Hydrocarbon Play Ranking and Production Trends in Saskatchewan to Year End 2011

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Abstract

Hydrocarbon production from plays within Ordovician to Cretaceous strata in Saskatchewan has been statistically assessed to evaluate average per-well production, cumulative production, and overall production trends.

This assessment, based on production to December 31, 2011, indicates that Mississippian Madison Group carbonates, Cretaceous Mannville and Viking sandstones, Jurassic Roseray and Upper Shaunavon strata, and Mississippian-Devonian Bakken reservoirs are the major oil producers in Saskatchewan. Cumulative oil production rankings indicate that Mississippian Midale reservoirs have produced the largest volume of oil in Saskatchewan.

The Bakken play ranks first, based on monthly oil production for December 2011. The sharp increases in oil production from the Bakken, Viking, and Lower Shaunavon plays since 2008 reflect the successful application of horizontal well drilling and multi-stage hydraulic fracturing completion to tight oil plays.

The Upper Cretaceous Milk River, Medicine Hat, and Belle Fourche (Second White Specks) formations are the major shallow-gas producers in Saskatchewan with a total production of 109 x 10^9 m^3 to December 31, 2011 or 43% of total gas production in the province. The Lower Cretaceous Mannville and Viking play has produced a total of 91.6 x 10^9 m^3 of associated and non-associated gas or 36% of total gas. The sub-Cretaceous oil plays in Saskatchewan have produced 51.6 x 10^9 m^3 of associated gas during oil production, accounting for 20% of the total gas production in the province.

Keywords: *statistical assessment, hydrocarbon plays, oil production, gas production, ranking, well count.*

1. Introduction

Historic hydrocarbon production to December 31, 2007 was statistically assessed to rank the major plays and identify highly prolific plays in southern Saskatchewan in Yang (2008). Since then, the successful application of horizontal well drilling and multi-stage hydraulic fracturing completions in tight reservoirs such as the Bakken, Lower Shaunavon, and Viking, has initiated a new era of oil production in Saskatchewan. The current study includes the entire province and production information has been updated to year end 2011. The impact of new drilling and completion technology on the production trends is assessed using historical and current production data.

The number of wells producing 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 2011 is used for the total production-well count. The total oil or gas 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.

The objectives of this study are: 1) to monitor hydrocarbon production trends for the major plays using historical production data; 2) to indicate the relationship between production and well count through the production history and pool development; 3) to investigate the impact on the production trends of water flooding, infill-drilling, horizontal well drilling, CO_2 enhanced oil recovery, and multi-stage hydraulic fracturing completion; and 4) to identify highly prolific plays in Saskatchewan. The results of this study will aid in the development of future petroleum exploration strategies in Saskatchewan.

2. Oil Plays in Saskatchewan

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 1). The Mesozoic succession is dominated by shale, siltstone, and sandstone. The two successions are separated by a basin-wide unconformity.

Stratigraphic distribution of major hydrocarbon-producing plays in Saskatchewan is shown in Figure 1. Oil production from these plays has been ranked by cumulative production, current monthly production, and average per-well production. Data from the top 20 plays in each of these categories is illustrated in Figure 2. Table 1 provides a summary of production data from plays that have each produced more than 10 x 10^3 m^3 of oil.

a) Silurian-Ordovician Plays

To the end of December 2011, 222 wells producing from Silurian-Ordovician plays in Interlake, Red River, and Winnipeg strata in southeastern Saskatchewan (Figure 3) produced a total of 4.2 x 10^6 m^3 of oil (Figure 4A).

The Upper Ordovician Winnipeg Formation is composed of a lower unit dominated by porous quartzose sandstone, and an upper unit dominated by typically green waxy shale (Paterson, 1971; Kreis, 2004). The Winnipeg play has produced 95.9 x 10^3 m^3 of oil (Table 1) from the lower sandstone unit in 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.

Upper Ordovician Red River strata (Yeoman and Herald formations) in southeastern Saskatchewan consist 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; Kreis and Haidl, 2004; Nimegeers and Haidl, 2004; Saskatchewan Ministry of Energy and Resources, 2012). Oil production is from dolomitized reservoirs in upper Yeoman and lower Herald strata; reservoir rocks commonly display burrowed textures, and variable amounts of vugs and fractures (Pu *et al*., 2003). The Red River play ranks 24th in total cumulative oil production (Table 1) with production of 4.1 x 10^6 m^3, but ninth by the per-well average with a value of 20.2 x 10^3 m^3 (Figure 2C). To December 2011, 201 wells have produced from the Red River play (Figure 4B), of which 78 are directional or horizontal wells drilled after 1995 following the discovery of the Midale Red River pool. The most prolific Red River producer is the NRK Minton 2Hz 191/11-26-003-21W2/00 horizontal well drilled in 2003 which has already produced 421 x 10^3 m^3 of oil to December 2011.

The Silurian Interlake Formation is composed of: 1) a lower carbonate fossiliferous sequence characterized by basin-wide argillaceous marker beds; 2) a middle carbonate succession with marine fauna in several beds, and 3) an upper carbonate unit with vadose diagenetic features and no identified marine fauna (Kreis *et al*., 2004; Haidl *et al*., 2006). In 2002, the first Interlake oil was produced from the uppermost portion of the upper unit. Reservoir quality is primarily linked to fracture porosity (Larson *et al*., 2003; Haidl *et al*., 2006). The Silurian Interlake has produced 31.7 x 10^3 m^3 of oil (Table 1) from four wells in the Bryant area (Tp. 5, Rge. 7W2) and one well in the Browning area (Tp. 6, Rge. 5W2).

b) Devonian Plays

The Devonian Winnipegosis, Birdbear, Duperow, Torquay, and Bakken-Torquay hydrocarbon plays have produced a total of 5 x 10^6 m^3 of oil from 557 wells (Figure 5A). The oil well locations are shown in Figure 3.

In southeastern Saskatchewan, the Winnipegosis is subdivided into a lower unit of 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 is from upper Winnipegosis carbonate reservoirs. East of about Range 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 Ministry of Energy and Resources, 2007). In the Minton area (Tp. 3, Rge. 21W2), production is from shoal deposits (Potter and St. Onge, 1991). Among all the Devonian plays, the Winnipegosis play has the highest total oil production (2.7 x 10^6 m^3) and highest per-well average production (24.3 x 10^3 m^3), ranking this play 26th in Saskatchewan by total oil production (Table 1) and fourth by per-well average production (Figure 2C). A total of 112 wells have produced oil from the Winnipegosis play, 28 of which are directional or horizontal wells. The highest per-well production is 144.2 x 10^3 m^3 of oil from the Longview Macoun 121/16-23-004-09W2/00 well. The overall production started to decline in 1992 even though the well count continued to increase (Figure 5B). 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).

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

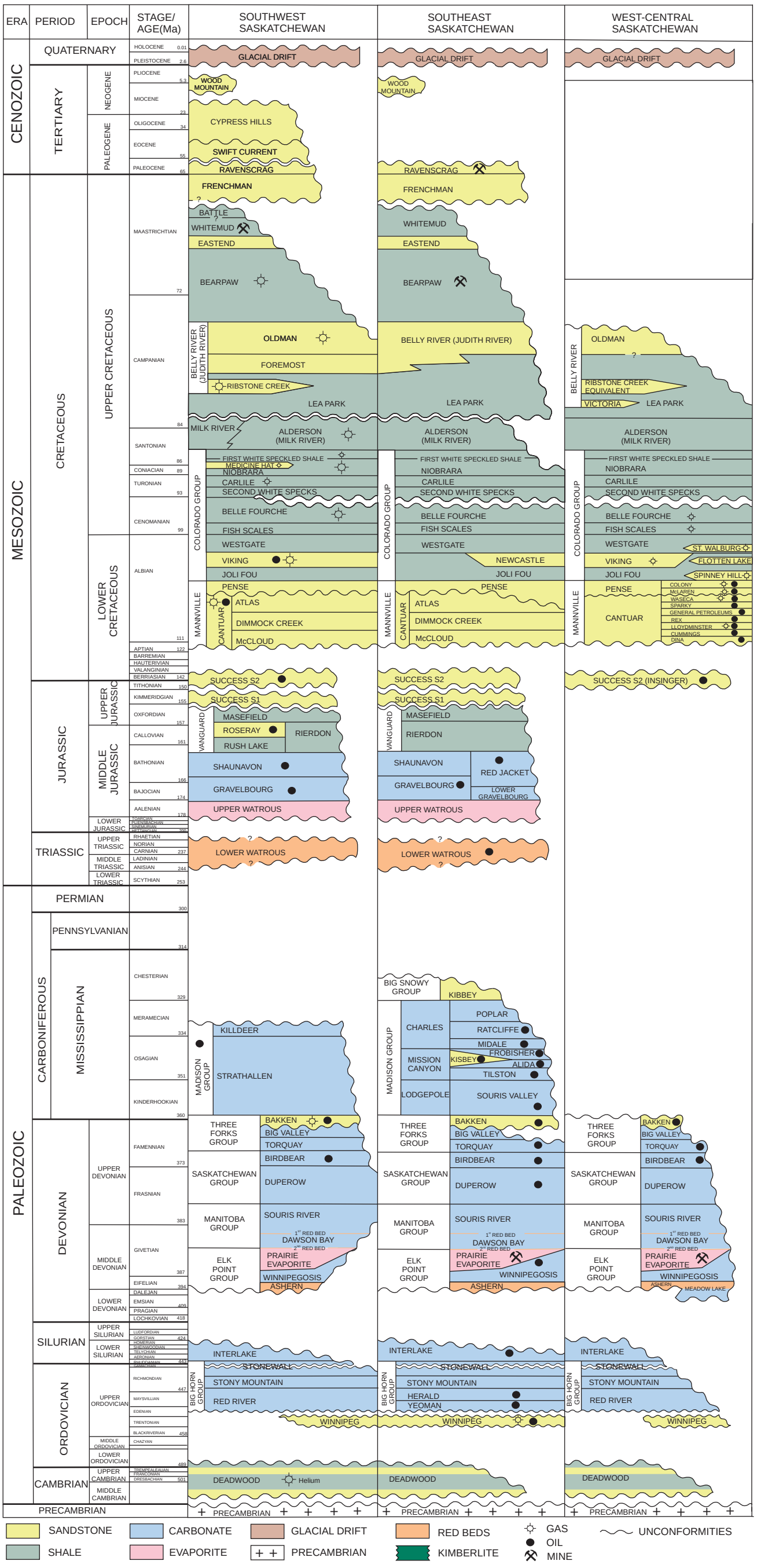

Figure 1 – Stratigraphic chart for southwestern, southeastern, and west-central Saskatchewan showing major hydrocarbon-producing plays (as indicated in the legend) in various lithostratigraphic units in each area (modified from Saskatchewan Stratigraphic Correlation Chart, Saskatchewan Ministry of Energy and Resources, 2011a).

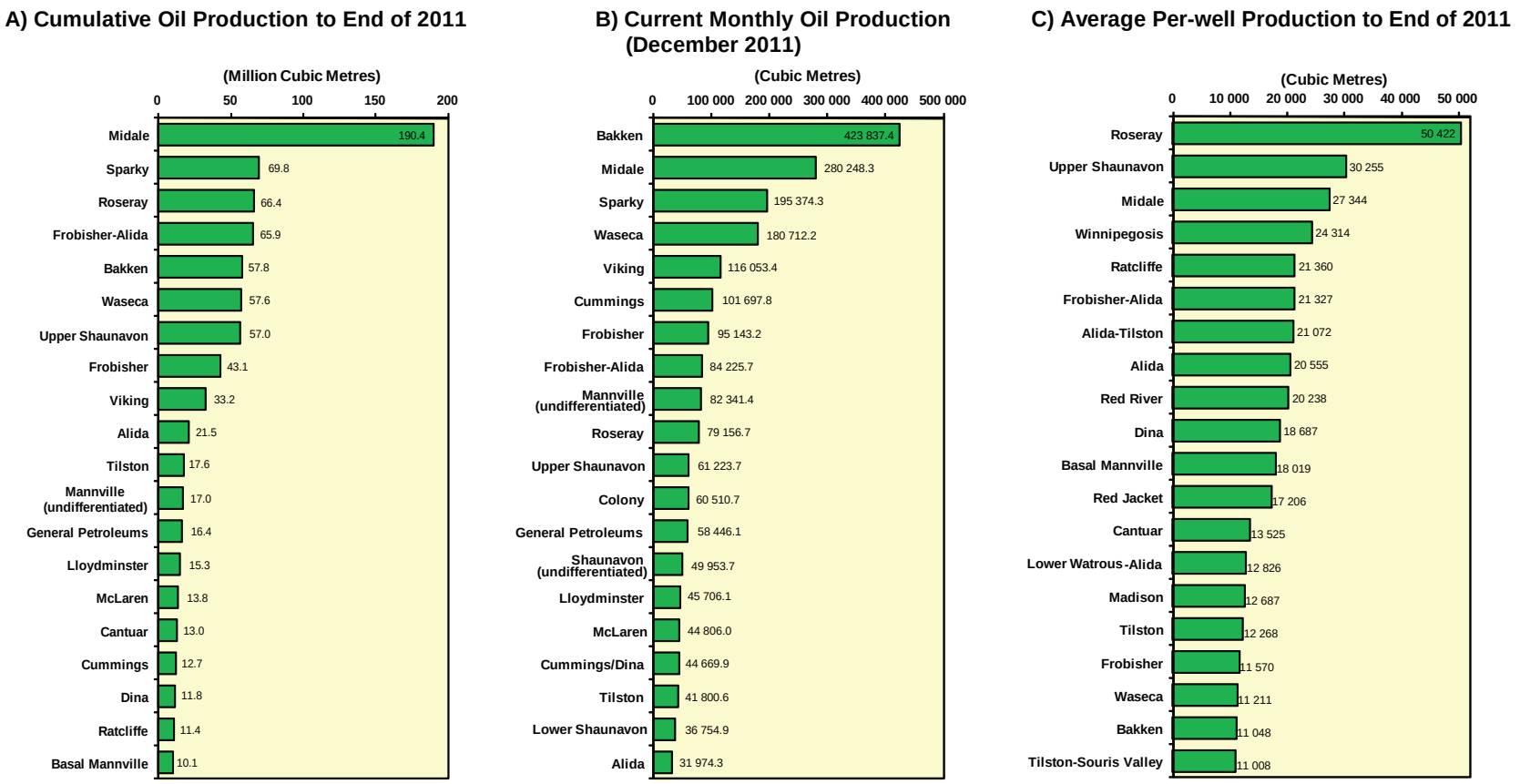

Figure 2 – Top 20 Saskatchewan oil plays by: A) cumulative oil production to December 2011, B) monthly oil production in December 2011, and C) average per-well oil production to December 2011.

Table 1 – Cumulative oil production ranking by play to December 2011 in Saskatchewan (data source is Saskatchewan Ministry of the Economy).

Play	Cumulative Oil Production (to December 2011) (m^3)	Rank	Year to Start Production	Total Number of Oil Wells	Average Per-well Oil Production (m^3)
Midale	190 367 902	1	1953	6,962	27 344
Sparky	69 834 789	2	1944	7,883	8 859
Roseray	66 354 966	3	1952	1,316	50 422
Frobisher-Alida	65 878 984	4	1953	3,089	21 327
Bakken	57 780 131	5	1950	5,230	11 048
Waseca	57 559 125	6	1949	5,134	11 211
Upper Shaunavon	56 970 046	7	1953	1,883	30 255
Frobisher	43 111 503	8	1954	3,726	11 570
Viking	33 209 694	9	1952	9,647	3 442
Alida	21 520 587	10	1954	1,047	20 555
Tilston	17 567 078	11	1954	1,432	12 268
Mannville (undifferentiated)	17 006 328	12	1946	2,565	6 630
General Petroleums	16 416 297	13	1947	1,869	8 783
Lloydminster	15 303 771	14	1953	1,548	9 886
McLaren	13 833 887	15	1948	2,174	6 363
Cantuar (SW Sask only)	13 011 178	16	1952	962	13 525
Cummings	12 702 402	17	1965	1,312	9 682
Dina	11 772 654	18	1965	630	18 687
Ratcliffe	11 406 422	19	1953	534	21 360
Basal Mannville	10 126 957	20	1951	562	18 019
Tilston-Souris Valley	9 335 179	21	1956	848	11 008
Red Jacket	6 675 829	22	1952	388	17 206
Colony	6 223 332	23	1961	656	9 487
Red River	4 067 818	24	1958	201	20 238
Shaunavon (undifferentiated)	3 653 812	25	1953	564	6 478
Winnipegosis	2 723 135	26	1976	112	24 314
Lower Watrous-Alida	2 257 327	27	1966	176	12 826
Birdbear	1 502 227	28	1966	175	8 584
Souris Valley	1 477 244	29	1957	310	4 735
Madison (undifferentiated)	1 268 715	30	1966	100	12 687
Alida-Tilston	1 201 086	31	1980	57	21 072
Success	983 677	32	1952	248	3 966
Lower Shaunavon	972 326	33	1953	269	3 615
Bakken-Torquay	515 053	34	2001	226	2 279
Lower Watrous	185 739	35	1971	48	3 870
Duperow	163 105	36	1997	15	10 874
Rex	138 103	37	1972	88	1 569
Winnipeg	95 898	38	1998	15	5 994
Gravelbourg	43 975	39	1971	9	4 886
Torquay	40 415	40	2005	27	1 497
Interlake	31 701	41	2002	5	6 340
Kisbey	31 417	42	1994	7	4 488
Total	**845 321 816**				

Note: Plays that have produced less than 10×10^3 m^3 of oil are not included in this table.

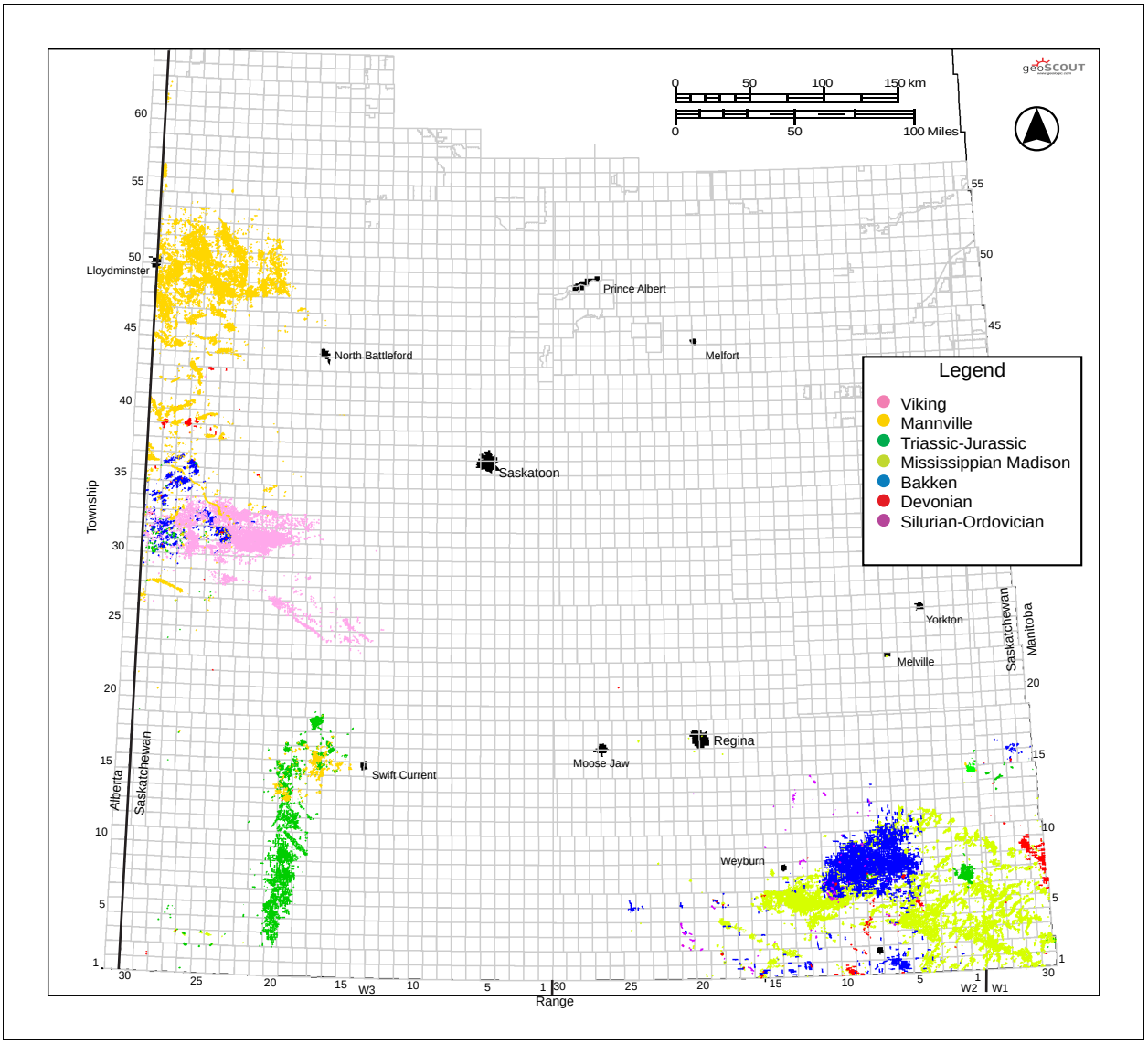

Figure 3 – Location of areas of oil production from seven major stratigraphic units in Saskatchewan. Note that Devonian production near the Saskatchewan-Manitoba boundary is from the Bakken-Torquay play.

into more restricted lime- and dolo-mudstone and evaporite (Cen and Salad Hersi, 2006; Dunn, 1975). Stromatoporoids and corals are common frame builders that form localized bank or mound structures (Kent, 1998). A total of only 15 wells produce from the Duperow play with a total production of 163.1 x 10^3 m^3(Figure 5C). Eight of these wells are located in the Midale Duperow Pool (Tp. 7, Rge. 11W2) in southeastern Saskatchewan which was discovered in 1997. The first horizontal well, Longview Midale 91/04-02-007-11W2/00, drilled in 1998, is the top producer; it has produced 37.2 x 10^3 m^3 of oil to the end of December 2011. In the Unity area (Tp. 42, Rge. 24W3) in west-central Saskatchewan, five horizontal wells have produced from the Duperow, beginning in 2010.

The Birdbear Formation is divided into lower carbonate and upper carbonate-anhydrite units in southeastern Saskatchewan (Nichols, 1970; Halabura, 1982); in west-central Saskatchewan, it is composed of a lower argillaceous carbonate member and an upper dolostone member (Kent, 1968; Yang and Kent, 2010; Saskatchewan Ministry of Energy and Resources, 2011b). Hydrocarbons are produced from the upper part of this formation in both the southeast and west-central areas (Figure 3). In total, the Birdbear has produced 1.5 x 10^6 m^3 of oil from 175 production wells (Figure 5D), ranking 28th by cumulative oil production (Table 1).

The first recovery of Birdbear oil in southeastern Saskatchewan occurred in 1966 from dolostone in the Northrock Hummingbird 001/10-26-002-19W2/00 well in the Hummingbird Pool. This well has produced 254.3 x 10^3 m^3 of oil up to December 2011. The second Birdbear oil discovery well in southeastern Saskatchewan was Northrock Kisbey 101/10-27-007-06W2/00 in the Kisbey Pool, drilled in 1968. To the end of December 2011, the Birdbear

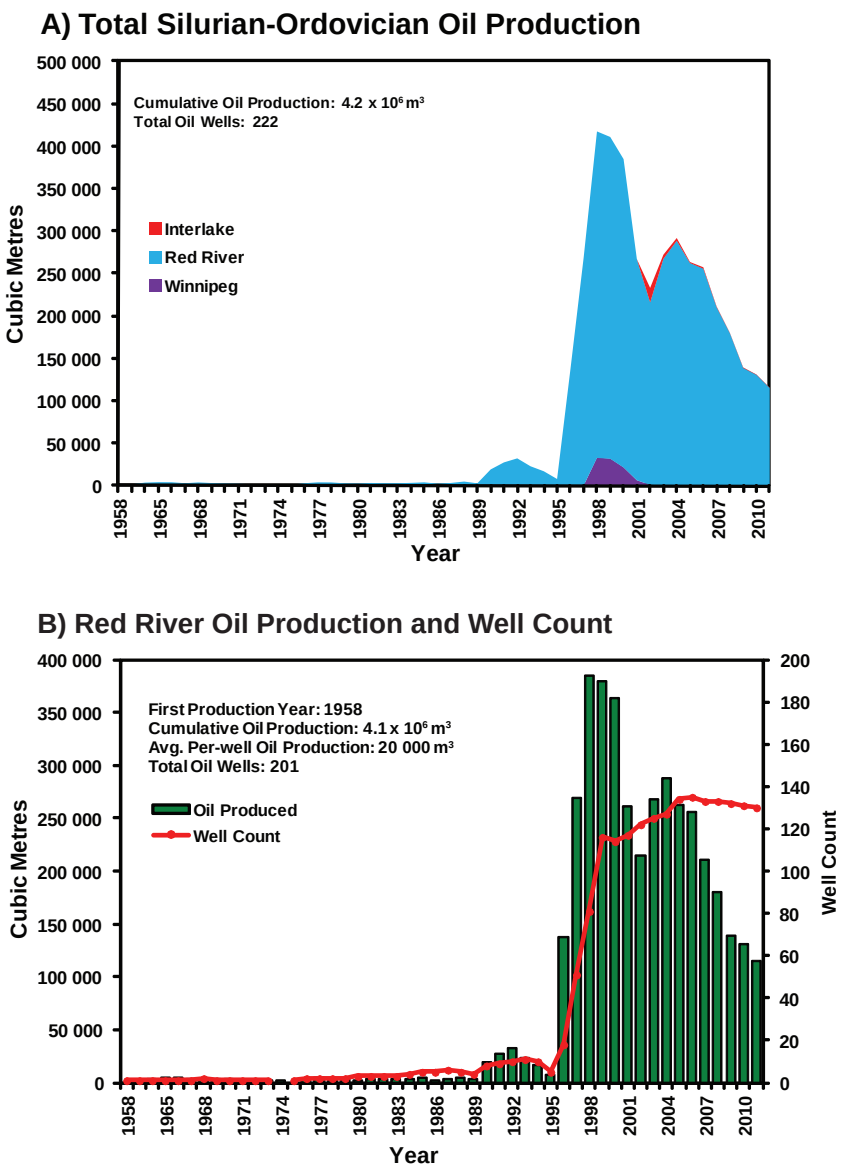

Figure 4 – The Silurian-Ordovician oil-production trends to December 2011 in Saskatchewan. A) The total production from the Red River, Winnipeg, and Interlake plays; and B) oil-production and well-count trends for the Red River play.

Formation in southeastern Saskatchewan has yielded in total of 1.1 million m^3 oil from a total of 58 producing wells, of which 13 are horizontal wells. Among the total production, 84% are produced from wells in the Hummingbird and Kisbey pools. In this area, both the Duperow and Birdbear plays are controlled by the Williston Basin petroleum system.

In west-central Saskatchewan, Upper Devonian oil is associated with the Devonian "Nisku" petroleum system of the Alberta Basin. Heavy oil has been intermittently produced from the Birdbear since 1968. The recent successful application of horizontal technology in west-central Saskatchewan has sparked drilling in the Birdbear subcrop area where part of the Birdbear is truncated by the sub-Cretaceous unconformity (Yang and Kent, 2010; Saskatchewan Ministry of Energy and Resources, 2011b). This activity has resulted in a sharp increase of production from 2 m^3/day in January 2007 to 770 m^3/day in December 2011. The Birdbear in this area produced 366.1 x 10^3 m^3 of oil to December 2011 (Saskatchewan Ministry of Energy and Resources, 2011b).

The Upper Devonian Torquay Formation consists of a series of repeating siltstone, breccia, and dolostone beds (Nickel, 2010). Dolostones and dolomitic siltstones in the Torquay are productive in an area along the Saskatchewan-Manitoba boundary where the Lower Bakken shale is absent and the Torquay is directly overlain by the Middle Bakken making it impossible to assess the volume of oil attributable to each of the two reservoirs. A total of 515 x 10^3 m^3 of oil has been produced from the Bakken-Torquay play in this area. In 2007, new Torquay oil was discovered in the Tableland region (Tp. 1, Rge. 10W2) where uppermost Torquay dolostone strata lie immediately below the Lower Bakken shale (Nickel, 2010). To December 2011, 27 wells have produced 40 x 10^3 m^3 of oil from the Torquay in this region (Table 1); 21 of these wells are horizontal wells drilled since 2009. Despite the small volume of oil produced from the Torquay so far (Figure 5A), the rapid increase of production from 175 m^3/day in January 2008 to 659 m^3/day in December 2011, and the increase in the level of drilling activity targeting the Torquay Formation in recent years, indicate industry's strong interest in this play.

c) Mississippian Plays

Mississippian strata are cumulatively the most prolific oil-producing reservoirs in Saskatchewan with a total production of 423 x 10^6 m^3 of oil (Figure 6A) or about 50% of all oil produced in the province (Table 1). Except for a small fraction (587.9 x 10^3 m^3) of oil produced from Madison pools in the southwestern Saskatchewan and 42.8 x

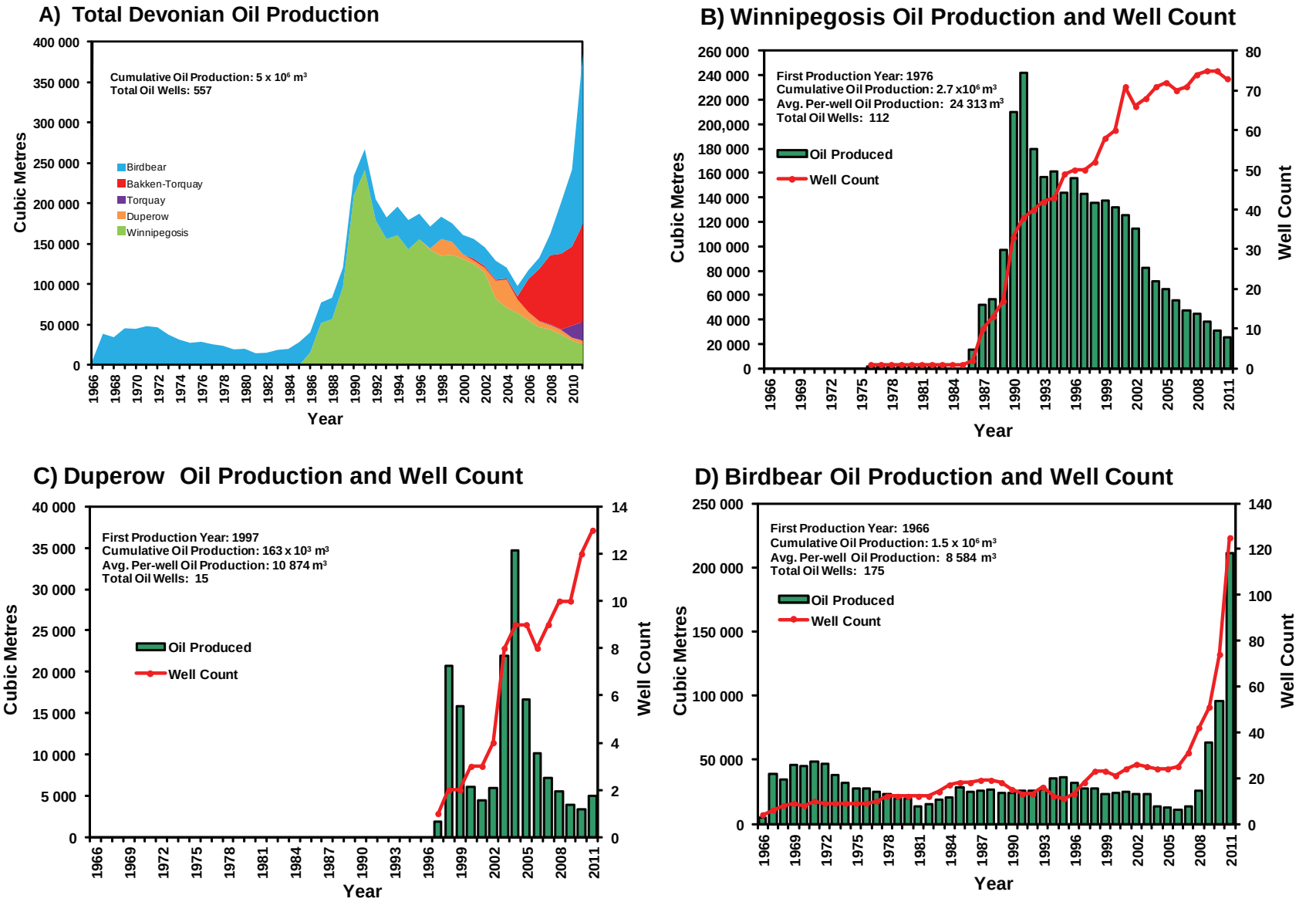

Figure 5 – Saskatchewan Devonian oil-production trends to end of December 2011. Note the wide range of vertical scales used on the graphs. A) Total Devonian oil-production trends, including production from the Torquay and Bakken-Torquay plays; B) oil-production and well-count trends for the Winnipegosis play; C) oil-production and well-count trends for the Duperow play; and D) oil-production and well-count trends for the Birdbear play.

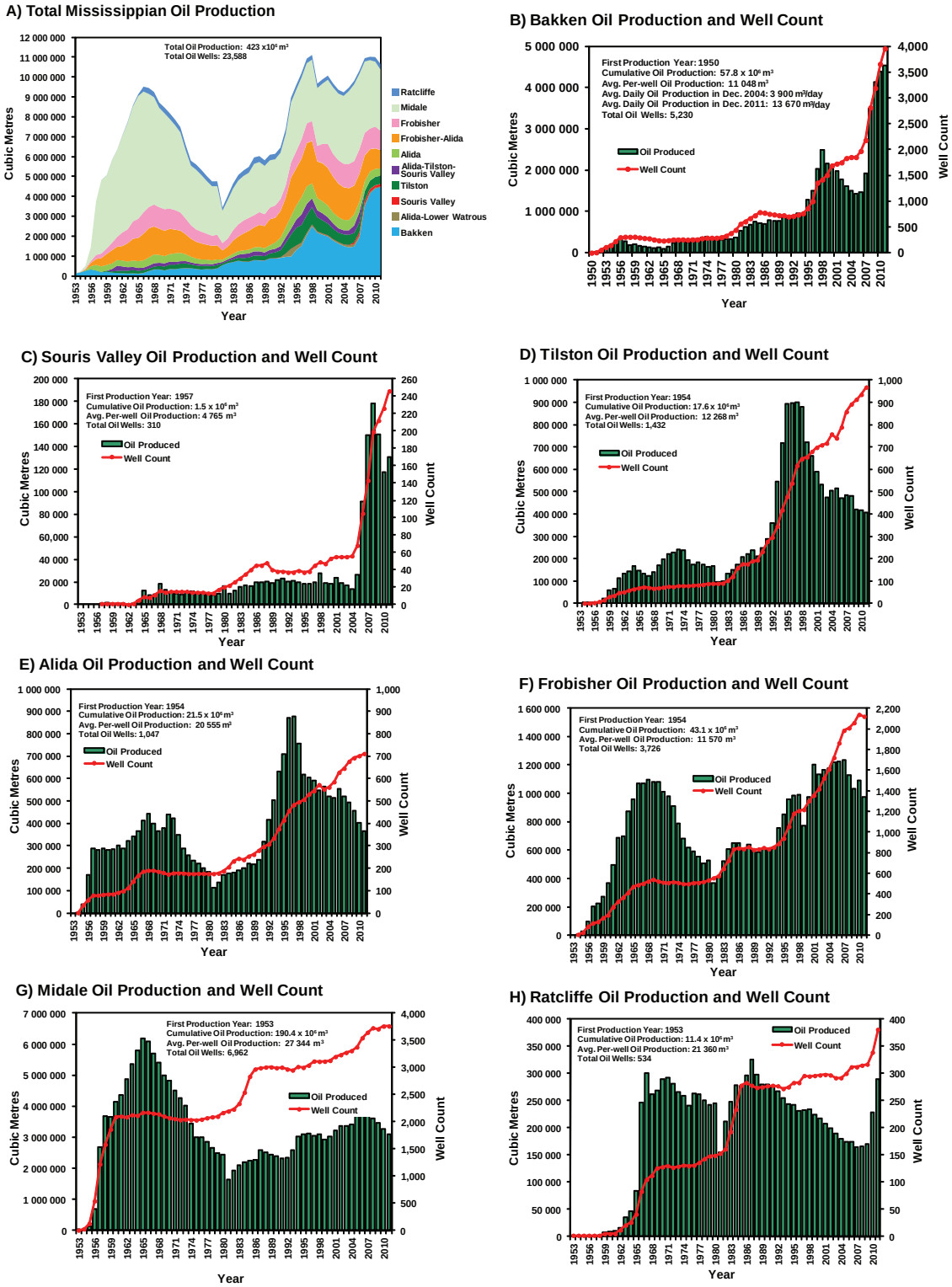

Figure 6 – The Mississippian oil-production trends in Saskatchewan to December 2011. Note the wide range of vertical scales used on the graphs. A) Total Mississippian oil production; B) oil-production and well-count trends for the Bakken play; note that production from the Bakken-Torquay play is included as Devonian production (Figure 5A) and is not included here; 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; and 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, productions from the Alida-Tilston and Tilston–Souris Valley plays have been combined.

10^6 m^3 of oil from the Bakken Formation in west-central Saskatchewan, all production is from southeastern Saskatchewan (Figure 3).

The Upper Devonian to Lower Mississippian Bakken Formation is subdivided into three members with a Middle Member of dolomitic siltstone and sandstone sandwiched between Lower and Upper members of black organic-rich shales (Kreis *et al*., 2006; Kohlruss and Nickel, 2009; Saskatchewan Ministry of Energy and Resources, 2010). Bakken oil is produced from the Middle Member in two widely separated areas, the southeast and west-central (Marsh *et al.,* 2011; Nickel and Yang, 2011).

In southeastern Saskatchewan, oil has been produced from the porous and permeable sandstone of the Middle Member in the Rocanville, Weyburn, Roncott, and Hummingbird areas since 1956. 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 other areas in southeastern Saskatchewan (Kreis *et al*., 2006; Kendall, 2008; Kohlruss and Nickel, 2009; Saskatchewan Ministry of Energy and Resources, 2010). Since the discovery well for the Viewfield North Bakken Pool (Bison Viewfield 111/08-06-008-08W2/00) in 2003, Bakken reservoirs have produced a total of 15 x 10^6 m^3 of oil, 92% of which has been produced in the last seven years (2005 to 2011; Nickel and Yang, 2011). As of the end of December 2011, 2,521 wells have produced oil from the Bakken; 2,322 of them are horizontal wells of which 2,310 were drilled from 2005 to 2011. Bakken oil production has increased from 177 m^3/day in January 2005 to 11 000 m^3/day in December 2011. The Bakken Formation in southeastern Saskatchewan is currently considered to be one of North America's hottest oil plays.

In west-central Saskatchewan, the Bakken Middle Member started producing heavy oil in 1950 and has produced a total of 42.8 x 10^6 m^3 to the end of December 2011. The average daily oil production of 6.6 x 10^3 m^3 reached its highest level in 1998 (Marsh *et al*., 2011).

In total, the Bakken has produced 57.8 x 10^6 m^3 of oil from 5,230 production wells (Figure 6B; Table 1). The Bakken play ranks first by monthly production in the December 2011 (Figure 2B), but fifth place by total cumulative oil production (Figure 2A), and 19th by average per-well production (Figure 2C), because most wells drilled into the Bakken Formation in southeastern Saskatchewan are still in their initial production stage.

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 consist 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 by the sub-Mesozoic unconformity (Fuzesy, 1983; Kent *et al*., 2004; Marsh and Heinemann, 2005; TGI Williston Basin Working Group, 2008; Nickel and Yang, 2011). The repeated occurrences of porous and non-porous layers, and truncation of layers at the sub-Mesozoic unconformity have formed multilayered hydrocarbon plays in these rocks (Kent *et al*., 1988; Nimegeers *et al*., 2006).

The Souris Valley play has cumulatively yielded 1.5 x 10^6 m^3 of oil from 310 production wells (Figure 6C). Of the 78 Souris Valley horizontal production wells in southeastern Saskatchewan, 73 were drilled between 2005 and 2011, resulting in production growth from 38.5 m^3/day in 2004 to 358 m^3/day in 2011. It ranks 29th in total oil production (Table 1). The commingled production from the Tilston-Souris Valley plays is 9.3 x 10^6 m^3 from 848 production wells, ranking 21st by cumulative production (Table 1), and 20th by per-well average production in Saskatchewan (Figure 2C).

The Tilston and Alida plays have very similar production and well-count trends over the years (Figure 6D and 6E). Commingled production from the Alida-Tilston play is impossible to allocate to the individual plays. Oil production from the Tilston, Alida, and Alida-Tilston plays and their rankings are shown in Figure 2. Since the first horizontal well (191/13-05-004-30W1/00) was drilled in the Alida play in October 1990, 82% of Alida production wells have been completed as horizontal wells. To December 2011, 534 horizontal wells have produced 9.3 x 10^6 m^3 of oil, amounting to 43% of total Alida production. The first Tilston horizontal well 191/05-24-006-32W1/00 started production in 1992. To December 2011, 648 horizontal wells have been drilled to produce oil from the Tilston play, yielding total horizontal well production of 7.4 x 10^6 m^3 or 42% 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 6D and 6E).

Since its initial discovery in 1954, the Frobisher play has cumulatively produced 43.1 x 10^6 m^3 of oil from 3,726 production wells (Figure 6F). The number of Frobisher horizontal production wells increased from four in 1990 to 1,362 in 2011 with total oil production of 12.7 x 10^6 m^3 or 30% of total Frobisher production. 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 65.9 x 10^6 m^3 of oil from 3,089 production wells. The ranking for Frobisher and Frobisher-Alida plays is illustrated in Figure 2.

In some areas, there is a sandstone interval (Kisbey Sandstone) between the Frobisher Beds and Alida Beds (Perras, 1990; Kent, 2007). Oil produced from this interval is included as Frobisher-Alida production except for seven wells that have produced 31.4 x 10^3 m^3 of oil designated as Kisbey (Table 1).

The Midale play started commercial production in 1953 and the production peak was reached in 1966 (Figure 6G). Production declined from 1967 to 1981 with a very consistent well count. Production increments recur in the 1980s, the mid-1990s and after 2000 on the production trend, responding to infill vertical drilling, horizontal drilling, and the CO_2 miscible flood in the Weyburn and Midale pools, respectively. To December 2011, the Midale play has produced 190 x 10^6 m^3 of oil from a total of 6,962 production wells, ranking it first by total oil production (Figure 2A; Table 1), second by current production (Figure 2B), and third by average per-well production (Figure 2C). The Midale play alone has yielded about 23% of the total oil production in Saskatchewan.

The Ratcliffe production trend is shown in Figure 6H. The trend shows big production increments in the mid-1960s, between 1982 and 1987, and in 2010 and 2011. The first spike was largely attributed to the discoveries of the Flat Lake, Lake Alma, Freda Lake, Neptune, and Hummingbird Ratcliffe pools. The second spike resulted from infill drilling, as shown by the increasing oil well count during these years. In 2010 and 2011, 95 horizontal wells were drilled in the Ratcliffe play; these wells have produced 185 x 10^3 m^3 of oil, resulting in the most recent production spike (Figure 6H). The Ratcliffe play has cumulatively produced 11.4 x 10^6 m^3 of oil from 534 production wells, ranking it 19th by cumulative production (Figure 2A; Table 1) and fifth by average per-well production of 21.3 x 10^3 m^3 (Figure 2C).

d) Triassic-Jurassic Plays

The Triassic Lower Watrous Formation 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). The fine-grained mudstone unit forms a regional and effective seal to hydrocarbon migration (Whittaker and Gilboy, 2003). Locally, dissolution of anhydrite that had infilled porosity in the underlying "altered zone" associated with the sub-Mesozoic unconformity has allowed oil to migrate upwards into the Lower Watrous sandstone reservoirs that are capped by argillaceous mudstones (Bates *et al.*, 2007; Bates and Kendall, 2008). The Lower Watrous play has produced 185.7 x 10^3 m^3 of oil from 48 wells in southeastern Saskatchewan (Table 1), mostly in the Carlyle area (Tp. 7 to 8, Rge. 1W2 to 3W2). Of the 48 wells, 37 are horizontal with oil production of 154.6 x 10^3 m^3 from 1992 to 2011. When production from the Lower Watrous is commingled with production from the underlying Alida Beds, production from the Lower Watrous–Alida play is 2.3 x 10^6 m^3 from 176 oil wells, ranking 27th by cumulative production (Table 1), and 14th by per-well average production in Saskatchewan (Figure 2C).

Led by the Roseray and Upper Shaunavon plays, Jurassic strata in Saskatchewan have produced 135.7 x 10^6 m^3 of oil (Figure 7A), about 16% of the overall production from Saskatchewan.

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 Jurassic Gravelbourg has produced 44 x 10^3 m^3 of oil (Table 1) from six wells in the Red Jacket area (Tp. 13 to 14, Rge. 31W1 to 1W2) and three wells in the Cypress Lake South area (Tp. 5, Rge. 27W3).

The Shaunavon Formation is divided into two members in southwestern Saskatchewan. 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 comprised of homogeneous limestone and calcareous mudstone (Christopher, 1964; Marsh and Jensen, 2010; Grisak *et al.*, 2011). Locally, oil has been produced from a fossiliferous-oolitic, vuggy-moldic, porous and low permeability reservoir at the topmost few metres of the lower member along the flanks of the paleosyncline that form the Shaunavon Oil Field Trend (Tp. 3 to 16, Rge. 16W3 to 20W3; Figure 3).

The Upper Shaunavon is a major oil producer in Saskatchewan (Figure 7B), ranking seventh by oil production of 57 x 10^6 m^3 (Figure 2A; Table 1), 11th by currently production (Figure 2B), and second by the per-well average production of 30.3 x 10^3 m^3 (Figure 2C); all production is from wells in southwestern Saskatchewan. The Dollard Upper Shaunavon Pool, discovered in 1953 by the 101/05-21-007-20W3/00 well, is the largest Upper Shaunavon pool and has cumulatively produced 16.2 x 10^6 m^3 of oil to the end of December 2011, amounting to almost 29% of

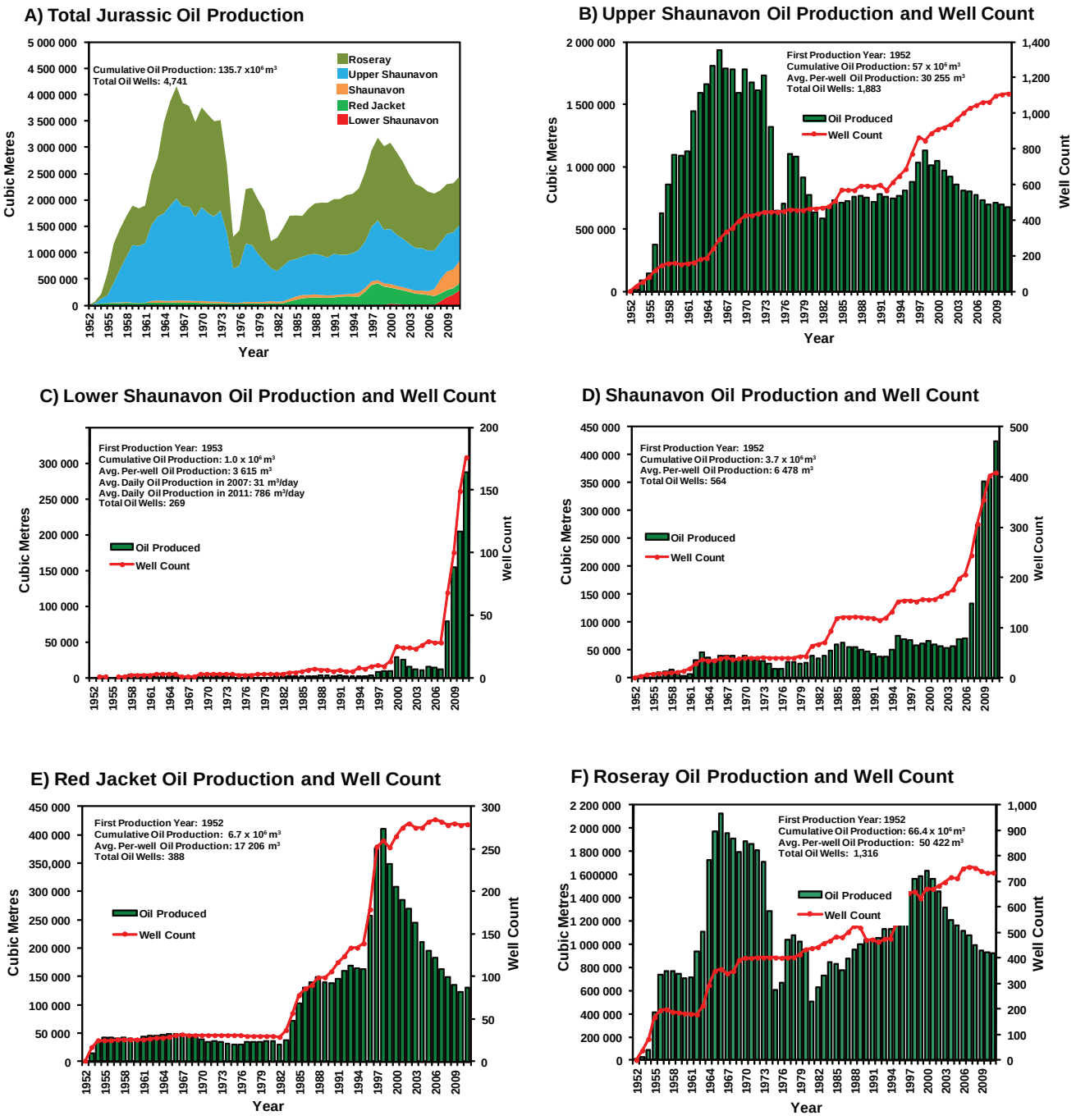

Figure 7 – The Jurassic oil-production trends to December 2011 in Saskatchewan. Note the wide range of vertical scales used on the graphs. A) Total Jurassic oil-production trends; the total Jurassic oil production of 135.7 x 10^6 m^3 includes insignificant amounts of oil from the Lower Watrous, Gravelbourg, and Success 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 Lower Shaunavon play; D) oil-production and well-count trends for the Shaunavon play; E) oil-production and well-count trends for the Red Jacket play; and F) oil-production and well-count trends for the Roseray play.

total Upper Shaunavon production. The Tide Water Dollard Crown 101/13-22-007-20W3/00 well has the highest single well production of 872.5 x 10^3 m^3 of oil. The first horizontal well, 191/11-34-002-26W3/00, which started

production in 1991, has produced 221.8 x 10^3 m^3 of oil to December 2011. Forty-one horizontal wells produce from the Upper Shaunavon.

The Lower Shaunavon play in southwestern Saskatchewan has produced 972.3 x 10^3 m^3 of oil from 269 wells. Its oil production increased from 31 m^3/day in 2007 to 786 m^3/day in 2011 (Figure 7C). This rapid production growth can be attributed to successful application of horizontal drilling and staged hydraulic fracturing completions to the low permeability reservoirs. Commingled production from the Shaunavon play, when the Lower and Upper Shaunavon are not differentiated, is 3.7 x 10^6 m^3 from 564 production wells (Figure 7D), ranking 25th by production (Table 1) and 14th by current production in Saskatchewan (Figure 2B).

The Middle Jurassic Red Jacket Formation in southeastern Saskatchewan, which is stratigraphically equivalent to the Upper Gravelbourg and Shaunavon formations in southwestern Saskatchewan, comprises a complex succession of sandstones, siltstones, mudstones, and minor carbonates (Kreis, 1991). Production from the Red Jacket play in southeastern Saskatchewan started in 1952, but became more significant in the mid-1980s 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 7E). Total oil production of 6.7 x 10^6 m^3 and the per-well average production of 17.2 x 10^3 m^3 of oil rank this play 22nd by cumulative production (Table 1) and 12th by per-well production (Figure 2C).

The Roseray Formation in southwestern Saskatchewan is composed primarily of sandstone clinothems lying between Ranges 21W2 and 20W3, from Townships 1 to 20 (Labelle, 1997). 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 Roseray play is another major oil producer in Saskatchewan, ranking third by the total oil production of 66.4 x 10^6 m^3 (Figure 7F; Figure 2A; Table 1), tenth by current production (Figure 2B) and first by the per-well average production of 50.4 x 10^3 m^3 (Figure 2C); all production is from wells in southwestern Saskatchewan (Tp. 12 to 19, Rge. 14W3 to 19W3; Figure 3).

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 early marine conditions in the extreme south of the province (Christopher, 2003). Since 1952, the Success has produced 983.7 x 10^3 m^3 of oil from 248 wells (Table 1), 203 of which are located in west-central Saskatchewan (Tp. 24 to 31, Rge. 23W3 to 29W3) and 45 are located in west of Swift Current (Tp. 15 and 16, Rge. 15W3 to 16W3).

e) Cretaceous Plays

The Lower Cretaceous Mannville Group hosts the oil sand deposits and the majority of heavy oil accumulations in the Western Canada Sedimentary Basin (Pemberton and James, 1997), as well as medium oil pools in southwestern Saskatchewan (Figure 3). The Mannville Group 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 Saskatchewan. The Mannville Group is the major Cretaceous oil producer in the province with cumulative oil production of 249 x 10^6 m^3 from 25,646 wells in Saskatchewan or 29% of oil production in the province. The Sparky and Waseca members are the highest producers with oil production of 69.8 and 57.6 x 10^6 m^3 (Table 1), accounting 8% and 7% of oil production in the province. They rank second and sixth by cumulative production (Figure 2A), and third and fourth by current production (Figure 2B), respectively. The highest production increment on the Mannville production trend since the early 1990s to the mid of 2000s is largely attributable to intensive horizontal well drilling and steam-assisted gravity drainage (SAGD) and other enhanced oil recovery (EOR) projects during that period (Figure 8A). Advanced EOR technologies are playing more important roles in heavy oil production.

Another major Cretaceous play is the Viking Formation which is composed of interbedded fine grained sandstones and highly bioturbated muddy sandstones. Multiple sea-level rises and falls resulted in merging of regressive surfaces with transgressive surfaces and a complex internal stratigraphy (Reinson *et al.*, 1994; Walz, 2007). The Viking ranks ninth by the total oil production of 33.2 x 10^6 m^3 (Figure 2A; Table 1) and fifth by current production (Figure 2B); all production is from wells in west-central Saskatchewan (Figure 3). Among the total of 9,647 production wells, 865 horizontal wells with multi-stage hydraulic fracturing completions were drilled over the last three years, resulting in the surge of production since 2008 (Figure 8B).

3. Gas Plays in Saskatchewan

Saskatchewan's natural gas production includes non-associated gas produced in southwest and west-central Saskatchewan from Cretaceous reservoirs that do not contain significant quantities of crude oil, and associated gas that comes from crude oil wells as a by-product. The top 20 producers in each category are ranked in Figures 9A and 9B.

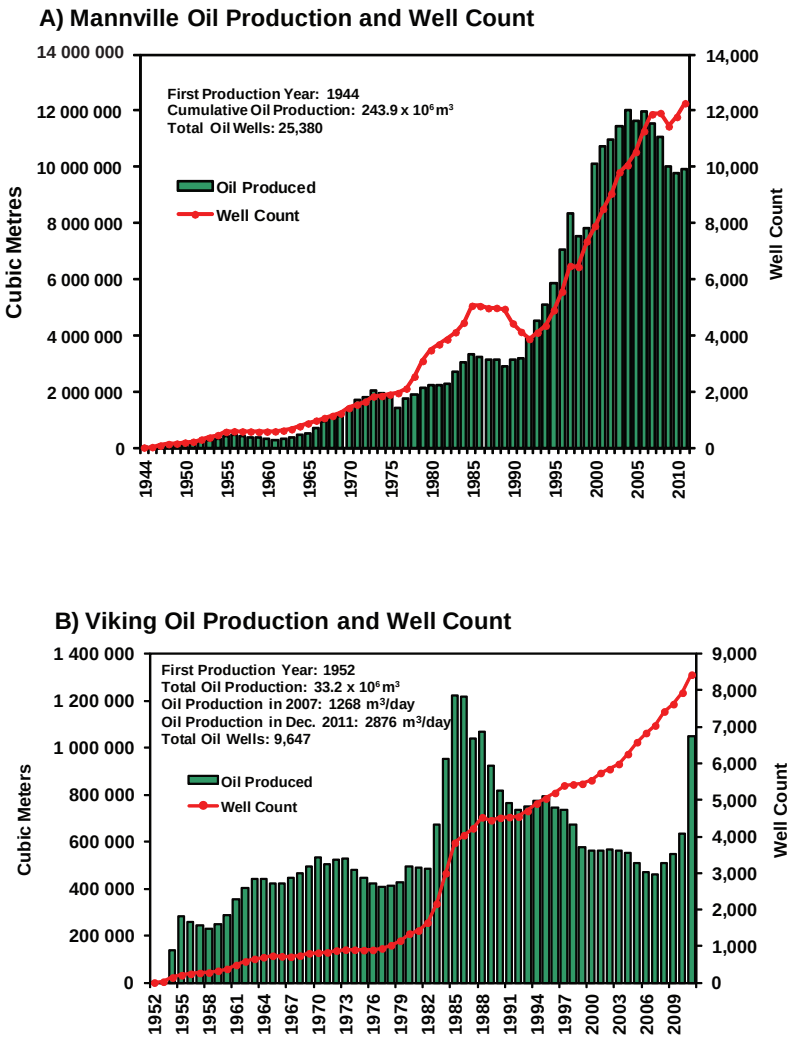

Figure 8 – Oil-production and well-count trends to December 2011 for Cretaceous plays in Saskatchewan. A) Oil-production and well-count trends for the Mannville play, including oil from the Dina, Cummings, Lloydminster, Rex, General Petroleums, Sparky, Waseca, McLaren, and Colony members and the Cantuar and Pense formations, the Basal Mannville, and undifferentiated Mannville reservoirs (Table 1); and B) oil-production and well-count trends for the Viking play.

The current major monthly gas producers are the Milk River, Medicine Hat, Bakken, Viking, Mannville, and Midale plays (Figure 9C). Together, the top six plays have produced a total of 342 million m^3 of gas, or 65% of gas production in Saskatchewan for December 2011.

The top ten non-associated gas producers by average per-well gas production are the Belle Fourche, Medicine Hat, Ribstone Creek, Milk River–Medicine Hat, Bearpaw, Bearpaw–Belly River, Milk River, Lea Park, Milk River–Medicine Hat–Belle Fourche, and Belly River plays (Figure 9D) of the Upper Cretaceous.

a) Cretaceous Gas Production

A total of 204.4 x 10^9 m^3 of shallow gas is produced from Cretaceous strata in Saskatchewan (Figure 10A). The natural gas reservoirs in the Upper Cretaceous Milk River, Medicine Hat, and Belle Fourche (commonly referred to as the Second White Specks sandstone) are the major shallow non-associated gas producers. 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 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 (Second White Specks). 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), includes shallowing-upward facies ranging from offshore sandstones and shales to shoreline sandstones, plus non-marine coastal-plain deposits (Gilboy, 1987, 1988; Pederson, 2004). The gas production trends of the Milk River, Medicine Hat, and Belle Fourche reservoirs are shown in Figures 10B to 10D. Gas production from the Mannville and Viking includes both non-associated shallow gas and associated gas from oil wells (Figures 10E and 10F).

In addition to the major shallow-gas plays, small volumes of gas are produced from Ribstone Creek (1.3 x 10^9 m^3), Belly River (456.9 x 10^6 m^3), Bearpaw (229.6 x 10^6 m^3), Bearpaw–Belly River (169.9 x 10^6 m^3), Fish Scales (29.4 x 10^6 m^3), and Lea Park (4.8 x 10^6 m^3) reservoirs.

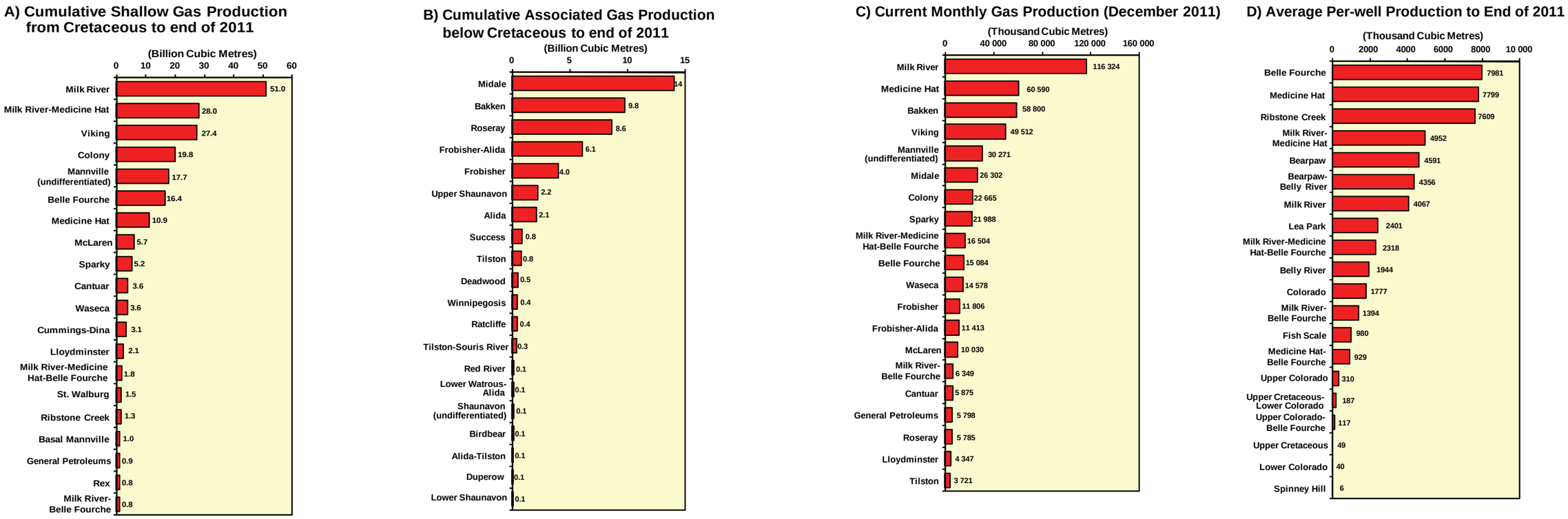

Figure 9 – Top 20 Saskatchewan gas plays by: A) cumulative shallow-gas production from Cretaceous reservoirs to end of December 2011, B) cumulative associated gas production from reservoirs below the Cretaceous to end of December 2011, C) monthly gas production in December 2011, and D) average per-well gas production to end of December 2011.

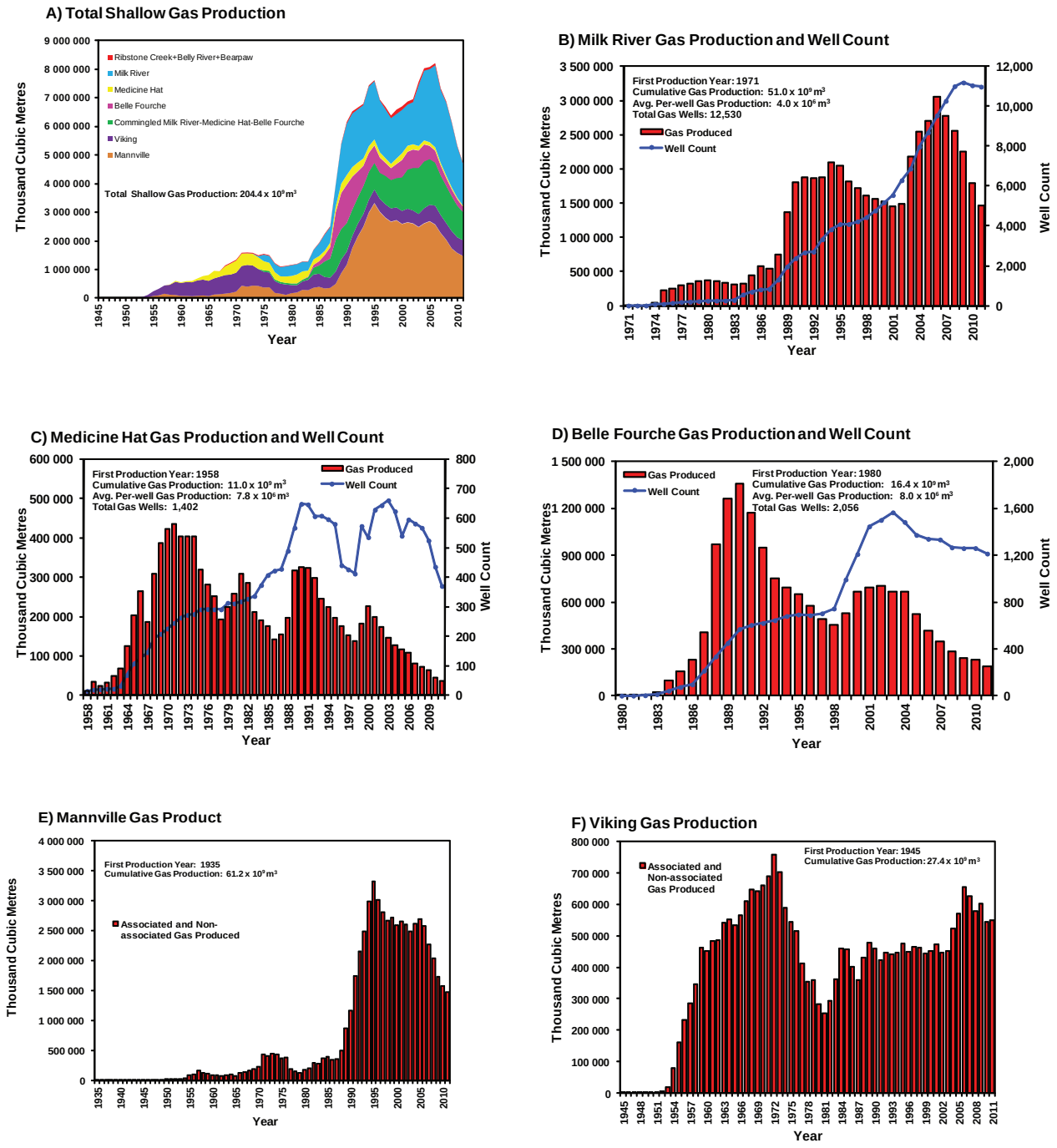

Figure 10 – The shallow-gas production trends to end of December 2011 in Saskatchewan. Note the wide range of vertical scales used on the graphs. A) The total unconventional shallow-gas production trend; this graph does not show gas production from the Fish Scales and Lea Park formations because of the small volumes involved; B) the shallow-gas production and well-count trends for the Milk River play; C) the shallow-gas production and well-count trends for the Medicine Hat play; D) the shallow-gas production and well-count trends for Belle Fourche play; E) the shallow associated and non-associated gas production and well-count trends for the Mannville play; and F) the shallow associated and non-associated gas production and well-count trends for the Viking play.

b) Conventional Associated-gas Production from Sub-Cretaceous Strata

Many major oil plays in strata older than Cretaceous have produced large amounts of associated gas (50.7 x 10^9 m^3) during oil production in Saskatchewan. Figure 11 shows production trends of the Bakken (Figure 11B), Roseray (Figure 11C), Frobisher (Figure 11D), Frobisher-Alida (Figure 11E), Midale (Figure 11F), and Upper Shaunavon (Figure 11A).

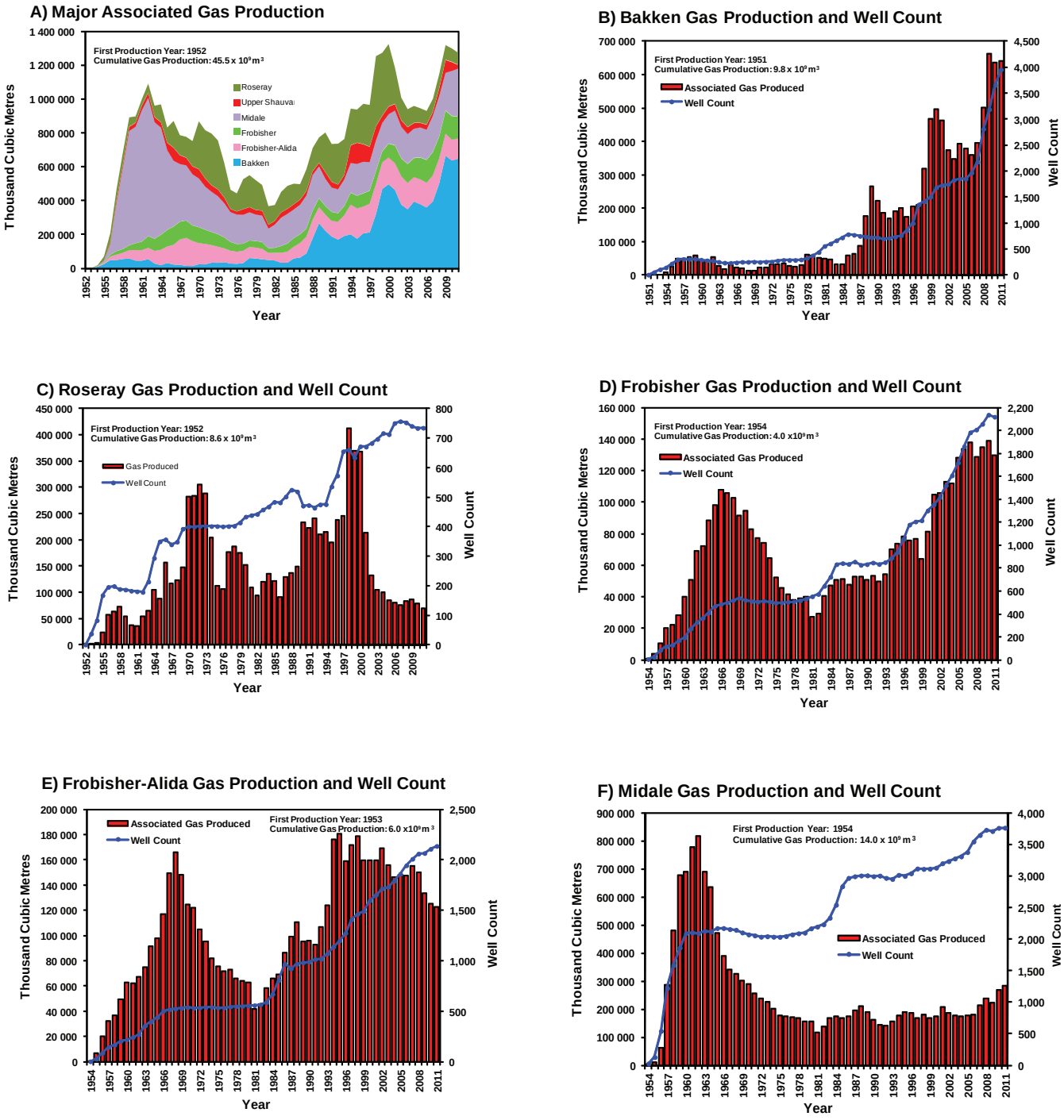

Figure 11 – The conventional associated-gas production trends to end of December 2011 in Saskatchewan. Note the wide range of vertical scales used on the graphs. A) The total conventional associated-gas production trend for the top six associated gas-producing plays; B) the associated-gas production and well-count trends for the Bakken play; C) the associated-gas production and well-count trends for the Roseray play; D) the associated-gas production and well-count trends for the Frobisher play; not including commingled production; E) the associated-gas production and well-count trends for the Frobisher-Alida play, when the production cannot be separated from each formation; and F) the associated-gas production and well-count trends for the Midale play. The recovery volume of injected CO_2 in the Weyburn Midale Pool is deducted from gas production, but the impact of injected CO_2 in the Midale Central Midale Pool (a pool to the east of the Weyburn Midale Pool also undergoing CO_2 injection) is not determined currently.

4. Conclusions

Mississippian Madison Group carbonates, and sandstones of Cretaceous Mannville and Viking, Jurassic Roseray and Upper Shaunavon plays, and Mississippian-Devonian Bakken in Saskatchewan have produced the largest volumes of oil to end of December 2011. The Upper Cretaceous Milk River, Medicine Hat, and Belle Fourche plays are the major unconventional shallow-gas producers; all are in southwestern Saskatchewan. The major oil producers are also the major associated-gas producers in 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 EOR technologies such as SAGD and CO_2 miscible floods have had significant impacts on the production trends of mature plays. Appropriate application of these recovery technologies and other EOR methods will optimize recovery and prolong the life of hydrocarbon pools.

Most oil production in Saskatchewan has been from Madison Group (Mississippian) carbonates in southeastern Saskatchewan, cumulatively amounting to 365 x 10^6 m^3 of medium and light oil or about 43% of oil production in the province. The Midale play alone has yielded about 190 million m^3, about 23% of the total oil production from a total of 6,962 production wells.

Cretaceous sandstone reservoirs rank the second with a total oil production of 282 million m^3 or 33% of oil production in the province from 35,298 production wells. The major oil producer from Cretaceous reservoirs is the Mannville plays in central west Saskatchewan, amounting to 249 million m^3 of heavy oil from 25,646 production wells. The Sparky, Waseca, and Viking plays are highest producers with oil production of 70, 58, and 33 million m^3 accounting for 8%, 7%, and 4%, respectively.

Led by the Roseray and Upper Shaunavon plays, the total Jurassic crude oil production in southwestern Saskatchewan has amounted to 135.7 million m^3, about 16% of the overall production from Saskatchewan. It is interesting to note that Roseray and Upper Shaunavon production is from a total of only 1,316 and 1,883 producing wells, yielding the highest per-well average of 50.4 x 10^3 m^3 and 30.3 x 10^3 m^3, respectively.

Recent intensive horizontal drilling and multistage fracturing activities in southeastern Saskatchewan have resulted in light oil production booming from the Bakken (and Torquay) play which yielded a total production of 58 million m^3 or 7% of total oil production.

Although a total of only 5 x 10^6 m^3 of oil has been produced from the Devonian Winnipegosis, Birdbear and Duperow plays, the total well count of 302 is substantially lower than the other major plays. The recent application of horizontal technology on the Birdbear heavy oil reservoirs in west-central Saskatchewan has resulted in a sharp increase in average production from 38 m^3/day in 2007 to 578 m^3/day in 2011. This increase highlights the hydrocarbon potential of Devonian reservoirs in Saskatchewan.

The Red River play is the major Ordovician oil producer, having a total production of 4 x 10^6 m^3 of oil and a per-well average of 20 x 10^3 m^3, which rank 24th and ninth, respectively.

The Upper Cretaceous Belle Fourche, Medicine Hat, and Milk River formations are the major shallow-gas producers in Saskatchewan with a total production of 111 x 10^9 m^3 or 43% of total gas production in the province. The Mannville and Viking produced both non-associated shallow gas from gas wells and associated gas from oil wells, amounting to 91.6 x 10^9 m^3 of gas or 35% of gas production in the province.

The major Jurassic and Mississippian oil plays in Saskatchewan have produced a total of 50 x 10^9 m^3 of associated gas during oil production, accounting for 20% of the total gas production in the province.

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 Saskatchewan, which help highlight hotspots for future exploration.

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