A Geological Comparison of Six Projects in the Athabasca Oil Sands*

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Search and Discovery Article #20301 (2015)
Posted March 30, 2015

*Adapted from extended abstract prepared in conjunction with a presentation given at CSPG/CSEG 2004 GeoConvention, Calgary, AB, Canada, May 31-June 4, 2004,

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Abstract

Several projects in the Athabasca Oil Sands are in the pilot stage or early stages of commercial production using Steam Assisted Gravity Drainage (SAGD). Information on the projects may be gleaned from EUB applications, annual reports and conference presentations. Production data is also becoming available and cores from each project are now in the public domain. A search and compilation of available data provides a basis for the geological comparison of six of the most advanced projects. The projects selected for this comparison are Suncor Firebag, Petro-Canada MacKay, ConocoPhillips Surmont, EnCana Foster Creek, OPTI/Nexen Long Lake and EnCana Christina Lake. All of these projects are located in areas where there is good development of multiple stacked channels and estuarine sands within the middle member of the Lower Cretaceous McMurray Formation.

Suncor Firebag has the greatest reservoir thickness, up to 75m thick, with no top water and negligible associated gas. The reported oil viscosity is higher than in any other project, but this is offset by the coarse-grained nature of the reservoir and consequent lower residual water. ConocoPhillips Surmont has a reservoir thickness of up to 63m, but there is abundant top water and gas in contact with the reservoir. The reservoir also contains abundant shale clast breccia beds. OPTI/Nexen Long Lake contains bitumen reservoirs up to 50m thick, but exhibits the most geological variability of the six projects in terms of sand continuity, shale clast breccias, and flushed zones. The initial development areas at both Petro-Canada MacKay and EnCana Foster Creek contain about 30m of bitumen, but both projects contain slightly thicker areas to be exploited in later phases. The reservoir at Foster Creek is clean, but contains lower saturation flushed zones. At MacKay, the reservoir contains abundant shale clast breccia, but does not contain flushed zones. The shallow depth at MacKay will dictate maximum operating pressure. EnCana has reported excellent early production from their Christina Lake pilot, where the net pay ranges from 15m to 40m. Development will be complicated by relief on the sub-Cretaceous Unconformity and by a structurally complex bitumen to water contact at the base of the reservoir.

The clean channel and estuarine sands of the Middle McMurray are terrific reservoirs with porosities of 33 to 36% and permeabilities of over five darcies. Bitumen content in the best reservoirs averages 14 to 15 weight percent with oil saturations of 0.8 to 0.85. All of the six projects exploit reservoirs of this quality. What differentiates the projects are the continuity and thickness of the best quality sands, as well as the

presence or absence of shale clast breccia beds, top water, top gas and flushed zones. Many of these features are demonstrated in cross-sections and cores from the initial development areas of each of the projects.

Introduction

The Athabasca Oil Sands Deposit is the largest hydrocarbon deposit in the world. Until recently, the low API gravity and high viscosity of the crude bitumen caused great difficulties in extraction of the resource. Bitumen separation experiments by Dr. Karl Clark of the Research Council of Alberta during the 1920's had led the way to development of the world's two largest mines, run by Syncrude and Suncor, which together produce over 400,000 barrels of crude oil per day from the Athabasca Oil Sands. However, 90% of the resource lies too deeply buried to be surface mined, and could not be economically extracted until development of the steam assisted gravity drainage (SAGD) process. The SAGD process utilizes dual horizontal wells placed near the base of the reservoir, consisting of a steam injection well placed about five metres above a production well. Steam rises into the formation, heating the bitumen and lowering the viscosity. Bitumen then flows down under the force of gravity to the production well, where it is pumped to the surface. While it may seem obvious, topography of the Devonian surface may play a very important role in the selection of horizontal well locations.

While the SAGD process is relatively simple and very gentle on the formation, it is affected by areas of lower porosity or permeability in the reservoir. These "baffles" and "barriers" may delay or halt the movement of steam into parts of the reservoir. An additional problem is the presence of high porosity and permeability zones containing gas or water, which can act as thief zones for pressure and/or heat. Top water ("paleo-depleted" gas caps) can be especially detrimental. Within the bitumen zone, the reservoir is typically at maximum possible So; i.e. the sand grains being water wet, only irreducible residual water remains. However, it is not uncommon to encounter zones of higher water saturations, referred to here as "Flushed Zones", causing bitumen grade to tail off. Furthermore, it is not always a straightforward exercise to calculate bitumen grade from wireline logs alone; a major problem being highly variable, and often uncertain, Rw with depth in some areas. Core analysis is typically relied upon to provide more dependable data for bitumen grade.

Examining core provides visual confirmation of reservoir parameters and reservoir facies, which are otherwise only interpreted from the wireline logs. Shale clast breccias, a common and significant reservoir facies, cannot be reliably interpreted from wireline logs alone, and must be visually observed in core. Known intervals of shale clast breccia are shown on the cross-sections. However, wells where core was not available or was not examined may contain shale clast breccia intervals that are not shown on the cross-sections.

In order to understand and optimize the SAGD process, a thorough knowledge of the reservoir characteristics of each reservoir is necessary. Table 1 summarizes the reservoir character of each of the six project areas in this study. From a reservoir perspective, all of the pilot or commercial sites (Figure 1) have been developed in areas where there are thick intervals of multiple stacked channels and estuarine sands. Regionally, these may be difficult to identify and may require extensive exploration drilling.

The primary sources of data for the study are the applications for commercial project development, which have been submitted to the Alberta Energy and Utilities Board for each project. These documents become public once they are submitted. While the details of the contents vary, certain basic data are contained in each application. A commercial database of the oil and gas wells in Alberta was used for generating base maps, historical maps, core control, core analysis data, and information of well length and spacing of horizontal wells. An additional source of information is technical talks, conference presentations and journal publications. A majority of the reservoir information, such as depth, thickness, temperature, gas, water and flushed zones, and reservoir seals has either been generated from wireline logs or the logs were used to verify data from other sources. Certain information about some of the bitumen projects has become available through the gas-over-bitumen hearings before the EUB and has been incorporated into this report.

Suncor Firebag

The Firebag reservoir (Figure 2) exhibits significant lateral variation in reservoir thickness from 12m to over 65m. Locally, minor gas is present at the top of the McMurray Formation but is isolated from the reservoir. The Devonian surface exhibits moderate relief. The top of the bitumen reservoir in the McMurray Formation at Firebag lies at depths of 242m to 267m. The McMurray Formation ranges in thickness from 64m to 98m, and the bitumen reservoir within it is typically about 45m thick. It consists of stacked channels and estuarine sands whose grain size is coarser than any of the other projects in this study. Notwithstanding its thickness, the reservoir is remarkably clean, with very little interbedded shale. Porosity is reported to be 32%, but ranges up to 41% in the coarser intervals. Average bitumen saturation is given as 84% but can be as high as 97%. Native reservoir pressure is about 800kPa. Reported permeabilities are seven darcies horizontal and three darcies vertical.

The reservoir temperature is reported to be about 9°C but Bottom Hole Temperature logs commonly measure values in the range of 13°C to 17°C at the base of the delineation wells in the development area. Bitumen within the reservoir is very heavy, about 7° API, with a viscosity of about 6,000,000 centipoise, the heaviest of any bitumen reported here. The Firebag reservoir has no top water and only minor top gas, up to a maximum 3m. The middle of the reservoir contains minor flushed zones, and no gas or water. At the base, the bitumen reservoir sits directly on the Devonian limestone at the sub-Cretaceous Unconformity, with no basal water zone.

Petro-Canada Mackay River

At the MacKay River project (Figure 3), the reservoir averages 30m in thickness, becoming thinner and increasingly interspersed with shale towards both the north and south. The depth to the top of the reservoir is relatively shallow, averaging 95m. Gentle topographic relief can be observed on the Devonian surface.

The reservoir at MacKay River is the shallowest of the six projects studied, the top of the bitumen lying as shallow as 75m. Up to 37m of continuous bitumen pay is present in clean, uniform, stacked channels and estuarine sands within the central part of the commercial development. Shale clast breccias can make up as much as 25% of the reservoir. The reservoir becomes more shaly and interbedded toward the edges of the proposed development. Permeability is reported in the EUB application simply as 'high', but is expected to be similar to the best quality reservoir at the nearby Dover project where measured permeabilities have ranged as high as 8 to 12 darcies. Porosity is reported as 32% and bitumen saturation as greater than 70% in the EUB application. These are believed to be average values, and porosities above 35% and saturations as high as 90% may be present in the best sands.

Reservoir temperature at the base of the reservoir is about 16°C. The viscosity of the bitumen is about 1,000,000 centipoise. The reservoir is usually capped by shale, sometimes abruptly at the top of the good reservoir and sometimes in interbedded contact with the top of the oil sands. There is local top gas to the north of the commercial area, but it is not within the reservoir zone. Top water is rare and flushed zones are not known at MacKay River. The bitumen reservoir usually sits on the Devonian limestone of the sub-Cretaceous Unconformity, but up to 2m of basal water may be present.

Opti/Nexen Long Lake

The reservoir at Long Lake (Figure 4) exhibits extreme variability with numerous flushed zones, and the presence of both top and bottom water in local areas. The reservoir is approximately 40m thick including the presence of breccia zones, which may slow but not stop steam chamber development. Gas may be present in the upper McMurray both in contact with, and isolated from, the reservoir. Gentle variations in topographic relief of the Devonian surface should be noted.

The presence of a Quaternary age channel cutting down to the level of the Wabiskaw Member of the Clearwater Formation is an important point to note in well 1AA/02-32-085-06W4. Channel features on a scale such as this have only recently been identified and represent a concern to the regulatory authorities in terms of reservoir isolation and steam containment.

At Long Lake, the top of the McMurray Formation bitumen reservoir is found at depths of 165m to 220m. The McMurray Formation ranges in thickness from 47m to 118 m, while the bitumen reservoir ranges up to about 50 m, but averages 30m to 40m. Permeability is reported in the EUB application to be about 8 darcies in the horizontal direction, and vary from 0.2 to 4 darcies in the vertical direction, depending upon the amount of intercalated shale. Porosity of 35% and saturations of 85% are reported for the best parts of the reservoir. Reservoir temperature at the base of the reservoir ranges from 9°C to 16°C based on bottom hole temperature logs. The viscosity of the bitumen is reported to be about 5,000,000 centipoise.

The bitumen reservoir at Long Lake consists of stacked estuarine channels with very abrupt lateral facies changes. Shale clast breccia zones are common throughout the reservoir. The reservoir typically becomes increasingly interbedded with shale towards the top. Bitumen saturations are sometimes lower than expected in the sands in these interbedded sands and shales near the top. Overlying the interbedded sands and shales are thin, cleaner shoreface sands with good lateral continuity, which sometimes contain up to 6m of gas. Flushed zones are relatively common throughout the bitumen reservoir at Long Lake. These flushed zones are too irregular in distribution to be mapped, but they are more common in some areas than others. The base of the bitumen reservoir usually overlies either water sand or shale, with the occasional gradational or flushed zone.

ConocoPhillips Surmont

The Surmont reservoir (Figure 5) has abundant and widespread top water up to 12m thick and up to about 11m of top gas, which is often in pressure communication with the bitumen through the top water zone. The middle of the reservoir contains minor flushed zones. The base of the bitumen reservoir sometimes sits directly on the Devonian limestone at the sub-Cretaceous Unconformity, with no basal water zone.

Regionally, however, other wells have shale below the bitumen zone or as much as 20m of water sand. Elevation on the Devonian surface gently increases to the southeast.

The top of the bitumen reservoir at Surmont lies at depths of about 330m. However, the depth is quite variable as the surface topography is extremely rugged in many parts of the Surmont lease. The McMurray Formation ranges in thickness from 55m to 85m., while the bitumen reservoir within it is typically about 40- 45m thick, but can be 50m or greater in thickness. It consists of stacked channels and estuarine sands of fine to medium grain size. The reservoir in places is remarkably clean, with very little interbedded shale. However, areas of interbedded sands and shales are common, and shale clast breccia zones are abundant. Porosity is reported to be 35%, and average bitumen saturation is given as 80%. Permeability is given as greater than four darcies, but permeability measurements range much higher in some of the cleaner sands.

The reservoir temperature in the cluster of wells around the Surmont pilot averages about 16°C from bottom hole temperature measurements. However, these measurements were found to be dependent upon which geophysical logging company logged the hole, with Reeves recording the lowest temperatures around 9°C, Tucker and Computalog recording temperatures in the 23°C to 26°C range, and Schlumberger in the middle. The bitumen has a viscosity of about 1,000,000 centipoise.

EnCana Christina Lake

The Christina Lake reservoir (Figure 6) has widespread top gas within the Wabiskaw Member of the Clearwater Formation and within the upper beds of the McMurray Formation. Sometimes the gas directly overlies thick bitumen pay. The base of the bitumen reservoir sometimes sits directly on the Devonian limestone at the sub-Cretaceous Unconformity, with no basal water zone. However, other wells have shale below the bitumen zone or as much as 20m or more of water sand. Elevation on the Devonian surface is quite variable as the entire Christina Lake project sits within what EnCana has referred to as a tributary to the main McMurray valley lying to the east.

The top of the bitumen reservoir in the McMurray Formation at Christina Lake lies at depths of about 350m. The McMurray Formation ranges in thickness from 50m to over 85m., depending on where the well is in relation to the ancient valley. The bitumen reservoir is typically 30m thick, but can be up to 68m in thickness. It consists of stacked channels and estuarine sands of fine to medium grain size. The reservoir in places is clean, with very little interbedded shale. However, areas of interbedded sands and shales are common, and shale clast breccia zones are abundant. Porosity is reported on the EnCana website to be 33%, and average bitumen saturation is given as 85% and average permeability is eight darcies. The reservoir temperature in the cluster of wells around the Christina Lake pilot averages about 19°C from bottom hole temperature measurements. The bitumen is reported to have an API Gravity of 7.5 to 9º.

EnCana Foster Creek

Locally around the Foster Creek site, minor water or gas occurs in contact with the reservoir. Basal flushed and/or water zones may occur at the base of the reservoir (Figure 7). The horizontal well pairs have been placed within a basal flushed zone. There is almost no relief on the Devonian surface. The reservoir lies below 435m and the McMurray Formation ranges in thickness from 46m to 76m. Up to 31m of continuous bitumen pay is present in clean, uniform stacked channels and estuarine sands within the central part of the commercial development. The reservoir becomes more shaly and interbedded toward the edges of the proposed development. In the EUB application, horizontal permeability is reported as high as 5 to 10 darcies with vertical permeability in the 3 to 5 Darcy range. Porosity is reported to be 33%, but ranging as high as 38%; and bitumen saturation at 80%.

Reservoir temperature is recorded by EnCana as 12°C, but measured bottom hole temperatures range up to 24°C. The viscosity of the bitumen is in the range of 200,000 to 1,000,000 centipoise. No reservoir pressure measurements were found from within the McMurray Formation. The reservoir is usually capped by shale, sometimes abruptly at the top of the good reservoir and sometimes in interbedded contact with the top of the oil sands. There is minor top gas but it is not widespread. Most of the gas production from the area is from shallower horizons. Flushed zones are common at Foster Creek at both the top and base of the reservoir and therefore the richest bitumen saturation is present through the middle of the reservoir.

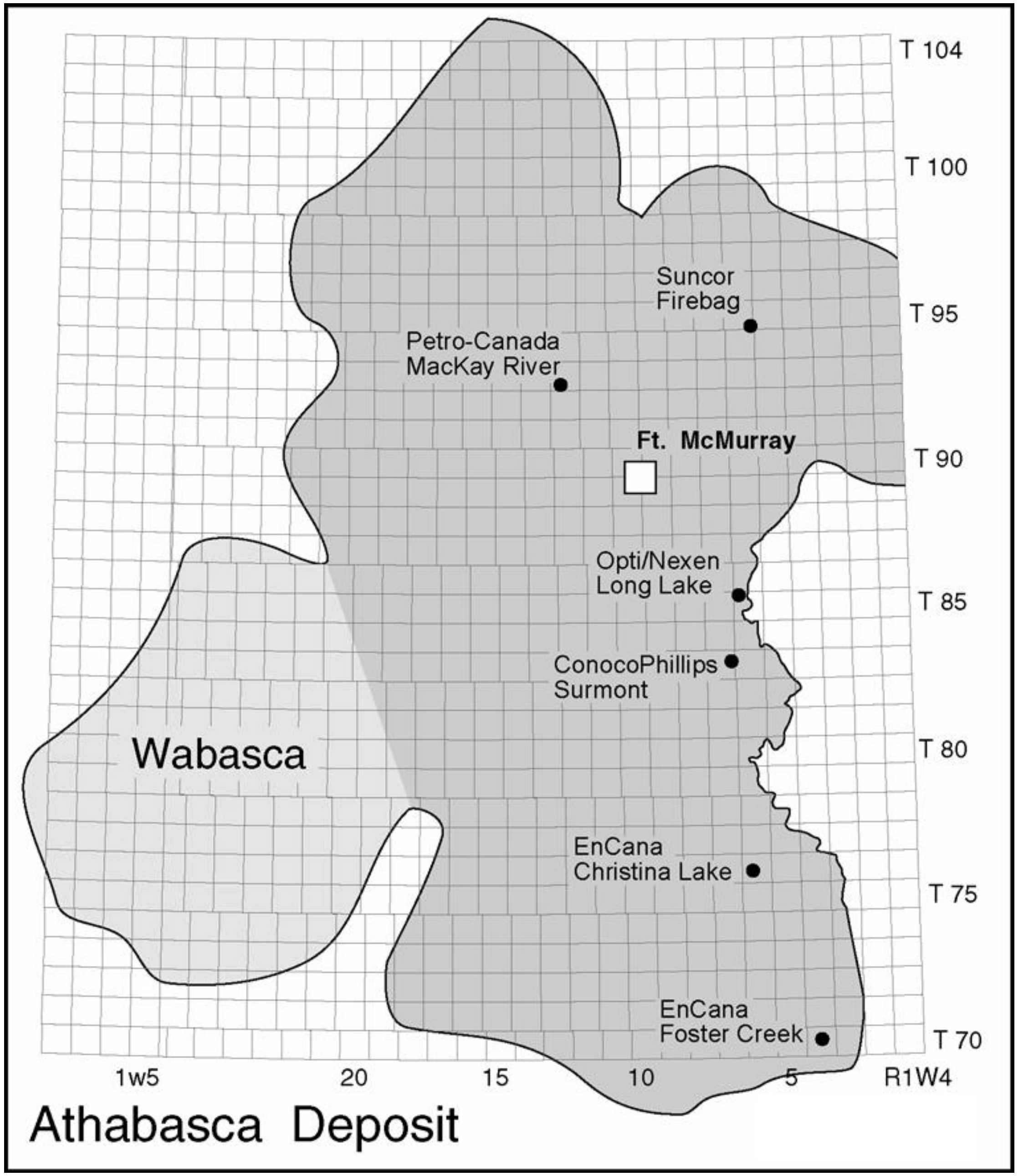

Figure 1. Core Location Map.

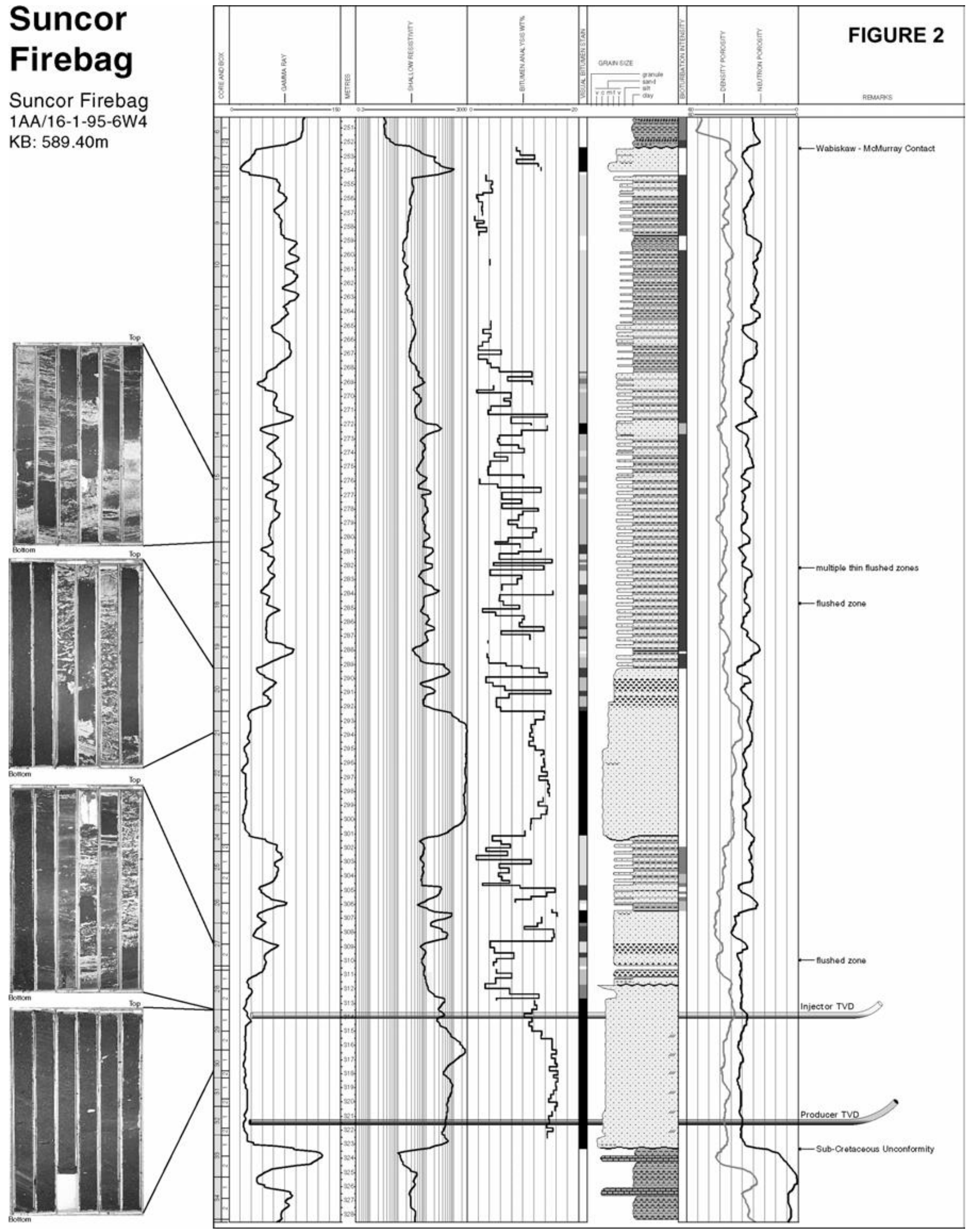

Figure 2. Suncor Firebag log.

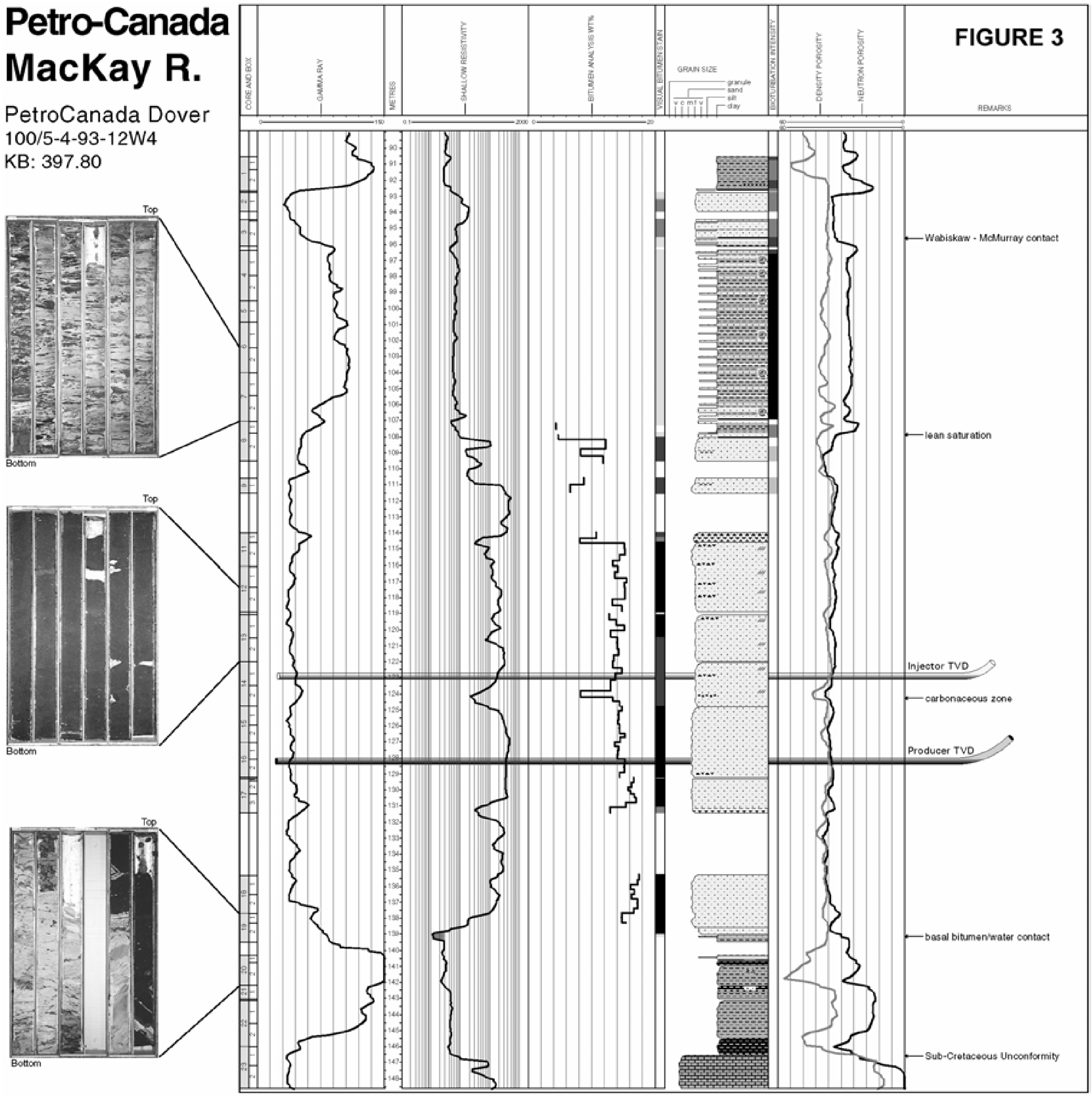

Figure 3. Petro-Canada MacKay River log.

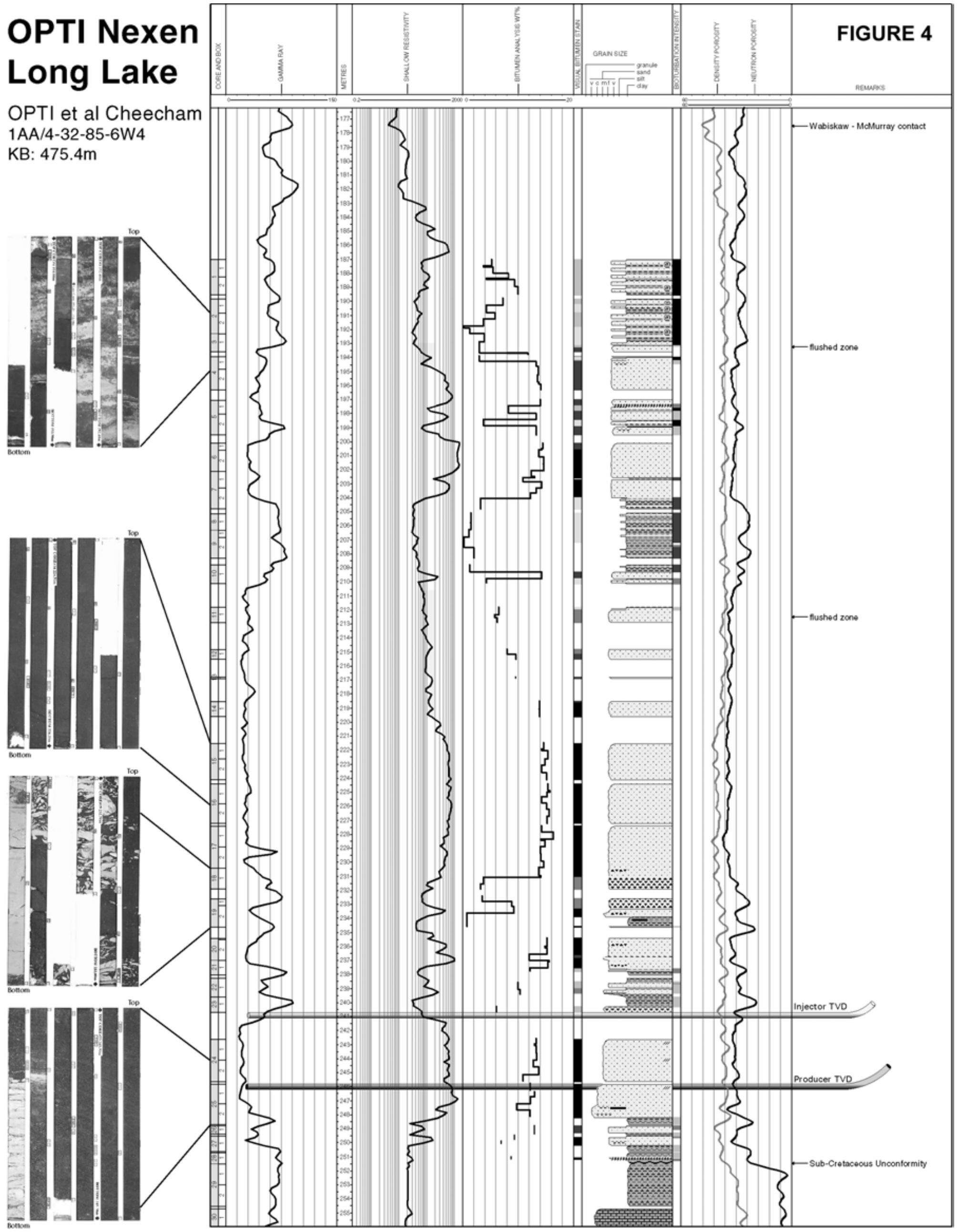

Figure 4. OPTI Nexen Long Lake log.

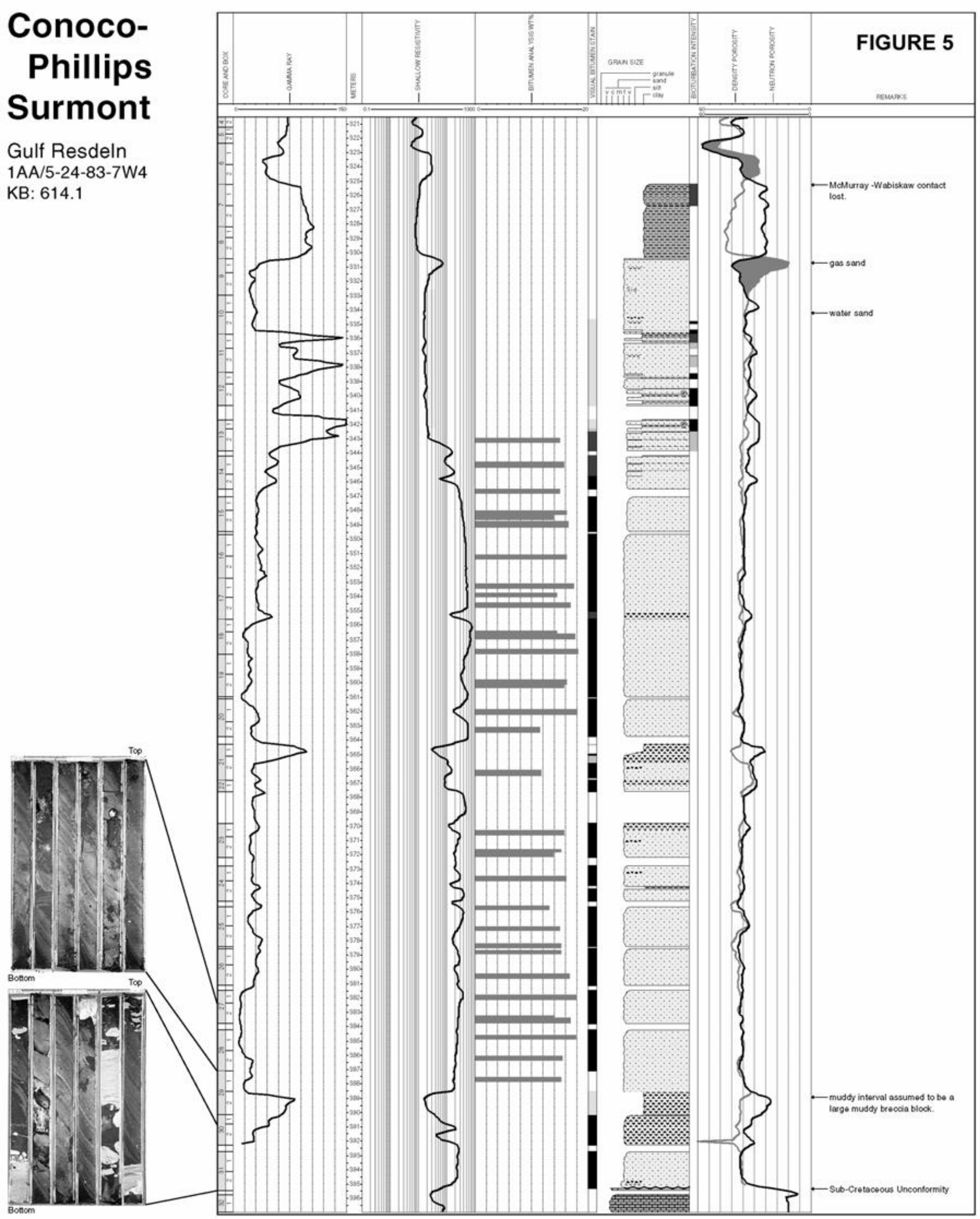

Figure 5. ConocoPhillips Surmont log.

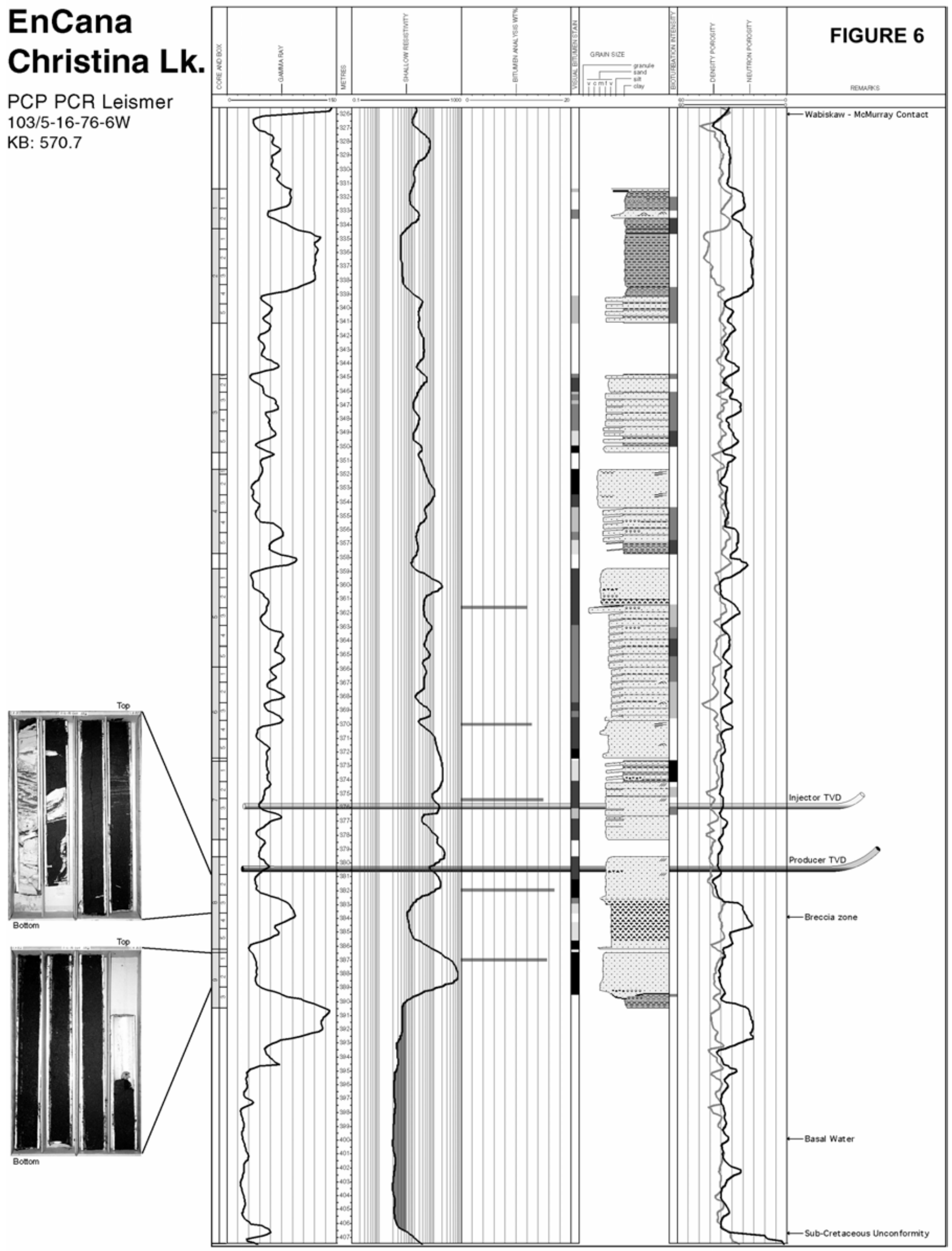

Figure 6. EnCana Christina Lake log.

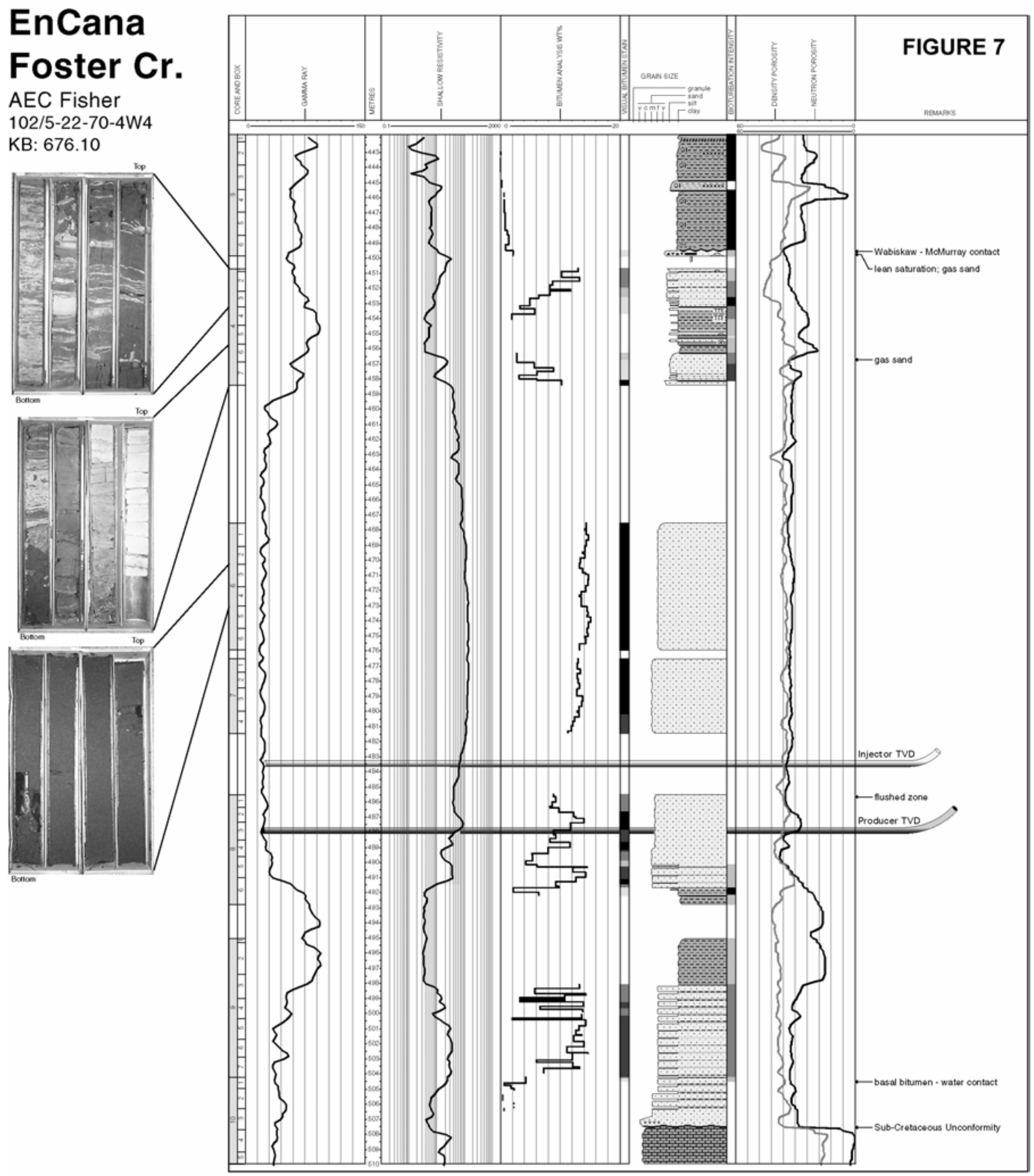

Figure 7. EnCana Foster Creek log.

RESERVOIR PROPERTIES						
	Christina Lake.	**Firebag**	**Foster Creek**	**Long Lake**	**MacKay**	**Surmont**
Reservoir Depth (m)	350	250	435	200	95	330
Wt.% Bitumen	15	15	14	14	14	14
S_o (Calc.)	.85	.84	.8	.85	>.7	.8
S_w (Calc.)	.15	.16	.2	.15	<.3	.2
Porosity	.33	.32+	.33	.35	.32+	.35
Permeability (Darcies)	8	7	5+	8	High	4+
1st Development Thickness	46	65	30	36	30	58
Maximum Thickness	68	75	31	50	37	63
Top Gas	Yes	Minor	Minor	Occasional	No	Yes
Top Water	No	No	Minor	Yes	No	Widespread
Bottom Water	Yes	No	Yes (Flushed)	Minor	Rare	No
Flushed Zones	No	Minor	Yes	Yes	No	Minor

Table 1. Reservoir properties comparison.