Natural Resources Canada | Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7647

Petrographic Study of the Nanaimo Group from OW-11-01-Nanaimo Obs Well 390

L. Zhai and S.E. Grasby

2015

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7647

Petrographic Study of the Nanaimo Group from OW-11-01-Nanaimo Obs Well 390

L. Zhai[1], S.E. Grasby[2]

[1]Remaining Oil Technology Inc., 210 Hawkdale Bay NW, Calgary Alberta
[2]Geological Survey of Canada (Calgary), 3303 33rd Street, N.W., Calgary, Alberta

2015

doi:10.4095/295719

This publication is available for free download through GEOSCAN (http://geoscan.nrcan.gc.ca/).

Recommended citation
Zhai, L. and Grasby, S.E. 2015. Petrographic Study of the Nanaimo Group from OW-11-01-Nanaimo Obs Well 390; Geological Survey of Canada, Open File 7647, 74 p. doi:10.4095/295719

Publications in this series have not been edited; they are released as submitted by the author.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Thin section petrography was conducted on forty-four (44, see Table 1) samples from the OW-11-01-Nanaimo OBS well 390, to determine their mineralogical, textural, diagenetic and reservoir characteristics. Work was focused on pore systems and processes affecting the porosity evolution.

The 44 Nanaimo Group samples include 43 sandstones and 1 silty mudstone. Most samples are massive; some finer-grained samples show clay and organic material-rich lamination, shale/siltstone cross lamination, burrows and bioturbated structures. All Nanaimo Group samples show low mature features in texture and composition with significant amounts of matrix clay (most samples are between 10 to 30% clay). Grain composition was characterized by abundant feldspar, chert and volcanic rock fragments. Quartz, feldspar and rock fragments are the three major components; although their proportions vary between samples. Coarser grained sandstone samples have a wide grain size range, varying from coarse silt to very coarse sand. The framework grains are angular, subangular to subrounded and poorly sorted or poorly to moderately sorted, showing a grain supported, moderately compacted fabric. Whereas finer (very fine to fine, or silt to very fine) grained sandstone samples demonstrated a grain-supported, well sorted or moderately to well sorted fabric. Grains are subangular to subrounded or rounded, with most grain size ranging from very fine to fine.

Common diagenetic phases include authigenic chlorite coating, quartz overgrowth, feldspar overgrowth, dissolution, emplacement of pyrite, calcite and organic matter or bitumen. Evolution of the pore system is apparently controlled by depositional environment and later diagenesis. Various diagenetic features have affected the reservoir quality to varying degrees, both creating and destroying porosity. The original intergranular pores are blocked by matrix clay and further reduced by early chlorite lining, quartz overgrowth, feldspar overgrowth and compaction, therefore no original

intergranular pores were observed in any sample. Later stage dissolution produced secondary intergranular pores and improved the reservoir quality of Nanaimo Group sandstones to some degree. The formation of pyrite, calcite cement and organic matter emplacement locally occludes secondary pore spaces, all sandstone samples show very low to low visible porosity (trace to 2-3%).

The porosity types of the Nanaimo Group sandstones can be generalized as: secondary porosity (sp), microporosity (mp) and microfractures.

Secondary porosity (as a result of feldspar dissolution) is the major pore type in the Nanaimo sandstones. Microporosity is abundant and is extensive within the clay matrix, leached feldspars, chert, and rock fragments (volcanic, plutonic and metomorphic rock fragments) and has little contribution to reservoir quality due to the very smaller pore size. Microfractures appeared in two directions to cut through the rocks and locally enhanced the reservoir permeability.

INTRODUCTION

A Groundwater Assessment in the Nanaimo Lowlands project was initiated by the British Columbia Department of Environment, related local municipalities, and the Geological Survey of Canada in 2010 to evaluate groundwater resources in the Nanaimo Basin of eastern Vancouver Island. This included studies of both surficial and bedrock aquifers, including the Upper Cretaceous Nanaimo Group (Nanaimo Group stratigraphy is summarized in Hamblin 2012). During drilling of a bedrock monitoring well, a core of the Nanaimo Group was collected. Detailed descriptions of lithology, porosity and permeability are provided in Hamblin and McCartney (2014). In addition to this work, thin section petrography was conducted on forty-four (44, see Table 1) samples from the OW-11-01-Nanaimo OBS well 390, to determine their mineralogical, textural, diagenetic and reservoir characteristics. The results are presented here.

The prepared thin sections were examined petrographically. Major mineralogical compositions, grain constituents and porosity are semi-quantified using visual estimate method. Petrographic data is summarized in table format (Table 1), including framework mineralogy, diagenetic minerals, rock type, texture and porosity.

Representative photomicrographs with descriptions of the thin sections are provided in an appendix (Plates 1 to 44) at the end of report. Plates are sorted by depths and sample IDs. When examples are used in text report, they are referred to certain plates by their sample numbers.

Table 1A：Petrographic Summary

Sample ID	Spot Depth (m)	Structure	Grain Size (μm)	Sorting	Lithology	Porosity (Helium) Fraction
1	384.75	Massive	Fine - Medium	Poor - Moderate	Litharenite	0.096
2	367.00	Massive	Medium - Coarse	Poor	Fd Litharenite	0.077
4	361.75	Massive - Fracture	Fine - Medium	Moderate	Fd Litharenite	0.052
7	340.00	Massive	Fine - Medium	Moderate	Lithic Arkose	0.033
9	332.08	Laminated - Burrowed	Silt - Very Fine	Moderate - Well	Litharenite	0.073
10	328.50	Massive	Fine - Medium	Poor - Moderate	Fd Litharenite	0.048
12	318.75	Massive	Fine - Medium	Poor - Moderate	Lithic Arkose	0.048
14	305.75	Massive	Fine	Poor	Litharenite	0.056
16	294.75	Massive	Fine - Coarse	Poor	Fd Litharenite	0.035
17	286.50	Massive	Fine	Well - Very Well	Fd Litharenite	0.098
19	279.00	Massive - Laminated	Very Fine - Coarse	Poor	Lithic Arkose	0.076
21	267.00	Massive	Very Fine - Coarse	Poor	Fd Litharenite	0.040
22	253.00	Massive	Medium - Coarse	Medium	Fd Litharenite	0.057
24	236.25	Massive	Fine - Medium	Moderate - Well	Lithic Arkose	0.018
26	227.50	Massive - Laminated	Fine	Very Well	Lithic Arkose	0.082
28	216.75	Massive	Fine - Medium	Moderate	Fd Litharenite	0.051
29	214.50	Massive	Medium - Coarse	Moderate	Fd Litharenite	0.072
30	207.50	Massive	Medium - Coarse	Poor - Moderate	Fd Litharenite	0.075
32	194.50	Massive	Very Fine - Coarse	Poor	Fd Litharenite	0.059
34	180.00	Massive	Fine - Medium	Poor - Moderate	Lithic Arkose	0.092
35	171.75	Massive - Burrowed	Very Fine - Fine	Well	Lithic Arkose	0.085
36	163.75	Massive	Very Fine - Fine	Well - Very Well	Fd Litharenite	0.091
37	161.25	Massive	Fine - Medium	Medium - Well	Fd Litharenite	0.108

Table 1B: Petrographic Summary Continued

Sample ID	Spot Depth (m)	Structure	Grain Size	Sorting	Lithology	Porosity (Helium) Fraction
38	158.75	Massive	Medium - Coarse	Medium	Fd Litharenite	0.019
39	153.00	Massive	Fine - Medium	Poor	Lithic Arkose	0.099
41	148.00	Massive	Very Fine - Poor	Poor	Fd Litharenite	0.089
42	144.92	Massive - Laminated	Silt - Very Fine	Well - Very Well	Sublitharenite	0.076
43	139.00	Massive - Burrowed	Very Fine - Fine	Moderate - Well	Fd Litharenite	0.083
44	135.58	Massive - Burrowed	--	--	Silty mudstone	0.058
45	127.50	Massive	Very Fine - Coarse	Poor	Fd Litharenite	0.068
46	122.50	Massive	Fine - Coarse	Poor - Moderate	Fd Litharenite	0.036
48	106.67	Massive	Fine - Coarse	Poor	Lithic Arkose	0.026
50	100.67	Massive	Fine - Coarse	Poor	Lithic Arkose	0.087
51	96.00	Massive - Bioturbated	Very Fine - Fine	Well	Lithic Arkose	0.092
52	89.50	Massive	Medium - Coarse	Poor - Moderate	Fd Litharenite	0.067
53	78.50	Massive	Fine - Medium	Moderate	Fd Litharenite	0.091
55	73.33	Massive - Bioturbated	Fine - Coarse	Poor	Fd Litharenite	0.073
56	68.50	Massive - Laminated	Very Fine - Fine	Moderate	Lithic Arkose	0.063
57	62.00	Massive	Fine - Medium	Moderate - Well	Lithic Arkose	0.102
60	47.75	Massive	Fine - Medium	Poor - Moderate	Fd Litharenite	0.097
62	33.00	Massive - Bioturbated	Very Fine - Fine	Poor - Moderate	Subarkose	0.083
63	30.50	Massive	Medium - Coarse	Moderate	Fd Litharenite	0.080
64	26.25	Massive - Laminated	Very Fine - Fine	Well	Lithic Arkose	0.090
66	19.42	Massive	Medium - Coarse	Moderate - Well	Fd Litharenite	0.077

*Note: Fd Litharenite-----Feldspathic Litharenite

PETROGRAPHIC SUMMARY & DISCUSSION

The 44 Nanaimo samples from the OW-11-01-Nanaimo OBS well 390, include 43 sandstones and 1 silty mudstone (Table 1), all 43 sandstone samples can be further classified as feldspathic litharenites (25), lithic arkoses (14), litharenites (2), sublitharenite (1) and subarkose (1) according to Folks classification, 1968. Summary of the petrographic data is given in Table-1. The details of rock constituents, texture and diagentic features are elaborated in 44 Plates. Key petrographic features are summarized and discussed together in the following text.

Structure: Most Nanaimo sandstones are massive. Some very fine to fine grained sandstones show well developed ellipse shaped burrows (samples 19, 30, 35, 43, 44) and other bioturbation structures (samples 9, 14, 51, 55, 56). Samples 9, 35 and 42 show laminated structure which are defined by organic matter-rich and clay-rich lamina, dark brown to black organic matter and clay compressed into thin strips or lamina paralleling to bedding plane. Also elongated grains and mica are preferentially oriented and aligned along bedding planes.

Texture/fabrics: The petrographic analysis indicates that most Nanaimo Group samples are low mature in texture and composition, especially in medium to coarse grained sandstone samples. Sand grains and matrix clay were deposited together, clays blocked the intergranular pore spaces and therefore the primary pores are not well preserved before compaction. Coarser grained sandstone samples have a wide range in grain size, varying from coarse silt to very coarse sand. The framework grains are angular, subangular to subrounded and poorly sorted or poorly to moderately sorted, showing a grain supported, moderately compacted fabric. Grains are commonly point-planar contacted to slightly concave-convex-contacted (as indicated by deformation of ductile grains; eg. mica, shale clasts, volcanic and metamorphic rock fragments). Whereas finer (very fine to fine or silt to fine) grained sandstone samples demonstrated a

grain-supported, well sorted or moderately to well sorted fabric. Grains are subangular to subrounded or rounded, with most grain size ranging from very fine to fine.

Compositions: The Nanaimo Group sandstone framework grains are composed of three major components: quartz, feldspars and rock fragments (chert, shale clasts, volcanic, plutonic and metamorphic rock fragments etc.). Minor mica, glauconite and trace heavy minerals and glauconite are also present.

Quartz (qtz) grains include monocrystalline and polycrystalline quartz, they are mainly monocrystalline, inclusion free or with rare mica and heavy mineral (e.g. zircon) inclusions. Quartz tends to increase its quantity in finer (very fine to fine) grained sandstones. Quartz grains are moderately to well sorted and subangular to subrounded. Trace to minor authigenic quartz overgrowths are mainly found in coarser grained sandstone samples (samples 4, 16, 21, 29, 30, 32, 38, 41, 46, 48, 52, 46, 48, 52, 63, 66). **Feldspar (fd)** occurs mainly as plagioclase with minor potassium feldspar, all Nanaimo Group sandstones are characterized by considerable feldspar. Feldspar grains are identified by elongated shape, weathered surfaces (sericited), cleavages, Carlsbad twining, albite twining, polysynthetic twining (microcline) and Carlsbad-albite twining (plagioclase). Dissolution or leaching of feldspar grains generated minor secondary porosity within feldspar grains or volcanic rock fragments and improved reservoir quality in some degree. **Chert (cht)** often inclusion-rich (clays, dolomite and pyrite), is the main constituent of the framework, characterized by crypto- to microcrystalline and rare fibrous chalcedony textures. Also chert grains can be leached to various extents, generating microporosity and secondary porosity in kerogen mature stage. **Volcanic rock fragments (VRF)** are characterized by their unique fabric, with feldspar laths floating in cryptocrystalline groundmass. Both feldspar laths and groundmass are commonly leached to various extents (like chert grains), forming secondary intragranular porosity and microporosity. Chloritization and pyritization are the most common alteration products in volcanic rock fragments. **Metamorphic rock fragments (MRF)** consist of micaceous

schist and phyllite clasts, and are often compressed between harder grains. Metamorphic rock fragments are also frequently altered by chlorite and pyrite. However, no secondary pore spaces are found within metamorphic rock fragments. Sedimentary rock fragments are mainly **shale clasts (sh)** with trace to minor **bioclasts**. Shale clasts occur in all sandstone samples regardless of grain size variation. They are ductile grains, sub-preferentially oriented, often squeezed between other grains, even forming pseudo matrix and lowered reservoir quality.

Diagenesis: Reservoir quality in the Nanaimo Group sandstone is a function of a complex interrelationship of both depositional and diagenetic processes. Common diagenetic phases encountered in the Nanaimo sandstones include authigenic chlorite, quartz overgrowth, feldspar overgrowth, chlorite filling, feldspar filling, emplacement of pyrite, calcite and organic matter or bitumen.

Chlorite (chl) exists extensively in all Nanaimo Group samples, it has two different kinds of forms: ① chlorite as products of alteration of volcanic/ metamorphic rock fragments, replacement of chert/feldspar; ② it occurs as tiny needle-like crystals coating grains and lining pores. Chlorite is characterized by its bluish green interference color. It is a few microns to tens of microns in size. In some coarse sand grained samples, pore lining chlorite crystals appear larger in size and form thin films surround grains (samples 28, 32, 34 39, 46, 50, 51, 57, 62, 63, 66). Some unstable grains such as feldspars and volcanic rock fragments were leached to various extent, even completely, leaving relict chlorite rims. This indicates that chlorite coating had formed before the grain dissolution, and is the first stage of intergranular pore-filling followed by quartz and feldspar overgrowths. Minor medium to coarse crystalline, pore-filling chlorite was also observed in several samples 32, 36, 50, 51, 57.

Quartz overgrowths (qtz) appear as trace or minor quantities surrounding monocrystalline quartz grains, they are not commonly developed due to abundant matrix clay and chlorite coating, locally occluded intergranular pores and have the adverse effect on reservoir quality

in most sandstone samples. **Feldspar cement (fd)** was found as overgrowths around feldspar grains in most samples and as prismatic crystals filling intergranular pores (sample 39) in several samples. Apparently, feldspar cement also lowered the reservoir quality**.**

Calcite cement (cal) is a major porosity reducing diagenetic phase in the Nanaimo Group sandstones. We detected variable amounts of calcite cement, varying from trace to 17-20% (sample 17), it occurs as fine to coarse crystals filling intergranular pores and secondary pores within feldspar and volcanic/plutonic rock fragments, severely decreasing reservoir porosity and permeability. It is recommended that thin sections should be stained for the future work using Alizarin Red-S and potassium ferricyanide to assist identifying calcite versus dolomite, and ferroan versus non-ferroan carbonate.

Pyrite (pyr) was found in minor to moderate volume existing in all Nanaimo Group samples. It occurs as both pore-filling and replacement of chert and rock fragments, especially volcanic, plutonic, metamorphic rock clasts. Thin section analysis shows that pore-filling pyrite usually combined or intergrowthed with organic matter or bitumen. Samples 50, 64 show pyrite first filled secondary dissolution pores from pore wall and followed by black organic matter or bitumen at the pore center, and formed a pyrite ring around organic matter or bitumen. Precipitation of pore-filling pyrite is associated with organic matter that was in the oil window, kerogen became mature and released organic acid and H_2S, H_2S encountered Fe^{2+} and had produced pyrite. In general, the quantities of the pyrite are supposed to be high enough to affect their resistivity log responses. Neither pyrite nor siderite has caused considerable reduction of pore spaces.

Organic matter (org) or bitumen (bitm) was detected in most Nanaimo samples, its content varies from minor to 16-18% in sample 42. This dark brown to black, amorphous material occurred as patches or spots occluding intergranular pores or locally lining or filling secondary dissolution pores (samples 57, 63 and 66). In samples 35 and 42, considerable organic matter (bitumen?) mixed with pyrite appeared as thin strips paralleling to bedding planes. Some burrows and bioturbated structures are porous and also filled with black

bituminous material and sands (sample 44). Emplacement of organic matter or bitumen occludes and lowers secondary enhanced porosity and permeability, it is the final diagenetic phase in the Nanaimo Group intervals. Fluorescence microscopy should be conducted to confirm the occurrence of bitumen in the Nanaimo sandstones, and its impact on diagenesis and pore evolution should be further investigated.

Degrees of mechanical compaction are reflected by various grain contact patterns, ranging from point-contact, planar-contact, and locally concave-convex-contact, deformation of ductile grains (mica, shale and VRF, MRF fragments, etc.) and pseudo matrix. No sutured contact is observed between grains. Framework compositions apparently control the mechanical compaction process. Higher degrees of compaction took place where sandstones are finer grained, containing considerable amount of soft grain constituents.

Pore system: Depositional factors that affect porosity and reservoir quality include sediment grain size, sorting, framework composition, volumes of matrix and pseudo matrix and primary fabric. In general, coarser grained sandstone should be more permeable than similar, finer grained sandstone. Well sorted sand should have higher porosity than more poorly sorted sand. The framework composition plays a key role in the evolution of reservoir quality, as more lithic (chert, feldspar, volcanic and plutonic, metamorphic rock fragments) rich sand tends to be highly susceptible to grain leaching, while highly quartzose sediment is susceptible to severe quartz cementation. Development of intergranular porosity in both coarser and finer grained sandstones depends largely on whether interstitial spaces are filled with matrix clay, therefore the primary depositional environment (e.g. energy level of water body) has a direct control on initial intergranular pore spaces. All Nanaimo Group samples are immature in texture and composition, especially coarser grained sandstones are usually poorly or poorly to moderately sorted, rich in feldspar, chert and unstable rock fragments (volcanic, plutonic, metomorphic rock fragments), considerable detrital matrix clay deposited with sand

grains together, the original intergranular pores are not preserved and plugged by matrix clay, therefore the original intergranular pores are not developed in the Nanaimo Group sandstone samples. But various diagenetic features have affected the reservoir quality to varying degrees of creating and destroying porosity, thin section observation reveals that the later stage dissolution produced secondary intergranular and intragranular pores and improved the reservoir quality of Nanaimo Group sandstones to some degree. Also groups of microfractures cut through the rocks and enhanced the reservoir permeability.

The porosity types of the Nanaimo Group sandstones can be generalized as: secondary porosity (sp), microporosity (mp) and microfractures.

Secondary porosity (sp) include secondary intergranular porosity and secondary intragranular porosity, they were detected in coarser grained samples (57, 63 and 66) with very low visible porosity from trace to 2-3%. Secondary porosity generally has smaller pore sizes within grains, it is a dissolution product of feldspar grains (along cleavages), chert and unstable rock fragments (volcanic, plutonic, metomorphic rock fragments, selectively leaching of feldspar laths), as well as in organic matter and kerogen. With continuously stronger leaching, some feldspar or volcanic ash grains are completely dissolved with a relict of chlorite rims left behind (samples 63 and 66) or formed an enlarged intergranular pore without chlorite clay films. These type of secondary pores are prone to be filled by calcite cement, pyrite and bituminous material (samples 63 and 66) spaces. Burial history of the Nanaimo and source rock should be examined to better understand the late stage diagenesis and secondary porosity development.

Microporosity (mp) is smaller than a few microns in size; however, it accounts a greater percentage than secondary porosity. Microporosity is commonly found within leached feldspars, chert and unstable rock fragments (volcanic, plutonic and metomorphic rock fragments), and within detrital clay matrix, within micritic limemud. All the Nanaimo sandstone samples contain significant amounts of matrix clay, varying from less than

10% to more than 30%, abundant microporosity exists between these matrix clays. Impregnations of blue epoxy often turn the microporous grains bluish color (artifact). SEM study is suggested to further document this type of porosity.

Natural fractures (frac): two groups of microfractures had developed in some sample intervals, they can be classified as vertical mrofractures and oblique microfractures according to the fracture direction. Vertical microfractures are more common than oblique microfractures, they are perpendicular to bedding plane and cut through the rocks, usually 1-10um in width and can extend longer distance (samples 4,); in contrast, oblique microfractures extends a short distance. All these fractures are the passages for the pore fluid system and improved the reservoir quality, they are sealed by calcite cement in the later diagenetic stage.

Diagenetic features recognized from each individual sample are shown in the petrographic descriptions (Appendix). Based on various authigenic minerals, diagenetic phases and their crosscutting relationships, a general paragenetic sequence is summarized as: Deposition - Compaction - Chloritization - Chlorite filling - Quartz and feldspar overgrowth - Feldspar filling - Grain dissolution - Pyritization- Calcite Cementation - Organic matter or bitumen emplacement.

The relevant diagenesis and their effects on porosity are summarized semi-quantitatively in following table:

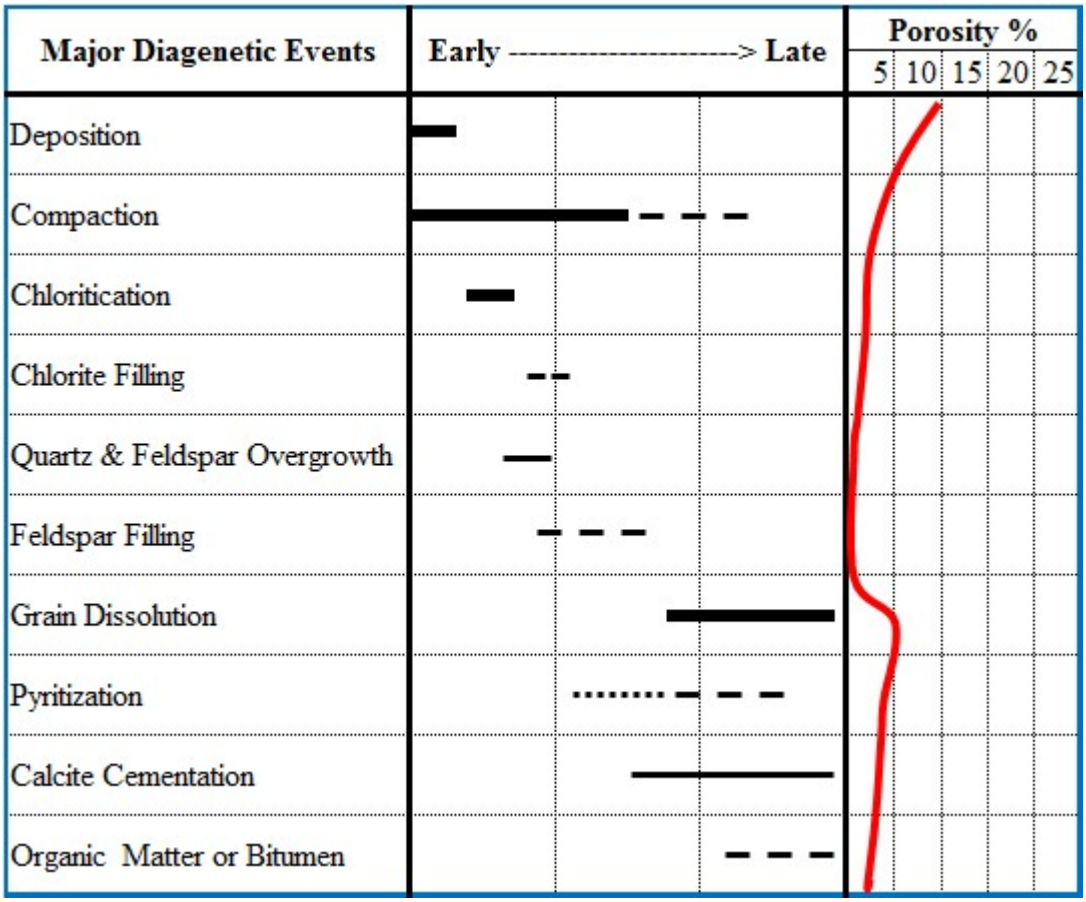

Major Diagenetic Events
Early ----------> Late
Porosity %
5 10 15 20 25
Deposition
Compaction
Chloritication
Chlorite Filling
Quartz & Feldspar Overgrowth
Feldspar Filling
Grain Dissolution
Pyritization
Calcite Cementation
Organic Matter or Bitumen

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Thin section petrography was conducted on forty-four (44, see Table 1) samples from the OW-11-01-Nanaimo OBS well 390, to determine their mineralogical, textural, diagenetic and reservoir characteristics. Work was focused on pore systems and processes affecting the porosity evolution.

The 44 Nanaimo Group samples include 43 sandstones and 1 silty mudstone. Most samples are massive; some finer-grained samples show clay and organic material-rich lamination, shale/siltstone cross lamination, burrows and bioturbated structures. All Nanaimo Group samples show low mature features in texture and composition with significant amounts of matrix clay (most samples are between 10 to 30% clay). Grain composition was characterized by abundant feldspar, chert and volcanic rock fragments. Quartz, feldspar and rock fragments are the three major components; although their proportions vary between samples. Coarser grained sandstone samples have a wide grain size range, varying from coarse silt to very coarse sand. The framework grains are angular, subangular to subrounded and poorly sorted or poorly to moderately sorted, showing a grain supported, moderately compacted fabric. Whereas finer (very fine to fine, or silt to very fine) grained sandstone samples demonstrated a grain-supported, well sorted or moderately to well sorted fabric. Grains are subangular to subrounded or rounded, with most grain size ranging from very fine to fine.

Common diagenetic phases include authigenic chlorite coating, quartz overgrowth, feldspar overgrowth, dissolution, emplacement of pyrite, calcite and organic matter or bitumen. Evolution of the pore system is apparently controlled by depositional environment and later diagenesis. Various diagenetic features have affected the reservoir quality to varying degrees, both creating and destroying porosity. The original intergranular pores are blocked by matrix clay and further reduced by early chlorite lining, quartz overgrowth, feldspar overgrowth and compaction, therefore no original

intergranular pores were observed in any sample. Later stage dissolution produced secondary intergranular pores and improved the reservoir quality of Nanaimo Group sandstones to some degree. The formation of pyrite, calcite cement and organic matter emplacement locally occludes secondary pore spaces, all sandstone samples show very low to low visible porosity (trace to 2-3%).

The porosity types of the Nanaimo Group sandstones can be generalized as: secondary porosity (sp), microporosity (mp) and microfractures.

Secondary porosity (as a result of feldspar dissolution) is the major pore type in the Nanaimo sandstones. Microporosity is abundant and is extensive within the clay matrix, leached feldspars, chert, and rock fragments (volcanic, plutonic and metomorphic rock fragments) and has little contribution to reservoir quality due to the very smaller pore size. Microfractures appeared in two directions to cut through the rocks and locally enhanced the reservoir permeability.

INTRODUCTION

A Groundwater Assessment in the Nanaimo Lowlands project was initiated by the British Columbia Department of Environment, related local municipalities, and the Geological Survey of Canada in 2010 to evaluate groundwater resources in the Nanaimo Basin of eastern Vancouver Island. This included studies of both surficial and bedrock aquifers, including the Upper Cretaceous Nanaimo Group (Nanaimo Group stratigraphy is summarized in Hamblin 2012). During drilling of a bedrock monitoring well, a core of the Nanaimo Group was collected. Detailed descriptions of lithology, porosity and permeability are provided in Hamblin and McCartney (2014). In addition to this work, thin section petrography was conducted on forty-four (44, see Table 1) samples from the OW-11-01-Nanaimo OBS well 390, to determine their mineralogical, textural, diagenetic and reservoir characteristics. The results are presented here.

The prepared thin sections were examined petrographically. Major mineralogical compositions, grain constituents and porosity are semi-quantified using visual estimate method. Petrographic data is summarized in table format (Table 1), including framework mineralogy, diagenetic minerals, rock type, texture and porosity.

Representative photomicrographs with descriptions of the thin sections are provided in an appendix (Plates 1 to 44) at the end of report. Plates are sorted by depths and sample IDs. When examples are used in text report, they are referred to certain plates by their sample numbers.

Table 1A：Petrographic Summary

Sample ID	Spot Depth (m)	Structure	Grain Size (μm)	Sorting	Lithology	Porosity (Helium) Fraction
1	384.75	Massive	Fine - Medium	Poor - Moderate	Litharenite	0.096
2	367.00	Massive	Medium - Coarse	Poor	Fd Litharenite	0.077
4	361.75	Massive - Fracture	Fine - Medium	Moderate	Fd Litharenite	0.052
7	340.00	Massive	Fine - Medium	Moderate	Lithic Arkose	0.033
9	332.08	Laminated - Burrowed	Silt - Very Fine	Moderate - Well	Litharenite	0.073
10	328.50	Massive	Fine - Medium	Poor - Moderate	Fd Litharenite	0.048
12	318.75	Massive	Fine - Medium	Poor - Moderate	Lithic Arkose	0.048
14	305.75	Massive	Fine	Poor	Litharenite	0.056
16	294.75	Massive	Fine - Coarse	Poor	Fd Litharenite	0.035
17	286.50	Massive	Fine	Well - Very Well	Fd Litharenite	0.098
19	279.00	Massive - Laminated	Very Fine - Coarse	Poor	Lithic Arkose	0.076
21	267.00	Massive	Very Fine - Coarse	Poor	Fd Litharenite	0.040
22	253.00	Massive	Medium - Coarse	Medium	Fd Litharenite	0.057
24	236.25	Massive	Fine - Medium	Moderate - Well	Lithic Arkose	0.018
26	227.50	Massive - Laminated	Fine	Very Well	Lithic Arkose	0.082
28	216.75	Massive	Fine - Medium	Moderate	Fd Litharenite	0.051
29	214.50	Massive	Medium - Coarse	Moderate	Fd Litharenite	0.072
30	207.50	Massive	Medium - Coarse	Poor - Moderate	Fd Litharenite	0.075
32	194.50	Massive	Very Fine - Coarse	Poor	Fd Litharenite	0.059
34	180.00	Massive	Fine - Medium	Poor - Moderate	Lithic Arkose	0.092
35	171.75	Massive - Burrowed	Very Fine - Fine	Well	Lithic Arkose	0.085
36	163.75	Massive	Very Fine - Fine	Well - Very Well	Fd Litharenite	0.091
37	161.25	Massive	Fine - Medium	Medium - Well	Fd Litharenite	0.108

Table 1B: Petrographic Summary Continued

Sample ID	Spot Depth (m)	Structure	Grain Size	Sorting	Lithology	Porosity (Helium) Fraction
38	158.75	Massive	Medium - Coarse	Medium	Fd Litharenite	0.019
39	153.00	Massive	Fine - Medium	Poor	Lithic Arkose	0.099
41	148.00	Massive	Very Fine - Poor	Poor	Fd Litharenite	0.089
42	144.92	Massive - Laminated	Silt - Very Fine	Well - Very Well	Sublitharenite	0.076
43	139.00	Massive - Burrowed	Very Fine - Fine	Moderate - Well	Fd Litharenite	0.083
44	135.58	Massive - Burrowed	--	--	Silty mudstone	0.058
45	127.50	Massive	Very Fine - Coarse	Poor	Fd Litharenite	0.068
46	122.50	Massive	Fine - Coarse	Poor - Moderate	Fd Litharenite	0.036
48	106.67	Massive	Fine - Coarse	Poor	Lithic Arkose	0.026
50	100.67	Massive	Fine - Coarse	Poor	Lithic Arkose	0.087
51	96.00	Massive - Bioturbated	Very Fine - Fine	Well	Lithic Arkose	0.092
52	89.50	Massive	Medium - Coarse	Poor - Moderate	Fd Litharenite	0.067
53	78.50	Massive	Fine - Medium	Moderate	Fd Litharenite	0.091
55	73.33	Massive - Bioturbated	Fine - Coarse	Poor	Fd Litharenite	0.073
56	68.50	Massive - Laminated	Very Fine - Fine	Moderate	Lithic Arkose	0.063
57	62.00	Massive	Fine - Medium	Moderate - Well	Lithic Arkose	0.102
60	47.75	Massive	Fine - Medium	Poor - Moderate	Fd Litharenite	0.097
62	33.00	Massive - Bioturbated	Very Fine - Fine	Poor - Moderate	Subarkose	0.083
63	30.50	Massive	Medium - Coarse	Moderate	Fd Litharenite	0.080
64	26.25	Massive - Laminated	Very Fine - Fine	Well	Lithic Arkose	0.090
66	19.42	Massive	Medium - Coarse	Moderate - Well	Fd Litharenite	0.077

*Note: Fd Litharenite-----Feldspathic Litharenite

PETROGRAPHIC SUMMARY & DISCUSSION

The 44 Nanaimo samples from the OW-11-01-Nanaimo OBS well 390, include 43 sandstones and 1 silty mudstone (Table 1), all 43 sandstone samples can be further classified as feldspathic litharenites (25), lithic arkoses (14), litharenites (2), sublitharenite (1) and subarkose (1) according to Folks classification, 1968. Summary of the petrographic data is given in Table-1. The details of rock constituents, texture and diagentic features are elaborated in 44 Plates. Key petrographic features are summarized and discussed together in the following text.

Structure: Most Nanaimo sandstones are massive. Some very fine to fine grained sandstones show well developed ellipse shaped burrows (samples 19, 30, 35, 43, 44) and other bioturbation structures (samples 9, 14, 51, 55, 56). Samples 9, 35 and 42 show laminated structure which are defined by organic matter-rich and clay-rich lamina, dark brown to black organic matter and clay compressed into thin strips or lamina paralleling to bedding plane. Also elongated grains and mica are preferentially oriented and aligned along bedding planes.

Texture/fabrics: The petrographic analysis indicates that most Nanaimo Group samples are low mature in texture and composition, especially in medium to coarse grained sandstone samples. Sand grains and matrix clay were deposited together, clays blocked the intergranular pore spaces and therefore the primary pores are not well preserved before compaction. Coarser grained sandstone samples have a wide range in grain size, varying from coarse silt to very coarse sand. The framework grains are angular, subangular to subrounded and poorly sorted or poorly to moderately sorted, showing a grain supported, moderately compacted fabric. Grains are commonly point-planar contacted to slightly concave-convex-contacted (as indicated by deformation of ductile grains; eg. mica, shale clasts, volcanic and metamorphic rock fragments). Whereas finer (very fine to fine or silt to fine) grained sandstone samples demonstrated a

grain-supported, well sorted or moderately to well sorted fabric. Grains are subangular to subrounded or rounded, with most grain size ranging from very fine to fine.

Compositions: The Nanaimo Group sandstone framework grains are composed of three major components: quartz, feldspars and rock fragments (chert, shale clasts, volcanic, plutonic and metamorphic rock fragments etc.). Minor mica, glauconite and trace heavy minerals and glauconite are also present.

Quartz (qtz) grains include monocrystalline and polycrystalline quartz, they are mainly monocrystalline, inclusion free or with rare mica and heavy mineral (e.g. zircon) inclusions. Quartz tends to increase its quantity in finer (very fine to fine) grained sandstones. Quartz grains are moderately to well sorted and subangular to subrounded. Trace to minor authigenic quartz overgrowths are mainly found in coarser grained sandstone samples (samples 4, 16, 21, 29, 30, 32, 38, 41, 46, 48, 52, 46, 48, 52, 63, 66). **Feldspar (fd)** occurs mainly as plagioclase with minor potassium feldspar, all Nanaimo Group sandstones are characterized by considerable feldspar. Feldspar grains are identified by elongated shape, weathered surfaces (sericited), cleavages, Carlsbad twining, albite twining, polysynthetic twining (microcline) and Carlsbad-albite twining (plagioclase). Dissolution or leaching of feldspar grains generated minor secondary porosity within feldspar grains or volcanic rock fragments and improved reservoir quality in some degree. **Chert (cht)** often inclusion-rich (clays, dolomite and pyrite), is the main constituent of the framework, characterized by crypto- to microcrystalline and rare fibrous chalcedony textures. Also chert grains can be leached to various extents, generating microporosity and secondary porosity in kerogen mature stage. **Volcanic rock fragments (VRF)** are characterized by their unique fabric, with feldspar laths floating in cryptocrystalline groundmass. Both feldspar laths and groundmass are commonly leached to various extents (like chert grains), forming secondary intragranular porosity and microporosity. Chloritization and pyritization are the most common alteration products in volcanic rock fragments. **Metamorphic rock fragments (MRF)** consist of micaceous

schist and phyllite clasts, and are often compressed between harder grains. Metamorphic rock fragments are also frequently altered by chlorite and pyrite. However, no secondary pore spaces are found within metamorphic rock fragments. Sedimentary rock fragments are mainly **shale clasts (sh)** with trace to minor **bioclasts**. Shale clasts occur in all sandstone samples regardless of grain size variation. They are ductile grains, sub-preferentially oriented, often squeezed between other grains, even forming pseudo matrix and lowered reservoir quality.

Diagenesis: Reservoir quality in the Nanaimo Group sandstone is a function of a complex interrelationship of both depositional and diagenetic processes. Common diagenetic phases encountered in the Nanaimo sandstones include authigenic chlorite, quartz overgrowth, feldspar overgrowth, chlorite filling, feldspar filling, emplacement of pyrite, calcite and organic matter or bitumen.

Chlorite (chl) exists extensively in all Nanaimo Group samples, it has two different kinds of forms: ① chlorite as products of alteration of volcanic/ metamorphic rock fragments, replacement of chert/feldspar; ② it occurs as tiny needle-like crystals coating grains and lining pores. Chlorite is characterized by its bluish green interference color. It is a few microns to tens of microns in size. In some coarse sand grained samples, pore lining chlorite crystals appear larger in size and form thin films surround grains (samples 28, 32, 34 39, 46, 50, 51, 57, 62, 63, 66). Some unstable grains such as feldspars and volcanic rock fragments were leached to various extent, even completely, leaving relict chlorite rims. This indicates that chlorite coating had formed before the grain dissolution, and is the first stage of intergranular pore-filling followed by quartz and feldspar overgrowths. Minor medium to coarse crystalline, pore-filling chlorite was also observed in several samples 32, 36, 50, 51, 57.

Quartz overgrowths (qtz) appear as trace or minor quantities surrounding monocrystalline quartz grains, they are not commonly developed due to abundant matrix clay and chlorite coating, locally occluded intergranular pores and have the adverse effect on reservoir quality

in most sandstone samples. **Feldspar cement (fd)** was found as overgrowths around feldspar grains in most samples and as prismatic crystals filling intergranular pores (sample 39) in several samples. Apparently, feldspar cement also lowered the reservoir quality**.**

Calcite cement (cal) is a major porosity reducing diagenetic phase in the Nanaimo Group sandstones. We detected variable amounts of calcite cement, varying from trace to 17-20% (sample 17), it occurs as fine to coarse crystals filling intergranular pores and secondary pores within feldspar and volcanic/plutonic rock fragments, severely decreasing reservoir porosity and permeability. It is recommended that thin sections should be stained for the future work using Alizarin Red-S and potassium ferricyanide to assist identifying calcite versus dolomite, and ferroan versus non-ferroan carbonate.

Pyrite (pyr) was found in minor to moderate volume existing in all Nanaimo Group samples. It occurs as both pore-filling and replacement of chert and rock fragments, especially volcanic, plutonic, metamorphic rock clasts. Thin section analysis shows that pore-filling pyrite usually combined or intergrowthed with organic matter or bitumen. Samples 50, 64 show pyrite first filled secondary dissolution pores from pore wall and followed by black organic matter or bitumen at the pore center, and formed a pyrite ring around organic matter or bitumen. Precipitation of pore-filling pyrite is associated with organic matter that was in the oil window, kerogen became mature and released organic acid and H_2S, H_2S encountered Fe^{2+} and had produced pyrite. In general, the quantities of the pyrite are supposed to be high enough to affect their resistivity log responses. Neither pyrite nor siderite has caused considerable reduction of pore spaces.

Organic matter (org) or bitumen (bitm) was detected in most Nanaimo samples, its content varies from minor to 16-18% in sample 42. This dark brown to black, amorphous material occurred as patches or spots occluding intergranular pores or locally lining or filling secondary dissolution pores (samples 57, 63 and 66). In samples 35 and 42, considerable organic matter (bitumen?) mixed with pyrite appeared as thin strips paralleling to bedding planes. Some burrows and bioturbated structures are porous and also filled with black

bituminous material and sands (sample 44). Emplacement of organic matter or bitumen occludes and lowers secondary enhanced porosity and permeability, it is the final diagenetic phase in the Nanaimo Group intervals. Fluorescence microscopy should be conducted to confirm the occurrence of bitumen in the Nanaimo sandstones, and its impact on diagenesis and pore evolution should be further investigated.

Degrees of mechanical compaction are reflected by various grain contact patterns, ranging from point-contact, planar-contact, and locally concave-convex-contact, deformation of ductile grains (mica, shale and VRF, MRF fragments, etc.) and pseudo matrix. No sutured contact is observed between grains. Framework compositions apparently control the mechanical compaction process. Higher degrees of compaction took place where sandstones are finer grained, containing considerable amount of soft grain constituents.

Pore system: Depositional factors that affect porosity and reservoir quality include sediment grain size, sorting, framework composition, volumes of matrix and pseudo matrix and primary fabric. In general, coarser grained sandstone should be more permeable than similar, finer grained sandstone. Well sorted sand should have higher porosity than more poorly sorted sand. The framework composition plays a key role in the evolution of reservoir quality, as more lithic (chert, feldspar, volcanic and plutonic, metamorphic rock fragments) rich sand tends to be highly susceptible to grain leaching, while highly quartzose sediment is susceptible to severe quartz cementation. Development of intergranular porosity in both coarser and finer grained sandstones depends largely on whether interstitial spaces are filled with matrix clay, therefore the primary depositional environment (e.g. energy level of water body) has a direct control on initial intergranular pore spaces. All Nanaimo Group samples are immature in texture and composition, especially coarser grained sandstones are usually poorly or poorly to moderately sorted, rich in feldspar, chert and unstable rock fragments (volcanic, plutonic, metomorphic rock fragments), considerable detrital matrix clay deposited with sand

grains together, the original intergranular pores are not preserved and plugged by matrix clay, therefore the original intergranular pores are not developed in the Nanaimo Group sandstone samples. But various diagenetic features have affected the reservoir quality to varying degrees of creating and destroying porosity, thin section observation reveals that the later stage dissolution produced secondary intergranular and intragranular pores and improved the reservoir quality of Nanaimo Group sandstones to some degree. Also groups of microfractures cut through the rocks and enhanced the reservoir permeability.

The porosity types of the Nanaimo Group sandstones can be generalized as: secondary porosity (sp), microporosity (mp) and microfractures.

Secondary porosity (sp) include secondary intergranular porosity and secondary intragranular porosity, they were detected in coarser grained samples (57, 63 and 66) with very low visible porosity from trace to 2-3%. Secondary porosity generally has smaller pore sizes within grains, it is a dissolution product of feldspar grains (along cleavages), chert and unstable rock fragments (volcanic, plutonic, metomorphic rock fragments, selectively leaching of feldspar laths), as well as in organic matter and kerogen. With continuously stronger leaching, some feldspar or volcanic ash grains are completely dissolved with a relict of chlorite rims left behind (samples 63 and 66) or formed an enlarged intergranular pore without chlorite clay films. These type of secondary pores are prone to be filled by calcite cement, pyrite and bituminous material (samples 63 and 66) spaces. Burial history of the Nanaimo and source rock should be examined to better understand the late stage diagenesis and secondary porosity development.

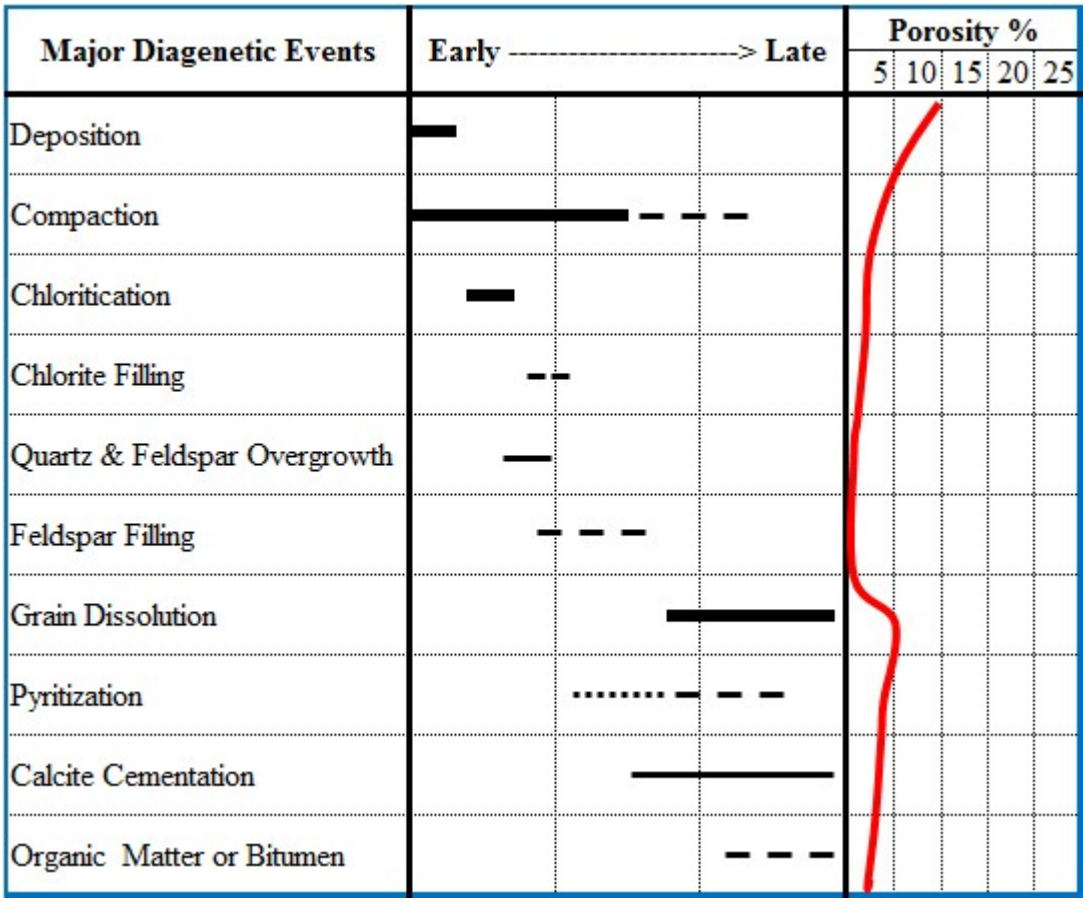
Microporosity (mp) is smaller than a few microns in size; however, it accounts a greater percentage than secondary porosity. Microporosity is commonly found within leached feldspars, chert and unstable rock fragments (volcanic, plutonic and metomorphic rock fragments), and within detrital clay matrix, within micritic limemud. All the Nanaimo sandstone samples contain significant amounts of matrix clay, varying from less than

10% to more than 30%, abundant microporosity exists between these matrix clays. Impregnations of blue epoxy often turn the microporous grains bluish color (artifact). SEM study is suggested to further document this type of porosity.

Natural fractures (frac): two groups of microfractures had developed in some sample intervals, they can be classified as vertical mrofractures and oblique microfractures according to the fracture direction. Vertical microfractures are more common than oblique microfractures, they are perpendicular to bedding plane and cut through the rocks, usually 1-10um in width and can extend longer distance (samples 4,); in contrast, oblique microfractures extends a short distance. All these fractures are the passages for the pore fluid system and improved the reservoir quality, they are sealed by calcite cement in the later diagenetic stage.

Diagenetic features recognized from each individual sample are shown in the petrographic descriptions (Appendix). Based on various authigenic minerals, diagenetic phases and their crosscutting relationships, a general paragenetic sequence is summarized as: Deposition - Compaction - Chloritization - Chlorite filling - Quartz and feldspar overgrowth - Feldspar filling - Grain dissolution - Pyritization- Calcite Cementation - Organic matter or bitumen emplacement.

The relevant diagenesis and their effects on porosity are summarized semi-quantitatively in following table:


Major Diagenetic Events
Early ----------> Late
Porosity %
5 10 15 20 25
Deposition
Compaction
Chloritication
Chlorite Filling
Quartz & Feldspar Overgrowth
Feldspar Filling
Grain Dissolution
Pyritization
Calcite Cementation
Organic Matter or Bitumen

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 1		**Depth:**	384.75

Image A:

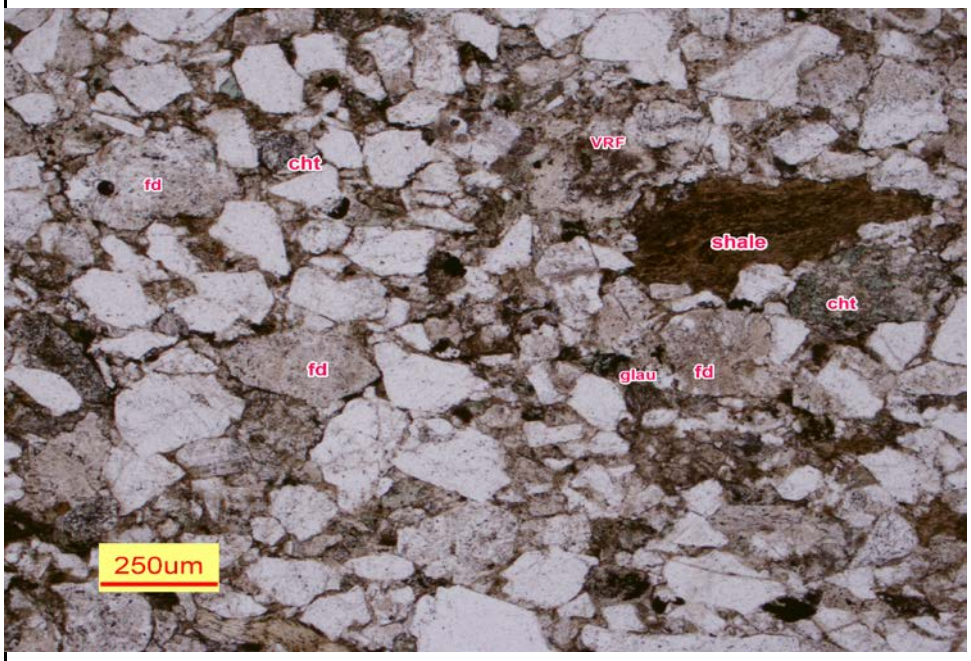


Image B

Composition: (vision estimate)

Grains:	
Q%	27-30
F%	25-27
R%	35-40
Others: 1.5-2.0% mica, trace: glau.	
Matrix:	15-17
Rock Type:	**Feldspathic Litharenite**

Texture	
Grain size	fine to medium
Sorting:	poor- moderately
Roundness:	subang.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	1
Organic matter	1.5-2.0
Pyrite	0.5
Replacement	
Chlorite	tr
Calcite	tr
Pyrite	0.5

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A massive, fine to medium grained feldspathic litharenite shows a grain-supported, non-porous fabric. Poorly - moderately sorted grains are subangular, consisting mainly of quartz, feldspar (fd) and chert (cht) with lesser amounts of volcanic rock fragments (VRF), shale clasts (sh) and metamorphic rock fragments (MRF). Elongated grains are preferentially aligned along bedding plane. Contacts between grains vary from point to planar (image A). Intergranular pores are predominantly reduced by clay matrix (15-17%) and moderate compaction. Image B shows black organic matter (bitumen?) mixed with pyrite (org+pyr) are found between grains. Minor calcite cement (cal) filled intergranular pore and feldspar moldic pore (image B). Microporosity is abundant and exists within matrix clays.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 2		**Depth:**	367.00m

Image A:

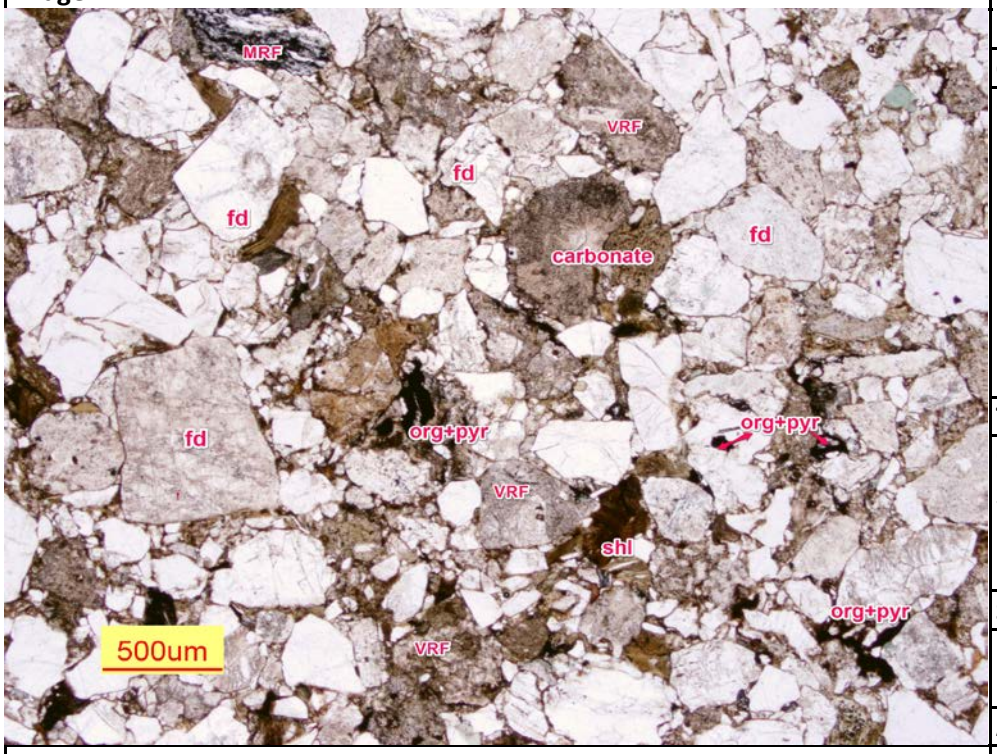
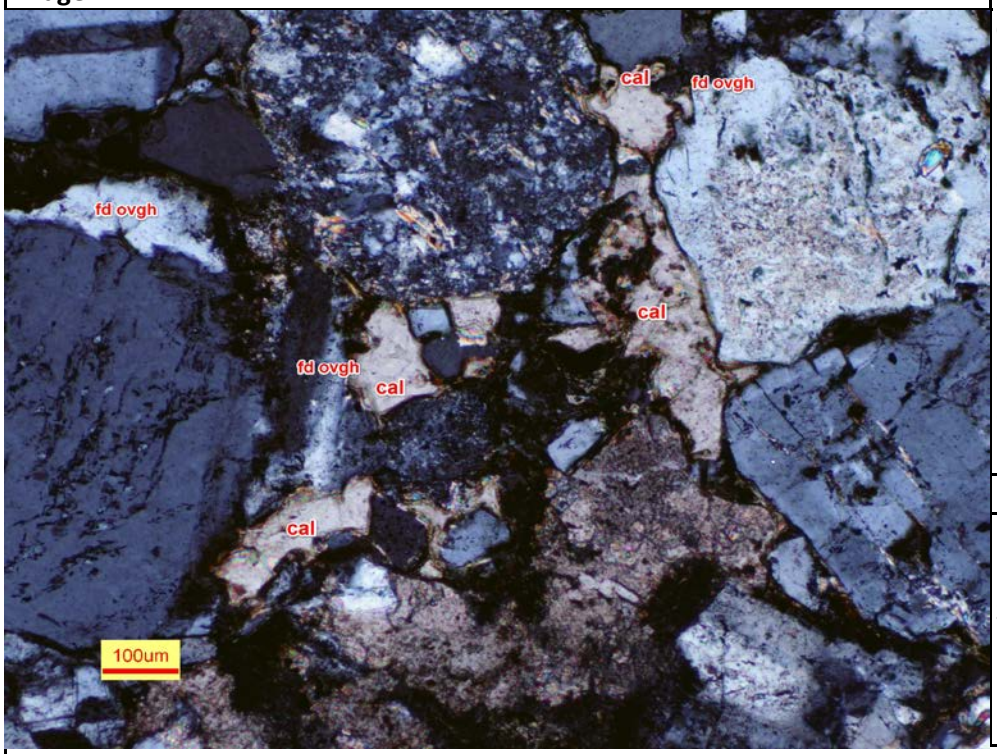


Image B



Composition: (visual estimate)

Grains:	
Q%	25-27
F%	23-25
R%	43-45
Others:	2-3% mica ,0.5% glau.
Matrix:	10-12
Rock Type:	
	Feldspathic Litharenite

Texture	
Grain size	Medium to coarse
Sorting:	poorly
Roundness:	ang. - subang.
Fabric:	grain supported

Structure
Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	3-5
Organic matter	0.5-1.0
Pyrite	0.5
Replacement	
Chlorite	Minor
Calcite	tr
Pyrite	0.5

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A shows a non-porous, massive, medium to coarse grained feldspathic litharenite. Framwork grains are dominated by sub-equal quartz, feldspar (fd) and chert (cht), with lesser amounts of volcanic rock fragments (VRF), shale clasts (sh) and metamorphic rock fragments (MRF). Minor mica, glauconite and bivalves are also present. Grains are angular to subrangular and poorly sorted (image A). Intergranular pores are reduced by clay matrix (10-12%), trace to minor authigenic minerals (calcite, org+pyrite, quartz and feldspar overgrowth) and compaction. Image B shows the rough and dirty feldspar grains with clear overgrowth thin rim. Note the minor calcite cement (cal) filling intergranular pores.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 4		**Depth:**	361.75m

Image A:

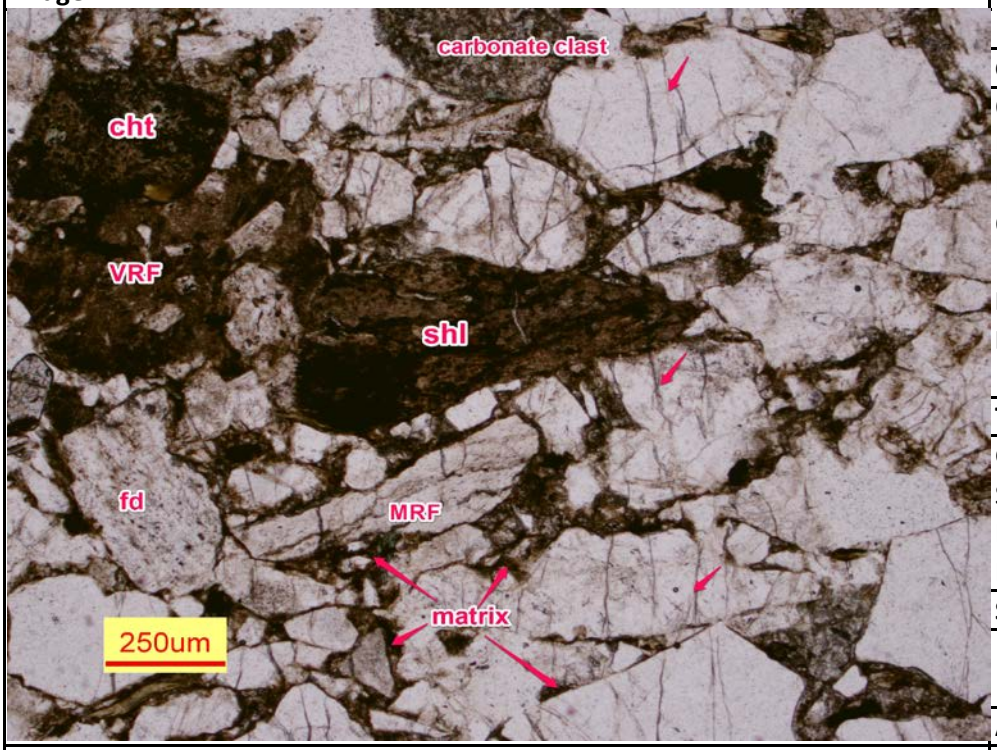
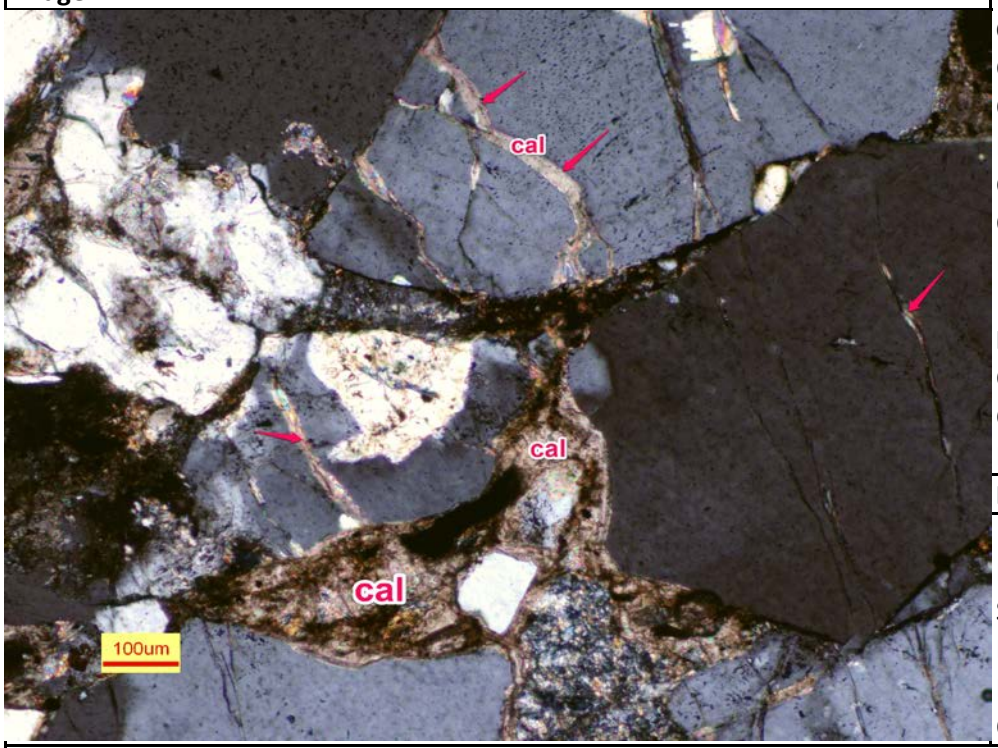


Image B



Composition: (visual estimate)

Grains:	
Q%	30-33
F%	20-22
R%	40-43
Others:	2% mica , trace glau.,
Matrix:	13-15
Rock Type:	
	Feldspathic Litharenite

Texture	
Grain size: fine upper to medium lower	
Sorting:	Moderately
Roundness:	subang.-subrou.
Fabric:	grain supported

Structure
Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	
Feldspar ovgh	tr
Calcite	1
Organic matter	0.5
Pyrite	0.5
Replacement	
Chlorite	Minor
Calcite	tr
Pyrite	0.5

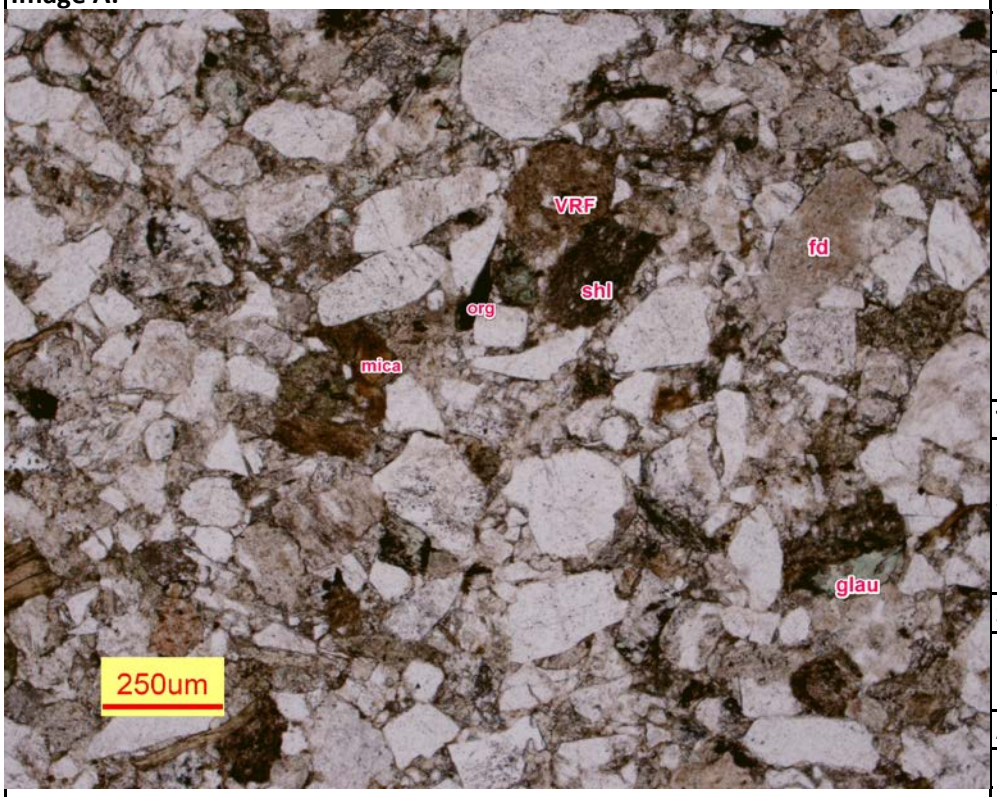
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	common
Microporosity:	common
Others:	

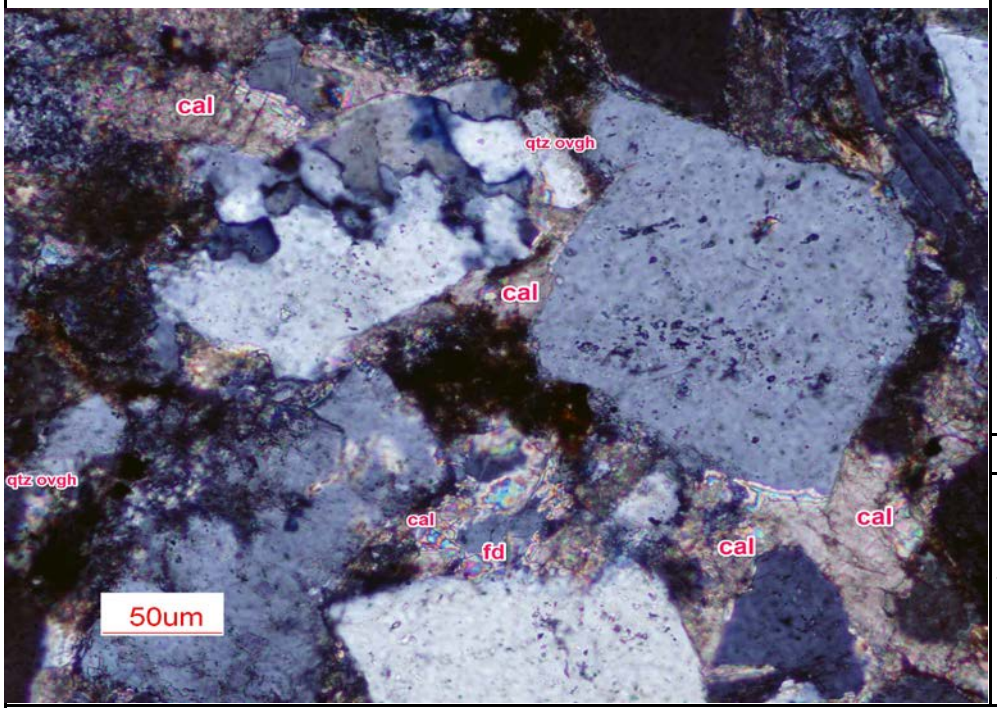
A massive, fine to medium grained feldspathic litharenite is characterized by abundant rock fragments (chert, volcanic rock fragments (VRF), shale clasts (sh), metamorphic rock fragments (MRF) and lesser feldspar grains. Platy and elongated grains are compacted parallel to bedding planes (image A). Considerable detrital matrix clays (13-15%) blocked Intergranular pores and produced a tight, non-porous fabric. Note a group of vertical thin fractures (10-20um width) cut through the rock and improved the reservoir quality to some degree (image A). Image B shows some oblique microfractures broke through framework grains and were sealed by calcite (cal).

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 7		**Depth:**	340.00m

Image A:





Composition: (visual estimate)

Grains:	
Q%	38-40
F%	30-32
R%	22-23
Others:	2% mica , 2% glau.,
Matrix:	5-7
Rock Type:	
Lithic Arkose	

Texture	
Grain size: fine upper to medium lower	
Sorting:	Moderately
Roundness:	subang.-subrou.
Fabric:	grain supported

Structure
Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	17-20
Organic matter	tr
Pyrite	tr
Replacement	
Chlorite	Minor
Calcite	tr
Pyrite	0.5

Porosity (Visual Estimate):
Intergranular:
Secondary:
Fracture:
Microporosity:
Others:

Image A displays a moderately sorted, fine to medium grained lithic arkose with a massive, non-porous fabric. Framework grains are composed mainly of quartz, feldspar (fd) and lesser rock fragments (chert, volcanic rock fragments (VRF), shale clasts (sh), metamorphic rock fragments (MRF)). Minor mica and glauconite are also present (image A). Extensive calcite cement (17-20%) and minor matrix clay blocked intergranular pores, resulting in a tight rock. Image B shows that calcite cement (cal) occluded interstitial pore space and also replaced unstable grains (feldspar and VRF etc.). Trace quartz overgrowth was also found in the sample (Image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 9		**Depth:**	332.08m

Image A:

Image B

Composition: (visual estimate)

Grains:

Q%	48-50
F%	13-15
R%	15-20
Others: 3-5 %mica , 0.5% glau,	
Matrix:	27-30
Rock Type:	
Litharenite	

Texture

Size Average:	silt to very fine
Sorting:	moderately-well
Roundness:	subang. - subroun.
Fabric:	grain supported

Structure

Laminated and burrowed

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	
Feldspar ovgh	
Calcite	
Organic matter	3.0-5.0
Pyrite	2

Replacement

Chlorite	tr
Calcite	
Pyrite	0.5

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	abudant
Others:	

A silt to very fine grained, moderately to well sorted litharenite shows a laminated structure locally disturbed by burrows. Laminations are defined by quartz-rich laminae and clay-rich laminae, dark brown to black organic matter concentrated in the clay-rich laminae and compressed into thin stripes paralleling to bedding plane. Considerable amount of clay matrix (27-30%) occurs within grain-supported fabric (image A). Image B shows the tight fabric, with Intergranular pore spaces plugged by abundant matrix and minor chlorite rims (chl). Greenish chlorite occurred as thin rims coating grains in the very early diagenetic stage. Framework grains are mainly quartz, chert and detrital feldspar. Abundant microporosity occurs within the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 10		**Depth:**	328.50m

Image A:

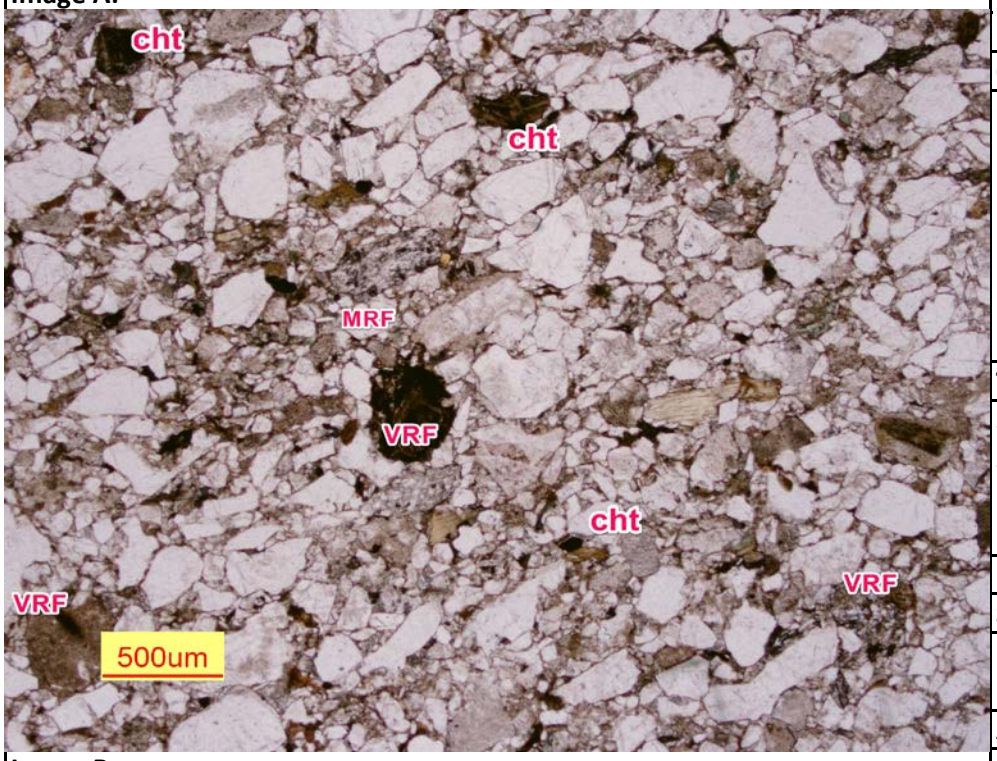
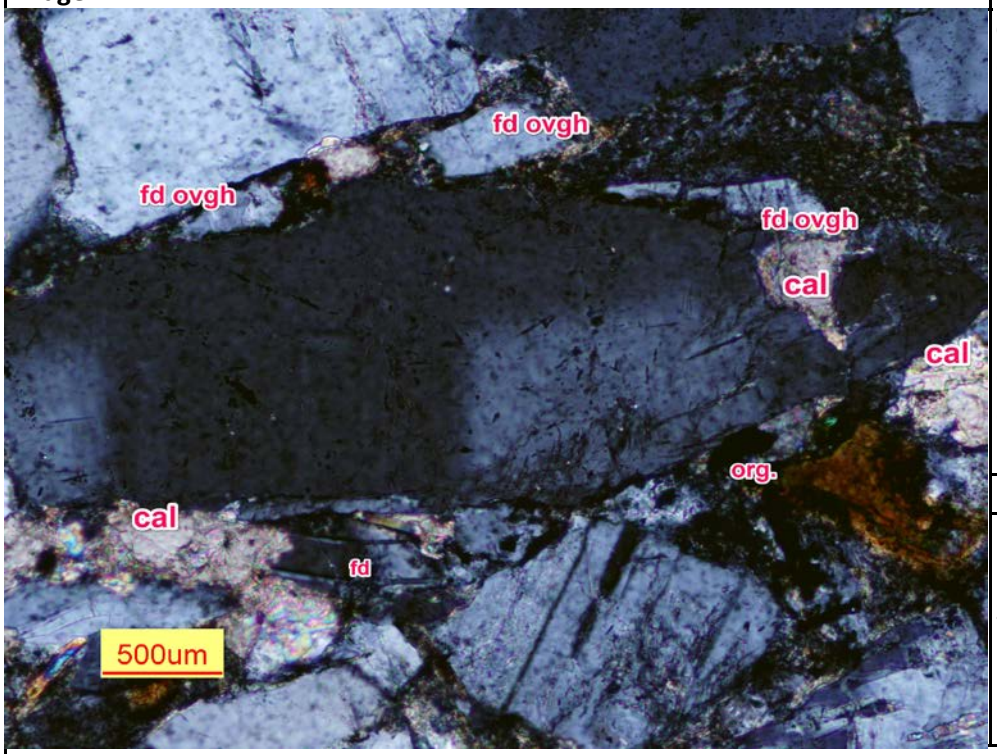


Image B



Composition: (visual estimate)

Grains:	
Q%	40-45
F%	20-23
R%	25-30
Others: 2 % mica, 1% glau,	
Matrix:	8.0-12
Rock Type:	
Feldspahic Litharenite	

Texture	
Size Average:	fine to medium
Sorting:	poor-moderately
Roundness:	subang. - subroun.
Fabric:	grain supported

Structure
Massive

Authigenic Components	
Cements (Pore Fillings):	
Chlorite	tr
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	5.0-7.0
Organic matter	0.5-1.0
Pyrite	tr
Replacement	
Chlorite	tr
Calcite	tr
Pyrite	tr

Porosity (Visual Estimate):
Intergranular:
Secondary:
Fracture:
Microporosity:
Others:

A massive, fine to medium grained, poor to moderately sorted feldsparthic litharenite is composed mainly of quartz, feldspar (fd) and lesser rock fragments (chert, volcanic rock fragments (VRF), shale clasts (sh), metamorphic rock fragments (MRF). Elongated grains are compacted parallel to bedding planes and tightly packed. The interstitial pore spaces are mainly blocked by 8-12% matrix clay and 5-7% calcite cement. Image B shows calcite cement filled intergranular pore and also replaced feldspar grains. Note authigenic feldspar overgrowth on the feldspar grain surfaces.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 12		**Depth:**	318.75m

Image A:

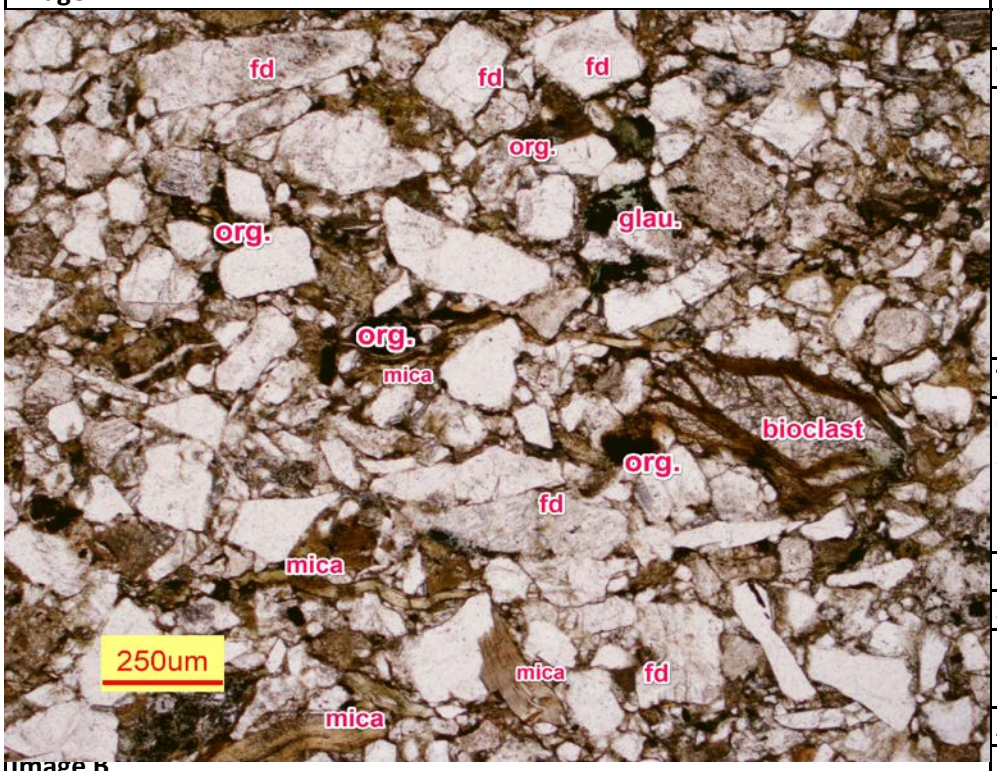
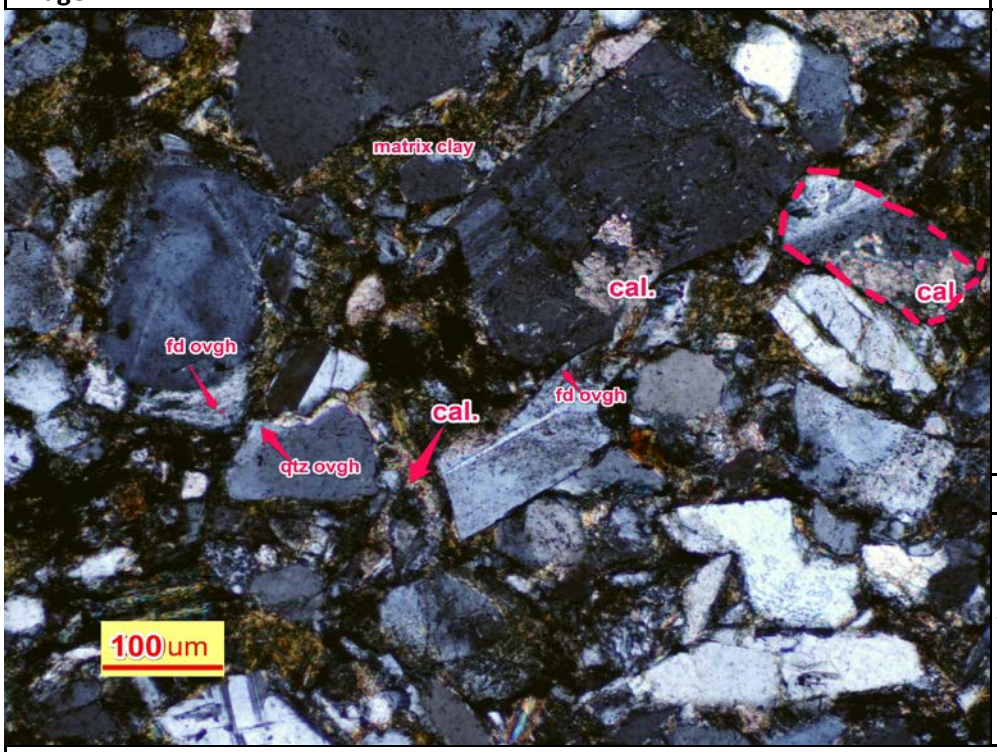


Image B



Composition: (visual estimate)

Grains:

Q%	33-35
F%	28-30
R%	25-27
Others: 5 %mica, 0.5% glau.	
Matrix:	10.0-15.0
Rock Type:	
Lithic Arkose	

Texture

Size Average:	fine to medium
Sorting:	poor
Roundness:	subang. - subroun.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	2.0-3.0
Organic matter	1.0-1.5
Pyrite	0.5

Replacement

Chlorite	tr
Calcite	0.5-1.0
Pyrite	tr

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A massive, fine to medium grained lithic arkose exhibits a grain-supported, non-porous fabric. Grains are subangular to subrounded, poorly sorted, consisting of sub-equal quartz, feldspar (fd) and rock fragments (chert, volcanic rock fragments (VRF), shale clasts (sh), metamorphic rock fragments (MRF) (image A). Intergranular pores are mainly reduced by compaction, clay matrix (10-15%) and minor calcite cement. Image B displays major interstitial components: matrix clay and calcite cement (cal). Note that feldspar grains contain irregular shaped calcite spots, indicating that calcite was replacing feldspar grains (image B). Trace to minor feldspar and quartz overgrowth developed on the grain surfaces.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 14		**Depth:**	305.75m

Image A:

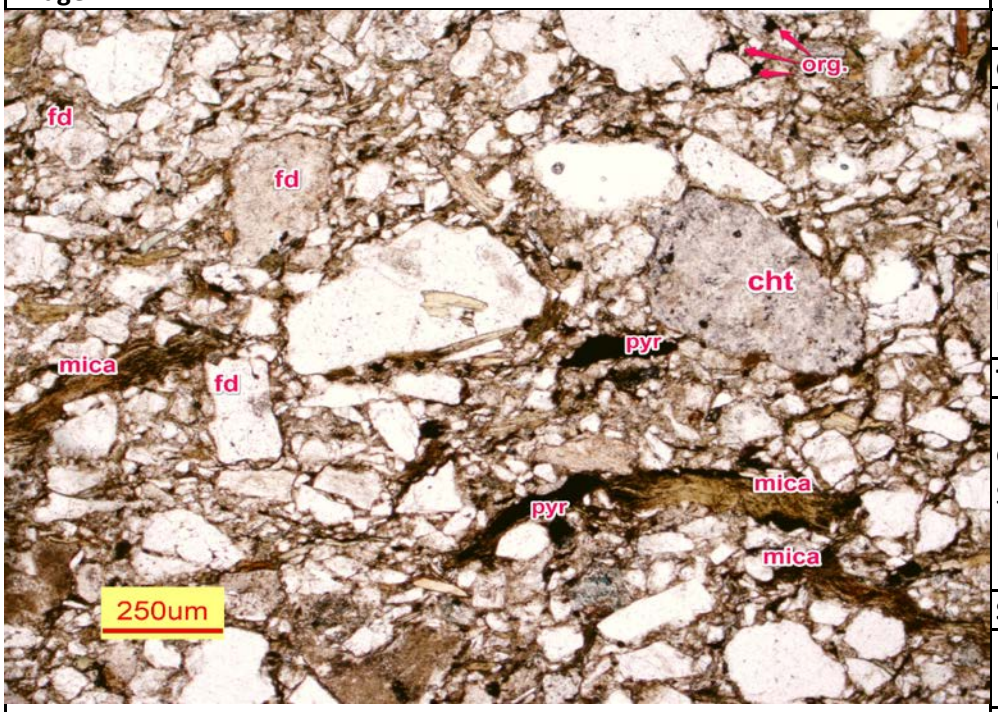
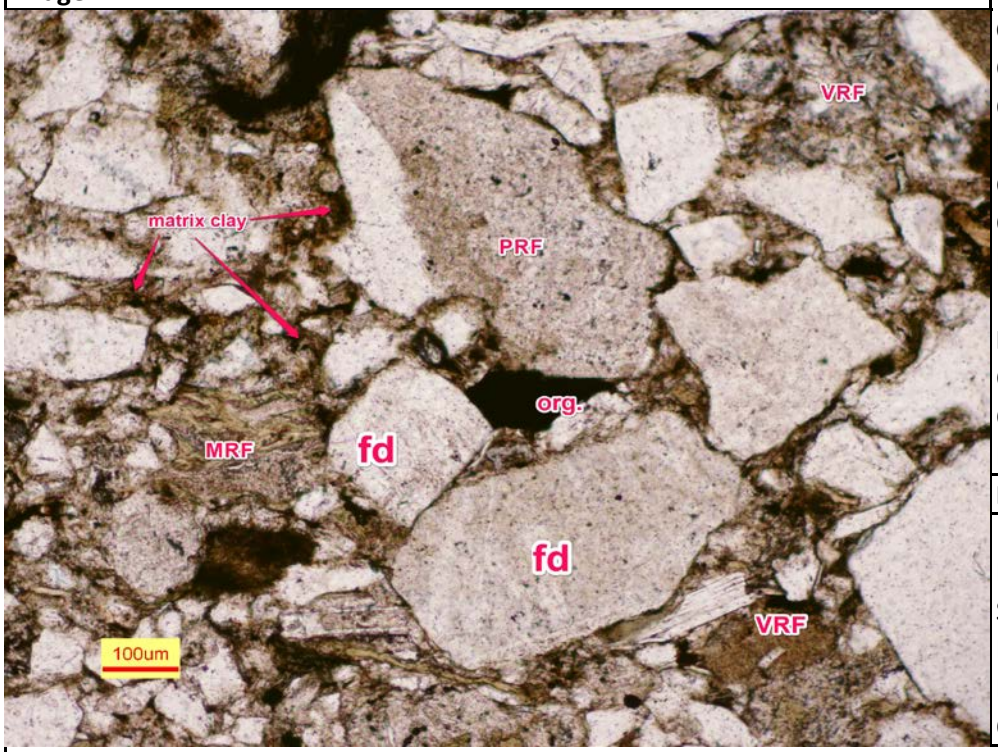


Image B



Composition: (visual estimate)

Grains:

Q%	28-30
F%	10-15
R%	40-50
Others: 3-5 % mica , 0.5% glau,	
Matrix:	25-27

Rock Type:

Litharenite

Texture

Grain size	fine
Sorting:	poor
Roundness:	subang. - subroun.
Fabric:	grain supported

Structure

Massive, burrowed

Authigenic Components

Cements (Pore Fillings):

Chlorite	minor
Qtz ovgh	
Feldspar ovgh	
Calcite	
Organic matter	1.0-2.0
Pyrite	0.5

Replacement

Chlorite	tr
Calcite	
Pyrite	

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	Abundant
Others:	

A fine grained litharenite shows an overall massive structure slightly disturbed by burrows. Poorly sorted grains are subanguler to subrounded, size ranging from coarse silt (30um) to coarse sand (750um). This sample contains 25-27% clay matrix which blocked interstitial pore spaces (image A). Some ductile grains (mica and volcanic rock fragments) are deformed between harder grains due to compaction (image A). Image B shows the tight fabric, with Intergranular pore spaces reduced by abundant matrix and minor grain rimming chlorite(chl) in the early diagenetic stage, and remaining pore spaces occluded by late stage organic matter (bitumen?). Microporosity is abundant in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 16		**Depth:**	294.75m

Image A:

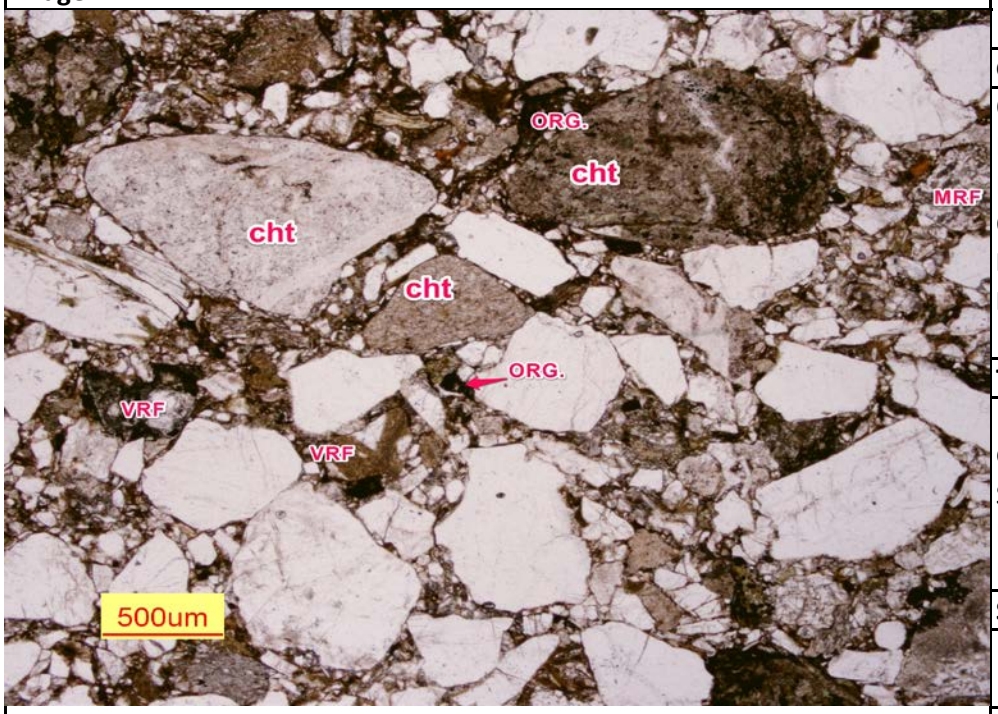
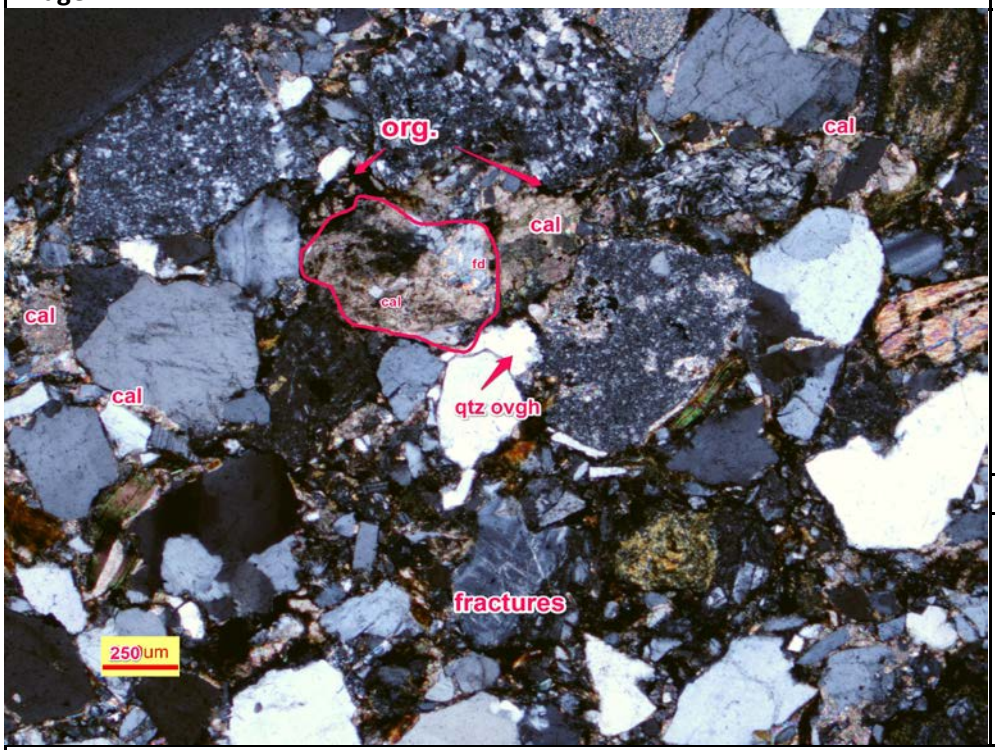


Image B



Composition: (visual estimate)

Grains:

Q%	30-35
F%	15-20
R%	35-42
Others: 2 % mica, trace glau,	
Matrix:	8-10
Rock Type:	
Feldspathic Litharenite	

Texture

Grain size: fine to coarse sand	
Sorting:	poorly
Roundness:	subang. - subroun.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	tr
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	5.0-6.0
Organic matter	0.5-1.0
Pyrite	tr

Replacement

Chlorite	tr
Calcite	1.0-2.0
Pyrite	tr

Porosity (Visual Estimate):

Intergranular:	
Secondary:	tr
Microfracture:	minor
Microporosity:	abundant
Others:	

Image A exhibits a massive, fine to coarse grained feldsparthic litharenite with a grain-supported, non-porous fabric. Poorly sorted grains are subanguler to subrounded, size ranging from coarse silt (30um) to very coarse sand (1500um). Grains are dominated by rock fragments (chert, VRF, PRF, MRF) and quartz with lesser feldspars. The primary intergranular pores were predominantly plugged by 8-10% matrix clay and 5-6% calcite cement (image A). Note some vertical microfractures cut through rocks and are sealed by calcite. Image B shows calcite occurs as both replacement of grains and pore filling phase. Some volcanic rock fragments developed secondary pores due to dissolution of unstable minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 17		**Depth:**	286.50m

Image A:

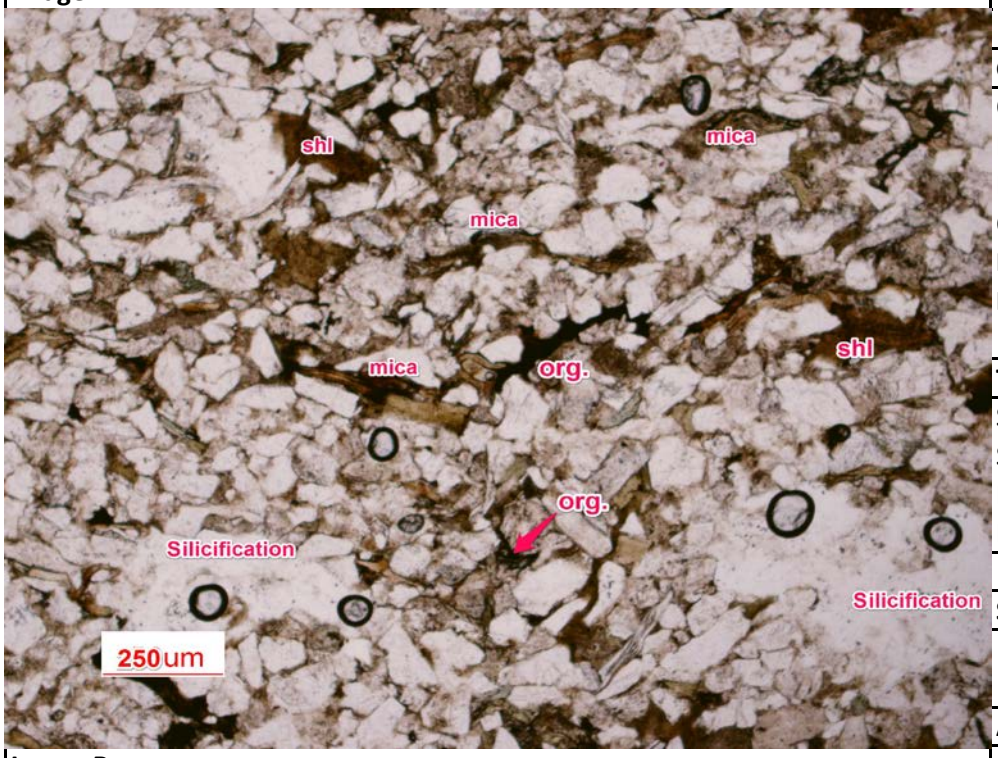
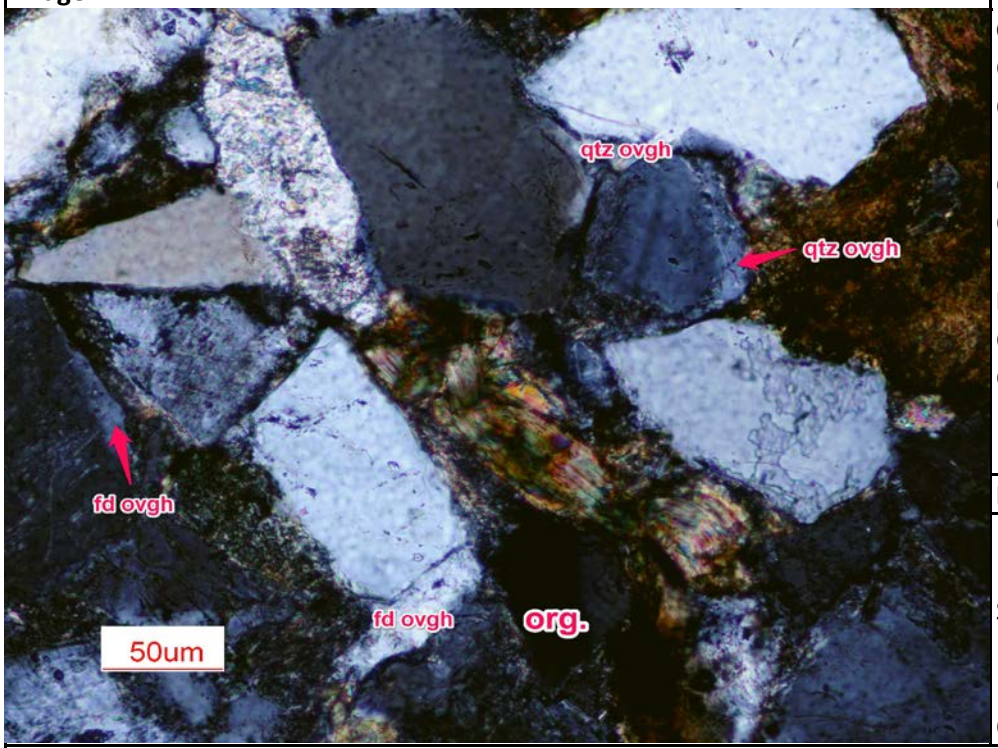


Image B



Composition: (visual estimate)

Grains:

Q%	45-50
F%	15-20
R%	25-27
Others: 2-3 % mica , 0.5% glau,	
Matrix:	23-25
Rock Type:	
Felfspathic Litharenite	

Texture

Size Average:	fine
Sorting:	well-very well
Roundness:	subround-rounded.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	tr
Organic matter	1.0-2.0
Pyrite	tr
Replacement	
Chlorite	tr
Calcite	tr
Pyrite	tr

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	abudant
Others:	

Image A is an overview of a massive, fine grained, well-very well sorted feldsparthic litharenite. The subrounded framework grains consist mainly of quartz and rock fragments (chert, VRF, PRF, MRF) with lesser feldspars, minor mica and glauconitic are also present. Considerable amount of clay matrix (23-25%) occurred within grain-supported fabric and reduced intergranular pores (image A). Image B shows the primary Intergranular pore spaces plugged by abundant matrix and minor quartz and feldspar overgrowth (image B), no visible porosity was detected in the sample. Microporosity is abundant in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 19		**Depth:**	279.00m

Image A:

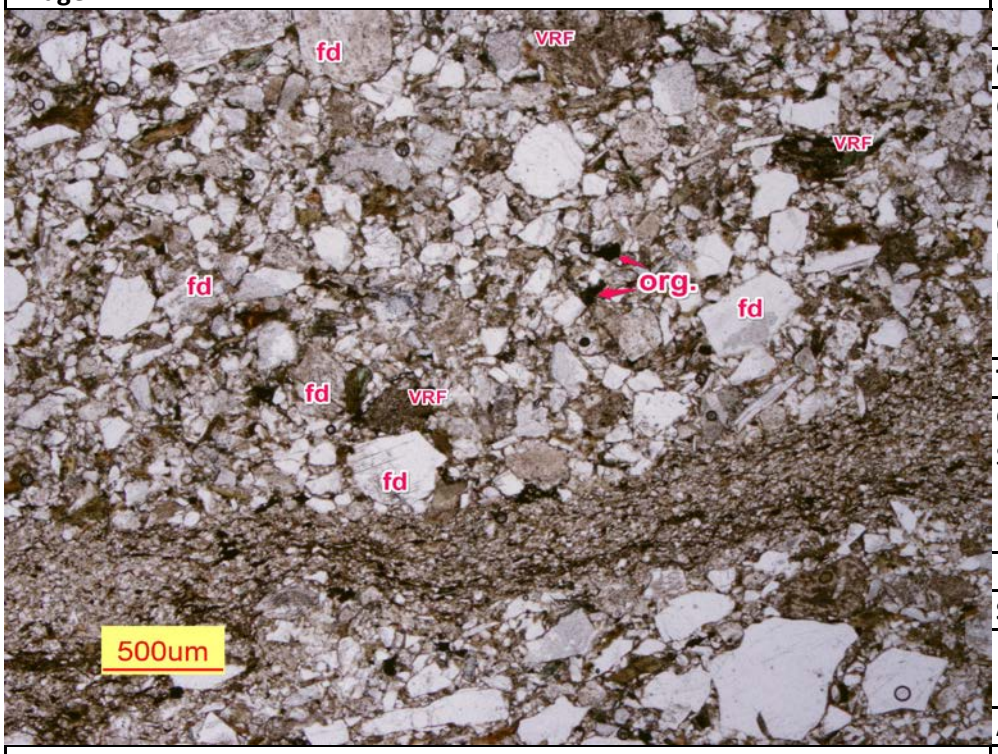
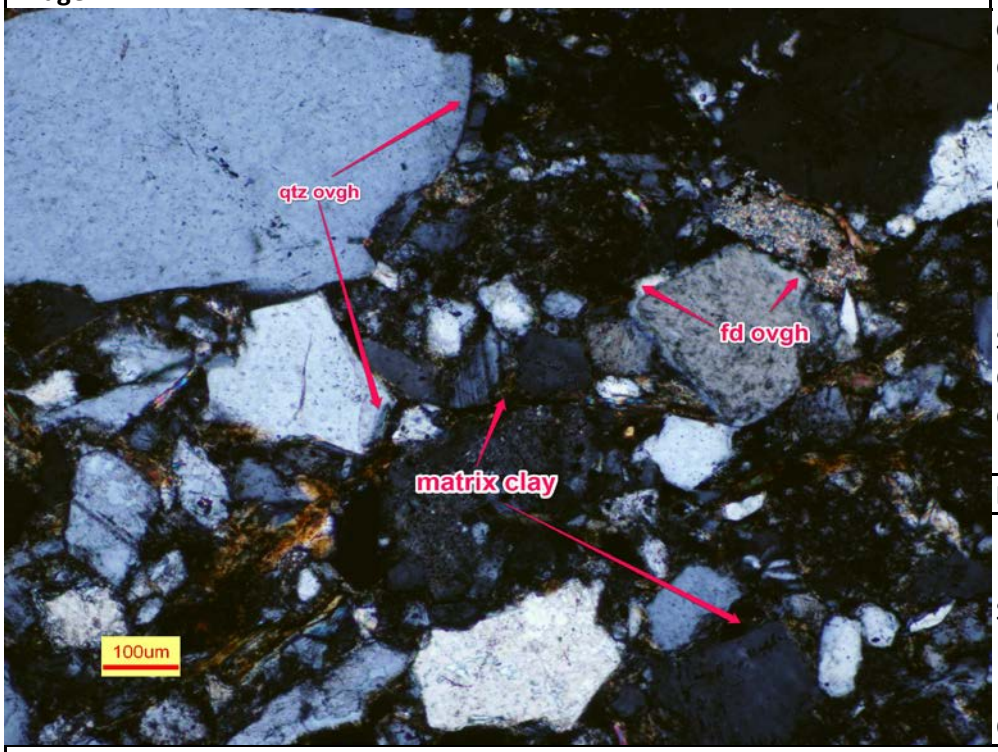


Image B



Composition: (visual estimate)

Grains:	
Q%	35-40
F%	30-32
R%	23-25
Others: mica 2-3 %, glau,	
Matrix:	20-22
Rock Type:	
Lithic Arkose	

Texture	
Grain size	very fine to coarse
Sorting:	poor
Roundness:	ang.-subrounded
Fabric:	grain supported

Structure

Massive, locally laminated

Authigenic Components

Cements (Pore Fillings):	
Chlorite	tr
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	0.5-1.0
Pyrite	tr
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	tr-0.5

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	
Others:	

Image A is an overview of a locally laminated to massive, very fine to coarse grained lithic arkose. Poorly sorted grains are angular to subrounded, size ranging from very fine (50um) to very coarse sand (1100um). Grains are dominated by quartz, feldspars and rock fragments (chert, VRF, PRF, MRF). Minor dark brown to black organic matter (bitumen?) occluded intergranular pores. The primary intergranular pores were predominantly reduced by compaction and 20-22% matrix clay, and produced a tight, non-porous fabric (image A). Image B shows quartz and feldspar overgrowth was identified by clear rims around grains. Considerable matrix clay occurred between grains , and microporosity is abundant in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 21		**Depth:**	267.00m

Image A:

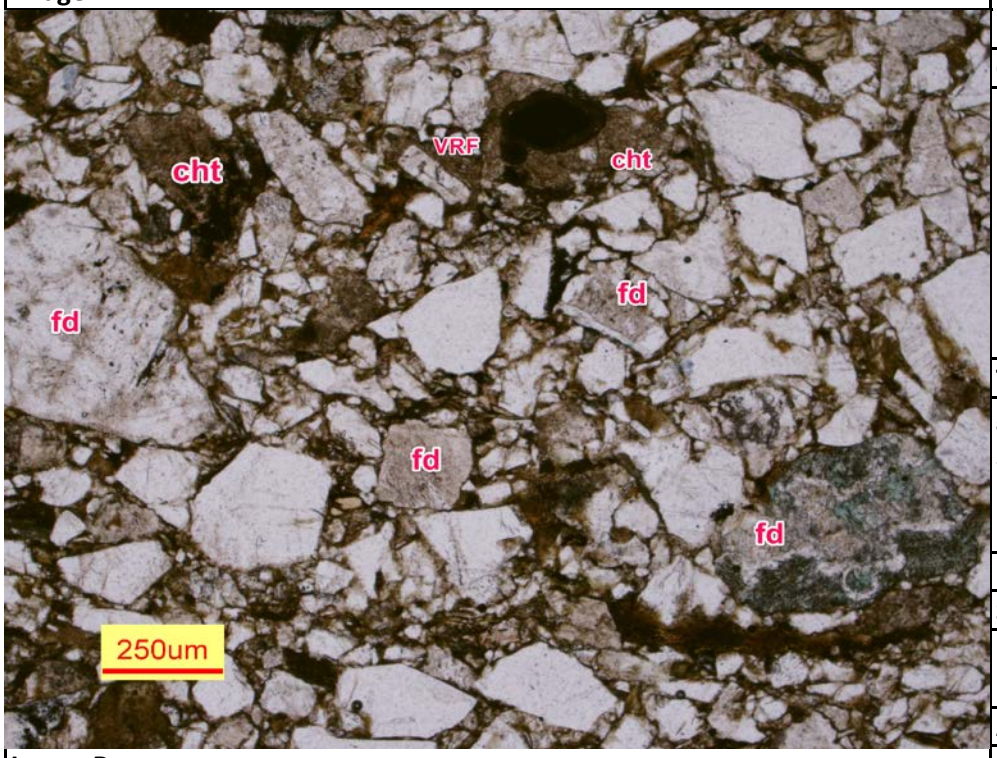
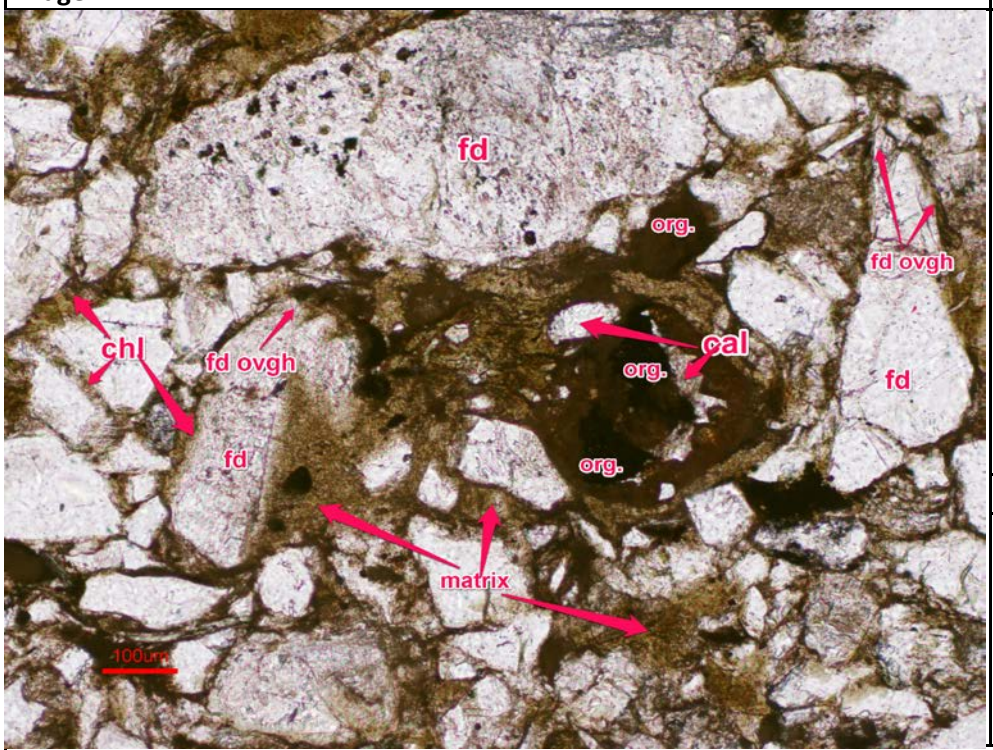


Image B



Composition: (visual estimate)

Grains:	
Q%	38-42
F%	22-25
R%	25-30
Others: 2% mica , trace glau,	
Matrix:	25-30
Rock Type:	
Feldspathic Litharenite	

Texture	
grain size	very fine to coarse
Sorting:	poorly
Roundness:	ang.-subrounded
Fabric:	grain supported

Structure
Massive

Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	0.5
Organic matter	0.5-1.0
Pyrite	tr-0.5
Replacement	
SiO2	
Chlorite	tr
Calcite	0.5-1.0
Pyrite	1.0

Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	abundant
Others:	

This massive, very fine to coarse grained feldspathic litharenite is mainly composed of quartz, rock fragments (chert, VRF, PRF, MRF) and feldspars. Poorly sorted grains are angular to subrounded, size ranging from very fine (60um) to very coarse sand (1250um). Moderate compaction and 25-30% matrix clay reduced and blocked intergranular pores, and produced a tight, non-porous fabric (image A). Image B shows dissolution of unstable grains (VRF, PRF, feldspar etc.) formed secondary porosity which in filled with organic matter or bitumen? and followed by calcite cement. The early diagenetic phases included chlorite rimming and feldspar overgrowth. Considerable matrix clay occurred between grains, and microporosity is abundant in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 22		**Depth:**	253.00m

Image A:

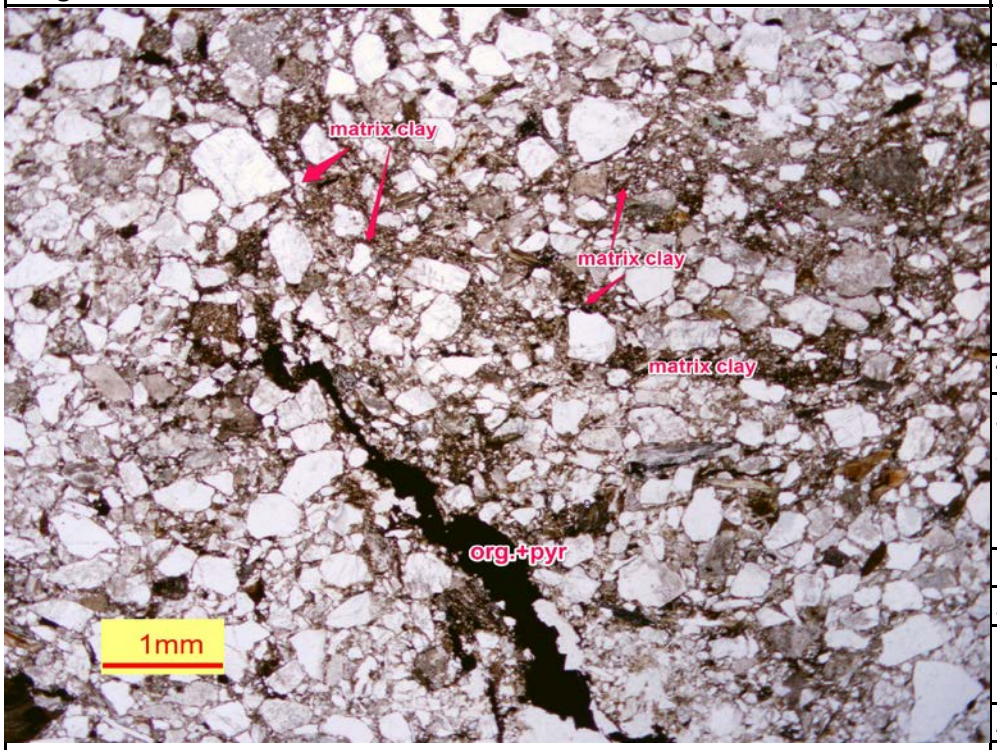
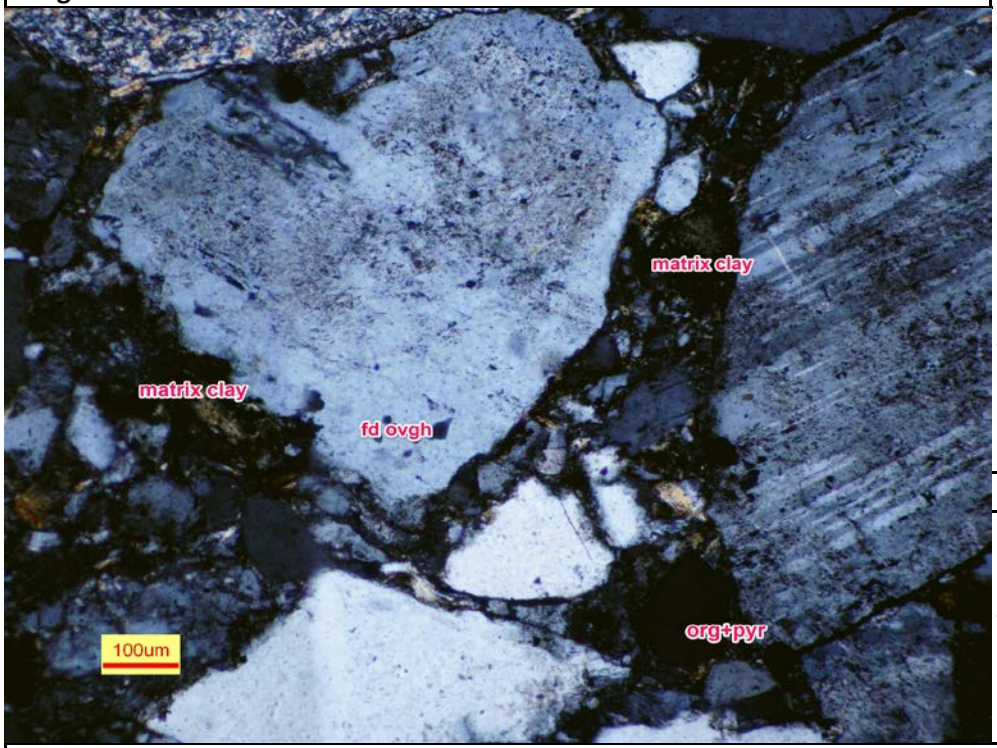


Image B



Composition: (visual estimate)

Grains:	
Q%	30-35
F%	28-30
R%	30-32
Others: 1-2 % mica , 0.5% glau,	
Matrix:	15-17
Rock Type:	
Feldspathic Litharenite	

Texture	
grain size	medium to coarse
Sorting:	moderately
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	1.0
Pyrite	0.5-1.0
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	tr

Porosity (Visual Estimate):

Intergranular:	
Secondary:	tr
Microfracture	tr
Microporosity:	common
Others:	

Image A exhibits a massive, medium to coarse grained feldsparthic litharenite with a grain-supported, non-porous fabric. Moderately sorted grains are subanguler to subrounded, size ranging from coarse silt (60um) to very coarse sand (1500um). Grains consists of sub-equal quartz, rock fragments (chert, VRF, PRF, MRF) and quartz (image A). Note some vertical microfractures cut through rocks and are filled with bitumen? and pyrite (image A). Image B shows the primary intergranular pore spaces plugged by abundant matrix clay and minor feldspar overgrowth (image B), no visible porosity was detected in the sample. Microporosity is abundant and exists in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 24	**Depth:**	236.25m

Image A:

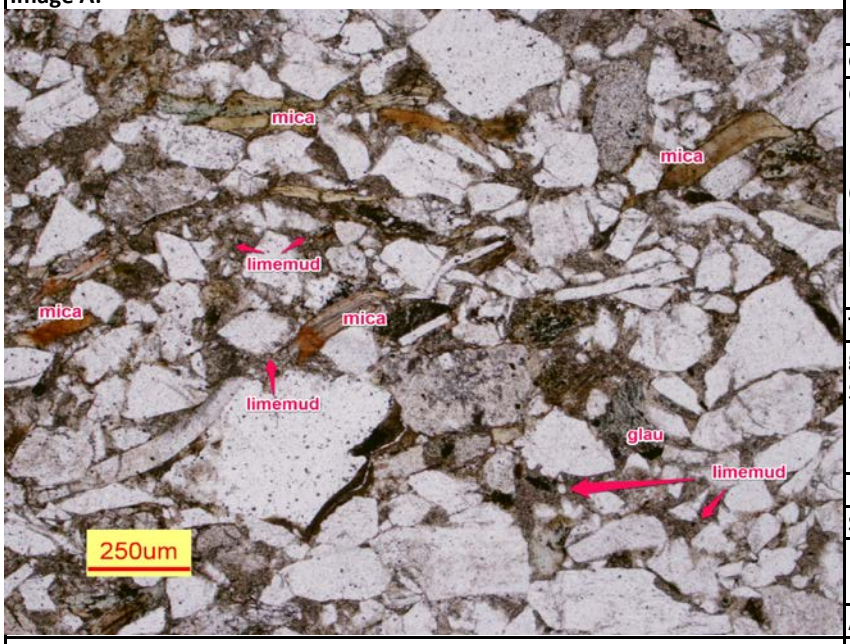
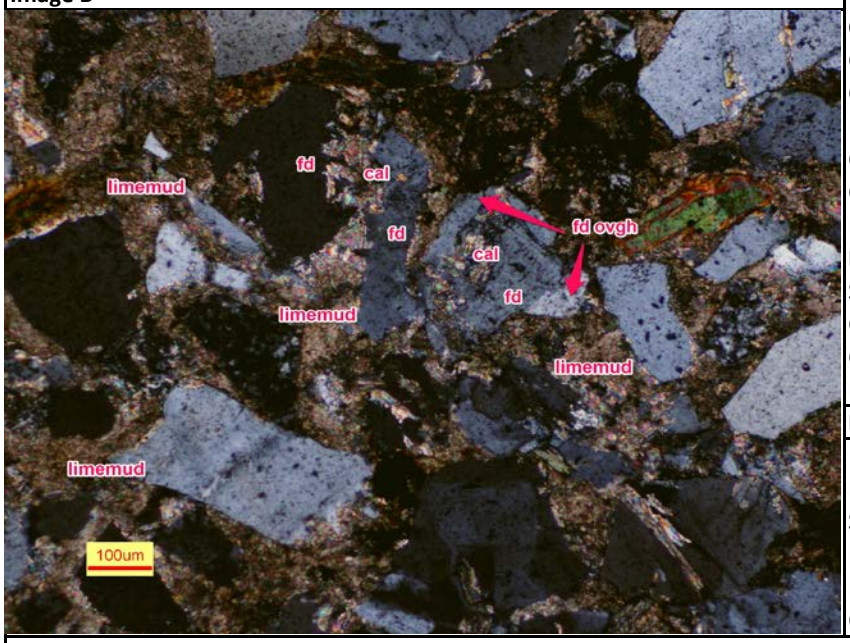


Image B



Composition: (visual estimate)

Grains:

Q%	45-50
F%	25-30
R%	15-17

Others: 2-3 % mica , 0.5% glau,

Matrix: 20-22 (micritic limemud)

Rock Type:

Lithic Arkose

Texture

grain size	fine to medium
Sorting:	moderately well
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	minor
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	tr
Pyrite	tr

Replacement

SiO2	
Chlorite	
Calcite	
Pyrite	tr

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A shows a massive, fine to medium grained lithic arkose. Grains are moderately well sorted, and composed mainly of quartz and feldspar with lesser rock fragments (chert, VRF, PRF, MRF). Grain supported fabric shows subtle preferential orientation of grains due to compaction. The sample has very low visible porosity, and pores are blocked by considerable micritic lime mud (image A). Image B is closer view of micritic lime mud between grains. Also note that grain boundaries often look corroded (image B) in contact with lime mud, suggesting a replacement modification of the grains by microcrystalline calcite (image B). Microporosity is abundant and exists in the micritic lime mud.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 26	**Depth:**	227.50m

Image A:

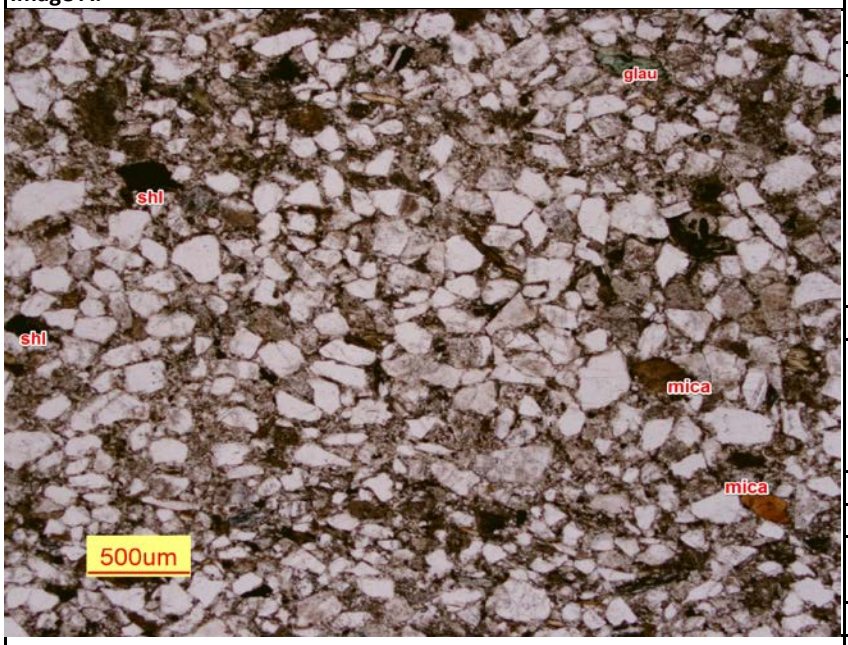
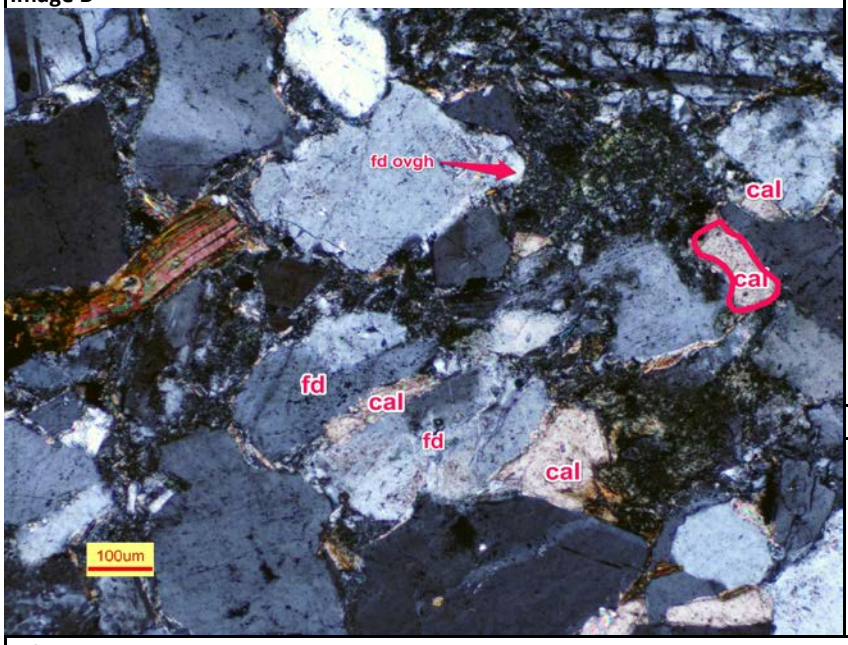


Image B



Composition: (visual estimate)

Grains:	
Q%	48-50
F%	25-26
R%	20-22
Others: 2% mica, trace glau,	
Matrix:	25-26
Rock Type:	
Lithic Arkose	
Texture	
Grain size	fine
Sorting:	very well
Roundness:	subrounded
Fabric:	grain supported
Structure	
Massive, locally laminated	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	minor
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	0.5-1
Organic matter	0.5
Pyrite	tr
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	tr
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A fine grained, very well sorted lithic arkose shows an overall massive texture with minor shale laminae. The subrounded framework grains consist mainly of quartz, feldspars and rock fragments (chert, VRF, shale clasts, PRF, MRF), minor mica and glauconitic are also present. Considerable amount of clay matrix (25-26%) occurred within grain-supported fabric and reduced intergranular pores (image A). Image B shows the primary Intergranular pore spaces plugged by abundant matrix and minor calcite cement. Feldspar overgrowth (image B) was recognized by clear rims, no visible porosity was detected in the sample. Microporosity is abundant and exists in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 28	**Depth:**	216.75m

Image A:

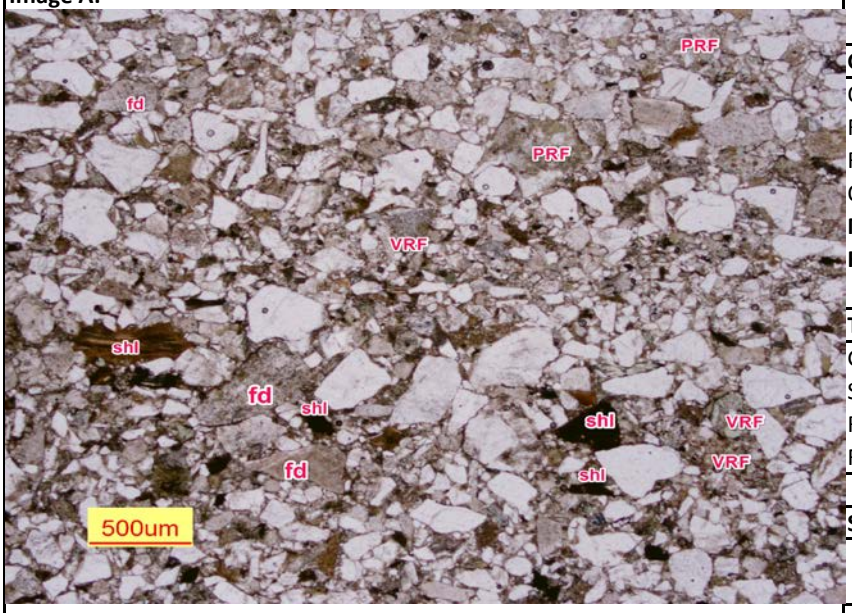
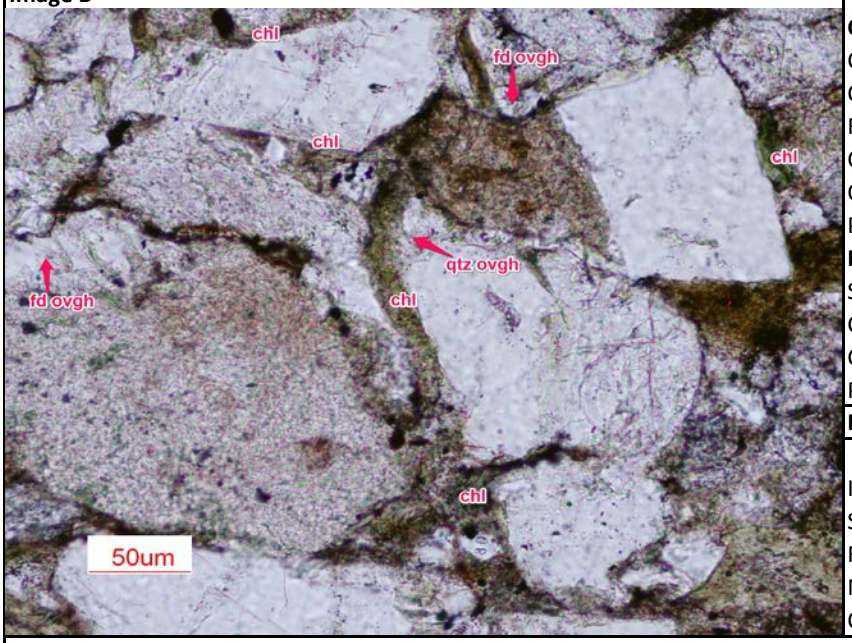


Image B



Composition: (visual estimate)

Grains:	
Q%	40-42
F%	20-23
R%	30-32
Others: 2% mica, trace glau,	
Matrix:	17-18
Rock Type:	
Feldspathic Litharenite	
Texture	
Grain size	fine to medium
Sorting:	moderately
Roundness:	subang.-subroun.
Fabric:	grain supported
Structure	
Massive	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	0.5-1
Pyrite	0.5
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	tr
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

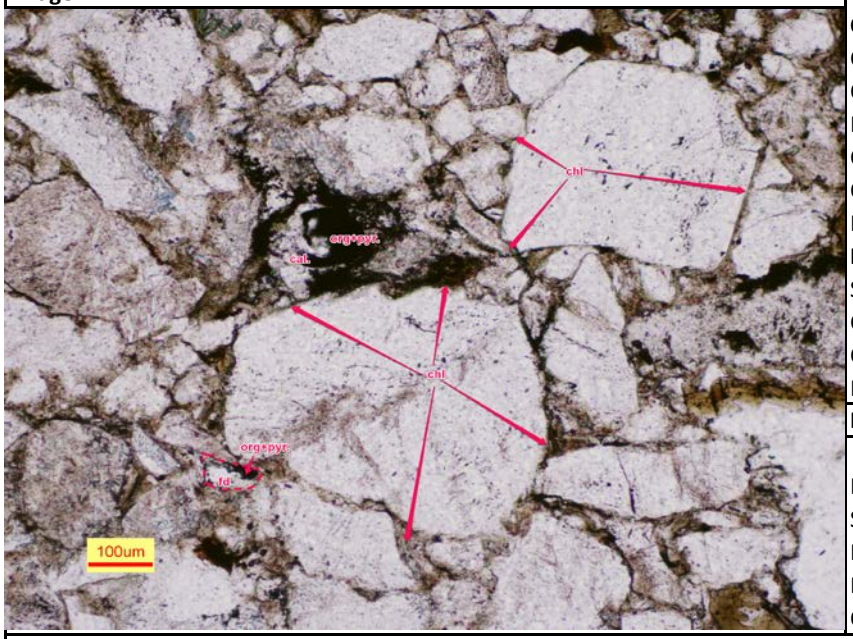
Image A is an overview of a massive, fine to medium grained feldsparthic litharenite. The moderately sorted, subangular to subrounded framework grains consist mainly of quartz and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) with lesser feldspars, minor mica and glauconitic are also present. The original primary pores are reduced by moderate compaction and further blocked by 17-18% clay matrix, indicating by tight, non-porous fabric. Image B shows the early diagenetic phases: chlorite lining pores and followed by feldspar and quartz overgrowth (image B). Microporosity is abundant and exists in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada		WELL ID: OW-11-01-NANAIMO OBS WELL 390
Sample ID: 29	**Depth:**	214.50m

Image A:

Image B



Composition: (visual estimate)

Grains:	
Q%	35-37
F%	27-28
R%	30-32
Others: mica: 2-3%, glau: tr.	
Matrix:	18-20
Rock Type:	
Feldspathic Litharenite	

Texture	
Grain size	medium to coarse
Sorting:	moderatly
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	0.5-1
Calcite	tr
Organic matter	0.5
Pyrite	0.5
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	0.5

Porosity (Visual Estimate):

Intergranular:	tr
Secondary:	tr
Fracture:	
Microporosity:	common
Others:	

A massive, medium to coarse grained feldsparthic litharenite shows a framework consisting mainly of quartz and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) with lesser feldspars, minor mica and glauconitic are also present (image A). Platy and elongated grains are compacted parallel to bedding planes (image A). The moderately sorted, subangular to subrounded fabric is tight, non-porous because the primary pores are reduced by moderate compaction and further blocked by 18-20 % clay matrix. Image B shows the early chlorite grain coating. Note some feldspar grains were dissolved and produced secondary pores which filled by calcite and black org.+pyr. or bitumen? (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**WELL ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 30	**Depth:**	207.50m

Image A:

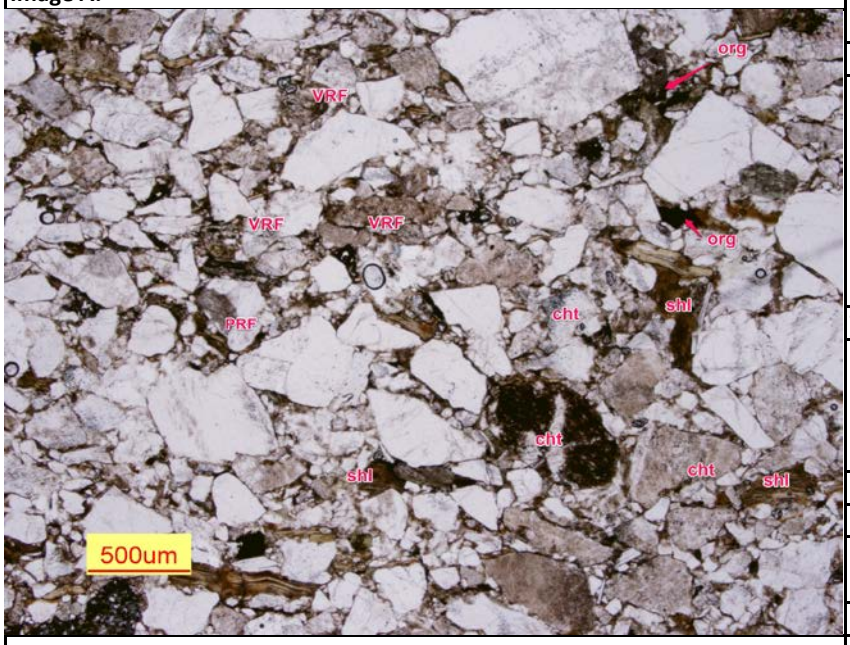
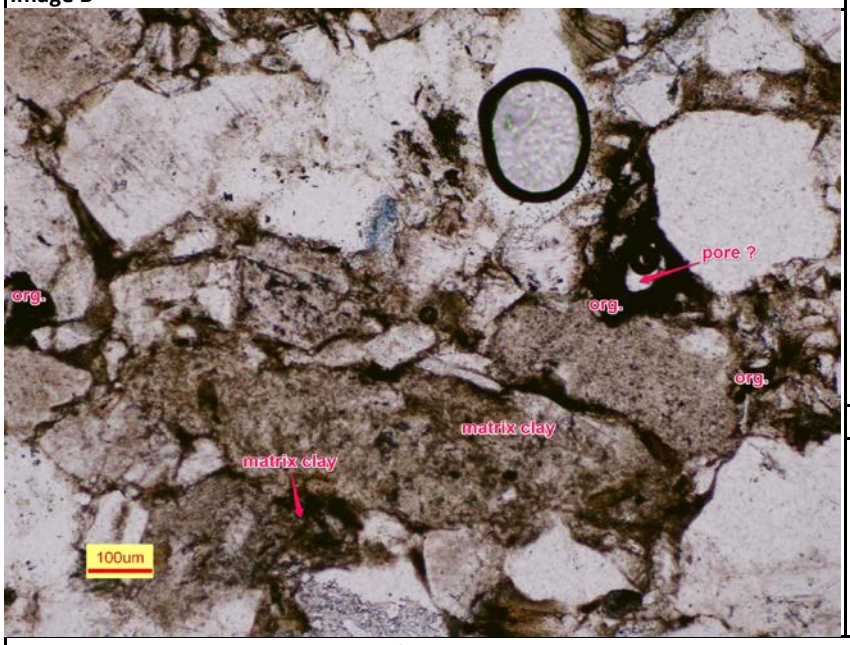


Image B



Composition: (visual estimate)

Grains:

Q%	37-40
F%	24-25
R%	27-30
Others: mica: 1-2%, glau: tr.	
Matrix:	15-16
Rock Type:	

Feldspathic Litharenite

Texture

Size Average:	medium to coarse
Sorting:	Poorly - moderatly
Roundness:	ang.-subroun.
Fabric:	grain supported

Structure

Massive, borrowed

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	
Feldspar ovgh	
Calcite	
Organic matter	1-1.5
Pyrite	0.5-1
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	0.5

Porosity (Visual Estimate):

Intergranular:	tr
Secondary:	tr
Fracture:	
Microporosity:	common
Others:	

A massive, medium to coarse grained feldspathic litharenite shows a grain-supported, poorly to moderately sorted, angular to subrounded framework. Grains are dominated by quartz, rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) and feldspars (image A). The original primary pores are reduced by moderate compaction and further blocked by 15-16 % clay matrix, therefore the sample has a very low visible porosity. Image B shows minor black organic matter (bitumen?) mixed with pyrite filled remaining pore spaces (image B) between grains after pore-blocking matrix clay. Note the red arrow shows the pore could be a remaining intergranular pore or grain secondary dissolution pore?

Description of Thin Section Photomicrograph

Geological Survey of Canada	**WELL ID:** OW-11-01-NANAIMO OBS WELL 390
Sample ID: 32	**Depth:** 194.50m

Image A:

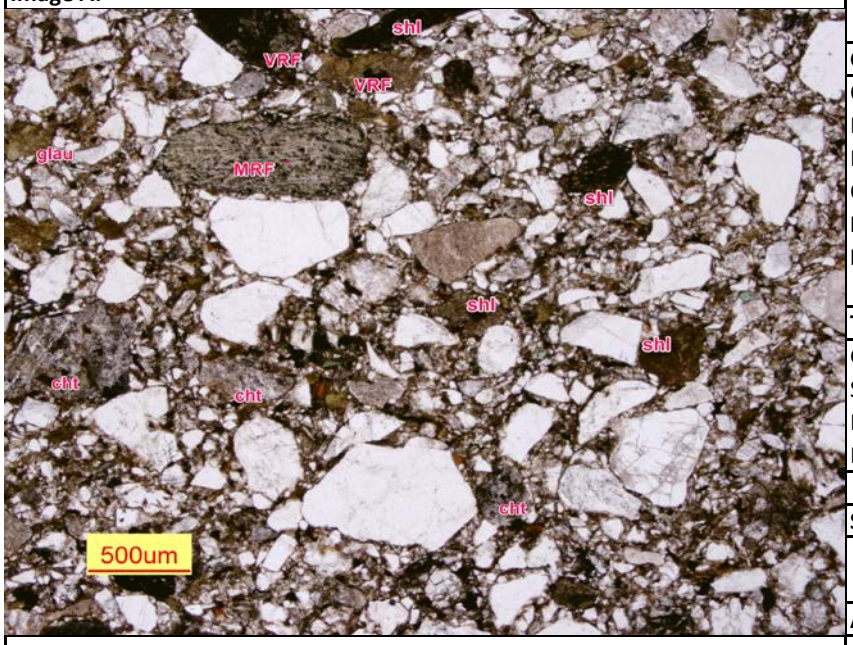


Image B

Composition: (visual estimate)

Grains:

Q%	35-40
F%	23-25
R%	30-33
Others: mica: 1-2%, glau: tr.	
Matrix:	25-27
Rock Type:	
Feldspathic Litharenite	

Texture

Grain size	very fine to coarse
Sorting:	Poorly
Roundness:	ang.-subroun.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr-0.5
Feldspar ovgh	tr-0.5
Calcite	
Organic matter	0.5-1
Pyrite	0.5

Replacement

SiO2	
Chlorite	tr
Calcite	
Pyrite	0.5-1

Porosity (Visual Estimate):

Intergranular:	tr
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A shows a massive, very fine to coarse grained feldspathic litharenite with a grain-supported, tight and non-porous fabric. Poorly sorted grains are angular to subrounded, size ranging from coarse silt (30um) to very coarse sand (1200um). Grains are dominated by quartz, rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) and feldspars. The primary intergranular pores were predominantly reduced by compaction and 25-27% matrix clay (image A), therefore the sample has a very low visible porosity. Image B shows minor green-coloured authigenic chlorite and black organic matter (bitumen?) filled intergranular pores (image B). Considerable matrix clay occurred between grains and blocked pores.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 34		**Depth:**	180.00m

Image A:

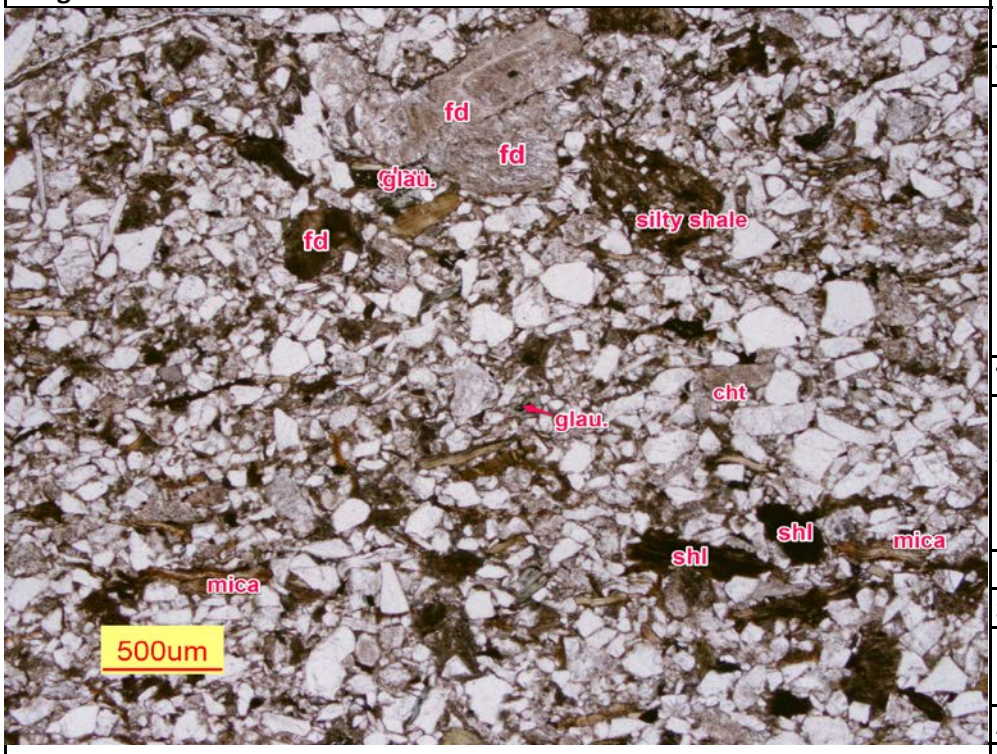
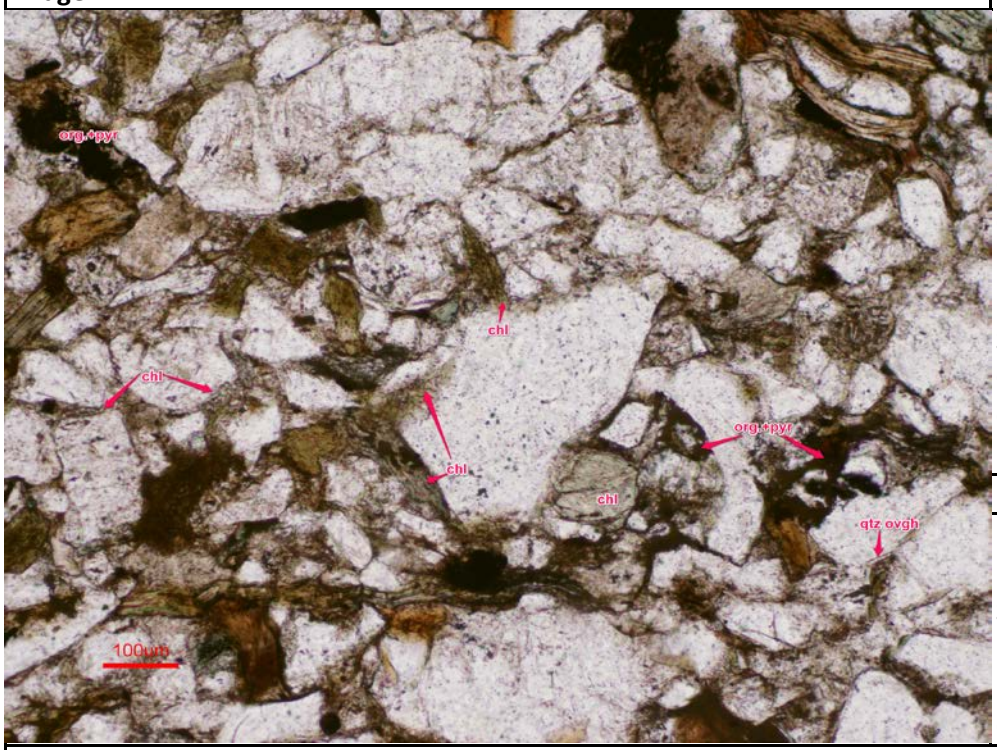


Image B



Composition: (visual estimate)

Grains:	
Q%	35-40
F%	30-32
R%	23-25
Others: mica 2-3 %, glau,	
Matrix:	16-18
Rock Type:	
Lithic Arkose	

Texture	
Grain size	fine to medium
Sorting:	poorly-moderately
Roundness:	subang.-subrounded
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	0.5-1.0
Pyrite	tr-0.5
Replacement	
SiO2	
Chlorite	tr
Calcite	tr
Pyrite	0.5-1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A massive, fine to medium grained lithic arkose shows a framework consisting mainly of quartz, feldspars and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.), minor mica and glauconitic are also present (image A). Platy and elongated grains are compacted parallel to bedding planes (image A). The poorly to moderately sorted, subangular to subrounded fabric is tight, non-porous because the primary pores are reduced by moderate compaction and further blocked by 16-18% clay matrix. Image B shows the early chlorite grain coating and later chlorite filling in the feldspar dissolved moldic pore?. Minor black org.+pyr. or bitumen? locally pugged the intergranular pores (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 35		**Depth:**	171.75m

Image A:

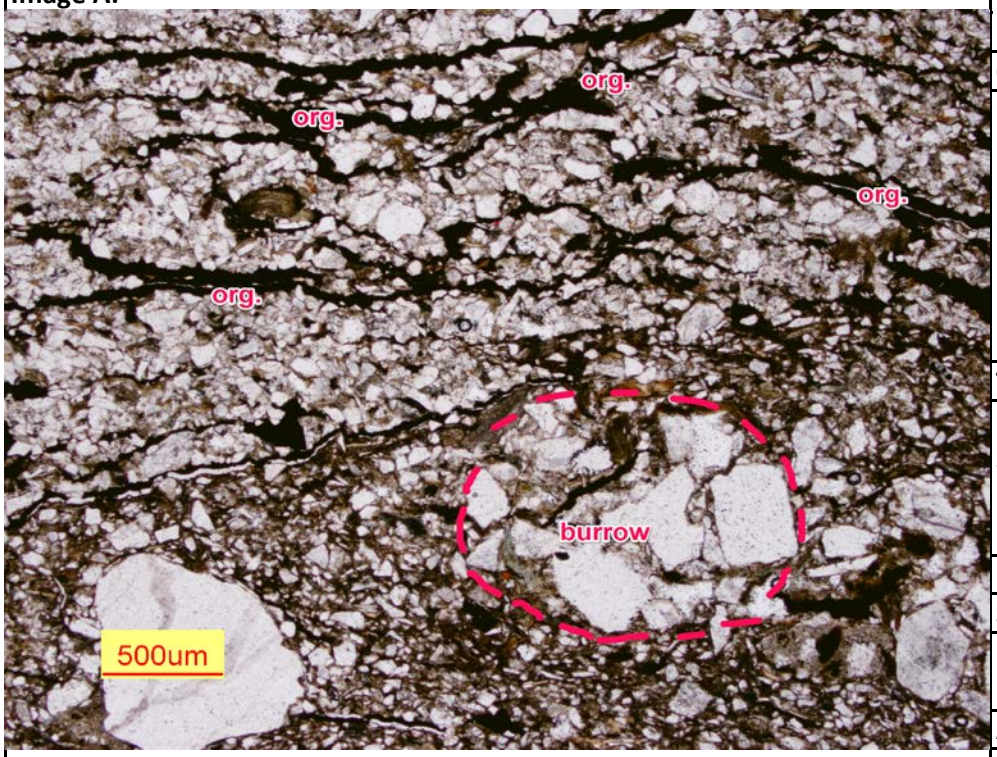
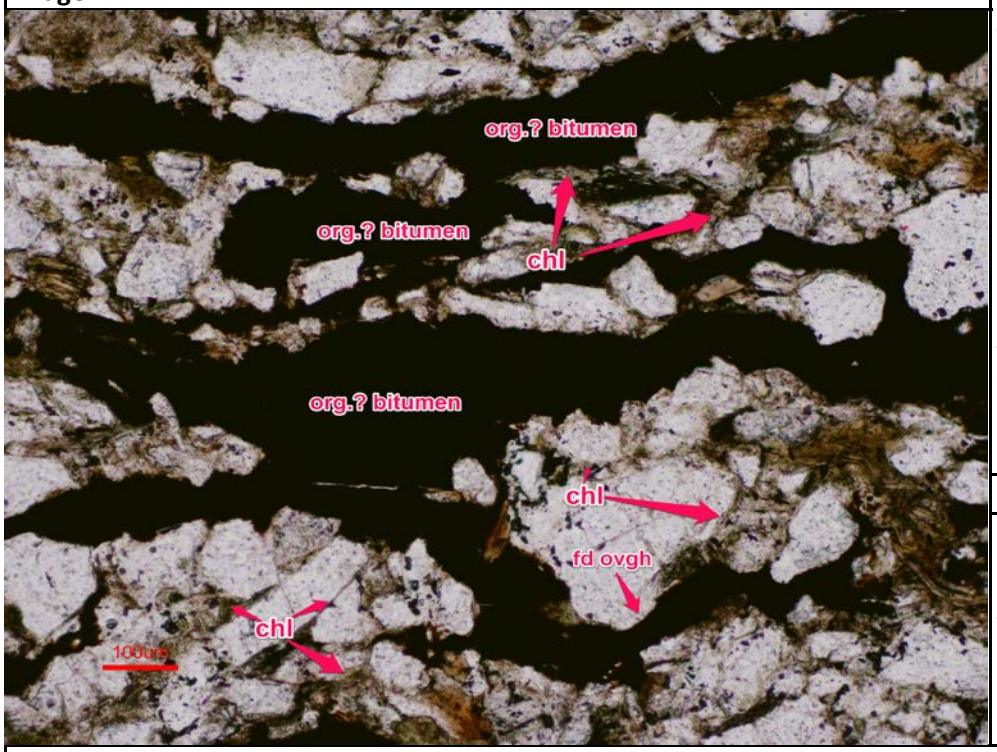


Image B



Composition: (visual estimate)

Grains:	
Q%	45-47
F%	26-28
R%	15-20
Others: mica 3-5 %, glau,	
Matrix:	27-30
Rock Type:	
Lithic Arkose	
Texture	
Grain size	very fine to fine
Sorting:	moderately-well
Roundness:	subroun.-rounded
Fabric:	grain supported
Structure	
Massive, burrowed	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	tr
Organic matter	10-12
Pyrite	3-5
Replacement	
SiO2	
Chlorite	tr
Calcite	tr
Pyrite	1
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

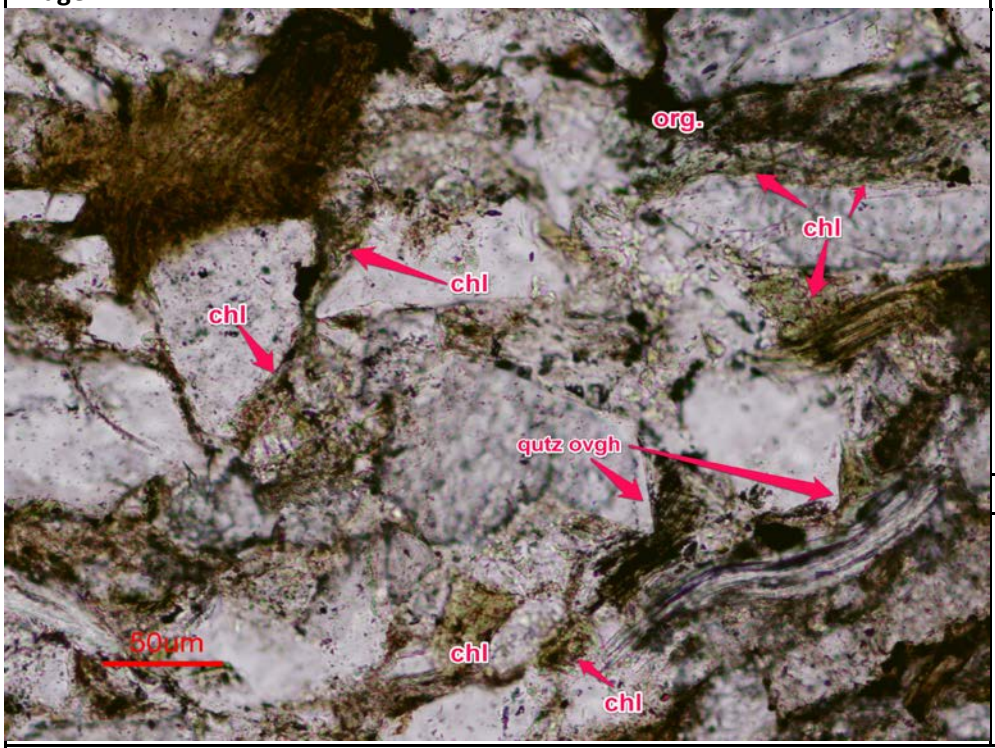
A very fine to fine grained lithic arkose shows an overall laminated to massive structure slightly disturbed by burrows, which are identified by cleaner, coarser and rotated grains (imageA). Moderately-well sorted grains are subrounded to rounded, and consist mainly of quartz, feldspars and lesser chert, shale clasts and volcanic rock fragments. This sample contains 27-30% clay matrix and 10-12% organic matter (bitumen) which blocked interstitial pore spaces (image A), indicated by tight, non-porous fabric. Image B displays black organic matter (bitumen?) mixed with pyrite occurred as thin strips paralleling to bedding planes (image B). Note the extensive early chlorite grain coating and trace feldspar overgrowth (image B) had developed.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 36		**Depth:**	163.75m

Image A:

Image B



Composition: (visual estimate)

Grains:	
Q%	38-40
F%	18-20
R%	35-37
Others: mica 2 %, glau. 0.5-1%	
Matrix:	20-22
Rock Type:	
Feldspathic Litharenite	
Texture	
Grain size	very fine to fine
Sorting:	well-very well
Roundness:	subrounded
Fabric:	grain supported
Structure	
Massive	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	1-2
Pyrite	tr
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	0.5-1
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A is an overview of a massive, very fine to fine grained feldsparthic litharenite with a tight, non-porous fabric (image A). Well to very well sorted framework grains are subrounded to rounded, and consist mainly of quartz, rock fragments (chert, shale clasts, VRF etc.) and lesser feldspars. The primary pores are first reduced by moderate compaction and further blocked by 20-22% matrix clay (mage A). Image B displays chlorite occurred as thin rims coating grain surfaces and also as cement filling intergranular pores (image B). Note the trace quartz overgrowth (image B) and minor pore-plugging black organic matter (bitumen?) are also present.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 37		**Depth:**	161.25m

Image A:

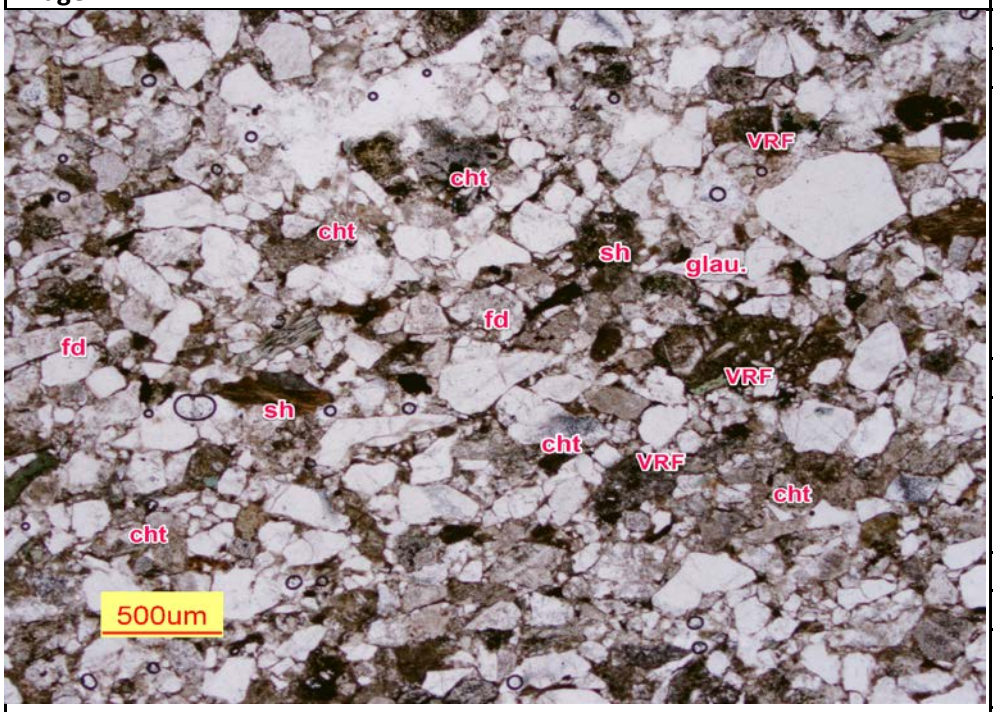
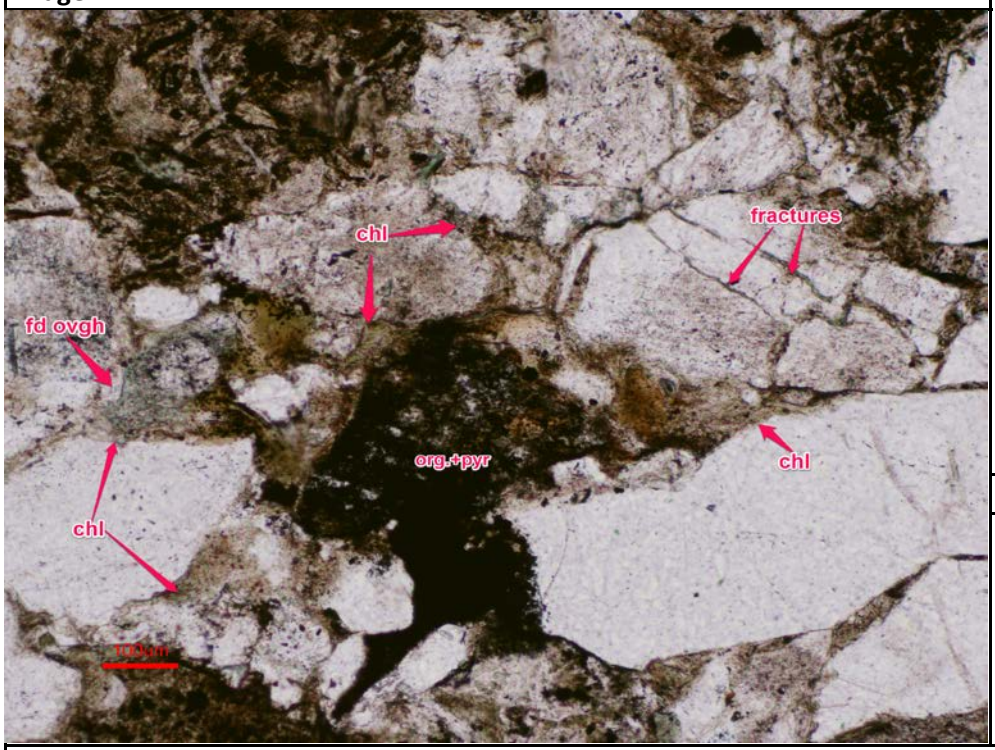


Image B



Composition: (visual estimate)

Grains:	
Q%	33-35
F%	23-25
R%	35-37
Others: mica 1 %, glau. 0.5-1%	
Matrix:	18-20
Rock Type:	
Feldspathic Litharenite	

Texture	
Grain size	fine to medium
Sorting:	moderately
Roundness:	subang.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	1
Pyrite	1
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	2-3

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Microfracture:	
Microporosity:	common
Others:	

A massive, fine to medium grained feldspathic litharenite shows a grain-supported, non-porous fabric. Framework exhibits a low mature features in texture and composition. Grains are subangular, moderately sorted, and consisting mainly of quartz, rock fragments (chert, shale clasts, VRF etc.) and lesser feldspars. The primary pores are first reduced by moderate compaction and further blocked by 18-20% matrix clay (image A). Image B displays chlorite occurred as thin rims lining pores and also as cement filling intergranular pores (image B). Minor quartz overgrowth grew around grains. Later stage organic matter (bitumen?) and pyrite filled remaining pore spaces (image B). Note microfractures cut through the rock and sealed with authigenic chlorite (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 38		**Depth:**	158.75m

Image A:

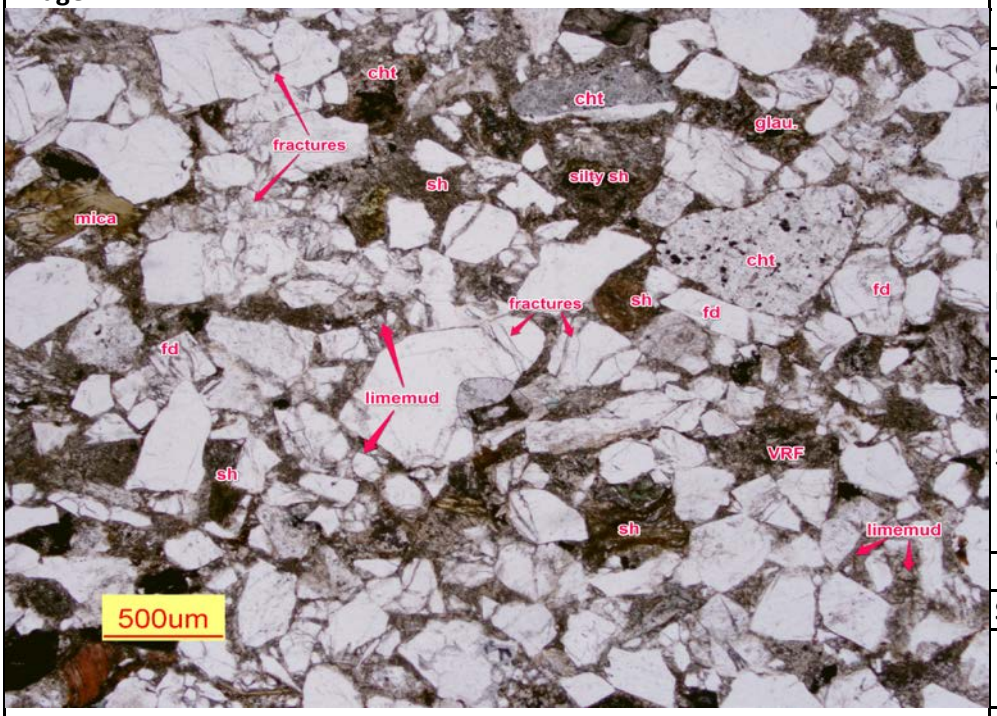
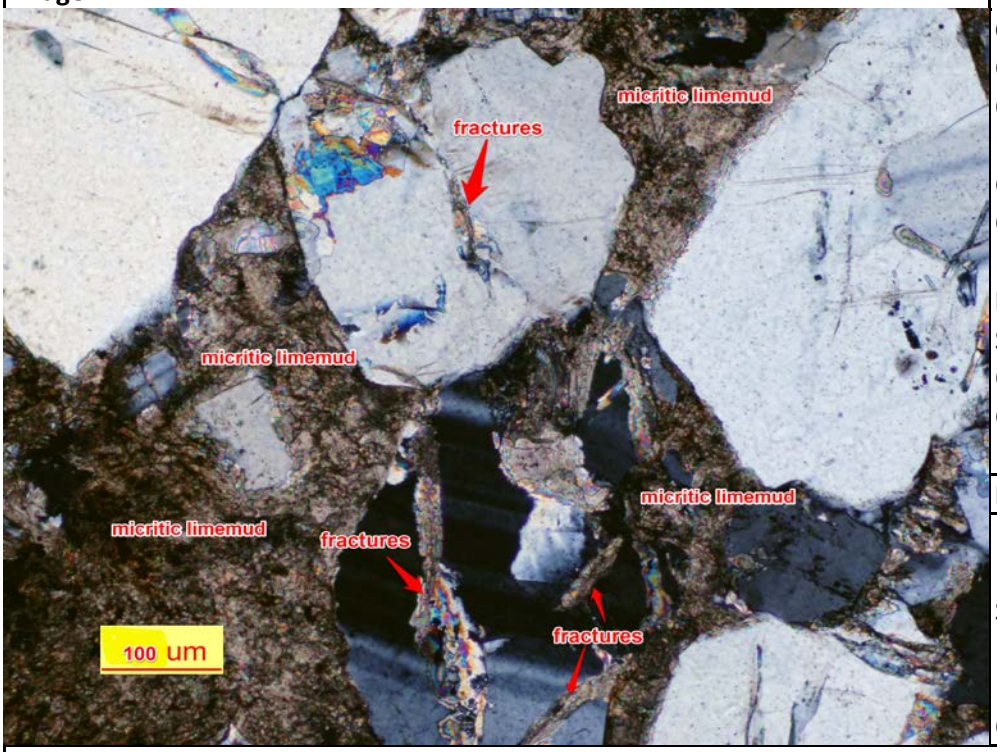


Image B



Composition: (visualestimate)

Grains:	
Q%	34-36
F%	27-28
R%	33-34
Others: mica 1 %, glau. 0.5%	
Matrix:	23-25
Rock Type:	
Feldspathic Litharenite	

Texture	
Grain size	medium to coarse
Sorting:	moderately
Roundness:	subrouned
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	tr
Organic matter	0.5
Pyrite	tr
Replacement	
SiO2	
Chlorite	tr
Calcite	1-2
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Microfracture:	common
Microporosity:	common
Others:	

Image A shows a massive, medium to coarse grained feldspathic litharenite with a tight, non-porous fabric, moderately sorted framework grains are subrounded, and dominated by quartz, rock fragments (chert, shale clasts, VRF etc.) and feldspars. This sample was characterized by abundant micritic lime mud (23-25%), which totally pugged the original intergranular pores. Two groups of microfractures cut through the rock and improved reservoir quality in some degree. Image B is a closer view of the fractures and matrix lime mud. Interstitial lime mud appeared as very fine crystals blocked intergranual pores and also filled some microfractures. Note the corroded boundaries of some grains, suggesting lime mud locally replaced grains.

Description of Thin Section Photomicrograph

Geological Survey of Canada		**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 39		**Depth:**	153.00m

Image A:

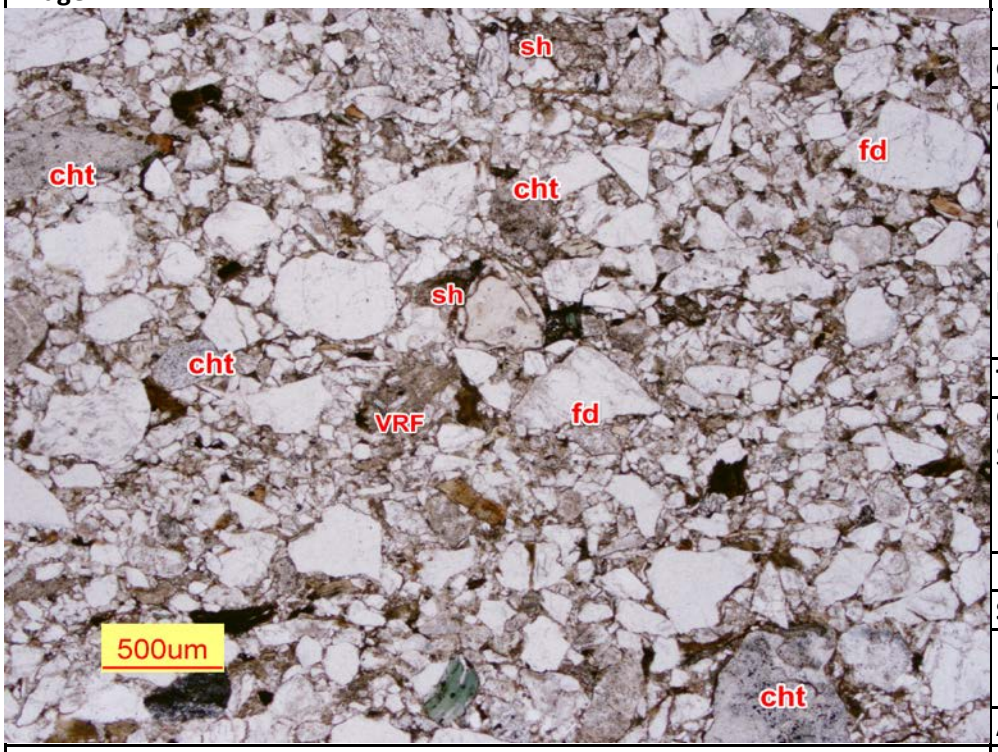
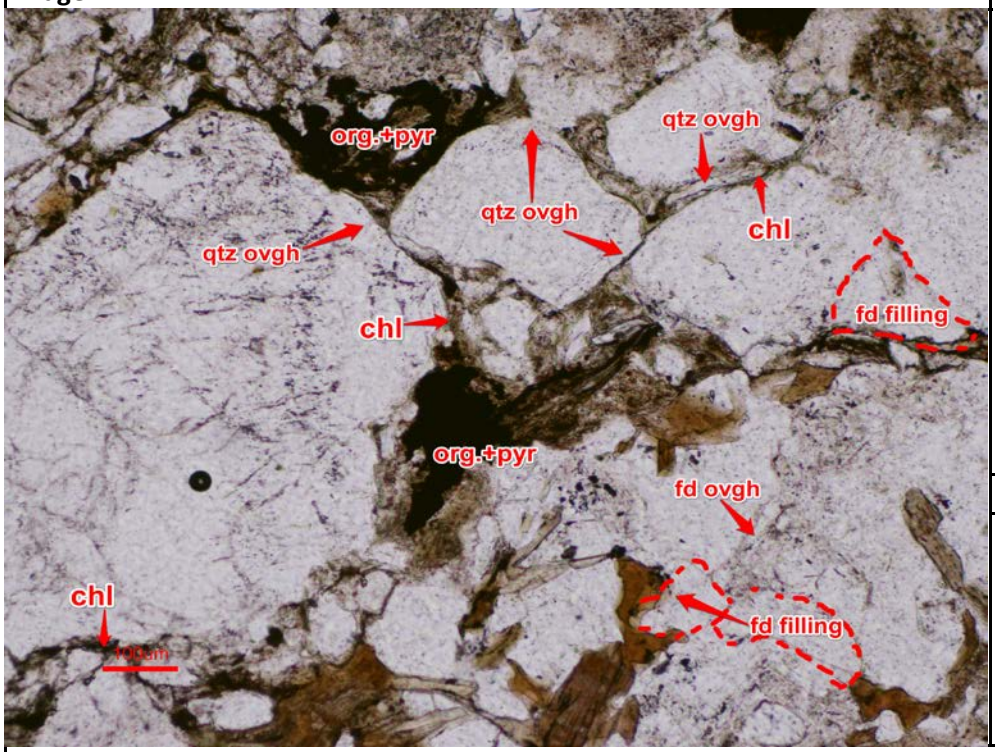


Image B



Composition: (visual estimate)

Grains:

Q%	3-35
F%	28-30
R%	30-33
Others: mica 2-3 %, glau. trace	
Matrix:	18-20

Rock Type:

Lithic Arkose

Texture

Grain size	fine to medium
Sorting:	poorly
Roundness:	ang.- subang.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	0.5-1.0
Pyrite	1.5

Replacement

SiO2	
Chlorite	tr
Calcite	
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Microfracture:	minor
Microporosity:	common
Others:	

A massive, fine to medium to grained lithic arkose shows a framework consisting mainly of quartz, feldspars and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.), minor mica and glauconitic are also present (image A). Platy and elongated grains are compacted parallel to bedding planes (image A). The poorly to moderately sorted, subangular to subrounded fabric is tight and non-porous because the primary pores are reduced by moderate compaction and further blocked by 16-18% clay matrix. Image B shows the early chlorite grain coating and later chlorite filling in the feldspar dissolved moldic pore?. Minor black org.+pyr. or bitumen? locally pugged the intergranular pores (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 41	**Depth:**	148.00m

Image A:

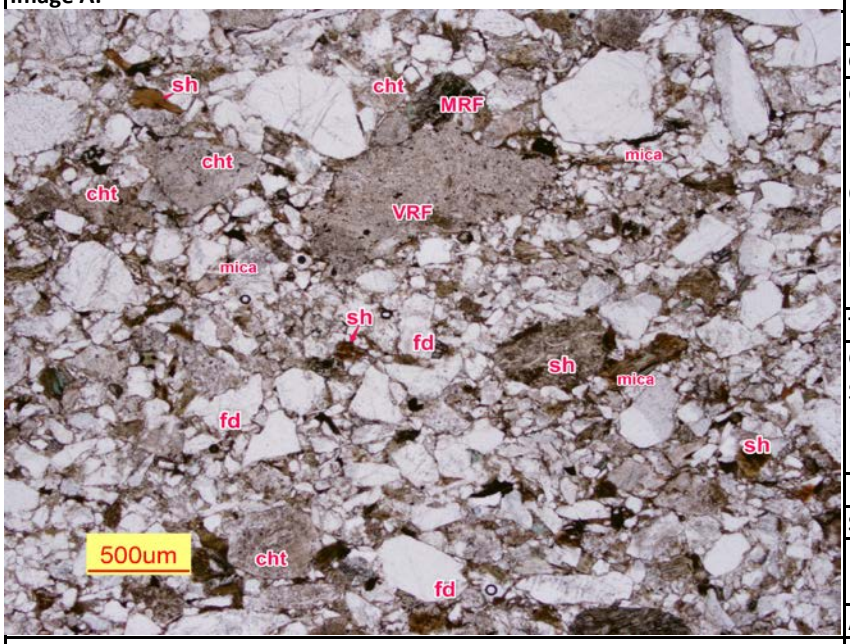
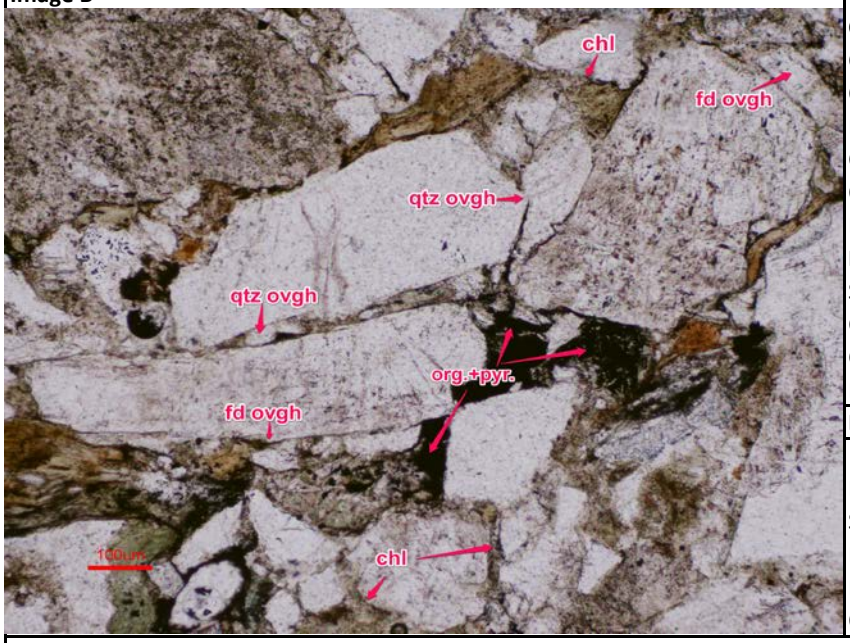


Image B



Composition: (visual estimate)

Grains:	
Q%	25--27
F%	28-30
R%	40-42
Others: 1-2% mica, 1% glau,	
Matrix:	16-18
Rock Type:	
Feldspathic Litharenite	
Texture	
Grain size	very fine to coarse
Sorting:	poorly
Roundness:	subang.-subroun.
Fabric:	grain supported
Structure	
Massive	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	0.5
Pyrite	0.5
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	1.5
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A is an overview of a massive, very fine to coarse grained feldspathic litharenite with a grain-supported, non-porous fabric. The poorly sorted, subangular to subrounded framework grains, size ranging from very fine (50um) to coarse sand (1700um), consist mainly of rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) with subequal amounts of quartz and feldspars. The original primary pores are reduced by moderate compaction and further blocked by 16-18% clay matrix. Image B shows the early diagenetic phases: chlorite lining pores and followed by feldspar and quartz overgrowth. Later stage organic matter (bitumen?) plugged remaining pore spaces (image B). Microporosity are abundant and exist in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 42	**Depth:**	144.92m

Image A:

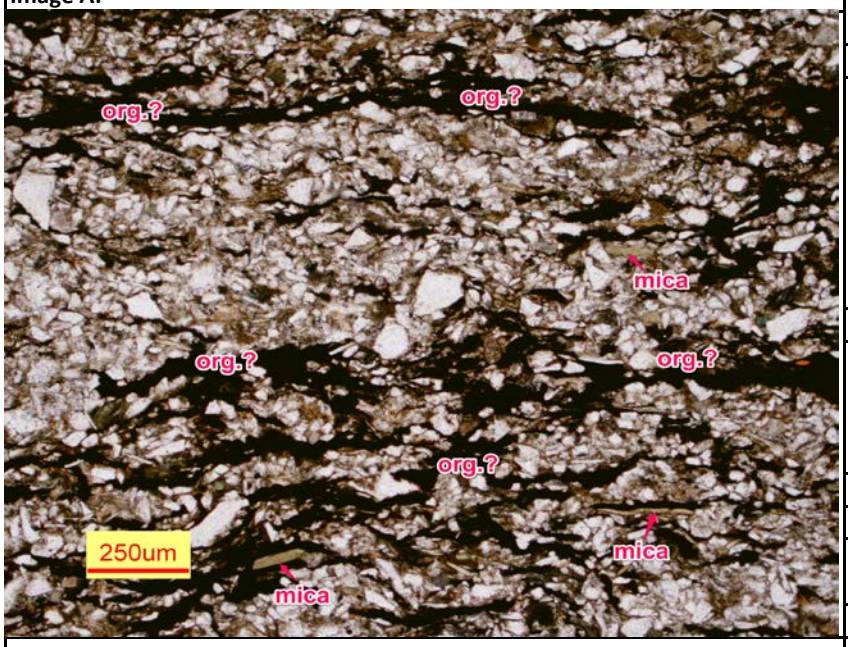
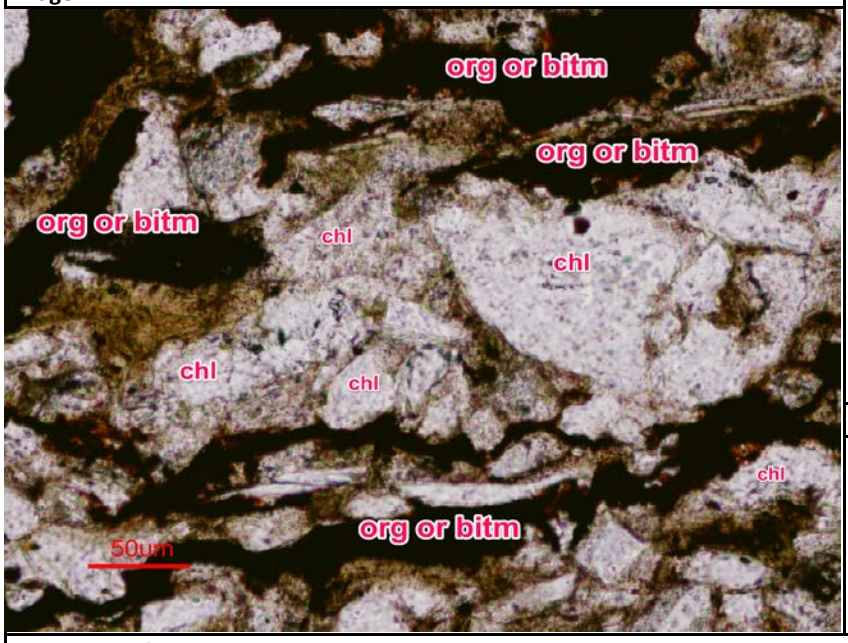


Image B



Composition: (visual estimate)

Grains:

Q%	60-63
F%	10-12
R%	20-22
Others: 2-3% mica, trace glau,	
Matrix:	27-30
Rock Type:	
Sublitharenite	

Texture

Grain size	silt to very fine
Sorting:	well-very well
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive, laminated

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	
Feldspar ovgh	
Calcite	
Organic matter	16-18
Pyrite	2

Replacement

SiO2	
Chlorite	tr
Calcite	
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A silt to very fine grained sublitharenite shows an overall massive texture with clay-rich and organic matter-rich laminae. The framework grains are subangular to subrounded, well to very well sorted, consisting mainly of quartz with lesser amounts of rock fragments (chert, shale clasts, VRF, etc.) and feldspars. This sample contains 27-30% clay matrix and 16-18% organic matter (bitumen?) which blocked interstitial pore spaces (image A), indicated by tight, non-porous fabric. Image B shows the early authigenic chlorite coating grain surfaces (image B). Abundant black organic matter (bitumen?) mixed with pyrite occurred as thin strips parallel to bedding planes (image B). Microporosity is abundant and exist in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 43	**Depth:**	139.00m

Image A:

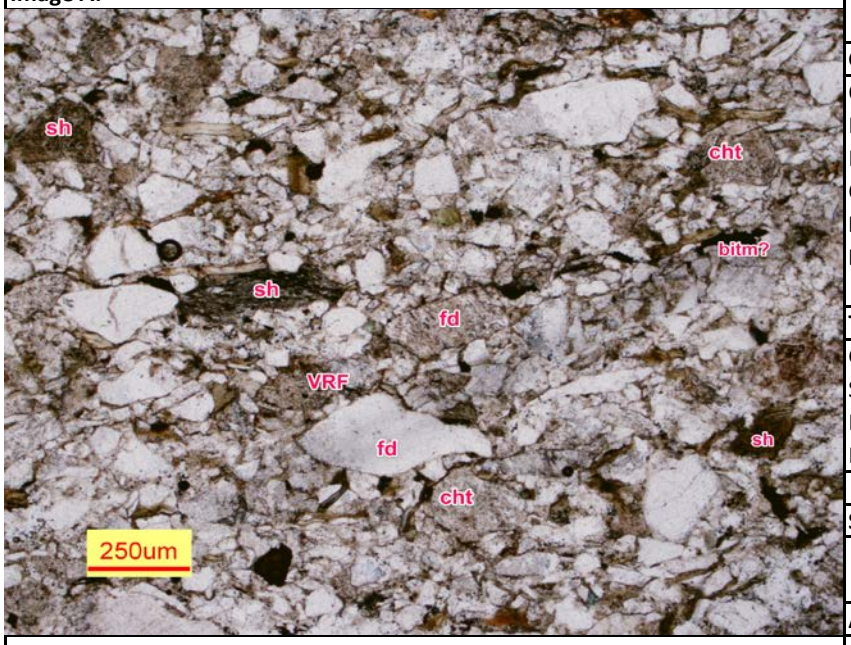
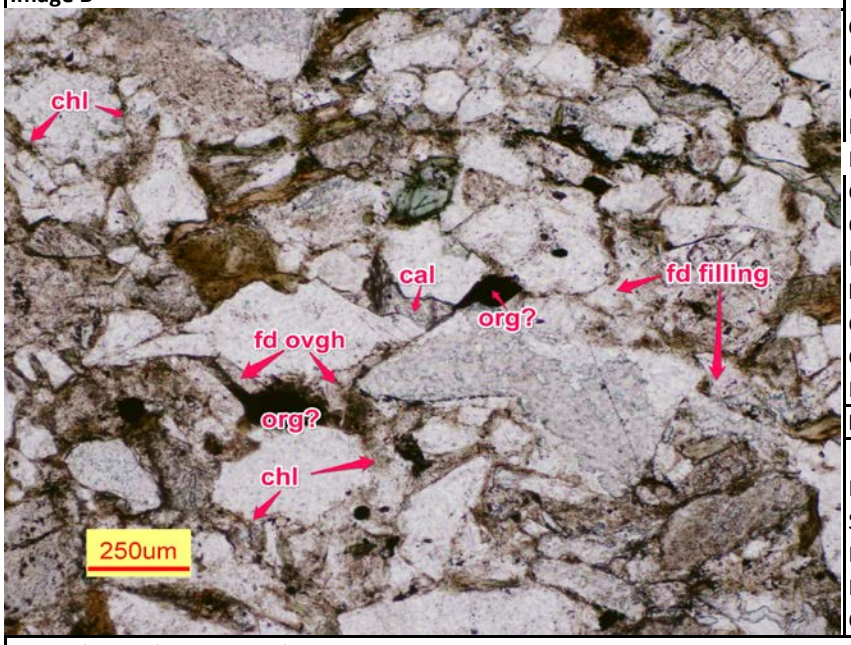


Image B



Composition: (visual estimate)

Grains:

Q%	45-48
F%	18-20
R%	25-28
Others: 2-3% mica, trace glau,	
Matrix:	19-22
Rock Type:	
Feldspathic Litharenite	

Texture

Grain size	very fine -fine
Sorting:	moderate to well
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive, burrowed

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Feldspar filling	minor
Calcite	tr
Organic matter	16-18
Pyrite	2
Replacement	
Chlorite	tr
Calcite	tr
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

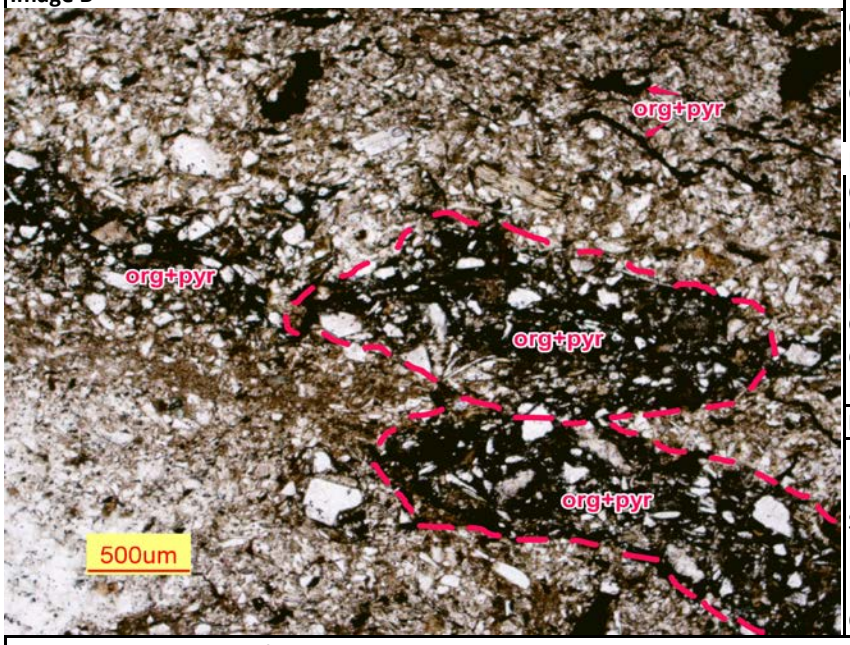
A very fine to fine grained feldspathic litharenite shows an overall massive texture slightly disturbed by burrows. Subangular to subrounded, moderate to well sorted framework consist mainly of quartz with lesser amounts of rock fragments (chert, shale clasts, VRF, etc.) and feldspars. This sample contains 19-22% clay matrix which blocked interstitial pore spaces (image A), resulting in a tight, non-porous fabric. Image B shows major diagenesis sequences: chlorite lining pores - feldspar overgrowth- feldspar filling - calcite filing - later stage organic matter (bitumen?) filling (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 44	**Depth:**	135.58m

Image A:

Image B



Composition: (visual estimate)

Grains:

Q%
F% 25-30
R%
Others: 3-5% mica, 0.5-1% glau,
Matrix: 70
Rock Type:
Silty Shale

Texture

Grain size
Sorting:
Roundness:
Fabric:

Structure

Massive, burrowed

Authigenic Components

Cements (Pore Fillings):
Chlorite
Qtz ovgh
Feldspar ovgh
Feldspar filling
Calcite
Organic matter 5-6
Pyrite 0.5-1
Replacement
Chlorite
Calcite
Pyrite 0.5

Porosity (Visual Estimate):

Intergranular:
Secondary:
Fracture:
Microporosity: common
Others:

Image A is an overview of silty shale with a massive texture locally disturber by burrows . Cleaner, coarser and quartz-rich sands are found in burrows (image A). Total about 25-30% silts are floating in the clay matrix, consist mainly of quartz , feldspar s and lesser chert, shale clasts. Pyrite appeared as black spots scattered in the sample (image A). Image B shows dark brown to black organic matter (or bitumen?) mixed with pyrite filled borrows which are porous due to bioturbating (image B). Locally organic matter occurred as thin strips paralleling to bedding plane.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 45	**Depth:**	127.50m

Image A:

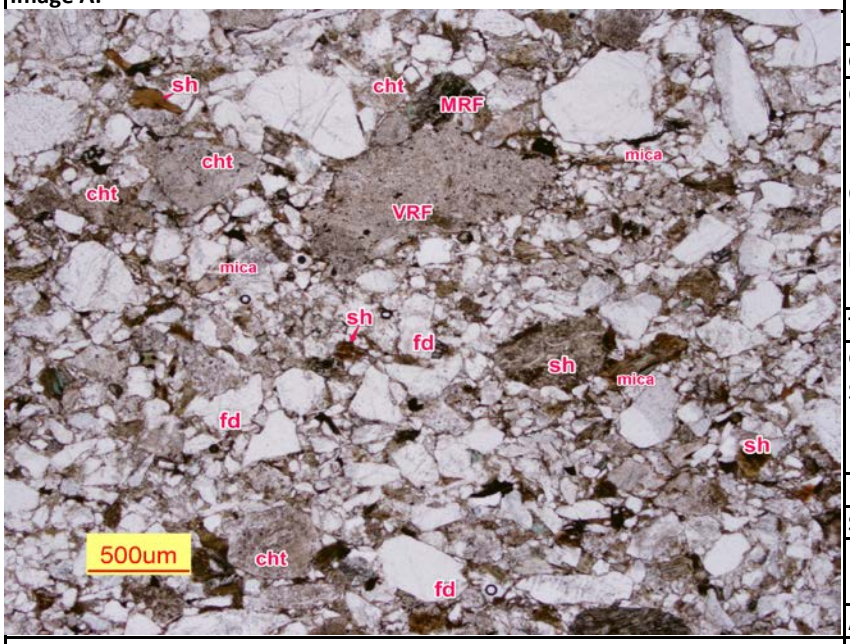
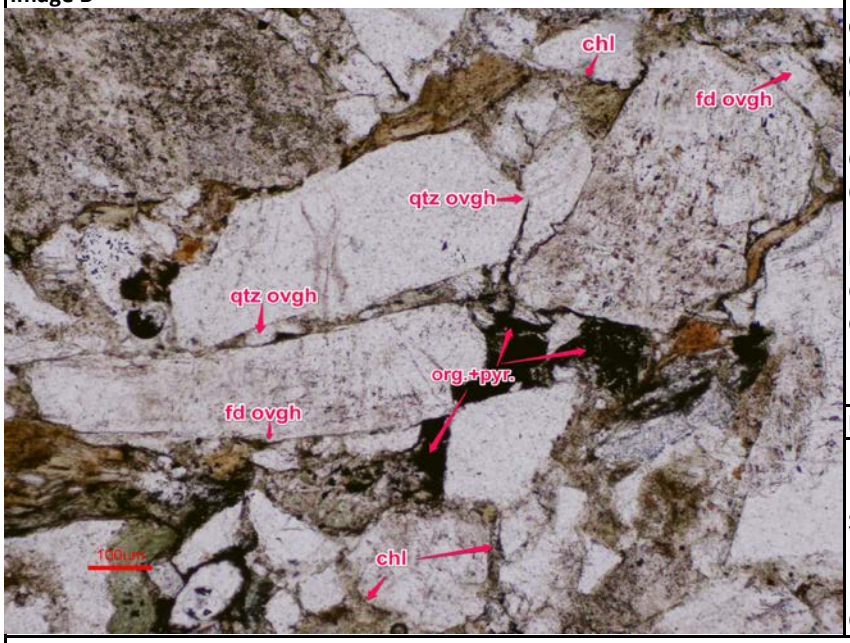


Image B



Composition: (visual estimate)

Grains:

Q%	27-28
F%	28-32
R%	35-37
Others: 2-3% mica, 1% glau,	
Matrix:	10-12

Rock Type:

Feldspathic Litharenite

Texture

Grain size	very fine to coarse
Sorting:	poorly
Roundness:	subang.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	1-2
Pyrite	0.5-1.0

Replacement

Chlorite	tr
Calcite	
Pyrite	0.5

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A massive, very fine to coarse grained feldspathic litharenite with a grain-supported, non-porous fabric (image A). The poorly sorted, subangular framework grains, size ranging from very fine (50um) to coarse sand (1200um), consist mainly of rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) with subequal amounts of quartz and feldspars (image A). The original primary pores are reduced by moderate compaction and further blocked by 10-12% clay matrix. Image B shows the early diagenetic phases: chlorite lining pores and followed by feldspar and quartz overgrowth. Later stage organic matter (bitumen?) plugged remaining pore spaces (image B). Microporosity are abundant and exist in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 46	**Depth:**	122.50m

Image A:

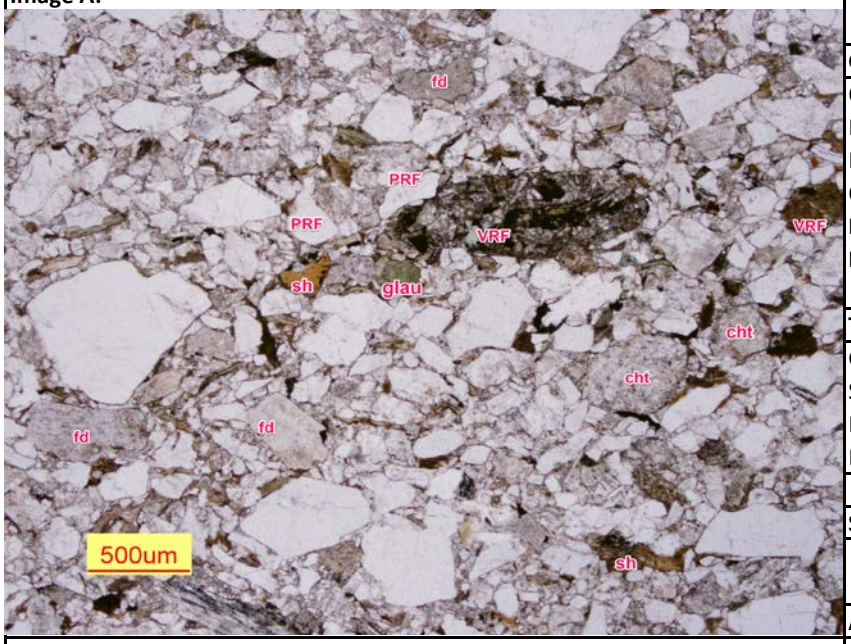
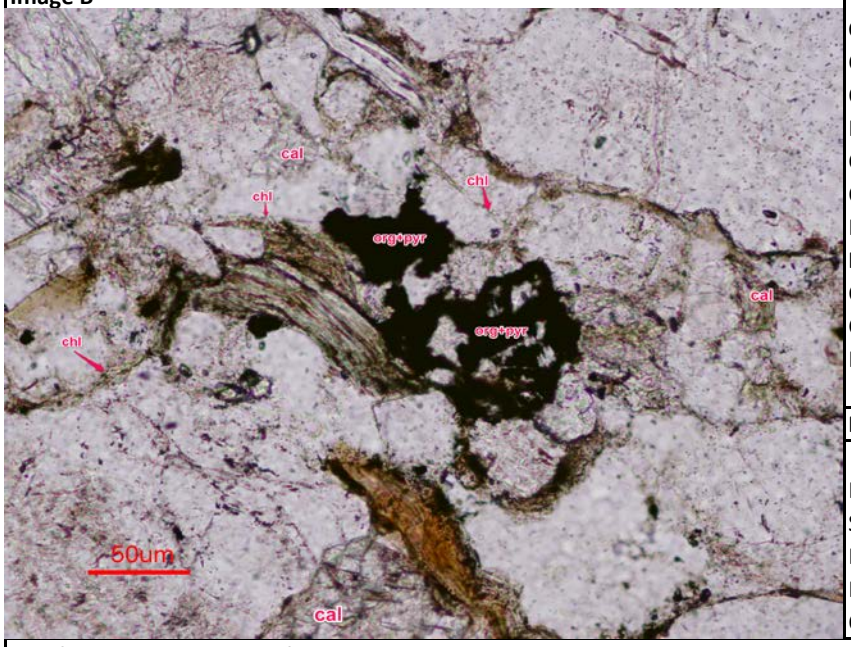


Image B



Composition: (visual estimate)

Grains:	
Q%	33-35
F%	29-30
R%	30-32
Others: 2-3% mica, 0.5-1% glau,	
Matrix:	5-7
Rock Type:	
Feldspathic Litharenite	

Texture	
Grain size	fine to coarse
Sorting:	poorly-moderaterly
Roundness:	subang.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	
Feldspar ovgh	
Calcite	10-12
Organic matter	1-2
Pyrite	0.5
Replacement	
Chlorite	tr
Calcite	
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

This fine to coarse grained feldspathic litharenite exhibits a grain-supported, calcite-cemented, non-porous fabric, consisting of subequal amounts of quartz, feldspars and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) (image A). The subangular framework grains are poorly to moderately sorted, size ranging from fine (60um) to coarse sand (1500um). Minor matrix clay (5-7%) and 10-12% calcite cement occluded the original primary pores. Image B shows intergranular pore were first lined with chlorite rims and filled by calcite cement, remaining pore spaces were further plugged by later stage organic matter (bitumen?). The centre of the image B displays the organic matter also filled secondary dissolution pores within unstable feldspar or VRF grains (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 48	**Depth:**	106.67

Image A:

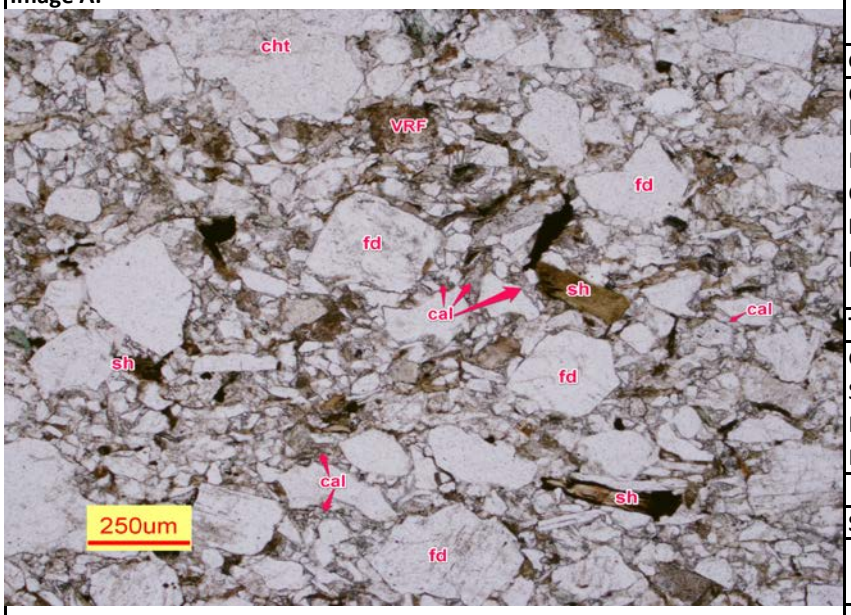
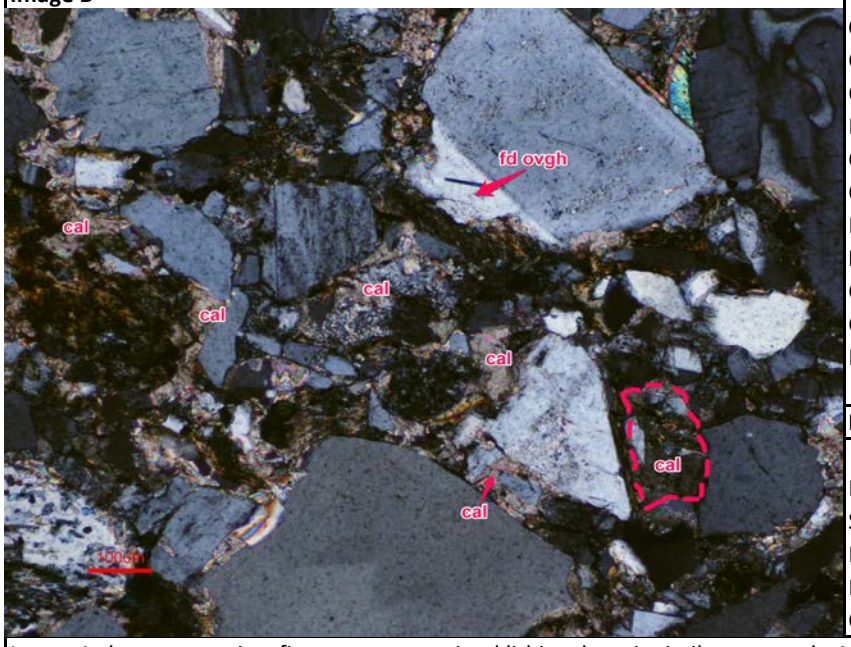


Image B



Composition: (visual estimate)

Grains:

Q%	48-50
F%	25-26
R%	20-21
Others: 2-3% mica, 0.5-1% glau,	
Matrix:	3-5

Rock Type:

Lithic Arkose

Texture

Grain size	fine to coarse
Sorting:	poorly
Roundness:	subang.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	
Feldspar ovgh	
Calcite	15-16
Organic matter	1
Pyrite	1.5
Replacement	
Chlorite	tr
Calcite	2-3
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A shows a massive, fine to coarse grained lithic arkose is similar to sample 46 in texture and fabric, but contains more quartz and lesser feldspars and rock fragments (chert, shale clasts, VRF etc.). The subangular framework grains are poorly sorted, size ranging from very fine (50um) to coarse sand (1100um). Grain-supported fabric is tight and non-porous due to extensive calcite cementation. Image B shows calcite cement (Cal) occluding intergranular pore spaces after feldspar and quartz overgrowth. Note calcite also filled secondary porosity (sp) within some unstable grains (feldspar, VRF) or moldic pores from dissolution (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 50	**Depth:**	100.67m

Image A:

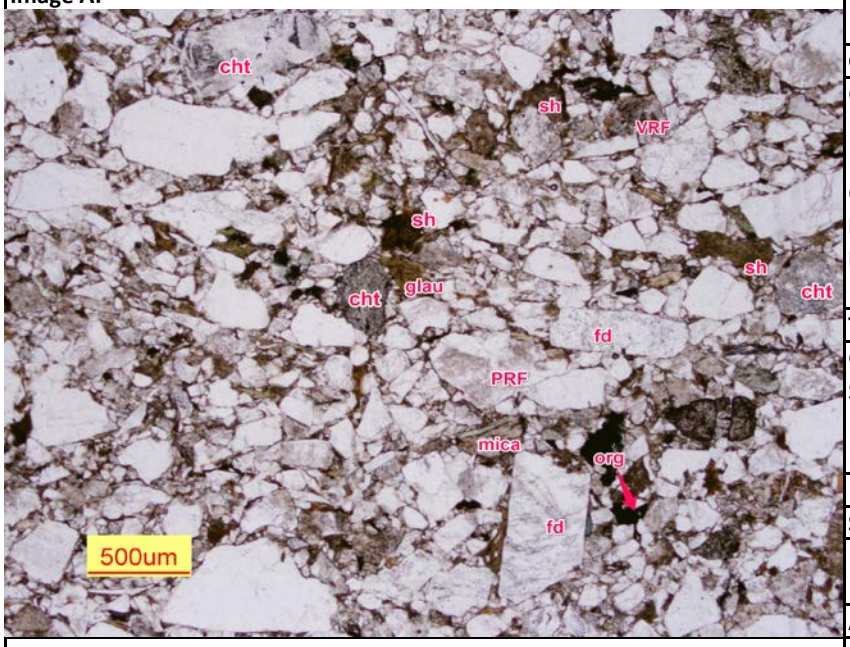
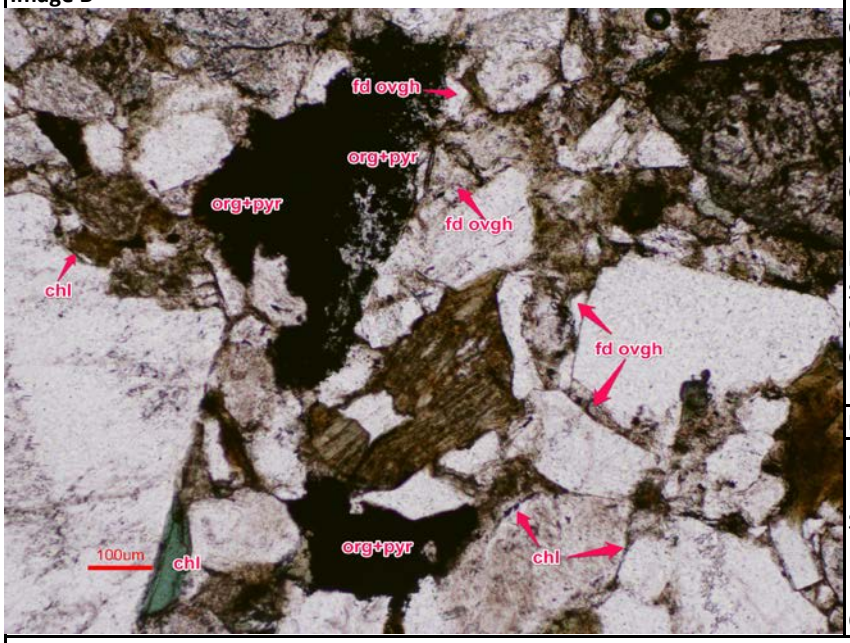


Image B



Composition: (visual estimate)

Grains:	
Q%	36-38
F%	31-32
R%	26-28
Others: 1% mica, trace: glau,	
Matrix:	18-19
Rock Type:	
Lithic Arkose	
Texture	
Grain size	fine to coarse
Sorting:	poorly
Roundness:	subang.-subroun.
Fabric:	grain supported
Structure	
Massive	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	0.5-1
Calcite	
Organic matter	0.5-1
Pyrite	0.5
Replacement	
SiO2	
Chlorite	tr
Calcite	
Pyrite	2
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A is an overview of a massive, non-porous, fine to coarse grained lithic arkose. Grain-supported fabric is poorly sorted. Grains are subangular to subrounded, size ranging from very fine (50um) to coarse sand (2000um), consist mainly of quartz, feldspar and rock fragments (chert, shale clasts, VRF, etc.) (image A). The original primary pores are reduced by moderate compaction and further blocked by 18-19% clay matrix. Image B shows major diagenesis sequences: chlorite (chl) lining pores - feldspar overgrowth (fd ovgh)- chlorite filling - later stage organic matter (bitumen?) filling (image B). Note organic matter (bitumen?) also filled the dissolution pores within a feldspar grain (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 51	**Depth:**	96.00m

Image A:

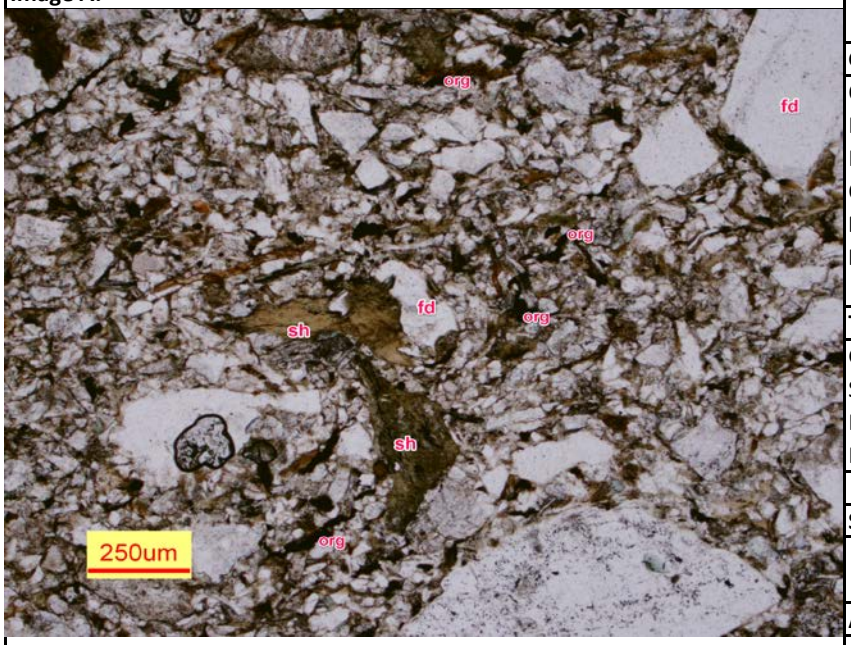
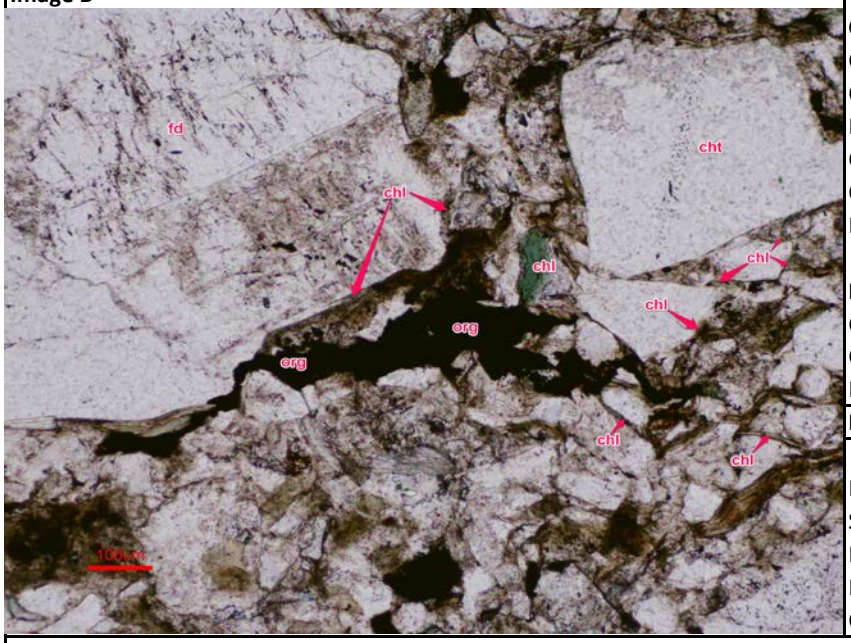


Image B



Composition: (visual estimate)

Grains:	
Q%	50-52
F%	23-25
R%	15-18
Others: 5-6% mica, trace glau,	
Matrix:	25-26
Rock Type:	
Lithic Arkose	
Texture	
Grain size	very fine-fine
Sorting:	moderately well
Roundness:	subang.-subroun.
Fabric:	grain supported
Structure	
Massive, bioturbated	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	5-6
Pyrite	1
Replacement	
Chlorite	tr
Calcite	
Pyrite	2
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A very fine to fine grained lithic arkose shows an overall massive texture combined with bioturbated structure, indicated by rotated sand grains and rip-up shale clasts (image A). Moderately well sorted framework grains are subangular to subrounded, consist mainly of quartz with lesser amounts of rock fragments (chert, shale clasts, VRF, etc.) and feldspars. The 25-26% clay matrix and 5-6% organic matter (bitumen?) had blocked interstitial pore spaces (image A), and formed a tight, non-porous fabric. Image B shows the early authigenic chlorite (chl) coating grain surfaces (image B). Abundant black organic matter (bitumen?) mixed with pyrite occurred as thin strips paralleling to bedding planes (image B). Microporosity are abundant and exist in the clay minerals.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 52	**Depth:**	89.50m

Image A:

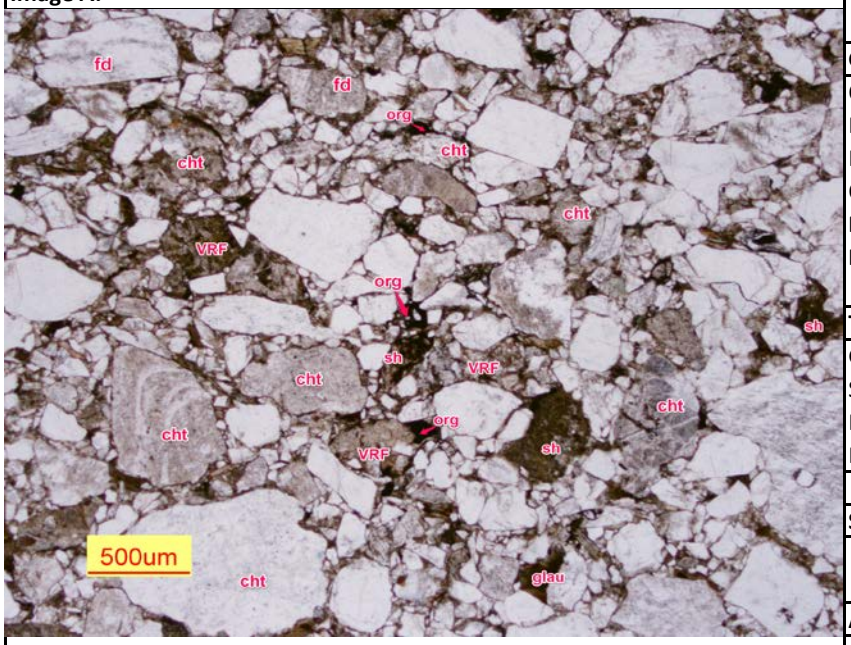
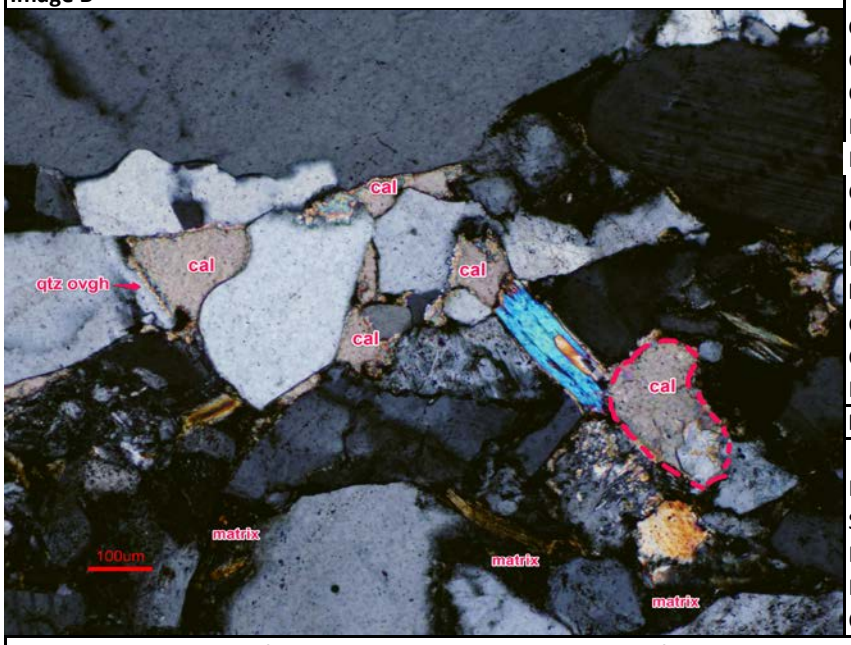


Image B



Composition: (visual estimate)

Grains:	
Q%	28-30
F%	26-27
R%	38-40
Others: 2% mica, trace glau,	
Matrix:	18-19
Rock Type:	
Feldspathic Litharenite	
Texture	
Grain size	medium-coarse
Sorting:	poorly-moderately
Roundness:	subang.-subroun.
Fabric:	grain supported
Structure	
Massive	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Feldspar filling	
Calcite	1
Organic matter	1
Pyrite	0.5
Replacement	
Chlorite	tr
Calcite	0.5
Pyrite	1-2
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A is an overview of a massive, medium to coarse grained feldspathic litharenite with a grain-supported, non-porous fabric. The poorly - moderately sorted, subangular to subrounded framework grains, size ranging from very fine (50um) to coarse sand (1600um), consist mainly of rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) with subequal amounts of quartz and feldspars. The original primary pores are reduced by moderate compaction and further blocked by 18-19% clay matrix. Image B shows calcite cement (Cal) locally occluding intergranular pore spaces after feldspar overgrowth. Note calcite also filled secondary porosity (sp) within some unstable grains (feldspar, VRF) (image B). Abundant clay matrix plugged majority pore spaces (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 53	**Depth:**	78.50m

Image A:

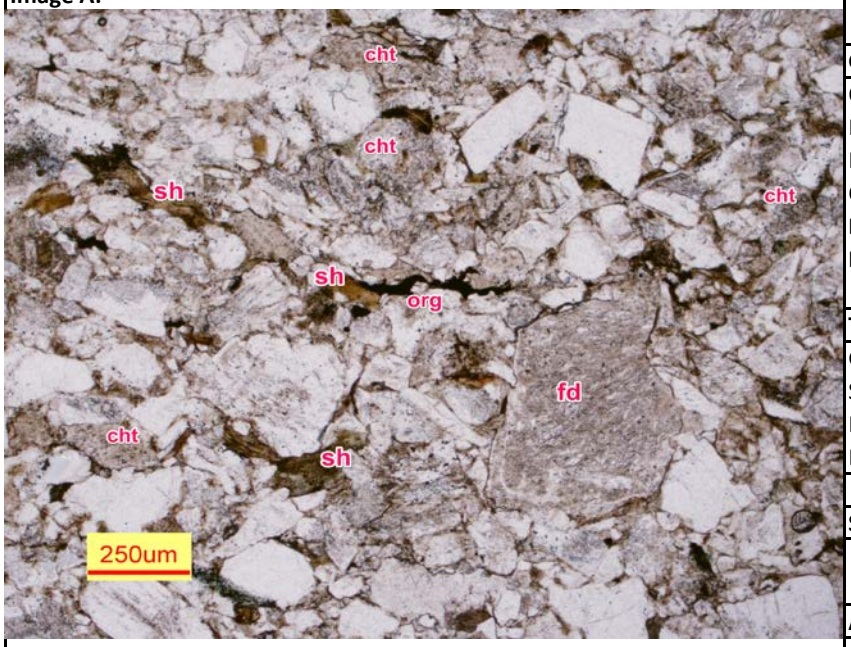


Image B

Composition: (visual estimate)

Grains:	
Q%	38-40
F%	25-26
R%	29-30
Others: 3-4% mica, 0.5-1% glau,	
Matrix:	15-17
Rock Type:	
Feldspathic Litharenite	
Texture	
Grain size	fine to medium
Sorting:	moderaterly
Roundness:	subrounded
Fabric:	grain supported
Structure	
Massive	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	0.5-1
Feldspar filling	
Calcite	1
Organic matter	0.5-1
Pyrite	1
Replacement	
Chlorite	tr
Calcite	1
Pyrite	0.5-1
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A massive, fine to medium grained feldspathic litharenite exhibits a grain-supported, tightly packed, non-porous fabric, The subrounded framework grains are moderately sorted, consisting mainly of quartz with subequal amounts of rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) and feldspars (image A). The original primary pores are reduced by moderate compaction and further blocked by 15-17% clay matrix. Image B shows calcite (Cal) locally occluded intergranular pore spaces and also filled dissolution pores within feldspar and chert grains (image B). Note feldspar overgrowth developed on the grains.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 55	**Depth:**	73.33m

Image A:

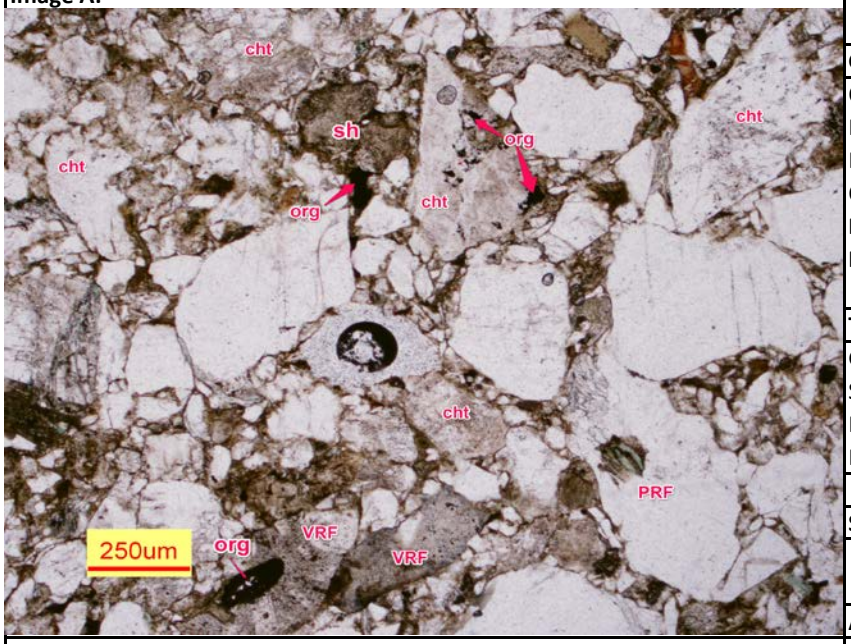


Image B

Composition: (visual estimate)

Grains:	
Q%	33-35
F%	25-26
R%	35-37
Others: 1-2% mica, 0.5-1% glau,	
Matrix:	20-22
Rock Type:	
Feldspathic Litharenite	
Texture	
Grain size	fine to coarse
Sorting:	poorly
Roundness:	subang.
Fabric:	grain supported
Structure	
Massive, bioturbated	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	
Feldspar ovgh	
Calcite	1
Organic matter	3-4
Pyrite	0.5
Replacement	
Chlorite	tr
Calcite	0.5
Pyrite	0.5
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A fine to coarse grained feldspathic litharenite shows an overall massive texture was disturbed by bioturbation (image A). The poorly sorted, subangular framework grains, consist of subequal amounts of quartz and rock fragments (chert, shale clasts, VRF, PRF, etc.) with lesser feldspars. The intergranular pores reduced by compaction and 20-22% clay matrix. Minor organic matter or (bitumen) filled dissolution pores within feldspar and VRF or remaining original pore spaces (image A), and formed a tight, non-porous fabric. Image B shows calcite (Cal) locally occluded intergranular pore spaces and also filled dissolution pores within feldspar grains (image B). Note abundant matrix clay between grains blocked primary pores.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 56	**Depth:**	68.50m

Image A:

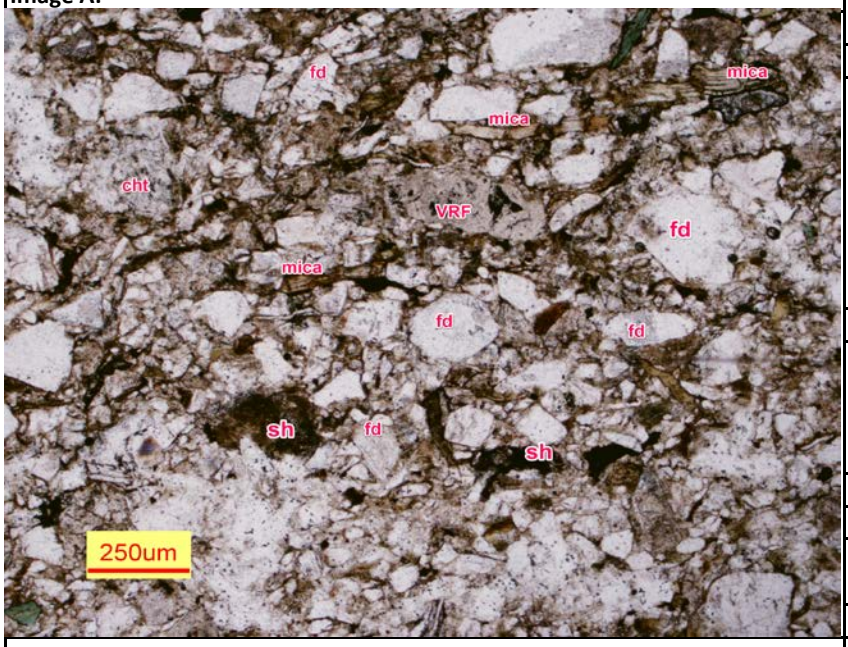
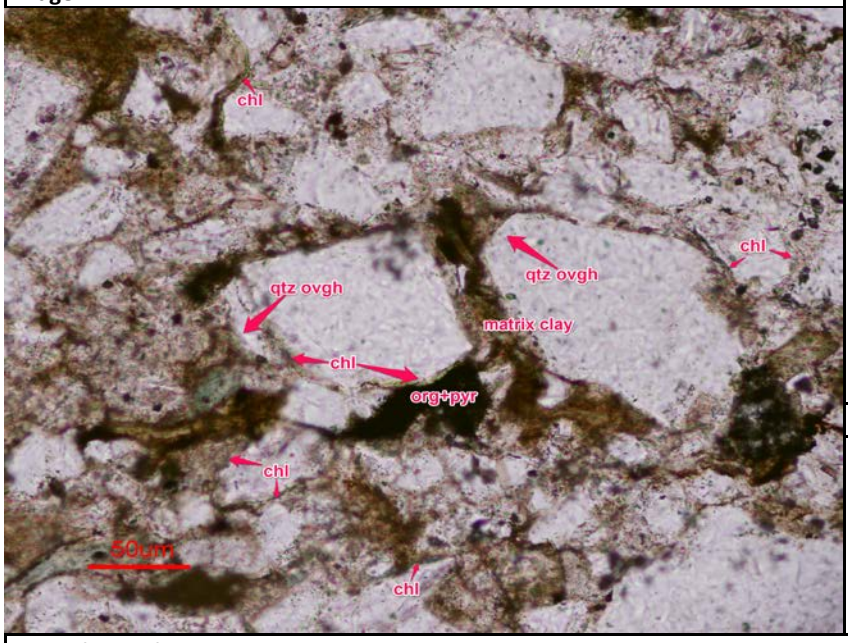


Image B



Composition: (visual estimate)

Grains:

Q%	43-45
F%	29-30
R%	21-23
Others: 1-2% mica, trace: glau,	
Matrix:	28-30

Rock Type:

Lithic Arkose

Texture

Grain size	very fine to fine
Sorting:	moderaterly
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive, laminated

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Calcite	
Organic matter	3-4
Pyrite	1

Replacement

Chlorite	tr
Calcite	
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A very fine to fine grained lithic arkose shows an overall massive texture with dark brown to black organic matter-rich laminae. The framework grains are subangular to subrounded, moderately sorted, consist mainly of quartz and feldspars with lesser rock fragments (chert, shale clasts, VRF, etc.). This sample contains 28-30% clay matrix and 3-4% organic matter (bitumen?) which blocked interstitial pore spaces (image A), indicated by tight, non-porous fabric. Image B shows the early diagenetic phases: chlorite lining pores and followed by quartz overgrowth. Later stage organic matter (bitumen?) plugged remaining pore spaces (image B). Microporosity are abundant and exist in the matrix clays.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 57	**Depth:**	62.00m

Image A:

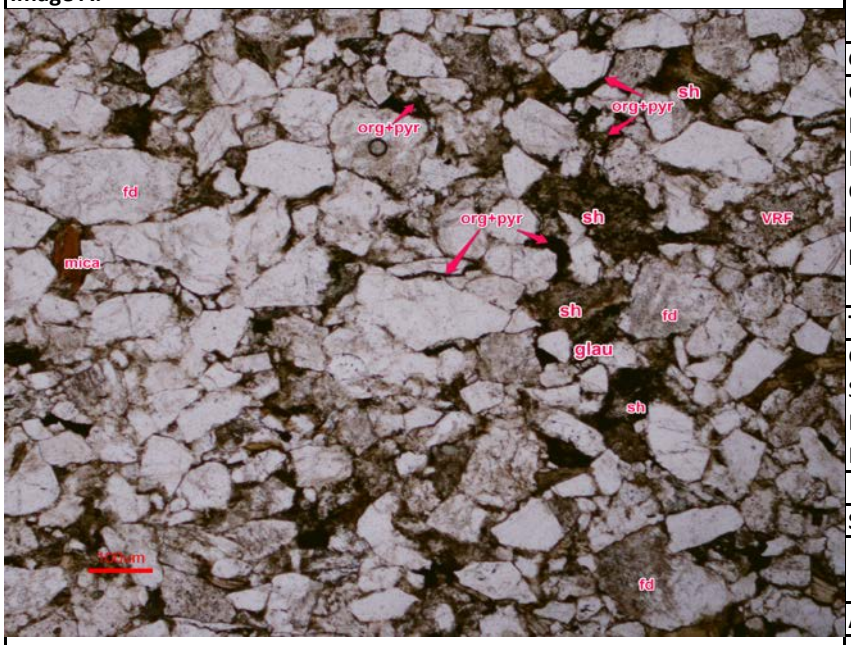
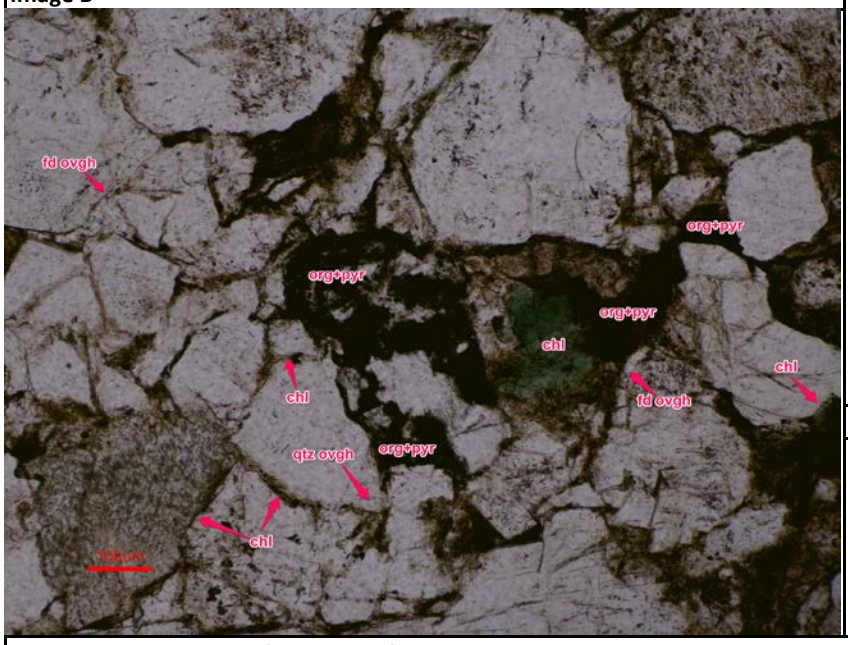


Image B



Composition: (visual estimate)

Grains:	
Q%	38-40
F%	33-35
R%	22-23
Others: 1-2% mica, trace: glau,	
Matrix:	18-20
Rock Type:	
Lithic Arkose	

Texture	
Grain size	fine to medium
Sorting:	moderately-well
Roundness:	subang. - subroun.
Fabric:	grain supported

Structure
Massive

Authigenic Components

Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	
Feldspar ovgh	
Calcite	
Organic matter	1
Pyrite	1.5-2
Replacement	
Chlorite	tr
Calcite	
Pyrite	0.5

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A is an overview of a massive, fine to medium grained lithic arkose with a grain-supported, non-porous fabric. The moderately to well sorted, subangular to subrounded framework grains consist mainly of quartz and feldspars with lesser rock fragments (chert, shale clasts, VRF, etc.). No visible porosity was observed due to moderate compaction and 18-20% clay matrix. Image B shows major diagenesis sequences: chlorite (chl) lining pores - feldspar overgrowth (fd ovgh)- chlorite filling - later stage organic matter (bitumen?) filling (image B). Note organic matter (bitumen?) also filled the dissolution pores within a feldspar grain (image B).

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 60	**Depth:**	47.75m

Image A:

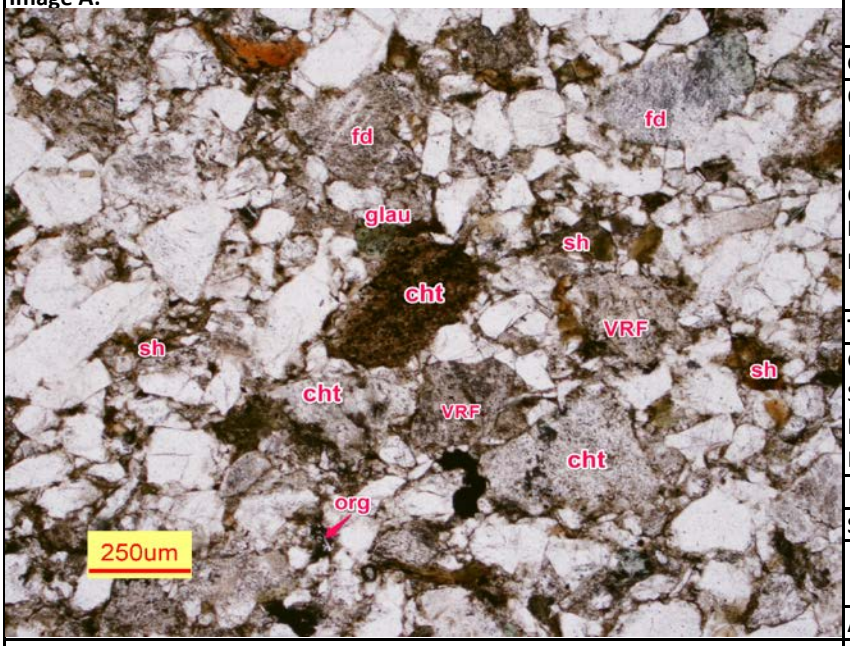
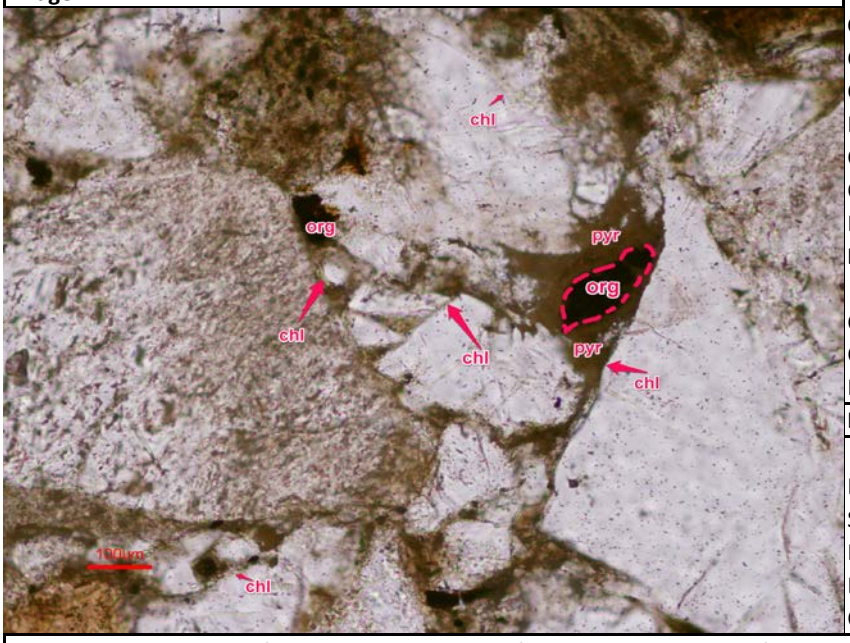


Image B



Composition: (visual estimate)

Grains:

Q%	30-32
F%	26-28
R%	33-35
Others: 2-3% mica, 0.5-1% glau,	
Matrix:	16-18
Rock Type:	

Feldspathic Litharenite

Texture

Grain size	fine to medium
Sorting:	poorly-moderately
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	2
Feldspar ovgh	0.5-1
Calcite	
Organic matter	1
Pyrite	0.5-1

Replacement

Chlorite	tr
Calcite	
Pyrite	1-1.5

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

Image A is an overview of a massive, non-porous, fine to medium grained feldspathic litharenite. Grain-supported fabric is poorly to moderately sorted. Grains are subangular to subrounded, size ranging from very fine (50um) to coarse sand (1000um), consist of subequal amounts of quartz and rock fragments (chert, shale clasts, VRF, etc.) with lesser feldspar (image A). No visible porosity was observed due to compaction and abundant interstitial matrix clay (16-18%). Image B was taken under reflective lights, it displays that pyrite (with golden shinny dots) filled intergranular porosity from pore edges and followed by later stage organic matter (black) or (bitumen) in pore center (image B). Note extensive greenish chlorite (chl) coating.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 62	**Depth:**	33m

Image A:

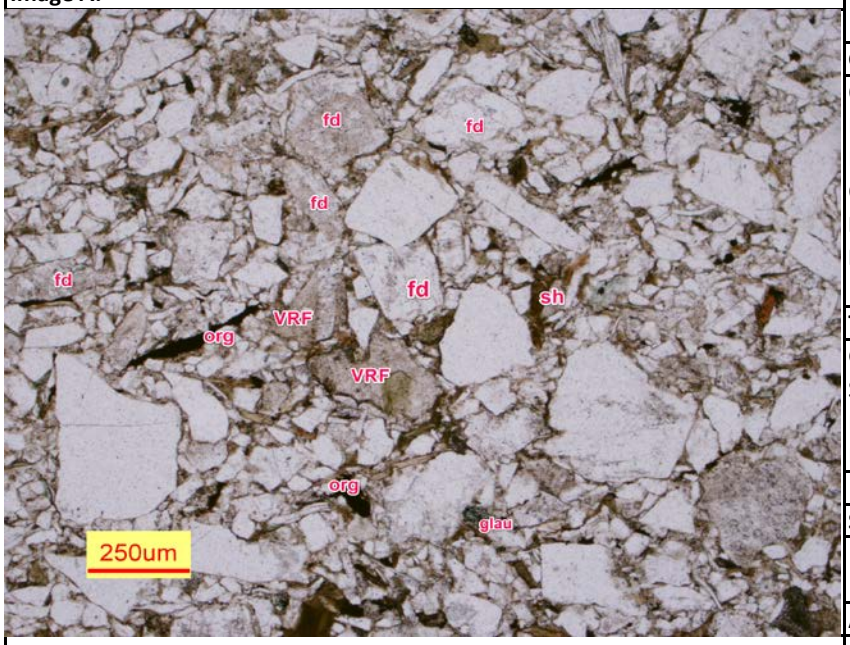
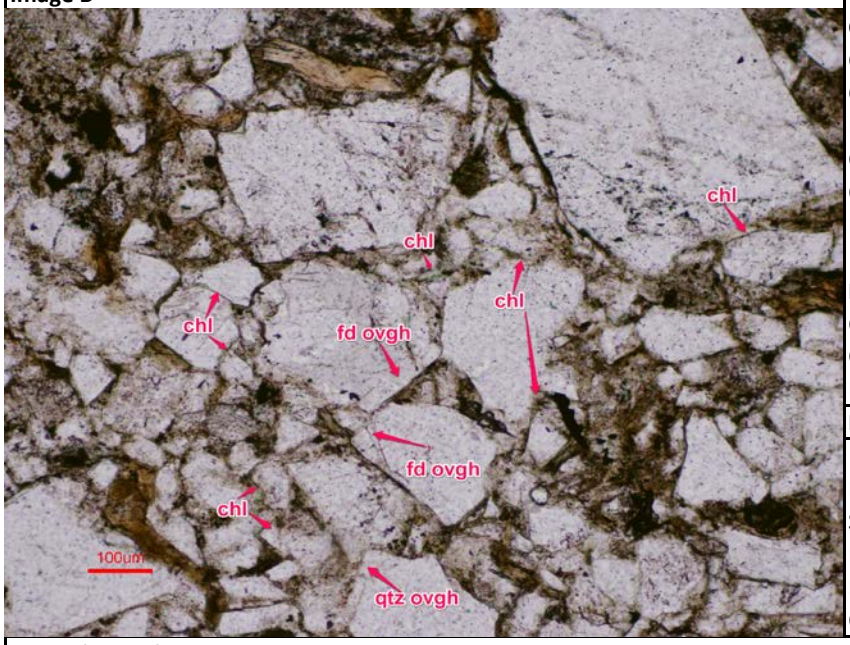


Image B



Composition: (visual estimate)

Grains:

Q%	55-56
F%	20-23
R%	13-14
Others: 5-6% mica, trace glau,	
Matrix:	15-16

Rock Type:
Subarkose

Texture

Grain size	very fine-fine
Sorting:	poorly-moderately
Roundness:	subang.-subroun.
Fabric:	grain supported

Structure

Massive, bioturbated

Authigenic Components

Cements (Pore Fillings):

Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	1
Calcite	
Organic matter	1-2
Pyrite	0.5-1

Replacement

Chlorite	tr
Calcite	
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A very fine to fine grained subarkose displays an overall massive texture locally with bioturbated structure (image A). The poorly to moderately sorted fabric is subangular to subrounded. Grain composition was characterized by 55-56% quartz with lesser feldspars and rock fragments (shale clasts, chert, VRF, etc.). The intergranular pores reduced by compaction and 15-16% clay matrix, and indicated by a tight, non-porous fabric. Image B shows that after the early chlorite (chl) coating grain(image B), feldspar and quartz overgrowth had locally developed (image B). Note considerable matrix clay plugged intergranular pores.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-Nainamo OBS well 390
Sample ID: 63	**Depth:**	30.5m

Image A:

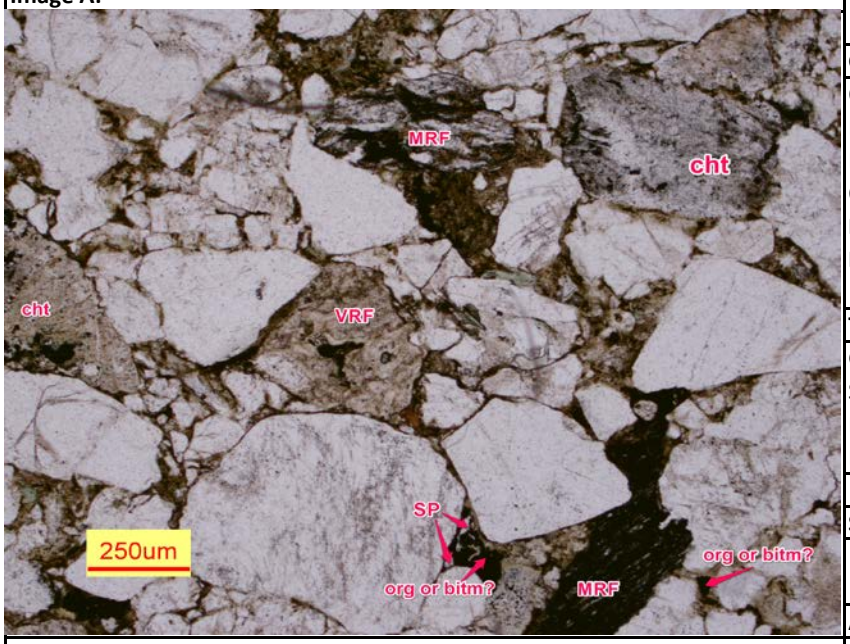
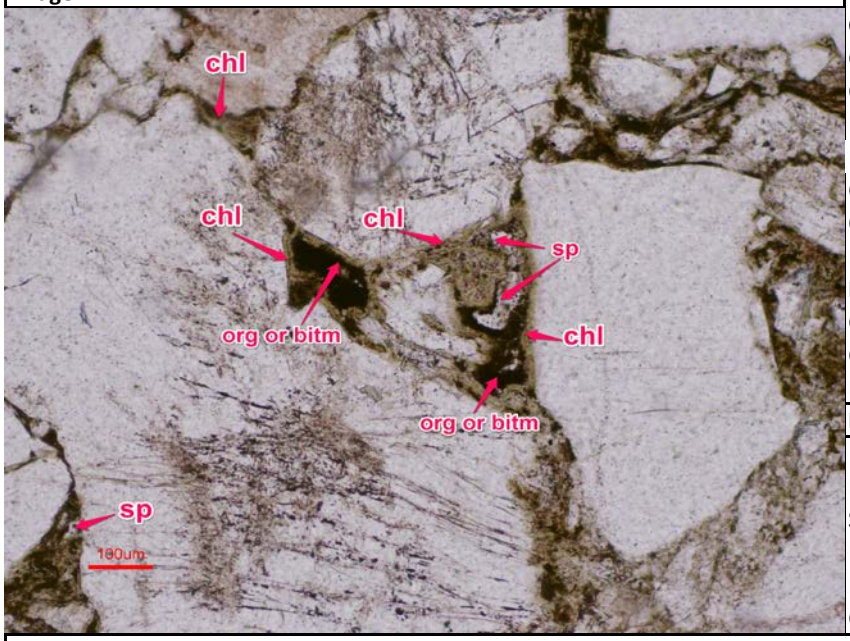


Image B



Composition: (visual estimate)

Grains:	
Q%	45-46
F%	18-20
R%	32-33
Others: 1% mica, 0.5% glau,	
Matrix:	10-12
Rock Type:	
Feldspathic Litharenite	
Texture	
Grain size	medium-coarse
Sorting:	moderately
Roundness:	subang.-subroun.
Fabric:	grain supported
Structure	
Massive	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	abundant
Qtz ovgh	tr
Feldspar ovgh	tr
Feldspar filling	
Calcite	0.5
Organic matter	1
Pyrite	2-3
Replacement	
Chlorite	minor
Calcite	0.5-1
Pyrite	1
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	2-3
Fracture:	
Microporosity:	common
Others:	

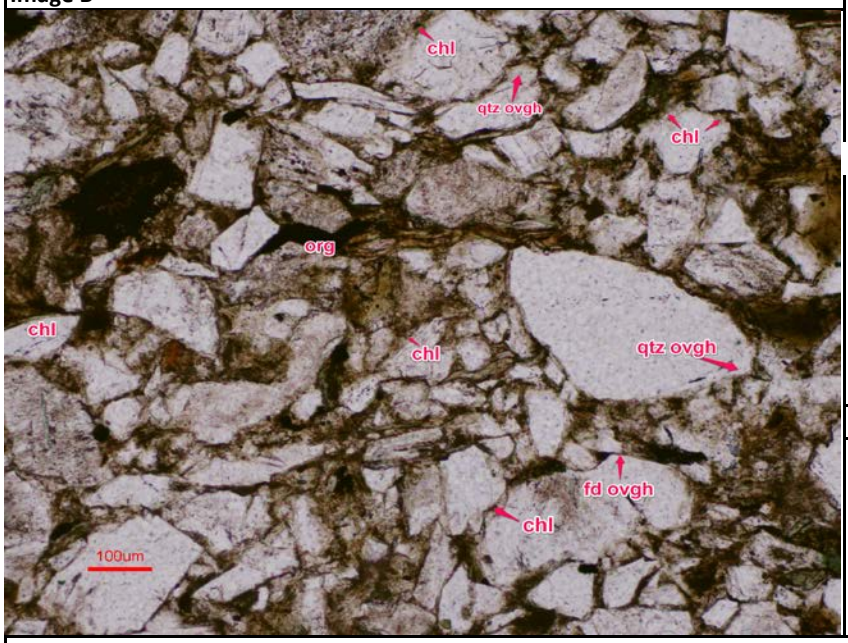
Image A is an overview of a massive, medium to coarse grained feldsparthic litharenite. Grain composition was dominated by quartz and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) with lesser feldspars. Grain-supported, moderately sorted fabric was low mature in texture with 10-12% matrix clay. The original intergranular pores are not preserved. Image B is closer view showing minor secondary inter or intragranular pores with relict of chlorite thin rims, they are formed by the leaching of unstable grains (image B). Black organic matter or bitumen (image B) filled secondary porosity or lined pore walls and left some space open.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 64	**Depth:**	26.25m

Image A:

Image B



Composition: (visual estimate)

Grains:	
Q%	48-50
F%	25-27
R%	18-20
Others: 3% mica, 1% glau,	
Matrix:	20-23
Rock Type:	
Lithic Arkose	
Texture	
Grain size	very fine to fine
Sorting:	well
Roundness:	subangu.- subroun.
Fabric:	grain supported
Structure	
Massive, Laminated	
Authigenic Components	
Cements (Pore Fillings):	
Chlorite	common
Qtz ovgh	tr
Feldspar ovgh	tr
Feldspar filling	
Calcite	
Organic matter	1-2
Pyrite	1
Replacement	
Chlorite	tr
Calcite	
Pyrite	1
Porosity (Visual Estimate):	
Intergranular:	
Secondary:	
Fracture:	
Microporosity:	common
Others:	

A massive, very fine to fine grained lithic arkose exhibits a grain-supported, tightly packed, non-porous fabric. The well sorted framework grains are subangular to subrounded, consisting mainly of quartz with subequal amounts of feldspars and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.) (image A). The original primary pores are reduced by moderate compaction and further blocked by 20-23% clay matrix. Image B shows some early diagenetic phases: chlorite grain coating, quartz and feldspar overgrowths (image B) (image B). Note black organic matter mixed with pyrite between grains.

Description of Thin Section Photomicrograph

Geological Survey of Canada	**Well ID:**	OW-11-01-NANAIMO OBS WELL 390
Sample ID: 66	**Depth:**	19.42m

Image A:

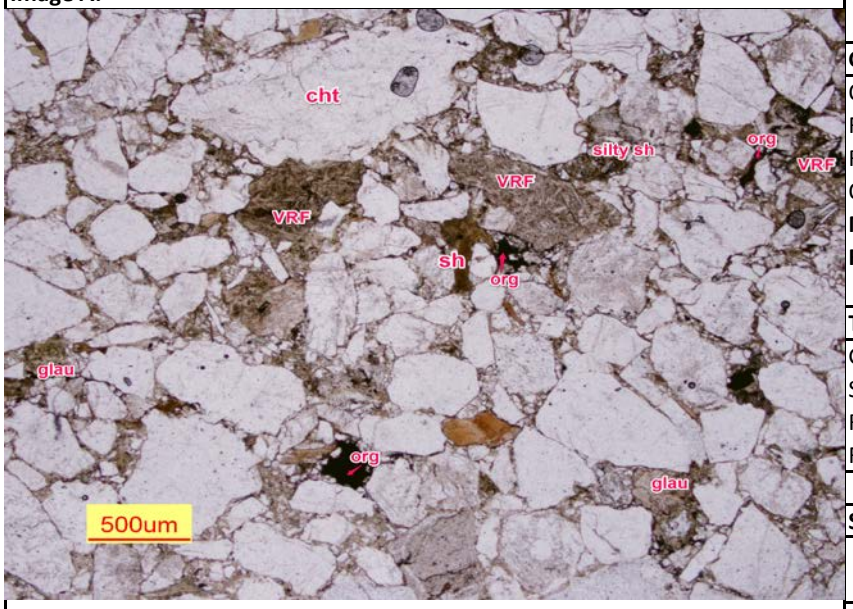
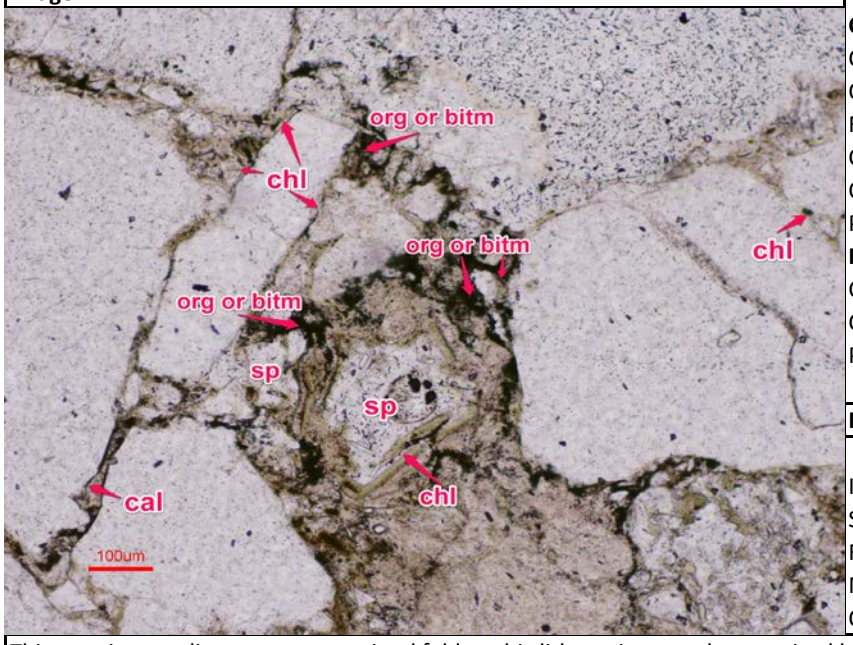


Image B



Composition: (visual estimate)

Grains:

Q%	45-47
F%	22-23
R%	26-28
Others: 1% mica, 0.5-1% glau,	
Matrix:	11-13
Rock Type:	

Feldspathic Litharenite

Texture

Grain size	medium to coarse
Sorting:	Moderately - well
Roundness:	subrounded.
Fabric:	grain supported

Structure

Massive

Authigenic Components

Cements (Pore Fillings):

Chlorite	abundant
Qtz ovgh	0.5
Feldspar ovgh	tr
Calcite	
Organic matter	1
Pyrite	2
Replacement	
Chlorite	minor
Calcite	
Pyrite	1

Porosity (Visual Estimate):

Intergranular:	
Secondary:	1-1.5
Fracture:	
Microporosity:	common
Others:	

This massive, medium to coarse grained feldspathic litharenite was characterized by a significant amounts of feldspar and rock fragments (chert, shale clasts, VRF, PRF, MRF etc.). Grain-supported, moderately to well sorted fabric was low mature in texture with 11-13% matrix clay. The original intergranular pores are not preserved due to moderate compaction and considerable matrix clay. Image B is closer view showing secondary intragranular pores within grains or secondary intergranular pores between grains were the dissolution products of unstable grains (image B), they were partially occluded or completely filled by minor calcite and black organic matter or bitumen (image B). Note the greenish chlorite thin films cast grain shapes (image B).