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Paleotopographic Reconstruction and Subcrop Geological Mapping of the Sub-Cretaceous Unconformity in Central Alberta: Methodology and Results

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Abstract

This report presents a methodology for reconstructing the topography of the sub-Cretaceous unconformity surface and creating a subcrop geological map, using picks of the tops of stratigraphic units and geostatistical analysis. It also presents a paleotopographic map and a subcrop geological map for an area in central Alberta near Edmonton, generated using this methodology. The paleotopographic map depicts the relief and river valley networks of the ancient ground surface represented by the sub-Cretaceous unconformity. The subcrop geological map defines subcropping areas and edges of the underlying Jurassic-to-Devonian stratigraphic units at the unconformity surface. These maps provide more detail at a higher resolution compared to similar maps previously published. The subcrop geological map provides additional insight for assessing pathways of potential hydraulic communication between the Lower Mannville aquifer and aquifers of the underlying Jurassic to Middle Devonian succession.

1 Introduction

The Alberta Geological Survey's groundwater program continues to investigate regional groundwater flow in the Alberta basin with the objective of mapping saline aquifers and providing a better understanding of their physical and chemical properties at a provincial scale. A pilot study area was selected to evaluate high-resolution geological mapping methodologies and results applicable to regional hydrogeological studies. The study area for the pilot project is in central Alberta, from Townships 49 to 60 and Range 17, west of the 4th Meridian to Range 5, west of the 5th Meridian, and includes the city of Edmonton and the Alberta Industrial Heartland (Figure 1). Aquifer units in the Upper Devonian, Mississippian, and Jurassic periods subcrop at the sub-Cretaceous unconformity and are in direct contact with the Lower Mannville aquifer (Figure 2), allowing for potential hydraulic communication between aquifers at the sub-Cretaceous unconformity. As a result, mapping the sub-Cretaceous unconformity surface and the subcrop extents of the geological units at the unconformity is recognized as a geological control for groundwater flow. This report presents the data used, methodology employed, and results obtained in modelling the sub-Cretaceous unconformity surface and subcropping Jurassic-to-Devonian stratigraphic units at the unconformity.

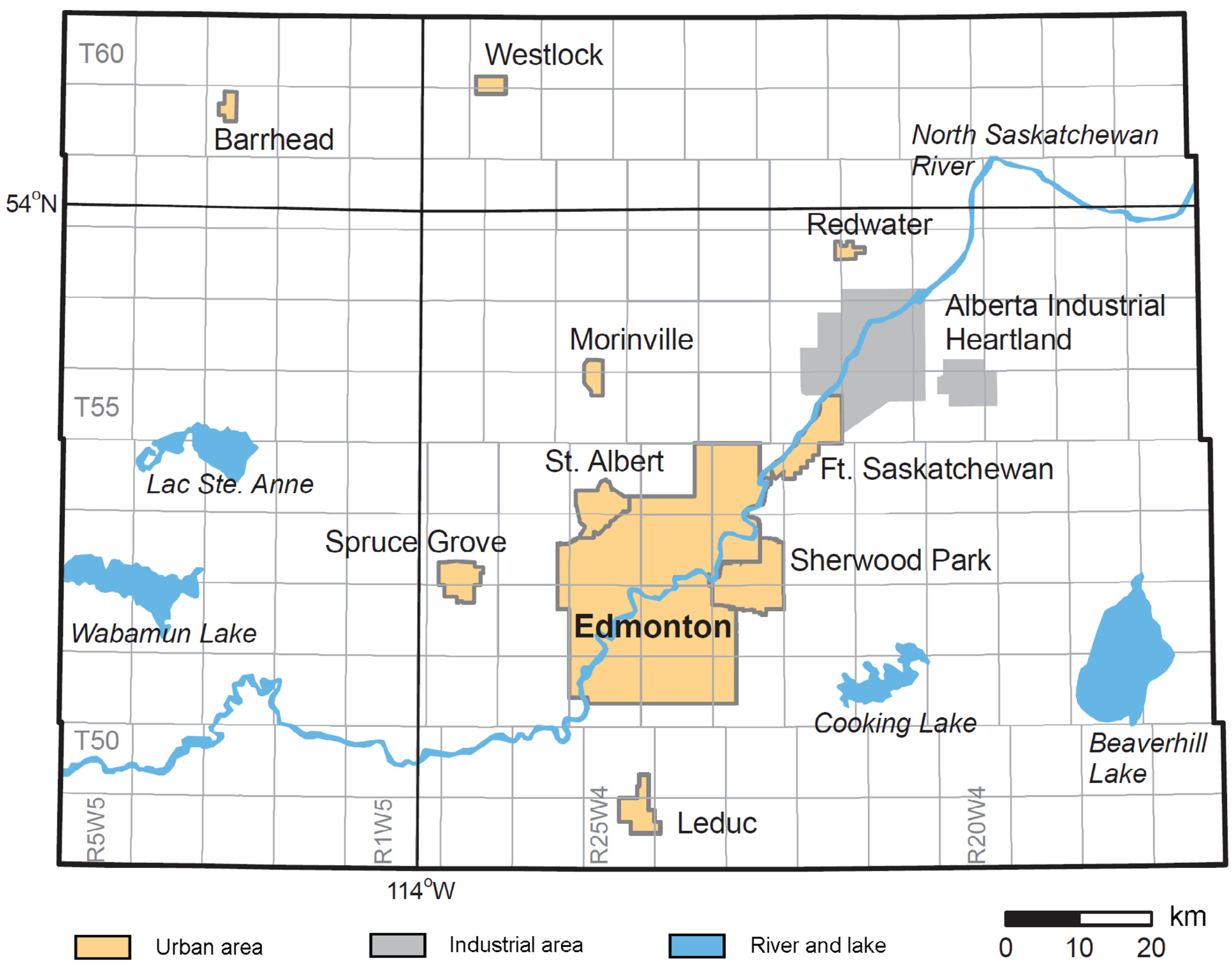

Figure 1. Map of the study area.

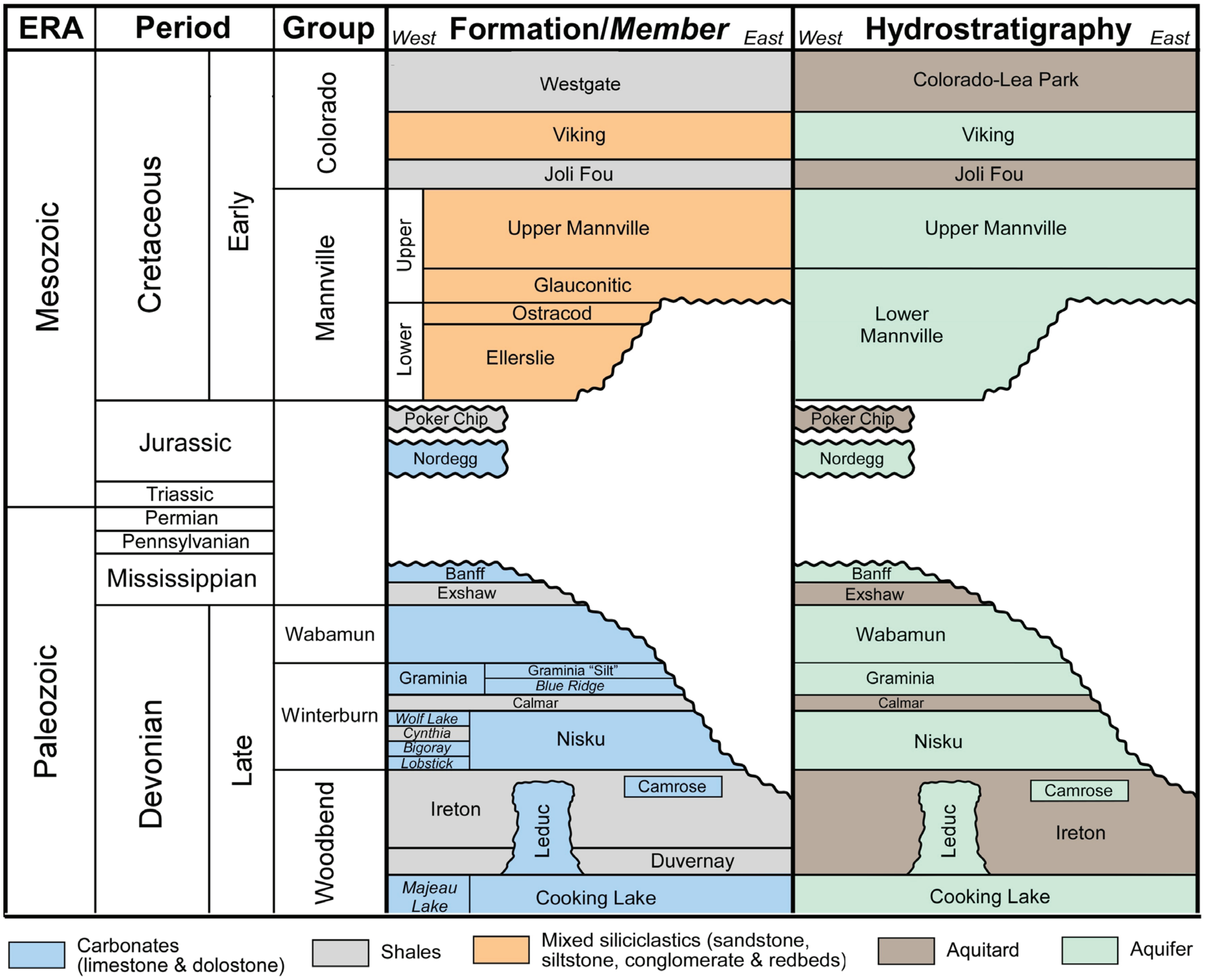

Figure 2. Lithostratigraphic and hydrostratigraphic chart of the relevant sedimentary succession in the study area.

2 Geological Background of the Sub-Cretaceous Unconformity

The study area (Figure 1) is located at the centre of the south-central part of the Alberta basin, which is bordered by the Rocky Mountain Fold and Thrust Belt to the west and southwest, the paleostructural high of the Peace River Arch to the north, the Precambrian Canadian Shield to the northeast, and is separated from the Williston Basin by the Bow Island Arch to the southeast (Wright et al., 1994, Figure 3.1). Below a relatively thin veneer of unconsolidated Quaternary-Neogene sediments, the study area is predominantly composed of Cambrian to Paleogene sedimentary rocks deposited on top of the crystalline Precambrian basement (Figures 2–4).

The sedimentary rocks consist of two sequences with profoundly different depositional histories and lithologies (Figures 2–4). The lower sequence was deposited on a passive continental margin and includes a succession of Cambrian, Devonian, Carboniferous, and Lower Jurassic rocks that are dominated by shallow marine carbonates and evaporites with some intervening deeper-water shales. The upper sequence was deposited with the development of a foreland basin from the Late Jurassic to Paleogene and is dominated by synorogenic clastic rocks. The foreland basin sequence consists of three distinct successions. The lower succession, represented by the Mannville Group, was deposited corresponding to

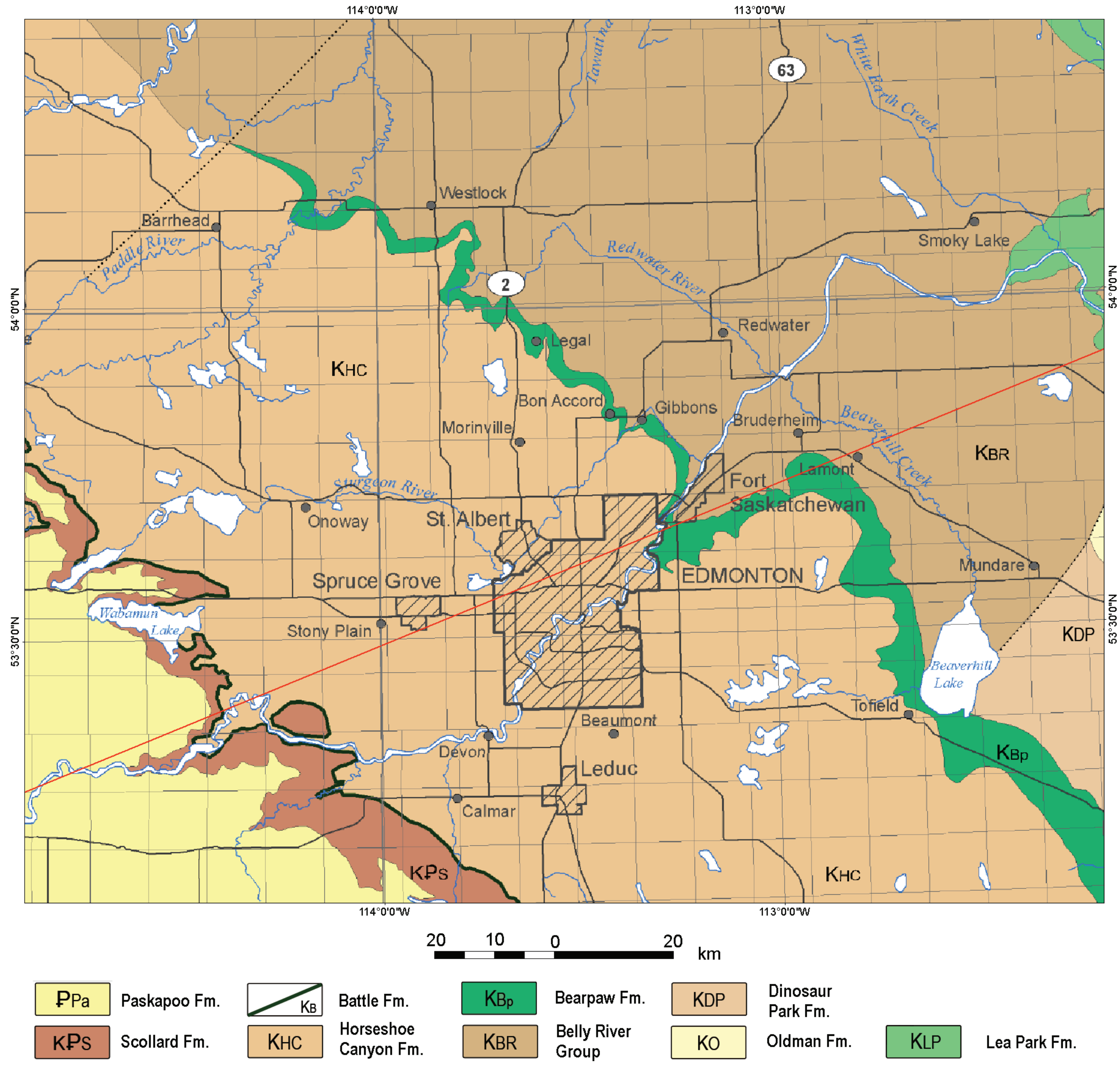

Figure 3. Bedrock geology map of the study area (clipped from Prior et al., 2013). The red line indicates the location of the cross-section shown in Figure 4.

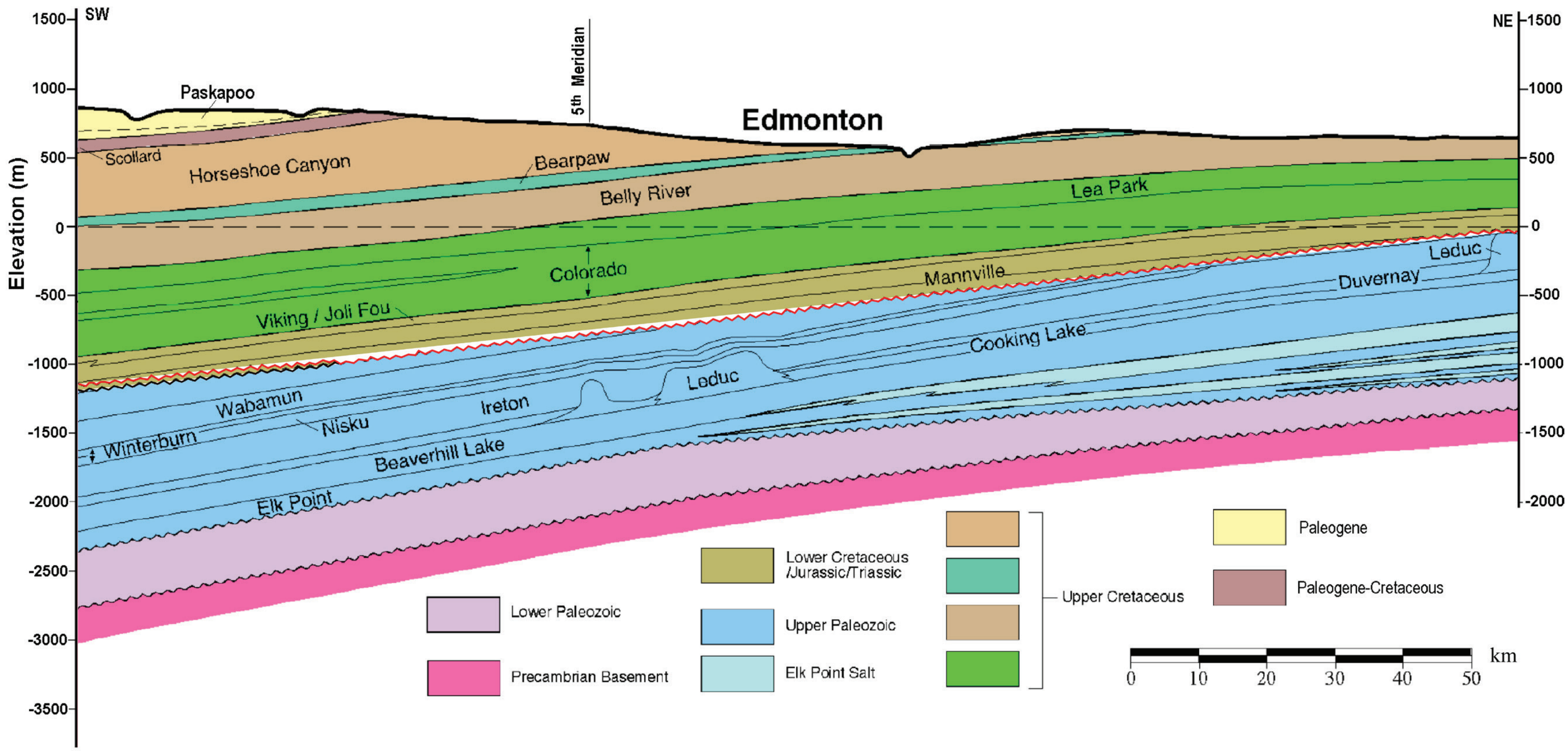

Figure 4. Geological cross-section of the study area. The location of the cross-section is indicated by the red line in Figure 3. Modified from Hamilton et al. (1999).

the Early Cretaceous Columbian orogeny (Porter et al., 1982) and is characterized by fluvial and estuarine valley-fill sediments, sheet sands, and shales deposited by repeated marine transgression-regression cycles. The middle succession is represented predominantly by thick shales with some intervening thin sandstones of the Colorado Group and Lea Park Formation and was deposited during an early Late Cretaceous tectonic lull when the basin was subject to a widespread marine transgression. The upper succession was deposited corresponding to the Late Cretaceous and Paleogene Laramide orogeny and includes nonmarine fluvial clastic rocks of the Belly River Group and Horseshoe Canyon Formation in the lower and upper part, respectively, and marine mudstones of the Bearpaw Formation sandwiched in the middle.

All the sedimentary rocks in the study area tilt to the southwest following a regional dip (Figure 4) caused by lithospheric loading and isostatic flexure during the Columbian and Laramide orogenies. The dip starts with a gentle slope of <4 m/km in the northeast and passes into a steeper slope up to >20 m/km southwestward near the deformation front (Bachu et al., 2008).

Within the study area, a major unconformity, known as the sub-Cretaceous unconformity, separates the foreland basin sequence from the underlying passive margin succession, with the latter dipping at a greater angle than that of the overlying sequence (Figure 4). For example, the top of the Nisku Formation in the study area dips with a gradient of 6.5 m/km in the northeast changing to 10.5 m/km in the southwest, while the top of the Glauconitic Sandstone Formation dips with a gradient of 3.8 m/km in the northeast increasing to 7.7 m/km in the southwest. The sub-Cretaceous unconformity in the study area represents a cumulative hiatus of about 220 to 230 million years (Ma) and a complex history of exposure and erosion. Progressively older Jurassic to Middle Devonian strata subcrop from southwest to northeast at the unconformity (Figure 2 and Figure 4).

During the Devonian, the study area experienced a general trend of marine transgression. A seaway started to spread from the northwest into the interior of the cratonic platform through a southeast-trending embayment (Kent, 1994, Figure 7.7) resulting in the deposition of the shallow shelf carbonates and evaporites of the Middle Devonian Elk Point Group. The seaway was flanked by the Peace River Arch and the West Alberta Ridge in the west and the Canadian Shield to the east. During the course of the Devonian, the west flank of the seaway was progressively submerged: first the West Alberta Ridge was submerged during the deposition of the basinal shales and carbonates of the Middle to Upper Devonian Beaverhill Lake Group (Kent, 1994, Figure 7.8); second, after deposition of the shallow-water platform and reef carbonates and deeper-water calcareous shales and argillaceous limestones of the Upper Devonian Woodbend and Winterburn groups (Kent, 1994, Figure 7.9), the Peace River Arch was also submerged with the deposition of open-marine shelf carbonates of the Upper Devonian Wabamun Group (Halbertsma, 1994, Figure 13.1).

During the latest Devonian and earliest Carboniferous, a trough, known as the Prophet Trough, developed along the western Canadian cratonic margin (Richards, 1989). A marine embayment also developed at the former site of the Peace River Arch in the northern part of the cratonic platform margin and subsequently became connected to the Prophet Trough. These developments resulted in a different sedimentary pattern in Carboniferous strata, with marine carbonates deposited in a narrow belt along the passive margin and with facies changing from shelf to basin towards the west (Kent, 1994, Figure 7.10). By the time of deposition of the Banff Formation, the study area was located in the shallower part of the shelf and sedimentation was marked by transgressive-regressive cycles of skeletal-oolitic carbonates passing landwards into restricted carbonates and to nearshore siliciclastics and evaporites (Richards, 1989; Richards et al., 1994; Kent, 1994, Figure 7.10).

The sea-level change during the Carboniferous is characterized by a general trend of regression as indicated by the inferred coastal line moving westward towards the basin (Kent, 1994, Figures 7.10 and 7.12). By the time of deposition of the Mississippian Rundle Group, the study area was already located in the continental sabkha environment (Kent, 1994, Figure 7.12). The uppermost Mississippian deposits of the Mattson assemblage, which are currently confined to the Peace River Embayment (Richards et al., 1994, Fig. 14.35), record the culmination of the general regressive trend that predominated during sedimentation of the Rundle Group, and late Carboniferous marine sedimentation was further restricted to the passive margin (Richards et al., 1994). The regressive trend continued in the Permian with a significant drop in relative sea level, resulting in sedimentation confined mainly to the Peace River Embayment and the Prophet Trough. The low sea-level stand continued in the Triassic with some minor transgression (Kent, 1994, Figures 7.13 and 7.14). The study area, which is located on the cratonic platform to the east of the Prophet Trough and to the southeast of the Peace River Embayment, was probably constantly exposed since the late early Carboniferous. Marine conditions did not return to the study area until the deposition of the Lower Jurassic Nordegg Formation, suggesting that the Upper Devonian and Mississippian rocks in the study area underwent exposure and erosional bevelling for a period that lasted about 120 Ma. It is not clear how much of the Carboniferous and Devonian rocks were eroded during this period.

The inundation of the study area in the Early Jurassic was of short duration and ceased with the initiation of the Columbian orogeny during the middle-late Jurassic. Isostatic flexure of the lithosphere induced by the Columbian orogeny tilted the pre-orogenic rocks towards the southwest. This was followed by an episode of tectonic and magmatic quiescence in the Canadian Cordillera from 140 to 125 Ma when tectonic compression associated with the Columbian orogeny may have decreased or changed direction (Leckie, 2009). This period is characterized by basin rebound/uplift after the Late Jurassic foreland subsidence episode, resulting in significant erosion of the pre-orogenic sediments.

To sum up, the study area underwent two major stages of subaerial exposure and erosion since the deposition of Upper Devonian and Mississippian carbonates. The first stage lasted about 120 Ma and resulted in a slight angular unconformity between the Mississippian Banff Formation and the Lower Jurassic Nordegg Formation (Bokman, 1963; Cruden and Charlesworth, 1966). The second stage includes the Middle Jurassic to the earliest Cretaceous Neocomian and lasted about 70 Ma, with the culmination of erosion and incision in the Neocomian after deposition of the first foreland basin clastic wedge during the Late Jurassic Oxfordian and Kimmeridgian (Leckie, 2009). As a result, successively older Jurassic-to-Devonian rocks were exposed towards the northeast, and the topographic relief of the sub-Cretaceous unconformity was created (Cant, 1996; Leckie, 2009).

Deposition in the study area resumed in the Early Cretaceous Aptian when fluvial and deltaic sediments of the Ellerslie Formation of the lower Mannville Group were deposited in the drainage network developed around exposed highlands of Jurassic to Upper Devonian rocks on the sub-Cretaceous unconformity (Jackson, 1984; Cant and Abrahamson, 1996; Pemberton and James, 1997).

The lower Mannville strata form an aquifer and provide hydraulic communication between aquifers of the underlying Jurassic to Middle Devonian succession that subcrop at the sub-Cretaceous unconformity and are otherwise separated by intervening aquitards in the uneroded part of each hydrostratigraphic unit.

3 Data, Sources of Error, and Quality Control

The data used for structural and geometric modelling are the tops of stratigraphic units (picks). Table 1 shows the number of stratigraphic picks used for constructing the paleotopographic map and the subcrop geological map. These picks were mainly made by the authors using digital geophysical borehole logs and were subsequently combined and prepared for geostatistical analysis. Additional infilling and refined picks were added during geostatistical analysis and geomodelling.

The main source of uncertainty in the elevation of picks was identified as the potential error found in the elevation of the kelly bushing (KB), which propagated into the elevation of picks because the elevation of a pick is calculated from the KB. The error in KB could be caused by errors in surveying the ground elevation of the well site because the KB elevation is usually derived from adding the height of the drilling platform above the ground surface to the surveyed ground elevation.

The second source of error was the uncertainty in well location. In Western Canada, wells are licensed based on the bottomhole location, and the coordinates that define the location are based on a survey grid that is tied to known markers. In Alberta, the grid currently used by the petroleum industry is the Alberta Township Survey version 4.1 (ATS 4.1) (AltaLIS, 2014). The ATS grid has gone through several revisions, and each revision has resulted in corrections to previously derived grid points, with each successive grid being more accurate than the one that preceded it. The accuracy for the ATS 4.1 is ±3 metres. The surfacehole location is first defined as metes and bounds based on the ATS grid, which are the offsets relative to the southeast corner of the section in a township. Then, the bottomhole location is calculated based on the shifts from the directional survey and the surfacehole coordinates (Alberta Energy Regulator, 2011). Some uncertainty in well location is inevitably introduced in the above-mentioned calculations and conversions, and this then translates into uncertainty in the elevation of formation-top picks when the formation-top surface is not flat.

The third source of error in the pick elevation results from human error due to inconsistency or incorrect placement of the pick on the well logs; this can be partly caused by using inconsistent interpretation or correlation models (see Tinker, 1996), limited availability and poor resolution of logs, and complexity of log signatures due to facies change. Other sources of error include data entry mistakes and incorrect well log depth calibration.

Table 1. Picks of stratigraphic unit tops used for constructing the subcrop geological map.

Stratigraphic unit top	Number of picks
Cooking Lake	420
Majeau Lake	92
Leduc	1 463
Ireton	3 259
Nisku	3 764
Calmar	3 179
Blueridge	569
Graminia	2 194
Wabamun	4 945
Exshaw	499
Banff	3 027
Nordegg	776
Poker Chip	267
Sub-Cretaceous unconformity	10 348
Ellerslie	7 703

The first step in quality control of picks is identifying outliers. In this study, the method described by Mei (2009) for quality control was used, which includes the following steps:

1) A local trend surface was generated around each data point using the surrounding data points; then, the deviation of the data point from the local trend was calculated.
2) The histogram of deviations was examined and the data points with deviations larger than an initially determined threshold (e.g., two or three standard deviations away from the mean deviation) were identified as outliers.
3) The outliers were then visually examined against the structure map and grouped into two based on their distribution patterns. One category contained outliers that were clustered in a linear or circular pattern, potentially indicating local structural features. The other category contained outliers that were randomly distributed across the study area, likely representing erroneous picks.
4) The outliers were then examined against well logs to confirm the existence of local structures or to correct other errors. Data points identified with KB errors were examined, corrected, or refined with available digital elevation model (DEM) data (e.g., light detection and ranging (LiDAR) or Shuttle Radar Topography Mission (SRTM) DEM), or using offset well KBs in a flat area. The data points associated with picking errors were reassessed. Wells with errors that were undetermined or could not be corrected (e.g., lack of good quality logs for repicking) were removed from the analysis.
5) The above-mentioned steps were repeated until a minimized and acceptable level of uncertainty was reached.

4 Methodology

The general geometric modelling workflow employed in this study includes the following:

- Interpolating top surfaces of stratigraphic units both underlying and overlying the sub-Cretaceous unconformity.
- Interpolating the sub-Cretaceous unconformity surface and modelling the topography of the paleoground surface represented by the unconformity.
- Generating the subcrop geological map of stratigraphic units subcropping at the sub-Cretaceous unconformity surface.

After deposition, sedimentary units in the Alberta basin have been affected by regional compaction, regional deformation, and local structural disturbances that may be related to differential compaction, faulting, salt dissolution collapse, karst development, and glaciotectonics, to name a few. Consequently, the present-day elevation of a stratigraphic unit top represents the final result of the combined effects of both the regional and local processes. In generating formation-top surfaces, a regional trend surface is first modelled to account for the combined effect of the regional processes using the methodology described by Mei (2009). The trend is removed from the data and simple kriging is applied to the residuals to account for local variations using ArcGIS Geostatistical Analyst. The final surface is obtained by adding the trend back to the kriged values.

For the sub-Cretaceous unconformity, both the regional erosion and the local valley incision during the long period of exposure were also involved in shaping the topography of the ground surface represented by the unconformity. In generating the sub-Cretaceous unconformity surface, the modelled trend accounts for the combined effect of the regional processes that also include the regional erosion.

Like a geological map that displays rock units outcropping at the present-day ground surface, a subcrop geological map illustrates the rock units subcropping at a subsurface unconformity. In effect, a subcrop geological map is a map of the geology as a prehistoric geologist would have mapped just before the renewed deposition began to bury the ancient ground surface represented by the unconformity. In this study, the intersection of the sub-Cretaceous unconformity and an underlying unit-top surface is referred to as the formation-top subcrop edge of that stratigraphic unit; it coincides with the subcrop zero edge of the overlying unit. The formation-top subcrop edge is the boundary between a region where the stratigraphic unit was completely preserved and buried below the unconformity and a region where it was partially eroded and therefore subcrops at the unconformity. It also defines the boundary between the subcropping area of one stratigraphic unit and that of the overlying unit. Consequently, the formation-top subcrop edges of stratigraphic units constitute the main elements of a subcrop geological map.

It is quite intuitive to determine the formation-top subcrop edges by finding the intersections of the surfaces of the subcropping stratigraphic units and the unconformity surface. However, the resultant intersections generated in this study were found to not honour the data points well. This can be attributed to both the uncertainty associated with the data (as discussed previously) and the smoothing effect of the interpolation process.

Interpolation is the process of using original data points to generate calculated data points on a regularly spaced grid. When the grid is presented as a raster surface, the value of the grid node is assigned to the pixel encompassing the grid node. Like most of the interpolation algorithms, kriging is a weighted average interpolation. As a result, the interpolated surface is smoother than the actual surface and seldom honours the original data. This results in the simplification of the modelled formation-top subcrop edges. In areas where unit-top picks are not available, such as along the formation-top subcrop edge of a unit or in areas that contain no original data, the kriged estimates approach the mean of the data when distances from data points are larger than the range of the variogram model used. This effect will add to the inaccuracy in locations of the formation-top subcrop edges.

To overcome the shortcomings caused by simply intersecting the surfaces of the subcropping formations with the unconformity surface, the methodology and principles used in field geological mapping of stratigraphic unit outcrop boundaries were instead employed in this study. The basic rules for constructing a field geological map include the following:

- The outcrop edge of a horizontal bedrock boundary is parallel to the topographic contours.
- For surfaces with a dip that is gentler than the typical hill slopes of topography in the region, the outcrop edges will generally follow topographic contours. When the stratigraphic unit is nearly planar and its thickness is known, the relative position of the unit's top and bottom contacts can be inferred from the local topography. For example, if the outcrop edge of the bottom boundary, which is defined by the top of the underlying unit, is known, then the top of the unit must be exposed at a higher elevation by the value of isopach at that location. For a dipping stratigraphic unit, the true thickness is less than the vertical thickness at a given location. For gently dipping strata this may be negligible, but for more steeply dipping strata it makes a difference.
- An outcrop edge should not cross a topographic contour except where the unit-top structural contours and topographic contours of the same elevation intersect.

This above-mentioned methodology was implemented by using a topographic base map, as the topographic contour is the most-needed, fundamental information for mapping the modern-day outcrop. On a geological map, a unit-top surface reaches the ground surface at locations where the topographic contour cuts the unit-top contour. This fact makes it possible to complete an outcrop map by using a topographic base map and a minimum of three data locations where the bed is exposed, assuming that the unit-top surface is a flat plane. First, the elevations of the three locations can be derived from the topographic map. Then, the three-point elevations can be used to define the dip and strike of the unit-top plane and construct the contours of the unit-top surface. Finally, the geological map can be completed by inserting the outcrop points where the unit-top contours intersect the topographic contours and then connecting these intersection points in a smooth and continuous curve.

For this study, a paleotopographic surface for the sub-Cretaceous unconformity (Figure 5) was modelled. First, the sub-Cretaceous unconformity picks were used to model a smooth surface (i.e., trend surface) to account for the compounded effect of regional compaction, regional structural tilt, and regional erosion. This trend was removed from the data points and a residual map was created to accentuate the local paleotopographic reliefs using simple kriging.

The paleotopographic map was then used for constructing the subcrop geological map (Figure 6). The tops of the subcropping units are dipping to the southwest with a gentle slope of ~6 m/km to 10 m/km; they are nearly horizontal (less than ~0.5 degree) relative to the paleotopographic surface after removal of the regional dip. Following the rules mentioned above, the formation-top subcrop edges at the unconformity should generally follow the topographic contours. In constructing the subcrop map, the

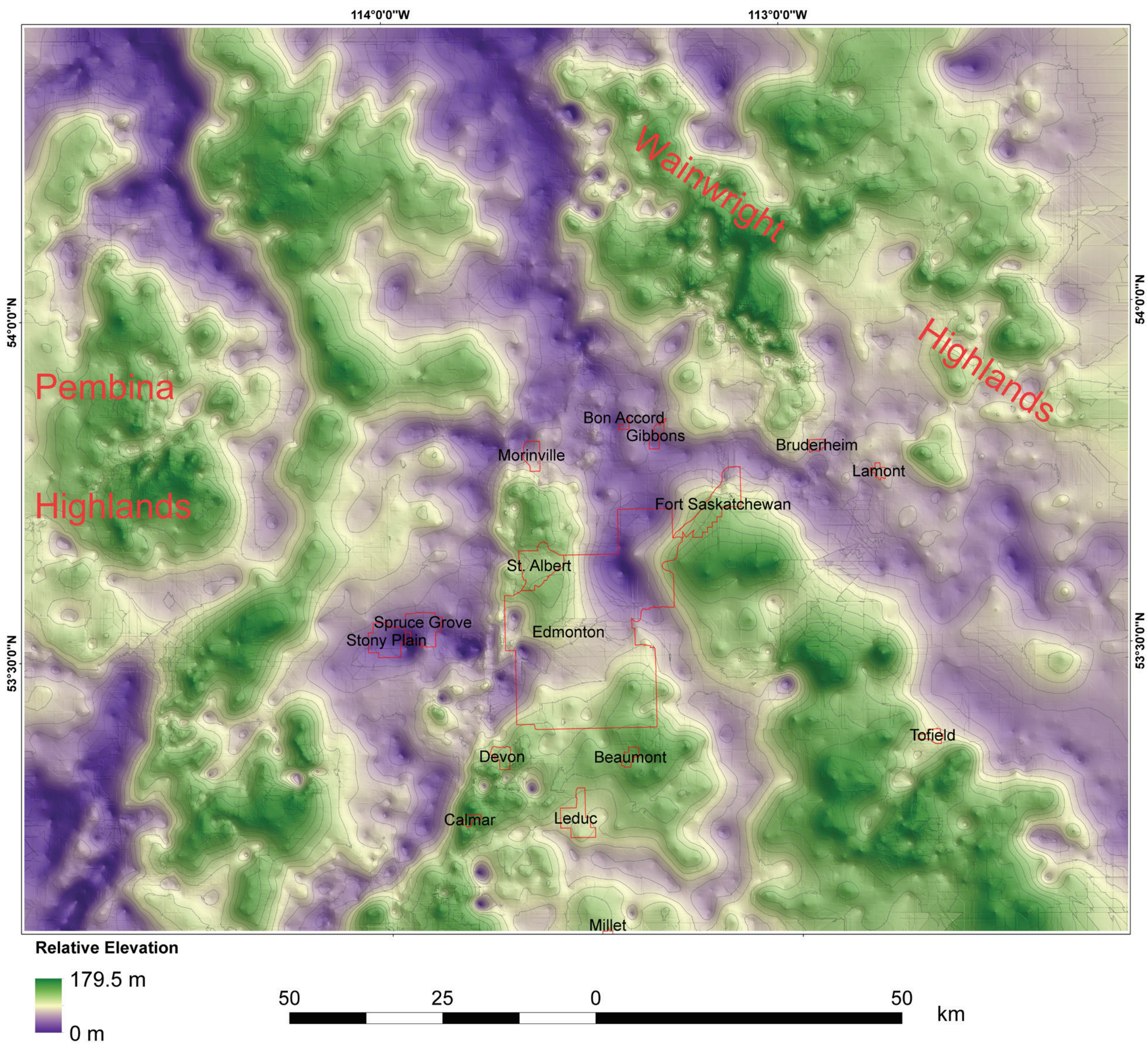

Figure 5. Paleotopography of the sub-Cretaceous unconformity surface in the study area.

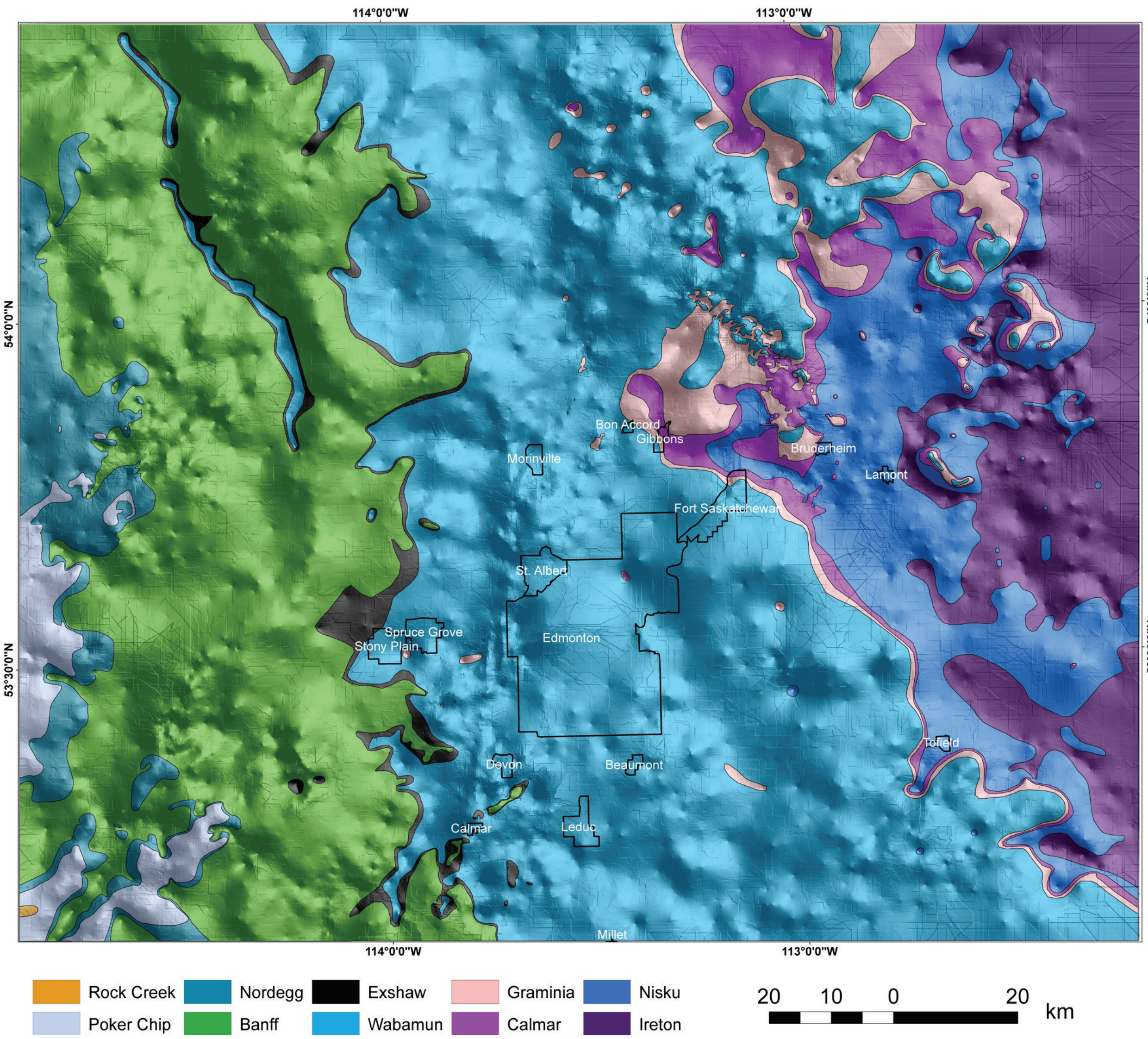

Figure 6. Subcrop geological map of the sub-Cretaceous unconformity draped on the hill-shaded relief image of the paleotopography (Figure 5).

intersection of an underlying unit-top surface and the unconformity surface was first generated and only used for focusing on an approximate zone where the formation-top subcrop edge may be located. Then, the data points that indicate subcropping of the stratigraphic unit in this zone were identified; these data points are identified as those with a zero isopach of the overlying formation. The data points representing the uneroded formation top are also identified in this zone; these data points are identified as those with minimal isopach of the overlying formation in the zone. The location of the formation-top subcrop edge was then estimated to be at a point between a data point indicating subcropping and the nearest data point of uneroded formation top. The geological map was finally completed by applying the method mentioned previously to connect these estimated formation-top subcrop edge points in a smooth and continuous curve guided by both the paleotopographic contour and the trend of the intersection.

5 Results and Interpretation

In the study area, two highlands, named the Pembina Highlands and the Wainwright Highlands, and a valley system between them, named the Edmonton Valley, had been recognized previously (McLean and Wall, 1981; Smith, 1994, Figure 17.3). The sub-Cretaceous paleotopographic map (Figure 5) provides high-resolution details of the highlands and valley networks. It illustrates a landscape with a relief of up to nearly 180 m, including the eastern part of the Pembina Highlands, part of the Wainwright Highlands in the northeast and detailed valley systems between them. West of the Wainwright Highlands is a major valley branching out into three tributaries to the southwest, south, and southeast. The network pattern suggests a paleodepositional flow direction from south to north. To the west of this network is a south-trending range that is the divide between the above-mentioned valley network and other valleys that flank the eastern margin of the Pembina Highlands in the western part of the study area.

A linear feature is shown running along the west sides of Morinville, St. Albert, Edmonton/Acheson, Devon, and Calmar from north to south-southwest (Figure 4 and Figure 5). This feature coincides with the west margin of the Rimbey-Meadowbrook Reef trend and offsets the southwest-running valleys. It is interpreted to have been caused by differential compaction over the reef trend or by faulting after the formation of the valley system.

The topography of the sub-Cretaceous unconformity exerted important control over the nature and distribution of the overlying lower Mannville Group deposits. The Ellerslie Formation, recognized as the first foreland basin deposition in the study area, is represented by up to 123 m of predominantly fluvial deposits accumulated in the valley system with up to 66 m of net porous sand (Figure 7), corresponding to rising base level during Aptian time (Smith, 1994, Figure 17.3). As the relative sea level continued to rise with continued basin subsidence, the valleys were progressively inundated from the north; this resulted in tide-dominated embayments advancing southwards along the Edmonton Valley, reworking the fluvial Ellerslie Formation sands during the deposition of the Ostracod Beds. At the peak of the transgression, most of the study area, including the Pembina Highlands, was underwater; only the Wainwright Highlands remained emergent (Smith, 1994, Figure 17.4). The northern part of the Wainwright Highlands was progressively submerged by the renewed transgression of the Moosebar/Clearwater sea southward during the deposition of the Glauconitic Sandstone Formation (Smith, 1994, Figure 17.5).

Figure 7 shows the distribution of net porous sand of the Ellerslie Formation superimposed on the sub-Cretaceous paleotopographic map. The net porous sand map was generated using gamma-ray and density porosity logs, with a gamma-ray threshold of 75 API and a porosity threshold of 9 per cent. Figure 7 indicates a coincidence of the thick porous sand areas with the major valleys, suggesting that the channel sands of the Ellerslie Formation were deposited in the incised valley network. Since the net porous sand map and the sub-Cretaceous paleotopographic map were generated using data that are independent of each other (the former used gamma-ray and porosity logs and the latter unit-top picks) and by employing independent methodologies, the coincidence of the patterns in the two maps also suggests that the distribution of net porous sand of the Ellerslie Formation and the valley network constructed in the current report are mutually validated.

Figure 6 shows the subcrop geological map. It provides more detail and higher resolution than previously published subcrop maps (e.g. Hayes et al., 1994, Figure 19.3; Bachu et al., 2008, Figure 15). Among these results are the incised river valleys that flank the eastern margin of the Pembina Highlands in the northwest of the study area and that cut through the Banff Formation and down to the Wabamun Group. The subcrop geological map and distribution of net porous sand in the Ellerslie Formation provides new insights for assessing potential hydraulic communication between the Lower Mannville aquifer and aquifers of the underlying Jurassic to Upper Devonian succession.

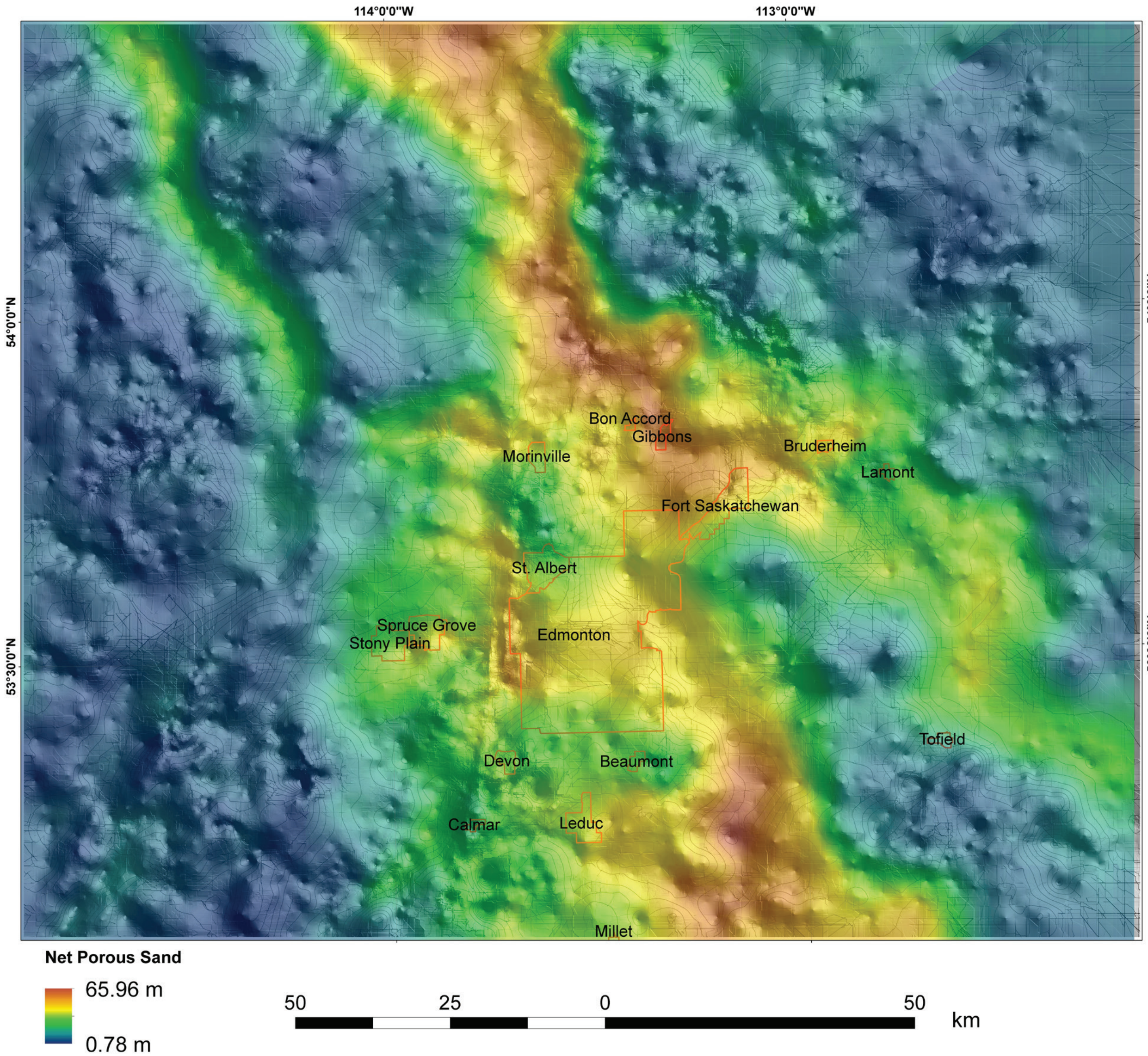

Figure 7. Net porous sand map of the Ellerslie Formation draped on the hill-shaded image of the sub-Cretaceous paleotopography in the study area.

6 References

Alberta Energy Regulator (2011): Bottom and surface hole integrity project (BSHIP) frequently asked questions (last updated: September 12, 2011); URL <http://www.aer.ca/data-and-publications/information-quality-program/bship-q-and-as> [February 2014].

AltaLIS (2014): ATS; URL <http://www.altalis.com/products/property/ats.html> [February 2014].

Bachu, S., Buschkuehle, B.E., Haug, K. and Michael, K. (2008): Subsurface characterization of the Edmonton-area acid-gas injection operations; Energy Resources Conservation Board, ERCB/AGS Special Report 092, 134 p.

Bokman, J. (1963): Post-Mississippian unconformity in the western Canadian basin; in Backbone of the Americas: tectonic history from pole to pole, O.E. Childs and B.W. Beebe (ed.), Tulsa, Oklahoma, American Association of Petroleum Geologists, Memoir 2, p. 252–263.¬

Cant, D.J. (1996): Sedimentological and sequence stratigraphic organization of a foreland clastic wedge, Mannville Group, Western Canada Basin; Journal of Sedimentary Research, v. 66, no. 6, p. 1137–1147.

Cant, D.J. and Abrahamson, B. (1996): Regional distribution and internal stratigraphy of the Lower Mannville; Bulletin of Canadian Petroleum Geology, v. 44, no. 3, p. 508–529.

Cruden, D.M. and Charlesworth, H.A.K. (1966): The Mississippian-Jurassic unconformity near Nordegg, Alberta; Bulletin of Canadian Petroleum Geology, v. 14, p. 266–272.

Halbertsma, H.L. (1994): Devonian Wabamun Group of the Western Canada Sedimentary Basin; in Geological atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, p. 203–220.

Hamilton, W.N., Langenberg, C.W., Price, M.C. and. Chao, D.K. comp. (1999): Geological Map of Alberta; Alberta Geological Survey, Alberta Energy and Utilities Board, map No. 236, scale 1:1 000 000. URL < http://www.ags.gov.ab.ca/publications/abstracts/MAP_236.html> [February 2014].

Hayes, B.J.R., Christopher, J.E., Rosenthal, L., Los, G., McKercher, B., Minken, D., Tremblay, Y.M. and Fennell, J. (1994): Cretaceous Mannville Group of the Western Canada Sedimentary Basin; in Geological atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, p. 317–334.

Jackson, P.C. (1984): Paleogeography of the Lower Cretaceous Mannville Group of Western Canada; in Elmworth: case study of a deep basin gas field, J.A. Masters (ed.), Tulsa, Oklahoma, American Association of Petroleum Geologists, Memoir 38, p. 49–78.

Kent, D.M. (1994): Paleogeographic evolution of the cratonic platform: Cambrian to Triassic; in Geological atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, p. 68–86.

Leckie, D.A. (2009): Geomorphology of the basinwide Sub-Cretaceous unconformity, Western Canada Foreland Basin. Frontiers & Innovation, 2009 CSPG CSEG CWLS convention abstract, May 4–8, 2009, Calgary, Alberta. p. 131, URL <http://geoconvention.org/archives/2009abstracts/022.pdf> [August 2014].

McLean, J.R. and Wall, J.H. (1981): The Early Cretaceous Moosebar Sea in Alberta; Bulletin of Canadian Petroleum Geology, v. 29, p. 334–377.

Mei, S. (2009): Geologist-controlled trend versus computer-controlled trend: introducing a high-resolution approach to subsurface structural mapping using well-log data, trend surface analysis, and geospatial analysis; Canadian Journal of Earth Sciences, v. 46, p. 309–329.

Pemberton, S.G. and James, D.P., ed. (1997): Petroleum geology of the Cretaceous Mannville Group, Western Canada; Canadian Society of Petroleum Geologists Memoir 18, 486 p.

Prior, G.J., Hathway, B., Glombick, P.M., Pana, D.I., Banks, C.J., Hay, D.C., Schneider, C.L., Grobe, M., Elgr, R. and Weiss, J.A. (2013): Bedrock Geology of Alberta; Alberta Energy Regulator, AER/Alberta Geological Survey Map 600. URL <http://www.ags.gov.ab.ca/publications/abstracts/MAP_600.html> [August 2014]

Porter, J.W., Price, R.A. and McCrossan, R.G. (1982): The Western Canada Sedimentary Basin; Philosophical Transactions of the Royal Society of London, v. A305, p. 169–182.

Richards, B.C. (1989): Upper Kaskaskia Sequence: uppermost Devonian and Lower Carboniferous; in Western Canada Sedimentary Basin: a case history, B.D. Ricketts (ed.), Canadian Society of Petroleum Geologists, p. 165–201.

Richards, B.C., Barclay, J.E., Bryan, D., Hartling, A., Henderson, C.M. and Hinds, R.C. (1994): Carboniferous strata of the Western Canada Sedimentary Basin; in Geological atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, p. 221–250.

Smith, D.G. (1994): Paleogeographic evolution of the Western Canada Foreland Basin; in Geological atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, p. 277–296.

Tinker, S.W. (1996): Building the 3-D jigsaw puzzle: applications of sequence stratigraphy to 3-D reservoir characterization, Permian Basin; American Association of Petroleum Geologists Bulletin, v. 80, no. 4, p. 460–485.

Wright, G., McMechan, M. and Potter, D. (1994): Structure and architecture of the Western Canada Sedimentary Basin; in Geological atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and the Alberta Research Council, p. 25–40.