Cyclic Sedimentation and Three-Dimensional Stratigraphic Architecture in Point Bar Deposits, Cretaceous McMurray Formation, Alberta: Implications for Reservoir Characterization and Heterogeneity Prediction

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The Cretaceous McMurray Formation is the most volumetrically important bitumen-bearing unit of Alberta's Athabasca Oil Sands deposit. Point bar deposits (PBD's) account for a significant proportion of the subsurface reservoir, and are characterized by bedded, sandstone-dominated strata with a net:gross ratio that, in some parts, approaches 1.0. In-situ development of subsurface reservoirs is accomplished through steam assisted gravity drainage (SAGD). This method is sensitive to interbedded siltstone beds which are locally common in the formation. The objectives of this study are to sedimentologically and statistically assess the spatial distribution of siltstone beds, which affects the transmission of steam through the reservoir and subsequent bitumen recovery.

The McMurray Formation consists of an amalgamation of numerous large-scale depositional elements including point bars developed through downstream migration, point bars developed through lateral migration, counter point bars, sandstone-filled channels, and abandoned channels. This research documents lithological cyclicity within sediments in a point bar that developed through both lateral and downstream migration (Fig. 1A). Numerous studies have identified cyclic features within heterogeneous sediments, particularly those deposited in shoreline environments along lakes and oceans. Recognizing cyclicity in the rock record helps geologists to understand some of the mechanisms controlling deposition and aids modelling of fluid flow and heat transfer. Nonetheless, there are depositional environments where cyclicity is less expected because the results of naturally cyclic processes may be erased by later erosion and redeposition. Fluvial deposits often lack well-developed cyclicity because of erosion and redeposition of sediment by a river as it meanders and, when near coastal regions, reworking by tidal processes.

The three-dimensional architecture of the point bar is delineated by a series of 30 high-quality 3-D seismic time slices in 1 ms intervals (e.g., Fig. 1A). Individual point bars in the study area are approximately 10 km^2, and the dimensions of the channel examined, ~30 m deep and 500 m wide, are well constrained by seismic and well data. Approximately 100 tightly-spaced wells penetrate the studied point bar deposits of the McMurray Formation. Investigation of cores through the point bar deposit led to the assignment of 7 lithofacies based on sandstone/siltstone content and physical and biogenic structures. Contour maps for ten successive three-meter vertical intervals through the point bar sequence were constructed by averaging gamma radiation values from digital logs. These maps provide a lithological basis for interpreting both depositional and sedimentological trends across the point bar deposit. Approximately 5-10 m of the uppermost point bar strata is interpreted to be either muddy abandoned channel deposits or mud plug sediments deposited during channel abandonment (Fig. 1B) while the lowermost 20-30 m of the point bar strata is bedded, sandstone-dominated strata (Fig. 1C).

From qualitative examination of cores and geophysical logs, lithological cyclicities are evident within the upward-fining 30 m thick packages of point bar deposits. Statistical analysis of wireline logs using correlograms, Fourier transforms and wavelet transforms demonstrate cyclicities of varying strengths in both gamma radiation and density porosity logs over wavelengths ranging from 1-10 m in the spectra. The origins of these well-defined cycles are most likely attributable to: (1) seasonal shifts in point bar sedimentation; (2) inter-annual climatic variations (e.g., El-Niño Southern Oscillations) with periods of 7 years or less; and/or (3) depositional fluctuation related to celestial sunspot cycles (~11 year period). Maximum Fourier component amplitudes at various wavelengths in each well were contoured to demonstrate locations on the point bar where lithological cyclicity is best preserved. These maps indicate that depositional cyclicity is most pronounced in the muddy portions of point bars, including: (1) distal, downstream areas, including counter point bars, and (2) the youngest scrolls, which were less exposed to erosion (Fig. 1D).

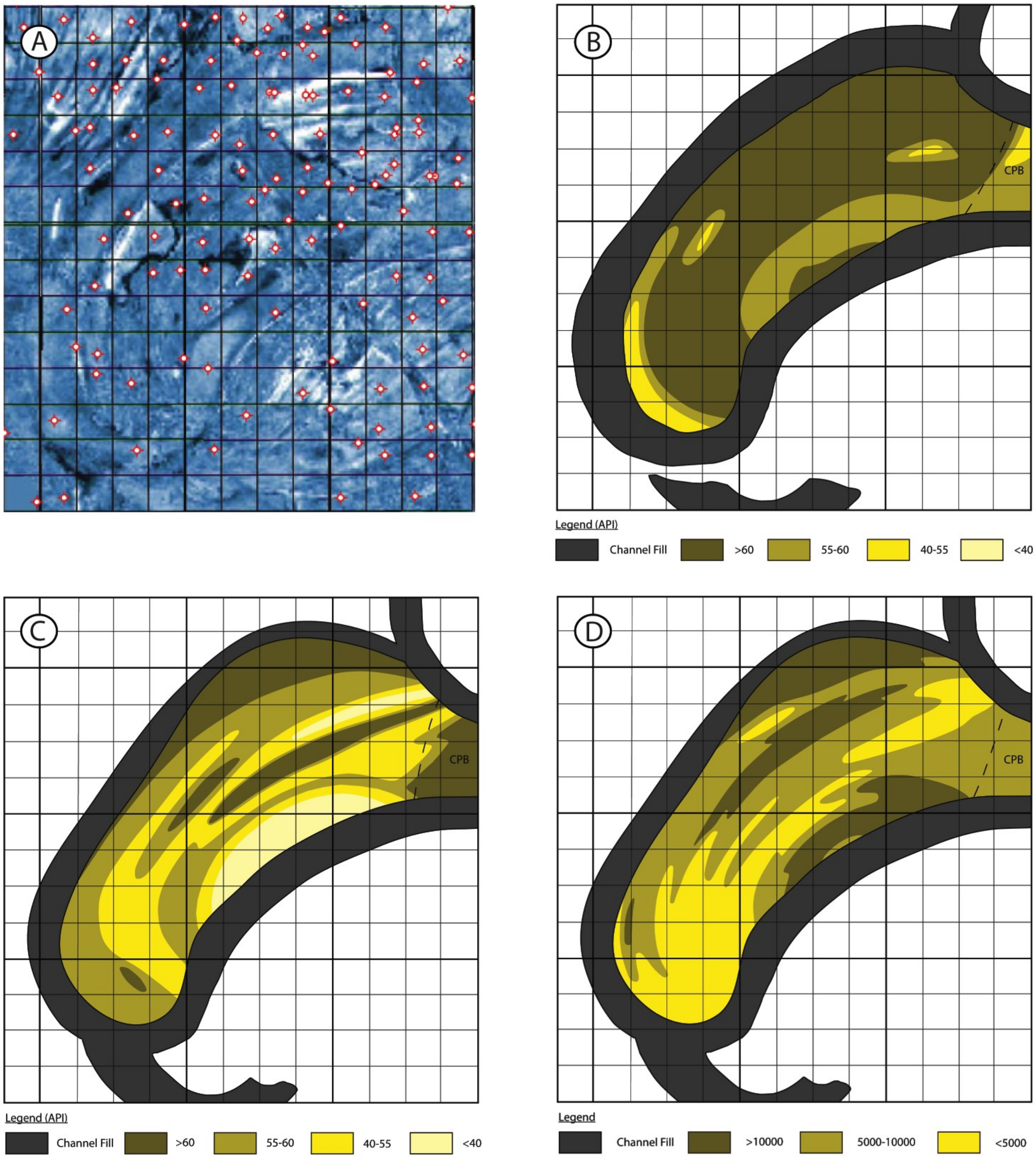

Fig. 1. (A) High quality 3-D seismic time slice of a point bar developed through lateral and downstream migration. Overall paleoflow direction is northward. (**B)** Contour map based on data from wells showing gamma radiation variability (proxy for lithology) in an interval 6-9 m below the top of the point bar sequence. Contours tend to follow the scrolls that are visible in the time slice in Fig. A. A sandstone cutoff of 60 API was used. This map shows muddy deposits over most of the point bar, representative of mud plug and abandonment sediments deposited late in the evolution of the point bar. CPB = Counter point bar. **(C)** Contour map showing gamma radiation variability in the interval 12-15 m below the top of the point bar sequence. The dominant lithology is sandstone, and mudstone is generally limited to the youngest meander scrolls in the system, and distal, downstream parts of the point bar where current energy was lower. (**D)** Contour map showing the maximum magnitude of the Fourier component at the 10 m wavelength across the point bar. Fourier Transform analyses were conducted on each gamma radiation log in the study area, and essentially, the stronger the cyclic signal, the higher the count measured in each well. This map shows that cyclicity is best preserved in muddy, downstream deposits where current energy was lower and the sediments were less exposed to erosion.