3$ of oil to the end of December 2007.

The two major Birdbear hydrocarbon pools (Hummingbird and Kisbey) in southeastern Saskatchewan are found in structural traps associated with multiple-stage salt solution and collapse (Smith, 1985; Kent, 1998). In 1966, the first recovery of Birdbear oil in southeastern Saskatchewan occurred from dolostone in the Northrock Hummingbird 01-10-26-002-19W2 well in the Hummingbird Pool. This well has produced $248.1 \times 10^3 \text{ m}^3$ of oil up to the end of December 2007. The second Birdbear oil discovery well in southeastern Saskatchewan was Northrock Kisbey 01-10-27-007-06W2 in the Kisbey Pool, drilled in 1968. To the end of December 2007, total oil production from the Hummingbird and Kisbey pools is 568.6×10^3 and $369.3 \times 10^3 \text{ m}^3$, respectively. Together, these two pools account for more than 86% of the total Birdbear production of $1.1 \times 10^6 \text{ m}^3$ in southeastern Saskatchewan (Table 1, Figure 6C). Only 55 wells have been perforated for production in the Birdbear Formation. Of these, 16 are directional or horizontal wells. Although the Birdbear play is ranked 16th by total oil production (Table 1), the average per-well production of $19.6 \times 10^3 \text{ m}^3$ ranks it in 8th place in southern Saskatchewan (Figure 4). These data highlight the potential for future discoveries of oil in the Birdbear Formation.

Since 2005, the Torquay Formation has been recognized as a separate Devonian play in southeastern Saskatchewan; 54 wells have produced $48 \times 10^3 \text{ m}^3$ of oil to the end of December 2007. A total of 13 horizontal wells have produced $18.4 \times 10^3 \text{ m}^3$ of oil; eight of these wells were drilled in 2007. Because most wells drilled into the Torquay Formation are still in their initial production stage, the average per-well production ranking is not meaningful. In

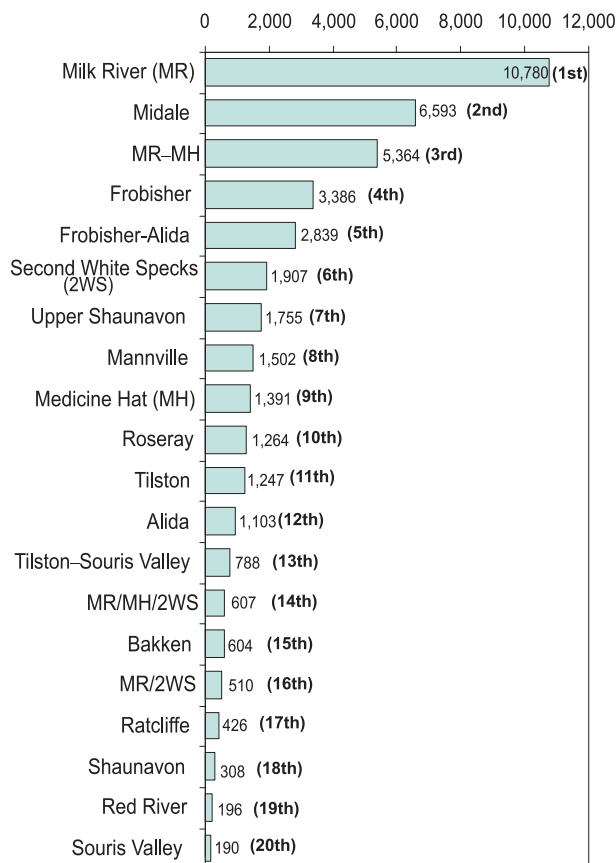


Figure 3 - Top 20 plays by well count to the end of December 2007 in southern Saskatchewan.

areas in southeastern Saskatchewan where the Lower Bakken Shale is absent between the Bakken reservoir and the Torquay, production is classified as Bakken-Torquay, making it impossible to assess the volume of oil attributable to each of the two plays, but certainly some of the produced oil from this zone is from the Torquay. Despite the small volume of oil produced from the Torquay so far (Figure 6D), the level of drilling activity targeting the Torquay Formation in recent years indicates industry's strong interest in this play.

A total of $3.9 \times 10^6 \text{ m}^3$ of oil has been produced from only 275 wells in the Devonian plays (Figure 6D). The comparable per-well average production between the Devonian ($19.4 \times 10^3 \text{ m}^3$) and Mississippian plays ($19.6 \times 10^3 \text{ m}^3$) highlights the hydrocarbon potential of the Devonian plays in southern Saskatchewan.

c) Mississippian Oil Production

Mississippian Madison Group carbonates are cumulatively the most prolific oil-producing reservoirs in southern Saskatchewan with a total production of $339 \times 10^6 \text{ m}^3$ of oil (Figure 7A) or about 70% of all oil produced in the study area. Except for a small fraction ($53.8 \times 10^3 \text{ m}^3$) of low-gravity oil produced from Madison pools in the southwest corner of Area III (Figure 1, Table 1), all production is from southeastern Saskatchewan.

Bakken oil has been produced from a few pools in southern Saskatchewan since 1956, but the drilling in 2003 of the discovery well for the Viewfield North Bakken Pool (Bison Viewfield 11-08-06-008-08W2) heralded the beginning of a new era of Bakken oil production in Saskatchewan. Up to the end of December 2007, Bakken reservoirs in the study area have produced a total of $2.4 \times 10^6 \text{ m}^3$ of oil, 50% of which has been produced in the last four years (2004 to 2007; Figure 7B). The successful application of horizontal drilling and large sand-fracture completions has been instrumental in the success of Bakken exploration and development activity in southeastern Saskatchewan. As of the end of December 2007, 604 wells have produced oil from the Bakken; 421 of them are horizontal wells of which 410 were drilled from 2004 to 2007. Bakken oil production has increased from $94 \text{ m}^3/\text{day}$ in January 2004 to

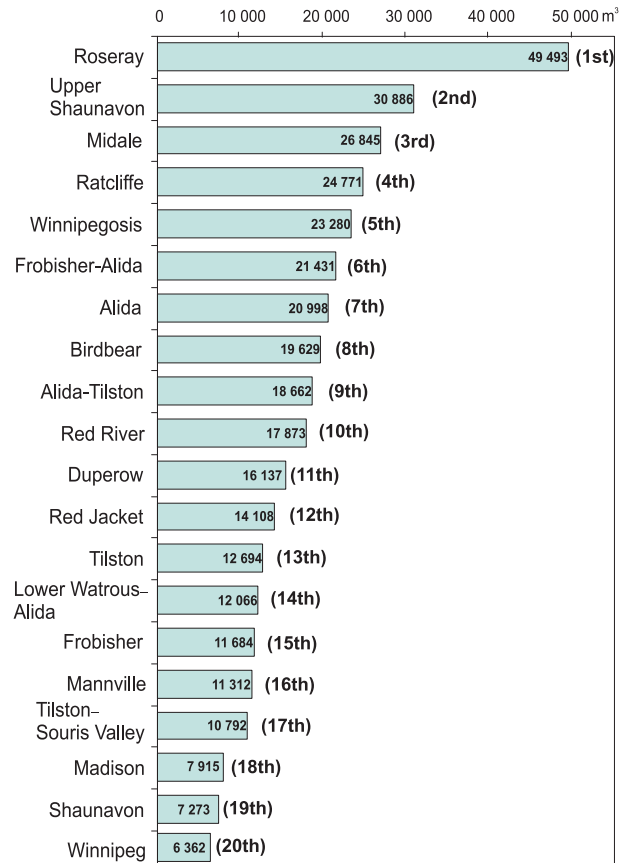


Figure 4 - Top 20 plays by average per-well oil production (in m³) to the end of December 2007 in southern Saskatchewan. Average per-well production for each play is calculated by dividing the cumulative production by the total number of wells that have produced oil from a given play from the year of initial production to the end of December 2007 (Table 1).

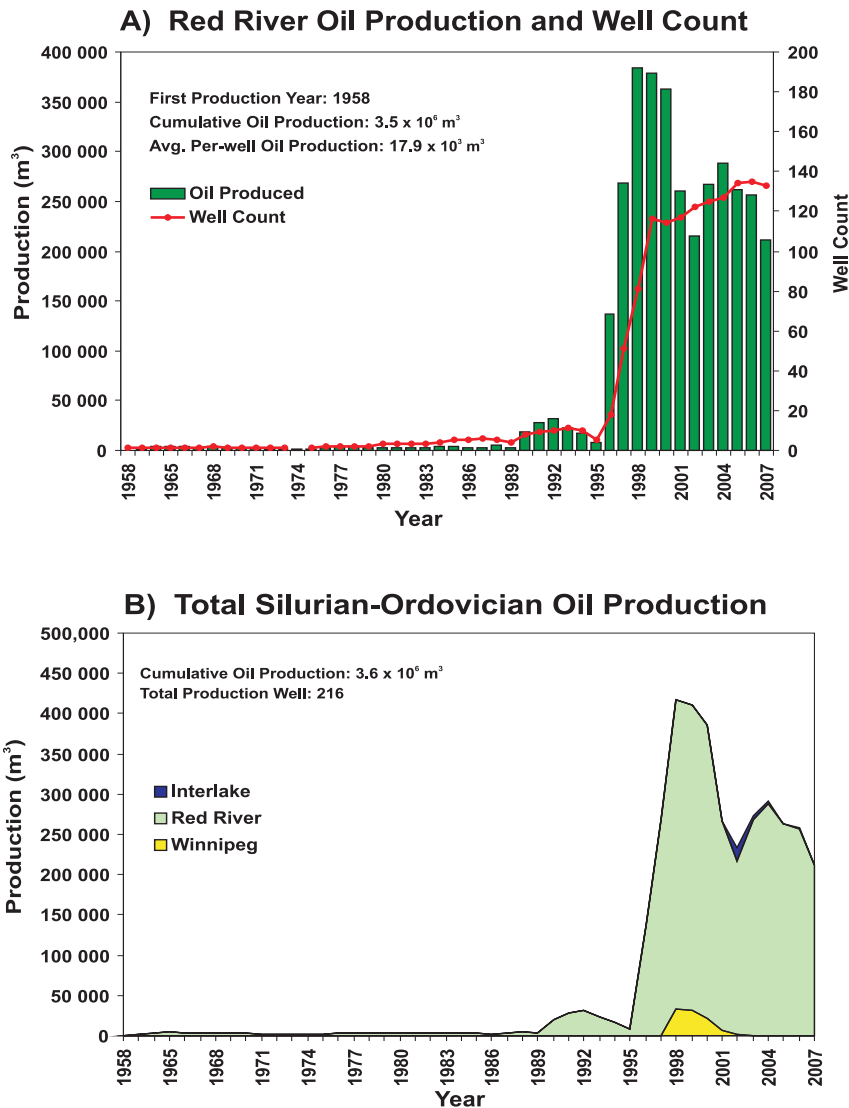


Figure 5 - The Silurian-Ordovician oil-production trends to the end of December 2007 in southern Saskatchewan. A) Oil-production and well-count trends for the Red River play. B) The total Silurian-Ordovician oil-production trend, including production from the Red River, Winnipeg, and Interlake plays.

ranking of 12th, 11th and lower than 20th (Figure 3); and average per-well production of 21.0×10^3 , 12.7×10^3 , and $18.7 \times 10^3 \text{ m}^3$ with ranking of 7th, 13th, and 9th (Figure 4), respectively. Since the first horizontal well (91-13-05-04-30W1) was drilled in the Alida play in October 1990, 85% of Alida production wells have been completed as horizontal wells. To the end of December 2007, 600 horizontal wells have produced $9.7 \times 10^6 \text{ m}^3$ of oil, amounting to 45% of total Alida production. The first Tilston horizontal well 91-05-24-06-32W1 started production in 1992. To the end of December 2007, 480 horizontal wells have been drilled to produce oil from the Tilston play, yielding total horizontal well production of $6.1 \times 10^6 \text{ m}^3$ or 38% of total Tilston production. Production from horizontal wells was largely responsible for the highest production peaks in the mid-1990s on the Alida and Tilston production trends in southern Saskatchewan (Figures 7D and 7E).

Since its initial discovery in 1954, the Frobisher play has cumulatively produced $39.6 \times 10^6 \text{ m}^3$ of oil from 3,386 production wells, ranking it 5th by production (Table 1), 4th by well count (Figure 3) and 15th by per-well average production (Figure 4). The production peak in the mid-1960s (Figure 7F) reflects reservoir response to water flooding. Infill vertical drilling has contributed to increased production since the 1980s and horizontal wells have likewise added to total oil production since 1990. The number of Frobisher horizontal production wells increased from four in 1990 to 99 in 2007 with total oil production of $10.0 \times 10^6 \text{ m}^3$ or 25% of total Frobisher production. The good correlation between production and well count trends augers well for continued success in the Frobisher play.

$4369 \text{ m}^3/\text{day}$ in the month of December 2007. The Bakken Formation in southeastern Saskatchewan is presently considered to be one of North America's hottest oil plays.

The Souris Valley play shows a similar production trend to the Bakken play (Figure 7C). Of the 81 Souris Valley horizontal production wells in southeastern Saskatchewan, 77 were drilled between 2005 and 2007, resulting in production growth from $38.5 \text{ m}^3/\text{day}$ in 2004 to $412.3 \text{ m}^3/\text{day}$ in 2007. The Souris Valley play has cumulatively yielded $0.9 \times 10^6 \text{ m}^3$ of oil from 190 production wells. It ranks 18th in total oil production (Table 1) and 20th by well count (Figure 3). The commingled production from the Tilston-Souris Valley plays is $8.5 \times 10^6 \text{ m}^3$ from 788 production wells, ranking 10th by production (Table 1), 13th by well count (Figure 3), and 17th by per-well average production in southern Saskatchewan (Figure 4).

The Alida and Tilston plays have very similar production and well-count trends over the years (Figures 7D and 7E). Commingled production from the Alida-Tilston play is impossible to allocate to the individual plays. The Alida, Tilston, and Alida-Tilston plays have oil production of 21.7×10^6 , 15.8×10^6 , and $1.0 \times 10^6 \text{ m}^3$ with ranking of 6th, 8th, and 17th (Table 1); production-well counts of 1,103, 1,247, and 56 with

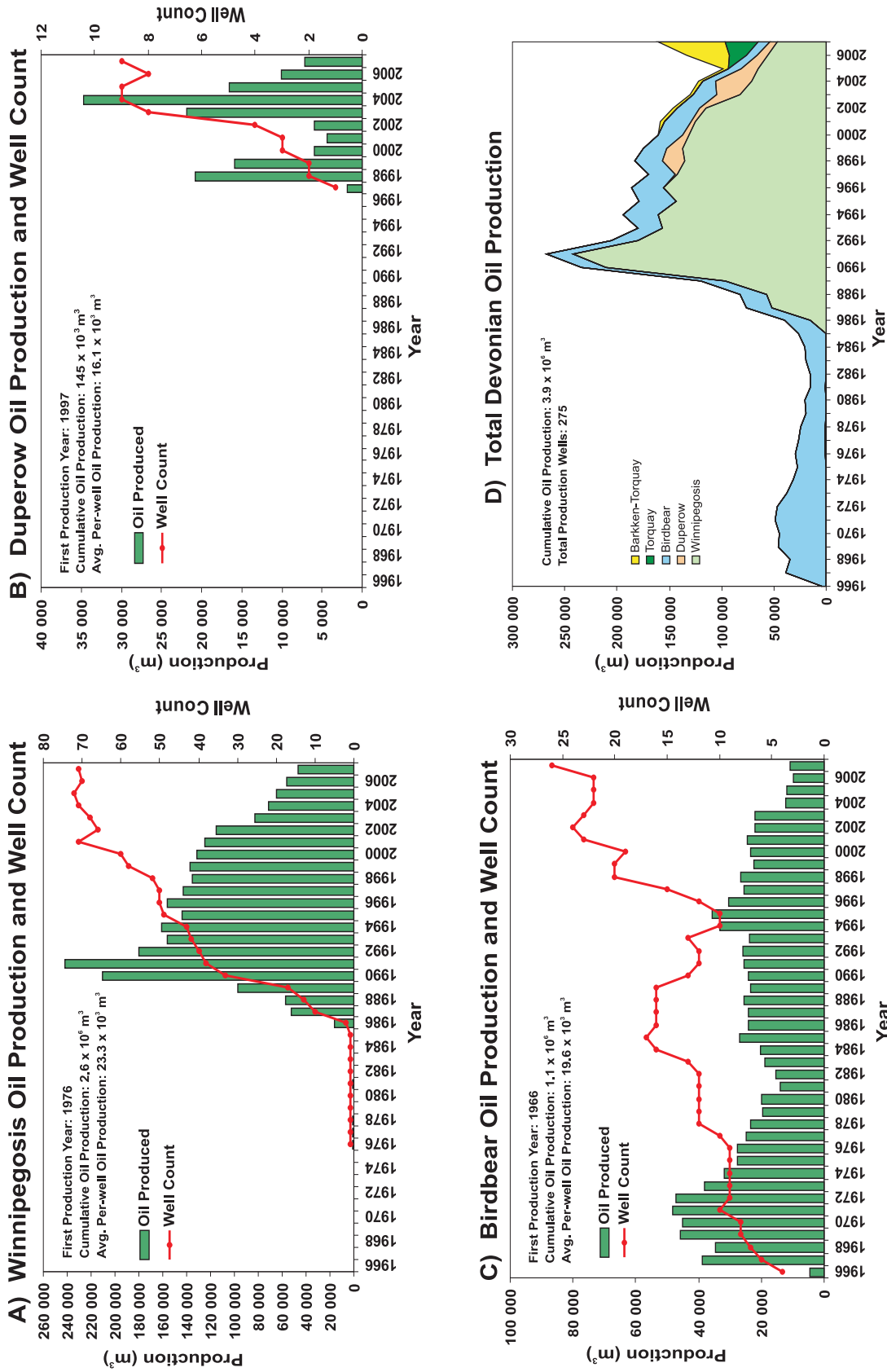


Figure 6 - The Devonian oil-production trends to the end of December 2007 in southern Saskatchewan. Note the wide range of vertical scales used on the graphs. A) Oil-production and well-count trends for the Winnipegosis play. B) Oil-production and well-count trends for the Duperow play. C) Oil-production and well-count trends for the Birdbear play. D) Total Devonian oil-production trends, including production from the Torquay and Barkken-Torquay plays.

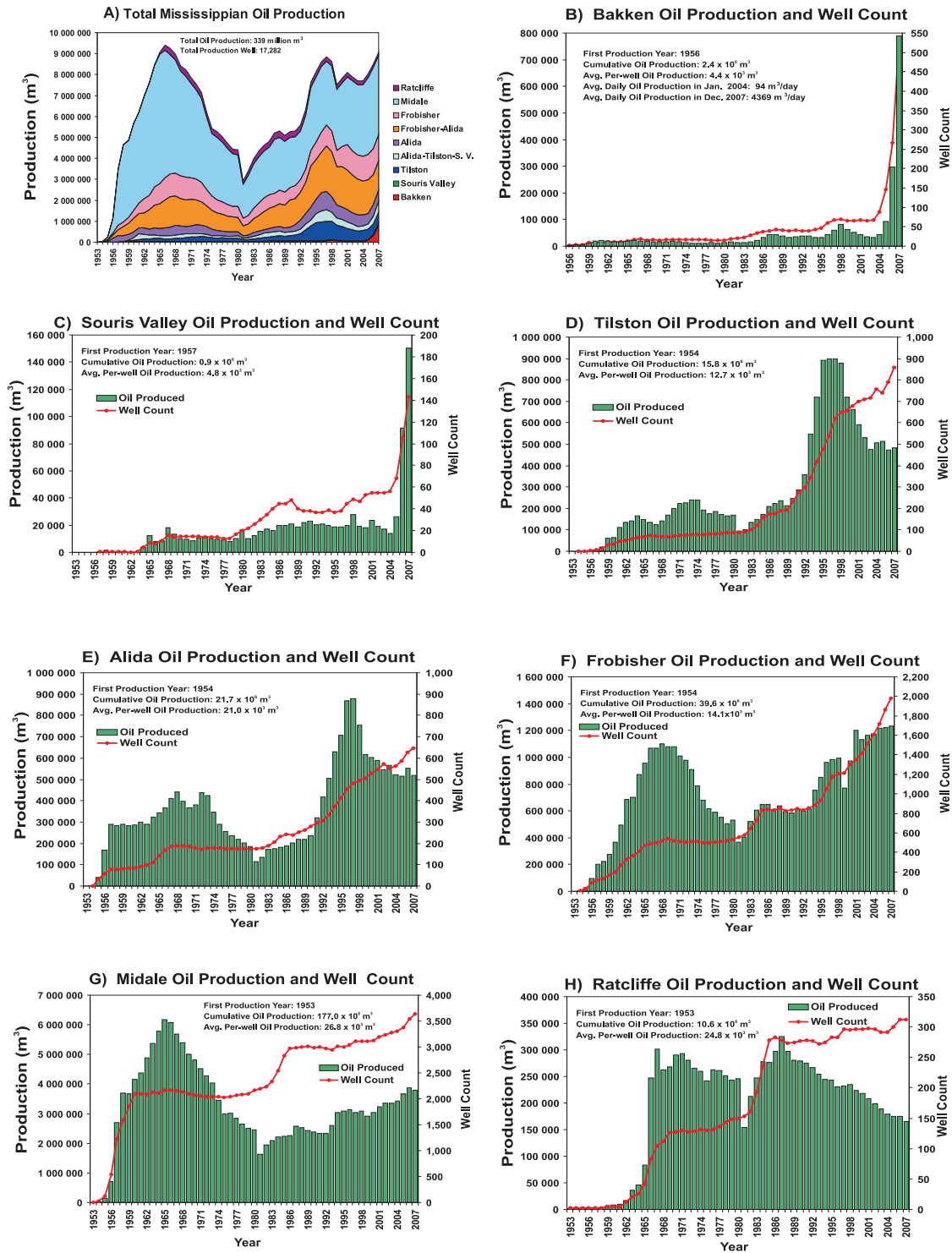


Figure 7 - The Mississippian oil-production trends in southern Saskatchewan to the end of December 2007. Note the wide range of vertical scales used on the graphs. A) Total Mississippian oil production; S.V., Souris Valley. B) Oil-production and well-count trends for the Bakken play. C) Oil-production and well-count trends for the Souris Valley play. D) Oil-production and well-count trends for the Tilston play. E) Oil-production and well-count trends for the Alida play. F) Oil-production and well-count trends for the Frobisher play. G) Oil-production and well-count trends for the Midale play. H) Oil-production and well-count trends for the Ratcliffe play. Note that whereas production from commingled plays (e.g., Frobisher-Alida) is included in the graph of total oil production (A), graphs are not provided for production from individual commingled plays. Also note that in (A), to achieve graphic clarity, production from the Alida-Tilston and Tilston-Souris Valley plays have been combined.

In areas where the contact between the Frobisher and Alida beds cannot be clearly identified, these units are combined as Frobisher-Alida. The Frobisher-Alida play has cumulatively produced $60.8 \times 10^6 \text{ m}^3$ of oil from 2,839 production wells, ranking it 3rd by production (Table 1), 5th by well count (Figure 3), and 6th by per-well average production (Figure 4).

The Midale play started commercial production in 1953. The Weyburn Midale Pool, one of the largest oil pools in Canada, was discovered by the Central Del Rio Ralph 14-06-07-13W2 well in 1954. The historical oil production from the Weyburn Midale Pool illustrates the production increments corresponding to waterflood in the mid-1960s, infill vertical drilling in the mid-1980s, horizontal infill drilling in the mid-1990s, and CO_2 miscible flood after 2000 (Petroleum Technology Research Centre, 2008). To the end of December 2007, the Weyburn Midale Pool has cumulatively produced $72.5 \times 10^6 \text{ m}^3$ of oil and its production history has significant impact on production trend of the Midale play in southern Saskatchewan. The Midale oil-production trend (Figure 7G) shows a similar pattern to that of the Weyburn Midale Pool, with the production peak being reached in 1966. Production started to decline from 1967 to 1981 with very consistent well counts. Production increments recur in the mid-1980s, the mid-1990s, and after 2000 on the production trend, responding to infill vertical drilling, horizontal infill drilling, and the CO_2 miscible flood, respectively. With implementation of a CO_2 flood in the Weyburn Midale Pool in 2000 (Saskatchewan Geological Survey, 2003; Petroleum Technology Research Centre, 2008), Midale production has recovered to the level of 1970s and is still growing with increasing well count. To the end of December 2007, the Midale play has produced $177 \times 10^6 \text{ m}^3$ of oil from a total of 6,593 production wells, ranking it 1st by total oil production (Table 1), 2nd by well count (Figure 3), and 3rd by average per-well production (Figure 4). The Midale play alone has yielded about 36% of the total oil production in southern Saskatchewan.

The Ratcliffe production trend shows a plateau between 1966 and 1980 with a significant drop in 1981, a quick increase between 1982 and 1987 with increasing well counts, and a steady decline since 1991 with continually increasing well counts (Figure 7H). The first big production increment in the mid-1960s was largely attributed to the discoveries of the Flat Lake, Lake Alma, Freda Lake, Neptune, and Hummingbird Ratcliffe pools. There have been 38 horizontal wells drilled in the Ratcliffe play since 1990; these wells have produced $342.6 \times 10^3 \text{ m}^3$ of oil. The Ratcliffe play has cumulatively produced $10.6 \times 10^6 \text{ m}^3$ of oil from 426 production wells, ranking it 9th by production (Table 1), 17th by production-well count (Figure 3), and 4th by average per-well production of $24.8 \times 10^3 \text{ m}^3$ (Figure 4).

d) Jurassic Oil Production

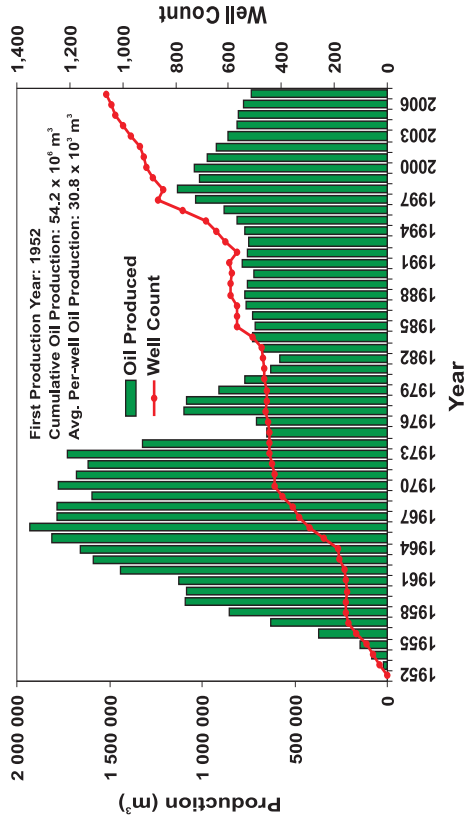
Led by the Roseray and Upper Shaunavon plays, the total Jurassic crude oil production in southwestern Saskatchewan has amounted to $121.8 \times 10^6 \text{ m}^3$ (Figure 8A), about 25% of the overall production from southern Saskatchewan.

The Upper Shaunavon is a major oil producer in southern Saskatchewan, ranking 4th by oil production of $54.2 \times 10^6 \text{ m}^3$ (Table 1), 7th by production-well count of 1755 (Figure 3), and 2nd by the per-well average production of $30.9 \times 10^3 \text{ m}^3$ (Figure 4); all production is from wells in southwestern Saskatchewan. A major production peak occurs between 1962 and 1974 on the production trend and production has been quite consistent since 1975 with two small production peaks in the late-1970s and late-1990s (Figure 8B). The Dollard Upper Shaunavon Pool, discovered in 1953 by the 01-05-21-07-20W3 well, is the largest Upper Shaunavon pool and has cumulatively produced $15.8 \times 10^6 \text{ m}^3$ of oil to the end of December 2007, amounting to almost 30% of total Upper Shaunavon production. The Tide Water Dollard Crown 01-13-22-07-20W3 well has the highest single well production of $872.5 \times 10^3 \text{ m}^3$ of oil. The first horizontal well, 91-11-34-02-26W3, which started production in 1991, has produced $216.6 \times 10^3 \text{ m}^3$ of oil to the end of December 2007. Only 20 horizontal wells produce from the Upper Shaunavon.

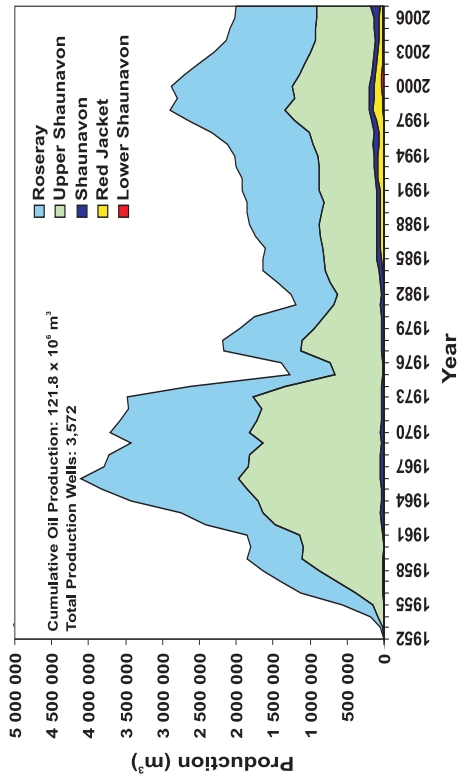
The Lower Shaunavon play has produced $235.3 \times 10^3 \text{ m}^3$ of oil from 48 wells along the paleosyncline that forms the Shaunavon Oil Field Trend (Tp 3 to 16, Rge 16W3 to 20W3) (Marsh and Yurkowski, 2008). The commingled production from the Shaunavon play, when the Lower and Upper Shaunavon are not differentiated, is $2.2 \times 10^6 \text{ m}^3$ from 308 production wells, ranking 14th by production (Table 1), 18th by well count (Figure 3), and 19th by per-well average production in southern Saskatchewan (Figure 4).

The Roseray play is another major oil producer in southern Saskatchewan, ranking 2nd by the total oil production of $62.6 \times 10^6 \text{ m}^3$ (Table 1), 10th by total production-well count of 1,264 (Figure 3) and 1st by the per-well average production of $49.5 \times 10^3 \text{ m}^3$ (Figure 4); all production is from wells in southwestern Saskatchewan. Based on the average per-well production, the Roseray is the most prolific play in southern Saskatchewan. The historical production trend indicates two dominant production peaks. The first peak occurred between 1964 and 1973 in response to new discoveries. The first Roseray discovery was in 1952 from sandstones in the Fosterton Roseray Pool. The discovery well, Saskoil Fosterton 01-02-10-017-18W3, has produced $795.0 \times 10^3 \text{ m}^3$ of oil to the end of December 2007. The later discoveries of Main Success, Success Alpha, South Success, North Premier, Battrum, Verlo, Hazlet, Suffield, Cantuar, and Success North between 1952 and 1966 boosted the production to its highest peak. A second peak occurs between 1997 and 2002 in response to the drilling of horizontal wells which started in

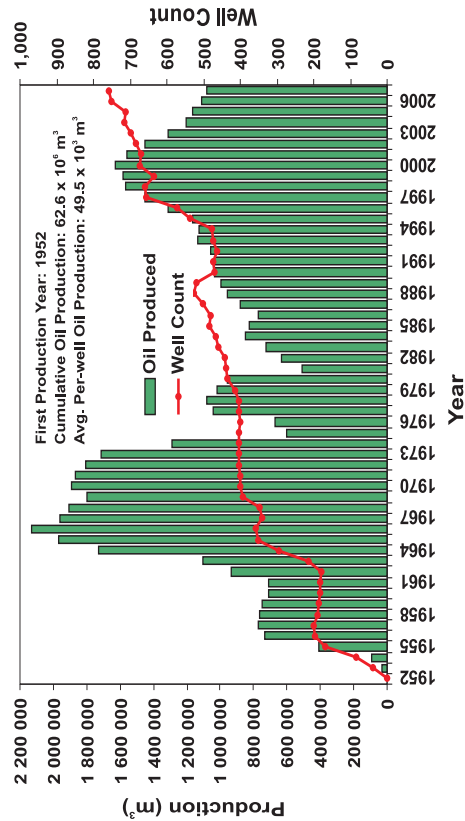
B) Upper Shaunavon Oil Production and Well Count



A) Total Jurassic Oil Production



C) Rosearay Oil Production and Well Count



D) Red Jacket Oil Production and Well Count

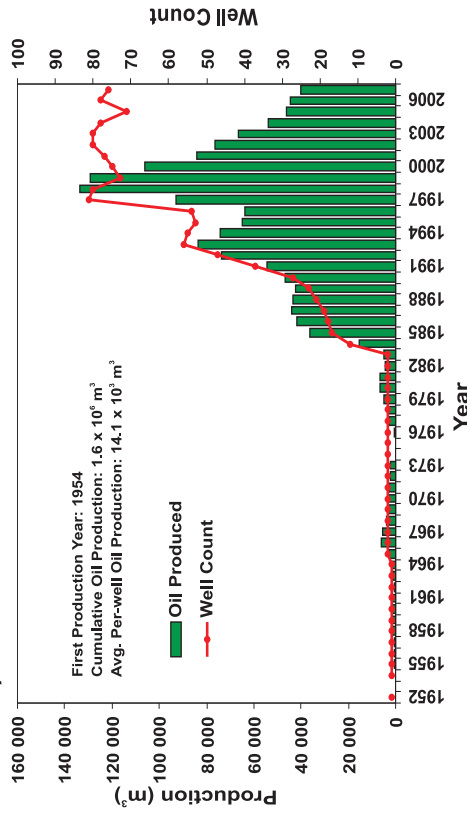


Figure 8 - The Jurassic oil-production trends to the end of December 2007 in southern Saskatchewan. Note the wide range of vertical scales used on the graphs. A) Total Jurassic oil-production trends. The total Jurassic oil production of $121.8 \times 10^6 \text{ m}^3$ includes insignificant amounts of oil from the Lower Watrous and Gravelbourg formations which are not visible in the graph because of the small volumes involved. B) Oil-production and well-count trends for the Upper Shaunavon play. C) Oil-production and well-count trends for the Rosearay play. D) Oil-production and well-count trends for the Red Jacket play.

the mid-1990s (Figure 8C). There are 98 horizontal wells producing from the Rosera play, 45 of which came on production in 1997. The total horizontal well production has amounted to $4.0 \times 10^6 \text{ m}^3$ with an average per-well production of $40.4 \times 10^3 \text{ m}^3$. The implementation of an *in situ* combustion project at Battrum between 1965 and 2001 contributed to the total pool production of $4.5 \times 10^6 \text{ m}^3$, but had little impact on the Rosera production trend.

Production from the Red Jacket play in southeastern Saskatchewan started in 1954, but became more significant in the mid-80s with discoveries of the Red Jacket Red Jacket, Moosomin Red Jacket, and Coothill Red Jacket pools. The production reached its peak in 1998-99 (Figure 8D). Total oil production of $1.6 \times 10^6 \text{ m}^3$ and the per-well average production of $14.1 \times 10^3 \text{ m}^3$ of oil rank this play 15th and 12th in the respective categories (Table 1, Figure 4).

The major Jurassic oil plays show a similar pattern in their oil-production and well-count trends in recent years whereby production decreases with increasing well count (Figures 8B, 8C, and 8D). Discovery of new pools and application of new enhanced-recovery methods in existing pools may be a future exploration and development strategy for petroleum companies.

The Lower Watrous, Gravelbourg, and Success formations are additional Triassic-Jurassic-Cretaceous plays. The Triassic Lower Watrous play has produced $145.2 \times 10^3 \text{ m}^3$ of oil from 40 wells in southeastern Saskatchewan (Table 1), mostly in the Carlyle area (Tp 7 to 8, Rge 1W2 to 3W2). Of the 40 wells, 30 are horizontal with oil production of $115.9 \times 10^3 \text{ m}^3$ from 1992 to 2007. The Jurassic Gravelbourg has produced $41.6 \times 10^3 \text{ m}^3$ of oil (Table 1) from five wells in the Red Jacket area (Tp 13 to 14, Rge 31W3 to 1W2) and three wells in the Cypress Lake South area (Tp 5, Rge 27W3). Since 1991, the Success has produced $143.9 \times 10^3 \text{ m}^3$ of oil (Table 1) from 31 wells, of which 18 are in the Java North area (Tp 16, Rge 15W3), 12 are in the Seward North area (Tp 15, Rge 15W3 to 16W3), and one in the Gull Lake area.

e) Cretaceous Mannville Oil Production

The Mannville Group is the major Cretaceous oil producer in the study area with cumulative oil production of $17.0 \times 10^6 \text{ m}^3$ from 1,502 wells in southwestern Saskatchewan. This play ranks 7th by production (Table 1), 8th by production-well count (Figure 3), and 16th by per-well average production (Figure 4). The first horizontal well, Wascana Cantuar 10-22-16-17W3, was drilled in 1994, and, to the end of December 2007, a total of 41 Mannville horizontal wells have produced oil; 27 of these started production in 1996 and 1997. As of the end of December 2007, a total of 220 directional wells have produced Mannville oil; 202 of these started production between 1995 and 2001. The highest production peak on the Mannville production trend in the late 1990s is largely attributable to the intensive directional and horizontal well drilling during that period (Figure 9). Production started to decline in 2000 despite an increasing well count.

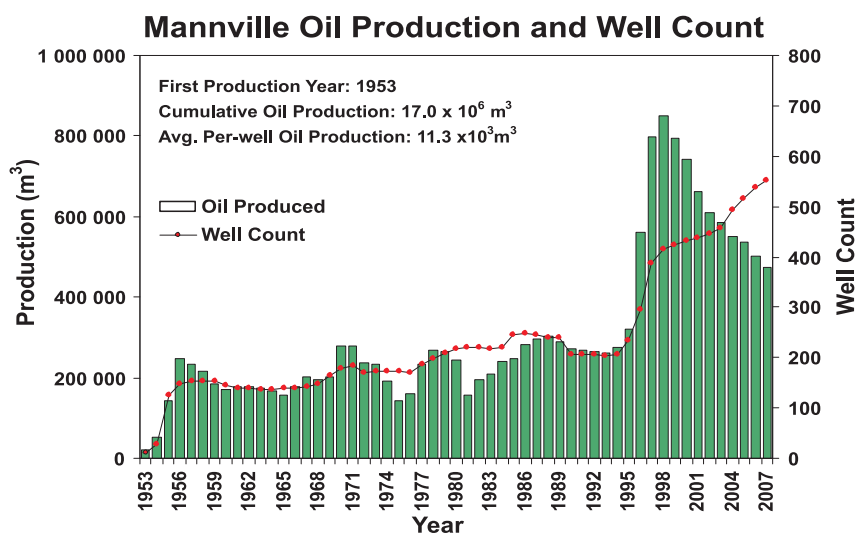


Figure 9 - Oil-production and well-count trends to the end of December 2007 for the Cretaceous Mannville play in southwestern Saskatchewan.

4. Gas-production Results

a) Shallow-gas Production

The total shallow-gas production in southern Saskatchewan amounts to $94.9 \times 10^6 \text{ m}^3$ from a total of 20,936 production wells with an average per-well production of $4.5 \times 10^3 \text{ m}^3$ (Table 2; Figure 10A).

The Upper Cretaceous Belle Fourche (Second White Specks), Medicine Hat, and Milk River formations are the major shallow-gas producers in southwestern Saskatchewan. There are approximately 10,780 wells producing from the Milk River: 5,364 from commingled Milk River and Medicine Hat; 1,907 from the Second White Specks; 1,391 from the Medicine Hat; 607 from commingled Milk River, Medicine Hat, and Second

Table 2 - Gas-production ranking by play to the end of December 2007 in southern Saskatchewan (data source is Saskatchewan Ministry of Energy and Resources, Petroleum Statistics Branch).

| Play | Cumulative Gas Production to December 2007 | | Year to Start Production | Total Wells in Production |
|---|--|------|--------------------------|---------------------------|
| | (m ³) | Rank | | |
| Milk River | 42 193 865 | 1 | 1971 | 10,780 |
| Milk River–Medicine Hat | 24 683 331 | 2 | 1974 | 5,364 |
| Midale | 16 148 416 | 3 | 1953 | 6,593 |
| Second White Specks | 14 650 721 | 4 | 1980 | 1,907 |
| Medicine Hat | 10 718 174 | 5 | 1958 | 1,391 |
| Roseray | 8 311 850 | 6 | 1952 | 1,264 |
| Frobisher-Alida | 5 485 968 | 7 | 1953 | 2,839 |
| Frobisher | 3 527 163 | 8 | 1954 | 3,386 |
| Mannville | 3 359 781 | 9 | 1954 | 1,502 |
| Upper Shaunavon | 2 013 224 | 10 | 1953 | 1,755 |
| Alida | 1 927 343 | 11 | 1954 | 943 |
| Milk River–Medicine Hat–Second White Specks | 886 877 | 12 | 1998 | 607 |
| Tilston | 647 801 | 13 | 1954 | 1,249 |
| Ribstone Creek | 524 492 | 14 | 1984 | 125 |
| Deadwood | 464 903 | 15 | 1963 | 4 |
| Belly River | 422 507 | 16 | 1994 | 134 |
| Milk River–Second White Specks | 404 192 | 17 | 1998 | 510 |
| Winnipegosis | 394 525 | 18 | 1976 | 111 |
| Ratcliffe | 375 953 | 19 | 1953 | 426 |
| Tilston–Souris Valley | 301 169 | 20 | 1956 | 788 |
| Bearpaw | 196 591 | 21 | 1998 | 50 |
| Bearpaw–Belly River | 147 999 | 22 | 1998 | 39 |
| Red River | 134 995 | 23 | 1958 | 196 |
| Viking | 132 468 | 24 | 1984 | 17 |
| Lower Watrous–Alida | 111 691 | 25 | 1966 | 160 |
| Bakken | 103 306 | 26 | 1956 | 604 |
| Birdbear | 87 302 | 27 | 1966 | 55 |
| Alida-Tilston | 64 890 | 28 | 1980 | 56 |
| Duperow | 46 251 | 29 | 1997 | 10 |
| Shaunavon | 35 326 | 30 | 1953 | 308 |
| Medicine Hat–Second White Specks | 20 009 | 31 | 2003 | 16 |
| Souris Valley | 12 946 | 32 | 1957 | 190 |
| Winnipeg | 10 455 | 33 | 1998 | 15 |

Note: Production smaller than $10 \times 10^3 \text{ m}^3$ from a play are not included in this table.

White Specks; and 510 from commingled Milk River and Second White Specks. These plays rank 1st, 3rd, 6th, 9th, 14th, and 16th, respectively in total well count for southern Saskatchewan (Figure 3). The cumulative gas production from the Milk River, Milk River–Medicine Hat, Second White Specks, Medicine Hat, Milk River–Medicine Hat–Second White Specks, and Milk River–Second White Specks plays are 42.2×10^6 , 24.7×10^6 , 14.7×10^6 , 10.7×10^6 , 0.9×10^6 , and $0.4 \times 10^6 \text{ m}^3$; their rankings for this parameter are 1st, 2nd, 4th, 5th, 12th, and 17th, respectively (Table 2; Figures 10B, 10C, and 10D).

The Second White Specks play started gas production in 1980 and its highest production peak occurred around 1990 (Figure 10B). Although the well count has increased from 683 in 1997 to 1,509 in 2003, the gas production only increased from $455.8 \times 10^3 \text{ m}^3$ in 1997 to $607.5 \times 10^3 \text{ m}^3$ in 2003.

The Medicine Hat play had its highest production peak from the late-1960s to early-1970s with an average per-well production of $7.7 \times 10^3 \text{ m}^3$ (Figure 10C). The production has been declining since 2000 without a significant decrease in well count.

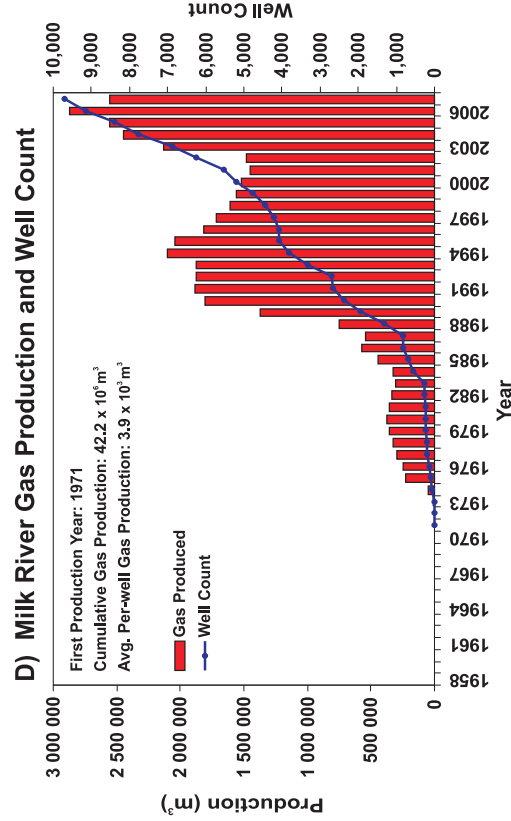
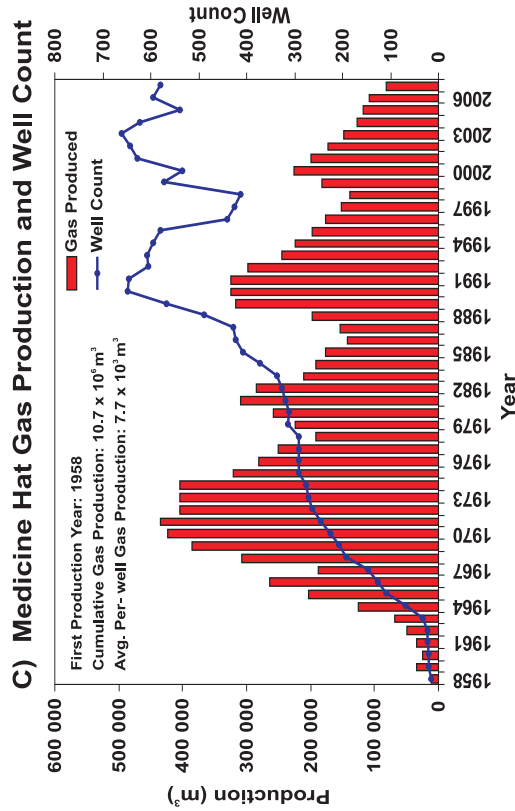
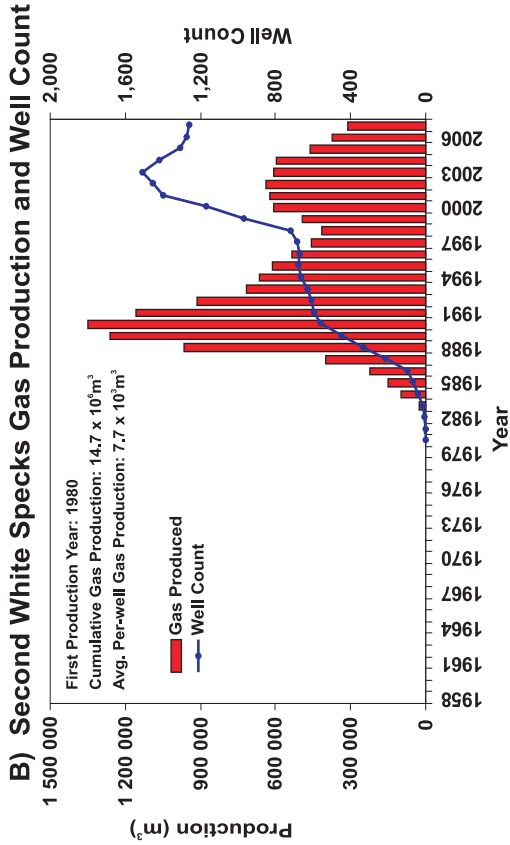
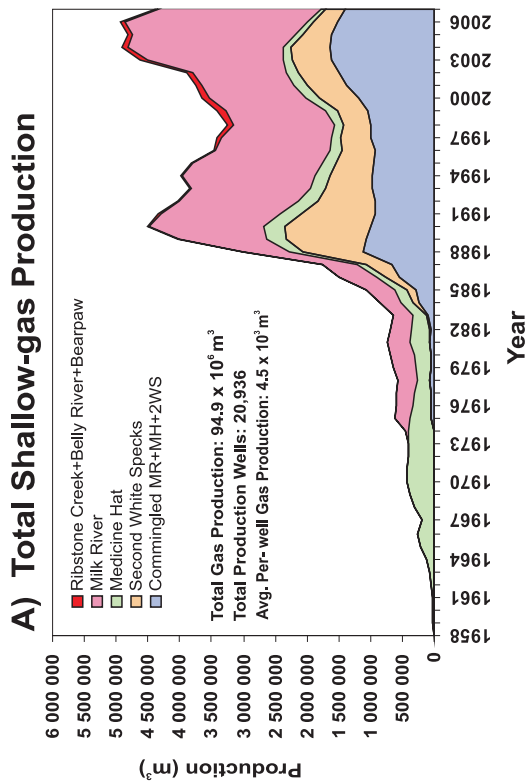


Figure 10 - The unconventional shallow-gas production trends to the end of December 2007 in southern Saskatchewan. Note the wide range of vertical scales used on the graphs. A) The total unconventional shallow-gas production trend. This graph does not show production from the Fish Scale and Lea Park formations because of the small volumes involved; MH, Medicine Hat; MR, Milk River; and 2WS, Second White Specks. B) The unconventional shallow-gas production and well-count trends for the Second White Specks play. C) The unconventional shallow-gas production and well-count trends for the Medicine Hat play. D) The unconventional shallow-gas production and well-count trends for the Milk River play.

A general good correlation between gas production and well count is observed in the gas production and well trends for the Milk River play (Figure 10D). Up to the end of December 2007, the Milk River produced a total of $42.2 \times 10^6 \text{ m}^3$ of gas, of which $6.3 \times 10^6 \text{ m}^3$ have been produced since 2003 in southwestern Saskatchewan (Figure 10D). As of the end of December 2007, there are 10,780 Milk River gas-production wells, of which 5,430 started production since 2000. Milk River gas production in southwestern Saskatchewan has increased from $0.9 \times 10^3 \text{ m}^3/\text{day}$ in 1984 to $7.0 \times 10^3 \text{ m}^3/\text{day}$ in 2007 with an average per-well production of $3.9 \times 10^6 \text{ m}^3$. The Milk River play had peak production in 2006 (Figure 10D).

In addition to the major shallow-gas plays, small volumes of gas are produced from the Fish Scales (884 m^3), Lea Park (4744 m^3), Ribstone Creek ($524.5 \times 10^3 \text{ m}^3$), Belly River ($422.5 \times 10^3 \text{ m}^3$), Bearpaw ($196.6 \times 10^3 \text{ m}^3$), and Bearpaw–Belly River ($148.0 \times 10^3 \text{ m}^3$) reservoirs (Table 1). Gas production is less than $10 \times 10^3 \text{ m}^3$ from both the Fish Scale and Lea Park formations, which are not, therefore, included in Table 1.

b) Conventional Associated-gas Production

The major oil plays in southeastern Saskatchewan have produced large amount of associated gas during oil production. The Midale, Roseray, Frobisher-Alida, Frobisher, Mannville, and Upper Shaunavon plays are respectively ranked 3rd, 6th, 7th, 8th, 9th, and 10th by gas production in southern Saskatchewan (Table 2). The Frobisher gas-production trend (Figure 11A) shows the same pattern as its oil-production trend (Figure 7F). The Midale gas-production trend (Figure 11B) is also comparable to its oil-production trend (Figure 7G), but, in recent years, incremental increases in gas production are more pronounced than in oil production. The more significant gas-production increase reflects the recovery of injected CO_2 in the Weyburn Midale Pool following the commencement of CO_2 miscible-flooding in 2000. In Weyburn, the impact of CO_2 recovery on gas production is illustrated by 2005 data which indicate that, of the $394.6 \times 10^3 \text{ m}^3$ of gas produced, $365.9 \times 10^3 \text{ m}^3$ were recycled CO_2 and $28.7 \times 10^3 \text{ m}^3$ were associated hydrocarbon gases (Saskatchewan Industry and Resources, 2007a). The Roseray gas-production trend (Figure 11C) is similar to its oil-production trend (Figure 8C); its highest peak is around year 2000.

The associated gas production trends for Frobisher-Alida beds, Mannville, and Upper Shaunavon plays are shown in Figure 11D. Together, the top six plays have produced a total of $43.8 \times 10^6 \text{ m}^3$ of associated gas in southern Saskatchewan.

5. Conclusions

Mississippian Madison Group carbonates in southeastern Saskatchewan, and sandstones of the Jurassic Roseray and Upper Shaunavon plays in southwestern Saskatchewan have produced the largest volumes of oil in the study area to the end of December 2007. The Upper Cretaceous Milk River, Medicine Hat, and Second White Specks plays are the major unconventional shallow-gas producers in southwestern Saskatchewan. The major oil producers are also the major associated-gas producers in southern Saskatchewan.

For most of the mature plays, hydrocarbon production and well count generally correlate well during the earlier stage of the production. Water flooding, infill-drilling, horizontal well drilling and CO_2 miscible flood technology have had significant impacts on the production trends of mature plays, such as the Midale. Appropriate application of these recovery technologies will optimize recovery and prolong the life of hydrocarbon pools.

This statistical study cannot predict future drilling and production, but it does point out the production trends, effective recovery methods, and the most prolific plays in southern Saskatchewan, which help highlight hotspots for future exploration.

6. Acknowledgments

I am grateful to Janice Loseth of the Petroleum Statistics Branch, for providing the database of this contribution. My thanks also go to Fran Haidl, Erik Nickel, Chris Gilboy, and Melinda Yurkowski for comments and suggestions for improvement of this paper, and to Megan Love for assistance with finalizing the graphs.

7. References

Bates, G. and Kendall, A. (2008): Understanding the origin of the sub-unconformity diagenetic caprock, in the Mississippian of the Williston Basin, southeast Saskatchewan; CSPG abstract, URL<<http://www.geoconvention.org/2008abstracts/094.pdf>>, accessed 3 July 2008.

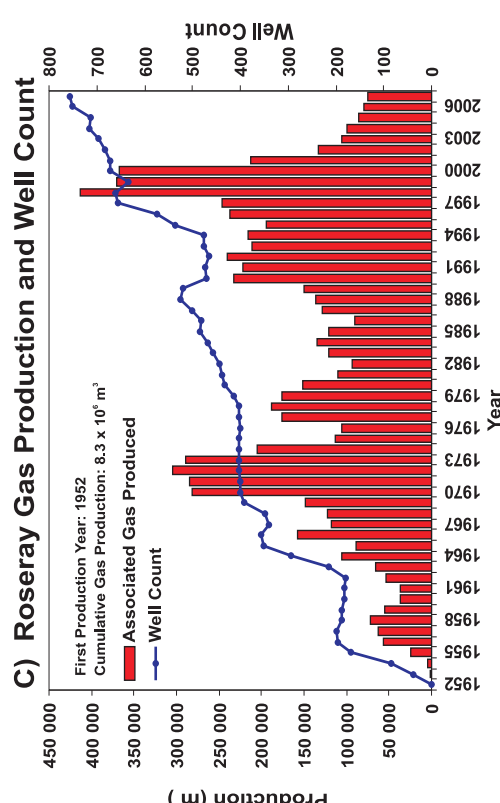
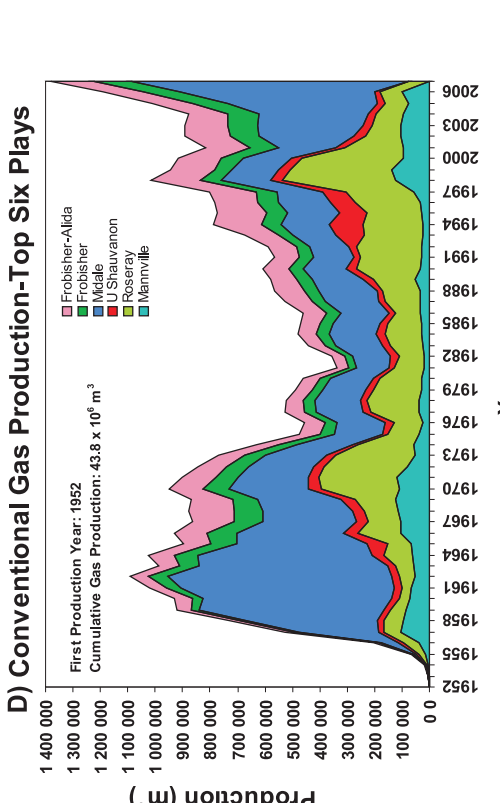
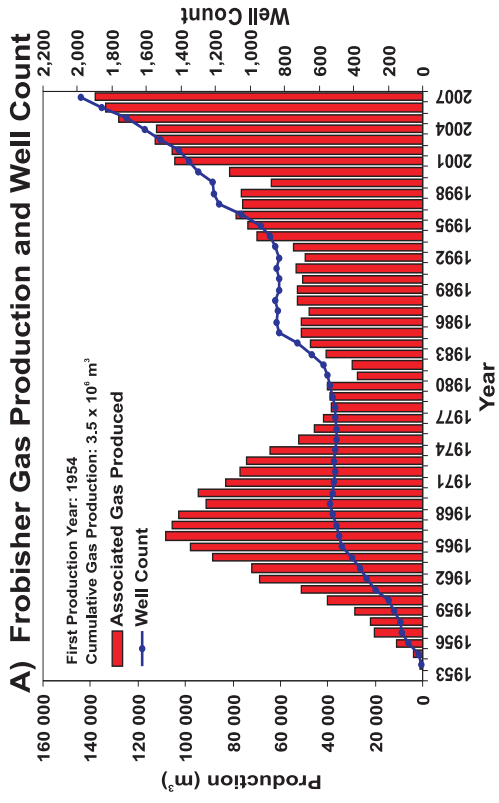
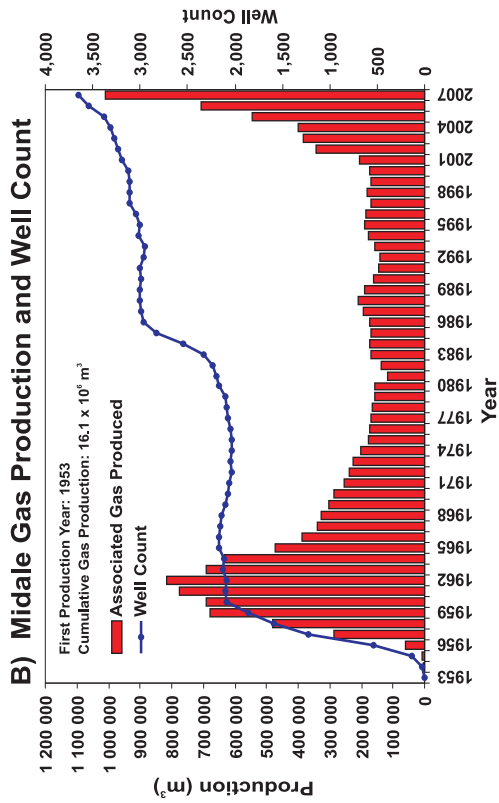


Figure 11 - The conventional associated-gas production trends to the end of December 2007 in southern Saskatchewan. Note the wide range of vertical scales used on the graphs. A) The associated-gas production and well-count trends for the Frobisher play, not including commingled production. B) The associated-gas production and well-count trends for the Midale play. The significant increase in gas production since 2000 reflects the recovery of injected CO₂ in the Weyburn Midale Pool. C) The associated-gas production and well-count trends for the Roseray play. D) The associated-gas production trends for the top six associated gas-producing plays; U, Upper.

- Blair, M. and Bergman, K. (2002): Allostratigraphic analysis of the Middle Jurassic in southern Saskatchewan; CSPG abstract, URL<<http://www.cspg.org/conventions/abstracts/2002abstract/entended/18950124.pdf>>, accessed 13 July 2008.
- Cen, X.C. and Salad Hersi, O. (2006): A revised lithostratigraphic framework and characteristics of the Upper Devonian Duperow Formation, southeastern Saskatchewan; *in* Summary of Investigations 2006, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.1, CD-ROM, Paper A-9, 17p.
- Christopher, J.E. (1964): The Middle Jurassic Shaunavon Formation of Southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 95, 95p.
- _____ (1974): The Upper Jurassic Vanguard and Lower Cretaceous Mannville Groups of Southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 151, 349p.
- _____ (2003): Jura-Cretaceous Success Formation and Lower Cretaceous Mannville Group of Saskatchewan; Sask. Industry Resources, Rep. 223, CD-ROM.
- Dunn, C.E. (1975): The Upper Devonian Duperow Formation in Southern Saskatchewan; Sask. Dep. Miner. Resour., Sask. Geol. Surv., Rep. 179, 151p.
- Edwards, D.E., Barclay, J.E., Gibson, D.W., Kvill, G.E., and Haltone, E. (1994): Triassic strata of the Western Canada Sedimentary Basin; *in* Mossop, G.D. and Shetson, I. (comp.), Geological Atlas of the Western Canada Sedimentary Basin, Can. Soc. Petrol. Geol./Alta. Resear. Counc., Calgary, URL <http://www.ags.gov.ab.ca/publications/ATLAS_WWW/A_CH16/CH_16_F.shtml>, accessed 10 July 2008.
- Fu, Q., Qing, H., and Bergman, K. (2006): Paleokarst in Middle Devonian Winnipegosis mud mounds, subsurface of south-central Saskatchewan, Canada; Bull. Can. Petrol. Geol. v54, p22-36.
- Fuzesy, L.M. (1983): Correlation and Subcrops of the Mississippian Strata in Southeastern and South-Central, Saskatchewan; Sask Energy Mines, Rep. 51, 63p.
- Gilboy, C.F. (1987): Aspects of the regional geological framework of the low-permeability shallow gas reservoirs in Upper Cretaceous strata (Colorado and Montana groups), southwestern Saskatchewan; *in* Summary of Investigations 1987, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 87-4, p199-213.
- _____ (1988): Geology and natural gas production of the Upper Cretaceous Second White-Speckled Shale, southwestern Saskatchewan; *in* Summary of Investigations 1988, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 88-4, p183-195.
- Haidl, F., Nimegeers, A., and Marsh, A. (2006): Stratigraphy and hydrocarbon potential of Silurian Interlake strata, southeastern Saskatchewan; *in* Gilboy, C.F. and Whittaker, S.G. (eds.), Saskatchewan and Northern Plains Oil & Gas Symposium 2006, Sask. Geol. Soc., Spec. Publ. No. 19, p74-91.
- Halabura, S.P. (1982): Depositional environments of the Upper Devonian Birdbear Formation, Saskatchewan; *in* Christopher, J.E. and Kaldi, J. (eds.), Fourth International Williston Basin Symposium, Sask. Geol. Soc., Spec. Publ. No. 6, p113-124.
- Jones, L. (1965): The Middle Devonian Winnipegosis Formation of Saskatchewan; Sask. Dep. Miner. Resour., Rep. 98, 101p.
- Kendall, A.C. (1976): The Ordovician Carbonate Succession (Big Horn Group) of Southeastern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 180, 185p.
- Kendall, R. (2008): Microseismic monitoring of a multi-stage frac in the Bakken Formation, SE Saskatchewan; Back to Exploration – 2008 CSPG CSEG CWLS Convention, May 12 to 15, Calgary, abstract, URL<<http://www.geoconvention.org/2008abstracts/279.pdf>>, accessed 3 July 2008.
- Kent, D.M. (1998): Diagenetically altered stromatoporoid banks; Seals for dolomitic reservoirs in Birdbear and Duperow rocks of southern Saskatchewan; *in* Kreis, L.K. (ed.), Eighth International Williston Basin Symposium, Sask. Geol. Soc., Core Workshop, Vol. 8, p105-142.
- _____ (2001): Mississippian Madison and Jurassic Gravelbourg low-gravity oil accumulations in southwestern Saskatchewan: examples of unconformity traps related to regional hydrodynamics, basement

- structure and local paleotopography; Rock the Foundation – 2001 CSPG Convention, Calgary, abstract, URL<<http://www.cspg.org/conventions/abstracts/2001abstracts/C-146.pdf>>, accessed 3 July 2008.
- Kent, D.M., Haidl, F.M., and MacEachern, J.A. (1988): Mississippian oil fields in the northern Williston Basin; *in* Goolsby, S. and Longman, N.W. (eds.), *Occurrence and Petrophysical Properties of Carbonate Reservoirs in the Rocky Mountain Region*, Rky. Mtn. Assoc. Geol., Denver, p381-417.
- Kent, D.M. and Kreis, L.K. (2001): Mississippian Madison Formation low-gravity oilfields in southwestern Saskatchewan: examples of unconformity diagenesis controlling reservoir quality; *in* Summary of Investigations 2001, Volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.1, p46-55.
- Kent, D.M., Thomas, P.L., and Heck, T. (2004): Geological mapping of Mississippian strata in southeastern Saskatchewan, northwestern North Dakota, and northeastern Montana (IEA Weyburn CO₂ Monitoring and Storage Project); *in* Summary of Investigations 2004, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.1, CD-ROM, Paper A-7, 22p.
- Kreis, L.K. (1991): Stratigraphy of the Jurassic System in the Wapella-Moosomin Area, Southeastern Saskatchewan; Sask. Energy Mines, Rep. 217, 90p.
- _____ (2004): Geology of the Middle Ordovician Winnipeg Formation in Saskatchewan; Lower Paleozoic Map Series – Saskatchewan, Sask. Industry Resources, Misc. Rep. 2004-8, CD-ROM, Sheet 3 of 8.
- Kreis, L.K., Costa, A.L., and Osadetz, K. (2005): New perspectives on the hydrocarbon potential of Bakken and Torquay formations, southeastern Saskatchewan; Global Roundup – Exploring Energy Systems – CSPG 2005 Core Conference, URL<http://www.searchanddiscovery.com/documents/abstracts/2005annual_calgary/abstracts/kreis.htm>, accessed 15 July 2008.
- _____ (2006): Hydrocarbon potential of the Bakken and Torquay formations, southeastern Saskatchewan; *in* Gilboy, C.F. and Whittaker, S.G. (eds.), *Saskatchewan and Northern Plains Oil & Gas Symposium 2006*, Sask. Geol. Soc., Spec. Publ. No. 19, p119-137.
- Kreis, L.K. and Haidl, F.M. (2004): Geology of the Upper Ordovician Red River strata (Herald and Yeoman formations) in Saskatchewan; Lower Paleozoic Map Series – Saskatchewan, Sask. Industry Resources, Misc. Rep. 2004-8, CD-ROM, Sheet 7 of 8.
- Kreis, L.K., Haidl, F.M., and Nimegeers, A.R. (2004): Geology of the Silurian Interlake Formation in Saskatchewan; Lower Paleozoic Map Series – Saskatchewan, Sask. Industry Resources, Misc. Rep. 2004-8, CD-ROM, Sheet 4 of 8.
- Larson, B.W., Martindale, W., Nimegeers, A., and Haidl, F.M. (2003): Saskatchewan's first Silurian oil producer: Nexen Bryant 7-4T-5-7W2; *in* Summary of Investigations 2003, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2003-4.1, CD-ROM, Paper A-4, 15p.
- Longman, M.W., Fertal, T.G., and Glennie, J.S. (1983): Origin and geometry of Red River dolomite reservoirs, western Williston Basin; AAPG Bull., v67, p744-771.
- Marsh, A. and Heinemann, K. (2005): Report on the Regional Stratigraphic Framework of Western Saskatchewan – Phase 1; Petroleum Technology Research Centre, Regina, URL<http://www.ptrc.ca/publications.php?f_action=news_detail&news_id=14022>, accessed 11 July 2008.
- Marsh, A. and Yurkowski, M. (2008): Sedimentology and Stratigraphy of the Middle Jurassic Shaunavon Formation Oil Fields in Southwestern Saskatchewan; Back to Exploration – 2008 CSPG CSEG CWLS Convention, May 12 to 15, Calgary, abstract, URL<<http://www.geoconvention.org/2008abstracts/147.pdf>>, accessed 14 July 2008.
- Martindale, W., Erkmen, U., Metcalfe, D., and Potts, E. (1991): Winnipegosis buildups of the Hitchcock area, southeastern Saskatchewan – a case study; *in* Christopher, J.E. and Haidl, F.M. (eds.), *Sixth International Williston Basin Symposium*, Sask. Geol. Soc., Spec. Publ. No. 11, p47-63.
- Nichols, R.A.H. (1970): The Petrology and Economic Geology of the Upper Devonian Birdbear Formation in Southeastern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 125, 93p.

- Nickel, E. and Yang, C. (comps.) (2008): Mississippian subcrop map and selected oil-production data, southeastern Saskatchewan; Saskatchewan Ministry of Energy and Resources, Open File 2008-2, poster.
- Nimegeers, A.R. and Haidl, F.M. (2004): Lower Paleozoic anhydrites in southeastern Saskatchewan: Townships 1 to 17, Ranges 1W2 to 24W2; *in* Summary of Investigations 2004, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.1, CD-ROM, Paper A-4, 18p.
- Nimegeers, A.R., Kent, D., Marsh, A., and Nickel, E. (2006): Hydrocarbon trapping in Mississippian strata of southeastern Saskatchewan; *in* Gilbo, C.F. and Whittaker, S.G. (eds.), Saskatchewan and Northern Plains Oil & Gas Symposium 2006, Sask. Geol. Soc. Spec. Publ. No. 19, p165-172.
- Paterson, D.F. (1971): The Stratigraphy of the Winnipeg Formation (Ordovician); Sask. Dep. Miner. Resour., Rep. 140, 57p.
- Pedersen, P.K. (2004): Shallow gas research project in southwestern Saskatchewan: revised lithostratigraphy of the Colorado Group and reservoir architecture of the Belle Fourche and Second White Specks in the Senate Pool; *in* Summary of Investigations 2004, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.1, CD-ROM, Paper A-16, 15p.
- Pemberton, S.G. and James, D.P. (1997): Petroleum Geology of the Cretaceous Mannville Group, Western Canada; CSPG Mem. 18, 486p.
- Petroleum Technology and Research Centre (2008): Weyburn-Midale CO₂ Project, URL<http://www.ptrc.ca/weyburn_statistics.php>, accessed 10 July 2008.
- Potter, D. and St. Onge, A. (1991): Minton Pool, south-central Saskatchewan: a model for basement induced structural and stratigraphic relationships; *in* Christopher, J.E. and Haidl, F.M. (eds.), Sixth International Williston Basin Symposium, Sask. Geol. Soc., Spec. Publ. No. 11, p21-33.
- Pu, R., Qing, H., Kent, D., and Urban, M. (2003): Pool characterization of Ordovician Midale field: implication for Red River play in northern Williston Basin, southern Saskatchewan, Canada; AAPG Bull., v87, p1699-1715.
- Saskatchewan Geological Survey (2003): Geology, and mineral and petroleum resources of Saskatchewan; Saskatchewan Industry Resources, Misc. Rep. 2003-7, 173p.
- Saskatchewan Industry and Resources (2004): Saskatchewan Stratigraphic Correlation Chart; URL<<http://www.ir.gov.sk.ca/stratchart>>, accessed 17 July 2008.
- _____ (2007a): Saskatchewan Mineral Statistics Yearbook 2005; Petroleum and Natural Gas, Misc. Rep. 2006-3, URL <<http://www.ir.gov.sk.ca/adx/asp/adxGetMedia.aspx?DocID=3732,3620,3384,5460,2936,Documents&MediaID=18143&Filename=2005+Yearbook.pdf>>, accessed 3 July 2008.
- _____ (2007b): The Ratner Laminites: Porous Dolostone in an "Inter-Reef Setting; Prospect Saskatchewan, Issue 5, Sask. Industry Resources, URL <http://www.er.gov.sk.ca/adx/asp/adxGetMedia.aspx?DocID=4404,3967,3625,3384,5460,2936,Documents&MediaID=16804&Filename=Prospect_Sask_Ratner.pdf>, accessed 10 July 2008.
- Saskatchewan Ministry of Energy and Resources (2008): Transitional passive-margin to convergent-margin phase rocks (Late Triassic or Early Jurassic to Jura-Cretaceous); URL <<http://www.er.gov.sk.ca/Default.aspx?DN=3792,3790,3539,3538,3385,2936,Documents>>, accessed 10 June 2008.
- Smith, D.D. (1985): Hummingbird structure in southeastern Saskatchewan; AAPG Bull. v69, p867.
- TGI Williston Basin Working Group (2008): Stratigraphic Map Series; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Stratigraphic Map SM2008-MME-I, scale 1:1 000 000, URL<www.WillistonTGI.com>, accessed 10 July 2008.
- Whittaker, S. and Gilbo, C. (2003): IEA Weyburn CO₂ Monitoring and Storage Project: Geoscience Framework update; *in* Summary of Investigations 2003, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2003-4.1, CD-ROM, Paper A-7, 9p.
- Yurkowski, M. (2006): Shallow Gas Potential of Saskatchewan; URL <https://www.dmr.nd.gov/ndgs/wbpc/pdf/Melinda_Yurkowski.pdf>, accessed 10 June 2008.