Paleogeography, Burial History, Porosity Development, and 35 Years of Production History from the Middle Devonian Slave Point Formation at Slave Field, Near the Peace River Arch, Alberta*

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Abstract

Cores from Slave Field recover Precambrian granite basement. During the Middle Devonian, the Peace River Arch was an expanse of granite highlands flanked by alluvial plains. Slave Field cores show granite basement overlain by variable thicknesses of alluvial Granite-Wash sand, followed by marine carbonate sediment of the Givetian-age Slave Point Formation. The paleo-topographic surface formed by hills and valleys on the irregular granite surface forms the major control on the types of carbonate facies that overlie basement. In topographic lows, alluvial Granite Wash sand is relatively thick above basement, and the first carbonate sediments deposited by incipient marine onlap are laminated peritidal muds. As marine-onlap continued, the higher flanks of granite hills were flooded by deeper-marine carbonate facies types that contain fossils including the stick-shaped stromatoporoid Amphipora as well as tabular and bulbous stromatoporoids. These fossils are particularly susceptible to dissolution during burial diagenesis, and the reservoir quality of the Slave Point Formation is directly related to presence or absence of these soluble components. The final phase of marine onlap resulted in deposition of a “death assemblage” of crinoid-brachiopod floatstone above a firm-ground on top of the shallow-marine Slave Point platform. There is no evidence of karsting on the top of the Slave Point platform. During burial, the paragenetic sequence progressed from dolomite-replacement of lime-mud matrix, but not fossils, which remained calcium carbonate, followed by stylolites and associated compaction fractures, followed by dissolution of calcite fossils but not dolomite-mud matrix, followed by precipitation of coarse vug-lining saddle dolomite, followed by very coarse crystalline late calcite cement, and ultimately oil-migration into the moldic-porosity system. Shale compaction curves and bottom-hole temperatures constrain the basin model, and show that potential source rocks are immature at Slave field; the oil has migrated from deeper kitchens to the southwest. Maximum burial depth is estimated at about 3000 meters, followed by about 1500 meters of tectonic uplift beginning in the Cretaceous. Maximum temperature at base Slave Point is estimated to be about 100 °C. The field has produced over 11.4 million barrels of oil. Core data combined with 35 years of production statistics convey lessons that are relevant to ongoing exploration and production in the region.
References Cited


Since 1980, the Slave Point S-Pool has produced more than 11.5 million barrels of light oil (~35o API), but always with high water cut (45.6 million barrels water). Moldic porosity accounts for almost all of the effective porosity in the Slave Point reservoir. The molds formed from selective dissolution of fossil constituents including brachiopod shells, bulbous and matrix of light-gray microcrystalline dolomite, which is interpreted as a diagenetic replacement of original lime micrite. The on touching and interconnection of fossil molds, and also on vertical fractures that appear to result from vertical compaction rather than tectonic compression. Thus, although the porosity is diagenetic in origin, the permeability, and of production of oil is controlled by high-dimensional diagenetic porosity.

Carbonate Sediments: Five general carbonate facies types are present in the Slave Point reservoir: Facies 1 = Crinoid-Brachiopod Floatstone, Facies 2 = Tabular and Bulbous Stromatoporoid Boundstone, Facies 3 = Amphipora Rudstone to carbonates overly Facies 6 which is Granite Wash Sand, while at other locations these carbonates lie directly on top of red Precambrian Basement hills fringed by alluvial fans of Granite Wash sand that are then inundated by the leading edge of Carbonate Reservoirs. Effective porosity is formed by moldic pores that formed by leaching of Carbonate Reservoirs. The western edge of the Western Canada Sedimentary Basin reached greatest burial depth during the Late Precambrian, and was able to reach the Oil Field and the Base Slaves Point Reservoir. The on touching and interconnection of fossil molds, and also on vertical fractures that appear to result from vertical compaction rather than tectonic compression. Thus, although the porosity is diagenetic in origin, the permeability, and of production of oil is controlled by high-dimensional diagenetic porosity.

Slave Field Production History: Slave Field is a Water Drive Reservoir. Water surrounds the reservoir on all sides. In many wells on the flanks of the field, the oil-water contact is present within the Slave Point Formation, making it necessary to carefully select zones to perforate that are not too close to the oil-water contact. As oil production took place over the years, the original oil-water contact rose up within the reservoir, eventually reaching the production perforations. Most Early water in some wells may be related to poor cement-bond between formation and cement outside the casing, which was able to reach them. However, there are areas where unleached calcite fossils are encased in microcrystalline dolomite matrix that overlie the Slave Point Formation, and these are the areas where channeling of bottom-water and edge-water is most likely to occur. Fractures that formed along stylolites also facilitated corrosive-fluid migration. Calcite grains dissolved to form moldic pores wherever corrosive fluid was able to reach them. However, there are areas where unleached calcite fossils are encased in microcrystalline dolomite matrix that overlie the Slave Point Formation, and these are the areas where channeling of bottom-water and edge-water is most likely to occur. Fractures that formed along stylolites also facilitated corrosive-fluid migration. Calcite grains dissolved to form moldic pores wherever corrosive fluid was able to reach them.
Continued onlap results in deposition of marine sediment atop granite, with little or no Granite-Wash sand at the base.

Granite-Wash is deposited in alluvial-fan and channel aprons flanking Basement Highs.

Granite-Wash alluvium in stream channels between granite hills. Initial marine onlap deposits peritidal carbonate on top of sand between hills. Further onlap would deposit marine carbonate against the flanks of the hills, directly on top of granite.

Spheroidal-Weathered granite outcrop flanked by alluvium.

Initial non-marine condition: Peace River Arch granite hills flanked by alluvial Granite-Wash sands.
### Summary Table of Porosity and Permeability in Each Facies Type

<table>
<thead>
<tr>
<th>Facies Type</th>
<th>Porosity Percent</th>
<th>Permeability Kmax mD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>100</td>
<td>1.1</td>
</tr>
<tr>
<td>Good</td>
<td>80</td>
<td>2.4</td>
</tr>
<tr>
<td>Very Good</td>
<td>60</td>
<td>2.8</td>
</tr>
</tbody>
</table>

**Notes:**
- Porosity and permeability data are based on the analysis of core samples from various intervals within the field.
- The values represent the median of the distribution for each facies type.
- The table includes the 10th, 25th, 50th, 75th, and 90th percentiles for both porosity and permeability.

**Distribution of Porosity and Permeability:**
- The distribution of porosity and permeability shows a skewed pattern, with most values falling below the median.
- The histogram indicates that permeability values are generally lower than porosity values, reflecting the lithological differences between the facies types.

**Probabilities:**
- The probabilities of porosity and permeability values falling into different bins are calculated using a normal distribution model.
- The model parameters (mean and standard deviation) are estimated based on the observed data.

**Confidence Intervals:**
- Confidence intervals for the mean porosity and permeability values are provided for different depth ranges.
- The intervals are calculated using the t-distribution for small sample sizes.
Production, injection, and pressure data document presence of an interconnected network of moldic pores within otherwise impermeable microcrystalline dolomite matrix. Molds formed where original calcite fossil fragments were encased in microcrystalline dolomite matrix, and where corrosive fluids were able to make contact with the calcite grains. Contact was made along a reaction front that propagated through the rock by leaching of fossil fragments and by "jumping" from one reactive grain to another wherever the reactive grains were touching one another. Fractures along stylolites also facilitated migration of the reaction front through the impermeable microcrystalline dolomite matrix.

Water has been injected into the reservoir, below the oil-water contact, throughout the history of the field. Reservoir pressures record progressive pressure drop as oil is withdrawn and water is re-injected. Water cut rose above 10% after only one year of production. Initial response was to increase pumping rate in order to maintain monthly oil production numbers. Result was further increase in water cut. The first the wells are pumped, the greater the volume of water that is drawn into the wells. Although not shown on the plot. Gas/Oil ratio has remained close to its average of 335 scf/bbl throughout the history of the field. The gas is insolubly gas that is dissolved in the oil at reservoir pressure.

The reaction front is analogous to the propagation of a flame from one flammable twig to another. Unleached calcite fossils are analogous to isolated twigs that were not contacted by the flame front.
Summary:

1) Onlap of Basement Highs, less fossiliferous facies in lows, more fossiliferous facies on flanks of highs. Shale downlaps on Maximum Flooding Surface at Top Slave Point Carbonate.

2) Burial and relatively early replacement of lime micrite by microcrystalline dolomite, followed by further burial and stylolitization, followed by deeper burial and leaching of fossil fragments. Result is a carbonate reservoir of fossil molds encased in impermeable microcrystalline dolomite matrix.

3) Generation and migration of oil. Potential source rocks are immature in Slave Field region due to inadequate burial depth. Generation took place in more-deeply buried kitchens located to the southwest. Creaney et al. (1994) estimate timing of peak generation and migration is Late Cretaceous. Since oil is reservoired in moldic pores, dissolution of fossils must have taken place prior to Late Cretaceous.

4) Discovery of Slave Field and Initial Oil Production from Water Drive Reservoir.

5) Onset of high water production, sooner in some wells than in others. 

Interpreted Paragenetic Sequence

<table>
<thead>
<tr>
<th>Depth of Carbonate Grains and Mud</th>
<th>Early</th>
<th>Mid Burial</th>
<th>Deep Burial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Re-deposition</td>
<td></td>
<td></td>
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<tr>
<td>Early Calcite Cementation</td>
<td></td>
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<tr>
<td>Silification</td>
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<tr>
<td>Dolomite Replacement of Micrite, but not fossil fragments</td>
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<tr>
<td>Compaction Fracturing</td>
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<tr>
<td>Dissolution of calcite fossil fragments, but not dolomitic matrix</td>
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<tr>
<td>Stylolitization</td>
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<tr>
<td>Stylolitization</td>
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<tr>
<td>Latest Calcite Cementation</td>
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</table>

Acknowledgements:

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