Recognizing Potential in the Bitumen Saturated Dolostones of the Upper Devonian Nisku Formation through Comparison with the Grosmont Formation*

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Abstract

The Grosmont-Upper Ireton-Nisku Devonian succession in northeastern Alberta is estimated to contain 508 billion bbl (80.8·109 m^3) of bitumen. Pilot testing of the Grosmont is demonstrating the commercial production potential of these reservoirs, which stand to become some of the largest carbonate fields in the world. Comparison of Grosmont reservoir characteristics with Nisku reservoir characteristics, using two selected core intervals, reveals a number of important similarities and differences that are important to understand when evaluating Nisku potential.

Introduction

The Woodbend-Winterburn succession in northeastern Alberta is estimated to contain more than 500 billion bbl of bitumen and constitutes the largest carbonate-hosted bitumen deposit in the world. Whereas the resource in the Grosmont Formation (~406 billion bbl) has been well-documented for a number of years, only recently has the resource potential of the Nisku Formation been described; in 2012 the ERCB revised their bitumen resource assessment of the Nisku Formation from ~65 billion to >100 billion bbl of bitumen in place, an upwards revision of 57% (ERCB ST98-2012). A production pilot at Saleski (operated by Laricina, 40% joint venture with Osum Oil Sands) is currently demonstrating the producibility of the Grosmont bitumen. Based on results from the pilot, Osum has proposed a 60,000 bbl/day commercial development in Township 85, Range 18W4, called Sepiko Kesik. As the Grosmont emerges as one of the largest carbonate fields in the world, assessment of the Nisku-hosted bitumen includes comparison of its reservoir attributes with the better understood and pilot-tested Grosmont Formation. It is found that dolostones in especially the lower part of the Nisku Formation share a number of important attributes with bitumen-saturated dolostones of the Grosmont Formation, including significant development of vuggy porosity, intense fracturing, and brecciation. Differences between the two formations include reservoir distribution and matrix porosity. Reservoir characteristics of the Nisku Formation are demonstrated with one of Osum's recently off-confidential Nisku wells (1AA/03-16-085-20W400) and compared with a "typical" Grosmont Formation well (1AB/07-19-085-18W400) from the Sepiko Kesik project.

Stratigraphic Overview

The study area (Figure 1) is located halfway between Peace River and Fort McMurray. It is characterized by a gently west-southwesterly dipping ~800 m thick homoclinal succession of Devonian strata sharply overlain by a ~ 350 m thick horizontal succession of Cretaceous and Quaternary deposits. The sub-Cretaceous angular unconformity separates the two sequences and from west to east successively truncates the Nisku, Upper Ireton, and Grosmont formations to 0 m thickness (Figrue 2). The middle Devonian Prairie Evaporite Formation in the study area is approximately 190 m thick and located west of the salt-dissolution edge such that deformation of the Upper Devonian succession by evaporite karst, as seen in the Fort McMurray area for example, is not present. There is, however, variable meteoric karst topography at the sub-Cretaceous unconformity that impacts the Grosmont and Nisku formations in the study area.

The study area is subdivided into the Sepiko Kesik area for characterization of the Grosmont C reservoir and Saleski West for characterization of the Nisku Formation (Figure 1). At Sepiko Kesik, the Grosmont Formation is ~110 m thick and is subdivided in ascending order into the Grosmont A, Grosmont B, Grosmont C, and Grosmont D units (Figure 2), following well-established regional subdivisions for the Grosmont Formation (Harrison, 1982; Cutler, 1983). Whereas the Grosmont A and Grosmont B units are limestone to variably dolomitized limestones, the Grosmont C and Grosmont D units consist of argillaceous dolostones and dolostones with intermittent marl deposits (e.g. a marl divides the C and D units from each other). The overall succession is a shallowing-upwards succession of shallow marine to peritidal and sabkha-type facies associations from a restricted west facing ramp environment that existed in an equatorial arid to semi-arid climate.

At a regional scale the Nisku Formation is ~ 90 m thick and can be informally divided into lower and upper units; the lower unit consists of vuggy dolostones and the upper unit consists of interbedded dolostones and argillaceous dolostones with intermittent marl deposits. In the Saleski West area, the Nisku Formation is 15-40 m thick depending on proximity of the zero thickness subcrop edge, and only the Lower Nisku Formation and lower part of the Upper Nisku Formation is preserved (Figure 2). The succession was deposited in a variably open to restricted inner ramp position characterized by very muddy (lime mud), sparsely fossiliferous depositional environments that were overall shallowing upwards after an initial major flooding event.

Grosmont C Reservoir Characteristics

The Grosmont C reservoir at Sepiko Kesik is an essentially flat, stratiform, 17-18 m thick reservoir that is underlain by low porosity argillaceous dolostones of the Lower Grosmont C (non-reservoir) and overlain by bitumen-saturated, variably brecciated dolostones of the Grosmont D (Figure 2 and Figure 3). Average porosity is 20% and average horizontal permeability is ~ 1,200 mD, although this is believed to underestimate true reservoir-scale permeability due to the difficulty in collecting intact samples from fractured, vuggy core that are suitable for analysis. Average bitumen saturation is 85%. The key reservoir facies (Figure 3) are (1) vuggy dolomudstone, (2) sucrosic dolostone, and (3) laminated to thin-bedded dolostone. Vertical permeability is enhanced by vertical to sub-vertical fractures.

Grosmont C Reservoir Facies at 7-19

1) Vuggy Dolomudstones – pervasively dolomitized lime mudstones with open and connected vuggy porosity (vugs typically 0.5-2 cm across). Alteration haloes around vugs are associated with enhanced matrix porosity. Rare molds after brachiopods and ghosts of crinoid ossicles and coral fragments may be found. Average combined matrix and vug porosity of 20%. Intense fracturing of the unit, characterized by crackle brecciation, is common and bitumen usually fills the fracture networks.

2) Sucrosic Dolostone – soft, relatively friable unit saturated with bitumen such that observation of its features in core is difficult. From petrographic examination the facies is characterized by euhedral, fine to coarsely crystalline (average 60 microns) crystals that are weakly cemented or disaggregated. Leaching and partial leaching of the dolomite rhombs, and dissolution of the cores of zoned crystals, is common. The facies, as a result, is characterized by unusually high porosities typically in the range of 33%.

3) Laminated to Thin-Bedded Dolostone – pervasively dolomitized mudstone and wackestone, in some cases with stromatolitic laminae. Light green wisps and laminae of green clays that are 1-2 mm thick are common. Average porosity of 15%.

Grosmont C Fracturing at 7-19

Fracturing in 7-19 is dominated by bed-bound fractures and crackle brecciation textures. These are short, discontinuous fractures that connect vugs and matrix porosity. Large scale through-going fractures of tectonic origin (e.g. extensional fractures) are less common; typically these fractures dip ~ 70 degrees with effective apertures 0.5-1 mm in width. The greatest intensity of fracturing is found in the upper part of the vuggy dolomudstone (335-340 m) where the intensity of crackle brecciation and bed bound fractures is 3-4 times greater than crackle brecciation in the lower part of the unit (based on image log interpretation). The highly porous sucrosic dolostone has the lowest intensity of fracturing, reflecting its more plastic nature. The laminated dolostone unit has a greater abundance of bed bound fractures, and has an overall fracture intensity comparable to the lower part of the vuggy dolomudstone facies.

Nisku Reservoir Characteristics

Nisku reservoir facies at Saleski West are best developed in the Lower Nisku and range in thickness from 6-12 m; the overlying column of variably saturated dolostone, including non-reservoir facies, typically exceeds 20 m. The average porosity of the reservoir facies is 14%; the permeability is dominated by the fracture system and may locally exceed 10 Darcies but core measured vertical perm, which does not consider the larger fractures or breccia fabrics because of sample integrity limitations, averages only 275 mD. The average matrix permeability is 150 mD. Average bitumen saturation in the Lower Nisku is highly variable but typically ranges between 50-85%. The dominant reservoir facies is an intensely fractured vuggy dolostone; moldic dolostone is a second reservoir facies common in the upper part of the Lower Nisku. As demonstrated in 3-16, the upper part of the Nisku has well developed karst features that include large-aperture fractures filled with sediment and horizontal fissures.

Nisku Reservoir Facies at 3-16

1. Vuggy Dolostones – massive or thin-bedded pervasively dolomitized units. The original depositional texture appears to have been a wackestone or floatstone dominated by shell fragments, although most of these primary features have been obliterated by the dolomitization. Centimetre-scale vugs are connected by fractures or isolated; matrix porosity adjacent to vugs is locally enhanced.

2. Moldic Dolostone – packstone and floatstone deposits, pervasively dolomitized, with molds after disarticulated and variably fragmented shells that include a mix of brachiopods and molluscs. Rare molds after coral fragments. Local bioturbation including lined burrows, possibly indicating a higher-energy depositional environment.

Nisku Fracturing at 3-16

Intense crackle brecciation and extensional fractures connect the vug and matrix porosity systems. Apertures are typically 0.1-1 mm and while crackle brecciation fractures are short and discontinuous, extensional fractures in core are steeply dipping and present over 20-30 cm intervals before extending beyond core diameter. Locally, fractures may be solution enhanced and/or dolostone adjacent to the fractures may have enhanced porosity-permeability. Greatest fracture intensity, including crackle brecciation, is in the 2-3 m directly above the contact with the underlying Upper Ireton Formation. Fractures that appear to be karst-related features associated with horizontal fissures are present in the upper part of the core and have much larger apertures, in some cases exceeding 1 cm in width. These fractures, however, are sediment filled and would generally be ineffective in the subsurface.

Comparison of Grosmont C and Nisku Reservoir Attributes

The Grosmont C reservoir and Nisku Formation share a number of similar reservoir attributes (Table 1). Both reservoirs are characterized by vuggy, intensely fractured and brecciated dolostones from similar depositional environments. Important differences include reservoir distribution and matrix porosity. Whereas the best reservoir development in the Grosmont Formation is in the Grosmont C and Grosmont D units, the best reservoir development in the Nisku Formation is in its lower parts (at least in the Saleski West region). The Lower Nisku reservoir distribution is interpreted to have been the result of facies stacking patterns and enhanced fracturing at its base. An overall basinward shift of the depositional system from Grosmont through Nisku time, such that the facies belt at Lower Nisku time in Saleski West was comparable to the mid-Grosmont C facies belt at Sepiko Kesik at Grosmont time, is interpreted to have deposited the same type of facies that subsequently altered to form vuggy dolostones. Cutler (1983) detailed the sedimentology of these shallowing-upwards cycles in the Grosmont and the overall basinward shift of environments. The intense fracturing and brecciation at the base of the Lower Nisku is interpreted to be the result of mechanical differences with the underlying Upper Ireton Formation. With regards to matrix porosity, Grosmont C dolostones have 3-4% more matrix porosity (e.g. intercrystalline porosity) than typical Nisku dolostones. A general observation is that matrix porosity and the size of vugs are inversely related – larger vugs typically occur in matrix with lower porosity and vice versa. This is assumed to reflect conduit- versus diffusive-type flow of the undersaturated waters that controlled porosity evolution in these units.

Grosmont C bitumen saturation in the Sepiko Kesik area is ~86% (Grosmont C reservoir). Bitumen saturation in the Nisku is more variable with reservoir units typically ranging between 50 and 85% saturation. In the Upper Nisku, non-reservoir argillaceous dolostones limit contiguous thickness of bitumen-saturated dolostones. Vertical fracturing is very intense in the Nisku Formation, including fracture development in the argillaceous dolostones, so it does appear that one can predict vertical communication between units. A key to unlocking the Nisku Formation, therefore, will be understanding reservoir/resource distribution and its relationship with fracture intensity.

Conclusions

- The Grosmont C in the Sepiko Kesik area is a world-class reservoir.
- The Grosmont C dolostones at Sepiko Kesik and the Nisku Formation dolostones in the Saleski West area share a number of similarities. These include fractured, vuggy dolostones with locally intense brecciation.
- The Nisku Formation contains significant amounts of bitumen (>100 billion bbl; ERCB ST98-2012).
- As understood from the Saleski West area, there is significant opportunity in the Nisku Formation – the challenge is variable bitumen saturation and the intercalation of fractured low reservoir quality and non-reservoir units with high-quality reservoir units.

Acknowledgements

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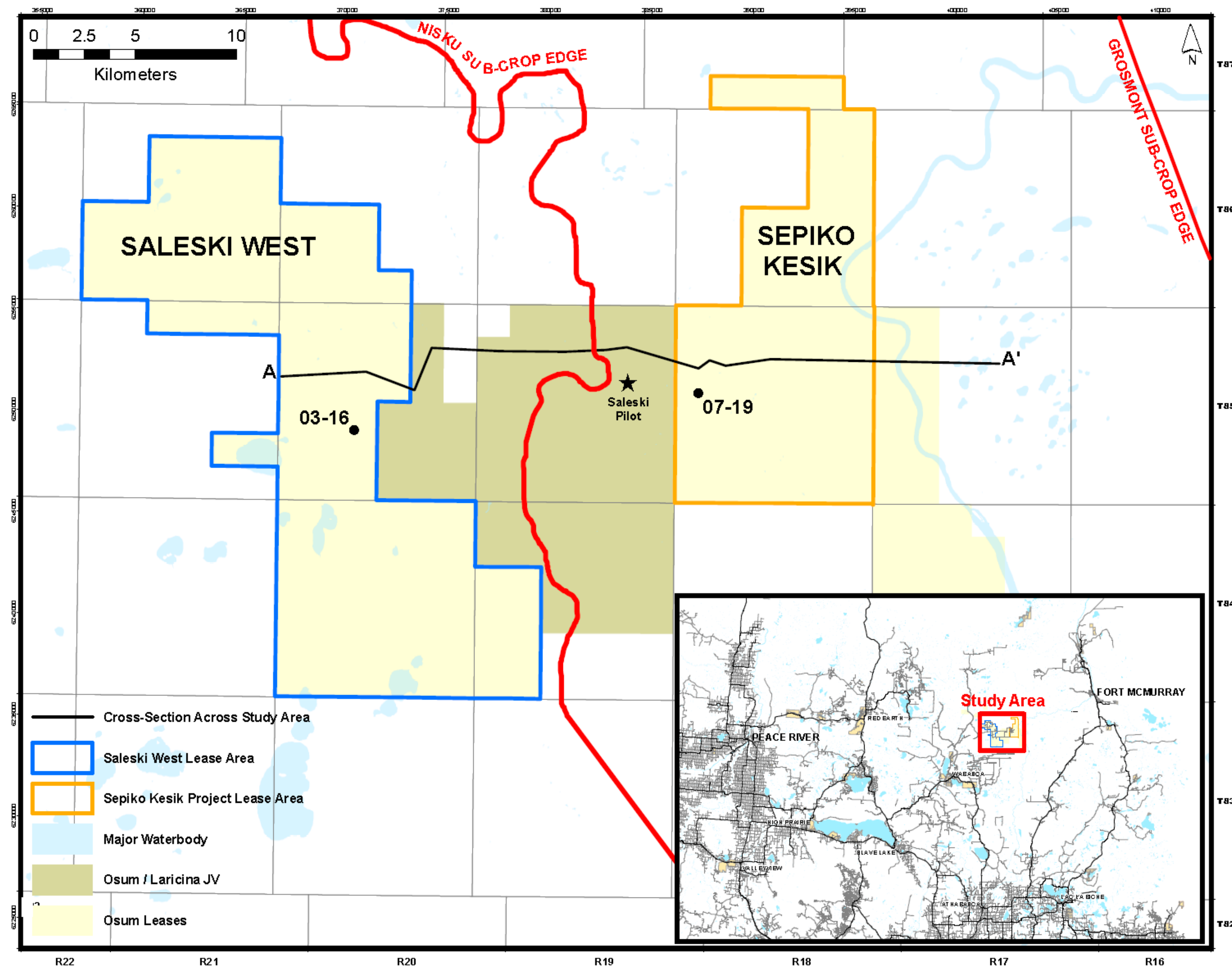

Figure 1. Map of study area.

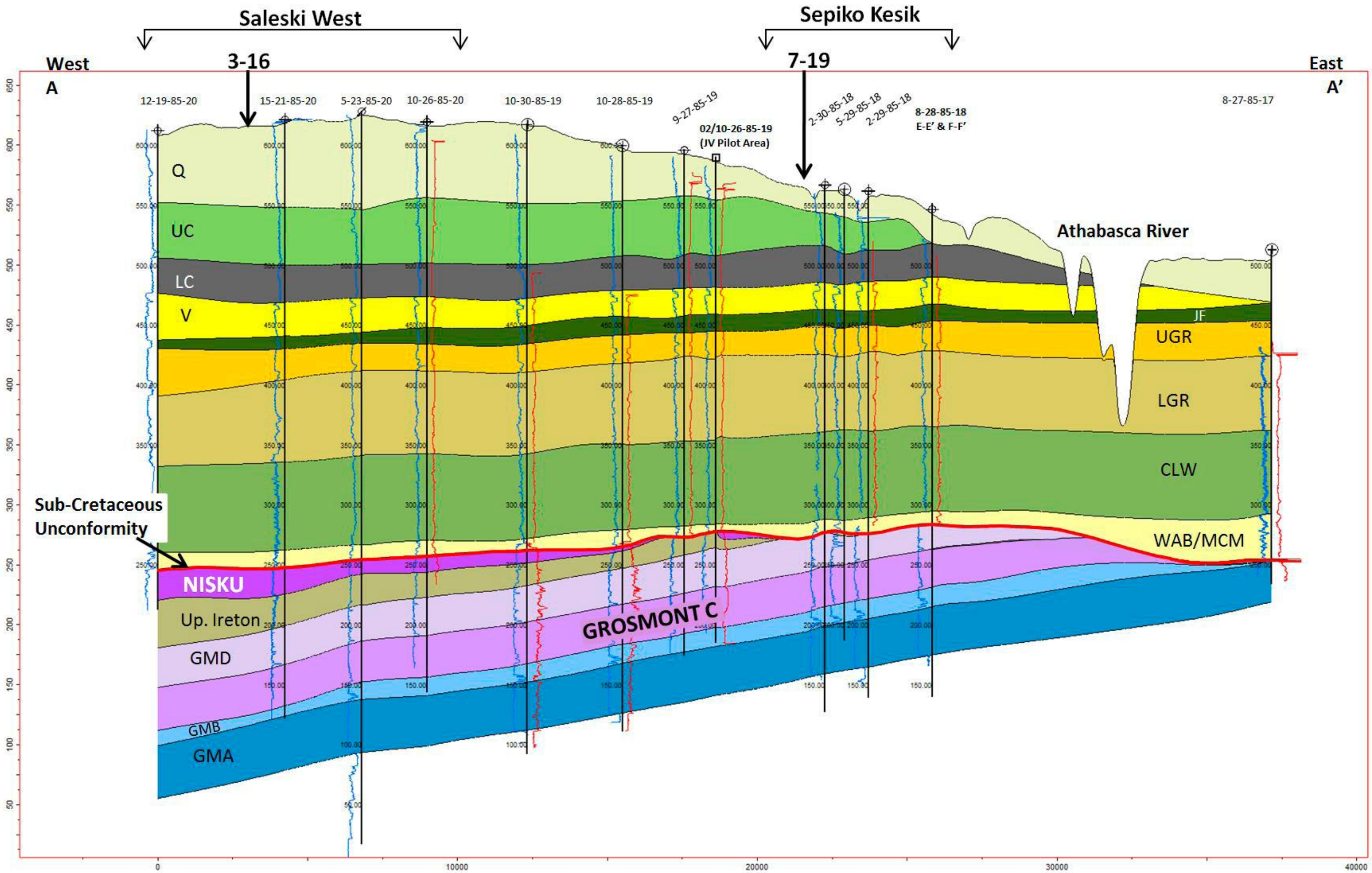

Figure 2. Cross section across study area.

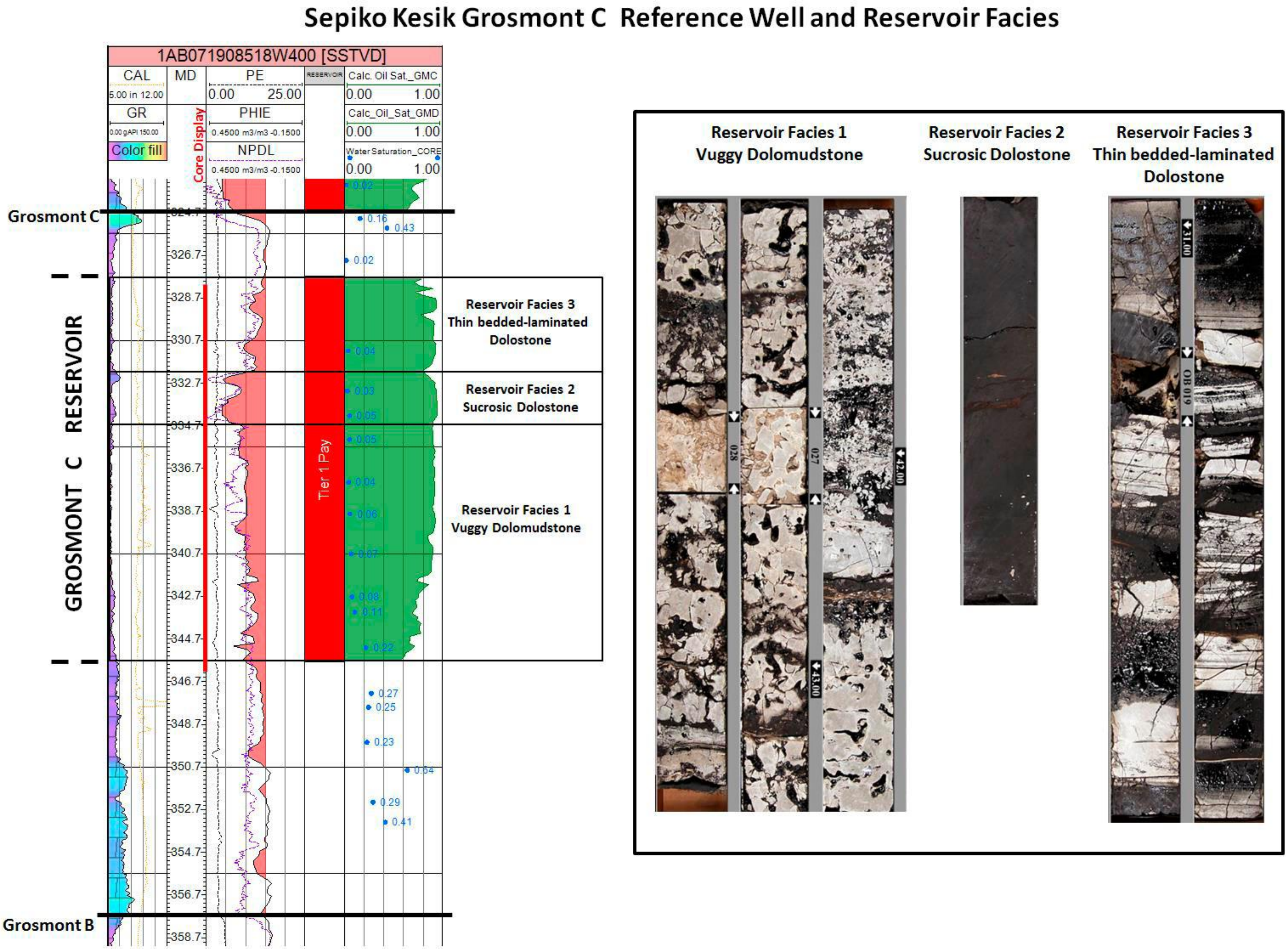

Figure 3. Grosmont C reference well 7-19.

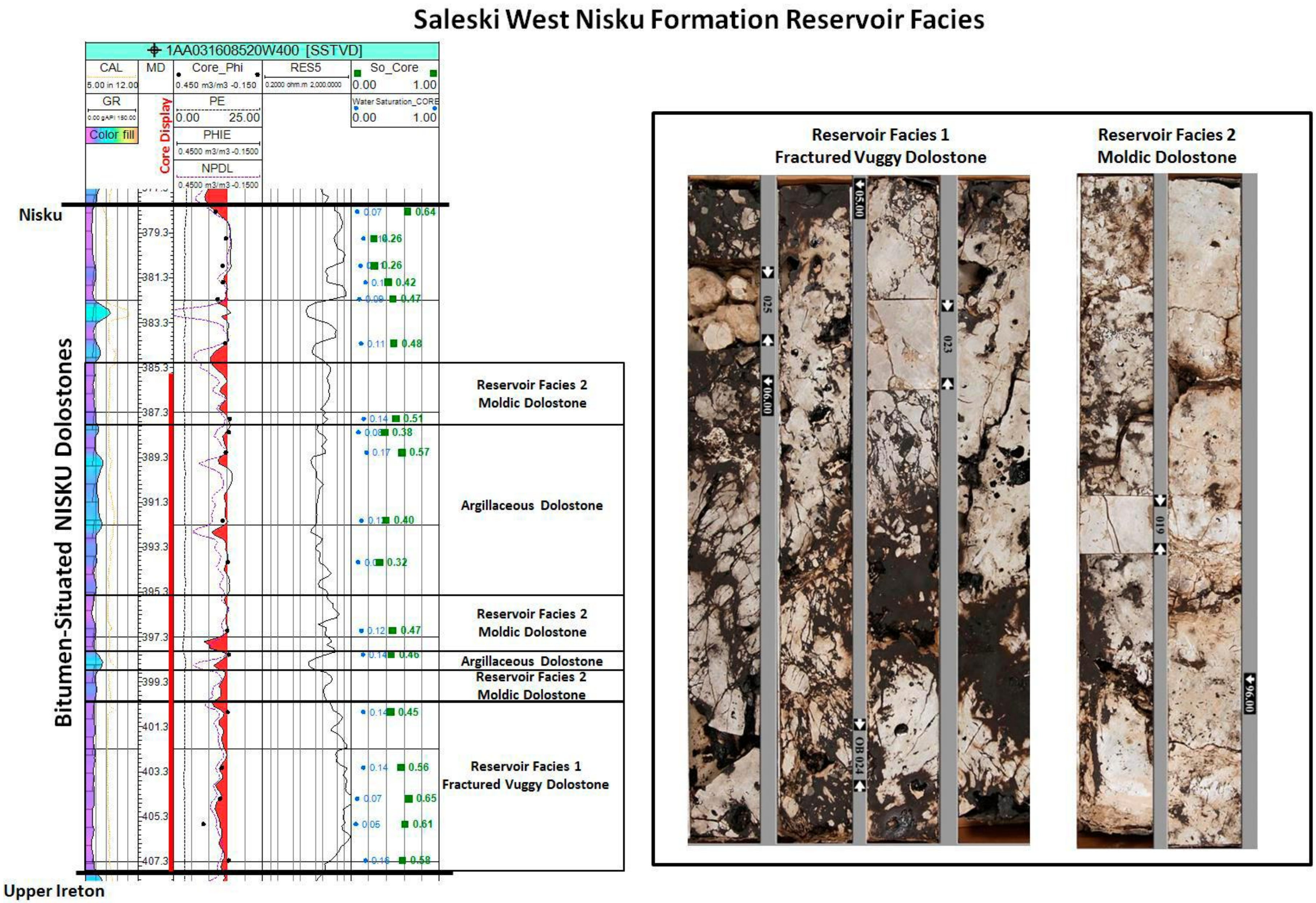

Figure 4. Nisku Formation reference well 3-16.

Reservoir Property	7-19 Grosmont C	3-16 Nisku
Lithology	Dolostone	Dolostone
Average Total Porosity	20%	14%
Average Matrix Porosity[1]	10%	7%
Average Vuggy/Fracture Porosity[1]	10%	7%
Vertical Open Effective Fractures[1]	Yes	Yes
Average Fracture Height[1]	<0.5 m – connect vugs and breccias	<0.5 m-connect vugs and breccias
Average Open Fracture Aperture[1]	0.5-1 mm	0.5-1 mm
Average HZ Permeability (kMax)[1,2]	528 mD	280 mD
Average Vertical Permeability[1,2]	2100 mD	275 mD
Average Net Bitumen Saturation	86%	72%[3]
Reservoir Thickness	18 m	8 m +discontinuous reservoir in overlying 16 m
Brecciation[1]	Locally intense	Locally intense

[1]Excludes sucrosic dolostone; [2]Breccias, large fractures not measured; perm values are conservative. [3]Corrected core data.

Table 1. Reservoir attributes of Grosmont C compared with Nisku at reference well locations.