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Alberta Energy and Utilities Board

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F. Hein, J. Weiss, and H. (Mike) Berhane

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Alberta Energy and Utilities Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
T6B 2X3
Canada
Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@eub.ca
Website: www.ags.gov.ab.ca

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## Acknowledgements

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## Abstract

This preliminary assessment of regional stratigraphy of the Cold Lake oil sands area involved a comprehensive literature review, followed by detailed picking of logs, construction of a grid of cross-sections, and assembling of a database of regional picks for the area. At least four major transgressive surfaces subdivide the Clearwater (in ascending order):

- the T31, marking the top of the Clearwater C;
- the T41 the top of the Clearwater B;
- the T51, a surface below the top of the Clearwater A; and
- the T61, the top of the Clearwater A.

Each of these T surfaces is a transgressive surface of erosion and indicates a transgression of the Clearwater Sea and the base of a more regionally mappable, coarsening-upward, shallow-marine succession. In the sequence-stratigraphic model, the various units clinoform-downsection from Lloydminster in the south to Athabasca in the north. Each of the original shoreline successions, near the Cold Lake oil sands/Lloydminster heavy-oil contact, is the result of a fall in relative sea level, followed by cut and backfill of associated estuarine incised valley-fills. The estuarine incised valley-fills terminate northward (seaward), discharging into lowstand delta lobe, shoreface and submarine non-deltaic lobes in areas of low accommodation space. Further detailed work in the Cold Lake oil sands deposit will reconcile differences in correlation and definition of formation tops used by various workers in the study area.

# 1 Introduction

This is a preliminary assessment of regional stratigraphy of the oil sands in the Cold Lake (Figure 1) and surrounding area (Figure 2). Part of this study was to conduct a literature review as background work to the regional assessment (see next section). This was followed by detailed picking of logs, construction of a grid of cross-sections, and creation of a database of regional picks for the area. The aim of this project was to assess stratigraphic nomenclature and to do regional correlation that would ultimately help in booking of oil sands and heavy oil reserves in the area by formation. This work arose out of need for the Alberta Energy and Utilities Board (EUB) to have an assessment of areas in the northeastern/east-central part of Alberta, where nomenclature regarding stratigraphy in the Cold Lake oil sands in some areas followed schemes developed for the north in the Clearwater–Grand Rapids successions, whereas other areas followed schemes developed for the south in the Lloydminster–Grand Rapids successions. In addition, there is a current need to place the various in situ schemes being developed in Cold Lake into a geological framework to assist the EUB in its review of in situ applications and submissions.

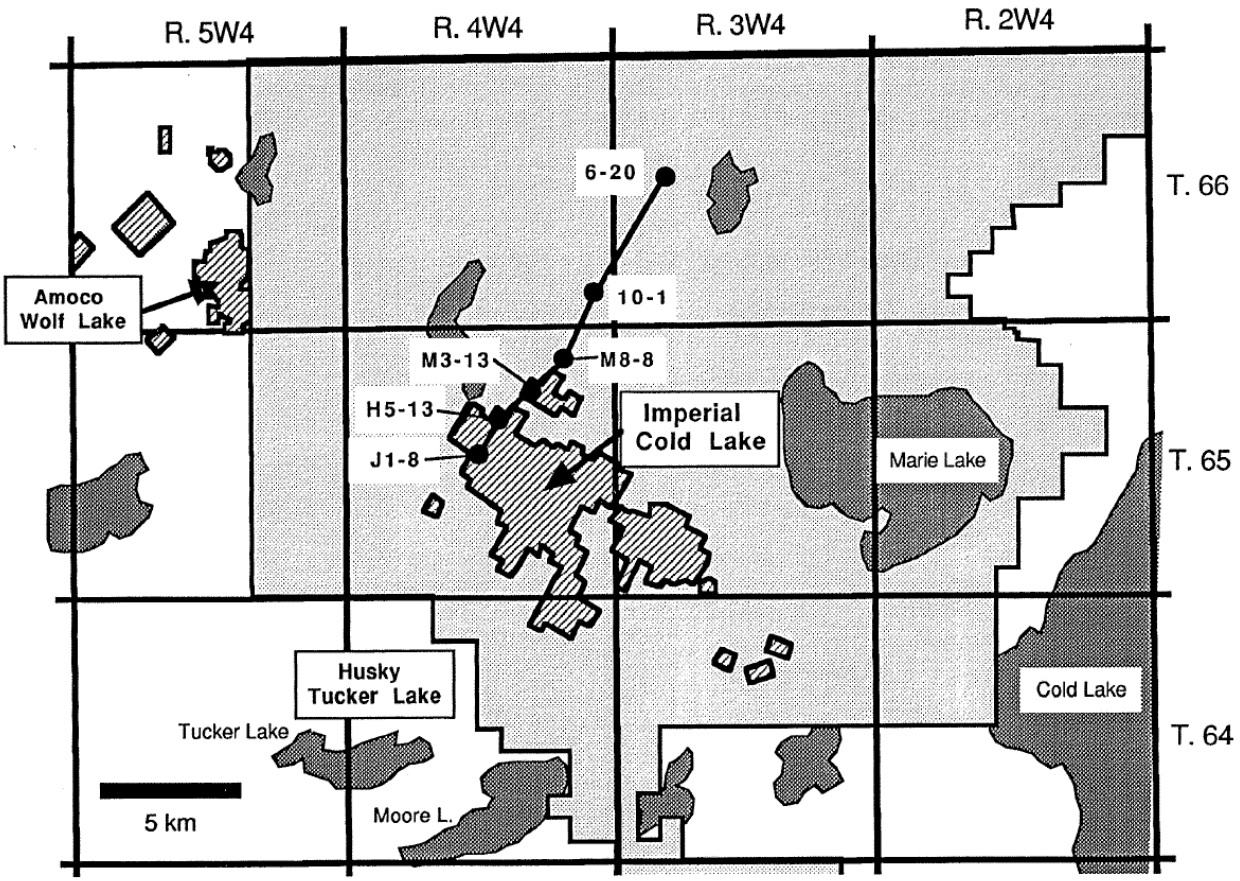


Figure 1. Map showing historical development of the Clearwater Formation in the Cold Lake oil sands area. Symbols: light stippled, Imperial Oil's Cold Lake Historic Leases; diagonal hachured, main development areas; heavily stippled, lakes (from Cheadle et al., 1995).

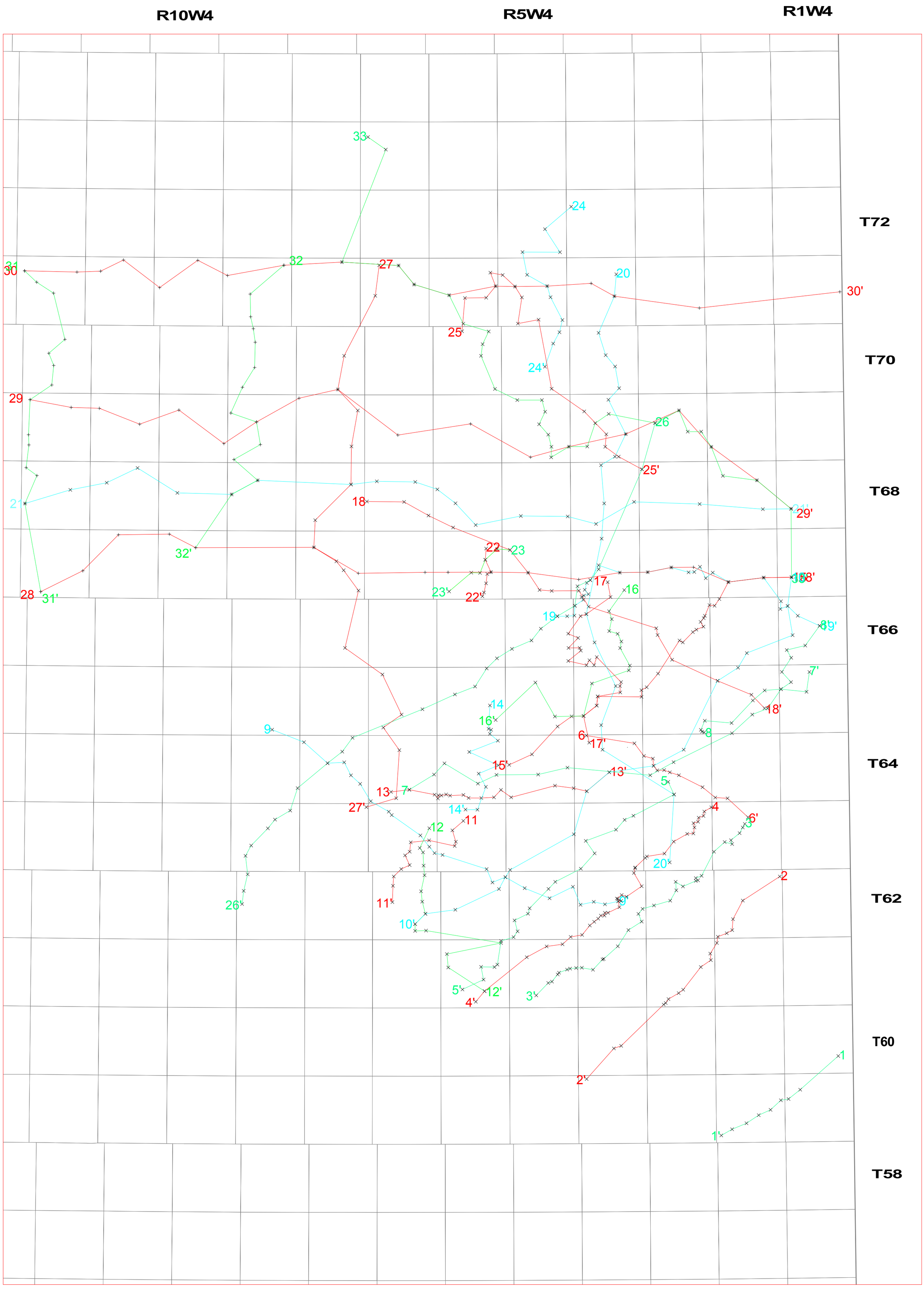


Figure 2. Cold Lake and surrounding area of northeastern and eastern Alberta assessed for regional nomenclature and correlation, showing the detailed and more regional cross-sections and locations of wells for which picks were made (included as files on CD).

## 2 Previous Work

Regional overviews of the geology of the area include Glaister (1959), Jackson (1984), Mellon (1967), Outtrim and Evans (1978), and Williams (1963). Detailed work on bedrock stratigraphy includes the original work by Badgley (1952) and Glaister (1959), which were updated by Green and others (1970) in their bedrock map of northern Alberta. Lloydminster stratigraphy was originally defined by Wickenden (1948), with revisions by Kent in 1959. Regional correlation between the McMurray and Clearwater formations was done by McPhee (1987, 1994). Further finer-scale subdivision of the internal stratigraphy of the Cold Lake oil sands was done by Mattison (1991), with a contrasting model for the Clearwater Formation used by Imperial at Cold Lake (cf. Cheadle et al., 1995; McCrimmon, 1996; McCrimmon and Cheadle, 1997; McCrimmon and Arnott, 2002; Feldman et al., 2003 ).

Comparisons between the ichnology of brackish water deposits in Cold Lake and Lloydminster are given by Pemberton and Wightman (1994), largely based on the original work of Wightman and Berezniuk (1985, 1986). In Alberta, other stratigraphic, paleontological and paleoenvironmental studies include Clack (1967), Williams and Stelck (1975), Stelck and Kramers (1980), and Mattison and Wall (1993). Regional stratigraphy, sedimentology and petroleum geology has been assessed of the Grand Rapids Formation in the northeastern and east-central Alberta (Beynon et al., 1988; Beynon, 1991; Cant and Abrahamson (1997), and of the Clearwater Formation in the Leismer area (Maher, 1989). Most recently, stratigraphy of the Colorado Group in the Cold Lake oil sands area has been revised by Tu et al. (2006).

Detailed reservoir description and mineralogical analysis was conducted by a number of workers mainly to assess in situ technologies for the recovery of bitumen from Cold Lake and Primrose (Schooley, 1975; Bayliss and Levinson, 1976; Kendall, 1977; Harrison et al., 1981; Sedimentology Research Group, 1981; Putnam and Pedskalny, 1983; Waywanko, 1984; Kirk et al., 1987; Wightman and Kirk, 1987; Hutcheon et al., 1988, 1989; Visser et al., 1988; Racki, 1991; Wickert, 1992; McKay and Longstaffe, 1997). Engineering reviews concerning processes for in situ recovery of bitumen at Cold Lake include Adegbesan et al. (1991), Sharpe et al. (1997) Donnelly (1999, 2000), Zhou et al. (1999) and Smith et al. (2003). Most recently, the Alberta Energy and Utilities Board (2003) in its Regional Geological Study of the Athabasca Oil Sands has redefined the stratigraphy in the subsurface of Athabasca South, and some of these units have been carried into the subsurface of North Cold Lake (Nina Sitek, pers. comm., 2006). Younger, overlying drift thickness and stratigraphy was addressed by Parks (2001) and Parks et al. (2005) as part of regional groundwater resource appraisals in the Athabasca and Cold Lake oil sands in situ areas.

## 3 Cold Lake Oil Sands Stratigraphy

A full historical review of stratigraphic nomenclature for Lower Cretaceous and lower Upper Cretaceous units associated with the oil sands and heavy oil deposits in Alberta is given by Schooley (1975), with updating of units into a sequence stratigraphic framework by Mattison (1991), Wickert (1992) Cant and Abrahamson (1997), (Figure 3). In the sequence-stratigraphic model, various units clinoform downsection from Lloydminster in the south, to Athabasca in the north. Each of the original shoreline successions near Lloydminster and the southern part of Cold Lake is the result of a fall in relative sea level, as shown by the associated incised valley-fills. The incised valley-fills terminate northward (seaward), discharging into lowstand shoreface, delta lobe and submarine lobes not associated with deltas, in areas of low accommodation space (cf. Cant and Abrahamson, 1997; Feldman et al., 2003).

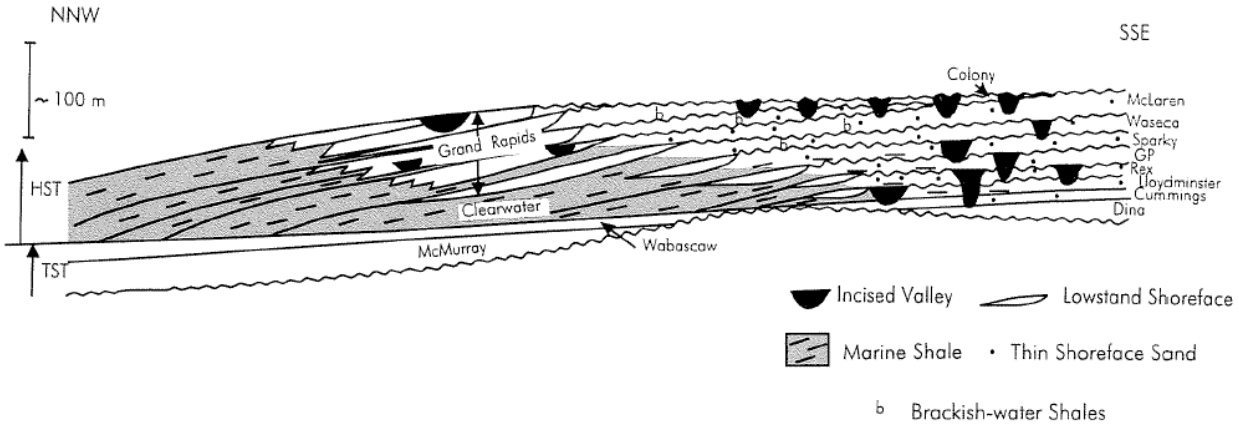


Figure 3. Sequence stratigraphic model for the east-central and northeastern Alberta subsurface, showing Lloydminster stratigraphy in the south, being replaced by Clearwater and Grand Rapids stratigraphy to the northwest. Each of the differently labelled shoreline successions in the Lloydminster area is the result of a fall in relative sea level, as shown by the associated incised valley-fills. Regional correlation work all shows that the Grand Rapids sands offlap from surfaces in the Colony, McLaren and Waseca formations (from Cant and Abrahamson, 1997).

The stratigraphic nomenclature in the present study follows the formations as defined by Glass (1990). The various transgressive and erosional surfaces follow the scheme defined by Wynne et al. (1994), which was published by Wightman et al. (1995) (Table 1). The contact between the Clearwater and the overlying Lower Grand Rapids formations is at the T61 surface. This scheme differs from that recently used by EUB, which places the top of the Clearwater Formation just above the T31 marker (Figures 4 and 5).

**Table 1. Definition of picks and quality codes used in the access database included on the CD (modified from Wynne et al., 1994).**

| Pick | Type of Surface | Description | Quality Codes |
|---|---|---|---|
| Mannville | Disconformity/ Unconformity | Major Erosion Surface<br>Top of Grand Rapids Fm<br>Top of Mannville Grp | Very Good<br>. |
| T61 | Transgressive | Top of Clearwater A | Very Good |
| T51 | Transgressive | Marker below Clearwater A | Good |
| T41 | Transgressive | Top of Clearwater B | Poor to Very Poor<br>not picked regionally |
| T31 | Transgressive | Top of Clearwater C | Good |
| T21 | Transgressive | Top of Wabiskaw A | Good to Very Good |
| T15 | Transgressive | Top of Wabiskaw B | Good to Very Good |
| E14 | Erosional | Incision during Wabiskaw | Good to Very Good |
| T11 | Transgressive | Base of First Regional Shale; Top of Wabiskaw C | Very good to Excellent |
| T10.5 | Transgressive | Top of Incised Valley-Fill<br>Top of Wabiskaw D | Excellent to Very Good |
| E10 | Disconformity/ Unconformity | Major Erosion Surface<br>Top of McMurray Formation | Excellent to Very Good |
| E5 | Erosional | Incision during McMurray | Variable, Fair to Poor |
| Pz | Unconformity | Major Erosion Surface<br>Base of McMurray Formation | Variable, Excellent to Poor (in karst areas) |

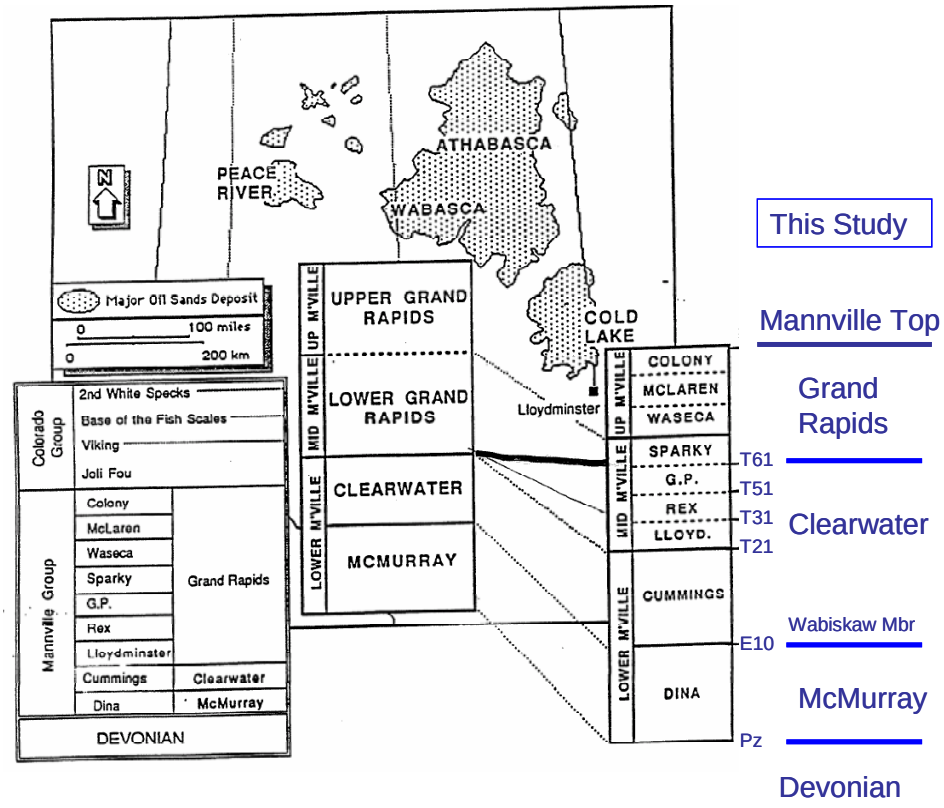


Figure 4. Schematic illustrating Mannville stratigraphic nomenclature of northeast and east central Alberta, compared with the different T and E surfaces picked in this study (shown in blue on the right hand side) (modified from Mattison, 1991).

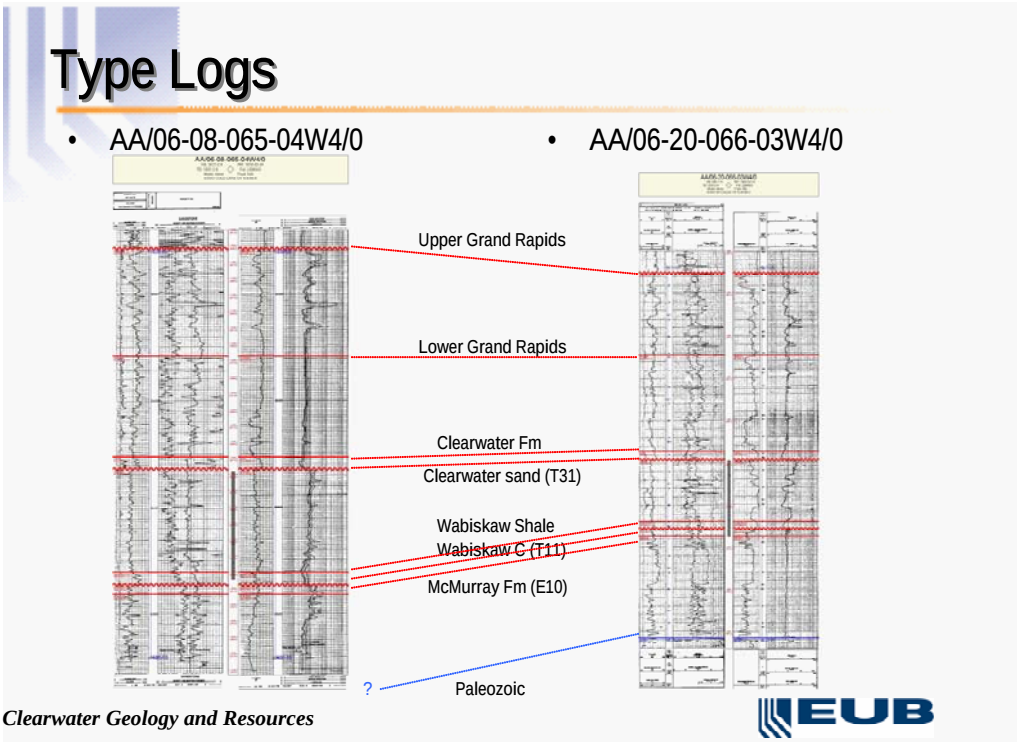


Figure 5. Type logs from recent resource assessment work at the EUB, showing an interpretation that places the top of the Clearwater Formation just above the T31 marker. This differs from the scheme used here that places the top of the Clearwater Formation at the T61 surface (cf. Table 1) (diagram courtesy of Nina Sitek).

In mapping the units in the Cold Lake and surrounding areas, it was necessary to identify the various T and E surfaces outside of the main areas of valley-incision (Figure 6), where more regional stratigraphy is preserved, then work in, well-by-well, to the Cold Lake oil sands proper area (Figure 1). One has to work within the context of the regional transgressive surfaces first, tying in the regional erosional surfaces to one another, to unravel the complex stratigraphy in areas of multistacked erosional cut and fills (Figure 6). A similar approach was done by other workers (cf. Mattison, 1991; Cant and Abrahamson, 1997), who also identified links between the regional transgressive surface of erosion (T) and the major unconformities (erosional E surfaces) and incised valley-fills.

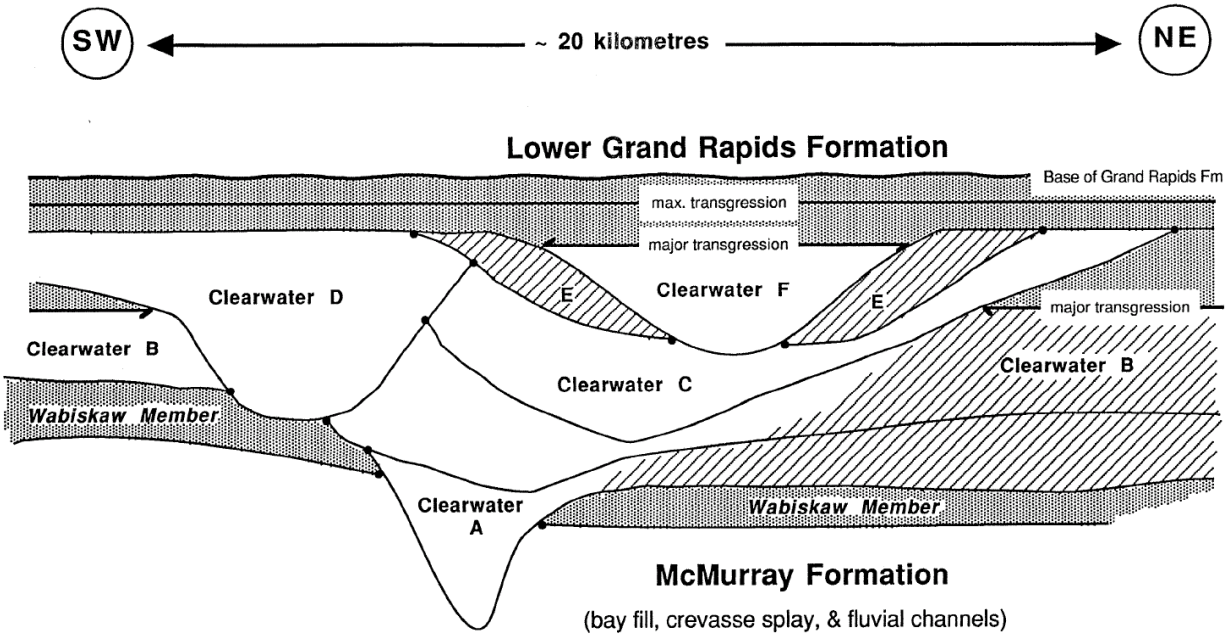


Figure 6. Schematic cross-section of the Clearwater Formation at Cold Lake, Alberta. Six depositional sequences (Clearwater A through F) are bounded by sequence boundaries produced during valley incisions. Symbols: white, proximal subtidal estuarine fill; diagonal hachured, distal estuarine fill; heavily stippled, open marine sediments. Total thickness of the Clearwater Formation is approximately 50 to 75 metres (from Cheadle et al., 1995).

### 3.1 Stratigraphy and Brief Descriptions of Formations

The Clearwater Shale of the Mannville Group was originally defined by McConnell in 1893, which was raised to formation status by McLearn (1917). In this original work, the Clearwater Formation was identified as those black and greenish grey shales, with interbedded grey and green lithic sands, and some siderite concretions. In the Cold Lake area, in particular, it was noted that the sands thicken to more continuous, lithic, salt-and-pepper sands interbedded with glauconitic sands and shales, with original bitumen resources estimated at 40.3 x $10^9$ bbl (Outtrim and Evans, 1978). Carrigy (1963) later outlined criteria for differentiating the McMurray and Clearwater formations in the Athabasca Oil Sands deposit.

The Cold Lake oil sands lie within a package of stacked incised valleys that lie encased within more regional deltaic, shoreface sands and marine muds (Figures 3 and 6). These overlie the fluvial and estuarine units of the Wabiskaw-McMurray succession that host the oil sands in the Athabasca deposit. The Clearwater Formation is overlain by regional deltaic, progradational barrier complexes and incised valley-fills of the Lower and Upper Grand Rapids Formation, which extends to the top of the Mannville Group (Figures 3, 4 and 6).

At least four major transgressive surfaces subdivide the Clearwater (in ascending order):

- the T31, marking the top of the Clearwater C;
- the T41, the top of the Clearwater B;
- the T51, a surface below the top of the Clearwater A; and
- the T61, the top of the Clearwater A.

Each of these T surfaces is a transgressive surface of erosion and indicates a transgression of the Clearwater Sea and the base of a more regionally mappable, coarsening-upward, shallow-marine succession. In the sequence-stratigraphic model, the various units clinoform-downsection from Lloydminster in the south to Athabasca in the north. Each of the original shoreline successions, near the Cold Lake oil sands/ Lloydminster heavy-oil contact, is the result of a fall in relative sea level, followed by cut and backfill of associated estuarine incised valley-fills. The estuarine incised valley-fills terminate northward (seaward), discharging into lowstand delta lobe, shoreface and submarine non-deltaic lobes in areas of low accommodation space.

### 3.2 Correlation of Formations in the Cold Lake and Surrounding Area

Figure 2 shows the locations of 52 cross-sections completed in the study area as of March 27, 2006. The digital cross-sections and picks are included on the CD. The results of this work show there are some areas of variable stratigraphy (cross-sections 1-1' to 9-9'), contrasting with other areas that show more consistent stratigraphy (cross-sections 11-11' to 46-46'). In addition, the more regional cross-sections show broad interfingering of the different stratigraphic units that change from north to south, or northwest to southeast. These relationships most likely indicate the true interfingering of the various fluvial, estuarine and marine packages that, in general, show downward clinoforming to the north-northwest. Similar regional variations in stratigraphy were noted by Mattison (1991), McPhee (1994), and Cant and Abrahamson (1997) concerning the relationships between the Lower and Upper Mannville successions of east-central and northeast Alberta subsurface. The detailed correlation and regional picking of different stratigraphic units show that there are regionally consistent packages within the Clearwater, and overlying, Grand Rapids successions in the Cold Lake area, and that these can be consistently mapped and correlated. However, what is not clear is why the present scheme, at a finer scale of resolution, differs from that used recently by the EUB in its resource assessment of the Cold Lake project area (Townships 59 to 70, Ranges 1 to 13 West of the 4$^{th}$ Meridian). This issue will be addressed by further ongoing work at the EUB that ties in the different in situ thermal project areas to the larger scale geological framework presented here.

## 4 Summary

This study describes the Clearwater Formation to regionally mappable transgressive surfaces of erosion (T-surfaces) that can be correlated throughout the Cold Lake oil sands and surrounding areas of northeastern and east central Alberta subsurface. The top of the Clearwater, at its contact, with the overlying Grand Rapids Formation is placed at the T61 surface. This contrasts with recent work being done in resource assessment by the EUB that places the top of the Clearwater Formation lower down section, just above the T31 surface. Further detailed work in the Cold Lake oil sands deposit will reconcile these differences in correlation and definition of formation tops.

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