RESEARCH COUNCIL OF ALBERTA

REPORT 70-1

SILICA SAND
IN THE VICINITY OF EDMONTON, ALBERTA

by

M. A. Carrigy

Research Council of Alberta
Edmonton, Alberta
1970

CONTENTS

ILLUSTRATIONS

TABLES

Page

SILICA SAND IN THE VICINITY OF EDMONTON, ALBERTA

Abstract

Eighteen samples of quartzose sand were collected from dune deposits near Edmonton. In order to determine their suitability for glass manufacture the samples were screened, washed, and analysed for silica, alumina, iron, calcium and magnesium.

Preliminary analyses indicated that 5 of the 18 samples merited further treatment involving heavy liquid separation, magnetic separation, and acid leaching to determine the lower limits of iron removal. The test results suggest that simple washing and screening treatments will upgrade approximately 50 per cent of the sand to meet the specifications of sand used in the manufacture of fibreglass, green and amber containers, and possibly some types of window glass. The limits of silica and iron contents after heavy liquid separation, magnetic separation, and acid leaching appear to be 95 - 96 per cent silica (SiO_2), 2 - 3 per cent alumina (Al_2O_3) and 0.15 - 0.20 per cent iron (Fe_2O_3). This iron content is too high for good quality plate and sheet glass manufacture.

INTRODUCTION

Silica sand is defined as sand which contains more than 90 per cent silica, the most common mineral form of which is quartz (SiO_2). Pure quartz sands [those composed entirely of SiO_2] are unknown; sands containing 98 - 99 per cent SiO_2 are extremely rare and eagerly sought for the manufacture of glass and for many other industrial uses.

At present, most silica sand needed in the Edmonton area is imported from other provinces or from the United States for use in the manufacture of glass fibre, for moulding purposes, in some asphalt roofing products, and for sandblasting. Special grades of high quality silica sand are also used by oil servicing companies for hydraulic fracturing. The specifications and uses of various grades of silica sand are given in tables 1 and 2.

This report contains the results of a preliminary survey of the most likely sources of silica sand within a 50-mile radius of the City of Edmonton. During the summer of 1968, 18 samples of sand were collected from dune fields to the north and southwest of Edmonton. The sample locations are given in table 3 and shown on figure 1. On each sample a

Table 1. Specifications for Glass Sand

A. Limits recommended by U.S. Bureau of Standards

Quality	Uses	Chemical Constituents*					
		SiO_2 (min.)	Fe_2O_3 (max.)	Al_2O_3 (max.)	CaO MgO (max.)	TiO_2	L.O.I.
1st	- optical glass	99.8	0.020	0.1	0.1		
2nd	- flint glass containers	98.5	0.035	0.5	0.2		
3rd	- flint glass	95.0	0.035	4.0	0.5		
4th	- sheet glass, rolled and polished plate	98.5	0.060	0.5	0.5		
5th	- rolled and polished plate	95.0	0.060	4.0	0.5		
6th	- green glass containers, window glass	98.0	0.300	0.5	0.5		
7th	- green glass	95.0	0.300	4.0	0.5		
8th	- amber glass	98.0	1.000	0.5	0.5		
9th	- amber glass	95.0	1.000	4.0	0.5		

B. Analyses of some sands used in glass manufacture

Locality	Uses	Chemical Constituents*						
		SiO_2 (min.)	Fe_2O_3 (max.)	Al_2O_3 (max.)	CaO	MgO	TiO_2	L.O.I.
Ottawa, Illinois		99.607	0.021	0.160	0.050	0.03	-	0.08
Perth, Australia	- bottle glass	97.42	0.51	-	-	-	-	0.70
Corona, California		94.5-96.0	0.03-0.04	2.5-3.5	1.8-2.3		-	-

* In addition to the requirements for chemical purity, all sand particles must pass through a 20-mesh sieve and 95 per cent should be retained on a 100-mesh sieve. The sand should also be free from organic impurities and flakes of mica.

mechanical analysis, bulk chemical analysis, and a chemical analysis of the washed, modal size fraction were performed. On those samples for which the silica content in the bulk chemical analysis exceeded 90 per cent, the iron content was less than 1 per cent, and the quantity of sand retained on a 100-mesh sieve was greater than 90 per cent, heavy liquid and magnetic separations were made and the quartz-sand fraction then treated with dilute hydrochloric acid before chemical analysis. The test data obtained are tabulated in the appendices.

Acknowledgments

The writer wishes to acknowledge his indebtedness to numerous colleagues and technicians who assisted in this investigation. Dr. L. A. Bayrock outlined the location of the dune fields shown on figure 1 and accompanied the writer in the field during the initial sampling program. Max Baaske assisted with the field sampling and, under the writer's direction, performed much of the laboratory work. Mrs. I. J. McLaws made the estimates of the mineral composition, shape, and staining shown in tables 5, 8, and 10, and helped to locate specifications for silica sand products.

Table 2. Some Uses of and Requirements for Silica Sand

Use	Requirements
Manufacture of sodium silicate and silicon carbide	Same as for high-grade glass sand
Sand blasting	Hard, angular grains closely graded to meet size specifications, 99 per cent in 14- to 65-mesh range
Glass grinding	Clean, hard, rounded grains closely graded to meet size specifications
Molding for ferrous or nonferrous castings	Sand containing sufficient indigenous clay for molding; SiO_2 content usually greater than 85 per cent
Coal washing	Clean sand, between 30- to 140-mesh in size; clay content less than 0.5 per cent; no organic matter
Hydraulic fracturing	Must be well rounded and closely graded to specifications; high strength (greater than 25 lbs per particle); must not react with hydrochloric acid
Asphalt roofing tile	High in silica; free of clay and organic impurities; white in color; grain size between 20- and 100-mesh sieve size

The chemical analyses were performed by D. J. Benkie and H. Oikawa.

DESCRIPTION OF DUNE FIELDS

Prospecting Rationale

Glacial outwash sands of Late Pleistocene (Wisconsin) age with heterogeneous mineral compositions and large variations in grain size cover extensive areas in the vicinity of the City of Edmonton (Fig. 1). During postglacial time, before a cover of vegetation was established, much of this sand was reworked locally by wind and blown into dune forms. The dunes, which vary in height from less than 10 feet up to 50 feet, developed downwind from areas of glacial outwash deposits. These dune fields, although now stabilized by vegetation, are easily recognized on aerial photographs. Because wind winnows out the sand and silt-size grains from the outwash deposits and redistributes these grains according to their size, shape, and specific gravity, dunes commonly

Table 3. Locations of Silica Sand Samples

Sample No.	Depth (feet)	Locality * Lsd. or 1/4	Sec.	Tp.	R.	Remarks
1	0-7	1	2	58	23	4 miles SW Opal
2	0-5	5	7	57	21	2.5 miles S Redwater
3	0-3	NE	16	57	20	8.5 miles W, 1.5 miles S Redwater
4	10-15	13	21	56	20	4 miles N Bruderheim
5	10-20	SW	18	52	25	3.5 miles S Winterburn
6	0-5	NE	16	51	26	3 miles N Devon
7	0-10	NW	9	52	27	1 mile W, 4.5 miles S Spruce Grove
8	0-5		25	60	25	1 mile S Nestow
9	0-3	1	8	60	25	5 miles NE Westlock
10	0-3	1	8	60	25	5 miles NE Westlock
11	3-10	NW	15	57	17	3 miles S Ukalta
12	0-5	NW	30	57	17	3 miles W, 1 mile S Ukalta
13	0-10	NE	20	57	18	7 miles W, 2 miles S Ukalta
14	0-10		27	57	19	12 miles W, 1.5 miles S Ukalta
15	5-15	SW	4	56	21	5.5 miles W Bruderheim
16	0-10		32	57	22	1.5 miles S Opal
17	1-5		13	57	31	5.5 miles E, 1.5 miles S Redwater
18	0-8		34	56	22	4 miles E Coronado

* All locations are west of the Fourth Meridian.

contain a higher percentage of single quartz grains of uniform size and hence have a higher silica content than the original outwash sand. Therefore, these dune fields are the logical areas to explore for large quantities of high-grade silica sand.

Locations of Dune Fields

Eight large dune fields are located to the north and east of the City of Edmonton on both sides of the North Saskatchewan River, one major field has its center about 5 miles west of the southwest corner of the city. The approximate locations of these dune fields are shown on figure 1. The most easterly area is south of Ukalta, about 45 miles northeast of the city limits; the most northerly area is south of Nestow, about 45 miles north of the city limits. The most extensive dune fields are on the northwest side of the North Saskatchewan River near the Town of Redwater, 25 miles north-northeast of Edmonton, and near the Town of Fort Saskatchewan, 10 miles northeast of Edmonton. More detailed maps showing the distribution of individual dunes within the dune fields are given in Bowser et al. (1962) and Bayrock and Hughes (1962).

Post-Depositional Modifications

After the dunes were formed and as the climate ameliorated, vegetation became established on them, soils were formed at the surface, and groundwaters of varying chemical composition percolated through them. As a result of these processes, the original sand has been modified by the deposition of mineral matter on and around the grains. The most significant consequence of this post-depositional modification in the Edmonton area is the ubiquitous presence of a thin film of iron oxide on the sand grains, which gives the deposit a yellowish color and seriously reduces its value as a raw material for the manufacture of glass.

Soils

Several soil types have developed on the dunes in the Edmonton area. Most of the northern deposits have a regosolic soil. This soil, which lacks discernible horizons, consists of a thin organic layer on the surface of the dune. On dunes to the southwest of Edmonton and on the southwest portion of the dune field northeast of Fort Saskatchewan, a grey wooded soil is present that consists of organic, light-colored eluvial, and illuviated horizons in which clay is the main accumulation product, and in the deeper layers lime concretions are common. Chemical analyses of samples from these areas (Nos. 5, 6, 7, and 15) thus show a higher percentage of lime (CaO) than sands overlain by regosolic soils. Chernozemic soils which develop under grassland are present on some dunes. The areas between dunes are commonly poorly drained and occupied by swamps or organic soils.

In general, the dune fields in the vicinity of Edmonton remain undeveloped; some areas are used for grazing cattle, others, close to the City of Edmonton, are being developed for recreational purposes.

PETROGRAPHY OF DUNE SANDS

Particle-Size Distribution

The particle-size distribution of a sand sample is estimated by decanting the clay-size material and then passing the sand fraction through a nest of sieves. This procedure is called mechanical analysis and is done in the laboratory according to the procedure set out by the American Society for Testing Materials.

The results of the mechanical analyses of the 18 sand samples collected for this study are presented here in tabular (Table 4) and graphical form (Fig. 3). From the results of mechanical analyses of a deposit the percentage of sand which falls between specified limits may be estimated. It is important for the supplier to choose a deposit in which a minimum amount of washing and screening is required to meet a manufacturer's specifications. It should be noted here that screening operations at a processing plant are seldom as efficient as the laboratory procedure; up to 20 per cent more fine material will be retained on a processing plant screen than on a laboratory sieve of the same screen size. For this study, to approximate plant conditions the sieves were heavily loaded and a shorter sieving period was used during the separation of the bulk samples into the different size fractions for heavy liquid and magnetic treatment as shown on the flow sheet (Fig. 2).

Shape

The shape of 100 sand-size grains in each sample was estimated visually under a stereomicroscope. Each grain was assigned to one of four categories depending on its degree of rounding. A grain was classed as "angular" if it had sharp corners without signs of abrasion; "subrounded" if the corners were worn; "rounded" if it had no angular projections; and "spherical" if it approached a sphere in shape.

The shape analyses (Tables 5, 8) indicated that most of the sand grains in these dunes are angular or subrounded.

Mineralogical Composition

The mineralogical composition of a sand is directly related to the size and specific gravity of the individual particles. The largest and most abundant constituents are usually quartz, feldspars and dark-colored chert (a form of quartz) fragments. Clay minerals are more abundant in the finer-sized materials. In addition, a small but ubiquitous proportion of grains with high specific gravity is transported along with quartz and feldspars in all sands; this is known as the "heavy" mineral content and,

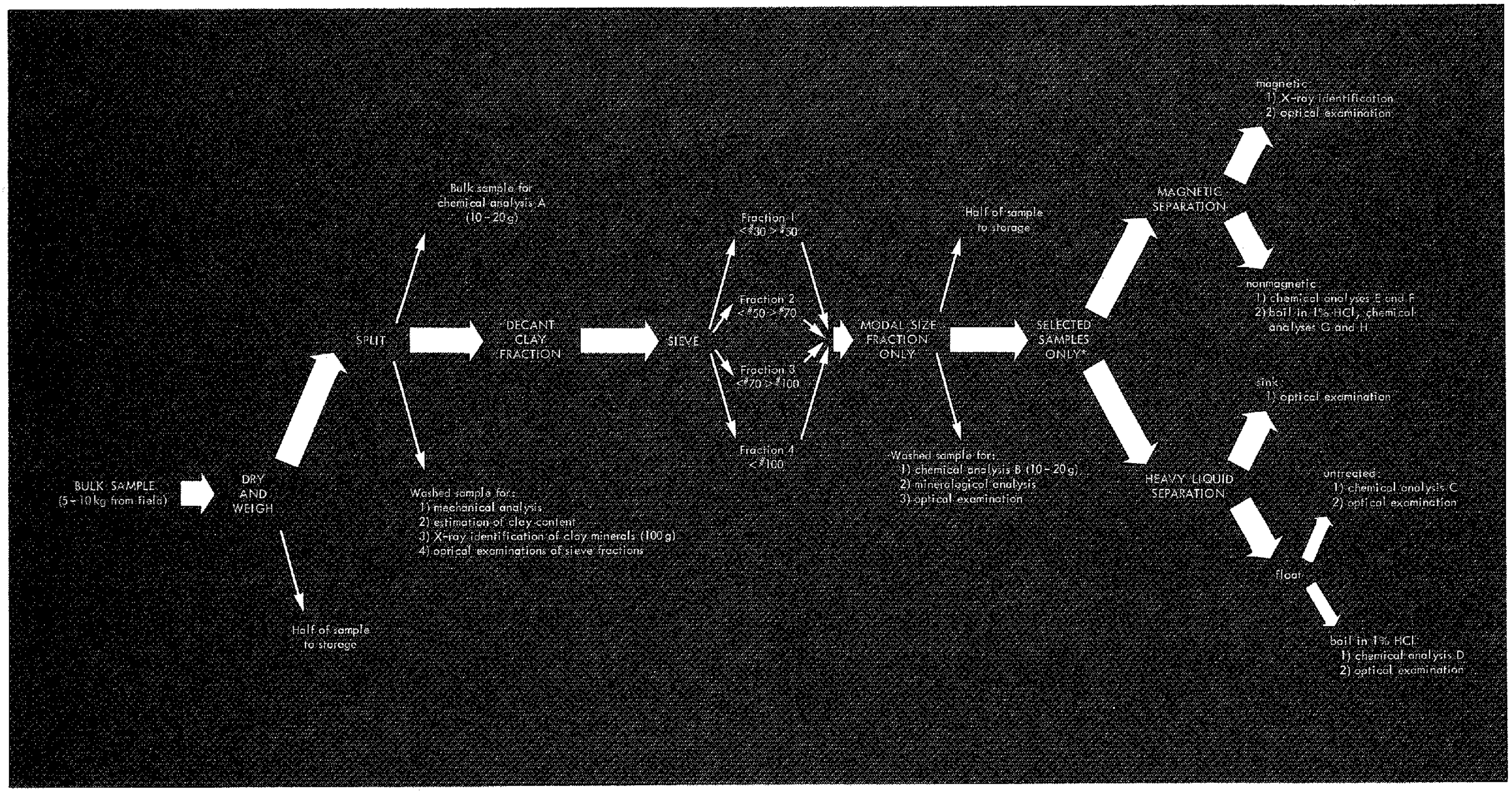

Figure 2. Flow diagram illustrating laboratory treatment of silica sand samples

being rich in iron, is a major contributor to the iron impurity in potential glass sands.

Sand

Examination under the stereomicroscope of 100 grains from each sample (Table 5) shows that quartz, feldspars, and chert account for more than 98 per cent of the sand-size grains. Quartz grains constitute between 76 and 90 per cent; feldspars between 7 and 16 per cent, and chert between 3 and 9 per cent. Mica is present in only three samples. The mineral composition of the sand-size fractions of the dune deposits is fairly constant, thus accounting for the similarity in the chemical analyses of the washed sands from different areas. The main non-quartz mineral is feldspar which accounts for most of the alumina (Al_2O_3) and lime (CaO) in the chemical analyses. In these sands plagioclase feldspar is two to three times more abundant than orthosclase. As feldspar is one of the mineral ingredients used in the manufacture of glass, its presence in these sands is not considered deleterious.

Clay

X-ray analyses of the clay-size material (Table 6) show that montmorillonite is the most abundant clay mineral, although other clay minerals such as kaolinite, chlorite, and illite are also present. The predominance of montmorillonite in the clayey material is not surprising in view of its extensive distribution in the bedrock over most of the Alberta plains.

Heavy Minerals

Heavy minerals — those which sink in a liquid with a specific gravity of 2.9 — form less than 1 per cent of the sand-size fractions and consist of opaque and nonopaque grains. The opaque grains are mostly metallic oxides, such as magnetite (FeO, Fe_2O_3) and ilmenite (Fe, TiO_3), which are most easily identified from X-ray diffraction patterns. The non-opaque grains, identified from their habit and optical properties as observed under a petrographic microscope, consist of a relatively few resistant minerals, the most common being hornblende, garnet, tourmaline, kyanite, and rutile.

Surface Iron Staining and Inclusions

All of the dune sands examined are tan to pale orange in surface exposures owing to a small amount of iron oxide deposited as a yellow coating or stain on the grain surfaces. In addition, some of the quartz grains contain small opaque inclusions that probably contribute a minor amount to the iron content of the samples.

The amounts of stained grains and grains containing inclusions in the sand-size fractions of the eighteen dune sands are shown in table 5. The yellow iron coating on the grains is considered to be heavy if it covers more than half of the grain surface and light if it covers less than half. Clear grains are those grains free of surface staining and free of inclusions. The grains with a clean surface but with interior inclusions were counted separately. The data in table 5 show that in their natural state about 90 per cent of the grains are coated with a thin film of iron oxide.

Chemical Composition

The chemical compositions of the eighteen dune sands in their natural state are shown in table 7, column A. These results show that there are wide variations in the quantities of most oxides, mainly due to differences in clay content. The values in column A should be compared with those in column B, which lists the analyses of the same sands after the fine-sand fraction and the clay have been removed by washing and screening. The effect of washing and screening is to reduce significantly the differences in chemical composition by decreasing the alumina and iron contents and thus increasing the silica values in the best sands by equivalent amounts.

DETAILED ANALYSES OF SELECTED SAMPLES

Five samples in which 90 per cent or more of the natural sand was retained on a 100-mesh sieve and the total iron content was less than 1 per cent were selected for detailed mineralogical and chemical analysis to determine, if possible, the disposition of the various oxides within the samples (Tables 14, 16). A flow sheet of the treatment given each of these five samples is presented in figure 2. Basically, the procedure was designed to isolate various fractions by size, specific gravity, and magnetic susceptibility, then to identify the minerals in these fractions by optical and X-ray techniques and to determine the compositions of these fractions by chemical analysis.

Variation in Mineral Composition, Shape, and Surface Staining with Size

Some idea of the variation in mineral composition, shape, and surface staining of the sand-size fraction in each of the five samples is given in table 8. The grain counts indicate that the feldspar content of the sand increases with increasing grain size, whereas the amount of surface staining appears to remain constant. There is some evidence that, in some samples the proportion of clear grains increases with decreasing size. In general, the shape of the grains does not show any constant trend with size, but spherical grains are noticeably absent from material less than 0.2mm in size.

The results of the shape tests indicate that these sands are probably more suitable for sandblasting than for hydraulic fracturing.

Variation in the Proportion of Heavy Minerals with Size

The weight-percentages of heavy minerals in each of the three sieve fractions of the five selected samples are shown in table 9. Most of the heavy minerals are concentrated in the 0.15 to 0.21 mm fraction; the amounts are significantly less in the 0.25 to 0.6 mm fraction. It is estimated from the difference in iron content of these sands before and after removal of the heavy minerals (Tables 7, 11, columns B, C respectively) that the heavy mineral fraction contains mainly iron-bearing minerals and that between 40 and 60 per cent of their total weight is composed of magnetite (Fe_2O_3). Thus, removal of the heavy minerals will produce a significant increase in the quality of these sands at a relatively modest cost and should be part of any beneficiation process.

Surface Iron Staining

After heavy mineral separation, the sand (largely quartz, feldspars, and chert) was examined under a stereomicroscope, it was then boiled in 1 per cent hydrochloric acid solution and examined again to determine the effectiveness of this treatment in removing surface iron stains. The results of this treatment are given in table 11; although the number of clear grains increases markedly after the acid treatment, many grains retain a fairly high proportion of iron oxide in cracks and surface depressions. Other experiments with hydroflouric acid show that weak hydrochloric acid treatment removes only half of the surface iron stain. For some commercial purposes it might be preferable to use an attrition cell or scrubbing process instead of weak acid treatment, but for a high quality product a strong acid treatment seems to be essential.

Magnetic Separation

Magnetic separations were performed at various magnetic intensities with a Franz Isodynamic Separator set at the appropriate slope and tilt to achieve the best results. The data in table 13 indicate that the weight percentage of sand removed is directly proportional to the magnetic intensity, as measured by the current supplied to the electromagnet. It is significant that there is no sharp distinction between magnetic and non-magnetic grains in these samples. The chemical analyses of the non-magnetic fractions (Table 14) show that no marked reduction in any of the oxides or increase in silica content occurs when the current is increased beyond 0.9 amps. Probably, most of the magnetic iron is in the form of magnetite, which can be removed by the inclusion of a simple permanent magnet in the beneficiation process. High intensity magnetic separation does not seem to be warranted.

Results of Beneficiation Tests

A summary of the changes in chemical compositions of the five dune sands subjected to the treatments described above is shown in table 15. These test results indicate that the most significant improvement in quality of these sands results from a combination of washing, screening, gravity separation, and acid treatments. The most promising samples in terms of size distribution and chemical composition are from the dune field west of Opal, a few miles northeast of Redwater, Alberta.

One deposit of dune sand near Bruderheim has been beneficiated and used in the manufacture of fibreglass. Thus, it is probable that dune sand from other deposits can be upgraded sufficiently to produce a sand suitable for the production of fibreglass and, green and amber glass containers.

RESULTS OF GLASS MANUFACTURING TESTS

Sample Preparation

Subsequent to the analysis and testing of the various dune sands described above, several hundred pounds of sand were collected from the deposit near Opal (Fig. 1, Locality 16) for glass-making tests. The sand was sieved and the -30 to +70 mesh fraction (0.595-0.310 mm) was divided into two batches, one of which was washed in water and the other in a mild solution of Calgon (2 teaspoons to 4 liters of water), a commerical water softener. A 25-pound sample of the Calgon-treated batch was subsequently washed in a dilute solution of hydrofluoric acid (0.8 per cent by volume) to remove traces of iron staining.

The Calgon treatment effected a noticeable change in the color of the sand, changing it from a pronounced tan color to a much cleaner-looking, slightly pinkish color. The hydrofluoric acid-treated sample is somewhat lighter-colored than the Calgon-treated material, although chemical analyses of the two sands indicate little or no change in the iron content. The iron contents of the treated fractions are summarized in table 17.

Glass-Making Tests

A 25-pound sample of Calgon-treated sand was submitted to a glass manufacturing firm in Calgary, Alberta, for test production of glass objects. The sand was mixed with the following materials: 10.5 lbs soda ash, 1.25 lbs potash, 0.5 lbs sodium nitrate, 0.5 lbs borax, 0.5 lbs arsenic, 0.5 lbs fluorspar, 4 tablespoons selenium, and 2 tablespoons hard coal.

Table 17. Reduction in Iron Contents Effected on Large Samples of Opal Sand by Various Treatments

Treatment	Total iron (as Fe_2O_3)
Natural sand (as found in field) (A)	0.75
Sieved but otherwise untreated (B)	0.57
Sieved and tumbled in tap water for 30 minutes (C)	0.50
Sieved and tumbled in calgon solution for 30 minutes* (D)	0.44
Same treatment as D plus 10 minutes tumbling in 0.8% hydroflouric acid solution (E)	0.41
Same treatment as D plus removal of heavy minerals (F)	0.21

* Sample used in glass manufacturing test.

The melting characteristics of the mixture and the workability of the molten glass are normal. The annealed product consists of transparent glass with a pleasant amber hue, somewhat lighter than observed in local brown glass containers. Undoubtedly, removal of the heavy mineral fraction from the screened and washed sand would result in an even lighter colored product.

REFERENCES CITED

Bayrock, L. A. and G. M. Hughes, (1962): Surficial geology of the Edmonton district, Alberta; Research Council of Alberta, Prelim. Rept. 62-6, 40 pages.

Bowser, W. E., A. A. Kjearsgaard, T. W. Peters, and R. E. Wells, (1962): Soil survey of Edmonton Sheet (83-H); Alberta Soil Survey Report 21, 66 pages.

APPENDIX A

TEST RESULTS ON ALL SAMPLES

Table 4. Mechanical Analyses of Dune Sands near Edmonton

Sample No.	Per Cent Sample Retained (by mesh no.)									Clay %
	12 (1.68)*	20 (0.841)	30 (0.595)	40 (0.420)	50 (0.247)	70 (0.210)	100 (0.149)	140 (0.105)	200 (0.074)	
1	0.01	0.41	2.07	8.28	33.25	72.18	90.12	95.97	97.57	1.1
2	0.01	0.54	2.27	9.58	40.95	74.50	86.48	93.51	96.69	1.7
3	-	-	0.02	0.07	0.20	2.16	48.86	87.85	96.34	2.4
4	-	0.01	0.03	0.38	11.52	66.99	88.79	95.44	97.56	1.7
5	-	0.03	0.08	0.47	3.65	25.31	66.33	87.89	94.18	3.2
6	-	0.03	0.33	2.73	11.44	42.91	76.37	89.70	92.88	4.9
7	-	0.08	0.44	1.91	8.13	30.42	63.93	83.85	91.01	4.9
8	-	0.01	0.06	0.63	7.54	33.03	62.42	84.31	92.48	4.8
9	0.04	0.50	2.24	7.35	20.60	42.93	64.37	81.64	90.35	2.5
10	-	0.11	1.36	6.48	21.58	46.92	71.05	88.06	95.15	1.9
11	-	-	0.01	0.09	0.78	6.47	50.19	87.18	95.54	2.6
12	-	0.03	0.13	0.48	2.28	10.57	57.06	87.67	95.07	3.2
13	-	0.09	0.55	2.42	8.50	24.30	54.24	80.10	92.39	3.4
14	-	0.05	0.45	2.50	8.97	26.11	53.68	80.57	93.27	3.7
15	0.04	0.42	1.55	5.17	23.43	56.49	82.29	93.39	95.77	3.2
16	-	0.21	1.36	8.40	42.94	80.04	92.74	96.64	97.85	1.5
17	-	0.56	3.39	14.17	43.96	75.18	92.65	97.72	98.61	1.3
18	-	0.02	0.09	0.54	5.18	41.83	74.73	91.28	96.26	2.8

* Screen size (mm) corresponding to mesh no.

Table 5. Shape, Mineral Composition and Staining of Dune Sands near Edmonton

Sample No.	Shape (%)				Mineral Composition (%)					Iron Staining (%)			
	Angular	Subrounded	Rounded	Spherical	Quartz	Feldspars	Chert	Mica	Others	Heavy	Light	Inclusions	Clear
1	41	45	11	3	86	10	4			32	61	4	3
2	66	33	1		86	7	5		2	8	85	1	6
3	63	31	6		76	14	9	1		17	69	1	13
4	43	34	20	3	88	8	4			4	82	4	10
5	65	29	6		79	14	7			8	86	1	5
6	50	37	10	3	84	13	3			12	79	5	4
7	47	42	9	2	85	11	4			31	64	3	2
8	44	48	8		88	9	3			68	31	1	
9	66	30	4		78	16	5	1		53	33	2	12
10	55	36	9		81	14	4	1		54	23	7	16
11	55	36	9		83	14	3			60	34	4	2
12	59	39	2		83	10	7			39	48	2	11
13	50	42	8		86	8	6			40	50	1	9
14	57	37	6		85	9	6			39	53	2	6
15	52	39	8	1	83	9	8			43	53	1	3
16	57	31	12		90	7	3			16	81		3
17	69	27	4		85	12	3			14	81	3	2
18	54	35	11		86	11	3			23	70	4	3

Table 6. Relative Proportions* of Clay Minerals in Clay-size Fraction of Dune Sands near Edmonton

Sample No.	Clay Minerals
1	Illite > chlorite > montmorillonite
2	Montmorillonite > illite
3	Montmorillonite > illite
4	Montmorillonite > illite > chlorite + kaolinite
5	Montmorillonite > chlorite + kaolinite
6	Montmorillonite > illite > chlorite
7	Montmorillonite > kaolinite + chlorite > illite
8	Montmorillonite > kaolinite + chlorite > illite
9	Chlorite + kaolinite > illite > mixed layer clays
10	Montmorillonite > illite > kaolinite
11	Montmorillonite > kaolinite + chlorite > illite
12	Montmorillonite > kaolinite + chlorite > illite
13	Montmorillonite > kaolinite + chlorite > illite
14	Montmorillonite > illite > kaolinite + chlorite
15	Montmorillonite > kaolinite + chlorite > illite
16	Montmorillonite > illite > kaolinite + chlorite
17	Illite > kaolinite + chlorite > mixed layer clays
18	Montmorillonite > kaolinite + chlorite > illite

* Estimated from relative peak heights on x-ray diffractograms

Table 7. Chemical Analyses of Bulk and Modal Size Fractions of Dune Sands near Edmonton

Sample No.		Per Cent of Original Sample	SiO_2	Al_2O_3 P_2O_5 TiO_2	Total Iron (Fe_2O_3)	CaO	MgO	L.O.I.
1	A*	100	93.49	3.19	0.78	0.35	0.29	0.44
	B+	44	95.44	2.16	0.35	0.28	0.19	0.18
2	A	100	92.35	3.66	0.99	0.41	0.29	0.49
	B	52	95.07	2.40	0.34	0.28	0.25	0.16
3	A	100	88.47	5.90	1.10	0.70	0.39	0.88
	B	60	89.96	5.04	0.78	0.41	0.30	0.55
4	A	100	92.06	3.76	1.11	0.49	0.30	0.50
	B	44	93.95	2.98	0.59	0.36	0.27	0.29
5	A	100	88.21	5.72	1.10	0.87	0.43	1.20
	B	36	90.47	4.62	0.68	0.88	0.31	0.68
6	A	100	85.14	6.48	1.38	1.54	0.61	1.98
	B	40	88.11	5.39	0.88	1.08	0.48	1.10
7	A	100	85.62	6.15	1.28	1.71	0.62	2.16
	B	33	88.80	6.11	0.76	1.53	0.45	1.18
8	A	100	88.50	5.46	1.23	0.79	0.41	1.17
	B	30	92.74	3.78	0.64	0.46	0.27	0.46
9	A	100	91.13	4.51	0.79	0.48	0.30	0.67
	B	27	95.75	2.35	0.35	0.20	0.15	0.18
10	A	100	91.44	4.22	0.72	0.43	0.29	0.68
	B	32	95.64	2.26	0.32	0.10	0.19	0.21
11	A	100	89.56	5.39	1.05	0.62	0.30	0.93
	B	51	90.59	5.00	0.62	0.28	0.37	0.55
12	A	100	89.59	5.24	1.05	0.62	0.34	0.94
	B	45	90.71	4.81	0.63	0.57	0.33	0.49
13	A	100	89.59	5.01	1.13	0.69	0.33	1.04
	B	30	90.77	4.77	0.69	0.62	0.36	0.47
14	A	100	89.98	5.33	1.07	0.60	0.36	0.99
	B	29	89.90	5.18	0.69	0.53	0.39	0.54
15	A	100	86.70	5.13	1.19	1.64	0.51	2.02
	B	37	92.86	3.15	0.67	0.53	0.27	0.56
16	A	100	93.61	2.94	0.92	0.67	0.22	0.50
	B	62	95.48	2.09	0.44	0.21	0.18	0.17
17	A	100	93.49	4.22	0.79	0.42	0.36	0.47
	B	55	95.04	2.25	0.40	0.17	0.18	0.17
18	A	100	91.30	4.38	1.07	0.57	0.36	0.68
	B	41	93.74	3.30	0.53	0.35	0.26	0.24

* A = Bulk sample

\+ B = Washed modal size fraction

APPENDIX B

TEST RESULTS ON FIVE SELECTED SAMPLES

Table 8. Shape, Mineral Composition and Staining in Washed Sieve Fractions of Five Dune Sands

Sample No.	Mesh No.	Shape (%)				Mineral Composition (%)					Iron Staining (%)			
		Angular	Subrounded	Rounded	Spherical	Quartz	Feldspars	Chert	Mica	Others	Heavy	Light	Inclusions	Clear
1	-12+20 (1.7-0.8)	38	40	15	7	77	20	1		2		59	8	33
	-20+30 (0.8-0.6)	22	47	20	11	81	17	1		1	3	79	6	12
	-30+40 (0.6-0.4)	33	42	23	2	85	13	1		1	2	64	6	28
	-40+50 (0.42-0.25)	35	44	19	2	91	8	1			5	58	4	33
	-50+70 (0.25-0.20)	47	42	11		86	10	3		1	4	53	6	37
	-70+100 (0.20-0.15)	49	36	15		89	7	2	1	1	3	48	3	46
2	-12+20 (1.7-0.8)	29	43	23	5	87	10	3			3	44	16	37
	-20+30 (0.8-0.6)	35	40	20	5	87	11	1		1	2	40	8	50
	-30+40 (0.6-0.4)	30	48	18	4	90	7	2		1	6	43	5	46
	-40+50 (0.42-0.25)	37	46	17		93	3	4			8	44	3	45
	-50+70 (0.25-0.20)	34	47	18	1	92	6	2			5	50	3	42
	-70+100 (0.20-0.15)	29	65	6		86	9	3		2		25	4	71
4	-12+20 (1.7-0.8)													
	-20+30 (0.8-0.6)													

	(0.6-0.4)													
	-40+50 (0.42-0.25)	45	42	12	1	90	6	4			6	34	8	52
	-50+70 (0.25-0.20)	44	37	18	1	90	4	5		1		15	5	80
	-70+100 (0.20-0.15)	48	38	14		85	6	6		3	2	8	4	86
16	-12+20 (1.7-0.8)	35	54	9	2	78	16	1		5**	4	82	2	12
	-20+30 (0.8-0.6)	42	39	15	4	88	11	1			13	72	2	13
	-30+40 (0.6-0.4)	43	33	21	3	90	9	1			8	49	4	39
	-40+50 (0.42-0.25)	45	31	21	3	90	5	5			13	54	5	28
	-50+70 (0.25-0.20)	44	42	14		88	7	4		1	6	50	6	38
	-70+100 (0.20-0.15)	44	48	7	1	78	10	9		3	8	39	3	50
17	-12+20 (1.7-0.8)	36	44	16	4	69	27	2		2**	5	72	3	20
	-20+30 (0.8-0.6)	37	38	19	6	80	17	2		1	5	58	6	31
	-30+40 (0.6-0.4)	51	38	9	2	91	7	2			6	69	5	20
	-40+50 (0.42-0.25)	51	33	15	1	93	6			1	8	60	4	28
	-50+70 (0.25-0.20)	55	33	11	1	84	11	5			5	54	3	38
	-70+100 (0.20-0.15)	61	31	8		83	9	7		1	2	31	1	66

* Screen size (mm) corresponding to mesh no.
** Includes some mica

Table 9. Percentages of Heavy Minerals in Three Sieve Fractions of Five Dune Sands near Edmonton

Sample No.	Sieve Fraction No.*	Weight per cent of Total Sample	Weight per cent of Heavy Minerals (s.g. 2.9)
	1	44.29	0.29
1	2	30.96	0.68
	3	13.46	1.96
	1	52.48	0.33
2	2	23.06	1.08
	3	9.59	2.91
	1	31.56	0.28
4	2	44.49	0.85
	3	16.07	3.10
16	1	62.02	0.35
	2	21.63	1.26
	3	8.23	4.13
	1	55.15	0.46
17	2	24.72	0.91
	3	10.73	1.88

* Fraction No. 1: 0.25-0.6 mm
Fraction No. 2: 0.21-0.25 mm
Fraction No. 3: 0.15-0.21 mm

Table 10. Surface Iron Staining on the Grains of the Light Fraction of the Modal Size of Five Dune Sands before and after Acid Treatment

Sample No.	Treatment	Heavy	Light	Inclusions	Clear
1	C*		79	2	19
	D**		24	3	73
2	C	2	56	1	41
	D	3	14	5	78
4	C		49	1	50
	D	1	9	1	89
16	C		80	3	17
	D	1	29	3	67
17	C	1	70		29
	D		45	5	50

* C: Light mineral fraction untreated
** D: Light mineral fraction after boiling in 1% HCl for 10 minutes

Table 11. Chemical Analyses of Light Minerals (s.g. < 2.9) of Modal Size Fraction of Five Dune Sands

Sample No.		Per cent of original sample	Percentage of heavy minerals removed	SiO_2	Al_2O_3 P_2O_5 TiO_2	Total Iron as Fe_2O_3	CaO	MgO	L.O.I.
1	C*	44	0.29	96.01	2.16	0.23	0.18	0.15	0.20
	D**			95.69	1.86	0.14	0.20	0.27	0.11
2	C	52	0.33	95.46	2.33	0.21	0.17	0.18	0.19
	D			95.20	2.34	0.15	0.27	0.25	0.09
4	C	44	0.85	95.41	2.83	0.28	0.38	0.19	0.24
	D			94.55	2.74	0.20	0.29	0.23	0.15
16	C	62	0.35	95.99	2.09	0.21	0.32	0.20	0.17
	D			95.61	1.81	0.14	0.20	0.16	0.08
17	C	55	0.46	95.83	2.14	0.20	0.25	0.14	0.19
	D			95.54	2.11	0.14	0.15	0.15	0.11

*C: Light mineral fraction (floats on liquid of s.g. 2.9)
**D: Light mineral fraction boiled in 1% HCl for 10 minutes

Table 12. Magnetic Minerals Removed from Three Sieve Fractions of Five Dune Sands at Three Magnetic Intensities

Sample No.	Sieve Fraction No.**	Magnetic Minerals (weight per cent)		
		0.1 amps*	0.9 amps	1.7 amps
	1	0.05	1.08	1.92
1	2	0.05	1.66	3.07
	3	0.13	3.31	5.58
	1	0.05	1.24	2.17
2	2	0.06	2.25	3.79
	3	0.23	4.59	7.16
	1	0.05	1.18	2.28
4	2	0.05	2.18	3.80
	3	0.24	5.60	8.51
	1	0.05	1.07	1.90
16	2	0.07	2.23	3.57
	3	0.32	5.43	7.43
	1	0.06	1.37	2.24
17	2	0.06	2.16	3.83
	3	0.16	3.59	6.18

* Power applied to electromagnet when Franz Isodynamic Separator set at a slope of 10° and tilt of 10°

Power applied to electromagnet when Franz Isodynamic Separator set at a slope of 18° and a tilt of 10°

** Fraction No. 1: 0.25 - 0.6 mm
Fraction No. 2: 0.21 - 0.25 mm
Fraction No. 3: 0.15 - 0.21 mm

Table 13. Chemical Analyses of Nonmagnetic Minerals in Modal Size Fractions of Five Dune Sands near Edmonton

Sample No.	Sieve Fraction No.**	Composition	No acid treatment		Boiled in 1% HCl for 10 mins	
			E 0.9 amps*	F 1.7 amps	G 0.9 amps	H 1.7 amps
1	1	SiO_2	95.53	95.80	95.75	95.62
		Al_2O_3	2.10	1.98	1.98	2.83
		Fe_2O_3	0.18	0.16	0.12	0.10
		CaO	0.30	0.17	0.15	0.17
		MgO	0.22	0.19	0.19	0.11
		L.O.I.	0.10	0.11	0.11	0.13
2	1	SiO_2	-	-	95.56	95.77
		Al_2O_3	-	-	2.25	2.09
		Fe_2O_3	-	-	0.11	0.10
		CaO	-	-	0.24	0.21
		MgO	-	-	0.14	0.12
		L.O.I.	-	-	0.14	0.13
4	2	SiO_2	94.67	95.06	94.83	95.20
		Al_2O_3	2.81	2.65	2.65	2.54
		Fe_2O_3	0.20	0.16	0.18	0.10
		CaO	0.33	0.22	0.27	0.24
		MgO	0.25	0.16	0.19	0.15
		L.O.I.	0.19	0.17	0.15	0.13
16	1	SiO_2	95.62	95.70	95.60	96.12
		Al_2O_3	2.09	1.91	2.00	1.86
		Fe_2O_3	0.17	0.16	0.12	0.10
		CaO	0.19	0.15	0.17	0.17
		MgO	0.19	0.16	0.11	0.15
		L.O.I.	0.13	0.16	0.13	0.11
17	1	SiO_2	-	-	95.65	96.10
		Al_2O_3	-	-	2.08	1.99
		Fe_2O_3	-	-	0.12	0.10
		CaO	-	-	0.21	0.15
		MgO	-	-	0.12	0.11
		L.O.I.	-	-	0.11	0.12

* Power applied to electromagnet on Franz Isodynamic Separator (slope 18°, tilt 10°).

** Fraction No. 1: 0.25-0.6 mm
Fraction No. 2: 0.21-0.25 mm

See footnote listing treatments, table 15

Table 14. Iron Contents of Two Nonmagnetic Portions from Three Sieve Fractions of Five Dune Sands Near Edmonton

Sample No.	Sieve Fraction No.**	No acid treatment		Boiled for 10 mins in 1% HCl	
		E 0.9 amps*	F 1.7 amps	G 0.9 amps	H 1.7 amps
1	1	0.18	0.16	0.12	0.10
	2	0.24	0.20	0.16	0.13
	3	0.31	0.26	0.20	0.15
2	1	0.17	0.14	0.11	0.10
	2	0.22	0.17	0.16	0.11
	3	0.34	0.27	0.22	0.14
4	1	0.17	0.15	0.13	0.11
	2	0.20	0.16	0.18	0.10
	3	0.31	0.23	0.21	0.15
16	1	0.17	0.16	0.12	0.10
	2	0.23	0.20	0.17	0.13
	3	0.31	0.24	0.21	0.15
17	1	0.17	0.17	0.12	0.10
	2	0.25	0.21	0.17	0.14
	3	0.32	0.26	0.21	0.17

* Power applied to electromagnet on Franz Isodynamic Separator (slope 18°, tilt 10°)

** Fraction No. 1: 0.25 - 0.6 mm
Fraction No. 2: 0.21 - 0.25 mm
Fraction No. 3: 0.15 - 0.21 mm

Table 15. Summary of Results of Laboratory Treatments on Five Dune Sand Samples

Sample No.	Treatment*	Chemical Analysis					
		SiO	Al_2O_3 TiO_2 P_2O_5	Total Iron as Fe_2O_3	CaO	MgO	L.O.I.
1	A	93.49	3.19	0.78	0.35	0.29	0.44
	B	95.44	2.16	0.35	0.28	0.19	0.18
	C	96.01	2.16	0.23	0.18	0.15	0.20
	D	95.69	1.86	0.14	0.20	0.27	0.11
	E	95.53	2.10	0.18	0.30	0.22	0.10
	F	95.80	1.98	0.16	0.17	0.19	0.11
	G	95.75	1.98	0.12	0.15	0.19	0.11
	H	95.62	2.83	0.10	0.17	0.11	0.13
2	A	92.35	3.66	0.99	0.41	0.29	0.49
	B	95.07	2.40	0.34	0.28	0.25	0.16
	C	95.46	2.33	0.21	0.17	0.18	0.19
	D	95.20	2.34	0.15	0.27	0.25	0.09
	E	-	-	0.17	-	-	-
	F	-	-	0.14	-	-	-
	G	95.56	2.25	0.11	0.24	0.14	0.14
	H	95.77	2.09	0.10	0.21	0.12	0.13
4	A	92.06	3.76	1.11	0.49	0.30	0.50
	B	93.95	2.98	0.59	0.36	0.27	0.29
	C	95.41	2.83	0.28	0.38	0.19	0.24
	D	94.55	2.74	0.20	0.29	0.23	0.15
	E	94.67	2.81	0.20	0.33	0.25	0.19
	F	95.06	2.65	0.16	0.22	0.16	0.17
	G	94.83	2.65	0.18	0.27	0.19	0.15
	H	95.20	2.54	0.10	0.24	0.15	0.13
16	A	93.61	2.94	0.92	0.67	0.22	0.50
	B	95.48	2.09	0.44	0.21	0.18	0.17

Sample No.	Treatment	Chemical Analysis					
		SiO_2	Al_2O_3 TiO_2 P_2O_5	Total Iron as Fe_2O_3	CaO	MgO	L.O.I.
	C	95.99	2.09	0.21	0.32	0.20	0.17
	D	95.61	1.81	0.14	0.20	0.16	0.08
	E	95.62	2.09	0.17	0.19	0.19	0.13
	F	95.70	1.91	0.16	0.15	0.16	0.16
	G	95.60	2.00	0.12	0.17	0.11	0.13
	H	96.12	1.86	0.10	0.17	0.15	0.11
17	A	93.49	4.22	0.79	0.42	0.36	0.47
	B	95.04	2.25	0.40	0.17	0.18	0.17
	C	95.83	2.14	0.20	0.25	0.14	0.19
	D	95.54	2.11	0.14	0.15	0.15	0.11
	E	-	-	0.17	-	-	-
	F	-	-	0.17	-	-	-
	G	95.65	2.08	0.12	0.21	0.12	0.11
	H	96.10	1.99	0.10	0.15	0.11	0.12

*A Bulk sample

B Modal size fraction (washed and screened)

C Modal size fraction after removal of heavy minerals (s.g. >2.9)

D Modal size fraction after removal of heavy minerals, boiled in 1% HCl solution for 10 minutes

E Modal size fraction after magnetic minerals are removed by electromagnet at 0.9 amps

F Modal size fraction after magnetic minerals are removed by electromagnet at 1.7 amps

G Modal size fraction after magnetic minerals are removed by electromagnet at 0.9 amps, boiled in 1% HCl solution for 10 minutes

H Modal size fraction after magnetic minerals are removed by electromagnet at 1.7 amps, boiled in 1% HCl solution for 10 minutes

Table 16. Disposition of Iron in Five Dune Sands Near Edmonton

Location of Iron-Bearing Minerals	Sample No.					Method of Removal
	1	2	4	16	17	
Clay, silt, and sand less than 0.21 mm in size	0.43 (55%)	0.65 (66%)	0.52 (47%)	0.48 (52%)	0.39 (50%)	Washing and screening
Heavy minerals in modal size sand	0.12	0.13	0.31	0.23	0.20	Heavy liquid (s.g. = 2.9)
Surface coating on light mineral grains	0.09	0.06	0.08	0.07	0.06	Boiling for 10 mins in 1% HCl solution
Residue of insoluble* coatings and magnetite inclusions in modal size sand	0.14	0.15	0.20	0.14	0.14	
Total iron as Fe_2O_3	0.78	0.99	1.11	0.92	0.79	
Magnetic grains	0.19	0.20	0.43	0.28	0.23	Franz Isodynamic Separator (slope 18°, tilt 10°, current 1.7 amps)

* Experimental treatment with hydroflouric acid indicates that approximately half of this iron (0.07%) is locked inside quartz grains in the form of magnetite inclusions

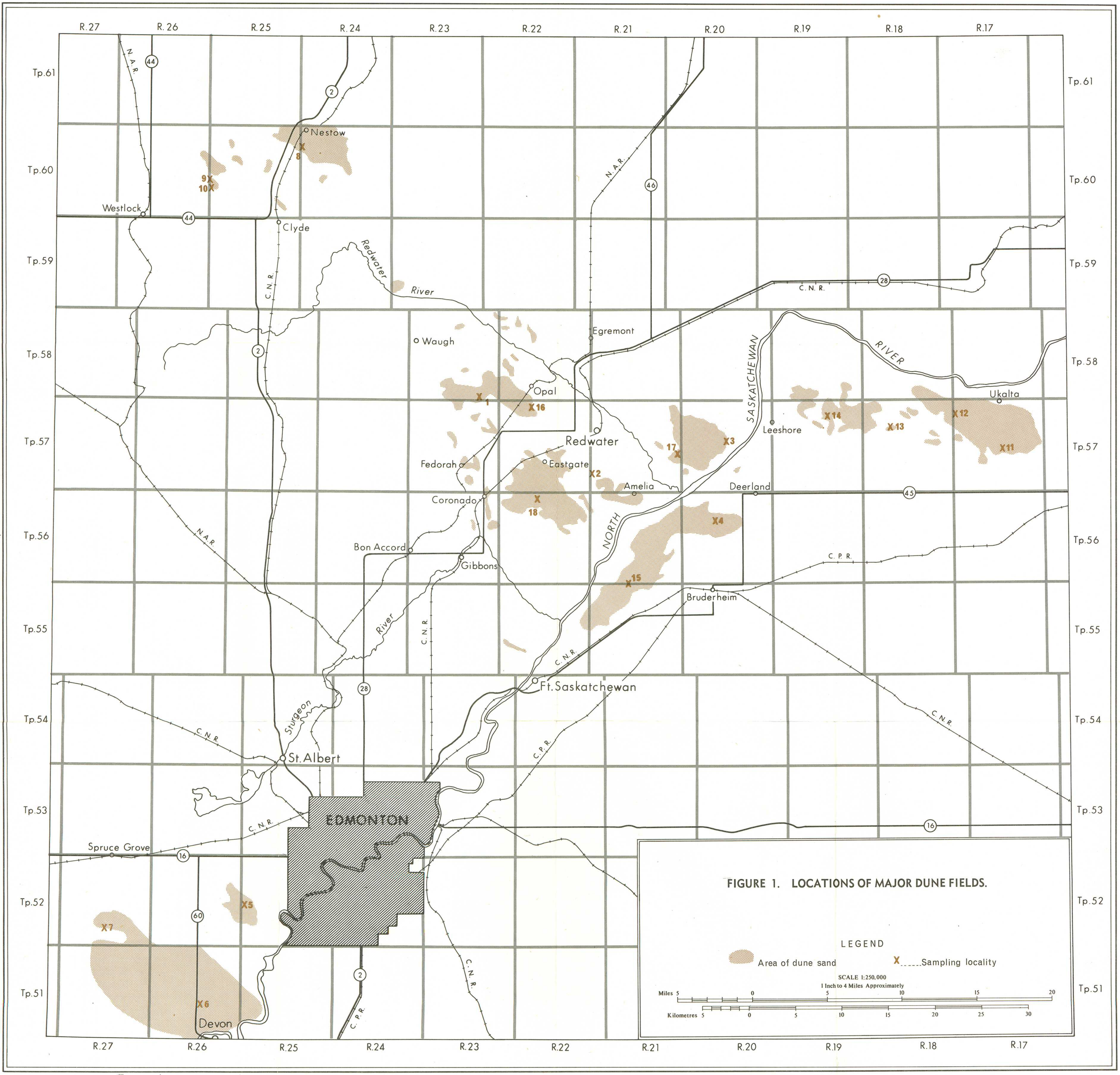

FIGURE 1. LOCATIONS OF MAJOR DUNE FIELDS.

To accompany Research Council of Alberta Report 70-1, by M. A. Carrigy

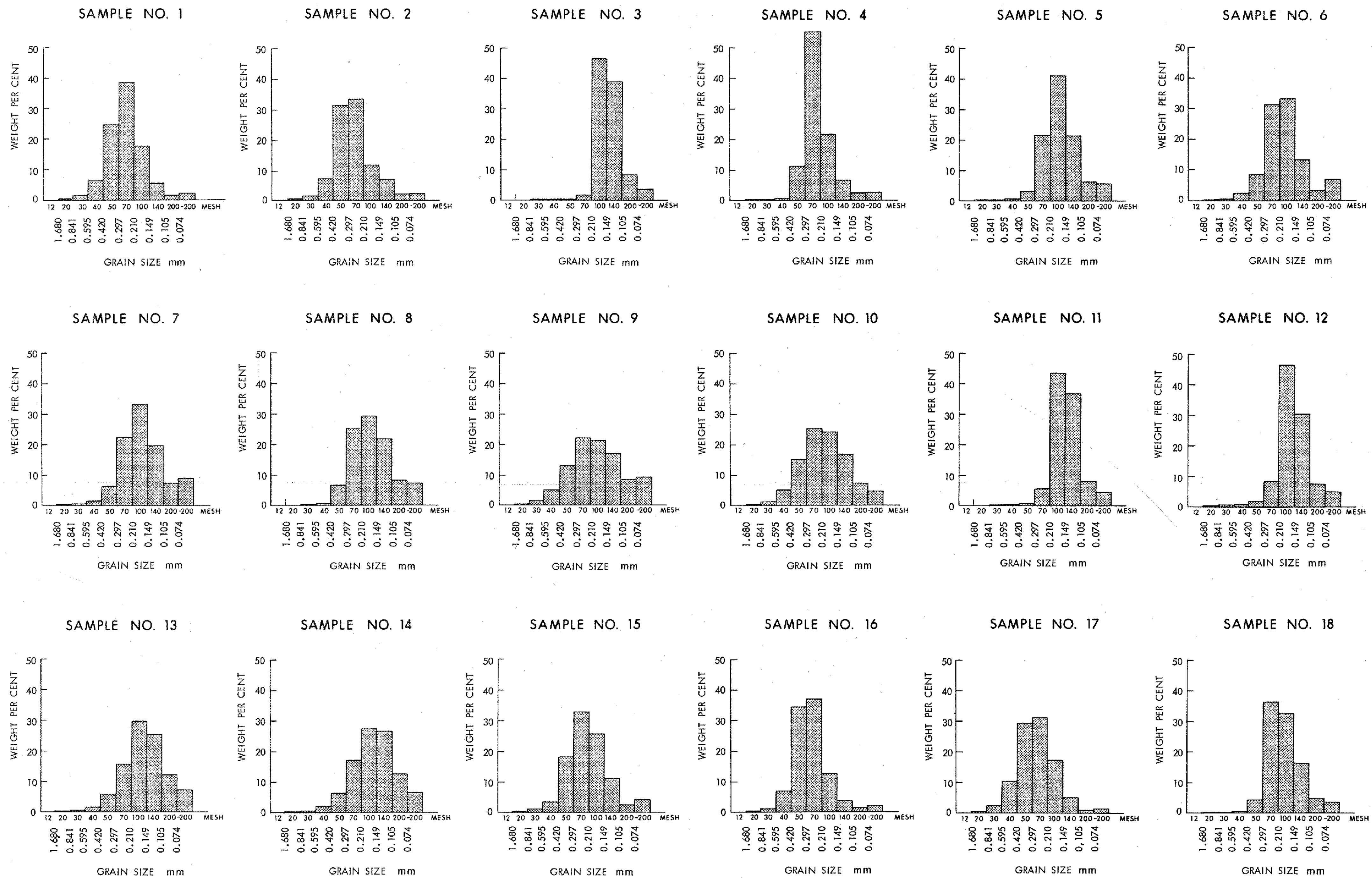

FIGURE 3. HISTOGRAMS SHOWING THE GRAIN SIZE DISTRIBUTIONS OF EIGHTEEN DUNE SAND SAMPLES.

To accompany Research Council of Alberta Report 70-1, by M. A. Carrigy