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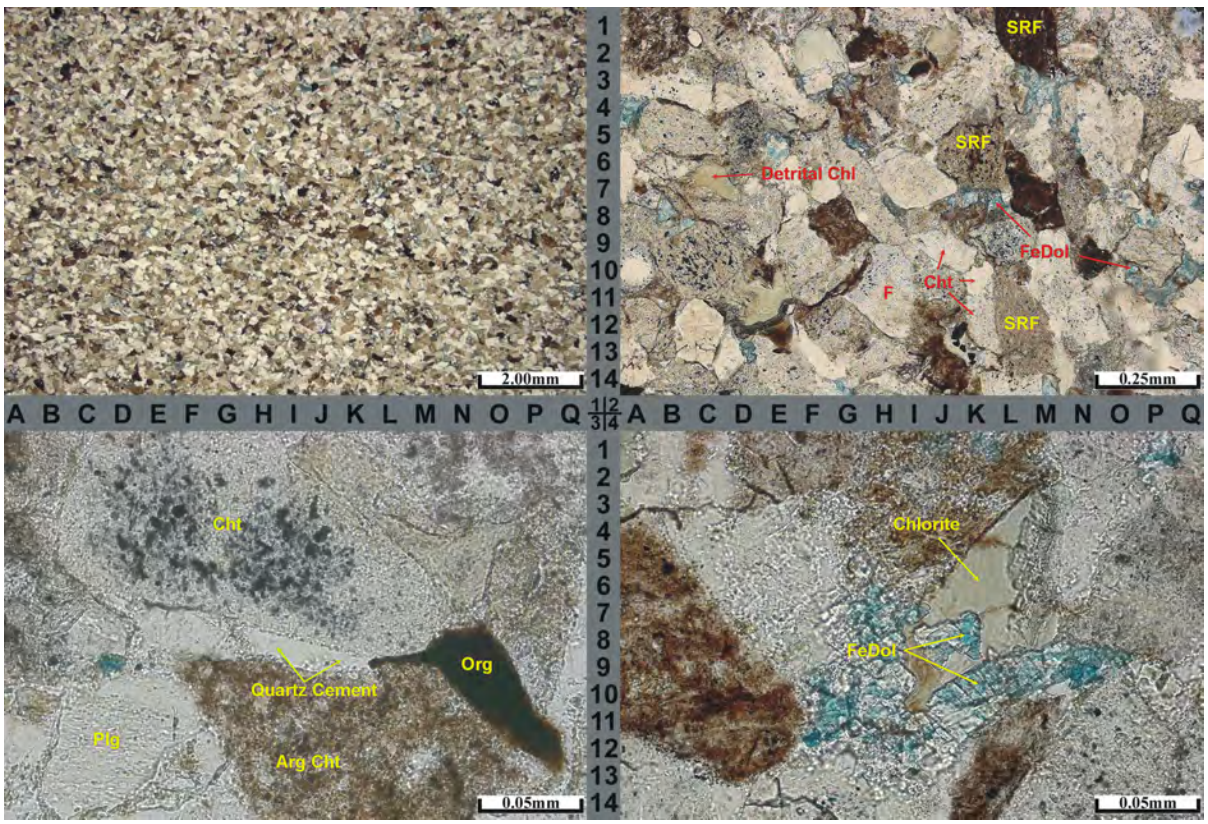
Reservoir Quality Assessment of Samples from the Skeena and Bowser Lake Groups, Northern British Columbia



Petroleum Geology Paper 2006-1

By: Iftikhar Abid
and Filippo Ferri

BRITISH COLUMBIA

Ministry of Energy, Mines and Petroleum Resources
Resource Development and Geoscience Branch

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COVER PHOTO: *Photomicrograph of Sample SP013; litharenite from the Bowser Lake Group, Skelhorne Assemblage.*

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By Iftikhar Abid[1]

Twenty-two outcrop samples, representing the Skeena (3 samples) and the Bowser Lake (19 samples) groups of Upper Jurassic to Lower Cretaceous age were examined. Samples from the Bowser Lake Group are further divided into Jenkins Creek (1 sample), Groundhog-Gunanoot (1 sample), Muskaboo Creek (7 samples), Skelhorne (1 sample) and Todagin (1 sample) assemblages. Eight samples from the Bowser Lake Group were not subdivided.

Samples from the Skeena Group are classified as upper medium-grained chert rich litharenite (SP006 and SP020) and lower coarse-grained volcanic rock fragment rich feldspathic litharenite (SP011). Diagenetic minerals include pyrite, chlorite, calcite, and kaolinite. Kaolinite is absent from SP011. Significant dissolution occurred prior to kaolinite precipitation. Visible pores are either absent or present in minor amounts. Sandstones from the Skeena Group show poor to very poor reservoir quality.

One grain-supported conglomerate from the Jenkins Creek (SP008) is classified as chert rich litharenite. Diagenetic minerals include pyrite, quartz, rare bitumen and hematite/limonite. Trace amount of intragranular pores are present. Higher permeability value (5.02 mD) is due to microfractures present in the analyzed plug. The reservoir quality of the Jenkins Creek conglomerate is considered poor.

Lower medium-grained Groundhog-Gunanoot sandstone is classified as chert rich litharenite (SP010). Diagenetic minerals include siderite (?), quartz, limonite/hematite and ferroan dolomite. Oxidation of siderite and other iron minerals has created yellow spots and some pores deep into the outcrop sample. These pores are poorly interconnected and the reservoir quality is considered poor.

Based on mineral composition, seven samples from the Muskaboo Creek Assemblage are divided into two groups: chert rich samples (SP012, SP015, SP018) and volcanic rock fragment rich samples (SP001, SP009, SP021, SP022). It is important to note that chert rich sandstones are located in the northern half of the study area and the volcanic rock fragment rich sandstones in the southern half.

Medium-grained chert rich sandstones of the Muskaboo Creek are classified as litharenite (SP012, SP015, SP018). Diagenetic minerals include pyrite, chlorite, fibrous illite, quartz and calcite. Near surface weathering has created some porosity that is absent deep inside the outcrop samples (e.g. SP012). Thin section porosity is rare and the reservoir quality is very poor.

Medium to coarse-grained volcanic rock fragment rich sandstones of the Muskaboo Creek are classified as feldspathic litharenite or lithic arkose (SP001, SP009, SP021, SP022). Olivine and pyroxene are present in these sandstones. Diagenetic minerals include chlorite, fibrous illite, anhydrite, laumontite and calcite. Thin section porosity is rare and the reservoir quality is poor to very poor.

The diagenetic history of chert rich and volcanic rock fragments rich sandstones of the Muskaboo Creek Assemblage show some differences. Pore filling quartz cement is absent from sandstones that are rich in volcanic rock fragments. Authigenic laumontite is absent from chert rich samples. Furthermore, chlorite cement is more common in sandstones that contain higher percentage of volcanic rock fragments.

Fine-grained Skelhorne sandstone is classified as chert rich litharenite (SP013). Diagenetic minerals include pyrite, chlorite, quartz and ferroan dolomite. Pores are absent and the reservoir quality is very poor.

Fine-grained Todagin sandstone is classified as chert rich litharenite (SP014). Diagenetic minerals include, pyrite, chlorite, illite, quartz and ferroan calcite. Pores are rare and the reservoir quality is very poor.

Based on mineral composition, eight undifferentiated samples from the Bowser Lake Group are also divided into two groups: chert rich samples (SP007, SP016, SP017, SP019) and volcanic rock fragment rich samples (SP002, SP003, SP004, SP005). Chert rich sandstones are located in the northern half of the study area and the volcanic rock fragment rich sandstones in the southern half. Their mineral composition and diagenesis is generally comparable to Muskaboo Creek samples as mentioned above. Weathering related dissolution pores (SP016) and hematite/limonite (SP019) are locally present. The reservoir quality for these samples is poor to very poor except in SP016 (poor to moderate).

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The important conclusion of this study is that the source of these sediments is different in the northern and southern half of the study area. Most sandstones in the southern part of the study area are rich in volcanic rock fragments and they often contain small amounts of olivine and pyroxene, suggesting the presence of basalt and andesite rocks in the source area. Sandstones in the north are rich in chert where mafic minerals are absent.

Overall, these sandstones show poor to very poor reservoir quality. Thin section porosity is either absent or rare. Only two samples show more than 1% thin section porosity and these pores appear to be weathering related (SP016). Advanced degree of compaction and cementation has destroyed most of the porosity in these samples. Production of hydrocarbons from similar rocks would be difficult, unless these stratigraphic units contain good subsurface fractures. Alternately, it is also possible that under subsurface environments calcite and some framework grains are dissolved and subsequently not extensively cemented.

FOREWORD

Reservoir Quality Assessment of Samples from the Skeena and Bowser Lake Groups, Northern British Columbia

By Filippo Ferri[1]

INTRODUCTION

The Resource Development and Geoscience Branch (RDGB) of the BC Ministry of Energy, Mines and Petroleum Resources is mandated to identify, quantify and promote the hydrocarbon potential of onshore regions of British Columbia. In onshore regions outside of the WCSB, oil and gas potential occurs primarily within Mesozoic and Cenozoic clastic sediments of the Interior Basins. The main areas include, from north to south: the Whitehorse Trough, the Bowser and Sustut basins and the Nechako area (Figure 1). Although the Bowser and Nechako Basins have seen limited subsurface exploration, these regions remain 'frontier basins' based on infrastructure challenges and lack of extensive geological information.

In accordance with the goals of the Interior Basins Strategy (Hayes *et al*., 2004), the RDGB has initiated or supported several projects within these areas leading to the capture of new energy-related geoscience information. The RDGB is a partner, with the Canadian government, in the Bowser-Sustut Basin Project, a 4 year (2003-2007) program which will better define the geology and energy resources of the Bowser and Sustut basins, and provide improved data to refine hydrocarbon resource potential models. During the first two years of the Bowser-Sustut basin project, regional mapping studies within western McConnell Creek (94D), Bowser Lake (104A) and west Hazelton (93M) mapsheets were completed (Evenchick *et al*., 2004, 2005; Ferri *et al*., 2005). Regional-scale mapping was carried out within the western Hazelton map area during the summer of 2004, with the major objectives of delineating the extent of the Skeena Group and identifying its relationship to underlying rocks of the Bowser Lake Group (Ferri *et al*., 2005). Detailed objectives of the project included sampling Skeena and Bowser Lake groups for reservoir characterization. During the 2004 field season, rocks were sampled for this purpose. Twenty-two samples of sandstone and conglomerate from the Bowser Lake and Skeena groups were collected from the Hazelton and Bowser Lake map areas. This report details the results of these analyses.

Core plugs were obtained at the outcrop or drilled in the laboratory from large samples collected in the field. Analyses were conducted by AGAT Laboratories in Calgary, Alberta, and include basic porosity and permeability measurements together with a description of clast lithotypes and characterization of interclast mineralogy based on thin section examination. Results are summarized in Table 1, and detailed in the body of the report.

Although the samples obtained for this study are not geographically exhaustive and are by no means a thorough representation of all possible lithotypes, the resultant porosity and permeability failed to demonstrate that suitable reservoir quality is present in these samples of Bowser Lake and Skeena rocks. A more detailed regional sampling and analysis program would provide a more definitive characterization of the Bowser Basin. The main findings of the analyses by AGAT Laboratories are: 1) Overall, the sandstones analysed show poor to very poor reservoir quality. Thin section porosity is either absent or rare. Production of hydrocarbons from similar rocks would be difficult, unless these stratigraphic units contain good subsurface fractures. 2) Samples from the northern part of the study area differ significantly in clast content from those from the southern part, reflecting different sediment sources. Most sandstones in the southern part of the study area are rich in volcanic rock fragments and they commonly contain small amounts of olivine and pyroxene, indicating the presence of basaltic to andesitic rocks in the source area. Sandstones from the north are rich in chert, while mafic minerals are absent.

GEOLOGICAL FRAMEWORK

The Bowser and Sustut basins are located in north-central British Columbia, within the northern part of the Intermontane Belt. These basins represent overlap assemblages deposited subsequent to amalgamation of Stikine, Cache Creek and Quesnel terranes onto ancestral North America (Figures 1 and 2). They primarily overlie Devonian to Jurassic rocks of Stikinia. Development of the Bowser Basin most likely began with thrust loading of Cache Creek Terrane rocks onto Stikinia in Early to Middle Jurassic times (Ricketts *et al*., 1992). The Bowser Basin contains two main successions: the Middle Jurassic to mid-Cretaceous Bowser Lake Group and the Lower to mid-Cretaceous Skeena Group. The Sustut Basin is

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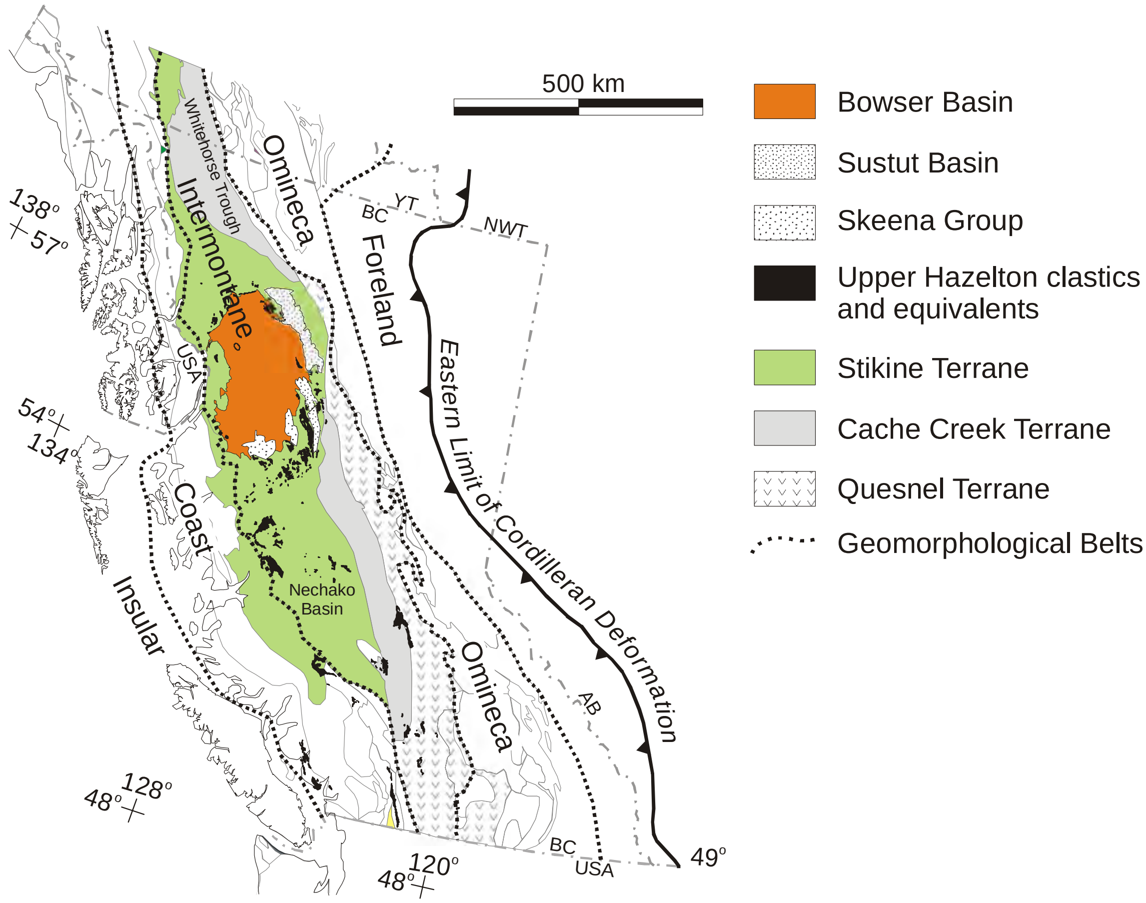

Figure 1. Location of the Bowser and Sustut basins within the geological framework of the Canadian Cordillera (modified from Evenchick *et al.*, 2004).

represented by the mid- to Upper Cretaceous Sustut Group. Stratigraphic relationships in the northern and southern parts of the study area are summarized in Figure 3, and relevant units are described below. More detailed descriptions of the stratigraphy and tectonic history are available in Ferri *et al.*, 2005, and references therein. The following descriptions of the Ritchie-Alger, Muskaboo, Todagin, Eaglenest, Skelhorne, Groundhog-Gunanoot and Jenkins Creek assemblages are taken from Evenchick and Thorkelson (2005) (direct excerpts are in quotes).

BOWSER LAKE GROUP

Ritchie-Alger Assemblage (middle to upper Jurassic)

The Ritchie-Alger assemblage is exposed along the western edge of the Bowser Basin, and on either side of the Skeena River in the central part of the basin. The assemblage represents a submarine fan facies, and is at least 1800 metres thick.

"It is characterized by two lithofacies; one dominantly silty, and one dominantly sandy, each forming units 3-40 metres thick. The two varieties alternate vertically to five a distinctive pattern of light-coloured cliffs (sandstone lithofacies), separated by dark-weathering, more recessive areas (fine-grained lithofacies)." "Fossils in the fine-grained intervals include uncommon belemnites, pelecypods, and ammonites…"

Muskaboo Creek Assemblage (middle to upper Jurassic)

The Muskaboo Creek marine shelf assemblage occurs in the central Bowser basin. It is:

"…a succession 300 to more than 1500 metres thick which is dominated by sheets of planar bedded, medium-grained sandstone, interbedded with lesser, fine-grained sandstone, siltstone, and conglomerate. The sandstone lithofacies is well bedded, thin- to thick-bedded, locally has calcareous matrix, and includes bivalve coquinas and ammonites."

Todagin Assemblage (middle Jurassic to lower Cretaceous)

The Todagin assemblage is in part equivalent to the Ashman Formation of Tipper and Richards (1976). It represents a slope lithofacies, and underlies large parts of the northern Bowser Basin. Rocks are

TABLE 1. SUMMARY OF AGAT LABORATORIES ANALYSES.

Field Number	AGAT Lab #	Map Sheet	Easting [1]	Northing[1]	Unit	Lithofacies Assemblage	Rock Type	Grain Size	Porosity	Bulk Density	Grain Density	Permeability (mD)
EPF-04-13B	SP001	093M13	571414	6199356	Bowser/Skeena	undivided	lithic arenite	medium-coarse	0.01	2694	2713	0.00
EPF-04-57-C	SP002	093M12	568008	6165181	Bowser Lk Gp	Muskaboo Ck	arkosic arenite	fine-medium	0.03	2625	2718	0.05
EPF-04-61A	SP003	093M12	569345	6166446	Bowser Lk Gp	Muskaboo Ck	arkosic arenite	medium-coarse	0.04	2544	2655	0.34
EPF-04-65B	SP004	093M12	574865	6167562	Bowser Lk Gp	Muskaboo Ck	arkosic arenite	medium-coarse	0.03	2571	2657	0.08
EPF-04-69C	SP005	093M12	579279	6169445	Bowser Lk Gp	Muskaboo Ck	arkosic arenite	fine-medium	0.01	2691	2727	0.01
EPF-04-95C	SP006	093M05	577389	6125433	Skeena Gp	undivided	lithic arenite	fine-medium	0.02	2620	2666	0.01
EPF-04-162A	SP007	104A14	484578	6292306	Bowser Lk Gp	undivided	lithic arenite	fine-medium	0.01	2653	2689	0.00
EPF-04-182A	SP008	104A15	505718	6295800	Bowser Lk Gp	Jenkins Ck	conglomerate	pebble	0.04	2543	2642	5.02*
EPF-04-221A	SP009	104A07	521294	6254760	Bowser Lk Gp	Muskaboo Ck	arkosic arenite	fine-medium	0.01	2673	2691	0.00
EPF-04-319A	SP010	104A15	506972	6298347	Bowser Lk Gp	Groundhog-Gunanoot	lithic arenite	fine-medium	0.02	2608	2660	0.00
EPF-04-359A	SP011	093M05	588218	6140466	Skeena Gp	undivided	lithic arenite	medium-coarse	0.01	2664	2690	0.00
EP-04-49A	SP012	104A11	482385	6283027	Bowser Lk Gp	Muskaboo Ck	lithic arenite	fine-medium	0.02	2602	2661	0.00
EP-04-90H	SP013	104H05	463936	6354585	Bowser Lk Gp	Skelhorne	lithic arenite	fine-medium	0.01	2638	2661	0.00
EP-04-91D	SP014	104H12	441927	6385725	Bowser Lk Gp	Todagin	lithic arenite	fine-medium	0.01	2670	2685	0.01
EP-04-92D	SP015	104H12	442732	6380523	Bowser Lk Gp	Muskaboo Ck	lithic arenite	fine-medium	0.01	2636	2658	0.00
EP-04-94D	SP016	104H04	459229	6322370	Bowser Lk Gp	Todagin/Ritchie-Alger	lithic arenite	fine	0.01	2650	2674	0.00
EP-04-101A	SP017	104A14	480712	6298521	Bowser Lk Gp	Groundhog-Gunanoot	lithic arenite	fine-medium	0.01	2644	2662	0.00
EP-04-104A	SP018	104A11	477128	6278145	Bowser Lk Gp	Muskaboo Ck	lithic arenite		0.02	2624	2668	0.00
EPM-04-201A	SP019	104A14	473190	6307941	Bowser Lk Gp	Groundhog-Gunanoot	lithic arenite	medium-coarse	0.01	2638	2660	0.00
EPR-04-101A	SP020	093M05	580532	6144855	Bowser/Skeena	undivided	lithic arenite	medium	0.04	2578	2673	0.02
EPS-04-MS1-04	SP021	093M13	568600	6193814	Bowser Lk Gp	Muskaboo Ck	lithic arenite		0.04	2596	2706	0.18
EPS-04-MS2-09	SP022	093M12	576550	6164247	Bowser Lk Gp	Muskaboo Ck	lithic arenite		0.05	2490	2620	0.09

mD: millidarcies
*fractured
[1]NAD27

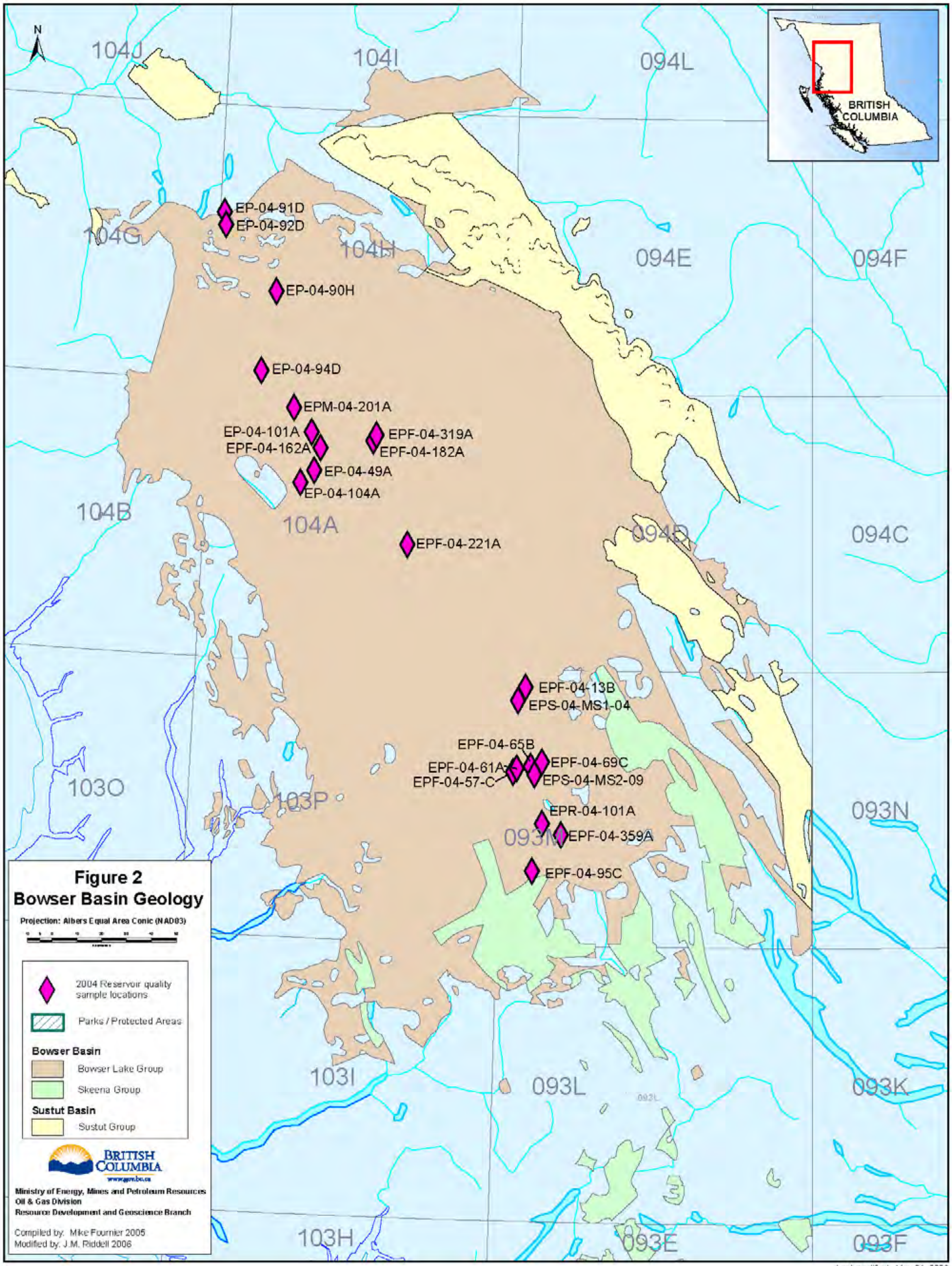

Figure 2. Bowser Basin geology.

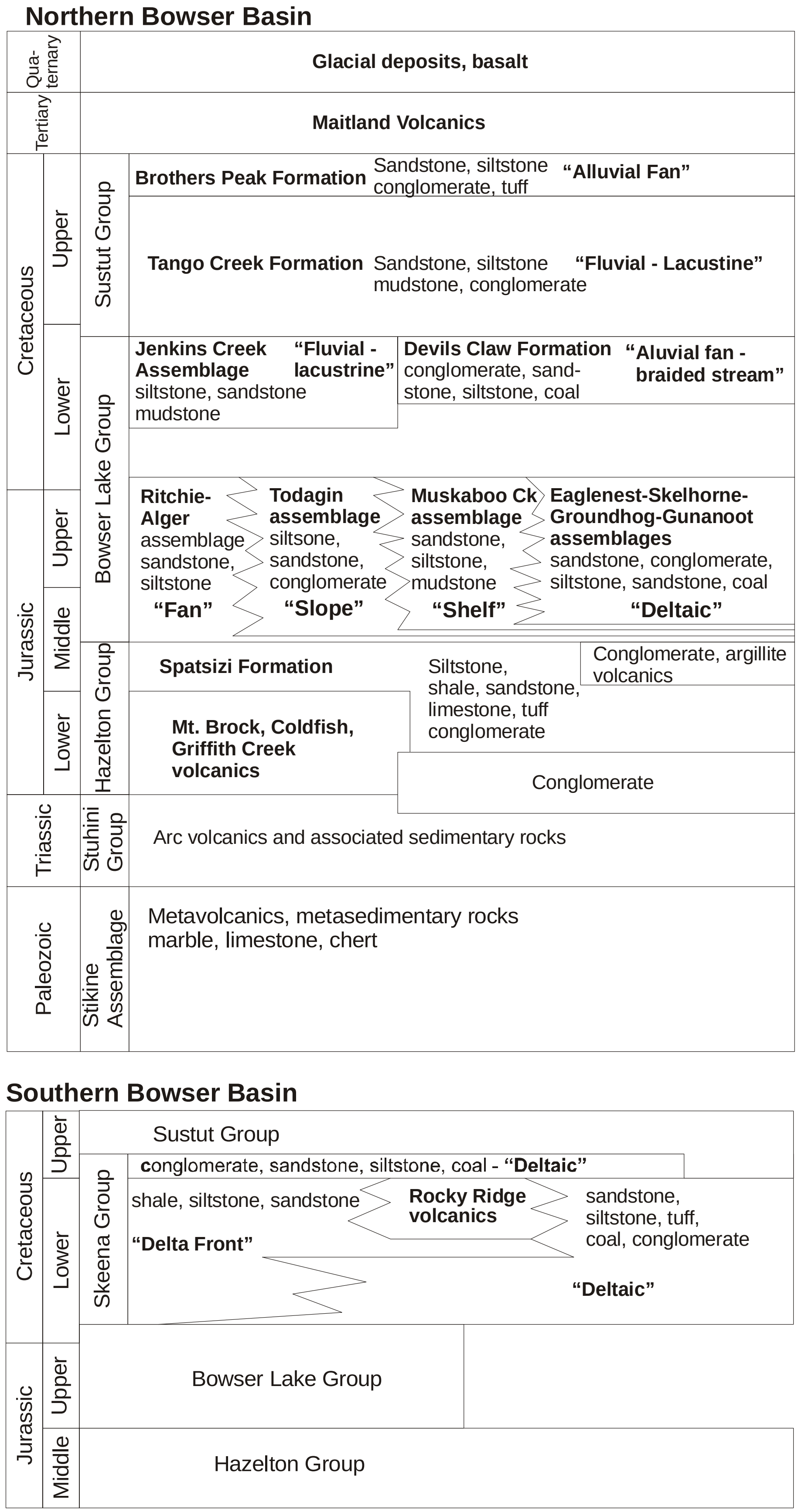

Figure 3. Stratigraphy of the Bowser and Sustut basins.

“dominantly dark-grey or black-weathering, laminated to massive siltstone and shale. Included are laterally continuous rusty orange-weathering claystone beds 2-15 centimetres thick, fine-grained sandstone, rare limestone, and lenses of light-grey-weathering chert pebble conglomerate. Sedimentary structures in the fine-grained lithofacies include parallel lamination, cross-lamination, starved ripples, graded bedding, and syndepositional folds and faults. Trace fossils are curvilinear tubes 0.5-1 millimetre in diameter and a few millimeters long. Orange-weathering claystone beds give the otherwise dark, fine-grained facies a characteristic ‘pin-striped’ appearance in many places. Lenses of conglomerate occur as isolated or laterally overlapping bodies; many are 20-50 metres thick, but some are stacked vertically to as much as 350 metres…”

Eaglenest Assemblage (middle to late Jurassic)

The Eaglenest assemblage represents a deltaic lithofacies.

“Distinctively rusty-weathering, gravelly, conglomeratic strata occur in northern-most exposures of the Bowser Lake Group. Sections 200 metres to more than 1000 metres thick are comprised of 30-80% chert-pebble conglomerate and include interbedded sandstone, siltstone, mudstone, and rare coal. Dominant features are normal bedding, reverse grading within conglomerate, and coarsening- and fining-upward cycles of mudstone to pebble conglomerate. Cross-bedding and clast imbrication in conglomerate are well displayed locally.”

Skelhorne Assemblage (upper Jurassic)

The Skelhorne assemblage crops out in the northern part of the Bowser Basin.

“The Skelhorne assemblage represents a deltaic facies, and underlies much of the southern part of the Spatsizi River map area (104H). The unit comprises “a thinly intermixed assemblage of siltstone and sandstone with varied amounts of coal (up to 5%) and/or conglomerate (5-40%). Plant fossils and marine fossils are ubiquitous with minor exceptions. Cross-bedding, coarsening- and thickening-upward cycles, and the trace fossils *Skolithus* and *Diplocraterion* are common features.”

Groundhog-Gunanoot Assemblage (probably latest Jurassic to early Cretaceous)

The Groundhog-Gunanoot assemblage represents a deltaic lithofacies. It occurs between the Nass and Skeena rivers, and at the headwaters of the Klappan and Little Klappan rivers.

“…a succession of marginal marine through no-marine strata that are part of the Groundhog-Klappan Coalfield….” “The unit is dominantly fine-grained, comprised of coal, carbonaceous mudstone and siltstone, calcareous mudstone, fine-grained sandstone, and medium-grained sandstone, with minor thin conglomerate. Fossil plants are common as molds and carbonaceous films as well as densely packed masses in fine-grained sandstone and siltstone. Silicified logs to 1 metres in diameter are found in talus, and locally silicified trees are *in situ* in siltstone and sandstone; marine fossils are rare. Planar tabular cross-bedding is the most common sedimentary structure in sandstone.”

Jenkins Creek Assemblage (lower Cretaceous)

The Jenkins Creek is a non-marine assemblage consisting of mainly:

“..mudstone, siltstone, fine-grained sandstone, and medium-grained sandstone. Conglomerate is rare, comprising less than 3% of the succession northeast of the Skeena River, and locally up to 15% of the succession west of the Nass River. Strata are commonly arranged in fining-upward cycles with abundant plants and no marine fossils. Abundant fining-upward cycles, the paucity of conglomerate, and absence of marine fossils are features which distinguish them from deltaic strata further north, but they have many similarities with the upper part of the neighbouring Groundhog-Gunanoot deltaic assemblage.”

Devil’s Claw Formation (lower Cretaceous)

“Overlying the mainly fine-grained, non-marine top of the Groundhog-Gunanoot delta-plain assemblage is a well exposed succession at the 1000 metres thick with a high proportion of conglomerate…” “Sheets of conglomerate make up between 30% and 80% of the unit and commonly form cliffs and flatirons depending on their orientation. The sheets are laterally continuous for up to several kilometres, and cliff exposures exhibit large-scale crossbeds and lateral accretion surfaces. Intervening strata are carbonaceous siltstone, fine-grained sandstone, medium-grained sandstone and minor coal. Fossil plants are common and marine fossils are absent.”

SKEENA GROUP (Cretaceous)

Generally, rocks of the Skeena Group appear to be less indurated than those of the underlying Bowser Lake Group, and cleavage is poorly developed (although this may be a reflection of the greater abundance of sandstone in this sequence). Sandstone is generally grey to beige or light yellow-brown. Although chert is the dominant clast type, Skeena sandstones commonly contain trace amounts of muscovite or biotite in addition to appreciable amounts of feldspar and quartz (though in the Hazelton map area muscovite was not common even in strata that clearly belong in the Skeena Group). Metamorphic and igneous clasts were also noted in conglomeratic sections. Carbonaceous material, primarily as coaly bits or plant impressions, is very common and can locally form thin coal seams, a few centimetres thick. More extensive coal layers between 15 to 45 centimetres thick occur within Skeena Group rocks on the lower slopes east of Kispiox Mountain. Fining upwards sequences, capped by coal, are common in the succession southeast of Kispiox Mountain. Lenticular, fining upwards sandstone sections, up to 10 metres thick, within grey to brown siltstones, are well exposed east of Hazelton Peak. The true thickness of this unit in the study area is difficult to determine due to lack of adequate exposure.

STRUCTURAL GEOLOGY

All 3 successions, Bowser Lake and Skeena groups, along with the Sustut Group and underlying Stikinia, are deformed in the Skeena Fold Belt, a thin skinned contractional fold and thrust belt of Cretaceous and possibly early Tertiary age (Evenchick, 1991). Northeast vergent open to closed folds of about 100 to 1000 m wavelengths are the dominant structures at exposed levels, but larger wavelength folds often outlined by anticlinoria and synclinoria in Bowser Lake Group are associated with structural culminations and depressions inferred to be controlled by the involvement of Stikine Assemblage volcanic and clastic strata. The fold hinges trend northwest dominantly, but domains of northeast fold hinge trends occur in western Skeena Fold Belt.

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BC Ministry of Energy and Mines

PETROGRAPHIC ANALYSIS AND RESERVOIR QUALITY ASSESSMENT OF TWENTY TWO OUTCROP SAMPLES FROM THE SKEENA GROUP AND THE BOWSER LAKE GROUP BRITISH COLUMBIA

Work Order No. A11384

March 2005

AGAT Laboratories

3801 – 21st Street N.E.
Calgary, Alberta
T2E 6T5

RESERVOIR QUALITY ASSESSMENT OF SAMPLES FROM THE SKEENA AND BOWSER LAKE GROUPS, NORTHERN BRITISH COLUMBIA

By Iftikhar Abid[1]

INTRODUCTION

At the request of BC Ministry of Energy and Mines this study was initiated to describe the petrographic characteristics and the reservoir quality of twenty two outcrop samples from British Columbia. These samples represent the Skeena Group (3 samples) and the Bowser Lake Group (19 samples). The Bowser Lake Group is further subdivided into different assemblages. Eight samples from the Bowser Lake Group are termed "Undifferentiated" where detailed stratigraphic information was not available. Figure 1 shows the location of samples and Figure 2 gives basic stratigraphic information. The following table provides further sample information.

OBJECTIVE

The purpose of the study was to determine mineralogy, diagenesis, reservoir quality and fluid sensitivity of 22 sandstone and conglomerate samples.

METHODS OF ANALYSIS

All samples were collected from outcrops in the Northern British Columbia (Figure 1). Small plugs were drilled through these samples to obtain fresh and unaltered samples. An attempt was made to use fresh samples for thin sections as the outer surfaces of these samples are often altered due to weathering processes. The fresh rock samples were impregnated with blue epoxy (to identify porosity), polished and mounted onto a glass slide. After hardening of the resin the samples were ground down to a total thin section thickness of 30µm and stained with a combined carbonate stain of Alizarin Red-S (for calcite) and potassium ferricyanide (for ferroan carbonates). Finally a second glass slide was glued on the polished surfaces. The prepared thin sections were examined petrographically and point counted (300 points per sample). The petrographic data summary, including framework mineralogy, diagenetic minerals and cements, textures, average grain size, core porosity and permeability, is provided in Table 1. Figure 3 shows sample compositions plotted on the ternary classification diagram of Folk (1974).

PETROGRAPHIC DESCRIPTION AND INTERPRETATION

Twenty-two outcrop samples, representing the Skeena (3 samples) and the Bowser Lake (19 samples) groups of Upper Jurassic to Lower Cretaceous age were examined. Samples from the Bowser Lake Group are further divided into different assemblages:

(a) Jenkins Creek Assemblage (1 sample),

(b) Groundhog-Gunanoot Assemblage (1 sample),

(c) Muskaboo Creek Assemblage (7 samples),

(d) Skelhorne Assemblage (1 sample),

(e) Todagin Assemblage (1 sample) and

(f) Undifferentiated Bowser Lake Group (8 samples).

Petrographic analysis and reservoir quality assessment for each Group/Assemblage is described and interpreted separately.

SKEENA GROUP (Samples SP006, SP011, SP020)

Three outcrop samples were collected from the Skeena Group, British Columbia. All these samples are located in the southern part of the study area (Figure 1). Samples SP006 and SP011 are light to medium gray and sample SP020 light greenish gray.

Samples SP006 and SP020 are classified as chert rich litharenite and sample SP011 as volcanic rock fragment rich feldspathic litharenite (Table 1, Figure 3). These samples are upper medium-grained (Samples SP006 and SP020) and lower coarse-grained (Sample SP011) sandstones. The framework grains are moderately (SP006, SP011) to well sorted (SP20).

Framework grains within samples SP006 and SP020 are dominated by chert and volcanic rock fragments (Plates 1, 3). Small amounts of quartz, detrital calcite, feldspars, plutonic and sedimentary rock fragments are also present. Several framework grains have been partially to completely replaced with calcite in sample SP006 (Plate 1). On the other hand, several grains were completely dissolved and subsequently filled with kaolinite in sample SP020 (Plate 3-3).

[1]*AGAT Laboratories, 3801 - 21st Street NE, Calgary, Alberta, T2E 6T5*

Plug #	Field #	Group	Assemblage	Plate #
SP006	EPF-04-95C	Skeena	N/A	1
SP011	EPF-04-359A	Skeena	N/A	2
SP020	EPR-04-101A	Skeena	N/A	3
SP008	EPF-04-182A	Bowser Lake	Jenkins Creek	4
SP010	EPF-04-319A	Bowser Lake	Groundhog-Gun.	5
SP001	EPF-04-13B	Bowser Lake	Muskaboo Creek	6
SP009	EPF-04-221A	Bowser Lake	Muskaboo Creek	7
SP012	EP-04-49A	Bowser Lake	Muskaboo Creek	8
SP015	EP-04-92D	Bowser Lake	Muskaboo Creek	9
SP018	EP-04-104A	Bowser Lake	Muskaboo Creek	10
SP021	EPS-04-MS1-04	Bowser Lake	Muskaboo Creek	11
SP022	EPS-04-MS2-09	Bowser Lake	Muskaboo Creek	12
SP013	EP-04-90H	Bowser Lake	Skelhorne	13
SP014	EP-04-91D	Bowser Lake	Todagin	14
SP002	EPF-04-57C	Bowser Lake	Undifferentiated	15
SP003	EPF-04-61A	Bowser Lake	Undifferentiated	16
SP004	EPF-04-65B	Bowser Lake	Undifferentiated	17
SP005	EPF-04-69C	Bowser Lake	Undifferentiated	18
SP007	EPF-04-162A	Bowser Lake	Undifferentiated	19
SP016	EP-04-94D	Bowser Lake	Undifferentiated	20
SP017	EP-04-101A	Bowser Lake	Undifferentiated	21
SP019	EPM-04-201A	Bowser Lake	Undifferentiated	22

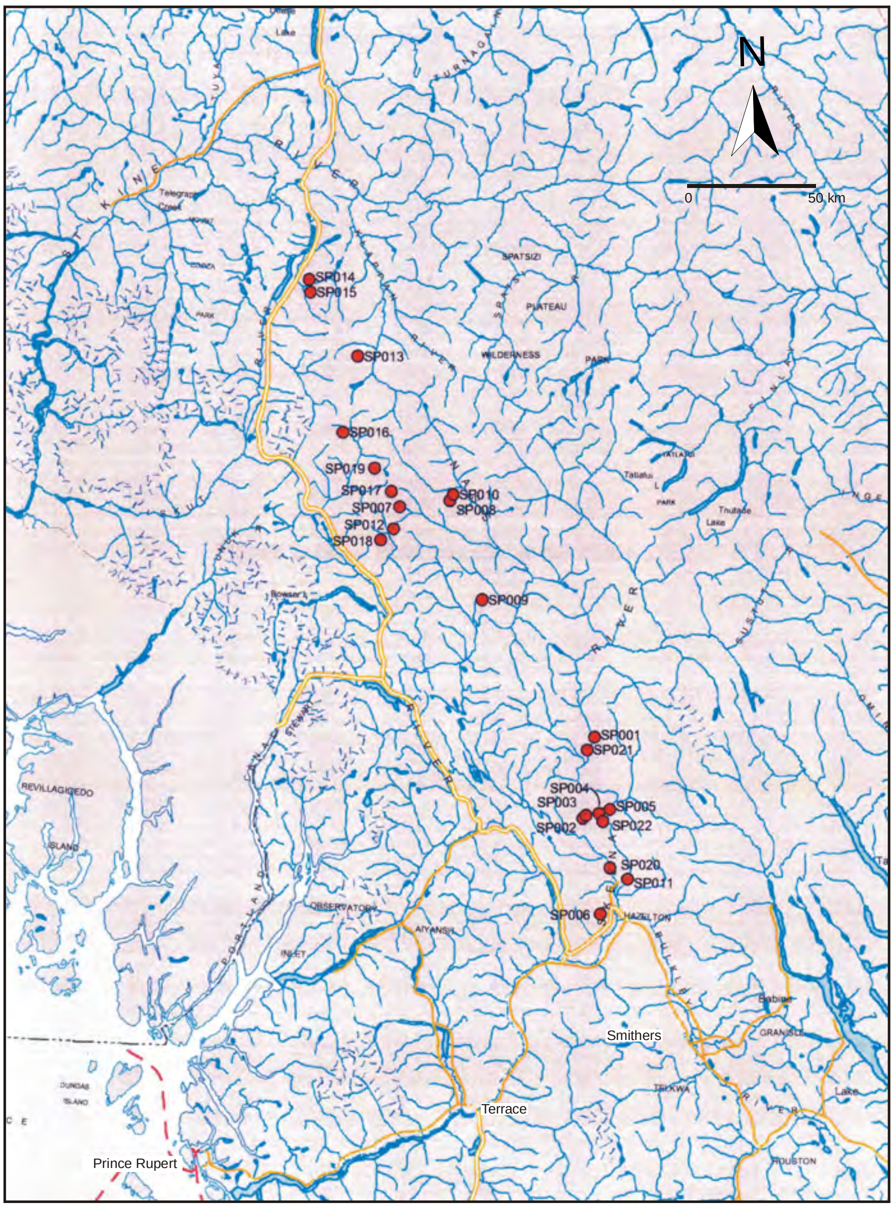


Figure 1. Location of samples.

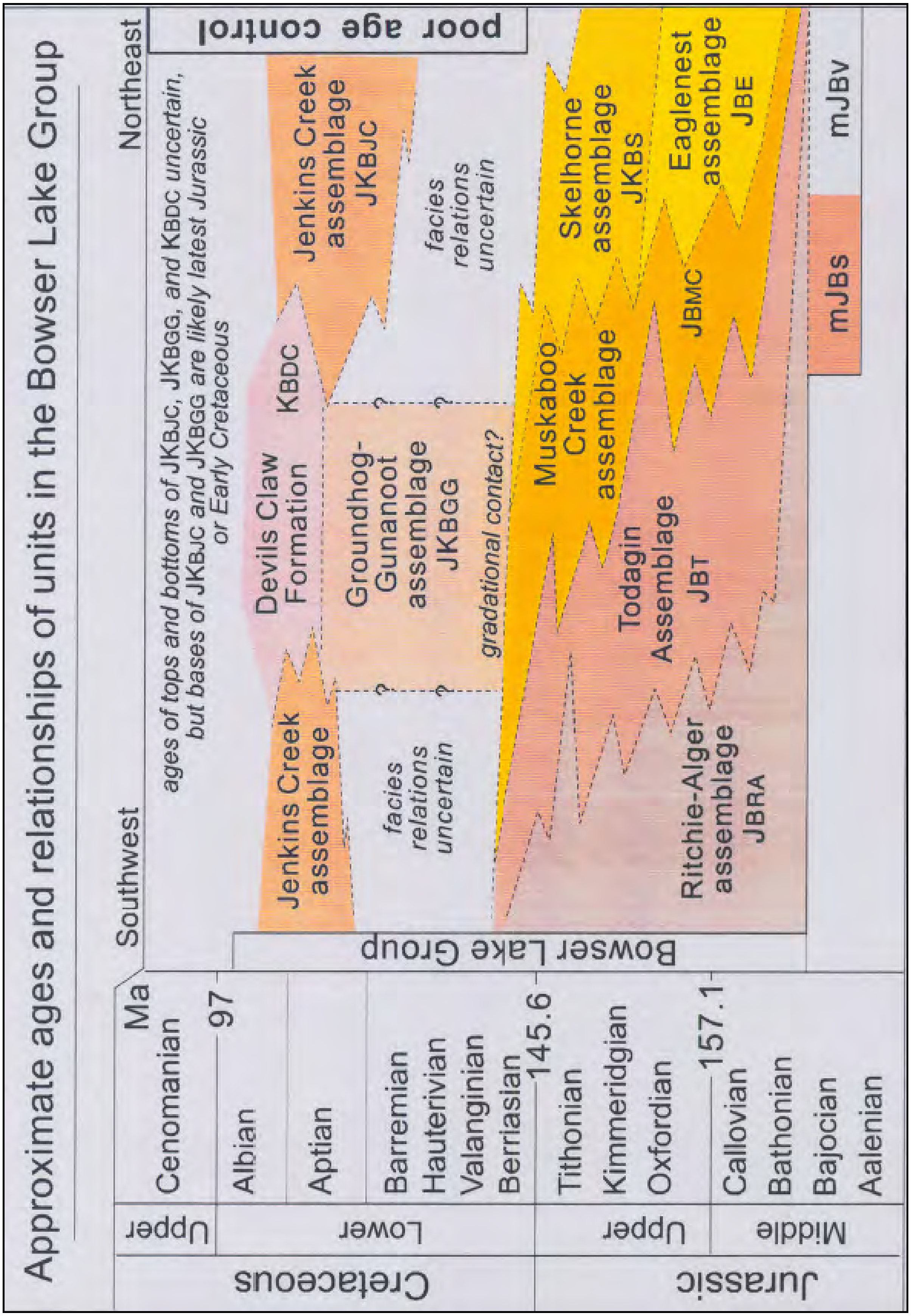


Figure 2. Basic stratigraphy of the study area.

In many cases the nature of the original dissolved or replaced grains is not clear and this may have altered the original composition of sandstones. Only trace amount of metamorphic rock fragments are present in one sample (SP006). Lower percentage of feldspar and higher concentration of authigenic kaolinite in samples SP006 and SP020 could be the result of feldspar dissolution and resultant kaolinite precipitation.

The composition of sample SP011 is different than SP006 and SP020 as it is predominantly consists of volcanic rock fragments and feldspars (Plate 2, Table 1). Plutonic rock fragments, chert and quartz grains are present in minor amounts (Table 1). Pore filling chlorite is common in this sample (Plates 2-3, 2-4). Kaolinite, present in other two samples of the Skeena Group (SP006, SP020), is absent in SP011 (Plate 2).

Chert grains with variable colour appears in crypto- to microcrystalline textures. Some chert grains could be chertified volcanic rock fragments where ghosts or relic features of volcanic grains have been completely silicified. Many chert grains are surrounded with dark brownish material (Plates 1, 3). A few chert grains with lath shaped features suggest that these grains were of volcanic nature prior to chertification. Some chert grains were partially replaced with calcite.

Volcanic rock fragments are common in these samples, particularly in sample SP011 (Plate 2). Type and colour of volcanic rock fragments are variable. Plagioclase laths are usually surrounded with fine groundmass (Plate 2-2). This groundmass is often chloritized and in some cases chertified (Plate 2-2). Within the individual volcanic rock fragment, the size of plagioclase laths could be uniform or variable. These plagioclase laths could be randomly oriented or they may show preferred orientation (Plate 2-2). The abundance of plagioclase laths is also variable. Some volcanic rock fragments are partially chertified where plagioclase laths are still preserved. Other volcanic rock fragments are extensively chertified including the plagioclase laths. Some feldspar laths in volcanic rock fragments are replaced with calcite or dissolved and later filled with kaolinite. Some volcanic rock fragments are extremely fine crystalline. Olivine or pyroxene minerals were generally absent or rare in the volcanic rock fragments of the Skeena Group. Some volcanic rock fragments contain common opaque minerals.

Plutonic rock fragments consists of feldspar, quartz and mica crystals (Plate 2-3). Some plutonic rock fragments are rich in mica. In some plutonic rock fragments, crystals are heavily altered and sericitized. Monocrystalline quartz with straight-extinction is more common than polycrystalline quartz. Inclusions and well developed crystal outlines are not common in monocrystalline quartz (Plates 1-3, 3-2). Quartz grains are rarely replaced with calcite. Sedimentary rock fragments are either absent (SP011) or rare and include shale and sandstones. Feldspar grains are altered or sericitized. Some feldspar grains are partially replaced with calcite. Some calcite grains may have been originally feldspars.

Matrix clays occur in minor amounts as grain coatings, localized pore-fill and as concentration along concavo-convex grain contacts. In this study, matrix clays refer to all clays that are distinguished from authigenic clays. We recommend that XRD and SEM analyses to further characterize clay minerals.

Diagenesis and Paragenetic Sequence

Both mechanical compaction and cementation have reduced porosity in these sandstones (Plates 1, 2, 3). Framework grains show moderate to high degree of compacted as revealed by long (Plate 1-2) and concavo-convex grain contacts (Plate 2-2). Reduced intergranular pores were later filled with chlorite (Plate 2-3), kaolinite (Plate 1-2) and less commonly with calcite. Pyrite and quartz cements are rare.

Diagenetic features, in a paragenetic order, include: on set of compaction, pyrite, grain coating and pore filling authigenic chlorite, replacement and pore filling calcite with variable iron content, dissolution of calcite and feldspars and finally precipitation of kaolinite.

Authigenic chlorite and kaolinite are important diagenetic features in these samples. Grain coating chlorite precipitated fairly early during the diagenetic history (Plate 3), however, pore filling chlorite cement precipitated after some compaction, as it is present in reduced intergranular pores (Plate 2-3). Chlorite rims show uniform thickness (~25 microns). These delicate authigenic chlorite crystals are growing at nearly right angle to the grain surfaces and reduce pore throats significantly (Plate 3-4). These chlorite crystals would also provide a large surface area to react with incompatible drilling and completion fluids. The size of pore filling chlorite crystals becomes larger toward the center of the pore (Plate 2-4). Closer to the pore wall, chlorite crystals are smaller in size and appear almost black under the crossed polars (see inset in Plate 2-4).

Most of the calcite appears to be replacing framework grains (feldspars, volcanic, chert etc.). Pore filling calcite cement is less common. The colour of stained calcite varies, indicating variable iron concentration in calcite (Plate 1). The later stage pore filling calcite appears to be more iron-rich (darker blue). In a few grains it is difficult to differentiate between detrital calcite and calcite that has replaced the framework grains completely (compare Plate 1-3 and Plate 3-4).

Both calcite and feldspar grains were dissolved prior to the precipitation of authigenic kaolinite (Plates 1-2, 3-3). Irregular calcite boundaries surrounded by kaolinite suggest that calcite has been dissolved (see inset in Plate 1-4). Authigenic kaolinite crystals are very fine and individual crystals cannot be resolved under standard petrographic microscope. Micropores could be present between kaolinite crystals. Textural relationships suggest that kaolinite is younger than chlorite (Plate 3-4). Some of the kaolinite may have developed in pores where feldspar or other grains were completely dissolved (Plate 3-3). Authigenic quartz overgrowths and pyrite are not common cements in these sandstones.

Some visible pores in Sample SP011 were created due to dissolution of feldspars. These pores were not filled with kaolinite, as late stage kaolinite cement is absent in this sample. The absence of kaolinite in Sample SP011 is partly due to the fact that all early pores were filled with chlorite and that feldspar grains were not extensively dissolved to provide the source material for kaolinite.

Porosity, Permeability and Reservoir Quality

Visible pores are either absent (SP006, SP020) or present in minor amount (1% in SP011). Core porosity varies from 1.0 to 3.6% and gas permeability <0.01 to 0.02 mD. Visible pores in SP011 are intragranular due to partial dissolution of feldspars and other grains. These pores are very poorly interconnected. Secondary porosity created due to dissolution of calcite and framework grains was occluded by kaolinite (SP006, SP020). Slightly higher core porosity in Sample SP020 is probably, at least in part, due to higher amounts of clay minerals present in this sample. Much of the core porosity is believed to be microporosity present between clay minerals. Extremely low thin section porosity, core porosity and permeability values suggest that the Skeena Group represented by these samples show poor to very poor reservoir quality.

BOWSER LAKE GROUP

(a) Jenkins Creek Assemblage (Sample SP008)

Only one outcrop sample was collected from the Jenkins Creek Assemblage of the Bowser Lake Group, British Columbia. It is located in the central part of the study area (Figure 1). This sample is characterized by medium to dark brownish gray colour. The surface of this sample is intensely stained, probably due to oxidation and weathering of iron-rich opaque minerals. One mineralized fracture was observed in hand specimen.

This sample is classified as chert rich litharenite (Table 1, Figure 3). It is a grain-supported conglomerate where medium-grained sand is present between pebbles and granules (Plate 4). It is the only conglomerate among all samples in this project. Overall, it is moderately sorted.

Framework grains are dominated by chert. Sand-sized grains between granules and pebbles are also predominantly chert. Quartz grains and organic particles are present in small amounts. Sedimentary, volcanic, plutonic and metamorphic rock fragments are present only in trace amounts. Plagioclase and magnetite grains were rarely observed (Table 1).

Chert grains with variable colour appears in crypto- to microcrystalline and rarely as fibrous chalcedony textures. Rounded relics of carbonate grains (probably calcispheres) and rarely relics of bioclasts are present in many pebbles and granules (Plates 4-1, 4-3). These rounded calcispheres are generally filled with chalcedony. Some of these calcispheres have been deformed due to compaction (E8 in Plate 4-1). Pyrite and clay impurities are present in chert grains. A few dissolution pores are present in chert grains (Plate 4-4). Silica filled fractures in chert grains reflect the character of the source rocks. A few chert grains were extensively fractured and healed with silica in the source areas prior to deposition. Quartz grains are locally surrounded by quartz overgrowths (Plate 4-2). Brownish shale rock fragments are deformed between rigid grains (Plate 4-2). Feldspars and volcanic rock fragments are altered and in places partially dissolved (Plate 4-4).

Matrix clays occur in minor amounts (traces) as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays. Some of the matrix could be due to deformation of soft mud clasts between competent grains (pseudo matrix).

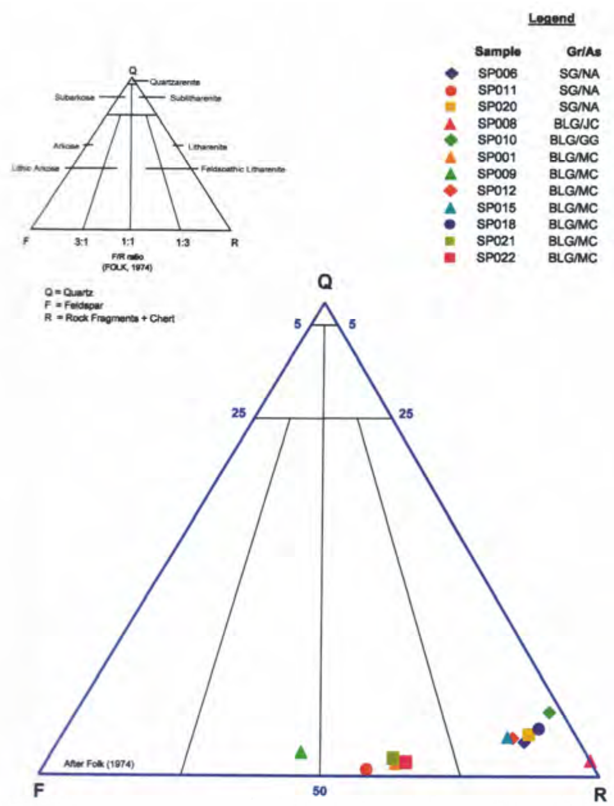
Diagenesis and Paragenetic Sequence

Mechanical compaction has significantly reduced the original porosity in this sample. Framework grains show high degree of compaction as revealed by long and concavo-convex grain contacts as well as local grain fracturing (Plate 4-3). The remaining pores were commonly filled with silica cement (Plate 4-2) and hematite/limonite (Plate 4-1). This hematite/limonite

LIST OF ABBREVIATIONS (SANDSTONES)

ROCK TYPE	**GRAIN SIZE**
QA – QUARTZARENITE	P – PEBBLE
SA – SUBARKOSE	GR – GRANULE
SL – SUBLITHARENITE	vcU – UPPER VERY COARSE
AR – ARKOSE	vcL – LOWER VERY COARSE
LA – LITHIC ARKOSE	cU – UPPER COARSE
FL – FELDSPATHIC LITHARENITE	cL – LOWER COARSE
LR – LITHARENITE	mU – UPPER MEDIUM
SORTING	mL – LOWER MEDIUM
VW – VERY WELL SORTED	fU- UPPER FINE
W – WELL SORTED	fL – LOWER FINE
M – MODERATELY SORTED	vfU – UPPER VERY FINE
P – POORLY SORTED	vfL – LOWER VERY FINE
	slt – SILT
RESERVOIR QUALITY	**ROUNDNESS**
VG – VERY GOOD	WR – WELL ROUNDED
G – GOOD	R – ROUNDED
M – MODERATE	SR – SUBROUNDED
F - FAIR	SA – SUBANGULAR
P – POOR	A - ANGULAR

Figure 3. Sandstone classification from the Skeena Group and the Bowser Lake Group, British Columbia.



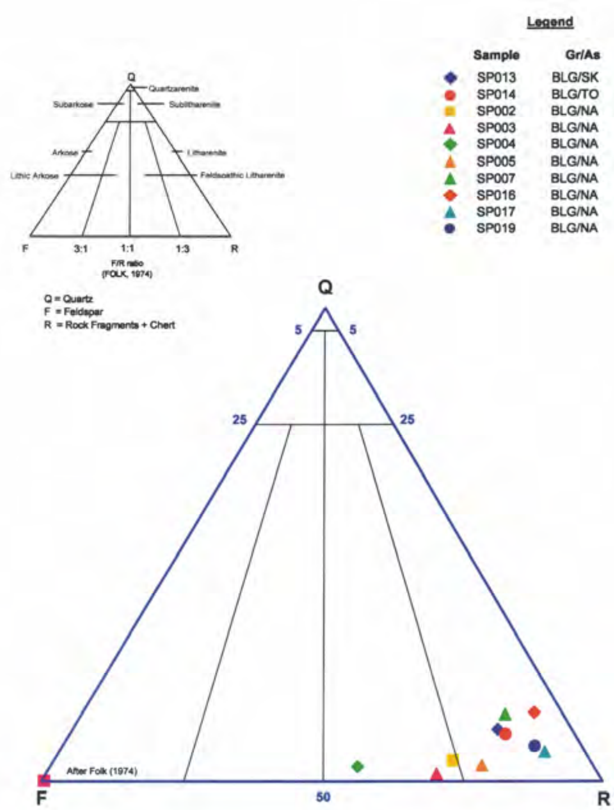


Figure 3. Sandstone classification from the Skeena Group and the Bowser Lake Group, British Columbia, continued.

TABLE 1. PETROGRAPHIC SUMMARY OF TWENTY-TWO SANDSTONE SAMPLES FROM THE SKEENA GROUP AND THE BOWSER LAKE GROUP, BRITISH COLUMBIA

Sample ID Group/Assem. Rock Type		SP006 SG/NA LR	SP011 SG/NA FL	SP020 SG/NA LR	SP008 BLG/JC LR	SP010 BLG/GG LR	SP001 BLG/MC FL
Quartz	*Monocrystalline*	5	1	5	3	8	2
	Polycrystalline	TR	TR	1	-	2	TR
	Total	**6**	**1**	**6**	**3**	**10**	**2**
Feldspar	*Potassium Feldspar*	-	10	-	-	1	2
	Plagioclase	-	15	-	TR	TR	14
	Total (or Fld not classified)	**3**	**25**	**3**	**TR**	**1**	**16**
Rock Fragments	*Chert*	26	7	30	88	52	17
	Sedimentary Rock Fragments	2	-	2	TR	6	-
	Volcanic Rock Fragments	15	43	19	TR	4	35
	Metamorphic Rock Fragments	TR	-	-	TR	-	TR
	Plutonic Rock Fragments	5	11	3	TR	1	14
	Detrital Calcite / Replacement	17	-	6	-	-	-
	Detrital Dolomite	-	-	-	-	-	-
	Total	**65**	**61**	**60**	**88**	**63**	**66**
Accessories	*Mica*	TR	-	-	-	-	-
	Heavy Minerals	-	-	-	-	-	-
	Olivine/Pyroxene	-	-	-	-	-	1
	Organic Matter	2	1	1	1	2	TR
	Magnitite	-	TR	TR	TR	3	-
	Detrital Chlorite	-	-	-		2	-
	Total	**2**	**1**	**1**	**1**	**7**	**1**
Matrix	*Micrite (Calcite/Dolomite)*	-	-	-	-	-	-
	Clay	4	-	1	TR	4	-
	Total	**4**	**0**	**1**	**TR**	**4**	**0**
Authigenic Clays	*Kaolinite*	13	-	11	-	-	-
	Illite	-	-	-	-	-	-
	Chlorite	-	12	14	-	-	4
	Smectite	-	-	-	-	-	-
	Unidentified	-	-	-	-	-	-
	Total	**13**	**12**	**26**	**0**	**0**	**4**
Cements/ Replacement	*Quartz*	-	-	-	2	8	-
	Feldspar	-	-	-	-	-	-
	Calcite	-	-	-	-	-	2
	Ferroan Calcite	9	-	4	-	-	-
	Dolomite	-	-	-	-	-	-
	Ferroan Dolomite	-	-	-	-	1	-
	Hematite/Limonite	-	-	-	6	6	-
	Laumontite	-	-	-	-	-	TR
	Pyrite	TR	TR	TR	TR	-	TR
	Anhydrite	-	-	-	-	-	9
	Siderite	-	-	-	-	-	-
	Residual Hydrocarbon	-	-	-	TR	-	-
	Total	**9**	**TR**	**4**	**8**	**15**	**11**
Total Rock Volume (%)		**100**	**100**	**100**	**100**	**100**	**100**
Structures		-	-	-	-	-	-
Textures	*Grain Size Average*	mU	cL	mU	P	mL	cU
	Grain Size Range	vfU-vcU	vfU-vcU	fU-cU	mL-P	fU-cL	fL-vcU
	Sorting	M	M-G	G	M	G	P
	Roundness	SR-SA	R-A	R-SR	R-SA	R-SA	R-A
Diagenesis	*Compaction*	XXX	XX-XXX	XX-XXX	XXX	XXX	XXX
	Grain Fabric	G, F, CC	G, F, CC	G	G, F	G, F, CC	G, F, CC
	Cementation	Cem	Cem	Cem	Cem	Cem	Cem
	Dissolution	GR, GD	GD	GD	GD	GD, SCD	GR
Visible Porosity	*Intergranular*	-	-	-	TR	TR	-
	Dissolution (unclassified)	-	1	TR	TR	3	-
	Grain Dissolution	-	-	-	-	-	-
	Cement Dissolution	-	-	-	-	-	-
	Total Visible Porosity (%)	**0**	**1**	**TR**	**TR**	**3**	**0**
Petrophysical Results	*Core Porosity (%)*	**1.7**	**1.0**	**3.6**	**3.8**	**2.0**	**0.7**
	Gas Permeability (mD)	**0.01**	**<0.01**	**0.02**	**6.02**	**<0.01**	**<0.01**
Reservoir Quality		**Very Poor**	**Poor**	**Very Poor**	**Poor**	**Poor**	**Very Poor**

Structures:	Mss-massive, Lm-laminae; Xlm-cross laminae; Xb-cross bedded; Bd-bedded; Bt-bioturbated
Compaction:	X-slightly; XX-moderately; XXX-highly
Grain Fabric:	G-grain supported; M-matrix supported; C-cement supported; P-point contacts; F-flat contacts; CC-concavo-convex contacts; S-sutured contacts
Cementation:	Cem-completely cemented; NCem-non-cemented; PCem-partly cemented
Dissolution:	Cor-corroded surfaces; GD-grain dissolution; GR-grain replacement; CCD-complete cement dissolution; SCD-selective cement dissolution

TABLE 1. CONT'D

Sample ID Group/Assem. Rock Type		SP009 BLG/MC LA	SP012 BLG/MC LR	SP016 BLG/MC LR	SP018 BLG/MC LR	SP021 BLG/MC FL	SP022 BLG/MC FL
Quartz	*Monocrystalline*	3	3	4	6	2	2
	Polycrystalline	1	3	3	2	1	TR
	Total	**4**	**6**	**7**	**8**	**3**	**2**
Feldspar	*Potassium Feldspar*	7	5	5	2	4	5
	Plagioclase	16	2	1	2	8	8
	Total (or Fld not classified)	**23**	**7**	**6**	**4**	**12**	**13**
Rock Fragments	*Chert*	11	44	51	48	13	15
	Sedimentary Rock Fragments	2	9	7	9	1	-
	Volcanic Rock Fragments	23	7	9	10	33	36
	Metamorphic Rock Fragments	-	TR	1	-	3	TR
	Plutonic Rock Fragments	19	2	5	1	17	14
	Detrital Calcite/Replacement	-	-	-	-	-	-
	Detrital Dolomite	-	-	-	-	-	-
	Total	**55**	**62**	**73**	**68**	**67**	**65**
Accessories	*Mica*	-	1	TR	-	-	TR
	Heavy Minerals	TR	-	-	TR	-	-
	Olivine/Pyroxene	3	-	-	-	2	1
	Organic Matter	2	3	1	1	TR	TR
	Magnetite	-	TR	-	-	-	-
	Detrital Chlorite	1	13	3	7	TR	1
	Total	**6**	**17**	**4**	**8**	**2**	**2**
Matrix	*Micrite (Calcite/Dolomite)*	-	-	-	-	-	-
	Clay	-	1	TR	1	-	1
	Total	**0**	**1**	**TR**	**1**	**0**	**1**
Authigenic Clays	*Kaolinite*	-	-	-	-	-	-
	Illite	-	-	1	1	2	-
	Chlorite	9	3	3	1	7	8
	Smectite	-	-	-	-	-	-
	Unidentified	-	-	-	-	-	-
	Total	**9**	**3**	**4**	**2**	**9**	**8**
Cements/ Replacement	*Quartz*	-	3	5	1	-	-
	Feldspar	-	-	-	-	-	-
	Calcite	2	1	1	-	1	-
	Ferroan Calcite	-	-	-	4	-	-
	Dolomite	-	-	-	-	-	-
	Ferroan Dolomite	-	-	-	-	-	-
	Hematite/Limonite	-	TR	-	-	-	-
	Laumontite	-	-	-	-	6	9
	Pyrite	1	TR	TR	4	TR	-
	Anhydrite	-	-	-	-	-	-
	Siderite	-	-	-	-	-	-
	Residual Hydrocarbon	-	-	-	-	-	-
	Total	**3**	**4**	**6**	**9**	**7**	**9**
Total Rock Volume (%)		**100**	**100**	**100**	**100**	**100**	**100**
Structures		-	-	-	-	-	-
Textures	*Grain Size Average*	mL	mL	mU	mL	mL	mL
	Grain Size Range	vfU-mU	vfU-mU	fL-cL	vfU-vU	vfU-cL	vfU-cU
	Sorting	G	M	M	M	M	P
	Roundness	R-A	R-A	R-SA	R-A	R-A	R-A
Diagenesis	*Compaction*	XX	XXX	XXX	XX-XXX	XXX	XXX
	Grain Fabric	G, F	G, F, CC	G, F, CC	G, P, F, CC	G, F, CC	G, F, CC
	Cementation	Cem	Cem	Cem	Cem	Cem	Cem
	Dissolution	GD	Cor	GR	GD	GR	GR, GD
Visible Porosity	*Intergranular*	-	-	TR	TR	-	-
	Dissolution (unclassified)	TR	-	-	TR	-	1
	Grain Dissolution	-	-	-	-	-	-
	Cement Dissolution	-	-	-	-	-	-
	Total Visible Porosity (%)	**TR**	**0**	**TR**	**TR**	**0**	**1**
Petrophysical Results	*Core Porosity (%)*	**0.7**	**2.2**	**0.8**	**1.7**	**4.0**	**6.0**
	Gas Permeability (mD)	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.18**	**0.09**
Reservoir Quality		**Very Poor**	**Very Poor**	**Very Poor**	**Very Poor**	**Very Poor**	**Poor**

Structures: Mss-massive; Lm-laminae; Xlm-cross laminae; Xb-cross bedded; Bd-bedded; Bt-bioturbated
Compaction: X-slightly; XX-moderately; XXX-highly
Grain Fabric: G-grain supported; M-matrix supported; C-cement supported; P-point contacts; F-flat contacts; CC-concavo-convex contacts; S-sutured contacts
Cementation: Cem-completely cemented; NCem-non-cemented; PCem-partly cemented
Dissolution: Cor-corroded surfaces; GD-grain dissolution; GR-grain replacement; CCD-complete cement dissolution; SCD-selective cement dissolution

TABLE 1. CONT'D

Sample ID Group/Assem. Rock Type		SP013 BLG/SK LR	SP014 BLG/TO LR	SP002 BLG/NA FL	SP003 BLG/NA FL	SP004 BLG/NA FL	SP006 BLG/NA LR
Quartz	*Monocrystalline*	3	5	3	1	2	2
	Polycrystalline	5	3	TR	TR	TR	TR
	Total	**8**	**8**	**3**	**1**	**2**	**2**
Feldspar	*Potassium Feldspar*	5	4	7	2	3	TR
	Plagioclase	3	2	3	5	12	5
	Total (or Fld not classified)	**8**	**6**	**10**	**7**	**15**	**5**
Rock Fragments	*Chert*	39	34	13	10	11	9
	Sedimentary Rock Fragments	18	18	TR	-	TR	-
	Volcanic Rock Fragments	4	8	28	42	27	16
	Metamorphic Rock Fragments	-	1	-	-	-	-
	Plutonic Rock Fragments	2	4	8	15	15	8
	Detrital Calcite/Replacement	-	-	10	-	-	9
	Detrital Dolomite/Shell Frag.	-	-	-	-	-	15
	Total	**63**	**65**	**59**	**67**	**53**	**57**
Accessories	*Mica*	TR	TR	-	TR	TR	-
	Heavy Minerals	1	-	6	TR	TR	-
	Olivine/Pyroxene	-	-	-	4	3	1
	Organic Matter	-	1	2	-	TR	-
	Magnitite	-	1	1	-	-	-
	Detrital Chlorite	5	4	TR	-	TR	TR
	Total	**6**	**6**	**9**	**4**	**3**	**1**
Matrix	*Micrite (Calcite/Dolomite)*	-	-	-	-	-	-
	Clay	2	2	TR	1	4	5
	Total	**2**	**2**	**TR**	**1**	**4**	**5**
Authigenic Clays	*Kaolinite*	-	-	-	-	-	-
	Illite	-	-	-	-	-	TR
	Chlorite	1	8	6	7	12	TR
	Smectite	-	-	-	-	-	-
	Unidentified	-	-	-	-	-	-
	Total	**1**	**8**	**6**	**7**	**12**	**TR**
Cements/ Replacement	*Quartz*	6	2	-	-	-	1
	Feldspar	TR	-	-	-	-	-
	Calcite	-	-	-	2	TR	5
	Ferroan Calcite	-	3	13	-	-	20
	Dolomite	-	-	-	-	-	-
	Ferroan Dolomite	4	TR	-	-	-	-
	Hematite/Limonite	-	-	-	-	-	TR
	Laumontite		-	-	11	11	-
	Pyrite	TR	TR	-	TR	-	4
	Anhydrite	-	-	-	-	-	-
	Siderite	-	-	-	-	-	-
	Residual Hydrocarbon	-	-	-	-	-	-
	Total	**10**	**5**	**13**	**13**	**11**	**30**
Total Rock Volume (%)		**100**	**100**	**100**	**100**	**100**	**100**
Structures		-	-	-	-	-	-
Textures	*Grain Size Average*	fU	fU	mL	cL	fU	mU
	Grain Size Range	vfU-mU	vfU-mU	slt-cU	fU-vcL	slt-mU	slt-GR
	Sorting	M	M	M	M	M	P
	Roundness	R-SA	SR-A	SR-A	SR-SA	R-A	R-A
Diagenesis	*Compaction*	XXX	XXX	XXX	XXX	XXX	XXX
	Grain Fabric	G, F, CC	G, F, CC	G, F, CC	G, F, CC	G, F, CC	G, F, CC
	Cementation	Cem	Cem	Cem	Cem	Cem	Cem
	Dissolution	GR	GR	GR	GR	GR	GR
Visible Porosity	*Intergranular*	-	TR	-	-	-	-
	Dissolution (unclassified)	-	-	-	-	-	TR
	Grain Dissolution	-	-	-	-	-	-
	Cement Dissolution	-	-	-	-	-	-
	Total Visible Porosity (%)	**0**	**TR**	**0**	**0**	**0**	**TR**
Petrophysical Results	*Core Porosity (%)*	**0.9**	**0.8**	**3.4**	**4.1**	**3.2**	**1.3**
	Gas Permeability (mD)	**<0.01**	**0.01**	**0.05**	**0.34**	**0.08**	**0.01**
Reservoir Quality		**Very Poor**	**Very Poor**	**Very Poor**	**Very Poor**	**Very Poor**	**Very Poor**

Structures:	**Mss**-massive, **Lm**-laminae; **Xlm**-cross laminae; **Xb**-cross bedded; **Bd**-bedded; **Bt**-bioturbated
Compaction:	X-slightly; XX-moderately; XXX-highly
Grain Fabric:	**G**-grain supported; **M**-matrix supported; **C**-cement supported; **P**-point contacts; **F**-flat contacts; **CC**-concavo-convex contacts; **S**-sutured contacts
Cementation:	**Cem**-completely cemented; **NCem**-non-cemented; **PCem**-partly cemented
Dissolution:	**Cor**-corroded surfaces; **GD**-grain dissolution; **GR**-grain replacement; **CCD**-complete cement dissolution; **SCD**-selective cement dissolution

TABLE 1. CONT'D

Sample ID Depth (m) Rock Type		SP007 BLG/NA LR	SP016 BLG/NA LR	SP017 BLG/NA LR	SP019 BLG/NA LR		
Quartz	*Monocrystalline*	9	7	2	2		
	Polycrystalline	3	4	3	4		
	Total	**12**	**11**	**5**	**6**		
Feldspar	*Potassium Feldspar*	7	2	2	3		
	Plagioclase	1	1	1	1		
	Total (or Fld not classified)	**8**	**3**	**3**	**4**		
Rock Fragments	*Chert*	34	41	50	51		
	Sedimentary Rock Fragments	23	15	13	14		
	Volcanic Rock Fragments	6	4	3	2		
	Metamorphic Rock Fragments	-	TR	2	-		
	Plutonic Rock Fragments	1	1	3	3		
	Detrital Calcite/Replacement	-	-	-	-		
	Detrital Dolomite	-	-	TR	-		
	Total	**64**	**61**	**71**	**70**		
Accessories	*Mica*	1	-	-	-		
	Heavy Minerals	TR	-	-	TR		
	Olivine/Pyroxene	-	-	-	-		
	Organic Matter	7	3	2	1		
	Magnetite	1	TR	TR	-		
	Detrital Chlorite	2	6	2	2		
	Total	**11**	**9**	**4**	**3**		
Matrix	*Micrite (Calcite/Dolomite)*	-	-	-	-		
	Clay	4	TR	TR	2		
	Total	**4**	**TR**	**TR**	**2**		
Authigenic Clays	*Kaolinite*	-	-	-	-		
	Illite	-	-	-	-		
	Chlorite	1	1	TR	-		
	Smectite	-	-	-	-		
	Unidentified	-	-	-	-		
	Total	**1**	**1**	**TR**	**0**		
Cements/ Replacement	*Quartz*	TR	5	10	10		
	Feldspar	-	-	-	-		
	Calcite	-	-	-	-		
	Ferroan Calcite	TR	10	-	-		
	Dolomite	-	-	-	-		
	Ferroan Dolomite	TR	-	7	3		
	Hematite/Limonite	-	TR	-	2		
	Laumontite	-	-	-	-		
	Pyrite	TR	TR	TR	TR		
	Anhydrite	-	-	-	-		
	Siderite	-	-	-	-		
	Residual Hydrocarbon	-	-	-	-		
	Total	**TR**	**16**	**17**	**16**		
Total Rock Volume (%)		**100**	**100**	**100**	**100**		
Structures		-	-	-	-		
Textures	*Grain Size Average*	fL	fU	mL	mL		
	Grain Size Range	slt-mU	vfL-mU	fL-mU	vfU-mU		
	Sorting	M	G	G	G		
	Roundness	SR-A	R-A	R-SA	R-SA		
Diagenesis	*Compaction*	XXX	XX-XXX	XXX	XXX		
	Grain Fabric	G, CC, F	G, F	G, CC, F	G, CC, F		
	Cementation	Cem	PCem	Cem	Cem		
	Dissolution	GD	SCD, GD	GR	GD		
Visible Porosity	*Intergranular*	TR	-	TR	-		
	Dissolution (unclassified)	TR	5	TR	1		
	Grain Dissolution	-	-	-	-		
	Cement Dissolution	-	-	-	-		
	Total Visible Porosity (%)	**TR**	**5**	**TR**	**1**		
Petrophysical Results	*Core Porosity (%)*	**1.3**	**0.9**	**0.7**	**0.8**		
	Gas Permeability (mD)	**<0.01**	**<0.01**	**<0.01**	**<0.01**		
Reservoir Quality		**Very Poor**	**Poor-Mode.**	**Very Poor**	**Poor**		

Structures: Mss-massive, Lm-laminae; Xlm-cross laminae; Xb-cross bedded; Bd-bedded; Bt-bioturbated
Compaction: X-slightly; XX-moderately; XXX-highly
Grain Fabric: G-grain supported; M-matrix supported; C-cement supported; P-point contacts; F-flat contacts; CC-concavo-convex contacts; S-sutured contacts
Cementation: Cem-completely cemented; NCem-non-cemented; PCem-partly cemented
Dissolution: Cor-corroded surfaces; GD-grain dissolution; GR-grain replacement; CCD-complete cement dissolution; SCD-selective cement dissolution

THIN SECTION DESCRIPTION: PLATE 1
LOCATION: OUTCROP
SKEENA GROUP
LITHARENITE

Sample # SP006 **Thin section Porosity 0.0%** **Core Porosity 1.7** **Permeability 0.01mD**

1 Overview showing light to medium gray, upper medium-grained, moderately sorted litharenite with sub-angular to sub-rounded framework grains. The grain size varies from 100 to 1500 microns. Framework grains are highly compacted as revealed by long and concavo-convex grain contacts. The framework grains are dominated by chert (Cht) and volcanic rock fragments. Calcite rock fragments and or framework grains replaced with calcite are common. Small amounts of quartz, feldspars, plutonic and sedimentary rock fragments are also present. Metamorphic rock fragments are present in trace amounts. Fine crystalline authigenic kaolinite (K) is common in intergranular pores and in dissolution pores. Visible thin section pores are absent in this sample. The reservoir quality is considered very poor.

2 Authigenic, fine crystalline kaolinite is present in intergranular primary pores (H4) as well as in secondary dissolution pores (J5). Secondary pores were created due to dissolution of calcite fragments and dissolution of replacement calcite. Some of the unknown grains were completely dissolved (or replaced) and subsequently those pores were filled with kaolinite (C9). The ghosts of the outer boundary of these dissolved grains are still present (A8). Cht=chert.

3-4 Photomicrograph 3 shows a possible limestone rock fragment (LRF), kaolinite cement (K), dark brown coating around grains (K11) and advanced level of mechanical compaction. Photomicrograph 4 shows a close-up view of kaolinite and its relationship with calcite (Cal) dissolution. Calcite fragment or replacement calcite in the lower part of the picture (J8, G8) was extensively dissolved prior to the kaolinite (K) precipitation. These dissolution or secondary pores (L8, L13) and the intergranular pores (E6) were later occluded with kaolinite. Inset photomicrograph (crossed polars) elaborate irregular and corroded calcite (Cal) that is surrounded by kaolinite (K).

1	2
3	4

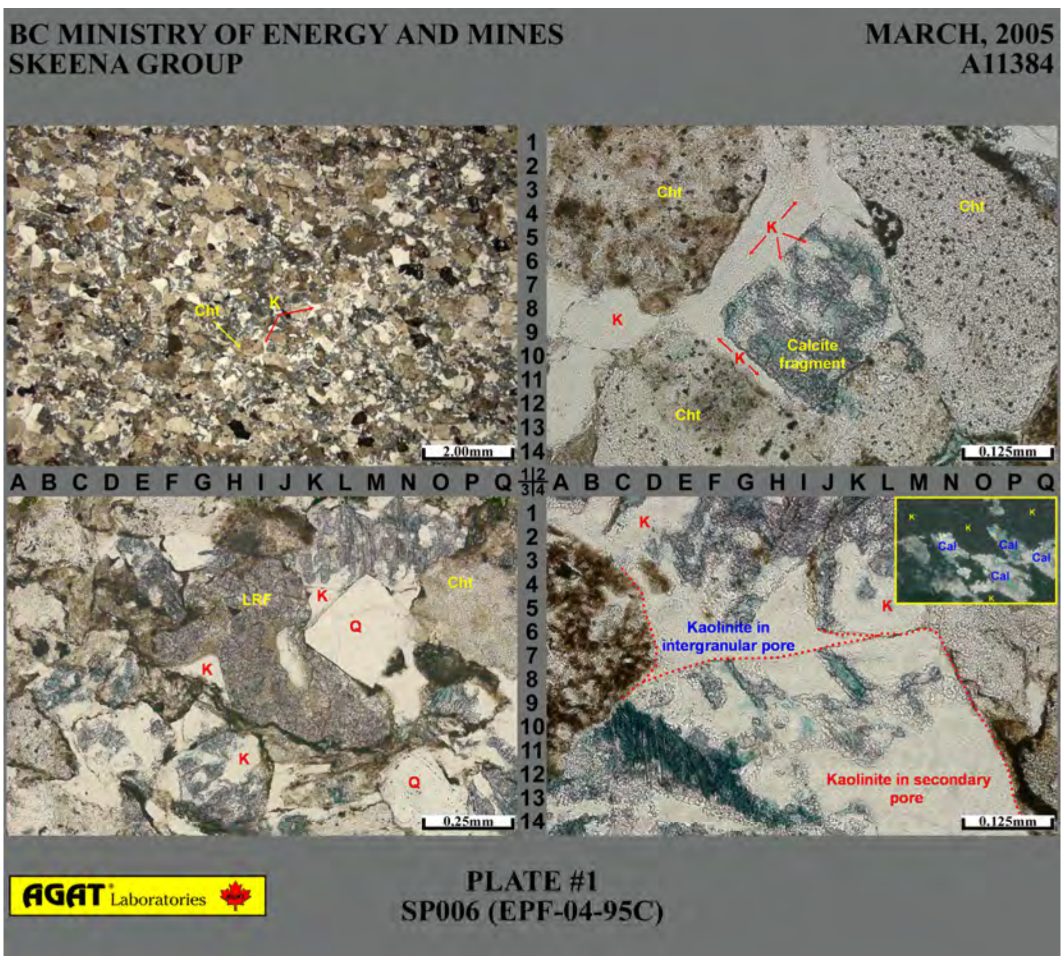


Plate 1. Skeena Group; litharenite.

LOCATION: OUTCROP
SKEENA GROUP
FELDSPATHIC LITHARENITE

Sample # SP011 **Thin section Porosity 1.0%** **Core Porosity 1.0%** **Permeability <0.01mD**

1 Overview showing light to medium gray, lower coarse-grained, moderate to well sorted feldspathic litharenite with rounded to angular framework grains. The grain size varies from 100 to 2000 microns. Framework grains are moderate to well compacted as revealed by long and some concavo-convex grain contacts. Volcanic rock fragments and feldspars dominate the framework grains. Plutonic rock fragments, chert and quartz grains are present in minor amounts. The grain size decreases upward. Pore filling chlorite is common in this sample. Kaolinite cement, present in other two samples of the Skeena Group, is absent from this sample. Minor amount of visible thin section porosity is due to dissolution of framework grains (arrows). The reservoir quality is considered poor.

2 Photomicrograph 2 shows abundant volcanic rock fragments (VRF), degree of mechanical compaction (J7) and pore filling green authigenic chlorite (Chl). The volcanic rock fragments have been partially chloritized as indicated by greenish groundmass around plagioclase laths (Plg laths).

3-4 Photomicrograph 3 shows a close-up view of reduced intergranular pores that were later occluded with chlorite cement (Chl). A plutonic rock fragment is shown in the lower left corner (PRF). Photomicrograph 4 shows a high magnification view of pore filling chlorite (Chl). Chlorite crystals are near perpendicular to the grain surfaces. The same view under crossed polars is shown in the upper right corner (inset). The size of chlorite crystals increases toward the center of the pore. Small chlorite crystals close to the pore walls appear darker (arrows in inset picture). Up to 100 microns long chlorite crystals are present in the central part of the pore. F=feldspar, VRF=volcanic rock fragment, Plg=plagioclase.

1	2
3	4

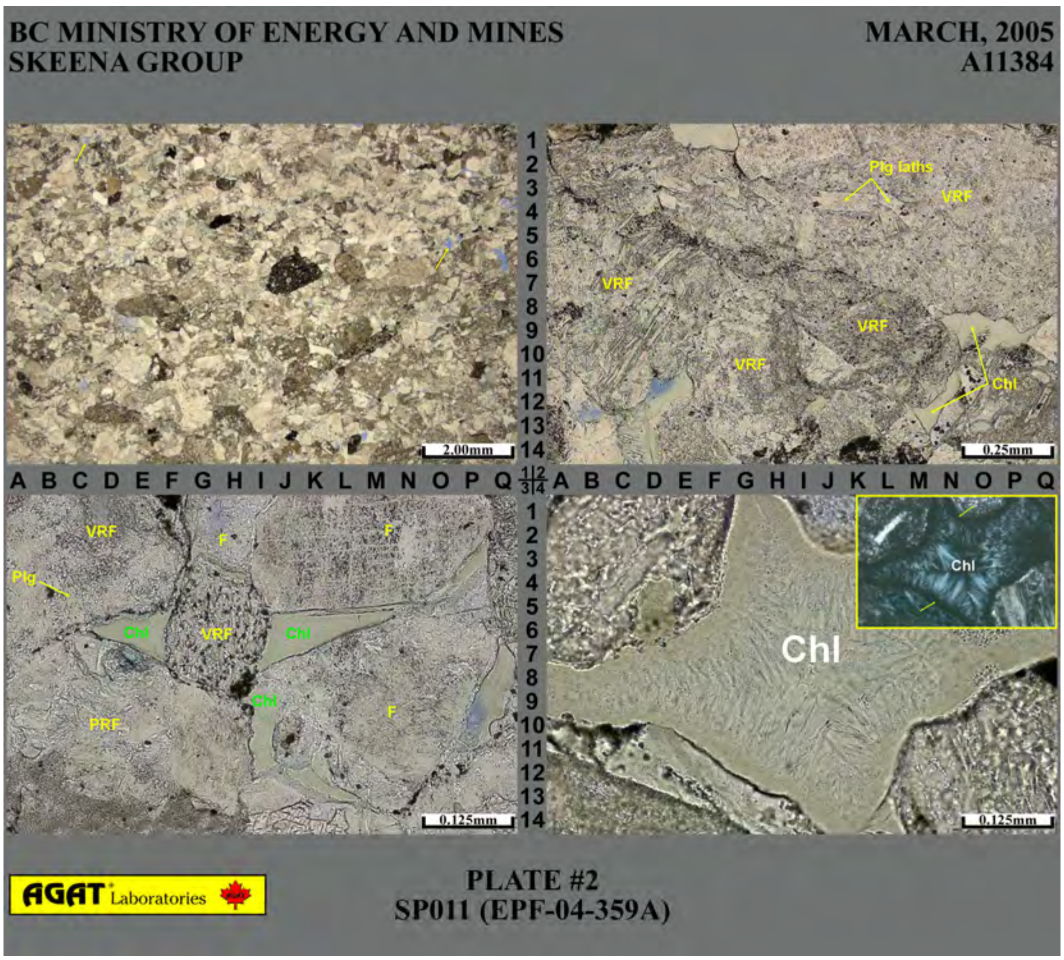


Plate 2. Skeena Group; feldspathic litharenite.

THIN SECTION DESCRIPTION: PLATE 3
LOCATION: OUTCROP
SKEENA GROUP
LITHARENITE

Sample # SP020 **Thin section Porosity TR** **Core Porosity 3.6%** **Permeability 0.02mD**

1 Overview showing light greenish gray, upper medium-grained, well sorted litharenite with rounded to sub-rounded framework grains. The grain size varies from 200 to 800 microns. Framework grains are moderate to well compacted as revealed by long and some concavo-convex grain contacts. The framework grains are dominated by chert and volcanic rock fragments. Small amounts of quartz, detrital calcite, feldspars, plutonic and sedimentary rock fragments are also present. Grain coating and pore filling chlorite is common. Kaolinite is present in intergranular pores and in grain dissolution secondary pores. Visible thin section porosity is minor. The reservoir quality is considered very poor.

2 Close-up view from the previous photomicrograph (H9) showing widespread grain coating early chlorite cement (Chl). Kaolinite is fairly common as well (K). Kaolinite is late stage cement. In places calcite (Cal) was dissolved and later these pores were filled with kaolinite (J5). VRF=volcanic rock fragment, LRF=limestone rock fragment, Cht=chert, Q=quartz.

3-4 Both photomicrographs 3 and 4 show the relationship of authigenic chlorite and kaolinite. Photomicrograph 3 shows a single calcite crystal (Cal) that has been dissolved at three different locations (L4, L6 L13) and later these dissolution pores were filled with kaolinite (K). Some unknown grain, surrounded by chlorite rims (Chl-rims), was completely dissolved prior to kaolinite precipitation (E9). Note silicified mudclasts (P10). Photomicrograph 4 shows a volcanic rock fragment (left side) that has been almost completely replaced with calcite. A plagioclase lath is still present in it (Plg lath). Note near uniform thickness of chlorite rims (Chl-rims) where the remaining pore spaces were filled with kaolinite (K). The inset photomicrograph shows the same view under crossed polars.

1	2
3	4

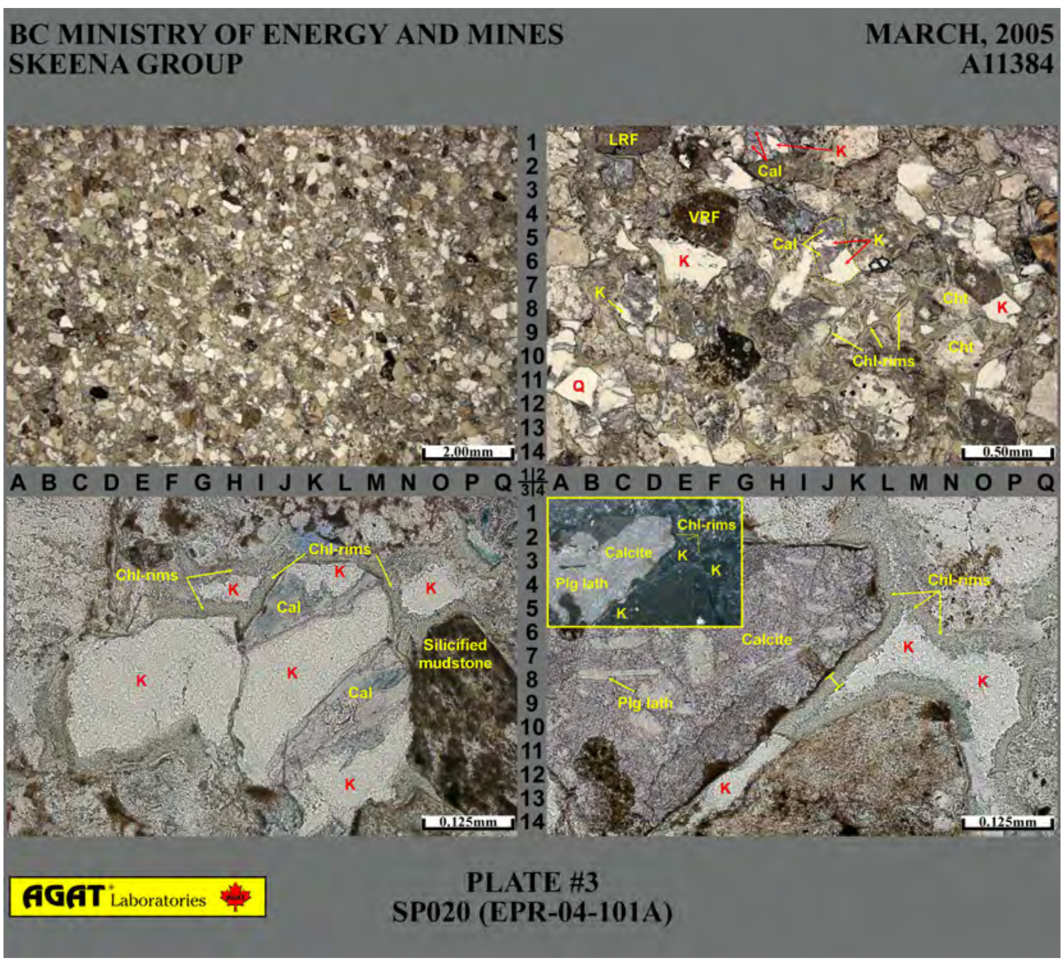


Plate 3. Skeena Group; litharenite.

THIN SECTION DESCRIPTION: PLATE 4
LOCATION: OUTCROP
BOWSER LAKE GROUP, JENKINS CREEK ASSEMBLAGE
LITHARENITE

Sample # SP008	Thin section Porosity TR	Core Porosity 3.8%	Permeability 5.02mD

1 Overview showing medium to dark brownish gray, grain-supported conglomerate. It is classified as chert rich litharenite. Medium-grained sand matrix (K6) is present between pebbles and granules. Overall, it is moderately sorted. The framework grains are well compacted as revealed by long and concavo-convex grain contacts. Beside chert (Cht), small to trace amounts of quartz and organic particles, sedimentary, volcanic, plutonic and metamorphic rock fragments are also present. Plagioclase and magnetite grains were rarely observed. Larger chert grains (K8) show ghosts of carbonate grains (calcispheres). Hematite/limonite cement is present between grains and in fractured grains (lower left corner). Only trace amount of thin section porosity was observed.

2 Close-up from the previous photomicrograph (I6) showing sand matrix that is cemented with pore filling silica (Qc) and quartz overgrowths (Qov). Note pyrite (Py) and a few pores (blue). The sand matrix is consists mainly of chert. Volcanic (VRF), plutonic (PRF), shale (SRF) and metamorphic (MRF) rock fragments are present in trace amounts.

3-4 Photomicrograph 3 shows a fractured chert grain (Cht). Fractures are filled with residual organic material and crushed rock material. Note some preserved bioclasts (lower left corner) in a chert grain. Photomicrograph 4 shows dissolution pore (DP) developed due to dissolution of a plagioclase crystal. Note stained surface of a volcanic rock fragment (VRF, upper right corner). Traces of bitumen (B) and pore occluding silica cement (Qc) are also shown. Qp=polycrystalline quartz.

1	2
3	4

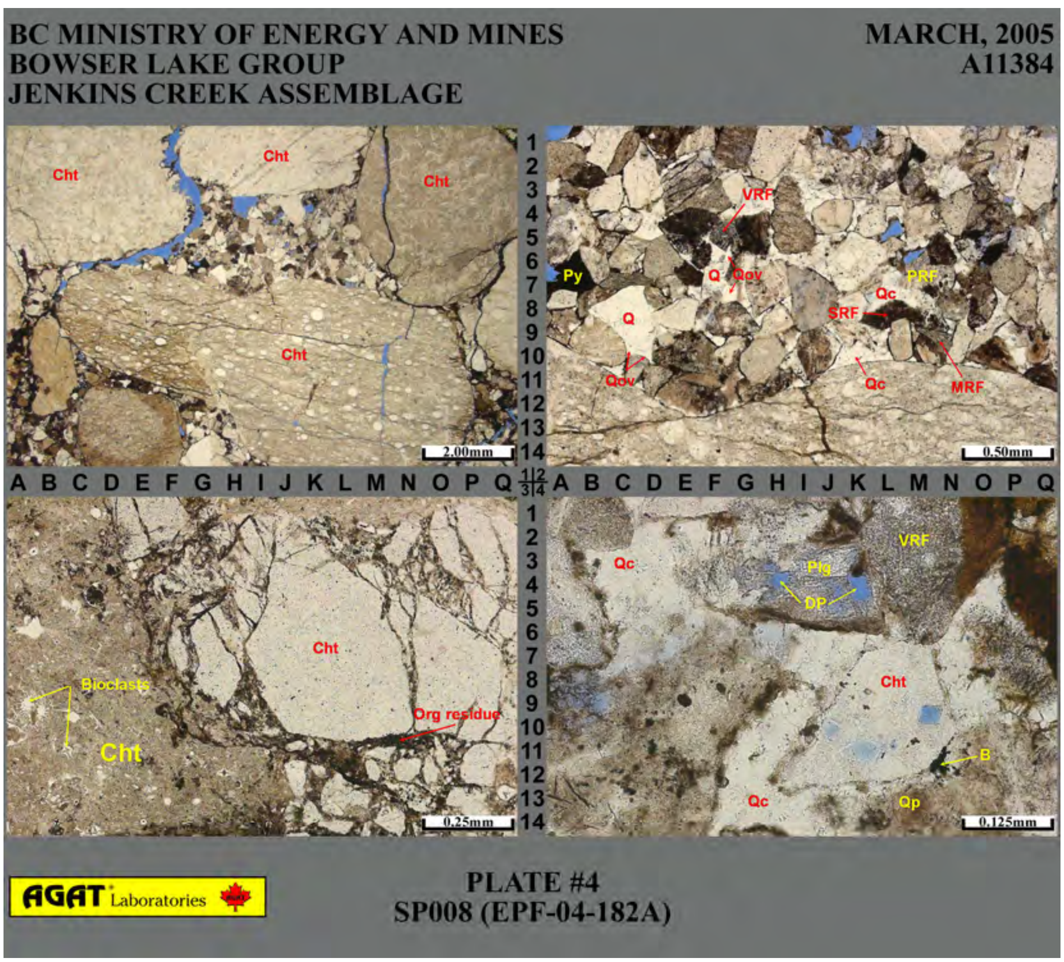


Plate 4. Bowser Lake Group, Jenkins Creek Assemblage; litharenite.

material is brown to reddish under reflected light. Pyrite and bitumen were rarely observed (Plate 4-4).

Diagenetic features, in a paragenetic order, include: on set of compaction, pyrite, formation of quartz cement between chert grains and as overgrowths around detrital quartz grains, in situ grain fracturing, rare bitumen and hematite/limonite.

Small amount of pyrite was precipitated in the intergranular areas during the early stage of diagenetic history (Plate 4-2). Pore-occluding quartz cement between chert grains is more common than quartz overgrowths on detrital quartz grains (Plates 4-2, 4-4). With time, increasing mechanical compaction (burial and compressional stresses) created fractures in some larger grains (Plate 4-3). Pore filling bitumen is extremely rare (Plate 4-4). It is assumed that hematite/limonite cements were deposited mainly after the uplift of these sediments. Some of the fractures in chert grains were also stained or filled with hematite/limonite cements. A few pores were developed due to dissolution of feldspar and other grains (Plate 4-4).

Porosity, Permeability and Reservoir Quality

Visible pores are present in trace amount. Core porosity is 3.8% and gas permeability 5.02 mD. Visible pores are intragranular due to partial dissolution of feldspars (Plate 4-4), chert and possibly some iron bearing minerals. These pores are poorly interconnected. This sample gives the highest permeability value (5.02 mD) and it is believed to be largely due to microfractures present in the analyzed plug. Much of the core porosity is believed to be microporosity present in chert and other grains. Based on low visible thin section porosity, core porosity, microfractures in the plug and permeability value this sample is considered to represents poor reservoir quality.

(b) Groundhog-Gunanoot Assemblage (Sample SP010)

Only one outcrop sample was collected from the Groundhog-Gunanoot Assemblage of the Bowser Lake Group, British Columbia. It is located in the central part of the study area (Figure 1). This sample is characterized by medium gray sandstone. Fine crystalline yellow spots are present near the outcrop surfaces and as well as deep inside the sample. Some pores surrounded by this yellow stuff can be observed under the binocular microscope.

This sample is classified as chert rich litharenite (Table 1, Figure 3). It is lower medium-grained, well sorted sandstone with subangular to rounded framework grains.

Framework grains are dominated by chert. Moderate to small amounts of quartz, sedimentary rock fragments, volcanic rock fragments, magnetite, organic matter and detrital chlorite are also present. Feldspars and plutonic rock fragments are not common (Table 1).

Chert grains with variable colours appear in crypto- to microcrystalline textures (Plate 5-3). Most chert grains are microcrystalline with no obvious features to suggest that they were originally volcanic rock fragments. Mica and other clay inclusions are common in chert grains. A few chert grains show silica filled fractures that were developed in the source areas prior to deposition. Monocrystalline quartz is more common than polycrystalline quartz (Plate 5-2). Quartz overgrowths are rare (Plate 5-2). Sedimentary rock fragments and detrital chlorite grains have been deformed between rigid grains and it lowered the reservoir porosity (Plate 5-2). Both potassium feldspar and plagioclase grains are present. These grains are altered and show sericitization. Volcanic rock fragments are altered and partially chloritized (Plate 5-3). Volcanic rock fragments often contain plagioclase laths, however, olivine or pyroxene grains were not observed. Angular to subrounded magnetite grains shows metallic luster under reflected lights (Plate 5-4). Some of the magnetite grains were probably oxidized and weathered into limonite/hematite.

Matrix clays occur in minor amounts as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays. Some of the matrix is due to deformation of softer mud clasts between competent grains (pseudo matrix).

Diagenesis and Paragenetic Sequence

Mechanical compaction has significantly reduced the original porosity as revealed by long and concavo-convex grain contacts in this sample (Plate 5-2). The remaining pores were commonly filled with silica cement and limonite/hematite and less commonly with ferroan dolomite. Diagenetic features, in a paragenetic order, include: on set of compaction, siderite (?), formation of quartz cement between chert grains and rarely as overgrowths around detrital quartz grains, alteration and dissolution of siderite and magnetite helped to develop limonite/ hematite, ferroan dolomite precipitated in dissolution pores around altered material and finally some ferroan dolomite was itself dissolved.

It appears that early siderite was present in this sample that has been largely altered or dissolved (see below). Quartz cement precipitated after some compaction (Plate 5-2), as it is present in reduced intergranular pores. Blocky pore-occluding quartz cement between chert grains is common. Quartz overgrowths are less common. Uplift/exposure or incursion of meteoric water oxidized and partially dissolved siderite. As a result of this alteration, limonite/hematite precipitated around altered areas (Plate 5-3). Some limonite/hematite probably also developed due to the alteration of magnetite grains. This limonite/hematite material is brownish yellow to reddish brown under reflected light. Plate 5-C shows part of this complex diagenetic history. It appears that early siderite crystals first filled pores and also replaced some adjacent framework grains (rhomb shaped original crystal in Plate 5-3). Subsequently, the siderite crystals was altered, oxidized (limonite) and partially dissolved. These dissolution pores were later partially filled with ferroan dolomite. Ferroan dolomite is always lined with altered limonite/hematite and brownish

THIN SECTION DESCRIPTION: PLATE 5
LOCATION: OUTCROP
BOWSER LAKE GROUP, GROUNDHOG-GUNANOOT ASSEMBLAGE
LITHARENITE

Sample # SP010	Thin section Porosity 3.0%	Core Porosity 2.0%	Permeability <0.01mD

1 Overview showing medium gray, lower medium-grained, well sorted litharenite with rounded to sub-angular framework grains. The grain size varies from 200 to 700 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert followed by quartz grains, sedimentary rock fragments and volcanic rock fragments. Magnetite, organic matter and detrital chlorite grains are also present. Feldspars and plutonic rock fragments are not common. Visible thin section pores (3%) are poorly interconnected (yellow arrows). The reservoir quality is considered poor.

2 Photomicrograph 2 shows concavo-convex grain contacts due to advanced mechanical compaction (C9). Feldspar grains (F) are partially chloritized (green patches in feldspar). Note detrital chlorite grain (F13) and organic matter rich shale fragment (SRF). Blocky quartz cement is common, however, minor quartz overgrowths are also present (Qov).

3-4 Photomicrograph 3 shows complex diagenetic history. It appears that siderite first filled a pore space and also replaced adjacent framework grains (L5). Subsequently, the siderite crystals was altered, oxidized (limonite) and partially dissolved (brown to dark brown). This dissolution pores (P) was later partially filled with ferroan dolomite (FeDol). In places, this ferroan dolomite was itself partially dissolved. Photomicrograph 4 shows magnetite (C5) and unknown heavy minerals (D9).

1	2
3	4

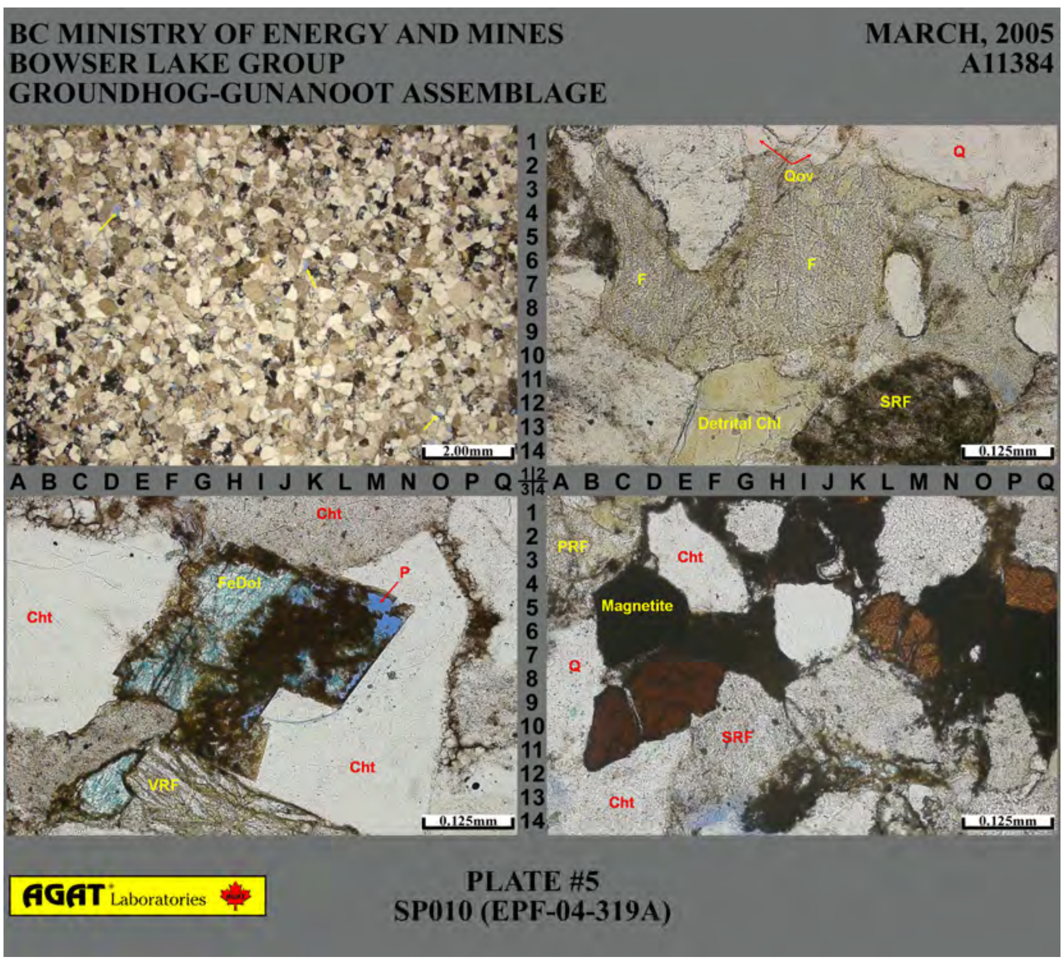


Plate 5. Bowser Lake Group, Groundhog-Gunanoot Assemblage; litharenite.

material suggesting that ferroan dolomite is post date limonite/hematite. With changing pore fluid compositions, this ferroan dolomite itself was partially dissolved.

Porosity, Permeability and Reservoir Quality

Thin section porosity is estimated 3%. Core porosity is 2.0% and gas permeability <0.01 mD. Visible pores include dissolution pores (Plate 5-3) and minor reduced intergranular pores. Dissolution pores were developed due to alteration and dissolution of siderite, magnetite, ferroan dolomite and chert grains. These pores are poorly interconnected. Slightly higher thin section porosity than the routine core porosity value may be due to slightly different sample locations. Based on low visible thin section porosity, core porosity and permeability value this sample is considered to represents poor reservoir quality.

(c) Muskaboo Creek Assemblage (SP001, SP009, SP012, SP015, SP018, SP021, SP022)

Seven outcrop samples were collected from the Muskaboo Creek Assemblage of the Bowser Lake Group, British Columbia. These samples are spread all over the study area (Figure 1). Samples SP001 and SP009 are light to medium greenish grey and samples SP012, SP015, SP018 and SP021 medium gray. Sample SP022 is light brownish gray. Some of these outcrop samples show filled or partially filled fractures (SP001, SP009, SP018). Examination of these outcrop samples under the binocular microscope indicates the presence of porosity near the weathered surfaces; however, deep inside the sample these pores are either missing or less common (SP012). Based on mineral composition, the Muskaboo samples can be divided into two units:

(1) Chert rich unit (SP012, SP015, SP018),

(2) Volcanic rock fragment rich unit (SP001, SP009, SP021, SP022).

These two units will be described separately as their diagenetic minerals are also different to some extent.

Chert Rich Unit (SP012, SP015, SP018)

All these samples are located in the northern half of the study area (Figure 1). These samples are classified as chert rich litharenite (Table 1, Figure 3). These sandstones are lower to upper medium-grained, moderately sorted sandstones with rounded to angular framework grains (Plates 8, 9, 10).

Framework grains are dominated by chert (Plate 8-2). Moderate amounts of quartz, feldspars, sedimentary and volcanic rock fragments and detrital chlorite grains are also present (Plates 8-3, 9-2, 10-2). Plutonic and metamorphic rock fragments, mica and magnetite are present either in small amounts or locally absent. Compared to samples SP015 and SP018, detrital chlorite is more common in sample SP012 (Plate 8-3).

Chert grains with variable colors appears in crypto- to microcrystalline textures. Fibrous chert was rarely observed. Most chert grains are very fine crystalline (Plate 8-2). Some chert grains contain micaceous material. Pyrite and organic matter inclusions are also present in some chert grains. Rare silica filled fractures in chert grains reflect the character of the source rocks.

Sedimentary rock fragments consist mainly of shale (Plate 9-2). Brown to dark brown shale fragments has been deformed between competent grains. Some of them appear to contain lot of organic matter (Plate 10-2) and others partially chertified. Fine-grained sandstone rock fragments were rarely observed (SP012). These sandstone fragments were cemented with quartz overgrowths and calcite. Volcanic rock fragments contain plagioclase laths in fine groundmass and they are partially altered into chlorite (Plate 8-3). In some volcanic rock fragments, pyrite inclusions are common. Some darker volcanic rock fragments with fine crystalline olivine/pyroxene like material may represent basaltic and or andesitic volcanic rocks. More or less equal amount of monocrystalline and polycrystalline quartz is present in these sandstones where quartz overgrowths rarely developed (Plate 10-4). Both plagioclase and K-feldspars are present, often with mica inclusions (Plate 8-2). A few feldspar grains are partially replaced with calcite. Plutonic rock fragments contain multiple crystals of feldspars and quartz. Detrital chlorite grains are present in all three samples; however, it is more common in SP012 (Plate 8-3). These chlorite grains often contain pyrite and other opaque inclusions and show plastic deformation between rigid grains (Plate 10-4). Biotite grains have been deformed due to mechanical compaction. Metamorphic rock fragments contain mica and quartz crystals.

Matrix clays occur in minor amounts as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays. Some of the matrix is due to deformation of soft mud clasts between competent grains (pseudo matrix).

Diagenesis and Paragenetic Sequence

Much of the porosity in the chert rich sandstones of the Muskaboo Assemblage was destroyed due to mechanical compaction (Plates 8, 9, 10). Framework grains show advanced degree of compaction as revealed by concavo-convex and long grain contacts (Plate 9-2). The remaining pores were occluded with chlorite rims (Plates 8-3, 9-3), illite (Plate 9-4), quartz cement (Plates 8-4, 9-4) and calcite (Plates 8-4, 10-2). Replacement and pore filling ferroan calcite (and calcite) is more common in SP018 than in the other two samples (SP012, SP015).

Diagenetic sequence of these samples, particularly for samples SP012 and SP015, resemble the Todagin sandstone (SP014). Diagenetic features, in a paragenetic order, include: on set of compaction, local pyrite, chlorite rims, fibrous illite, quartz cement and calcite (ferroan calcite in SP018). Some of these diagenetic features may be locally absent. For example, illite was not observed in

THIN SECTION DESCRIPTION: PLATE 8
LOCATION: OUTCROP
BOWSER LAKE GROUP, MUSKABOO CREEK ASSEMBLAGE
LITHARENITE

Sample # SP012 **Thin section Porosity 0.0%** **Core Porosity 2.2%** **Permeability <0.01mD**

1 Overview showing medium gray, lower medium-grained, moderately sorted litharenite with rounded to angular framework grains. The grain size varies from 100 to 400 microns. Framework grains are well compacted as revealed by long and some concavo-convex grain contacts. The framework grains are dominated by chert and detrital chlorite. Sedimentary and volcanic rock fragments, quartz and feldspar are present in moderate amounts. Minor amounts of plutonic and metamorphic fragments, mica and magnetite are present as well. Quartz, chlorite and calcite are present in intergranular pores. Visible thin section pores were not observed. The reservoir quality is considered very poor.

2 Photomicrograph 2 (crossed polars) shows abundant chert grains (Cht). Small amount of quartz cement (Qc) is present between chert and other framework grains. A few feldspar (F) and quartz (Q) grains are also shown.

3-4 Photomicrograph 3 shows a sub-triangular shaped primary pore first lined with light greenish chlorite followed by pore filling quartz cement. Chert grains (Cht), detrital chlorite, plagioclase and volcanic rock fragments (VRF) are present in the sample. The volcanic rock fragment is partially chloritized and compressed against relatively competent grains. Photomicrograph 4 shows a higher magnification view of calcite and quartz (Q) cements. Textural relationship suggests that calcite developed after quartz cement.

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3	4

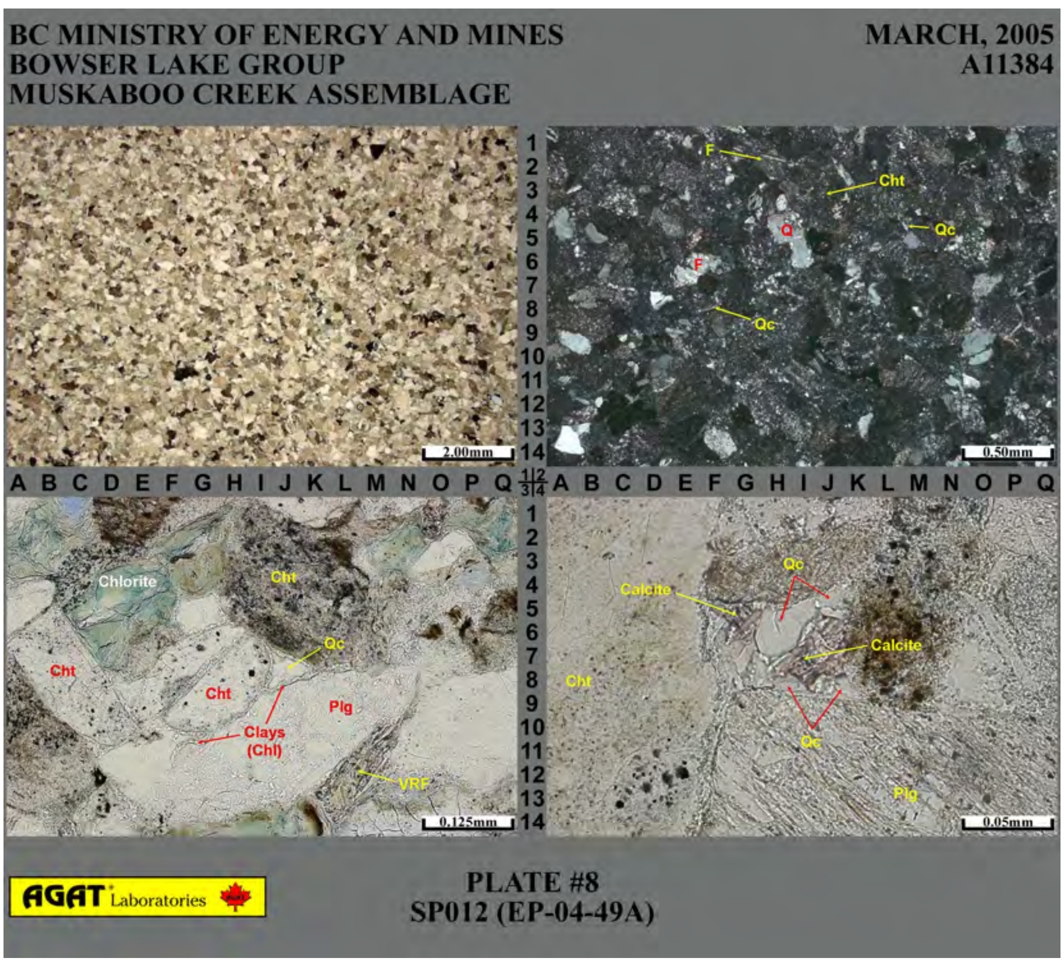

Plate 8. Bowser Lake Group, Muskaboo Creek Assemblage; litharenite.

THIN SECTION DESCRIPTION: PLATE 9
LOCATION: OUTCROP
BOWSER LAKE GROUP, MUSKABOO CREEK ASSEMBLAGE
LITHARENITE

Sample # SP015 | Thin section Porosity TR | Core Porosity 0.8% | Permeability <0.01mD

1 Overview showing medium gray, upper medium-grained, moderately sorted litharenite with rounded to sub-angular framework grains. The grain size varies from 150 to 700 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert. Volcanic, sedimentary and plutonic rock fragments, quartz, feldspar and detrital chlorite are present in moderate amounts. Mica and metamorphic rock fragments are present in minor amounts. Authigenic quartz, chlorite, illite and calcite are present as cements. Only traces of visible thin section pores are present. The reservoir quality is considered very poor.

2 Photomicrograph 2 shows well-compacted framework grains. Note concavo-convex grain contacts (thick arrows). In places, calcite cement was precipitated after grain coating chlorite (Chl-rims). After grain coating chlorite (Chl-rims), some pores were filled with quartz cement (Qc, upper left corner). SRF=shale rock fragment, Cht=chert.

3-4 Photomicrograph 3 shows an excellent view of three authigenic minerals and their paragenetic relationships. Pores were first lined with chlorite (Chl-rims, Clay 1) and subsequently fibrous illite (Clay 2) developed on top of chlorite. After illite, quartz cement (Qc) occluded the remaining pore. In relatively smaller pores (left side), chlorite and illite alone completely occluded the pores and there was no space for quartz cement (F5). The yellow boxed area has been further enlarged in the next photomicrograph. Photomicrograph 4 (crossed polars) shows a close-up view of three authigenic minerals (chlorite, illite and quartz) as mentioned in the previous photomicrograph.

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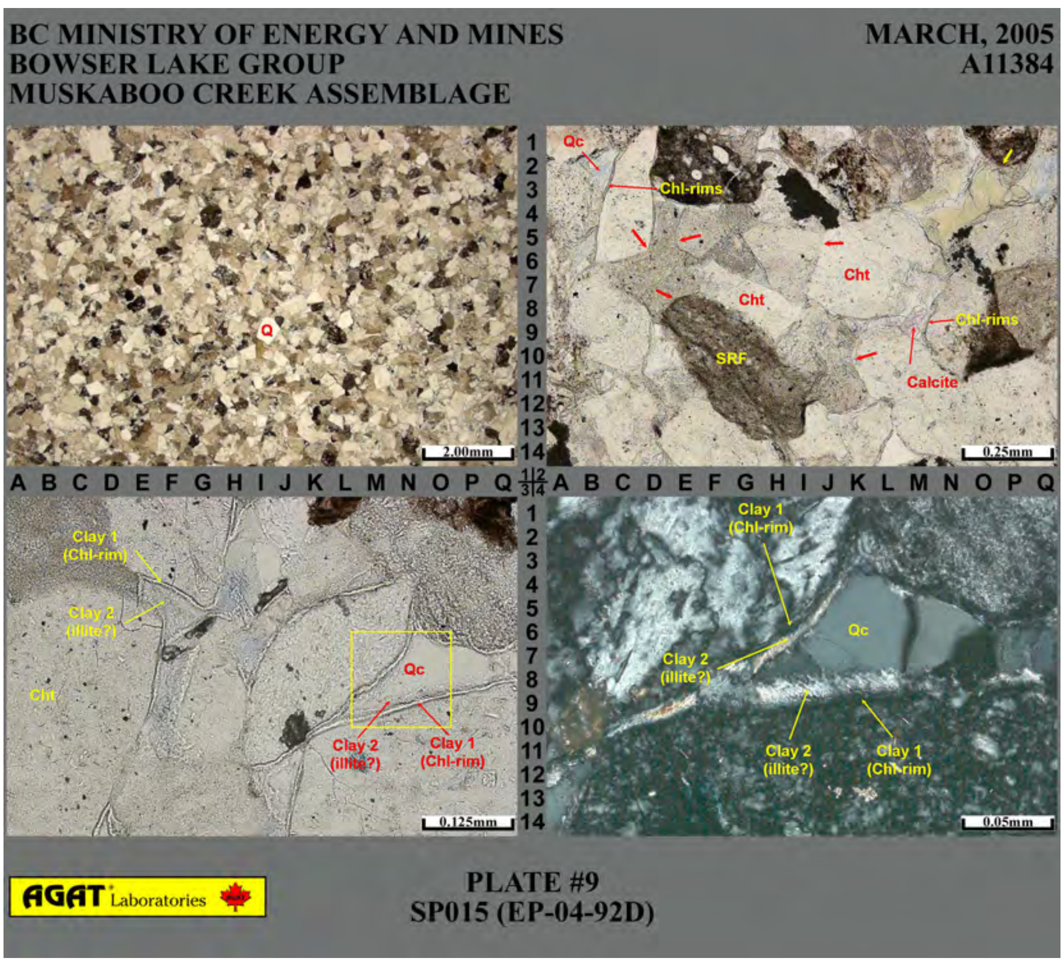

Plate 9. Bowser Lake Group, Muskaboo Creek Assemblage; litharenite.

THIN SECTION DESCRIPTION: PLATE 10
LOCATION: OUTCROP
BOWSER LAKE GROUP, MUSKABOO CREEK ASSEMBLAGE
LITHARENITE

Sample # SP018 **Thin section Porosity TR** **Core Porosity 1.7%** **Permeability <0.01mD**

1 Overview showing medium gray, lower medium-grained, moderately sorted litharenite with rounded to angular framework grains. The grain size varies from 100 to 1000 microns. Framework grains are moderately to well compacted as revealed by long and some concavo-convex grain contacts. The framework grains are dominated by chert. Moderate amounts of volcanic and sedimentary rock fragments, quartz, detrital chlorite and feldspar are also present. Metamorphic rock fragments and mica are not common. Only traces of thin section pores are present. The reservoir quality is considered very poor.

2-3 Photomicrograph 2 shows a close-up view of early pyrite (Py) and ferroan calcite (FeCal) cements. Shale clasts (P12) have been deformed due to mechanical compaction. The yellow arrow shows a concavo-convex grain contact. Photomicrograph 3 shows another view of ferroan calcite cement (FeCal). The iron content within the calcite probably varies as indicated by variable staining colours. The inset photomicrograph (lower left) shows that the reduced intergranular pore is completely filled with illite cement. Grain coating chlorite did not develop in this pore (compare with Plate 9). Py=pyrite, VRF=volcanic rock fragment, Cht=chert.

4 Photomicrograph 4 shows deformed detrital chlorite that contains inclusions of opaque mineral (arrows). The possibility of chloritization of detrital mica cannot be ruled out. Q=quartz, Cht=chert.

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3	4

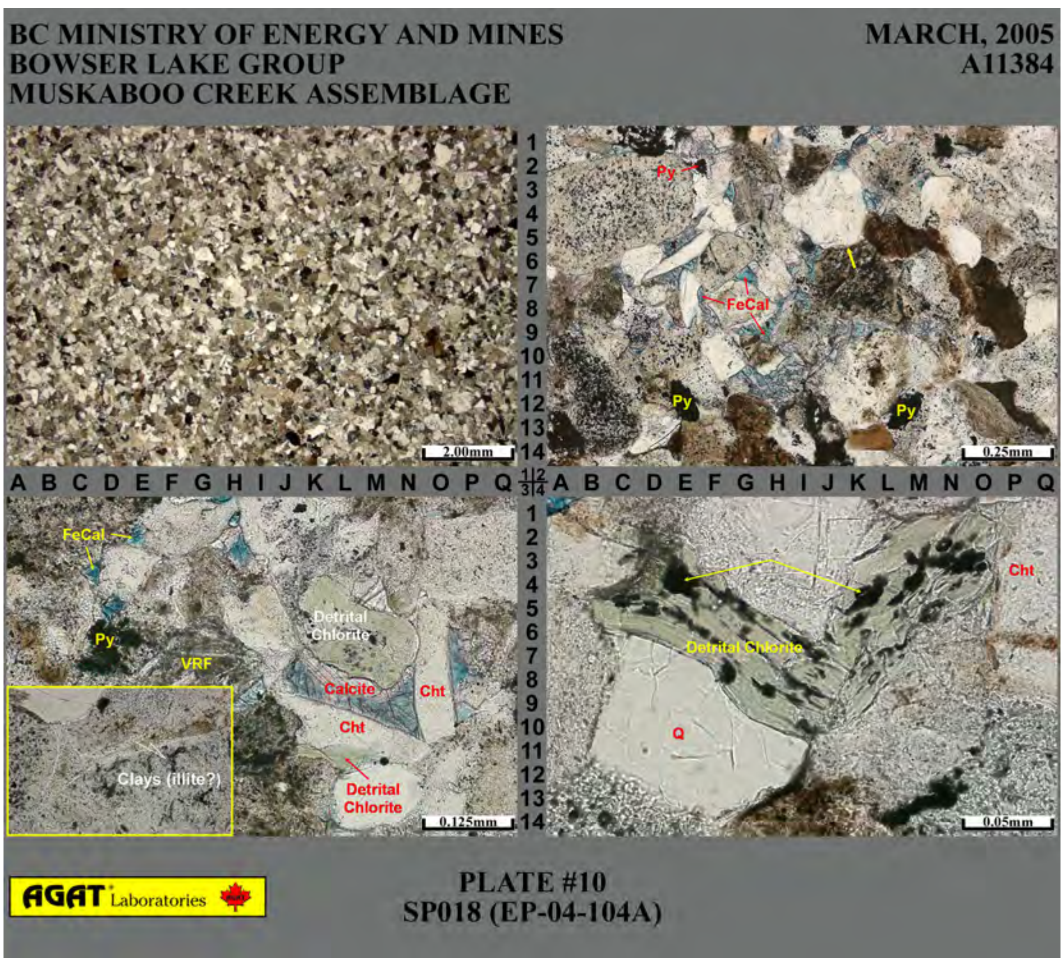

Plate 10. Bowser Lake Group, Muskaboo Creek Assemblage; litharenite.

SP012. Grain coating chlorite and quartz cement is less common in SP018. Note that detailed SEM work is required to confirm these authigenic clays.

Chlorite rims are discontinuous and absent at grain contacts (Plate 9-3). They were developed after some mechanical compaction. The thickness of these rims is fairly uniform. Fibrous illite clays developed after chlorite (Plates 9-3, 9-4). It is more pronounced in SP015 (Plate 9-4). Often, the remaining pores were filled with authigenic quartz (Plate 9-4). Compared to pore filling quartz cement, quartz overgrowths are rare in these samples. Where chlorite was not developed, pores may contain only illite (inset in Plate 10-3). Only a few remaining pores were filled with calcite or ferroan calcite (Plate 8-4). Significant amount of calcite in SP018 appear to have replaced grains (Plate 10-3). The amount of iron in calcite is variable as revealed by variable staining colours. In summary, compaction and some cementation has destroyed almost all of the porosity in these samples.

Porosity, Permeability and Reservoir Quality

Thin section porosity varies from zero to trace amounts. Core porosity varies from 0.8 to 2.2% and gas permeability <0.01 mD in all samples. Visible pores include intergranular and chert dissolution. These pores are poorly interconnected. Some microporosity may be present between clays. Based on low to zero percent visible thin section porosity, very low core porosity and permeability values, these samples are considered to represent very poor reservoir quality.

Volcanic Rock Fragment Rich Unit (SP001, SP009, SP021, SP022)

Four samples from the Muskaboo Creek Assemblage are relatively rich in volcanic rock fragments (SP001, SP009, SP021, SP022). All these samples are located in the southern half of the study area. The colour of these sandstones varies from light to medium greenish gray (SP001, SP009) to medium gray (SP021) and light brownish gray (SP022). These samples are classified as feldspathic litharenite (SP001, SP021, SP022) and lithic arkose (SP009) (Table 1, Figure 3). Most of these samples are lower medium-grained (SP009, SP021, SP022). One sample is upper coarse-grained (SP001). Sorting is poor in two samples (SP001 and SP022) and moderate to good in the SP021 and SP009 samples respectively. The shape of grains varies from rounded to angular.

Framework grains are dominated by volcanic rock fragments (Plates 6, 7, 11, 12). Substantial amounts of feldspar, plutonic rock fragments and chert grains are also present (Plates 7-2, 12-2). Other grains (quartz, sedimentary or metamorphic rock fragments, mica, olivine/pyroxene and detrital chlorite) are present in minor to trace amounts (Plate 7-3).

Type and colour of volcanic rock fragments are variable. Plagioclase laths are usually surrounded with fine groundmass (Plate 6-2). Occasionally, the groundmass appears to contain small crystals of olivine and pyroxene (Plate 6-2). The amount of plagioclase laths in volcanic fragments is variable. The groundmass is often chloritized (Plate 12-2). Some feldspar laths are completely or partially altered into chlorite (Plate 6-2). Feldspar laths may show preferred orientation in some volcanic rock fragments. Some volcanic rock fragments contain a few or no plagioclase laths. A few volcanic rock fragments are darker brown and extremely fine crystalline. Some darker volcanic rock fragments with fine crystalline olivine/pyroxene like material may represent basaltic and or andesitic volcanic rocks (Plates 6-2, 11-2). Some volcanic fragments have been significantly compacted between other grains (Plate 12-2). A few volcanic rock fragments contain abundant opaque minerals. Magnetite inclusions are present in some volcanic rock fragments. Dark brown to black lining around grains is believed to be opaque oxide minerals (SP001, SP022; Plates 6, 12).

Plutonic rock fragments contain multiple crystals of feldspars and quartz. Some plutonic rock fragments contain olivine and pyroxene crystals and others contain abundant plagioclase crystals. Mica may be present in trace amount. The size of crystals in plutonic rock fragments varies from small to relatively larger crystals. The presence of olivine and pyroxene in some plutonic rock fragments suggests that intermediate or basic igneous rocks also contributed for these sandstones. Metamorphic rock fragments usually contain lot of micaceous minerals. Plagioclase is more common than K-feldspar (Plate 7-2). Inclusions of mica are often present in feldspars. Inclusions of olivine and pyroxene were rarely observed in feldspar crystals (SP022). Feldspar grains may be partly altered into chlorite or sericitized. A few feldspar grains have been partially replaced with calcite. Chert grains with variable colors appears in crypto- to microcrystalline textures. Some chert grains contain micaceous material and traces of hematite. Pyrite and organic matter inclusions are also present in some chert grains.

Monocrystalline quartz is more common than polycrystalline quartz (Plate 7-2). Note that olivine/pyroxene grains were not observed from the chert rich Muskaboo Creek samples. This may suggests different source areas for the Muskaboo Creek sandstones present in the north and south (Figure 1). A few pyroxene and olivine crystals were partially dissolved (SP022). Note that additional olivine and pyroxene are present within the volcanic rock fragments. Detrital chlorite grains are present in small amount. Biotite grains have been deformed due to mechanical compaction. Sedimentary rock fragments are minor or absent.

Matrix clays occur in minor amount as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays.

THIN SECTION DESCRIPTION: PLATE 6
LOCATION: OUTCROP
BOWSER LAKE GROUP, MUSKABOO CREEK ASSEMBLAGE
FELDSPATHIC LITHARENITE

Sample # SP001 **Thin section Porosity 0.0%** **Core Porosity 0.7%** **Permeability <0.01mD**

1 Overview showing light to medium greenish gray, upper coarse-grained, poorly sorted feldspathic litharenite with rounded to angular framework grains. The grain size varies from 150 to 2000 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. Volcanic rock fragments with substantial amounts of chert, plutonic rock fragments and feldspars dominate the framework grains. Small to trace amounts of quartz, olivine / pyroxene and metamorphic rock fragments are also present. Note thin calcite filled fracture. Visible thin section pores are absent. The reservoir quality is considered very poor. Cht=chert, VRF=volcanic rock fragments, Q=quartz.

2 Photomicrograph 2 shows strongly compacted framework grains. Most framework grains are of volcanic origin. Note some chloritized phenocrysts (E6). Small intergranular pores (M8, J11) are filled with chlorite (Chl) and other clay minerals (E12). Most grains are rimmed with opaque oxide minerals (black). The inset photomicrograph (crossed polars) shows small crystals of olivine and pyroxene (Olv/Pyr) embedded in the groundmass and surrounded by plagioclase laths (F) in a volcanic rock fragment.

3-4 Photomicrograph 3 shows intergranular pores filled with laumontite cement. The inset photomicrograph shows the enlarged area (J10) under crossed polar light. Photomicrograph 4 shows anhydrite cement. The inset photomicrograph shows the higher magnification view of anhydrite.

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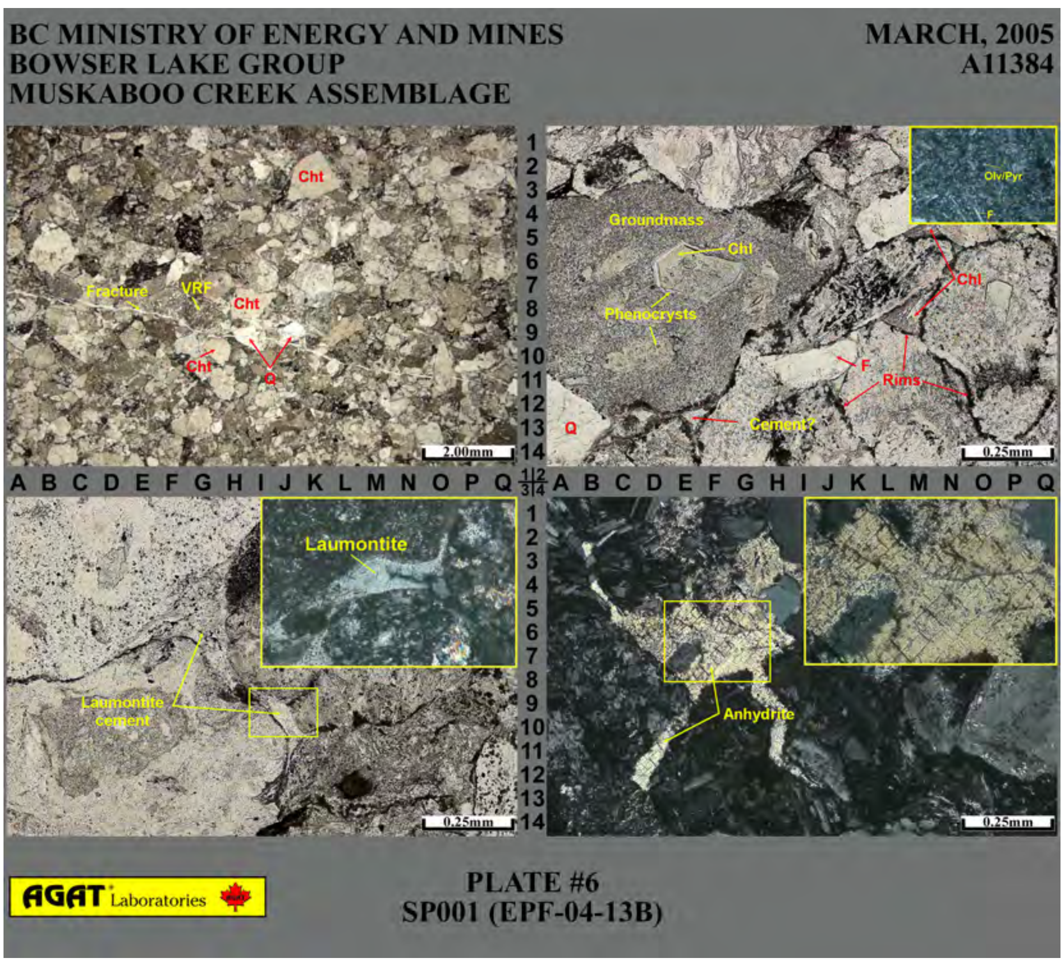

Plate 6. Bowser Lake Group, Muskaboo Creek Assemblage; feldspathic litharenite.

THIN SECTION DESCRIPTION: PLATE 7
LOCATION: OUTCROP
BOWSER LAKE GROUP, MUSKABOO CREEK ASSEMBLAGE
LITHIC ARKOSE

Sample # SP009 **Thin section Porosity TR** **Core Porosity 0.7%** **Permeability <0.01mD**

1 Overview showing medium greenish gray, lower medium-grained, well sorted lithic arkose with rounded to angular framework grains. The grain size varies from 100 to 350 microns. Framework grains are moderately compacted and the intergranular areas are filled with authigenic chlorite. Volcanic rock fragments and feldspar grains dominate the framework grains. Substantial amounts of plutonic rock fragments and chert grains are also present. Quartz, olivine/pyroxene, sedimentary rock fragments and detrital chlorite are present in small amounts. Visible thin section pores are rare. The reservoir quality is considered very poor. VRF=volcanic rock fragment, Q=quartz.

2 Close-up from the previous photomicrograph (I10) showing common pore occluding chlorite cement. Several plagioclase grains (Plg) and volcanic rock fragments (VRF) are present in this sample. Q=quartz.

3-4 Photomicrograph 3 (crossed polars) shows olivine grains (Olv) characterized by high relief, high birefringence and random cracks. Photomicrograph 4 shows authigenic calcite. It occludes intergranular pores and also replaces the surrounding chlorite (Chl).

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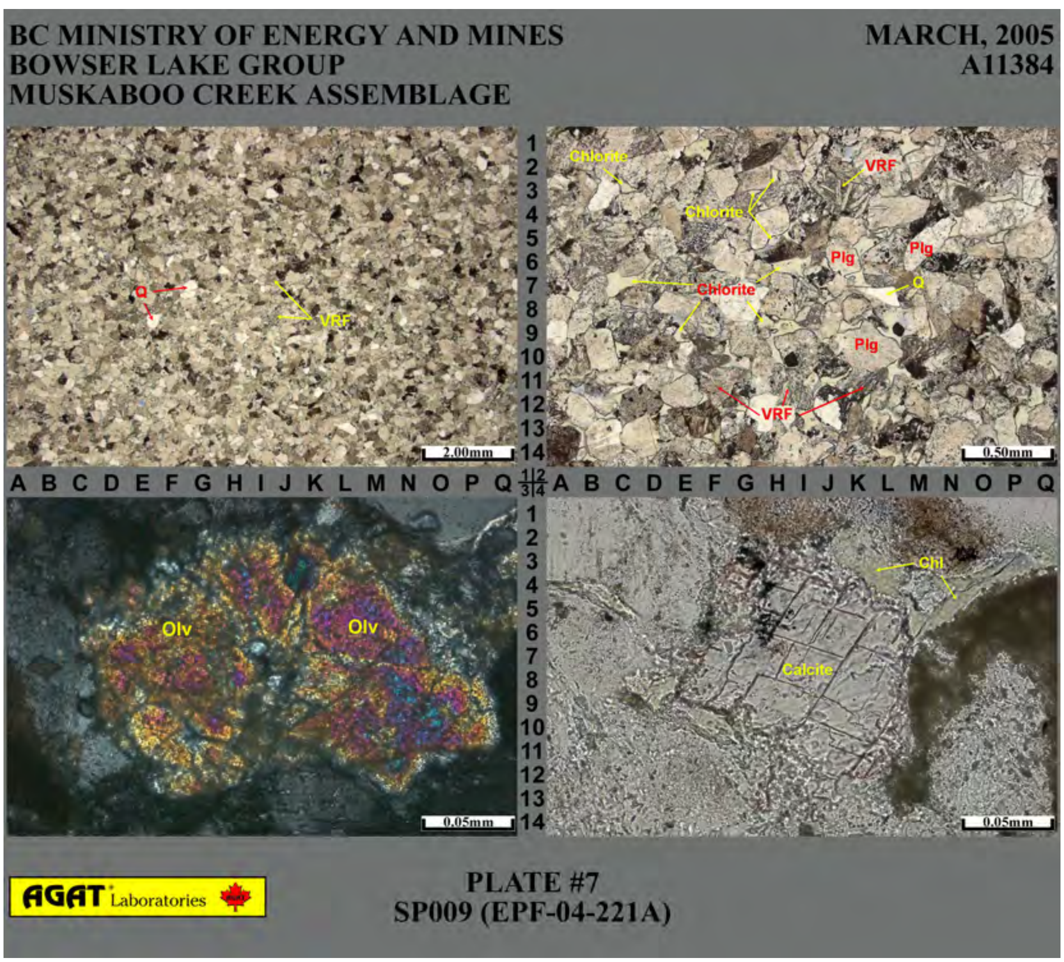

Plate 7. Bowser Lake Group, Muskaboo Creek Assemblage; lithic arkose.

THIN SECTION DESCRIPTION: PLATE 11
LOCATION: OUTCROP
BOWSER LAKE GROUP, MUSKABOO CREEK ASSEMBLAGE
FELDSPATHIC LITHARENITE

Sample # SP021 **Thin section Porosity 0.0%** **Core Porosity 4.0%** **Permeability 0.18mD**

1 Overview showing medium gray, lower medium-grained, moderately sorted feldspathic litharenite with rounded to angular framework grains. The grain size varies from 100 to 700 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. Volcanic rock fragments with substantial amounts of plutonic rock fragments, chert and feldspars dominate the framework grains. Small amounts of quartz, metamorphic rock fragments, olivine/pyroxene and sedimentary rock fragments are also present. Only traces of detrital chlorite were observed. Visible thin section pores are absent. The reservoir quality is considered very poor.

2 Close-up view from the previous photomicrograph (I9) showing well compacted framework grains (G8). The pores were first lined with chlorite and fibrous illite (L9) and the remaining part of the pores were occluded with laumontite cement (Lau). Pore filling calcite is also present (Cal). Note darker volcanic rock fragments (VRF) and weathered olivine (Olv) grains.

3-4 Photomicrograph 3 shows a higher magnification view of pore lining chlorite and fibrous illite (arrow). Laumontite (Lau) completely occluded the remaining pore. Photomicrograph 4 shows a clinopyroxene crystal (CPX) in a volcanic rock fragment where the groundmass contains fine crystalline olivine and pyroxene (small arrows).

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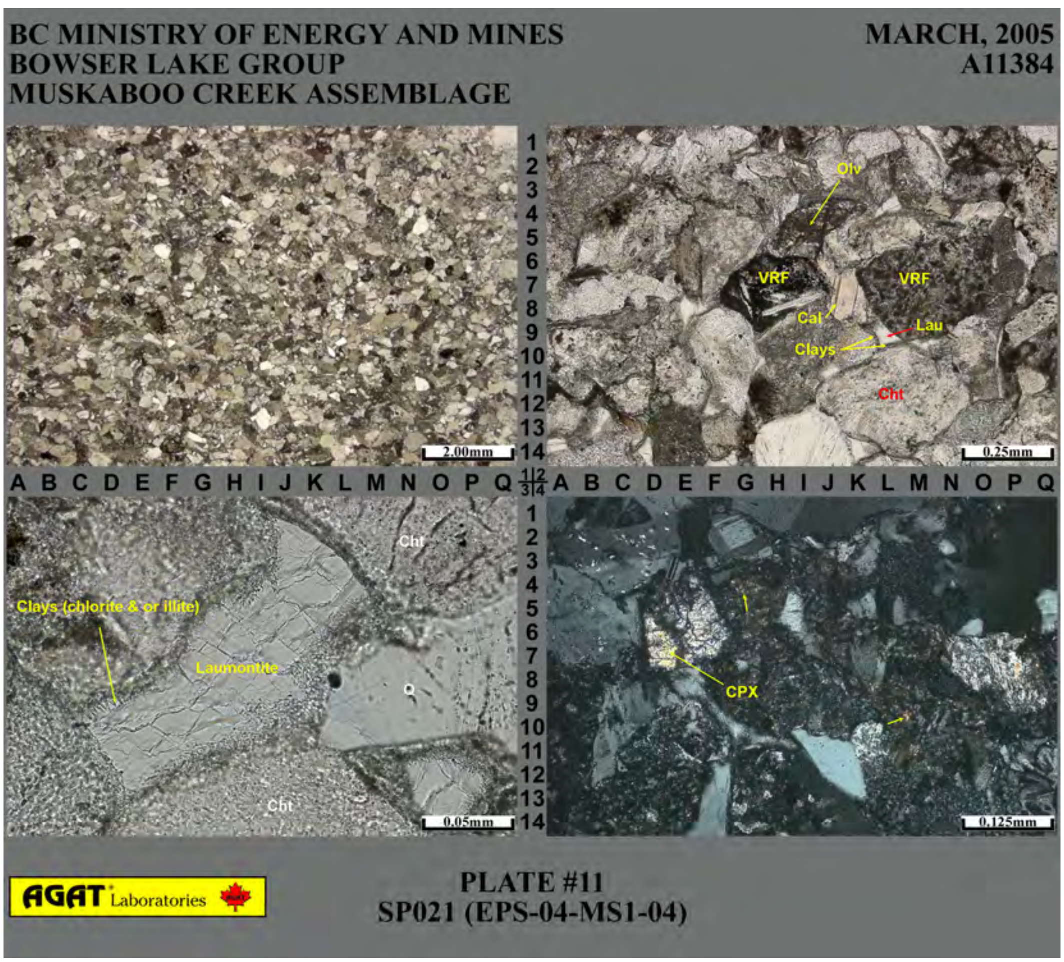

Plate 11. Bowser Lake Group, Muskaboo Creek Assemblage; feldspathic litharenite.

THIN SECTION DESCRIPTION: PLATE 12
LOCATION: OUTCROP
BOWSER LAKE GROUP, MUSKABOO CREEK ASSEMBLAGE
FELDSPATHIC LITHARENITE

Sample # SP022 **Thin section Porosity 1.0%** **Core Porosity 5.0%** **Permeability 0.09mD**

1 Overview showing light brownish gray, lower medium-grained, poorly sorted feldspathic litharenite with rounded to angular framework grains. The grain size varies from 100 to 1000 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. Volcanic rock fragments with substantial amounts of chert, plutonic rock fragments and feldspars dominate the framework grains. Small to trace amounts of quartz, olivine/pyroxene, detrital chlorite, mica and metamorphic rock fragments are also present. Only 1.0% thin section porosity is present. These pores are poorly interconnected. The reservoir quality is considered poor.

2 Photomicrograph 2 shows well compacted framework grains (J9). Volcanic rock fragments (VRF) are common and they are partially chloritized as indicated by green colours. Small intergranular pores are occluded with chlorite cement (L9, Chl cement). A few framework grains have been replaced with laumontite (Lau). Dark brown to black lining around grains (N8) is believed to be opaque oxide minerals. Cht=chert.

3-4 Photomicrograph 3 highlights an olivine grain (Olv) under transmitted light and crossed polarized light (inset). Note brown staining on chlorite (upper left corner) probably due to weathering. Photomicrograph 4 shows higher magnification view of a plagioclase crystal (Plg) that has been partially replaced with laumontite (Lau). Grain replacement laumontite is fairly common in this sample.

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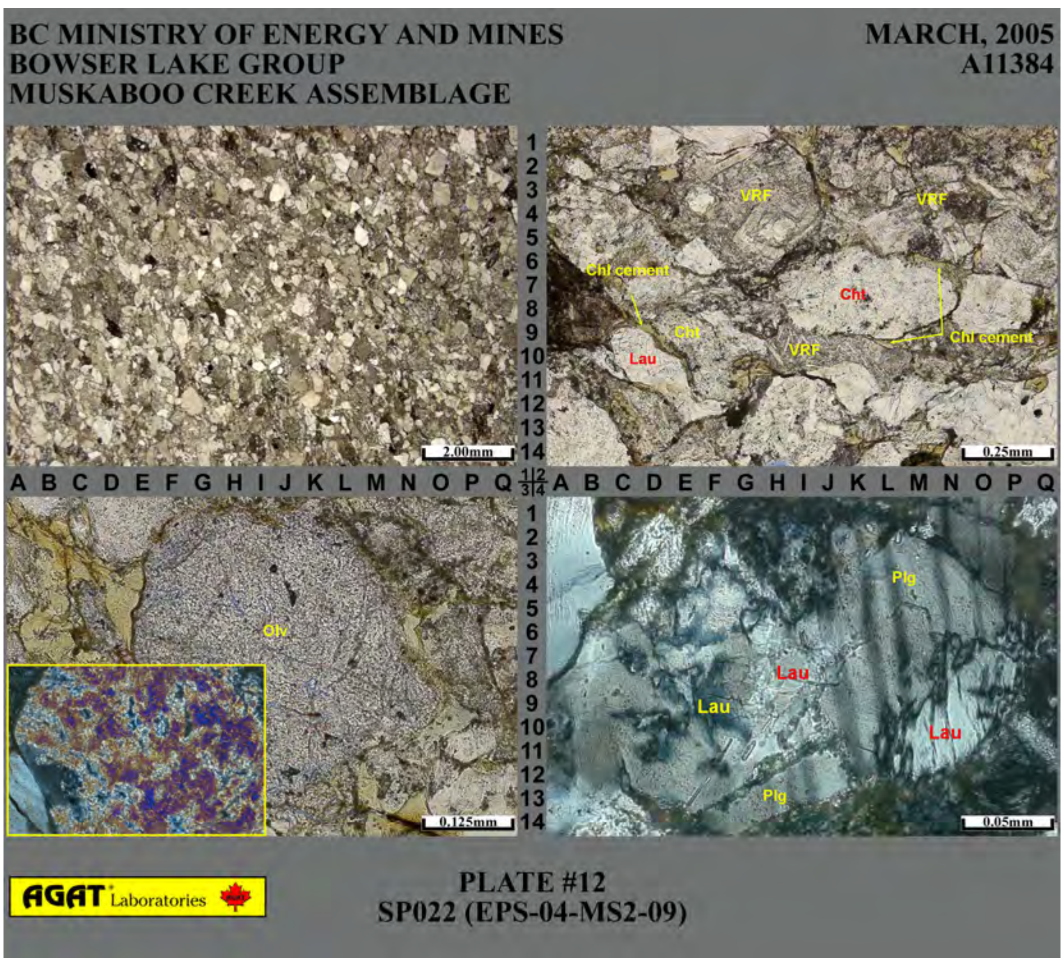

Plate 12. Bowser Lake Group, Muskaboo Creek Assemblage; feldspathic litharenite.

Diagenesis and Paragenetic Sequence

Much of the porosity in the volcanic rock fragment rich sandstones of the Muskaboo Assemblage was destroyed due to mechanical compaction (Plates 6, 7, 11, 12). Framework grains show advanced degree of compaction as revealed by concavo-convex and long grain contacts (Plates 6-2, 12-2). The remaining pores were occluded with chlorite and laumontite and less commonly with calcite, illite, and anhydrite.

Diagenetic sequence of these samples, in a paragenetic order, include: on set of compaction, pore filling and grain coating chlorite, local fibrous illite (SP021), anhydrite (SP001), laumontite, fracturing and calcite (local quartz in fractures). Some of these diagenetic features may be locally absent. Note that detailed SEM work is required to confirm authigenic clays. Chlorite is present in reduced intergranular pores as pore filling cement (Plates 7-2, 12-2). Grain coating chlorite is less common (Plate 11-2). Fibrous illite clays locally developed after chlorite (SP21; Plate 11-3). Pore filling and replacement anhydrite probably developed after chlorite cement (Plate 6-4). Sparry laumontite is present as pore filling cement (Plate 11-3) as well as grain replacement phase (Plate 12-4). Laumontite often replaces plagioclase (Plate 12-4). Laumontite is absent in sample SP009, probably because all pores in this sample were filled with relatively early chlorite cement (Plate 7-2). Laumontite is type of zeolite consisting of calcium, aluminum and silica (Deer et. al, 1983). It often shows well developed cleavage and undulatory extinction and it has been reported in sandstones from other areas (Helmold and van de Kamp, 1984). Fractures were developed at later stage. These fractures were filled with calcite and quartz (Plate 6-1). Note that quartz was only observed in one fracture (SP001). Much of the calcite is grain replacive. In places, calcite replaces early chlorite (Plate 7-4). In summary, both mechanical compaction and cementation has destroyed almost all of the porosity in these samples.

In term of diagenesis, the chert rich and volcanic rock fragments rich sandstones of the Muskaboo Creek Assemblage show some differences. Pore filling authigenic quartz is absent from sandstones that are rich in volcanic rock fragments. Quartz cement is present in chert rich samples. Laumontite was not observed in chert rich samples. Furthermore, chlorite cement is more common in sandstones that contain higher percentage of volcanic rock fragments (SP001, SP009, SP021, SP022) than in chert rich sandstones (SP012, SP015, SP018).

Porosity, Permeability and Reservoir Quality

Thin section porosity is absent in two samples (SP001, SP021), rare in one sample (SP009) and about one percent in one sample (SP022). Core porosity varies from 0.7 to 5.0% and gas permeability <0.01 to 0.18 mD. Visible pores include mainly dissolution pores. Dissolution of olivine, pyroxene and feldspars has created minor amounts of pores, particularly in sample SP022. These pores are poorly interconnected. Some microporosity may be present between clays. Based on low to zero percent visible thin section porosity, low core porosity and low permeability values, these samples are considered to represents very poor to poor reservoir quality.

(d) Skelhorne Assemblage (SP013)

Only one outcrop sample was collected from the Skelhorne Assemblage of the Bowser Lake Group, British Columbia. The sample is located in the northern part of the study area (Figure 1). This sample is characterized by medium to dark gray massive sandstone.

The sample is classified as chert rich litharenite (Table 1, Figure 3). It is upper fine-grained, moderately sorted sandstone with subangular to rounded framework grains.

Framework grains are dominated by chert and sedimentary rock fragments. Moderate amounts of quartz and feldspars grains are also present. Detrital chlorite, volcanic and plutonic rock fragments are present in smaller amounts (Table 1).

Chert grains with variable colour appear in cryptocrystalline to microcrystalline textures (Plate 13). Some chert grains were partially replaced with ferroan dolomite. Sedimentary rock fragments mainly consist of shale fragments of variable colours. These relatively softer rock fragments have been deformed around rigid framework grains (Plate 13-2). This plastic deformation reduces the reservoir porosity significantly. Polycrystalline quartz is more common than monocrystalline quartz. Both K-feldspar and plagioclase are present. Inclusions of mica were observed in feldspar grains. The groundmass of volcanic rock fragments is often chloritized. Green detrital chlorite grains are often squeezed between rigid grains (Plate 13-2). Size, shape and relationship to the pores indicate that this chlorite is detrital rather than authigenic. Some of them could be chloritized biotite grains. Biotite grains have been deformed and squeezed between rigid grains and in places ferroan dolomite replaces biotite grains.

Matrix clays occur in minor amounts as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays. Most of the pore-filling matrix could be due to deformation of soft mud clasts between competent grains (pseudo matrix).

Diagenesis and Paragenetic Sequence

Much of the porosity in the Skelhorne sandstone was destroyed due to mechanical compaction (Plate 13-1). The remaining pores were filled with quartz cement (Plate 13-3). Ferroan dolomite is minor cement. Most of the ferroan dolomite is a replacement phase (Plate 13-4). Framework grains, particularly shale fragments and detrital chlorite, show advanced degrees of compaction as revealed by concavo-convex and long grain contacts.

Diagenetic features, in a paragenetic order, include:

THIN SECTION DESCRIPTION: PLATE 13
LOCATION: OUTCROP
BOWSER LAKE GROUP, SKELHORNE ASSEMBLAGE
LITHARENITE

Sample # SP013 **Thin section Porosity 0.0%** **Core Porosity 0.9%** **Permeability <0.01mD**

1 Overview showing medium to dark gray, upper fine-grained, moderately sorted litharenite with rounded to sub-angular framework grains. The grain size varies from 100 to 350 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert and sedimentary rock fragments. Moderate amounts of quartz and feldspar grains are also present. Detrital chlorite, volcanic and plutonic rock fragments are present in small amounts. Quartz is the most common cement. Ferroan dolomite is mainly grain replacive. Thin section shows no visible porosity. The reservoir quality is considered very poor.

2 Close-up view showing advanced level of mechanical compaction where shale fragments (SRF) and detrital chlorite grains (left side) have been squeezed between competent grains. Ferroan dolomite (FeDol) often replaces framework grains (K8). Cht=chert, F=feldspar.

3-4 Photomicrograph 3 shows that beside compaction, silica cementation (center) has also destroyed the intergranular porosity. The organic matter has been squeezed into near by pore (M9). Photomicrograph 4 shows a close-up view of a detrital chlorite hat has been partially replaced with late stage ferroan dolomite (FeDol). Cht=chert, Arg Cht=argillaceous chert, Plag=plagioclase.

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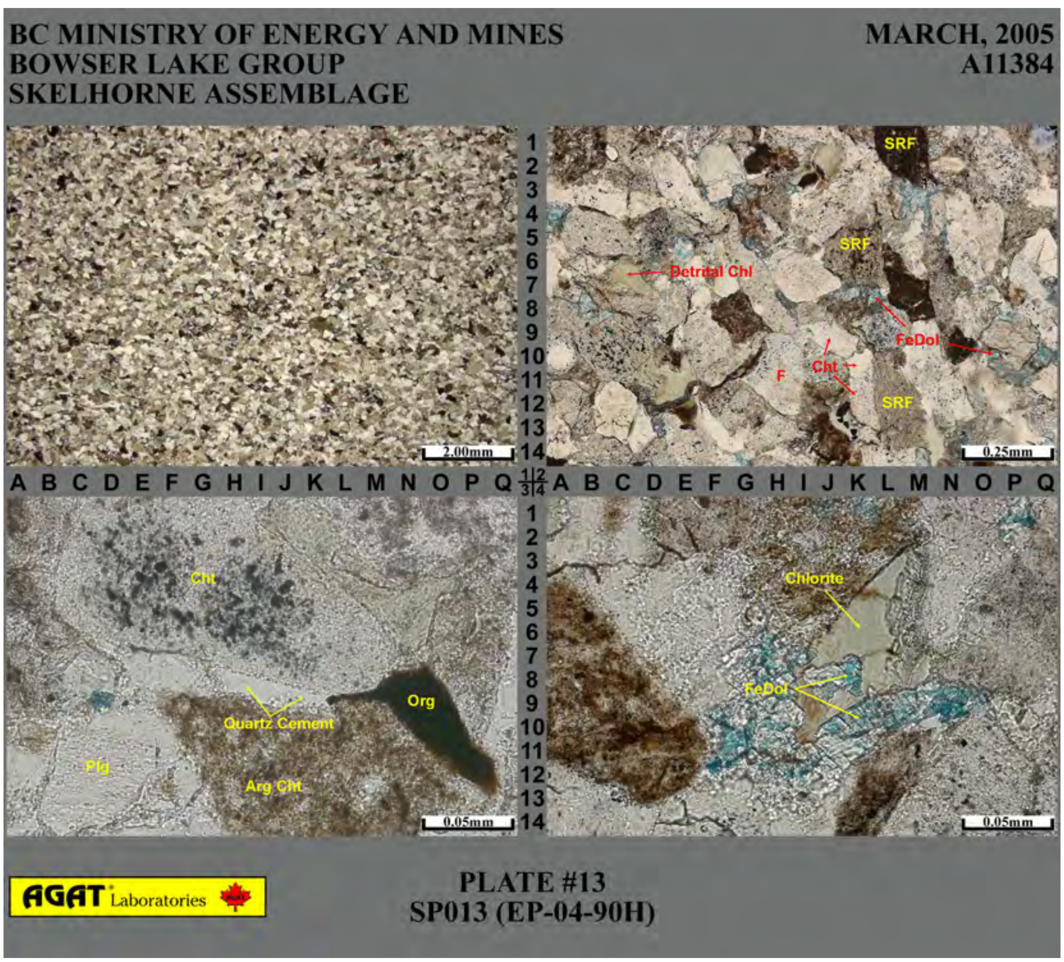

Plate 13. Bowser Lake Group, Skelhorne Assemblage; litharenite.

onset of compaction, pyrite, chlorite, quartz cement, rare feldspar overgrowths and ferroan dolomite (replacement and cement). The quartz cement precipitated in reduced pores after substantial mechanical compaction. It is often blocky or represents the shape of reduced pores (Plate 13-3). Ferroan dolomite replaces different grain types (shale fragments, detrital chlorite, feldspars, chert etc.).

Porosity, Permeability and Reservoir Quality

Visible pores were not observed in this sample. Core porosity is 0.9% and gas permeability <0.01 mD. Based on no visible thin section porosity, very low core porosity and permeability value this sample is considered to represent very poor reservoir quality.

(e) Todagin Assemblage (SP014)

Only one outcrop sample was collected from the Todagin Assemblage of the Bowser Lake Group, British Columbia. The sample is located in the northern part of the study area (Figure 1). This sample is characterized by medium to dark gray massive sandstone. Local pebbly layers were observed in the outcrop sample.

This sample is classified as chert rich litharenite (Table 1, Figure 3). It is upper fine-grained, moderately sorted sandstone with subangular to angular framework grains.

Framework grains are dominated by chert and sedimentary rock fragments. Moderate amounts of quartz, feldspars and volcanic rock fragments are also present. Plutonic rock fragments, detrital chlorite and metamorphic rock fragments are present in small amounts. The detrital composition of both Todagin and Skelhorne assemblages is more or less similar (Table 1).

The characteristics of framework grains are more or less similar to Skelhorne Assemblage as mentioned in the previous section. Chert grains with variable colour appear in crypto- to microcrystalline textures (Plate 14). Traces of dolomite rhombs replace chert grains. Sedimentary rock fragments consist of shale fragments of variable colours and they are generally deformed between rigid framework grains (Plate 14-2). Some shale fragments are rich in organic matter and others are more micaceous. Monocrystalline quartz is more common than polycrystalline quartz (Plate 14-2). Both K-feldspar and plagioclase grains are present. Several feldspar grains are partially replaced with ferroan calcite. Rarely, plagioclase grains were fractured. Some feldspars grains show sericitization and others show larger mica inclusions. The groundmass of volcanic rock fragments is often chloritized. Green detrital chlorite grains are often squeezed between rigid grains (Plate 14-3 at K6). In addition, grain coating authigenic chlorite is present in the Todagin sandstone (see below). Grain coating authigenic chlorite cement was not observed in the Skelhorne sandstone. Biotite grains have been deformed and squeezed between rigid grains.

Matrix clays occur in minor amounts as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays. Some of the matrix could be due to deformation of soft shale clasts between competent grains (pseudo matrix).

Diagenesis and Paragenetic Sequence

Much of the porosity in the Todagin sandstone was destroyed due to mechanical compaction (Plate 14-2). Framework grains, particularly shale fragments and detrital chlorite, show advanced degree of compaction as revealed by concavo-convex and long grain contacts. The remaining pores were occluded with chlorite rims (and illite?) and quartz cement (Plate 14-4). Ferroan calcite cement is present in minor amount. Much of the ferroan calcite replaces framework grains, particularly feldspar grains.

Diagenetic features, in a paragenetic order, include: onset of compaction, pyrite, chlorite rims, fibrous illite (?), quartz cement and ferroan calcite. Chlorite rims are discontinuous and absent at grain contacts (Plate 14-4). They were developed after some mechanical compaction. In places, chlorite rims were deformed due to continuously increasing overburden pressures. The thickness of these rims is fairly uniform (about 20 microns). Fibrous clays (illite) often follow these chlorite rims (Plate 14-4). In relatively larger pores, the remaining pore spaces were filled with authigenic quartz. Compared to pore filling quartz cement, quartz overgrowths are rare. Most of the ferroan calcite replaces feldspar and other grains. Only a few remaining pores were filled with ferroan calcite. The amount of iron in calcite is variable as revealed by variable staining colours. Dolomite crystals replacing chert grains may have developed in the source areas.

Porosity, Permeability and Reservoir Quality

Visible pores are extremely rare. Some pores (blue areas) were created due to grain plucking during thin section preparation. These artificial pores were not included in the point counting. Core porosity is 0.6% and gas permeability 0.01 mD. Based on rare thin section porosity, very low core porosity and lower permeability value this sample is considered to represent very poor reservoir quality.

(f) Undifferentiated Bowser Lake Group (8 samples)

Eight outcrop samples from the Bowser Lake Group are not subdivided into various assemblages. In this report, these samples were grouped together as “Undifferentiated”. Four samples are clustered in the northern part of the study area (SP007, SP016, SP017, SP019), and the remaining samples are clustered in the southern part of the study area (SP002, SP003, SP004, SP005). Some of these outcrop samples show filled or partially filled fractures (SP003, SP005, SP019). Based on mineral composition, these samples can be divided into two units:

(1) Chert rich unit (SP007, SP016, SP017, SP019),

(2) Volcanic rock fragment rich unit (SP002, SP003,

THIN SECTION DESCRIPTION: PLATE 14
LOCATION: OUTCROP
BOWSER LAKE GROUP, TODAGIN ASSEMBLAGE
LITHARENITE

Sample # SP014 **Thin section Porosity TR** **Core Porosity 0.6%** **Permeability 0.01mD**

1 Overview showing medium to dark gray, upper fine-grained, moderately sorted litharenite with subrounded to angular framework grains. The grain size varies from 100 to 500 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert and sedimentary rock fragments. Moderate amounts of quartz, feldspar and volcanic rock fragments are also present. Plutonic rock fragments, detrital chlorite, and metamorphic rock fragments are present in smaller amounts. Chlorite rims are common. Ferroan calcite and quartz cements are relatively minor. Thin section pores are rare. The reservoir quality is considered very poor.

2 Close-up from the previous photomicrograph (I9) showing tightly packed framework grains. Note deformed and squeezed ductile grains (P7, F9) and sub-triangular pores lined with chlorite coating (Chl-rims) and filled with quartz cement (Qc). Cht=chert, SRF=shale rock fragment, MRF=metamorphic rock fragment, Q=quartz.

3-4 Photomicrograph 3 shows pore lining chlorite rims (Chl-rims) and pore filling quartz (Qc) cements (left side). A detrital chlorite grain (Chl) is shown toward the right side (N8). Ferroan calcite (FeCal) filled pores does contain remnants of relatively early chlorite rims (K11), suggesting that calcite developed after chlorite rims. Photomicrograph 4 shows a further close-up view of chlorite rims (Chl-rims) and pore filling quartz cement (Qc). It also shows fibrous clay (illite?) that grew on top of the chlorite rims. F=feldspar, SRF=shale rock fragment.

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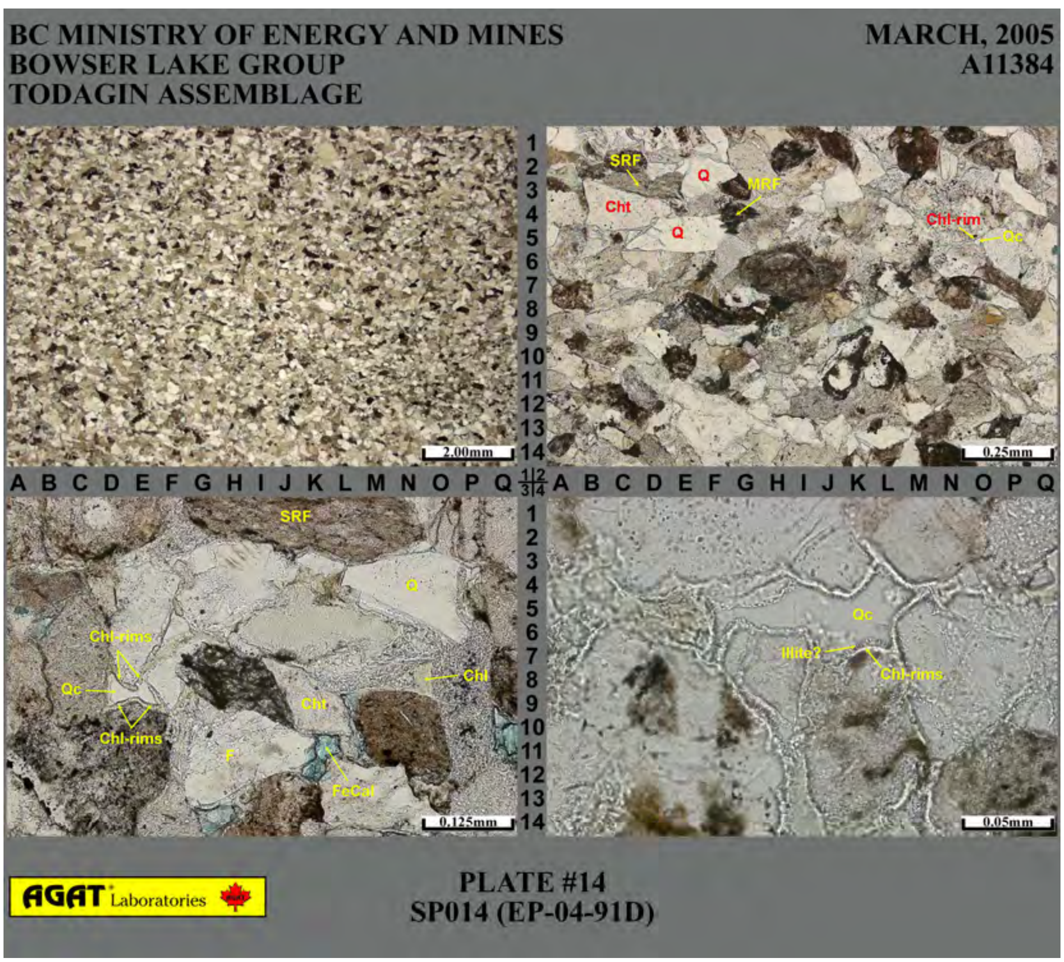

Plate 14. Bowser Lake Group, Todagin Assemblage; litharenite.

SP004, SP005).

These two units are described separately.

Chert Rich Unit (SP007, SP016, SP017, SP019)

All these samples are located in the northern part of the study area (Figure 1). Sample SP007 is dark gray, lower fine-grained, moderately sorted sandstone. The remaining samples (SP016, SP017, SP019) are medium to dark gray, upper fine to lower medium-grained, well sorted sandstones. All four samples are classified as chert rich litharenite (Table 1, Figure 3).

Framework grains are dominated by chert and sedimentary rock fragments. Moderate amounts of quartz, feldspars, volcanic rock fragments and organic matters are also present. Plutonic and metamorphic rock fragments, detrital chlorite, magnetite and detrital dolomite are present either in small amounts or locally absent (Table 1).

Chert grains with variable colors appear in crypto- to microcrystalline textures (Plates 19-2, 20-4, 21-2). Pyrite and organic matter inclusions are present in some chert grains. In places, chert grains are replaced with ferroan dolomite and ferroan calcite (Plate 22-4). Sedimentary rock fragments consist mainly of shale (Plate 19-2). Most of them show brown to dark brown colours. Some of them are rich in organic matter. They are often squeezed between more competent grains (Plate 19-2). Both monocrystalline and polycrystalline quartz are present in these sandstones (Plate 21-4). Quartz overgrowths are not common (Plate 22-3). K-feldspar is more common than plagioclase. A few feldspar grains have been replaced with ferroan carbonates. Volcanic rock fragments are partially altered into chlorite (Plate 20-4). The amount of volcanic rock fragments is much less compared to other “Undifferentiated” samples (SP002, SP003, SP004, SP005). Detrital chlorite grains are present in all four samples; however, it is more common in SP016 (Plates 19-2, 16-4). Organic matter is more common in sample SP007 (Plate 19-1). Plutonic rock fragments contain multiple crystals of feldspars and quartz. Metamorphic rock fragments contain mica and quartz (Plate 21-3).

Matrix clays occur in minor amounts as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays. Some of the matrix is due to deformation of soft mud clasts between competent grains (pseudo matrix).

Diagenesis and Paragenetic Sequence

Much of the porosity in the chert rich sandstones of the Bowser Lake Group (Undifferentiated) was destroyed due to mechanical compaction (Plates 19, 20, 21, 22). Framework grains show advanced degree of compaction as revealed by concavo-convex and long grain contacts. The remaining pores were occluded with quartz (Plates 20-3, 22-3) and in places with ferroan calcite (Plate 20). Other cements (pyrite, hematite/limonite and chlorite) are either local or rare (Plate 22-2). Sample SP007 contains very little cement.

Diagenetic features, in a paragenetic order, include: onset of compaction, rare pyrite, minor chlorite, quartz, ferroan calcite and ferroan dolomite, dissolution and alteration of ferroan calcite and ferroan dolomite and other grains and local development of hematite/limonite. Some of these diagenetic features may be locally absent. For example, hematite/limonite were observed in only two samples (SP016, SP019).

Early pyrite crystals were rarely observed in the intergranular areas. Unlike some chert rich samples of the Muskaboo Assemblage, authigenic chlorite is not well developed in these sandstones. Quartz cement is rare in SP007 and more common in SP017 and SP019 (Plate 22-3). Pore filling quartz cement was precipitated after substantial mechanical compaction when the intergranular pores were reduced into smaller pores (Plate 20-3). Compared to pore filling quartz cement, quartz overgrowths are rare in these samples (Plate 22-3). Replacement and pore filling ferroan calcite is present in SP007 and SP016. It is more common in sample SP016 where its distribution is heterogeneous (Plate 20-2). It shows both sparry and poikilotopic textures.

Ferroan calcite replaces feldspar, chert, shale clasts as well as detrital chlorite (Plate 20). Replacement ferroan dolomite is present in SP017 and SP019. Euhedral dolomite crystals are common (Plate 22-4). Replacement of quartz cement with ferroan dolomite was rarely observed. It suggests that ferroan dolomite postdates quartz cement. Dissolution and alteration of carbonates and framework grains occurred later in the diagenetic history. Dissolution is relatively more pronounced in SP016 and SP019 and appears to be weathering related (Plates 20-2, 22-1). In SP016, dissolution of ferroan calcite and some grains have created more visible porosity than in any other sample examined for this study. In both samples, this dissolution is present only on one side of the thin sections where the brownish material either line or partially fill these pores. Under reflected light, this brownish material appears to be hematite/limonite (Plate 22-2). Some dolomite rhombs have been partially altered into hematite/limonite in SP019 (Plate 22-4). In summary, compaction and some cementation has destroyed almost all of the porosity in these samples. Most porosity in SP016 and SP019 is probably due to surface weathering.

Porosity, Permeability and Reservoir Quality

Thin section porosity varies from traces to 5%. Core porosity varies from 0.7 to 1.3% and gas permeability <0.01 mD in all samples. Higher thin section porosity in SP016 and SP019 (1 to 5%) is related to surface dissolution features that were probably not encountered in plugs used for routine core analysis. Excluding the weathering related pores; these samples are considered to represent poor to very poor reservoir quality. Poor to

THIN SECTION DESCRIPTION: PLATE 19
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
LITHARENITE

Sample # SP007 **Thin section Porosity TR** **Core Porosity 1.3%** **Permeability <0.01mD**

1 Overview showing dark gray, lower fine-grained, moderately sorted litharenite with subrounded to angular framework grains. The grain size varies from silt to 500 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert and sedimentary rock fragments. Quartz, feldspar, volcanic rock fragments and organic matter are present in moderate amounts. Detrital chlorite, plutonic rock fragments and possibly magnetite grains are present in minor amounts. Intergranular cement is not common in this sample. Only traces of visible thin section pores are present. The reservoir quality is considered very poor.

2-4 Photomicrograph 2 shows well-compacted framework grains. Note concavo-convex grain contacts and deformation of shale and organic matter. Photomicrograph 3 shows a further close-up view showing advanced degree of mechanical compaction. A possible magnetite grain is also shown. Photomicrograph 4 also shows deformed sedimentary rock fragments and intergranular matrix. SRF=shale rock fragment, Cht=chert, Plg=plagioclase, F=feldspar, Q=quartz.

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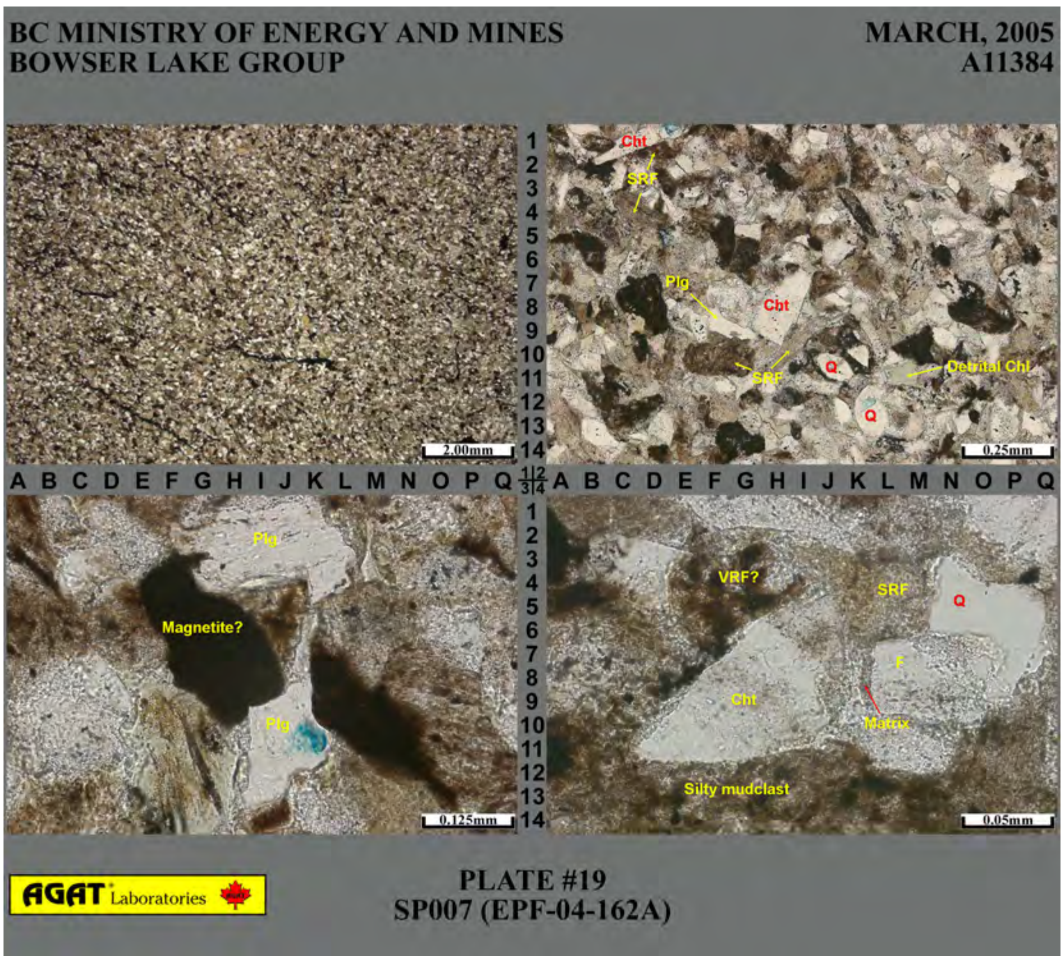

Plate 19. Bowser Lake Group; undifferentiated litharenite.

THIN SECTION DESCRIPTION: PLATE 20
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
LITHARENITE

Sample # SP016 **Thin section Porosity 5.0%** **Core Porosity 0.9%** **Permeability <0.01mD**

1 Overview showing medium to dark gray, massive upper fine-grained, well sorted litharenite with rounded to angular framework grains. The grain size varies from 70 to 350 microns. Framework grains are moderately to well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert and sedimentary rock fragments. Quartz, detrital chlorite, feldspar, organic matter and volcanic rock fragments are present in moderate amounts. Plutonic and metamorphic rock fragments and magnetite grains are present in minor amounts. Ferroan calcite and quartz are common cements. Five percent thin section porosity is present.

2 Photomicrograph 2 shows a close-up view from the previous photomicrograph (I9). It shows several pores (P) that were created due to the dissolution of ferroan calcite (FeCal) and margins of framework grains. Some of these pores are lined with yellow to brownish material (hematite/limonite, not shown here). Dissolution is absent from the opposite side of the sample, suggesting that dissolution is due to surface weathering. Cht=chert, Org=organic matter.

3-4 Photomicrograph 3 shows that quartz cement (Qc) was precipitated after substantial mechanical compaction as the intergranular pores were reduced to smaller sizes. Photomicrograph 4 shows ferroan calcite (FeCal), quartz cement (Qc) and a volcanic rock fragment (VRF).

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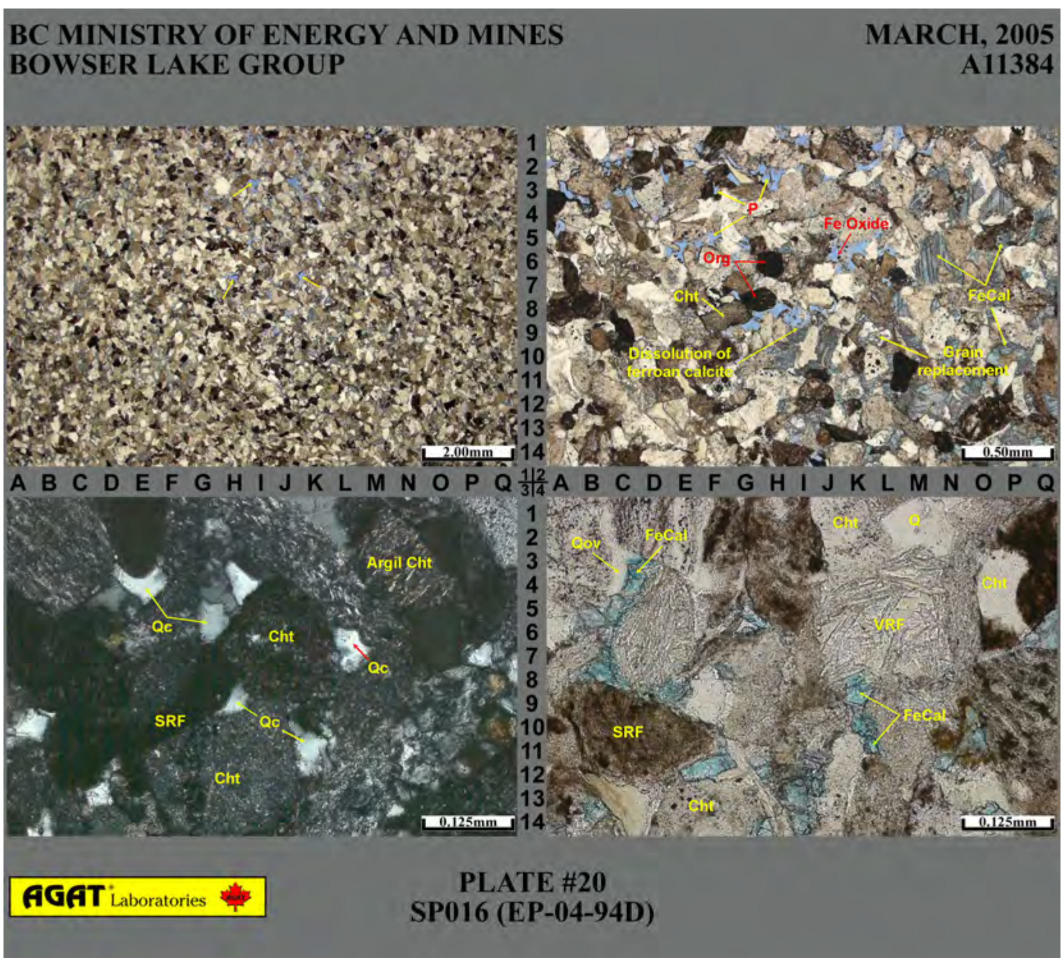

Plate 20. Bowser Lake Group; undifferentiated litharenite.

THIN SECTION DESCRIPTION: PLATE 21
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
LITHARENITE

Sample # SP017 | Thin section Porosity TR | Core Porosity 0.7% | Permeability <0.01mD

1 Overview showing medium gray, massive lower medium-grained, well sorted litharenite with rounded to sub-angular framework grains. The grain size varies from 150 to 500 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert and sedimentary rock fragments. Quartz, feldspar, volcanic rock fragments and metamorphic rock fragments are present in moderate. Metamorphic rock fragments, organic matter, detrital chlorite, detrital dolomite and magnetite (?) grains are present in minor amounts. Quartz is the main cement and ferroan dolomite is mainly replacive mineral. Only traces of visible thin section pores are present. The reservoir quality is considered very poor.

2-4 Photomicrograph 2 (crossed polars) shows abundant chert grains (Cht) and some organic particles. Note intergranular quartz cement (Qc). Photomicrograph 3 shows that most of the ferroan dolomite (FeDol) replaces framework grains. At the time of ferroan dolomite development, most of the pores were destroyed due to compaction and quartz cementation. Photomicrograph 4 shows a deformed rock fragment. Argil Org=argillaceous organic matter, MRF=metamorphic rock fragment, SRF=shale rock fragment, Plg=plagioclase, F=feldspar, Q=quartz.

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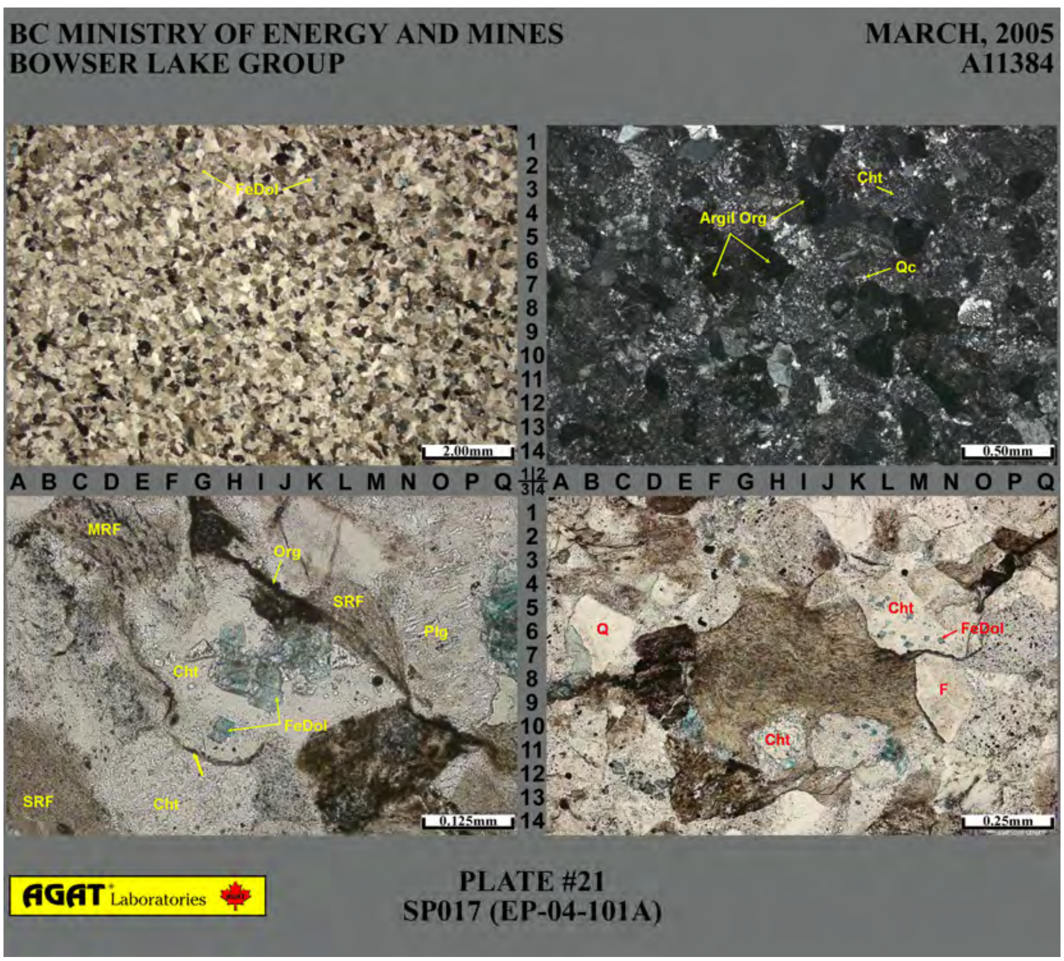

Plate 21. Bowser Lake Group; undifferentiated litharenite.

THIN SECTION DESCRIPTION: PLATE 22
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
LITHARENITE

Sample # SP019 **Thin section Porosity 1.0%** **Core Porosity 0.8%** **Permeability <0.01mD**

1 Overview showing medium to dark gray, lower medium-grained, well sorted litharenite with rounded to sub-angular framework grains. The grain size varies from 100 to 500 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. The framework grains are dominated by chert and sedimentary rock fragments. Quartz, feldspar and plutonic rock fragments are present in moderate amounts. Volcanic rock fragments, detrital chlorite and organic matter are present in minor amounts. Quartz is the main cement. Ferroan dolomite mainly replaces framework grains. About 1% thin section porosity is present. Pores (upper left) are lined with yellow to brownish material (hematite/limonite). The reservoir quality is considered very poor.

2-4 Photomicrograph 2 shows a close-up view of an altered grain or a pore that has been partially filled with this brownish material (center). This brownish material appears to be hematite/limonite under reflected light (inset). Photomicrograph 3 shows pore filling quartz cement (Qc) and quartz overgrowth (Qov). Photomicrograph 4 shows replacive ferroan dolomite crystals (FeDol) in a chert grain. These crystals have been partially altered into iron oxide (hematite/limonite). Note sub triangular pores filled with quartz cement (Qc). P=pore, Cht=chert, Q=quartz, SRF=shale rock fragment.

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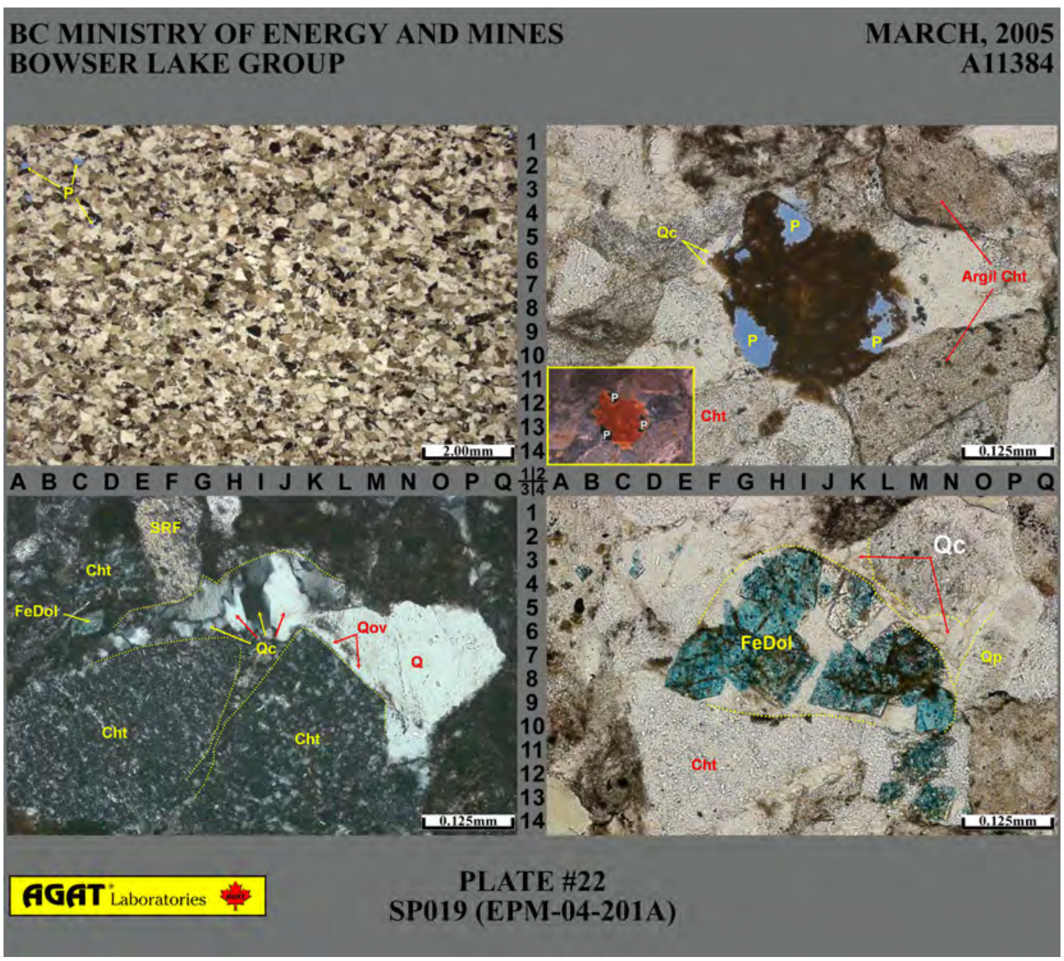

Plate 22. Bowser Lake Group; undifferentiated litharenite.

moderate reservoir quality is assigned for sample SP016.

Volcanic Rock Fragment Rich Unit (SP002, SP003, SP004, SP005)

Four samples from the "Undifferentiated" Bowser Lake Group are relatively rich in volcanic rock fragments (SP002, SP003, SP004, SP005). All these samples are located in the southern part of the study area (Figure 1). Sample SP002 is medium brownish gray and sample SP003 is light greenish gray. The remaining two samples are medium gray. Sample SP004 is upper fine-grained, sample SP003 lower coarse-grained and samples SP002 and SP005 are lower to upper medium-grained sandstones. Sample SP005 is poorly sorted and the remaining samples are moderately sorted. The shape of grains varies from rounded to angular. Samples SP002, SP003 and SP004 are classified as feldspathic litharenite and sample SP005 litharenite (Table 1, Figure 3).

Framework grains are dominated by volcanic rock fragments (Plate 16-2). Substantial amounts of plutonic rock fragments, chert and feldspar grains are also present. Two samples (SP002, SP005) also contain substantial amounts of calcite rock fragments and bioclastic fragments (Plates 15, 18). Other grains (quartz, olivine/pyroxene, heavy minerals, organic matter, detrital chlorite, mica, magnetite and sedimentary rock fragments) are present in small to trace amounts (Plates 15-2, 17-3).

The relatively higher percentage of volcanic rock fragments in sample SP003 is probably due to the coarser nature of the sandstone (lower coarse-grained). Relatively lower percentage of volcanic rock fragments in sample SP005 is due to the presence of calcite and shell fragments (Plate 18). The general characteristics of these volcanic rock fragments are similar to the volcanic rock fragments rich sandstones of the Muskaboo Creek Assemblage (SP001, SP009, SP021, SP022). Some darker volcanic rock fragments with fine crystalline olivine/pyroxene like material may represent basaltic and or andesitic volcanic rocks. Individual olivine and pyroxene grains are also present (Plate 17-3). Mechanical compaction of volcanic rock fragments is shown in Plate 16-2. A few volcanic rock fragments contain opaque material (Plates 15-2, 18-3). A few pyrite inclusions in volcanic rock fragments have been altered into hematite (SP005).

Some plutonic rock fragments contain olivine and pyroxene crystals and others contain quartz and feldspar crystals. The presence of olivine and pyroxene in some plutonic rock fragments suggests that intermediate and/or basic igneous rocks also contributed clastic material to these sandstones.

Chert grains with variable colors appear in crypto- to microcrystalline textures. Some chert grains may be originally volcanic rock fragments. A few chert grains have been replaced with calcite. Pyrite and other unknown darker inclusions are present in some chert grains. Plagioclase (Plate 15-2) is generally more common than K-feldspar. A few feldspar grains are significantly replaced with calcite (Plate 15-3).

Sample SP005 is the only sample where bioclastic fragments are present (Plate 18). This sample also contains limestone rock fragments and common calcite cement. In places, these shell fragments were replaced with silica and with some unknown mineral(s). Note that some calcite rock fragments could be originally silicate grains (feldspar) that have been completely replaced with calcite where no relic of the original grain was preserved. Sample SP002 also contain calcite rock fragments and common calcite cement (Plate 15).

Monocrystalline quartz is more common than polycrystalline quartz. Excluding sample SP002, olivine/pyroxene grains are present in all samples. Olivine/pyroxene grains were generally absent from the chert rich undifferentiated Bowser Lake samples. This may suggest different source areas for the Bowser Lake Group sediments present in the north and south. Opaque heavy minerals are more common in sample SP002 (Plate 2-1). Both biotite and muscovite grains are present. Detrital chlorite grains are present in trace amounts. Sedimentary rock fragments are minor or absent.

Matrix clays occur in minor amount as grain coatings and localized pore-fill. In this study, matrix clays refer to all clays that are distinguished from authigenic clays.

Diagenesis and Paragenetic Sequence

Much of the porosity in the volcanic rock fragment rich sandstones of the undifferentiated Bowser Lake Group was destroyed due to mechanical compaction and cementation (Plates 15, 16, 17, 18). The cementing minerals include chlorite, calcite, laumontite (SP003, SP004) and pyrite (SP003, SP005).

The diagenetic sequence in samples SP003 and SP004 is relatively simple and can be summarized, in a paragenetic order, as: onset of compaction, rare pyrite, pore lining and pore filling chlorite, fibrous illite (?), pore filling and grain replacement laumontite and minor calcite (Plates 16, 17).

In sample SP002 grain rimming and pore filling early chlorite is fairly common (Plate 15). The remaining pores were later filled with ferroan calcite (Plate 15-4). Ferroan calcite also replaced some of the early chlorite. In places, ferroan calcite also developed on calcite fragments. Some grains were also replaced with calcite at various degrees (Plate 15-3).

Diagenetic history of sample SP005 is rather complex (Plate 18). Pyrite and minor chlorite developed early in the diagenetic history (Plate 18-2). Subsequently, common calcite cement was formed (Plate 18-2). Calcite also replaced some silicate grains. Authigenic silica replaced some of the bioclasts in this sample. Dissolution of small amount of calcite and oxidation of some pyrite

THIN SECTION DESCRIPTION: PLATE 15
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
FELDSPATHIC LITHARENITE

Sample # SP002 | **Thin section Porosity 0.0%** | **Core Porosity 3.4%** | **Permeability 0.05mD**

1 Overview showing medium brownish gray, lower medium-grained, moderately sorted feldspathic litharenite with subrounded to angular framework grains. The grain size varies from silt to 700 microns. Framework grains are moderately to well compacted as revealed by long and some concavo-convex grain contacts. Volcanic rock fragments dominate the framework grains. Substantial amounts of chert, feldspar, plutonic rock fragments and calcite fragments are also present. The mounts of quartz, heavy minerals and organic matter are small. Chlorite and ferroan calcite are common cements. No thin section porosity was observed. The reservoir quality is considered very poor.

2 Note pore filling chlorite (Chl) and ferroan calcite (FeCal). Q=quartz, Plg=plagioclase, VRF=volcanic rock fragments, CRF=calcite rock fragment.

3-4 Photomicrograph 3 shows a silicate grain that has been almost completely replaced with calcite. A few remnants of silicate grains (feldspar) are still present. Note pore filling chlorite (Chl) and ferroan calcite (light blue) around feldspar grain (right side). Part of the early chlorite cement may have been replaced with ferroan calcite (see next photomicrograph). Photomicrograph 4 shows the relationship of chlorite (Chl) and ferroan calcite (FeCal) cements. Ferroan calcite postdates chlorite cement. Irregular margins of the chlorite suggest that some of the chlorite has been replaced with ferroan calcite. F=feldspar, Q=quartz.

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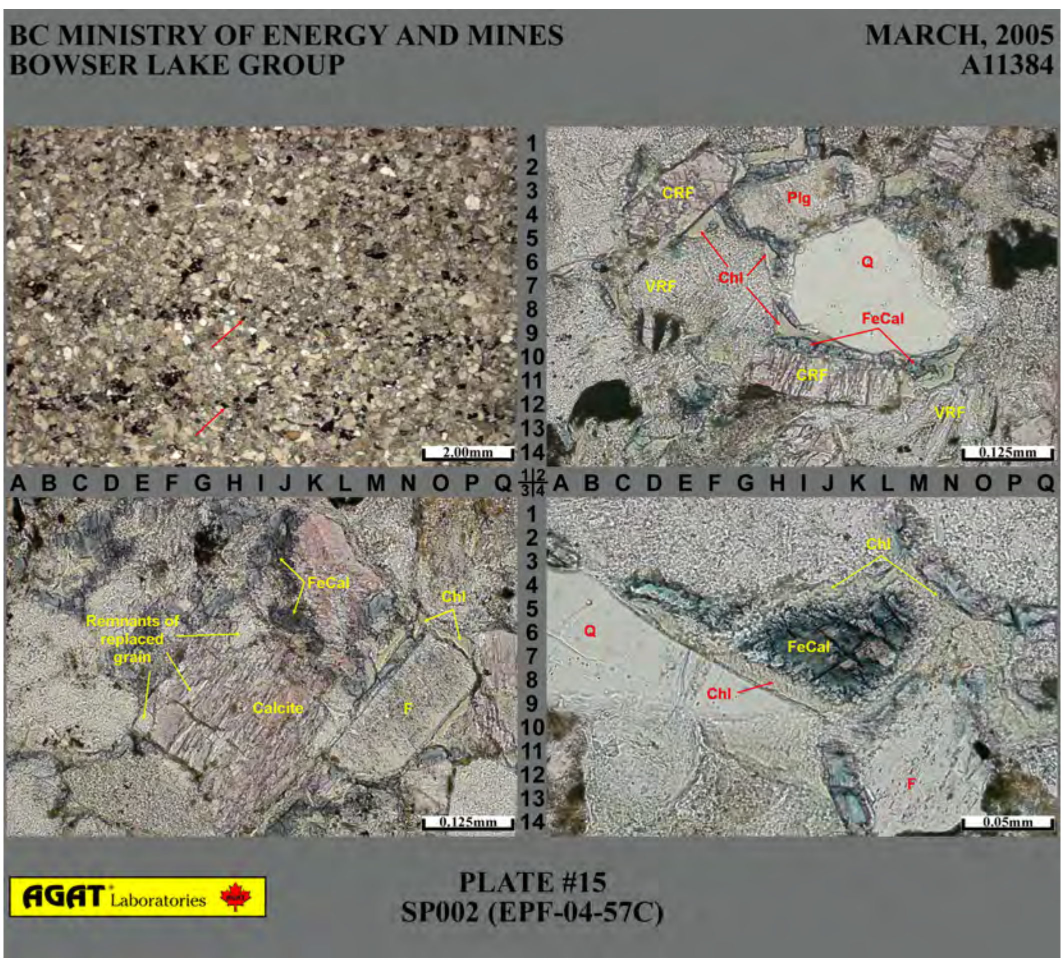

Plate 15. Bowser Lake Group; undifferentiated feldspathic litharenite.

THIN SECTION DESCRIPTION: PLATE 16
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
FELDSPATHIC LITHARENITE

Sample # SP003 | **Thin section Porosity 0.0%** | **Core Porosity 4.1%** | **Permeability 0.34mD**

1 Overview showing light greenish gray, lower coarse-grained, moderately sorted feldspathic litharenite with subrounded to subangular framework grains. The grain size varies from 200 to 1200 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. Volcanic rock fragments dominate the framework grains. Substantial amounts of plutonic rock fragments, chert and feldspar are also present. Olivine, pyroxene and quartz grains are present in small amounts. Chlorite and laumontite are common cements. No thin section porosity was observed. The reservoir quality is considered very poor.

2 Note advanced degree of mechanical compaction. Grain coating and pore filling chlorite cement (Chl) is also shown. Some of the remaining pores were filled with laumontite (Lau). VRF=volcanic rock fragments.

3-4 Photomicrograph 3 shows a higher magnification view of pore lining chlorite (Chl) and fibrous illite (red arrow). The laumontite cement (Lau) completely occludes the remaining pore. Photomicrograph 4 (crossed polars) also shows pore lining chlorite (Chl) and pore filling laumontite cement (Lau). Note fine crystalline groundmass of olivine and pyroxene in a volcanic rock fragment. This volcanic rock fragment was partially chertified. F=feldspar.

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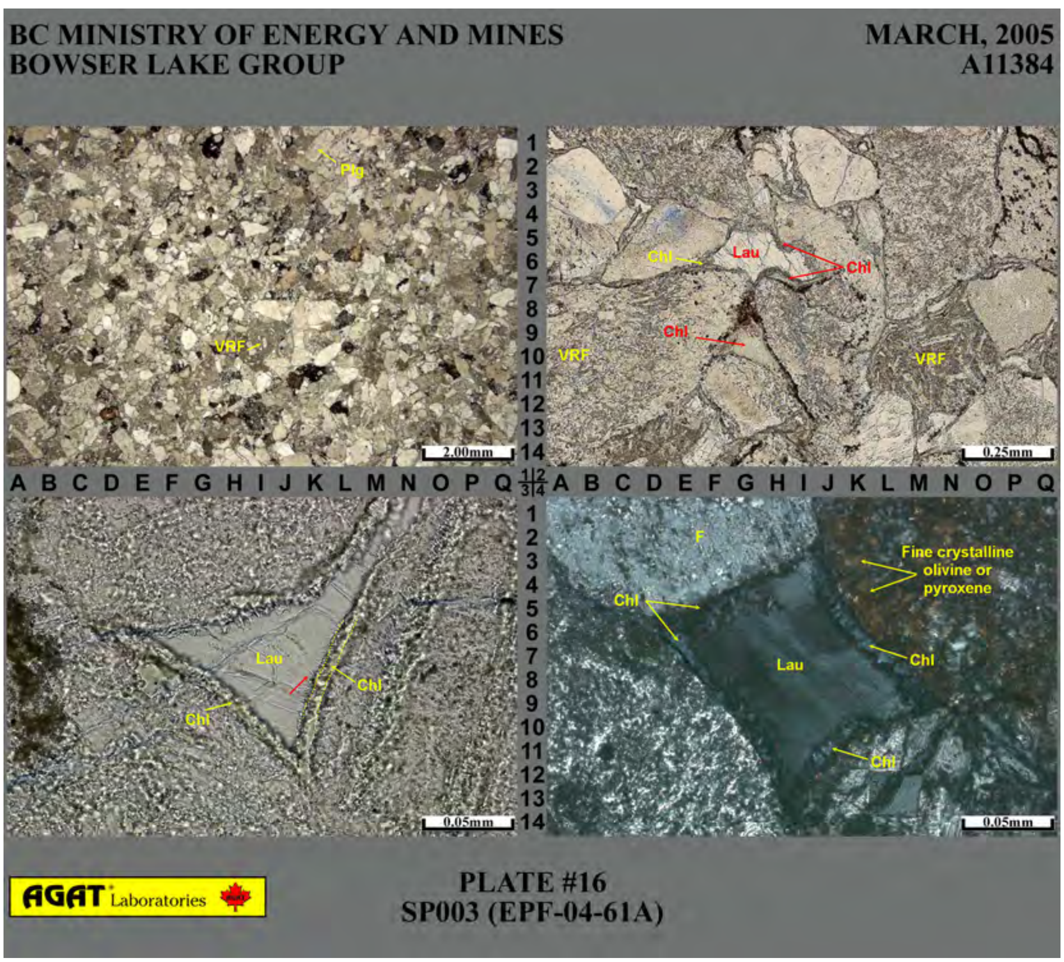

Plate 16. Bowser Lake Group; undifferentiated feldspathic litharenite.

THIN SECTION DESCRIPTION: PLATE 17
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
FELDSPATHIC LITHARENITE

Sample # SP004 **Thin section Porosity 0.0%** **Core Porosity 3.2%** **Permeability 0.08mD**

1 Overview showing medium gray, upper fine-grained, moderately sorted feldspathic litharenite with rounded to angular framework grains. The grain size varies from silt to 500 microns. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. Volcanic rock fragments followed by plutonic rock fragments, feldspar and chert dominate the framework grains. Olivine, pyroxene and quartz grains are present in small amounts. Chlorite and laumontite are the main authigenic minerals present. No thin section porosity was observed. The reservoir quality is considered very poor.

2-4 Photomicrograph 2 shows advanced mechanical compaction. Chlorite clays are present between framework grains. Photomicrograph 3 (crossed polars) shows an olivine grains (Olv) characterized by high relief, high birefringence and random cracks. Photomicrograph 4 shows a higher magnification view of pore lining chlorite (Chl) and pore filling laumontite (Lau). F=feldspar, VRF=volcanic rock fragments.

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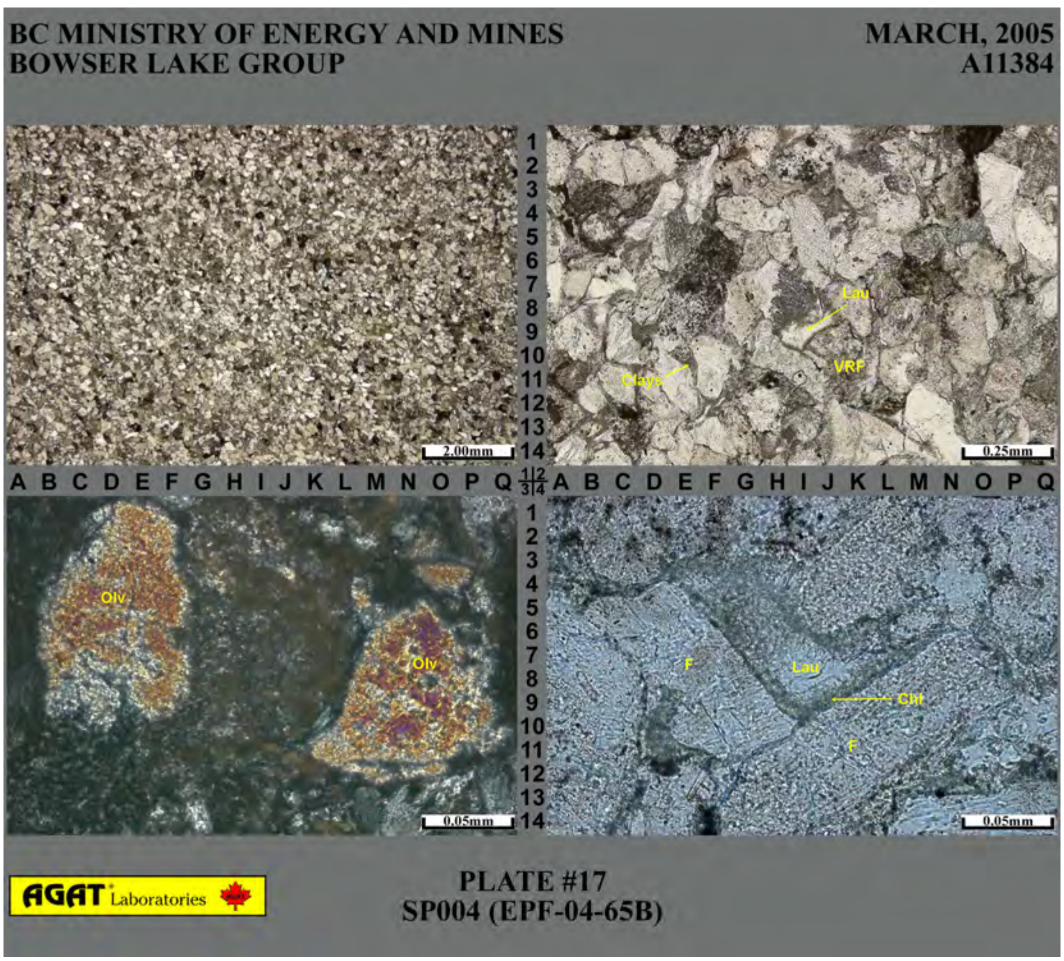

Plate 17. Bowser Lake Group; undifferentiated feldspathic litharenite.

THIN SECTION DESCRIPTION: PLATE 18
LOCATION: OUTCROP
BOWSER LAKE GROUP, UNDIFFERENTIATED
LITHARENITE

Sample # SP005 **Thin section Porosity TR** **Core Porosity 1.3%** **Permeability 0.01mD**

1 Overview showing medium gray, upper medium-grained, poorly sorted litharenite with rounded to angular framework grains. The grain size varies from silt to 1.5 cm. Framework grains are well compacted as revealed by concavo-convex and long grain contacts. Volcanic rock fragments, bioclasts, calcite rock fragments, chert and plutonic rock fragments are the dominant framework grains. Calcite and pyrite are the main cements present. Only trace thin section pores are present. The reservoir quality is considered very poor.

2-3 Beside compaction, calcite (FeCal), pyrite (Py) and minor chlorite (J8 in frame 2) have destroyed much of the porosity. Note volcanic (VRF) and calcite (CRF) rock fragments.

4 Photomicrograph 4 shows an andesite or basaltic rock fragment (VRF). The insert photomicrograph (crossed polars) shows the presence of olivine crystals in this volcanic rock fragment. Cal=calcite, FeCal=ferroan calcite.

1	2
3	4

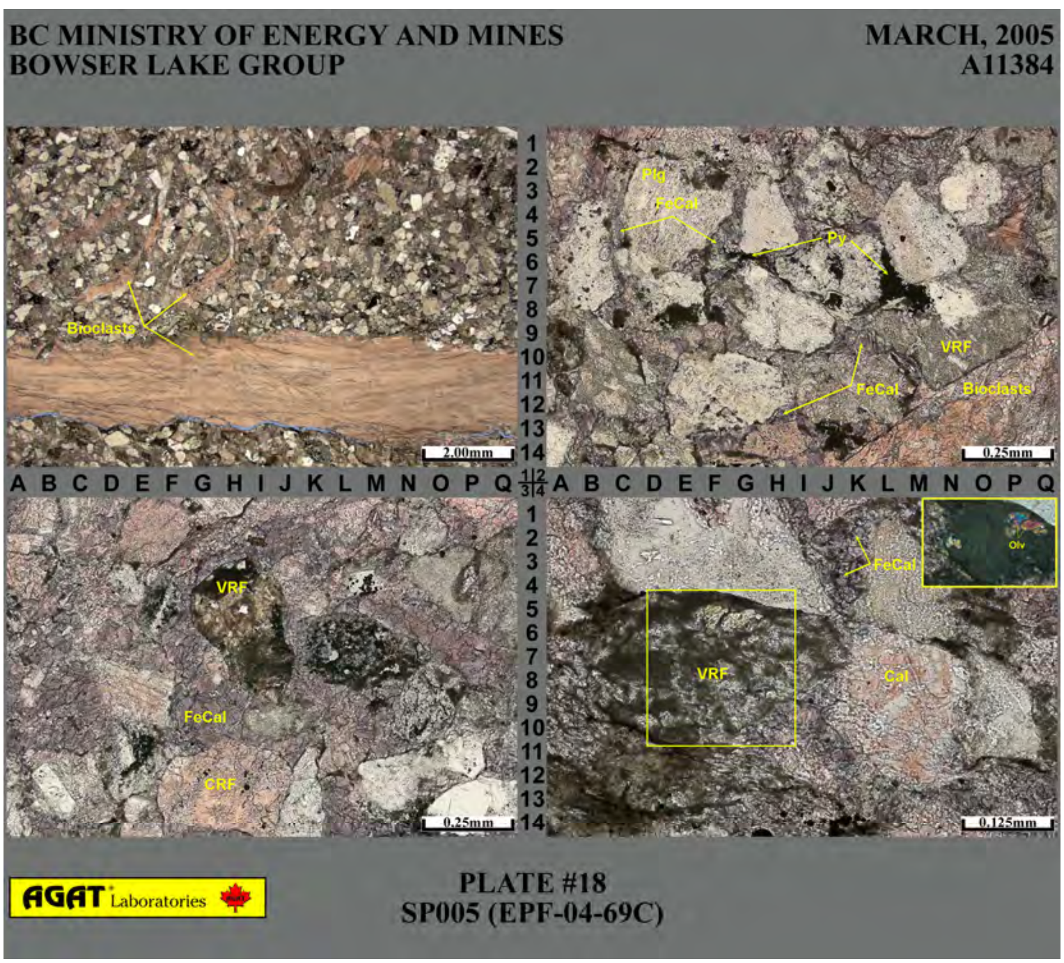

Plate 18. Bowser Lake Group; undifferentiated litharenite.

crystals probably occurred due to weathering. During weathering, some framework grains and cements were also stained with brown colour. In places, the bioclasts have also been replaced with some unknown minerals.

In terms of diagenesis, the chert rich and volcanic rock fragments rich sandstones show some differences. Pore filling authigenic quartz is absent from sandstones that are rich in volcanic rock fragments (except SP005). Quartz cement is present in chert rich samples. Laumontite was not observed in chert rich samples. Furthermore, chlorite cement is more common in sandstones that contain higher percentage of volcanic rock fragments (SP002, SP003, SP004) than in chert rich sandstones (SP007, SP016, SP017, SP019).

SOURCE OF SEDIMENTS

The important conclusion of this study is that the source of these sediments is different in the northern and southern half of the study area. Most sandstones in the southern part of the study area are rich in volcanic rock fragments and they often contain small amounts of olivine and pyroxene. These mafic minerals are absent from the northern half of the study area where chert grains are predominant. Significant amounts of sediments in the south were derived from volcanic and igneous rocks. The presence of olivine and pyroxene grains in the south suggests that mafic and intermediate volcanic rocks contributed clastic material to these sediments. Olivine and pyroxene are relatively less stable minerals during weathering and transportation. The presence suggests a nearby source for these sediments.

RESERVOIR QUALITY AND FLUID SENSITIVITY

Reservoir quality rating is based on the abundance of thin section porosity (or effective porosity), interconnectivity of these pores, pore sizes and routine core data. Generally, the reservoir quality is controlled by depositional environment (mineralogical composition, texture, sorting, grain size, etc.) and diagenetic events (mechanical/chemical compaction, abundance and distribution of authigenic clays, carbonate cements, quartz cement, kaolinite, dissolution features etc.).

Overall, these samples show poor to very poor reservoir quality. Thin section porosity is either absent or rare. Only two samples show more than 1% thin section porosity and these pores appear to be weathering related (SP016). Advanced degree of compaction and cementation has destroyed most of the porosity in these samples. Production of hydrocarbons from similar rocks would be difficult, unless these stratigraphic units contain good subsurface fractures. Alternately, it is also possible that under subsurface environments calcite and some framework grains are dissolved and subsequently not extensively cemented.

Sensitive minerals for potential formation damage include kaolinite, ferroan carbonates and chlorite. The presence of kaolinite in a viable reservoir can cause problems with the migration of fines. If production rates are kept below the "critical" velocity, then permeability reduction as a result of fines migration may not be expected. The use of hydrochloric acid (HCl) will dissolve ferroan carbonates and chlorite in sandstone. As the acid is spent, pH rises above 3, and the iron in solution may precipitate as a permeability reducing iron hydroxide gel. Iron sequestering agents should be used to keep dissolved iron in solution as stable complex. It is important to determine the optimum concentration of sequestering agents because overuse may result in severe gel precipitation. Organic acids such as acetic, citric and lactic acids are commonly used as sequestrants in hydrochloric acid treatments.

SUMMARY AND CONCLUSIONS

First the main conclusions of this study are briefly summarized. This is followed by a brief summary of individual stratigraphic units.

Sandstones and conglomerate from the Skeena and the Bowser Lake groups show advanced degree of mechanical compaction. This compaction and cementation has destroyed almost all of the visible porosity in these samples. Overall, these sediments show poor to very poor reservoir quality.

The source of sediments was different in the northern and southern half of the study areas. Samples from the north are chert rich whereas southern samples are rich in volcanic rock fragments. This difference in the original mineralogy has caused somewhat different diagenetic minerals in the north and south.

The presence of mafic minerals in the south suggests the presence of mafic rocks in the source area. In the south, the source area was not far away from the site of deposition.

Weathering related alteration and dissolution has occurred in some samples. Some of the porosity in these samples was developed due to weathering related dissolution.

Samples from the Skeena Group are classified as upper medium-grained chert rich litharenite (SP006 and SP020) and lower coarse-grained volcanic rock fragment rich feldspathic litharenite (SP011). Quartz, detrital calcite, feldspars, plutonic and sedimentary rock fragments are also present. Kaolinite and chlorite are important authigenic minerals. However, kaolinite is absent from the volcanic rock fragment rich sandstone (SP011). Diagenetic features include onset of compaction, pyrite, grain coating and pore filling chlorite, replacement and pore filling calcite, dissolution of calcite and feldspars and finally precipitation of kaolinite. Secondary porosity created due to dissolution of calcite and framework grains was occluded by kaolinite (SP006, SP020). Visible pores are either absent (SP006, SP020) or present in minor amounts (SP011) and they are not well interconnected. Much of the core porosity in SP020 is believed to be microporosity present between clay minerals. Sandstones from the Skeena Group show poor to very poor reservoir quality.

One grain-supported conglomerate from the Jenkins Creek (SP008) is classified as chert rich litharenite. The sample is intensely stained due to oxidation of iron-rich opaque minerals. Besides chert, quartz grains and organic particles are present. Magnetite, volcanic, plutonic and metamorphic fragments are rare. Hematite/limonite and silica are common cements. Bitumen is rare. Beside compaction, diagenetic features include pyrite, quartz cement, grain fracturing, rare bitumen and hematite/limonite. Trace amounts of intragranular pores are present due to partial dissolution of feldspar and chert grains. Higher permeability value (5.02 mD) is due to microfractures present in the analyzed plug. The reservoir quality of Jenkins Creek conglomerate is considered poor.

Lower medium-grained Groundhog-Gunanoot sandstone is classified as chert rich litharenite (SP010). Framework grains are dominated by chert with lesser amounts of quartz, shale clasts, volcanic fragments, magnetite, organic matter and detrital chlorite. Quartz and hematite/limonite are the main cements. Diagenetic features include on set of compaction, siderite (?), quartz cement, alteration of siderite and magnetite to limonite/hematite, precipitation of ferroan dolomite in secondary pores and partial dissolution of ferroan dolomite. Oxidation of siderite and other iron minerals has created yellow spots and pores deep into the outcrop sample. These pores are not well interconnected and the reservoir quality is considered poor.

Based on mineral composition, seven samples from the Muskaboo Creek Assemblage are divided into two groups: chert rich samples (SP012, SP015, SP018) and volcanic rock fragment rich samples (SP001, SP009, SP021, SP022). It is important to note that chert rich sandstones are located in the northern half of the study area and the volcanic rock fragment rich sandstones in the southern half. It is true for the undifferentiated eight samples as well.

Medium-grained chert rich sandstones of the Muskaboo Creek are classified as litharenite (SP012, SP015, SP018). Their framework grains are dominated by chert followed by quartz, feldspars, shale clasts and volcanic rock fragments. Quartz, clays and calcite are the main cements. Diagenetic features include onset of compaction, pyrite, chlorite rims, fibrous illite, quartz cement and calcite. Near surface weathering has created some porosity that is absent deep inside the outcrop samples (e.g. SP012). Thin section porosity is rare and the reservoir quality considered very poor.

Medium to coarse-grained volcanic rock fragment rich sandstones of the Muskaboo Creek are classified as feldspathic litharenite or lithic arkose (SP001, SP009, SP021, SP022). Their framework grains are dominated by volcanic rock fragments followed by feldspar, chert and plutonic rock fragments. Olivine and pyroxene are characteristic of these sandstones. Chlorite, laumontite and calcite are common cements. Diagenetic sequence include on set of compaction, chlorite, fibrous illite, anhydrite, laumontite and calcite. Thin section porosity is rare and the reservoir quality considered very poor to poor.

The diagenetic history of chert rich and volcanic rock fragments rich sandstones of the Muskaboo Creek Assemblage show some differences. Pore filling quartz cement is absent from sandstones that are rich in volcanic rock fragments. Authigenic laumontite is absent from chert rich samples. Furthermore, chlorite cement is more common in sandstones that contain higher percentage of volcanic rock fragments.

Fine-grained Skelhorne sandstone is classified as chert rich litharenite (SP013). Framework grains are dominated by chert and sedimentary rock fragments. Moderate amounts of quartz and feldspars grains are also present. Quartz and ferroan dolomite are common authigenic minerals. Diagenetic features include onset of compaction, pyrite, chlorite, quartz cement and ferroan dolomite. Pores are absent and the reservoir quality is very poor.

Fine-grained Todagin sandstone is classified as chert rich litharenite (SP014). Framework grains are dominated by chert and sedimentary rock fragments. Moderate amounts of quartz, feldspars and volcanic rock fragments are also present. Chlorite, ferroan calcite and quartz are common authigenic minerals. Diagenetic features include onset of compaction, pyrite, chlorite, illite, quartz and ferroan calcite. Pores are rare and the reservoir quality is very poor.

Based on mineral composition, eight undifferentiated samples from the Bowser Lake Group are also divided into two groups: chert rich samples (SP007, SP016, SP017, SP019) and volcanic rock fragment rich samples (SP002, SP003, SP004, SP005). Chert rich sandstones are located in the northern half of the study area and the volcanic rock fragment rich sandstones in the southern half. Their mineral composition and diagenesis is generally comparable to Muskaboo Creek samples as mentioned above. Weathering related dissolution pores (SP016) and hematite/limonite (SP019) are locally present. The reservoir quality for these samples is poor to very poor except in SP016 (poor to moderate).

REFERENCES

Deer, W.A., Howie, R.A. and Zussman, J. (1983): An Introduction to the Rock Forming Minerals, Longman, England.

Folk, R.L. (1974): Petrology of Sedimentary Rocks, Hemphill, Austin, Texas, USA.

Helmold, K.P. and van de Kamp, P.C. (1984): Diagenetic mineralogy and controls on albitization and laumontite formation in Paleogene arkoses, Santa Ynez Mountains, California, *in* Clastic Diagenesis, AAPG Memoir 37, pages 239-276.

APPENDIX A

FINAL CORE ANALYSIS, OUTCROP SAMPLES

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FINAL CORE ANALYSIS REPORT

OUTCROP SAMPLES

Prepared for:

BC MINISTRY OF ENERGY & MINES

RC12352

January 2005

"In Pursuit of Excellence"

- **AIHA Accredited**
- **CAEAL Accredited**
- **Registered with APEGGA**

TABLE OF CONTENTS

CORE ANALYSIS DATA

OUTCROP SAMPLES

COMPANY : BC MINISTRY OF ENERGY & MINES
LOCATION : MISC
FORMATION :
WELL NAME : OUTCROP SAMPLES
DRILLING FLUID : WATER BASE MUD

PAGE : 1
DATE : 17-Jan-2005
W/O No : RC12352

ROUTINE CORE ANALYSIS

Sample	Interval (m)		Rep Thick (m)	Sample Length (m)	Gas Permeability			Capacity Kmax mD·m	Porosity	Capacity Ø·m	Density (Kg/m³)		Residual Saturation		Remarks
	Top	Base			Kmax (mD)	K90 (mD)	Kv (mD)				Bulk	Grain	Oil	Water	
SP001	0.00	0.00	0.00	-	<.01	-	-		0.007	0.000	2690	2710	-	-	ss:f-cgr:calc:pyr
SP002	0.00	0.00	0.00	-	0.05	-	-		0.034	0.000	2630	2720	-	-	ss:vf-mgr:carbptg:calc:pyr:fracs
SP003	0.00	0.00	0.00	-	0.34	-	-		0.041	0.000	2540	2660	-	-	ss:vf-cgr:carbptg:calc
SP004	0.00	0.00	0.00	-	0.08	-	-		0.032	0.000	2570	2660	-	-	ss:vf-fgr:calc
SP005	0.00	0.00	0.00	-	0.01	-	-		0.013	0.000	2690	2730	-	-	ss:vf-cgr:calc:dol:pyr
SP006	0.00	0.00	0.00	-	0.01	-	-		0.017	0.000	2620	2670	-	-	ss:vf-cgr:calc:dol
SP007	0.00	0.00	0.00	-	<.01	-	-		0.013	0.000	2650	2690	-	-	ss:vfgr:carbptg:dol
SP008	0.00	0.00	0.00	-	5.02 *	-	-		0.038	0.000	2540	2640	-	-	cgl:fracs
SP009	0.00	0.00	0.00	-	<.01	-	-		0.007	0.000	2670	2690	-	-	ss:vf-mgr:calc:pyr
SP010	0.00	0.00	0.00	-	<.01	-	-		0.020	0.000	2610	2660	-	-	ss:vf-mgr:carbptg:dol
SP011	0.00	0.00	0.00	-	<.01	-	-		0.010	0.000	2660	2690	-	-	ss:f-cgr:calc:dol
SP012	0.00	0.00	0.00	-	<.01	-	-		0.022	0.000	2600	2660	-	-	ss:vf-mgr:carbptg:calc:dol
SP013	0.00	0.00	0.00	-	<.01	-	-		0.009	0.000	2640	2660	-	-	ss:vf-mgr:carbptg:dol
SP014	0.00	0.00	0.00	-	0.01	-	-		0.006	0.000	2670	2690	-	-	ss:vf-mgr:calc:dol
SP015	0.00	0.00	0.00	-	<.01	-	-		0.008	0.000	2640	2660	-	-	ss:vf-cgr:calc
SP016	0.00	0.00	0.00	-	<.01	-	-		0.009	0.000	2650	2670	-	-	ss:vf-mgr:calc:pyr
SP017	0.00	0.00	0.00	-	<.01	-	-		0.007	0.000	2640	2660	-	-	ss:vf-mgr:argptg:calc:pyr
SP018	0.00	0.00	0.00	-	<.01	-	-		0.017	0.000	2620	2670	-	-	ss:vf-cgr:calc:pyr
SP019	0.00	0.00	0.00	-	<.01	-	-		0.008	0.000	2640	2660	-	-	ss:vf-mgr:dol
SP020	0.00	0.00	0.00	-	0.02	-	-		0.036	0.000	2580	2670	-	-	ss:f-cgr:calc
SP021	0.00	0.00	0.00	-	0.18	-	-		0.040	0.000	2600	2710	-	-	ss:vf-cgr:calc:dol:pyr

* - affected by fracture or crack as mentioned in remarks

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ROUTINE CORE ANALYSIS

Sample	Interval (m)		Rep Thick (m)	Sample Length (m)	Gas Permeability			Capacity Kmax mD·m	Porosity	Capacity Ø·m	Density (Kg/m³)		Residual Saturation		Remarks
	Top	Base			Kmax (mD)	K90 (mD)	Kv (mD)				Bulk	Grain	Oil	Water	
SP022	0.00	0.00	0.00	-	0.09	-	-		0.050	0.000	2490	2620	-	-	ss:vf-cgr

CORE ANALYSIS - QUALITY CONTROL REPORT

SP001 0.00 - 0.00

- GRAIN DENSITY (2710) OUT OF LIMITS FOR LITHOLOGY SPECIFIED (ss [2580-2690]) calcite;pyrite;results verified

SP002 0.00 - 0.00

- GRAIN DENSITY (2720) OUT OF LIMITS FOR LITHOLOGY SPECIFIED (ss [2580-2690]) calcite;pyrite;results verified

SP003 0.00 - 0.00

SP004 0.00 - 0.00

SP005 0.00 - 0.00

- GRAIN DENSITY (2730) OUT OF LIMITS FOR LITHOLOGY SPECIFIED (ss [2580-2690]) calcite;dolomite;pyrite;results verified

SP006 0.00 - 0.00

SP007 0.00 - 0.00

SP008 0.00 - 0.00

SP009 0.00 - 0.00

SP010 0.00 - 0.00

SP011 0.00 - 0.00

SP012 0.00 - 0.00

SP013 0.00 - 0.00

SP014 0.00 - 0.00

SP015 0.00 - 0.00

SP016 0.00 - 0.00

SP017 0.00 - 0.00

SP018 0.00 - 0.00

SP019 0.00 - 0.00

SP020 0.00 - 0.00

SP021 0.00 - 0.00

- GRAIN DENSITY (2710) OUT OF LIMITS FOR LITHOLOGY SPECIFIED (ss [2580-2690]) calcite;dolomite;pyrite;results verified

SP022 0.00 - 0.00

COMPANY	: BC MINISTRY OF ENERGY & MINES	PAGE	: 4
LOCATION	: MISC	DATE	: 17-Jan-2005
FORMATION	:	W/O No	: RC12352
WELL NAME	: OUTCROP SAMPLES		
DRILLING FLUID	: WATER BASE MUD		

CORE ANALYSIS - QUALITY CONTROL REPORT

Approved : ______________________ Quality Control Supervisor ______________ Date

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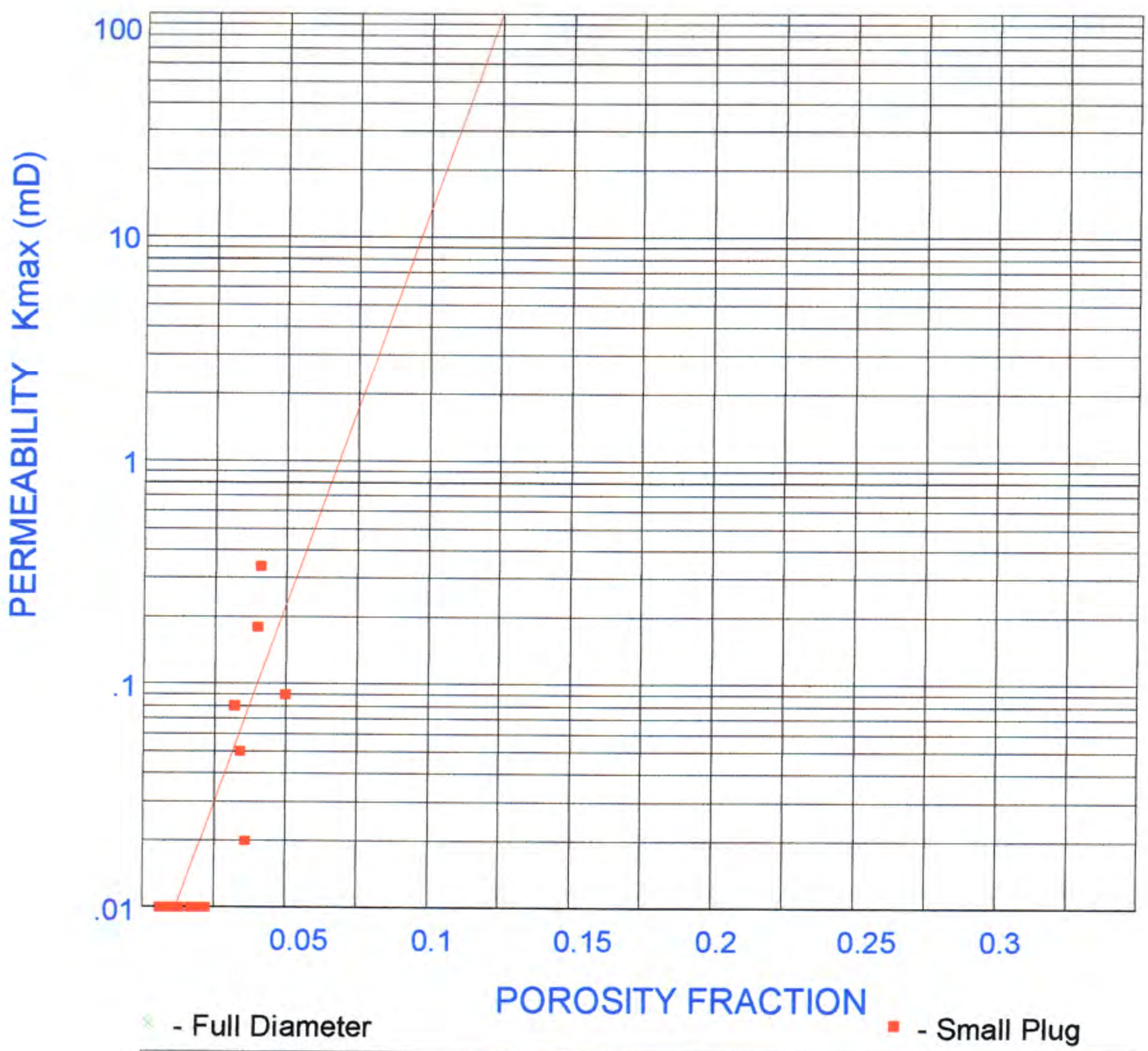
Company : BC MINISTRY OF ENERGY & MINES
Location : MISC
Well Name : OUTCROP SAMPLES
Interval : 000.00-000.000
Formation :

FIGURE : 4
Date : 17-Jan-2005
AGAT Job : RC12352

POROSITY-PERMEABILITY CORRELATION



Equation of Line : Log (Kmax) = -2.41 + 35.29* Porosity
Correlation Coefficient r = 0.86

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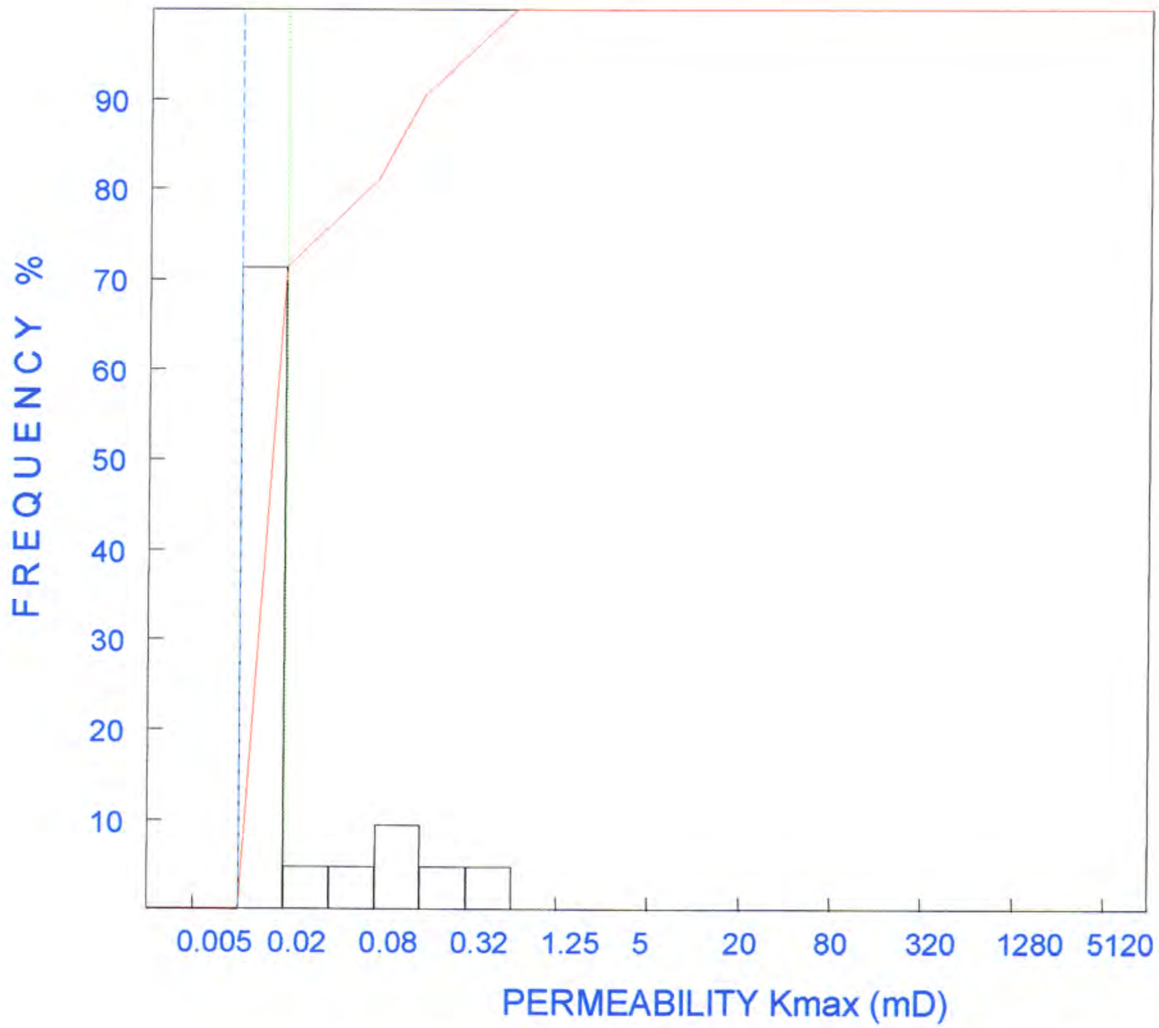
Formation :

FIGURE : 3
Date : 17-Jan-2005
AGAT Job : RC12352

PERMEABILITY Kmax DISTRIBUTION



Arithmetic Mean
Median
Cum. Frequency %

Mean: 0.02
Median: 0.01

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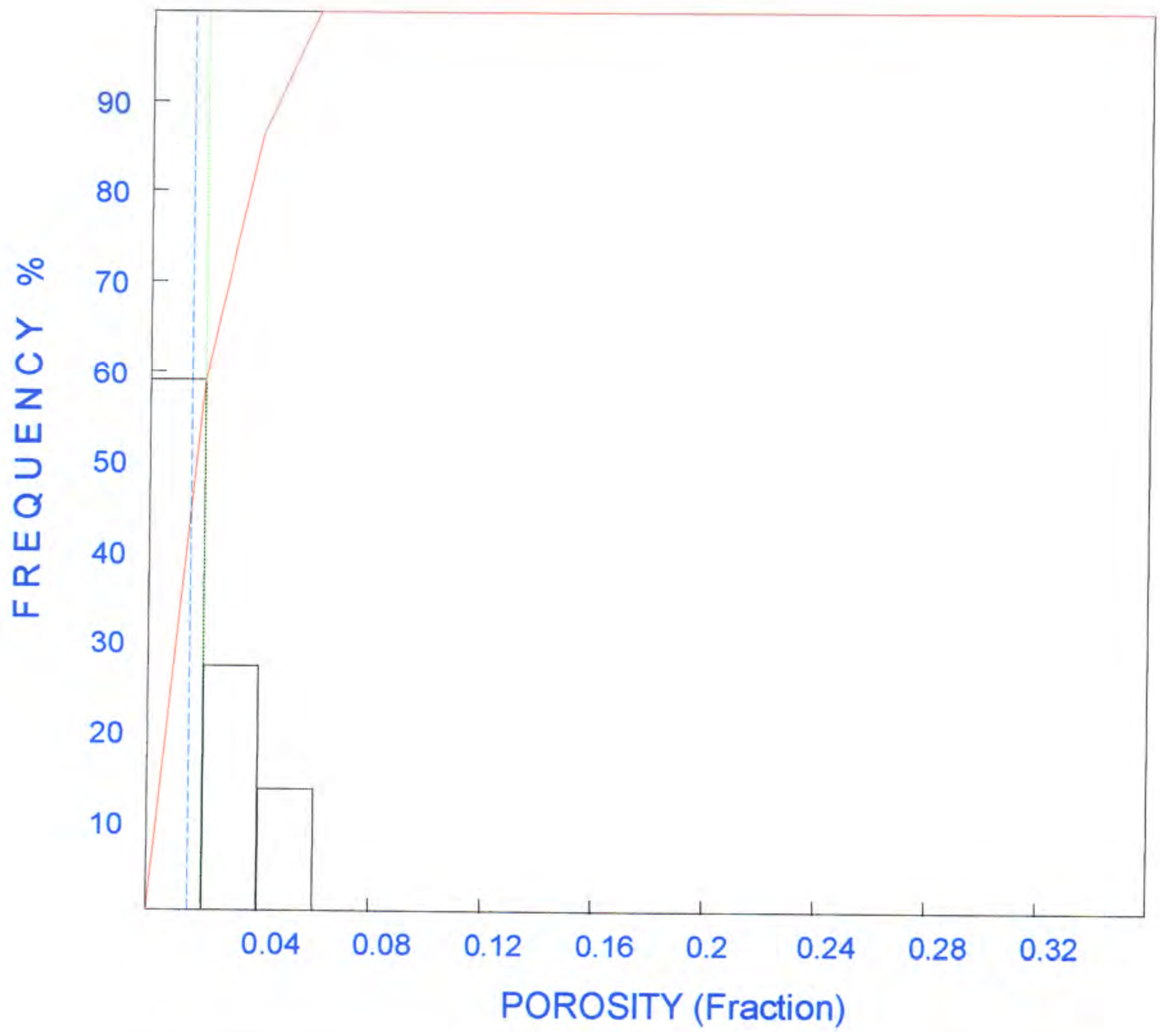
Location : MISC
Well Name : OUTCROP SAMPLES
Interval : 000.00-000.000
Formation :

FIGURE : 2
Date : 17-Jan-2005
AGAT Job : RC12352

POROSITY DISTRIBUTION



Arithmetic Mean		Mean: 0.02
Median		Median: 0.015
Cum. Frequency %		

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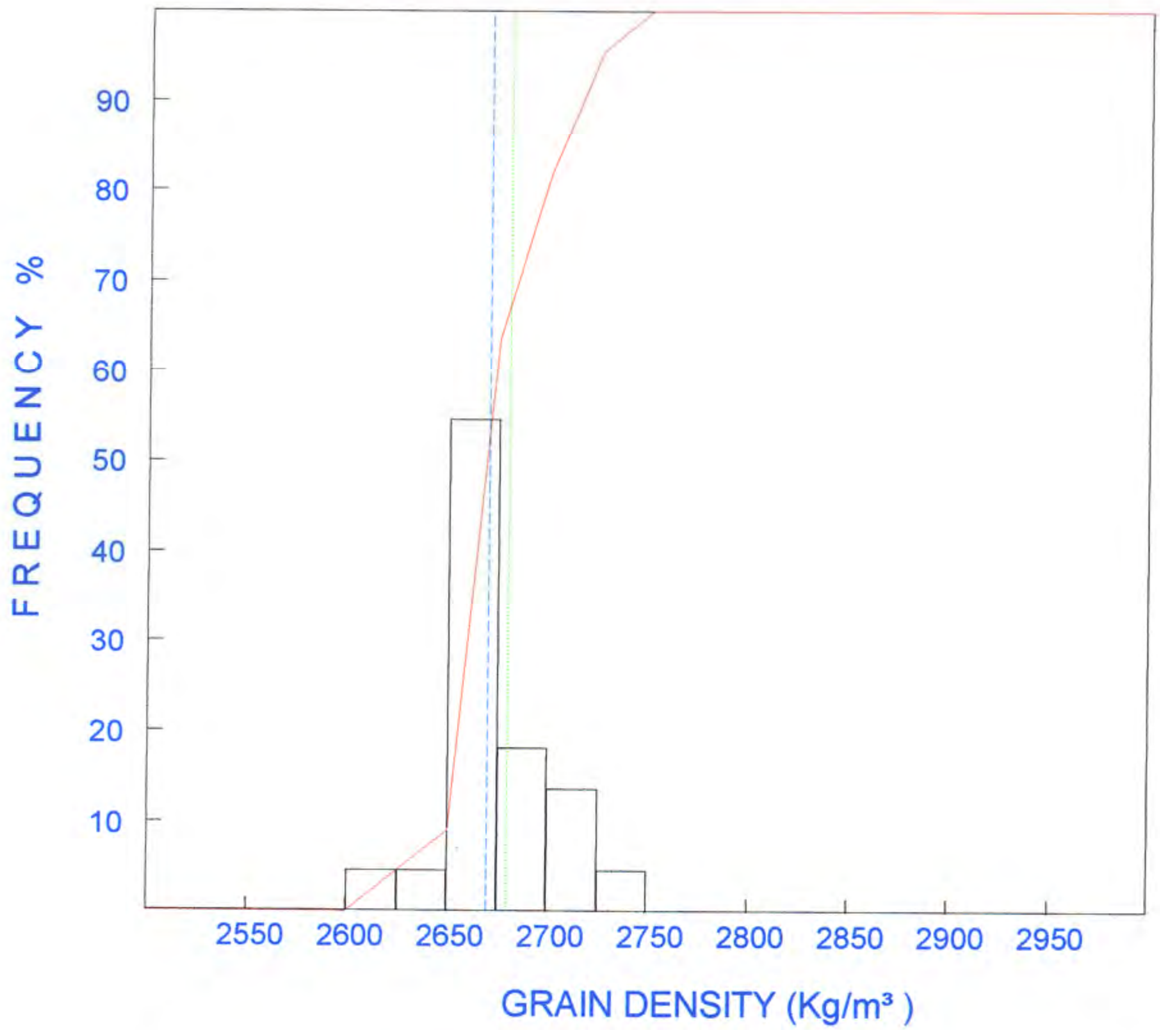
Company : BC MINISTRY OF ENERGY & MINES
Location : MISC
Well Name : OUTCROP SAMPLES
Interval : 000.00-000.000
Formation :

FIGURE : 1
Date : 17-Jan-2005
AGAT Job : RC12352

GRAIN DENSITY DISTRIBUTION



Arithmetic Mean	....	Mean: 2680
Median	- - - - - - -	Median: 2670
Cum. Frequency %	———	

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OUTCROP SAMPLES

EPF-04-13B	=	SP001
EPF-04-57-C	=	SP002
EPF-04-61A	=	SP003
EPF-04-65B	=	SP004
EPF-04-69C	=	SP005
EPF-04-95C	=	SP006
EPF-04-162A	=	SP007
EPF-04-182A	=	SP008
EPF-04-221A	=	SP009
EPF-04-319A	=	SP010
EPF-04-359A	=	SP011
EP-04-49A	=	SP012
EP-04-90H	=	SP013
EP-04-91D	=	SP014
EP-04-92D	=	SP015
EP-04-94D	=	SP016
EP-04-101A	=	SP017
EP-04-104A	=	SP018
EPM-04-201A	=	SP019
EPR-04-101A	=	SP020
EPS-04-MS1-04	=	SP021
EPS-04-MS2-09	=	SP022

SAMPLE HANDLING

AGAT LABORATORIES CORE SERVICES

SAMPLE HANDLING AND ANALYSIS INFORMATION

Company	: BC MINISTRY OF ENERGY & MINES	Coring Equipment	: Diamond	W/O Number	: RC12352
Well	: "OUTCROP SAMPLES"	Coring Fluid	: Water Base Mud	Date	: 17-Jan-2005

HANDLING

Core Transported in	: Boxes
Cutting Solution	: Water
Drying Time/Temp	: 48 hours @ 108°C
Drying Equipment	: Convection Oven

ANALYSIS

Grain volume measured by Boyle's Law using helium
Bulk volume measured by calipering on right-cylindrical samples
Permeability measured on 38.1/25.4 mm diameter drilled plugs

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ABBREVIATIONS

COMMON ABBREVIATIONS

abnt	Abundant
abv	Above
Alg	Algae (al)
alt	Altered (ing)
amor	Amorphous
Amph	Amphipora
ang	Angular
anhy	Anhydrite (ic)
app	Appear
apr	Apparent
aprox	Approximate (ly)
arg	Argillaceous
ark	Arkose (ic)
asph	Asphalt (ic)
AST	Assigned similar to (no actual sample taken)
apha	Aphanitic
bcm	Become (ing)
bd	Bed
bdd	Bedded
bdg	Bedding
Belm	Belemnites
bent	Bentonite (ic)
bf	Buff
biocl	Bioclastic
bioturb	Bioturbated
bit	Bitumen (inous)
bl	Blue (ish)
blk	Black
blky	Blocky
bnd	Band (ed)
Brac	Brachiopod
brec	Breccia (ted)
bri	Bright
brit	Brittle
brn	Brown
Bry	Bryozoa
bulb	Bulbous
bur	Burrowe
	Cor

calc	Coarse (ly)
carb	Calcite (areous)
cbl	Carbonaceous
Ceph	Cobble (64-256 mm)
cgl	Cephalopod
chk	Conglomerate
chlor	Chalk (y)
cht	Chlorite
chty	Chert
cl	Cherty
cln	Clastic
clr	Clean
cly	Clear
com	Clay (ey)
coq	Common
Cor	Coquina
crbnt	Coral
Crin	Carbonate
crm	Crinoid (al)
crpxl	Cream
ctc	Cryptocrystalline
	Contact
deb	
decr	Debris
desi	Decrease (ing)
dism	Desiccation
dk	Disseminated
dns	Dark (er)
dol	Dense (er)
drsy	Dolomite (ic)
dtrl	Drusy
	Detrital (us)
elg	
euhed	Elongate
	Euhedral

f	Fine (ly)
fau	Fauna
Fe	Iron-Ferruginous
Fe-mag	Feromagnesian
fenst	Fenestral
fis	Fissile
fl	Fill (ed)
fld	Feldspar (thic)
flk	Flake
flky	Flaky
flor	Fluorescence
flt	Fault (ed)
fltg	Floating
foram	Foraminifera
fos	Fossil (iferous)
fr	Fair
frac	Fracture (ed)
frag	Fragment (al)
fri	Friable
frmwk	Framework
fros	Frosted
g	Good
Gast	Gastropod
gl	Glass (y)
glau	Glauconite (ic)
gn	Green
gr	Grain (ed)
gran	Granular
grd	Grade (ed)
grnl	Granule (2-4 mm)
gy	Grey
gyp	Gypsum (iferous)

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COMMON ABBREVIATIONS (CONTINUED)

hal	Halite
hd	Hard
hfrac	Horizontal Fracture
hi	High
hrtl	Horizontal
hvy	Heavy
hydc	Hydrocarbon
ig	Igneous
imbed	Imbedded
imp	Impression
incl	Included (sion)
incr	Increase
indst	Indistinct
intbd	Interbedded
intcl	Intraclast (s)
intfrag	Interfragmental
intgran	Intergranular
intlam	Interlaminated
intr	Intrusion (ive)
intv	Interval
intxl	Intercrystalline
ireg	Irregular
ird	Iridescent
intrsk	Intraskeletal
kao	Kaolin
lam	Laminated
lchd	Leached
len	Lentil (cular)
lith	Lithographic
lmy	Limy
lrg	Large (er)
ls	Limestone
lse	Loose
lstr	Lustre
lt	Light (er)

m	Medium
mar	Maroon
mas	Massive
mat	Material, matter
mica	Mica (ceous)
mic	Micro
mky	Milky
mnr	Minor
mnrl	Mineral (ized)
mnut	Minute
Mol	Mollusca
mot	Mottled
mrly	Marly
mtx	Matrix
n	No,none,non
nod	Nodule
num	Numerous
o	Oil
occ	Occasional
od	Odor
ool	Oolite (ic)
op	Opaque
org	Organic
orng	Orange
orth	Orthoclase
Ost	Ostracod
ovgth	Overgrowth
ox	Oxidized
p	Preliminary (as suffix)
pbl	Pebble (4-64 mm)
pel	Pellet
perm	permeability
pet	Petroleum (iferous)
phos	Phosphate (ic)

pk	Pink
plag	Plagioclase
plcy	Pelecypod
pl	Plant
plty	Platy
por	Porous (sity)
pos	Possible (ility)
p-p	Pin-Point
pred	Predominant (ly)
prim	Primary
prob	Probable (ly)
prom	Prominent (ly)
pt	Part (ly)
ptch	Patch (es)
ptg	Parting
purp	Purple
pyr	Pyrite (ic) (ized)
pyrbit	Pyrobitumen
qtz	Quartz
qtzc	Quartzitic
qtzs	Quartzose
rd	Round (ed)
repl	Replaced (ing) (ment)
rexl	Recrystallized
rmn	Remains (nant)
rr	Rare
rsns	Resinous
rthy	Earthy
s	Small
sa	Salt (y)
S	Sulphur
s&p	Salt & Pepper
sat	Saturated
sb	Sub

COMMON ABBREVIATIONS (CONTINUED)

sc	Scales
scat	Scattered
sd	Sand (1/16 - 2mm)
sdy	Sandy
sec	Secondary
sed	Sediment (ary)
sft	Soft
sh	Shale
shad	Shadow
shy	Shaly
sid	Siderite (ic)
sil	Silica
sks	Slickensided
sl	Slight (ly)
sln	Solution
slt	Silt
sltst	Siltstone
slty	Silty
sm	Smooth
SP	Small Plug (as prefix)
sp	Spot (ted) (ty)
spec	Speck (led)
spl	Sample
srt	Sort (ed) (ing)
strg	Stringer
Strom	Stromatoporoid
stromlt	Stromatolite
struc	Structure
styl	Stylolite (ic)
suc	Sucrosic
sug	Sugary
sup	Supported
surf	Surface
sz	Size

tab	Tabular
tex	Texture
Tham	Thamnopora
thk	Thick
thn	Thin
thru	Throughout
tr	Trace
trnsl	Translucent
trnsp	Transparent
tt	Tight
tub	Tubular
uncons	Unconsolidated
unident	Unidentifiable
up	Upper
v	Very
var	Variable
vcol	Varicolored
vfrac	Vertical Fracture
vgt	Varigated
vn	Vein
vrtl	Vertical
vug	Vug (gy) (ular)
w	Well
wh	White
wk	Weak
wthrd	Weathered
wtr	Water
wvy	Wavy
wxy	Waxy
wsrt	Well sorted

xbd	Cross-bedded
xbdg	Cross-bedding
xl	Crystal (line)
xlam	Cross-laminated
yel	Yellow
zn	Zone
*	Broken core
/	With
>10000	Permeability over 10000 mD
<0.01	Permeability less than 0.01 mD
CC	Cracked Core
DR	Drilled
LC	Lost Core
RU	Rubble
mD	milliDarcy