

Overview of the Oil Sands and Carbonate Bitumen of Alberta: Regional Geologic Framework and Influence of Salt-Dissolution Effects*

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Introduction

Oil sands consist of bitumen (soluble organic matter) and host sediment in which the natural reservoir conditions are such that the oil is too viscous to flow into a well bore. The oil sands of northern Alberta are the largest bitumen sands in the world and cover a surface area exceeding 140,000 km², with an estimated initial volume in place of 270 billion cubic metres (1.7 trillion barrels) (AEUB, 2006a). Most of the presently exploitable bitumen is hosted by unconsolidated Lower Cretaceous sands in the Athabasca, Cold Lake, and Peace River areas. Other bitumen reserves are hosted within Devonian and Mississippian carbonate reservoirs that unconformably underlie the Athabasca and Peace River oil sands; but, to date, these have not been commercially produced (Figure 1). As of April 2006, about 40 companies are operating 143 schemes in the Alberta oil sands, including 97 primary production schemes (including waterflood and enhanced production), 37 commercial *in-situ* thermal schemes, 9 experimental pilots, 3 existing surface mines, with another 6 approved or proposed surface mines (AEUB, 2006b).

Background and Previous Work

Based on published work, the bitumen in the Cretaceous oil sands and underlying Paleozoic carbonates had similar source rocks as other conventional Mississippian and Lower Cretaceous hydrocarbon reservoirs in the basin (Fowler and Riediger, 2000). The main source rock was the Exshaw Shale, presently located 100s km to the southwest and outcropping near Exshaw, Alberta. During Tertiary time hydrocarbon generation was associated with the Laramide orogeny. Later oil migration and biodegradation of Exshaw oils commenced prior to or coincident with Early Cretaceous sedimentation, ending with the termination of the Laramide orogeny in Early Tertiary time. The oil sands were never deeply buried and show little evidence of diagenesis (including the presence of unfossilized (mummified) organic debris and the general absence of cement, aside from the bitumen that is holding the sand together). In northeastern Alberta biodegradation of the oil reservoirs continues today in the shallow subsurface and in outcrops in the surface mineable area. General comparisons with modern analogues show similarities with modern hydrocarbon seeps, with pronounced biodegradation in areas of active faulting and subsurface hydrologic recharge, and remobilization and emplacement of hydrocarbons (including bitumen) into younger (including Quaternary) successions.

Since the mid 1980s the government of Alberta has been involved with regional resource characterization of the oil sands deposits, with most of the initial effort focused on the Athabasca deposit. Since the late 1990s, this regional work continued, with updating of recent drilling, regional outcrop-subsurface correlation, and release of the information as digital products in the public domain. Much of this oil-sands and carbonate-bitumen work has relied on facies mapping on a regional basis, along with subsurface correlation and the development of regional sequence geologic frameworks. In this overview, the general aspects with type examples are given for each of the oil-sands and carbonate-bitumen deposits.

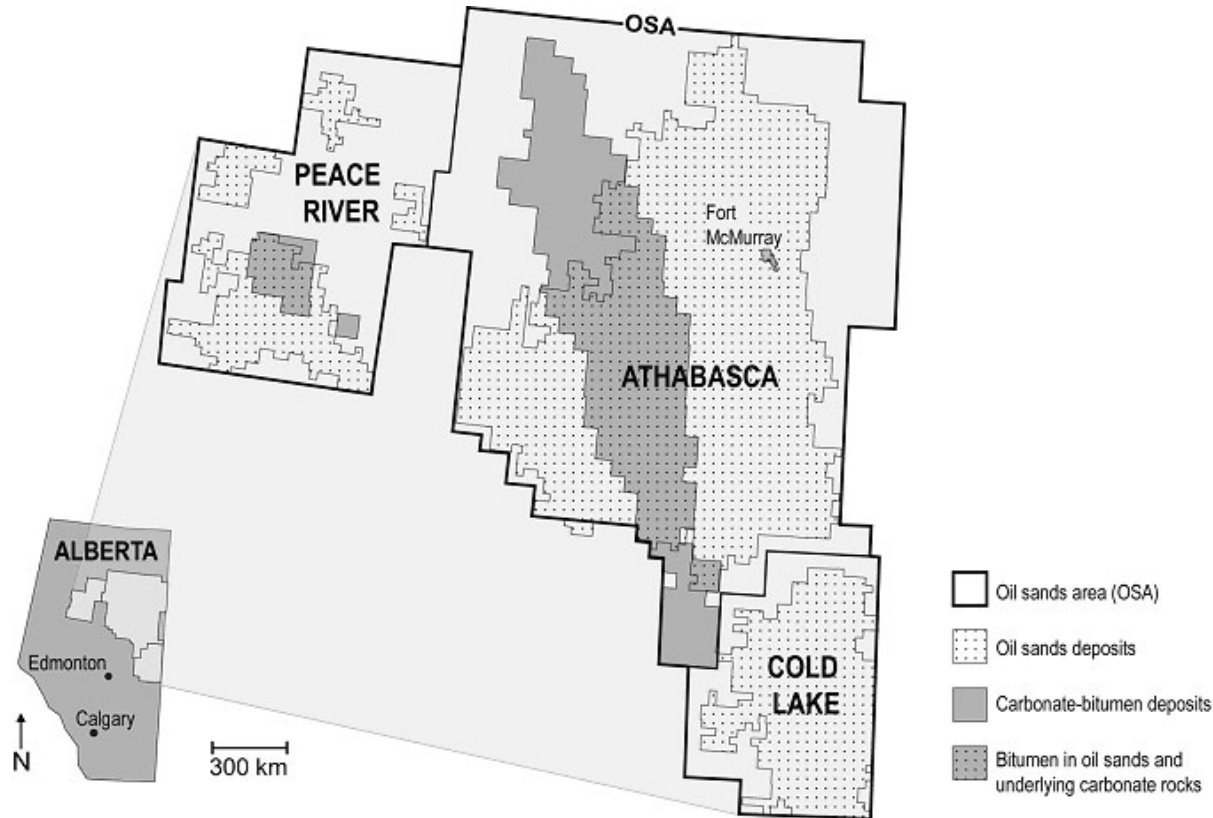


Figure 1. Location map of main bitumen deposits, Alberta, Canada.

Regional Geologic Frameworks

Lower Cretaceous Mannville Group host sediments include: the Wabiskaw-McMurray for the Athabasca Oil Sands Area (OSA); the Bluesky-Gething for the Peace River OSA; and the younger, Grand Rapids – Clearwater for the Cold Lake OSA. Older carbonates that underlie the oil sand deposits and also have estimated in-place volumes of crude bitumen are the Devonian Nisku and the Grosmont formations, which underlie the West Athabasca deposit (previously named the Wabasca deposit); and, the Mississippian

Debolt and Shunda formations, which underlie the Peace River OSA (Figure 2). Other prospective carbonate bitumen reservoirs are in the Mississippian Pekisko Formation (Rundle Group) beneath the Peace River OSA. No carbonates host bitumen beneath the Cold Lake OSA.

For the oil sands deposits, structure associated with the regional salt-dissolution front mainly affected Athabasca and Cold Lake, whereas controls at Peace River relate to the sub-Cretaceous unconformity. Influences of the salt-dissolution front included creation of extensive NNW valley systems for the main Athabasca, E-W valley systems for eastern and southern Athabasca, and two superimposed N-S and NW-SE valley systems for Cold Lake. Other salt-dissolution effects in Athabasca and Cold Lake relate to the development of more regional bay-fill deposits outside of the main incised valleys; local karstification, and development of thick, organic and deltaic successions. Additional post-depositional effects for oil sands include: development of salt 'roll-over' and anticlinal structures, younger paleokarst, and local faulting, all of which resulted in combined stratigraphic-structural traps for much of the bitumen and associated water and gas reservoirs in Athabasca and Cold Lake. At Peace River controls on the NE-SW incised valleys relate to paleotopographic effects, largely due to erosion on the sub-Cretaceous unconformity. Enhanced accommodation at Peace River allowed for the vertical and lateral separation of reservoirs; whereas more reduced accommodation at Athabasca and Cold Lake resulted in superimposed, inherently complex reservoir interconnections.

As with the Lower Cretaceous oil-sands deposits, the underlying Devonian and Mississippian carbonate-bitumen reservoirs also show significant lateral and vertical heterogeneity. However, for these carbonates, the heterogeneity is mainly related to complex patterns of dolomitization and later multiple stages of karstification. The Grosmont subcrop edge defines the western edge of the regional salt-dissolution front. For the carbonate-bitumen deposits, structure associated with the regional salt-dissolution front, in combination with processes along the sub-Cretaceous unconformity, mainly affected the Devonian Grosmont Formation. Controls on Mississippian carbonate-bitumen reservoirs in the Pekisko, Shunda, and Debolt successions relate more to processes of erosion and paleokarst development along the sub-Cretaceous unconformity, without a direct overriding influence of regional salt-dissolution effects.

Geological Summary

Table 1 presents a summary of the geological frameworks for the main oil-sand and carbonate-bitumen deposits in northern Alberta. Athabasca overlies an area of complete salt dissolution, with partial dissolution underneath Cold Lake and partial to none along the eastern margin of the Grosmont carbonate-bitumen deposit. Peace River is in an area that had no salt dissolution effects. For most of the oil-sand and carbonate-bitumen deposits the internal stratigraphy and reservoir heterogeneity is complex, with less complex patterns in the Peace River oil sands. At Peace River there was increased accommodation space (relative to Athabasca and Cold Lake) that was largely restricted by erosion and relatively narrow confinement of the depositional systems tracts. At Athabasca and Cold Lake the topography along the sub-Cretaceous unconformity worked in consort with local salt-dissolution tectonics that affected both accommodation space and relative changes in base level. For the Grosmont carbonate-bitumen deposit, reservoir heterogeneity is complex and relates mainly to karstification and salt-dissolution influences along the eastern margin, to karstification and erosional effects along the western margin, and throughout the deposit to a complex history of burial diagenesis. For all deposits the reservoirs must be understood with regard to the geological frameworks, such that proper sedimentological, stratigraphic, and diagenetic models are used in regional reservoir characterization of these important hydrocarbon deposits.

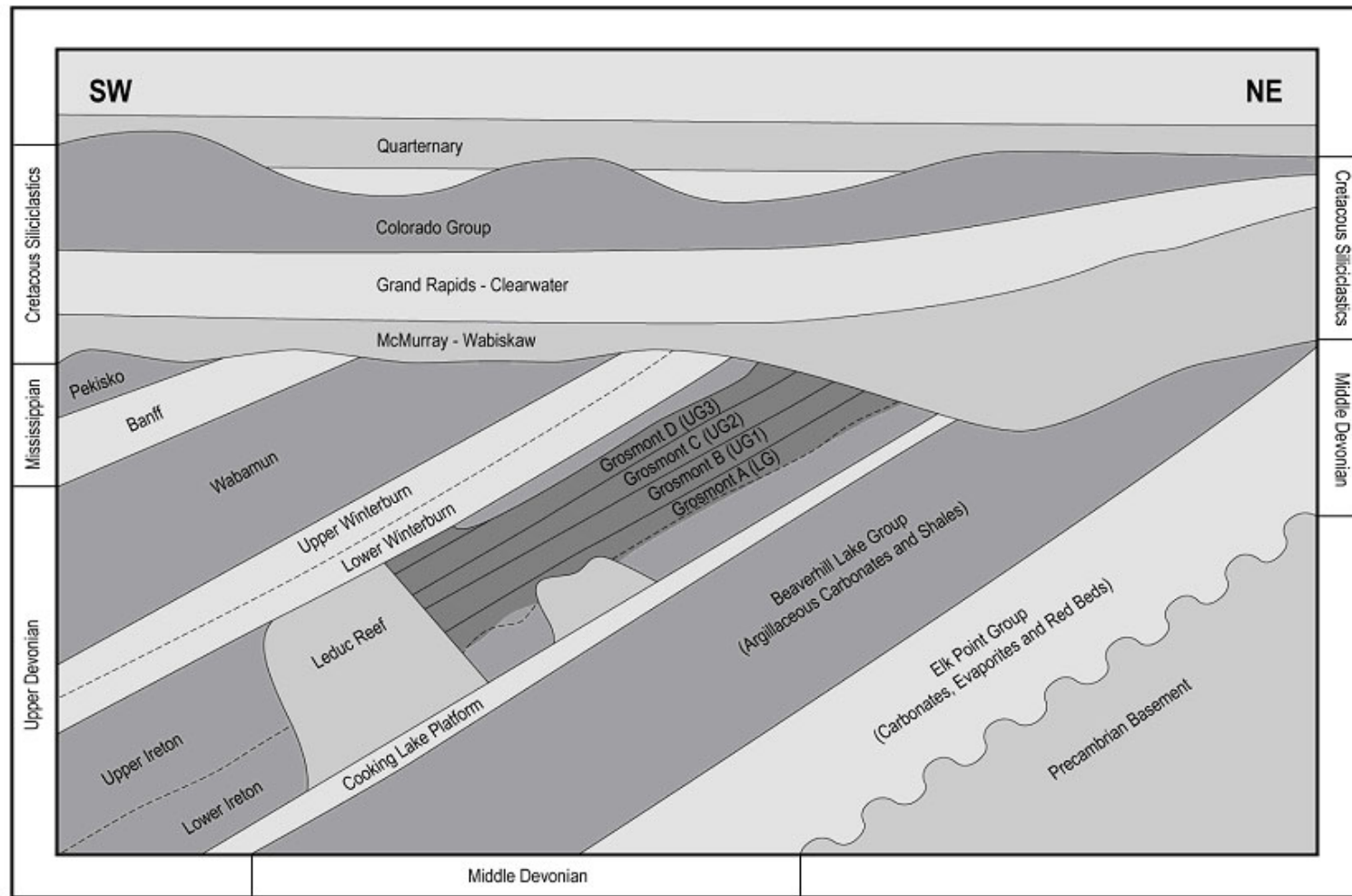


Figure 2. Stratigraphic nomenclature chart, northern Alberta, Canada.

References

- Alberta Energy and Utilities Board (AEUB), 2006a, Alberta's energy reserves 2005 and supply/demand outlook 2006-2015: Alberta Energy and Utilities Board Report ST98-2006, p. 1-1 - 8-7.
- Alberta Energy and Utilities Board (AEUB), 2006b, Active oil sand schemes map: Alberta Energy and Utilities Board Map ST-44, Scale 1: 1,000,000.
- Fowler, M., and Riediger, C., 2000, Origin of the Athabasca tar sands, *in* Barson, D., Bartlett, R., Hein, F., Fowler, M., Grasby, S., and Riediger, C., Hydrogeology of heavy oil and tar sand deposits: Water flow and supply, migration and degradation, GeoCanada 2000 Field Trip Guidebook 14, Stop 14, p. 117-127.

Table 1. Geological frameworks for main oil sand and carbonate bitumen deposits, northern Alberta.

<i>Deposit</i>	<i>Athabasca Oil Sands</i>	<i>Cold Lake Oil Sands</i>	<i>Peace River Oil Sands</i>	<i>Grosmont Carbonate Bitumen</i>
<i>Salt Dissolution</i>	Complete	Partial	None	Partial At Edge of Salt Dissolution Front
<i>Accommodation Space</i>	Low	Moderate	Restricted by Erosion	Restricted by Erosion & Karsting
<i>Confinement</i>	Relatively Broad	Relatively Narrow	Relatively Narrow	Relatively Broad
<i>Internal Stratigraphy</i>	Extremely Complex	Very Complex	Very Complex	Complex
<i>Reservoirs</i>	Stacked Complex	Stacked Complex	Isolated by Ridges	Stacked Complex
<i>Diagenesis</i>	Relatively Minor	Carbonate Concretions and Increased Clay due to Breakdown of Lithic Fragments	Relatively Minor But More Deeply Buried than Athabasca oil sands	Complex Burial History and Multiple Karsting Events