Working Hypotheses for McMurray Formation Stratigraphy: Focusing the Search for Modern Analogues

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Abstract

The Athabasca Oil Sands basin (informally the "Athabasca Basin") is blessed by a large amount of data of various sources including not only cores, well logs and seismic, but outcrop as well. Subsurface stratigraphic and sedimentological studies naturally lead to the search for modern analogues to provide insight to ancient systems. It is good science that a search for modern analogues should be guided by one or more working hypotheses. We review here elements of the various working hypotheses that we perceive to be guiding the research community in interpreting the history of the Athabasca Basin. We suggest constraints on the models and attempt to point out the most relevant features of the system that a search for modern analogues should address.

The configuration of the Athabasca Basin is reasonably well known on a regional scale. The basin is relatively elongate comprising a major trunk valley system with several mappable tributary valley features entrenched into the underlying Paleozoic carbonate terrain. The eastern part of the basin is less well-known due to a lack of data and the effects of Quaternary erosion. The entire basin was ultimately flooded in the Lower Cretaceous due to incremental sea level rise totaling about 150 m, a figure based on the approximate maximum thickness of sediment fill between Late Aptian and the Early Albian Clearwater marine shales. There should be little contention that on some low order the basin fill represents a transgressive, probably eustatic, regime.

The rate of sedimentation in the Lower Cretaceous of northeast Alberta is not well-known, but it can be conjectured that, at least on a relative scale, sedimentation was slow to starved in the western and northwestern parts of the basin; medium to high along the central trunk basin valley system; and high to extreme in the east where tributary valleys were fed by proximal, immature, Precambrian-sourced sediments off the Canadian Shield.

The McMurray Fm. is subdivided here into the traditional but informal upper, middle and lower McMurray members based on the fact that they conveniently correspond to what is believed to be primary evolutionary episodes in the basin. In some earlier working hypotheses, the lower, middle and upper are thought to represent fluvial, estuarine and marine episodes respectively in the basin. Current models find little basis for this.

The lower McMurray member is probably the least known and least understood. That is because it is the early fill in the basin and regionally constrained to the deepest parts of the entrenched valley basin. Many lease/study areas in the basin, especially in south Athabasca, rarely encounter the lower McMurray. Where present in subsurface or outcrop, the lower McMurray is easily recognised since it is capped by facies of an alluvial plain consisting of paleosols, coals, organic-rich muds, heavily rooted horizons, and coarse grained fluvial channels. It is the only known interval to date that has yielded non-marine trace fossils.

In our experience it is the middle and upper McMurray members that generate the most debate, have been most studied, and for which there are multiple, competing working hypotheses. The

most popular working hypotheses for the McMurray Fm. are perceived to be threefold, -referred to here as: the Super-channel Model, the Incised Valley Model and the Delta Model.

The Super-channel model contends that the middle McMurray is dominated by auto-cyclic migrating channels 40 to 50 m deep filled by a single genetic unit of point bars and thalweg sands.

The Incised Valley Fill hypothesis is an extension of the superchannel model wherein the channels are thought to be lowstand incisions, such that the migrating channels sediments are true Incised Valley Fills. This implies the presence of multiple unconformities in an extremely complex relationship throughout the McMurray sedimentary package. In most manifestations of the IVF model, the incisions are initiated higher up, hanging from within the upper McMurray or even younger units of the Wabiskaw Member (Clearwater Fm.), such that the incisions cut relatively deeply through almost the entire middle Murray.

We remain biased towards a third working hypothesis, the Delta model, which suggests that the McMurray sedimentary package is mainly regressive/progradational in response to multiple, incremental episodes of sea level rise. In this model the system is thought to have been dominated by tidal processes during the middle McMurray when the basin had a confined, elongate morphology, but evolved to wave/fluvial influences in the upper McMurray, when basin topography had attenuated to large open bays with long fetch. Where sedimentation rates are high, aggradation has resulted in overthickening. In the Delta model the main reservoir sands are, nonetheless, thought to be a transgressive system tract. Furthermore although there may be incision events in the upper McMurray, these are not observed to be extremely deep incisions, and many can be interpreted as autocyclic and not exclusively due to sea level drop.

The upper McMurray of our stratigraphic scheme is probably of prime importance to the understanding of McMurray stratigraphy, primarily for the presence of easily recognised, stacked, parasequence sets showing classic coarsening- and shallowing- upwards development of a wave/fluvial progradational system. The parasequences are bounded by transgressive surfaces of erosion and flooding surfaces expressed by widespread regional marine muds. Various studies have mapped out the areal extent of individual parasequences, and there appear to be at least three making up a stacked set; (six if one includes similar parasequences known as the Wabiskaw "A", "B", and "C" sands). The parasequences probably result from deltaic lobes and shorefaces prograding into shallow, somewhat brackish, high stand bays at upper McMurray time. Where well-developed in various parts of the basin, both outcrop and subsurface, the entire parasequence set is in the range of 20 to 27 m. Each parasequence ranges from 7 to 9 metres in thickness.

The importance of the upper McMurray parasequence sets is at least twofold: they provide evidence for the range of incremental sea level rise; and they provide a "background" stratigraphy -presumably highstand, to which other basin events can be related.

We conclude from the presence of the parasequences that sea level rise was "stuttering" upwards incrementally in the range of 8 to 12 metres per episode (taking into account sediment compaction). Some published and unpublished studies invoking the IVF model propose a drop in base level at the top of each upper McMurray parasequence. This is the basis for invoking deep incised valley fills. Some incisions are interpreted to be in the range of 50m or more and to include as fill, the reservoir sands and estuarine point bars of the middle McMurray. Such a model sets up a basin scenario of an asymmetrical "yo-yo" sea level history where small increases in sea level are followed by multiple large sea level drops with deep incisions.

There indeed seem to be incisions through the upper McMurray parasequences, recognised in core and well logs where the coarsening/shallowing upwards signature of the parasequence is missing and replaced by anomalous and more complex facies. These may be of two sources: in some instances these can be show to constitute autocyclic facies equivalents, (e.g. a distributary channel extending through a wave/fluvial delta front). In other cases the interpretation and facies relationship is not obvious and may indeed result from incision due to sea level drop. It is this interpretation that is at the heart of the deep incision - IVF working hypothesis.

At some outcrops there are filled incisions in the upper part of the McMurray. These are observed to be relatively thin: 8-12m in thickness, and not in the 40 to 50 m range. These incisions are easily recognised where they cut somewhat into the estuarine point bar beds (IHS) at the top of the middle McMurray (e.g. Hangingstone outcrop). It should be emphasize here that the IHS beds are never observed to be incision fills themselves. They are observed in outcrop and seismic to be preserved scroll bar deposits resulting from channel migration repeatedly incising and cannibalizing more-or-less contemporaneous point bars.

No simple parasequence sets have been recognised in the middle McMurray. This may be because of a strong meso-, possibly macro-tidal influence on the middle McMurray, in contrast to the upper McMurray parasequences in which evidence of strong tides is lacking. Intense tidal ravinement is likely to have removed any direct evidence for sea level rise in middle McMurray time in the basin. In general, but with many exceptions, the middle McMurray of the current stratigraphic scheme is dominated in outcrop by two major facies associations: 1) thick sets of lateral accretion beds generally known as "IHS", widely accepted as being brackish point bars preserved in a large estuarine system; and 2), almost always underlying the IHS, thick sandy bedsets of megarippled subaqueous dunes and bars. These clean dune/bar sands are one of the primary target reservoirs for bitumen recovery.

In the middle McMurray outcrops, we observe a regional erosional discontinuity between the IHS and the dune sands, a contention that is accepted by some researchers, but discounted by many others. Nonetheless we have observed the regional discontinuity between the IHS and the underlying dune beds in every outcrop where the host units are exposed, and yet by their nature (often sand-on-sand) the discontinuity is difficult to discern in core and well logs. In the Delta model, the presence of the discontinuity has become the main source of debate regarding the relationship of the IHS and the dune beds. One interpretation is that the dune sands represent the transgressive systems tract in a basin that was strongly tide-dominated due the elongate basin configuration at the time of middle McMurray. Since younger parasequences in the upper McMurray imply 8 to 12 m incremental sea level rise, it is reasonable to assume the same magnitude of incremental sea level rise in the middle McMurray too, a magnitude approximately equal to the tidal range at the time. The dune/tidal sands then migrated up valley on transgressive phases. (Indeed it is our empirical observation that many of the mega-rippled dune fields in outcrop appear to flow-oriented dominantly towards the south, i.e. the flood direction.) In some of the major tributary basin valleys on the west side, it is difficult to comprehend where the source sand may have come from except up the mouth of the basin valley. Drainage along the western tributaries was mainly off of the carbonate highlands making up the western watershed of the Athabasca basin, and there is no obvious source of siliciclastic sediment from the west except perhaps for minor biogenic silica.

A key component of the superchannel working hypothesis is that IHS point bars are continuous into the underlying the dune sands such that the IHS are the point bars accreting into thalweg sands of the of the high energy traction load of a very deep (30-50m) channel. If the observation of a regional discontinuity between the Dune sands and the IHS is a reality, then the superchannel model is considerably compromised. A further difficulty for the superchannel model is that in outcrop the IHS beds are rarely observed to be continuous point bars from top to bottom. They are subtle but discrete sets of channel fills that erode and cannibalize each other both laterally and vertically. Most are seen to be channel fills in the range of a few to perhaps 8 metres in thickness.

The Incised Valley Fill Model is extensively used in subsurface lease studies. Yet it is difficult to interpret thick valley fills anywhere in the McMurray outcrops. There is certainly a strong argument that the IHS estuarine point bars do not themselves constitute elements of an incised valley fill. If Incised valleys do exist, they are probably incising the middle McMurray IHS point bars, and concentrated more in subsurface south Athabasca where they cannot be examined in outcrop.