

## Salty Stratigraphy: Salt Caverns in the Elk Point Group of Alberta

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### Introduction

The Middle Devonian Elk Point Basin is host to one of the Earth's most extensive ancient evaporite deposits (Warren, 2006). The areal extent of the Elk Point Basin within western Canada is estimated at 1.2 million km<sup>2</sup>, with at least 500 000 km<sup>2</sup> of halite-bearing strata (Zharkov, 1988). Based on current mapping, halite volume is 33 200 km<sup>3</sup> in the Alberta portion of the Elk Point Basin (Hauck, 2020a). Salt deposits within the Alberta have been the target of solution mining since 1947, when a solution-mined cavern was constructed near the hamlet of Lindbergh northeast of Edmonton. There are currently more than 150 active salt caverns within the province, many used for hydrocarbon storage, and some for effluent and solids disposal (Figure 1). All current caverns have been constructed within the upper Lotsberg Formation and the Prairie Evaporite Formation, with ~80% of caverns within the Lotsberg. This paper will focus on the upper Lotsberg and Prairie Evaporite formations (Figure 2). As the demand for storage and disposal options within the province increases, salt caverns in the Elk Point group may continue to play a role.

Recently, lithostratigraphic units within the Elk Point Group have been mapped at the provincial scale from over 4600 wells comprising 24 700 individual stratigraphic picks (Hauck, 2020a). These picks provided the framework for a detailed assessment of evaporite strata within the Lotsberg and Prairie Evaporite formations. The evaporite minerals halite, anhydrite, and gypsum were mapped at the bed scale in over 740 wells, comprising 23 600 intervals describing the top and base of individual evaporite beds (Hauck, 2020b). These data provide a robust picture of the distribution and net thickness of evaporite strata within Alberta. Additionally, the bed-scale mapping of salt and anhydrite allows for an assessment of the degree of non-salt heterogeneities. These non-salt beds, especially dolomite and shales, can pose a challenge to the construction of salt caverns, as they can affect cavern washing (time) and ultimately alter the morphology of the cavern. Purity of the salt deposit can similarly affect washing times, which differs within Elk Point Group evaporite strata.

In this contribution, we will present the results of province-wide mapping of the upper Lotsberg and Prairie Evaporite formations and salt deposits therein, providing an updated paleogeographic picture of these strata. Non-salt heterogeneities will be discussed as they pertain to the construction of salt caverns within these two salt deposits.

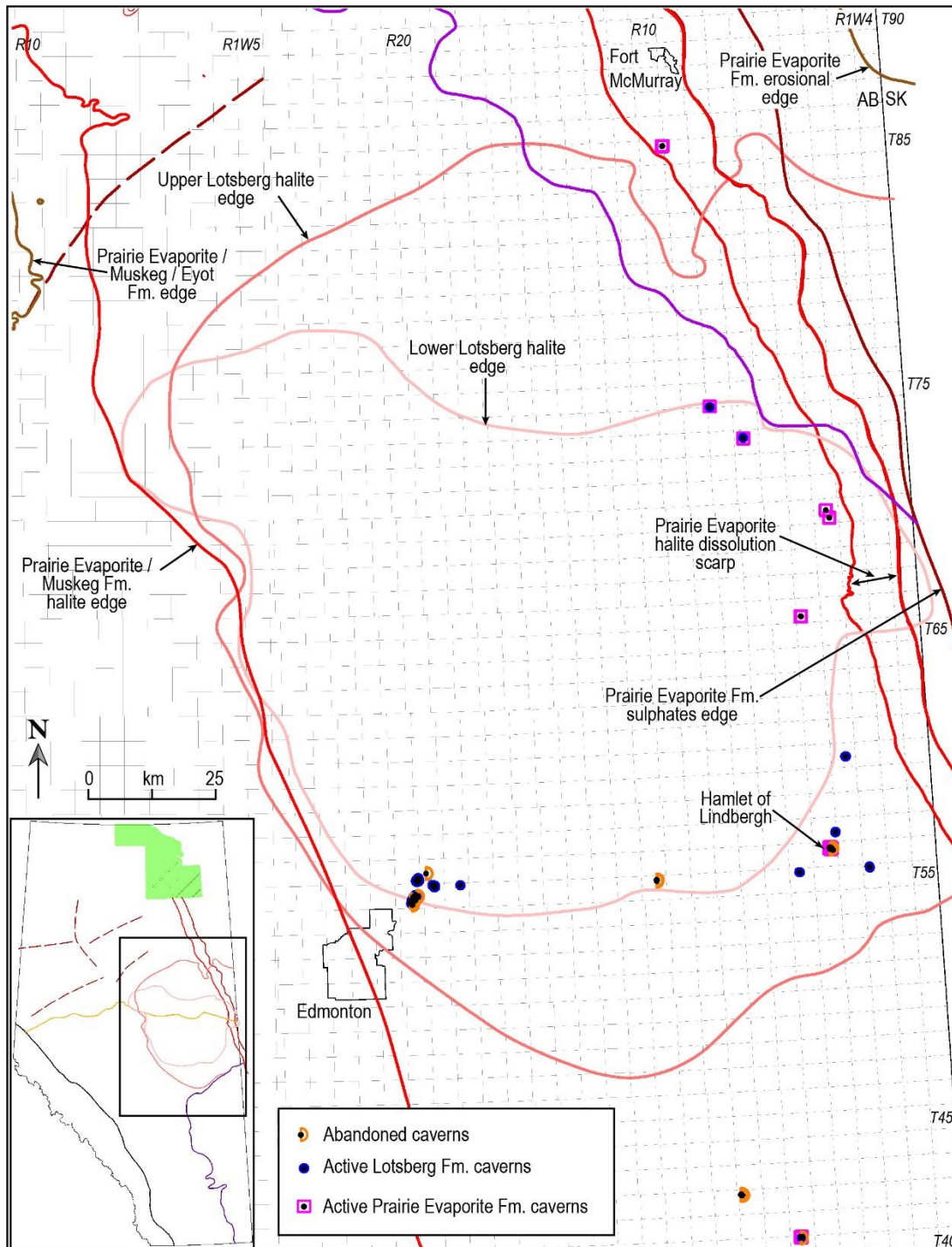


Figure 1. Location of salt caverns in Alberta. Edges of Elk Point Group salt deposits are shown. The purple line is the edge of the La Crete sub-basin—a Keg River paleogeographic element (see Figure 5).

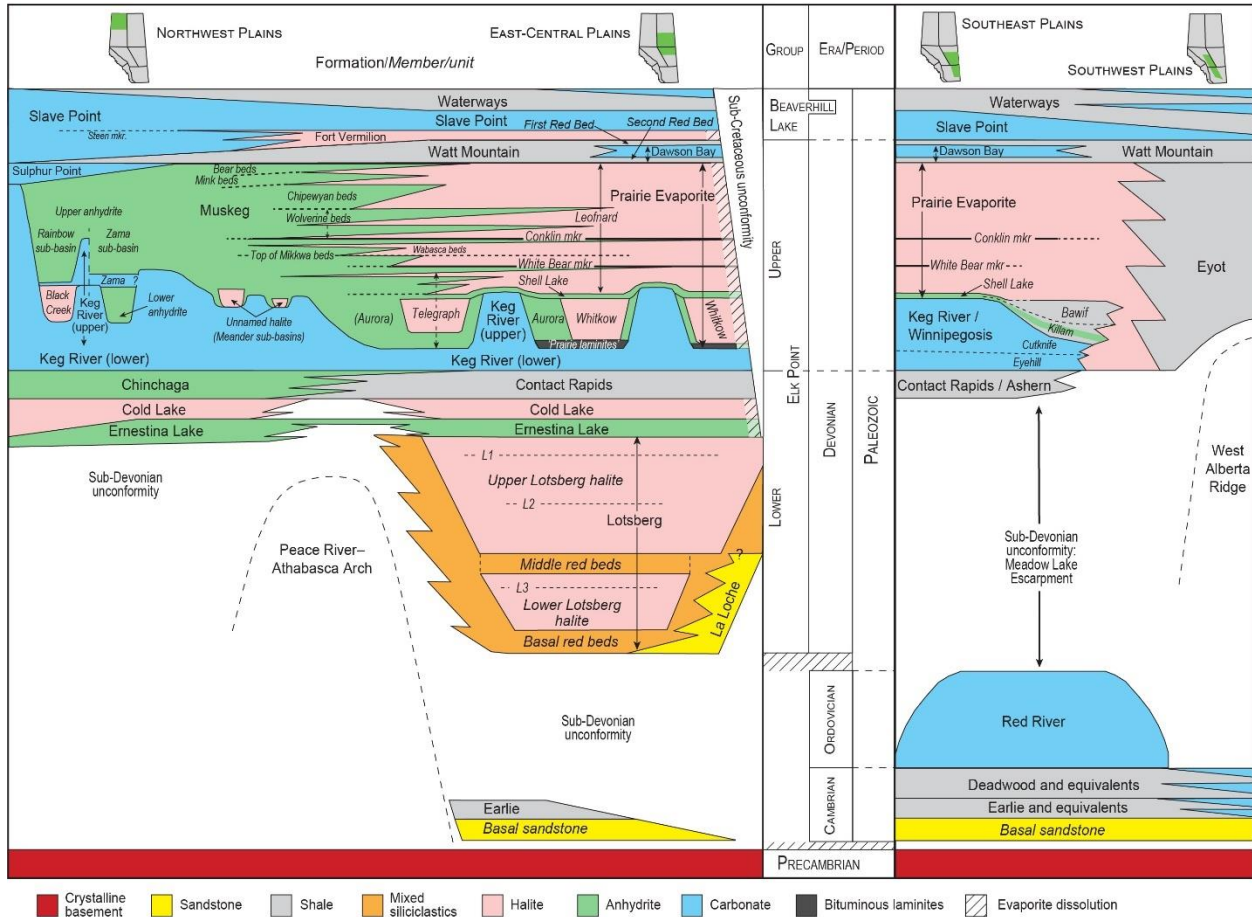


Figure 2. Stratigraphic correlation chart of Elk Point Group strata and adjacent units in the Alberta Basin. Strata with current caverns include the upper Lotsberg halite, and the Leofnard Member of the Prairie Evaporite Formation. Within the Lotsberg Formation, marker beds L1–L3 represent mappable ‘discontinuities’ within the halite succession. Abbreviation: mkr., marker bed.

## Methods

The presence and abundance of three evaporite minerals, halite, anhydrite, and gypsum, were assessed with a net-evaporite methodology using raster wireline logs in Petra. In areas where modern well log suites were not available, additional data for halite and anhydrite, derived from the interpretation of electric well logs supplemented with observations from core and drill cuttings, were used. These data were transcribed from archival field notes taken by W.N. Hamilton and coworkers for the study of Elk Point Group salt deposits in east-central Alberta (Hamilton, 1971).

Based on the petrophysical properties of evaporite minerals, a top and base for individual beds of the respective minerals were picked on raster logs. Halite, anhydrite, and gypsum all have distinct petrophysical properties when compared with each other and with the carbonate and

siliciclastic rocks they are associated with (see Hauck, 2020a). Gypsum is only present in a very limited area east of the Prairie Evaporite halite dissolution scarp (Hauck, 2020a). Additionally, potassium-bearing potash salts do not form a significant component of the evaporite succession in Alberta (Holter, 1969), with the exception of the Prairie Evaporite Formation in southeastern Alberta (Eccles et al., 2009; Lopez et al., 2020). As such, over most of the areal extent of Elk Point Group evaporites, the successions have a basic tripartite division of mineralogies/lithologies: halite, anhydrite, and 'insolubles'—the latter comprising carbonate and shale. Cumulative thickness of individual beds of halite, anhydrite, and gypsum were contoured in Petra.

### **Halite Distribution and Heterogeneities: Upper Lotsberg Salt**

The upper Lotsberg salt is found within a bowl-shaped depression known as the Central Alberta sub-basin (CAS) (Figure 3), which is one of two main depocentres that formed on the highly eroded sub-Devonian unconformity (Figure 1). The southern boundary of the CAS is bordered by a deeply eroded Ordo-Cambrian succession at the Meadow Lake Escarpment (Figure 3). The northern boundary coincides with the Athabasca Arch—the eastern extension of the Peace River Arch.

Cumulative thickness of salt within the upper Lotsberg reaches a maximum of 165 m close to the Alberta Saskatchewan border (Figure 3). Salt thickness decreases gradually toward the margins of the bowl-shaped CAS. The minimum and maximum halite bed thickness (133 wells) was measured as 1.6 m and 82.4 m (106.1 m in a local anomaly; see Hauck et al., 2018), respectively.

Salt within the upper Lotsberg is a relatively pure, high quality, translucent variety, with no observed anhydrite interbeds. Non-halite interbeds comprising vari-coloured shales and dolostone occur throughout the succession but tend to be more common near the margins of the CAS, and at the base of the unit (Figure 4). Correlation of non-salt interbeds is difficult, however, two such discontinuities were correlated across the central part of the CAS within the upper Lotsberg—the L1 and L2 (Figure 4). A lack of correlatable discontinuities may speak to the persistence of dissolution (freshening events) and reprecipitation functioning during deposition of the Lotsberg Formation.

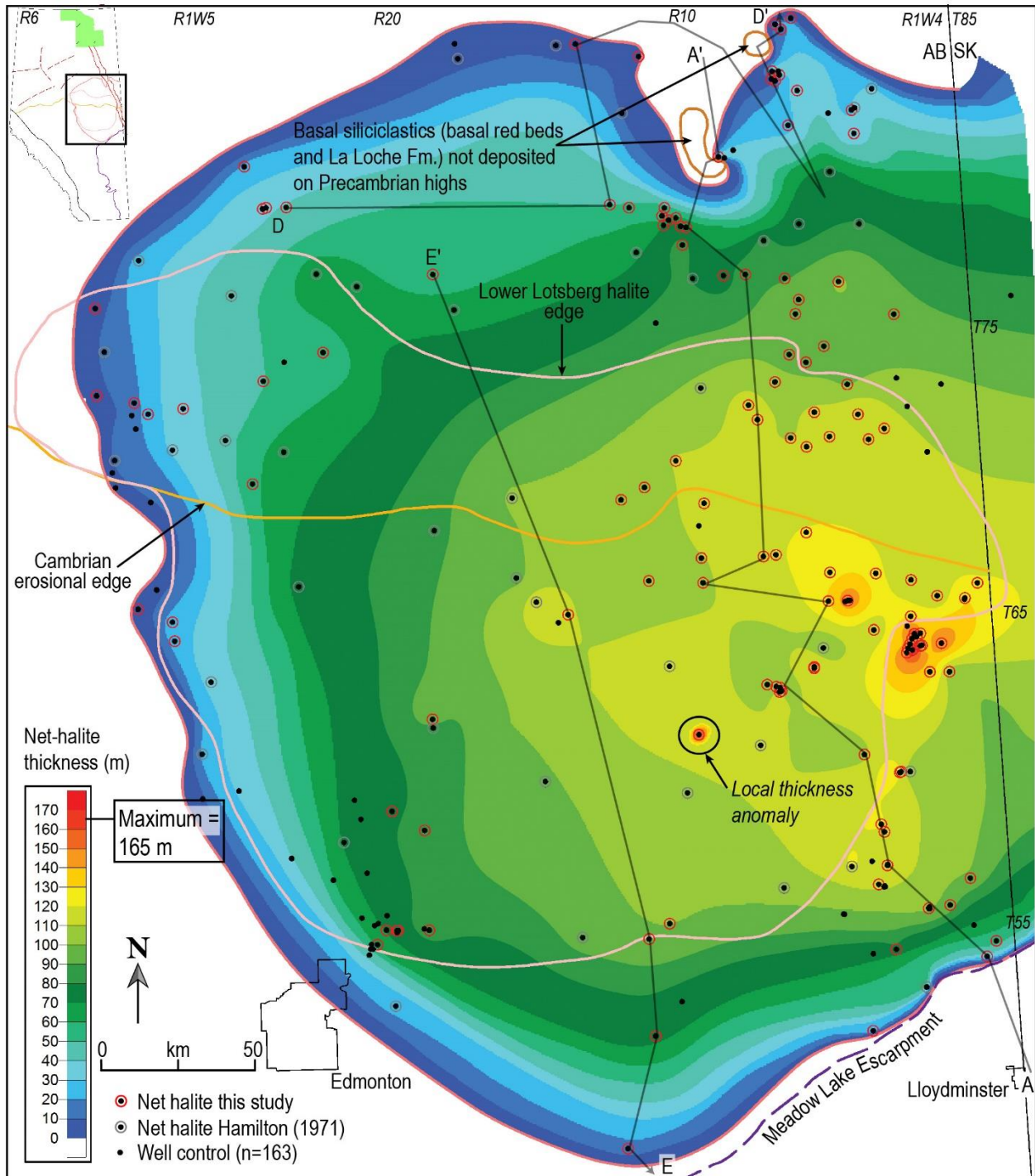


Figure 3. Cumulative halite thickness in the upper Lotsberg halite in the central Alberta sub-basin, east-central Alberta. Location of A-A' cross-section in Figure 3 is shown.

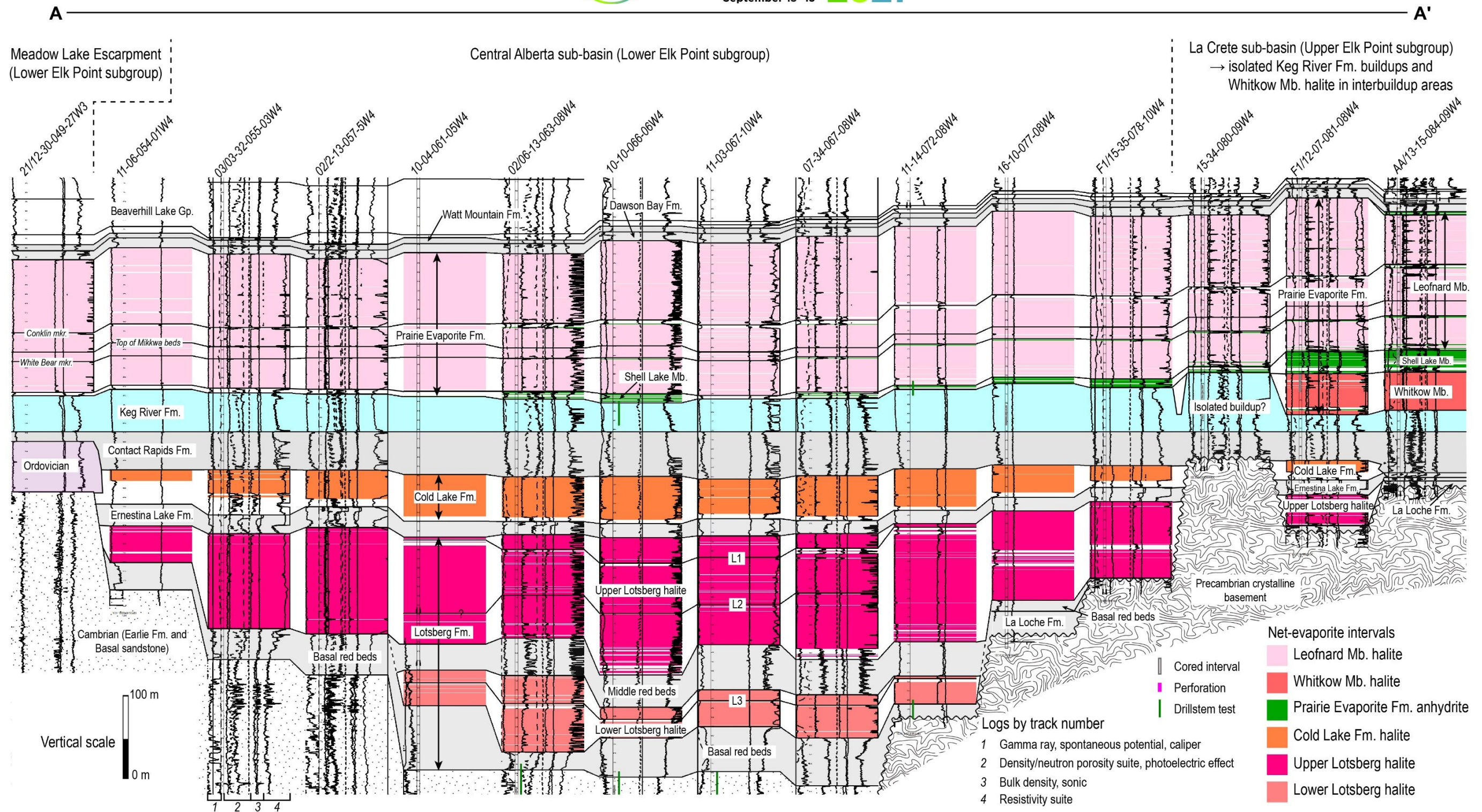


Figure 4. Stratigraphic cross-section A–A'. The cross-section runs north–south across the central Alberta sub-basin in east-central Alberta. Net-evaporite intervals are colour-coded according to the legend. The Keg River Formation is highlighted in light blue. The remaining Elk Point Group nonevaporite strata are coloured light grey. Abbreviation: mkr., marker bed.

## **Halite Distribution and Heterogeneities: Prairie Evaporite Formation**

The distribution of salt within the Prairie Evaporite Formation is controlled by two main factors: 1) location relative to the open-ocean connection to the northwest at the Presqu'île Barrier— anhydrite borders the barrier and gradually transitions southeastward into salt-dominant strata, and 2) the underlying paleogeography of the Keg River formation carbonate buildups, with the La Crete sub-basin playing a major role in the distribution and thickness of the overlying Prairie Evaporite salt deposits. Prairie Evaporite salt forms in a linear fairway trending NW-SE, with its eastern edge coinciding with the Prairie Evaporite halite dissolution scarp (Figure 5). The northern edge is the gradual transition to anhydrite-dominant strata of the Muskeg Formation (see Figure 2). The western edge of the salt records a gradual facies change to clastics shed from the Peace River arch, and to the south, clastics of the Eyot Formation as it approaches the West Alberta Ridge (figures 2 and 5).

The thickest salt deposits are found within the La Crete sub-basin—a paleogeographic element of the underlying Keg River Formation where upper Keg River differentiated into a series of isolated buildups of varying dimensions, surrounded by interbuildup basins (figures 5 and 6). The interbuildup basins saw the initial accumulation of the Whitkow Member salt and the Aurora Member anhydrite (figures 2, 5 and 6), which are overlain by the laterally continuous salt of the Leofnard Member (figures 2 and 6). Cumulative thickness of salt reaches 213 m within the La Crete sub-basin south of Fort McMurray (Figure 5). Minimum and maximum individual salt-bed thickness is 1.4 m and 93 m, respectively.

Salt within the Prairie Evaporite, especially the Leofnard Member where current caverns are placed, is typically rich with impurities (i.e., “dirty salt”). Within the Leofnard Member, north of Township 80, non-salt interbeds become increasingly common, comprising anhydrite, dolomite, and shale, and record the gradual transition to the anhydrite-dominant Muskeg Formation. A number of these interbeds have been correlated over large areas of the province, such as the Conklin marker bed (Figure 6). Marker beds like the Conklin record significant pauses in evaporitic drawdown within the Elk Point Basin (freshening events).

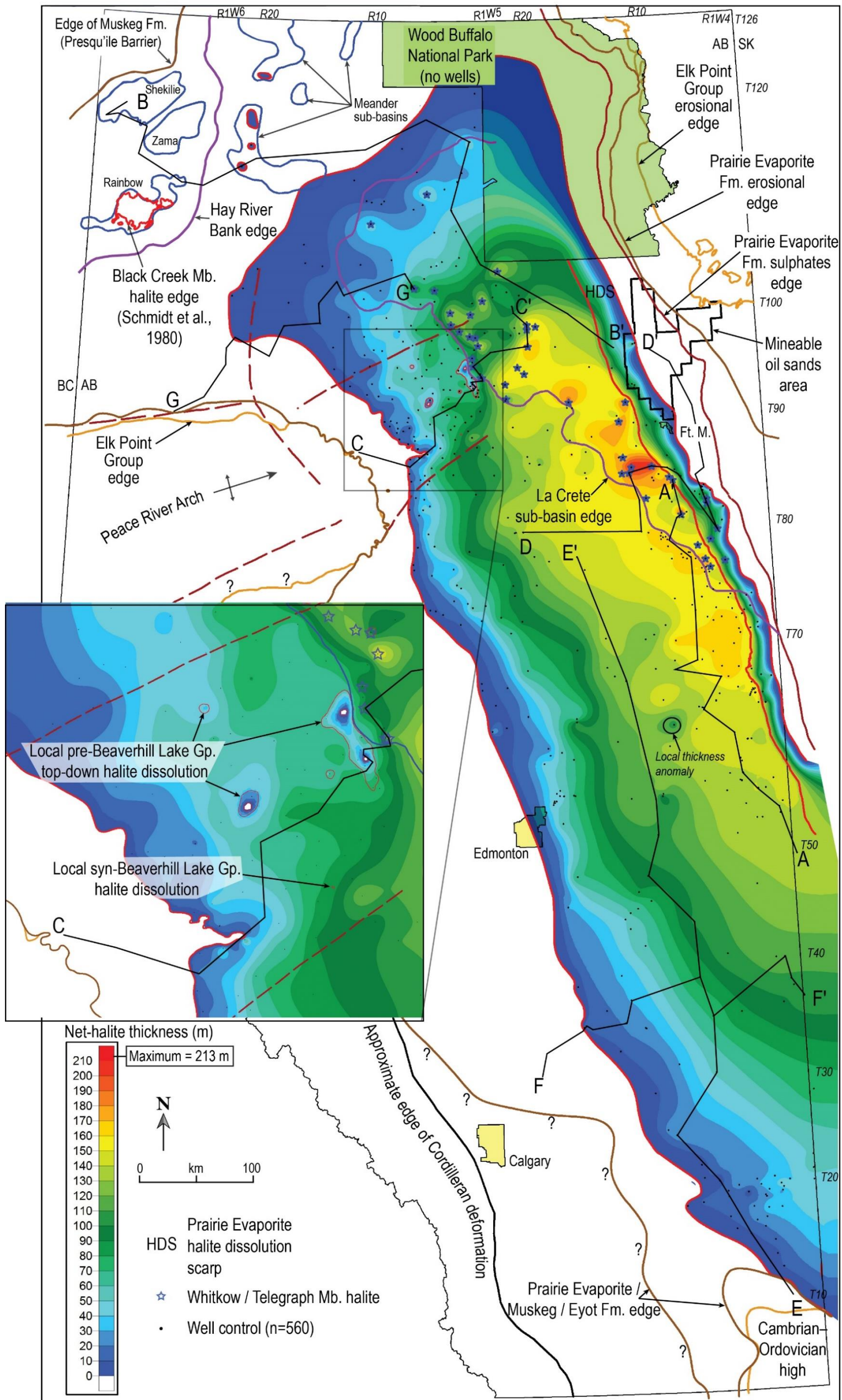


Figure 5. Cumulative salt thickness in the Prairie Evaporite and Muskeg formations, Alberta. The location of cross-section A-A' is shown. The Shekille, Zama and Rainbow sub-basins on the Hay River Bank are from Davies and Smith (2006). Red long-dash lines outline the Peace River Arch (from O'Connell, 1994). Abbreviation: Ft. M., Fort McMurray. To view the other labelled cross-sections and a discussion thereof, see Hauck (2020).

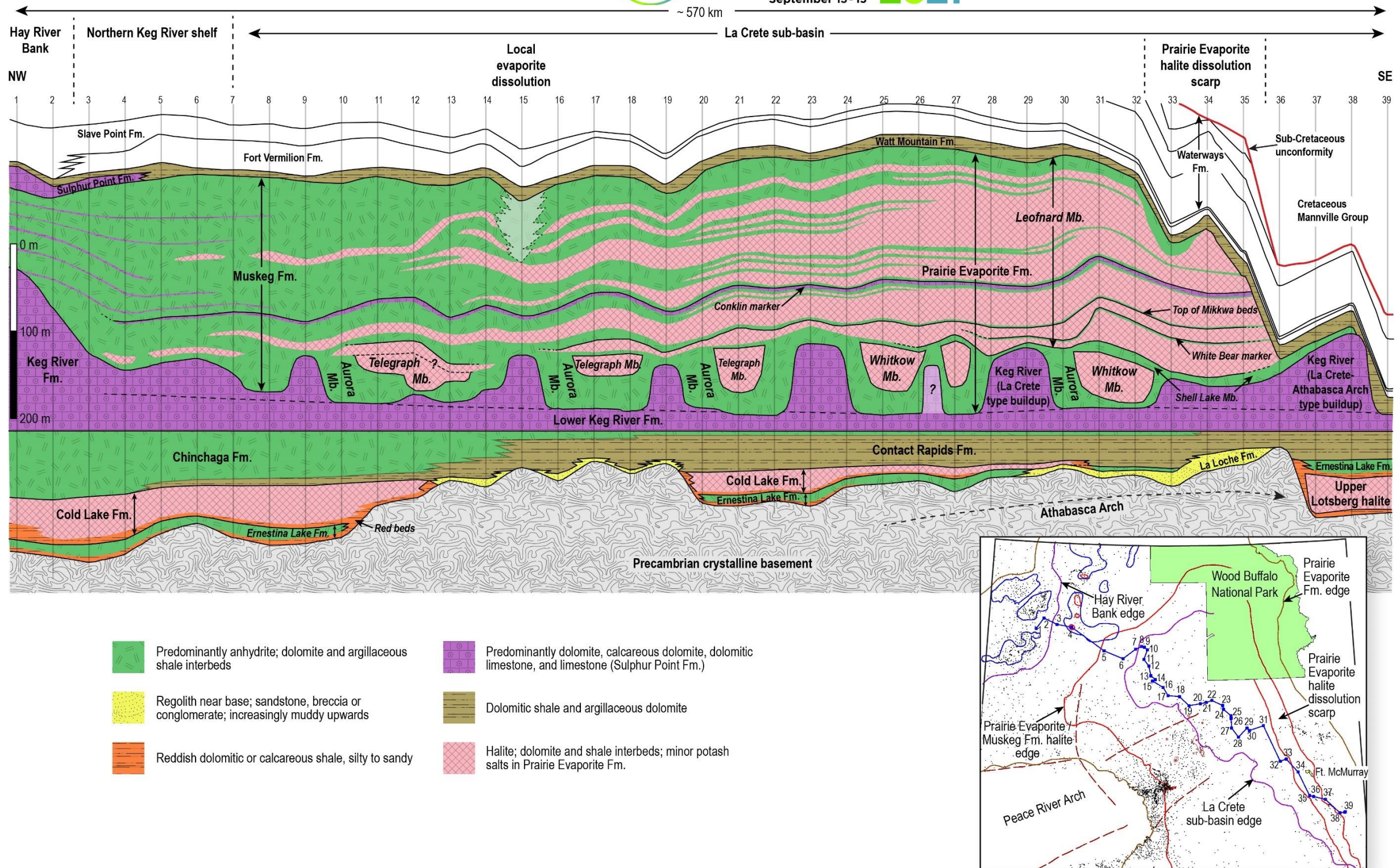


Figure 6. Stratigraphic cross-section in northern Alberta running from the Hay River Bank in the northwest, through the La Crete sub-basin to the Prairie Evaporite halite dissolution scarp in the southeast. The depiction of halite and anhydrite intervals above the Shell Lake, Whitkow and Telegraph members is schematic but based on net-evaporite data. Abbreviations: Ft. Fort; NW, northwest; SE, southeast.

## Existing Salt Caverns and Implications for New Caverns

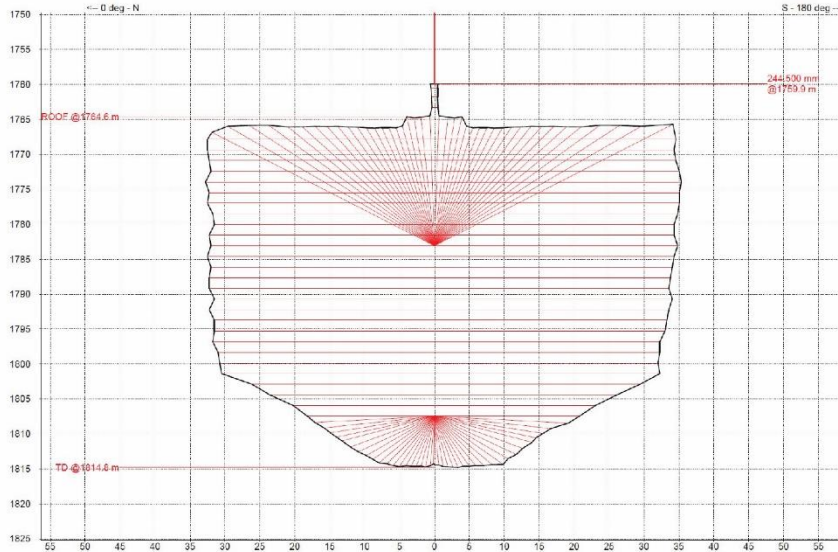
The salt deposits of the upper Lotsberg and Prairie Evaporite formations differ in degree of impurities (dirty vs. clean), and in the degree of non-salt interbedding. The upper Lotsberg tends to be relatively clean, with fewer non-salt interbeds. This results in contrasting cavern-washing effectiveness (brineability) and resulting cavern geometry (Figure 7). Cavern geometries in the upper Lotsberg salt have smooth margins, as the relative lack of non-salt interbeds leads to less bleed-off of the cavern washing fluids. Cavern geometries within the Leofnard Member of the Prairie Evaporite Formation tend to be more complex, owing to bleed-off of cavern washing fluids into non-salt interbeds (Figure 7).

The prevalence of non-salt interbeds in the Prairie Evaporite Formation means that, in addition to overall salt thickness, the consideration of cavern placement is more important for this unit. As mentioned, the degree of non-salt interbeds increases towards the margins of the main salt fairway (Figure 5). Placing salt caverns close to the margins of the succession will have consequences for cavern construction and resulting cavern geometry.

Salt of the Lotsberg is purer, making it a more brineable (soluble) salt during cavern washing, decreasing cavern washing times compared to the Prairie Evaporite. However, the greater thickness of the Prairie Evaporite means that larger caverns can be constructed (e.g., Figure 7). However, material comprising the non-salt interbeds will accumulate on the cavern floor, thereby reducing slightly the cavern volume. Cavern washing times also depend on the salinity of the washing fluid, with increasing TDS of the washing fluids resulting in slower wash times. Cavern washing operations may use non-potable water from the subsurface, which will increase the duration of cavern construction.

Although dependant on salinity of the washing fluid and purity of the salt, estimates are 6–7 m<sup>3</sup> of water for dissolving 1 m<sup>3</sup> of salt. Expect 50–75 m<sup>3</sup>/hour as a wash rate, which is a balance between the residence time for water dissolving the salt, and higher pump rates to minimize the time to wash the cavern. A good balance allows for sufficient residence time to dissolve more salt and therefore is a more efficient use of the washing fluid. Given these factors, estimates for cavern washing time are as follows: 1) for a 200 000 m<sup>3</sup> cavern, expect ~2.5 years for construction, and 2) for a 125 000 m<sup>3</sup> cavern, expect ~1.5 years for construction.

### Upper Lotsberg Cavern Geometry



### Prairie Evaporite Cavern Geometry

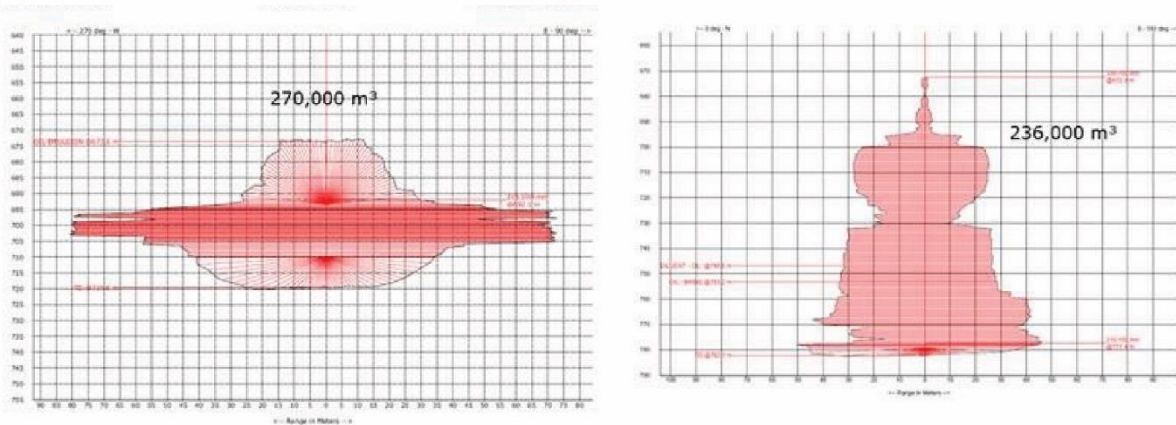


Figure 7. Examples of cavern geometries from the upper Lotsberg and Prairie Evaporite (Leonard Member) formations. Volume for the Lotsberg cavern is 142 413 m<sup>3</sup>.

### Summary

Regional lithostratigraphic mapping of the Elk Point Group in Alberta provides insight on the distribution, thickness, and non-salt interbedding of salt bearing successions. In particular, the mapping of non-salt beds provides a detailed picture of heterogeneities that have an effect on

cavern construction and resulting geometries. Areas of known salt dissolution, such as the Prairie Evaporite halite dissolution scarp should be avoided for Prairie Evaporite caverns.

There are currently more than 150 active caverns within the upper Lotsberg Formation and Leofnard Member of the Prairie Evaporite Formation. The greatest potential for new caverns exists within the Central Alberta sub-basin, which contains the relatively pure salt of the upper Lotsberg, but is also coincident with the area of the Prairie Evaporite with the fewest non-salt interbeds and thickest cumulative salt.

## Acknowledgements

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