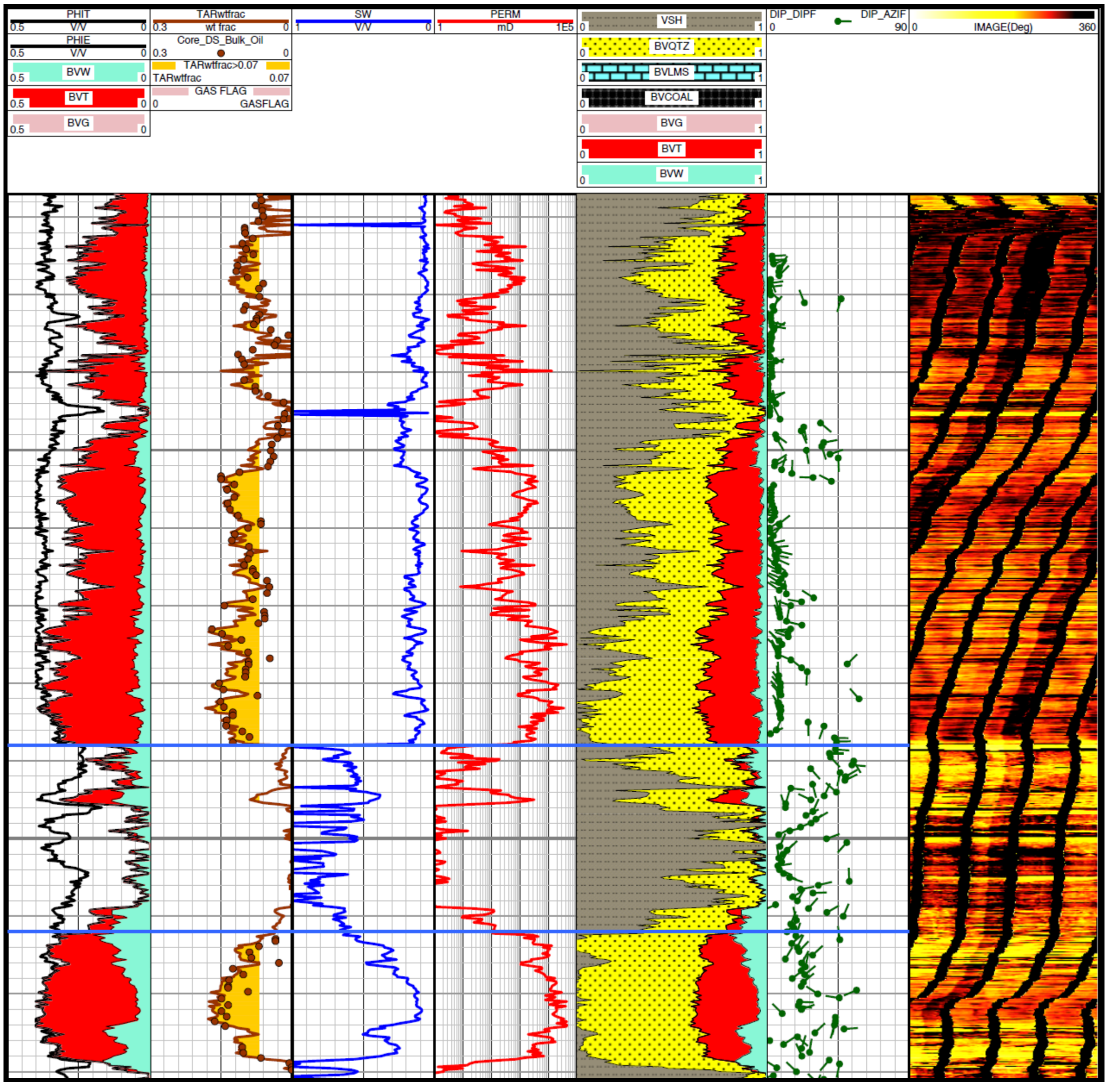
# Depositional Environments Of The Athabasca Oil Sands (McMurray Formation)



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## Abstract

**The sediments which comprise the McMurray Formation, as they appear in outcrop within the Fort McMurray area, are examined. Environments of deposition for each of the three prevalent facies are discussed. A qualitative relationship between the accretion of terranes to the western margin of North America, and the formation of clastic wedges in the Western Canadian Sedimentary basin is reviewed.**

## Introduction

The lower Cretaceous McMurray / Wabiskaw stratigraphic interval contains approximately 143 x $10^9$ $m^3$ (902 x $10^9$ barrels) of bitumen (Alberta Energy and Utilities Board, 1996), making it the largest oil sands deposit in Alberta. Approximately 24 x $10^9$ $m^3$ (152 x $10^9$ barrels) of bitumen occur in the surface mineable area around Fort McMurray, with production in 1995 of about 43,500 $m^3$/day (273,000 barrels/day) of synthetic crude oil from two mining operations. (Alberta Energy and Utilities Board, 1996a). This output represents about 16% of Canada's oil production for 1995, reserves to production ratios indicate that major increases in production are possible (Singh et al., 1991). Thus, surface mineable oil sands are fundamental to Canada's energy future (Wightman and Pemberton, 1997).

In the Athabasca Oil Sands area, the McMurray Formation constitutes the basal Formation in the Lower Cretaceous Mannville Group and directly overlies a regional unconformity developed on Paleozoic carbonates. It outcrops in the vicinity of Fort McMurray and reaches depths of about 500m (subsurface) in the southern part of the deposit. The surface minable area lies just north of Fort

McMurray and is associated with the topographic low along the Athabasca River valley (Wightman *et al.*, 1989).

The McMurray Formation represents the initial response to a relative rise of the Boreal Sea to the north (Flach, 1984; Wightman *et al.*, 1991). The relative rise in sea level and initiation of sedimentation were related to a second major episode within the Columbian Orogeny (Stott, 1984), which probably resulted from the accretion of several allochthonous terranes in the Cordillera (Stockmal *et al.*, 1992). Sedimentation was affected by the topography of the unconformity surface and the bulk of the McMurray Formation was deposited in a large, north westerly trending paleovalley, developed on Devonian carbonates in this area (Wightman et al., 1989). The deepest McMurray Formation, has been termed the Main Valley (Keith *et al.*, 1990; McGillvray *et al.*, 1992). Salt dissolution in the underlying Middle Devonian evaporites controlled the location of the Main Valley as it trends along the salt scrap of the Prairie Evaporite formation (McPhee and Wightman, 1991; Wightman *et al.*, 1991; Wightman *et al.*, 1995).

The lowest portion of the McMurray Formation contains continental sediments deposited within the poorly organized drainage system that existed on the irregular carbonate surface (Flach, 1984). The middle and upper parts of the McMurray formation were deposited by a major, northward flowing fluvial system that occupied the paleovalley. The valley fill consists predominantly of a channelized interval of fresh to brackish sediments, with the thickest channel deposits occurring in the Main Valley. The degree of marine influence generally increases stratigraphically upwards and geographically to the north (Jeletzky, 1971). The McMurray Formation can be comprised entirely of channel or off channel deposits and are generally more abundant in the upper part of the Formation. Thus, within the regional Athabasca area, there is no correlateble lithostratigraphic or chronostratigraphic surface. (Wightman and Pemberton, 1997).

At the end of McMurray time, the carbonate ridges were nearly completely covered, but a relative drop in sea level resulted in the incision of valleys in the upper part of the McMurray Formation (Strobl et al., 1993; Wightman *et al.*, 1995). This was followed by a major southward transgression of the Boreal Sea (Albian) which created a marine environment of deposition for the Wabiskaw Member (Jeletzky, 1971; Jardine, 1974).

The upward transition from continental or brackish water sediments to marine deposits (Wabiskaw Member) has been interpreted by many as an overall transgressive setting (Mellon and Wall, 1956; Carrigy , 1959; Williams, 1963; Jardine, 1974; Flach, 1984; Strobl *et al.*, 1993). The top of the Wabiskaw Member has been interpreted by many as an overall transgressive systems tract for the Mannville Group in the area (McPhee, 1994; Wynne *et al.*, 1994; Wightman *et al.*, 1995; Cant and Abrahamson, 1996).

The Late Cretaceous to Early Laramide Orogeny resulted in the major petroleum generation event in the Western Canada Sedimentary Basin (Deroo et al., 1977) and of the liquid petroleum that was generated, the oil sands contain the bulk of that which was captured (Masters, 1984).

## Outcrops

Prominent outcrops of the McMurray Formation in the Fort McMurray area have been thouroghly studied. The McMurray Formation outcrops along the Steepbank, MacKay and High Hill Rivers. Mossop *et al.,* (1982) treat the McMurray Formation as a genetic unit, a single upward-fining cycle of channel sedimentation. Within the genetic unit, they identify three distinct facies. These include: thick-bedded sand facies, epsilon cross-stratified facies, and argillaceous sand facies.

### Thick-Bedded Sand Facies

Mossop *et al.* describe this facies as follows: a moderately well sorted, fine grained quartz sand, with virtually no significant shale intercalations and only minor shale clast breccias. Characteristic porosities for the interval as a whole are on the order of 30 percent, with bitumen content averaging 14 percent by weight (29 percent by volume). It is the richest portion of the reservoir for the sole reason that it has the most favourable primary porosity and permeability characteristics.

Mossop *et al.* state that in outcrop, this facies is thick bedded to massive in appearance. Close inspection reveals that it is characterized by large scale cross-stratification, in sets commonly a metre to a metre and a half in thickness. The trough cross-beds vary from very broad forms, up to six metres across and a metre and a half thick, to much more compact forms, rarely mor than a metre thick and with much steeper sides.

The shale brecias are between 2 and 20 centimetres across and a few centimetres thick, but blocks upto 1.5 metres thick are found locally (Mossop *et al.* 1982). Mossop *et al.* feel the shale clasts originated outside this facies, but were not transported far based on the angularity of the clasts. On these premises, they interpret the shale clasts as being derived from bank caving on the cutbank side of the channel, or through gravity sliding of mud-drape partings from the epsilon slip-off slope.

This facies is interpreted as being deposited by a fluvial channel.

## Epsilon Cross-Stratified Facies

Mossop *et al.* describe the following attributes of the facies: individual sets average 15 metres in thickness; cross-stratal dip averages between 8 to 12 degrees; depositional strike and dip is generally consistent in any given exposure, but adjacent exposures, perhaps only a few hundred metres apart, show wide divergence in attitude; individual exposures normally contain only one set of epsilon cross-strata, with a gradational lower boundary, and a gradational or abrupt upper contact; in exposures normal to the depositional strike, beds within a set can be seen to have a straight line profile from the base to the top of the slope. The sloping strata consist of decimetre to metre thick beds of fine to very fine-grained sand, separated by partings of argillaceous silt that are normally two to five centimetres thick. The mud/sand ratio in a typical set varies from less than 0.1 at the base to about 0.2 at the top. Upward-fining within a set is manifest in part by the upward increase in the proportional abundance of silt and clay partings.

Abundant and well preserved ichnofossils are found within this facies. These include *Skolithos, Cylindrichnus, Monocraterion, Planolites* and *Palaeophycus. Skolithos* is by far the most abundant ichnofossil. Burrows decrease in number towards the base of the epsilon sets.

Mossop *et al.* interpret the epsilon cross-strata as originating from lateral accretion deposits on the thinner bends of channel meanders. The advocated system involves deposition of the sand beds in association with flood stage flow in the channel, with the silty partings accumulating as mud drapes during the remainder of the cycle.

Ranger *et al.* (1997) interpret this facies as containing inclined heterolithic stratification. In their opinions, this deposit is not strictly fluvial in nature as Mossop *et al.* would indicate. Ranger *et al.* bring to our attention that nowhere in modern environments is inclined heterolithic stratification associated solely with fluvial environments (Smith, 1988); but it has been documented in many modern and Holocene, tidally influenced river dominated estuaries (Smith, 1988, and references therein). Hence, it is valid to say the epsilon cross stratification facies of Mossop *et al.* was most probably influenced tidally during its deposition.

### Argillaceous Sand Facies

Mossop *et al.* describe this facies as horizontally bedded argillaceous sands and silts, with overall thickness of five to twelve metres. The majority of the sediments within this facies do not appear to be directly related to the underlying material.

Mossop *et al.* also state that the contact between the epsilon cross-strata and the upper horizontal beds is often one of truncation, but transitional contact relationships are observable in selected field exposures.  This facies is interpreted as representing a marine environment of depostion.

## Correlation with Accreted Terranes

Stockmal *et al.* (1992) have shown that the evolution of forland sedimentary basins can be simulated using quantitative geodynamic models that account for the flexural response of the Earth's lithosphere to tectonic loads. By properly modelling a basin, an improved understanding of the tectonic subsidence, sediment supply, and gross stratigraphy of the basin is achieved.

Present evidence suggests a loose temporal correlation between the docking of accretionary terranes on the western edge of North America and the development of clastic wedges in the Western Canada Foreland basin. Initial terrane accretion at passive margins, and subsequent inboard deformation associated with accretion of more outboard terranes and changes in plate boundary processes, provide the tectonic loads that deflect the lithosphere to produce foreland basins. An idealized foreland basin sequence, derived in a qualitative fashion from the predictions of these geodynamic models, can be compared with observed foreland basin stratigraphy to identify discrete wedges associated with discreet tectonic loading events. Such wedges, identified in the Western Canada foreland basin, correlate loosely in time with the accretion of allochthonous terranes in the Canadian Cordillera. Therefore, we may be able to use the ages of clastic wedges to make inferences regarding the timing of tectonic loading events. In the simplest terms, we would anticipate these loading events to be caused by significant terrane accretions (if there is a convergent component to their motion, rather than purely strike slip) or by changes in plate boundary dynamics (Stockmal *et al.*, 1992).

In response to the accretion of terranes on the western margin, clastic wedges were deposited in the Western Canada Sedimentary basin. These wedges are usually bounded by unconformities and contain transgressive and regressive sequences. The McMurray Formation comprises part of a clastic wedge which was formed during the accretion of the Insular Superterrane (Stockmal *et al.*).

## Conclusions

Through reading and writing about the tar sands, I have formed the following conclusions:

1. There is a tremendous amount of heavy oil within the McMurray Formation capable of modulating the world's demand for oil for many years to come. With production changing from light to heavy oil (high API to low API), and the development of new extraction techniques, the Athabasca Oil sands will become extremely important.
2. The unconformity which underlies the McMurray Formation is Paleozoic in age and carbonate in lithology. Its surface was eroded unevenly creating highs and lows. We find the McMurray Formation deposited in the low areas; for this reason it is essential to have an understanding of the paleotopography of the Paleozoic carbonate surface.
3. The environment of deposition changed throughout the deposition of the McMurray Formation from fluvial channels to estruarine channels and thence to marine. Many small scale transgressions took place.
4. The accretion of the Insular Superterrane to the western margin of North America can be qualitatively related to a clastic wedge in the Western Canadian Sedimentary basin. This wedge contains many Formations, of which, the McMurray is one.

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