PRELIMINARY ASSESSMENT OF POTENTIAL HYDRAULIC FRACTURE SAND SOURCES AND THEIR DEPOSITIONAL ORIGIN, NORTHEAST BRITISH COLUMBIA

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ABSTRACT

The demand for hydraulic fracture proppant ('frac sand') in northeast British Columbia has increased because of the enormous volume of frac sand required to develop unconventional shale gas resources. The increased North American demand on existing frac sand sources and the tremendous cost of transporting the product to northeast British Columbia means that local sand sources once deemed marginal or unsatisfactory may be economic despite the expense of processing.

A preliminary assessment of 7 bedrock samples and 17 unconsolidated sand samples from northeast British Columbia is presented. For bedrock samples, thin sections and a distribution map of prospective units in the Rocky Mountain Foothills are provided. For unconsolidated samples, thin sections, grain photographs (binocular, plane light and crossed nicols), major oxide geochemistry and grain-size distribution are provided.

Results suggest that the Liard and Charlie Lake formations (Triassic) and the Monteith and Monach formations of the Minnes Group (Late Jurassic to Cretaceous) are the most prospective bedrock units of those assessed. The Liard Formation is mainly a quartz arenite and the Charlie Lake Formation is a feldspathic arenite, both with carbonate cement. The Monteith and Monach formations are quartz arenites.

The unconsolidated deposits that are most prospective originate from three depositional environments: glaciodeltaic, aeolian and glaciofluvial. The Komie area is a priority target, located near the intersection of Geetla and Komie roads on the western edge of the Horn River Basin. It is a glaciofluvial delta (~8 km^2) comprising mainly well-rounded, medium-grained quartz-rich sand. The Redwillow glaciofluvial delta is a large (2 km^2) sand deposit south of Dawson Creek with abundant quartz grains mixed with lithic grains. Aeolian deposits of the Fontas Dune Field (Wolfe et al., 2007) contain monocrystalline, fine-grained quartz sand and are an excellent target. Other potential dune sources include the Kiskatinaw and Pine River dune fields, but abundant lithic grains make these fields less prospective than those of the Fontas Dune Field. Eskers associated with the Laurentide Ice Sheet, including the Courvoisier Esker Complex, eskers of the Horn River Basin and those found near the northern part of the Sierra-Yoyo-Desan Road may also be viable exploration targets. Despite common lithic fragments, they also contain abundant, well-rounded quartz grains.

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INTRODUCTION

The excessive cost associated with transporting hydraulic fracture proppants ('frac sand') from established sources to northeastern British Columbia, and the anticipated demand that will result from increased development of this area's unconventional shale gas resources, has prompted the British Columbia Ministry of Energy, Mines and Petroleum Resources (BCMEMPR) to compile an initial inventory of promising local frac sand sources. This paper examines the location, nature and origin of naturally occurring quartz-rich unconsolidated sand deposits and bedrock outcrop in northeast British Columbia. The deposits were documented during bedrock and surficial geology mapping activities by the BCMEMPR in partnership with the Geological Survey of Canada. Some of the samples collected during these mapping programs are evaluated here for frac sand potential.

Northeast British Columbia has become a focus for the development of unconventional shale gas resources. Over the last few years, this interest has resulted in a significant increase in the amount of land sold as well as the price per hectare of petroleum and natural gas rights (Adams et al., 2008). Recent exploration activity has been focused in the Fort St John, Dawson Creek (Montney) and Fort Nelson (Horn River, Cordova Embayment and Liard River) areas, where shale gas is the target. The production of natural gas from organic-rich shale, a rock previously considered as a gas source or reservoir seal, is possible because of advances in directional drilling and production stimulation. To liberate gas from relatively impermeable shale, long horizontal sections are drilled into the formation of interest and the rock fractured, thereby providing conduits (through increased permeability) for gas to move from the rock to the well bore. Fracturing ('frac'ing') is achieved by pumping water at high pressure into the horizontal section and out into the rock. Fractures in the rock are prevented from closing by forcing proppants such as frac sand into the fractures (Figure 1).

A simulation by Kerr (2009) predicts that over the next 20 years, the demand for frac sand in the Horn River Basin, under pessimistic and optimistic drilling scenarios, to be approximately 8.8–19.7 million tons, respectively. At a cost of \$100–\$200 per ton, the expense associated with this component of well-completion costs could range from \$880 million to \$3.4 billion. As the number of fracs per well increases, along with a shift to higher-tonnage fracs, this demand and the associated cost will also increase.

There are three major sources of frac sand in North America (Dumont, 2007; Zdunczyk, 2007): 1) Middle–Late Ordovician St. Peter sandstone of the Ancell Group (commercially referred to as 'Ottawa' or 'White' sand) from the northeast United States; 2) the Cambrian Hickory Member of the Riley Formation ('Brown' or 'Brady' sand) from Texas; and 3) the Middle Ordovician Black Island Member of the Winnipeg Formation around Hanson Lake, Saskatchewan. There are also a number of smaller frac sand producers in Canada, of which the closest to northeast British Columbia is the Cretaceous Paddy Member sandstone of the Peace River Formation (Fort St John Group) in Peace River, Alberta (Alberta Geological Survey, 1989).

Sand, used as a frac proppant, has rigid engineering standards, as outlined in American Petroleum Institute (API) report numbers API RP 56 (American Petroleum Institute, 1995a), API RP 60 (American Petroleum Institute, 1995b) and International Organization for Standards (ISO) report number ISO 13503-2 (International Organization for Standards, 2006). Critical characteristics include grain-size distribution, average particle sphericity and rounding, acid solubility, crush resistance and particle mineralogy. Most northeast British Columbian quartzite, sandstone and unconsolidated sand deposits, in raw form, fail to meet these

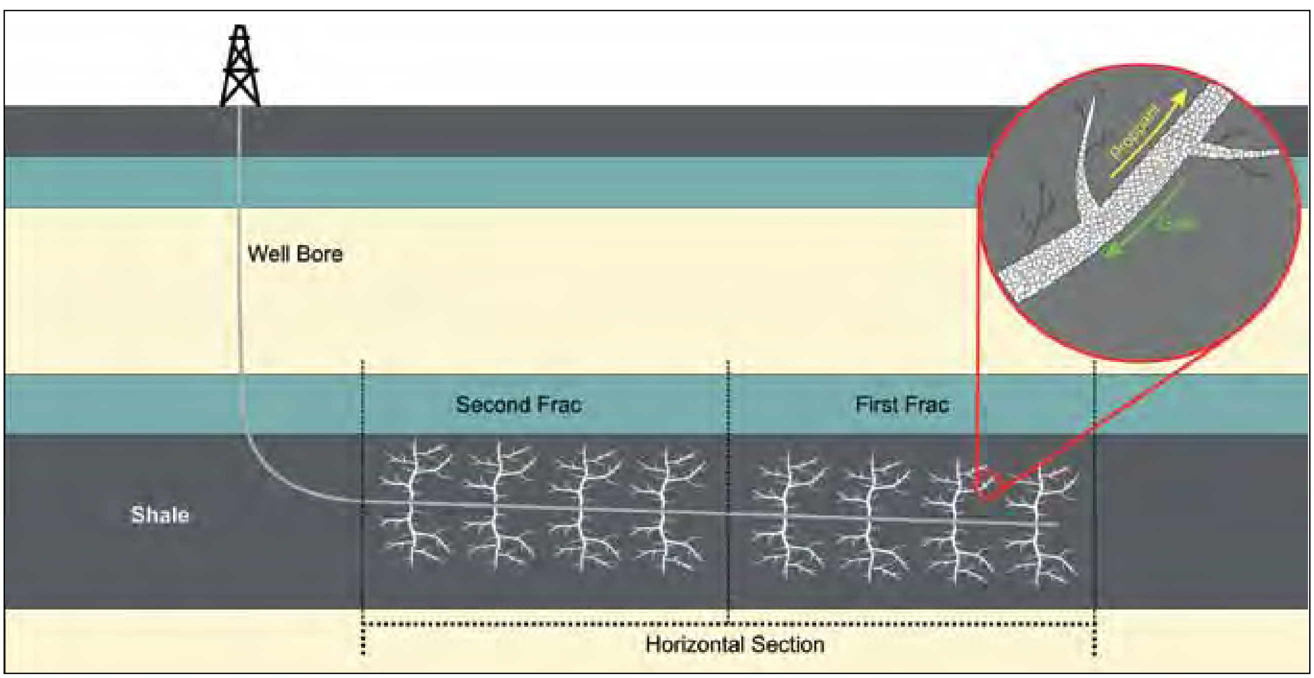

Figure 1. Simplified example of a typical frac'ing operation in northeast British Columbia. Frac'ing is performed on the horizontal section of production wells. Water is pumped into the well bore at high pressure and forced into the rock, causing it to fracture. Proppant is introduced into the fractures to keep them from closing, thereby permitting the gas to travel from the shale back to the well bore.

requirements. However, given that the transportation of frac sand to northeast British Columbia represents a significant cost, it may be economically beneficial to process local sources to meet these stringent frac sand guidelines.

METHODS

Sample Collection

BEDROCK

Bedrock samples are from the Rocky Mountain Foothills physiographic region (Holland, 1976) and are part of a representative suite of samples from outcrop documented during a regional 1:50 000 scale bedrock mapping program in the Halfway River map area (094B/02 and 07; Ferri, 2009). This area encompasses clastic rocks of Carboniferous to Cretaceous age and includes the Carboniferous to Permian Stoddart Group; Triassic rocks of the Toad, Liard and Charlie Lake formations; and Jurassic to Cretaceous rocks of the Fernie, Minnes and Bullhead groups. Results presented are limited to units with >80% quartz grains, which include only the Cretaceous Monach and Monteith formations of the Minnes Group and the Triassic Charlie Lake and Liard formations.

UNCONSOLIDATED

Sand samples collected from known and recently discovered sand deposits identified during surficial geology and aggregate potential mapping programs were evaluated for their frac sand potential. Samples are from a variety of genetic deposits including aeolian dunes, subglacial glaciofluvial (eskers) and proglacial glaciofluvial deposits, and deltaic glaciofluvial deposits.

Laboratory

BEDROCK

Thin sections were prepared and qualitatively evaluated to estimate proportions of matrix to grains and the quantity of quartz, feldspar and lithic grains for use within the classification scheme of Dott (1964) and Williams et al. (1982; Figure 2).

UNCONSOLIDATED

Grain-size distribution was established by wet sieving raw samples using the Wentworth grain-size classification (Wentworth, 1922). The weight proportion of the sample retained in >2.0 mm, >1.0 mm, >0.5 mm, >0.25 mm, >0.125 mm and >0.063 mm sieves, and the proportion <0.063 mm is plotted both as histograms and cumulative percent charts. A split of the sand-sized fraction (<2.0 mm to >0.063 mm) was washed and separated from each raw sample for imaging and analysis. A photomicrograph was taken of the grains using a binocular microscope. Thin sections were made and imaged under plane light and cross nicols. Part of the sand split was milled to <0.063 mm and then analyzed for major oxide geochemistry by inductively coupled plasma–emission spectroscopy (ICP-ES) following a lithium metaborate/tetraborate fusion and dilute nitric digestion.

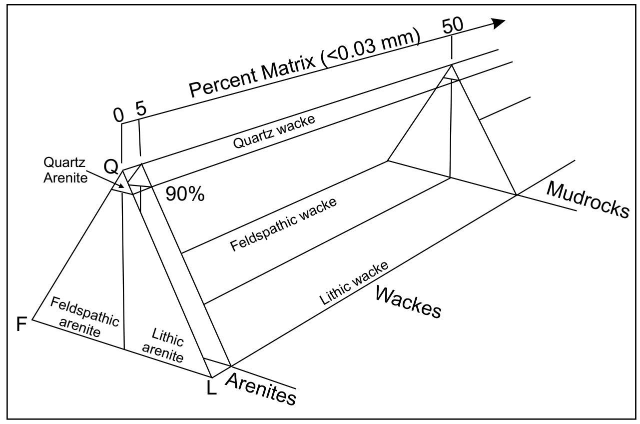

Figure 2. Classification diagram for sandstones used in this report, modified from Dott (1964) and Williams et al. (1982).

RESULTS

Bedrock

Forty-four samples were collected and evaluated; seven promising samples are presented in Table 1 and Appendix 1. The high-potential samples are from the Liard and Charlie Lake formations and the Minnes Group (Monteith and Monach formations) (Figure 3). Liard and Charlie Lake rocks record marine environments, although the latter also documents sabkha environments. The Minnes Group represents a westward-thickening foreland wedge, with the Monteith and Monach formations deposited in deltaic settings.

Unconsolidated

Seventeen unconsolidated sand samples were collected from eleven distinct areas (Table 2; Appendix 2). These areas are shown in Figure 4 and include Bear Lake (aeolian; area 1), Lower Pine River (aeolian; area 2), Kiskatinaw Dune Field (aeolian; area 3), Redwillow River (deltaic; area 4), Fort Nelson Airport (glaciofluvial; area 5), Fontas Dune Field (aeolian; area 6), KM 176 — SYD (esker; area 7),

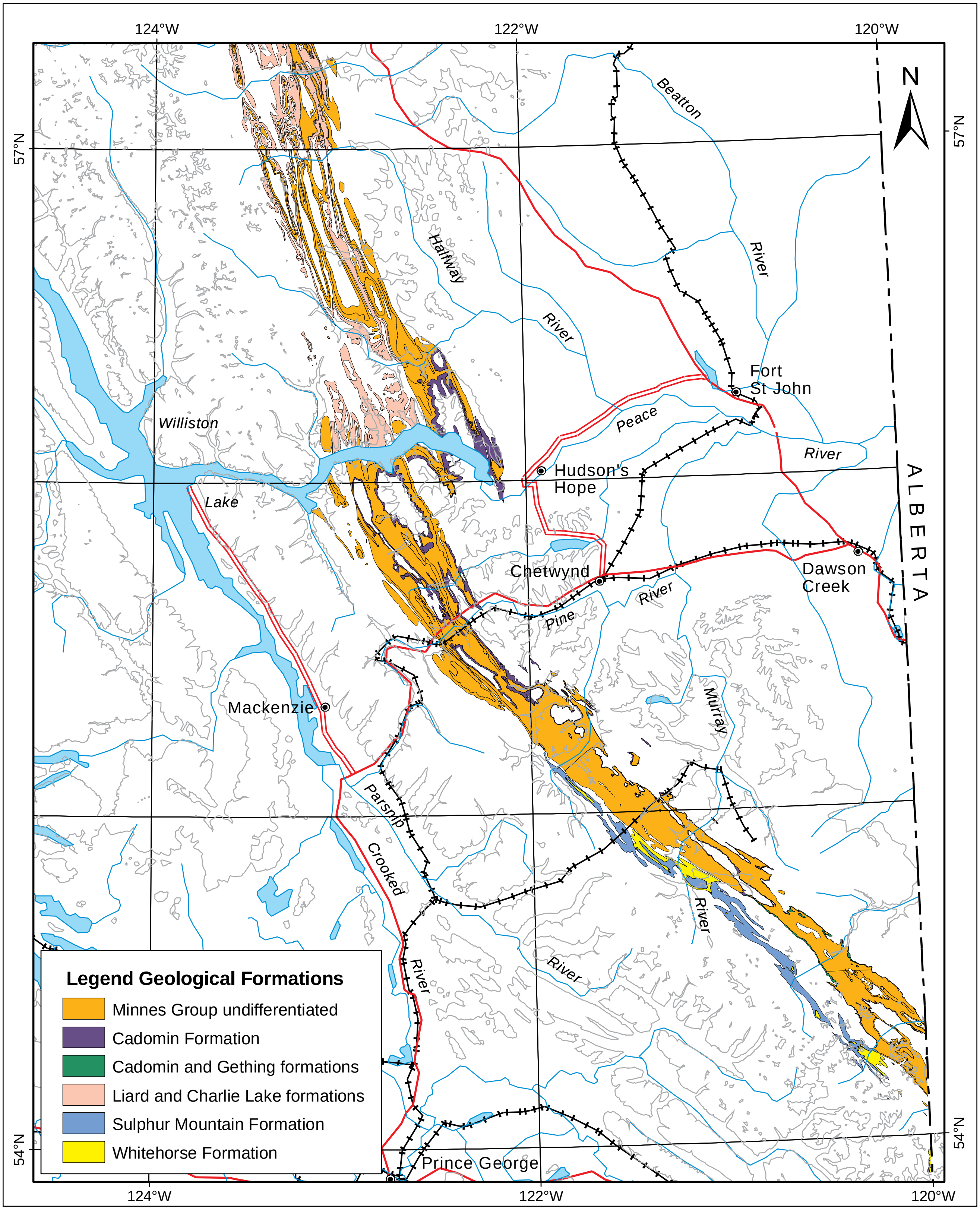

Figure 3a. Distribution within the Rocky Mountain Foothills of outcropping bedrock units discussed in this report: a) Fort St John area; b) Fort Nelson area; Modified from Massey et al., 2005.

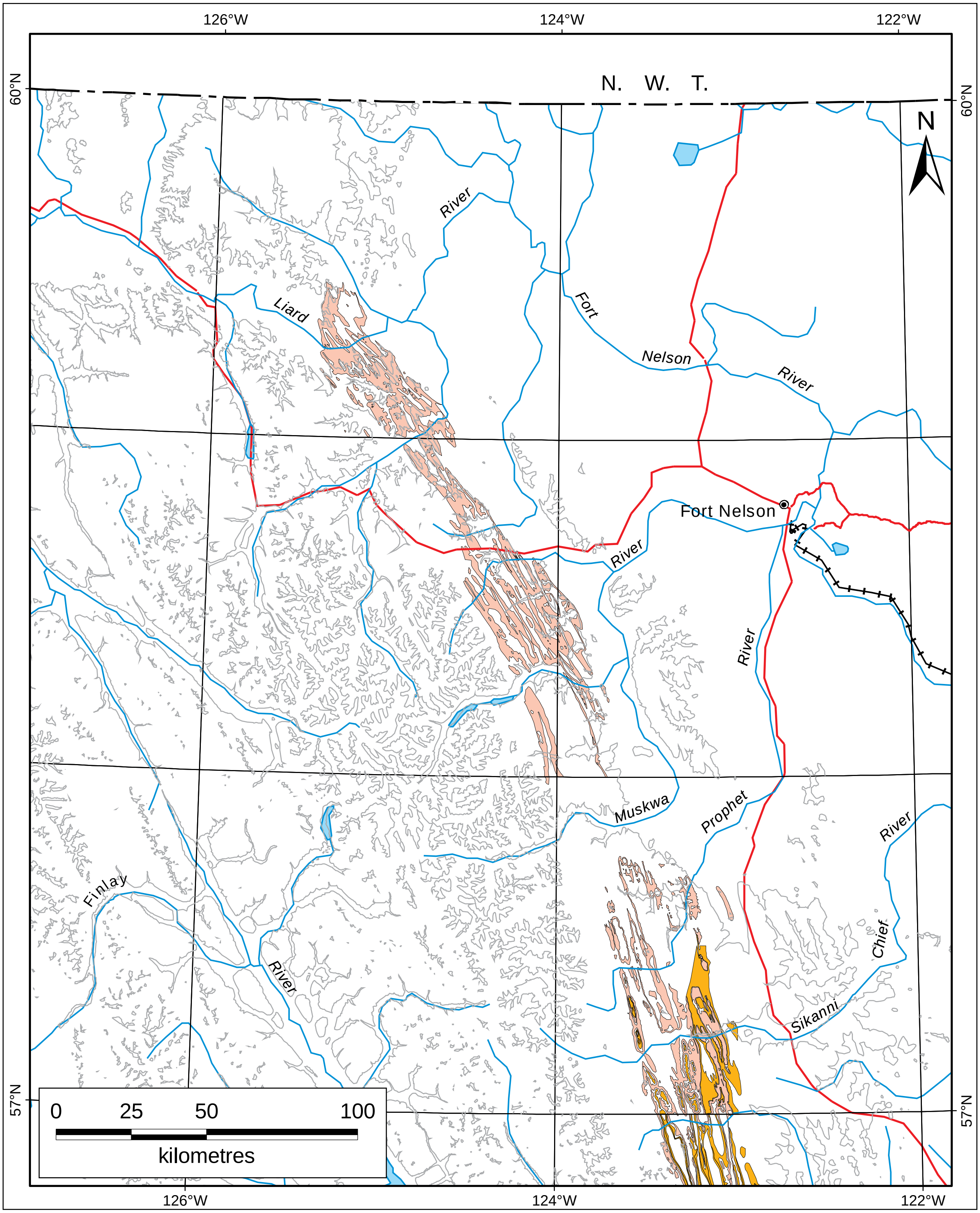

Figure 3b. Distribution within the Rocky Mountain Foothills of outcropping bedrock units discussed in this report: a) Fort St John area; b) Fort Nelson area; Modified from Massey et al., 2005.

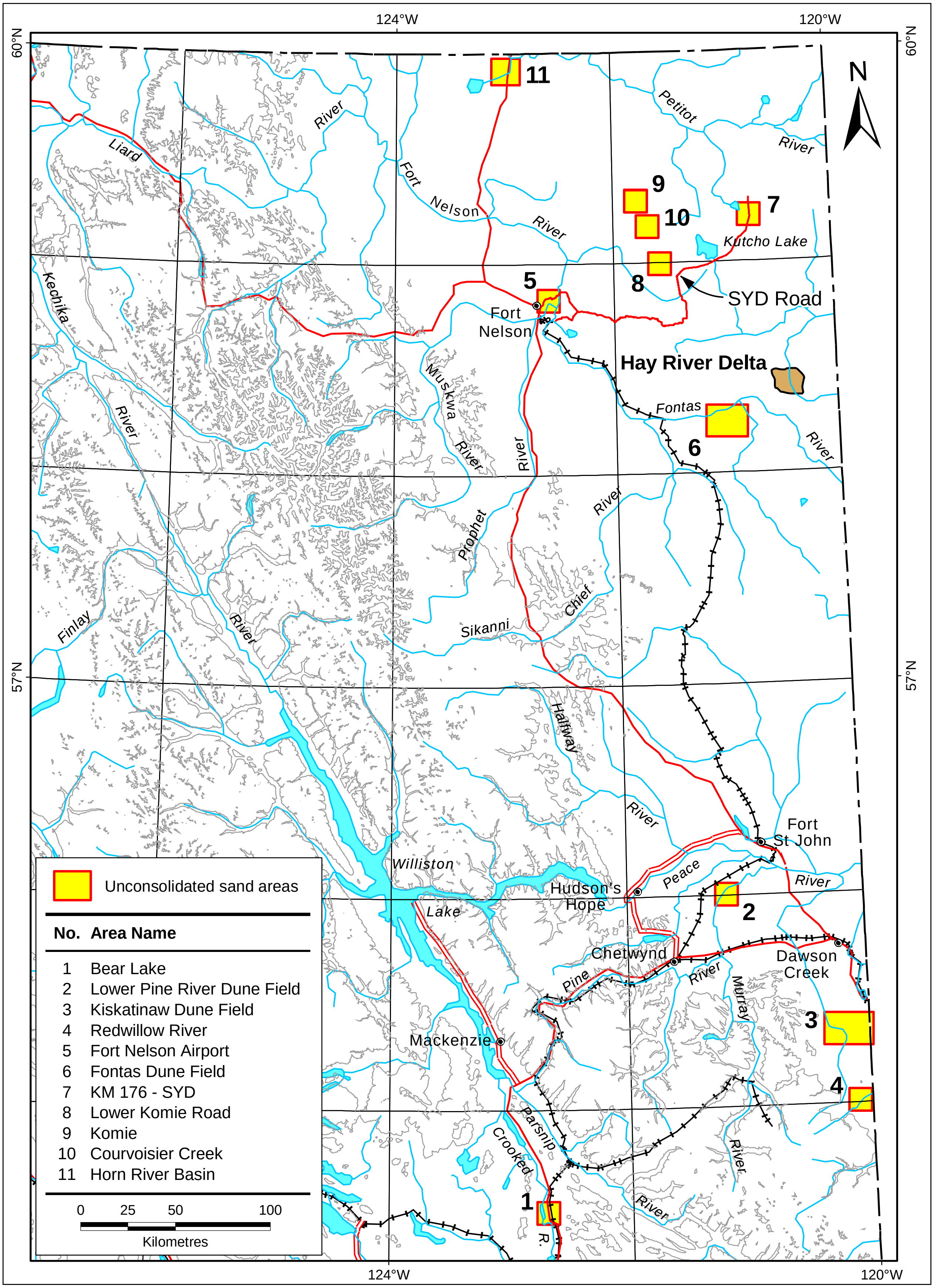

Figure 4. Location of the areas where preliminary evaluation of unconsolidated deposits indicates potential to host a frac sand source.

TABLE 1. SUMMARY OF BEDROCK FRAC SAND SAMPLES.

Sample	Easting	Northing	Classification	Formation	% Quartz	% Feldspar	% Lithic
08DFM063	519797	6222783	Quartz Arenite	Monteith	95	0	5
08FFE125	521738	6224224	Quartz Arenite	Monteith	95	0	5
08FFE220A	527687	6231355	Quartz Arenite	Monach	95	0	5
08FFE205A	526315	6236536	Quartz Arenite	Monach	95	0	5
08FFE021B	510894	6217773	Feldspathic Arenite	Charlie Lake	80	15	5
08FFE309	522190	6235343	Quartz Arenite	Liard	90	5	5
08FFE114	507488	6221073	Quartz Arenite	Liard	90	2	8

Lower Komie Road (esker; area 8), Komie (deltaic; area 9), Courvoisier Creek (esker; area 10) and Horn River Basin (esker; area 11).

DISCUSSION

Several deposits are excellent candidates for further evaluation, as processing may upgrade the deposits to a usable frac sand product (i.e., meeting API and ISO standards). The following is a discussion of the most promising of these deposits.

Bedrock units that show the most potential for use as frac sand are the Liard, Charlie Lake, Monteith and Monach formations. Outcrops of the Liard and Charlie Lake formations (and their southern equivalents, the Sulphur Mountain and Whitehorse formations) can be traced throughout the entire length of the inner and western parts of the Rocky Mountain Foothills and therefore represent an extensive target (Figure 3; Gibson, 1975). Although these sandstones can be high in carbonate cement (up to 15%), they are medium to coarse grained and rich in well-rounded quartz (>80%). The carbonate cement in these rocks would make the disassociation of these rocks easier than the disassociation of quartz-cemented sandstone. Charlie Lake rocks record sabkha environments indicating arid conditions in northeast British Columbia for much of the Triassic. The well-rounded nature of the grains in these rocks is probably, in part, a reflection of aeolian transport. Aeolian deposits are considered highly prospective because abrasion due to wind can be 100–1000 times more effective at rounding grains than transport by water (Kuenen, 1959, 1960). A coastal aeolian environment has been suggested for the St Peter sandstone (Mazzullo and Ehrlich, 1983), which is a major source of frac sand in the United States.

Rocks of the Minnes Group can be traced along the entire length of the outer Rocky Mountain Foothills of British Columbia. These fluvial-deltaic rocks form a westward-thickening package formed as a result of Jura-Cretaceous mountain building, which occurred in response to terrane accretion. The two thickest coarse clastic sequences within the Minnes Group belong to the Monteith and Monach formations (Figure 5). Both units are rich in medium- to coarse-grained quartz sand (>90%) and are typically quartz

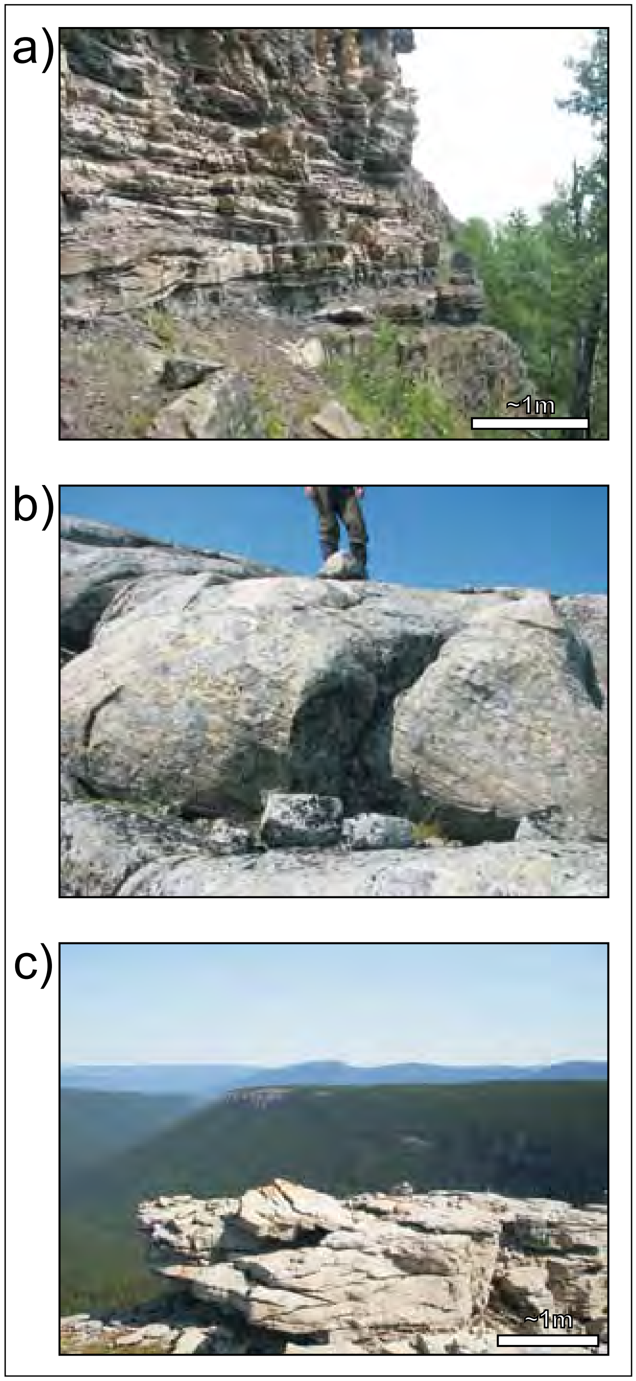

Figure 5. Photographs of the a) Monteith, b) Monach and c) Liard formations from the Halfway River map area (NTS 094B).

TABLE 2. SUMMARY OF PRELIMINARY UNCONSOLIDATED FRAC SAND TARGETS IN NORTHEAST BRITISH COLUMBIA.

Sample	General Area	Areas (Figure 4)	Easting	Northing	NTS Map Sheets	Depositional Origin	Dominant Grain Size	% Silica
ASH080616-01	Bear Lake	1	519588	6040819	093J/10	Aeolian	Fine/Medium Sand	85.55
ASH080623-02	Lower Pine River Dune Field	2	614822	6207694	094A/03	Aeolian	Fine Sand	88.49
ASH080711-03	Kiskatinaw Dune Field		686542	6140750	093P/08	Aeolian	Very Fine Sand	89.43
ASH080711-01A	Kiskatinaw Dune Field	3	671684	6134020	093P/08	Aeolian	Fine Sand	90.15
ASH080710-03	Kiskatinaw Dune Field		670194	6133138	093P/08	Aeolian	Fine Sand	86.34
ASH080923-01	Redwillow River	4	685093	6099906	093P/01	Glaciofluvial	Fine Sand	88.44
TPAP03-32	Fort Nelson	5	522972	6520875	094J/15	Glaciofluvial	Fine Sand	81.10
SUV05302	Fontas Dune Field		621520	6456212	094I/02	Aeolian	Fine Sand	91.42
SUV05303	Fontas Dune Field	6	621098	6456288	094I/02	Aeolian	Fine Sand	90.96
SUV05309	Fontas Dune Field		611404	6460199	094I/06	Aeolian	Fine Sand	90.62
TFE0704-01	KM 176 - SYD	7	628362	6566463	094P/02	Glaciofluvial	Medium Sand	85.01
TFE0704-02	Lower Komie Road	8	581274	6540078	094I/13	Glaciofluvial	Medium Sand	83.89
TFE0704-03	Komie	9	569040	6573180	094P/05	Glaciofluvial	Medium Sand	89.99
TFE0704-04	Courvoisier Creek	10	574987	6560341	094P/04	Glaciofluvial	Medium Sand	87.01
TDE05-04	Courvoisier Creek		575001	6559192	094P/04	Glaciofluvial	Medium Sand	85.97
TFE0711-08	Horn River	11	501341	6641887	094O/15	Glaciofluvial	Very Fine Sand/Silt	80.57
TFE0711-06	Horn River		500943	6642203	094O/15	Glaciofluvial	Fine Sand	80.41

cemented or show compactional welding of grain contacts. The stratigraphically higher Monach Formation tends to contain coarser-grained sandstone with well-rounded grains. Sandstone in this unit also displays higher porosity in surface exposures (up to 15%), which may make mechanical disaggregation easier than Monteith sandstone. The Minnes Group is absent in the north because these units have been eroded at the sub-Cretaceous unconformity. A more thorough description of the Minnes Group and its distribution is given by Stott (1998).

Geologically young deposits are not traditionally considered good sources of frac sand (Zdunczyk, 2007); however, some of the unconsolidated deposits sampled in this study show potential. These are Quaternary deposits that were emplaced during, or shortly after, the glaciation of northeast British Columbia in the Late Wisconsinan (ca. 22 000–10 000 years ago; Mathews 1978, 1980; Clague, 1989; Liverman et al., 1989; Catto et al., 1996; Dyke et al., 2003; Wolfe et al., 2004; Bednarski and Smith, 2007; Bednarski, 2008). The area was affected by three glacial systems: 1) local montane glaciers, 2) the Cordilleran Ice Sheet (CIS) and 3) the continental Laurentide Ice Sheet (LIS). Preliminary evaluation of unconsolidated samples suggests that those associated with the LIS are more likely to host material with favourable properties for use as frac sand than those derived from the CIS or montane glacial deposits.

One of the most prospective landforms is a glaciofluvial delta located in the Komie area (area 9; Figures 4, 6). This feature formed in a shallow proglacial lake (T. Demchuk, pers comm 2009) and has been extensively mapped and evaluated for aggregate potential (Blyth et al., 2003; Dewer and Polysou, 2003; Levson et al., 2004; Demchuk et al., 2005; Ferbey et al., 2005). Although originally targeted as part of gravel resource investigations, volumetrically, much of the granular material encountered is sand. A sample (TFE0704-03) collected from a sandy portion of this feature consists of 89.99% SiO_2, with 79.38% of the grains falling within the medium-sand–sized fraction. A large proportion of the quartz grains are rounded to well-rounded and have

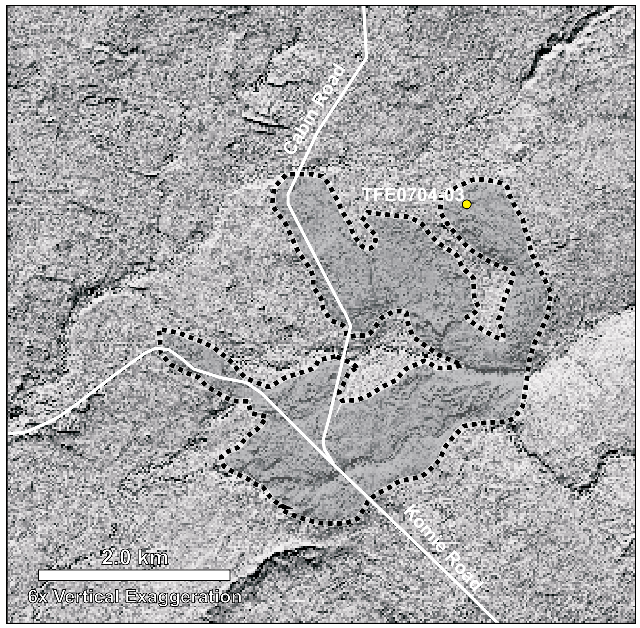

Figure 6. The Komie delta, shown in a high-resolution LiDAR image, consists of a series of incised lobes. Several of the lobes host active gravel mines, while others consist of up to 14 m of sand (location 9 in Figure 4).

moderate to well-developed sphericity. The maturity of the sand in this deposit suggests that despite the glacial origin of the deposit, the sand fraction may have been transported a significant distance or is recycled from older sediments. The deposit is well situated to service the mounting demand for frac sand in the emerging Horn River Basin shale gas play. The feature is located near the intersection of Geetla and Komie roads, providing year-round access to the area.

Another glaciofluvial delta evaluated in this study is situated in the Redwillow River area south of Dawson Creek (area 4; Figure 7). This feature forms a well-defined sand plain that is interpreted to be a delta, subaqueous fan or subaqueous sand plain. The delta was deposited in glacial Lake Peace from sand-laden water flowing from the melt of westerly derived ice (montane or CIS). Sample

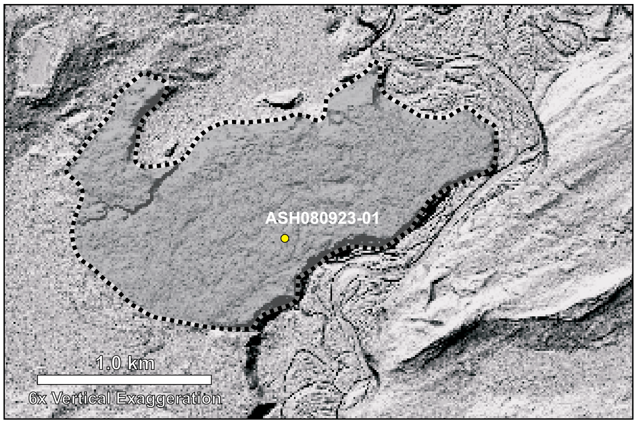

Figure 7. The Redwillow River delta, shown in a high-resolution LiDAR image, forms an extensive plain and consists of up to 10 m of uniform sand (location 4 in Figure 4).

ASH080923-01 is dominated by fine- to medium-grained sand with SiO_2 content over 88%. A thin section of the sand grains shows that although quartz grains are common, there are abundant polycrystalline quartz grains that are likely chert and fine-grained mudstone with high quartz content. Although the high proportion of lithic fragments reduces the potential of this deposit, the large volume of sand associated with it and the abundance of quartz grains in the smaller size fraction (see Appendix 2) suggest that this deposit may be prospective.

As mentioned earlier, aeolian deposits are considered highly prospective because of grain attrition (which causes the reduction of unstable grains, such as lithic fragments) and enhanced grain rounding (Kuenen, 1959, 1960). The types of grains in an aeolian deposit will be inherited from the types of grains in the source sediments, but will become more mature with distance travelled from the source area. Deposits derived from compositionally mature sediments (high proportion of stable framework grains) will be more prospective, as will deposits that have travelled farther from the source sediment. Four dune fields were sampled in this study, including the Fontas Dune Field (area 6), the Kiskatinaw Dune Field (area 3), the Lower Pine River Dune Field (area 2) and the Bear Lake Dune Field (area 1).

Three samples (SUV05302, SUV05303 and SUV05309) were collected from the Fontas Dune Field near Dazo Creek (area 6; Figures 4, 8–10). Dunes in this field are compound parabolic forms and have been described by Wolfe et al. (2007) and mapped by Trommelen and Smith (2007) and Smith (2009). These dunes formed from glacial outwash and glaciolacustrine sediments associated with distal deposits of the large Hay River fan-delta (Figure 4) described by Levson et al. (2004) and Smith (2009). The delta formed where subglacial drainage and water from glacial Lake Peace incised a spillway channel across the divide north of the Clear Hills in Alberta and emptied into glacial Lake Hay, a proglacial lake of the LIS. It is speculated that the fan-delta sands are derived directly from glacial comminution and subglacial erosion of Dunvegan Formation sandstone, which may account for its relative maturity. The Hay River fan-delta itself represents an uninvestigated sand source of immense size (~181 km^2, up to 30 m thick at its apex; Smith, 2009). The dunes are excellent targets for frac sand evaluation because they represent an additional cycle of transport and deposition, thereby extending their maturity. All three samples from the Fontas Dune Field contain over 90% SiO_2 and the majority of the sand grains fall within the fine-sand–sized fraction. The grains are angular to well-rounded with poor to well-developed sphericity. There is currently no all-season road access to these deposits; however, there is an abundance of seismic cut lines intersecting the deposits and a winter road that crosses the northwesternmost portion of the dune field.

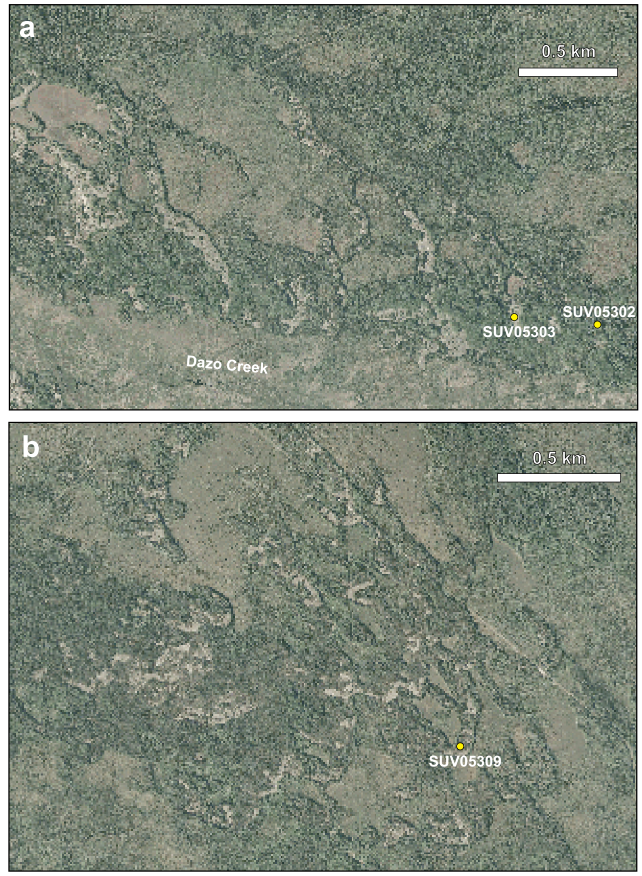

Figure 8. The Fontas Dune Field, shown in a 1:20 000 scale colour orthophoto, consists of several related fields including the north section of the main dune field a) straddling Dazo Creek and b) the northwestern dune field. The dunes are compound parabolic sand dunes derived from sandy glaciolacustrine and glacial outwash sediments (location 6 in Figure 4).

Another aeolian dune field is located south of Dawson Creek in the Kiskatinaw River area (Figure 9). These dunes are highly elongated parabolic dunes that are similar in morphology to the so-called ‘Cree Lake–type’ dunes described by David (1981). The dunes formed from winds blowing from the west to east, transporting sediment from sandy glaciolacustrine deposits associated with an early

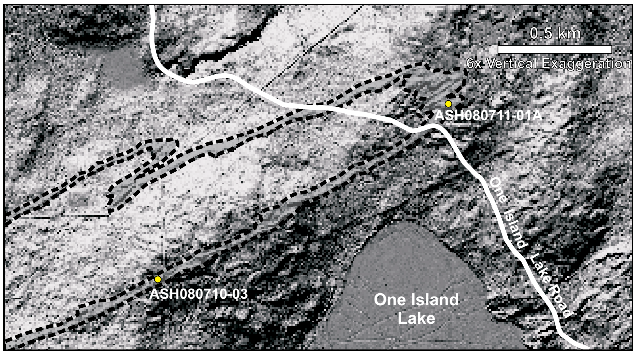

Figure 9. A high-resolution LiDAR image of one of the elongated sand dunes of the Kiskatinaw Dune Field (location 3 in Figure 4).

Figure 10. The Pine River Dune Field, shown in a 1:20 000 scale colour orthophoto, consists of well-developed parabolic dunes (location 2 in Figure 4).

stage of glacial Lake Peace (Mathews, 1980). Much of the glaciolacustrine sediments are associated with sediments derived from the Rocky Mountains. Samples ASH080710-03, ASH080711-01A and ASH080711-03 contained SiO_2 proportions of 86.34%, 89.43% and 90.15%, respectively. There is a high proportion of well-rounded monocrystalline quartz in these samples, which indicates that there is potential for these dunes to serve as a frac sand source. Unfortunately, thin sections show that there is an abundance of quartz-rich mudstone fragments and some chert, making these dunes less prospective than those in the Fontas Dune Field. Three other samples from dunes on the proximal side of the field (west; upwind) are not included in this report because their SiO_2 content is below 80%. This suggests that the distal dunes (east; downwind) have a higher proportion of quartz grains and are therefore more prospective. Regardless, the abundance of lithic fragments in all samples would necessitate extensive processing before this sand could be considered for use as a proppant.

Two other dune fields that were sampled returned relatively poor results. The Lower Pine River Dune Field is approximately 6 km long and consists of well-developed parabolic dunes (Figure 10). These dunes are likely derived from glaciofluvial and glacial diamict (till) sediments associated with the CIS. The dunes formed from valley-parallel winds blowing from southwest to northeast. Despite high SiO_2 content in sample ASH080623-02 (88.49%), the thin section reveals a large proportion of angular grains, of which quartz-rich mudstone grains make up a significant portion. This deposit, therefore, has only limited prospectivity. The sample was, however, collected from the proximal end of the dune field in a relatively poorly developed dune; therefore, additional sampling downwind of this sample may show more promising results. The dune field at Bear Lake (area 1; Figure 4) also has a relatively high SiO_2 content (85.55%), but an abundance of lithic fragments and poor rounding and sphericity render this deposit marginal.

Several eskers associated with the LIS show promising results. This is very encouraging as depositional environments associated with glaciofluvial deposits are not generally well suited for frac sands. Eskers form in or under ice where closed-channel hydraulics result in sediments that are typically poorly sorted. Nonetheless, results from samples TFE0704-04 and TDE05-04 (area 10; Figures 4, 11) collected from a sandy portion of an extensive esker complex near the Courvoisier Creek area (the Courvoisier Esker Complex; Ferbey et al., 2005; T. Demchuk, pers comm 2009), indicate well-sorted sand with SiO_2 values of 87.01% and 85.97%, respectively. Furthermore, despite an abundance of lithic fragments, there is a substantial population of well-rounded, moderately spherical, monocrystalline quartz grains that would be excellent for frac sand. As mentioned earlier, the ability to process out the undesirable grains will be critical in determining the suitability and economics of these deposits. Other eskers were sampled (TFE0704-01, area 7; TFE0704-02, area 8; and TFE0711-06 and TFE0711-08, area 11). All of these glaciofluvial features have a high proportion of well-rounded grains with moderate to well-developed sphericity, and warrant additional evaluation. Ongoing aggregate mapping in northeast British Columbia is showing that sediments associated with subglacial deposits (e.g., eskers) are more likely to host sand-sized material than gravel-sized material. Given the promising results discussed here and the abundance of eskers near the Horn River Basin, these features may represent a local frac sand exploration target.

Sample TPAP03-32 is from a sand-dominated glaciofluvial deposit (likely subglacial) located at the Fort Nelson Airport. The deposit was tested during a detailed granular aggregate assessment conducted by BCMEMPR for the Northern Rockies Regional District (Ferbey et al.,

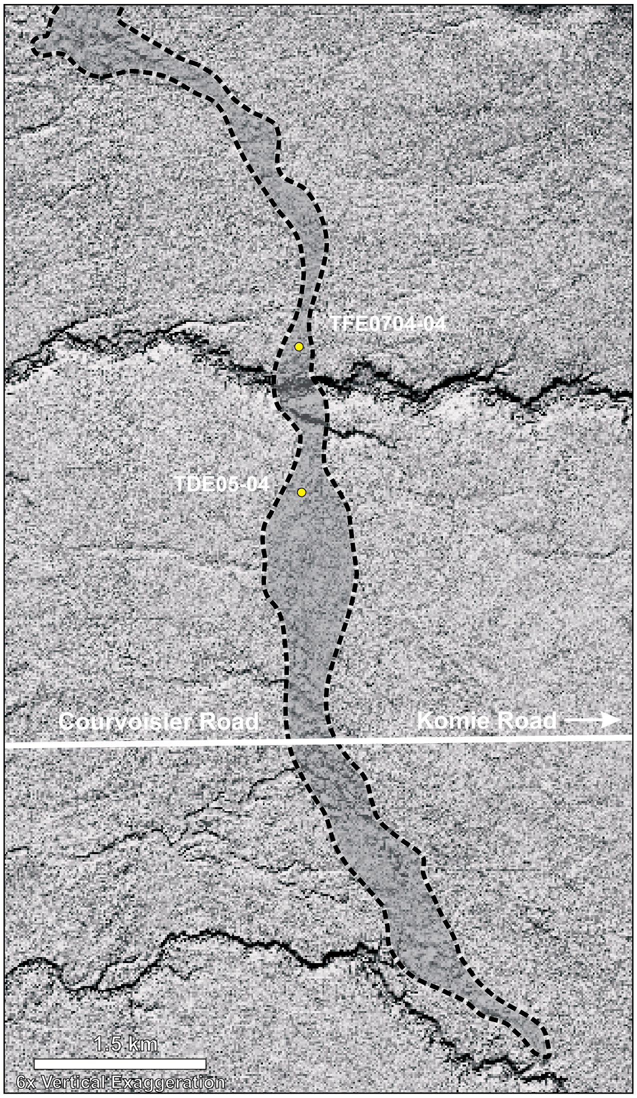

Figure 11. Courvoisier Ridge, a long esker complex that hosts sand and gravel, is outlined from high-resolution LiDAR imagery (location 10 in Figure 4).

2004; Johnsen et al., 2004). This deposit consists entirely of moderately sorted fine-grained sand that contains 81.1% SiO_2. There are abundant lithic grains, but a population of well-rounded, monocrystalline quartz grains dominates. With processing, this deposit may also have the potential to be a frac sand source.

CONCLUSION

Preliminary evaluation of bedrock units suggests the Liard and Charlie Lake formations (Triassic) and the Monteith and Monach formations of the Minnes Group (Late Jurassic to Cretaceous) are the most encouraging bedrock units for a potential frac sand source in northeast British Columbia. The Liard Formation is a quartz arenite that contains 90% quartz grains in carbonate cement. The Charlie Lake Formation is a feldspathic arenite with well-rounded grains, also in carbonate cement. These units are present throughout the Rocky Mountain Foothills from Williston Lake north to the Liard River. The Monteith and Monach formations of the Minnes Group are classified as quartz arenite and consist of more than 95% quartz grains. The Minnes Group is present in the foothills south of the Profit River on the eastern edge of the deformed belt.

The unconsolidated deposits that are most prospective are associated with three depositional environments: deltaic, aeolian and glaciofluvial. In the Komie area, a glaciofluvial delta consists of sand and gravel. A sample from this feature mainly consists of well-rounded, well-sorted, medium-grained quartz sand. The deposit is located on the western rim of the Horn River Basin and is an excellent target for further evaluation. Another deltaic feature of interest occurs in the Redwillow River valley. This large sandy glaciofluvial delta has a significant proportion of lithic fragments, but does contain an abundance of quartz grains in the finer sand-sized fraction; therefore, is a potential frac sand exploration target.

Another highly prospective target is the Fontas Dune Field near Dazo Creek. This dune field includes three distinct subfields consisting of either parabolic or compound parabolic sand dunes. Three samples from different dunes contain mostly monocrystalline fine-sand quartz grains. Other dunes were investigated from the Kiskatinaw and Pine River dune fields, but abundant lithic grains make these fields less prospective.

Several eskers associated with the LIS are prospective. The Courvoisier Esker Complex consists of sand and gravel, with portions hosting well-sorted, medium-grained sand with a population of well-rounded, moderately spherical quartz grains. Several other eskers in the Horn River Basin and around KM 176 – SYD Road also show encouraging results. Although lithic fragments are common in these deposits, abundant, well-rounded quartz grains make LIS eskers a target for evaluation.

ACKNOWLEDGMENTS

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APPENDIX ONE - BEDROCK SAMPLES

Sample	08DFM063
Easting	519797
Northing	6222783

Group	Minnes Group
Formation	Monteith Formation
Age	Early Cretaceous

% Matrix	<5
% Grains	>95

% Quartz	95
% Feldspar	0
% Lithic	5

Classification
Quartz Arenite

Origin
Deltaic

Comment:

Medium to coarse grained sandstone.
Sub-angular.
Quartz cement.
Lithics consist of chert, polycrystalline quartz and hornblende.

Plane Light

Crossed Nicols

Sample	08FFE125	**Group**	Minnes Group
Easting	521738	**Formation**	Monteith Formation
Northing	6224224	**Age**	Late Jurassic to Early Cretaceous

% Matrix	5
% Grains	95

Classification
Quartz Arenite

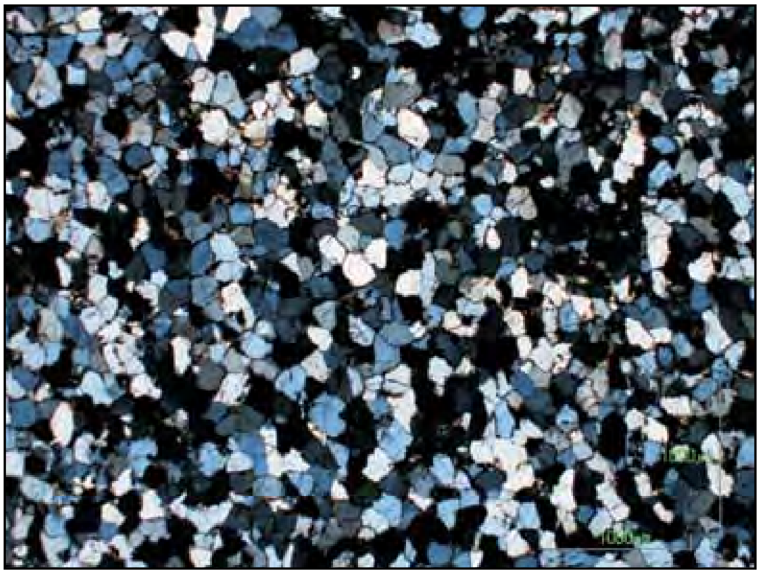
% Quartz	95
% Feldspar	0
% Lithic	5

Origin
Deltaic

Comment:

Fine grained sandstone. Relatively uniform grain size distribution.
Sub-angular to sub-rounded grains.
Lithics are chert, siltstone, carbonate and polycrystalline quartz.
Matrix consists of quartz overgrowths and fine opaques.

Plane Light



Crossed Nicols

Sample	08FFE220A	**Group**	Minnes Group
Easting	527687	**Formation**	Monach Formation
Northing	6231355	**Age**	Early Cretaceous

% Matrix	<2
% Grains	98

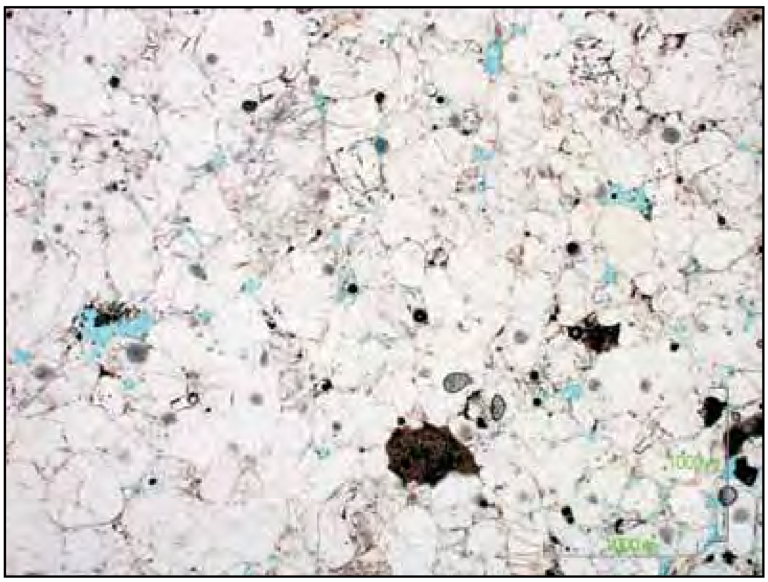
Classification
Quartz Arenite

% Quartz	95
% Feldspar	0
% Lithic	5

Origin
Deltaic

Comment:

Medium to coarse grained sandstone.
Spherical, sub-rounded to rounded.
Very little matrix, quartz plus opaques.
Lithics consist of chert and polycrystalline quartz.



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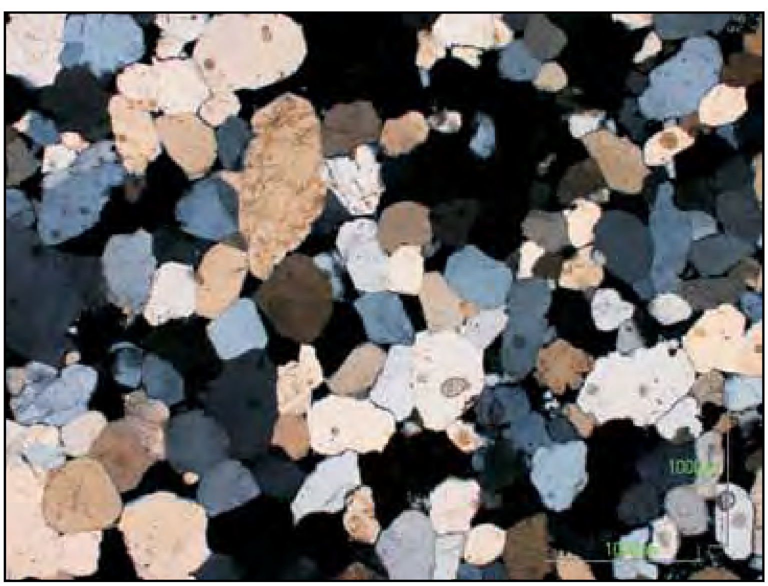


Crossed Nicols

Sample	08FFE205A		**Group**	Minnes Group
Easting	526315		**Formation**	Monach Formation
Northing	6236536		**Age**	Early Cretaceous

% Matrix	<2
% Grains	98

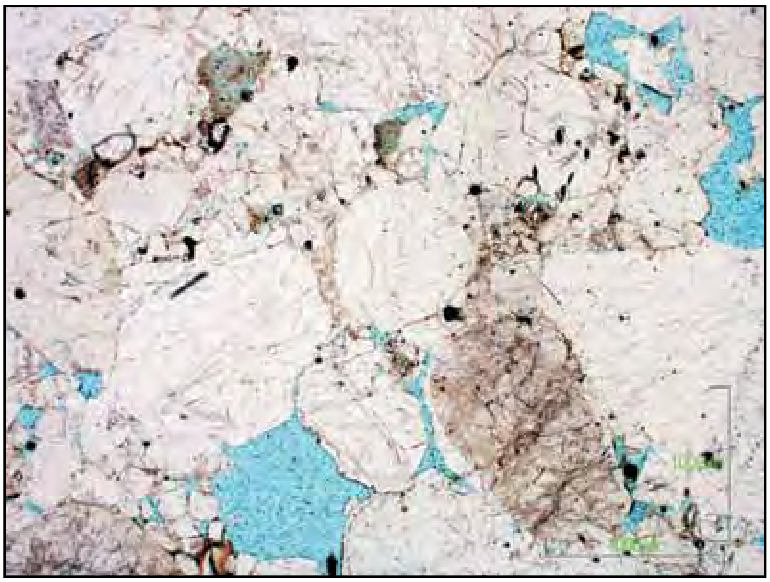
Classification
Quartz Arenite

% Quartz	95
% Feldspar	0
% Lithic	5

Origin
Deltaic

Comment:

Bimodal size distribution consisting of coarse to granule conglomerate with matrix of fine to coarse sandstone. Spherical and rounded grains (60 to 70%) with sub-rounded matrix (30-40%).
Lithics are chert and polycrystalline quartz.
5-10% porosity.



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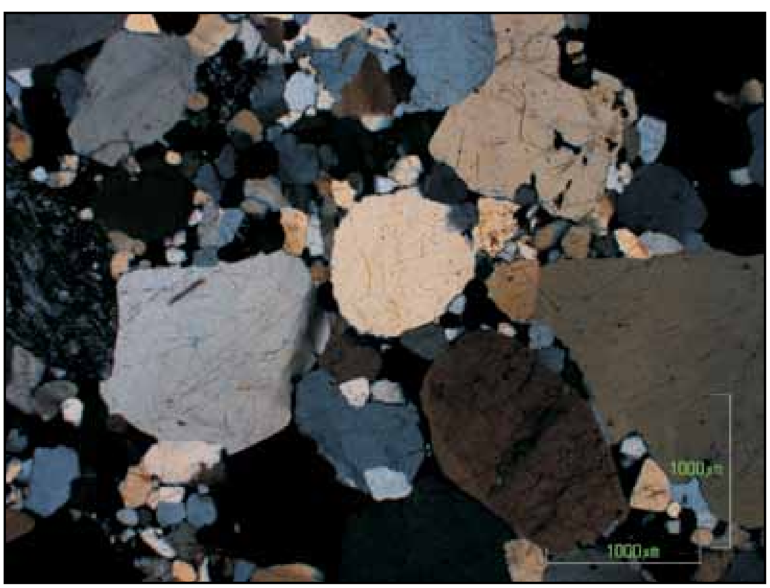


Crossed Nicols

Sample	08FFE021B		**Group**	
Easting	510894		**Formation**	Charlie Lake Formation
Northing	6217773		**Age**	Late Triassic

% Matrix	<1
% Grains	99

Classification
Feldspathic Arenite

% Quartz	80
% Feldspar	15
% Lithic	5

Origin
Intertidal (Marine)

Comment:

Fine to medium sandstone. Relatively good grain size distribution.
Clasts are oblate to spherical, well- to sub-rounded.
Lithic fragments include chert, sitlstone and calcite.
Cement is calcite.

Plane Light

Crossed Nicols

Sample	08FFE309	**Group**	
Easting	522190	**Formation**	Liard Formation
Northing	6235343	**Age**	Middle to Late Triassic

% Matrix	<1
% Grains	99

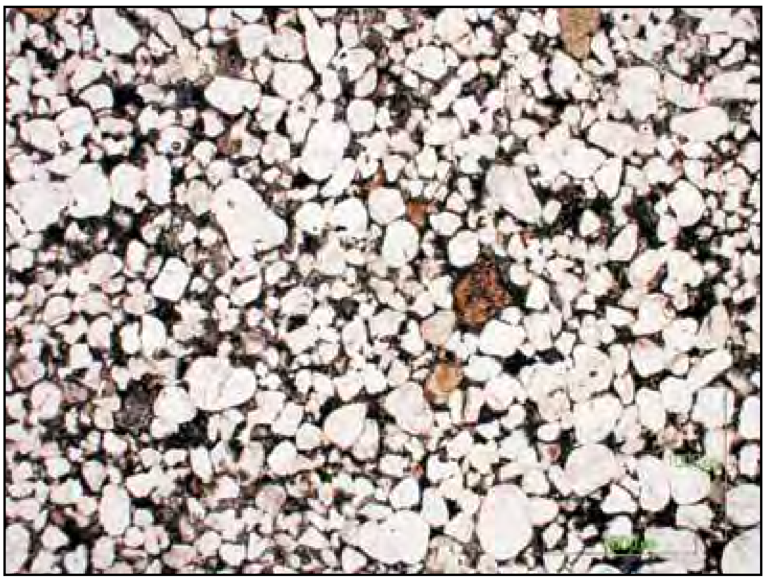
% Quartz	90
% Feldspar	5
% Lithic	5

Classification
Quartz Arenite

Origin
Shoreface

Comment:

Fine to medium grained sandstone. Larger grains are well rounded and spherical whereas smaller grains tend to blade or tabular shapes and are sub-rounded to sub-angular.
Grains size can range down to silt size within matrix areas and these grains are quite angular.
Lithics are chert (brown and clear), platy poly crystalline quartz, hornblende, calcite.
Cement is calcite



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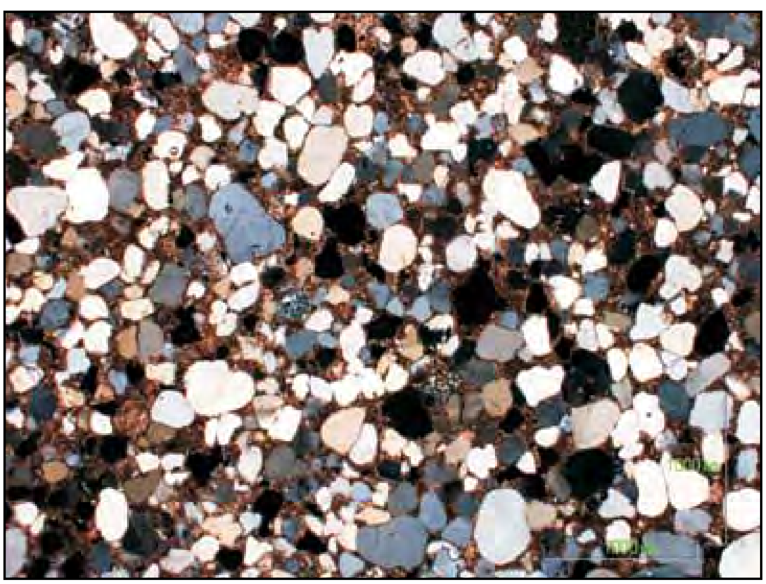


Crossed Nicols

Sample	08FFE114		**Group**		
Easting	507488		**Formation**	Liard Formation	
Northing	6221073		**Age**	Middle to Late Triassic	

% Matrix	<1
% Grains	99

% Quartz	90
% Feldspar	2
% Lithic	8

Classification
Quartz Arenite

Origin
Shoreface

Comment:

Fine to medium grained sandstone. Fairly uniform grain size distribution. Some coarser grains.
Sub-rounded to sub-angular and spherical grains, larger grains tend to be well rounded.
Lithics include chert, siltstone, hornblende, calcite and fossil material.
Cement is calcite.

Plane Light

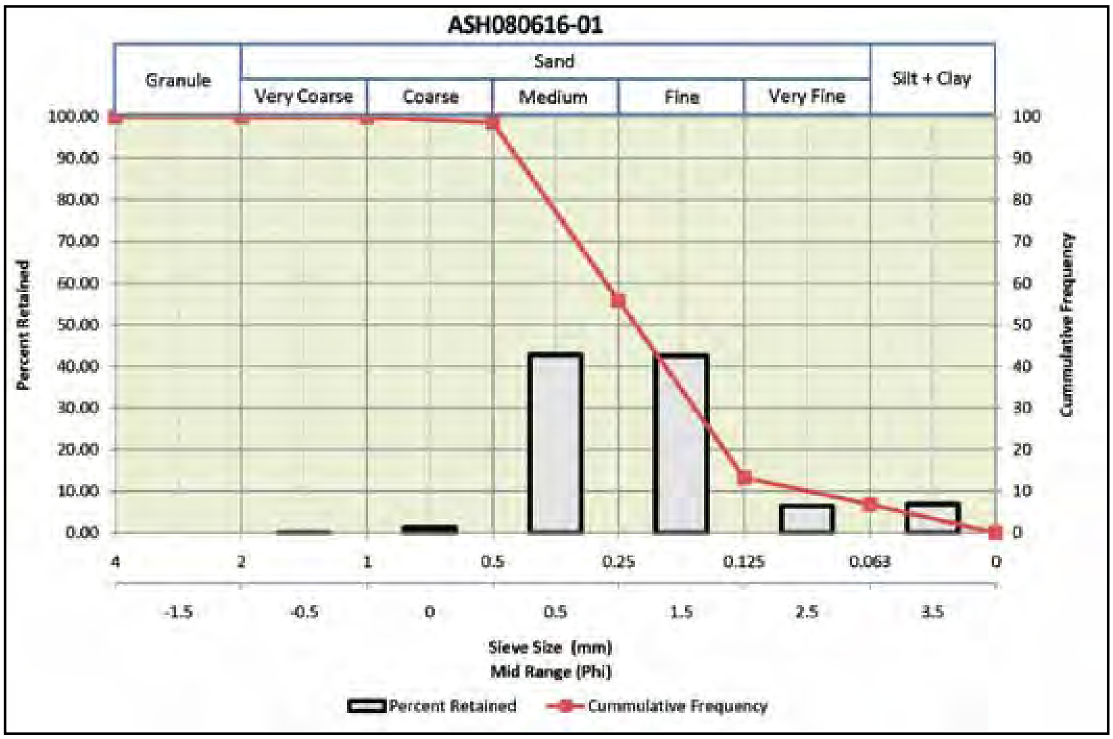
Crossed Nicols

APPENDIX TWO - UNCONSOLIDATED SAMPLES

Sample	ASH080616-01
Easting	519588
Northing	6040819
Genetic Origin	Aeolian Dune

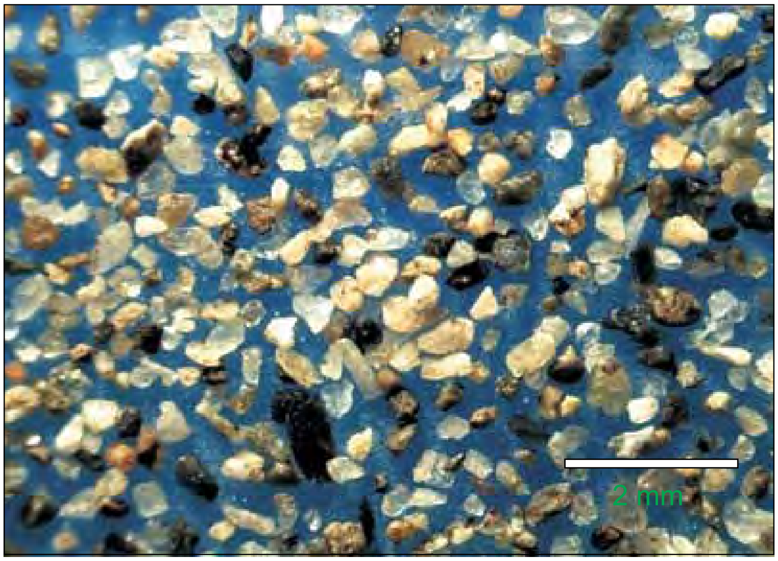
Comment:

This sample was collected from an excavation in an aeolian sand dune along Highway 97 near Bear Lake, British Columbia, west of the Rocky Mountains.

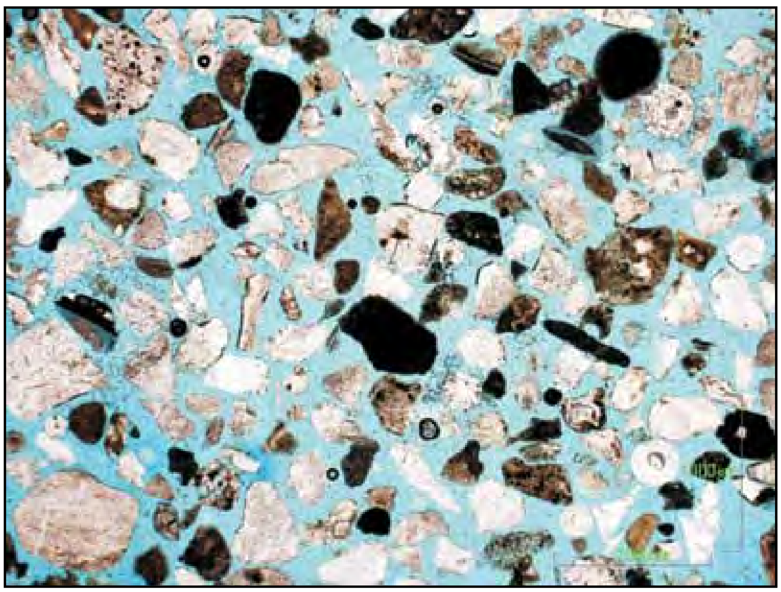


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	0.4	0.08	99.92
0.500	6.4	1.23	98.69
0.250	222.2	42.84	55.85
0.125	220.8	42.57	13.28
0.063	33.4	6.44	6.84
<0.063	35.5	6.84	0.00

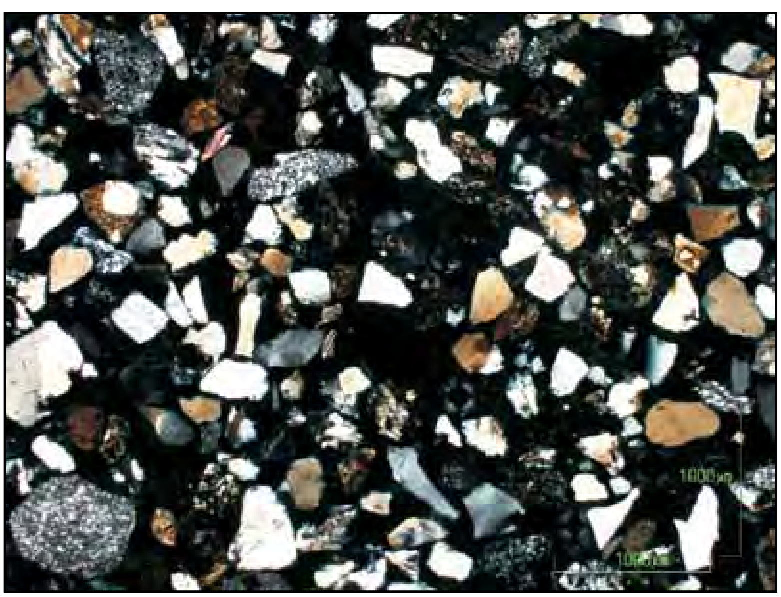
Element	Percent
SiO_2	85.55
Al_2O_3	6.02
Fe_2O_3	2.66
MgO	0.77
CaO	0.77
Na_2O	1.17
K_2O	1.17
TiO_2	0.34
P_2O_5	0.09
MnO	0.04
Cr_2O_3	0.013
LOI	1.3



Binocular Microscope



Plane Light

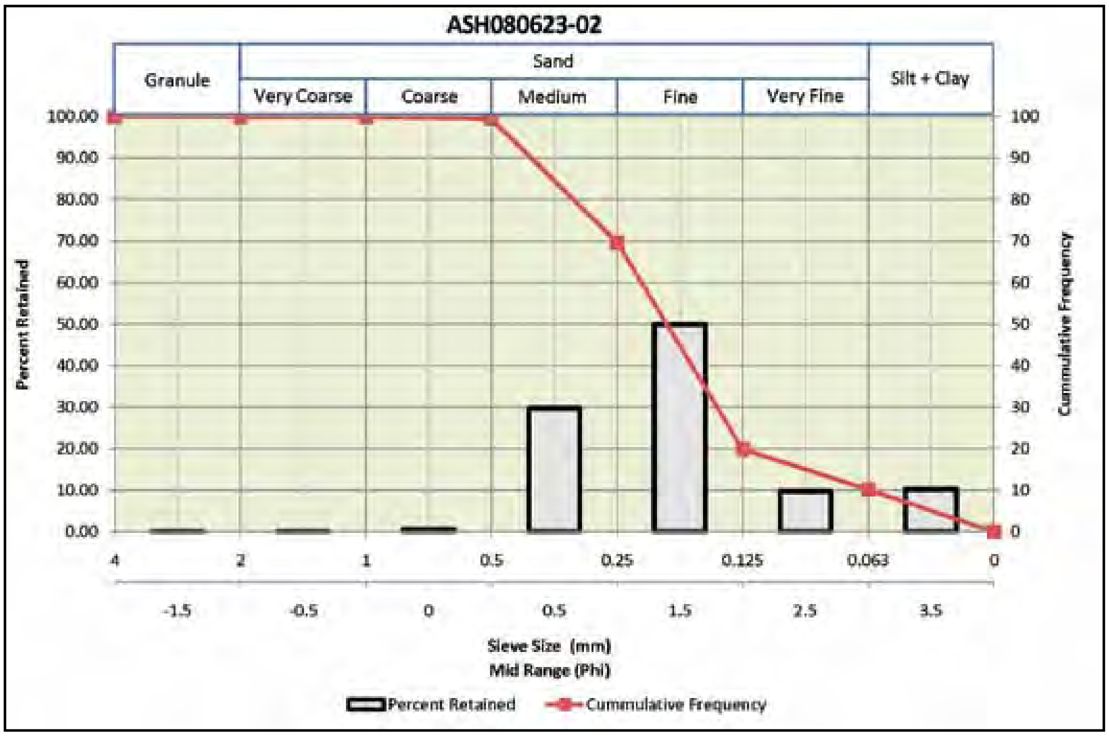


Crossed Nicols

Sample	ASH080623-02
Easting	614822
Northing	6207694
Genetic Origin	Aeolian Dunes

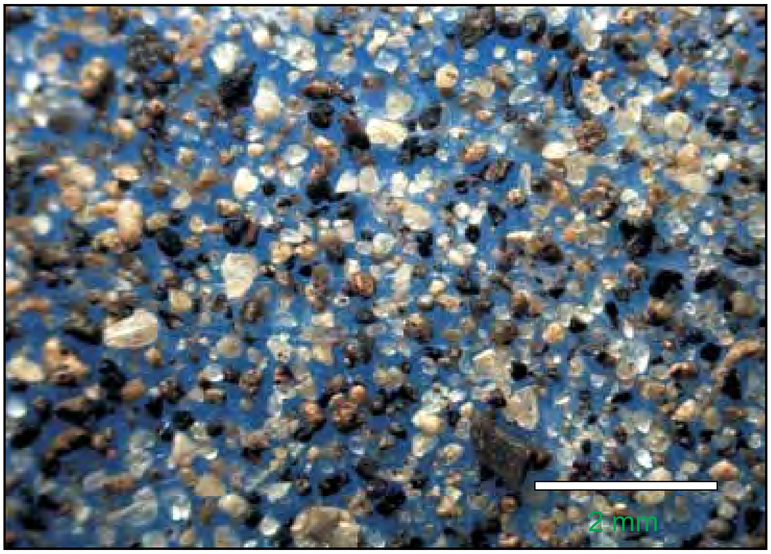
Comment:

Sample was collected from well-developed parabolic sand dunes on a terrace of the lower Pine River. Dunes are up to 10 metres high, several hundred metres long, and are derived from glaciofluvial outwash and glacial Lake Peace sediments.



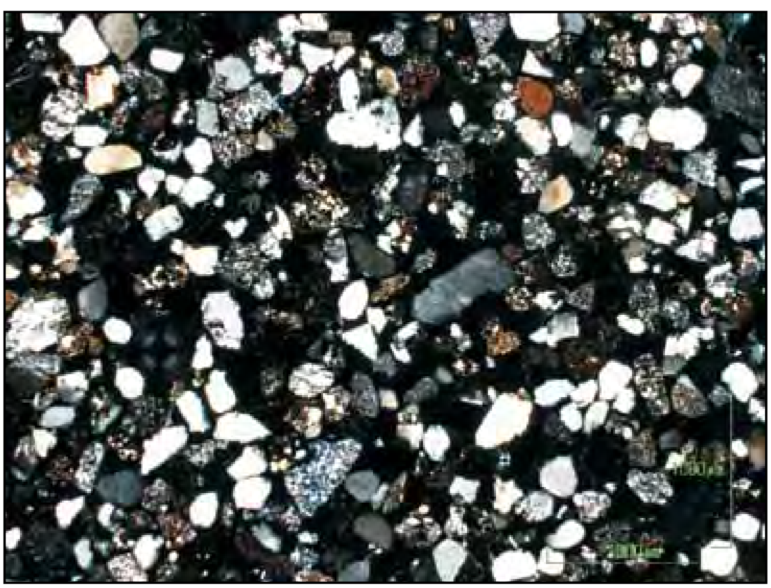
Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.1	0.02	99.98
1.0	0.2	0.04	99.94
0.500	2.4	0.51	99.43
0.250	139.4	29.68	69.74
0.125	234.0	49.83	19.91
0.063	45.7	9.73	10.18
<0.063	47.8	10.18	0.00

Element	Percent
SiO_2	88.49
Al_2O_3	3.61
Fe_2O_3	3.18
MgO	0.33
CaO	0.67
Na_2O	0.17
K_2O	0.74
TiO_2	0.20
P_2O_5	0.19
MnO	0.03
Cr_2O_3	0.005
LOI	2.3



Binocular Microscope

Plane Light

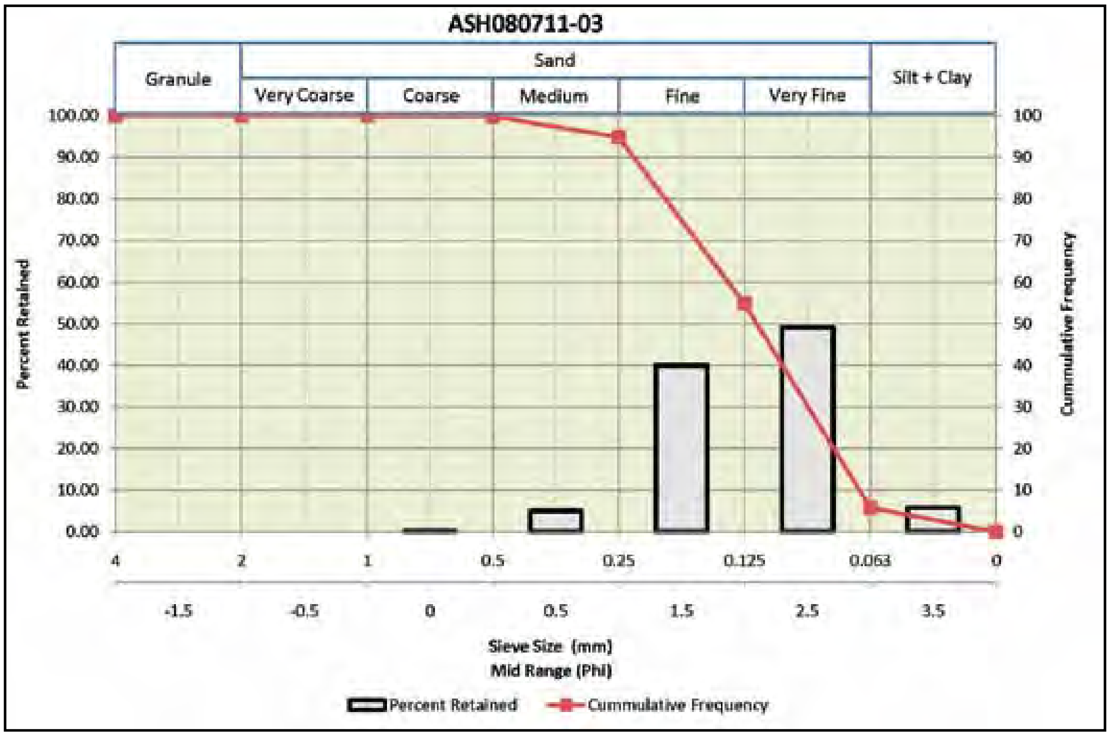


Crossed Nicols

Sample	ASH080711-03
Easting	686542
Northing	6140750
Genetic Origin	Aeolian Dune

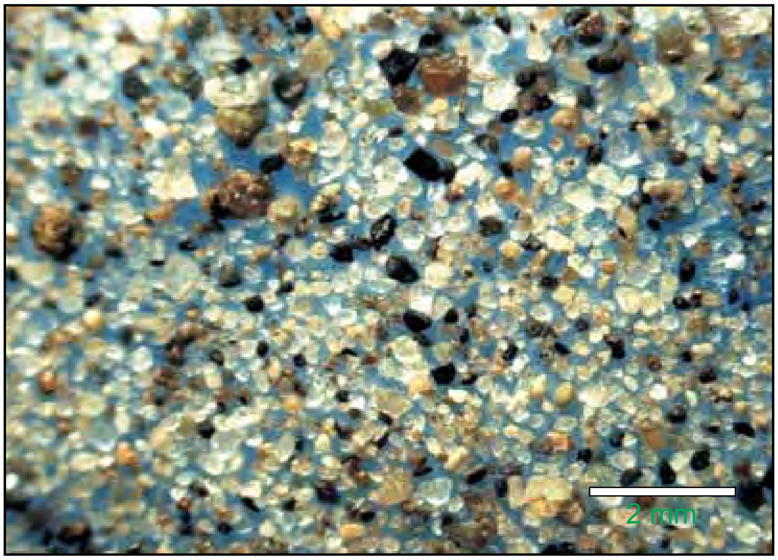
Comment:

Sample was taken from the arm of a elongate parabolic sand dune on the distal side (east; downwind) of the Kiskatinaw Dune Field south of Dawson Creek.

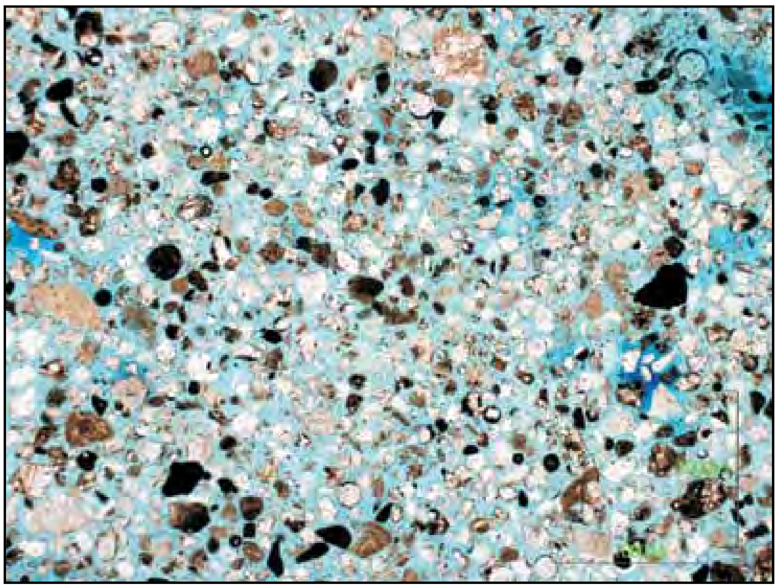


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	0.0	0.00	100.00
0.500	0.6	0.14	99.86
0.250	20.9	4.97	94.89
0.125	168.2	39.96	54.93
0.063	206.8	49.13	5.80
<0.063	24.4	5.80	0.00

Element	Percent
SiO_2	89.43
Al_2O_3	4.23
Fe_2O_3	2.22
MgO	0.28
CaO	0.35
Na_2O	0.59
K_2O	0.90
TiO_2	0.19
P_2O_5	0.14
MnO	0.02
Cr_2O_3	0.005
LOI	1.5



Binocular Microscope



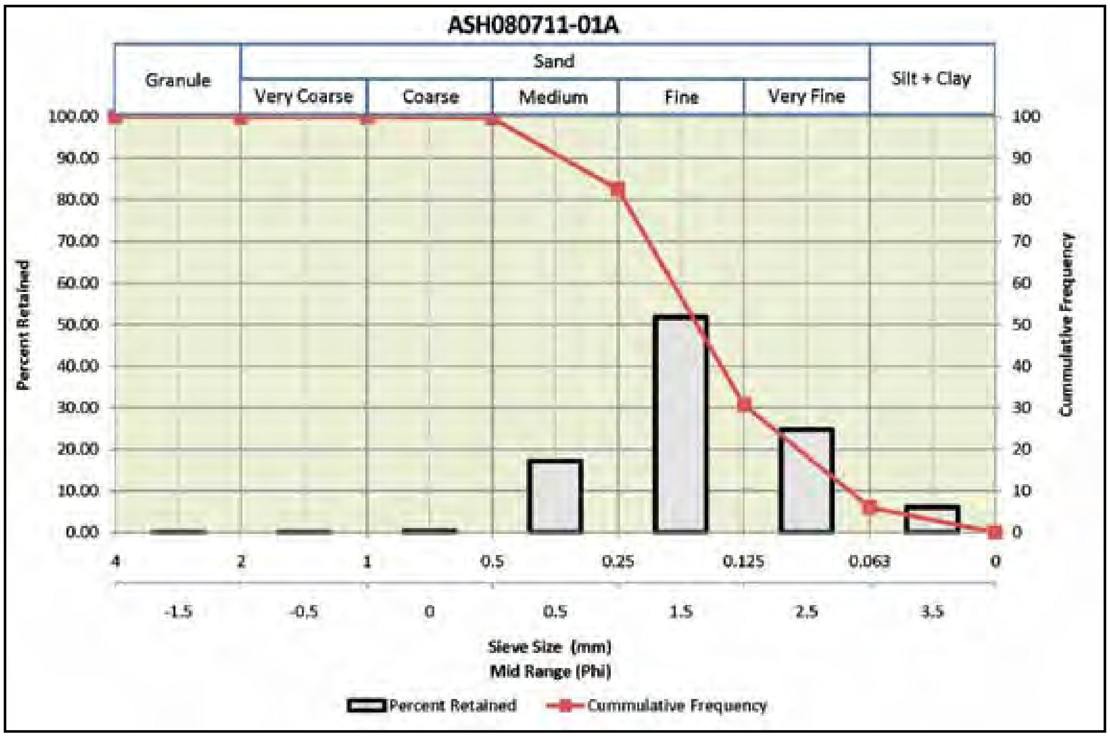
Plane Light

Crossed Nicols

Sample	ASH080711-01A
Easting	671684
Northing	6134020
Genetic Origin	Aeolian Dune

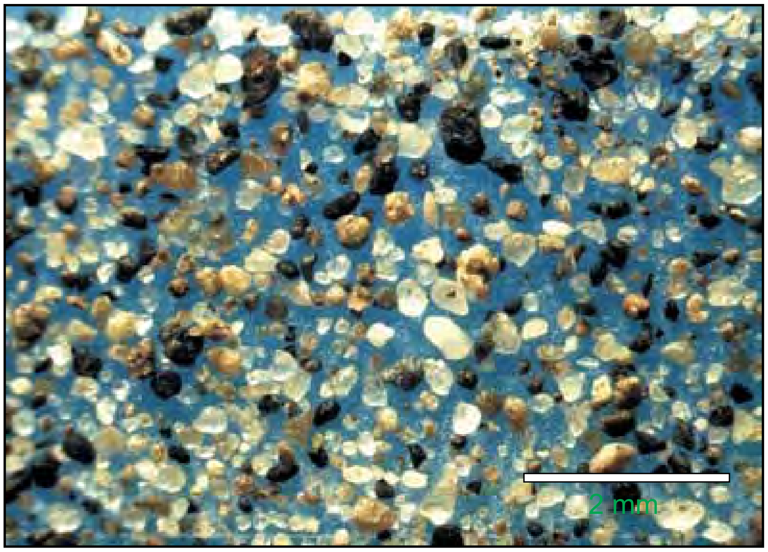
Comment:

This samples was collected from the head of a sand dune in the Kiskatinaw Dune Field south of Dawson Creek. These dunes are more distal from source and appear to have a higher proportion of silica than more proximal dunes.

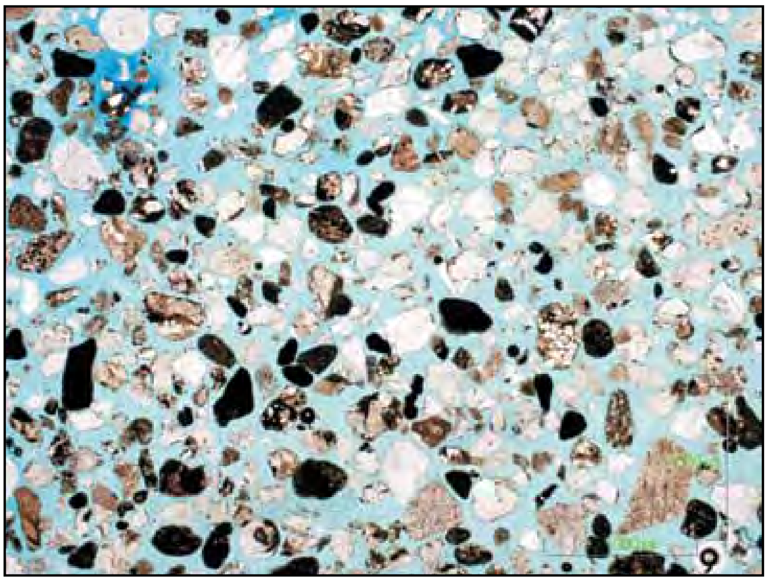


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.1	0.02	99.98
1.0	0.1	0.02	99.96
0.500	1.4	0.30	99.66
0.250	81.0	17.14	82.52
0.125	244.7	51.78	30.74
0.063	116.6	24.67	6.07
<0.063	28.7	6.07	0.00

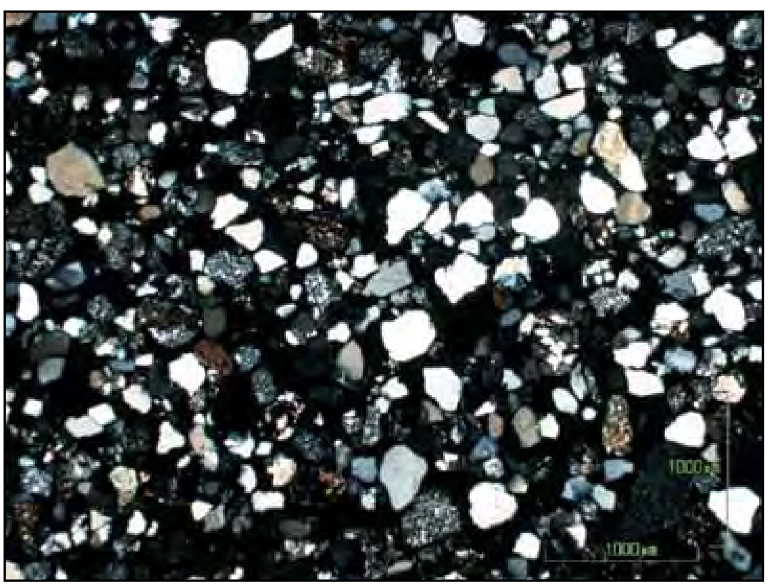
Element	Percent
SiO_2	90.15
Al_2O_3	3.62
Fe_2O_3	2.33
MgO	0.31
CaO	0.31
Na_2O	0.28
K_2O	0.77
TiO_2	0.22
P_2O_5	0.17
MnO	0.02
Cr_2O_3	0.004
LOI	1.7



Binocular Microscope



Plane Light

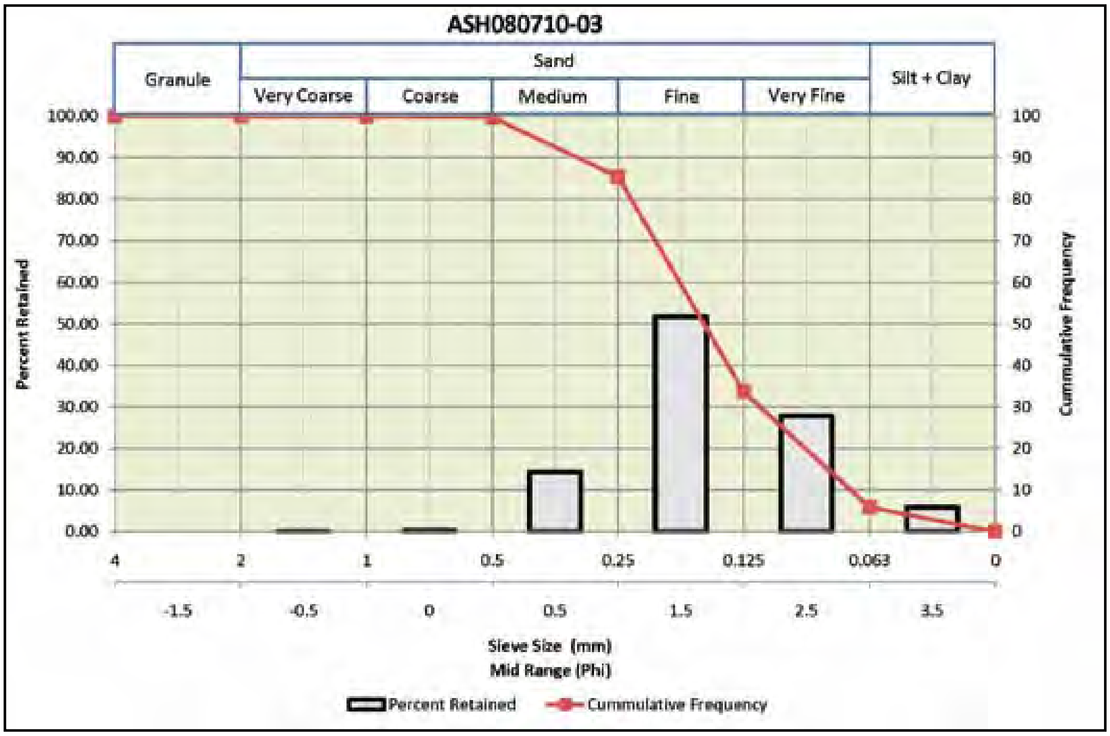


Crossed Nicols

Sample	ASH080710-03
Easting	670194
Northing	6133138
Genetic Origin	Aeolian Dune

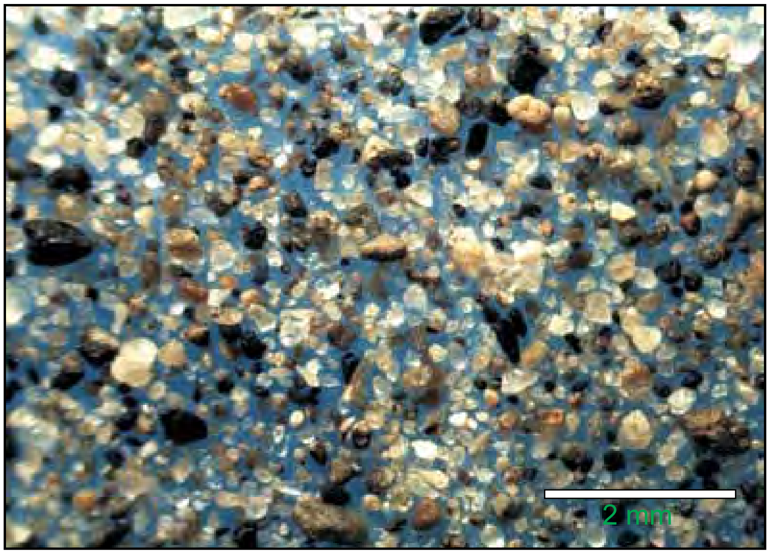
Comment:

This sample was collected from an elongate parabolic dune in the Kiskatinaw Dune Field south of Dawson Creek. The dunes are 3 to 20 metres high, can extend for over a kilometre, and my be several hundred metres across at the dune head.

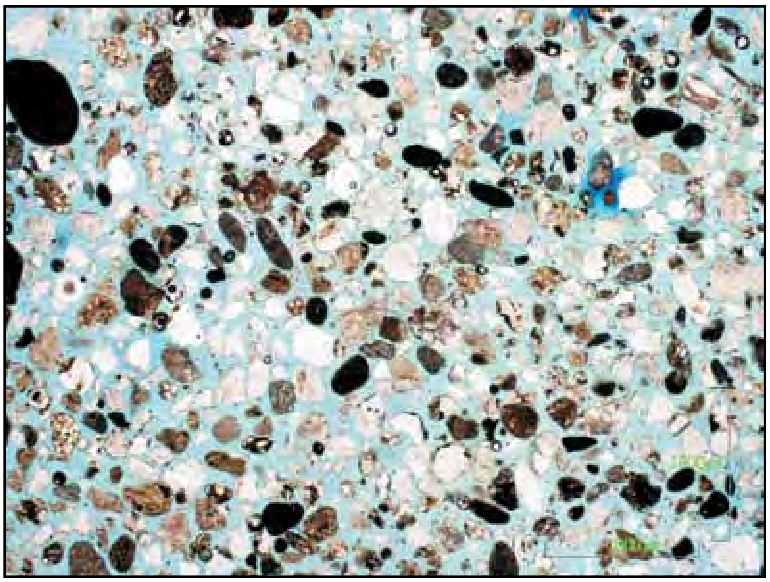


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	0.2	0.04	99.96
0.500	1.2	0.23	99.73
0.250	74.5	14.25	85.48
0.125	270.6	51.77	33.71
0.063	145.6	27.86	5.85
<0.063	30.6	5.85	0.00

Element	Percent
SiO_2	86.34
Al_2O_3	3.47
Fe_2O_3	2.33
MgO	0.59
CaO	2.32
Na_2O	0.27
K_2O	0.76
TiO_2	0.21
P_2O_5	0.19
MnO	0.02
Cr_2O_3	0.005
LOI	3.4



Binocular Microscope



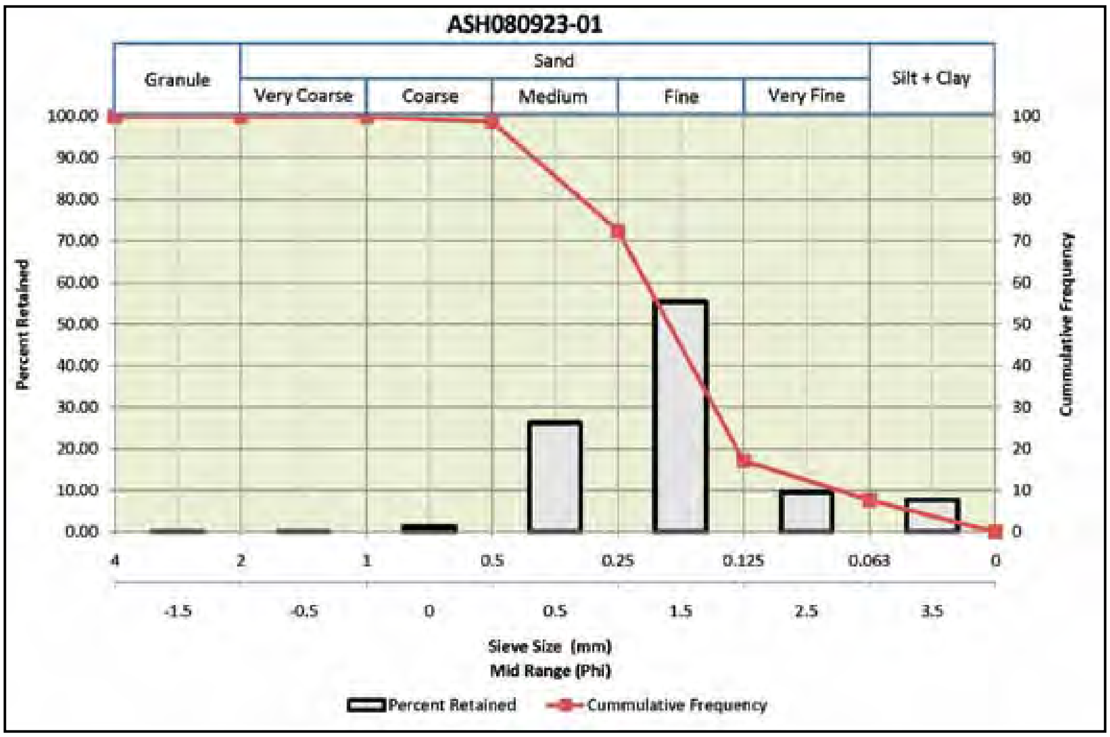
Plane Light

Crossed Nicols

Sample	ASH080923-011
Easting	685093
Northing	6099906
Genetic Origin	Glaciofluvial (Delta?)

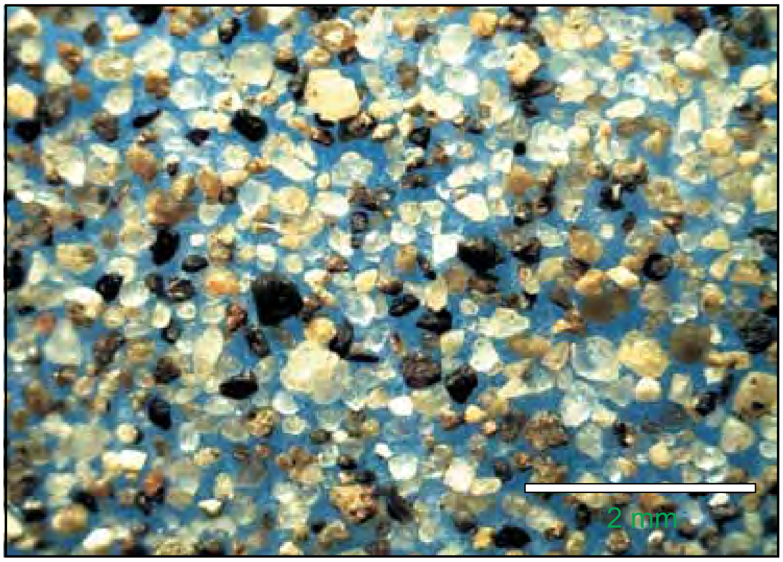
Comment:

This sample was collected from a large sandy terrace near the Redwillow River. The material is up to 5 metres thick and consists of uniform medium sand. The feature may be a delta associates with glacial Lake Peace.

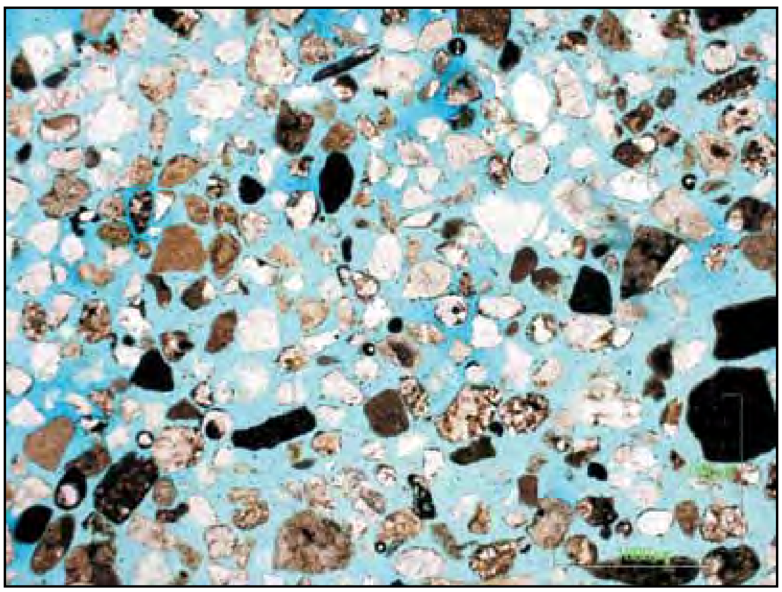


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.3	0.00	100.00
2.0	0.2	0.04	99.96
1.0	0.3	0.06	99.89
0.500	5.7	1.21	98.69
0.250	123.7	26.23	72.46
0.125	260.8	55.30	17.15
0.063	44.6	9.46	7.70
<0.063	36.3	7.70	0.00

Element	Percent
SiO_2	88.44
Al_2O_3	4.59
Fe_2O_3	2.41
MgO	0.35
CaO	0.28
Na_2O	0.54
K_2O	0.95
TiO_2	0.24
P_2O_5	0.12
MnO	0.03
Cr_2O_3	0.005
LOI	2.0



Binocular Microscope



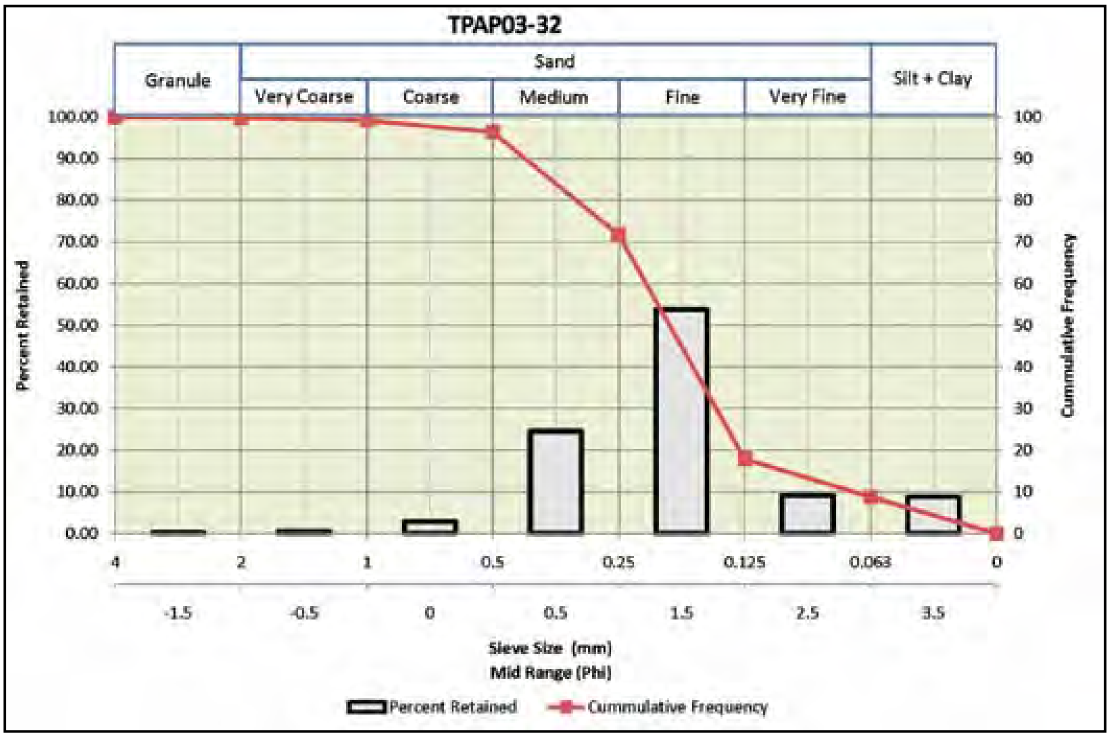
Plane Light

Crossed Nicols

Sample	TPAP03-32
Easting	522972
Northing	6520875
Genetic Origin	Glaciofluvial

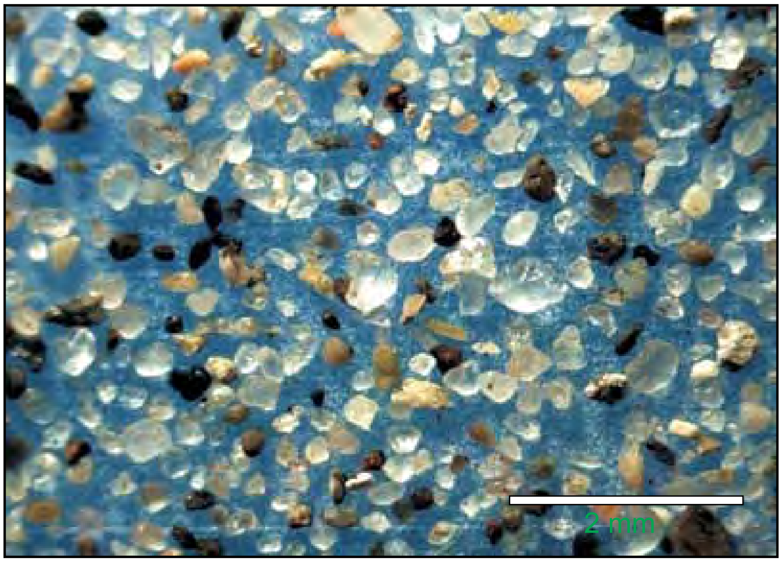
Comment:

This sample was collected from a 5 metre deep test pit on a sandy hill near the Fort Nelson Airport.

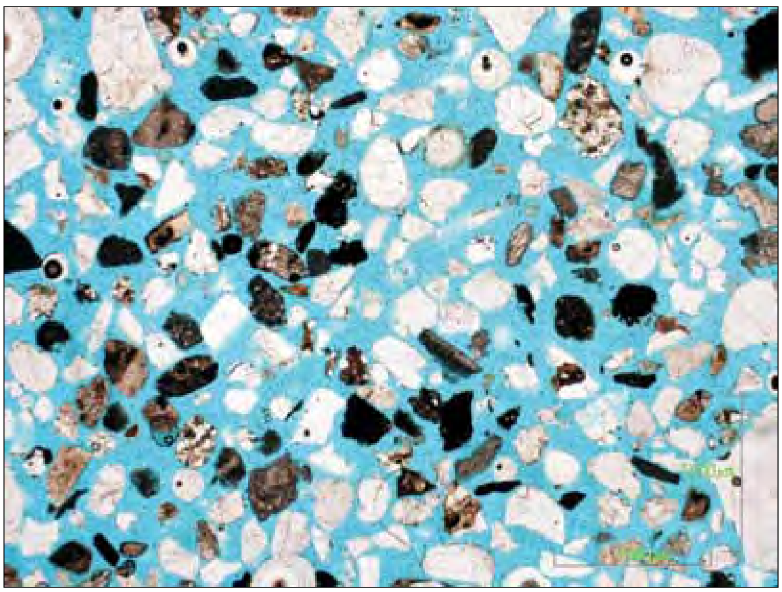


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.7	0.00	100.00
2.0	1.1	0.25	99.75
1.0	2.5	0.58	99.17
0.500	12.1	2.80	96.37
0.250	106.5	24.62	71.75
0.125	232.8	53.81	17.94
0.063	39.5	9.13	8.81
<0.063	38.1	8.81	0.00

Element	Percent
SiO_2	81.1
Al_2O_3	4.58
Fe_2O_3	2.04
MgO	0.84
CaO	4.38
Na_2O	0.89
K_2O	1.23
TiO_2	0.15
P_2O_5	0.11
MnO	0.03
Cr_2O_3	<0.002
LOI	4.5



Binocular Microscope



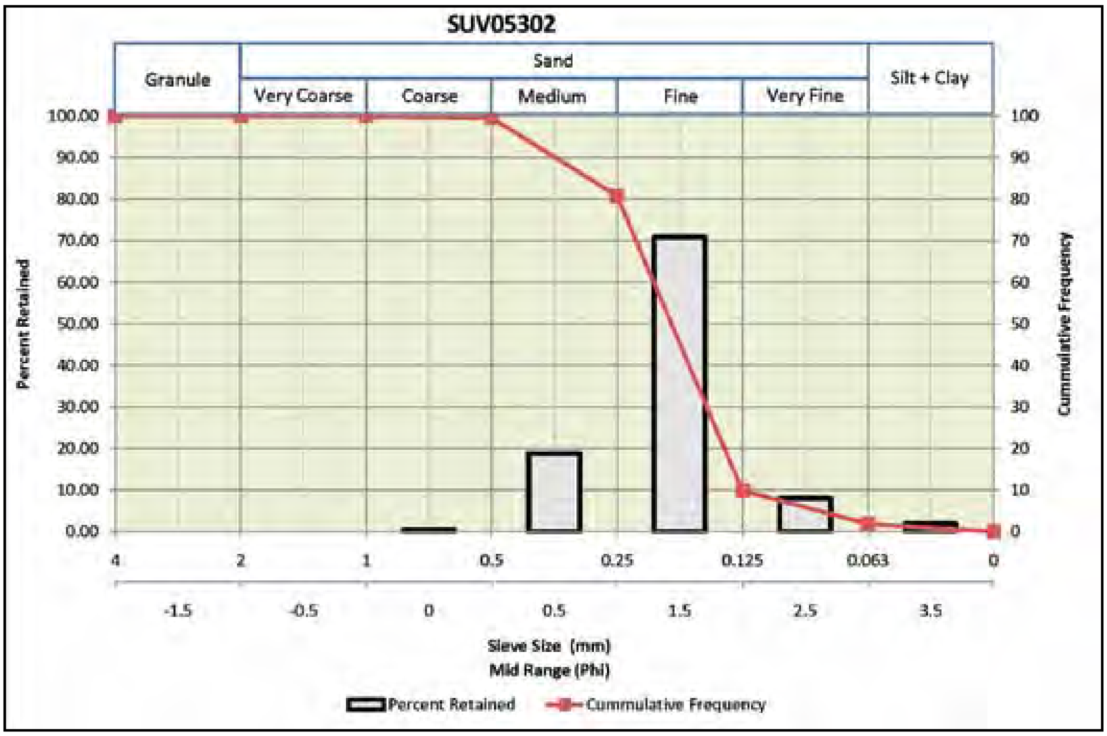
Plane Light

Crossed Nicols

Sample	SUV05302
Easting	621520
Northing	6456212
Genetic Origin	Aeolian Dunes

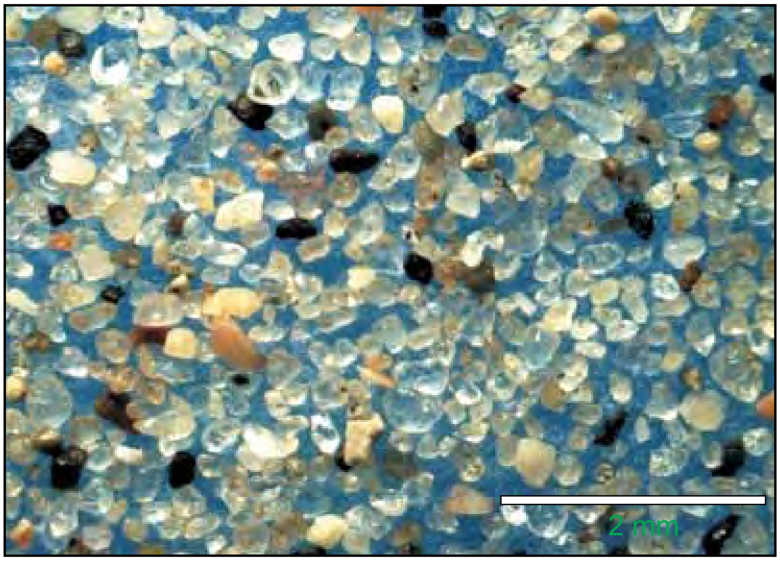
Comment:

This samples was collected from a compound parabolic dune from the main dune field north of Dazo Creek in the Fontas River Dune Field, east of Fort Nelson. Dune crests are up to 7 m high, with average sand thicknesses across the field estimated to be 10 m.

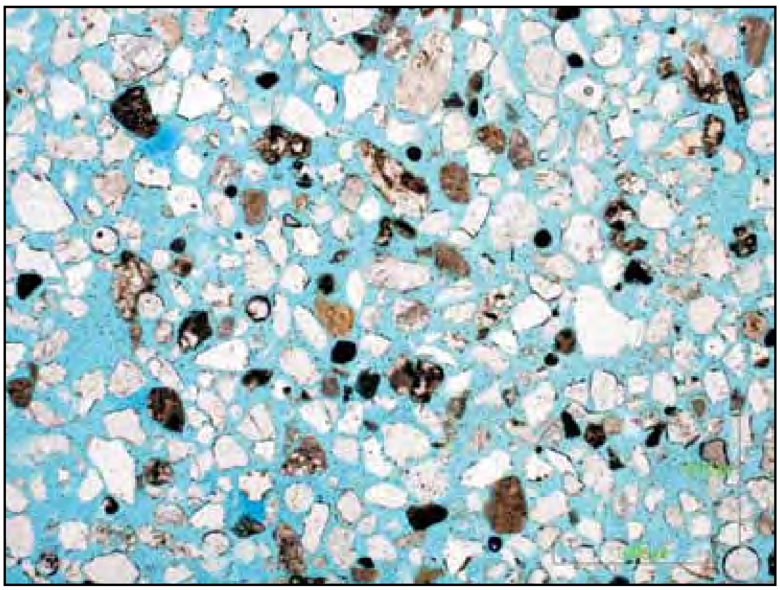


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	0.0	0.00	100.00
0.500	0.5	0.37	99.63
0.250	25.1	18.80	80.82
0.125	94.7	70.94	9.89
0.063	10.7	8.01	1.87
<0.063	2.5	1.87	0.00

Element	Percent
SiO_2	91.42
Al_2O_3	3.58
Fe_2O_3	2.22
MgO	0.18
CaO	0.44
Na_2O	0.74
K_2O	0.93
TiO_2	0.11
P_2O_5	0.07
MnO	0.03
Cr_2O_3	0.002
LOI	0.2



Binocular Microscope



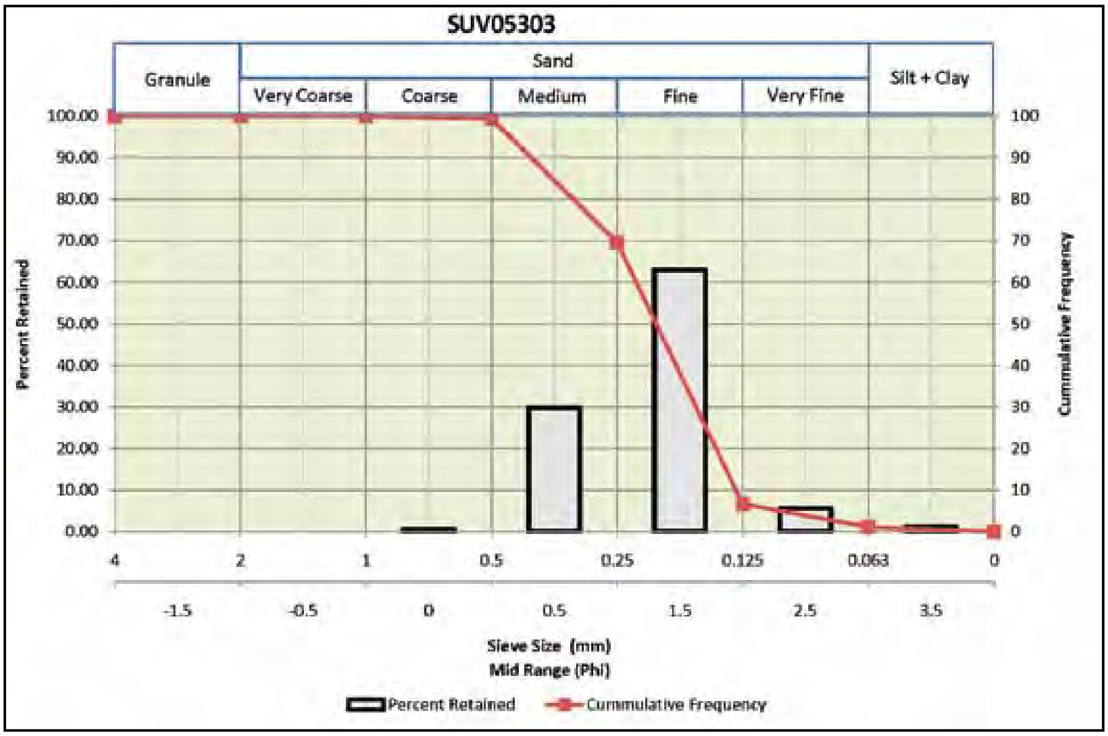
Plane Light

Crossed Nicols

Sample	SUV05303
Easting	621098
Northing	6456288
Genetic Origin	Aeolian Dune

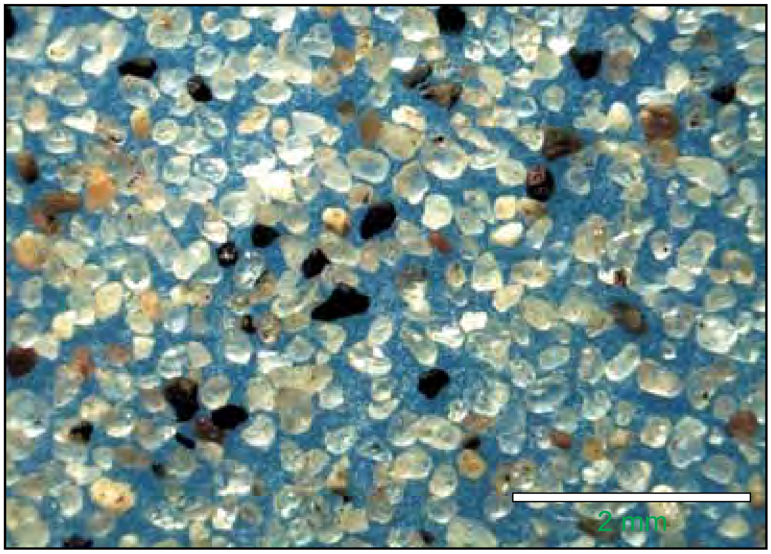
Comment:

This samples was collected from a compound parabolic dune from the main dune field north of Dazo Creek in the main Fontas River Dune Field, east of Fort Nelson. Dune crests are up to 7 m high, with average sand thicknesses across the field estimated to be 10 m.

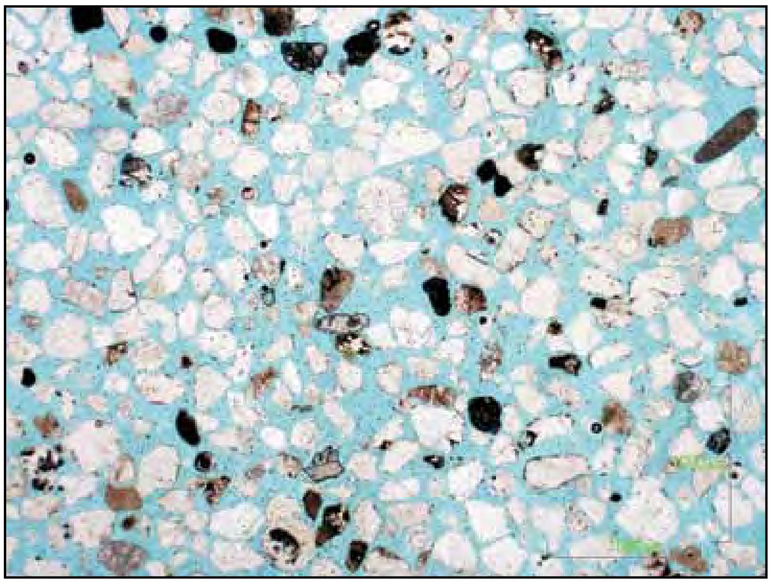


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	0.0	0.00	100.00
0.500	0.8	0.57	99.43
0.250	41.9	29.76	69.67
0.125	88.7	63.00	6.68
0.063	7.8	5.54	1.14
<0.063	1.6	1.14	0.00

Element	Percent
SiO_2	90.96
Al_2O_3	3.51
Fe_2O_3	2.49
MgO	0.22
CaO	0.48
Na_2O	0.74
K_2O	0.85
TiO_2	0.16
P_2O_5	0.08
MnO	0.03
Cr_2O_3	0.003
LOI	0.4



Binocular Microscope



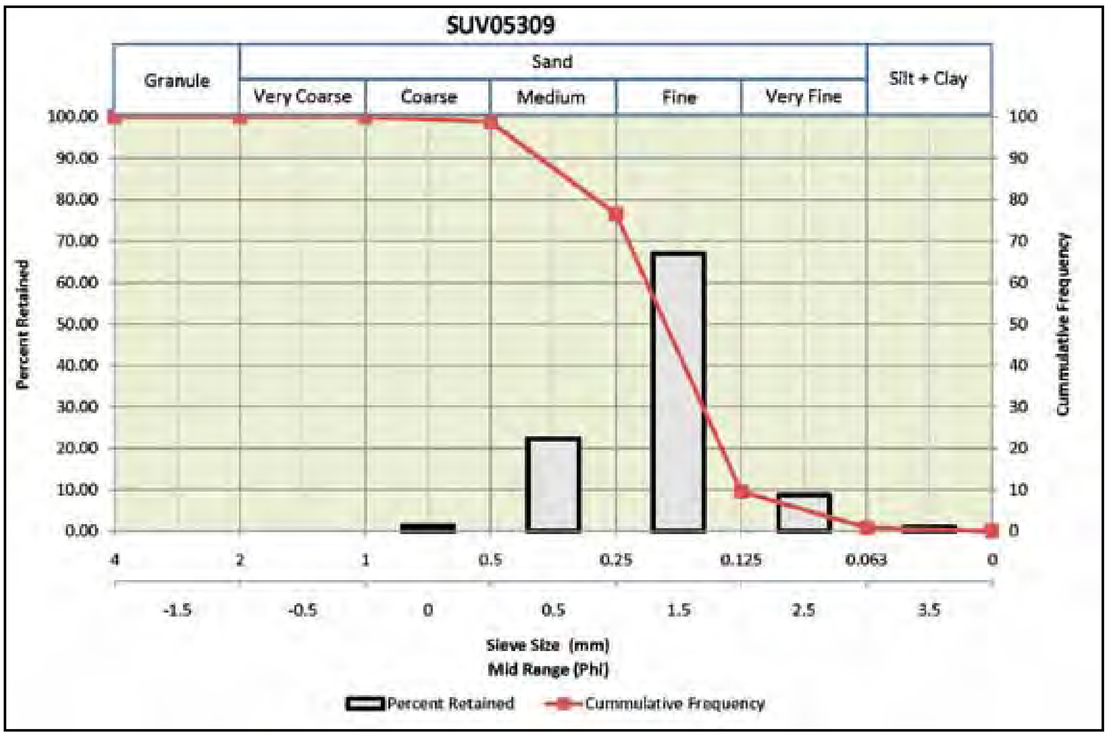
Plane Light

Crossed Nicols

Sample	SUV05309
Easting	611404
Northing	6460199
Genetic Origin	Aeolian Dune

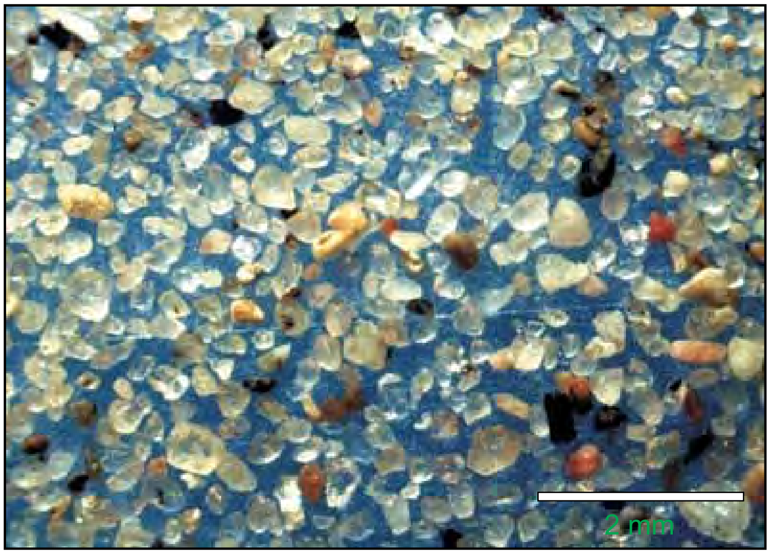
Comment:

This sample was collected from a parabolic sand dune in the northwestern sub-field of the Fontas Dune Field. Dunes are up to 4 m high large parabolic forms several hundreds of metres in length, with only thin sand cover in the inter-dune regions.

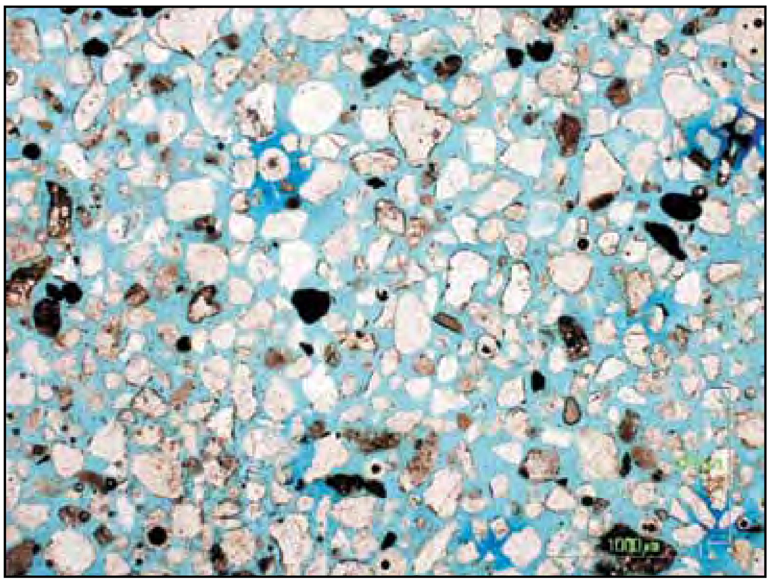


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	0.0	0.00	100.00
0.500	1.5	1.19	98.81
0.250	28.0	22.28	76.53
0.125	84.2	66.98	9.55
0.063	10.9	8.67	0.88
<0.063	1.1	0.88	0.00

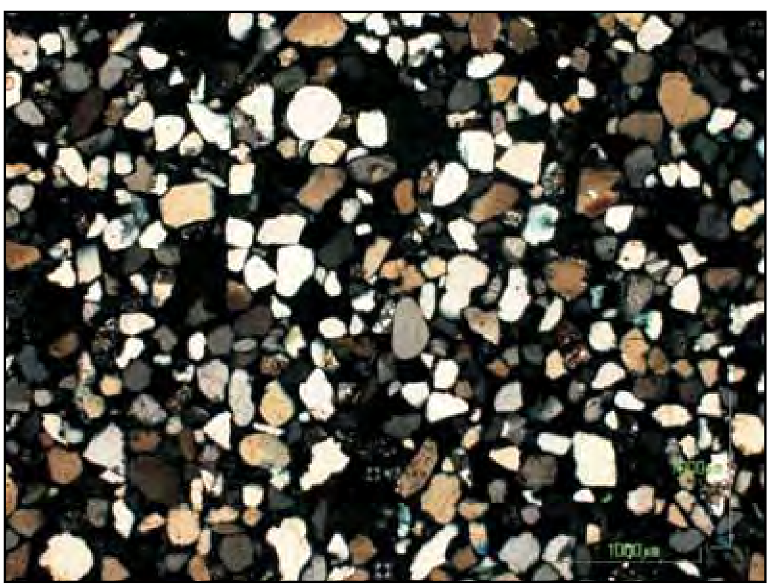
Element	Percent
SiO_2	90.62
Al_2O_3	3.83
Fe_2O_3	2.36
MgO	0.19
CaO	0.45
Na_2O	0.78
K_2O	0.99
TiO_2	0.13
P_2O_5	0.08
MnO	0.03
Cr_2O_3	0.002
LOI	0.5



Binocular Microscope



Plane Light

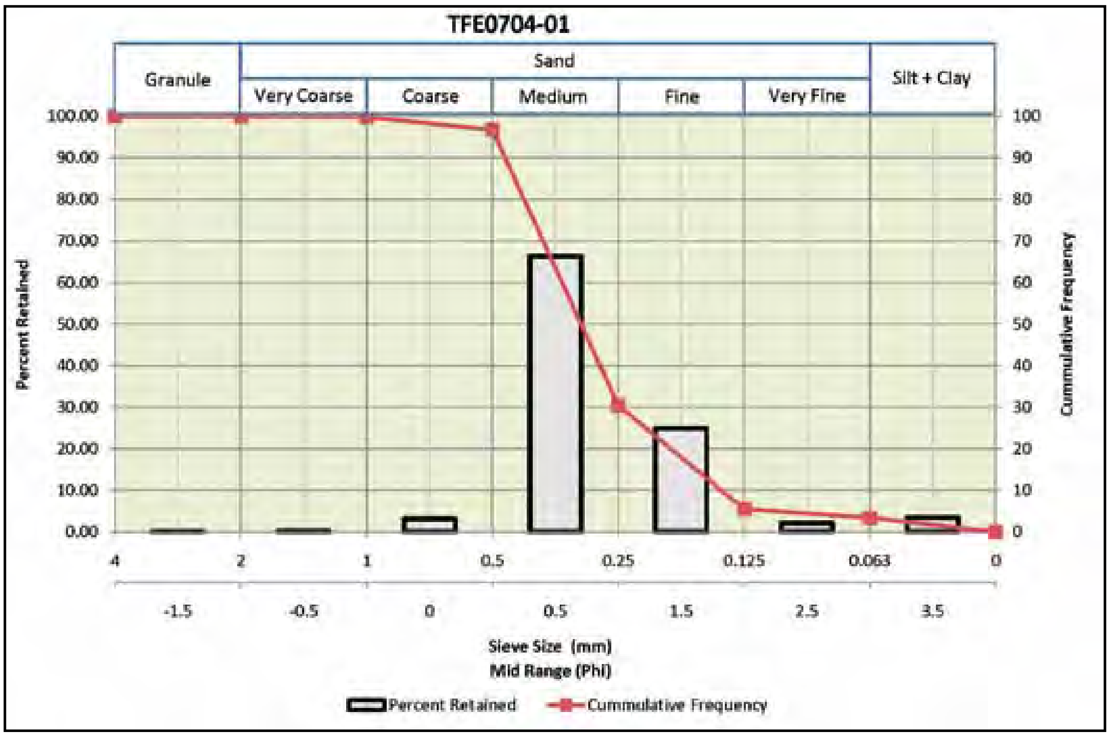


Crossed Nicols

Sample	TFE0704-01
Easting	628362
Northing	6566463
Genetic Origin	Glaciofluvial (Esker)

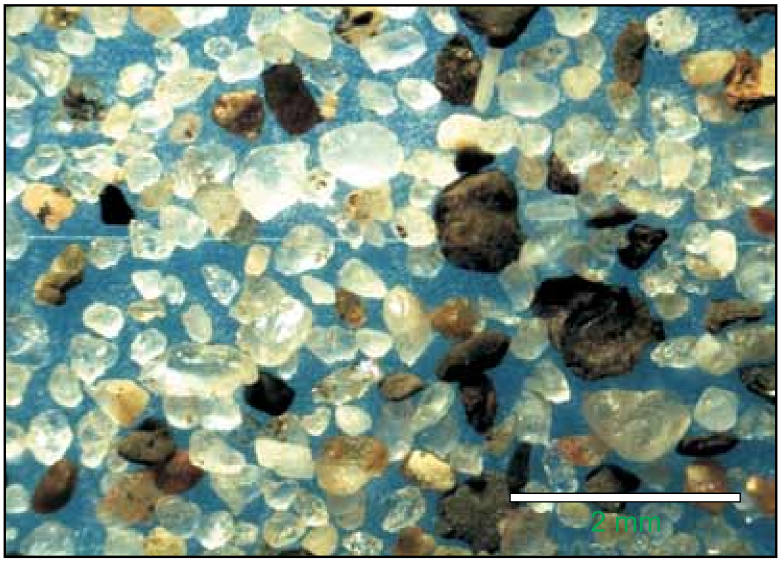
Comment:

The sample was collected from an esker that crosses Sierra-Yoyo_Desan road at kilometre 176. The sample was taken approximately 2 metres below the surface where an excavation has exposed the interior of the esker.

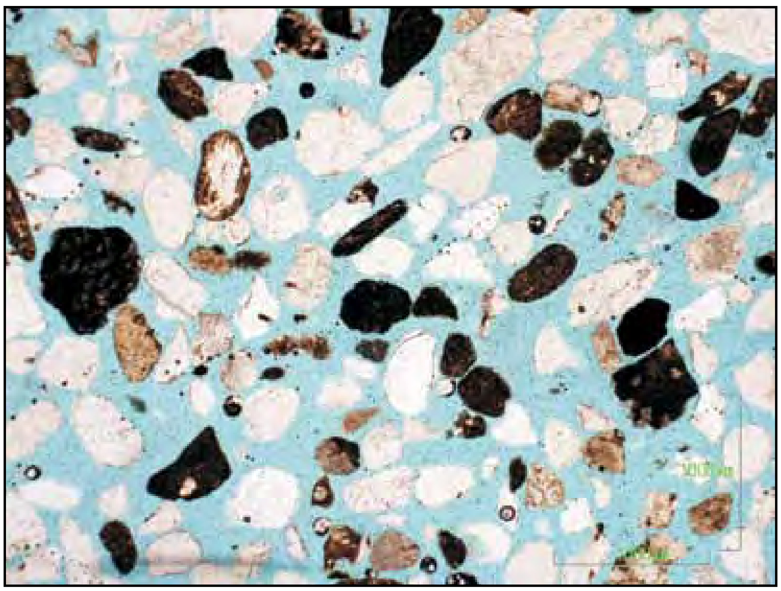


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	1.1	0.04	99.96
1.0	3.4	0.12	99.84
0.500	87.7	3.08	96.76
0.250	1886.6	66.32	30.43
0.125	707.6	24.88	5.56
0.063	60.5	2.13	3.43
<0.063	97.6	3.43	0.00

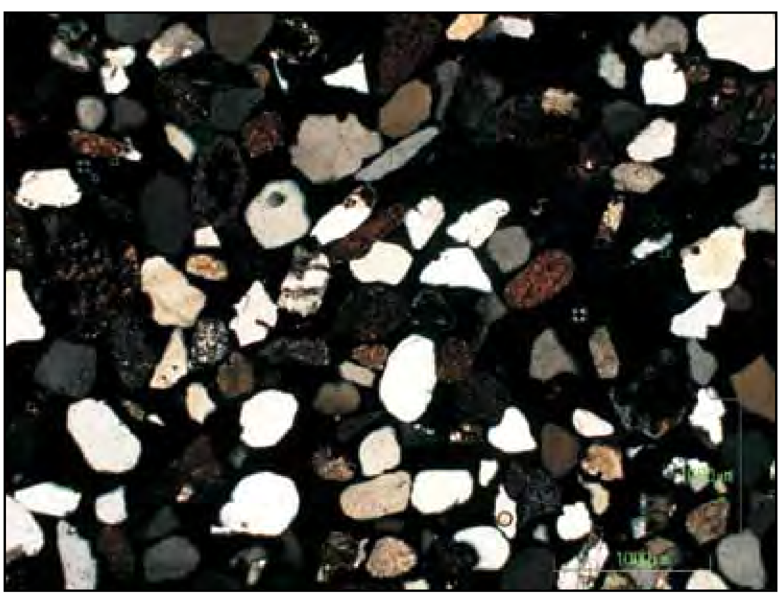
Element	Percent
SiO_2	85.01
Al_2O_3	4.86
Fe_2O_3	1.70
MgO	0.60
CaO	2.30
Na_2O	0.85
K_2O	1.35
TiO_2	0.13
P_2O_5	0.10
MnO	0.02
Cr_2O_3	<0.002
LOI	3.0



Binocular Microscope



Plane Light

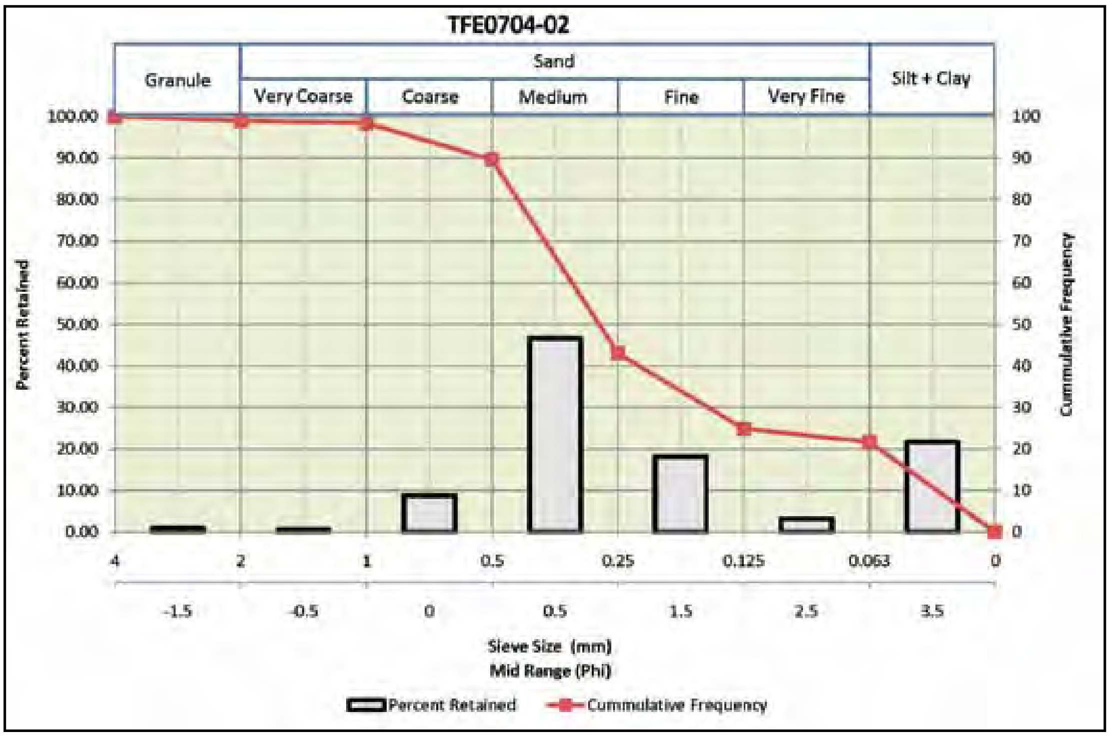


Crossed Nicols

Sample	TFE0704-02
Easting	581274
Northing	6540078
Genetic Origin	Glaciofluvial (Esker)

Comment:

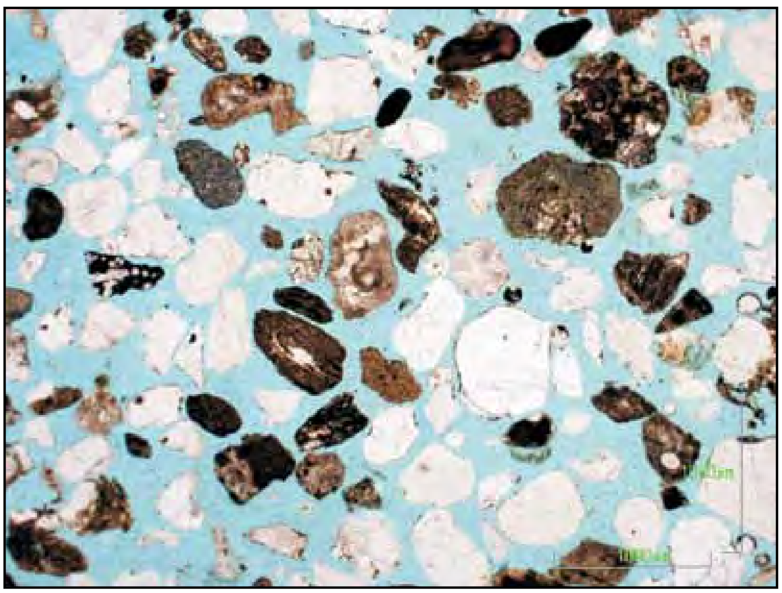
This sample was collected from the top of an esker (ridge) located west of the Komie Road. The esker is approximately 10 metres high, consisting mainly of sand with a thin 20 centimetre gravel lag at the surface.



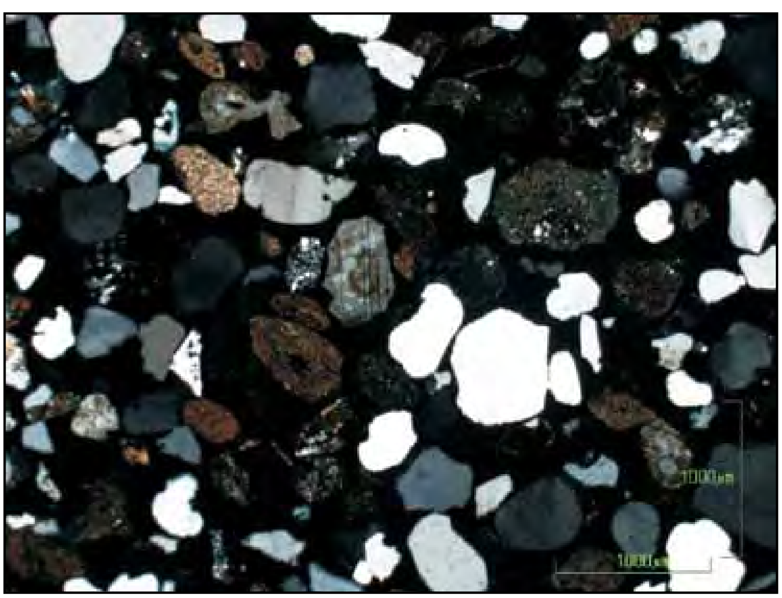
Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	18.2	0.94	100.00
1.0	11.2	0.58	99.06
0.500	171.5	8.82	98.49
0.250	906.4	46.61	89.67
0.125	352.7	18.14	43.05
0.063	62.3	3.20	24.92
<0.063	422.2	21.71	21.71

Element	Percent
SiO_2	83.89
Al_2O_3	6.08
Fe_2O_3	2.45
MgO	0.53
CaO	1.35
Na_2O	0.96
K_2O	1.51
TiO_2	0.17
P_2O_5	0.08
MnO	0.03
Cr_2O_3	0.003
LOI	2.9

Binocular Microscope



Plane Light

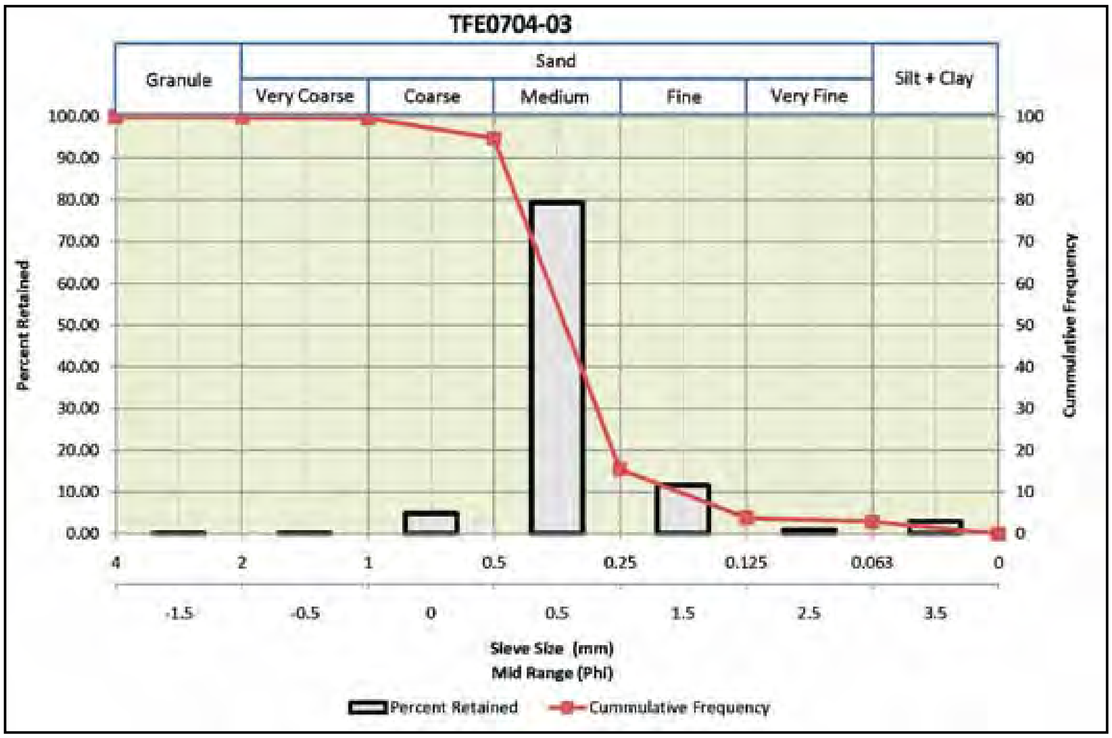


Crossed Nicols

Sample	TFE0704-03
Easting	569040
Northing	6573180
Genetic Origin	Glaciofluvial

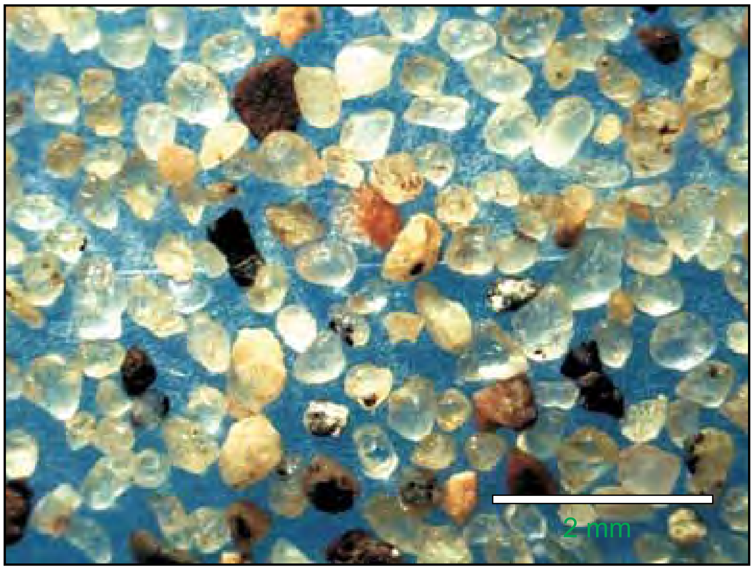
Comment:

The sample was taken from a borrow pit in the Komie area east of the Geetlah Road. This is interpreted as a a glaciofluvial delta that formed in a shallow glacial lake. There are several active and past producing sand and gravel pits in the area.

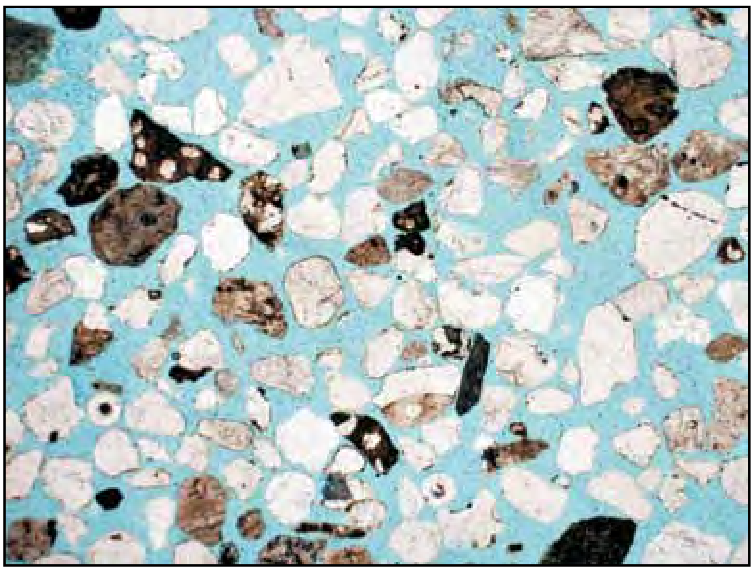


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	1.3	0.10	99.90
1.0	2.6	0.19	99.71
0.500	65.3	4.87	94.84
0.250	1065.1	79.38	15.46
0.125	156.0	11.63	3.83
0.063	12.0	0.89	2.94
<0.063	39.4	2.94	0.00

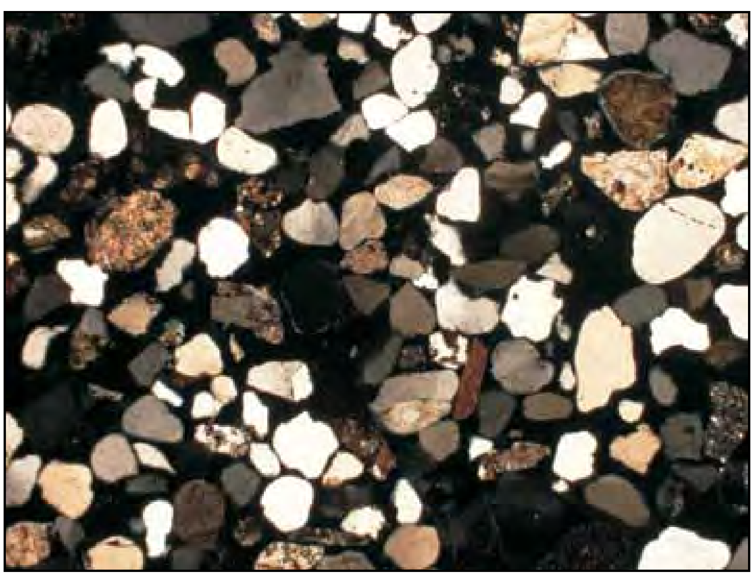
Element	Percent
SiO_2	89.99
Al_2O_3	4.26
Fe_2O_3	2.00
MgO	0.23
CaO	0.43
Na_2O	0.90
K_2O	1.25
TiO_2	0.10
P_2O_5	0.06
MnO	0.02
Cr_2O_3	<0.002
LOI	0.7



Binocular Microscope



Plane Light

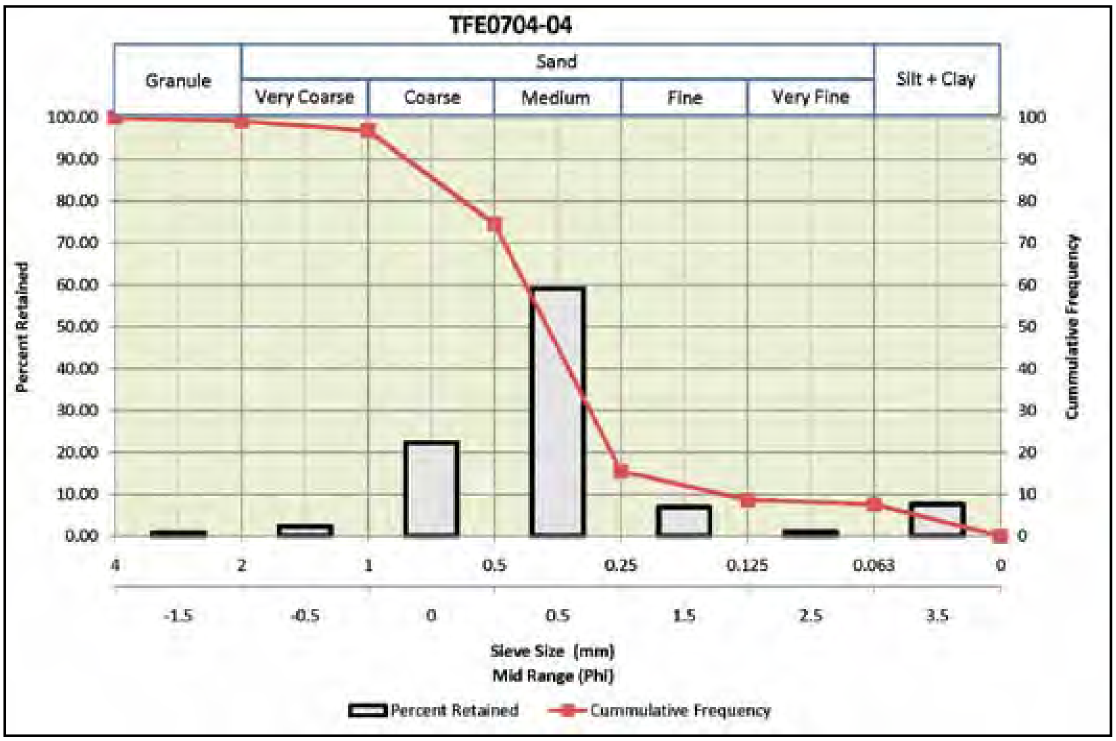


Crossed Nicols

Sample	TFE0704-04
Easting	574987
Northing	6560341
Genetic Origin	Glaciofluvial (Esker)

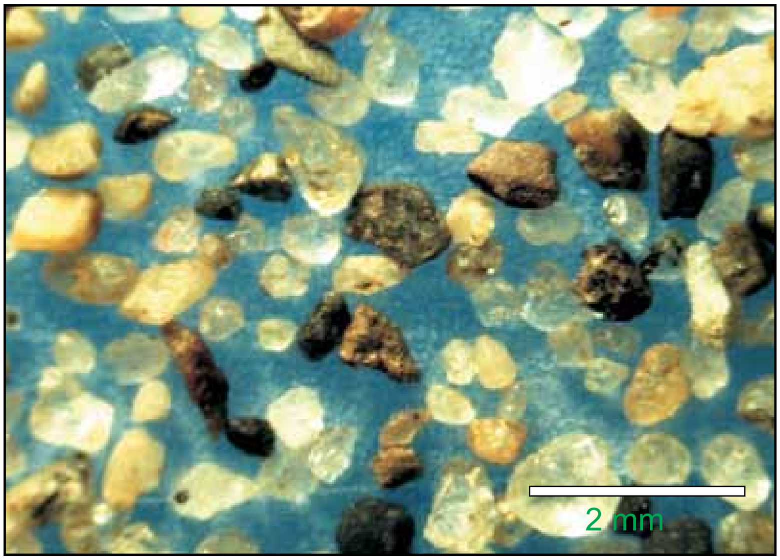
Comment:

Sample was collected from a recontoured borrow pit north of Courvoisier Creek, west of the Komie Road. The feature that hosts this deposit is an esker complex.

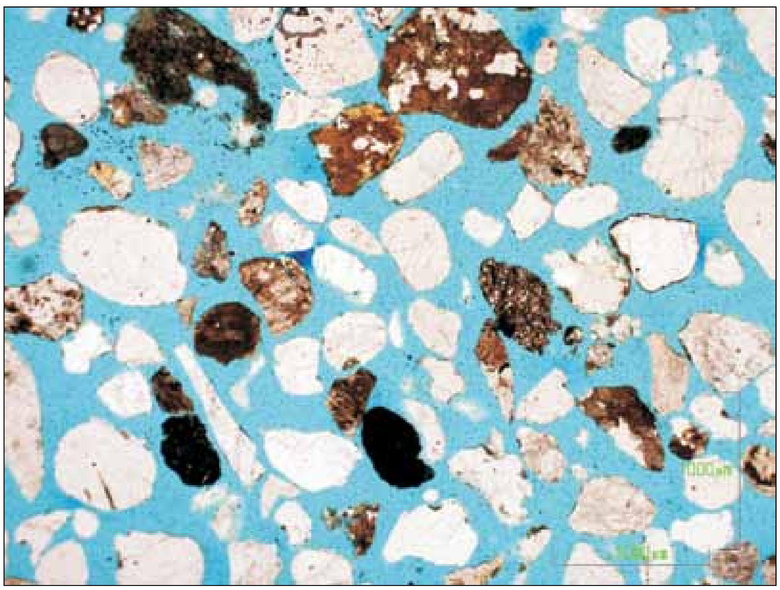


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	25.6	0.78	99.22
1.0	75.8	2.32	96.89
0.500	727.5	22.28	74.61
0.250	1929.0	59.08	15.53
0.125	224.0	6.86	8.67
0.063	35.0	1.07	7.59
<0.063	247.9	7.59	0.00

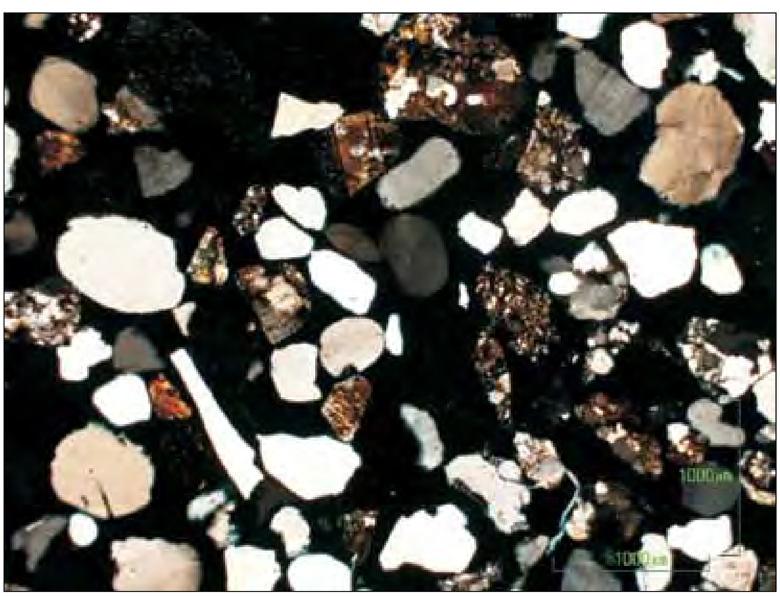
Element	Percent
SiO_2	87.01
Al_2O_3	5.70
Fe_2O_3	2.28
MgO	0.31
CaO	0.52
Na_2O	1.14
K_2O	1.65
TiO_2	0.13
P_2O_5	0.08
MnO	0.03
Cr_2O_3	<0.002
LOI	1.1



Binocular Microscope



Plane Light

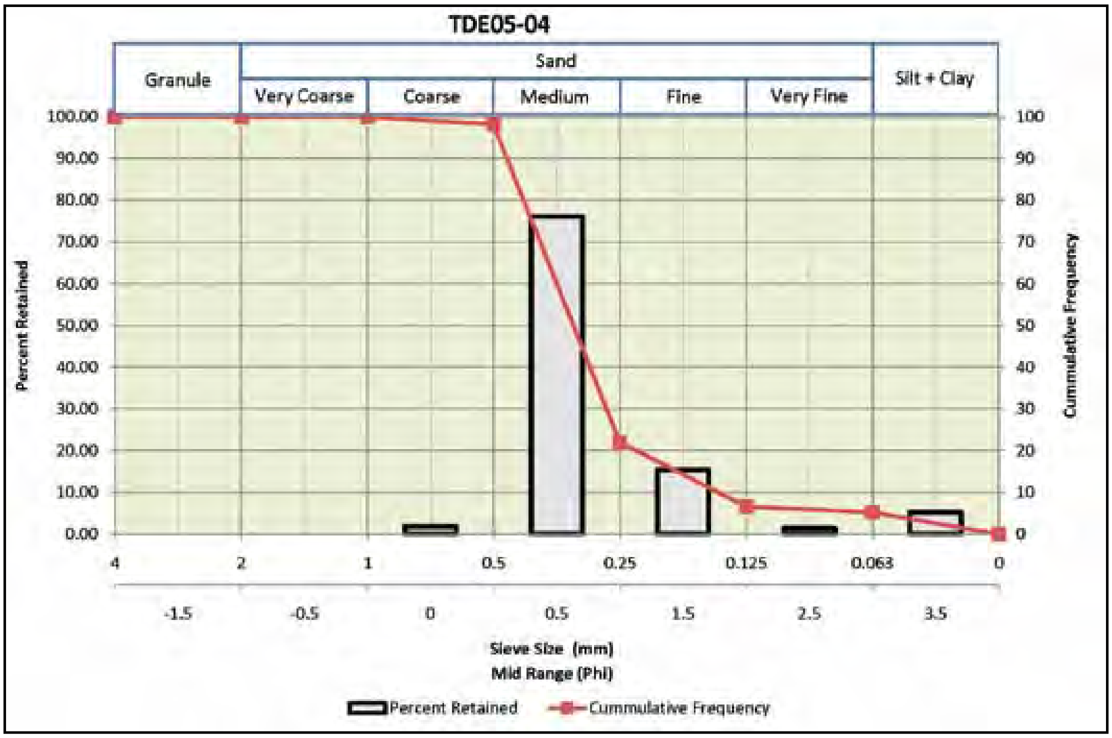


Crossed Nicols

Sample	TDE05-04
Easting	575001
Northing	6559192
Genetic Origin	Glaciofluvial (esker)

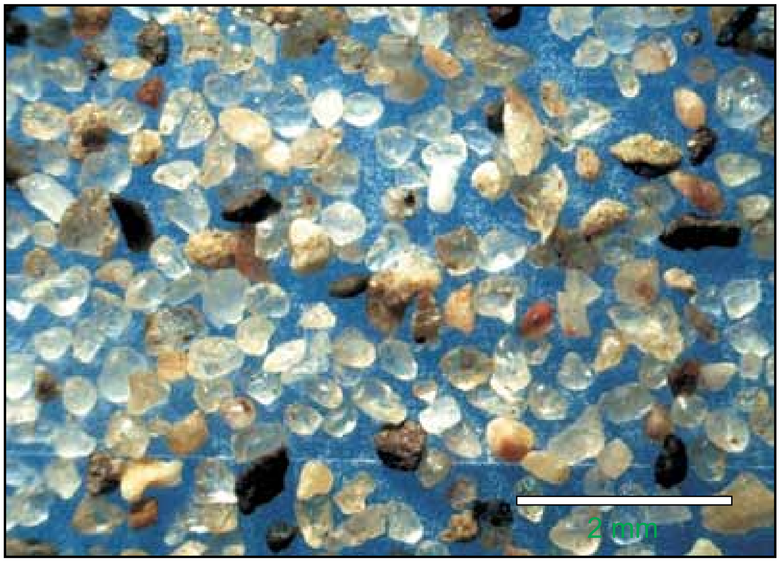
Comment:

This sample was collected from a borrow pit near Courvoisier Creek. The pit is in an esker complex that contains sand and gravel.



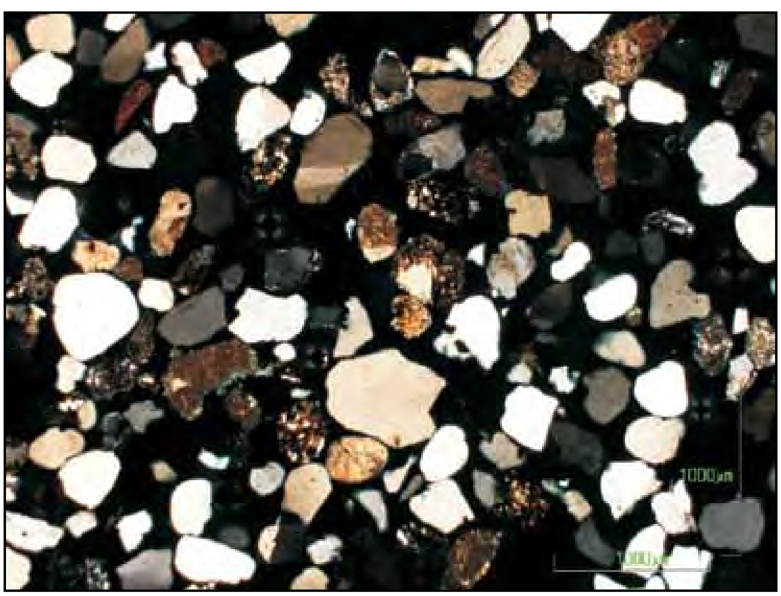
Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	0.0	0.00	100.00
0.500	8.2	1.84	98.16
0.250	339.2	76.11	22.06
0.125	68.7	15.41	6.64
0.063	6.1	1.37	5.27
<0.063	23.5	5.27	0.00

Element	Percent
SiO_2	85.97
Al_2O_3	4.16
Fe_2O_3	2.84
MgO	0.51
CaO	2.05
Na_2O	0.84
K_2O	1.16
TiO_2	0.13
P_2O_5	0.09
MnO	0.02
Cr_2O_3	0.002
LOI	2.1



Binocular Microscope

Plane Light

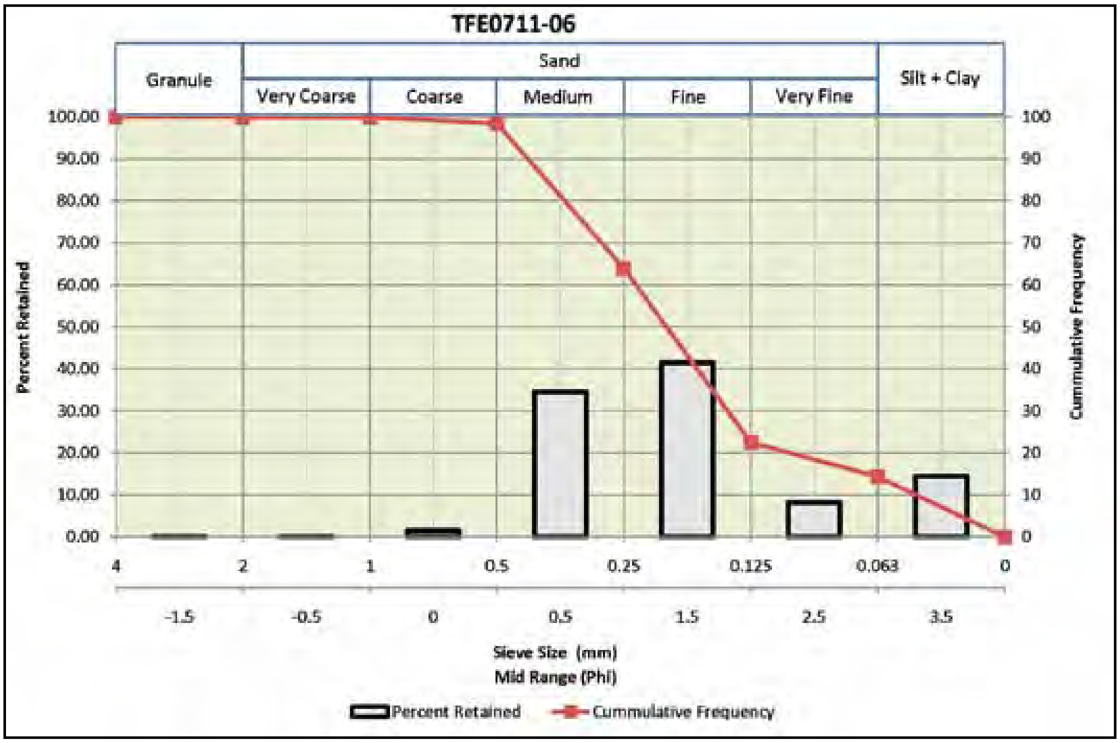


Crossed Nicols

Sample	TFE0711-06
Easting	500943
Northing	6642203
Genetic Origin	Glaciofluvial (Esker)

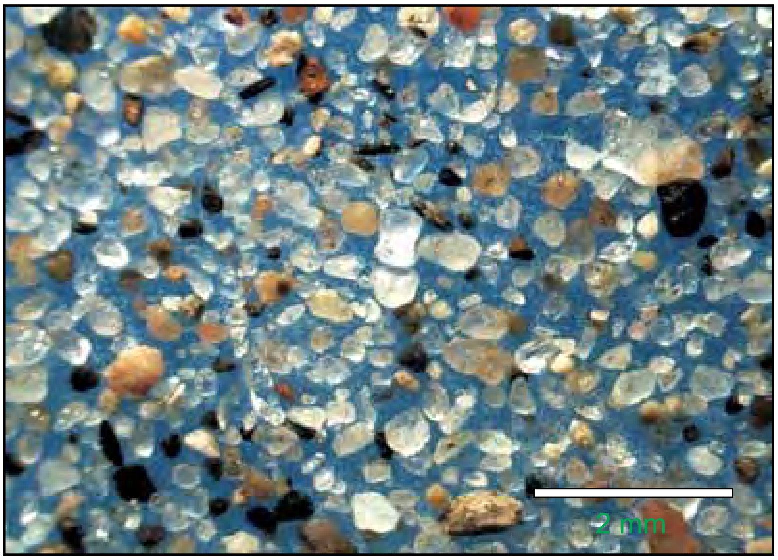
Comment:

The sample was collected from a 4 metres high esker west of the Liard Highway (Highway 77). The material in this deposit consist of a range of grain sizes ranging from pebble gravel to fine sand.

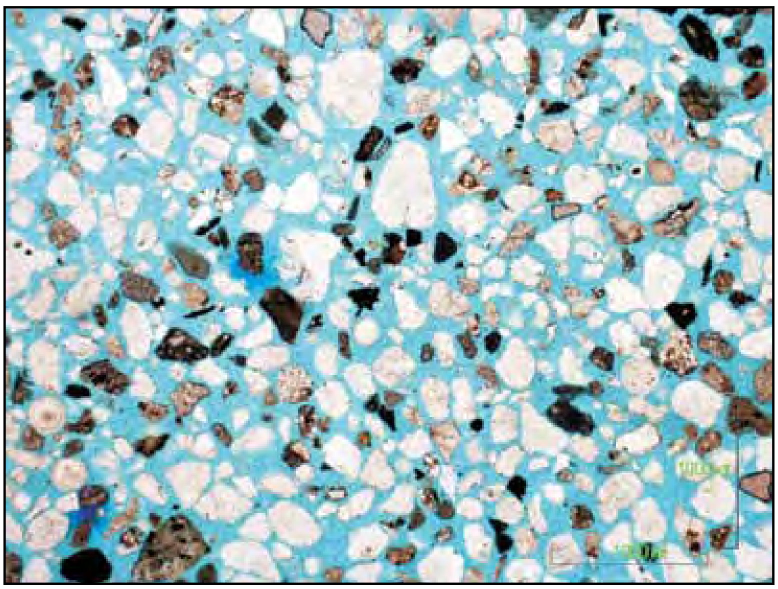


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	1.3	0.10	99.90
1.0	2.6	0.19	99.71
0.500	65.3	4.87	94.84
0.250	1065.1	79.38	15.46
0.125	156.0	11.63	3.83
0.063	12.0	0.89	2.94
<0.063	39.4	2.94	0.00

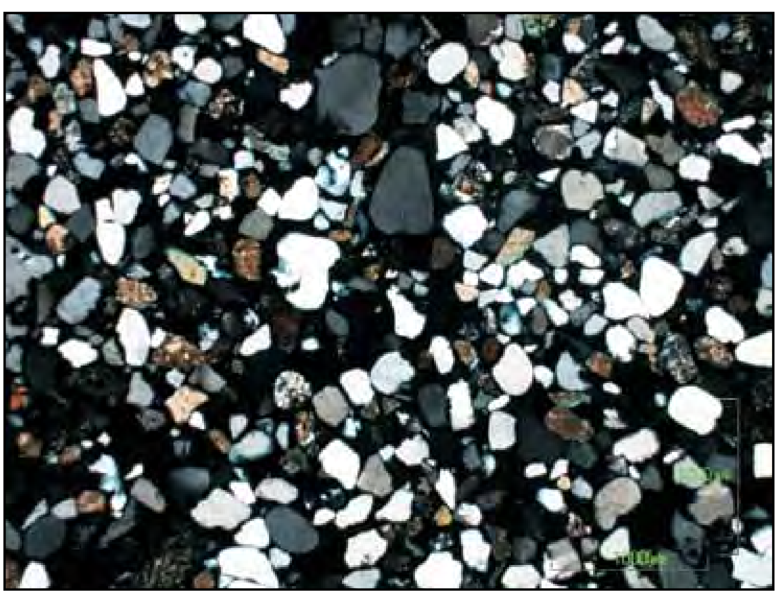
Element	Percent
SiO_2	80.41
Al_2O_3	4.51
Fe_2O_3	1.66
MgO	0.97
CaO	5.00
Na_2O	0.97
K_2O	1.26
TiO_2	0.12
P_2O_5	0.08
MnO	0.02
Cr_2O_3	<0.002
LOI	4.9



Binocular Microscope



Plane Light

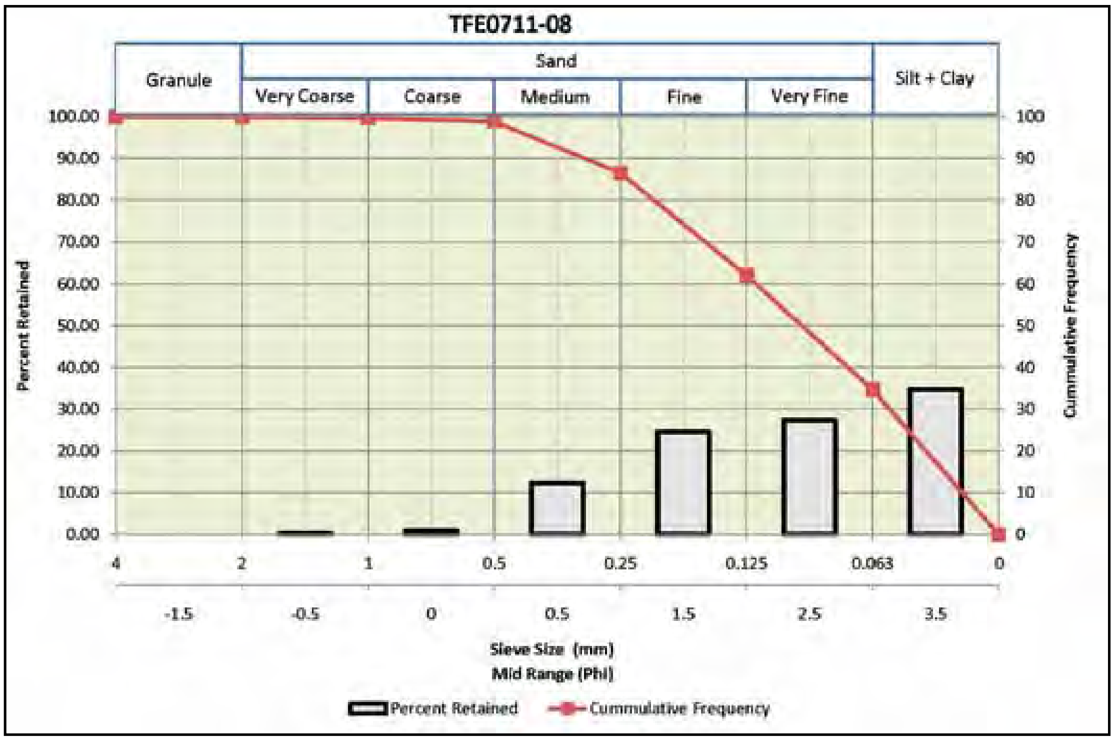


Crossed Nicols

Sample	TFE0711-08
Easting	501341
Northing	6641887
Genetic Origin	Glaciofluvial (Esker)

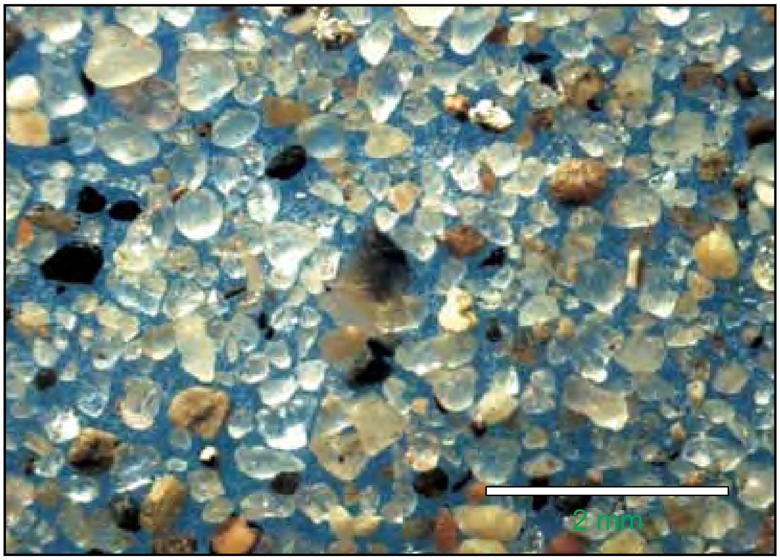
Comment:

Sample was collected one metre below surface in a small esker west of the Highway 77.

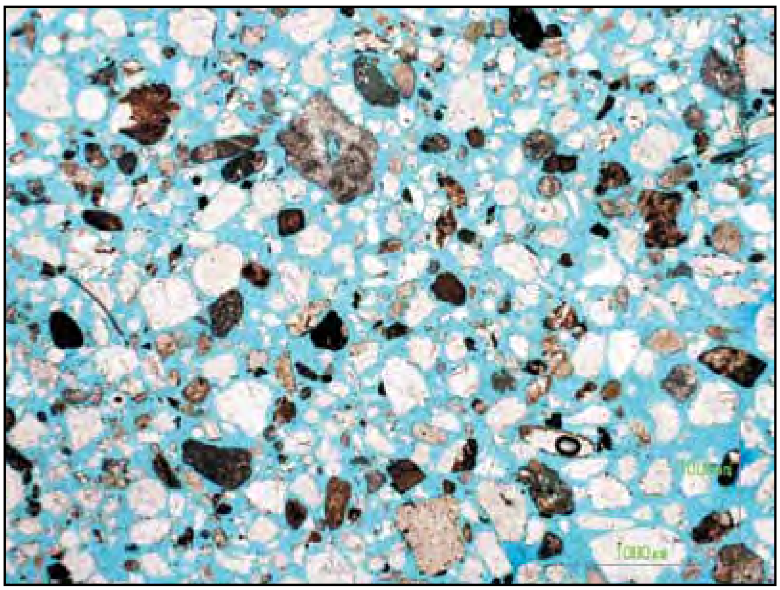


Sieve Size	Mass	Percent Retained	Cummulative Frequency
4.0	0.0	0.00	100.00
2.0	0.0	0.00	100.00
1.0	5.6	0.25	99.75
0.500	18.9	0.85	98.89
0.250	272.6	12.30	86.60
0.125	544.6	24.57	62.02
0.063	605.5	27.32	34.70
<0.063	769.2	34.70	0.00

Element	Percent
SiO_2	80.57
Al_2O_3	5.00
Fe_2O_3	1.72
MgO	1.03
CaO	4.19
Na_2O	1.03
K_2O	1.42
TiO_2	0.15
P_2O_5	0.10
MnO	0.03
Cr_2O_3	0.002
LOI	4.7



Binocular Microscope



Plane Light

Crossed Nicols