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ELEMENTS OF A STRATIGRAPHIC FRAMEWORK FOR THE McMURRAY FORMATION IN SOUTH ATHABASCA AREA, ALBERTA

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Abstract

It is a common belief that the sand bodies constituting the potential reservoirs in the McMurray Formation are extremely heterogeneous and almost impossible to correlate. This makes exploration difficult and limits recovery schemes to the few areas that contain thick channel sands.

A new stratigraphic framework is proposed for the McMurray Formation of south Athabasca. Detailed log correlations from 1700 wells demonstrate that stacked, prograding, shoreface parasequence sets that can be regionally correlated over the entire southern Athabasca Oil Sands Deposit. These parasequence sets represent highstand systems tracts. They are best preserved in the south, and are also preferentially preserved towards the top of the McMurray Formation. However, the dominant depositional elements in the basin are lowstand channels incised into the parasequence sets. During sea level rise, these channels are filled with a transgressive estuarine facies complex, consisting dominantly of sandy to muddy estuarine point bars. The basal fill of some of the deeper channel valleys consists of freshwater fluvial point bars.

Statistical facies analysis, using clustering techniques and Markov analysis, differentiates a large database of facies descriptions into three major successions that correspond closely with the proposed stratigraphic framework for the McMurray Formation. These successions are interpreted as: 1) a simple coarsening-upward shoreface succession 2) a complex of interrelated channel fill deposits and 3) rooted paleosols. The top of the McMurray Formation appears to be an erosion surface and may be a sequence boundary.

Introduction

The consequences of understanding the McMurray Formation of northeastern Alberta cannot be overstated. It is the main reservoir for the Athabasca Oil Sands Deposit and hosts one of the largest hydrocarbon accumulations in the world. Unfortunately, the reality faced by every geologist who undertakes a study of the McMurray Formation is that these Lower Cretaceous sediments appear to be amongst the most complex depositional systems in the Western Canada Basin. Even with good quality cores and geophysical logs from closely spaced wells, which in some cases may be only a few hundred metres apart, lithostratigraphic units within the McMurray Formation are difficult or impossible to correlate for any significant distance (Carrigy, 1971; Mossop, 1980; Flach, 1984).

Most published studies on the facies and stratigraphy of the McMurray Formation in the Athabasca Oil Sands Deposit deal with relatively local areas, typically over a potential production site (*e.g.* Benthin and Orgnero, 1977; James and Oliver, 1977; Nelson and Glaister, 1978; Knight *et al.*, 1981; Dekker *et al.*, 1984; Rennie, 1987; Beckie and McIntosh, 1989). Almost all of the available data are from the subsurface, although a few excellent outcrop exposures exist in the northeastern part of the deposit (Fig. 1).

The main objective of this study was to resolve the stratigraphy and sedimentology of the subsurface McMurray Formation on a regional scale. Given the perceived complexity of the stratigraphy and the apparent difficulties in correlation, it was evident that small study areas supported by only a limited database were inadequate to identify the principal stratigraphic features of the McMurray Formation. It was therefore proposed that the acquisition and analysis of a very large database of well logs and core descriptions could reveal "significant" stratigraphic horizons and sedimentological trends, either through simple observation using advanced digital displays, or through the use of statistical techniques.

In a formal statistical sense, "significance" is partly dependent on the number of samples or observations of a population. With this in mind, data was collected from as many wells as possible (but limited to a maximum density of one well per section), over a wide regional area (Fig. 2). This data density and the size of the regional study area are larger than that of any previous published study, and if it is possible to discern a regional stratigraphic scheme for the McMurray Formation, this approach would seem to have the highest potential for success.

Only one other notable regional study has been published on the Athabasca Oil Sands, that is the work of Flach (1984),

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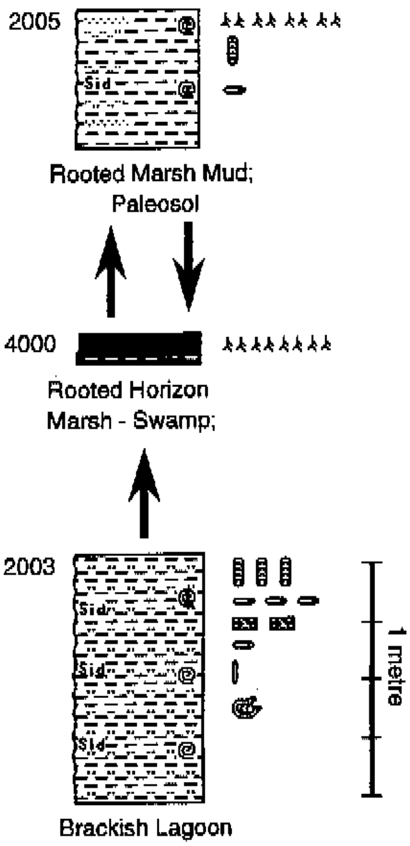

Fig. 9. Significant succession of facies resolved from Markov analysis with 95% confidence, and interpreted as marsh/lagoon overlain by rooted horizons, coal swamps, rooted marsh mud and oxidized muddy paleosols. For legend see Figure 15.

and the Wabiskaw Member is not obvious on the gamma-ray logs or any other log, and this horizon had to be tied into the core observations. The contact is almost always distinctive in core, being characterized by a change in mineralogy from the quartz arenite of the McMurray Formation to the glauconitic litharenite of the Wabiskaw Member. There is also a distinct change in ichnofossil assemblages from a stressed, apparently brackish assemblage in the McMurray Formation to a robust, apparently more fully marine assemblage in the Wabiskaw Member. The sub-Cretaceous unconformity also is rarely recognisable on the gamma-ray logs, but is distinctive on density logs.

Despite the commonly held belief that there are no regionally correlatable horizons in the McMurray Formation, the processed, standardized, digital log displays reveal that several regional shale units are readily discerned (Fig. 10). Furthermore, these shales bound stratigraphic units whose log signatures are distinct and relatively persistent over a wide area, in both an east-west (Fig. 10a) and north-south direction (Fig. 10b). The three upper stratigraphic units are especially obvious. These are here termed the "red", "green" and "blue" intervals from top to bottom, rather than assigning rank designation because additional study may allow further subdivision. These intervals can be correlated over much of the south Athabasca area. Both the upper "red" and the lower "blue" units have a distinct gamma ray signature indicating that they constitute, for the most part, a simple coarsening upward interval, 8 to 12 metres in thickness. The middle "green" interval has a more complex log signature, and may represent amalgamated units. The upper "red" interval, which constitutes the top of the McMurray Formation, appears to have an erosional upper boundary (see Fig. 10b, well 14-18-74-12W4).

The distinct signatures of the three units cannot, however, be correlated through all wells without fail. There are many areas where the signature is anomalous, suggesting that the correlatable unit has been eroded. Maps of the distribution and thickness of the three intervals demonstrate this (Figs. 11, 12, 13). The areas in black are areas where the gamma ray signature is anomalous. These anomalous signatures indicate a wide variety of fining upwards, sandy, shaly or heterogeneous fills with no discernible pattern. Many of the wells with anomalous signatures form contiguous linear areas suggestive of incised valleys a few kilometres wide and up to 75 kilometres long (*e.g.* Fig. 1 along Twp. 77).

Discussion

The results of the facies analysis and the regional gamma-ray log correlations complement each other and suggest a new, comprehensive, stratigraphic framework for the McMurray Formation. The McMurray Formation did aggrade due to Early Cretaceous sea-level rise, but the standard belief that the overall vertical record reflects a transition from fluvial through estuarine to marine is a gross over-simplification.

The McMurray Formation accumulated as a series of thin parasequences, 8 to 12 metres in thickness, consisting of prograding shoreface deposits that are probably the result of eustatic sea-level fluctuation. The McMurray sub basin developed near the craton at the eastern edge of the foreland basin, on the opposite side of the basin from the actively subsiding foreland trough, and underwent relatively little subsidence. Given little accommodation space during each sea-level rise, shoreface deposits probably prograded rapidly and over long distances. Little is known of the rates and volumes of sediment input, but the McMurray valley system did drain a major part of west-central Canada, which included large tracts of Jurassic siliciclastic sediments, and all of the southwestern Canadian Shield during late Aptian to early Albian time (Ranger, 1984). One may thus surmise that the basin was not starved.

Ichnofossil evidence indicates that the basin never reached fully marine conditions during aggradation of the McMurray Formation. This is probably due to the restricted nature of the northern part of the basin caused by the convergence of the Grosmont High in the west and the Canadian Shield in the east. The continued influx of fresh water from the McMurray valley system even during highstand sea level induced brackish conditions, and the constriction in the basin prevented rapid dispersion into the Boreal Sea to the north.

Additionally, because of the low rate of subsidence, even a minor sea-level drop would have wide-reaching effects, expos-

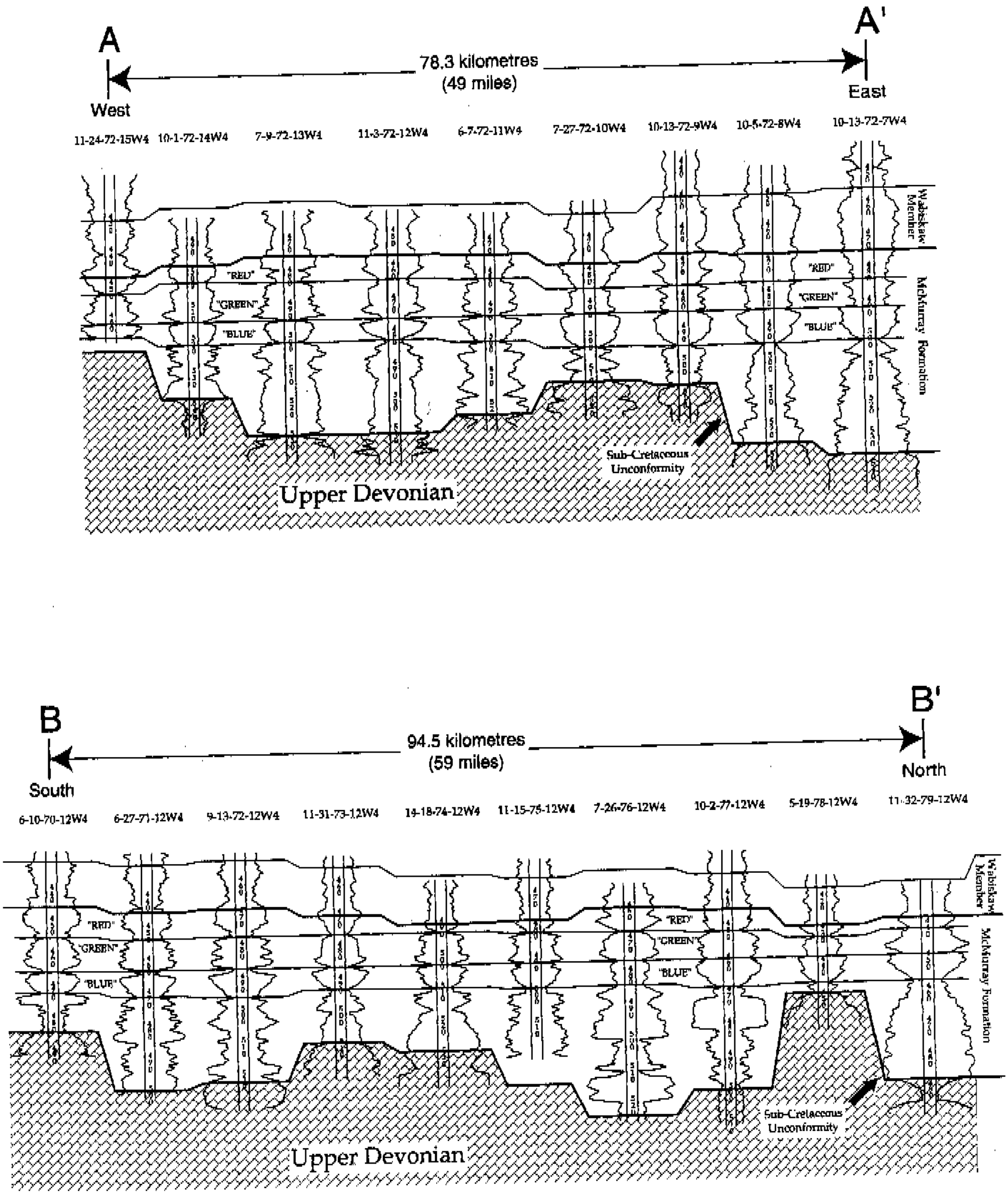

Fig. 10. These cross-sections demonstrate the existence of regional, correlatable parasequences or parasequence sets in the McMurray Formation. Three are shown here designated "Red", "Green" and "Blue", which have been mapped over the entire South Athabasca area (Figures 11, 12 and 13). For convenience, the datum is the top of the "Blue" parasequence. The log curves are twinned gamma-ray plots in mirror image, which greatly facilitates the visual correlation of the shapes. For locations, see A-A', and B-B' in Figures 11, 12 and 13. A-A' East-west cross-section across township 72 at one well per township. B-B' North-south cross-section across range 12 at one well per township.