# Stratigraphy, Depositional Setting, and Reservoir Quality of the Logan Canyon Formation, Offshore Nova Scotia

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## Summary

The Mid-Cretaceous Logan Canyon Formation has been proposed as a drilling target for hydrocarbons in the Sable Subbasin, offshore Nova Scotia. The thick Jurassic to Cretaceous fluvial-deltaic to shallow marine sands of the Logan Canyon and deeper Missisauga and Mic Mac formations form basin-wide reservoir rocks. Chemostratigraphic analysis can determine variations in elemental concentrations in reservoir and seal rocks. Results are integrated with a geochemical classification system, allowing for classification of the Logan Canyon Formation beyond just lithology type. High-resolution X-ray fluorescence measurements define five common and three uncommon facies for the Logan Canyon Formation. Handheld air permeameter measurements record the permeability of lithofacies and show variations in the reservoir both laterally and vertically. Borehole history reports contain laboratory measured permeability and porosity values throughout the cored intervals. This data can be combined with the recently measured data to gauge reservoir quality further and confirm depositional settings. Results indicate the cored intervals have a variable reservoir quality, relating to different depositional settings within the fluvial-deltaic and shallow marine realms.

## Introduction

The Logan Canyon Formation contains fluvial-deltaic to shallow marine sediments representing the latter stages of basin fill of the Scotian Basin in the Lower Cretaceous. Past studies include stratigraphy (e.g. McIver, 1972; Jansa and Wade, 1975; Given, 1977; Wade and MacLean, 1990; Wade et al., 1995; Wade, 2000), tectonic setting (e.g. McIver, 1972; Jansa and Wade, 1975; Given, 1977; Wade and MacLean, 1990), depositional environments (e.g. Karim et al., 2011; Sibuet et al., 2012), sediment provenance (e.g. Pe-Piper and MacKay, 2006; Tsikouras et al., 2011), thermal history (e.g. Grist et al., 1992), geochemistry (e.g. Powell and Snowdon, 1979) and reservoir attributes (e.g. Karim et al., 2011; Gould et al., 2012; Wach et al., 2014). The goals of this study were to determine and document the reservoir quality and facies of the Marmora, Sable, Cree, and Naskapi members of the Logan Canyon Formation using the integration of modern chemostratigraphic methods with a well-established sandstone classification scheme and porosity/permeability analysis. Chemostratigraphic data was measured directly from ten conventional, slabbed core intervals from the Logan Canyon Formation. Porosity and permeability values were taken from borehole history reports and in a few instances, a portable, handheld permeameter was used to collect permeability values. The formation contains laterally and vertically extensive successions of paralic channel bodies deposited in a deltaic setting. The chemostratigraphic method delivers a greater vertical resolution of mineralogical variations than conventional methods, which is important for facies definition and for placing results of sample analysis in stratigraphic context. It also provides a basis for calibrating and interpreting borehole logs. The findings offer new insights into the Logan Canyon Formation and its members not available from previous studies.

## Study Area and Stratigraphy

The Sable Megamerge (Figure 1, Left) is located offshore Nova Scotia and spans 3,000 km$^2$. It contains 41 exploration boreholes and 17 development wells. It is part of the Sable Sub-basin (~ 63,000 km$^2$) of the Scotian Basin (~ 300,000 km$^2$). The Logan Canyon Formation (Figure 1, Right) is part of the Cretaceous Nova Scotia Group and is a common reservoir rock interval occurring in the Scotian Basin (McIver, 1972; Wach et al., 2014). It comprises of a fining upward trend of thick, fluvial-deltaic to shallow marine sandstone (Wade and MacLean, 1990; Wach et al., 2014). It is subdivided into alternating shale dominated (Naskapi and Sable members) and sandstone dominated (Cree and Marmora members) intervals deposited over 25 million years from 121 M.A. to 96 M.A., forming reservoir seal pairs (Wade and MacLean, 1990; Smith et al., 2010).

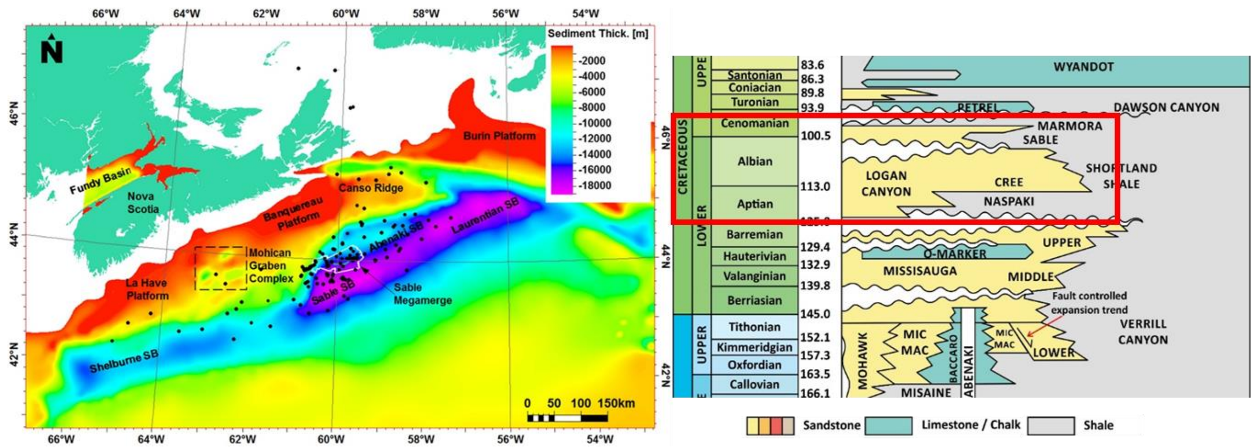

*Figure 1. Left) Sediment thickness map showing the study area. Right) Lithostratigraphic chart for the Scotian Basin showing the interval of interest outlined in red (Weston et al., 2012; Campbell, 2018).*

## Methods and Equipment

**Slabbed Core Description.** The core was examined, described, and photographed at the Canada-Nova Scotia Offshore Petroleum Board's Geoscience Research Centre (CNSOPB GRC). Core description involved grain size determination, lithology, depositional environment, physical and biogenic sedimentary structures, and all surfaces.

**Borehole History Reports.** Reports were reviewed for information pertaining to the interpretation and description of the Logan Canyon Formation. Core analysis reports provided laboratory results of air permeability and porosity measurements. Permeability and porosity were assigned a rank and range (e.g. Levorsen, 1954; Nabawy et al., 2009), allowing qualitative and quantitative descriptions.

**Portable Handheld X-Ray Fluorescence Analyzer.** A factory-calibrated, portable-handheld Niton XL3t 950 GOLDD+ X-Ray Fluorescence analyzer was used for a chemostratigraphic analysis of the ten cored intervals.

**Portable Handheld Air Permeameter.** A portable handheld air permeameter indirectly measured permeability along the slabbed core face of three cored intervals.

## Results

**Sandstone Classification Scheme.** Table 1 summarizes the various lithofacies that occur within each of the ten cored intervals. The 386 points (Figure 2) occupy all fields of the SandClass sandstone classification plot except the quartzarenite field.

*Table 1. Summary of lithofacies occurring in each of the ten cored intervals. The lithofacies follow the classification scheme set out by Herron (1988).*

| **Borehole/ SandClass** | 2H-58 Core 1 | 3H-58 Core 1 | 3H-58 Core 2 | 3H-58 Core 3 | 5H-58 Core 1 | 5H-58 Core 2 | 5H-58 Core 3 | C-67 Core 1 | C-67 Core 2 | M-32 Core 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Arkose | Y | N | N | N | N | N | N | N | N | N |
| Fe-Sand | Y | Y | Y | Y | Y | N | Y | Y | Y | Y |
| Fe-Shale | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Litharenite | Y | N | Y | Y | Y | Y | Y | Y | N | Y |
| Quartzarenite | N | N | N | N | N | N | N | N | N | N |
| Shale | Y | N | Y | Y | Y | Y | Y | Y | Y | Y |
| Subarkose | Y | N | N | N | N | N | Y | Y | Y | N |
| Sublitharenite | N | N | N | Y | N | N | Y | N | Y | Y |
| Wacke | Y | N | Y | Y | Y | Y | Y | Y | Y | Y |

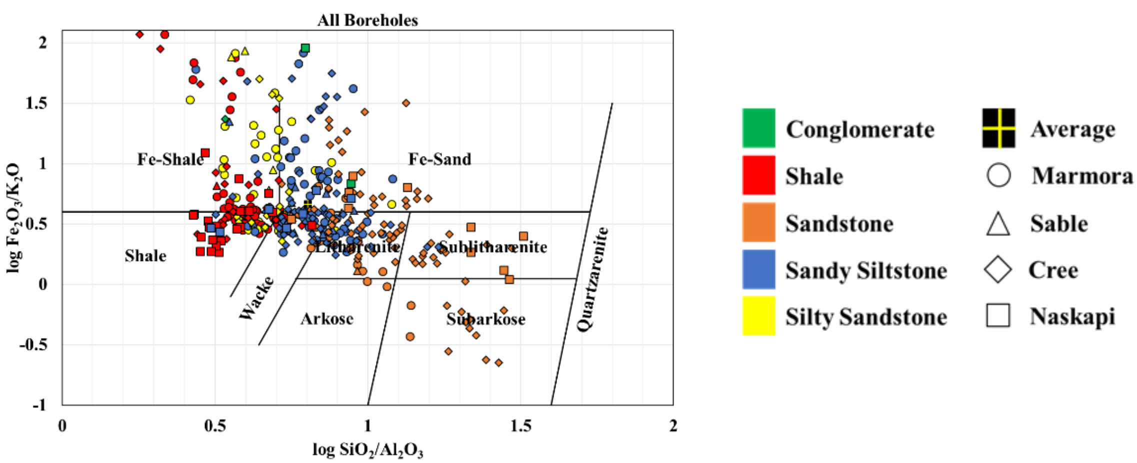


*Figure 2. Sandstone chemical classification graph showing all points from the ten cored intervals.*

Chemostratigraphic data from all ten cored intervals were used to define mineralogical facies (Figure 3) that are key to determining paleoenvironments and establishing correlations. Based on the SandClass classification scheme by Herron (1988), five common facies were identified based on major element variations from X-ray fluorescence: the ferruginous sandstone facies; the ferruginous shale facies; the litharenite facies; the shale facies, and the wacke facies. Uncommon facies include the sublitharenite facies; the subarkose facies, and the arkose facies.

**Porosity and Permeability.** Permeability values of the ten intervals from borehole reports ranged from 0.01 mD (negligible) to 4,026.00 mD (excellent), with an average of 101.89 mD (v. good). Permeability values measured on three cored intervals using the TinyPerm II ranged from 3.38 mD (fair) to 873.74 mD (v. good), with an average of 77.47 mD (good). Porosity values for all ten intervals ranged from 1.50%

(negligible) to 36.20% (excellent), with an average of 22.04% (v. good). These values are summarized in Table 2.

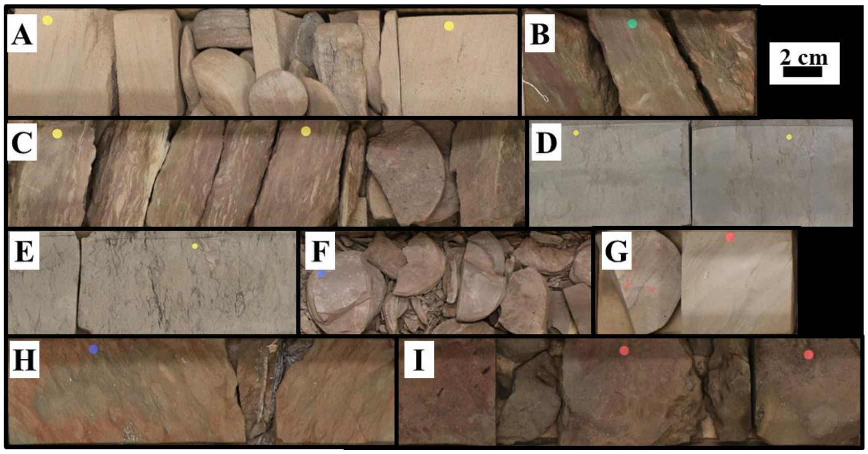


*Figure 3. Core slab photographs of the typical facies observed in the Logan Canyon Formation cored intervals. Examples are; A) subarkose, B) Fe-rich sandstone, C) wacke, D) sublitharenite, E) litharenite, F) shale, G) arkose, H) Fe-rich sandstone, and I) Fe-rich shale.*

*Table 2. Summary of maximum, minimum, and average permeability and porosity.*

| Borehole | Core | Perm. (TinyPerm) | | | Perm. (from reports) | | | Porosity (from reports) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Avg | Min | Max | Avg | Min | Max | Avg |
| 2H-58 | 1 | 14.13 | 641.71 | 92.09 | 2.54 | 553 | 112.47 | 16.40 | 31.90 | 24.80 |
| 3H-58 | 1 | - | - | - | 0.13 | 124.00 | 13.10 | 9.50 | 34.10 | 27.43 |
| | 2 | - | - | - | 0.15 | 99.90 | 27.59 | 15.40 | 31.00 | 23.50 |
| | 3 | - | - | - | 0.08 | 107.00 | 23.90 | 5.80 | 28.00 | 19.01 |
| 5H-58 | 1 | - | - | - | 2.22 | 145.00 | 41.28 | 14.07 | 36.20 | 22.55 |
| | 2 | - | - | - | 0.35 | 206.00 | 51.35 | 11.00 | 28.40 | 20.76 |
| | 3 | - | - | - | 0.06 | 4,026.00 | 312.10 | 6.00 | 32.00 | 18.33 |
| C-67 | 1 | 3.47 | 873.74 | 87.39 | 0.69 | 413.00 | 98.60 | 1.50 | 33.80 | 20.41 |
| | 2 | 3.38 | 41.03 | 14.77 | 0.20 | 6.40 | 3.54 | 11.90 | 23.90 | 17.32 |
| M-32 | 1 | - | - | - | 0.01 | 5.87 | 133.06 | 5.10 | 29.80 | 17.16 |

## Conclusions

Five common facies are represented (iron-rich sandstone, iron-rich shale, litharenite, shale, and wacke). Three less common facies occur (sublitharenite, subarkose, and arkose). The abundance of iron-rich samples indicates minerals such as glauconite and siderite, typical of a continental shelf marine depositional environment. Porosity and permeability reveal a variable reservoir quality with baffles and barriers causing heterogeneity over short intervals within the cored intervals. Overall, the core represents continental and marine sediments that interfinger with each other, reminiscent of a paralic depositional environment.

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**References**


Campbell, T.J. 2018. Seismic Stratigraphy and Architecture of the Jurassic Abenaki Margin, at Cohasset-Migrant, and Potential for Distal Organic-Rich Facies. Earth Sciences, Dalhousie University, Halifax, NS.

Given, M.M. 1977. Mesozoic and Early Cenozoic Geology of Offshore Nova Scotia. Bulletin of Canadian Petroleum Geology, **25**: 63-91.

Gould, K.M., Piper, D.J.W., Pe-Piper, G., Dehler, S., Deptuck, M., and Karim, A. 2012. Lateral variation in sandstone lithofacies from conventional core, Scotian Basin: implications for reservoir quality and connectivity. Canadian Journal of Earth Sciences, **49**: 1478-1503. doi:10.1139/e2012-064.

Grist, A.M., Reynolds, P.H., Zentilli, M., and Beaumont, C. 1992. The Scotian Basin offshore Nova Scotia: thermal history and provenance of sandstones from apatite fission track and 40Ar/39Ar data. Canadian Journal of Earth Sciences, **29**: 909-924. doi:10.1139/e92-077.

Herron, M.M. 1988. Geochemical Classification of Terrigenous Sands and Shales from Core or Log Data. SEPM Journal of Sedimentary Research, **58**. doi:10.1306/212f8e77-2b24-11d7-8648000102c1865d.

Jansa, L.F., and Wade, J.A. 1975. Geology of the continental margin off Nova Scotia and Newfoundland. *In* Offshore Geology of Eastern Canada. *Edited by* Willem J.M. Van Der Linden and J.A. Wade. Energy, Mines and Resources Canada, Ottawa, Ontario. p. 274.

Karim, A., Pe-Piper, G., and Piper, D.J.W. 2011. Distribution of diagenetic minerals in Lower Cretaceous sandstones and their relationship to lithofacies from a proximal to distal transect: Como P-21, Panuke B-90, Cohasset A-52, Balmoral M-32 and Lawrence D-14 wells, Scotian Basin. Geological Survey of Canada. p. 379.

Levorsen, A.I. 1954. Geology of Petroleum. W.H. Freeman Company, San Francisco, California.

McIver, N.L. 1972. Cenozoic and Mesozoic Stratigraphy of the Nova Scotia Shelf. Canadian Journal of Earth Sciences, **9**: 54-70. doi:10.1139/e72-005.

Nabawy, B.S., Rochette, P., and Géraud, Y. 2009. Petrophysical and magnetic pore network anisotropy of some Cretaceous sandstone from Tushka Basin, Egypt. Geophysical Journal International, **177**: 43-61. doi:10.1111/j.1365-246X.2008.04061.x.

Pe-Piper, G., and MacKay, R.M. 2006. Provenance of Lower Cretaceous sandstones onshore and offshore Nova Scotia from electron microprobe geochronology and chemical variation of detrital monazite. Bulletin of Canadian Petroleum Geology, **54**: 366-379. doi:10.2113/gscpgbull.54.4.366.

Powell, T.G., and Snowdon, L.R. 1979. Geochemistry of Crude Oils and Condensates from the Scotian Basin, Offshore Eastern Canada. Bulletin of Canadian Petroleum Geology, **27**: 453-466.

Sibuet, J.-C., Rouzo, S., Srivastava, S., Dehler, S., Deptuck, M., and Karim, A. 2012. Plate tectonic reconstructions and paleogeographic maps of the central and North Atlantic oceans. Canadian Journal of Earth Sciences, **49**: 1395-1415. doi:10.1139/e2012-071.

Smith, B.M., Deptuck, M.E., and Kendell, K.L. 2010. Upper Cretaceous Mass Transport Systems Above the Wyandot Formation Chalk, Offshore Nova Scotia.

Tsikouras, B., Pe-Piper, G., Piper, D.J.W., and Schaffer, M. 2011. Varietal heavy mineral analysis of sediment provenance, Lower Cretaceous Scotian Basin, eastern Canada. Sedimentary Geology, **237**: 150-165. doi:10.1016/j.sedgeo.2011.02.011.

Wach, G., Pimentel, N., and Reis, R.P.d. 2014. Petroleum Systems of the Central Atlantic Margins, from Outcrop and Subsurface Data. *In* Sedimentary Basins: Origin, Depositional Histories, and Petroleum systems of Continental Margins of the World. *Edited by* B.H. James Pindell, Norman Rosen, Paul Weimer, Menno Dinkleman, Allen Lowrie, Richard Fillon, Jarmes Granath, Lorcan Kennan, Houston, Texas. p. 20.

Wade, J.A. 2000. Depth to Pre-Mesozoic and Pre-Carboniferous basements - Open-File Report 3842. Geological Survey of Canada, Dartmouth, NS.

Wade, J.A., and MacLean, B.C. 1990. The Geology of the Southwestern Margin of Canada. *In* Geology of the Continental Margin of Eastern Canada *Edited by* M.J. Keen and G.L. Williams. Canadian Government Publishing Centre, Ottawa, Ontario. pp. 167-238.

Wade, J.A., Williams, G.L., and MacLean, B.C. 1995. Mesozoic and Cenozoic stratigraphy, eastern Scotian Shelf: new interpretations. Canadian Journal of Earth Sciences, **32**: 1462-1473. doi:10.1139/e95-118.

Weston, J.F., MacRae, R.A., Ascoli, P., Cooper, M.K.E., Fensome, R.A., Shaw, D., and Williams, G.L. 2012. A revised biostratigraphic and well-log sequence-stratigraphic framework for the Scotian Margin, offshore eastern Canada. Canadian Journal of Earth Sciences, **49**: 1417-1462. doi:10.1139/e2012-070.