PETROGRAPHIC STUDY OF THREE SAMPLES RECOVERED FROM THE NAHANNI FORMATION AT WELL LOCATION PARAMOUNT ET AL. LIARD M-25 300/M-25-6030-12330/0

Northwest Territories Geological Survey
Work Order No. 20A20310

March, 2020

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SERVICE BEYOND ANALYSIS

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The purpose of this study is to describe the observed lithological characteristics, associated reservoir quality and fluid sensitivity of three petrographic samples collected from the Nahanni Formation at well location PARAMOUNT ET AL LIARD M-25 300/M-25-6030-12300/0. Petrographic analyses and interpretations are based on the observation of thin section and SEM samples generated from core, while XRD analyses were also completed and confirm mineralogy and clay types. An overview of general sample information can be found below within **Table A:**

TS sample ID	Depth (ft/m)	Formation	Rock Classification	Analysis (*)	Reservoir Quality (*)
Location: Paramount et al Liard M-25 300/M-25-6030-12330/0					
X34,P6	11024.61ft 3360.30m	Nahanni	-	XRD; RCA	-
X33,P5	11138.45ft 3395.00m	Nahanni	-	XRD; RCA	-
T14,S14,P4	11325.46ft 3452.00m	Nahanni	Dolostone	TS; SEM; RCA	P-M
X32,P3	11327.10ft 3452.50m	Nahanni	-	XRD; RCA	-
T13,S13,P2	11328.54ft 3452.94m	Nahanni	Dolostone	TS; SEM; RCA	P-M
T12,S12,P1	11668.47ft 3556.55m	Nahanni	Dolostone	TS; SEM; RCA	P-M

(*) TS- Detailed thin section analysis with Images; XRD - Bulk X-ray Diffraction Analysis; RCA – Routine Core Analysis. Reservoir Quality: VP – Very Poor; P- Poor; M – Moderate; G - Good

All thin section samples from this well location are dolostones. The dolostone samples from this well location are comprised mainly of dolomite (93% to 95%). Secondary quartz is present in trace to minor amounts in samples T13 (3495.94ft) and T14 (3452.00ft) and occurs predominately as euhedral fracture fill (trace to 1%). Minor chert cement (microcrystalline quartz) locally fills fractures and microvugs in these samples (1% to 2%), while trace polycrystalline macro-quartz cement is also noted in T14. Minor calcite (2%) occurs as fracture-fill in samples T12 (3556.55ft) and T14, while fine crystalline dolomite (3%) occurs as fracture-fill in sample T12 only. Trace pyrite cement locally occludes intercrystalline porosity in sample T13. A trace possible calcium-bearing zeolite mineral was also observed under the Scanning Electron Microscope (SEM) within a fracture in sample T14. The samples lack the presence of detrital grains. Clays and organics (3% to 5%) within the dolostones are concentrated in stylolites, while portions of the samples contain dolomite with appreciable amounts of clay occlusions, notably samples T12 and T13.

Dolomite within these samples predominately displays non-planar replacement or alteration textures. 'Saddle' or baroque dolomite is represented by subhedral coarse dolomite that displays stepped or curved crystal faces, while sweeping or undulatory extinction can be viewed under cross-polarized light. Baroque dolomite is considered to be a high temperature precipitate that often replaces earlier calcite. The original depositional texture in these samples is poorly preserved. As stated above, portions of these samples also display planar fine crystalline subhedral to euhedral dolomite that contains appreciable amounts of clay inclusions, and localized overgrowth cements.

Reservoir quality for these samples is considered to be poor moderate and is mainly controlled by replacement texture and fracture systems. Compaction and pressure/solution (stylolites) are also evident in these dolostones, in addition to partial replacement by coarse to very coarse crystalline baroque (saddle) dolomite (typically considered to be a high temperature precipitate). Cemented and partially open fracture systems, in addition to stylolites, are generally subvertical to vertical within these samples. In addition to trace to minor amounts of partially open fractures

(1% to 3%), scattered intercrystalline porosity (1%) and isolated microvugs (trace to 2% - samples T12 and T13 only) were also observed. Trace amounts of micro-intercrystalline porosity was also noted in T12. Routine core data shows porosity ranges from 0.7-3% for these samples, while permeability values range from 2-12 mD. Variations between estimated thin section porosities may be in part due to isolated porosity (microvugs and intercrystalline pores), the presence of ineffective microporosity associated with the micritic matrix, in addition to partly open fracture systems. Please see the Petrographic Summary (**Table 1**) in the Data Tables section for details regarding mineralogy, texture and porosity.

The following table summarizes the most important factors that control the reservoir quality of the three samples recovered from Paramount et al. Liard M-25 300/M-25-6030-12330/0 location.

Sample ID	Depth (ft/m)	Total Micrite /Matrix (%)	Total Cement (%)	Total Porosity (%)						Main Porosity controlling factors (*)	RQ(*)
				IP	Int.	Ixl	Mv	Fr	M		
Location: Paramount et al. Liard M-25 300/M-25-6030-12330/0											
T14	11325.46ft 3452.00m	3	4	-	-	1	-	2	-	Frac; Qc: Cc	P-M
T13	11328.54ft 3452.94m	3	2	-	-	1	TR	3	-	Frac; Qc	P-M
T12	11668.47ft 3556.55m	5	7	-	-	1	2	1	TR	Frac; Qc; Dc; Cc	P-M

Porosity value (%): **IP** – interparticle porosity; **Int** – intraparticle; **Ixl** – intercrystalline; **Mv** – micro-vuggy; **Fr** – fracture porosity; **M** – micro-intercrystalline porosity
Main Porosity controlling factors: **Com –** compaction**;** M**ic** – micrite (calcite or dolomite); **Ms** – micro- and/or pseudospar; **SDol** - saddle dolomite; **Cc** – calcite cement (druse and spar); **Dc** – dolomite cement**; Qc -** quartz cement; **C** – clays and organics; **Ov** – quartz overgrowths; **Py** – pyrite (replacement and/or cement); **F** – fabric: [**CC** – concavo-convex orthochem contacts; **S –** sutured orthochem contacts]; **Frac** - fractures
RQ (*) - reservoir quality: **VP –** very poor; **P –** poor; **M –** moderate; **G** - good

Reservoir problems for the samples recovered from the Nahanni Formation at the Paramount et al. Liard M-25 300/M-25-6030-12330/0 location, may include the following: **(1)** Heterogeneity of the pore system, plus overall poor interconnectivity between pores could restrict the flow of hydrocarbons, **(2)** hydrochloric acid (HCl) treatment of this reservoir has the potential to loosen carbonate fines and/or clays that could migrate and block pore throats, plus cause fabric collapse, **(3)** Sensitivity of calcium carbonate to hydrofluoric acid (HF) in regard to precipitation of calcium fluoride scales.

Detailed mineralogical composition of each of the sample are summarized in the tables that can be find in the 'RESULTS' chapter of this report. Following the tabulated data there are images (with descriptions) that show specific features of the samples.

METHODS

Petrographic Microscopy

To prepare the thin section samples, select portions of the core samples were impregnated with blue epoxy, polished and mounted onto a glass slide. After drying of the epoxy the samples were ground down to a total thin section thickness of 30μm. One half of each thin section was then stained with a combination of Alizarin Red (for calcite) and potassium ferricyanide (for ferroan carbonate) to highlight carbonate mineralogy. The dual carbonate stain helps to differentiate the carbonate components within the samples, and affects them as follows: calcite appear pink to red-brown, ferroan calcite shows mauve to blue, ferroan dolomite colors vary from pale blue to turquoise, while non-ferroan dolomite remains unstained. Finally a second glass slide was glued on the samples to protect the polished surface. The prepared thin sections were point counted. The thin sections were examined in plain and cross polarized light conditions and photomicrographs taken at various magnifications (x12.5ppl; x25ppl; x50ppl, x100ppl, and x200ppl) to document structure, porosity, composition and nature of optically resolvable grains and matrix. To determine original texture of dolostone samples, the 'white card' technique has been used. Each sample has been described separately and the important features of it that includes framework mineralogy, diagenetic minerals and cements, textures, grain size range and average, porosity, etc., and the results are provided in the tabulated format. Annotated images of the thin sections with descriptions show the important aspects that were observed during the thin section examination. These images are placed after the tabulated data. A detailed petrographic summary which includes all samples (**Table 1**) is provided in the **Tables and Figures** section of this report.

SEM Analysis

A representative portion of each sample was adhered onto an aluminum stub specimen mount. The stubs were then sputter-coated with a conductive gold-palladium alloy for detailed Scanning Electron Microscopy (SEM) analysis and imaging. SEM analysis is useful in identifying lithological characteristics such as pore types, framework mineralogy, clay and cement composition, in addition to the potential deportment of clay constituents in relation to pore spaces and pore throats. Energy dispersive X-ray (EDX) was also used in conjunction with SEM observation in order to determine the elemental composition of the observed clay minerals and overall mineralogy.

Bulk XRD Analysis

Sample Preparation: Each sample, consisting of rock fragments, is manually crushed carefully using a mortar and pestle to reduce the size of the fragments. The sample is then ground with a vibratory disc mill (RS200; Retsch) to further reduce crystallite sizes. Finally, the sample is micronized using a planetary ball mill (PQN04; Across International) and scanned for X-ray diffraction analysis.

X-Ray Data Collection and Analysis:

Diffractometer Name: Bruker D4 Endeavor XRD with a Lynx-Eye detector

Instrumental Parameters: Radiation Source – Cobalt (Co)

Generator settings - 40 mA, 35 kV

Start position [°2θ] - 4

End position [°2θ] - 80

Step size [°2θ] - 0.02

Scan step time [s] - 1

Data Analysis: ICDD PDF-4 Mineral 2020 powder diffraction database

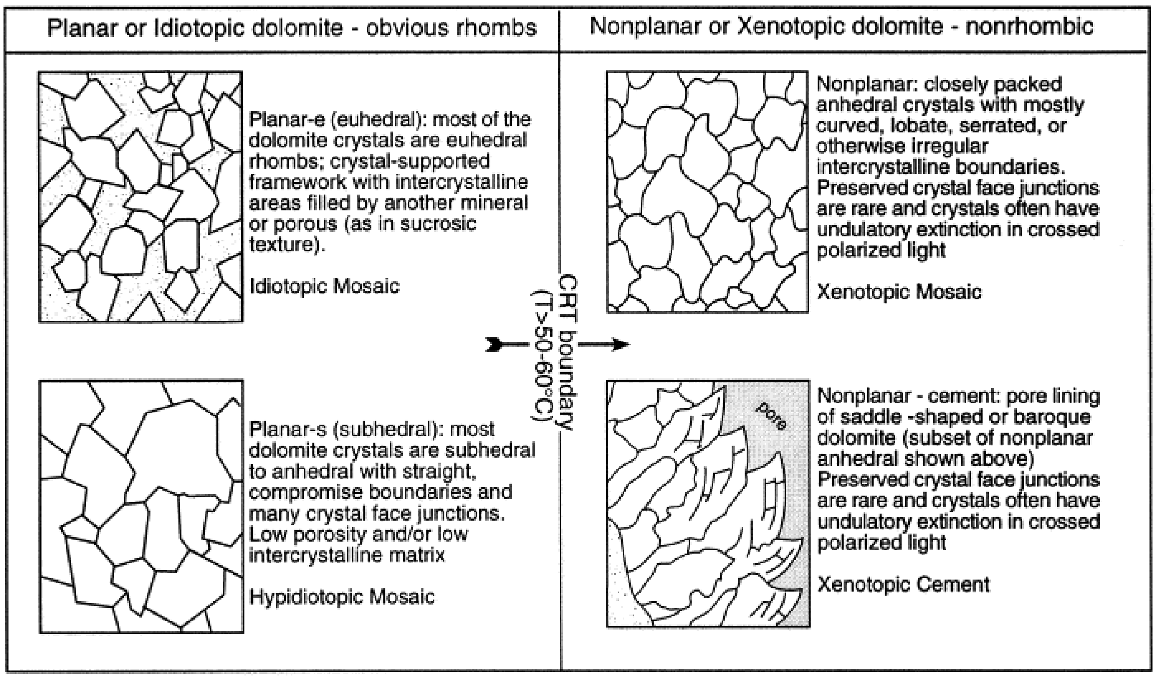
X'PERT HighScore Software for mineral identification

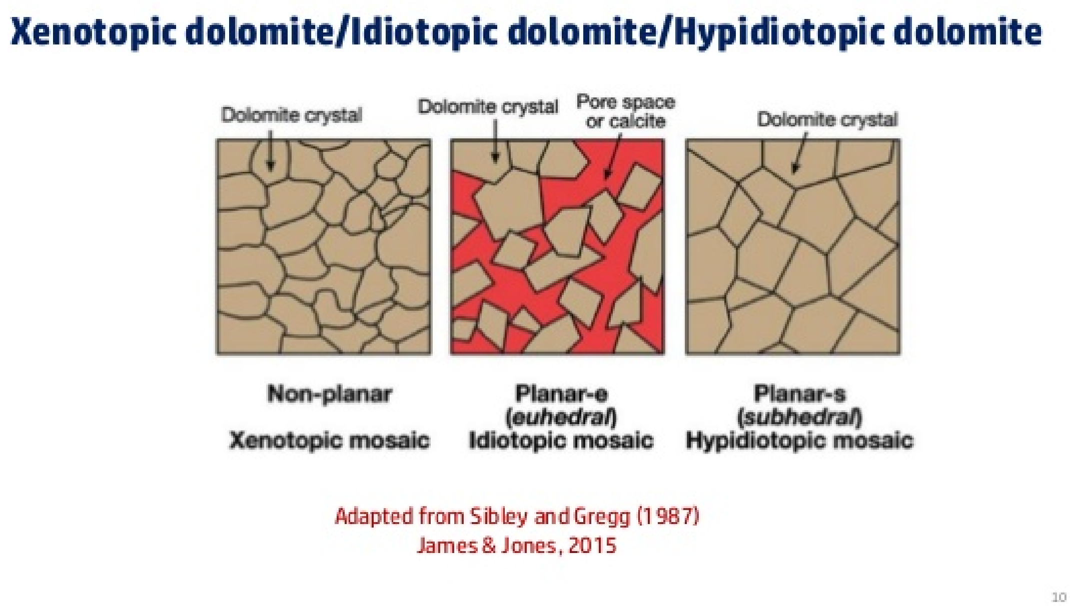
TOPAS Software for quantitative phase analysis

Detection Limit: 0.1 – 0.5 % depending on the type and nature of sample

Quantitative Mineral Phase Analysis: Using the HighScore program, the different mineral phases of the XRD patterns are identified. Once the mineral phases are identified, Rietveld refinements are performed by importing the XRD trace pattern into TOPAS 5. This program (TOPAS 5) is used for Rietveld analysis to quantify the mineralogy. The quantitative mineral phases of all samples are given in Table 2. The refined diffractograms and **Table 2** are placed in the **Tables and Figures** section of this report.

For the dolomite crystal fabrics the classification proposed by Sibley and Gregg (1987) was used (see the chart below).





Abbreviations

The list of common thin section abbreviations in provided in the table below.

NAME	ABBREVIATION	NAME	ABBREVIATION
Anhydrite	Anh	Intragranular Porosity	Intr.
Barite	Ba	Kaolinite	Kao
Biotite	Bio	K-Feldspar	K-Fld
Bioclasts (indistinct)	Biocl	Laminae	Lam
Burrows/Bioturbation	Bur	Metamorphic Rock Frag.	MRF
Bioturbation	Bt	Muscovite	Musc
Calcite	Cal	Matrix	Mtx
Carbonaceous	Carb	Micro-vuggy pore	Mv
Chert	Cht	Organic material	OM
Chlorite	Chl	Phosphate	Phos
Concavo-convex	CC	Plutonic Rock Fragments	PRF
Dolomite	Dol	Polycrystalline quartz	PQ
Detrital Calcite	dC	Pseudo-matrix	P-mtx
Detrital Dolomite	dD	Pyrite	Py
Feldspar	Fld	Quartz	Qtz
Ferroan Dolomite	Fe-Dol	Quartz Cement	Qc
Ferroan Calcite	Fe-Cal	Quartz overgrowths	Ov
Glauconite	Glauc	Sedimentary Rock Frag.	SRF
Grain dissolution pore	GD	Secondary porosity	SP
Heavy minerals	HM	Sutured grain contact	S
Hematite	Hem	Volcanic Rock Fragments	VRF
Illite	Ill		
Intergranular Porosity	IP		
Intercrystalline Porosity	lxl		

RESULTS

In this section of the report, the three samples that were recovered from the PARAMOUNT ET AL. LIARD M-25 300/M-25-6030-12330/0 location will be described separately. Images showing the specific features of each sample will follow the tabulated sample description.

Sample T14/S14, 10015.50ft/3052.72m

Well Name	Paramount et al. Liard M-25	**Location**	300/M-25-6030-12330/0
Sample Type	Thin section/SEM grain mount from a core sample	**Depth (ft/m)**	11325.46ft/3452.00m
Stratigraphic Unit	Nahanni	**Reservoir Quality**	Poor-Moderate
Classification	Dolostone	**Stain type**	½ Dual carbonate stain

MINERALOGY

	Total Bulk mineralogy					
Thin Section Point counting (%)	**Calcite**	**Dolomite**	**Anhydrite**	**Quartz/Cht**	**Pyrite**	**Clays & organics**
	2	93	-	2	-	3
	Framework, Matrix, Cement, and Replacement					
	Carbonate clasts	**Bioclasts**	**Detrital grains**	**Matrix**	**Pore filling cement**	**Replacement**
	-	-	-	3	4	93

ADDITIONAL FEATURES and OTHER COMMENTS

Depositional	At the time of deposition, the sample was most likely massive. Generation of low amplitude stylolites and fracturing of the sediment typically occurs during burial diagenesis (mechanical and chemical compaction). Sub-vertical stylolites and fractures may have subsequently formed as a result of folding or compressional stresses. Saddle dolomite within the sample is a common product of late-stage diagenesis and hydrothermal activity.
Textures	Dolomite within this sample predominately displays replacement or alteration textures. 'Saddle' or baroque dolomite is represented by subhedral coarse dolomite that displays stepped or curved crystal faces, while sweeping or undulatory extinction can be viewed under cross-polarized light.
Framework (Carbonate clasts, Bioclasts)	Dolomitization and recrystallization fabrics have overprinted any original framework clasts/bioclasts within this sample.
Detrital Grains & Other Non-Carbonate Grains	There are no detrital grains in this sample.
Matrix	Minor clay and organics (3%) are observed predominately in association with stylolites which contain insoluble material that accumulates along the irregular dissolution surface.
Pore Filling	Minor calcite (2%) and quartz (2%) cements occur as fracture fill. Quartz occurs as both

Cements	macro-polycrystalline and microcrystalline chert cements. A trace possible calcium-bearing zeolite was also noted in the SEM sample.
Replacement Minerals	Coarse to very coarse crystalline dolomite (93%) is the dominant replacement mineral in this sample. Trace chert replacement is also noted.
Porosity	Visible porosity in this sample consists of partly open fractures (2%), plus scattered intercrystalline porosity (1%). Trace amounts of microprosity are also associated with localized chert dissolution.

Annotated microphotographs of the thin section and SEM samples with descriptions are provided below.

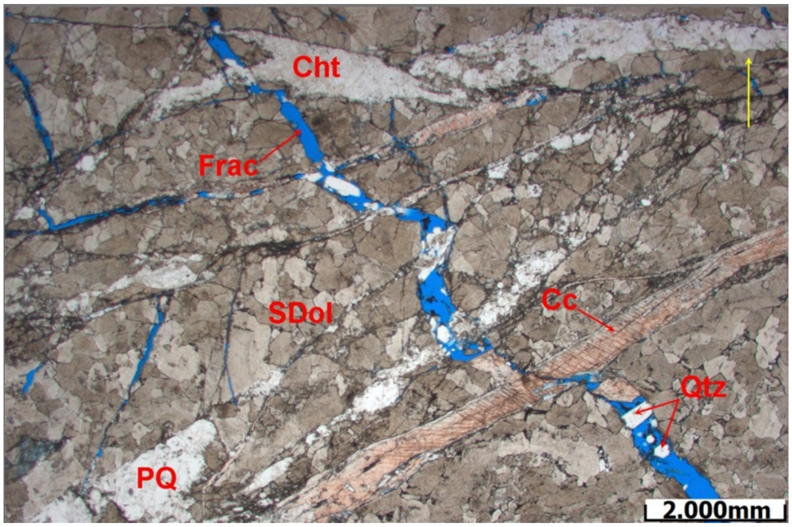


Figure 1.1. Sample T14, 11325.46ft/3452.00m. Low magnification view of the dolostone. The network of sub-vertical and sub-horizontal fractures (Frac) has resulted in a localized brecciated structure. Patchy microcrytalline chert (Cht) and macro-polycrystalline quartz (PQ) cements are noted. Euhedral secondary quartz (Qtz) is also noted to partly occlude an open fracture. Minor calcite cement (Cc) is also noted as fracture fill. SDol: coarse to very coarse crystalline saddle dolomite. **x12.5 ppl**

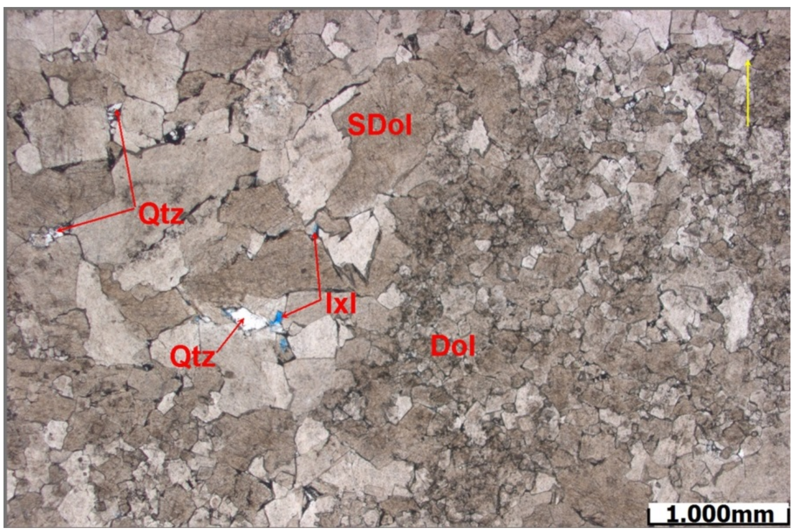


Figure 1.2. Sample T14, 11325.46ft/3452.00m. Low magnification view showing the crystal fabric which consists of fine crystalline to very coarse crystalline dolomite (Dol). Coarse crystalline dolomite within samples from this well location shows sweeping extinction and curved crystal faces, which is consistent with high temperature 'saddle' dolomite (SDol). Some crystal boundaries show isolated pressure-solution (chemical compaction). Intercrystalline pore spaces (Ixl) are locally occluded by secondary quartz cement (Qtz) and organic matter. **x25 ppl**

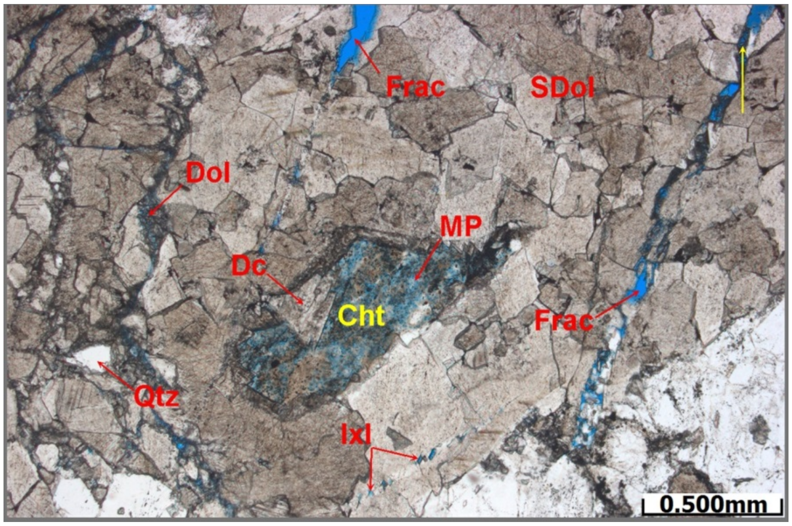


Figure 1.3. Sample T14, 11325.46ft/3452.00m. Moderate magnification view that highlights open fracture porosity (Frac) within the sample. Micro-intercrystalline pore spaces (Ixl) occur between stepped crystal faces of the coarse crystalline 'saddle' dolomite (SDol). Trace microporosity (MP) is associated with localized dissolution of chert cement (Cht). Dol: very fine crystalline dolomite; Dc: euhedral dolomite cement. **x50 ppl**

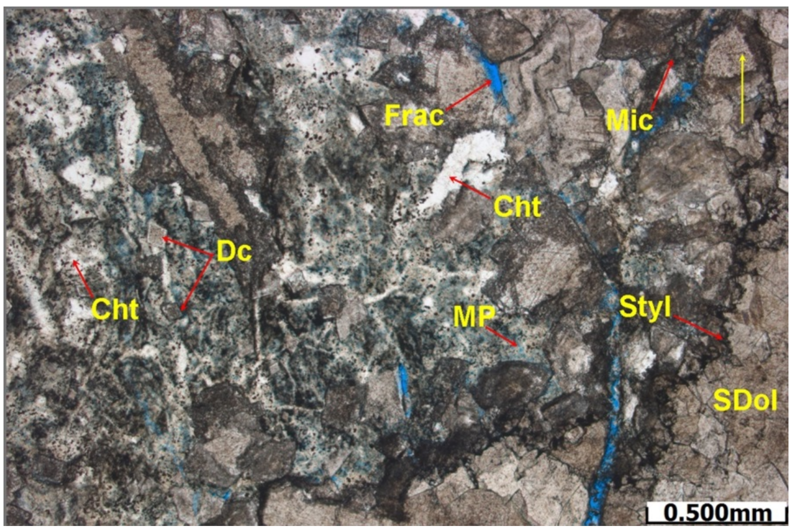
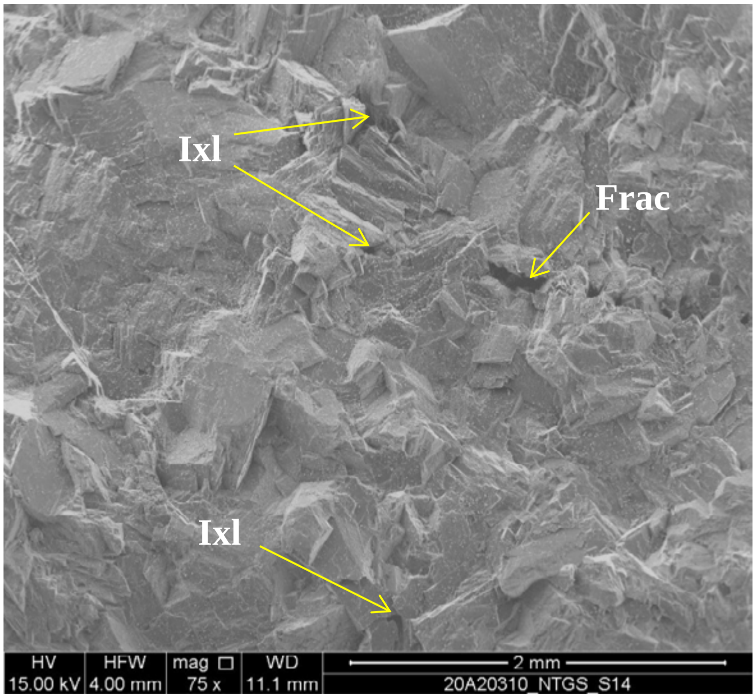
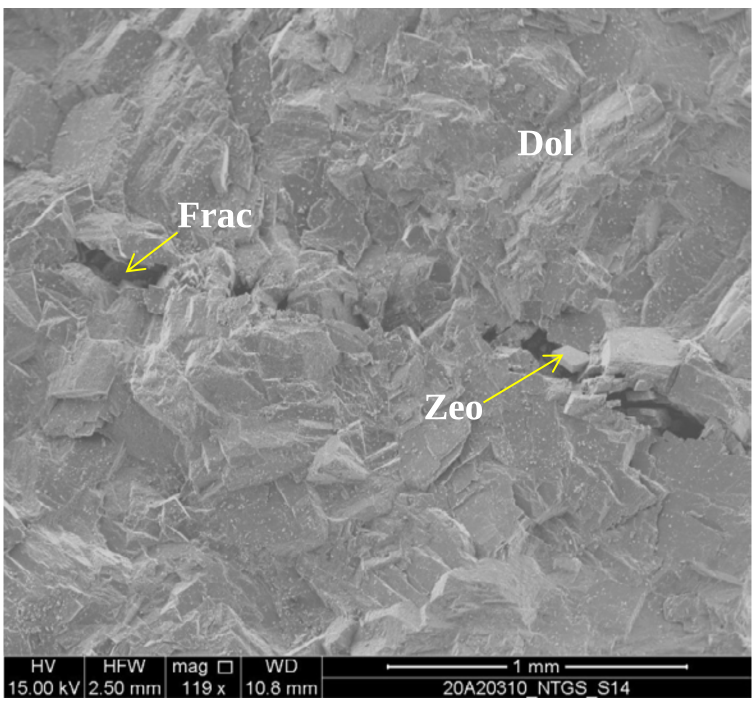


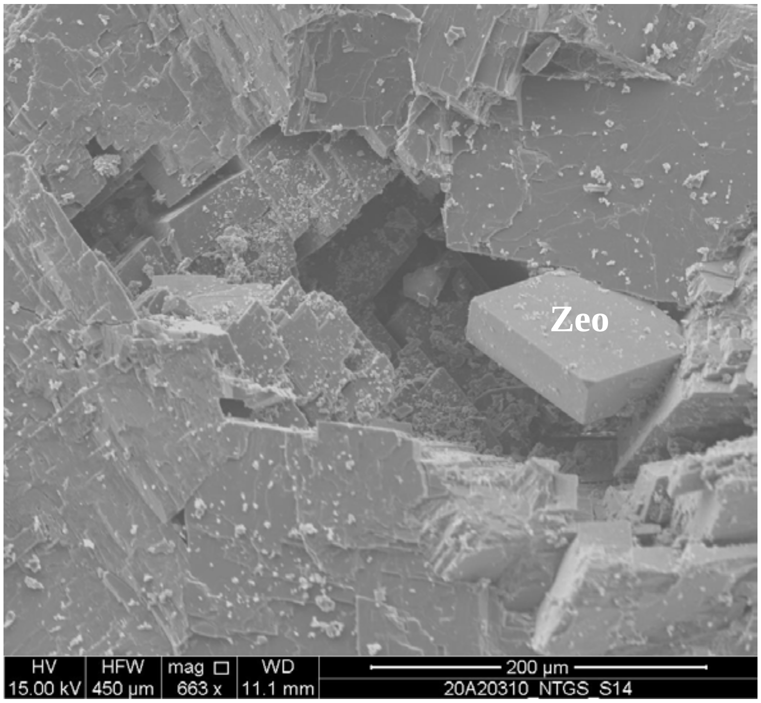
Figure 1.4. Sample T14, 11325.46ft/3452.00m. Alternate moderate magnification view of localized brecciated structure. Dc: sub-euhedral dolomite cement; Cht: chert cement; Mic: dolomicrite; MP: microporsity; Styl: stylolite; Frac: fracture porosity; SDol: saddle dolomite. **x50ppl**



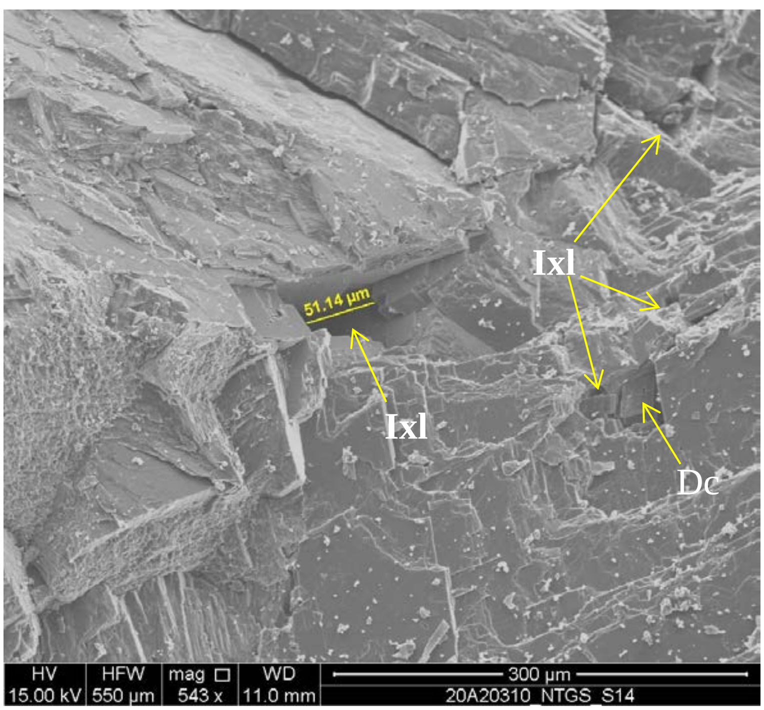
SEM Figure 1.5. Sample S14, 11325.46ft/3452.00m. Low magnification Scanning Electron Microscope (SEM) image of the dolostone focusing on the pore system which is characterized by scattered intercrstalline pores (Ixl) ranging in size from ~40-70µm, plus open fracture porosity (Frac). **x75**



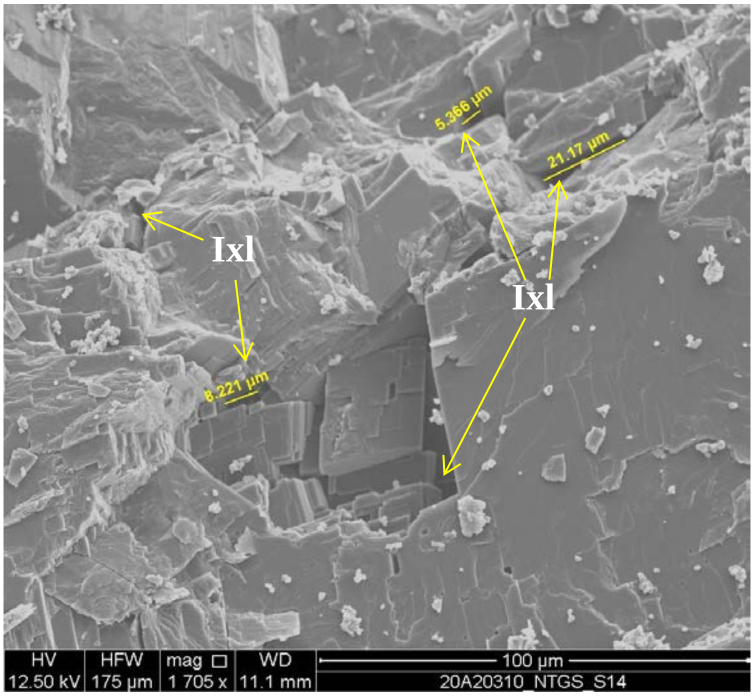
SEM Figure 1.6. Sample S14, 11325.46ft/3452.00m. Low magnification Scanning Electron Microscope (SEM) image highlighting open fracture porosity (Frac). The fracture measures ~50µm in width. A possible zeolite (Zeo) is noted within the fracture (see **Figure 1.7** for a detailed view). Dol:dolomite. **x119**



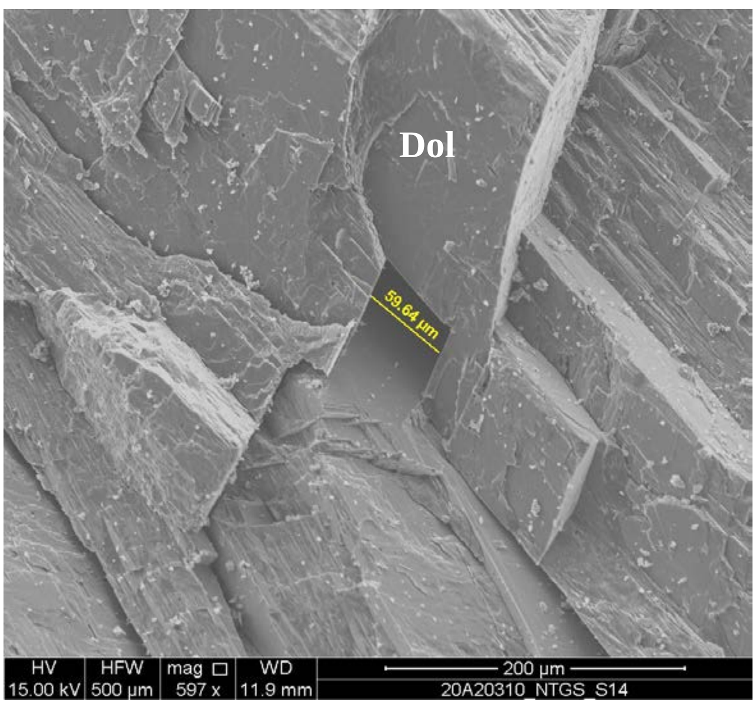
SEM Figure 1.7. Sample S14, 11325.46ft/3452.00m. Low magnification Scanning Electron Microscope (SEM) image showing details of a possible zeolite (Zeo) formed within an open fracture, as shown in **Figure 1.7**. Composition could not be confirmed by EDX due to poor detection as a result of sample topography. However, low levels of silicon and calcium detected, in addition to crystal shape, are suggestive of clinoptilolite or heulandite. **x663**



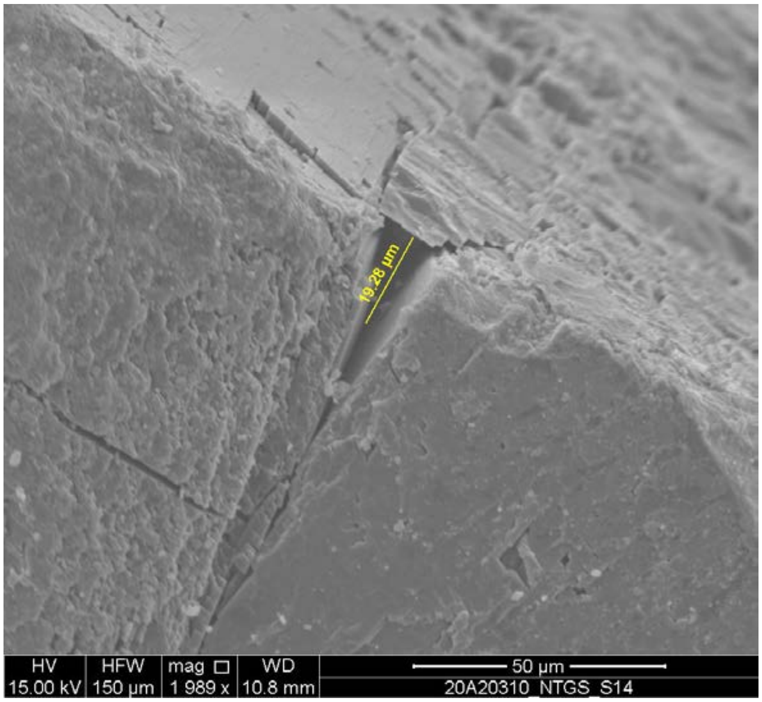
SEM Figure 1.8. Sample S14, 11325.46ft/3452.00m. Low magnification Scanning Electron Microscope (SEM) image of a relatively large intercrytalline pore measuring ~50µm (left-hand side of image), plus scattered intercrystalline porosity (Ixl) which has been partly occluded by relatively finer dolomite cements (Dc) which may potentially have been formed at a later diagenetic stage. See **Figure 1.9** for a more detailed view. **x543**



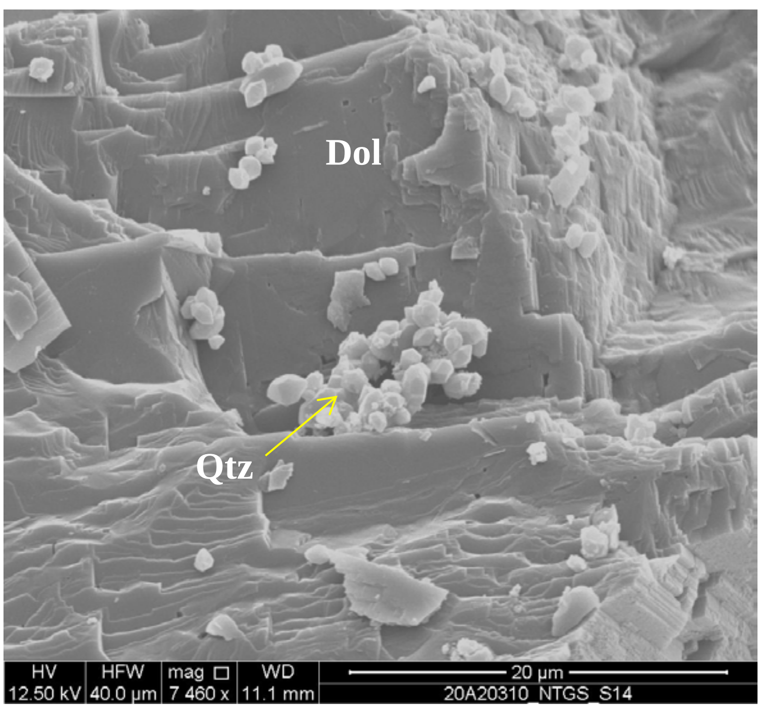
SEM Figure 1.9. Sample S14, 11325.46ft/3452.00m. Moderate magnification Scanning Electron Microscope (SEM) image featuring locally well-connected intercrystalline porosity (Ixl), ranging in size from ~1-20µm, as featured in **Figure 1.8**. **x1705**



SEM Figure 1.10. Sample S14, 11325.46ft/3452.00m. Low magnification Scanning Electron Microscope (SEM) image of an isolated blocky intercrystalline pore measuring ~60µm. Dol: dolomite. **x597**



SEM Figure 1.11. Sample S14, 11325.46ft/3452.00m. Moderate magnification Scanning Electron Microscope (SEM) image of an angular pore throat (~20µm) that appears free of fines such as clay minerals. **x1989**



SEM Figure 1.12. Sample S14, 11325.46ft/3452.00m. High magnification Scanning Electron Microscope (SEM) image featuring aggregated double-terminated authigenic quartz (Qtz). **x7460**

Sample T13/S13, 11328.54ft/3452.94m

Well Name	Paramount et al. Liard M-25	**Location**	300/M-25-6030-12330/0
Sample Type	Thin section/SEM grain mount from a core sample	**Depth (ft/m)**	11328.54ft/3452.94m
Stratigraphic Unit	Nahanni	**Reservoir Quality**	Poor-Moderate
Classification	Dolostone	**Stain type**	½ Dual carbonate stain

MINERALOGY

Thin Section Point counting (%)	Calcite	Dolomite	Anhydrite	Quartz/Cht	Pyrite	Clays & organics
	-	95	-	2	-	3
	Framework, Matrix, Cement, and Replacement					
	Carbonate clasts	Bioclasts	Detrital grains	Matrix	Pore filling cement	Replacement
	-	-	-	3	2	95

ADDITIONAL FEATURES and OTHER COMMENTS

Depositional	At the time of deposition, the sample was most likely massive. Generation of low amplitude stylolites and fracturing of the sediment typically occurs during burial diagenesis (mechanical and chemical compaction). Sub-vertical stylolites and fractures may have subsequently formed as a result of folding or compressional stresses. Saddle dolomite within the sample is a common product of late-stage diagenesis and hydrothermal activity.
Textures	Dolomite within this sample predominately displays replacement or alteration textures. 'Saddle' or baroque dolomite is represented by subhedral coarse dolomite that displays stepped or curved crystal faces, while sweeping or undulatory extinction can be viewed under cross-polarized light. This sample also contains patchy fine crystalline euhedral dolomite, which often displays compositional zoning characterized by a cloudy clay-included core with overgrowth cements that lack clay inclusions.
Framework (Carbonate clasts, Bioclasts)	Dolomitization and recrystallization fabrics have overprinted any original framework clasts/bioclasts within this sample.
Detrital Grains & Other Non-Carbonate Grains	There are no detrital grains in this sample.
Matrix	Minor clay and organics (3%) are observed predominately in association with stylolites which contain insoluble material that accumulates along the irregular dissolution surface. Clays also occur as occlusions associated with fine crystalline dolomite. Clay minerals with indistinct optical properties partly occlude open fractures and may represent drilling mud invasion.
Pore Filling Cements	Minor chert and euhedral quartz (2%) occurs as fracture-fill.
Replacement Minerals	Coarse to very coarse crystalline dolomite (95%) is the dominant replacement mineral in this sample.
Porosity	Porosity in this sample includes partly open fracture porosity (3%), minor scattered intercrstalline pores (1%), plus trace micro-vugs.

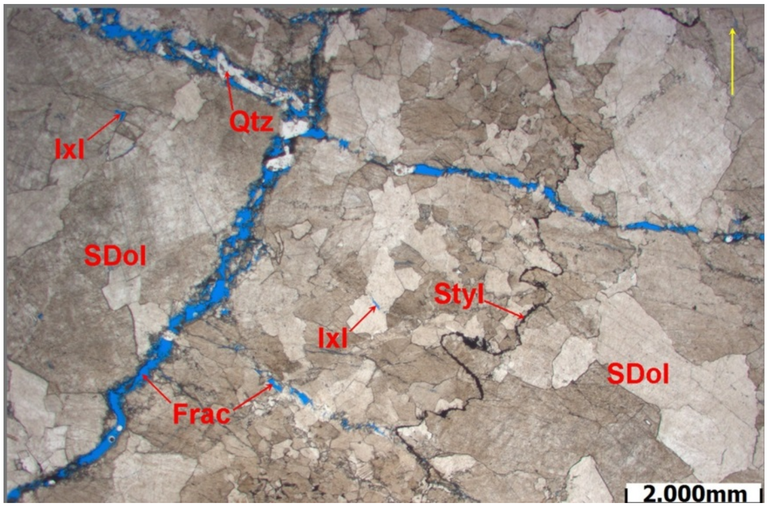


Figure 2.1. Sample T13, 11328.54ft/3452.94m. Low magnification overview of the dolostone. The crystal fabric within this portion of the sample is predominated by 'saddle' or baroque dolomite (SDol). This type of dolomite is generally considered to be a late stage, high temperature precipitate. Dolomitization has overprinted the original depositional fabric. Open fracture porosity is partly plugged by secondary quartz (Qtz). Styl: subvertical stylolite. **x12.5ppl**

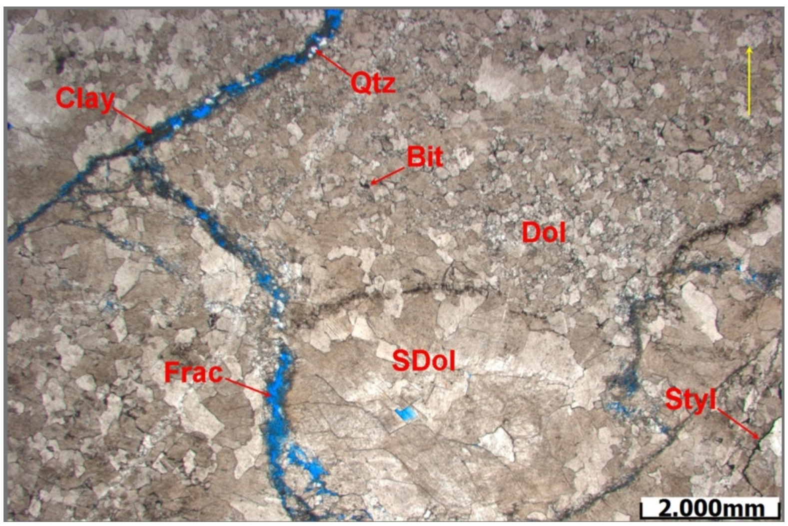


Figure 2.2. Sample T13, 11328.54ft/3452.94m. Alternate low magnification view showing a portion of the sample with sub- to euhedral fine crystalline dolomite (Dol). Intercrystalline pore spaces are mostly occluded with organic matter, such as possible bitumen/pyrobitumen (Bit). Transitions from very coarse crystalline 'saddle' dolomite (SDol) to fine-medium crystalline dolomite are often bound by stylolites (Styl) or fractures (Frac). Qtz: secondary quartz cement; Clay: indistinct clays, possible drilling mud invasion. **x12.5 ppl**

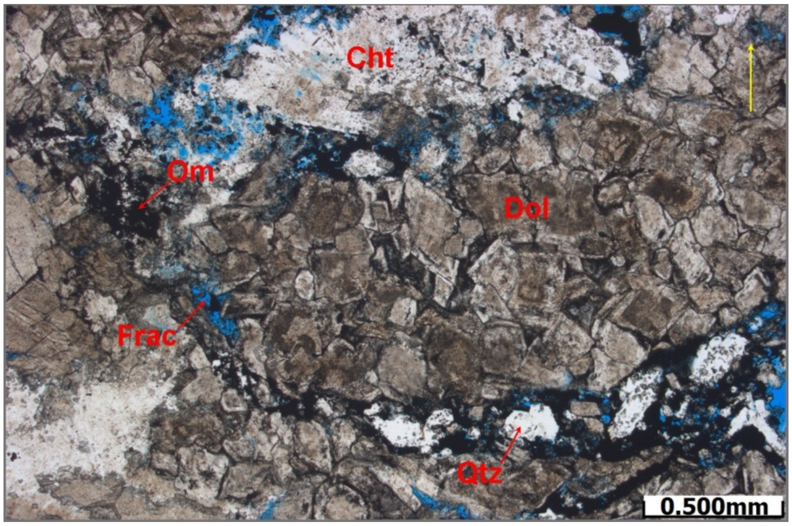


Figure 2.3. Sample T13, 11328.54ft/3452.94m. Moderate magnification view showing that portions of the sample have a localized fracture (Frac) induced brecciated structure. Various crystal fabrics are noted within this view including euhedral zoned dolomite (Dol), while the surrounding dolomite consists of coarse saddle dolomite. Organic matter (OM) lines the fracture in addition to euhe dral quartz cement (Qtz) and patchy secondary microcrystalline chert (Cht). **x50 ppl**

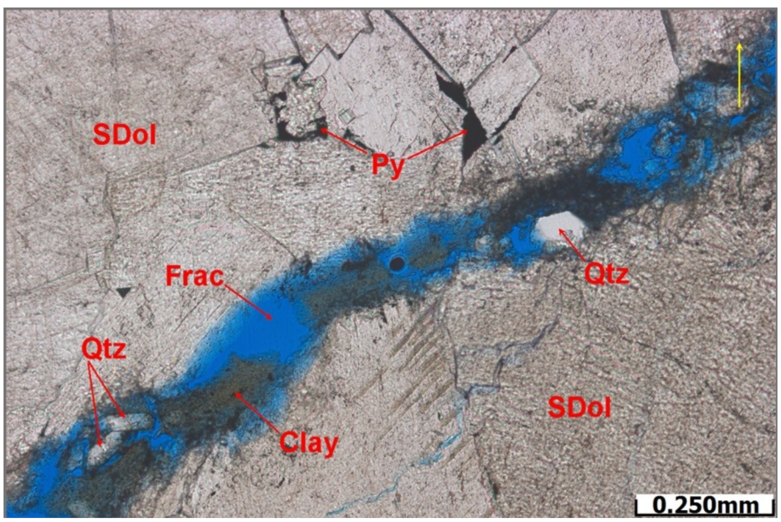
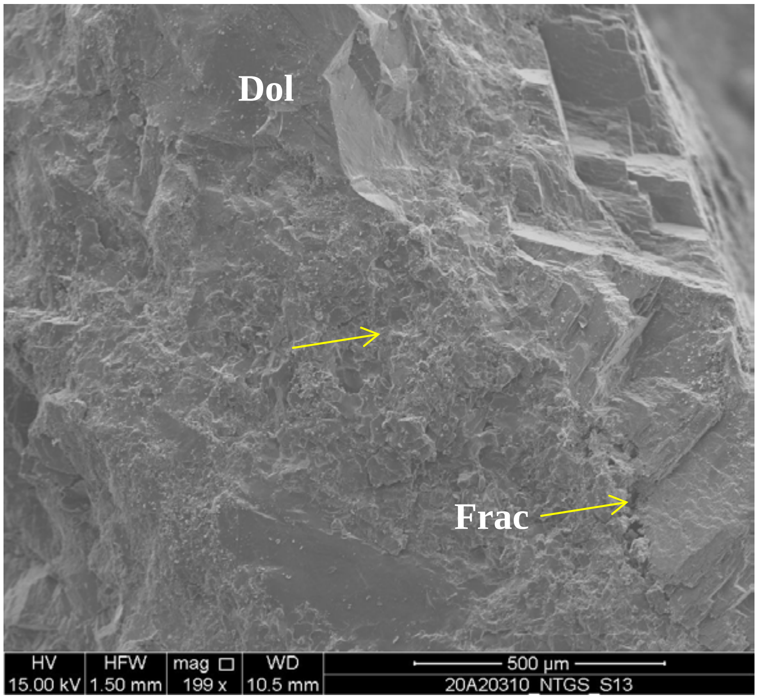
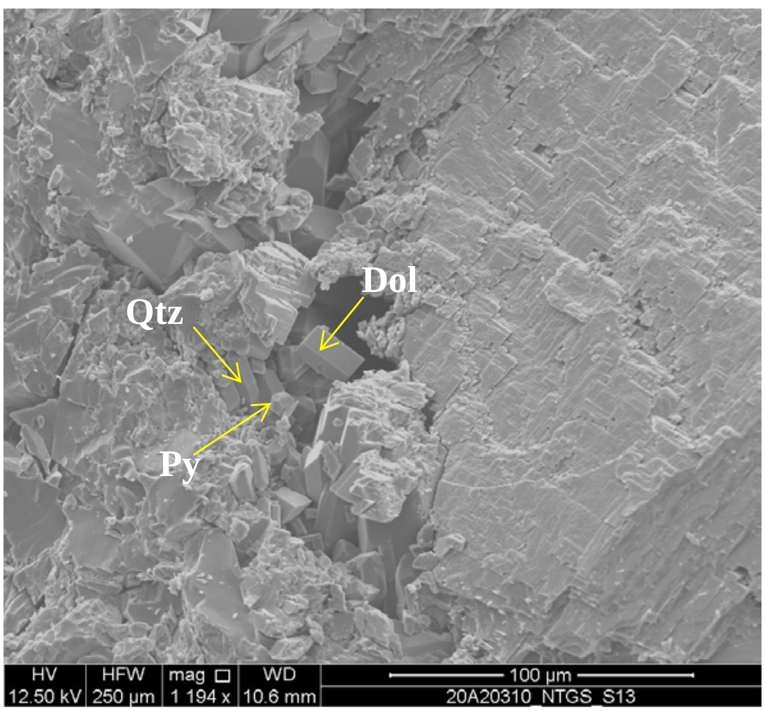


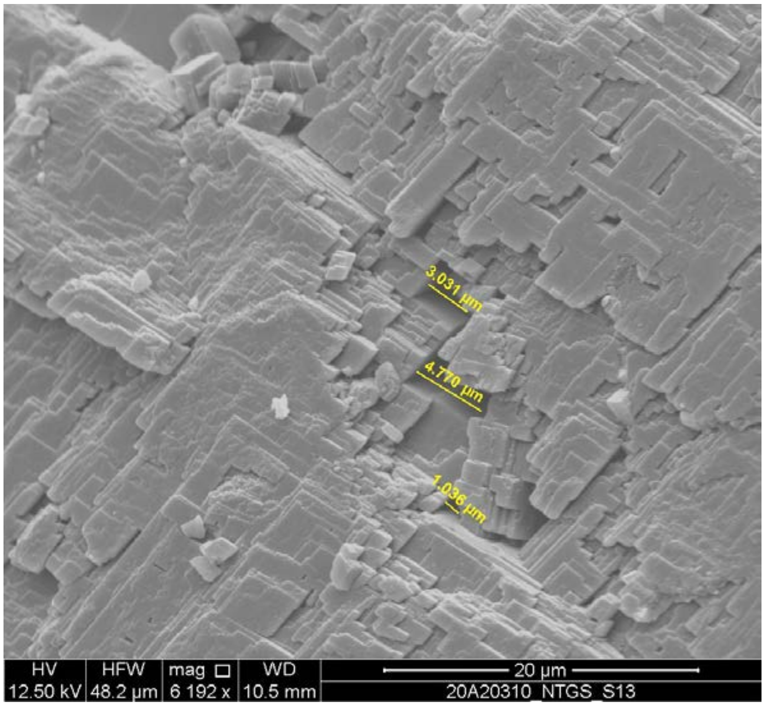
Figure 2.4. Sample T13, 11328.54ft/3452.94m. High magnification image of an open fracture (Frac) which contains euhedral secondary quartz (Qtz), in addition to clays (Clay) with indistinct optical properties. Clay content may represent possible drilling mud invasion. Intercrystalline pores spaces in this view have been occluded by secondary pyrite (Py). SDol: saddle dolomite. **x100ppl**



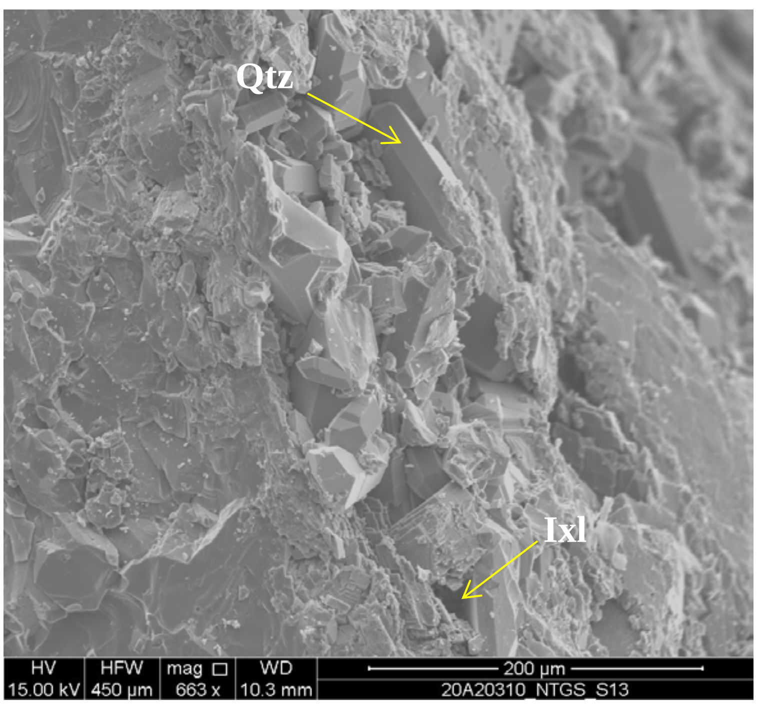
SEM Figure 2.5. Sample S13, 11328.54ft/3452.94m. Low magnification Scanning Electron Microscope (SEM) image of the dolostone which consists predominately of coarse to very coarse crystalline dolomite (Dol), with localized patches of fine to medium crystalline dolomite (yellow arrow). Open fracture porosity (Frac) was noted in the sample in proximity to euhdral hydrothermal quartz (**see Figure 2.6**). **x199**



SEM Figure 2.6. Sample S13, 11328.54ft/3452.94m. Scanning Electron Microscope (SEM) image showing a fracture which has partly infilled by secondary quartz (Qtz) and pyrite (Py) cements. **x1194**



SEM Figure 2.7. Sample S13, 11328.54ft/3452.94m. High magnification Scanning Electron Microscope (SEM) image showing details of the recrystallization/overgrowth texture shown in **Figure 2.6**. Featured micro-intercrystalline pore spaces range in size from ~1-3µm. **x6192**



SEM Figure 2.8. Sample S13, 11328.54ft/3452.94m. Alternate low magnification Scanning Electron Microscope (SEM) image of euhedral hydrothermal quartz (Qtz) which has partly infilled fracture porosity within the sample. Ixl: intercrystalline porosity. **x663**

Sample T12/S12, 11668.47ft/3556.55m

Well Name	Paramount et al. Liard M-25	**Location**	300/M-25-6030-12330/0
Sample Type	Thin section/SEM grain mount from a core sample	**Depth (ft/m)**	11668.47ft/3556.55m
Stratigraphic Unit	Nahanni	**Reservoir Quality**	Poor-Moderate
Classification	Dolostone	**Stain type**	½ Dual carbonate stain

MINERALOGY

Thin Section Point counting (%)	Calcite	Dolomite	Anhydrite	Quartz/Cht	Pyrite	Clays & organics
	-	87	-	7	3	3
	Framework, Matrix, Cement, and Replacement					
	Carbonate clasts	Bioclasts	Detrital grains	Matrix	Pore filling cement	Replacement
	3	-	-	3	9	84

ADDITIONAL FEATURES and OTHER COMMENTS

Depositional	At the time of deposition, the sample was most likely massive. Generation of low amplitude stylolites and fracturing of the sediment typically occurs during burial diagenesis (mechanical and chemical compaction). The presence of sub-vertical stylolites and fractures may have subsequently formed as a result of folding or compressional stresses. Saddle dolomite within the sample is a common product of late-stage diagenesis and hydrothermal activity.
Textures	Dolomite within this sample predominately displays replacement or alteration textures. ‘Saddle’ or baroque dolomite is represented by subhedral coarse dolomite that displays stepped or curved crystal faces, while sweeping or undulatory extinction can be viewed under cross-polarized light. Significant portions of this sample consist of fine crystalline euhedral dolomite that contains appreciable amounts of clay inclusions. Organic material (OM), such as possible bitumen, also appears to coat or occlude intercrystalline pore spaces. Compositional zoning is sometimes noted and is characterized by a cloudy clay-included core with overgrowth cements that lack clay inclusions.
Framework (Carbonate clasts, Bioclasts)	Dolomitization and recrystallization fabrics have mainly overprinted any original framework clasts/bioclasts within this sample.
Detrital Grains & Other Non-Carbonate Grains	There are no detrital grains in this sample.
Matrix	Minor clay and organics (5%) are observed predominately in association with stylolites and as clay occlusions associated with fine crystalline dolomite.
Pore Filling Cements	Pore-filling cements in this sample include minor dolomite (3%) and calcite (2%) fracture-fill, while minor chert cement locally occludes microvugs.
Replacement Minerals	In addition to dolomite (88%), which dominates the sample, trace pyrite replacement is also noted.
Porosity	The sample contains minor amounts of isolated microvugs (2%), along with lesser amounts of fracture porosity (1%), scattered intercrystalline porosity (1%) and trace micro-intercrystalline porosity.

Annotated microphotographs of the thin section and SEM samples with descriptions are provided below.

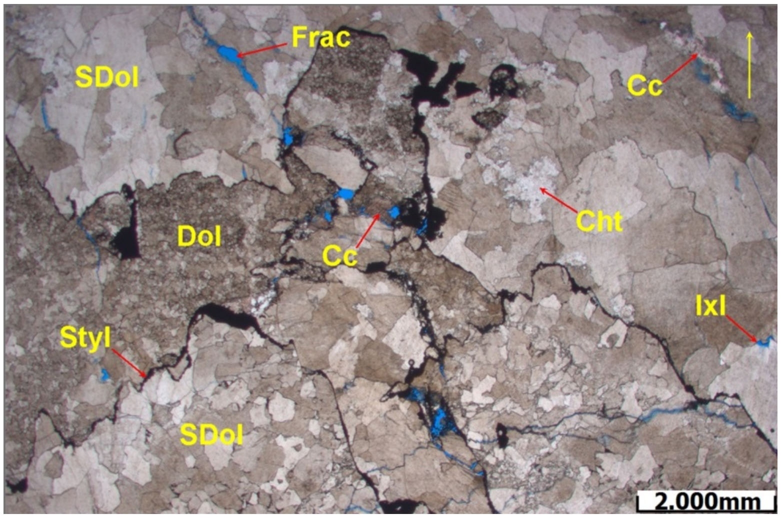


Figure 3.1. Sample T12, 11668.47ft/3556.55m. Low magnficiation view of the dolostone. Portions of the sample show replacement or alteration textures. 'Saddle' or baroque dolomite (SDol) is represented by subhedral coarse dolomite that displays stepped or curved crystal faces and sweeping extinction. Saddle dolomite is a common product of late-stage diagenesis and hydrothermal activity. A complex network of fractures (Frac) and stylolites (Styl) may have formed as a result of folding or compressional stresses. Ixl: intercrystalline porosity; Cc: calcite cement; Cht: secondary chert. **x12.5 ppl**

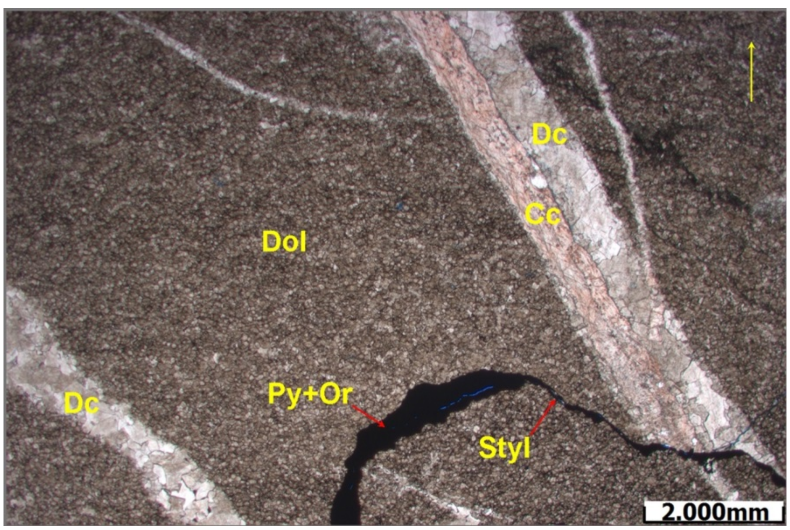


Figure 3.2. Sample T12, 11668.47ft/3556.55m. Alternate low magnification view of dolomite (Dc) and calcite (Cc) cements which comprise a subvertical vein. The vein is crosscut by a stylolite (Styl) representing a subhorizontal pressure-induced zone of dissolution. The surface contains insoluble organic residues that have been partly replaced by pyrite (Py+Or). Dol: fine crystalline dolomite. **x12.5ppl**

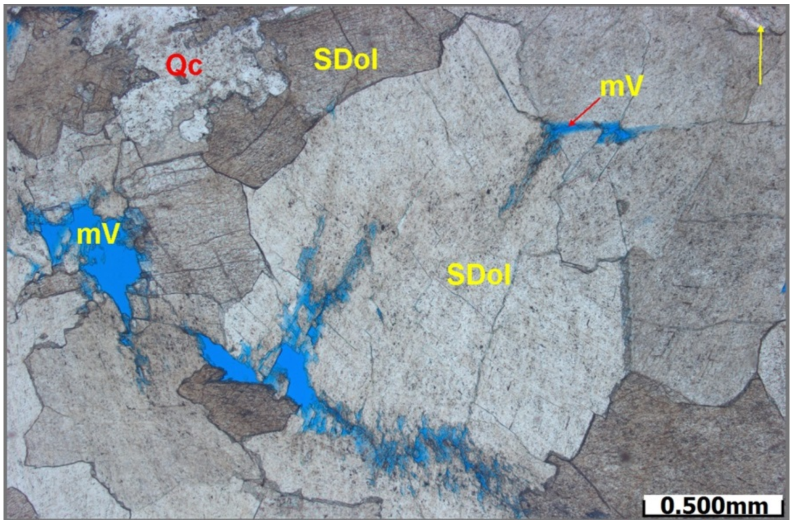


Figure 3.3. Sample T12, 11668.47ft/3556.55m. Moderate magnification view of micro-vuggy pore spaces (mV). Porosity (highlighted by blue epoxy) within this sample appears to be locally enhanced by dissolution resulting in irregular crystal surfaces. Some microvugs are occluded by secondary quartz cements (Qc). SDol: saddle dolomite. **x50 ppl**

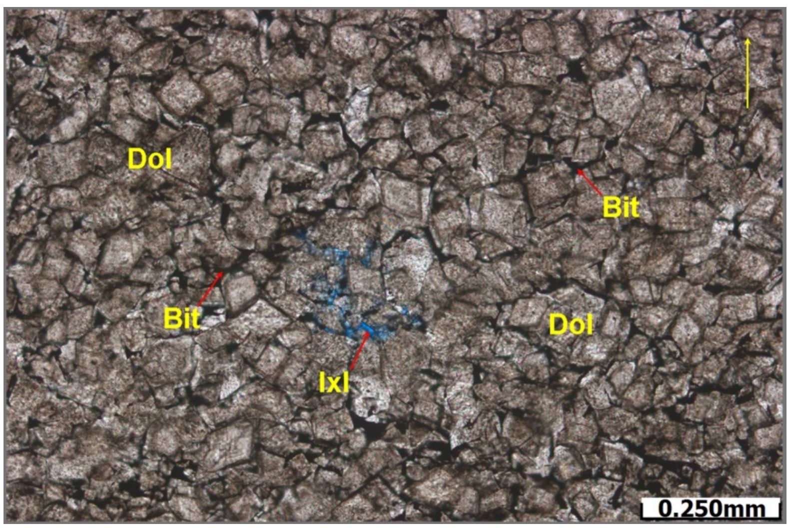
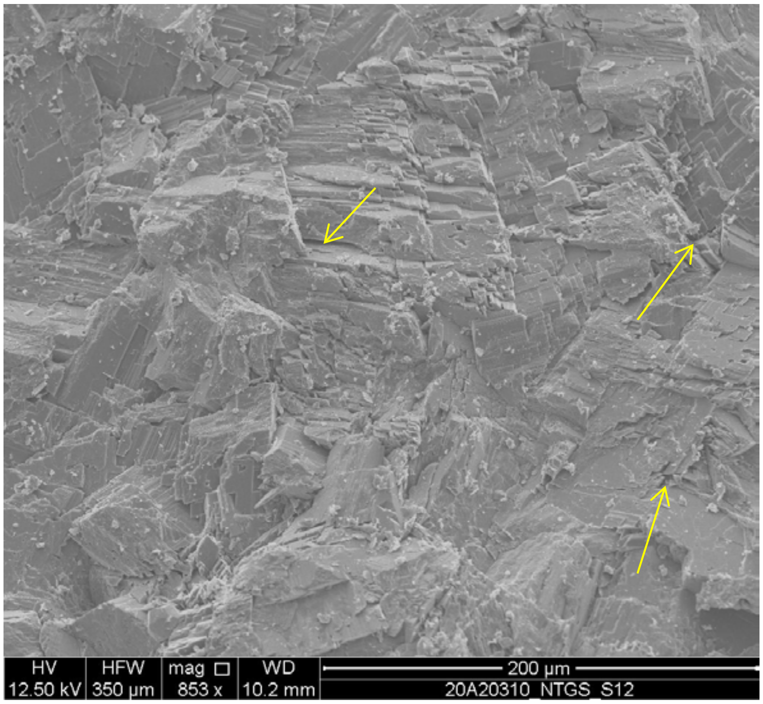
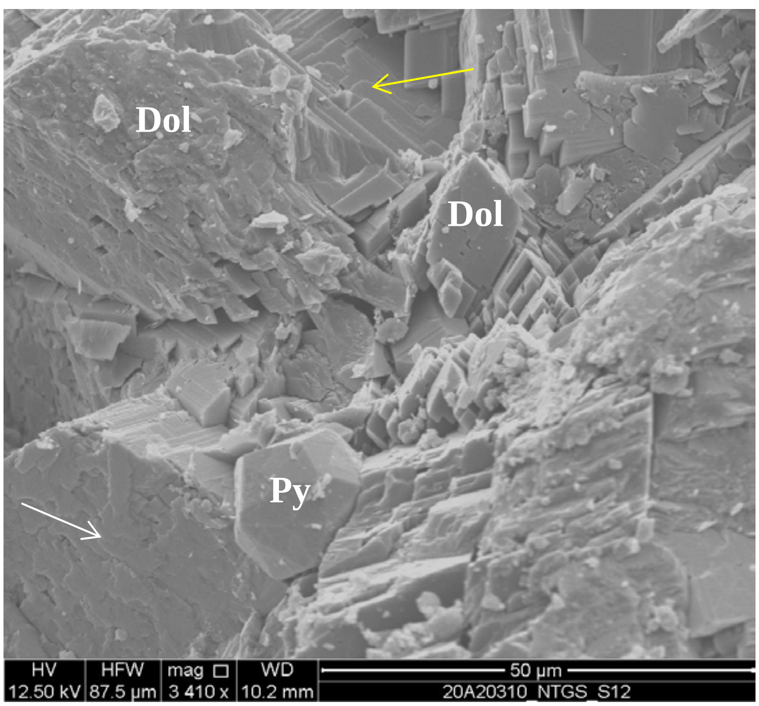


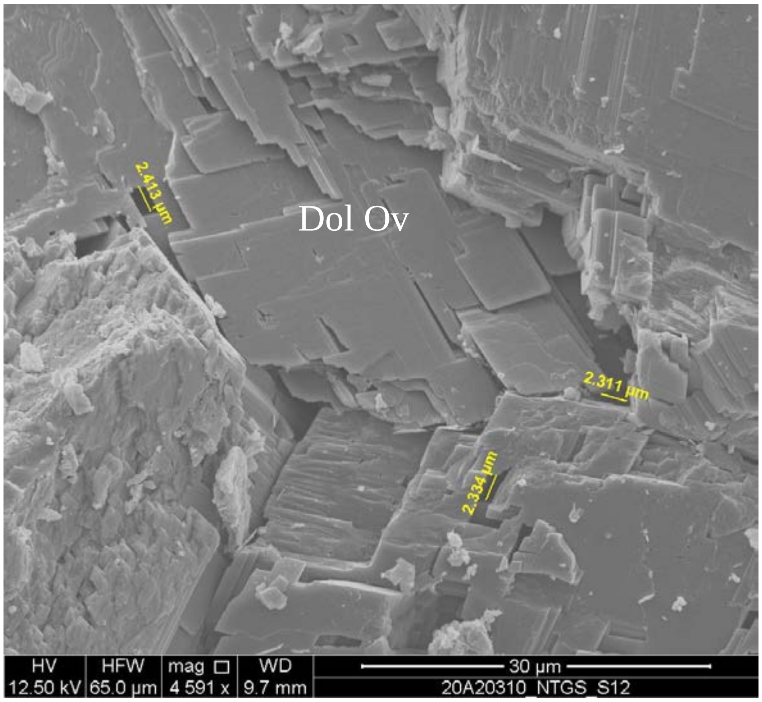
Figure 3.4. Sample T12, 11668.47ft/3556.55m. Close-up view highlighting micro-intercrystalline porosity (Ixl) associated with fine crystalline dolomite (Dol) that contains appreciable amounts of clay inclusions. Organic material (OM), such as possible bitumen, also appears to coat or occlude intercrystalline pore spaces. **x100 ppl**



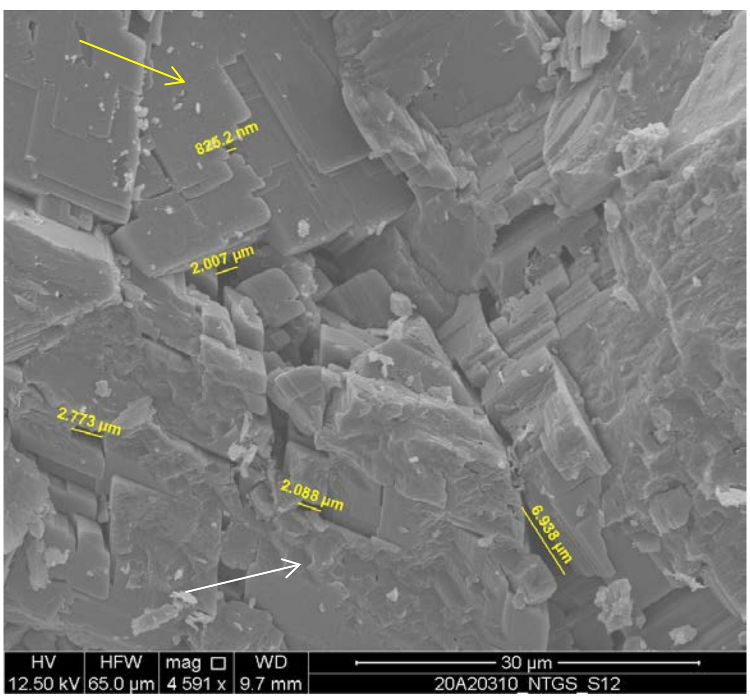
SEM Figure 3.5. Sample S12, 11668.47ft/3556.55m. Low magnification overview image of the dolostone. Visble porosity consists of intercrystalline porosity that has a size range of sub-micron to ~10µm pores (highlighted by yellow arrows). **x853**



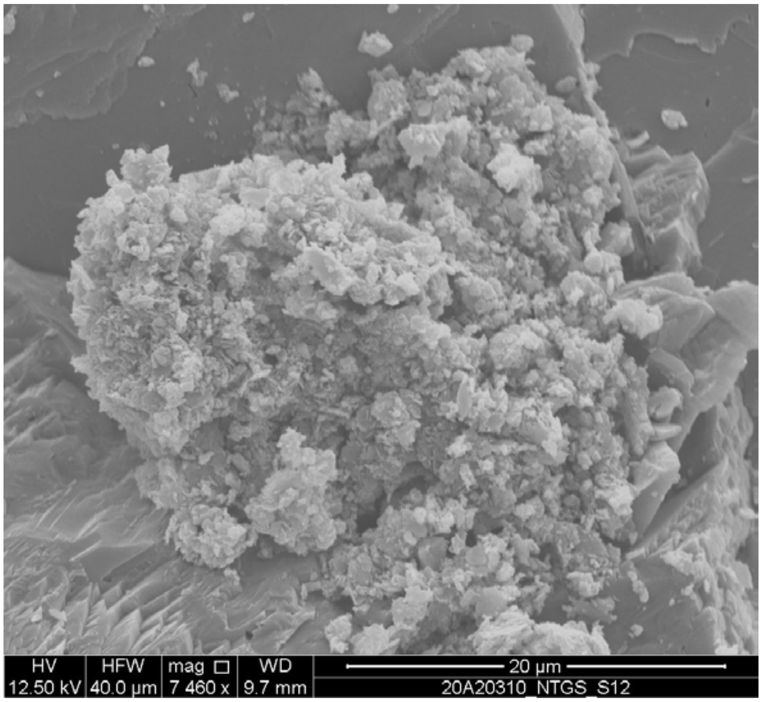
SEM Figure 3.6. Sample S12, 11668.47ft/3556.55m. Moderate magnification view of dolomite rhombs (Dol) that show possible overgrowth (white arrow) and/or recrystallization textures (yellow arrow). A pyritohedron (Py) is also shown within this view. **x3410**



SEM Figure 3.7. Sample S12, 11668.47ft/3556.55m. High magnification image highlighting dolomite overgrowth textures (Dol Ov) characterized by stepped euhedral crystal boundaries. Overgrowth cements appear to lack clay inclusions in relation to the surrounding groundmass. Scattered microporosity measures ~2µm on average. **x4591**



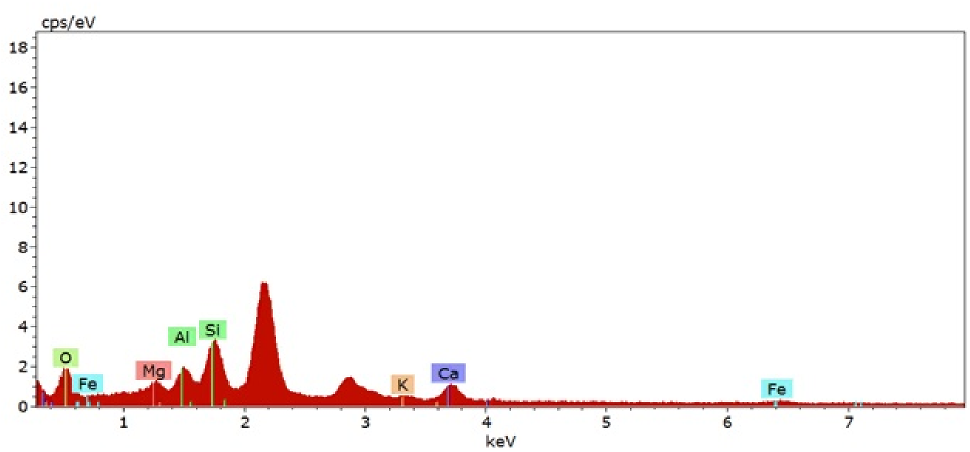
SEM Figure 3.8. Sample S12, 11668.47ft/3556.55m. Alternate high magnification view showing scattered microporosity that has a size range of sub-micron to ~7µm, and appears to be ~2µm on average. Some dolomite crystal surfaces show evidence of possible pitting or etching (white arrow), while overgrowth textures are also noted (yellow arrow). **x4591**



SEM Figure 3.9. Sample S12, 11668.47ft/3556.55m. High magnification image of a clay aggregate. See **Figure 3.9a** for EDX data. **x7460**

Results Figure 3.9a - Clay Aggregate

Element	series	[norm. wt.%]
Oxygen (O)	K-series	54.58028
Magnesium (Mg)	K-series	TR
Aluminium (Al)	K-series	4.057818
Silicon (Si)	K-series	23.4576
Calcium (Ca)	K-series	10.42692
Iron (Fe)	K-series	5.651472
Potassium (K)	K-series	1.825907
	Sum:	100



SUMMARY OF PORE SYSTEM, MAIN POROSITY CONTROLS AND RESERVOIR QUALITY

Porosity, permeability and overall reservoir quality of the observed samples from the study location can be function of various controls that includes depositional controls of grain size, sorting and mineralogy, and the diagenetic controls of compaction, dissolution and cementation.

Reservoir quality for these samples is considered to be poor to moderate and is mainly controlled by replacement texture and fracture systems. Compaction and pressure/solution (stylolites) are also evident in these dolostones, in addition to partial replacement by coarse to very coarse crystalline baroque (saddle) dolomite (typically considered to be a high temperature precipitate). Cemented and partially open fracture systems, in addition to stylolites, are generally subvertical to vertical within these samples. In addition to trace to minor amounts of partially open fractures (1% to 3%), scattered intercrystalline porosity (1%) and isolated microvugs (trace to 2% - samples T12 and T13 only) were also observed. Trace amounts of micro-intercrystalline porosity was also noted in T12. Routine core data shows porosity ranges from 0.7-3% for these samples, while permeability values range from 2-12 mD. Variations between estimated thin section porosities may be in part due to isolated porosity (microvugs and intercrystalline pores), the presence of ineffective microporosity associated with the micritic matrix, in addition to partly open fracture systems. Please see the Petrographic Summary (**Table 1**) in the Data Tables section for details regarding mineralogy, texture and porosity.

The following table summarizes the most important factors that control the reservoir quality of the three samples recovered from Paramount et al. Liard M-25 300/M-25-6030-12330/0 location.

Sample ID	**Depth (ft/m)**	**Total Micrite /Matrix (%)**	**Total Cement (%)**	**Total Porosity (%)**						**Main Porosity controlling factors (*)**	**RQ(*)**
				IP	Int.	Ixl	Mv	Fr	M		
Location: Paramount et al. Liard M-25 300/M-25-6030-12330/0											
T14	11325.46ft 3452.00m	3	4	-	-	1	-	2	-	Frac; Qc: Cc	P-M
T13	11328.54ft 3452.94m	3	2	-	-	1	TR	3	-	Frac; Qc	P-M
T12	11668.47ft 3556.55m	5	7	-	-	1	2	1	TR	Frac; Qc; Dc; Cc	P-M

Porosity value (%): IP – interparticle porosity; **Int** – intraparticle; **Ixl** – intercrystalline; **Mv** – micro-vuggy; **Fr** – fracture porosity; **M** – micro-intercrystalline porosity
Main Porosity controlling factors: Com – compaction**;** Mic – micrite (calcite or dolomite); **Ms** – micro- and/or pseudospar; **SDol** - saddle dolomite; **Cc** – calcite cement (druse and spar); **Dc** – dolomite cement**; Qc -** quartz cement; **C** – clays and organics; **Ov** – quartz overgrowths; **Py** – pyrite (replacement and/or cement); **F** – fabric: [**CC** – concavo-convex orthochem contacts; **S** – sutured orthochem contacts]; **Frac** - fractures
RQ (*) - reservoir quality: VP – very poor; **P –** poor; **M –** moderate; **G** - good

Reservoir problems for the samples recovered from the Nahanni Formation at the Paramount et al. Liard M-25 300/M-25-6030-12330/0 location, may include the following: **(1)** Heterogeneity of the pore system, plus overall poor interconnectivity between pores could restrict the flow of hydrocarbons, **(2)** hydrochloric acid (HCl) treatment of this reservoir has the potential to loosen carbonate fines and/or clays that could migrate and block pore throats, plus cause fabric collapse, **(3)** Sensitivity of calcium carbonate to hydrofluoric acid (HF) in regard to precipitation of calcium fluoride scales.

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Tucker, M. E. (1998). Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks. Second Edition, Blackwell Science Ltd., Malden, Massachusetts.

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Welton, J.E. 2003. SEM Petrology Atlas. Methods in Exploration Series No. 4. American Association of Petroleum Geologists, Tulsa, O.K.

DATA TABLES

Table 1
Petrographic Summary of Three Samples Recovered from the Nahanni Formation at the Paramount et al. Liard M-25 300/M-25-6030-12330/0 Location

Sample ID		**T14**	**T13**	**T12**			
Depth (m)		**3452.00**	**3495.94**	**3556.55**			
Rock Type		**DS**	**DS**	**DS**			
Mineralogy	*Calcite*	2	-	2			
	Dolomite	93	95	91			
	Anhydrite	-	-	-			
	Quartz	TR	1	-			
	Chert	2	1	2			
	Pyrite and Heavy Minerals	-	-	TR			
	Phosphate	-	-	-			
	Clays & organics	3	3	5			
Total Rock Volume (%)		**100**	**100**	**100**			
Carbonate Clasts	*Peloids*	-	-	-			
	Ooids	-	-	-			
	Intraclasts/Oncolintes	-	-	-			
	Total:	**0**	**0**	**0**			
Bioclasts/Fauna	*Mollusks*	-	-	-			
	Foraminifers	-	-	-			
	Brachiopod (shell & spines)	-	-	-			
	Bryozoa	-	-	-			
	Corals	-	-	-			
	Sponge Spicules	-	-	-			
	Echinoderms/Crinoids	-	-	-			
	Gastropods	-	-	-			
	Ostracodes	-	-	-			
	Stromatoporoid	-	-	-			
	Unidentified	-	-	-			
	Total:	**0**	**0**	**0**			
Detrital Grains and Other Non-Carbonate Grains	*Quartz*	-	-	-			
	Chert	-	-	-			
	Heavy Mineral	-	-	-			
	Total:	**0**	**0**	**0**			
Matrix	*Micrite (calcite or dolomite)*	-	-	-			
	Micro- and pseudospar	-	-	-			
	Clays & organics	3	3	5			
	Sutured allochems	-	-	-			
	Total:	**3**	**3**	**5**			
Pore Filling Cement	*Calcite Spar*	2	-	2			
	Calcite druse	-	-	-			
	Dolomite	-	-	3			
	Ferroan Dolomite	-	-	-			
	Quartz/Chert	2	2	2			
	Pyrite	-	TR	-			
	Anhydrite	-	-	-			
	Total:	**4**	**2**	**7**			
Replacement	*Calcite*	-	-	-			
	Dolomite	93	95	88			
	Anhydrite	-	-	-			
	Quartz/Chert	TR	-	TR			
	Pyrite	-	-	TR			
	Total:	**93**	**95**	**88**			
Total Rock Volume (%)		**100**	**100**	**100**			
Crystal Texture (Matrix)		-	-	-			
Crystal Texture (Cement)		Sub-Eu	Sub-Eu	Sub-Eu			
Crystal Size (Dolomite)		Frac; Styl	Frac; Styl	Frac; Styl			
Structure/Fabric		Fxl-VCxl	Fxl-VCxl	Fxl-Cxl			
Ratio Matrix/Clasts (approximate)		-	-	-			
Original Texture		-	-	-			
Porosity (%)	*Interparticle*	-	-	-			
	Intraparticle	-	-	-			
	Intercrystalline	1	1	1			
	Fracture	2	3	1			
	Micro-Vuggy	-	TR	2			
	Micro- intercrystalline pores	-	-	TR			
	Total TS Porosity (%)	**3**	**4**	**4**			
Petrophysical Results	*Core Porosity (%)*	**3.2**	**1.9**	**0.7**			
	Core Permeability (mD)	**2.1***	**12.1***	**4.17***			
Reservoir Quality		**P-M**	**P-M**	**P-M**			

LIST OF ABBREVIATIONS (CARBONATES)

SKELETAL GRAINS

Bry	-	BRYOZOAN
Ech	-	ECHINODERMS
Bra	-	BRACHIOPODS
Os	-	OSTRACODS
Cal	-	CALCISPHERES
Moll	-	MOLLUSKS
Plcy	-	PELECYPODS
Biv	-	BIVALVES
For	-	FORAMINIFERA
Strom	-	STROMATOPOROIDS
Cor	-	CORALS
Ga	-	GASTROPODS
Biocl	-	BIOCLASTS

OTHER GRAINS

Pel	-	PELOIDS
Ooi	-	OOIDS

ORIGINAL TEXTURE

GS	-	GRAINSTONE
PS	-	PACKSTONE
WS	-	WACKESTONE
MS	-	MUDSTONE
FS	-	FLOATSTONE
RS	-	RUDSTONE

CRYSTAL TEXTURE

Euh	-	EUHEDRAL
Sub	-	SUBHEDRAL
Anh	-	ANHEDRAL

CRYSTAL SIZE

Cxl	-	COARSE CRYSTALLINE
Mxl	-	MEDIUM CRYSTALLINE
Fxl	-	FINE CRYSTALLINE
Vfxl	-	VERY FINE CRYSTALLINE

CEMENT TYPES

Syn	-	SYNTAXIAL OVERGROWTHS
Blo	-	BLOCKY
Poik	-	POIKILOTOPIC
Dru	-	DRUSY
SD	-	SADDLE DOLOMITE
Lath	-	ANHYDRITE LATHS
Grm	-	GROUNDMASS
Iso	-	ISOPACHOUS RIMS
Spa	-	SPARITE

POROSITY TYPES

Mixl	-	MICRO-INTERCRYSTALLINE
Ixl	-	INTERCRYSTALLINE
Mo	-	BIOMOLDIC
mV	-	MICROVUGGY
mF	-	MICROFRACTURE
IG	-	INTERGRANULAR
IP	-	INTERPARTICLE
INTRP	-	INTRAPARTICLE

QUALITY

G	-	GOOD
M	-	MODERATE
P	-	POOR

Well Name: **Paramount et al. Liard M-25**
Well ID: **300/M-25-6030-12330/0**
NT WID # **N1867**

Table 2: Results of quantitative mineral analysis (relative weight %) of X-ray diffraction data for 3 (three) samples using Rietveld method

Geology ID	Depth (ft)	Depth (m)	Core & Box #	NTGS Sample Type & #	**Calcite**	**Dolomite**	**Quartz**	**Plagioclase feldspar**	**Pyrite**	**Total**
1	11024.6063	3360.30	2 & 4 of 5 R	X34 , P6	2.1	95.2	1.8	0.8	0.1	100
2	11138.45144	3395.00	2 & 3 of 5 L	X33, P5	0.4	96.1	2.9	0.6		100
3	11327.09974	3452.50	2 & 1 of 5 L	X32, P3	0.4	97.7	1.4	0.5		100

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