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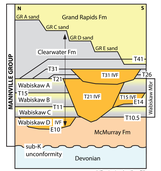
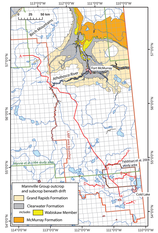
Regional Subsurface Mapping of the Clearwater Formation, Lower Cretaceous, Northeast Alberta

INTRODUCTION

The Lower Cretaceous Mannville Group hosts most of the bitumen deposits in the Athabasca and Cold Lake Oil Sands areas of northeastern Alberta. In the Athabasca Oil Sands Area, the basal Wabiskaw Member of the Clearwater Formation includes the upper part of the Wabiskaw-McMurray oil sands deposit, and overlying Clearwater Formation shale forms the cap rock to that reservoir (e.g., Wightman et al., 1995). Farther south, stacked, sand-dominated incised-valley fills in the lower Clearwater Formation form the primary bitumen reservoir in the Cold Lake Oil Sands Area (e.g., Hein et al., 2007). The regional-scale delineation and modelling of bounding lithostratigraphic surfaces and key internal subdivisions of the Clearwater Formation form an important component of a wider AGS/AER project to construct a digital 3D geological model for the Lower Athabasca Regional Plan (LARP) area in northeast Alberta using available wireline log data. Although industry project-scale models have been produced for parts of the Mannville succession, an integrated, regional-scale model has so far been unavailable. This presentation focuses on the time-transgressive top of the Clearwater Formation, illustrated using the regional dip cross-section A-A', and the complex incised-valley fill systems in the Cold Lake area, illustrated using cross-sections B-B' to F-F' and the accompanying isopach maps. A regionally applicable stratigraphic scheme of E surfaces (erosional surfaces with pronounced relief) and T surfaces (transgressive/flooding surfaces with low relief) was developed during Alberta Geological Survey mapping of the Athabasca Oil Sands Area from Township 67 northward from 1986 onward (e.g., Wynne et al., 1994; Wightman et al., 1995). This scheme has been extended south into the Cold Lake area, building on preliminary work by Hein et al. (2007), and allowing earlier, project-scale studies of the Clearwater Formation in that area (e.g., McCrimmon and Arnott, 2002; Feldman et al., 2008) to be placed in a wider regional context.



Schematic stratigraphic column for the Mannville Group in NE Alberta.

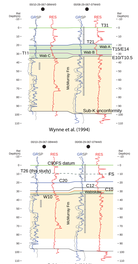


Map showing study areas and cross-section locations.

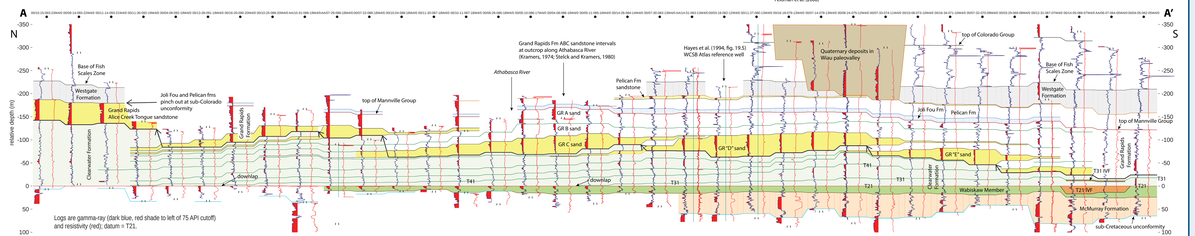
TOP OF CLEARWATER FORMATION

Generalized facies distribution at one time during Upper Mannville deposition (modified from Cant 1996)

The top of the Clearwater Formation steps up-section from south to north, recording stepwise northwestward progradation of shoreface sands of the overlying Grand Rapids Formation over Clearwater Formation shale deposited in the shallow marine Boreal Sea (see generalized facies map to left). The top of the formation is picked at the base of a series of regionally extensive Grand Rapids Formation sandbodies that 'terminate proximally by toplap, offlap to the north, clinoform and downlap distally' (Cant and Abrahamson, 1997). Where cross-section A-A' (below) crosses the Athabasca River, sandstone intervals in the Grand Rapids Formation can be identified with the 'A', 'B' and 'C' sandstone units noted at outcrop by Kramers (1974) and Stelck and Kramers (1980), with the base of the 'C' sandstone marking the top of the Clearwater Formation (e.g., Stelck and Kramers, 1980, fig. 2). Farther southeast, the cross-section includes the Hayes et al. (1994, fig. 19.5) Western Canada Sedimentary Basin Atlas reference well 03-18-082-12W4, in which the Clearwater Formation top is picked at the base of an older Grand Rapids sandstone interval, southeast of the offlap limit of the 'C' sandstone, here termed the 'D' sandstone. Continuing southward, the base of the Grand Rapids Formation is picked at the base of the 'E' sandstone, and then, in the southernmost part of the LARP area, at the base of the sandstone overlying the mudstone interval immediately above T31. This is consistent with industry practice in the Cold Lake area: see cross-sections of McCrimmon and Arnott (2002, their SBS) and Hayes and Quinn (2014, whose "Clearwater shale" lies between T31 at the top of their "Clearwater sandstone" and the base of the Grand Rapids Formation). To the northwest of the Athabasca River, the top of the Clearwater Formation is placed at the basal contacts of successive northwestward offlapping sandstone intervals, likely equivalent to the 'A' sand of Kramers (1974), and then at the base of the Alice Creek Tongue (Grand Rapids Formation) sandstone in the Birch Mountains area (Green et al., 1970; Glass, 1990: p. 9).

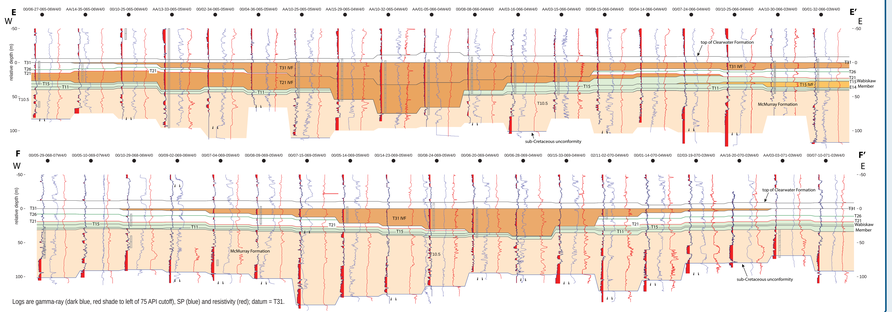


Integrating the AGS T and E surface scheme used here with different stratigraphic schemes used in previous project-scale studies was an important step towards understanding the complex Clearwater stratigraphy in the Cold Lake area. Gamma-ray, SP and resistivity logs for two wells with picks in both the Wynne et al. (1994) AGS dataset and the Feldman et al. (2008) Cold Lake area study are shown at left. Picking criteria are not identical, but key surfaces are consistently picked in both studies. C20 (Feldman et al., 2008) corresponds to the T21 Wabiskaw marker of Wynne et al. (1994), which defines the top of the Wabiskaw Member and represents the regional maximum flooding surface within the Mannville Group. The C90 FS (Feldman et al., 2008) corresponds to T31 of Wynne et al. (1994) which downlaps onto T21 to the north (see cross-section A-A' below). An unnamed flooding surface picked by Feldman et al. (2008) between their C20 and C90, but not picked in the Wynne et al. (1994) dataset, forms an important marker in the Cold Lake area and is named T26 in this study.

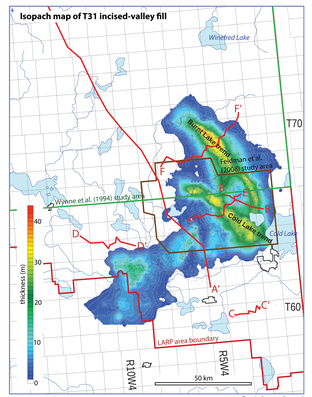


Logs are gamma-ray (dark blue, red shade to left of 75 API cutoff) and resistivity (red); datum = T21.

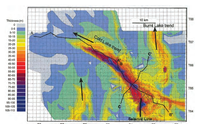
T31 INCISED-VALLEY SYSTEM



Logs are gamma-ray (dark blue, red shade to left of 75 API cutoff), SP (blue) and resistivity (red); datum = T31.



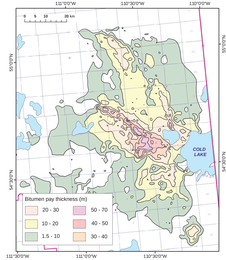
This compound IVF system (valley fill consisting of a number of sequences) broadly corresponds to the C30-C90 IVF sequence set mapped by Feldman et al. (2008). It has a common interfluve represented by T31, and the compound erosion surface (composite sequence boundary) at its base progressively truncates surfaces from T26 down to T11. Feldman et al. (2008) noted that the oldest and deepest valleys in their C30-C90 system were top-truncated by younger IVFs and could not be conclusively included in the set. Correlations proposed here indicate that those deeper valley-fills are part of the older T21 IVF system (see cross-section E-E' above), with the T31 and T21 systems amalgamating to form the main southeast to northwest Cold Lake valley fill trend mapped by Feldman et al. (2008: see their C30-C90 sequence isopach map reproduced below). Isopach maps for the T31 (left) and C30-C90 (below) IVF systems are similar, except for the reduced T31 IVF thickness along the Cold Lake trend resulting from reassignment of the deeper intervals. The Burnt Lake T31 IVF trend to the northeast (cross-section F-F') does not include underlying T21 IVF deposits. Its southern part was mapped by Feldman et al. (2008), and its northwestward extent beyond their study area is mapped here.



Isopach map of combined C30 through C90 IVF sequences (from Feldman et al., 2008).

CLEARWATER BITUMEN PAY

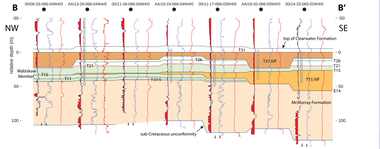
Bitumen pay in the Cold Lake Clearwater deposit (map below) is thickest along the main Cold Lake trend where the T31 and T21 IVF systems amalgamate to form composite sandstone intervals up to 75 m thick (cross-section E-E' above). There is also significant pay in the T31 IVF system along the Burnt Lake trend, and in areas of the T21 system to the south and southwest of Cold Lake.

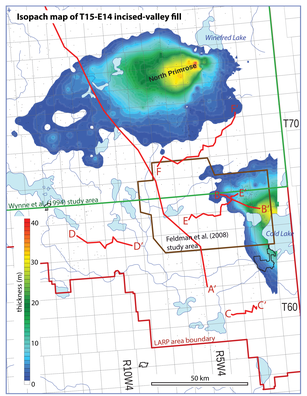


Bitumen pay thickness of Cold Lake Clearwater deposit (from Alberta Energy Regulator, 2015).

T15 INCISED-VALLEY SYSTEM

A series of simple or compound incised-valley fill (IVF) successions, with interfluves represented by T31, T21 and T15, can be correlated and mapped using the abundant, densely spaced well logs in the Cold Lake area. Basal erosion surfaces truncate regionally mappable, generally upward-coarsening, marine successions bounded by T surfaces in the Wabiskaw Member and lower part of the overlying Clearwater interval. The oldest IVF, below T15, corresponds to the C12 IVF of Feldman et al. (2008) and cross-section B-B' below follows their fig. 23 cross-section, with the basal erosion surface truncating T11 (top Wabiskaw C) and T10.5 (top McMurray Formation) from NW to SE. Farther north, the Cold Lake T15 IVF interval can be correlated with an erosionally based sandstone mapped in the North Primrose area by Wightman et al. (1991) and interpreted as an estuarine IVF, with the base marked by E14 of Wynne et al. (1994). T15 and E14 merge and cannot be separated in the area between Cold Lake and North Primrose (zero isopach on map to right), perhaps reflecting transgressive erosion at T15.



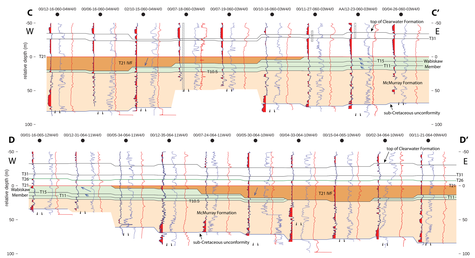


Logs are gamma-ray (dark blue, red shade to left of 75 API cutoff), SP (blue) and resistivity (red); datum = T31.

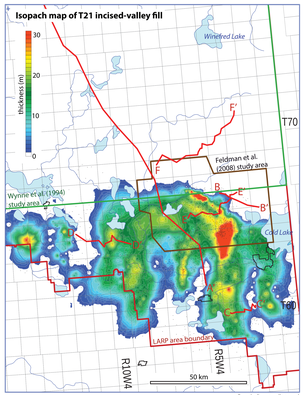
Dots indicate well control: data from this study and Wynne et al. (1994).

T21 INCISED-VALLEY SYSTEM

The interfluve for this IVF system is represented by the T21 Wabiskaw marker, and the basal erosion surface (or surfaces) progressively truncates T15, T11 and T10.5. The lateral change from upward coarsening Wabiskaw A, B and C shoreface intervals separated by T surfaces in the interfluve areas to a more uniform, slightly upward fining, blocky sand in the IVF is particularly clear on the SP curves in the cross-sections below. The isopach map (right) shows that the IVF system consists of a series of north-trending valleys which coalesce down dip to the north. This interval is identified as the C20 IVF on cross-sections by Feldman et al. (2008), but much of its extent lies outside their study area, and it was not mapped in that study.



Logs are gamma-ray (dark blue, red shade to left of 75 API cutoff), SP (blue) and resistivity (red); datum = T21.



Dots indicate well control.

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