AAPG Datapages/Search and Discovery Article #90174 CSPG©2014 CSPG/CSEG/CWLS GeoConvention 2012, (Vision) May 14-18, 2012, Calgary, AB, Canada

Carbonate Concretions in a Stratigraphic Framework, Clearwater Formation, Cold Lake Oil Sands, Alberta

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The Lower Cretaceous Clearwater Formation is a bitumen reservoir near Cold Lake, Alberta. The study area in Township 65, Range 2 west of the 4th meridian is part of the Taiga Project proposed by Osum Oil Sands Corp. On a regional scale, the Clearwater Formation has been previously interpreted as a set of nested valley fills. In the study area there are three superimposed sand-rich intervals of which the medial example forms a potential steam-assisted gravity drainage (SAGD) reservoir. Carbonate concretions are abundant near the base of the SAGD target; therefore, understanding the origin and distribution of the concretions is needed to optimize horizontal well placement. Furthermore, interpreting the formative processes governing concretion growth may allow for predictions to be made concerning continuity and the impact of these features on connectivity between injection and production wells, adjacent well pairs, and adjacent pads.

Concretions were investigated at three scales: megascopic, mesoscopic, and microscopic. At the largest scale, 3D seismic was used to map significant surfaces. At the mesoscopic scale, three cores from three wells were logged at a centimeter scale with the data incorporated into a Petrel™ model to correlate sedimentary units between twelve adjacent wells. At the microscopic scale, fifty-five thin sections of concretions were described and eight samples of calcite cement were analyzed for oxygen stable isotope ratios.

Within the SAGD reservoir there are two stratigraphic units, a high-net-to-gross heterolithic sandstone overlain by a homolithic sandstone. Log correlation shows the homolithic strata is 9 m (+/- 1 m) thick and present throughout the study area with a base 14 m (+/- 1 m) below the base of the laterally persistent shale that forms the uppermost Clearwater bed. In the Petrel™ model, the heterolithic reservoir is a maximum of 15 m thick with the base imaged with a seismic reflector; the ‘base pay reflector’. The vertical and lateral boundaries between heterolithic reservoir sediments and low-net-to-gross heterolithic sediments are coincident with this reflector. Where the heterolithic reservoir unit is not present, the ‘base pay reflector’ marks a vertical transition from homolithic sediments to non-reservoir heterolithic sediments. The most common occurrence of concretions is within 1 m of the ‘base pay reflector’ in heterolithic sediments.

The heterolithic reservoir unit is fine-grained sandstone with fluid mudstones, mudstone drapes, bioturbated mudstones, and current ripples. Non-reservoir heterolithic sediments are fine-grained and dominated by bioturbated mudstone interbeds. Homolithic deposits are very-fine grained, mainly well-sorted, and exhibit low-angle and parallel laminations interbedded with rare fluid mudstone.

Concretions are composed of multiple generations of calcite cement with fibrous, pore-filling and isopachous needle textures. Mud laminae are observed deformed into fibrous cement which is encased in pore filling cement. Isopachous needle cement occurs in bitumen saturated concretions. Oxygen isotope ratios for the three types of cement measured are: one sample of fibrous cement at $\delta^{18}O$ of 21.3‰ SMOW, five samples of pore-filling cement from 20.8 to 17.9‰ SMOW, and two samples of isopachous needle cement at 18.8‰ SMOW. These results are interpreted to reflect decreasing salinity of formative waters.

Heterolithic sediments are interpreted as tidal-fluvial deposits; homolithic sediments as wave-dominated deposits. The surface between these two strata is interpreted as a hiatus surface and a possible sequence boundary. Concretions formed in multiple generations starting within centimeters of the sediment-water interface and continuing to oil emplacement. Long residence in early diagenetic zones allowed for fibrous cements to precipitate providing nucleation sites. The permeability contrast at the ‘base pay reflector’ is interpreted as particularly susceptible to mixing of aquifers and repeated saturation and evaporation of pore waters. Lowering of base level associated with Clearwater and Lower Grand Rapids incision is advanced as the mechanism driving meteoric water influx.

Despite investigation at three scales, subsurface determination of specific concretion geometry and the lateral continuity of cemented intervals remain imprecise. The surface of exceptional concretion development appears mappable. Thus, Osum Oil Sands Corp. is planning to place the first SAGD wells above this horizon in order to eliminate any risk that cemented intervals inhibit vertical or lateral well connectivity.