Implications of Reservoir "Compartments" on the design and execution of the Christina Lake Thermal Recovery Project

John Cody*, Sung Youn, Aldean Riddy, and Simon Gittins
PanCanadian Resources, 150 – 9th Avenue, S.W. P.O. Box 2850, Calgary AB

INTRODUCTION

The Athabasca Oilsands are the largest, relatively unexploited hydrocarbon accumulations in Western Canada. With declining conventional oil resources, attention is being directed to the economic extraction of bitumen locked in the oilsands, especially in those reservoirs too deep to be mined. A variety of extraction techniques have been employed to mobilize the bitumen and coax it out of the reservoir, most of these involve thermal processes and the most promising technology for application in McMurray Formation sandstones the south Athabasca area is Steam Assisted Gravity Drainage (SAGD). SAGD involves a pair of horizontal wells drilled through the reservoir, one to inject steam and one to produce the hot hydrocarbons and condensed water. At the Christina Lake Thermal Project, PanCanadian plans one of the initial commercial scale applications of SAGD technology.

This presentation will illustrate how the geological architecture influences the application of SAGD and how SAGD changes the degree of detail needed in reservoir characterization and modelling. The McMurray Formation reservoir at Christina Lake is stratigraphically and lithologically complex, consisting of stacked estuarine channels each characterized by rapid lateral and vertical facies changes. The key to effective reservoir development using SAGD is the recognition and mapping of these lithological changes, asses their potential as steam barriers and develop strategies to minimize their impact.

BACKGROUND

The Christina Lake Thermal Project is located in northeast Alberta, approximately 170 km south of Fort McMurray and 130 km north of Lac LaBiche off of Hwy 881, near the hamlet of Conklin (Figure 1). The lease area consists of 35 sections or 22,400 acres, the bulk of which lies Township 76, Range 6W4. The project is a three phase development scheduled to last approximately 30 years, with the first phase located in Section 16 currently under construction and scheduled to start production early in 2002.

The McMurray Formation is approximately 400m deep and has been delineated by 2D and 3D seismic and 105 boreholes including stratigraphic test wells, observation wells and gas production wells. The current estimate of total oil in place is approximately 3 billion barrels (476 $\times 10^6$ m^3) of very heavy, (8-10 degree API), viscous (>1 x 10^6 cp) oil that is immobile at reservoir conditions.

To effectively develop the reservoir, PanCanadian will use **S**team **A**ssisted **G**ravity **D**rainage (SAGD), an advanced form of thermally enhanced oil recovery pioneered by AOSTRA in 1984 in the McMurray Formation at the Underground Test Facility (UTF). In theory, SAGD is a simple process involving a pair of horizontal wells drilled in parallel with approximately 4-6m of vertical separation. Steam is injected in the upper well and rises into the reservoir, forming a steam chamber which heats the bitumen to temperatures above 200°C where the effective viscosity of the hydrocarbons is similar to a 40° gravity oil. The resulting hot bitumen and condensed steam, fall through the steam chamber and are produced in the lower well (FIGURE 2).

For the Geologist, SAGD imposes particular constraints on the scope of investigation and the degree of detail required in reservoir description and modelling. SAGD is a relatively passive process, operating with buoyant rise of steam through the reservoir and the gravity drop of the produced fluids to the lower production well. This means that SAGD is particularly sensitive to the effect of abrupt changes in vertical permeability caused by changes in lithology, the presence of laterally continuous shale stringers or small faults. In addition, the size of the steam chamber (approximately 100m wide) limits the degree of lateral communication around the shale with high viscosity, immobile oil – a true no-flow boundary (Figure 3).

GEOLOGICAL SETTING

The bitumen reserves are hosted in Lower Cretaceous (Neocomian/Aptian) McMurray Formation fluvial, estuarine and marginal marine sandstone, deposited in a major valley system draining eastern Alberta and Southern Saskatchewan. The McMurray Valley is a structurally controlled paleotopographic low formed by the dissolution or structural removal of underlying Paleozoic evaporites. The main valley and its tributaries are separated from other drainage systems to the west by a series of exposed Devonian carbonate highlands, including the Wainwright Ridge in Central Alberta and the Grosmont High further to the north. Christina Lake is situated in a major tributary system to the east of the Main McMurray Valley, the location of which is due to local faulting and salt collapse. This dissolution or structural removal allowed for structural subsidence before, during and after deposition of the McMurray reservoir sediments.

At Christina Lake, the McMurray Formation is typically 80-90m which can be subdivided into 3 mappable units – the Lower, Middle and Upper McMurray. The Lower McMurray is a typically water bearing sandstone unit preserved in the stratigraphically lowest areas on the Paleozoic unconformity. The Middle McMurray consists of series of stacked estuarine channels deposited in a relatively low accommodation setting that have coalesced together to form a sand dominated reservoir section 25 to 45m thick. The channel sands are poorly consolidated, often held together by the bitumen alone. Reservoir quality of the sands is excellent with porosity often in excess of 35% and permeabilities ranging from 2-5 Darcies. The Upper McMurray consists of three regional correlatable coarsening upward cycles deposited as tidal shoreline or tidal bay bars. In response to a relative drop in base level at the end of the second cycle, an Upper McMurray channel cuts 25-30m into the underlying Middle McMurray. The upper channel is much more tidally influenced than the Middle McMurray channels and is often more heterolithic and mud-prone. In Section 16, the Upper McMurray and the Middle McMurray stack together to form vertical interval in excess of 60m, with over 35m of vertically continuous net thermal pay.

RESERVOIR ARCHITECTURE AND THE NATURE OF RESERVOIR HETEROGENEITIES

The McMurray Formation reservoir in the Phase 1 area at Christina Lake consists of two stacked, large scale estuarine point bars. The Middle McMurray channel consists of an amalgamated meander plain at least 2.5 km wide. The point bar was likely 30m thick with the lower 15 to 20m currently preserved. The basal 10-15m is typically massive sandstone consisting of trough to tabular cross bedded, coarse to medium grained sandstone gradually overlain by a transitional zone of current rippled, fine grained sandstone and/or mudstone intraclast breccia (FIGURE 4). This sandstone unit is an excellent reservoir with high porosity (35%) and excellent vertical and horizontal permeability, often in excess of 5 Darcies. The sandstone interval is overlain by sand to mud dominated Inclined Heterolithic Stratification (IHS). IHS consists of rhythmically repeating cycles of sandstone and mudstone and is common in estuarine channels due to the effects of tides. Core examination shows IHS spans a continuum from ~95% sand on the point bar gradually up to completely silt and mud dominated on the upper portions of the tidal point bar.

The Upper McMurray channel is 25-30 m thick and consists of a mappable meander scroll approximately 1.75km wide with lateral accretion surfaces radially dipping into a mud-filled abandoned channel. The sediment fill in the Upper Channel is more variable with a basal unit of more poorly sorted cross bedded unit but occasionally the overlying IHS unit extends to the base of the channel, especially in areas near the abandoned channel mud plug. The Upper McMurray channel is more heterolithic and often more mud dominated reflecting greater estuarine influence and more accommodation space.

For effective planning and implementation of SAGD, the technical team needs to understand the lateral and vertical dimensions of the IHS shale beds and assess their effectiveness as baffles or barriers to steam. The orientation of the IHS beds can be mapped using dip meter information to determine the type of channels (laterally or vertically accreting) and to map the gross orientation of the meander plain. Outcrop and modern analogues indicate that the IHS beds can be laterally continuous along the dipping surface in the direction perpendicular to paleoflow and essentially horizontal parallel to flow. However, the nature and thickness of the mudstone beds will vary depending on depositional current energy and relative salinity fluctuations. Three types of sandy IHS are recognised, depending on the degree of bedding in mudstone layers.

Well bedded - Sandy IHS where the mudstone beds are not or only slightly bioturbated and where the primary bedding of the mudstone beds is still visible and coherent.

Bioturbated but Continuous - Sandy IHS where the mudstone beds continuous across the width of the core but are highly bioturbated with a variety of traces, including *Gyrolithes*, *Cylindricnus* and *Bergaueria*. The degree of bioturbation is important as it introduces sand and silt and increases the vertical permeability.

Discontinuous - Sandy IHS but instead of continuous across the core, the rhythmically bedded mudstone layers consist of "starved" mud-filled burrows, often consisting only of *Cylindricnus* burrows.

Discontinuous IHS beds tend to occur lower on the point bar where the depositional current energy was higher, scouring much of the mud away during flood conditions. The well bedded IHS beds may represent deposition further up on the point bar where more mud was deposited during slack water conditions than could be burrowed or removed during the subsequent flood stage or it may be the result of salinity fluctuations too great to allow for colonization by burrowing fauna.

The depositional model can be combined with dip meter information, seismic attribute analysis, outcrop estimates of shale bed continuity and analogues with similar reservoirs to construct a high resolution geostatistical model. This model can be integrated with core and well log petrophysics to construct multiple realizations of a 3D petrophysical model. Using these models the technical team can test various configuration of wells and well designs to maximize well pair productivity and plan future well pair location to most effectively develop the reservoir at the lowest possible cost. The reservoir model can be used as a foundation to properly interpret the results of direct and indirect reservoir monitoring once steam is injected and to tailor future well pairs and direct future development phases.

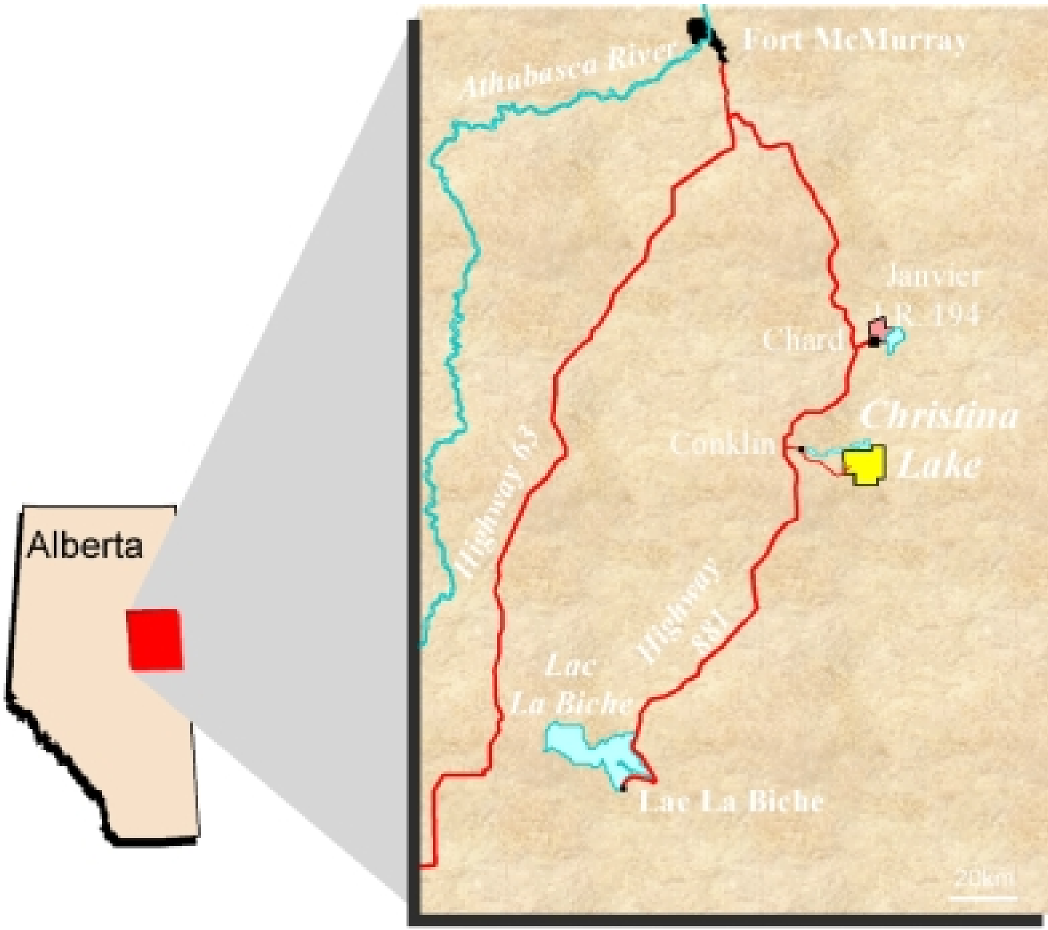

Figure 1. Location of the Christina Lake Thermal Project.

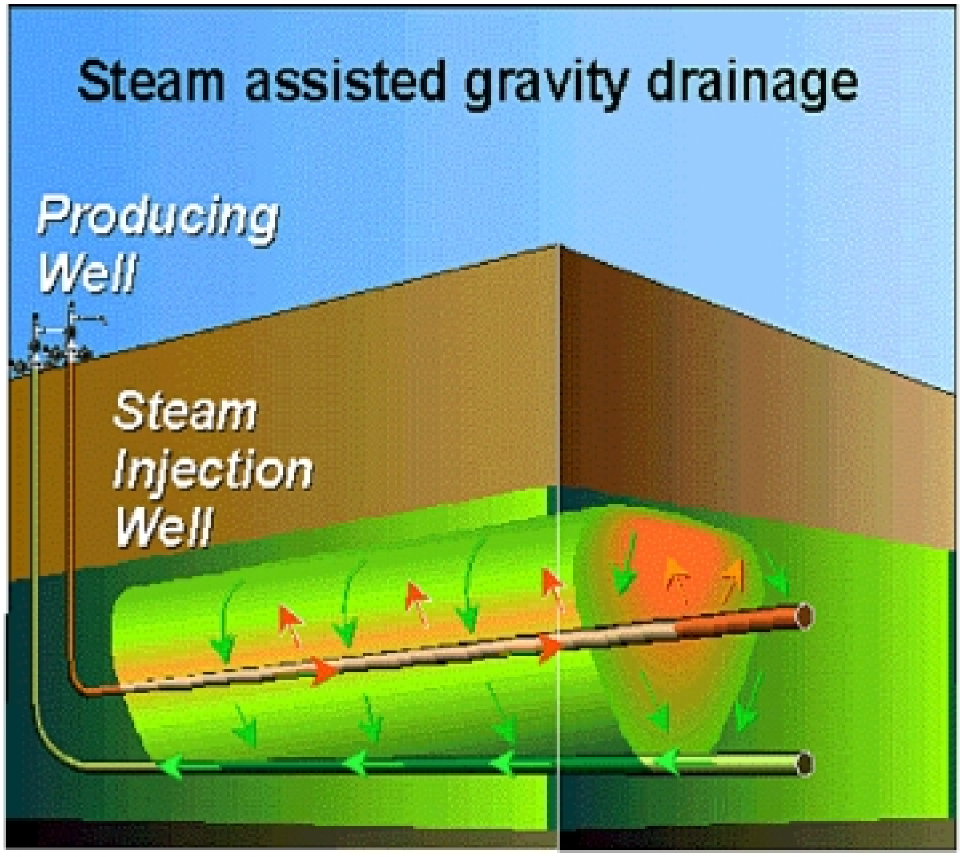

Figure 2. Schematic of a SAGD Well pair. Steam is injected in the upper horizontal well with the hot bitumen produced from the lower well.

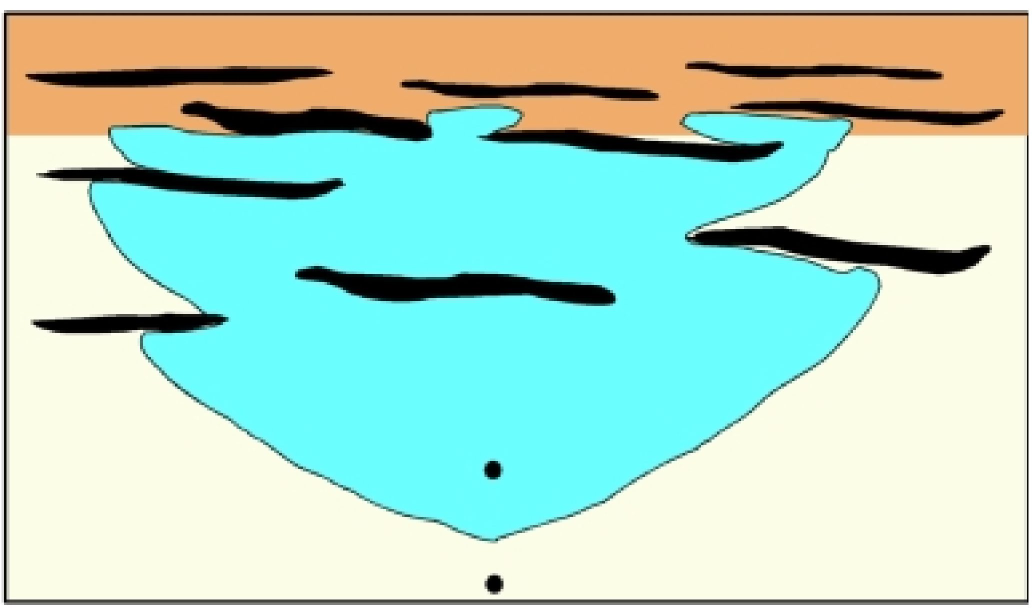

Figure 3. Schematic picture of a steam chamber in a heterolithic reservoir. Note how the steam cham ber goes around the edges of discontinuous shale barriers but the upper, more continuous shale beds are effective at limiting further steam rise.

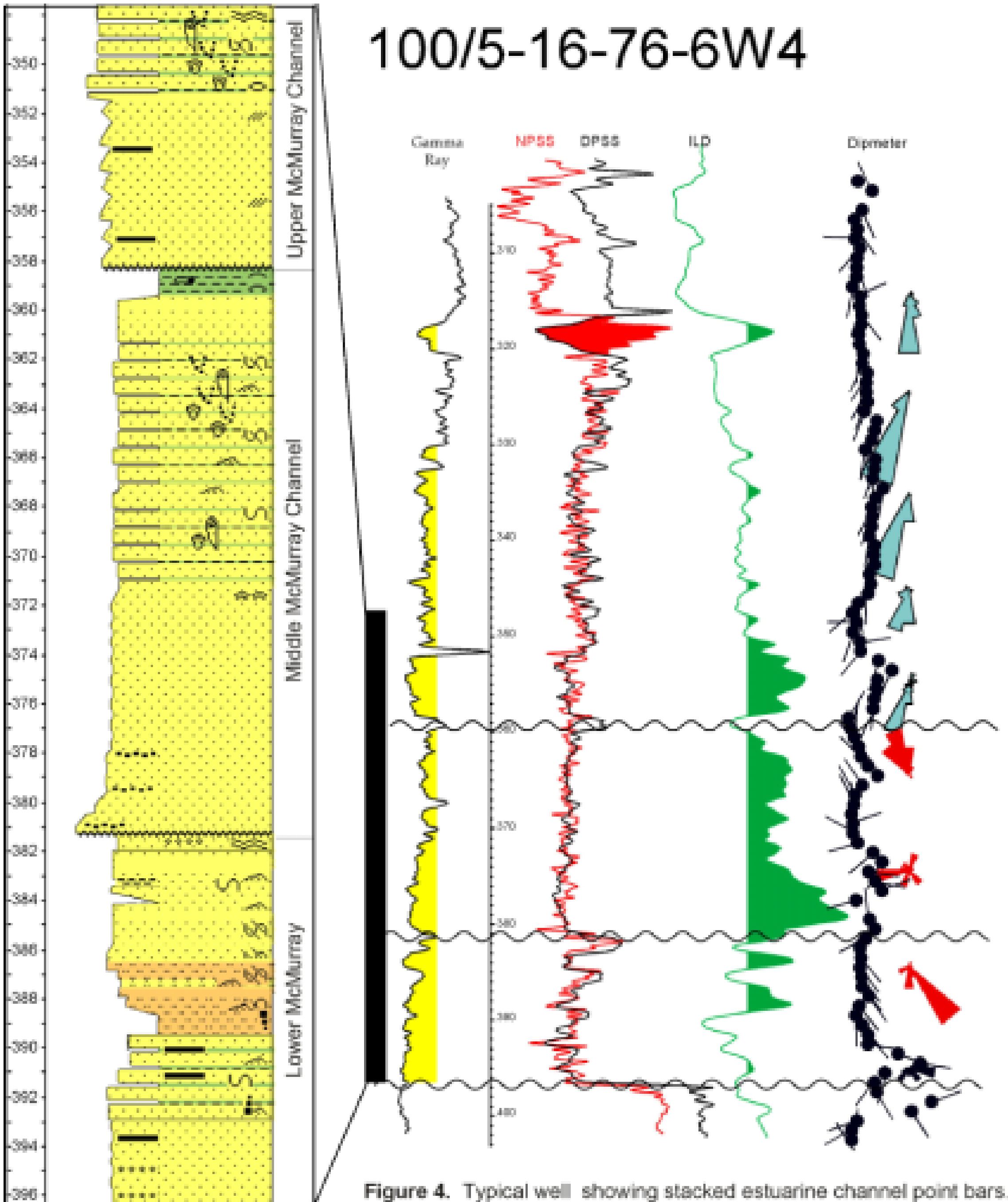

Figure 4. Typical well showing stacked estuarine channel point bars. Note the different the dip direction of the two channels.