Paleozoic Stratigraphic Framework beneath the Muskeg River Mine (Twp 95, Rge 9-10W4): Controls and Constraints on Present Day Hydrogeology

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The work presented here is part of the Devonian Geoscience Program (DGP), a program initiated by Shell Canada Energy in the area of the Muskeg River Mine (MRM), northeastern Alberta. The Program objectives are to proactively identify and characterize hydraulic pathways in Devonian strata that lie beneath the bitumen-bearing McMurray Formation. This includes review of all existing data, an active drilling program and geophysics to refine the understanding of the Devonian stratigraphy in the study area. Agreements have been established with oil sands operating companies to share data on regional aquifer flows and the geology of the Devonian strata underlying the oil sands deposits. Coordination now exists amongst operating companies to expand and develop the knowledge of regional subsurface conditions in this area.

This study deals with the Middle to Upper Devonian section that underlies the Muskeg River Mine, located on the eastern edge of the Western Canada Sedimentary Basin (Figure 1). It is a stratigraphic succession that has been the subject of little published geologic information. Evolution of the stratigraphic terminology has suffered due to a combination of early outcrop and later subsurface studies that evolved in widely separated geographic areas (Figure 2).

In this presentation, the focus will be on the Keg River (Winnipegosis) - Prairie Evaporite interval and overlying strata of the Watt Mountain Formation and Beaverhill Lake Group (Figure 2).

One of the most dramatic subsurface stratigraphic features in this general area is the pronounced stratigraphic thinning and resultant scarp associated with the Prairie Evaporite dissolution edge, which occurs just west of the present day Athabasca River Valley (Figures 1 and 3). A consequence primarily of halite dissolution, the thinning resulted from the influx of freshwater downdip and laterally from the basin margin as the pre-Cretaceous unconformity downcut.

The Prairie Evaporite section to the west of the dissolution edge comprises some 250 metres of interbedded anhydrite, dolomite and halite arrayed in highly correlatable layers (Figure 4). East of the dissolution edge there is a rapid decrease in thickness of the Prairie Evaporite section to around 60 metres, primarily through the removal of highly soluble halite and to a lesser extent other evaporitic components.

This basin margin dissolution event in large part predates the formation of the pre-Cretaceous unconformity in this area and overlying Beaverhill Lake Group strata (Slave Point and Waterways) show a pronounced dip reversal from southwest to northeast across this scarp (Figure 3). Consequently, the thinned Prairie Evaporite section to the east of the present day Athabasca River Valley can be viewed as the result of dissolution removal of a significant thickness of soluble halite accompanied by the collapse and accumulation of the less soluble dolomite and anhydrite interbeds.

It was recognized previously that the Keg River - Prairie Evaporite (often collectively referred to as the 'Methy', now a largely abandoned term) in the Oil Sands area constituted the primary Devonian aquifer in stark contrast to the full succession to the west, which acted primarily as an aquaclude. In late 2010, Shell undertook a drilling program to better understand this underlying aquifer system in the vicinity of their operating Muskeg River Mine (Twp 95, Rge 10W4) (Figure 1).

The Keg River (Winnipegosis) constitutes a widespread dolomitized deep water ramp (Lower Keg River) with more locally developed thick (up to 70 metres) pinnacle reefs and banks (Upper Keg River). This represents the open marine portion of the Elk Point Group depositional cycle (Figure 2). Prairie Evaporite sedimentation was initiated by the progressive restriction of marine waters into the basin, leading to evaporative drawdown and sedimentation of progressively more evaporative minerals, as so called basin centre evaporites.

Initially the degree of evaporation led to precipitation on the basin floor of laminated micritic dolomites, interbedded and interlaminated with anhydrite in small scale 'brining-upward' cycles. Where these sit directly on the Keg River ramp, the contact is sharp but observable only in core, where precipitated laminated dolomites overlie burrow nodular open marine dolomites. This led to the practice in uncored wells of including the basal Prairie dolomites into the Keg River (often grouped as 'Methy') with the Prairie Evaporite instead being picked at the base of the first thick anhydrite bed.

In the present study, the lower horizontally bedded dolomite-anhydrite section is referred to here as the 'intact' Prairie Evaporite. It is widely correlatable and onlaps the low flanks of the thicker Keg River buildups. Above this, the Prairie Evaporite is a chaotic mixture of brecciated and laminated dolomudstones, along with contorted and nodular anhydrites with a significant content of shaly beds, laminae and partitions. This unit varies widely in thickness and contains few widely correlatable levels. In this study, this section is referred to as the 'collapsed' Prairie Evaporite. Wells drilled into this section in the 1970's reported lost circulation and drilling string "drops" on the order of "several feet", leading to the conclusion that some portion of this unit had taken on the properties of an aquifer. Recovered water salinities measured from 40,000ppm to 70,000ppm TDS (NaCl) suggesting the ongoing interaction of freshwater with remnant halite in the section.

The Shell drilling program focused in part on recovering core from these discrete aquifer intervals. Encountered in five of the six wells (two with lost circulation), they were found to comprise laminated carbonate interbeds in various stages of dedolomitization and solution collapse (Figure 5). Furthermore, Devonian monitoring wells in the more regional area suggested that these levels constituted a connected aquifer system over a scale of 10's of kilometres.

In core, the balance of the Prairie Evaporite collapsed section was also observed to contain significant amounts of shale and in some cases sandstone, in stark contrast to the intact section to the west. Shales were sampled for palynological analysis, which revealed a significant content of Cretaceous-aged bisaccate pollen in four of the five wells. The pervasive nature of the shale within the largely anhydritic Prairie Evaporite collapse leads to the conclusion that during Cretaceous time it constituted an open system of cavities on various scales that were subjected to the influx of freshwater carrying Cretaceous pollen.

Overlying the Prairie Evaporite collapse in this area are strata of the Watt Mountain, Fort Vermilion, Slave Point and Firebag Member of the Waterways Formation (Figures 2 and 5). In core, the pre-Cretaceous unconformity was observed to be a sharp largely unaltered surface developed on the Firebag Member shales. Locally, the unconformity surface exhibited up to 60 metres of relief, which under normal circumstances would be thought to be the result, at least in part, of erosional downcutting. However, the topography of the unconformity surface was found to be paralleled by the underlying strata (Firebag log markers, Slave Point and Watt Mountain), leading to the conclusion that this topography represented a later stage of collapse (post-unconformity) (Figure 5). The areal distribution of the Lower McMurray sands corresponds closely to these ‘collapsed’ areas, where it was preserved from a later episode of erosion. It is thought possible that the open cavities that existed in the Prairie Evaporite may have undergone collapse in response to sediment loading of the Lower McMurray and leading to the conformable geometry of the unconformity and underlying stratigraphic units. The multiple stages of differential collapse that the Prairie Evaporite appears to have undergone in this area are thought to have resulted in the establishment of vertical pathways that connect the previously described Prairie Evaporite aquifer system up to the unconformity surface.

The Prairie Evaporite section in this part of the northeast Alberta has undergone several stages of dissolution collapse by fluids percolating from the exposed basin margin. This has continued to the present day resulting in the development of an aquifer system interconnected to varying extents over tens of kilometres on the eastern side of the present day Athabasca River Valley. The overlying stratigraphic section has been lowered 'in-situ' by hundreds of metres and, depending on the timing of each event, could result in the creation of vertical pathways up to the unconformity surface. Further work continues to map the nature and extent of this aquifer system and potential vertical pathways to fluid movement.

References

Meijer Drees, N.C., 1994. Devonian Elk Point Group of the Western Canada Sedimentary Basin. In: Geological Atlas of the Western Canada Sedimentary Basin. G.D. Mossop and I. Shetsen (*compilers*). Calgary, Canadian Society of Petroleum Geologists and Alberta Research Council, p. 129-147.

Wright, G.N.(ed), 1984. The Western Canada Sedimentary Basin, a series of geological sections illustrating basin stratigraphy and structure. Canadian Society of Petroleum Geologists and the Geological Association of Canada.

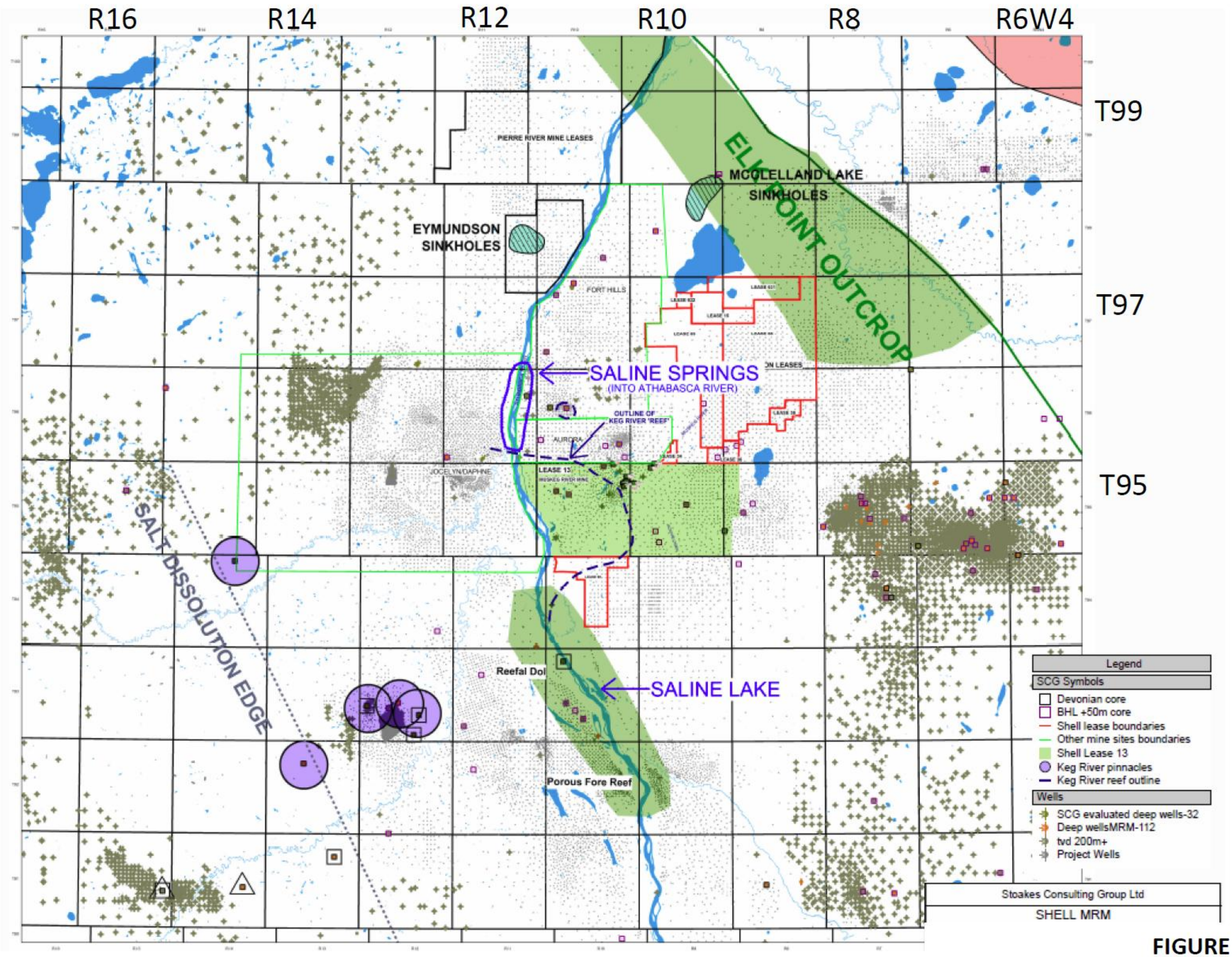
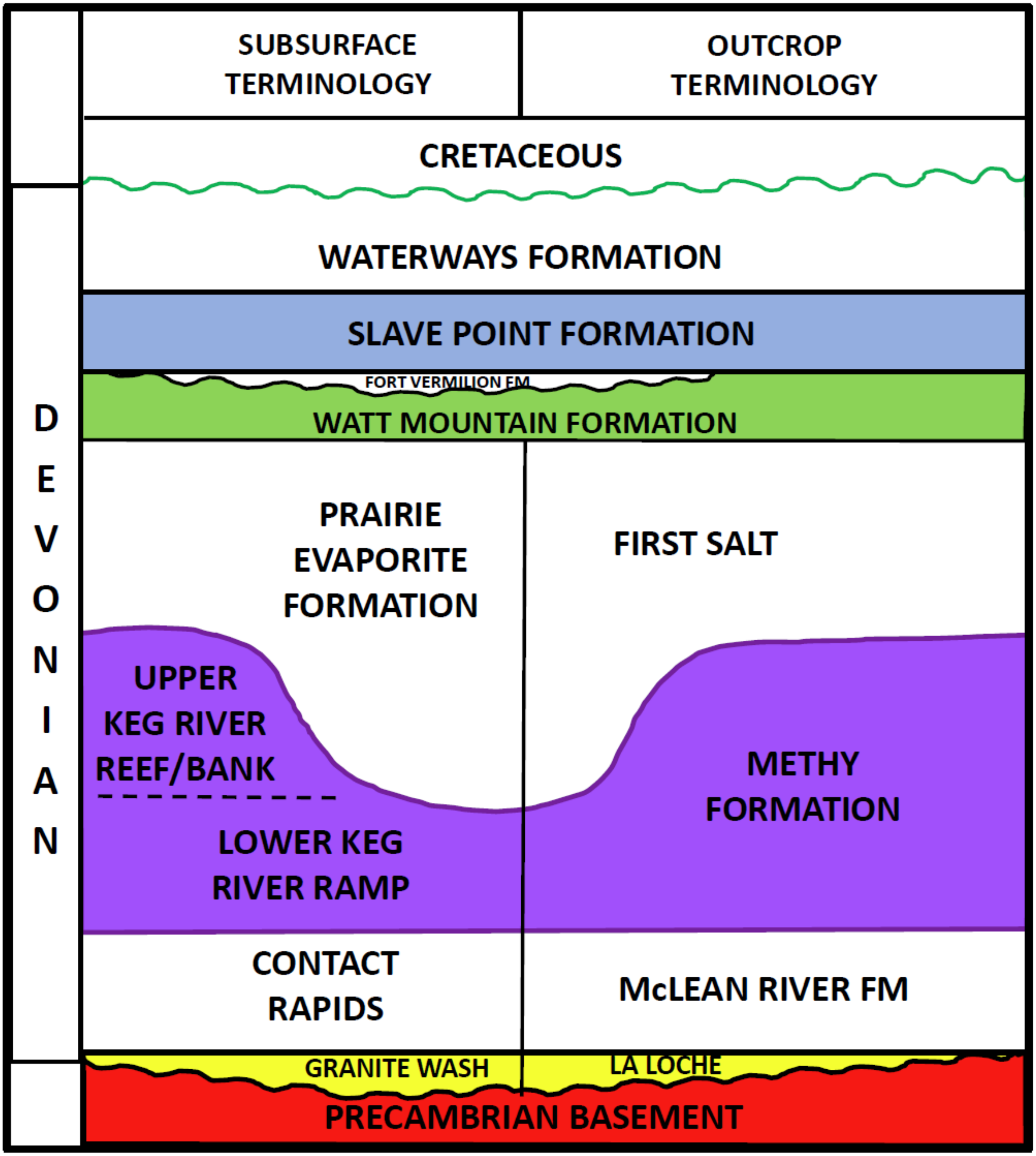
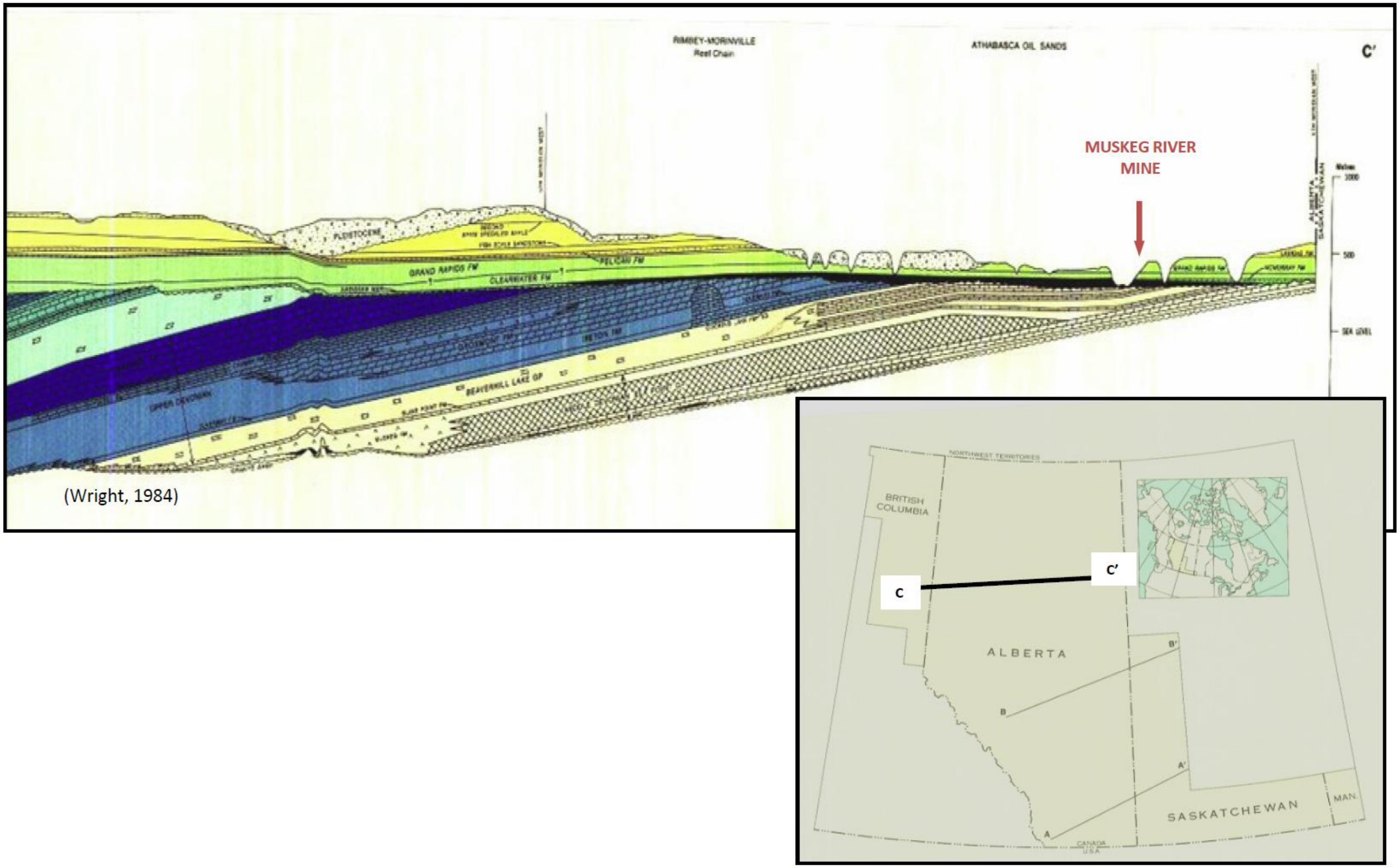

R16
R14
R12
R10
R8
R6W4
T99
T97
T95
PIERRE RIVER MINE LEASES
MCCLELLAND LAKE
SINKHOLES
ELK POINT OUTCROP
EYMUNDSON
SINKHOLES
FORT HILLS
SALINE SPRINGS
(INTO ATHABASCA RIVER)
OUTLINE OF
KEG RIVER 'REEF'
AURORA
JOCELYN/DAPHNE
LEASE 13
SALT DISSOLUTION EDGE
Reefal Dol
SALINE LAKE
Porous Fore Reef
Legend
SCG Symbols
Devonian core
BHL +50m core
Shell lease boundaries
Other mine sites boundaries
Shell Lease 13
Keg River pinnacles
Keg River reef outline
Wells
SCG evaluated deep wells-32
Deep wellsMRM-112
tvd 200m+
Project Wells
Stoakes Consulting Group Ltd
SHELL MRM

FIGURE 1



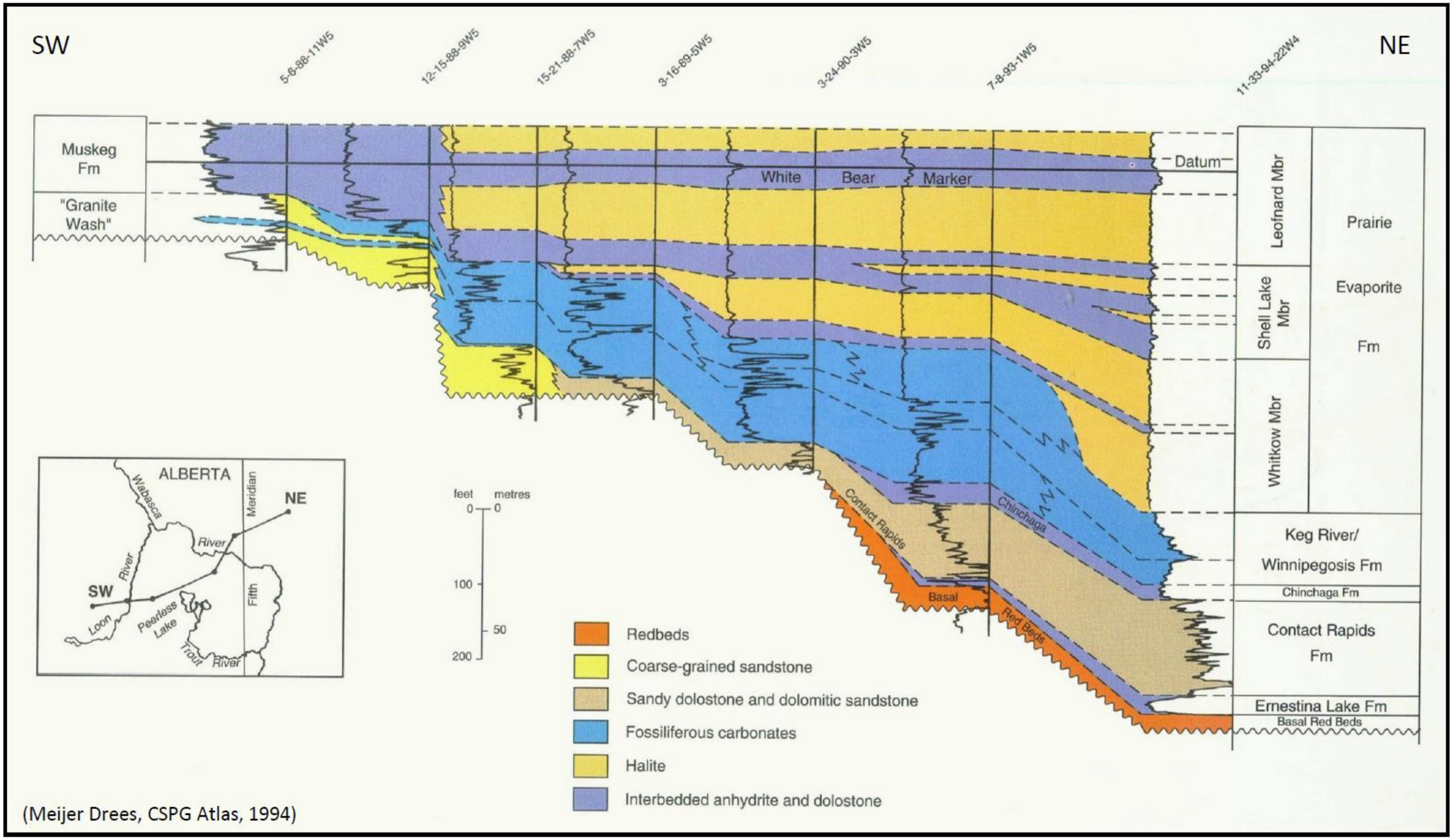
PALEOZOIC STRATIGRAPHY OF THE STUDY AREA SHOWING SUBSURFACE AND OUTCROP TERMINOLOGY

FIGURE 2



WEST – EAST REGIONAL GEOLOGICAL CROSS SECTION

FIGURE 3



(Meijer Drees, CSPG Atlas, 1994)

STRATIGRAPHIC CROSS SECTION OF THE KEG RIVER FORMATION, RED EARTH REGION, CENTRAL ALBERTA

FIGURE 4

SHELL MUSKEG RIVER MINE STRATIGRAPHIC CROSS SECTION SHOWING PHASE I DRILLING

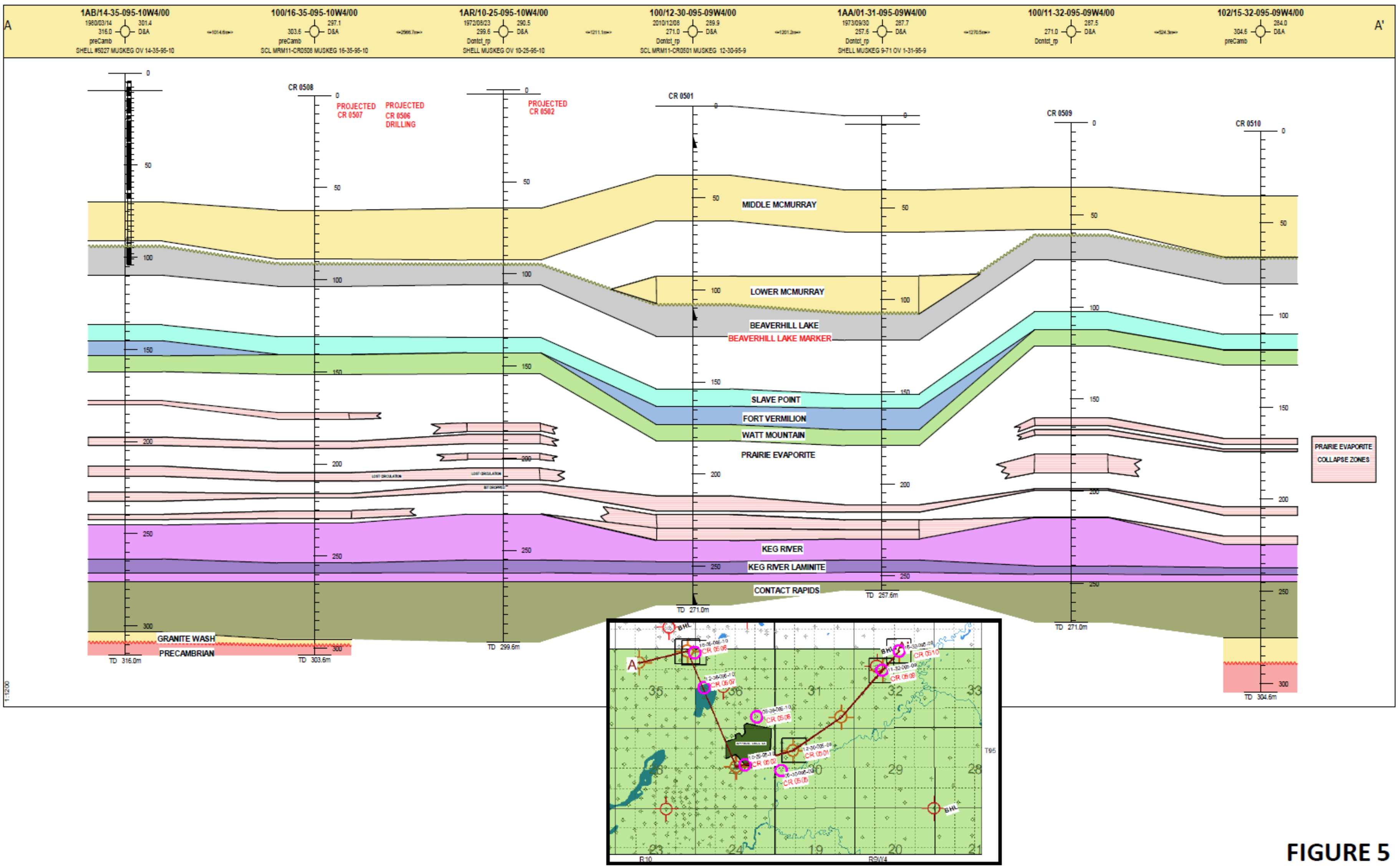


FIGURE 5