Report on the Regional Stratigraphic Framework of Western Saskatchewan – Phase 1

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Overview

The *Regional Stratigraphic Framework of Western Saskatchewan – Phase 1* is a substantial component of the Stratigraphic and Hydrogeological Framework of Western Saskatchewan – Phase 1 project, a multi-disciplinary study currently being undertaken by the Petroleum Technology Research Centre (PTRC) and funded by a grant from the provincial government. The purpose of this part of the project is to provide an up-to-date compilation of maps and cross-sections from updated, consistent stratigraphic data for the entire Phanerozoic succession underlying a large area of the western half of the province. The study area encompasses approximately 145,500 km^2 from Townships 1 to 52, Ranges 1W3 to the Alberta border (the area identified as Phase 2.1b (South) in Figure 1) and includes over 57,500 wells. Geophysical well-log data from a total of 5,203 of the deepest wells in the area have been stratigraphically analyzed in order to compile structure and isopach maps for all the major lithostratigraphic units from basement to the uppermost mappable unit below surface (see the Stratigraphic Correlation Chart for southwest and west-central Saskatchewan, Figure 2), and to construct several regional stratigraphic cross-sections. Emphasis was placed on deriving data from recent wells that typically have higher quality geophysical well-log information; the other wells that were used in the project were chosen based on their depth of penetration into the subsurface. At least four wells per township were selected, subject to availability. Depth of penetration and the number of wells per township are greatly variable throughout the region. From Ranges 1 to 11W3, all wells with available geophysical well-log data were studied. In the area from Townships 1 to 23, Ranges 17 to 30W3, only wells that penetrated the Viking Formation or deeper were considered, and all wells (approximately 740 in number) that penetrated Mississippian strata or deeper were studied. Throughout the rest of the study area, all recent wells and wells that penetrate the Birdbear Formation or deeper (approximately 3,360 in number) have been studied, with additional wells selected as required.

Over recent years, results of only three regional-scale studies of western Saskatchewan have been published (Christopher, 2003; Leckie *et al.*, 1997; Kreis *et al.*, 2004). No new regional maps for western Saskatchewan had previously been produced since the 1980s, and a systematic geoscientific study of the entire Phanerozoic succession has never been conducted. Information from this project can be utilized by industry in helping to generate new hydrocarbon plays, to develop new hydrocarbon and potash exploration strategies, and also, possibly, to improve production from existing hydrocarbon pools.

Methodology

For the purpose of this study, off-confidential geophysical well-log information from 5,203 wells was examined. Using MJ Systems' raster-image database software LogSleuth 2001, 89 major lithostratigraphic surfaces from the Precambrian basement to the top of the uppermost mappable unit below surface casing were identified based on their True Vertical Depths (TVD). Well-log data not present at the time of the study in the MJ Systems database were derived from hardcopy logs in Saskatchewan Industry and Resources' well files stored at the Subsurface Geological

Laboratory in Regina. All TVD well-log data were then amalgamated using a combination of GeoLogic's GeoScout software and various versions (97, XP, and 2003) of Microsoft Excel. Once these TVD values were organized in an Excel spreadsheet (Table 1), subsea (structure) and isopach (thickness) values were calculated for the majority of the intervals. Subsea (structure) and isopach (thickness) maps were then digitally contoured from the data using Golden Software's Surfer 8.05 mapping software package. The algorithm used to grid the contours is kriging, with all well locations (x, y data) recorded as surface-hole locations given in Universal Transverse Mercator North American Datum 1927 (UTM NAD27). Regional cross-sections were also produced from the TVD data using GeoLogic's GeoScout software. All figures shown in this report are in universal portable document format (.pdf), but all original files can be made available upon request to the authors.

Regional Stratigraphy

Precambrian Surface

The top of the Precambrian basement is a regional unconformity that is present throughout Saskatchewan. However, as only 43 wells penetrate its surface within the study area (Figure 3), the paleotopography of the Precambrian surface is not known in detail. The regional dip of the Precambrian surface within most of the study area is south toward the international Canada-U.S. border at 49ºN latitude. In the southwestern corner of the province, the surface dips to the northeast due to the presence of the structurally high Swift Current Platform (Wright *et al.*, 1994). Kreis *et al.* (2004) provide more detailed information regarding the Precambrian surface in Saskatchewan.

Deadwood Formation

As with Precambrian surface, data for the Deadwood Formation are limited within the study area as the unit is penetrated by only 103 wells. The Deadwood Formation is Middle Cambrian to Lower Ordovician in age, and is unconformably bounded by the Precambrian basement below and Ordovician sediments of the Winnipeg and Red River Formations above (Kent, 1994; Kreis, 2004). From regional maps derived from the available geophysical well-log data, the Deadwood Formation (Figure 4) is observed to be present throughout the area, its upper surface appearing to have a similar regional morphology to that of the underlying Precambrian surface. An isopach map of this distinct geological unit shows that the formation generally thickens towards the northwest of the study area (Figure 5). Localized thinning of the Deadwood Formation appears to occur over positive basement features in the area of the Swift Current Platform to the extreme southwest of the study area, and in an area centred around Townships 16 and 17, Ranges 16 to 18W3. A more regional thinning of the unit occurs toward the northeast of the study area. The thickness of the Deadwood Formation ranges from 187m in the southwest to 507m in the northwest of the study area. Kent (1994) and Kreis (2004) provide more detailed information regarding the Deadwood Formation, including its depositional history and sedimentology.

Winnipeg Formation

The Winnipeg Formation is an unconformably bound clastic wedge of Middle Ordovician age, and is present in a limited area in the extreme southeast of the study area (Kreis, 2004; Kent, 1994) (Figures 6 and 7). It is observed in only seven wells and, in its entirety, in only four wells, its thickness ranging from 1.5m in well 101/10-26-001-13W3/00 to 23.2m in well 121/12-03-

015-01W3/00. Kent (1994) and Kreis (2004) provide more information regarding the Winnipeg Formation and its depositional history and sedimentology.

Big Horn Group

The Big Horn Group (Figure 8) is Middle Ordovician to Lower Silurian in age, and is the lowermost carbonate-dominated unit in the Williston Basin. The carbonates and evaporites of this group unconformably overlie the Deadwood/Winnipeg, and are partially truncated at their upper boundary by the sub-Devonian unconformity. In Saskatchewan, the Big Horn Group comprises the Red River (Figures 9 and 10), Stony Mountain (Figures 11 and 12), and Stonewall (Figures 13 and 14) formations. The Red River Formation, which in the southeast of the province, is sub-divided into the Yeoman and Herald formations, is present throughout the study area. It is a burrow-mottled fossiliferous carbonate that is well known for its commercial use as building stone and its economic potential as a hydrocarbon producer. It generally thickens toward the deeper parts of the basin in the southeast of the study area, and thins toward the basin margin to the north and west. Conformably overlying the Red River Formation are carbonate and evaporite strata of the relatively evenly distributed Stony Mountain Formation. In the study area, the Stony Mountain Formation exhibits a slight thickening toward the south and southeast, with recognizable thins to the northwest possibly associated with the sub-Devonian unconformity and to the extreme southwest above the western edge of the Swift Current Platform. The uppermost unit, the Stonewall Formation, conformably overlies the Stony Mountain Formation and, except in the northwest and extreme southwest of the study area where the sub-Devonian unconformity has eroded the formation beyond the western edge of the Silurian Interlake Formation, has a depositional morphology similar to that of the Red River Formation. Kendall (1976), Kent (1994) and Kreis and Haidl (2004) provide more information regarding the depositional history, sedimentology, and diagenesis of the Big Horn Group in Saskatchewan.

Interlake Formation

Conformably overlying the Stonewall Formation of the Big Horn Group, the Interlake Formation is a Silurian-age carbonate unit that, in October 2001, had its first commercial oil production from the Nexen Bryant well in southeastern Saskatchewan (Kreis *et al*., 2004; Larson *et al*., 2003). The accumulation of commercially viable quantities of oil in the Bryant-Kingsford area, which is located at a considerable distance from this study area, was apparently related to locally developed basement structural highs that may have been genetically responsible for anomalously thin Interlake Formation deposits (Larson *et al*., 2003; Potter and St. Onge, 1991). In the study area, the Interlake Formation dips to the south and southeast (Figure 15) as is typical of many Lower Paleozoic strata in the western Williston Basin. Localized positive features are present around 017-14W3 and near the international border around 001-13W3. The latter feature is likely related to uplift of the Bowdoin Dome (Kent, 1994). The isopach map of the Interlake Formation (Figure 16) shows general thickening of the strata to the southeast and east. Toward the southwest and northwest, the Interlake Formation is absent due to truncation by the sub-Devonian unconformity. An elongate thinning of the Interlake strata can be seen in the vicinity of the area marking the positive feature at 017-14W3; it extends toward the southwest and may warrant investigation. Kent (1994), Kreis *et al*. (2004), Larson *et al*. (2003), and Potter and St. Onge (1991) have described the depositional history and sedimentology of the Interlake Formation in Saskatchewan.

Elk Point Group

Unconformably overlying Silurian through Ordovician strata within the study area, the Devonian Elk Point Group (Figure 17) is sub-divided into three major units: the Ashern (Figures 18 and 19), Winnipegosis (Figures 20 and 21), and Prairie Evaporite (Figures 22 and 23) formations. The latter formation is the world's most prolific producer of potash. This period in time marks a major change in basin morphology, due to tectonism, from the Williston Basin that was open to circulation toward the southeast to the Elk Point Basin that was periodically open to the northwest. The northwest-southeast trending Elk Point Basin was flanked to the west by the Peace River Arch and the West Alberta Ridge, to the south by the Swift Current Platform, to the southeast by the Transcontinental Arch, to the east by the Severn and Sioux arches, and to the north by the Laurussian hinterland (Kent, 1994). Also, periodically during Elk Point time, the basin is considered to have been severely restricted to the northwest by the Presqu'ile Barrier, thus creating hypersaline conditions perfect for the precipitation of evaporites such as anhydrite, halite, and potash (Holter, 1969; Kendall, 1975; Kent, 1994; Maiklem, 1971; Meijer Drees, 1994; Reinson and Wardlaw, 1972; Wardlaw and Reinson, 1971). An isopach map of the Elk Point Group (Figure 17) shows a considerably different depositional pattern than those of the underlying strata within the study area. Rather than thickening to the southeast, the Elk Point Group thins toward the south and to the north, and is thickest along a northwest–southeast axis located to the north of 021-01W3. However, the structural surfaces on top of each of the individual formations within the group indicate an overall southeastward regional dip (Figures 18, 20 and 22). Localized thinning of the Elk Point Group around Townships 32 to 34 Range 1W3 may be related to salt dissolution within the Prairie Evaporite Formation (Figure 23).

The Ashern Formation, largely made up of argillaceous dolomitic red beds with basal anhydrite (Jin *et al*., 1997), has a patchy thickness distribution throughout the study area (Figure 19); its thickness ranges from zero in the extreme southeast and south-centre to 30 m in Township 21 Range 10W3. The Middle Devonian Winnipegosis Formation contains carbonate pinnacle reefs (Kent, 1968) and also shows patchy thickness distribution in the northeast (Figure 21). However, this unit thins toward the southwest, and is absent over the Swift Current Platform, possibly a result of non-deposition rather than erosion. The Prairie Evaporite Formation is thickest (up to 221 m) in the Winnipegosis inter-reef areas in the east-northeast (Figures 21 and 23). It remains relatively thick (up to 156m) along a northwest-trending axis to the provincial border, and thins to zero to the northeast and to the south and southwest. The absence of Prairie Evaporite may be related in part to erosion, non-deposition, and/or salt dissolution from inter-formation fluid movement. Papers by Holter (1969), Jin *et al*. (1997), Kendall (1975), Kent (1968), Kent (1994), Maiklem (1971), Meijer Drees (1994), Reinson and Wardlaw (1972), and Wardlaw and Reinson (1971) describe aspects of the depositional history, sedimentology, and/or diagenesis of the Elk Point Group and, in particular, the Prairie Evaporite Formation in Saskatchewan.

Manitoba Group

The Middle to Upper Devonian Manitoba Group (Figure 24) disconformably to unconformably overlies the Prairie Evaporite Formation. It comprises the Second Red Beds (Figures 25 and 26), the Dawson Bay Formation (Figures 27 and 28), the First Red Beds (Figures 29 and 30) and the Souris River Formation (Figures 31 and 32) (Dunn, 1982; Oldale and Munday, 1994; Williams, 1984). The thickness of this group (Figure 24) ranges from 56 m at a local thin in the north-central region (052-16W3) to around 70 m in the southwest over the western margin of the Swift Current Platform to more than 200 m in an east-west trending thick zone located in the central and northern regions of the study area (between Townships 21 and 42). The thicker accumulations of Manitoba Group carbonates generally appear to form on the flanks of thicker Elk Point Group deposits and in areas where Elk Point Group accumulations are relatively thin, particularly in the north.

Separately considering each major sub-division of the Manitoba Group reveals intricate details of their distribution patterns. Networks of paleotopographic lows (paleovalley systems) that extended from the north of the study area changed morphology over the depositional period encompassed by this group. For instance, paleovalleys from the northeast appear to have narrowed due to infilling from Second Red Beds time to the close of Souris River time (Figures 25, 27, 29, and 31), whereas paleovalleys from the northwest widened and deepened over the same time period. This difference was possibly related to tectonic flexure in the basin as well as to the sedimentation patterns of the underlying strata. In the south and west, the basin morphology apparently continued to be controlled by the positions of the Swift Current Platform and the Peace River Arch, while the basin continued to deepen to the southeast.

Thickness distributions of the Manitoba Group strata are also variable throughout the study area. The Second Red Beds isopach (Figure 26) reveals a generally thin (0 to 8 m) veneer that occurs throughout most of the area thickening locally to 20 to 27 m. The strata of the Dawson Bay Formation (Figure 28), which includes the Second Red Beds and the First Red Beds, are thicker towards the eastern and central regions (24 to 38 m) and generally thin toward the northwest and west, becoming zero in the southwest. Dawson Bay strata thicken within a paleovalley that extends from the northeast of the study area. An elongate thin extending northeast of the westernmost margin of the Swift Current Platform can also be easily recognized, as well as a localized thin (11 m) at 027-11W3. Isopachs (Figure 30) of the First Red Beds, which mark the close of Dawson Bay Formation deposition, indicate general thickening toward the east-central region of the area. The uppermost unit of the Manitoba Group, the Souris River Formation, is present throughout the study area, thickening through central regions and toward the northwest (Figure 32). Thinning of the Souris River Formation occurs to the east of the northwestern paleovalley fills, and in the southwest, controlled by the western edge of the Swift Current Platform. Dunn (1982), Kent (1994), Oldale and Munday (1994), and Williams (1984) have published information about the depositional history and sedimentology of the Manitoba Group in Saskatchewan.

Saskatchewan Group

The carbonates of the Upper Devonian Saskatchewan Group conformably overly those of the Manitoba Group. They are the lowermost sedimentary rocks within the study area to be truncated to the northeast by the sub-Mesozoic unconformity. The Saskatchewan Group (Figure 33) is made up of two major units, the Duperow (Figures 34 and 35) and Birdbear Formations (Figures 36 and 37) that, over the years, have attracted much industry interest due to their hydrocarbon potential (Dunn, 1975; Halabura, 1982; Kent, 1968; Lake, 2004; Stasiuk *et al.*, 1998). The overall distribution of Saskatchewan Group strata is largely dominated by the thicker beds of the Duperow Formation. Generally, the isopach map of the Saskatchewan Group (Figure 33) shows the unit thickening through the central portion of the study area, thinning slightly toward the south, and truncated toward the north. The zero edge of the Saskatchewan Group and its lowermost unit, the Duperow Formation, is present in the northeast corner of the study area (Figures 33 and 35). Structurally, the Duperow Formation deepens to the southeast and shallows to the west and north, with paleovalleys mainly present in the northwest (Figure 34). The Birdbear Formation, which is correlative to the Nisku Formation in Alberta, has a more irregular thickness distribution pattern than that of the underlying Duperow Formation. In general it is less than 40 m thick, but is locally up to 65 m in areas in which patch reefs may have formed on the depositional slope (Figure 37). Towards the north, the Birdbear is truncated by the sub-Mesozoic unconformity, and is absent north of Township 40. The present day structural surface on the Birdbear Formation (Figure 36) deepens to the southeast, but noticeably shallows over the Bowdoin Dome (at the international border) and, to the west, across the westernmost flank of the Swift Current Platform. The depositional history, sedimentology, and hydrocarbon potential of the Saskatchewan Group in Saskatchewan have been described by Dunn (1975), Halabura (1982), Kent (1968), Lake (2004), and Stasiuk *et al*. (1998).

Three Forks Group

The mixed carbonates and clastics of the Three Forks Group (Figure 38) conformably overlie Saskatchewan Group strata, and are Upper Devonian to lowermost Mississippian in age. The Three Forks Group is made up of three major lithostratigraphic units: the Torquay (Figures 39 and 40), Big Valley (Figures 41 and 42), and Bakken formations (Figures 43 and 44). The Torquay and Bakken formations are proven hydrocarbon producers in southeastern Saskatchewan, western Maintoba, and parts of the northern United States. Bakken Formation shales are considered to be prolific source rocks within the Williston Basin, although only a fraction of the potential Bakken Formation sourced oil has been recovered (Kreis and Costa, 2005; LeFever *et al*., 1991; LeFever, 2005; Smith and Bustin, 2000). These units progressively back-step in a southerly direction due to truncation by the sub-Mesozoic unconformity, with the most northerly deposits of the Three Forks Group found in Township 39. The isopach map of the Three Forks Group (Figure 38) shows a general east-west trend of relatively constant thicknesses, with apparent depositional thinning (less than 60 m) toward the south and, toward the north, thickening (up to 122 m) on approach to an escarpment created by the sub-Mesozoic unconformity at around Townships 25 to 32.

The distribution of Torquay Formation (Figure 40) thickness is similar to that of the Three Forks Group in that it is thinner (15 to 35 m) toward the south, and thicker (up to 64 m) toward the north near the escarpment created by the sub-Mesozoic unconformity. The Big Valley Formation has a more limited distribution than the underlying Torquay Formation, due to truncation toward the north and toward the southeast (Figure 42) where it was probably eroded on a sub-Bakken unconformity. The thickest (up to 40 m) accumulation of the Big Valley Formation occurs toward the east-central region of the study area against the sub-Mesozoic unconformity escarpment. Toward the southwest, away from this island-like feature, the unit generally ranges in thickness from 5 to 20 m. The Bakken Formation unconformably overlies the Big Valley Formation, and is sub-divided into organic-rich Upper and Lower Shale members, and a Middle Sandstone Member. The thickest accumulation of the Bakken Formation (30 to 55 m) is in the west-central region, off of the western flank of the Big Valley thick (Figure 44). This unit also generally thins to around 5 to 10 m toward the southwest above the western extent of the Swift Current Platform, and is truncated to the north at around Townships 26 to 37 by the sub-Mesozoic unconformity. The structural surfaces of these three formations exhibit very similar characteristics to the underlying units, deepening toward the southwest, and shallowing to the north and west. Papers by Christopher (1961), Kreis and Costa (2005), LeFever *et al*. (1991), LeFever (2005), and Smith and Bustin (2000) contain more information regarding the depositional history, sedimentology, and hydrocarbon potential of the Three Forks Group in Saskatchewan.

Madison Group

Sedimentary rocks of the Early Mississippian Lower Madison Group (Lodgepole Formation) are found only in the southern two-thirds of the study area (south of Township 36), and are considered to represent a shift from shallow to deep water deposition (Kent, 1984; Kent *et al.*, 1984; Kent, 1987). The overlying Middle and Upper Madison Group (Mission Canyon and Charles formations) are present in the southern one-third to one-quarter of the study area. Their deposition probably occurred within a shallower carbonate environment (Kent, 1984; Kent *et al.*, 1984; Kent, 1987). Stratigraphically, the Madison Group in southwestern Saskatchewan unconformably overlies the Bakken Formation, which straddles the Devonian/Mississippian boundary, and is truncated by the sub-Mesozoic unconformity. This unconformity surface represents an erosional episode that is thought to have lasted for approximately 150 million years (Kent, 1984), and that helped create conditions that ultimately provided an excellent seal for trapping hydrocarbons in the prolific Mississippian oil pools in southeastern Saskatchewan (Henry, 1998; Kent, 1987; Mundy and Roulsten, 1998).

Each of the three formations within the Madison Group (Figure 45) is then also sub-divided into a succession of 'beds' (Figures 2 and 46). The lowermost formation of the Madison Group, the Lodgepole Formation, contains the Souris Valley Beds (Figure 46.1). This unit was deposited directly on the unconformity atop the Bakken Formation, and is composed of, mostly, limestone, some of which is contained within carbonate Waulsortion-type mud-mounds (Kent, 2005; Sereda and Kent, 1987; Tucker and Wright, 1996). It is the only unit within the Lodgepole Formation in Saskatchewan. In the study area, it ranges in thickness from 0 to 228 m. The Mission Canyon Formation contains (from oldest to youngest) the Tilston Beds (Figure 46.2), Alida Beds (Figure 46.3), Kisbey Sandstone (Figure 46.4), and Frobisher Beds (Figure 46.5). The Alida and Frobisher Beds are typically separated by a regional unconformity, which, in most areas, is overlain by the Kisbey Sandstone (Halabura, 2005; Kent, 1987; Mundy and Roulsten, 1998). The uppermost formation of the Madison Group, the Charles Formation, contains the Midale Beds (Figure 46.6), Ratcliffe Beds (Figure 46.7), and Poplar Beds (Figure 46.8).

The two most common interpretations for the depositional environment, in this part of the Williston Basin during the Mississippian, are a) a broad carbonate shelf setting (Lake, 1998; Mundy and Roulsten, 1998), or b) a carbonate ramp setting (Kent, 1984; Kent *et al.*, 1984; Kent, 1987; Smith and Dorobek, 1993). During the deposition of Mississippian-age sediments in Saskatchewan, the Williston Basin underwent a certain amount of subsidence, possibly related to movement of reactivated basement faults (Mundy and Roulsten, 1998). Papers by Fuzesy (1983), Halabura (2005), Henry (1998), Kent (1984), Kent *et al.* (1984), Kent (1987), Lake (1998), Marsh and Qing (2002), Mundy and Roulsten (1998), Sereda and Kent (1987), and Tucker and Wright (1996) offer more details regarding the depositional history, sedimentology, and hydrocarbon potential of the Madison Group in Saskatchewan.

Watrous Formation

The Triassic to Middle Jurassic Watrous Formation overlies the sub-Mesozoic unconformity (Figure 47) and represents the earliest Mesozoic depositional record in the Saskatchewan Williston Basin (Kent, 1994). The upper surface of the Watrous Formation is generally conformably overlain by the Gravelbourg Formation. In the study area, the Watrous Formation is present towards the south and southeast, ranging in thickness from zero at its depositional edge to 69 m at 025-01W3; thicknesses of 50 to 60 m are, however, fairly common toward the southeast corner (Figure 48). In Saskatchewan, the Watrous Formation is also sub-divided into two distinct lithologic units. The Lower Watrous Member (Figures 49 and 50) is easily recognizable as mud- and silt-dominated red beds ranging from zero to 63 m in thickness with local sandstone bodies, while the Upper Watrous Member (Figures 51 and 52) is typically an organic-rich mudstone that ranges in thickness from zero to 32m and contains highly pervasive and displacive anhydrite (Gerla, in preparation; Kent 1994; White *et al*., 2002). The structural surface of the sub-Mesozoic unconformity (Figure 47) forms a series of escarpments, cuestas, and various karst features that typically truncate older strata from the basin centre toward the flanks, with apparent subsidence in the Moose Jaw Syncline and/or uplift around the Bowdoin Dome and the Swift Current Platform (Kent, 1984; Kent, 1987; Mundy and Roulsten, 1998).

Gravelbourg Formation

The Middle Jurassic Gravelbourg Formation (Figure 53) generally conformably overlies the Upper Watrous Member, typically overstepping it to the north and west of its depositional edge. The Gravelbourg Formation is present throughout the southern half of the study area, generally thickening (45 to 74 m) toward the deeper part of the basin in the southeast. Thinning of the Gravelbourg Formation to the west appears to be depositional, whereas thinning to the north toward its zero edge is related to truncation by the sub-Cantuar unconformity. Regionally, the formation is sub-divided into a carbonate mudstone-dominated Lower Gravelbourg Member (Figures 54 and 55), and a mostly dolomitic limestone and shale Upper Gravelbourg Member (Figures 56 and 57). The Lower Gravelbourg Member is the thicker of the two sub-divisions ranging from zero at the erosional edge to 51 m in 010-13W3, with a general thickness-distribution pattern similar to that of the entire Gravelbourg succession. The Upper Gravelbourg Member has a similar areal distribution to that of the lower unit, depositionally thinning to the west and erosionally truncated to the north. Its thicker accumulations (from 25 to 40 m) are limited to the extreme southeast. More information regarding the depositional history and sedimentology of the Gravelbourg Formation in Saskatchewan has been published by Christopher *et al*. (2004), Francis (1956), Kreis (1991), and Wall *et al*. (2002).

Shaunavon Formation

Like the two underlying units, the Middle Jurassic Shaunavon Formation (Figure 58) is sub-divided into upper and lower members. It is present throughout the southern one-third of the study area (south of Township 27), and generally thickens towards the south on the western flank of the Moose Jaw syncline, and, in particular, to the southeast around the margin of the main basin. The Lower Shaunavon Member (Figures 59 and 60) is easily recognizable on geophysical well logs as a carbonate mudstone conformably overlying the Gravelbourg Formation. This unit is the dominant member of the Shaunavon Formation, its thickness typically ranging from 25 to 35 m but with a minimum of zero at its erosional edge to a maximum of over 40 m at 003-26W3. The Upper Shaunavon Member (Figures 61 and 62), regionally made up of interbedded carbonate-cemented sandstone and shale, unconformably overlies the Lower Shaunavon Member. It ranges in thickness from zero at the erosional edge to 31m at 015-19W3, generally thickest around the basin margin, with thick deposits also on both flanks of the Moose Jaw

Syncline. Christopher *et al*. (2004), Francis (1956), and Kreis (1991) have published more in-depth information regarding the depositional history and sedimentology of the Gravelbourg Formation in Saskatchewan.

Vanguard Group

The Vanguard Group (Figure 63) conformably overlies the Shaunavon Formation and is sub-divided into two major units, the uppermost Middle Jurassic Rierdon Formation (Figures 64 and 65) and the lowermost Upper Jurassic Masefield Formation (Figures 66 and 67). Both units are generally made up of fossiliferous shale and argillaceous limestone, the Masefield typically being the less calcareous. Within western Saskatchewan, the Rierdon Formation is sub-divided into a lower, shaly Rush Lake Member (Figure 65.1) and an upper, oil-prone, sandy Roseray Member (Figure 65.2). The Vanguard Group ranges in thickness from zero at its erosional edge to 172 m at 002-01W3. The Vanguard Group generally appears to thin depositionally towards the west and is truncated by the sub-Cantuar unconformity to the north such that the stratigraphically higher strata within the succession back-step towards the southeast due to erosion.

The Rierdon Formation (Figure 65) ranges in thickness from zero to 114 m, with the thickest accumulations generally occurring toward the southeast. The Rush Lake Member (Figure 65.1) of the Rierdon Formation also thickens to the southeast, but is also relatively thick (51 to 68 m) within the northern extension of the Moose Jaw Syncline. The shoreface sandstones of the Roseray Member (Figure 65.2) are thickest on the flanks of the Bowdoin Dome and around the basin margin, with localized thick bodies of sand slightly offshore into the main basin toward the extreme southeast of the area. The Masefield Formation erosionally back-steps to the south and has a similar thickness (40 to 60 m) and thickness-distribution pattern around the flanks of the Bowdoin Dome and towards the extreme southeast of the area to those of the Roseray Member, but is thinner (less than 10m) towards the basin margin. Christopher (1974), Christopher (2003), Christopher *et al*. (2004), and Francis (1956) provide more information regarding the depositional history and sedimentology of the Vanguard Group in Saskatchewan.

Success Formation

The Success Formation (Figures 68 and 69), a regionally developed, unconformity-bounded succession composed mainly of detrital sandstones and shales, is Upper Jurassic to lowermost Lower Cretaceous in age. Within the study area, it appears as erosional outliers of a once extensive clastic sheet (Christopher *et al*., 2004). Its thickness ranges from zero at its erosional margins to 67 m within randomly oriented, elongate lithologic packages. Christopher (1974), Christopher (2003), and Christopher *et al*. (2004) have described in more detail the history and sedimentology of the Success Formation in Saskatchewan.

Mannville Group

The clastic sediments of the Lower Cretaceous Mannville Group (Figures 70 and 71) directly overlie the regional deep erosional surface of the sub-Cantuar unconformity (Figure 72), and are present throughout the study area in thicknesses ranging from 13 to 253 m. The two main sub-divisions in the Mannville Group are the fluviatile to estuarine Cantuar Formation (Figures 73 and 74), and the marine Pense Formation (Figures 75 and 76) (Christopher, 1974; Christopher, 2003; Christopher *et al*., 2004). The Cantuar Formation has been sub-divided into three members (the Atlas, Dimmock Creek and McCloud members, which are not individually discussed in this report, although their isopach and structure maps can be created using appropriate data provided in Table 1), and into seven lithostratigraphic beds (Dina, Cummings, Lloydminster, Rex, General Petroleums, Sparky, and Waseca Beds). The thickness of the Cantuar Formation ranges from zero in south-central Saskatchewan to more than 200 m in the north of the study area. The thickness and distribution of each of the 'beds' within the Cantuar Formation are shown in Figures: 74.1; 74.2; 74.3; 74.4; 74.5; 74.6; and 74.7, and are seen to form a general overall northerly back-stepping succession from Dina through Waseca. The Pense Formation, present throughout the study area, ranges in thickness from less than 10 m in the north and west to more than 50 m in the southeast. It is sub-divided into the regionally extensive McLaren Member (Figure 76.1), and the more localized Colony Member (Figure 76.2). The McLaren Member, ranging in thickness from less than 2 m to more than 50 m, is present throughout the study area; it displays a similar thickness distribution pattern to that of the Pense Formation. The Colony Member is present only in the northwestern part of the study area (north of Township 15), where it is up to 15 m thick. Christopher (1974) and Christopher (2003) has published much more detailed information regarding the depositional history, sedimentology, and hydrocarbon potential of the Mannville Group in Saskatchewan.

Colorado Group

The Lower to Upper Cretaceous Colorado Group in Saskatchewan mainly comprises dark grey to green glauconitic shale with several sandstone intervals. This thick succession can be sub-divided into a lower clastic dominated unit and an upper mixed carbonate/clastic unit at a regional unconformity underlying the base of the Second White Specks Formation (Buckley and Tyson, 2003; Christopher *et al*., 2004; Pederson, 2004). Each of the upper and lower successions can then also be further sub-divided into several lithostratigraphic formations. The Lower Colorado Group (Figures 77 and 78) comprises the Joli Fou (Figures 79 and 80), Viking (Figures 81 and 82), Westgate (Figures 85 and 86), Fish Scales (Figures 87 and 88) and Belle Fourche (mapped as the top of the Lower Colorado Group) formations. It also includes the St. Walburg Sandstone (Figures 83 and 84), a locally developed unit within the Westgate Formation. For the purpose of this project, the upper successions within this group are recognized as the Second White Specks Formation (Figures 89 and 90) and the Upper Colorado Group/Niobrara Formation (Figures 91 and 92). An isopach map of the Medicine Hat A Sandstone (Figure 93), a gas-prone sandstone interval within the Upper Colorado Group/Niobrara Formation in the southwest, has also been constructed.

The Lower Colorado Group (Figures 77 and 78) is present throughout the study area. It ranges in thickness from 67 m in the northeast to an anomalous 328m in well 141/07-07-010-23W3/00. However, typical regional thickening in the range 200 to 270 m takes place toward the southwest, probably due to deepening within the Western Canada Sedimentary Basin related to orogenic events in the Cordillera west of the study area. This southwestward thickening is particularly pronounced within the shale-dominated Joli Fou Formation (Figure 80), which is up to 60 to 90 m thick, and the oil- and gas-prone quartz-sandstone dominated Viking Formation (Figure 82), which attains thicknesses of 35 to 55 m. In addition to the typical west-sourced sediments, northeast-derived components both of shales of the Joli Fou Formation and of sandstones of the Viking Formation (Figures 80 and 82) are evident. Dark grey to black, southward-thickening shales of the Westgate Formation overlie the sandstones of the Viking Formation. They are present throughout the area, and range in thickness from 20 m in the north to more than 100 m in the south. In the north, they contain the locally developed, hydrocarbonprone sandstones of the St. Walburg Sandstone (Figures 83, 84, 85, and 86), which reach thicknesses of 10 to 19 m. The Fish Scale Formation, present throughout most of the study area, is typically made up of fish-scale rich shales that contain locally developed sandstone lenses. Its thickness ranges from zero near the northern edge of the study area to 24 m toward the southwest corner of the province. The thickness-distribution pattern of the Fish Scale Formation is similar to that of the Westgate and Viking formations, with apparent derivation from sources located farther west although some of the thicker accumulations (15 to 20 m) are present to the east of the Bowdoin Dome.

The Second White Specks Formation (Figures 89 and 90) comprises light to dark grey calcareous shale and argillaceous limestone with abundant white coccoliths and other fossil fragments. Ranging in thickness from 1 m in the north to over 60 m in the southwest, it is present throughout the study area (Christopher *et al*., 2004; Pederson, 2004). In general, the thickest accumulations are toward the southwest corner of the province, although moderately thick (20 to 33 m) accumulations are present in west-central parts of the study area. The Upper Colorado Niobrara Formation (Figures 91 and 92) is present throughout most of the study area except the extreme northeast, where it is eroded by the sub-Lea Park unconformity. From there its thickness increases southwestward to over 200 m. In the southwest, this dark grey shaly unit interfingers with the gas-prone Medicine Hat A Sandstone (Figure 93), which is typically less than 20 m thick.

Buckley and Tyson (2003), Christopher *et al*. (2004), Pederson (2004), Ridgley and Gilboy (2001), Simpson (1984), and Tooth *et al*. (1984) provide further details regarding the depositional history, sedimentology, and hydrocarbon potential of the Colorado Group in Saskatchewan.

Milk River Formation

The Milk River Formation (Figures 94 and 95) is the lower unit of the Upper Cretaceous Montana Group, erosionally truncated to the north and northeast by the sub-Lea Park unconformity. In general, this unit comprises greenish grey bentonitic siltstones and shales that, in areas close to the western provincial boundary, have produced commercial volumes of biogenic gas (Fishman and Hall, 2004; Pederson, 2003). Regionally, the Milk River Formation is thicker (160 to 260 m) toward the southeast, becoming thinner to the southwest above the western margin of the Swift Current Platform and to the north of an escarpment at Township 31 from which it gradually thins to zero at its erosional edge. The Milk River has been locally affected by faulting (repeat sections are present on geophysical well logs) along and close to the Canada – U.S border in the southwestern corner of the province and in well 141/07-07-010-23W3/00. More information regarding the depositional history, sedimentology, and hydrocarbon potential of the Milk River Formation in Saskatchewan has been published by Fishman and Hall (2004), Pederson (2003), and Ridgley (2000).

Lea Park Formation

The Lea Park Formation (Figures 96 and 97) is the upper unit of the Upper Cretaceous Montana Group and is separated from the underlying Milk River Formation by a regional unconformity. It is generally made up of dark grey shale with minor sandstone interbeds (Christopher and Yurkowski, 2003). Present throughout most of the study area, it ranges in thicknesses from zero in localized thins in the north and, in particular, the northwest, to 200 to 260 m across the north-central region of the study area where it fills accommodation space left on top of the Milk River Formation by the sub-Lea Park unconformity. The localized thinning towards the northwest appears to be related to faulting (repeat sections can be identified and correlated in geophysical well logs) within two paleotopographic valleys that can be seen in structural surfaces through the stratigraphic column to the top of the Prairie Evaporite Formation, inferring that salt dissolution may be a possible mechanism in creating such features. Christopher *et al*. (2004), Christopher and Yurkowski (2003), and McLean (1971) have published information about the depositional history and sedimentology of the Lea Park Formation in.

Belly River Formation

The Upper Cretaceous Belly River Formation (Figures 98 and 99) is the uppermost regionally correlative stratigraphic unit that is identifiable below surface casing within the bounds of the Western Saskatchewan Project. Although not identifiable below surface casing throughout the entire study area, this typically very fine-grained sandy bentonitic mudstone with abundant interbeds of coal is present in the majority of the southern two-thirds of the area (Christopher *et al*., 2004; McLean, 1971). Where identifiable below surface casing, the Belly River Formation ranges in thickness from 19 to 189 m, generally thickening towards the shallower regions of the basin in the southwestern corner of the province. To the east of the Bowdoin Dome, however, a thick accumulation of Belly River Formation also extends northward from the international border. Further information regarding the depositional history and sedimentology of the Belly River Formation in Saskatchewan has been published by Caldwell (1968), Christopher *et al*. (2004), Christopher and Yurkowski (2003), Frank (2005), and McLean (1971).

Regional Cross-Sections

Twelve regional cross-sections were produced for this phase of the project, five oriented south-north (Figures 100, 101, 102, 103, and 104) and seven, west-east (Figures 105, 106, 107, 108, 109, 110, and 111). The datum for all of the cross-sections is the regionally conformable and regionally identifiable top of the Second White Specks Formation (2WS). For each cross-section, the most deeply penetrating wells on a one-well-per-Township basis wherever possible were used, and all major lithostratigraphic surfaces were correlated.

The south-north cross-sections show the general southward regional dip of strata within the study area, as well as the regional northward thinning of the Phanerozoic section in western Saskatchewan. The west-east cross-sections show more of the depositional trends of the various stratigraphic units, and can perhaps be used to interpret more about facies distributions within discrete sedimentological successions.

Summary

The information in this report, when combined with the data presented in Table 1 and the multitude of figures, is designed to provide a general understanding of the geological framework in western Saskatchewan for the complete Phanerozoic section from the top of the Precambrian basement to the uppermost mappable lithostratigraphic unit below surface casing. All the stratigraphic data within the project were derived using Saskatchewan Industry and Resources lithostratigraphic standards in analyzing geophysical well logs from 5,203 wells within an area bounded by a provincial border to the west, the third meridian to the east, the international border to the south, and Township 53 in the north (i.e., the area comprises Townships 1-52, Ranges 1-30 West of the Third Meridian). It is hoped that the information gathered here, when either used on its own, or combined with subsequent phases of this project (expected to include an expansion of the study area, the addition of new well data, detailed pool-analog studies, and the amalgamation of data with adjacent studies), will help industry and other researchers to substantially improve their overall understanding of the geological framework of the Williston Basin.

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