The Wabiskaw D Member, Clearwater Formation: A World Class Oil Sands Reservoir Hosted in an Incised Valley Complex

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Introduction

The Canadian Athabasca Oil Sands Deposit (north-eastern Alberta) contains vast quantities of bitumen emplaced in the Lower Cretaceous (Albian - Aptian) sandstones of the Clearwater – McMurray succession. The Wabiskaw D, a member of this succession, is preserved intermittently throughout the Athabasca Region and within the Kirby North Lease (T75, R9W4 – R8W4) this unit constitutes a high quality oil sands reservoir. Historically, the Region has seen bitumen production predominantly from the McMurray Formation; in contrast, this paper introduces the Wabiskaw D as an emerging yet under-studied oil sands reservoir.

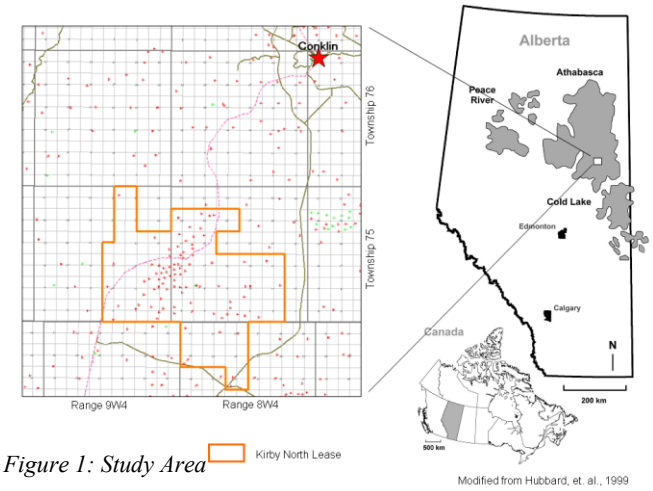

Figure 1: Study Area

Stratigraphy

The Wabiskaw D succession is stratigraphically overlain by the shallow marine sequences of the regional Wabiskaw Member, consisting of the Wabiskaw B and the erosional remnant of the Wabiskaw C, where preserved. The Wabiskaw B consists of 5 - 25 meters of lenticular interbedded to wave rippled sands and mudstones. These heterolithic sediments represent the distal elements of a delta system deposited in a structural low present through Townships 72 – 75, Ranges 4W4 – 10W4 (Mathison 2006). The Wabiskaw C is a thin (0 – 3 m) intermittently preserved unit which commonly exhibits intense bioturbation (predominantly *Asterosoma*), variable cementation, and is glauconite rich. The regional Wabiskaw is overlain by the Clearwater Shale packages representing a major marine incursion into the area. At Kirby the Wabiskaw D exhibits incision into the underlying McMurray Formation, removing up to 30 meters of upper McMurray sediments. The McMurray Formation can be grossly sub-divided into Upper (shoreface dominated) and Middle (estuarine dominated) successions and overlies the angular sub-Cretaceous Unconformity (Ranger

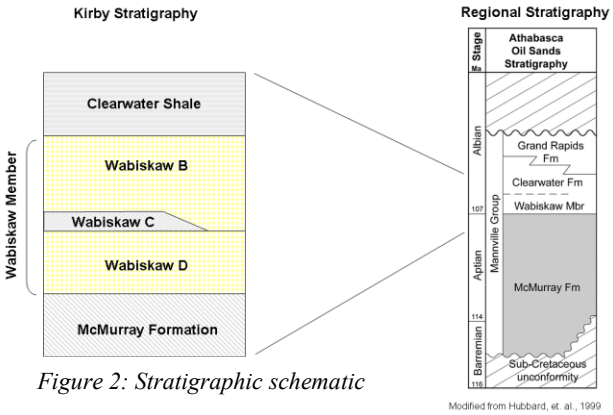

Figure 2: Stratigraphic schematic

and Gingras 2008). The Beaverhill Lake Formation (Devonian) underlies the sub-Cretaceous Unconformity and consists predominantly of detrital carbonate.

The Container

The Kirby incised valley has a complex architecture consisting of at least two erosional events, each with a unique sedimentological signature:

1. Following McMurray time, sea-level fell and a NE – SW trending valley was incised. As base level fell, Upper McMurray sediments were subaerially-exposed and subsequent erosion resulted in the incision of the ~30 meter deep central valley. Evidence for subaerial exposure include paleosols, rootlets and rhizoturbation, siderite concretions, and pyrite nodules (see figure 4). While base level remained low the Kirby valley is interpreted to be an area of sediment bypass.
2. Following the lowstand, sea-level began to rise and the central channel was backfilled with high energy estuarine sediments (predominantly massive sands and mudclast breccias) often in association with a coarse grained or woody lag deposit, preserved atop the channel scour. As transgression continued there is indication of subaqueous erosion as evidenced by preserved transgessive lag deposits in association with firm ground, passively filled burrows (*Glossifungites* ichnofacies) (see figure 4). This transgressive surface of erosion (TSE) resulted in the development of terraces adjacent to the central channel (see figure 3)

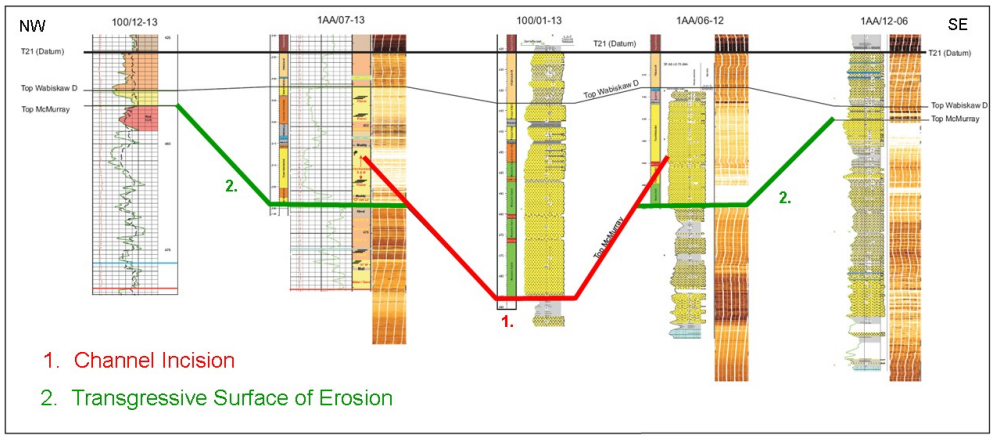

Figure 3: Stratigraphic cross-section perpendicular to channel strike. Areas of channel erosion are red; areas of TSE erosion are green.

Figure 4: Contrasting the sedimentology of the Channel scour (left) with the Transgressive Surface of Erosion (TSE) (right). Rootlet (R), Pyrite (Py), Glossifungites surface (GI).

Sedimentology

Within the study area the Wabiskaw D reservoir can be subdivided into two back-stepping depositional successions comprising a transgressive continuum of tidally influenced channel fill (FA1) overlain by high energy bay fill deposits (FA2). A third succession (FA3) consists of shore-face sediments which overlie the Wabiskaw D reservoir. FA1 consists of massive to cross-bedded, fine-grained quartzose sands interbedded with rare brecciated and toe-set intervals. FA2 is composed of flaser to wavy-bedded, hummocky cross stratified (HCS) sands and mudstones. FA3 comprises a shore-face succession which coarsens upwards from a semi-correlatable mudstone at its base to cross-bedded and fine-grained sands at its top. The highest quality reservoir units reside within FA1 and parts of FA2.

Facies Association 1 (FA1) – Tidally influenced channel fill

FA1 consists of massive to cross-bedded sands (F6) and intraformational mudstone breccias (F7). Grains are well sorted, well rounded, fL – fU, and predominantly quartzose (sub-litharenite). Bedsets are commonly 0.5 m in thickness, rarely exceeding 1m. Mudstone clasts are commonly present as isolated, armoured mudballs or as brecciated intervals 0.1 – 1.0 m thick. Clasts range from 1 – 40 mm in diameter and commonly fine upward in brecciated intervals. Ichnogenera are diminutive and comprise an impoverished suite of *Skolithos*, *Planolites* and rare *Thallassinoides,* indicative of a highly stressed environment. Oil saturation averages approximately 80%, with 30 – 33% porosity, and Darcy scale permeability. FA1 constitutes excellent quality reservoir.

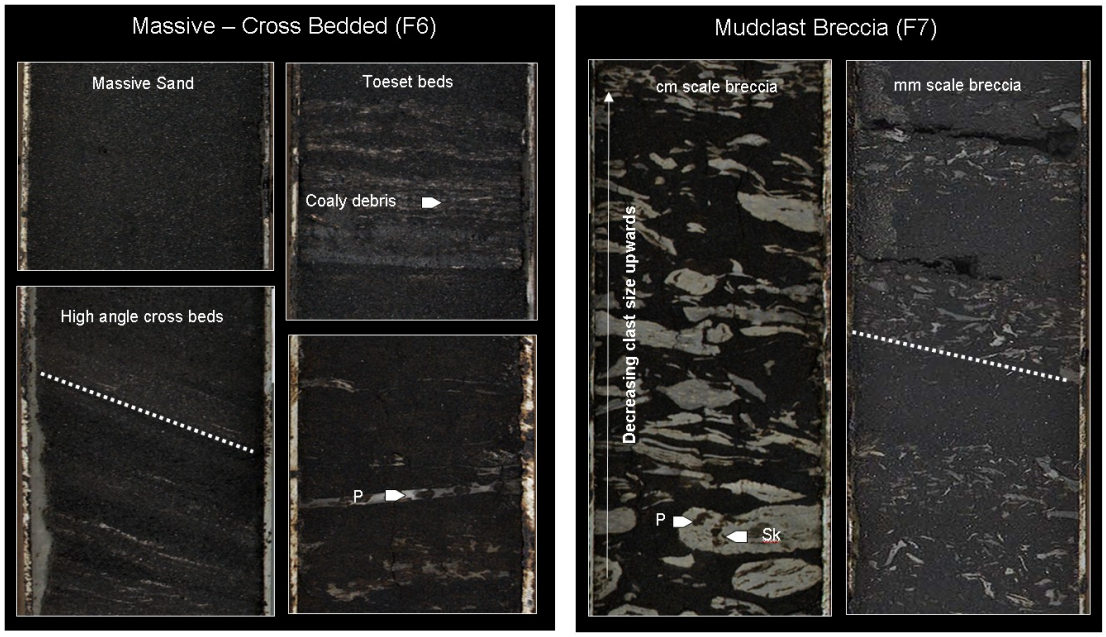

Figure 5: The facies of FA1. Planolites (P), Skolithos (Sk)

Facies Association 2 (FA2) – High energy bay fill deposits

FA2 consists of hummocky cross stratified sands and muds consisting of a flaser interbedded unit (F5) shaling upwards into a wavy to lenticular interbedded unit (F4). Volume of shale varies from <10% (F5) to 10 – 40% (F4). Mudstones typically occur as thin beds (less than 2 cm) and are composed of silt sized quartz particles. Mudstones often appear “wispy” in core and commonly pinch out over the core diameter indicating their limited spatial extent. Bioturbation is locally intense, dominated by *Thallassinoides*,

Planolites, and *Palaeophycus*. Millimetre scale ripples are common with indications of tidal couplets and combined-flow conditions. Oil saturation varies between 60 – 70%, with porosities ranging between 26 – 29%; permeability is a function of shale volume (although typically <1 Darcy). FA2 constitutes marginal - good quality reservoir.

Figure 6: The facies of FA2. Planolites (P), Thallassinoides (Th)

Sequence Stratigraphic Framework

Wabiskaw D sedimentation at Kirby represents a 4th order oscillation superimposed upon the overriding 3rd order Clearwater Transgression. Late highstand and lowstand channel incision resulted in the formation of an incised valley complex (the container). Ensuing transgression resulted in increased accommodation and deposition of early transgressive channel fill (FA1), overlain by transgressive bay fill (FA2), and finally highstand marine shoreface (FA3) sediments.

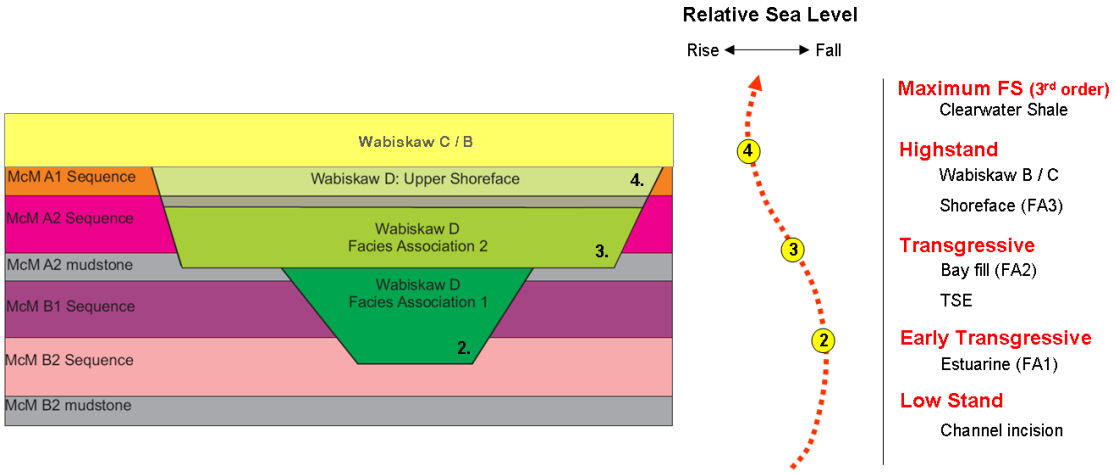

Figure 7: Evolution of the Kirby Valley Fill over time.

Conclusion

Following McMurray time, a relative drop in sea level resulted in the incision of a NE – SW elongate valley system through the Kirby Project Area. During the subsequent transgression the valley was backfilled with Wabiskaw D valley-fill deposits. The highest quality Wabiskaw D reservoir units were deposited under outer estuarine conditions, in marked contrast to the underlying fluvial / inner estuarine dominated McMurray Formation. This fundamental shift results in the Wabiskaw D manifesting a homogeneous and laterally continuous sandbar geometry; a significant departure from the inclined heterolithically stratified (IHS) point bar deposits which characterize much of the McMurray. The limited lateral extent of mudstone interbeds associated with the Wabiskaw D favour the unrestricted vertical growth of the SAGD steam chamber as well as a more consistent and predictable SAGD roof. In contrast, McMurray SAGD reservoirs typically contain IHS mudstone beds with significant lateral extent resulting in complex reservoir geometries and variable SAGD roof elevations. The increased reservoir continuity inherent to the Wabiskaw D significantly reduces geological risk, particularly for in-situ production schemes such as SAGD.

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