Reservoir Heterogeneity and its Effect on SAGD Oil Production from the McMurray Formation, Christina Lake Area, Alberta

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ABSTRACT
The Christina Lake property is located in the southern Athabasca region and is comprised of 37 sections of land centered in T76, R6W4 (Fig1), where EnCana has a 100 % working interest in the Oil Sands leases. The Oil Sands are primarily contained within the McMurray Formation. The McMurray Formation is the basal unit of the Lower Cretaceous Mannville Group, and is unconformably bounded by the Paleozoic carbonates at the base and by the Wabiskaw Member of the Clearwater Formation at the top (Fig2).

Sedimentation of the McMurray Formation was strongly controlled by topographic relief developed on the sub-Cretaceous unconformity, where the unconformity represents a prolonged period of subaerial exposure and erosion (Figure 3). Salt dissolution along the edge of the Prairie Evaporite Formation produced the deepest part of the Main Valley and exerted a primary control on the location of the major northward flowing fluvial system (Wightman et al., 1995). Transgression of the Boreal Sea established estuarine channel and marine shoreline environments that are represented in the middle to upper portion of the McMurray Formation. A relative drop in sea level at the end of McMurray Formation time resulted in the incision of valleys and the subsequent relative rise in sea level initiated deposition of the Wabiskaw Member (Wightman et al., 1995).

The McMurray Formation is informally subdivided into three units; lower, middle, and upper in ascending order. In the Christina Lake area, the McMurray Formation lies at about 330m to 400m in depth and varies in thickness from 60m to 90m. Bitumen rich intervals prevalent in the middle and upper units and the thickest oil sands are comprised of stacked channel deposits. Gas is present in both the middle and upper units and can be in direct contact with thick oil sands. Bottom water of variable thickness is present in the lower unit, but is often separated from the overlying oil sands by a thin mudstone bed.

EnCana’s Oil Sands project at Christina Lake (Fig1) was initiated in 1996 and the current production exceeds 5,000 barrels per day with four SAGD (steam assisted gravity drainage) well pairs. Of these, one well pair is still in the early stages of production and an additional two well pairs will be drilled in 2004.
Delineation wells were drilled on a minimum spacing of 400 m (16 wells/section) and an average of 6 wells per section were cored. In addition, three observation wells were drilled for each SAGD well pair. Formation Micro Imager (FMI) or Dipmeter (SHDT) logs were run, along with the standard logging suite, for every well, producing paleocurrent data for detailed reservoir characterization.

In the Phase I area, the reservoir is composed of stacked estuarine channel deposits with several lithofacies. As a result, the reservoir is inherently heterogeneous, and delineation of the reservoir and its facies distribution requires detailed geological and geophysical evaluation. The reservoir lithofacies include cross bedded sands (Fig4a) and sandy inclined heterolithic strata (IHS); (Fig4b). The muddy IHS facies (Fig4c) is considered non-exploitable. The cross bedded sands have high porosity (35%) and permeability (7 Darcys) and are considered to be the best facies for SAGD production. The reservoir quality of the sandy IHS lithofacies is inversely proportional to the thickness and frequency of the interbedded mudstones. However, bioturbation of the mudstones may enhance reservoir quality to some extent.

Cross bedded sands and IHS lithofacies of the McMurray Formation are well recognizable with FMI data (Fig5). Figure 5a illustrates the cross bedded sands within the middle McMurray unit where cross bedding dips about 25 degrees. The flow direction for this particular unit is westward. Figure 5b shows the IHS where the beds are mainly dipping less than 10 degrees towards the northwest.

3D seismic data was acquired over the current area of interest. In addition, time-lapse 3D seismic, crosswell seismic, and EM (electromagnetic) surveys have been conducted over the four currently producing SAGD well pairs to monitor the steam growth and its movement in various facies. Crosswell seismic profiles show detailed reservoir characteristics of the McMurray Formation. The high resolution data is critical to identify thin mudstone beds and their lateral and vertical distributions, which form permeability barriers in the reservoir. These reflection images depict the severe heterogeneity of the reservoir and rapid facies changes within the complex channel system. Figure 6 illustrates a crosswell up-going P wave reflection image of profile TO16 - EM13 (left) and surface 3D seismic for the same location (right). The most striking feature of this profile (left) is the delineation of the muddy IHS units in the Upper McMurray channel deposits.

For the SAGD process, both oil production and steam consumption rates are controlled by the growth rate of a steam chamber in the reservoir. The steam chamber growth rate is strongly influenced by the vertical and horizontal distribution of the facies described above throughout the reservoir. It is therefore crucial to delineate and map reservoir facies in detail. The integration of geological and geophysical data is necessary to develop a detailed reservoir model that reservoir engineers can utilize in planning the development of the Christina Lake project.
Reference

Figure 1 Christina Lake Property
Figure 2 Stratigraphic column of the Mannville Group and surrounding strata in Northeastern Alberta (from Wightman et al, 1995)
Figure 3  SW_NE Structural Cross-section (A1 Pair)
Figure 4 Various Lithofacies within McMurray Formation

4a Cross bedded Sands 106/11-16-76-6W4 377m
4b Sandy IHS 106/11-16-76-6W4 352m
4c Muddy IHS 103/5-16-76-6W4 354m
Figure 5  FMI showing examples of different facies: (a) Cross bedded Sands at 8-15-76-6W4 and (b) IHS at 3-10-76-6 (Depth in meters)
Figure 6 Crosswell up-going P wave reflection image of profile TO16 – EM13 (left) and surface 3D seismic for the same location (right).