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Preliminary Investigations of Silica Sand Resources of Saskatchewan

M.R. Gent

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Abstract

This project was initiated in 1990 due to the perceived increase in demand for specialty silica resources. The results of this investigation and subsequent metallurgical studies funded by the Canada Centre for Mineral and Energy Technology (CANMET) under the Canada-Saskatchewan Partnership Agreement for Mineral Development (MDA) have shown the Mannville and Winnipeg formation silica sands to be of high purity and a very significant resource commodity with excellent potential for benificiation to meet requirements of "high tech" and specialty silica applications.

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Introduction

As an industrial mineral, silica is one of the more important inorganic commodities. It is a ubiquitous compound that is a major component of many common rock types and, in fact, makes up about 60 percent by weight of the earth's crust (Coyle, 1969). Silica is composed of the binary compound of silicon and oxygen with quartz being its most common naturally occurring mineral form. Unconsolidated quartz sands, quartz sandstones, and their metamorphic equivalent, quartzites are by far the most abundant commercial sources of silica. Less significant volumes of silica, with very high degrees of purity, are also produced from some pegmatites, but the development of such resources generally requires abundant, low-cost labour.

Historically, silica has been an essential material to humanity. As human technical skills developed, its natural abundance resulted in the development of a considerable number of uses. Silica was probably first used for the making of knives, scrapers, spear, and arrow heads, and as a flint, for starting fires. Early civilizations extended its uses to making glass, which is still the largest end use product.

Consumption of silica has now increased to over 29 million tons per year in North America alone. Most of today's silica consumption is for the making of bricks, cement, ceramics, ferrosilicon, and glass. However, its uses have extended into thousands of products including some major high tech applications such as semiconductors, catalysts, desiccants, piezoelectrics, optical fibres, etc.

Applications and Products of Silica

The principal uses and primary products of silica can be grouped into three main categories:

i) high-volume, low-value uses in which silica is a major portion of the product,

ii) high-volume, value-added forms that typically have been mechanically ground for use as a product body (e.g. porcelain) or filler to function as an extender, and/or to modify the properties of a product, and

iii) as a low-volume, high-value specialty product that has been chemically or physically processed to produce a material with substantially different properties.

The general specifications (e.g. grain size and purity) for different silica applications vary significantly depending on the particular processing methods used (Table 1). Except for very low-value applications, a relatively pure silica product is normally required. In many instances the grades or specifications of a silica product are arbitrarily defined relative to the products of existing large-volume producers.

Until recently, silica sands were excluded from the production of silicon and ferrosilicon because a coarse grain size was required for their production. Agglomeration methods for silica sands and new processing techniques are being developed and tested that may facilitate their use in these major commodity categories.

Glass recycling is reducing the demand for silica used in container glass production but should not affect the demand for optical and colourless glass production, which have rigid specifications. This loss has been offset by an increasing demand for silica sand in the production of: (a) fused quartz, ferrosilicon, and silicon carbide; (b) silica fillers and extenders (Tables 2 and 3); and particularly (c) speciality or processed forms where the uses are especially diverse (Table 4).

Overview of Silica Specifications and Applications by Use

Glass

Amongst the high-volume silica uses, the specifications for flat, colourless, domestic, and optical glass production are the most rigid (Table 1). For example, the grain size of the silica used is tightly controlled, and impurities, such as iron, chrome, and boron that can produce strong colouring effects, are particularly detrimental. The absence of coarse refractory minerals that can cause nucleation or visual defects is essential.

Foundry Sands

Silica sands classified as foundry sands are not necessarily of high purity, but must meet specific physical properties subject to their intended uses as moulding, core, blasting, or abrasive sands.

Moulding and core sands are used in foundries where resistance to high temperatures is necessary. Approximately 7.9 million tonnes averaging U.S.$8.50 per tonne are reported to have been used in the United States in 1980 (Tepordei, 1980). Sands used to form the core of castings are treated chemically or baked and mixed with resins or oils. These sands generally have a low clay content (<0.5 percent), but can contain up to 24 percent. Nevada sand has an AFS Fineness of 57 with 98 percent being coarser than 140 mesh, (U.S. series) and 92 percent finer than 40 mesh. Other important sands include medium-grained, washed, Eastern Silica Sand and Lake Sand grades that have an AFS Fineness of 53 and 55 respectively (Wilborg and Henderson, 1983). Medium-grade Eastern Sands are 98 percent silica and have a fusion point above 1682°C.

Blasting and abrasive silica sands are not normally specified by purity, but must have closely sized angular grains that are not readily broken. Other more abrasion-resistant, natural and synthetically produced minerals, in-

Table 1 - Main uses and general specifications for silica (after Coope and Harben, 1977).

Applications	min% SiO_2	max% Al_2O_3	max% TiO_2	max% Fe_2O_3	max% CaO/MgO	Grain Size	Remarks
Glass sand							
Optical	99.5	0.01 to 0.5	0.006				Must be less than 6 ppm chromium and 2 ppm cobalt. Grain size and purity must be constant.
Colourless domestic	99.5	variable	0.01 to 0.5	0.013		0.1 to 0.5mm	
Container/flat	98.5	0.1 to 0.5	0.01 to 0.5	0.030			
Foundry sand	88 to 99	---------- Extremely variable ----------				20 to 200 mesh	Chemical composition variable; 98 to 99 percent SiO_2 now preferred. Sub-angular to rounded grains.
Packing and fracturing sand	Variable					8 to 40 mesh	Grains must have a high sphericity and compressive strength.
Ground silica	97 to 98	0.5		0.2		micron sizing	
Silicon carbide	99.5	0.06 to 0.25		0.1	absent	plus 100 mesh	No phosphorus allowed. 0.25 percent Al_2O_3 for black SiC. 0.1 percent for green SiC.
Silicon	99.6	0.15 to 0.4	0.15	0.2	0.2 each	>2.5 cm	No phosphorus or arsenic allowed.
Ferrosilicon	96	0.4		0.2		>2.5 cm	0.1 percent phosphorus maximum.
Silica brick (refractory)	96 to 98	0.1 to 1.5	0.2	2.5	4.0 to low	minus 8 mesh	
Sodium silicate	99	0.25		0.03	0.05	20 to 100 mesh	Broadly the same specifications as glass-grade sand.
Silica flux	90	1.5		1.5	0.2	<5% - 2.5 cm	

Note: The above figures are general indications only.

Table 2 - Major non-filler uses and specifications for ground silica (from Guillet and Kreins, 1984).

Applications	Function	General Specifications
Ceramics	Finely ground silica is a major ingredient in many ceramic products such as sanitary ware, dinnerware, and electrical porcelain.	Grades from 200 to 400 mesh. High purity, low iron, white firing.
Glass	Fine silica is used in the manufacture of reinforcing and textile fiberglass in which it is a major constituent of the glass batch.	325 mesh grade. Low in iron and alkalies.
Bricks	Finely ground silica is used in the manufacture of silica-lime brick.	200 mesh silica. Low purity is adequate.
Concrete Block	Fine silica is used in the manufacturing of autoclaved concrete block.	100 to 200 mesh silica of low purity.
White Cement	Fine silica is used in the manufacture of white cement.	200 mesh product. Medium purity.

cluding garnet, staurolite, and alumina, have substantially replaced silica for the large volume, low-value uses in blasting and abrasive sands.

Packing and Fracturing Sands

Sands with a high sphericity are required for packing and hydraulic fracturing sands to optimize groundwater and petroleum well production. Packing sands are used in groundwater wells to fill the space between the well wall and screen. The sand supports the well wall, offers maximum linear flow rates and enables the use of smaller sized, less expensive screens while maintaining the same well production capacity.

Fracturing sands are injected into petroleum-bearing formations as a hydraulic fracturing and propping agent. The grain size is closely controlled, and the required grain compressive strength increases with the depth of the producing formation. Grain size requirements are subject to the amount to which the sedimentary beds can be separated.

Silica Brick

Silica is used in the production of refractory bricks. Other refractory minerals have in large part replaced the use of silica bricks in the steelmaking industry, but silica bricks continue to be used in coke ovens, ceramic kilns, and glass tanks. There also appears to be a renewed interest by the steelmaking industry in using silica as a checker in blast furnaces. The selection of silica used in these bricks is based upon purity and burning characteristics that might affect brick strength (>3 MPa (500 psi) average modulus).

Decorative Applications

Applications of silica for decorative purposes are based upon its brightness, low cost, and chemical resistance. It has some use in stuccos, roof tiles, and aggregate, but the largest volumes are probably used for golf course sand traps. In all cases, brightness and coarseness are critical characteristics. Non-oxidizing contaminants such as rutile, garnets, corundum, ilmenite, and chromite are normally tolerated, but the presence of minerals such as magnetite, hematite, and limonite that may colour the silica upon weathering are especially detrimental for esthetic purposes.

Silica Flux

Fluxes are used in the smelting industry to: i) facilitate the fusing of ores; ii) reduce the density of the slag to improve the separation of metal from it; iii) remove undesirable contaminants that might otherwise combine with the metal being purified; and iv) enhance the fluidity and manipulative properties of melts, especially slags.

Silica is one of the most common and inexpensive fluxes used by the smelting industry. It is normally mined from highly siliceous shear zones or quartzite deposits in close proximity to the smelters using it. Provided that no detrimental compounds are present, very high purity is not generally a critical selection criterion. A silica content as low as 90 percent can be acceptable but the presence of alumina is considered undesirable. If the silica flux contains metal(s) in a compatible mineralogy with the ore, it is considered to have a 'sweetener' and a premium is frequently paid on this basis.

Table 3 - Major filler uses and specifications for silica (from Guillet and Kriens, 1984).

Applications	Function	General Specifications
Paint	Silica is used in paints to provide scrubability and film toughness. In exterior paints, it provides good weathering properties. Used in block fillers, porch and floor enamels, and traffic paints.	Grades ranging from 325 mesh to 10 microns are used. Some cryptocrystalline grades of silica have very fine sizes with low average particle size. Ground crystalline silica usually has a higher average particle size. High brightness and low oil absorption is essential.
Plastics	Silica is used in different polymer systems. Silica provides excellent dielectric properties, compression, and flexural strength. It is used in potting compounds made from epoxy or polyester resins.	Natural or cryptocrystalline grades of silica are used in plastics. Some grades are surface coated, or treated with coupling agents to aid dispersion, and improve bonding properties with polymers. High brightness grades of 325 mesh to 5 microns are used.
Putty, Caulks, and Sealants	Finely ground silica is used in epoxy based sealants and silicone caulking compounds. Used in electrical applications, silica provides good dielectric properties and has low binder demand allowing high loading levels.	Fine grades of 10 to 30 microns particle size are used in this application. High brightness is required.
Rubber	Finely ground silica is used in silicone rubbers as an extender pigment.	Fine-grained (30 to 10 micron) products are used. High brightness is important.
Adhesives	Finely ground silica is used in the compounding of vinyl adhesives.	Fine ground 40 to 10 micron grades.
Wood Fillers	Finely ground silica is used in paste wood fillers.	Grades from 30 to 5 microns.

Ground Silica

Mechanically crushed or ground silica is used extensively in a number of non-filler and filler industries (Tables 2 and 3). The specifications for ground-silica sand varies with its application. Most of the consumption of low-purity ground silica is in the production of fiberglass, ceramics, brick, concrete, and cement.

Non-filler ground silica products are used to dilute a product, or to modify its cost, chemical and abrasion resistance, flow characteristics, fire resistance, density, electrical and thermal conductivity, colour, brightness, opacity, hardness, brittleness, strength, surface texture, processing problems, thermal expansion, etc. The ceramics industry (non-filler) uses ground silica in the production of sanitary ware, electrical porcelain, whiteware bodies, whiteware glazes, and enamels. In the manufacturing of these products, the silica is fused with other minerals to form a new material of particular characteristics. In most cases the silica used in ceramics must contain 97 to 98 percent SiO_2 and in most cases must have a maximum grain size of less than 200 to 400 mesh. In some cases, such as for whiteware and enamels, the absence of iron, chrome, nickel, copper, and other metals, which might produce colourations when fused, is especially important. The chemical purity and grain size range specifications for other non-filler, ground silica applications are generally not as tightly constrained.

Extender and filler uses tend to be more specialized and generally necessitate finer grain size, higher purity, and brightness than do the non-filler applications.

Silicon Carbide

Silicon carbide is a synthetic abrasive made in resistance-type electric furnaces with glass-grade silica sands (99.5 percent SiO_2) and pure carbon. Iron and aluminum are considered objectionable contaminants in this process as they tend to cause graphitization of the carbon and reduction of the silica to metallic silicon.

Table 4 - Principal applications and function of speciality silicas (from Harris et al., 1987).

Silica Type	Applications	Function	$/lb[1]
Colloidal silica	Fibrous ceramics, investment casting, and wafer polishing	High temperature binder, abrasive	1.68
Fumed silica	Silicone rubber, unsaturated polyester, and specialty coatings	Reinforcement and thixotropy	2.27
Fused silica	Epoxy encapsulating compounds	Electrical and thermal properties	0.40
High purity quartz	Semiconductors, precision optics, and fiber optics	High purity silica source	0.67
Precipitated silica	Rubber, food, healthcare, battery, separators, pesticides, and catalysts	Physical properties	0.50
Silica gel	Food, healthcare, and industrial castings	Physical properties and flatting	1.04

Note:

1) Average price paid for all end uses in 1986 f.o.b. supplier.

Statistics for the production of synthetic abrasives in North America from 1975 to 1981, show that the production of silicon carbide has fallen severely since 1979, presumably due to the increased use of other abrasives. However, for reasons unknown to the author, its value has risen significantly (87 percent from 1975 to 1981 and over 17 percent from 1980 to 1981 alone).

Ferrosilicon

Metal alloys containing 6 to 95 percent silicon are extensively used in the iron and steel industry for alloying, deoxidizing, melt inoculation, and chemically reducing other alloying agents that would otherwise be trapped in the slag. Ferrosilicon with less than 15 percent silicon is produced in blast furnaces while all other production occurs in submerged-arc electric reduction furnaces. Nonfriable lump silica (>2.54 cm diameter) with 98 percent silica, 0.15 to 0.40 percent Al_2O_3, 0.1 to 0.2 percent Fe_2O_3, <0.2 percent magnesia and lime, as well as very low boron, arsenic, sulphur, and phosphorus contents are normally specified. Some successful results have been achieved in the use of silica sands in ferrosilicon production, but it is not expected to have any major impact on the use of these sands in the near future.

Sodium Silicate

Sodium silicate is one of the fundamental alkalis of the chemical industry. Most of the high-value specialty silicas listed in Table 4 are produced from this compound. Although specialty silicas constitute only 1 percent by weight of the total North American silica production, they comprise 43 percent of its value (Harris *et al.*, 1987). High-purity silica sand is fused in a glass furnace with an alkali, typically soda ash (Na_2CO_3); however, sodium sulphate (Na_2SO_4), with carbon as a reducing agent, can also be used.

The required purity of the silica sand is largely controlled by the final product to be made. In some cases only a few parts per million of total contaminants can be tolerated, but in most instances >99 percent SiO_2, <0.25 percent Al_2O_3, <0.03 percent Fe_2O_3, and <0.05 percent MgO and CaO are required. Sulphates, borates, and chlorides can also be serious contaminants if the soda ash method is used. Grain size specifications are generally similar to those for glass production.

Silica Consumption

The majority of silica production in Canada is situated in proximity to major, local markets in Ontario and Quebec. Approximately 32 percent of Canadian production is used in the manufacturing of glass and fiberglass, and 25 percent is used as a smelter flux (Collings and Andrews, 1989). Investigations by Hamilton (1986) suggest that in western Canada larger proportions of silica production are used as smelter flux and for glass and fiberglass production.

Data on North American production, value, and consumption of silica by application are unavailable, but reports by Harris *et al.* (1987) indicate that, in terms of price, the various speciality silica products constitute the most important markets for high purity silica. This is especially valid for any deposits remote from potential major markets. The North American specialty silica industry is considered to have an excellent economic potential, even though it is a mature industry suffering from overcapacity in some areas and from rising costs. Of all the specialty silica uses the electronics, optical, electro-optics, and plastics sectors were projected by

Harris et al. (1987) to have the highest average annual growth (Figure 1).

Although silica is one of the most commonly occurring industrial minerals, economically exploitable deposits are rare. As with other industrial minerals, economically mineable silica deposits must be favourably located either in close proximity to major consumers in an area not adversely affected by cultural conditions or requirements, or of sufficient purity to meet the demanding requirements of specialty users. Remote silica deposits of unusual purity or amenable to simple metallurgical processing could be economical if their product value and low cost of processing offset the difference in transport costs of more favorably located deposits. Consequently, the Saskatchewan silica sand deposits were investigated principally for their potential application in high-value, specialty silica products.

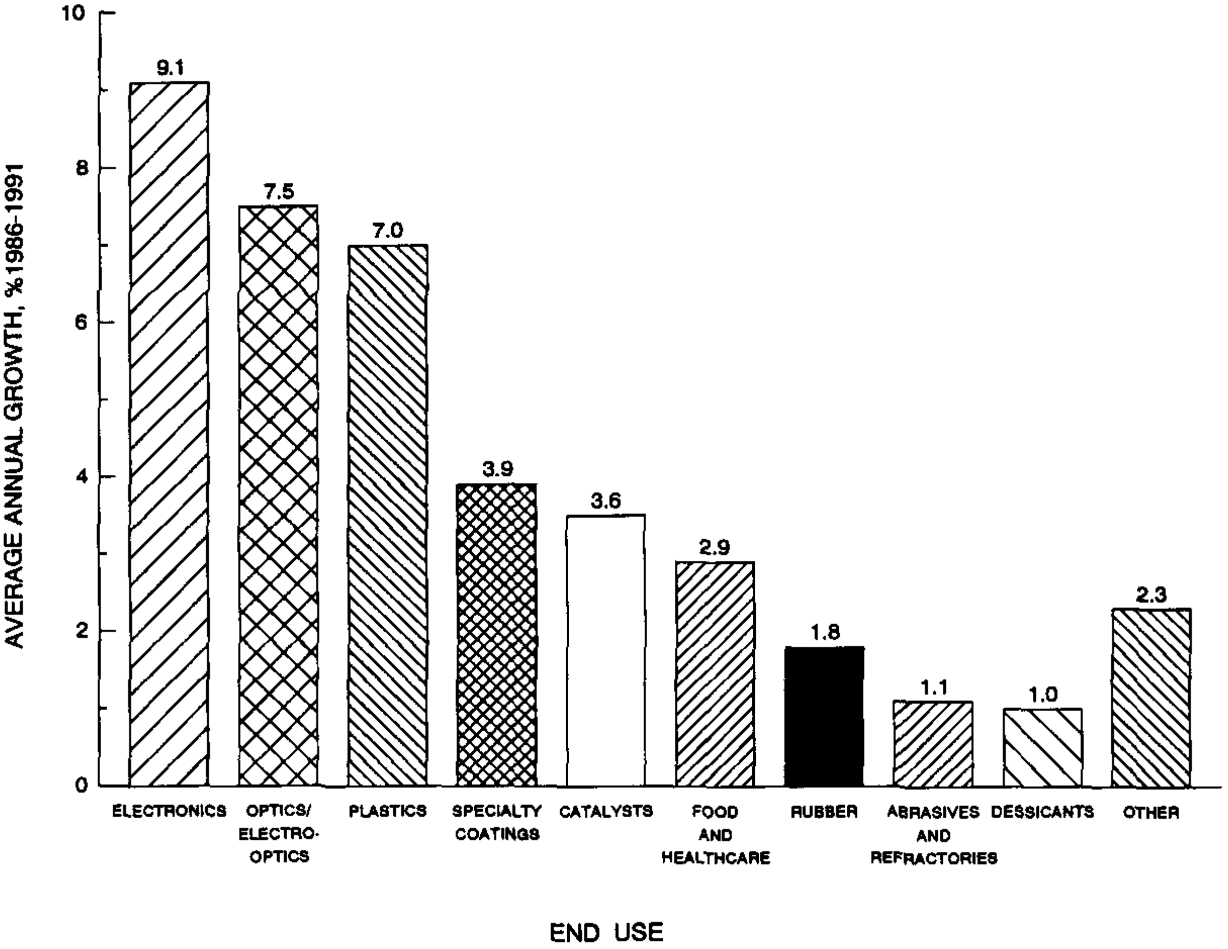

Figure 1 - Forecasted average annual growth for speciality silicas by end use, 1986 to 1991 (from Harris et al., 1987).

Silica Occurrences of Saskatchewan

Quartz-rich pegmatite veins and/or quartzites of sufficient purity and economic accessibility are not known to exist in the province. This study is therefore restricted to the relatively abundant silica sand deposits that occur in the sedimentary basin of Saskatchewan.

Silica-rich, feldspar-deficient sedimentary deposits occur in four stratigraphic units: a) the Early Ordovician Winnipeg Formation; b) the basal section of the Early Cretaceous Mannville Group; c) the Late Cretaceous kaolinized Whitemud Formation; and d) the Late Tertiary Cypress Hills Formation.

Only the Whitemud Formation has not been investigated as a potential silica source. The Cypress Hills Formation is unique among these in that it is a quartzite conglomerate rather than a sand. Guliov (1975) had investigated it as a potential source of lump silica for use in ferrosilicon production.

Babey (1955), Collings (1953), and Pearson (1961) suggest that early Cretaceous sands of the basal Mannville Group constitute an important and relatively pure silica resource suitable for glass production or as foundry sands. Similar indications of the purity of the silica sands in the Winnipeg Formation are reported by Kupsch (1952), Chernoff (1955), and Waters (1977, 1978a and b). These sediments are exposed in several areas of the northern part of the Phanerozoic Basin of Saskatchewan.

This investigation and the subsequent Canada Centre for Mineral and Energy Technology (CANMET) funded market and metallurgical studies by I.M.D. Laboratories Ltd. (1992a and b, 1993) were initiated primarily in response to the perceived growing demand for industrial silica of higher grades, suitable for products such as silicon metal. The work is of a preliminary nature and only covers the larger outcrops of Early Cretaceous silica sand deposits along the Red Deer River east of the town of Hudson Bay and along the Nipekamew River, and the Ordovician Winnipeg Formation sands in the Hanson Lake area. Other occurrences of these sands, not investigated in the current study, include those of the Mannville Group outcropping on the Carrot River (Beck, 1974), on the Bow River (Hudson, 1961), on the south shore of Wapawekka Lake (Pearson, 1961), and at Beauval (Pearson, 1963). It is believed that other outcrops or shallow subcrops of Mannville Group silica sands exist in other parts of central Saskatchewan (Figure 2).

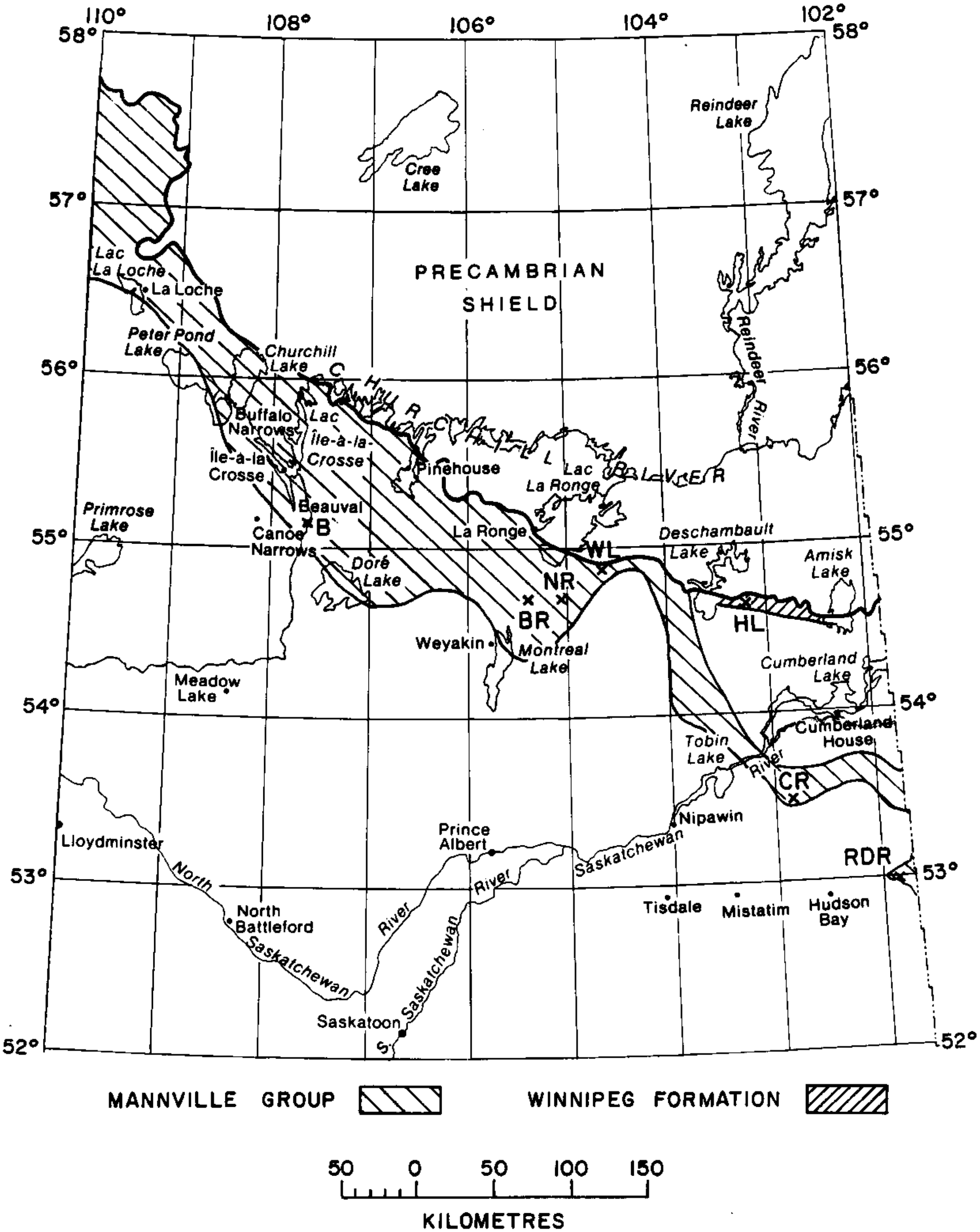

Figure 2 - Distribution of interpreted subcropping and known outcropping silica sands. B, Beauval; BR, Bow River; NR, Nipekamew River; WL, Wapawekka Lake; CR, Carrot River; RDR, Red Deer River of the Mannville Group; and HL, Hanson Lake area of the Winnipeg Formation, Saskatchewan.

Analytical Procedures

Sample Preparation

All samples were collected by trenching and averaged about 35 kg in weight. Many samples contained lumps of fine silt and clay as well as limonitic cemented nodules. Each sample was air-dried to facilitate sample blending and to minimize oxidation of any sulphides present. Any nodules and lumps present in the samples were broken up with plastic and wooden tools prior to homogenizing. Approximately 500 g of each sample was analysed for contaminants such as iron, alumina, titanium, etc. which are undesirable in the production of silicon metal and glass. The procedures were selected so that the analytical values obtained would represent the grades for a realistically feasible mining interval of a commercial operation that uses a single-stage, wet-screening process.

Granulometric and Chemical Analysis Procedures

Introduction

Analyses were conducted on portions of homogenized bulk sand samples from specific stratigraphic units.

The analytical procedures included the following:

1. sample preparation and grain size analyses of all samples,
2. chemical analysis of each size fraction constituting 5 percent or more of the original sample to determine the contaminant elements, and
3. silica content analysis to test the validity of using a silica content by "difference" model applied to the total of the contaminant elements measured.

Sample Preparation and Grain Size Analysis

The prime objectives of these procedures were to:

1. quantify contaminants by chemical analysis, and
2. determine the grain sizes in which the most significant quantities of contaminants occurred.

As a result, the sample preparation procedure minimized the use of metallic instruments for sieving, fracturing of coarse sand grains, and washing.

Pretreatment

Each sample was accurately weighed after drying at 105°C.

The entire sample was then soaked in distilled water for at least 12 hours prior to the grain size analysis to promote "wetting" of the silica/silicate grains. This assisted in dislodging the finer alumina-bearing particles during the wet screening process. An industrial screening operation would likely employ attrition scrubbing to remove more of the organic and alumina-bearing particles than was possible in the laboratory procedure.

Wet Screening

Each sample was passed through a dedicated set of 5, 10, 18, 35, 60, 120, and 200 U.S. Bureau of Mines standard size screens. The screens consisted of nylon (Nytex) bolt cloth set in plastic containers. The cloth was cut larger than required so that larger quantities of screened fractions were handled with minimum sample loss. Starting with the coarsest screen at the top of the set, the sample was washed generously with jets of distilled water and a nylon bristle brush. Large quantities of water were accumulated along with the minus 200 mesh fraction. After each fraction was screened, the discharged water was examined for fines. The subsequent stage was then processed in the same manner. Each screen with its contents was placed in a drying oven overnight. The wash water and minus 200 mesh portion were accumulated in large vessels and evaporated to dryness.

Each fraction was dried, weighed, and stored in kraft envelopes. To avoid contamination, no further sample preparation was carried out. The weight of the minus 200 mesh fraction was calculated by difference. The data are reported both as weight of individual fractions and percent weight of the total sample.

Chemical Analysis

All the fractions were analyzed for the following elements (contaminants) by the indicated techniques:

ICP Analysis for:	Al, Ba, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Ti, and Zr
Fusion, DCP and LECO analysis for:	B, C (Organic), S, and LOI
Gravimetric Analysis for:	SiO_2

In order to analyze the larger-sized particles and at the same time maintain a representative aliquot quantity from each fraction, larger aliquots were taken. Weights and volumes of the aliquots used are shown in Table 5.

Each of these aliquots was placed in a Teflon beaker and digested in $HF/HClO_4/HNO_3$ and then evaporated to dryness. Further digestion and evaporation were carried out after inspection of the residue to assure that the digestion was complete. The residue was dissolved in 10 percent HCl and brought up to final volume. The solution was then aspirated into an Inductively Coupled Argon Plasma (ICP) where the spectral intensities of the analysed species were compared to spectral intensities

Table 5 - Aliquot weights for size fractions subjected to ICP analysis.

Size Fraction	Weight of Aliquot (g)	Volume of Solution (ml)
+ 5	2.5	25
5 to 10	2.5	25
10 to 18	2.5	25
18 to 35	2.5	25
35 to 60	2.5	25
60 to 100	2.5	25
100 to 200	2.5	100
minus 200	2.5	250

of matrix-matched calibration standards. The concentrations of the elements (contaminants) were calculated by computer reduction.

Analyses for boron (B), sulphur (S), organic carbon (C), and loss on ignition (LOI) were carried out as shown in Table 6.

Only a selected suite of screened fractions were analyzed for SiO_2. The method, based on the Missouri or Bidtel technique of gravimetric determination of silica and silicates, is as follows:

1. An aliquot of the sample was weighed into a platinum crucible.
2. Sulphuric acid was added to the sample and evaporated to dryness to oxidize any alkali and base metal elements present.
3. The sample residue was ignited and then cooled in a desiccator. The crucible was then weighed to constant weight.
4. Hydrofluoric and sulphuric acids were added together to the residue to digest the silica. The silicon tetrafluoride produced along with excess HF are volatile and evaporate readily whereas the less volatile sulphuric acid was evaporated to dryness by increasing the temperature.
5. The crucible was heated to 1000°C, cooled in a desiccator, and weighed again to constant weight.
6. The silica content was computed from the difference in weight from the original weight of the aliquot.

Processing of Analytical Results

All cation contaminants detected were converted to simple oxides except for: zirconium which was calculated as being tied up in zircon ($ZrSiO_4$); iron as limonite ($FeO[OH]$); and aluminum as kaolin ($Al_4[Si_4O_{10}](OH)_8$) which was the most abundant cementing material present. Al_2O_3 and Fe_2O_3 were also calculated for reference to industry standards. The raw silica content was calculated as the difference in weight percentage of all contaminants calculated as oxides (excluding Al_2O_3 and Fe_2O_3) plus loss on ignition (LOI). Compensations were made for natural substitution of sulphur for oxygen with elements such as copper, nickel, or chrome. The dry silica content includes corrections for the presence of free water and carbon (LOI) to estimate the sand's kiln-dried silica content. All elements not detected (i.e. below detection limits) were assumed absent. Comparison of the calculated and gravimetric silica contents show that the calculated dry values very closely approximate the actual silica content. All calculated silica values were less than the analytically derived values. The method of calculating the silica content indicates the silica content is present as quartz and does not include any silicon present in contaminants which the analytical method does. The calculated method also does not compensate for any incomplete kaolinization of any feldspar grains present.

Table 6 - Analytical methods used for specific elements.

Element	Method
B	Fusion followed by Direct Coupled Plasma (DCP) analysis
S	LECO-Sulphur Dioxide Mode-Standard Technique
Org. C	LECO-Carbon Dioxide Mode
LOI	Furnace-weight loss at 1000°C

Heavy Mineral Separation and Analysis

The complete sections of the silica sand outcrops were tested for their heavy mineral content to identify major contaminants that might be readily separated. The silica sand was screened to minus 10 mesh to remove very coarse fractions that could not be processed with the shaker table and magstream separator.

The minus 10 mesh fractions were passed over a shaker table to acquire a preliminary heavy mineral concentrate from which all magnetic material was then removed. The non-magnetic concentrates were then put through a magstream separator (95 percent efficient) to collect all grains with a specific gravity (S.G.) greater than 3.0. The magstream reject material was then passed through tetrabromoethane (S.G. 2.9) to recover any other heavy minerals that might be present. This procedure was found to be relatively efficient but did not recover trace amounts of micas which 'floated off' during the shaker tabling. The recovered heavy minerals were separated into the same sieve fractions that were used for the granulometric and chemical analyses. These fractions were then analysed by proportional analysis of binary backscatter electron imagery to determine the relative proportions of the common heavy minerals present.

Filler Application Tests

A preliminary test of the minus 40 mesh fraction of waste material from the Red Deer Silica Inc. plant was submitted to CANMET for analysis of the optical properties as they relate to filler applications. Tests conducted by CANMET used a Data Colour Elrelripho 2000 Spectro-photometer and chemically precipitated magnesium oxide as a reference standard.

A 500 g sample of crushed minus 200 mesh fraction was used. Three sub-samples were prepared from this material: a raw fraction, a deslimed fraction, and a deslimed and magnetically separated fraction.

Silica Sands Of The Mannville Group: Hudson Bay Area

Location

Outcrops of white silica sand occur along the south bank of the Red Deer River in sections 15, 21, and 22, township 46, range 31, west of the first meridian. They are approximately 16 km north of the railway that services the town of Hudson Bay, located 40 km to the east. Access from Hudson Bay is by paved Highway 3 for 42 km eastward and 21 km northward on a gravel road into the Red Deer Silica Inc. quarry site. The area (Figure 2) is characterized by flat to gently rolling topography, forested with jackpine, and locally mantled by muskeg in low areas. The Red Deer River, flowing northeasterly, has steep banks that cut deeply into the silica sands.

Geologic Setting

The silica sand outcropping in this area is a well-sorted, fine-to coarse-grained marine beach sand, attributed to the Lower Cretaceous Mannville Group. Locally they are underlain by dolomitic limestones of the Middle Devonian Souris River Formation and to the south they are overlain by bentonites of the Joli Fou Formation. The sands in the region are of varying thickness. Twelve metres of section are exposed on the Red Deer River but up to 18.8 m have been intersected by drilling in the area. The DMR Armit well (NW6-32-44-30-W1), located 20 km to the south, intersected 18.6 m of Mannville sand. The Saskatchewan Research Council (SRC) Smoking Tent well (NW13-3-45-1-W2), located 25 km to the southwest, intersected 46.9 m of the same formation.

Sands in the exposed section are moderately consolidated with a kaolinitic cement. They grade normally from a coarse, cross-bedded sand at the base to a fine sand with common cross-bedding marked by the presence of silt and clay. Besides kaolin cement, the only visible accessory minerals found in the sand are coal fragments, mica, and local subhorizontal limonitic staining. The iron oxide stain is thought to be due to present and paleo-transient vadose groundwater and intermittent groundwater zones. The stained zones are, therefore, expected to be most common near the groundwater surface and in zones of coarse, permeable sands beneath more organic and sulfide-rich, finer-grained beds.

Previous Investigations

There are several reports describing the occurrence of silica sands along the Red Deer River. Most notable of these are by Worcester (1942), Babey (1955), Beck (1974), Collings (1953), Collings and Andrews (1986, 1989), and Quirt (1990). They have documented, to varying degrees, the extent, volume, grain size distribution, and chemical purity of these sands. In addition to its present use as a decorative sand for golf course sand traps, Murton (1946) has demonstrated its suitability for use as a foundry and moulding sand (except for core sand applications). Babey (1955) also reported similar results, and also suggested that these sands could be used as core sands. Beer (1947), Babey (1955), and Collings and Andrews (1986, 1989) reported that silica sand from this area would be suitable for use in manufacturing clear glass.

Investigations have been made by Red Deer Silica Inc., Northern Silica, Prairie Silica, Bruce Dunlop, and Hudson Bay Mining and Smelting Co. Ltd. who have held mineral leases for parts of this occurrence. Their studies have included: drilling-off of reserves; granulometric, chemical, and metallurgic analyses; and mine and mill planning. Only Red Deer Silica Inc. presently holds mineral leases in the area and is attempting to develop the deposit. Collings and Andrews (1989) stated that the Red Deer Silica Inc. deposit contains 14 million tonnes of sand grading 97 to 99 percent SiO_2.

Although the results achieved by earlier studies have been extremely encouraging, none of them have indicated the methods or degrees of accuracy of chemical analyses. They have, neither analysed the sands for all likely contaminants, nor indicated their vertical and lateral variations. This study supplements the earlier investigations with information on heavy mineral content, some filler application parameters, detailed chemistry, and some of the physical characteristics of the exposed sand sections.

Sampling Procedure

Samples were collected from the quarry face and a bluff on the Red Deer River, 1.5 km west of the pit operations. Prior to sampling, the outcrop faces were scraped clean to minimize the effects of leaching of kaolin cement, accumulation of dust, or preferential separation of grain sizes. All samples were taken by channelling the vertical face and were placed in 22 litre plastic containers. Where possible, cut glass and PVC sampling tools were used to avoid contamination by iron. This was unsuccessful due to the semi-consolidated nature of the sand and the rapid abrasion of these tools. Clean, unoxidized steel shovels were found to be the only effective hand excavation tools.

Eight samples from the working pit (Lat. 52° 58.65', Long. 101° 39.55') were collected over 1 m intervals from the surface of the exposed silica sand to a depth of 8 m. Six samples from the bluff (Lat. 52° 58.59', Long. 101° 45.07') were collected over 2 m intervals extending from the till-sand contact, 4 m below the top of the bluff, to the base of the exposed silica sands 16 m below the bluff top.

Analytical Results

Granulometry

The sieving results (Figures 3 and 4) indicate that both sections are well-sorted, fining upwards sequences. The

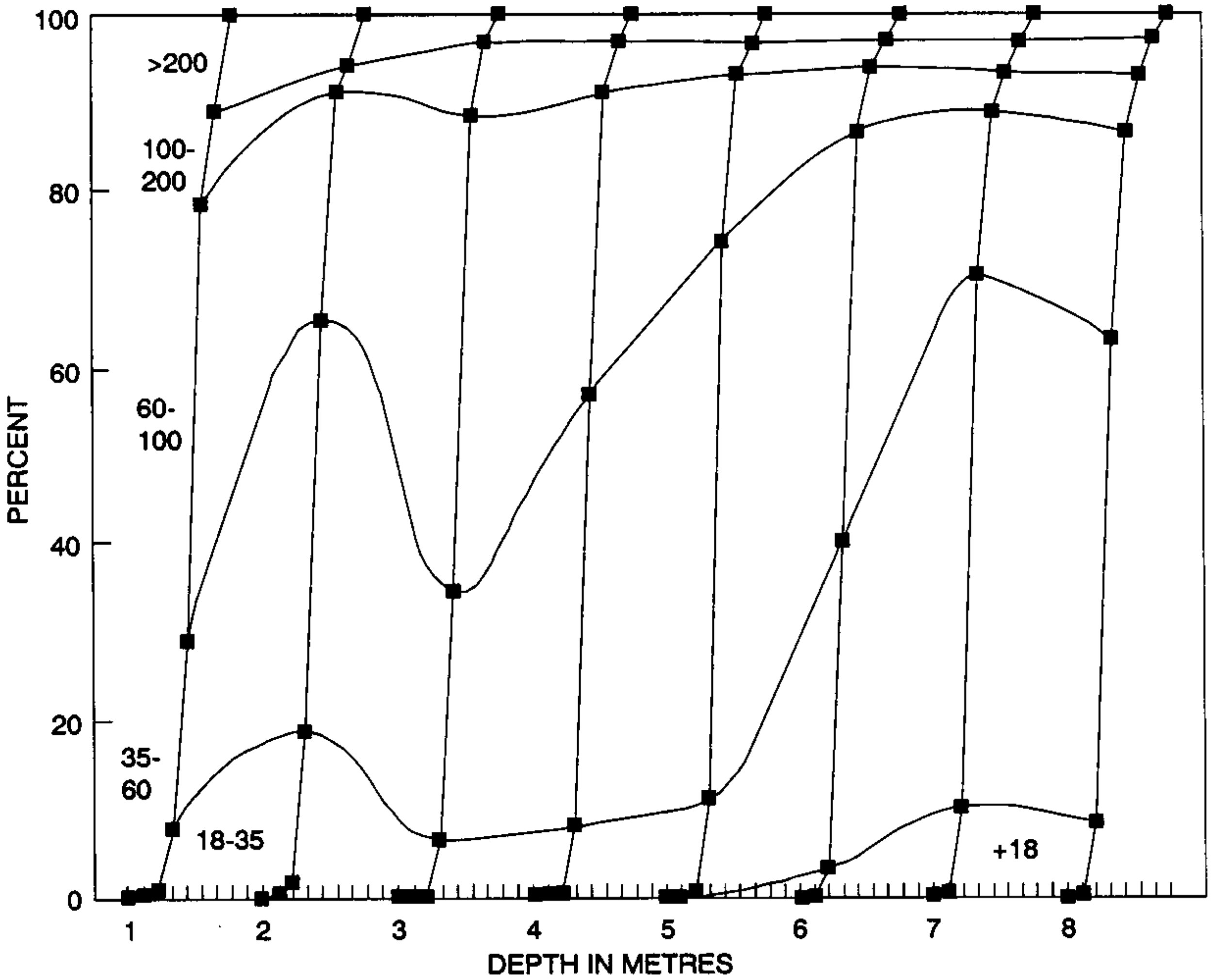

Figure 3 - Grain size distribution of the Mannville Group sands in the Red Deer Silica Inc. quarry, Saskatchewan.

sections match reasonably well stratigraphically on the basis of their granulometric distribution; however, the facies vary slightly based on differences in grain size distribution. Sands in the quarry section, especially at its base, have a coarser grain size than the bluff section and were likely deposited in a more active marine environment. The dramatic fining upwards transition of the river bluff section at the 8 to 10 m interval is noteworthy. A similar and probably contemporaneous, but much less pronounced, transition is present at the 3 to 6 m interval of the quarry section.

Chemical

The abundance of most contaminant elements in both sections varies inversely with grain size (Tables 7a, 7b, 8a, and 8b). In most cases there is a direct quantitative correlation between the clay fraction and the contaminant concentration (especially alumina and iron oxides). This suggests that kaolin is bonding the contaminants to the quartz grains and/or that a significant proportion of the contaminants are present as heavy minerals. Except for the alumina, carbon, and iron oxide contents, the wet screened >200 mesh fraction of these sands appears to meet the chemical specifications for most intermediate and some high tech silica sand applications.

Heavy Mineral Content

A sample weighing 17.40 kg from the Red Deer River outcrop was selected for processing. Of this, 0.05 kg (0.287 percent) was coarser than 10 mesh and eliminated from the processing procedure. The minus 10 mesh fractions were passed over a shaker table to acquire a heavy mineral concentrate, from which all magnetic material was then removed. A heavy mineral total of 15.953 g (0.092 percent) was recovered of which 0.028 g were magnetic minerals. Virtually all of the non-magnetic minerals recovered were from the 100 and 200 mesh fractions (47.5 percent and 48.7 percent respectively).

The plus 100 mesh heavy mineral fraction contained grains in the following proportions: rutile (56 percent), garnet (25 percent), and staurolite (12 percent). The

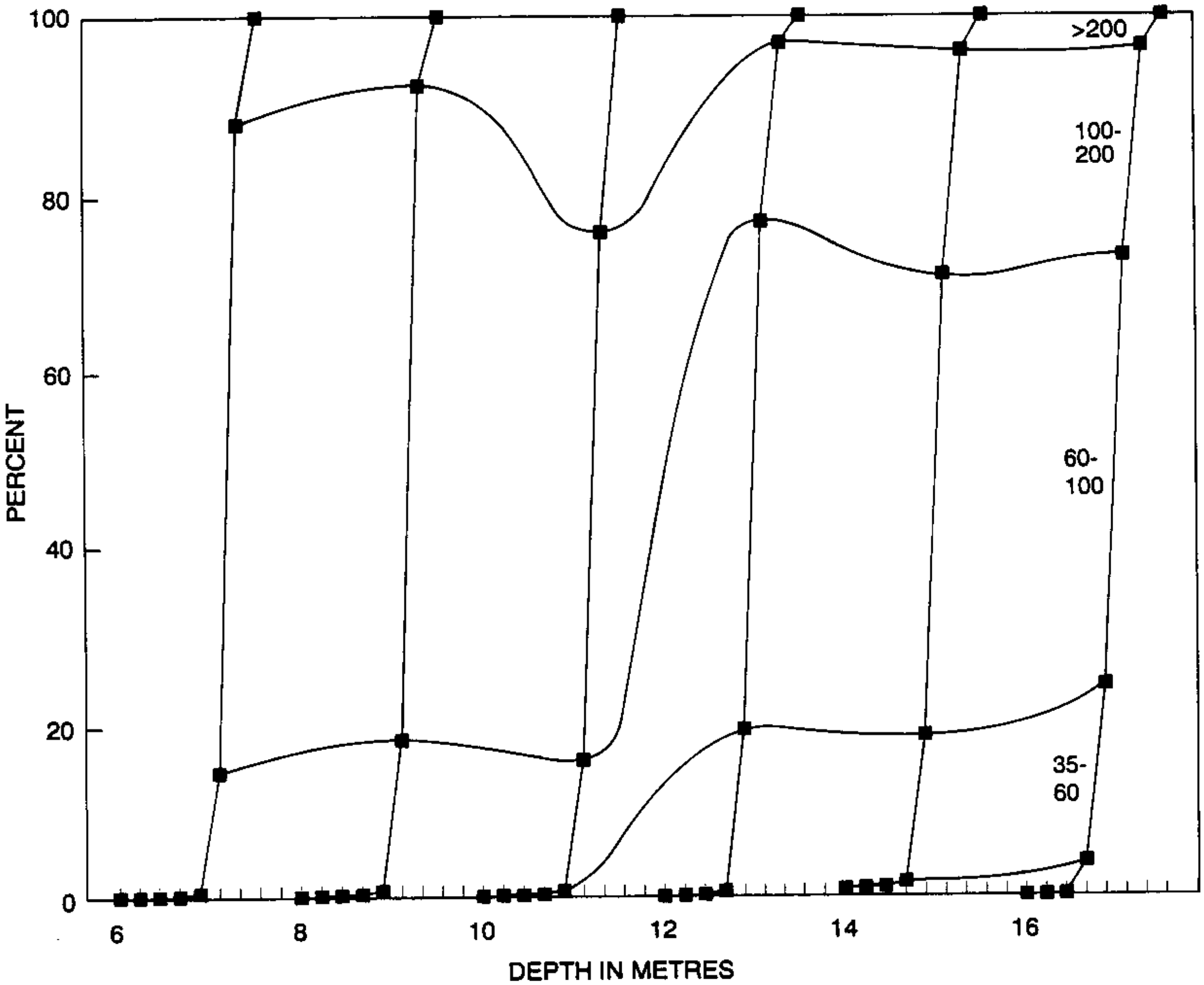

Figure 4 - Grain size distribution of the Mannville Group sands from a bluff section on the Red Deer River, Saskatchewan.

minus 100 mesh fraction contained zircon (51 percent) and rutile (42 percent) grains.

X-Ray Diffraction Results

Dr. Quirt of the SRC (pers. comm., 1991) has interpreted the results of X-ray diffraction analysis of two, minus 200 mesh fractions (presented in Table 9) as indicating that the samples are from *in situ* 'Swan River' (Mannville Group) sediments and are not reworked material. This is substantiated by the presence of carbonate in the samples which, if the sands had been reworked, would probably have been dissolved. The presence of fine-grained plagioclase feldspar suggests that some of the kaolin content is transported rather than authigenic. If the kaolin was formed *in situ*, the less stable plagioclase grains present in these samples would also have been altered. The intensely kaolinized nature of the coarser feldspar grains, which could not have undergone sedimentary transportation, and the absence of more stable potassium feldspar grains remains difficult to explain. However, the possibility of the kaolin or partially kaolinized feldspars having undergone sedimentary transportation implies the possibility of distal, deeper marine or lagoonal or back-levée equivalents of these sediments which may contain significant sections of kaolin with a much lower silica content.

Filler Brightness and Reflectance

Although not the best possible material, the sample tested provides an adequate indication of the sand's suitability for filler applications. The tests (Tables 10 to 13) show that these silica sands might be acceptable as a filler for products requiring excellent chemical stability and abrasion resistance (such as stuccos and skid proof paints).

The effect of attrition scrubbing of the grains prior to crushing was not tested, but it is anticipated that this would reduce the already low iron oxide content and thus further reduce the yellowness value. This process would also reduce or totally remove any carbon present and result in higher values than those obtained. Crushing of the sample to minus 400 or minus 600 mesh

Table 7a - Analyses of Mannville Group silica sands from the Red Deer Silica Inc. quarry, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	SiO_2 %	Al %	Fe %	Ca %	Mg %	Na %	K %	P %	Ti %	S %	C %	Mn ppm	Ba ppm	Co ppm	Cu ppm	Cr ppm	Ni ppm	Zr ppm	B ppm
0-1m	(+5)	0.0147																				
0-1m	(-5+10)	0.1151																				
0-1m	(-10+18)	0.4851																				
0-1m	(-18+35)	8.8211	<0.01		0.160	0.074	0.008	0.004	0.005	0.098	0.003	0.008	<0.01	0.08	1.0	23.9	<0.5	0.4	1.3	0.9	15.8	31
0-1m	(-35+60)	21.4220	<0.01		0.236	0.042	0.007	0.003	0.008	0.205	0.003	0.011	<0.01	0.08	1.0	47.0	<0.5	0.5	1.8	0.9	14.9	24
0-1m	(-60+100)	49.8568	0.20		0.143	0.029	0.006	0.003	0.004	0.093	0.002	0.015	<0.01	0.08	1.5	28.5	<0.5	0.5	1.8	0.7	9.6	25
0-1m	(-100+200)	10.3815	0.80		0.888	0.137	0.021	0.008	0.010	0.421	0.005	0.157	<0.01	0.20	19.2	104.8	<2.0	0.8	9.8	<2.0	50.0	39
0-1m	(-200)	10.9244	13.90		4.950	1.440	0.183	0.123	0.122	0.753	0.081	0.523	0.1	2.38	25.0	156.0	<5.0	13.0	111.0	29.0	322.0	84
1-2m	(+5)	0.0288																				
1-2m	(-5+10)	0.2098																				
1-2m	(-10+18)	1.1778																				
1-2m	(-18+35)	17.3899	0.10		0.172	0.106	0.015	0.008	0.005	0.085	0.006	0.009	<0.01	0.12	7.8	23.5	<0.5	0.8	1.8	0.8	18.6	30
1-2m	(-35+60)	46.8132	0.15		0.210	0.087	0.012	0.005	0.007	0.135	0.008	0.019	<0.01	<0.05	4.2	36.6	<0.5	0.7	2.0	1.1	16.3	24
1-2m	(-60+100)	25.8178	0.25		0.221	0.110	0.018	0.007	0.007	0.124	0.008	0.036	<0.01	<0.05	6.6	44.3	<0.5	0.6	2.7	0.8	15.0	27
1-2m	(-100+200)	3.0856	0.75		0.690	0.319	0.06	0.024	0.023	0.381	0.019	0.177	<0.01	0.24	28.0	136.0	<2.0	1.6	9.6	3.0	73.0	43
1-2m	(-200)	5.8695	10.90		9.220	2.270	0.373	0.228	0.125	1.030	0.133	0.581	0.1	1.64	58.0	248.0	<5.0	23.0	94.0	30.0	280.0	89
2-3m	(+5)	0.0073																				
2-3m	(-5+10)	0.0087																				
2-3m	(-10+18)	0.0642																				
2-3m	(-18+35)	8.3856	0.10		0.128	0.012	0.006	0.003	0.005	0.063	0.002	0.008	<0.01	<0.05	0.8	17.6	<0.5	0.3	1.3	0.7	15.8	36
2-3m	(-35+60)	28.4308	0.10		0.179	0.012	0.008	0.003	0.008	0.153	0.002	0.007	<0.01	<0.05	0.8	38.2	<0.5	0.5	1.2	0.9	14.6	23
2-3m	(-60+100)	53.6207	0.10		0.107	0.015	0.005	0.003	0.003	0.062	0.002	0.023	<0.01	<0.05	2.0	20.7	<0.5	0.4	1.8	0.8	9.0	28
2-3m	(-100+200)	8.4810	0.40		0.636	0.169	0.014	0.006	0.010	0.369	0.006	0.372	<0.01	0.16	48.0	94.1	<2.0	<0.4	16.3	<2.0	90.0	45
2-3m	(-200)	3.0216																				
3-4m	(+5)	0.0000																				
3-4m	(-5+10)	0.0000																				
3-4m	(-10+18)	0.0777																				
3-4m	(-18+35)	8.1943	<0.01		0.183	0.018	0.006	0.003	0.005	0.132	0.002	0.006	<0.01	<0.05	0.7	28.8	<0.5	0.3	1.4	0.7	18.8	30
3-4m	(-35+60)	48.8615	0.10		0.173	0.014	0.009	0.003	0.005	0.134	0.002	0.009	<0.01	<0.05	0.9	35.5	<0.5	0.5	1.4	0.8	15.9	28
3-4m	(-60+100)	34.1225	0.15		0.148	0.031	0.008	0.003	0.003	0.064	0.002	0.053	<0.01	<0.05	6.1	28.4	<0.5	0.3	4.0	0.9	14.5	26
3-4m	(-100+200)	5.4817	0.50		0.738	0.190	0.013	0.007	0.009	0.428	0.005	0.411	<0.01	0.16	51.2	105.0	<2.0	<0.4	18.5	3.0	70.0	39
3-4m	(-200)	3.2822																				

Table 7a (continued) - Analyses of Mannville Group silica sands from the Red Deer Silica Inc. quarry, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	SiO_2 %	Al %	Fe %	Ca %	Mg %	Na %	K %	P %	Ti %	S %	C %	Mn ppm	Ba ppm	Co ppm	Cu ppm	Cr ppm	Ni ppm	Zr ppm	B ppm
4-5m	(+5)	0.0000																				
4-5m	(-5+10)	0.0000																				
4-5m	(-10+18)	0.3901																				
4-5m	(-18+35)	10.5885	<0.01		0.175	0.013	0.011	0.003	0.005	0.115	0.002	0.007	<0.01	<0.05	0.8	32.1	<0.5	0.3	1.4	0.8	15.8	33
4-5m	(-35+60)	63.1988	0.10		0.134	0.014	0.007	0.003	0.003	0.079	0.002	0.009	<0.01	<0.05	1.0	25.3	<0.5	0.4	1.4	0.9	15.5	28
4-5m	(-60+100)	18.4805	0.20		0.150	0.027	0.006	0.003	0.003	0.083	0.002	0.048	<0.01	<0.05	4.7	28.1	<0.5	0.3	3.1	0.8	8.7	30
4-5m	(-100+200)	4.1583																				
4-5m	(-200)	3.2250																				
5-6m	(+5)	0.0000																				
5-6m	(-5+10)	0.0368																				
5-6m	(-10+18)	2.9472																				
5-6m	(-18+35)	37.4512	<0.01		0.122	0.012	0.005	0.002	0.003	0.076	0.002	0.008	<0.01	<0.05	0.8	19.8	<0.5	0.3	1.3	0.6	18.5	22
5-6m	(-35+60)	46.4530	0.10		0.138	0.019	0.006	0.003	0.004	0.094	0.002	0.025	<0.01	<0.05	2.1	27.3	<0.5	0.4	2.9	0.9	17.6	24
5-6m	(-60+100)	6.8243	0.20		0.259	0.048	0.006	0.003	0.005	0.139	0.002	0.084	<0.01	<0.05	9.6	38.1	<0.5	0.2	5.4	1.1	13.2	27
5-6m	(-100+200)	3.4115																				
5-6m	(-200)	2.8759																				
6-7m	(+5)	0.0466																				
6-7m	(-5+10)	0.2575																				
6-7m	(-10+18)	9.8494	<0.01	99.3	0.194	0.031	0.007	0.003	0.006	0.119	0.002	0.007	<0.01	<0.05	0.7	28.6	<0.5	0.1	1.7	0.5	15.5	15
6-7m	(-18+35)	60.2948	<0.01	99.31	0.150	0.025	0.006	0.003	0.004	0.077	0.002	0.008	<0.01	<0.05	0.8	20.4	<0.5	0.3	1.7	0.6	17.1	27
6-7m	(-35+60)	17.9473	<0.01	99.26	0.161	0.034	0.006	0.003	0.004	0.084	0.003	0.015	<0.01	<0.05	1.7	25.7	<0.5	0.5	2.4	1.0	18.0	24
6-7m	(-60+100)	4.7882	0.35	98.19	0.393	0.082	0.012	0.005	0.008	0.193	0.003	0.056	<0.01	0.08	6.0	49.9	<0.5	0.4	5.4	1.2	12.7	30
6-7m	(-100+200)	3.7512																				
6-7m	(-200)	3.0649																				
7-8m	(+5)	0.0435																				
7-8m	(-5+10)	0.2014																				
7-8m	(-10+18)	8.3006	<0.01		0.191	0.099	0.009	0.004	0.005	0.104	0.003	0.010	<0.01	<0.05	1.1	20.2	<0.5	0.3	2.5	0.8	18.9	14
7-8m	(-18+35)	54.3561	<0.01		0.176	0.074	0.007	0.003	0.004	0.097	0.003	0.008	<0.01	<0.05	0.9	27.0	<0.5	0.4	2.1	0.9	20.1	25
7-8m	(-35+60)	23.2085	0.15		0.180	0.083	0.008	0.004	0.004	0.084	0.004	0.012	<0.01	<0.05	0.9	25.9	<0.5	0.5	3.3	1.0	18.1	28
7-8m	(-60+100)	8.7804	0.25		0.339	0.137	0.013	0.005	0.006	0.160	0.004	0.045	<0.01	0.08	4.5	43.5	<0.5	0.5	5.8	1.1	19.8	27
7-8m	(-100+200)	4.2868																				
7-8m	(-200)	2.8426																				

Table 7b - Calculated oxides and some measured silica values of Mannville Group silica sands from the Red Deer Silica Inc. quarry, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	kaolin %	Al_2O_3 %	Fe_2O_3 %	FeO(OH) %	CaO %	MgO %	Na_2O %	K_2O %	P_2O_5 %	TiO_2 %	C %	S %	MnO %	BaO %	Co_2O_3 %	CuO %	Cr_2O_3 %	NiO %	$ZrSiO_4$ %	B_2O_3 %	raw SiO_2 %	dry SiO_2 %	SiO_2 (grav.) %
0-1m	(+5)	0.0147																								
0-1m	(-5+10)	0.1151																								
0-1m	(-10+18)	0.4851																								
0-1m	(-18+35)	6.8211	0.00	0.7654	0.3023	0.1058	0.1177	0.0112	0.0098	0.0087	0.1161	0.0068	0.0133	0.06	0.00	0.0001	0.0027	0.0000	0.0001	0.0002	0.0001	0.0031	0.0100	98.858	98.937	
0-1m	(-35+60)	21.4220	0.00	1.1366	0.4497	0.0800	0.0866	0.0098	0.0050	0.0081	0.2468	0.0068	0.0183	0.06	0.00	0.0001	0.0053	0.0000	0.0001	0.0002	0.0001	0.0030	0.0077	98.403	98.482	
0-1m	(-60+100)	49.8558	0.20	0.6841	0.2702	0.0415	0.0461	0.0064	0.0050	0.0064	0.1120	0.0048	0.0250	0.06	0.00	0.0002	0.0032	0.0000	0.0001	0.0003	0.0001	0.0018	0.0061	99.018	99.294	
0-1m	(-100+200)	10.3615	0.60	3.2813	1.3000	0.1958	0.2179	0.0294	0.0148	0.0136	0.5071	0.0115	0.2818	0.20	0.00	0.0025	0.0118	0.0000	0.0001	0.0014	0.0000	0.0100	0.0126	95.414	96.184	
0-1m	(-200)	10.9244	13.80	23.6603	9.3530	2.0586	2.2909	0.2581	0.2040	0.1645	0.8071	0.1856	0.8724	2.36	0.10	0.0032	0.0175	0.0000	0.0016	0.0182	0.0037	0.0847	0.0270	69.865	82.273	
1-2m	(+5)	0.0288																								
1-2m	(-5+10)	0.2098																								
1-2m	(-10+18)	1.1778																								
1-2m	(-18+35)	17.3680	0.10	0.8226	0.3250	0.1501	0.1670	0.0210	0.0098	0.0067	0.1024	0.0183	0.0150	0.12	0.00	0.0010	0.0026	0.0000	0.0001	0.0002	0.0001	0.0037	0.0097	98.888	98.917	
1-2m	(-35+60)	46.6132	0.15	1.0046	0.3968	0.0956	0.1066	0.0168	0.0083	0.0084	0.1626	0.0137	0.0317	0.00	0.00	0.0005	0.0043	0.0000	0.0001	0.0003	0.0001	0.0033	0.0077	98.638	98.778	
1-2m	(-60+100)	25.6176	0.25	1.0572	0.4178	0.1573	0.1750	0.0252	0.0116	0.0084	0.1494	0.0137	0.0584	0.00	0.00	0.0008	0.0050	0.0000	0.0001	0.0004	0.0001	0.0030	0.0087	98.482	98.729	
1-2m	(-100+200)	3.0956	0.75	3.3008	1.3038	0.4561	0.5075	0.0840	0.0398	0.0310	0.4580	0.0435	0.2952	0.24	0.00	0.0034	0.0152	0.0000	0.0002	0.0014	0.0004	0.0147	0.0138	94.950	95.899	
1-2m	(-200)	5.6895	10.80	44.1076	17.4212	3.2456	3.6113	0.5218	0.3781	0.1886	1.2407	0.3046	0.9856	1.84	0.10	0.0078	0.0279	0.0000	0.0028	0.0137	0.0038	0.0083	0.0287	48.850	53.868	
2-3m	(+5)	0.0073																								
2-3m	(-5+10)	0.0087																								
2-3m	(-10+18)	0.0842																								
2-3m	(-18+35)	6.3656	0.10	0.6028	0.2381	0.0172	0.0191	0.0084	0.0050	0.0067	0.1000	0.0046	0.0100	0.00	0.00	0.0001	0.0030	0.0000	0.0000	0.0002	0.0001	0.0031	0.0118	99.228	99.326	
2-3m	(-35+60)	28.4308	0.10	0.8563	0.3382	0.0172	0.0191	0.0084	0.0050	0.0081	0.1843	0.0046	0.0117	0.00	0.00	0.0001	0.0041	0.0000	0.0001	0.0002	0.0001	0.0028	0.0074	98.898	98.987	
2-3m	(-60+100)	53.8207	0.10	0.5118	0.2022	0.0214	0.0238	0.0070	0.0050	0.0040	0.0747	0.0046	0.0384	0.00	0.00	0.0003	0.0023	0.0000	0.0001	0.0002	0.0001	0.0018	0.0084	99.317	99.417	
2-3m	(-100+200)	8.4810	0.40	3.0428	1.2017	0.2416	0.2689	0.0198	0.0098	0.0136	0.4445	0.0137	0.8205	0.16	0.00	0.0082	0.0108	0.0000	0.0000	0.0024	0.0000	0.0181	0.0145	95.356	95.882	
2-3m	(-200)	3.0216																								
3-4m	(+5)	0.0000																								
3-4m	(-5+10)	0.0000																								
3-4m	(-10+18)	0.0777																								
3-4m	(-18+35)	6.1843	0.00	0.8755	0.3458	0.0228	0.0256	0.0084	0.0050	0.0087	0.1580	0.0046	0.0100	0.00	0.00	0.0001	0.0032	0.0000	0.0000	0.0002	0.0001	0.0033	0.0087	98.888	98.989	
3-4m	(-35+60)	48.8615	0.10	0.8276	0.3268	0.0200	0.0223	0.0084	0.0050	0.0087	0.1614	0.0046	0.0150	0.00	0.00	0.0001	0.0040	0.0000	0.0001	0.0002	0.0001	0.0032	0.0084	98.933	99.032	
3-4m	(-60+100)	34.1225	0.15	0.6984	0.2758	0.0443	0.0493	0.0084	0.0050	0.0040	0.1012	0.0046	0.0884	0.00	0.00	0.0006	0.0030	0.0000	0.0000	0.0008	0.0001	0.0028	0.0084	99.025	99.174	
3-4m	(-100+200)	5.4617	0.50	3.5306	1.3945	0.2716	0.3023	0.0182	0.0118	0.0121	0.5132	0.0115	0.6856	0.16	0.00	0.0069	0.0118	0.0000	0.0000	0.0027	0.0004	0.0141	0.0126	94.707	95.338	
3-4m	(-200)	3.2822																								
4-5m	(+5)	0.0000																								
4-5m	(-5+10)	0.0000																								
4-5m	(-10+18)	0.3801																								
4-5m	(-18+35)	10.5685	0.00	0.8372	0.3307	0.0188	0.0207	0.0154	0.0050	0.0067	0.1386	0.0046	0.0117	0.00	0.00	0.0001	0.0038	0.0000	0.0000	0.0002	0.0001	0.0032	0.0108	98.942	98.942	
4-5m	(-35+60)	63.1988	0.10	0.6410	0.2532	0.0200	0.0223	0.0098	0.0050	0.0040	0.0852	0.0046	0.0150	0.00	0.00	0.0001	0.0026	0.0000	0.0001	0.0002	0.0001	0.0031	0.0084	99.188	99.286	
4-5m	(-60+100)	18.4805	0.20	0.7178	0.2834	0.0388	0.0430	0.0084	0.0050	0.0040	0.1000	0.0046	0.0767	0.00	0.00	0.0006	0.0029	0.0000	0.0000	0.0006	0.0001	0.0018	0.0087	99.025	99.223	
4-5m	(-100+200)	4.1583																								
4-5m	(-200)	3.2256																								

Table 7b (continued) - Calculated oxides and some measured silica values of Mannville Group silica sands from the Red Deer Silica Inc. quarry, Saskatchewan.

Depth	Sieve	Sample	LOI	kaolin	Al_2O_3	Fe_2O_3	FeO(OH)	CaO	MgO	Na_2O	K_2O	P_2O_5	TiO_2	C	S	MnO	BaO	Ce_2O_3	CuO	Cr_2O_3	NiO	$ZrSiO_4$	B_2O_3	raw SiO_2	dry SiO_2	SiO_2 (grav.)
Interval	Fraction	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
5-6m	(+5)	0.0000																								
5-6m	(-5+10)	0.0366																								
5-6m	(-10+18)	2.9472																								
5-6m	(-18+35)	37.4512	0.00	0.5836	0.2305	0.0172	0.0181	0.0070	0.0033	0.0040	0.0915	0.0046	0.0100	0.00	0.00	0.0001	0.0022	0.0000	0.0000	0.0002	0.0001	0.0033	0.0071	99.264	99.264	
5-6m	(-35+60)	46.4530	0.10	0.6602	0.2808	0.0272	0.0302	0.0084	0.0050	0.0054	0.1132	0.0046	0.0417	0.00	0.00	0.0003	0.0031	0.0000	0.0001	0.0004	0.0001	0.0036	0.0077	99.116	99.215	
5-6m	(-60+100)	6.8243	0.20	1.2380	0.4884	0.0866	0.0784	0.0084	0.0050	0.0067	0.1874	0.0046	0.1401	0.00	0.00	0.0012	0.0043	0.0000	0.0000	0.0008	0.0001	0.0027	0.0087	98.335	98.532	
5-6m	(-100+200)	3.4115																								
5-6m	(-200)	2.8758																								
6-7m	(+5)	0.0486																								
6-7m	(-5+10)	0.2575																								
6-7m	(-10+18)	9.8494	0.00	0.9281	0.3686	0.0443	0.0483	0.0098	0.0050	0.0061	0.1433	0.0046	0.0117	0.00	0.00	0.0001	0.0032	0.0000	0.0000	0.0002	0.0001	0.0031	0.0048	98.829	98.829	99.30
6-7m	(-18+35)	60.2948	0.00	0.7176	0.2834	0.0357	0.0386	0.0084	0.0050	0.0054	0.0828	0.0046	0.0133	0.00	0.00	0.0001	0.0023	0.0000	0.0000	0.0002	0.0001	0.0034	0.0087	99.098	99.098	99.31
6-7m	(-35+60)	17.8473	0.00	0.7702	0.3042	0.0486	0.0541	0.0112	0.0050	0.0054	0.1012	0.0069	0.0250	0.00	0.00	0.0002	0.0028	0.0000	0.0001	0.0004	0.0001	0.0032	0.0077	99.008	99.008	99.26
6-7m	(-60+100)	4.7862	0.35	1.8801	0.7428	0.1172	0.1306	0.0168	0.0063	0.0061	0.2325	0.0069	0.0817	0.08	0.00	0.0008	0.0056	0.0000	0.0001	0.0006	0.0002	0.0039	0.0087	97.528	97.847	98.18
6-7m	(-100+200)	3.7512																								
6-7m	(-200)	3.0848																								
7-8m	(+5)	0.0435																								
7-8m	(-5+10)	0.2014																								
7-8m	(-10+18)	8.3008	0.00	0.9137	0.3809	0.1415	0.1575	0.0126	0.0066	0.0067	0.1253	0.0069	0.0167	0.00	0.00	0.0001	0.0023	0.0000	0.0000	0.0004	0.0001	0.0038	0.0045	98.743	98.743	
7-8m	(-18+35)	54.3581	0.00	0.8420	0.3326	0.1054	0.1177	0.0098	0.0050	0.0054	0.1164	0.0069	0.0133	0.00	0.00	0.0001	0.0030	0.0000	0.0001	0.0003	0.0001	0.0040	0.0081	98.887	98.887	
7-8m	(-35+60)	23.2085	0.15	0.8611	0.3401	0.1187	0.1320	0.0126	0.0066	0.0054	0.1012	0.0082	0.0200	0.00	0.00	0.0001	0.0029	0.0000	0.0001	0.0005	0.0001	0.0032	0.0084	98.837	98.985	
7-8m	(-60+100)	6.7804	0.25	1.8217	0.8405	0.1958	0.2179	0.0142	0.0083	0.0081	0.1827	0.0082	0.0751	0.08	0.00	0.0006	0.0049	0.0000	0.0001	0.0008	0.0001	0.0039	0.0087	97.750	98.073	
7-8m	(-100+200)	4.2868																								
7-8m	(-200)	2.8426																								

Table 8a - Analyses of Mannville Group silica sands from a bluff section on the Red Deer River, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	SiO_2 %	Al %	Fe %	Ca %	Mg %	Na %	K %	P %	Ti %	S %	C %	Mn ppm	Ba ppm	Co ppm	Cu ppm	Cr ppm	Ni ppm	Zr ppm	B ppm
4-6m	(+5)	0.0623																				
4-6m	(-5+10)	0.0166																				
4-6m	(-10+18)	0.0181																				
4-6m	(-18+35)	0.0606																				
4-6m	(-35+60)	0.3056																				
4-6m	(-60+100)	13.7310	0.45		0.694	0.030	0.025	0.005	0.011	0.372	0.002	0.020	<0.01	0.06	2.8	83.8	<0.5	0.8	2.8	2.2	10.8	24
4-6m	(-100+200)	73.8163	0.25		0.373	0.087	0.021	0.005	0.004	0.149	0.004	0.169	<0.01	0.16	28.5	53.0	<2.0	0.8	7.8	<2.0	75.0	32
4-6m	(-200)	12.1875	6.85		8.470	0.798	0.478	0.205	0.049	0.527	0.033	0.643	0.01	0.32	63.0	141.0	<5.0	18.0	83.0	46.0	504.0	75
6-8m	(+5)	0.0557																				
6-8m	(-5+10)	0.0940																				
6-8m	(-10+18)	0.0466																				
6-8m	(-18+35)	0.0992																				
6-8m	(-35+60)	0.3973																				
6-8m	(-60+100)	17.1536	0.35		0.569	0.045	0.019	0.004	0.011	0.311	0.002	0.017	<0.01	0.08	1.9	86.8	<0.5	0.7	2.4	2.1	11.9	24
6-8m	(-100+200)	74.2875	0.15		0.327	0.074	0.012	0.004	0.004	0.143	0.003	0.136	<0.01	0.08	21.1	50.0	<2.0	0.8	4.8	<2.0	46.0	32
6-8m	(-200)	7.8861	7.00		8.290	0.882	0.309	0.127	0.050	0.541	0.036	0.857	0.03	1.48	82.0	153.0	<5.0	13.0	79.0	42.0	651.0	91
8-10m	(+5)	0.0461																				
8-10m	(-5+10)	0.0747																				
8-10m	(-10+18)	0.0692																				
8-10m	(-18+35)	0.1103																				
8-10m	(-35+60)	0.3798																				
8-10m	(-60+100)	14.8703	0.35		0.671	0.037	0.039	0.009	0.014	0.356	0.002	0.016	<0.01	0.12	2.4	92.4	<0.5	0.7	2.7	2.1	10.4	23
8-10m	(-100+200)	59.9290	0.20		0.378	0.089	0.027	0.009	0.006	0.157	0.004	0.175	<0.01	0.12	29.1	57.7	<2.0	0.7	7.0	<2.0	79.0	28
8-10m	(-200)	24.5204	8.15		3.710	0.483	0.575	0.242	0.039	0.379	0.025	0.488	0.02	0.80	73.0	117.0	<5.0	4.0	41.0	19.0	564.0	73
10-12m	(+5)	0.0000																				
10-12m	(-5+10)	0.0690																				
10-12m	(-10+18)	0.0776																				
10-12m	(-18+35)	0.3961																				
10-12m	(-35+60)	18.4187	0.15	98.98	0.276	0.038	0.031	0.011	0.009	0.219	0.002	0.009	<0.01	<0.05	2.4	54.3	<0.5	0.5	1.6	1.1	16.3	25
10-12m	(-60+100)	57.7310	0.20	99.17	0.180	0.029	0.011	0.004	0.004	0.103	0.002	0.020	<0.01	<0.05	3.1	31.1	<0.5	0.5	1.7	1.1	9.5	26
10-12m	(-100+200)	20.1629	0.25	97.67	0.353	0.092	0.034	0.012	0.010	0.166	0.004	0.162	<0.01	0.08	24.9	52.6	<2.0	0.6	7.1	<2.0	56.0	43
10-12m	(-200)	3.1048																				
12-14m	(+5)	0.7752																				
12-14m	(-5+10)	0.1235																				
12-14m	(-10+18)	0.1494																				
12-14m	(-18+35)	0.5333																				
12-14m	(-35+60)	16.6639	0.25		0.332	0.039	0.082	0.027	0.015	0.244	0.002	0.010	<0.01	<0.05	4.9	57.9	<0.5	0.7	1.9	1.5	15.2	25
12-14m	(-60+100)	52.3885	0.15		0.199	0.032	0.021	0.008	0.005	0.106	0.002	0.018	<0.01	<0.05	3.3	30.5	<0.5	0.7	2.0	1.2	9.6	30
12-14m	(-100+200)	25.3892	0.30		0.357	0.171	0.081	0.029	0.016	0.147	0.007	0.312	<0.01	0.12	52.7	54.0	<2.0	0.7	10.2	3.0	103.0	46
12-14m	(-200)	3.9849																				

Table 8a (continued) - Analyses of Mannville Group silica sands from a bluff section on the Red Deer River, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	SiO_2 %	Al %	Fe %	Ca %	Mg %	Na %	K %	P %	Ti %	S %	C %	Mn ppm	Ba ppm	Co ppm	Cu ppm	Cr ppm	Ni ppm	Zr ppm	B ppm
14-16m	(+5)	0.0000																				
14-16m	(-5+10)	0.0574																				
14-16m	(-10+18)	0.1050																				
14-16m	(-18+35)	3.8014																				
14-16m	(-35+60)	20.0124	0.15		0.277	0.025	0.018	0.007	0.007	0.197	0.002	0.018	<0.01	<0.05	2.1	48.3	<0.5	0.7	1.9	1.3	14.4	25
14-16m	(-60+100)	48.8032	0.15		0.204	0.024	0.008	0.004	0.004	0.115	0.002	0.022	<0.01	<0.05	2.7	33.4	<0.5	0.8	1.8	1.0	10.9	28
14-16m	(-100+200)	23.6849	0.20		0.324	0.085	0.015	0.008	0.008	0.141	0.003	0.158	<0.01	0.12	18.8	47.8	<2.0	1.0	8.0	<2.0	41.0	42
14-16m	(-200)	3.5358																				

Table 8b - Calculated oxides and some measured silica values of Mannville Group silica sands from a bluff section on the Red Deer River, Saskatchewan.

Depth Interval	Sieve Fraction	Sample	LOI	kaolin	Al_2O_3	Fe_2O_3	FeO(OH)	CaO	MgO	Na_2O	K_2O	P_2O_5	TiO_2	C	S	MnO	BaO	Co_2O_3	CuO	Cr_2O_3	NiO	$ZrSiO_4$	B_2O_3	raw SiO_2	dry SiO_2	SiO_2 (grav.)
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
4-6m	(+5)	0.0823																								
4-6m	(-5+10)	0.0186																								
4-6m	(-10+18)	0.0161																								
4-6m	(-18+35)	0.0806																								
4-6m	(-35+60)	0.3088																								
4-6m	(-60+100)	13.7310	0.45	3.3200	1.3113	0.0429	0.0477	0.0360	0.0083	0.0148	0.4481	0.0046	0.0334	0.06	0.00	0.0003	0.0084	0.0000	0.0001	0.0004	0.0003	0.0021	0.0077	95.886	96.489	
4-6m	(-100+200)	73.6183	0.25	1.7844	0.7048	0.1244	0.1384	0.0294	0.0083	0.0054	0.1795	0.0082	0.2619	0.16	0.00	0.0037	0.0058	0.0000	0.0001	0.0011	0.0000	0.0151	0.0103	97.387	97.768	
4-6m	(-200)	12.1875	6.85	40.5186	16.0041	1.1409	1.2895	0.0698	0.3369	0.0881	0.8348	0.0756	1.0726	0.32	0.01	0.0081	0.0158	0.0000	0.0020	0.0121	0.0058	0.1013	0.0242	54.858	58.098	
6-8m	(+5)	0.0567																								
6-8m	(-5+10)	0.0840																								
6-8m	(-10+18)	0.0488																								
6-8m	(-18+35)	0.0892																								
6-8m	(-35+60)	0.2873																								
6-8m	(-60+100)	17.1538	0.35	2.7220	1.0751	0.0843	0.0716	0.0288	0.0088	0.0148	0.3748	0.0046	0.0284	0.08	0.00	0.0002	0.0087	0.0000	0.0001	0.0004	0.0003	0.0024	0.0077	96.800	97.087	
6-8m	(-100+200)	74.2875	0.15	1.5643	0.6178	0.1056	0.1177	0.0168	0.0088	0.0054	0.1723	0.0089	0.2302	0.08	0.00	0.0027	0.0058	0.0000	0.0001	0.0007	0.0000	0.0080	0.0103	97.771	97.987	
6-8m	(-200)	7.8861	7.00	38.6585	15.8840	1.2810	1.4031	0.4324	0.2108	0.0874	0.8517	0.0825	1.0858	1.48	0.03	0.0080	0.0171	0.0000	0.0018	0.0115	0.0053	0.1308	0.0283	54.698	58.767	
8-10m	(+5)	0.0461																								
8-10m	(-5+10)	0.0747																								
8-10m	(-10+18)	0.0892																								
8-10m	(-18+35)	0.1103																								
8-10m	(-35+60)	0.3798																								
8-10m	(-60+100)	14.8703	0.35	3.2100	1.2879	0.0529	0.0589	0.0546	0.0149	0.0189	0.4312	0.0046	0.0287	0.12	0.00	0.0003	0.0103	0.0000	0.0001	0.0004	0.0003	0.0021	0.0074	96.038	96.483	
8-10m	(-100+200)	59.9290	0.20	1.8083	0.7142	0.1272	0.1416	0.0376	0.0149	0.0081	0.1891	0.0082	0.2916	0.12	0.00	0.0036	0.0085	0.0000	0.0001	0.0010	0.0000	0.0158	0.0080	97.343	97.686	
8-10m	(-200)	24.5204	6.15	17.7463	7.0100	0.8906	0.7884	0.8045	0.4013	0.0526	0.4565	0.0573	0.6140	0.80	0.02	0.0094	0.0131	0.0000	0.0005	0.0080	0.0024	0.1173	0.0236	78.115	83.769	
10-12m	(+5)	0.0000																								
10-12m	(-5+10)	0.0690																								
10-12m	(-10+18)	0.0776																								
10-12m	(-18+35)	0.3861																								
10-12m	(-35+60)	18.4187	0.15	1.3204	0.5215	0.0515	0.0573	0.0434	0.0182	0.0121	0.2836	0.0046	-0.0150	0.00	0.00	0.0003	0.0061	0.0000	0.0001	0.0002	0.0001	0.0033	0.0061	96.247	96.395	98.86
10-12m	(-60+100)	57.7310	0.20	0.8611	0.3401	0.0415	0.0461	0.0154	0.0086	0.0054	0.1241	0.0046	0.0334	0.00	0.00	0.0004	0.0035	0.0000	0.0001	0.0002	0.0001	0.0016	0.0080	98.888	99.088	99.17
10-12m	(-100+200)	20.1829	0.25	1.6687	0.6870	0.1315	0.1464	0.0476	0.0198	0.0135	0.2000	0.0092	0.2702	0.06	0.00	0.0032	0.0058	0.0000	0.0001	0.0010	0.0000	0.0113	0.0136	97.488	97.812	97.67
10-12m	(-200)	3.1048																								
12-14m	(+5)	0.7752																								
12-14m	(-5+10)	0.1235																								
12-14m	(-10+18)	0.1494																								
12-14m	(-18+35)	0.5333																								
12-14m	(-35+60)	18.6839	0.25	1.5883	0.6273	0.0566	0.0620	0.1147	0.0446	0.0202	0.2839	0.0046	0.0187	0.00	0.00	0.0008	0.0085	0.0000	0.0001	0.0003	0.0002	0.0031	0.0081	97.836	98.061	
12-14m	(-60+100)	52.3885	0.15	0.9520	0.3760	0.0456	0.0509	0.0294	0.0133	0.0067	0.1277	0.0046	0.0300	0.00	0.00	0.0004	0.0034	0.0000	0.0001	0.0003	0.0002	0.0020	0.0097	98.799	98.918	
12-14m	(-100+200)	25.3892	0.30	1.7079	0.6746	0.2445	0.2720	0.1133	0.0451	0.0216	0.1771	0.0160	0.5204	0.12	0.00	0.0058	0.0080	0.0000	0.0001	0.0015	0.0004	0.0207	0.0146	96.953	97.382	
12-14m	(-200)	3.9889																								
14-16m	(+5)	0.0000																								
14-16m	(-5+10)	0.0574																								
14-16m	(-10+18)	0.1050																								
14-16m	(-18+35)	3.8014																								
14-16m	(-35+60)	20.0124	0.15	1.3251	0.5234	0.0357	0.0398	0.0224	0.0116	0.0084	0.2373	0.0046	0.0287	0.00	0.00	0.0003	0.0054	0.0000	0.0001	0.0003	0.0002	0.0038	0.0081	96.308	96.454	
14-16m	(-60+100)	48.8032	0.15	0.9759	0.3656	0.0343	0.0362	0.0112	0.0088	0.0054	0.1385	0.0046	0.0387	0.00	0.00	0.0003	0.0037	0.0000	0.0001	0.0003	0.0001	0.0022	0.0080	98.767	98.815	
14-16m	(-100+200)	23.6848	0.20	1.5500	0.6122	0.1358	0.1511	0.0210	0.0088	0.0081	0.1688	0.0089	0.2852	0.12	0.00	0.0028	0.0053	0.0000	0.0001	0.0009	0.0000	0.0082	0.0135	97.867	97.981	
14-16m	(-200)	3.5354																								

would have improved the values measured, but was not considered necessary at this time.

The raw sample contains a minor amount of carbon which produces a pronounced grey colour. Although the sample has a very low magnetic mineral content, it is sufficient to cause colouration. Separation of the carbon and magnetic minerals from these sands is necessary to produce an acceptable filler-grade product. Some of the low cost, high-tonnage methods that might be used effectively include:

1. magnetic separation for removing the magnetic minerals,
2. attrition scrubbing prior to grinding to remove carbon and iron oxides,
3. jigging to remove most heavy minerals, and
4. coning or spiral concentrating to remove heavy minerals and carbon.

Table 9 - X-ray diffraction analysis of minus 200 mesh fractions of silica sand samples from the Red Deer River area (Dave Quirt, Saskatchewan Research Council, 1991).

Sample	Interval	
	8 to 10 m	12 to 14 m
Quartz	90.1 %	38.4 %
Plagioclase	1.2 %	2.5 %
Calcite	0.3 %	4.3 %
Dolomite	1.0 %	21.2 %
Hematite	0.0 %	12.4 %
Illite	0.0 %	2.2 %
Kaolinite	7.4 %	18.9 %
Total	100.0 %	99.9 %

Table 10 - Tristimulus values of <200 mesh ground silica from a 40 to 60 mesh silica sand sample from the Red Deer Silica Inc. quarry, Saskatchewan.

Sample	X	Y	Z	x	y	Y
A	82.37	86.73	91.43	0.3162	0.3329	86.73
B	53.75	56.56	58.85	0.3177	0.3344	56.56
C	49.58	51.97	52.78	0.3213	0.3567	51.97
MgO	94.23	99.37	106.95	0.3135	0.3306	99.37

Note:
Sample A = deslimed <200 mesh silica sand with magnetic minerals removed
Sample B = deslimed <200 mesh silica sand
Sample C = raw <200 mesh silica sand
Sample MgO = precipitated MgO reference standard

Table 11 - CIE-colour coordinates (L, a, b, C, and H) of <200 mesh ground silica from a 40 to 60 mesh silica sand sample from the Red Deer Silica Inc. quarry, Saskatchewan.

Sample	L	a	b	C	H
A	94.62	0.3	1.1	1.16	76.48
B	79.93	0.3	1.7	11.73	79.59
C	77.26	0.8	2.9	3.04	74.02
MgO	99.76	0.0	-0.2	0.19	278.49

Note:
Sample A = deslimed <200 mesh silica sand with magnetic minerals removed
Sample B = deslimed <200 mesh silica sand
Sample C = raw <200 mesh silica sand
Sample MgO = precipitated MgO reference standard

Table 12 - Hunter colour coordinates of <200 mesh ground silica from a 40 to 60 mesh silica sand sample from the Red Deer Silica Inc. quarry, Saskatchewan.

Sample	L	aL	bL	x	y	Y
A	93.18	0.15	1.19	0.3124	0.3182	86.82
B	75.28	0.13	1.64	0.3139	0.3198	56.57
C	72.21	0.51	2.78	0.3174	0.3224	52.14
MgO	99.68	0.06	-0.221	0.3098	0.3158	99.35

L = lightness
aL = red-green axis
bL = yellow-blue axis
x, y = chromaticity coordinates
Y = lightness reference value

Note:
Sample A = deslimed <200 mesh silica sand with magnetic minerals removed
Sample B = deslimed <200 mesh silica sand
Sample C = raw <200 mesh silica sand
Sample MgO = precipitated MgO reference standard

Table 13 - R457 and yellowness values of <200 mesh ground silica from a 40 to 60 mesh silica sand sample from the Red Deer Silica Inc. quarry, Saskatchewan. (R457 is a reference standard from CANMET).

Sample	R457	Yellowness
A	85.31	2.39
B	55.00	4.05
C	49.40	7.38
MgO	99.66	-0.34

Note:
Sample A = deslimed <200 mesh silica sand with magnetic minerals removed
Sample B = deslimed <200 mesh silica sand
Sample C = raw <200 mesh silica sand
Sample MgO = precipitated MgO reference standard

Silica Sands of the Mannville Group: Nipekamew River Area

Location

Picturesque cliffs of kaolinized silica sands occur on both sides of the Nipekamew River south of Highway 165 (Figure 2). These sands are also exposed farther west in the Bow River valley (41.5 km by road from La Ronge) and to the north along the shore of Wapawekka Lake. The best exposures are found on the east side of the Nipekamew River where bends in the river have cut into the Mannville Group sediments.

The sample area is located 51 km (by road) southeast of the town of La Ronge, and was accessible by vehicle via a 1.8 km long trail that started 0.7 km east of the bridge crossing the Nipekamew River on Highway 165. The area is well drained and was covered by coniferous forest, much of which has recently been clear-cut.

Geologic Setting

The silica sand outcrops in this area are composed of moderately sorted continental alluvial deposits equivalent to the Early Cretaceous Mannville Group marine deposits that occur in the Red Deer River area. They are overlain by Upper Cretaceous shales in the area of the Wapawekka Hills and are thought to disconformably overlie Devonian limestone as well as the Precambrian Shield to the northeast.

The bluffs along the Nipekamew River are 17 m or more high with up to 12 m of the silica sand section exposed. Abundant, clean, silica-rich sands also occur in the overburden at locations over 2 km to the east of the river. As the overburden consists predominantly of these sands with only minor contamination by other glacially transported material, it is suggested that large parts of the area are overlain by very shallow basal-tills. The exposed section consists of approximately 8 m of pebbly, coarse-grained sands disconformably overlying approximately 4 m of medium- to fine-grained, cross-bedded sands with clay-rich foresets.

Previous Investigations

Although the best exposures of the Mannville Group silica sands are along the Nipekamew River, previous reports have tended to concentrate primarily on exposures along the shore of Wapawekka Lake (e.g. Padgham, 1966) where the mineable thickness is limited by the close proximity of the lake. Most notable of these investigations is that of Pearson (1961), who described several silica outcrops up to 10 to 13 m thick containing 98.5 to 98.6 percent silica. Hudson (1961) described kaolinized gravel with up to 98.5 percent silica occurring on the west bank of the Bow River, and having little or no glacial cover. The silica sands described by Pearson and Hudson appear to be identical or very similar to those exposed along the Nipekamew River. Langford (1973) had investigated the sand deposits in the area and speculated on the immensity of the resource.

Sampling Procedure

Samples were collected from the bluff (Lat. 54° 43.77', Long. 104° 59.07') on the east side of the Nipekamew River, 2.6 km south of the Nipekamew River bridge, on Highway 165. Prior to sampling, the outcrop face was scraped clear to remove any effects of possible leaching of kaolin cement, accumulation of dust, or preferential separation of grain sizes. All samples were collected in 22 litre plastic containers using vertical face channel sampling methods. The moderately competent nature of the bedrock required the use of a rock hammer to break off material from the bluff face. A clean (unoxidized) steel shovel was also used wherever possible to collect the silica sand.

Analytical Results

Palynology

Two samples of shale with minor silt and quartzose sand were taken from the top of a cross-bedded channel section and submitted to the Energy Research Centre at the University of Regina for palynological analyses. It was hoped the analyses would determine the age of the sediments and confirm whether or not they were equivalent to the Early Cretaceous basal Mannville Group (Success Formation or Dina Formation), or older Jurassic strata.

The shales were digested in hydrofluoric acid and the palynomorphs were subsequently concentrated using the zinc bromide heavy liquid separation method. Residues were mounted on glass slides and examined with a transmitted light microscope.

The entire palynomorph assemblage represents continentally derived pollen and spores. Species of *Trilobosporites* and conifer saccate grains are abundant. One sample contained, *Trilobosporites apiverrucatus, T. trioreticulosus, T. canadensis, Cyathidites sp., Podocarpidites sp., Alisporites sp., Cedripites canadensis*, and *Concavissimisporites variverrucatus*. The second sample contained *T. apiverrucatus*, as well as species of *Cicatricosisporites, Gleicheniidites, Lycospora, Laevigatosporites ovatus, Cyathidites australis, Appendicisporites sp.*, and *Deltoidospora sp.*

The above taxa represent only selected palynomorphs and not the exhaustive list of all species present.

Several indicator species in these samples confirm that the stratum is coeval with the lower Mannville (Swan River) Formation. According to Pocock (1967) and Srivastava (1978), the first appearances of *Cicatricosisporites* and *Arcellites* are considered indicative of basal Cretaceous age. On this basis it is concluded that the samples are not pre-Cretaceous. Also, the stratigraphic ranges of several of the other palynomorphs present in the samples are indicative of possible basal Cretaceous age. *T. apiverrucatus* occurs in Berriasian to Middle Albian sediments. Stratigraphic ranges of other palynomorphs in these samples are: *T. canadensis* (Barremian? to Middle Albian?), *T. trioreticulosus* (Aptian to Albian), and *Concavissimisporites variverrucatus* (Bajocian to Middle Albian). Singh (1964) considered *T. apiverrucatus* as an index palynomorph for the Cretaceous entrance level. *Cyathidites australis, Concavissimisporites variverrucatus,* and *T. apiverrucatus* also occur in the Lower Cretaceous Mannville Group in Saskatchewan and Manitoba (Playford, 1971).

Granulometry

The grain size distribution observed in outcrop and shown in Figure 5 indicates that the sediments consist of two depositional sequences. The lower section, of which only the top 3 m has been tested, appears to fine upwards and probably represents a levée facies. This is disconformably overlain by a pebbly, very much coarser grained, 10 m section of a channel facies that shows only moderate granulometric variation and appears to coarsen upwards.

Chemical

The analyses and calculated oxides of the sieve fractions (Tables 14a and 14b) show an inverse quantitative relationship between the total amount of contaminants and the grain size. Since the ratio of surface area per unit volume increases with decreasing grain size, a significant portion of the contamination is probably a surface coating on the quartz grains. This would be especially true for the alumina occurring in the very fine grains of kaolin, and iron oxide present as a staining on the grains.

A few of the tested intervals were found to have slightly higher alumina values in the coarsest fraction than in the next finer fraction. This is interpreted as being due to the presence of trace amounts of kaolinized feldspar grains that are too competent to break up during the wet sieving process.

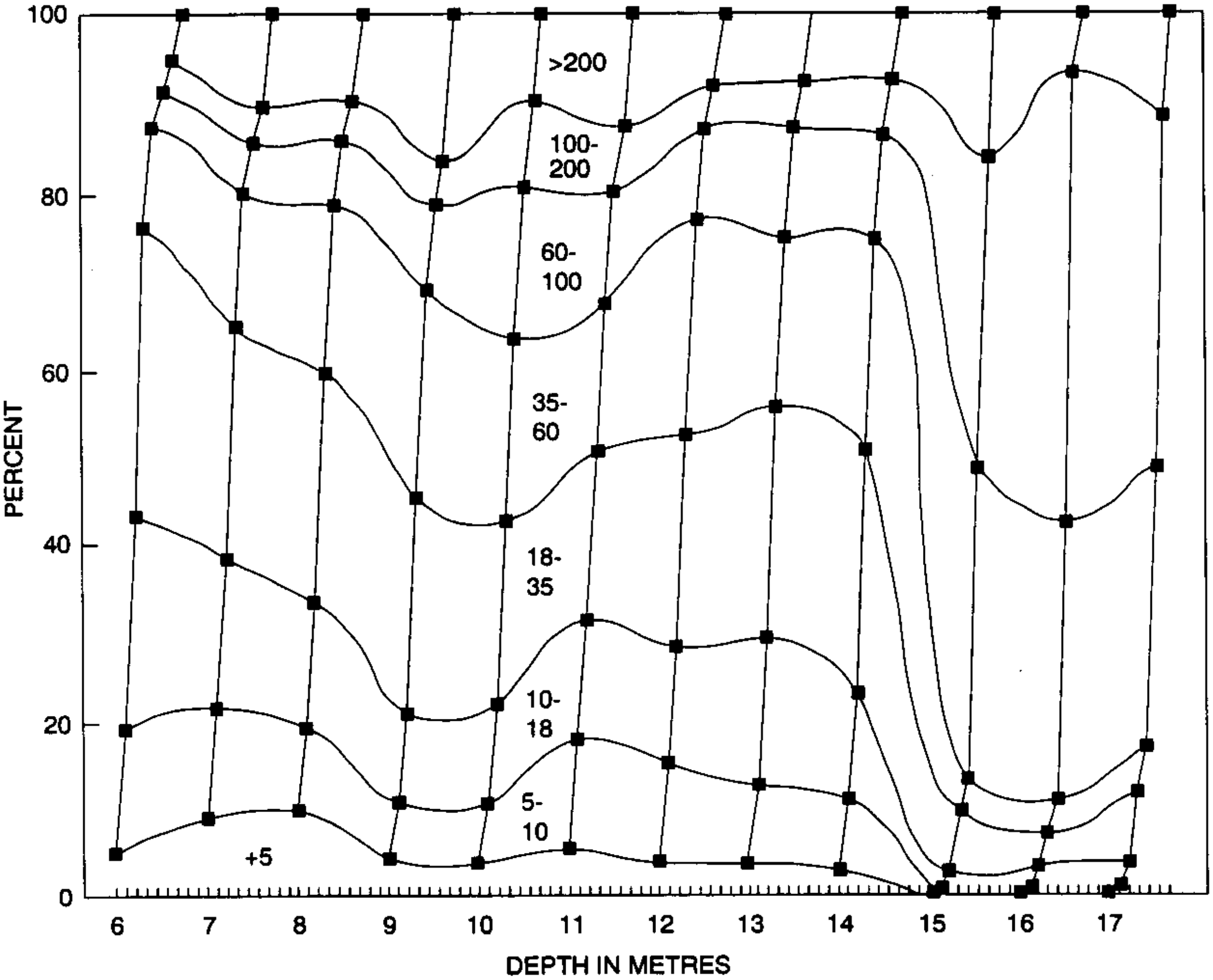

Figure 5 - Grain size distribution of Mannville Group silica sands on the Nipekamew River, Saskatchewan.

Table 14a - Analyses of silica sands from an exposed section on the Nipekamew River, Saskatchewan.

Depth	Sieve	Sample	LOI	SiO_2	Al	Fe	Ca	Mg	Na	K	P	Ti	S	C	Mn	Ba	Co	Cu	Cr	Ni	Zr	B
Interval	Fraction	%	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
5-6m	(+5)	5.4378	<0.01	99.55	0.147	0.014	0.005	0.002	0.002	0.013	0.005	0.010	<0.01	<0.05	0.8	10.3	<0.5	0.3	1.8	0.7	9.5	21
5-6m	(-5+10)	13.8257	<0.01	99.35	0.211	0.015	0.004	0.003	0.007	0.127	0.003	0.009	<0.01	<0.05	1.3	42.8	<0.5	0.2	1.3	0.7	20.4	17
5-6m	(-10+18)	24.0569	<0.01	98.31	0.286	0.014	0.005	0.002	0.012	0.224	0.003	0.007	<0.01	<0.05	0.9	75.2	<0.5	<0.1	1.3	<0.5	18.9	14
5-6m	(-18+35)	32.7352	<0.01	98.53	0.277	0.017	0.005	0.003	0.012	0.222	0.003	0.007	<0.01	<0.05	0.8	88.4	<0.5	0.2	1.8	0.5	13.8	28
5-6m	(-35+60)	11.4167	<0.01	98.13	0.446	0.021	0.008	0.003	0.018	0.362	0.004	0.014	<0.01	<0.05	1.9	111.0	<0.5	0.4	2.2	1.0	17.8	30
5-6m	(-60+100)	4.1540																				
5-6m	(-100+200)	3.8479																				
5-6m	(-200)	4.7258																				
6-7m	(+5)	8.4446	<0.01		0.145	0.013	0.004	0.002	0.002	0.024	0.002	0.012	<0.01	<0.05	0.9	9.3	<0.5	0.2	1.5	0.8	13.8	58
6-7m	(-5+10)	11.7676	<0.01		0.372	0.016	0.005	0.003	0.007	0.132	0.002	0.013	<0.01	<0.05	1.1	34.1	<0.5	0.2	2.5	1.0	21.3	17
6-7m	(-10+18)	17.0319	<0.01		0.238	0.017	0.005	0.003	0.008	0.084	0.002	0.012	<0.01	<0.05	0.8	14.4	<0.5	<0.1	1.9	<0.5	20.8	25
6-7m	(-18+35)	26.6834	0.20		0.387	0.019	0.005	0.003	0.007	0.135	0.002	0.013	<0.01	<0.05	0.8	37.5	<0.5	0.2	2.8	0.9	18.5	23
6-7m	(-35+60)	15.1643	0.25		0.817	0.029	0.006	0.003	0.015	0.287	0.003	0.038	<0.01	<0.05	2.7	77.5	<0.5	0.4	4.3	1.3	25.8	33
6-7m	(-60+100)	5.9420	0.55		1.090	0.073	0.008	0.004	0.024	0.420	0.004	0.123	<0.01	<0.05	11.7	185.0	<5.0	<0.1	7.7	1.8	27.8	49
6-7m	(-100+200)	3.8869																				
6-7m	(-200)	10.0491	11.10		12.800	0.718	0.087	0.059	0.056	0.575	0.083	0.541	0.02	0.38	20.0	198.0	<5.0	7.0	124.0	27.0	364.0	68
7-8m	(+5)	9.8371	<0.01		0.505	0.019	0.004	0.003	0.002	0.017	0.003	0.020	<0.01	<0.05	2.1	12.4	<0.5	0.3	4.1	1.2	18.0	19
7-8m	(-5+10)	9.5219	0.15		0.385	0.015	0.004	0.003	0.003	0.028	0.002	0.024	<0.01	<0.05	1.5	8.9	<0.5	0.2	2.9	1.2	20.9	19
7-8m	(-10+18)	13.8098	0.20		0.382	0.025	0.005	0.003	0.003	0.028	0.002	0.085	<0.01	<0.05	1.3	10.1	<0.5	<0.1	4.5	0.8	29.4	39
7-8m	(-18+35)	26.3053	0.20		0.494	0.019	0.005	0.004	0.005	0.078	0.002	0.018	<0.01	<0.05	1.5	21.2	<0.5	0.3	4.0	1.0	22.9	18
7-8m	(-35+60)	18.7409	0.30		0.649	0.039	0.005	0.004	0.010	0.200	0.003	0.049	<0.01	<0.05	3.2	53.5	<0.5	0.6	5.3	1.7	30.3	34
7-8m	(-60+100)	7.7848	0.55		1.020	0.074	0.008	0.004	0.028	0.380	0.005	0.185	<0.01	<0.05	14.7	150.0	<0.5	<0.1	9.2	1.7	47.1	45
7-8m	(-100+200)	4.2595																				
7-8m	(-200)	9.5408	11.10		8.320	0.478	0.049	0.049	0.085	0.558	0.085	0.700	0.03	0.24	25.0	167.0	<5.0	11.0	118.0	25.0	297.0	67
8-9m	(+5)	4.5954	0.33		3.410	0.059	0.01	0.009	0.005	0.080	0.008	0.088	<0.01	<0.05	1.9	23.5	<0.5	0.5	21.8	4.8	50.0	20
8-9m	(-5+10)	6.0685	<0.01		0.674	0.070	0.005	0.004	0.003	0.030	0.003	0.018	<0.01	<0.05	1.0	11.5	<0.5	0.4	4.1	1.5	23.4	14
8-9m	(-10+18)	10.0554	0.20		0.408	0.053	0.004	0.003	0.008	0.041	0.004	0.015	<0.01	<0.05	0.9	15.8	<0.5	0.2	2.8	0.5	19.4	15
8-9m	(-18+35)	24.4681	<0.01		0.399	0.020	0.005	0.003	0.003	0.038	0.002	0.013	<0.01	<0.05	1.3	12.3	<0.5	0.3	3.4	1.0	20.7	23
8-9m	(-35+60)	23.7527	0.25		0.492	0.026	0.005	0.003	0.008	0.118	0.002	0.029	<0.01	<0.05	1.8	35.3	<0.5	0.4	4.0	1.2	28.8	33
8-9m	(-60+100)	9.7165	0.55		0.911	0.051	0.008	0.003	0.018	0.372	0.002	0.105	<0.01	<0.05	7.6	125.0	<0.5	<0.1	6.3	1.4	32.0	38
8-9m	(-100+200)	5.0467	1.00		2.450	0.198	0.009	0.008	0.061	1.570	0.018	0.472	<0.01	0.08	31.1	374.0	<2.0	<0.4	23.8	5.0	265.0	25
8-9m	(-200)	16.2967	10.10		8.770	0.515	0.048	0.041	0.046	0.518	0.088	0.572	0.01	0.28	18.0	154.0	<5.0	7.0	110.0	28.0	302.0	23
9-10m	(+5)	4.3743	<0.01		0.395	0.013	0.005	0.003	0.002	0.008	0.002	0.029	<0.01	<0.05	1.1	3.8	<0.5	0.3	3.9	1.3	18.1	20
9-10m	(-5+10)	6.8870	<0.01		0.140	0.012	0.004	0.002	0.002	0.021	0.002	0.008	<0.01	<0.05	0.8	8.8	<0.5	0.2	1.3	0.6	18.8	61
9-10m	(-10+18)	10.8011	<0.01		0.219	0.020	0.005	0.003	0.004	0.063	0.002	0.011	<0.01	<0.05	0.8	22.5	<0.5	0.2	1.8	<0.5	23.4	19
9-10m	(-18+35)	20.8605	0.20		0.355	0.020	0.005	0.003	0.004	0.080	0.002	0.016	<0.01	<0.05	1.1	17.3	<0.5	0.2	3.0	0.9	19.9	20
9-10m	(-35+60)	20.6719	0.45		0.684	0.031	0.006	0.004	0.007	0.125	0.002	0.027	<0.01	<0.05	2.1	35.5	<0.5	0.4	5.5	1.7	24.0	34
9-10m	(-60+100)	17.1276	0.45		0.847	0.039	0.008	0.004	0.013	0.248	0.002	0.056	<0.01	<0.05	3.8	80.3	<0.5	0.3	5.5	1.8	27.8	45
9-10m	(-100+200)	9.5297	1.10		2.330	0.149	0.009	0.006	0.052	1.280	0.014	0.361	<0.01	0.12	22.8	330.0	<2.0	<0.4	18.3	4.0	212.0	37
9-10m	(-200)	9.7378	11.40		7.080	0.309	0.036	0.023	0.065	1.040	0.034	0.466	0.01	0.20	11.0	288.0	<5.0	4.0	85.0	19.0	339.0	59

Table 14a (continued) - Analyses of silica sands from an exposed section on the Nipekamew River, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	SiO_2 %	Al %	Fe %	Ca %	Mg %	Na %	K %	P %	Ti %	S %	C %	Mn ppm	Ba ppm	Co ppm	Cu ppm	Cr ppm	Ni ppm	Zr ppm	B ppm
10-11m	(+5)	5.6616	0.19		0.093	0.008	0.003	0.002	0.002	0.014	0.003	0.004	<0.01	<0.05	0.5	7.9	<0.5	0.8	1.4	<0.5	4.0	21
10-11m	(-5+10)	12.0873	<0.01	98.41	0.143	0.012	0.004	0.003	0.004	0.056	0.002	0.009	<0.01	<0.05	1.2	13.3	<0.5	0.3	1.5	0.6	12.5	15
10-11m	(-10+18)	13.5324	0.15		0.150	0.015	0.004	0.002	0.003	0.031	0.002	0.009	<0.01	<0.05	1.0	14.3	<0.5	<0.1	1.5	<0.5	21.4	16
10-11m	(-18+35)	19.0845	0.15	98.48	0.228	0.023	0.004	0.003	0.004	0.080	0.002	0.011	<0.01	<0.05	2.1	18.5	<0.5	0.3	2.0	0.6	18.8	26
10-11m	(-35+60)	17.0034	0.25	98.85	0.509	0.027	0.005	0.003	0.008	0.186	0.002	0.018	<0.01	<0.05	1.8	48.1	<0.5	0.5	3.5	1.2	33.7	33
10-11m	(-60+100)	12.8754	0.40	97.77	0.818	0.048	0.006	0.003	0.017	0.323	0.003	0.076	<0.01	<0.05	6.3	105.0	<0.5	0.3	5.4	1.4	25.2	38
10-11m	(-100+200)	7.0397	1.00	94.1	2.480	0.158	0.008	0.006	0.067	1.400	0.013	0.367	<0.01	0.18	23.4	344.0	<2.0	<0.4	19.6	4.0	173.0	48
10-11m	(-200)	12.7057	11.40		13.000	0.573	0.085	0.053	0.268	1.000	0.192	0.655	0.01	0.44	24.0	258.0	<5.0	7.0	122.0	28.0	456.0	63
11-12m	(+5)	3.9085																				
11-12m	(-5+10)	10.8855	<0.01		0.126	0.010	0.004	0.003	0.002	0.010	0.001	0.009	<0.01	<0.05	1.1	4.3	<0.5	0.2	1.1	0.6	23.8	18
11-12m	(-10+18)	13.2258	<0.01		0.156	0.012	0.004	0.003	0.003	0.040	0.001	0.009	<0.01	<0.05	0.9	9.2	<0.5	<0.1	1.6	<0.5	22.7	15
11-12m	(-18+35)	24.8280	0.20		0.271	0.013	0.004	0.003	0.005	0.071	0.001	0.008	<0.01	<0.05	0.9	25.2	<0.5	0.3	2.4	0.8	18.9	18
11-12m	(-35+60)	23.9022	0.20		0.421	0.019	0.005	0.003	0.009	0.178	0.002	0.014	<0.01	<0.05	1.2	50.8	<0.5	0.3	2.9	1.0	22.8	28
11-12m	(-60+100)	10.1284	0.45		0.817	0.031	0.005	0.003	0.024	0.484	0.003	0.046	<0.01	<0.05	3.7	148.0	<0.5	0.2	4.7	1.2	21.5	37
11-12m	(-100+200)	4.9859	0.85		2.630	0.118	0.008	0.005	0.075	2.040	0.010	0.242	<0.01	0.08	17.9	484.0	<2.0	<0.4	18.8	3.0	161.0	14
11-12m	(-200)	8.3375	10.10		12.800	0.370	0.055	0.041	0.048	0.928	0.045	0.433	0.01	0.32	12.0	223.0	<5.0	4.0	120.0	21.0	278.0	53
12-13m	(+5)	3.8041																				
12-13m	(-5+10)	8.7636	<0.01		0.188	0.023	0.004	0.003	0.002	0.022	0.002	0.011	<0.01	<0.05	1.3	6.9	<0.5	0.2	1.6	0.6	20.4	13
12-13m	(-10+18)	16.6009	<0.01		0.196	0.018	0.004	0.003	0.002	0.022	0.002	0.012	<0.01	<0.05	1.0	9.1	<0.5	0.4	1.9	<0.5	20.3	17
12-13m	(-18+35)	28.2619	<0.01		0.335	0.019	0.006	0.003	0.005	0.073	0.002	0.012	<0.01	<0.05	1.1	20.3	<0.5	0.2	2.9	0.8	20.4	23
12-13m	(-35+60)	19.0442	0.30		0.607	0.027	0.006	0.004	0.010	0.221	0.002	0.023	<0.01	<0.05	1.9	61.4	<0.5	0.3	4.3	1.3	29.1	30
12-13m	(-60+100)	12.6707	0.45		0.849	0.040	0.008	0.004	0.020	0.398	0.002	0.089	<0.01	<0.05	5.0	136.0	<0.5	0.1	5.2	1.3	24.5	40
12-13m	(-100+200)	4.9382	1.10		2.660	0.156	0.008	0.007	0.070	1.880	0.011	0.323	<0.01	0.08	22.4	436.0	<2.0	<0.4	20.2	3.0	203.0	27
12-13m	(-200)	7.8986	10.40		13.400	0.499	0.053	0.062	0.070	1.000	0.042	0.455	0.03	0.40	18.0	232.0	<5.0	3.0	118.0	21.0	332.0	49
13-14m	(+5)	2.8971																				
13-14m	(-5+10)	7.9327	0.15	98.41	0.150	0.009	0.004	0.003	0.004	0.053	0.001	0.010	<0.01	<0.05	0.9	18.7	<0.5	0.2	1.6	<0.5	15.9	15
13-14m	(-10+18)	11.4353	<0.01		0.133	0.009	0.004	0.003	0.001	0.012	0.001	0.009	<0.01	<0.05	0.8	5.1	<0.5	0.1	1.5	<0.5	15.2	14
13-14m	(-18+35)	27.7402	<0.01	98.48	0.168	0.009	0.004	0.003	0.004	0.057	0.001	0.008	<0.01	<0.05	0.9	25.0	<0.5	0.2	1.7	0.6	17.0	43
13-14m	(-35+60)	24.3843	<0.01	98.85	0.287	0.013	0.005	0.003	0.008	0.158	0.002	0.017	<0.01	<0.05	2.1	45.3	<0.5	0.4	2.2	1.1	21.1	34
13-14m	(-60+100)	12.1556	0.20	97.77	0.474	0.028	0.005	0.003	0.015	0.258	0.002	0.042	<0.01	<0.05	5.4	103.0	<0.5	0.5	3.8	1.0	12.8	165
13-14m	(-100+200)	6.1092	0.55	94.1	1.580	0.063	0.005	0.004	0.049	1.280	0.005	0.139	<0.01	0.12	11.4	334.0	<2.0	0.5	9.9	3.0	82.0	22
13-14m	(-200)	7.3653	10.20		14.200	0.353	0.067	0.063	0.081	1.090	0.035	0.407	0.01	0.16	18.0	237.0	<5.0	2.0	125.0	30.0	302.0	40

Table 14a (continued) - Analyses of silica sands from an exposed section on the Nipekamew River, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	SiO_2 %	Al %	Fe %	Ca %	Mg %	Na %	K %	P %	Ti %	S %	C %	Mn ppm	Ba ppm	Co ppm	Cu ppm	Cr ppm	Ni ppm	Zr ppm	B ppm
14-15m	(+5)	0.0000																				
14-15m	(-5+10)	0.2186																				
14-15m	(-10+18)	2.3404																				
14-15m	(-18+35)	7.0572	<0.01		0.082	0.015	0.005	0.003	0.002	0.010	0.001	0.008	<0.01	<0.05	1.3	8.6	<0.5	0.3	1.3	<0.5	19.6	42
14-15m	(-35+60)	4.2748	<0.01		0.087	0.014	0.005	0.003	0.002	0.022	0.001	0.011	<0.01	<0.05	1.5	32.8	<0.5	0.8	1.5	0.8	13.1	28
14-15m	(-60+100)	34.8785	0.20		0.088	0.015	0.005	0.003	0.002	0.015	0.001	0.007	<0.01	<0.05	1.8	37.3	<0.5	0.9	1.1	0.5	4.9	25
14-15m	(-100+200)	34.8922	0.30		0.341	0.044	0.005	0.005	0.004	0.078	0.002	0.064	<0.01	0.08	5.3	70.3	<2.0	1.8	3.9	<2.0	13.0	10
14-15m	(-200)	18.3370	8.65		7.020	0.345	0.048	0.057	0.061	0.818	0.025	0.480	<0.01	0.44	24.0	177.0	<5.0	10.0	97.0	24.0	181.0	46
16-17m	(+5)	0.1817																				
16-17m	(-5+10)	0.6794																				
16-17m	(-10+18)	2.5178																				
16-17m	(-18+35)	3.9049																				
16-17m	(-35+60)	3.7970																				
16-17m	(-60+100)	31.2787	0.20		0.102	0.043	0.005	0.004	0.002	0.017	0.001	0.010	<0.01	<0.05	1.8	39.9	<0.5	1.1	1.8	0.5	8.0	28
16-17m	(-100+200)	51.3978	0.20		0.304	0.087	0.005	0.006	0.005	0.092	0.002	0.082	<0.01	0.06	11.7	73.2	<2.0	1.8	4.8	<2.0	21.0	12
16-17m	(-200)	8.2426	5.10		9.380	1.050	0.09	0.083	0.108	0.703	0.039	0.442	0.03	0.48	28.0	184.0	<5.0	8.0	124.0	28.0	183.0	43
17-18m	(+5)	0.2079																				
17-18m	(-5+10)	0.6960																				
17-18m	(-10+18)	2.8486																				
17-18m	(-18+35)	8.1070	0.15		0.145	0.067	0.005	0.003	0.002	0.018	0.002	0.013	<0.01	<0.05	1.4	8.2	<0.5	0.6	2.1	0.8	24.8	33
17-18m	(-35+60)	4.7754	0.10		0.195	0.079	0.005	0.004	0.004	0.043	0.002	0.021	<0.01	<0.05	2.2	35.2	<0.5	1.3	2.7	0.9	14.3	31
17-18m	(-60+100)	32.1045	0.25		0.147	0.047	0.005	0.004	0.002	0.021	0.001	0.010	<0.01	<0.05	1.6	36.7	<0.5	1.1	1.8	0.8	8.1	25
17-18m	(-100+200)	39.2230	0.25		0.346	0.064	0.005	0.005	0.004	0.083	0.002	0.054	<0.01	0.08	8.8	65.8	<2.0	1.8	4.1	<2.0	15.0	28
17-18m	(-200)	12.0376	8.70		8.120	0.873	0.052	0.075	0.058	0.688	0.034	0.524	0.02	0.40	23.0	183.0	<5.0	11.0	110.0	21.0	197.0	122

Table 14b - Calculated oxides and some measured silica values of silica sands from an exposed section on the Nipekamew River, Saskatchewan.

Depth interval	Sieve Fraction	Sample %	LOI %	kaolin %	Al_2O_3 %	Fe_2O_3 %	FeO(OH) %	CaO %	MgO %	Na_2O %	K_2O %	P_2O_5 %	TiO_2 %	C %	S %	MnO %	BaO %	Co_2O_3 %	CuO %	Cr_2O_3 %	NiO %	$ZrSiO_4$ %	B_2O_3 %	raw SiO_2 %	dry SiO_2 %	SiO_2 (grav.) %
5-6m	(+5)	5.4376	0.00	0.7002	0.2776	0.0200	0.0223	0.0070	0.0033	0.0027	0.0157	0.0115	0.0167	0.00	0.00	0.0001	0.0012	0.0000	0.0000	0.0003	0.0001	0.0019	0.0088	99.207	99.207	99.55
5-6m	(-5+10)	13.8257	0.00	1.0084	0.3867	0.0214	0.0239	0.0056	0.0050	0.0054	0.1530	0.0069	0.0150	0.00	0.00	0.0002	0.0048	0.0000	0.0000	0.0002	0.0001	0.0041	0.0055	98.757	98.757	99.35
5-6m	(-10+18)	24.0586	0.00	1.2677	0.5007	0.0200	0.0223	0.0070	0.0033	0.0162	0.2896	0.0069	0.0117	0.00	0.00	0.0001	0.0084	0.0000	0.0000	0.0002	0.0000	0.0038	0.0045	98.378	98.378	99.31
5-6m	(-18+35)	32.7352	0.00	1.3251	0.5234	0.0243	0.0270	0.0070	0.0050	0.0162	0.2674	0.0069	0.0117	0.00	0.00	0.0001	0.0074	0.0000	0.0000	0.0002	0.0001	0.0027	0.0084	98.316	98.315	99.53
5-6m	(-35+60)	11.4167	0.00	2.1338	0.8427	0.0300	0.0334	0.0084	0.0050	0.0243	0.4240	0.0092	0.0234	0.00	0.00	0.0002	0.0124	0.0000	0.0001	0.0003	0.0001	0.0038	0.0097	97.312	97.312	99.13
5-6m	(-60+100)	4.1540																								
5-6m	(-100+200)	3.8479																								
5-6m	(-200)	4.7256																								
6-7m	(+5)	8.4448	0.00	0.6837	0.2740	0.0186	0.0207	0.0056	0.0033	0.0027	0.0289	0.0046	0.0200	0.00	0.00	0.0001	0.0010	0.0000	0.0000	0.0002	0.0001	0.0028	0.0180	99.188	99.188	
6-7m	(-5+10)	11.7878	0.00	1.7786	0.7028	0.0228	0.0255	0.0070	0.0050	0.0084	0.1560	0.0046	0.0217	0.00	0.00	0.0001	0.0038	0.0000	0.0000	0.0004	0.0001	0.0043	0.0056	97.974	97.974	
6-7m	(-10+18)	17.0319	0.00	1.1386	0.4487	0.0243	0.0270	0.0070	0.0050	0.0081	0.1012	0.0046	0.0200	0.00	0.00	0.0001	0.0016	0.0000	0.0000	0.0003	0.0000	0.0042	0.0081	98.674	98.674	
6-7m	(-18+35)	28.6834	0.20	1.8982	0.7501	0.0272	0.0302	0.0070	0.0050	0.0084	0.1628	0.0046	0.0217	0.00	0.00	0.0001	0.0042	0.0000	0.0000	0.0004	0.0001	0.0037	0.0074	97.844	98.040	
6-7m	(-35+60)	15.1643	0.25	2.9617	1.1658	0.0415	0.0461	0.0084	0.0050	0.0202	0.3467	0.0069	0.0601	0.00	0.00	0.0003	0.0087	0.0000	0.0001	0.0006	0.0002	0.0062	0.0108	96.530	96.772	
6-7m	(-60+100)	5.9420	0.55	5.2145	2.0588	0.1044	0.1161	0.0084	0.0066	0.0324	0.5058	0.0092	0.2062	0.00	0.00	0.0015	0.0186	0.0000	0.0000	0.0011	0.0002	0.0058	0.0158	93.859	94.378	
6-7m	(-100+200)	3.8868																								
6-7m	(-200)	10.0491	11.10	61.2338	24.1886	1.0286	1.1422	0.1217	0.0876	0.0782	0.8826	0.1802	0.8024	0.38	0.02	0.0028	0.0223	0.0000	0.0008	0.0161	0.0034	0.0771	0.0222	35.024	39.397	
7-8m	(+5)	9.9371	0.00	2.4158	0.9542	0.0272	0.0302	0.0056	0.0050	0.0027	0.0205	0.0069	0.0334	0.00	0.00	0.0003	0.0014	0.0000	0.0000	0.0006	0.0002	0.0036	0.0081	97.488	97.488	
7-8m	(-5+10)	9.5218	0.15	1.7481	0.6887	0.0214	0.0239	0.0056	0.0050	0.0040	0.0337	0.0046	0.0400	0.00	0.00	0.0002	0.0010	0.0000	0.0000	0.0004	0.0002	0.0042	0.0081	98.125	98.272	
7-8m	(-10+18)	13.9086	0.20	1.8753	0.7407	0.0357	0.0386	0.0070	0.0050	0.0040	0.0337	0.0046	0.1084	0.00	0.00	0.0002	0.0011	0.0000	0.0000	0.0007	0.0001	0.0069	0.0128	97.892	98.088	
7-8m	(-18+35)	28.3053	0.20	2.3832	0.9334	0.0272	0.0302	0.0070	0.0066	0.0067	0.0852	0.0046	0.0300	0.00	0.00	0.0002	0.0024	0.0000	0.0000	0.0006	0.0001	0.0046	0.0056	97.443	97.638	
7-8m	(-35+60)	18.7408	0.30	3.1048	1.2283	0.0558	0.0620	0.0070	0.0066	0.0136	0.2409	0.0069	0.0617	0.00	0.00	0.0004	0.0060	0.0000	0.0001	0.0008	0.0002	0.0061	0.0108	96.452	96.742	
7-8m	(-60+100)	7.7846	0.56	4.8786	1.8873	0.1058	0.1177	0.0084	0.0066	0.0350	0.4577	0.0115	0.3066	0.00	0.00	0.0018	0.0166	0.0000	0.0000	0.0013	0.0002	0.0085	0.0145	94.131	94.661	
7-8m	(-100+200)	4.2585																								
7-8m	(-200)	8.5408	11.10	39.8020	15.7208	0.6805	0.7573	0.0686	0.0812	0.1148	0.8898	0.1490	1.1676	0.24	0.03	0.0032	0.0187	0.0000	0.0014	0.0172	0.0032	0.0887	0.0219	56.010	64.076	
8-9m	(+5)	4.9854	0.33	16.3131	6.4432	0.0844	0.0939	0.0140	0.0149	0.0067	0.0723	0.0183	0.1134	0.00	0.00	0.0002	0.0028	0.0000	0.0001	0.0032	0.0008	0.0100	0.0084	83.330	83.606	
8-9m	(-5+10)	6.0885	0.00	3.2243	1.2736	0.1001	0.1114	0.0070	0.0066	0.0040	0.0381	0.0069	0.0300	0.00	0.00	0.0001	0.0013	0.0000	0.0001	0.0006	0.0002	0.0047	0.0045	96.362	96.362	
8-9m	(-10+18)	10.0554	0.20	1.9518	0.7708	0.0758	0.0843	0.0056	0.0050	0.0081	0.0484	0.0092	0.0250	0.00	0.00	0.0001	0.0018	0.0000	0.0000	0.0004	0.0001	0.0038	0.0046	97.851	98.047	
8-9m	(-18+35)	24.4681	0.00	1.9086	0.7539	0.0286	0.0318	0.0070	0.0050	0.0040	0.0458	0.0046	0.0217	0.00	0.00	0.0002	0.0014	0.0000	0.0000	0.0005	0.0001	0.0042	0.0074	97.858	97.858	
8-9m	(-35+60)	23.7527	0.25	2.3537	0.9298	0.0372	0.0414	0.0070	0.0050	0.0081	0.1421	0.0046	0.0484	0.00	0.00	0.0002	0.0040	0.0000	0.0001	0.0008	0.0002	0.0063	0.0108	97.369	97.613	
8-9m	(-60+100)	8.7165	0.55	4.3581	1.7213	0.0729	0.0811	0.0084	0.0050	0.0243	0.4461	0.0046	0.1751	0.00	0.00	0.0010	0.0140	0.0000	0.0000	0.0009	0.0002	0.0084	0.0122	94.861	95.385	
8-9m	(-100+200)	5.0487	1.00	11.7206	4.6283	0.2631	0.3150	0.0126	0.0086	0.0822	1.8812	0.0412	0.7873	0.08	0.00	0.0040	0.0418	0.0000	0.0000	0.0004	0.0008	0.0532	0.0081	84.948	85.878	
8-9m	(-200)	16.2867	10.10	41.8548	16.5709	0.7363	0.8163	0.0672	0.0680	0.0820	0.8240	0.1512	0.8541	0.28	0.01	0.0023	0.0172	0.0000	0.0009	0.0161	0.0033	0.0807	0.0074	54.808	61.288	
9-10m	(+5)	4.3743	0.00	1.8886	0.7464	0.0186	0.0207	0.0070	0.0050	0.0027	0.0072	0.0046	0.0484	0.00	0.00	0.0001	0.0004	0.0000	0.0000	0.0006	0.0002	0.0036	0.0084	98.003	98.003	
9-10m	(-5+10)	8.6970	0.00	0.6887	0.2645	0.0172	0.0191	0.0056	0.0033	0.0027	0.0253	0.0046	0.0133	0.00	0.00	0.0001	0.0010	0.0000	0.0000	0.0002	0.0001	0.0034	0.0196	99.232	99.232	
9-10m	(-10+18)	10.8011	0.00	1.0477	0.4136	0.0286	0.0318	0.0070	0.0050	0.0054	0.0759	0.0046	0.0183	0.00	0.00	0.0001	0.0025	0.0000	0.0000	0.0003	0.0000	0.0047	0.0061	98.781	98.781	
9-10m	(-18+35)	20.8805	0.20	1.6983	0.6708	0.0286	0.0318	0.0070	0.0050	0.0054	0.0723	0.0046	0.0267	0.00	0.00	0.0001	0.0019	0.0000	0.0000	0.0004	0.0001	0.0040	0.0084	98.136	98.333	
9-10m	(-35+60)	20.8719	0.45	3.2722	1.2924	0.0443	0.0493	0.0084	0.0066	0.0084	0.1506	0.0046	0.0450	0.00	0.00	0.0003	0.0040	0.0000	0.0001	0.0008	0.0002	0.0046	0.0108	96.433	96.869	
9-10m	(-60+100)	17.1276	0.45	4.0520	1.6004	0.0558	0.0620	0.0084	0.0066	0.0175	0.2887	0.0046	0.0934	0.00	0.00	0.0005	0.0090	0.0000	0.0000	0.0008	0.0002	0.0066	0.0145	95.426	95.857	
9-10m	(-100+200)	9.5287	1.10	11.1465	4.4025	0.2120	0.2370	0.0126	0.0086	0.0701	1.5419	0.0321	0.6022	0.12	0.00	0.0029	0.0370	0.0000	0.0000	0.0028	0.0006	0.0436	0.0119	86.130	87.104	
9-10m	(-200)	9.7378	11.40	33.7743	13.3395	0.4418	0.4918	0.0504	0.0381	0.0876	1.2528	0.0779	0.7773	0.20	0.01	0.0014	0.0298	0.0000	0.0005	0.0139	0.0024	0.0661	0.0180	63.110	71.391	
10-11m	(+5)	5.9815	0.18	0.4449	0.1757	0.0114	0.0127	0.0042	0.0033	0.0027	0.0149	0.0069	0.0067	0.00	0.00	0.0001	0.0009	0.0000	0.0001	0.0002	0.0000	0.0008	0.0088	99.493	99.662	
10-11m	(-5+10)	12.0873	0.00	0.6641	0.2702	0.0172	0.0181	0.0056	0.0050	0.0054	0.0863	0.0046	0.0150	0.00	0.00	0.0002	0.0015	0.0000	0.0000	0.0002	0.0001	0.0035	0.0046	99.186	99.186	
10-11m	(-10+18)	13.5324	0.15	0.7176	0.2834	0.0214	0.0239	0.0056	0.0033	0.0040	0.0373	0.0046	0.0150	0.00	0.00	0.0001	0.0016	0.0000	0.0000	0.0002	0.0000	0.0043	0.0062	99.177	99.326	
10-11m	(-18+35)	19.0846	0.15	1.0812	0.4270	0.0329	0.0366	0.0056	0.0050	0.0054	0.0723	0.0046	0.0183	0.00	0.00	0.0003	0.0021	0.0000	0.0000	0.0003	0.0001	0.0038	0.0084	98.756	98.905	
10-11m	(-35+60)	17.0034	0.25	2.4350	0.9618	0.0386	0.0430	0.0070	0.0050	0.0121	0.2000	0.0046	0.0300	0.00	0.00	0.0002	0.0054	0.0000	0.0001	0.0005	0.0002	0.0066	0.0108	97.240	97.483	
10-11m	(-60+100)	12.8754	0.40	3.9132	1.5456	0.0686	0.0764	0.0070	0.0050	0.0229	0.3891	0.0069	0.1286	0.00	0.00	0.0008	0.0118	0.0000	0.0000	0.0008	0.0002	0.0061	0.0122	95.422	95.805	
10-11m	(-100+200)	7.0397	1.00	11.9119	4.7048	0.2258	0.2514	0.0126	0.0086	0.0768	1.6864	0.0298	0.6122	0.16	0.00	0.0030	0.0385	0.0000	0.0000	0.0028	0.0006	0.0348	0.0158	85.153	86.153	
10-11m	(-200)	12.7057	11.40	62.1807	24.5635	0.8182	0.9118	0.1188	0.0876	0.3842	1.2046	0.4400	1.0828	0.44	0.01	0.0031	0.0289	0.0000	0.0008	0.0176	0.0038	0.0816	0.0203	32.864	37.380	

Table 14b (continued) - Calculated oxides and some measured silica values of silica sands from an exposed section on the Nipekamew River, Saskatchewan.

Depth Interval	Sieve Fraction	Sample %	LOI %	kaolin %	Al_2O_3 %	Fe_2O_3 %	FeO(OH) %	CaO %	MgO %	Na_2O %	K_2O %	P_2O_5 %	TiO_2 %	C %	S %	MnO %	BaO %	Co_2O_3 %	CuO %	Cr_2O_3 %	NiO %	$ZrSiO_4$ %	B_2O_3 %	raw SiO_2 %	dry SiO_2 %	SiO_2 (grav.) %
11-12m	(+5)	3.8085																								
11-12m	(-5+10)	10.8856	0.00	0.6028	0.2381	0.0143	0.0158	0.0056	0.0050	0.0027	0.0120	0.0023	0.0150	0.00	0.00	0.0001	0.0005	0.0000	0.0000	0.0002	0.0001	0.0046	0.0058	99.327	99.327	
11-12m	(-10+18)	13.2258	0.00	0.7568	0.2986	0.0172	0.0191	0.0056	0.0050	0.0040	0.0482	0.0023	0.0158	0.00	0.00	0.0001	0.0010	0.0000	0.0000	0.0002	0.0000	0.0048	0.0046	99.134	99.134	
11-12m	(-18+35)	24.6280	0.20	1.2964	0.5121	0.0186	0.0207	0.0056	0.0050	0.0067	0.0855	0.0023	0.0133	0.00	0.00	0.0001	0.0026	0.0000	0.0000	0.0004	0.0001	0.0034	0.0081	98.551	98.749	
11-12m	(-35+60)	23.8022	0.20	2.0140	0.7955	0.0272	0.0302	0.0070	0.0050	0.0121	0.2120	0.0046	0.0234	0.00	0.00	0.0002	0.0057	0.0000	0.0000	0.0004	0.0001	0.0045	0.0083	97.671	97.867	
11-12m	(-60+100)	10.1284	0.45	3.9084	1.5437	0.0443	0.0493	0.0070	0.0050	0.0324	0.5568	0.0069	0.0801	0.00	0.00	0.0005	0.0164	0.0000	0.0000	0.0007	0.0002	0.0043	0.0118	95.318	95.749	
11-12m	(-100+200)	4.8856	0.85	12.5817	4.9694	0.1687	0.1877	0.0112	0.0083	0.1011	2.4574	0.0229	0.4037	0.08	0.00	0.0023	0.0542	0.0000	0.0000	0.0025	0.0004	0.0023	0.0046	84.050	84.839	
11-12m	(-200)	8.3375	10.10	60.2771	23.8077	0.5288	0.5886	0.0770	0.0880	0.0820	1.1179	0.1031	0.7223	0.32	0.01	0.0015	0.0250	0.0000	0.0005	0.0175	0.0027	0.0881	0.0171	36.538	40.788	
12-13m	(+5)	3.8041																								
12-13m	(-5+10)	8.7836	0.00	0.9084	0.3588	0.0328	0.0366	0.0056	0.0050	0.0027	0.0285	0.0046	0.0183	0.00	0.00	0.0002	0.0008	0.0000	0.0000	0.0003	0.0001	0.0041	0.0042	98.892	98.892	
12-13m	(-10+18)	18.8008	0.00	0.9376	0.3703	0.0257	0.0286	0.0056	0.0050	0.0027	0.0286	0.0046	0.0200	0.00	0.00	0.0001	0.0010	0.0000	0.0001	0.0003	0.0000	0.0041	0.0055	98.856	98.856	
12-13m	(-18+35)	28.2818	0.00	1.6028	0.6330	0.0272	0.0302	0.0070	0.0050	0.0067	0.0679	0.0046	0.0200	0.00	0.00	0.0001	0.0023	0.0000	0.0000	0.0004	0.0001	0.0041	0.0074	98.221	98.221	
12-13m	(-35+60)	19.0442	0.30	2.9084	1.1488	0.0386	0.0430	0.0070	0.0066	0.0135	0.2882	0.0046	0.0384	0.00	0.00	0.0002	0.0088	0.0000	0.0000	0.0008	0.0002	0.0058	0.0097	96.693	96.984	
12-13m	(-60+100)	12.8707	0.45	4.0613	1.6042	0.0572	0.0636	0.0084	0.0066	0.0270	0.4784	0.0046	0.1151	0.00	0.00	0.0005	0.0151	0.0000	0.0000	0.0008	0.0002	0.0048	0.0128	95.199	95.630	
12-13m	(-100+200)	4.8382	1.10	12.7252	5.0281	0.2218	0.2468	0.0112	0.0116	0.0944	2.2846	0.0252	0.5368	0.08	0.00	0.0029	0.0488	0.0000	0.0000	0.0029	0.0004	0.0408	0.0087	83.868	84.800	
12-13m	(-200)	7.6685	10.40	64.1043	25.3183	0.7134	0.7938	0.0742	0.1028	0.0944	1.2048	0.0862	0.7580	0.40	0.03	0.0023	0.0280	0.0000	0.0004	0.0174	0.0027	0.0987	0.0158	32.225	36.128	
13-14m	(+5)	2.8871																								
13-14m	(-5+10)	7.9327	0.15	0.7176	0.2834	0.0129	0.0143	0.0056	0.0050	0.0054	0.0836	0.0023	0.0187	0.00	0.00	0.0001	0.0021	0.0000	0.0000	0.0002	0.0000	0.0032	0.0046	99.158	99.306	99.41
13-14m	(-10+18)	11.4353	0.00	0.6363	0.2513	0.0129	0.0143	0.0056	0.0050	0.0013	0.0145	0.0023	0.0150	0.00	0.00	0.0001	0.0008	0.0000	0.0000	0.0002	0.0000	0.0031	0.0045	99.297	99.297	
13-14m	(-18+35)	27.7402	0.00	0.8037	0.3174	0.0129	0.0143	0.0056	0.0050	0.0054	0.0887	0.0023	0.0150	0.00	0.00	0.0001	0.0028	0.0000	0.0000	0.0002	0.0001	0.0034	0.0138	99.080	99.080	99.48
13-14m	(-35+60)	24.3843	0.00	1.3730	0.5423	0.0186	0.0207	0.0070	0.0050	0.0108	0.1879	0.0046	0.0284	0.00	0.00	0.0003	0.0051	0.0000	0.0001	0.0003	0.0001	0.0042	0.0108	98.342	98.342	98.85
13-14m	(-60+100)	12.1558	0.20	2.2678	0.8958	0.0400	0.0445	0.0070	0.0050	0.0202	0.3084	0.0046	0.0701	0.00	0.00	0.0007	0.0115	0.0000	0.0001	0.0005	0.0001	0.0028	0.0631	97.204	97.399	97.77
13-14m	(-100+200)	8.1082	0.55	7.8064	3.0843	0.0901	0.1002	0.0070	0.0066	0.0661	1.5178	0.0115	0.2318	0.12	0.00	0.0015	0.0374	0.0000	0.0001	0.0014	0.0004	0.0165	0.0071	90.268	90.677	94.10
13-14m	(-200)	7.3853	10.20	67.8314	26.8309	0.5047	0.5618	0.0837	0.1045	0.0822	1.3130	0.0802	0.8789	0.16	0.01	0.0023	0.0285	0.0000	0.0003	0.0183	0.0038	0.0807	0.0129	28.885	32.201	
14-15m	(+5)	0.0000																								
14-15m	(-5+10)	0.2186																								
14-15m	(-10+18)	2.3404																								
14-15m	(-18+35)	7.0672	0.00	0.2966	0.1171	0.0214	0.0238	0.0070	0.0050	0.0027	0.0120	0.0023	0.0150	0.00	0.00	0.0002	0.0007	0.0000	0.0000	0.0002	0.0000	0.0038	0.0135	99.617	99.617	
14-15m	(-35+60)	4.2746	0.00	0.4640	0.1833	0.0200	0.0223	0.0070	0.0050	0.0027	0.0266	0.0023	0.0183	0.00	0.00	0.0002	0.0037	0.0000	0.0001	0.0002	0.0001	0.0038	0.0080	99.436	99.436	
14-15m	(-60+100)	34.8796	0.20	0.4114	0.1625	0.0214	0.0238	0.0070	0.0050	0.0027	0.0181	0.0023	0.0117	0.00	0.00	0.0002	0.0042	0.0000	0.0001	0.0002	0.0001	0.0018	0.0081	99.504	99.704	
14-15m	(-100+200)	34.8822	0.30	1.6313	0.6443	0.0629	0.0700	0.0070	0.0083	0.0054	0.0952	0.0046	0.0801	0.08	0.00	0.0007	0.0079	0.0000	0.0002	0.0006	0.0000	0.0026	0.0032	97.883	98.367	
14-15m	(-200)	16.3370	8.65	33.5830	13.2643	0.4933	0.5490	0.0672	0.0845	0.0867	0.7444	0.0573	0.8007	0.44	0.00	0.0031	0.0188	0.0000	0.0013	0.0142	0.0030	0.0384	0.0145	63.503	69.853	
16-17m	(+5)	0.1817																								
16-17m	(-5+10)	0.6784																								
16-17m	(-10+18)	2.5178																								
16-17m	(-18+35)	3.9048																								
16-17m	(-35+60)	3.7970																								
16-17m	(-60+100)	31.2787	0.20	0.4880	0.1927	0.0615	0.0684	0.0070	0.0066	0.0027	0.0205	0.0023	0.0167	0.00	0.00	0.0002	0.0045	0.0000	0.0001	0.0002	0.0001	0.0012	0.0084	99.373	99.572	
16-17m	(-100+200)	51.3978	0.20	1.4543	0.5744	0.1244	0.1384	0.0070	0.0083	0.0067	0.1108	0.0046	0.1368	0.06	0.00	0.0015	0.0062	0.0000	0.0002	0.0007	0.0000	0.0042	0.0038	98.034	98.310	
16-17m	(-200)	6.2428	5.10	44.8730	17.7235	1.5012	1.6704	0.1258	0.1542	0.1428	0.8468	0.0694	0.7373	0.46	0.03	0.0036	0.0208	0.0000	0.0010	0.0181	0.0036	0.0366	0.0138	50.768	53.798	
17-18m	(+5)	0.2070																								
17-18m	(-5+10)	0.6860																								
17-18m	(-10+18)	2.8488																								
17-18m	(-18+35)	8.1070	0.15	0.6937	0.2740	0.0978	0.1088	0.0070	0.0050	0.0027	0.0229	0.0046	0.0217	0.00	0.00	0.0002	0.0010	0.0000	0.0001	0.0003	0.0001	0.0080	0.0108	99.118	99.268	
17-18m	(-35+60)	4.7754	0.10	0.9329	0.3685	0.1129	0.1257	0.0070	0.0066	0.0054	0.0518	0.0046	0.0360	0.00	0.00	0.0003	0.0038	0.0000	0.0002	0.0004	0.0001	0.0028	0.0100	98.813	98.912	
17-18m	(-60+100)	32.1045	0.25	0.7032	0.2778	0.0672	0.0748	0.0070	0.0066	0.0027	0.0253	0.0023	0.0167	0.00	0.00	0.0002	0.0041	0.0000	0.0001	0.0003	0.0001	0.0012	0.0081	99.147	99.396	
17-18m	(-100+200)	39.2230	0.25	1.6552	0.6538	0.0915	0.1018	0.0070	0.0083	0.0054	0.1120	0.0046	0.0801	0.08	0.00	0.0008	0.0074	0.0000	0.0002	0.0006	0.0000	0.0030	0.0080	97.915	98.238	
17-18m	(-200)	12.0378	8.70	38.8453	15.3427	0.9622	1.0707	0.0728	0.1244	0.0782	0.8268	0.0779	0.8741	0.40	0.02	0.0030	0.0205	0.0000	0.0014	0.0181	0.0027	0.0388	0.0083	57.498	63.251	

Heavy Mineral Content

A sample weighing 13.80 kg was processed to recover heavy minerals. Of this, 1.3 kg (9.420 percent) was plus 10 mesh and removed from the testing. The remaining sample yielded 7.358 g (0.0589 percent) of heavy minerals, of which 0.01 g was non-magnetic. Of the heavy minerals recovered, 17.0 percent were from the 10 to 100 mesh fraction while the majority (61 percent) were from the 100 to 200 mesh fraction. Microprobe backscattered electron image analysis was used to identify the relative percentages of heavy minerals present in each of the grain size fractions.

Garnet (35 percent), rutile (27 percent), and cordierite (17 percent) are the most abundant minerals in the plus 100 mesh heavy mineral fraction. In the minus 100 mesh fraction a wide variety of minerals are present including: zircon (32 percent), rutile (20 percent), garnet (16 percent), corundum (11 percent), and monazite (10 percent).

Silica Sands of the Winnipeg Formation: Hanson Lake Area

Location

A well-sorted, white to beige silica sand, outcrops throughout a large area marginal to the exposed Precambrian Shield in the Amisk Lake to Hanson Lake—Deschambault Lake region of east-central Saskatchewan (Figure 6). The silica sands are erosionally incompetent, and outcrops are typically covered by a scree of dolomite blocks. Where the sands are not capped by dolomite they tend to occur under or on the edge of muskegs, or in some instances they form well-drained, gently rolling terrain with a well developed coniferous forest cover. The area is easily accessible from La Ronge, Prince Albert, and Flin Flon via paved Highway 106 (the Hanson Lake Road).

Geologic Setting

Silica sand, in the area investigated, belongs to the Black Island Member, the basal unit of the Middle Ordovician Winnipeg Formation. Its deposition was likely controlled by tectonics in the Williston Basin to the south and the ancestral Sweetgrass Arch to the west. The bulk of the Black Island sediments were likely derived from the erosion of Cambrian Deadwood Formation sediments in western and eastern Saskatchewan and Manitoba (Paterson, 1971). Throughout most of the Phanerozoic Basin in Saskatchewan, the Winnipeg Formation is underlain by clastic Cambrian sediments of the Earlie and Deadwood formations. However, in the known outcrop areas, the Winnipeg Formation silica sands were deposited on an erosional plain that constitutes the Precambrian unconformity. The sands in the area of investigation range in thickness from 3.65 to 5.18 m. The Black Island Member is capped by the erosionally competent Middle Ordovician dolomites of the Red River Formation which form escarpments and outliers throughout much of the region.

The Black Island Member is an unconsolidated orthoquartz sandstone that was deposited in a marine beach to off-shore bar environment. The sandstone is distinguished from all other sediments in the basin on the basis of the well rounded and uncemented grains. The quartz grains are thought to have undergone both fluvial and aeolian transport. They show distinctive frosting caused by wind transport. It has been suggested that these sediments may have been partially derived from the Upper Proterozoic Athabasca Group (Paterson, pers. comm., 1991). It is unknown whether the sands were cemented or if the cement has been leached out by groundwater. Carbonate cementation tends to be restricted to the upper, finer grained fraction of the sequence, and may be derived from downward migration of dissolved carbonate from the Red River Formation.

The stratigraphic equivalent of the sands in the Hanson Lake area have been mined at Black Island on Lake Winnipeg, Manitoba for glass production in Alberta. The sands at Black Island are finer grained and richer in iron oxides than those in the Hanson Lake area. Waters

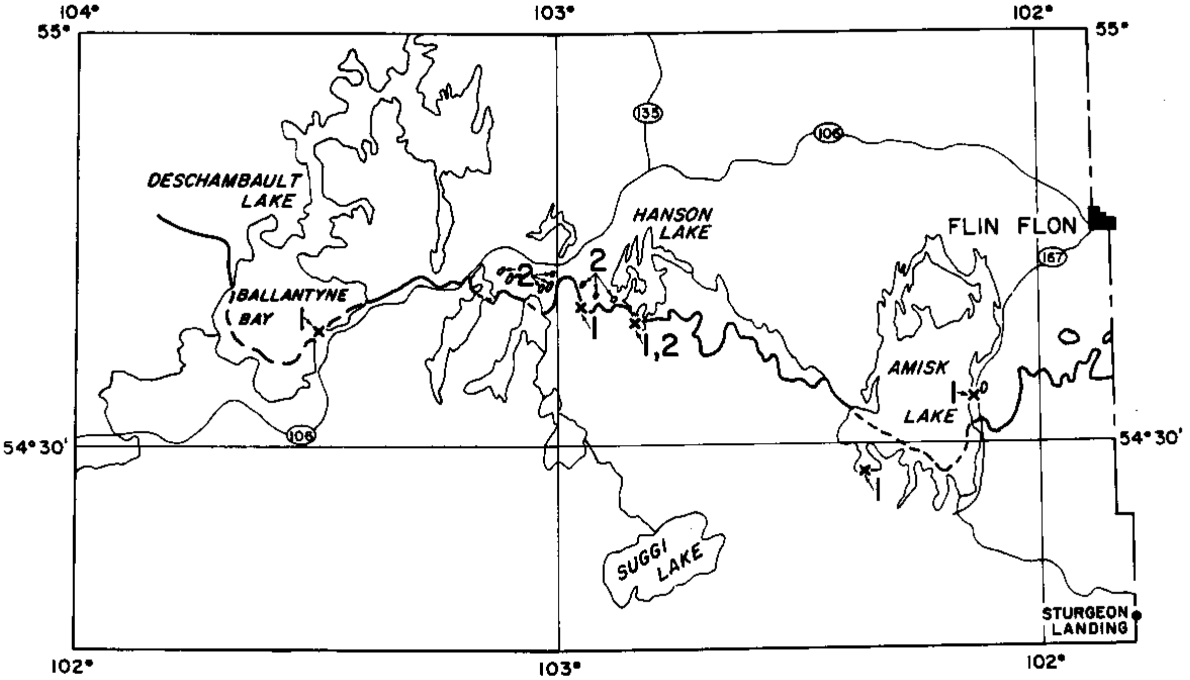

Figure 6 - Distribution of outcropping silica sands of the Winnipeg Formation and the edge of the capping Red River Formation, Saskatchewan. #1 outcrops reported by Kupsch (1952) and #2 outcrops reported by Waters (1977, 1978a and b).

(1978a and b) proposed that the quartz grains in the Black Island Member are derived from the local basement rock, and that the east-west difference in grain size is due to finer grained basement source rocks to the east. The high degree of rounding of these grains strongly suggests that these sediments are probably a third or fourth generation sandstone and that variations in grain size are more likely to be due to differences in depositional energy regimes.

Previous Investigations

The Winnipeg Formation sands have been the most extensively investigated of the silica sands in Saskatchewan. The investigations have generally been of regional scope with site specific tests. Work conducted to date consists of geologic mapping and specific engineering, chemical, granulometric, and mineralogical studies by industry, government, and academic agencies.

Geologic field mapping of the Winnipeg Formation in the region includes the work of: Byers and Dahlstrom (1954) in the Amisk-Wildnest lakes area; Byers (1957) in the Hanson Lake area; Byers, Kirkland, and Pearson (1965) in the Flin Flon area; and Coleman and Gaskarth (1970) in the Hanson Lake area.

The stratigraphy of the Winnipeg Formation was investigated by McLean (1960) and Paterson (1971). Other studies of the Winnipeg sandstone include those by Chernoff (1955) in the Hanson Lake area and a regional study by Genik (1952). Both of these studies provide information regarding the heavy mineral content, quartz grain size distribution, roundness, and sphericity of these sands from different localities.

Kupsch (1952) and Chernoff (1955) reported chemical analyses of the Black Island Member that warrant an evaluation of its potential as a silica sand resource. Subsequent investigations by industry include those of: Mr. H. Jacobson of Flin Flon, Manitoba in 1961 (internal correspondence); Holocene Resources Ltd. (Waters; 1977, 1978a and b); and Saskoil Ltd. (confidential assessment work).

In all cases, the sands are reported to be relatively pure, well sorted, and to have a high degree of roundness and sphericity. Of particular interest are the investigations of Holocene Resources (Waters; 1977, 1978a and b) that demonstrated the existence of significant ore reserves (>7 500 000 tonnes) of plus 40 mesh sands suitable for use as a fracturing medium.

Sampling Procedure

Samples were collected from an exposure on a westward-facing escarpment (Lat. 54° 39.96'N, Long. 102° 50.85'W) at the southwest end of Hanson Lake, which was previously investigated by Byers (1957) and Waters (1978a and b). Despite attempts to re-expose the entire section, which had been largely covered by sloughed sandstones, only the upper 4.6 m could be sampled. Byers (1957) described the section at this location as consisting of:

Thickness in cm	**Description**
260.0	Dolomite: beige
40.0	Dolomite: mottled greyish orange (10YR7/4) and very pale orange (10YR8/2). Has poor pin-point porosity with concentrations of iron oxide in the pores. Medio-crystalline with floating sand grains. Microscopic examination reveals 95 percent dolomite, 4 percent quartz, and 1 percent iron oxide coating.
12.7	Quartzose dolomite: greyish orange (10YR7/4). Quartz grains are silt size, sub-rounded, and medium sphericity. Dolomite and calcite are medio-crystalline. Has poor pin-point porosity with concentrations of iron oxide in the pores. Microscopic examination reveals 20 percent quartz, 77 percent dolomite and calcite, and 3 percent iron oxide (coating on carbonate and quartz grains). Carbonates fill fractures in the quartz grains.
7.6	Calcareous orthoquartz sandstone: dark yellowish orange (10YR6/6). Quartz grains are very fine grained, sub-rounded, and highly spherical. The carbonate matrix effervesces in cold, dilute HCl. Microscopic examination reveals 42 percent quartz (some grains contain gas bubble inclusions, many having undulatory extinction), 50 percent carbonate, 8 percent iron oxide (coating the grains and concentrated in pin head masses in the pores), traces of muscovite, biotite, tourmaline, and rounded grains of magnetite.
12.7	Calcareous orthoquartz sandstone: dark yellowish orange (10YR6/6). Quartz is very fine grained. The carbonate matrix effervesces in cold, dilute HCl and the rock has poor pin-point porosity. Microscopic examination reveals 55 percent quartz (well-rounded, highly spherical, bubble inclusions, and undulatory extinction), 40 percent carbonate (some rhombohedrons, probably dolomite, are well developed along the edges of the pores), and 5 percent iron oxide coating the grains.
10.2	Calcareous orthoquartz sandstone: moderate reddish brown (10R4/6). Quartz of fine sand-grain size. Carbonate matrix effervesces in cold dilute HCl. In thin section it consists of 45 percent quartz, 45 percent carbonate, and 10 percent iron oxide coating the grains, and traces of biotite.
101.6	Orthoquartz sandstone: very pale orange (5YR8/2). Well-sorted, well-rounded, highly spherical quartz grains in the coarse-grained sand range. Quartz grains have a very thin coating of iron oxide on them. The sand is easily shoveled, but stands up in vertical faces. Cross-bedding is visible throughout the layer.
43.2	Orthoquartz sandstone: same as above except that cross-bedding is confined to the lower part of the bed with no discernable cross-bedding in the upper part.
58.4	Orthoquartz sandstone: same as above, cross-bedding is visible in the lower part only.

10.2	Orthoquartz sandstone: same as above, no visible cross-bedding.
53.3	Orthoquartz sandstone: same as above, no visible cross-bedding.
203.2	Orthoquartz sandstone: same as above.
5.1	Oligomictic, quartz pebble breccia: greyish orange (10YR8/4). Very angular quartz pebbles up to 10 cm diameter in a coarse-grained, well-sorted matrix. The average diameter of the sand grains is 0.4 mm. Iron oxide coats the sand and pebbles and also fills fractures in the pebbles. The thickness of the bed varies from 0.7 to 5.0 cm.

Total thickness of Winnipeg sandstone = 518.2 cm

5.1	Kaolinitic clay: quartzose, white, silt to clay range, some quartz grains are up to fine sand-grain size, non-calcareous. Kaolinitic odour. No preferred orientation of the platy clay particles. Greasy when wet. Thickness varies from 2.5 to 5.0 cm.

Weathered Precambrian

(Modified after Byers (1957)).

Prior to sampling, the outcrop face was scraped clear to remove any effects of possible leaching of cement, accumulation of dust, or preferential separation of grain sizes. All samples were collected in 22 litre plastic containers using vertical face channel sampling methods. Extreme care was exercised to minimize contamination by iron from shovels. Only the top 4.6 m of the section was sampled due to extensive sloughing of sand and dolomite into the trench.

Four samples were collected at this location. The sandstone intervals were selected on the basis of their apparent granulometry, accessibility, and thickness. The sample intervals are 0 to 1.10 m, 1.10 to 2.36 m, 2.36 to 4.00 m, and 4.00 to 4.6 m relative to the top of the Black Island Member.

Analytical Results

Granulometry

The sieving results (Figure 7) indicate the sediments are well sorted, and that the top 4 m is very slightly coarser and better sorted than the base of the tested section.

Despite the very narrow range in grain size of the samples tested from this locality, coarser and/or finer material may occur at other locations and at different stratigraphic intervals. The quartz pebble breccia and kaolinitic horizons overlying the weathered Precambrian (Byers, 1957) at this location may have been eroded or not deposited at other locations and subsequently deposited at higher stratigraphic intervals during a later sedimentary transgression.

Chemical

The chemical analyses of these sands (Tables 15a and 15b) show the Winnipeg Formation to be an excellent potential source of high quality silica suitable for almost all general applications. Of particular note is the lack of carbonates in the chemical analyses of these sediments. It is uncertain whether this is representative of the deposit in general or due to local near surface leaching.

The amount of contaminants increases in the finer grain size fractions, but they are generally considered to be insignificant. The heavy minerals are interpreted to be a predominant source of contaminants such as iron, alumina, potassium, and possibly calcium. Kaolin may also be a source of alumina in these samples.

Heavy Mineral Content

The heavy mineral content of the Winnipeg Formation that outcrops in Ballantyne Bay, Deschambault Lake (Figure 6) is less than 1 percent, and consists of: well-rounded magnetite (25 to 50 percent) and tourmaline (10 to 25 percent); well-rounded to poorly rounded zircon (1 to 5 percent); poorly rounded pyrite (25 to 50 percent), rutile (1 percent), and garnet (1 to 5 percent); and staurolite (1 to 5 percent) of unspecified roundness (Kupsch, 1952). Kupsch also reported that an outcrop on Amisk Lake did not have more than 1 percent heavy minerals consisting of 5 to 10 percent magnetite, 10 to 25 percent tourmaline, 5 to 10 percent pyrite, 1 to 5 percent zircon, 25 to 50 percent garnet, and 1 to 5 percent staurolite. Waters (1978a and b) reported average heavy mineral contents of selected sand size fractions from four sample localities in the area to be: 0.038 percent (0.031 to 0.050 percent) for the 40 to 60 mesh fraction, 0.257 percent (0.154 to 0.397 percent) for the 60 to 100 mesh fraction, 0.976 percent (0.527 to 1.833 percent) for the 100 to 140 mesh fraction, and 1.296 percent (0.292 to 2.236 percent) for the minus 140 mesh fraction.

A sample weighing 33.07 kg of the minus 10 mesh fraction of sediments from the top 4.40 m of the exposed section investigated by this study consists only of 0.06009 percent heavy minerals. Magnetic minerals were found to constitute approximately $3.02 \cdot 10^{-5}$ percent of the sample. Only 30.13 percent of the non-magnetic minerals recovered were of minus 10 to plus 100 mesh grain size. The majority (61.77 percent) of the heavy minerals present occur within the 100 to 200 mesh fraction.

The most abundant mineral grains in the plus 100 mesh heavy mineral fraction are: ilmenite (51.7 percent), tourmaline (28.2 percent), zircon (10.1 percent), staurolite (5.4 percent), garnet (2.0 percent), rutile (2.0 percent), and corundum (0.6 percent). In the minus 100 mesh fraction, the most abundant mineral grains are: ilmenite (49.6 percent), zircon (31.7 percent), tourmaline (13.7 percent), and garnet (5.0 percent). Some of the heavy minerals have a strong prevalence by grain size; of particular note is the restriction of staurolite, rutile, and corundum (very rare) to the 10 to 35 mesh size frac-

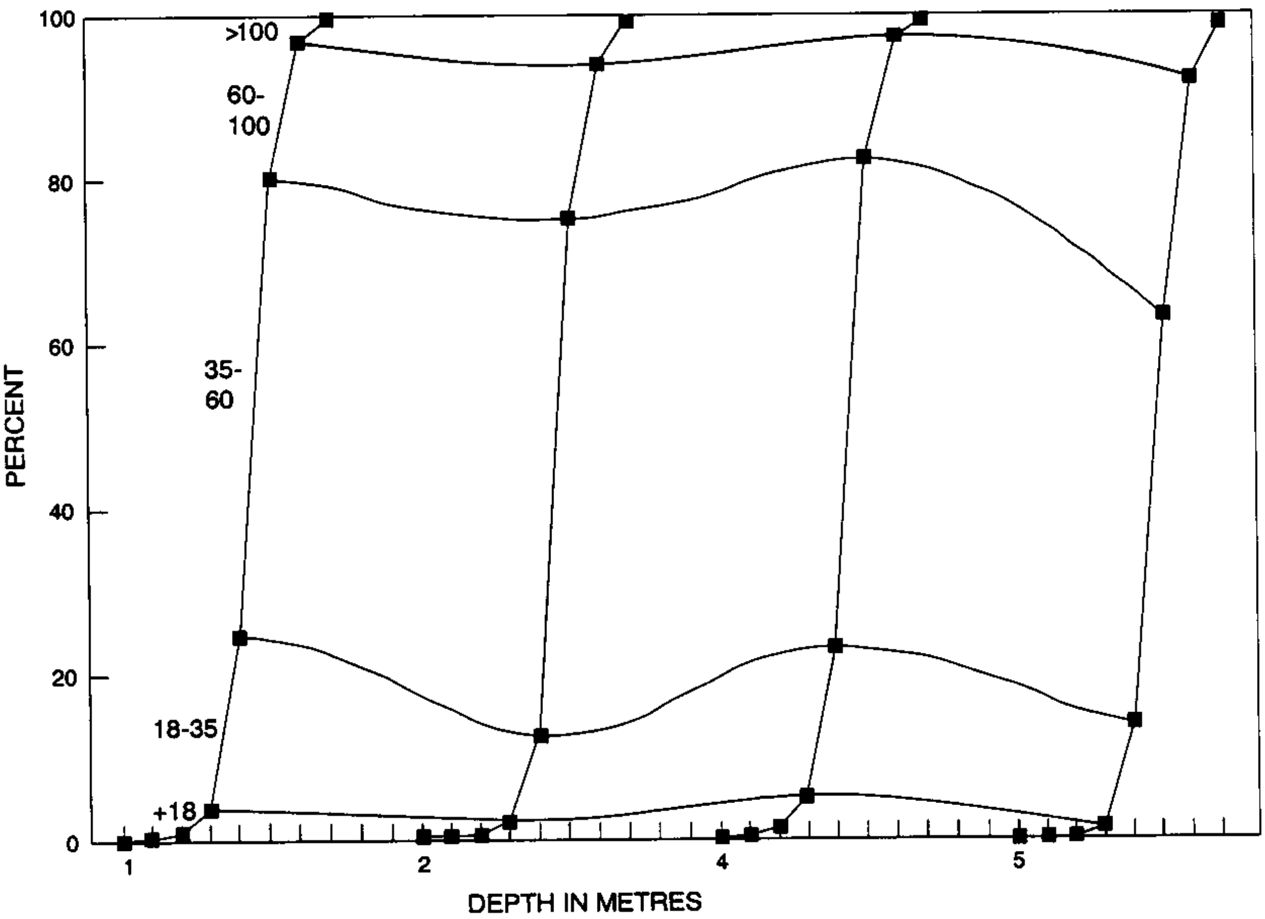

Figure 7 - Grain size distribution of the Winnipeg Formation sands from the southwest shore of Hanson Lake, Saskatchewan.

tion whereas zircon is most abundant in the minus 200 mesh fraction. Garnets are most common in the coarsest and finest fractions but rare to absent in the mid-range (minus 35 to plus 200) fractions. Tourmaline is most predominant in the 35 to 60 mesh range. Ilmenite is a major component in all grain size ranges, but is most significant in the 60 to 200 mesh size.

The samples from the present study have substantially lower heavy mineral content than those reported in earlier studies. Some variation between sample sites is expected. The differences are not considered significant except in ore processing design for a mining operation. However, they may result, in part, from statistical errors introduced by presumably smaller sample volumes in the earlier investigations and possibly by minor contamination from overburden material. The distribution of heavy minerals is similar with the exception of magnetite which was not detected in significant amounts in this study. It is speculated that ilmenite may have been incorrectly identified as magnetite in original microscopic examinations.

Pack and Fracturing Sand Analysis

Previous investigations by Kupsch (1952), Genik (1952), Chernoff (1955), and Waters (1977, 1978a and b) have shown the Winnipeg Formation sands are well suited to a number of applications including use as a pack sand for groundwater wells and as a fracturing sand in petroleum wells.

Pack sands require a high degree of chemical purity, uniform grain size, roundness, and sphericity to optimize fluid flow into a well without winnowing finer sediments from the aquifer or contaminating the water. Chernoff's (1955) determinations of grain roundness and sphericity for Hanson Lake sands (Table 16) and Kupsch's (1952) roundness values for Amisk Lake deposits (Table 17) are very encouraging with respect to pack sand applications. The Amisk Lake sand roundness and sphericity values are slightly lower but still have comparable values. The mid-size (14 to 28 mesh) grains are the most rounded and the finest are the least rounded. These characteristics also suggest that the range in grain sizes of these sands would be applicable to foundry sand, especially in core and moulding applications.

Table 15a - Analyses of the Winnipeg Formation silica sands from the southwest shore of Hanson Lake, Saskatchewan.

Sample interval		Weight	Weight	LOI	SiO_2	Al	Fe	Ca	Mg	Na	K	P	Ti	S	C	Mn	Ba	Co	Cu	Cr	Ni	Zr	B	CO_{3-2}
(metres)	Mesh	g	%	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%
0.0-1.10	(+5)	0.59	0.118																					
	(-5+10)	3.272	0.656																					
	(-10+18)	13.038	2.608																					
	(-18+35)	107.182	21.440	<0.01		0.037	0.010	0.005	0.006	0.002	0.013	0.003	0.008	<0.01	<0.05	1.3	4.6	<0.05	0.8	1.7	0.7	14.2	27	<0.05
	(-35+60)	273.448	54.710	0.20		0.032	0.010	0.006	0.005	0.002	0.011	0.004	0.008	<0.01	<0.05	1.4	5.7	<0.05	0.7	1.8	<0.5	13.6	15	<0.05
	(-60+100)	84.528	16.911	0.20		0.033	0.028	0.005	0.006	0.002	0.012	0.003	0.034	<0.01	<0.05	8.8	4.7	<0.05	0.7	2.5	<0.5	51.2	25	<0.05
	(-100+200)	14.336	2.868	0.10		0.043	0.270	0.010	0.009	0.002	0.014	0.006	0.386	<0.01	<0.05	118.0	13.6	<0.05	0.5	13.3	1.5	588.0	67	<0.05
	(-200)	3.445	0.689																					
		499.815	100.000																					
1.10-2.36	(+5)	0.469	0.094																					
	(-5+10)	1.412	0.283																					
	(-10+18)	9.034	1.811																					
	(-18+35)	53.247	10.673	0.20		0.036	0.007	0.008	0.006	0.002	0.013	0.003	0.008	<0.01	<0.05	1.3	4.4	<0.05	0.7	1.3	<0.5	13.8	16	<0.05
	(-35+60)	312.044	62.547	0.15		0.035	0.010	0.005	0.006	0.002	0.013	0.004	0.010	<0.01	<0.05	1.7	5.7	<0.05	0.7	1.4	<0.5	14.8	23	<0.05
	(-60+100)	91.3	18.301	<0.01		0.039	0.024	0.008	0.007	0.002	0.016	0.003	0.032	<0.01	<0.05	8.9	4.8	<0.05	0.9	2.8	<0.5	29.8	33	<0.05
	(-100+200)	27.298	5.472	0.20		0.051	0.158	0.011	0.010	0.002	0.019	0.006	0.242	<0.01	<0.05	74.0	8.8	<0.05	0.5	4.9	1.0	423.0	47	<0.05
	(-200)	4.088	0.819																					
		498.882	100.000																					
2.36-4.00	(+5)	0.317	0.063																					
	(-5+10)	4.8	0.956																					
	(-10+18)	18.564	3.698																					
	(-18+35)	91.76	18.280	0.25	99.76	0.033	0.006	0.004	0.005	0.002	0.011	0.003	0.008	<0.01	<0.05	1.3	4.3	<0.05	0.8	1.4	<0.5	12.7	<10	<0.05
	(-35+60)	297.798	59.325	0.15	99.71	0.032	0.012	0.004	0.006	0.001	0.011	0.003	0.012	<0.01	<0.05	2.1	5.8	<0.05	0.6	1.8	<0.5	12.6	14	<0.05
	(-60+100)	71.855	14.314	0.20	99.64	0.034	0.030	0.005	0.006	0.001	0.012	0.002	0.039	<0.01	<0.05	9.9	5.3	<0.05	0.5	2.3	<0.5	40.0	31	<0.05
	(-100+200)	14.186	2.826	0.25	99.65	0.045	0.226	0.010	0.009	0.002	0.015	0.006	0.321	<0.01	<0.05	87.0	10.4	<0.05	0.4	9.1	1.7	818.0	37	<0.05
	(-200)	2.692	0.536																					
		501.975	100.000																					
4.00-4.80	(+5)	0	0.000																					
	(-5+10)	0.87	0.178																					
	(-10+18)	6.062	1.241																					
	(-18+35)	60.902	12.467	0.25		0.042	0.008	0.006	0.007	0.002	0.016	0.003	0.007	<0.01	<0.05	1.5	4.8	<0.05	1.3	1.4	<0.5	16.7	20	<0.05
	(-35+60)	241.6	49.458	0.15		0.042	0.010	0.007	0.007	0.002	0.016	0.004	0.008	<0.01	<0.05	1.6	5.8	<0.05	1.3	1.4	<0.5	14.8	23	<0.05
	(-60+100)	139.006	28.456	0.20		0.045	0.020	0.007	0.008	0.002	0.018	0.003	0.028	<0.01	<0.05	7.4	4.9	<0.05	1.1	1.8	<0.5	29.8	42	<0.05
	(-100+200)	32.905	6.736	0.20		0.058	0.246	0.014	0.012	0.002	0.022	0.006	0.373	<0.01	<0.05	119.0	10.0	<0.05	0.8	5.3	1.5	581.0	60	<0.05
	(-200)	7.154	1.464																					
		488.499	100.000																					

Table 15b - Calculated oxides and some measured silica values of the Winnipeg Formation silica sands from the southwest shore of Hanson Lake, Saskatchewan.

Sample		LOI	kaolin	Al_2O_3	Fe_2O_3	FeO(OH)	CaO	MgO	Na_2O	K_2O	P_2O_5	TiO_2	C	S	MnO	BaO	Co	CuO	Cr_2O_3	NiO	$ZrSiO_4$	ZrO_2	B_2O_3	rawSiO_2	drySiO_2	SiO_2 (grav.)
Interval (m)	Mesh	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
0.0-1.10	(+5)																									
	(-5+10)																									
	(-10+18)																									
	(-18+35)	0.00	0.177	0.070	0.014	0.013	0.012	0.010	0.003	0.016	0.005	0.008	0.00	0.00	0.000	0.001	0.000	0.000	0.000	0.000	0.005	0.002	0.008	99.744	99.744	
	(-35+60)	0.20	0.153	0.080	0.014	0.013	0.012	0.008	0.003	0.013	0.007	0.011	0.00	0.00	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.002	0.005	99.571	99.771	
	(-60+100)	0.20	0.158	0.082	0.041	0.036	0.012	0.010	0.003	0.014	0.005	0.045	0.00	0.00	0.001	0.001	0.000	0.000	0.000	0.000	0.016	0.007	0.008	99.494	99.693	
	(-100+200)	0.10	0.208	0.081	0.366	0.352	0.023	0.015	0.003	0.017	0.014	0.488	0.00	0.00	0.015	0.002	0.000	0.000	0.002	0.000	0.128	0.081	0.022	99.622	99.720	
	(-200)																									
1.10-2.36	(+5)																									
	(-5+10)																									
	(-10+18)																									
	(-18+35)	0.20	0.172	0.088	0.010	0.008	0.014	0.010	0.003	0.016	0.006	0.008	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.006	99.554	99.753	
	(-35+60)	0.15	0.167	0.088	0.014	0.013	0.012	0.010	0.003	0.016	0.007	0.013	0.00	0.00	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.002	0.007	99.598	99.747	
	(-60+100)	0.00	0.167	0.074	0.034	0.031	0.014	0.012	0.003	0.018	0.005	0.043	0.00	0.00	0.001	0.001	0.000	0.000	0.000	0.000	0.008	0.004	0.011	99.689	99.689	
	(-100+200)	0.20	0.244	0.086	0.226	0.206	0.026	0.017	0.003	0.023	0.011	0.323	0.00	0.00	0.010	0.001	0.000	0.000	0.001	0.000	0.086	0.057	0.016	98.837	99.035	
	(-200)																									
2.36-4.00	(+5)																									
	(-5+10)																									
	(-10+18)																									
	(-18+35)	0.25	0.158	0.082	0.011	0.010	0.009	0.008	0.003	0.013	0.006	0.008	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.000	99.531	99.780	99.76
	(-35+60)	0.15	0.153	0.080	0.017	0.016	0.009	0.008	0.001	0.013	0.006	0.016	0.00	0.00	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.002	0.006	99.619	99.769	99.71
	(-60+100)	0.20	0.163	0.084	0.043	0.039	0.012	0.010	0.001	0.014	0.004	0.062	0.00	0.00	0.001	0.001	0.000	0.000	0.000	0.000	0.008	0.006	0.010	99.465	99.664	99.64
	(-100+200)	0.25	0.215	0.085	0.323	0.295	0.023	0.015	0.003	0.018	0.014	0.426	0.00	0.00	0.013	0.001	0.000	0.000	0.001	0.000	0.124	0.083	0.012	98.587	98.834	98.85
	(-200)																									
4.00-4.80	(+5)																									
	(-5+10)																									
	(-10+18)																									
	(-18+35)	0.25	0.201	0.079	0.011	0.010	0.014	0.012	0.003	0.018	0.006	0.009	0.00	0.00	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.002	0.008	99.465	99.714	
	(-35+60)	0.15	0.201	0.079	0.014	0.013	0.016	0.012	0.003	0.019	0.007	0.011	0.00	0.00	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.002	0.007	99.557	99.706	
	(-60+100)	0.20	0.215	0.085	0.028	0.026	0.016	0.013	0.003	0.022	0.006	0.036	0.00	0.00	0.001	0.001	0.000	0.000	0.000	0.000	0.006	0.004	0.014	99.443	99.642	
	(-100+200)	0.20	0.278	0.110	0.356	0.323	0.033	0.020	0.003	0.027	0.014	0.486	0.00	0.00	0.015	0.001	0.000	0.000	0.001	0.000	0.117	0.076	0.018	98.452	98.648	
	(-200)																									

Fracturing sands are used as a "propping agent" in the hydraulic fracturing of petroleum-bearing formations to enhance permeabilities. These require the same characteristics as pack sands but grains must also have a high compressive strength. Samples of the Winnipeg Formation silica sands from the Hanson Lake area were tested and found suitable for use as a hydraulic fracturing sand (Tables 18 and 19). Krumbein grain roundness analysis for these sands exceed the reported values of Texas Frac Sand (Waters, 1978a) which is thought to be the most widely used in North America. The compressive strength of the Winnipeg sands varies, but not substantially. The relatively abundant minus 20 to plus 40 mesh fraction compares favourably to Ottawa Sand, which is classified as a "deep frac sand". The less abundant minus 10 to plus 20 and minus 8 to plus 12 fractions were found to have slightly lower compressive strengths than the Texas Frac sands.

Table 16 - Krumbein roundness and sphericity of Winnipeg Formation sands from Hanson Lake, Saskatchewan (after Chernoff, 1955). The degree of roundness and sphericity increases from 0.1 to 0.9.

Sample	Tyler Mesh Size	Percentile Roundness			Percentile Sphericity		
		0.1 to 0.3	0.4 to 0.6	0.7 to 0.9	0.1 to 0.3	0.4 to 0.6	0.7 to 0.9
1	+9	27	55	18	0	36	64
	-9+16	10	27	63	0	3	97
	-16+32	5	20	75	0	3	97
	-32+60	12	27	61	0	28	72
	-60+115	25	50	25	6	60	34
	-115+250	50	44	6	30	40	30
2	+9	10	30	60	0	9	91
	-9+16	10	30	60	0	9	91
	-16+32	5	15	80	0	0	100
	-32+60	8	30	62	0	18	82
	-60+115	32	60	8	13	43	44
	-115+250	36	60	4	7	27	66
3	+9	0	100	0	0	0	100
	-9+16	10	30	60	0	24	76
	-16+32	0	30	70	0	3	97
	-32+60	15	35	50	0	30	70
	-60+115	12	60	28	0	27	73
	-115+250	36	58	6	12	33	55

Table 17 - Percentage distribution of roundness by sieve fraction of Winnipeg Formation sands from Amisk Lake, Saskatchewan (after Kupsch, 1952).

Tyler Mesh Size	Roundness		
	0.1 to 0.3	0.4 to 0.6	0.7 to 0.9
+14	40 %	40 %	20 %
+28 to 14	10 %	30 %	60 %
+48 to 28	10 %	30 %	60 %
+100 to 48	40 %	30 %	30 %
+200 to 100	85 %	10 %	5 %
-200	95 %	5 %	0 %

Table 18 - Average per grain compressive strengths for Saskatchewan Winnipeg Formation sands (after Waters, 1978a). Values expressed as decanewtons per grain.

Source	Tyler Mesh Size Range						
	-8+10	-10+12	-12+14	-14+16	-16+18	-18+20	-20+25
S.R.C.	14.38	10.00	9.37	10.24	14.66	7.91	10.01
Holoc. #1	N/A	N/A	11.34	10.78	9.59	10.62	7.90
Holoc. #2	N/A	N/A	10.25	9.40	8.58	6.58	6.90
Average Values	N/A	N/A	10.32	10.14	10.94	8.37	8.27

Notes:
S.R.C. = Saskatchewan Research Council
Holoc. #1 = Unit 3 in the Holocene Resources Ltd. Outlier H
Holoc. #2 = a pink sandstone in Holocene Resources Ltd. Outlier B

Table 19 - Computed compressive strength values for Winnipeg Formation sands from the Hanson Lake area, Saskatchewan (after Waters, 1978a). Values expressed as decanewtons per grain.

Tyler Mesh Size	Average per Average Particle Size (Tyler Mesh)	Computed* Grain Load (daN)	Compressive Strength (kPa)
-8+10	9	16.15	65 500
-8+12	10	12.19	55 200
-10+12	11	13.92	62 000
-12+14	13	11.17	58 600
-14+16	15	12.46	75 800
-16+18	17	12.50	93 000
-18+20	19	9.12	86 200
-10+20	15	9.95	62 000
-20+40	28	7.62	83 000

* Based on statistical average of all test data.

Metallurgical Processing Investigations of the Silica Sands from the Mannville and Winnipeg Formations, Saskatchewan

Saskatchewan Energy and Mines (S.E.M.) contracted[1] I.M.D. Laboratories Ltd. to investigate various methods for benificiating silica sands (I.M.D., 1992b and 1993) and evaluating their "high tech" market potential (I.M.D., 1992a). I.M.D. demonstrated that the sands of both the Mannville and Winnipeg formations can be benificiated to meet the specifications for most high tech applications.

I.M.D.'s tests (Tables 20 to 23) show that attrition scrubbing, magnetic separation, acid leaching, and calcination all substantially reduced contaminants, yielding a product of similar quality to the Quintus quartz produced by UNIMIN Corporation, Spruce Pine, North Carolina, U.S.A. With the exception of the Red Deer Bluff sample, froth flotation methods for removing refractory minerals were not found to be particularly successful. I.M.D. does suggest that further investigation of flotation processing is warranted.

Although it has already been shown by S.E.M. (this report) that most of the contaminants are present in the fine fraction (minus 100 mesh) for all of the silica sands tested, I.M.D.'s benification studies were based upon the minus 40 to plus 140 mesh sample fractions so as to minimize ore waste. However, this has resulted in higher concentrations of heavy minerals and feldspars in the sample fraction tested. I.M.D.'s silica values are also significantly lower than those obtained by S.E.M. because a large portion of the contaminants are kaolin. Most of the kaolin can be removed by wet screening, but some kaolin, that is bound to the quartz grains, can also be removed by attrition scrubbing and/or other processes.

Testing of a slightly coarser (minus 40 to plus 100 mesh) fraction would probably have significantly reduced the contaminants (e.g. garnets, staurolite, andalusite, rutile, and ilmenite) present in the samples.

Very little waste would have resulted in the case of the Winnipeg Formation sands which have 94.6 percent coarser than 100 mesh and 76 percent between 35 and 100 mesh. However, much larger wastage would occur with the Mannville Formation sands where:

1. the Red Deer quarry deposit is 91.3 percent plus 100 mesh but only 59.5 percent is between 35 and 100 mesh,
2. the top 4 m of the Red Deer Bluff samples are very fine but the lower 8 m have 73.9 percent plus 100 mesh and 72.2 percent 35 to 100 mesh, and
3. the Nipekamew River section has 74.9 percent plus 100 mesh but only 29.1 percent 35 to 100 mesh.

Losses would be significantly lowered if the sands processed are restricted to the plus 100 or 120 mesh fraction.

I.M.D. (1993) suggested testing a high gradient or permroll magnetic separator. Very high intensity magnetic separators might remove more of the paramagnetic minerals (e.g. limenite and almandine) and possibly quartz grains with inclusions of such minerals. Alternatively, density separation methods such as spiral concentrators, jigging or shaker tables, or Reichert cones might also prove effective in removing many of these contaminants.

Recent information (D. Weston, pers. comm., 1993) suggests that there are also other effective low cost upgrading methods that have not yet been tested on Saskatchewan silica sands. These methods could produce a product of significantly greater purity with high market value (up to U.S.$1,500 per tonne) suitable for high tech applications such as fused silica, metallurgical grade silicon, optical fibers, etc.

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(1) Funding provided by CANMET under the Canada-Saskatchewan Partnership Agreement on Mineral Development 1990-95.

Table 20 - Results of processing of Mannville Formation silica sand (35 to 140 mesh size) from the Red Deer Silica Inc. quarry, Saskatchewan.

	1	2	3	4	5	6	7	8	9
SiO_2 (%)	96.88	99.10	98.70	99.30	99.40	99.30	99.60	N.D.	N.D.
Al_2O_3 (ppm)	12 100	1 900	1 600	1 500	1 400	1 600	1 400	250	190
CaO (ppm)	<100	<100	<100	<100	<100	<100	<100	<20	<20
MgO (ppm)	600	500	400	300	200	500	400	3	<3
Na_2O (ppm)	<100	<100	<100	<100	<100	<100	<100	<5	<5
K_2O (ppm)	1 700	1 100	1 000	1 000	900	1 000	800	<20	13
Fe_2O_3 (ppm)	4 700	500	100	80	76	200	170	80	60
MnO (ppm)	100	100	100	100	100	100	100	3	3
TiO_2 (ppm)	1 200	700	570	290	300	300	240	110	160
P_2O_5 (ppm)	300	200	200	200	200	200	200	50	<10
LOI (ppm)	8 600	3 000	200	2 000	2 800	2 000	2 000	N.D.	N.D.
Cr (ppm)	600	78	13	19	13	17	13	5	<1
Rb (ppm)	12	16	32	32	<10	<10	<10	N.D.	N.D.
Sr (ppm)	7	<10	<10	<10	<10	<10	<10	<1	<1
Y (ppm)	13	<10	<10	<10	10	16	<10	<1	<1
Zr (ppm)	82	50	24	34	29	34	29	<1	19
Nb (ppm)	28	31	18	29	17	<10	<10	8	<1
Ba (ppm)	129	110	59	38	25	10	<10	22	4

Notes:
1 = Unprocessed sample analysis
2 = 5 minute attrition scrubbed (A.S.) sample analysis
3 = Two stage A.S., second stage with H_2SO_4 sample analysis
4 = A.S. and HCl acid leached sample analysis
5 = A.S. and H_2SO_4 acid leached sample analysis
6 = A.S. and magnetically separated (M.S.) sample analysis
7 = A.S., M.S., and froth flotated sample analysis
8 = A.S., M.S. and acid leached (HCl, H_2SO_4 and HF) sample analysis
9 = A.S., M.S., and calcined sample analysis
N.D. = not determined

Table 21 - Results of processing of Mannville Formation silica sand (35 to 140 mesh size) from the Red Deer River bluff, Saskatchewan.

	1	2	3	4	5	6	7	8
SiO_2 (%)	96.55	98.45	98.60	99.20	99.00	98.90	99.50	N.D.
Al_2O_3 (ppm)	14 500	4 200	3 900	3 200	3 300	4 100	700	260
CaO (ppm)	900	<100	<100	<100	<100	<100	<100	<20
MgO (ppm)	1000	700	500	300	200	300	<100	8
Na_2O (ppm)	<100	<100	<100	<100	<100	<100	<100	<5
K_2O (ppm)	2 400	2 100	2 000	1 800	1 800	2 000	100	<20
Fe_2O_3 (ppm)	3 700	500	470	86	71	300	110	80
MnO (ppm)	200	200	200	100	100	100	100	3
TiO_2 (ppm)	2 800	2 100	2 190	700	700	710	460	230
P_2O_5 (ppm)	300	300	200	200	200	200	200	70
LOI (ppm)	7 800	3 800	1 500	4 000	3 000	2 500	2 600	N.D.
Cr (ppm)	400	23	15	19	21	18	16	4
Rb (ppm)	18	10	14	25	18	16	15	N.D.
Sr (ppm)	<10	<10	<10	<10	<10	<10	<10	1
Y (ppm)	15	14	21	<10	<10	<10	<10	1
Zr (ppm)	514	382	665	505	535	544	62	<1
Nb (ppm)	24	19	14	<10	16	22	15	12
Ba (ppm)	149	125	90	41	57	25	58	61

Notes:
1 = Unprocessed sample analysis
2 = 5 minute attrition scrubbed (A.S.) sample analysis
3 = Two stage A.S., second stage with H_2SO_4 sample analysis
4 = A.S. and HCl acid leached sample analysis
5 = A.S. and H_2SO_4 acid leached sample analysis
6 = A.S. and magnetically separated (M.S.) sample analysis
7 = A.S., M.S., and froth flotated sample analysis
8 = A.S., M.S. and acid leached (HCl, H_2SO_4 and HF) sample analysis
N.D. = not determined

Table 22 - Results of processing of Mannville Formation silica sand from (35 to 140 mesh size) the Nipekamew River bluff, Saskatchewan.

	1	2	3	4	5	6	7	8
SiO_2 (%)	94.55	98.43	98.60	99.10	99.20	99.00	99.10	N.D.
Al_2O_3 (ppm)	30 300	2 100	2 300	2 500	2 800	2 500	2 000	150
CaO (ppm)	<100	<100	<100	<100	<100	<100	<100	<20
MgO (ppm)	600	600	500	300	200	300	100	10
Na_2O (ppm)	<100	<100	<100	<100	<100	<100	<100	<5
K_2O (ppm)	2 600	1 000	1 100	1 100	1 500	1 200	1 200	<20
Fe_2O_3 (ppm)	4 600	500	200	84	112	100	90	80
MnO (ppm)	100	100	100	100	100	100	100	3
TiO_2 (ppm)	1 800	700	820	480	510	510	460	200
P_2O_5 (ppm)	300	200	200	200	200	200	200	50
LOI (ppm)	14 800	3 900	2 000	3 500	3 000	4 000	2 600	N.D.
Cr (ppm)	600	14	15	17	23	25	16	2
Rb (ppm)	12	7	13	11	<10	12	15	N.D.
Sr (ppm)	27	<10	<10	<10	<10	<10	<10	1
Y (ppm)	11	5	<10	<10	<10	<10	<10	2
Zr (ppm)	142	71	83	79	76	114	62	<1
Nb (ppm)	4	25	24	30	17	29	15	16
Ba (ppm)	178	97	86	41	67	75	58	44

Notes:
1 = Unprocessed sample analysis
2 = 5 minute attrition scrubbed (A.S.) sample analysis
3 = Two stage A.S., second stage with H_2SO_4 sample analysis
4 = A.S. and HCl acid leached sample analysis
5 = A.S. and H_2SO_4 acid leached sample analysis
6 = A.S. and magnetically separated (M.S.) sample analysis
7 = A.S., M.S., and froth flotated sample analysis
8 = A.S., M.S. and acid leached (HCl, H_2SO_4 and HF) sample analysis
N.D. = not determined

Table 23 - Results of processing of Winnipeg Formation silica sand (35 to 140 mesh size) from Hanson Lake, Saskatchewan.

	1	2	3	4	5	6	7	8	9
SiO_2 (%)	99.10	99.20	99.20	99.50	99.50	99.50	99.60	N.D.	N.D.
Al_2O_3 (ppm)	1 400	<100	<100	<100	<100	<100	<100	180	180
CaO (ppm)	<100	<100	<100	<100	<100	<100	<100	<20	<20
MgO (ppm)	700	500	500	200	300	200	200	3	<2
Na_2O (ppm)	<100	<100	<100	<100	<100	<100	<100	<5	<5
K_2O (ppm)	300	<100	<100	<100	<100	<100	<100	<20	10
Fe_2O_3 (ppm)	4 600	300	114	70	80	100	70	50	50
MnO (ppm)	100	100	100	100	100	100	100	1	2
TiO_2 (ppm)	600	500	570	300	350	300	270	90	70
P_2O_5 (ppm)	300	200	200	200	200	200	200	40	<10
LOI (ppm)	1 600	4 000	1 500	2 000	1 500	3 000	2 800	N.D.	N.D.
Cr (ppm)	700	14	13	17	15	17	12	<1	<1
Rb (ppm)	16	11	<10	11	17	88	<10	N.D.	N.D.
Sr (ppm)	36	<10	<10	<10	<10	<10	<10	1	<1
Y (ppm)	11	12	<10	<10	<10	<10	<10	<1	<1
Zr (ppm)	148	71	75	75	84	56	34	<1	32
Nb (ppm)	<10	<10	15	17	17	11	<10	3	<1
Ba (ppm)	185	75	19	<10	<10	<10	<10	11	2

Notes:
1 = Unprocessed sample analysis
2 = 5 minute attrition scrubbed (A.S.) sample analysis
3 = Two stage A.S., second stage with H_2SO_4 sample analysis
4 = A.S. and HCl acid leached sample analysis
5 = A.S. and H_2SO_4 acid leached sample analysis
6 = A.S. and magnetically separated (M.S.) sample analysis
7 = A.S., M.S., and froth flotated sample analysis
8 = A.S., M.S. and acid leached (HCl, H_2SO_4 and HF) sample analysis
9 = A.S., M.S., and calcined sample analysis
N.D. = not determined

Potential Specialty Applications of Saskatchewan Silica Sands

The recent closure of the Domglass Inc. container glass plant at Redcliff, Alberta further limits the prairie region's viable market for silica sands in the glass industry. This limited market situation is probably true for all low-value, minimal processing applications such as in foundry and sand blasting uses. However, the high-value of high-purity silica sands, and specialty silicas in particular, would tend to insulate a producer from the effects of long transportation distances. Furthermore, deposits of silica sands in Saskatchewan are relatively well situated to serve specialized markets in both eastern and western North America.

I.M.D. (1992b and 1993) demonstrated that both the Mannville Formation and Winnipeg Formation sands can be processed to meet a number of applications. Since the Winnipeg Formation sands are the purest, they tend to require less processing to meet particular specifications. However, the difference in extent of processing required by any of these sands to meet given specifications is probably not significant.

Packing and Fracturing Sands

The Winnipeg Formation silica sands have the best potential to meet the physical and chemical requirements for packing and fracturing sands with minimal processing.

Deposits in the Hanson Lake to Deschambault Lake area in particular, have an excellent potential for supporting an economically viable packing and fracturing sand quarrying operation. This deposit is well located to compete for the petroleum and groundwater well markets in central North America. Currently Texas is the major supplier for the region. Packing sands may represent a higher market volume application than the fracturing sand applications, but the latter may have the higher market value. A resource meeting the requirements of both applications may constitute a particularly viable source to supply these markets.

Quartz Fibers

Silica sands of >99 percent purity, such as those in Saskatchewan, can be used to produce quartz fibers of remarkable strength and flexibility. Most applications are in the aerospace industry as ablatives for structural supports and in electrical applications for radomes and antennae. The higher mechanical strength of carbon-carbon composites valued at up to $1,000 per pound however, are replacing quartz fibers in some applications, even though they are valued at $5 to $150 per pound (Harris *et al.*, 1987).

High Purity Quartz

Silica of extremely high purity (<500 ppm contaminants), required to produce high purity quartz fibers, was valued at $0.20 to $2.00 per pound in 1987 (Harris *et al.*, 1987). Rock crystal/lasca has been a traditional source for this commodity, but the UNIMIN Corporation mine at Spruce Pine, N.C. has demonstrated that other sources can be exploited using crushing, screening, froth flotation, and high temperature calcining. I.M.D.'s 1993 investigations have demonstrated that such purity can be produced from the Mannville and Winnipeg formation sands. They would constitute the only source in western North America. Such a product could supply a number of markets including the production of fused quartz, cultured quartz, and optical glass with end uses for semiconductors, specialty lighting, fibre optics, and precision optics. The development of such an operation would require further metallurgical investigations and cost analyses.

Fused Silica

Harris *et al.* (1987) state that the fused silica market offers limited opportunities due mainly to: a lack of deposits of sufficiently high purity; increased exports by Japanese producers into North America; and excessive existing capacity in North America. If the Japanese have been able to expand their share of the North American market, then it is postulated that the market potential for this commodity may be much better than reported, provided that the required energy costs are low enough and that there are adequately pure deposits of silica or that the silica sands are amenable to purification at a sufficiently low cost. It is anticipated that both the Mannville and Winnipeg formation silica sands can meet the required specifications (99.60 to 99.85 percent SiO_2, 0.10 to 0.20 percent Al_2O_3, 0.02 percent Fe_2O_3, 0.01 percent TiO_2, 0.0015 percent Na, 0.0035 percent K, and 0.02 percent H_2O) with minimal processing (such as attrition scrubbing and wet sieving) with possibly high-intensity magnetic separation and high-temperature drying or calcining.

Silicon Metal

Based upon chemical purity, the Winnipeg Formation silica sands, and probably a treated form of the Mannville Formation silica sands, are suitable for production of silicon metal. The grain size of these sands is much too fine to be used in conventional silicon furnaces unless previously fused to form lump quartz; however, Dow Energy is presently testing a new process at a plant in Manitoba using a similar sand as feed-stock. If this plant proves to be effective, it is anticipated that the silica sands located close to transportation facilities and major power sources will be economically exploitable. This should include the Mannville sands near Hudson Bay (Red Deer River) and possibly those near Carrot River, as well as the Winnipeg Formation sands between Amisk Lake and Deschambault Lake.

Sodium Silicate

The sodium silicate market constitutes a major potential use for two of Saskatchewan's industrial mineral resources. A large volume of sodium silicate is consumed by the pulp and paper industry, as well as being used as the basis for producing a number of major commodities including zeolites, precipitated silica, silica gel, and colloidal silica.

Production of sodium silicate requires the reduction of quartz and sodium carbonate (soda ash), or sodium sulphate and carbon with the following reactions:

$$Na_2CO_3 + nSiO_2 = Na_2O \cdot nSiO_2 + CO_2$$

or

$$2Na_2SO_4 + 2C + nSiO_2 = 2Na_2O \cdot nSiO_2 + S + SO_2 + 2CO_2$$

The resources required in both of these processes are locally available. Saskatchewan is one of the world's major producers of sodium sulphate. Ormistron Mining and Smelting is presently developing soda ash production technology from its sodium sulphate deposit. Large reserves of coal and gas are available for heating and reduction. Saskatchewan is well located to supply a large part of the western pulp and paper market, as the only Canadian producers of sodium silicates are located in Toronto, Ontario; Valleyfield, P.Q.; Whitecourt, Alberta; and Nanaimo, British Columbia.

Silica sands for this application should contain SiO_2 >99.4 percent, Al_2O_3 and Fe_2O_3 <0.2 percent, TiO_2 <0.5 percent, and $CaO+MgO$ <0.05 percent. The silica sands from both the Mannville and Winnipeg formations meet these requirements.

The number of possible uses of synthetic zeolites produced from sodium silicate is considerable, and include: catalytic reforming, polymerization, alkylation, hydrodealkylation, hygrogenation, methanation, dehydrogenation, dehydration, dehydrohalogenation, ion exchange for collecting atomic waste and sewage treatment, nitrogen separation from air, and animal nutrition. The ability of zeolites to separate nitrogen and other gases from the atmosphere is expected to have major future environmental applications in reducing emissions (Breck, 1983; Mumpton, 1983).

Precipitated silica is used for: reinforcing fillers in rubbers and plastics; as an abrasive and thickening agent in dentifrice gels and tooth pastes; flatting agents in paints and coatings; for thixotropy and pigment suspension in unsaturated polyesters, adhesives, sealants and coatings; as a silica source in zeolite synthesis; as a carrier in pesticides; as a conditioning agent in foods and cosmetics such as deodorants, nail polishes, vitamin tablets, etc.; for battery separator applications; and as a dispersion-type defoamer (Harris *et al.*, 1987).

Silica gel is used for: modifying paint flatting, abrasion, scrub resistance, and rheological properties; in plastics for flatting, pigment dispersion, moisture absorption, and antiblocking applications; in pharmaceuticals as a carrier for liquid ingredients, defoamer, suspension aid, anticaking agent, and packing desiccant; for anticaking agent and chill stabilizer in beer; abrasive in polishes; support material in catalysts; image enhancer and antislip agent in paper; and for flow control and processing aid in adhesives (Harris *et al.*, 1987).

Colloidal silica is used as: a high temperature binder in investment casting, refractory cements, and vacuum-formed fibrous shapes; binder or support of catalysts; packing frictionization; anti-slip agent and cleaners for textiles; polishing electronic wafers; photographic film dye acceptor and crystal-growth regulator; paper frictionizer and contrast improver; adhesion promoter, wetting improver, and soil repellant in coatings; and antislip properties in waxes and polishes (Harris *et al.*, 1987).

All of these commodities are value-added products with relatively high market values. Of particular note are the present and potential environmental applications of zeolites. The development of synthetic zeolite production methods has enabled the design of zeolites of high efficiencies for particular applications. This could be of special interest to ongoing investigations in Saskatchewan and elsewhere into methods for reducing sulphur and CO_2 thermal-electric flue stack emissions. The mechanical removal of nitrogen from the atmosphere prior to combustion and the removal of CO_2 after combustion is extremely energy intensive. Zeolites are being used in Japan to accomplish this task with a pressure-swing adsorption process (Mumpton, 1983) which is probably far more energy efficient.

Conclusions

High purity and consistency is critical to most silica applications, particularly for the specialty silica market. Silica sands have an excellent potential for meeting these requirements because the natural process of sedimentary transport tends to separate or leach out many of the impurities from the quartz grains. The Early Ordovician Winnipeg Formation and the Cretaceous Mannville Group in Saskatchewan host an enormous reserve of relatively pure silica sand. Although the sands contain small amounts of impurities in the form of kaolin, carbon, mica, and heavy minerals, the impurities can be easily and effectively extracted using existing metallurgical methods.

The Canadian silica market for glass production is extremely competitive due to the relative abundance of this commonplace, low-value commodity. However, with only minor mechanical processing, these sands could meet the high specifications of the colourless and optical glass market where the supply is far more restricted. Since the unit value of silica is relatively small compared to the cost of the final products, silica consumers are frequently prepared to accept higher transport costs for a reliable source of consistently high quality raw material (Murphy and Henderson, 1983). Although resources are located near railways in the eastern part of the province, the silica sands in the Hanson Lake and Nipekamew River areas are more remote and might best be dedicated to the production of higher value specialty silica products that can support the higher production and shipping costs from these locations.

Silica Sands of the Mannville Group

The silica sands of the Mannville Group occurring in the Red Deer River and Nipekamew River areas, and those of the Winnipeg Formation occurring in the Hanson Lake area, are all of relatively high chemical purity and whiteness. The same quality is expected to persist laterally throughout large areas of east-central Saskatchewan that are underlain by these sediments. Investigations have shown that simple, low cost, high volume, processing methods could be used to beneficiate these silica sands to a grade suitable for the production of silicon, most silica-based chemicals, various types of glass, and many of the specialized silica applications.

The most obvious deleterious components of the sands are alumina and to a lesser extent iron, as well as trace amounts of other elements presumably tied up in the heavy minerals. Mica (probably phlogopite) and very friable grains of kaolinized feldspar are the most obvious contaminant minerals found in the sieve fractions. These minerals, and the heavy minerals, can be easily removed by low cost, large tonnage processing methods.

Carbon removal is required for the production of sand-lime bricks or for filler applications, but for silicon metal production, the presence of carbon is considered a bonus. Minor abrasion of the sand grains due to screening and homogenization of the samples reduces most of the carbon fraction to <200 mesh. The extraction of the heavy mineral and mica components of these sands is considered particularly important to meet the specifications of high-value silica market applications. This would also reduce the amounts of all other contaminants, especially iron oxides and alumina.

Attrition scrubbing with a deflocculant or an acid could be used to break down the kaolinized feldspars and separate the kaolin adhering to the quartz. Done in conjunction with heavy mineral and mica extraction or high intensity magnetic separation, this might be the best processing technique for specialized silica applications. The optical properties of the sample tested for filler applications appear encouraging and indicate that the if the sands were crushed finer, they might be well suited for such uses.

Silica Sands in the Hudson Bay Area

The silica sands outcropping along the Red Deer River appear to have a good potential for beneficiation. Iron oxide staining at the base of the exposed section represents a contamination problem, but fortunately it is not associated with higher concentrations of other contaminants. The iron staining may result from partial leaching of iron sulfide minerals and subsequent precipitation in present or paleo-vadose and intermittent phreatic zones. Similar, but very small-scale, localized *in situ* oxidation occurs in sulfide-rich zones which also tend to have a higher content of organic material.

The lateral and vertical variations in sorting and grain sizes between the base and the rest of the section are typical of continental sediments and probably persist throughout the deposit. Unless acids are to be used in the processing of these sands, a mining operation producing a particular grain size fraction would therefore be advised to map out the vertical and lateral granulometric stratigraphy.

The Red Deer River sands appear to be well suited to a number of applications, including specialty silicas. The area is in close proximity to excellent road and rail transportation facilities as well as the service infrastructure in the town of Hudson Bay. Although the reported occurrence of silica sands on the Carrot River (Beck, 1974) was not investigated, it is believed that these sands are probably very similar to those along the Red Deer River. If an occurrence with sufficient near-surface reserves and drainage also exists in that area, its close proximity to the Squaw Rapids hydro-electric plant and transportation facilities might also make it an ideal location for high-value silica production.

Silica Sands in the Nipekamew River Area

With proper processing, silica sands in the Nipekamew River area could yield suitable material for most silica sand applications. Their semi-remote location may prohibit their early development for the low-value silica markets; however, there is potential for the high-value market applications. They may contain sufficient material to warrant the separation and accumulation of the >1.52 cm fraction for use in silicon carbide production as a supplementary activity. Heavy mineral or high intensity magnetic separation alone will reduce most of the contaminants, especially iron and titanium oxides, and some of the alumina. Attrition scrubbing will be particularly effective in improving the quality of these sands. For high-value silica market applications mica and partially kaolinized feldspar must be removed.

It is suggested that the possibility of small amounts of gold being present in these sands be considered. The angularity of the silica grains suggests direct derivation from Shield rocks during a period of prolonged or intense chemical weathering so that only the relatively stable minerals have been preserved. Although economically mineable grades are highly unlikely, gold could be recovered as a secondary product during the heavy mineral extraction of a silica benification circuit.

Silica Sands of the Winnipeg Formation

The silica sands of the Winnipeg Formation that outcrop on Hanson Lake are of high purity. The purity is expected to be higher than normal because the rounded morphology of the grains indicates they have undergone considerable sedimentary transport and may be 3rd or 4th generation sands. This transportation process tends to liberate inclusions from grains as the silica grains break along plains of weakness and by chemical leaching of contaminants on grain surfaces.

Chemically, the Winnipeg Formation sands are adequate for a number of applications, including silicon production, specialty silicas, and all types of foundry, pack, and fracturing sands. These sands can be easily processed to remove most of the trace amounts of contaminants. High intensity magnetic and possibly heavy mineral separation methods, in conjunction with attrition scrubbing, should be effective in reducing the titanium, iron, and alumina contents, as well as some of the less common elements. Attrition scrubbing with or without the use of defloculants or acids is effective in reducing iron (present in the form of limonite) and alumina (present in the form of clays) which occur as coatings on some quartz grains. Attrition scrubbing alone will also help reduce any carbonate cement that may be present. Although micaceous minerals were not identified, some could be present; electrostatic separation should remove these along with any liberated clay minerals.

Mineable tonnages of Winnipeg Formation sands could be extremely large, as they probably outcrop or are at very shallow depths over a relatively large area from Deschambault Lake to Amisk Lake. Although the thin, well indurated dolomite that caps most of the silica sands in this area would have to be removed by any mining program, it would also protect the sand deposits from mixing with overburden material disturbed by the mining activities. Most of this area is in very close proximity to Highways 106 and 167. Excellent rail, energy, and service facilities are located at the nearby mining towns of Creighton, Saskatchewan and Flin Flon, Manitoba.

Recommendations

The relatively high purity and large reserves of silica sands in Saskatchewan warrants in-depth investigations to define these reserves as a function of quality, quantity, and stripping to ore ratios. Surface geophysical surveying with follow-up drill coring will be required to determine reliable reserve estimates and stripping ratios. Experimentation with correlating the sand quality with various electric well-logging parameters, including self-potential, resistivity, natural gamma, and nuclear logging methods, may prove especially useful in reducing the requirements for core analyses during a mining program.

Comprehensive metallurgical investigations are essential to define the optimum processing methods to meet a selected market(s) requirement(s) and should definitely include advanced processing methods to meet high-value silica applications. It is recommended that processing tests be directed toward various attrition scrubbing methods with and without acids or deflocculants, various heavy mineral separation techniques, high intensity magnetic and electrostatic separation, acid leaching, flotation cells, calcining, and chlorination treatments to supply the top end material for applications such as high purity optical fibre and fused quartz production.

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