Preliminary Investigation
into Possibilities
for Producing Silica Sand
from British Columbia
Sand Deposits

by

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Key to Map

No.	Type	Locality	Relative Proportions of			Remarks
			Quartz	Feldspar	Dark Constituents	
1	Beach	Shelter Pt.	Low	Medium	High	Tidal Flats
2	Beach	Oyster R.	High	Medium	Low	Tidal Flats
3	Beach	Kye Bay	High	Medium	Low	Tidal Flats
4	Beach	Seal and Sandy Is.	Low	Medium	High	Sand Spit
5	Bank	Qualicum R.	Medium	Medium	Low	Banks Along River
6	Bank	Horne L.Jct.	Medium	Medium	Low	Banks Along Highway
7	Beach	Qualicum Beach	High	Medium	Medium	Tidal Flats
8	Beach	Parksville Beach	Low	Medium	Medium	Tidal Flats
9	Beach	Englishman R.	Low	Medium	Medium	Tidal Flats
10	Bank	Nanoose	Medium	Medium	Low	Bank Along Highway
11	---	Nanaimo	Low	Medium	Low	Dredged from Nanaimo Harbor
12	Beach	Kuper Is.	Low	Medium	High	Sand Spit
13	Beach	Porlier Pass	Low	Medium	High	---
14	Beach	Telegraph Beach	Low	Medium	High	Typical Beach
15	Bank	Saanich Beach	Low	Medium	High	Sand and Gravel Pit
16	Beach	Cordova Bay	Low	Medium	High	Typical Beach
17	Bank	Mt. Tolmie	Low	Medium	High	Sand and Gravel Pit
18	Bank	Langford	Medium	Medium	Medium	Old Sand and Gravel Pit
19	Bank	Royal Roads	Medium	Medium	High	Sand and Gravel Pit
20	Bank	Sooke River	Low	Medium	High	Banks Along River
21	Bank	Muir Creek	Low	Medium	High	Bank Along Road

Key to Map

No.	Type	Locality	Quartz	Feldspar	Dark Constituents	Remarks
			Relative Proportions of			
22	Beach	China Beach	Low	Medium	High	Typical Beach
23	Beach	Mary Is.	Low	Medium	Low	Spit - North End Island
24	Beach	Manson Bay	Medium	Medium	Low	Spit
25	Beach and Bank	Cortes Is.	Medium	Medium	Low	Bank and Beach Below
26	Bank	Hernando Is.	Medium	Medium	Low	Sand Cliffs
27	Bank and Beach	Savary Is.	Medium	Medium	Low	Cliffs and Beach Below
28	Bank and Beach	Savary Is.	Medium	Medium	Low	Cliffs and Beach Below
29	Beach	Harwood Is.	Medium	Medium	Low	Spit North End Island
30	Bank and Beach	Harwood Is.	Medium	Medium	Low	Cliffs and Beach Below
31	Bank and Beach	Harwood Is.	Medium	Medium	Low	Cliffs and Beach Below
32	Bank	Thormanby Is.	Medium	Medium	Low	Cliffs
33	Bank	Howe Sound	Low	Medium	High	Sand and Gravel Pit
34	Bank and Beach	Point Grey	Low	Medium	Medium	Cliffs and Beach Below
35	Bank	Port Coquitlam	Medium	Medium	Low	Sand and Gravel Pit
36	--	Fraser R.	Low	Low	High	From River
37	Bank	English Bluff	Medium	Medium	High	Cliffs
38	Beach	Crescent	Medium	Medium	High	Tidal Flats

Note: The terms "low", "medium", and "high" are used
only in a relative sense. For instance, "high" may be con-
sidered to indicate more than 22 per cent. quartz, 60 per

cent. feldspar and 40 per cent. dark constituents; "medium" from 15 to 22 per cent. quartz, 30 to 60 per cent. feldspar, and 15 to 40 per cent. dark constituents; and "low" less than 15 per cent quartz; 30 per cent. feldspar and 15 per cent. dark constituents.

Preliminary Investigation into Possibilities

For

Producing Silica Sand from British Columbia Sand Deposits

INTRODUCTION

For many purposes silica sand is an essential industrial raw material. No commercial deposits have been discovered in British Columbia. As a result, the present investigation was undertaken to study the possibility of producing silica sand through beneficiation of locally available materials. As far as the writer is aware, this problem has not been previously investigated. On the other hand, such essential steps as the separation of feldspar from quartz, and of iron-bearing minerals from both, have been studied elsewhere, and patents covering such separations granted. Considerable research along these lines has been carried out by members of the United States Bureau of Mines. Their publications formed the basis of much of the experimental work described herein. A list of references is appended.

The writer gratefully acknowledges the cooperation of the following companies in supplying samples of reagents used in the tests described:-

> Harrisons and Crossfield (Canada)
> Ltd., Vancouver, B.C.
> Armour and Co., Chicago, Illinois.
> E.I. DuPont de Nemours and Co.,
> Wilmington, Del.
> Emulsol Corporation, Chicago, Ill.

The sand deposits discussed in the present report were examined in 1936 and laboratory work was done in 1941. All analyses were made by G. Cave-Browne-Cave, Chief Analyst. It is shown, in the following report, that silica sand can be produced from certain local deposits and that processing has at least possibilities of economic application. To prove or disprove the commercial feasibility of such bene- ficiation, however, the most suitable deposit must be deter- mined in light of the factors discussed and sufficient large- scale test-work done to establish approximate production costs.

In this respect the Department of Mines would welcome samples of sands from any large deposits close to transportation. Such samples will be examined microscopically and, if mineralogically suitable, will be tested in a preliminary way to determine their amenability to beneficiation.

DESCRIPTION OF DEPOSITS

Only the sands of the southern coastal region of British Columbia are considered here. Other deposits are distributed throughout the Province some of which are undoubtedly purer than those discussed. The latter, however, have been examined in detail, are more or less representative of all, and are easily accessible.

In general, all the sands of the area under discussion have been deposited either as outwash material from glaciers, or as delta or alluvial deposits from streams heavily laden with glacial debris. Even recent beaches and deltas are largely the result of the re-working of such materials. As might be expected, all sands are characterised by a relatively large proportion of fresh angular feldspar and other easily decomposed minerals and rock fragments.

Distribution of the more important sand deposits is indicated on the accompanying map. Deposits are classed as "bank" and "beach" for convenience. The former are typically interglacial in origin, the latter recent. A detailed description of the occurrence of these deposits is outside the scope of this report. Suffice it to say that all are of economic size.

Mineralogy:

Typical samples from deposits shown on the map were examined microscopically. The mineralogical composition is remarkably constant, differing chiefly in proportions of rock fragments, feldspar, quartz and heavy minerals.

The following minerals were identified in the samples examined:

Plagioclase	Biotite	Zircon
Orthoclase	Phlogopite (?)	Tourmaline
Quartz	Garnet	Apatite
Rock Fragments	Rutile	Topaz
Hornblende	Sphene	Kyanite
Muscovite	Augite	Chlorite
Iron Ores	Hypersthene	Brookite

The sands of Thormanby, Texada, Harwood, Savary, Hernando, Mary, Cortes and Quadra Islands, Cape Lazo, Pitt and Qualicum Rivers are characterised by comparative absence of rock fragments. They consist essentially of plagioclase and quartz, with lesser amounts of other minerals. The constituents of this group are present in proportions approximating those of quartz-diorite. All of the accessory minerals, with the exception of topaz, tourmaline, kyanite and phlogophite, have been reported in Coast Range batholithic rocks.

The sands of Shelter, Oyster, Kye and Qualicum Beaches contain a somewhat larger proportion of both rock fragments, quartz grains and iron ores relative to feldspar.

The sands of Parksville Beach, Denman Island, Kuper Island, Porlier Pass, Nanaimo District, Saanich District, Victoria and Sooke Districts, Jordan River area, Vancouver area, and Fraser River Delta, are in general impure, containing a much larger proportion of rock fragments of varied types and a smaller proportion of quartz grains.

As a rule, bank sands are finer-grained, contain more silt and clay, and slightly less quartz than those of recent beaches. The differences, however, are neither marked nor consistent over the region as a whole.

Chemical analyses of some representative samples are tabulated below: (Numbers refer to localities marked on the map).

Bank Deposits - Composition in Per Cent.:

	10	25	26	30	27	6	5
SiO_2	66.26	68.02	68.01	66.75	65.90	68.75	70.07
Al_2O_3	16.69	16.45	17.38	15.28	17.12	16.10	16.90
Fe_2O_3	2.34	2.81	1.74	3.36	2.20	1.88	1.18
FeO	1.62	nd	1.42	1.64	2.17	1.62	1.21
MgO	2.10	nd	1.58	1.32	2.00	1.79	1.32
CaO	5.65	5.40	5.53	5.59	6.41	5.36	5.12
Na_2O	3.56	nd	3.40	2.60	3.61	3.28	3.24
K_2O	1.12	nd	0.70	1.88	0.68	0.45	0.48
TiO_2	0.30	nd	nd	0.70	nd	0.36	nd
Ignition Loss	0.74	nd	0.73	1.02	0.56	0.31	0.94
	100.38	—	100.49	100.14	100.65	99.81	100.46

Beach Deposits - Composition in Per Cent:

	2	3	7	25	28	31
SiO_2	68.80	64.75	70.21	66.10	69.71	68.10
Al_2O_3	15.79	16.85	15.40	15.81	15.46	17.00
Fe_2O_3	0.75	1.74	1.67	2.70	1.72	2.50
FeO	1.60	2.28	1.47	2.15	0.70	nd
MgO	1.43	1.44	1.32	2.01	1.61	nd
CaO	6.07	6.67	5.31	6.32	5.62	4.70
Na_2O	3.89	4.16	3.41	3.80	2.89	nd
K_2O	0.30	0.68	0.54	0.90	0.97	nd
TiO_2	0.50	0.40	nd	nd	0.50	0.40
Ignition Loss	1.26	1.29	1.23	0.85	0.39	nd
	100.39	100.26	100.56	100.64	99.57	--

Portions of the above samples were fractionated by sink-and-float separation in bromoform (Sp. G. 2.85). The products were examined microscopically. Results are tabulated below:

Bank Sands:

	10	26	27	6	5
Floats					
Per cent. of total	88	94	85	89	91
Quartz[1]	c	c	c	c	c
Feldspar	a	a	a	a	a
Rock	r	t	t	r	r
Sinks					
Per cent. of total	12	6	15	11	9
Hornblende	c	a	a	a	a
Iron ores	r	r	r	r	r
Mica	a	c	c	r	p
Epidote	p	r	p	p	p
Hypersthene	nd	t	nd	t	t
Sphene	nd	t	nd	--	t
Zircon	nd	t	nd	t	t
Rutile	nd	--	nd	--	--
Garnet	nd	t	nd	t	t
Augite	nd	t	nd	--	--

1

Note: (on preceding page) "a" represents over 40 per cent. of fraction; "c", 15 to 40 per cent.; "p", 5 to 15 per cent.; "r", 1 to 5 per cent.; "t", less than 1 per cent.; "nd", not determined.

Beach Sands:

	2	3	7	25	28	31
Floats						
Per cent. of total	88	90	86	95	95	92
Quartz	c	c	c	c	c	c
Feldspar	a	a	a	a	a	a
Rock	t	t	t	t	t	t
Sinks						
Per cent. of total	12	10	14	5	5	8
Hornblende	a	a	a	a	a	a
Iron ores	r	r	r	r	r	r
Mica	c	c	c	c	c	c
Epidote	c	c	p	p	c	c
Hypersthene	r	r	r	nd	r	nd
Sphene	r	t	r	nd	t	nd
Zircon	t	t	—	nd	t	nd
Rutile	—	—	—	nd	—	nd
Garnet	t	r	r	nd	t	nd
Augite	r	—	—	nd	t	nd

In general, sand grains are angular to sub-angular and relatively free from visible clay coatings. Some are iron-stained, especially in creamy or yellowish-coloured samples. Feldspar grains are clear to opaque. With the exception of a very small proportion of potash-feldspar, their composition lies between albite-oligoclase and andesine. Golden-coloured mica is common in many samples. It is probably derived from the alteration of biotite.

Sieve analyses of characteristic samples are presented below:

Bank Sands: Per Cent. by Weight:

	10	25	26	30	27	6	5
✛10 mesh	--	0.14	0.14	0.12	--	--	--
-10 ✛20	--	0.42	0.51	0.42	0.20	0.95	1.15
-20 ✛40	0.33	8.22	17.72	13.75	1.85	16.17	9.20
-40 ✛60	1.89	20.15	28.95	23.60	12.70	50.80	41.30
-60 ✛80	9.90	20.80	18.45	17.45	23.20	21.80	25.00
-80 ✛100	19.50	22.45	15.28	12.42	30.00	6.90	10.90
-100	68.29	27.82	18.57	32.35	39.00	3.73	7.75

Beach Sands - Per Cent. by Weight:

	2	3	7	25	28	31
✛10 mesh	0.70	--	--	--	--	4.75
-10 ✛20	1.30	0.33	--	--	--	12.30
-20 ✛40	10.70	14.85	0.27	10.75	1.27	72.00
-40 ✛60	55.30	52.55	5.85	51.75	38.00	10.20
-60 ✛80	26.10	22.35	60.40	28.75	42.70	1.00
-80 ✛100	4.55	6.30	29.60	7.05	11.50	0.30
-100	1.10	3.70	3.95	1.90	6.57	0.10

Samples 2, 3, 7, 10, 20 showed a notable concentration of dark minerals in the -100 mesh fraction.

BENEFICIATION

Test-work on representative samples was done with the object of determining the technical feasibility of producing silica sand. Laboratory tests were reasonably successful and yielded much valuable information. More extensive investigation on a larger scale is required, however, to establish the commercial practicability of such processing. It is hoped that information contained in this report may serve, not only as a basis for further work, but to indicate the potentialities of sand treatment and hence encourage search for purer deposits. Before mentioning the actual results of tests, a resume of the fundamental factors involved will clarify future discussion.

The recovery of silica from impure sand is primarily a matter of eliminating all minerals but quartz from the final product. The quartz content of a sand, therefore, determines in large measure its amenability to practical treatment. Almost equally important, however, are the kinds and proportions of other minerals present, insofar as they may, or may not, respond to economical mineral dressing methods.

The separation of mineral grains in sand depends upon sufficient differences in mineral properties to permit application of simple processes. The differences which allow such separations to be made commercially are those of specific gravity, magnetic susceptibility, surface characteristics, form and electrical conductivity. From this point of view the composition of the sands under consideration is worthy of re-examination.

In general, the sands described are composed of the following essential constituents:

Mineral	Chemical Comp.	Sp. Gravity	Remarks
Quartz	SiO_2	2.65 - 2.66	Clear, glassy grains free from visible coatings or surface abrasion.
Plagioclase	$(X.NaAlSi_3O_8)$ $(Y.CaAl_2Si_2O_8)$	2.65 - 2.69	All degrees of alteration from glassy clear to white opaque grains.
Rock Fragments	"locked" grains of intrusive rocks, also greenstone, slate etc.	---	---
Hornblende	Complex Fe, Al, Ca, Mg, Na, K silicate	3.05 - 3.47	Relatively fresh.
Mica	Mainly biotite or "bleached" biotite. Complex Mg, Fe, Al, K silicate		Large proportion bleached to golden colour.
Accessory minerals	Including garnet, augite, sphene, magnetite, epidote, ilmenite, etc.	Mostly over 3.0	Relatively fresh.

The following points are suggested by examination of the above suite of minerals:-

(1) Iron is restricted to hornblende, mica, accessory minerals, and rock fragments. Removal of these will leave an iron-free product containing only SiO_2., Al_2O_3, CaO, Na_2O and K_2O in a mixture of quartz and feldspar.

(2) Specific gravities, form and magnetic properties of iron-bearing minerals differ enough from those of quartz and feldspar to suggest that they may be satisfactorily eliminated by simple mineral dressing operations.

(3) Physical properties of quartz and feldspar do not differ sufficiently to allow their separation by either gravity or magnetic methods. Flotation, or table agglomeration, and possibly electrostatic processes are the only obvious means of treatment.

Theoretically, the problem is resolved into a matter of eliminating iron-bearing minerals by gravity or magnetic separation, followed by removal of feldspar from the resulting low-iron concentrate by flotation or table agglomeration[*].

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[*]

The feasibility of electrostatic separation was not investigated through lack of appropriate equipment. Published information suggests that it might be applicable to the problem however. The following references are worthy of attention by the interested reader:

Electrostatic Separation -- H.B. Johnson, Eng. and Min. Journ., Oct. Nov. and Dec. 1938.

Selective Electrostatic Separation -- H.B. Johnson, TP 877, A.I.M.E., 1938.

Electrostatic Separation Scores Advance in Phosphate Recovery -- H.B. Johnson, Eng. and Min. Journ., March, 1941.

Special Methods for Concentrating and Purifying Industrial Minerals -- G.W. Jarman, TP 959, A.I.M.E. p. 8, 1938.

Dry Separation of Minerals -- T. Kipp, Bull. C.I.M.M., Oct., 1940, p. 8.

Principles of Mineral Dressing -- A.M. Gaudin, McGraw Hill, 1939, pp. 465-467.

Conceding the necessity of flotation, or allied processes, for the separation of feldspar and quartz, the possibility of direct removal of quartz from sands also seems a logical approach to the problem. Both lines of investigation were thoroughly studied in the laboratory.

Theoretically, the problem outlined above appears relatively clear-cut. Practically, the following complicating factors enter into it:

(1) Variable proportions of rock fragments of diverse composition and properties occur in all sands. As a whole the amenability of these to removal is unpredictable on theoretical grounds.

(2) Surface coatings on feldspar and quartz grains, as well as minute enclosed fragments of iron-bearing minerals, prevent total elimination of iron from quartz, or quartz-feldspar, products.

(3) A sand may be considered the result of natural crushing and classifying processes. In most respects it resembles an artificial "sand" produced by crushing and sizing a rock of similar composition. This is essentially true where beneficiation by gravity or magnetic methods is concerned. Where flotation is involved, however, a notable difference is apparent. An artificial "sand" is usually prepared shortly, or even immediately, before it is subjected to the action of flotation reagents. Consequently its grains have relatively fresh surfaces which are reasonably and consistently representative of the minerals present. As a result separations are not only fairly sharp, but results are in large measure predictable from sample to sample. In a natural sand, however, exposed over long periods of time to atmospheric agencies and percolating solutions, alteration of surfaces may be so marked that mineral composition has little influence on reaction to flotation processes. The essentially complex nature of sand deposits from the point of view of derivation and history introduces a further complication in the form of varying degrees of surface alteration or activation of grains of the same mineral. In brief, every sand deposit must be considered on its own merits where treatment by flotation methods is concerned.

(4)   The practical limitations of mineral dressing
methods are such that perfect separations are rarely
possible.

Review of Previous Work:

Silica sand is a relatively low-priced com-
modity. Production is in general restricted to pure
deposits requiring minimum processing. Operations on
the North American continent are confined almost entirely
to sand or loosely-consolidated sandstone deposits.

Treatment[x] is principally concerned with
washing to remove clay and fines, screening to meet
required size specifications and drying.

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[x]
   Excellent general review of methods used in proces-
sing silica sand are contained in the following publica-
tions:--

Technology and Uses of Silica and Sand - W.M. Weigel,
                         U.S. Dept. of Commerce, Bureau
                         of Mines, Bull. 266, 1927.
Silica in Canada - Pts. 1 and 2 -- L.H. Cole, Dept. of
                         Mines, Mines Branch, Ottawa,
                         Nos. 555 and 686, 1923 and 1928.
Glass Manufacture and Glass Sand Industry -- C.R. Pettke,
                         Top. and Geol. Survey of Penn. -
                         Rept. XII, 1919.

Although these publications are not recent, there have
been few fundamental changes in the principles involved
in preparing silica sand for the market.

In recent years increased competition, improved
technology, and more exacting specifications have resulted
in the adoption of additional methods of purification by
some producers. These include acid leaching, magnetic
separation, and tabling. Other processes, including
attrition milling (1,2) and flotation (2,3,4,5,6) have
been suggested. Several Canadian sands and sandstones
have been investigated (7,8,9,10,11,12,13) in the Ore
Dressing and Metallurgical Laboratories of the Depart-
ment of Mines and Resources at Ottawa. In general, how-

ever, all eforts have been directed towards further purification of materials already in the category of silica sands.

Although the immediate problem of producing silica sand from impure sands has not been investigated before, as far as the writer is aware, many aspects of it, as outlined in the preceding section, have received considerable attention. Subsequent discussion will be confined to flotation and magnetic separation insofar as few revolutionary developments in other processes bearing on the subject have taken place recently.

Removal of Iron-bearing Minerals:

Iron oxides have been floated (14[x], 2, 3, 1, 16) with varying degrees of success by such anionic collectors as oleic acid, sodium oleate, sodium oleyl sulphate, ammonium laurate, sodium stearate, "Aerofloat", etc. used in conjunction with suitable conditioners, modifiers and frothers.

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[x]
14 - Contains extensive bibliography. Only the more important references are noted in the present paper.

Little specific data are available on hornblende and biotite, but both are mentioned (14, 16, etc.) as responding to flotation by suitable reagents.

High-intensity magnetic separation (2, 17, 18, 19, 22) is employed in many industries for the elimination of iron-bearing impurities. Among these are the purification of silica sand, feldspar and nepheline syenite by removal of such minerals as biotite, hornblende, hematite and even muscovite.

Separation of Quartz and Feldspar:

Selective flotation of feldspar by means of sodium oleate and lead nitrate was reported (20) as early as 1932. Further extensive experimentation (14) along these lines was carried out in Germany with fair success. The first positive separation of feldspar from quartz, however, is attributable to workers (21) in the

laboratories of the United States Bureau of Mines at Tuscaloose, Ala. and College Park, Md., using the newer cationic reagents with suitable depressors for quartz.

Definite flotation of quartz from feldspar has not been satisfactorily achieved as yet, chiefly through lack of depressors for feldspar. Encouraging results have been reported (21, 14, 1), however, by several workers.

General:

The subject of non-metallic flotation has received considerable attention in recent years and a wealth of literature is available on many of its phases. Much of this, while bearing only indirectly on the problem at hand, is a source of invaluable general information. The following references were consulted in the course of the present investigation (14, 22, 23, 24, 25).

Agglomerate-Tabling:

A discussion of the theory and practice of flotation is beyond the scope of this report. On the other hand, a brief explanation of the principles of agglomerate-tabling may prove helpful to those unfamiliar with the process.

In the flotation process particles of a desired mineral are made to acquire water-repellant surfaces by filming with suitable reagents. Such filmed grains, in resisting wetting, attach themselves to air-bubbles introduced into the pulp mechanically or pneumatically. These bubbles, with their mineral burdens, rise to form a froth on the surface of the water. This froth is skimmed off carrying with it the mineral in question.

In the agglomerate-tabling process mineral grains are filmed by reagents in just the way described. Instead of aerating the pulp at this stage, however, a heavy inert oil is added which selectively superimposes an oily film upon grains that are water-repellant through action of the original reagents. The pulp now consists of a mixture of mineral particles, some coated with oil, others with water. Agitation of this pulp causes the oiled grains to adhere to each other in relatively large agglomerates or floccules. These may be removed from unoiled material by tabling.

Agglomerate-tabling is applicable to a much coarser feed than flotation, but is not satisfactory for very fine material. Its peculiar sphere of usefulness lies in the processing of granular material coarser than 50 mesh. Close-sizing of feed is a distinct aid in improving separations insofar as the limitations of gravity-tabling apply to some extent to the process. Chief advantages in comparison with flotation are lower plant and treatment costs; chief disadvantages are the oily nature of agglomerated products and less flexibility in retreatment of concentrates.

Further information on the theory and practical applications of agglomerate-tabling is contained in several publications to which the reader is referred (14, 22, 26, 27, 28).

REVIEW OF TEST-WORK

Approximately 300 tests were made to investigate various factors of the problem. In brief, the following variables were studied;

Sands:

Most work was done on two sands (Qualicum Beach No. 7) and Qualicum River (No. 5) selected on the basis of mineralogy and preliminary tests as being reasonably characteristic of the purer beach and bank deposits of the region. Several other sands, including certain obviously impure samples, were investigated extensively enough to relate them to the above types or to demonstrate their non-amenability to beneficiation.

Methods:

Applicability of the following methods, or combinations of methods, was studied: Washing, screening, classification, gravity-tabling, flotation, agglomerate-tabling and magnetic separation.

Two general lines of approach to the problem were followed:

1. Removal of iron-bearing minerals with consequent separation of quartz and feldspar from the resulting low-iron mixture.

2. Concentration of quartz in an initial product from which feldspar and iron-bearing minerals were eliminated.

Mineral determinations on various test-products were made microscopically. By this means accurate differentiation of quartz and feldspar is difficult if rapidity is essential. As a result, quantitative data, while approximately correct, are of relative value only. Products which seemed to merit greater accuracy were analysed chemically.

Reagents Tested for Agglomerate-Tabling and Flotation:

The following reagents were tested as collectors:

Anionic Reagents[*]

Crude Oleic Acid - (Beaver Soaps, Ltd., Winnipeg)
Sodium Oleate
Reagent 407 - Mahogany Soap - (Sherwood Petroleum
              Products, Warren, Pa.)
#50 Turkey Red Oil - Sulphonated Castor Oil - 50
              % moisture - (Yocum, Faust, Ltd.
              London, Ontario).
Sulphonated Oleic Acid - (Yocum, Faust, Ltd.
              London, Ontario).
No. 1 Sulphonated Oil - Sulphonated Salmon Oil -
              (Yocum, Faust, Ltd., London,
              Ontario).
Sulphonated Tall Oil - (courtesy of Harrisons and
              Crossfield (Canada), Vancouver).

Cationic Reagents[*]

Trimethyl Cetyl Ammonium Bromide - (E.I. du Pont de
              Nemours and Co., Wilmington, Del).
Trimethyl Stearyl Ammonium Bromide - (E.I. du Pont
              de Nemours and Co., Wilmington,
              Del.).
Cetyl Betaine - (E.I. du Pont de Nemours and Co.,
              Wilmington, Del.).

DP 243 - lauryl amine hydrochloride - (E.I. du
Pont de Nemours and Co., Wilmington, Del.).
12 NAM - 1180-C - mixture of n-monohexadecyl, n-
monooctadecyl, n-monooctadecenyl amines -
(Armour and Co., Chicago, Ill.).
AMAC 1180-C - mixture of n-monohexadecyl and n-
monooctadecyl amine acetates - (Armour
and Co., Chicago, Ill.).
AMAC 1120-A - n-monododecyl amine acetate - (Armour
and Co., Chicago, Ill.).
Catol 3E - (Emulsol Corporation, Chicago, Ill.).
607 CE - quaternary ammonium derivative - (Emulsol
Corp., Chicago, Ill.).

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x

Note - Anionic and Cationic reagents are discussed in
many publications, among the most useful of
which are:-

New Flotation Reagents - R.S. Dean and A.B. Hersberger-
TP605, A.I.M.E., 1935.
Use of Wetting Agents in Flotation - R.S. Dean, J.B.
Clemmer, and S.R.B. Cooke - R.I. 3333, U.S.B.M.,
1937.
Flotation and Agglomerate Concentration of Nonmetallic
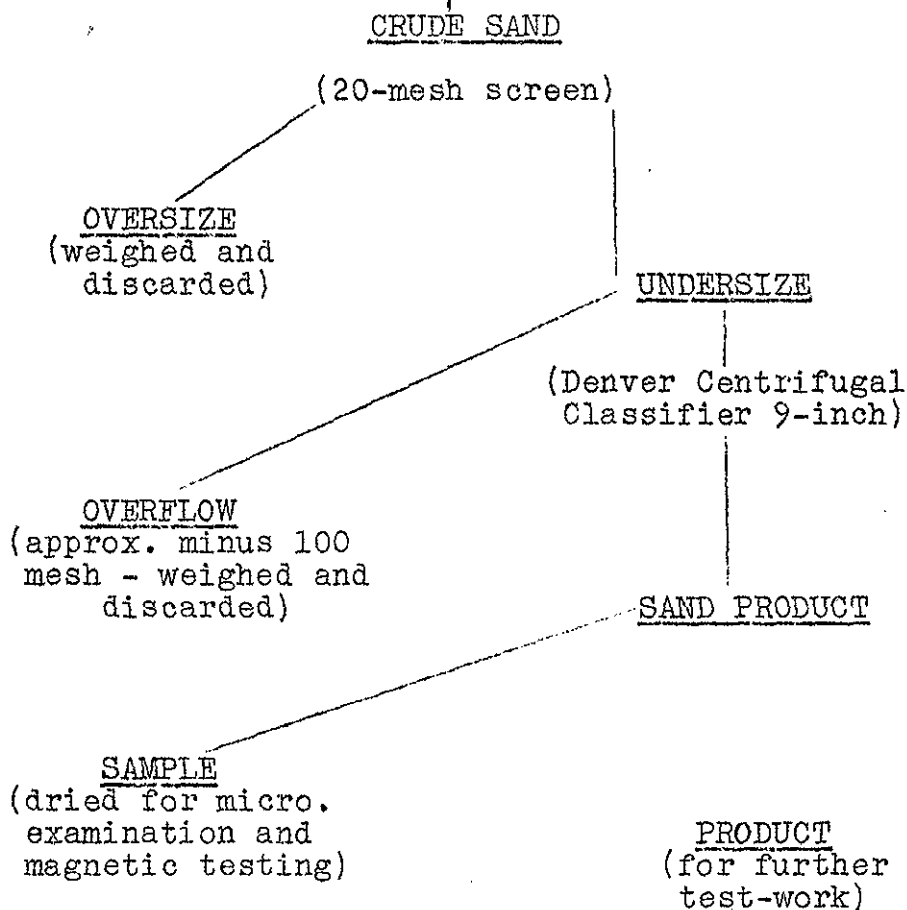Minerals - O.C. Ralston - R.I. 3397, U.S.B.M.,
1938.
Principles of Mineral Dressing - A.M. Gaudin - McGraw-
Hill, 1939, pp. 367-384.

A variety of reagents were tested as depressors,
activators, modifiers, and frothers.

Procedure in Testing:

Granulometric and microscopic analyses were
made of samples under consideration.

The following standardized procedure was used
in preparing samples for further testing:

CRUDE SAND

(20-mesh screen)

OVERSIZE
(weighed and
discarded)

UNDERSIZE

(Denver Centrifugal
Classifier 9-inch)

OVERFLOW
(approx. minus 100
mesh - weighed and
discarded)

SAND PRODUCT

SAMPLE
(dried for micro.
examination and
magnetic testing)

PRODUCT
(for further
test-work)

The classifier was so adjusted that the required separation was effected with minimum water and maximum agitation. By so doing it performed the dual role of sizing and washing.

Magnetic separation tests were made with a small separator designed by the writer. Its ability to remove weakly magnetic minerals was similar to that of standard super high-intensity machines. Small capacity, however, restricted its use to samples of 10 grams or less, with the result that non-magnetic feed for subsequent operations could not be prepared.

A Wilfley-type concentrating table with 18 by 40-inch deck, was used for both gravity- and agglomerate-tabling.

Two flotation cells were available; one of 125-gram capacity, built by the writer after United States Bureau of Mines design; the other a standard 500-

gram Denver "Sub-A" laboratory cell. The former served for preliminary tests, cleaning operations and with cell removed as an agitator for conditioning pulps. The latter was used to check results obtained in the smaller machine, and as a blunger for the removal of slimes.

Feed for agglomerate-tabling was conditioned at a pulp-density of 50 to 60 per cent. solids. Conditioned pulps were agitated and aerated with a high-velocity jet of water and vanned. Agglomerated products thus removed were re-vanned to eliminate entrapped grains. This procedure gave results comparable to tabling and was used for all preliminary tests. These were corroborated where necessary by tabling.

Reagents were added as dilute aqueous solutions or emulsions. Alkalinity or acidity was determined colorimetrically.

DETAILS OF TEST-WORK

QUALICUM BEACH SAND:

A composite sample of several hundred pounds was taken from shallow pits over a considerable area of sandflats exposed at low tide. This provides an interesting comparison with the small sample described previously and taken from the beach above high-tide. The latter is higher in silica and lower in iron; the former is more truly representative of sand which might be recovered commercially.

Washing and Sizing:

About 3 per cent. of the sand was coarser than 20-mesh and consisted largely of dark rock pebbles and broken shell. Five per cent. of the remaining sample was removed as overflow. Slime was not abundant.

The resulting minus 20 plus 100-mesh product represented a little more than 90 per cent. of the original sample. Its more important properties are

listed below:

	Per Cent.	Remarks
- 20 + 40 mesh	5	Contains larger proportions of rock fragments.
- 40 + 60 mesh	10	
- 60 + 80 mesh	60	
- 80 +100 mesh	15	Contains larger proportions of dark, heavy minerals, eg. hornblende, magnetite, etc.

Chemical Analysis:[*]

	Per Cent.
SiO_2	67
Al_2O_3	14
Fe_2O_3	6

---

[*] Note: Only SiO_2, Al_2O_3 and Fe_2O_3 were reported in routine analyses of test-products.

Microscopic Analysis:

	Per Cent.	Remarks
Quartz	20	Grains angular to sub-angular and relatively
Feldspar	45	free from iron-stains
Dark Minerals[*]	35	or obvious slime coatings.

---

[*] Note: Under the category of "dark minerals" are classed all undesirable impurities in sands other than feldspar.

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1. Elimination of Iron-bearing Minerals:

   A. Magnetic Separation: A small sample of washed
sand was dried and passed through the magnetic separator.
The non-magnetic fraction, approximately two-thirds of
the feed, contained 0.17 per cent. Fe_2O_3.

   B. Gravity-Tabling: Fifty pounds of washed sand
was tabled and three products recovered, designated
"light", "middling", and "heavy". The first was com-
posed of mica, shell fragments, and coarser sand grains.
The last contained nearly all the magnetite and related
minerals in the original feed, most of the epidote,
garnet, etc. and a large part of the hornblende. Inso-
far as sharp separation was impossible, the products were
cut arbitrarily to include a maximum of undesirable con-
stituents in the "light" and "heavy" fractions.

   The "middling" product, amounting to two-thirds
of table-feed, contained quartz, feldspar and rock frag-
ments, with only minor quantities of hornblende and mica.

   Microscopic Analysis:

	Per Cent.
Quartz	25
Feldspar	55
Dark	20

   The product contained 2.3 per cent. Fe_2O_3.

   Gravity-tabling removed one-third of the dark
constituents, equivalent to two-thirds of the original
iron content. So-called "heavy minerals" were almost
entirely eliminated. Remaining dark material comprised
interlocked grains, rock fragments and iron-stained
particles, with only a small proportion of hornblende
and mica. In brief, little improvement could be anti-
cipated by closer sizing of feed, larger rejects, or
full-scale operation.

   C. Agglomerate-Tabling: Tests were made with
anionic collectors under a variety of conditions. The
following conclusions were reached:

   1. Dark minerals agglomerated readily, but

recovery was incomplete even with excessive amounts of collectors.

2. Hornblende and biotite were most easily agglomerated, followed by certain rock fragments, iron-stained grains and even quartz and feldspar. No marked nor progressive selectivity between these was apparent.

3. Sodium oleate and tall oil were the most efficient collectors tested. Others, including sulphonated salmon oil, oleine and mahogany soap were equally effective in larger quantities. None showed notable differences in collecting power for specific minerals.

4. Optimum Ph for sodium oleate ranged from 7 to 8, and for Tall oil from 6 to 7. Sulphonated collectors in general were more effective in acid solutions and curdled when alkalinity was high. The collecting power of sodium oleate increased with greater alkalinity within limits, but at the expense of selectivity.

The following example demonstrates the order of results obtainable:

Reagents: Sodium Oleate - 2 lbs. per ton
              Fuel Oil   5 lbs. per ton

	Per cent. Weight	Per cent. Fe_2O_3
Dark Concentrate	15	--
Tailing	85	0.5

A minimum of 0.3 per cent. Fe_2O_3 could be obtained only by using 10 to 15 pounds per ton sodium oleate.

D. Flotation: Flotation of the "middling" product yielded inferior results than agglomerate-tabling, owing to the presence of relatively coarse grains in the feed. Results on minus 50-mesh material were in general comparable.

Combined flotation of the minus 50-mesh, accom-

panied by agglomerate-tabling of the plus 50-mesh
fractions gave only slightly superior results over
straight agglomeration of the whole product.

E. Conclusions re Elimination of Iron-bearing
Minerals: A feldspar-quartz product, containing from
0.3 to 0.5 per cent. Fe_2O_3, and amounting to one-half
the original unwashed feed, can be made by a combin-
ation of washing, sizing, gravity-tabling and agglomerate-
tabling. By drying and magnetic separation the iron-
content can be further lowered to about 0.1 per cent.
Fe_2O_3.

2. Separation of Quartz and Feldspar:

A. From Low-Iron Tailing: A large sample of the
gravity-table "middling" product was agglomerated with
sodium oleate and the low-iron (0.5 per cent. Fe_2O_3)
tailing tested for removal of quartz and feldspar with
the following results:

1. Trimethyl stearyl ammonium bromide
definitely tended to agglomerate quartz preferentially.
Reagent 607-CE and the long-chain mono-amines, 12 NAM
1180-C and AMAC 1180-C did likewise, but to a lesser
degree. Lauryl amine hydrochloride, trimethyl cetyl
ammonium bromide, Catol-3E and AMAC 1120-A were less
less selective. Cetyl betaine and short-chain amines
proved ineffective.

2. The following concentration was made with
1/2-lb. per ton trimethyl stearyl ammonium bromide and
5 lbs. per ton fuel oil:

	Per cent. Weight	Analysis		
Concentrate	20	SiO_2	- 82 per cent.	
		Al_2O_3	12 "	"
		Fe_2O_3[x]	0.09 "	"
Tailing	80	------		

[x] Note: Fe_2O_3 content after magnetic separation of
product.

The affects of a number of various chemicals upon the separation was studied but only ammonium hydroxide gave rise to any marked improvement. In this respect the following test may be compared with that above:

Reagents: Trimethyl stearyl ammonium bromide-
1/2-lb. per ton.
NH_4OH - 1 lb. per ton.
Fuel Oil - 5 lbs. per ton.

	Per cent. Weight	Analysis		
Concentrate	15	SiO_2	- 92 per cent.	
		Al_2O_3	5 "	"
		Fe_2O_3	0.07 "	"
Tailing	85	------		

The quoted tests represent the most satisfactory results obtained with trimethyl stearyl ammonium bromide. Greater amounts of collector increased overall recovery, but at the expense of selectivity. In other words, it proved impossible to make a clean-cut separation between quartz and feldspar by attempting to float the former.

3. A combination of DP 243 and hydrofluoric acid was used to float feldspar from quartz after the method (21) developed by the United States Bureau of Mines. A clean feldspar product could be made in this way, but the resulting tailing was impure owing to the presence of altered feldspar and rock fragments which could not be eliminated.

It was concluded that even if possible the production of silica sand by a combination of the steps so far outlined, was impractical owing to the complexity of processes involved, lack of selectivity and low recoveries. In view of this conclusion, further investigations were concerned with the direct concentration of quartz from impure sand.

B. From Gravity-Table "Middling" Product:

Previous tests suggested little likelihood of

recovering silica sand from impure sand in one step.
A complex process of some kind was clearly indicated,
yet this must be kept within the bounds of practica-
bility. The method finally chosen for investigation
involved removal of a high-silica concentrate followed
by separation of quartz and feldspar. The reasons for
adopting this line of attack were:

(a) The only positive means of separating
quartz and feldspar known to the writer was agglomera-
tion of the latter with suitable cationic reagents in
the presence of hydrofluoric acid or other fluorides.
This had failed previously to give a satisfactorily
clean quartz tailing owing to the presence of other con-
stituents which could not be eliminated by this process.
It was reasonable to suppose that a quartz-feldspar
concentrate made with the aid of cationic reagents
would contain a minimum of these undesirable constituents.

(b) Selective agglomeration of a high-silica
product would be automatically accompanied by rejection
of most iron-bearing minerals.

(c) The method showed promise of being econom-
ically feasible if the initial concentration could be
made inexpensively.

The following were the chief problems to be
solved in connection with the proposed process:

(1) Agglomerated products are remarkably stable.
The oily film on grains is maintained indefinitely under
ordinary conditions and prevents further separations
from being made. It was obviously necessary to over-
come this before fractionation of the initial quartz-
feldspar concentrate could be undertaken.

(2) Owing to the necessarily small recovery of
quartz possible from the sand, any hope of practical
success depended upon cheapness in the first step.
This in turn implied low reagent cost. Insofar as
cationic reagents are relatively expensive, research
was influenced largely by the dictates of economy.

De-Agglomeration of Products:

De-agglomeration implies either removal of the
oily film from agglomerated grains to allow further bene-

ficiation, or elimination of objectionable oil from
final products. Two methods suggest themselves:
leaching by organic solvents, or emulsification. The
first was discarded owing to its obvious expense and
complexity; the second was investigated in some detail.

Agglomerated products for testing were made
with cationic reagents and fuel oil. These were agitated
for short periods with various emulsifying agents. The
following results were obtained:

(a) Agitation in water, even over extended
times, had no appreciable effect.

(b) Addition of wetting agents, such as
Aerosol, caused immediate collapse of floccules. On
removal of Aerosol by washing, however, the product re-
agglomerated much as before.

(c) Almost complete de-agglomeration followed
violent agitation with sodium hydroxide in amounts ex-
ceeding 10 lbs. per ton. Results were too variable,
however, to be completely satisfactory. In some cases
where partial re-agglomeration accompanied removal of
sodium hydroxide, a tendency to concentrate quartz was
noted.

(d) As little as 1 lb. per ton sodium oleate
caused complete de-agglomeration of products with no
more than gentle agitation. The effect was permanent
for quartz and feldspar, but dark constituents re-
agglomerated after soap was removed by washing.

(e) The following reagents proved ineffective
or less satisfactory than sodium oleate: Tetraethanol
ammonium hydroxide, sulphonated oleic acid, sulphonated
castor oil and fish oils, mahogany soap, tall oil and
ammonium linoleate.

Sodium oleate showed promise as a de-agglomerator
in the method under consideration. Tests were, there-
fore, made to determine the feasibility of the process as
a whole.

Concentration of Quartz in High-Silica Products:

Low reagent cost was the chief consideration
in the initial step. A series of tests were consequently
made to compare relative collecting power of various

cationic reagents with respect to their costs. An additional step was first introduced however.

It had been noted that although washed sand was free from visible coating, heavy slimes had occurred during flotation. Tests were, therefore, made to determine the effect of de-sliming on reagent consumption. Most of the slime proved to be loosely held and a material saving in reagents could be effected by brief agitation and washing. The procedure adopted was agitation for two minutes in the conditioning tank followed by washing and decantation. This period was chosen arbitrarily to represent a degree of scrubbing easily obtained by standard sand washing equipment.

The following tests were run under identical conditions on samples of washed and gravity-tabled feed. Ph ranged from 6.8 to 7.0. Mineral content of products was determined microscopically and is approximate only.

(a) Trimethyl Stearyl Ammonium Bromide - 1/4-lb.
per ton.
Fuel Oil   5 lbs per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	13	66	33	1
Tailing	87	19	65	26

(b) Trimethyl Cetyl Ammonium Bromide:
1/2-lb. per ton.
Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	21	38	54	8
Tailing	79	20	56	24

(c)   DP243   1/4-lb. per ton.
       Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	30	37	53	10
Tailing	70	21	56	23

(d)   12NAM - 1180-C   1/20-lb. per ton.
       Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	20	50	47	3
Tailing	80	18	58	24

(e)   AMAC - 1180-C   1/20-lb. per ton.
       Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	45	45	51	4
Tailing	55	9	55	36

(f)   AMAC - 1120-A   1/10-lb. per ton.
       Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	12	24	68	8
Tailing	82	25	51	24

(g) Catol - 3E   1/2-lb. per ton.
     Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	30	32	56	12
Tailing	70	20	57	23

(h) 607 - CE   1/12-lb. per ton.
     Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	15	47	49	4
Tailing	85	21	57	22

AMAC - 1180-C was selected as the most suitable collector for the purpose at hand. It must be emphasized, however, that the above tests cannot be considered as any basis for general comparisons between the reagents concerned. With other materials, or even other sands, results might be entirely different, depending upon such unpredictable factors as freedom from slimes, prior activation of grains, etc.

A 10-lb. sample of gravity-table "middlings" was agitated for 2 minutes, washed free from resulting slimes, conditioned for 3 minutes at 50 per cent. solids and tabled.

Reagents - AMAC - 1180-C   1/20-lb. per ton.
           Fuel Oil   5 lbs. per ton.

	% Weight
Agglomerate Concentrate	30
Tailing	70

Attention was directed primarily to the removal of as pure a product as possible and since recovery was a secondary consideration middlings were discarded with tailings.

The concentrate was then agitated with 1 lb. per ton sodium oleate for 3 minutes, washed and re-tabled. About 10 per cent. of the feed, in the form of agglomerated dark constituents, was floated off. The remaining sand was relatively free from oil and showed no further tendency to form floccules. Its composition was as follows:

SiO_2 .... 80.2 per cent.
Al_2O_3 .... 12.6 " "
Fe_2O_3 .... 0.8 " "

Microscopic Examination:

Quartz .... 45 per cent.
Feldspar............. 50 " "
Dark .... 5 " "

Separation of Quartz and Feldspar:

The removal of feldspar from cleaned concentrate was next investigated. DP243 and AMAC - 1120-A were chosen as collectors.

Tests were made with the following reagent combinations:

(1) DP 243   1/2-lb. per ton.
    Hydrofluoric acid   3 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	60	10	85	5
Tailing	40	88	10	2

(2) AMAC - 1120-A   1/2-lb. per ton.
     Hydrofluoric acid   3 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	65	11	83	6
Tailing	35	95	4	1

As a check on the last of the above tests, the remainder of AMAC - 1180-C concentrate, about 2 lbs. in weight, was conditioned with 1/2-lb. per ton of AMAC - 1120-A and 3 lbs. per ton hydrofluoric acid and tabled. Three products were removed.

	% Weight
Agglomerate Concentrate	50
Middling	15
Tailing	35

The tailing was analysed, the other two were examined microscopically.

Chemical Analysis of Tailing:

SiO_2	98.7
Al_2O_3	1.6
Fe_2O_3	0.12

Microscopic Analysis of Middling and Agglomerate Concentrate:

Middling:

Quartz	20
Feldspar	77
Dark	3

Agglomerate Concentrate:

Quartz	6
Feldspar	90
Dark	4

By returning the middling to table feed and cleaning the tailing, overall recovery of quartz in a purer final product would be increased.

Summary of Tests on Qualicum Beach Sand:

1. The Fe_2O_3 content of washed and sized sand was reduced from 6 per cent. to 2 per cent. by gravity-tabling, or to 0.17 per cent. by magnetic separation.

2. Fe_2O_3 was lowered to 0.50 per cent. by agglomerate-tabling of gravity-tabled sand using about 2 lbs. per ton sodium oleate or tall oil. This was brought down to 0.10 per cent. by magnetic separation.
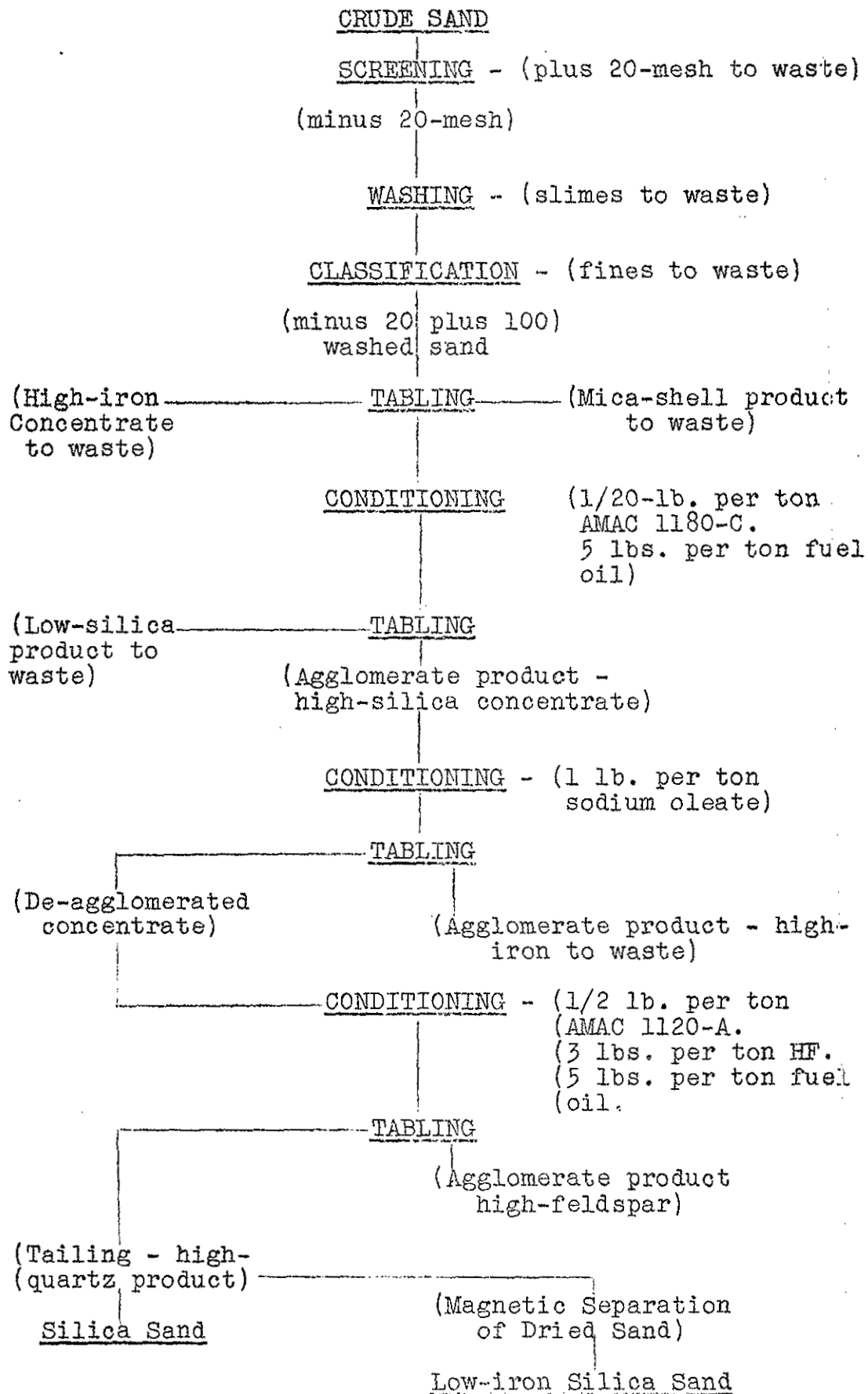
3. Clean separation of quartz and feldspar from low-iron agglomerate tailings was impractical.

4. A high-silica concentrate, equal to one-third of feed was made by agglomeration of gravity-tabled sand with 1/20-lb. per ton AMAC 1180-C. De-agglomeration of this with 1 lb. per ton sodium oleate followed by tabling gave a product containing 80 per cent. SiO_2, 12 per cent. Al_2O_3, and 0.8 per cent. Fe_2O_3.

5. Removal of feldspar from the above product with 1/2-lb. per ton of AMAC 1120-A and 3 lbs. per ton HF resulted in a final tailing containing 98.7 per cent. SiO_2; 1.6 per cent. Al_2O_3 and 0.12 per cent. Fe_2O_3. Magnetic separation reduced the iron oxide content to below 0.06 per cent.

Conclusions (Qualicum Beach Sand):

Silica sand was prepared from Qualicum Beach sand. The economic feasibility of such beneficiation will be discussed in a later section. The following flow-sheet was used in experimental tests:

<u>CRUDE SAND</u>

<u>SCREENING</u> - (plus 20-mesh to waste)

(minus 20-mesh)

<u>WASHING</u> - (slimes to waste)

<u>CLASSIFICATION</u> - (fines to waste)

(minus 20 plus 100)
washed sand

(High-iron ———————— <u>TABLING</u> ———————— (Mica-shell product
Concentrate   to waste)
to waste)

<u>CONDITIONING</u>   (1/20-lb. per ton
AMAC 1180-C.
5 lbs. per ton fuel
oil)

(Low-silica ————————— <u>TABLING</u>
product to
waste)   (Agglomerate product -
high-silica concentrate)

<u>CONDITIONING</u> - (1 lb. per ton
sodium oleate)

<u>TABLING</u>

(De-agglomerated
concentrate)   (Agglomerate product - high-
iron to waste)

<u>CONDITIONING</u> - (1/2 lb. per ton
(AMAC 1120-A.
(3 lbs. per ton HF.
(5 lbs. per ton fuel
(oil.

<u>TABLING</u>

(Agglomerate product
high-feldspar)

(Tailing - high-
(quartz product) ——————————
(Magnetic Separation
of Dried Sand)
<u>Silica Sand</u>

Low-iron Silica Sand

QUALICUM RIVER SAND:

Several hundred pounds of sand were obtained
from cuts along the old logging railway on the north
bank of Qualicum River 2 to 3 miles above the Island
Highway.

Washing and Sizing:

Washing and classification gave rise to copious
greyish-red slimes, which together with minus 100-mesh
sand, represented 9 per cent. of the sample. One per
cent. was coarser than 20-mesh.

The properties of the washed sand are listed
below:

Granulometric Analysis:

-20 ⚬ 40 mesh	- 9 per cent.
-40 ⚬ 60 mesh	- 50 " "
-60 ⚬ 80 mesh	- 31 " "
-80 ⚬100 mesh	- 10 per cent.

Chemical Analysis:

SiO_2	67.9 per cent.
Al_2O_3	17.6 " "
Fe_2O_3	3.5 " "

Microscopic Analysis:

Quartz	18 per cent.
Feldspar	54 " "
Dark	28 " "

(1) Elimination of Iron-bearing Minerals:

A. Magnetic Separation:

Magnetic separation of a small sample of dried
sand reduced the iron content to 0.22 per cent. Fe_2O_3.

B. Gravity-Tabling:

Fifty pounds of washed and sized sand was
tabled under similar conditions to those described in
the preceding section. The resulting "middling product"

amounted to 65 per cent. of the original feed and
had the following composition:

SiO_2 70.6 per cent.
Al_2O_3 16.5   "   "
Fe_2O_3 2.2   "   "

<u>Microscopic Analysis:</u>

Quartz   21 per cent.
Feldspar   64   "   "
Dark   15   "   "

       In view of results obtained with Qualicum
Beach sand, it was felt that little success could be
anticipated in efforts to produce silica sand by the
removal of iron-bearing minerals as an initial step.
Preliminary tests were made with anionic reagents,
however, for comparative purposes.

(2)   <u>Agglomerate-Tabling with Anionic Reagents:</u>

       Tests on washed and tabled feed with anionic·
reagents gave un-anticipated results. Marked concen-
tration of iron-bearing minerals had been previously
obtained by such treatment. In this case, however,
agglomerated products were invariably lighter in
colour than original sand and contained notable in-
creases in the proportion of quartz present.

       The following typical examples illustrate the
degree of separation obtained:

1.   Reagents – Sodium Oleate   2 lb. per ton.
                      Fuel Oil   5 lbs. per ton.
   Ph   6.8

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	73	27	64	9
Tailing	27	12	69	29

Analysis of Agglomerate Concentrate – SiO_2, 74.2;
Al_2O_3, 16.9; Fe_2O_3, 1.7 per cent.

2. Reagents - Sodium Oleate   1 lb. per ton.
                 Fuel Oil   5 lbs. per ton.
   Ph   6.8

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	61	30	60	10
Tailing	39	8	70	22

3. Reagents - Sodium Oleate 1/2-lb. per ton.
                 Fuel Oil   5 lbs. per ton.
   Ph   6.8

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	10	36	57	7
Tailing	90	19	65	16

Analysis of Agglomerate Concentrate - SiO_2, 78.9; Al_2O_3, 13.0; Fe_2O_3, 1.3 per cent.

The unconventional behaviour of quartz and feldspar must be attributed to prior activation in place by natural solutions. It is well known that both minerals are floatable with anionic reagents in the presence of metal ions such as iron, aluminium, lead, etc. The interesting feature in the present case, however, was the apparently preferential activation of quartz. Microscopic examination failed to reveal any visible coating on sand grains.

Further tests were made with mahogany soap, sulphonated salmon oil and tall oil. At a Ph of 6.8, 2 lbs., 3 lbs. and 1 lb. respectively were required to approximate results obtained with 1 lb. per ton sodium oleate. Collecting power tends to increase with decreased alkalinity but at the expense of selectivity.

Various reagents were tried with sodium oleate in an effort to improve selectivity, but without marked success.

A sample of washed and tabled sand was ground for 30 minutes in a jar mill at 50 per cent. solids with a light charge of pebbles. Actual comminution was slight but heavy slimes were liberated. These were removed by washing and decanting. The cleaned sand was agglomerated with sodium oleate.

Reagents - Sodium Oleate		2 lbs. per ton.		
Fuel Oil		5 lbs. per ton.		
Ph		7.6		

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate				
Concentrate	25	12	52	36
Tailing	75	24	68	8

More normal results were obtained in the above test as a result of cleaning sand grain surfaces.

The remainder of the sample was blunged vigorously for one hour in a flotation cell at 50 per cent. solids with 6 lbs. per ton NaOH added. Heavy slimes were formed as before. After thorough washing the following test was made:

Reagents - Sodium Oleate		2 lbs. per ton.		
Fuel Oil		5 lbs. per ton.		
Ph	7.8			

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate				
Concentrate	32	7	51	42
Tailing	68	28	73	2

Analysis of Tailing - SiO_2, 74.8; Al_2O_3, 17.1; Fe_2O_3, 0.2 per cent.

It is obvious from the above tests that de-activation of quartz may be accomplished by cleaning

grain-surfaces mechanically. On the other hand, the extensive processing required precludes such preparation of feed commercially.

(3) Agglomeration with Cationic Reagents:

Agglomeration of washed and tabled sand with cationic reagents was investigated. In general, results were abnormal or inconclusive as indicated by the following typical examples:

	Reagents - 12-NAM-1180-C		2/5-lb. per ton.
	Fuel Oil		5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	70	20	66	14
Tailing	30	21	60	19

	Reagents - DP 243		2/5-lb. per ton.
	Fuel Oil		5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	10	28	58	14
Tailing	90	20	65	15

	Reagents - Trimethyl Stearyl Ammonium Bromide -
	2/5-lb. per ton.
Fuel Oil	5 lbs. per ton.

Agglomerate Concentrate	- negligible quantity - largely mica.

On the basis of foregoing results, the only practical approach to the problem was concluded to be concentration of quartz by anionic reagents followed by de-agglomeration and separation of quartz and feldspar from the concentrate.

(4) Concentration of Quartz by Anionic Reagents:

Ten pounds of washed and tabled sand was agglomerate-tabled using Tall oil as collector.

	Reagents - Tall oil		1 lb. per ton.	
Ph	Fuel oil 6.6		5 lbs. per ton.	

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	40	32	60	8
Tailing	60	13	66	21

A. De-Agglomeration of Anionic Products:

Attempts to de-agglomerate the above Tall oil product by agitation with soap, cationic reagents, and sodium hydroxide were unsuccessful. On the other hand, acidification with HF gave satisfactory results.

Sodium oleate products were only de-agglomerated by agitation with large amounts of NaOH.

B. Separation of Quartz and Feldspar:

The agglomerate concentrate from Tall oil treatment was acidified with 1 lb. per ton HF and an additional 1 lb. per ton Tall oil added. After 3 minutes conditioning the product was tabled with fair removal of dark constituents.

The resulting de-agglomerated sand was then conditioned with the following reagents and tabled.

Reagents - AMAC 1120-A   1/2-lb. per ton.
          HF   2 lbs. per ton.
          Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	63	4	93	3
Tailing	37	84	14	2

Chemical analyses of these products were as follows:

Agglomerate Concentrate		Tailing	
SiO_2	64.8 per cent.	SiO_2	93.7 per cent.
Al_2O_3	22.8 " "	Al_2O_3	4.4 " "
Fe_2O_3	0.34 " "	Fe_2O_3	0.20 " "

Magnetic separation reduced the iron oxide content of the tailing to approximately 0.10 per cent.

Separation of feldspar from quartz was less positive in this case than for Qualicum Beach sand. Poorer selectivity was attributed to filmed grains. As a check a small sample of the de-agglomerated Tall oil concentrate was blunged for one hour in a flotation cell with 5 lbs. per ton sodium silicofluoride and 3 lbs. per ton sulphuric acid. After washing free from slimes the cleaned sand was agglomerated with the following reagents:

Reagents - AMAC 1120-A   1/2-lb. per ton.
          HF   3 lbs. per ton.
          Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	65	2	96	2
Tailing	35	95	4	1

Summary (Qualicum River Sand):

(1)   Quartz, rather than dark minerals, was concentrated by agglomeration with anionic reagents. Cationic reagents likewise failed to give conventional results. This anomalous behaviour was attributed to natural pre-activation of sand grains.

(2)   De-agglomeration of Tall oil products was effected by acidification with HF, of sodium oleate products by agitation with NaOH.

(3)   Separation of feldspar from quartz was less positive than for Qualicum Beach sand.

(4)   Samples responded normally to both anionic and cationic reagents after impure grain surfaces were cleaned by extended blunging in a flotation machine with a suitable dispersing agent.

Conclusions:

Thorough cleansing of sand grains is necessary before high-grade silica sand can be produced from Qualicum River sand. Insofar as this would be too costly in practice, there seems little likelihood that other than low-grade material can be obtained from this source.

OTHER SANDS

Preliminary tests were made on certain other sands to determine their possible amenability to beneficiation along the lines already studied. Among these were samples submitted by four commercial sand and gravel producers:

(1)   Pitkethly Bros. (No. 36 on map)

Microscopic examination revealed that the quartz content of the sand was too small to merit testwork.

<u>Microscopic Examination</u> - (minus 20 plus 100 mesh fraction):

	Approximate %
Quartz	9
Feldspar	28
Dark Constituents[x]	63

[x]
Dark constituents comprise rock fragments, hornblende, epidote, garnet, chlorite, etc.

    (2) <u>Hillside Sand and Gravel Ltd.</u> (No. 33 on map)

<u>Microscopic Examination</u> - (minus 20 plus 100 mesh fraction)

	Approximate %
Quartz	10
Feldspar	40
Dark Constituents[x]	50

[x]Dark constituents largely composed of rock fragments with lesser amounts of hornblende, etc.

    The quartz content of this sand was likewise too small to encourage further investigation.

    (3) <u>Producers Sand and Gravel Co. (1929) Ltd.</u> (No. 19 on map).

<u>Microscopic Examination</u> - (minus 20 plus 100 mesh fraction)

	Approximate %
Quartz	14
Feldspar	30
Dark Constituents[x]	56

[x]
Dark constituents largely rock fragments with lesser amounts of hornblende, etc.

Although the proportion of quartz is small in this sand a few preliminary tests were made to study its properties.

Gravity-tabling and magnetic separation failed to eliminate many of the dark constituents.

Anionic reagents tended to agglomerate dark minerals preferentially, but with insufficient selectivity to allow clean-cut separations to be made. Cationic reagents failed likewise to effect any promising recoveries.

(4)   Deeks Sand and Gravel Co. Ltd. (No. 35 on map)

This sand was lighter in colour than preceding samples and contained a higher proportion of quartz.

Microscopic Examination - (minus 20 plus 100 mesh fraction)

	Approximate %
Quartz	21
Feldspar	50
Dark Constituents	29

Insofar as this sand contained the highest proportion of quartz of the four commercial samples examined, a variety of tests were made.

Tall oil and sodium oleate had a slight tendency to concentrate quartz, but to a much lesser degree than with Qualicum River sand. It was found impossible to recover products sufficiently free from rock fragments to allow the separation of feldspar from a clean quartz tailing in the final step.

Cationic reagents agglomerated a heterogeneous collection of minerals without apparent selectivity.

It was decided that the sand was unamenable to beneficiation without thorough cleansing.

(5) <u>Savary Island Sands</u> (No. 28 on map)

<u>Chemical Analysis</u> <u>Beach Sand</u>			<u>Chemical Analysis</u> <u>Bank Sand</u>		
SiO_2	69 per cent.		SiO_2	67 per cent.	
Al_2O_3	15 " "		Al_2O_3	17 " "	
Fe_2O_3	3 " "		Fe_2O_3	4 " "	

<u>Microscopic Analysis</u> <u>Beach Sand</u>			<u>Microscopic Analysis</u> <u>Bank Sand</u>		
Quartz	26 per cent.		Quartz	21 per cent.	
Feldspar	62 " "		Feldspar	64 " "	
Dark x	12 " "		Dark x	15 " "	

x
Note: Dark constituents largely composed of hornblende, mica, iron ores, etc. with only minor amounts of rock.

<u>Test-Work:</u>

Test-work was restricted to a minimum by the limited quantity of samples available. Results were sufficiently instructive, however, to indicate in a general way the amenability of these sands to beneficiation.

Both beach and bank samples responded similarly to all reagents. The latter, however, contained more abundant slimes which were incompletely removed by washing. As a result reagent consumption was higher and selectivity less. There was no indication of the pre-activation which had marked Qualicum River sand.

Fairly clean removal of dark minerals was obtained with sodium oleate in the amounts of 2 lbs. per ton for beach sand and 4 lbs. per ton for bank sand.

The following results with cationic reagents are typical:-

<u>Beach Sand:</u>

Reagents - 12-NAM 1180-C   1/20-lb. per ton.
                   Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	15	65	30	5
Tailing	85	17	68	15

Beach Sand:

Reagents - Trimethyl Stearyl Ammonium Bromite -
3/4-lb. per ton.
Fuel Oil   5 lbs. per ton.

	% Weight	Quartz %	Feldspar %	Dark %
Agglomerate Concentrate	25	68	28	4
Tailing	75	12	73	15

A chemical analysis of the agglomerate concentrate after magnetic separation was as follows:

SiO_2 87 per cent.
Al_2O_3 8 " "
Fe_2O_3 0.07 " "

Results obtained by agglomerating bank sands were slightly less satisfactory, and required nearly double the quantity of collectors to give comparable recoveries.

In general, Savary Island sands as well as those of Harwood, Mary, Hernando, and Cortes Islands show promise of amenability to beneficiation.

GENERAL REVIEW OF SANDS:

The production of silica sand from impure sands through beneficiation was studied. Investigation was restricted to certain type deposits of the southern coastal area of British Columbia. The following points were established:

(1) Silica sand was produced from Qualicum Beach sand by agglomerate-tabling and magnetic separation. Comparable results may be expected from other beach

deposits including those of Oyster River, Kye Bay,
Savary, Harwood, Hernando Mary and Cortes Islands.
Pre-requisites for satisfactory treatment are:

(a) A sufficient proportion of quartz in
the sand to make processing worth-while.

(b) A minimum of rock fragments and iron-
coated grains.

(c) Clean, fresh surfaces on mineral grains,
or, in other words, absence of pre-activation and
excessive slimes.

(2) Efforts to recover silica sand from Qualicum
River sand were only partly successful. This was
attributed to prior activation of grain surfaces by
such metal ions as aluminium and iron, derived from
natural solutions. This phenomenon appears character-
istic of most bank sands in varying degree with the
result that each deposit must be investigated separately.

(3) Deleterious coatings may be removed from sand
grains by "attrition milling" thus exposing clean
mineral surfaces to reaction with reagents. The elimina-
tion of individual peculiarities of sands in this way
gives rise to cleaner, more selective separations as
well as greater consistency and predictability of
results. However, the degree of processing necessary to
effect de-activation of certain sands may be too costly
for commercial application.

General Discussion of Sands:

The technological feasibility of producing
silica sand from impure sand has been established by
test-work described. Much work remains to be done, how-
ever, to prove the process applicable to the commercial
production of silica sand. This can only be carried out
on a larger scale than that permitted by equipment at
the writer's disposal.

Chief features to be Investigated are:

(1) Most suitable sands: Samples tested by

the writer are representative of only a small propor-
tion of the sand deposits of the Province, many of which
undoubtedly contain more quartz. The higher the pro-
portion of quartz in the crude sand the higher the over-
all recovery, hence the lower the treatment cost on
the finished product. In addition to high quartz
content, however, a sand must be free from excessive
slimes, pre-activated grains, and in large measure
from rock fragments. Further its size range should
conform approximately to commercial specifications.

Perhaps the most vital consideration is
location. Silica sand at best is a low-priced commodity
and will not stand high freight charges. If, in
addition to these, the sand must bear beneficiation
costs, proximity to consuming centres becomes of para-
mount importance.

(2) Processing Details: Working details can only
be determined by testing of a specific deposit on a
larger scale. The flow sheet accompanying the section
on Qualicum Beach sand is offered merely to indicate the
essential steps required in the case of a particular
sand sample. For Qualicum Beach sand it was necessary
to divide the process into two stages to eliminate inter-
fering material from the final feldspar-quartz separation.
Sands may be found, however, in which a sufficiently
pure quartz tailing may be obtained by direct removal of
feldspar.

Gravity-tabling might be dispensed with, or
combined with, agglomerate-tabling in certain cases. In
general, however, maximum elimination of impurities
appears advantageous before agglomeration. In this con-
nection separation of undesirable constituents magnetically
might be suggested as an initial step. This would require
a free-flowing feed, which could only be obtained from
many deposits by artificial drying. Again, about one-third
of feed would be removed, a large part only weakly
magnetic, which would require large machine capacity.

The cost of magnetic separation, considerably
higher than that of gravity-tabling, would be multiplied
several times when charged against the final product.
Further, it is possible by agglomerate-tabling to re-
cover silica sand sufficiently pure for sand blasting
and foundry use. By restricting magnetic separation

to the final stage, therefore, dual drying is avoided
and cost of processing charged only against the
material actually treated.

Not only may operating details depend upon
the nature of the original sand, but also upon the scale
of production. For example, if required capacity is
too great to be handled on one gravity-table, overall
efficiency would be improved by prior classification of
minus 20 plus 100-mesh feed into two or more size fractions,
followed by parallel tabling of each.

(3) Economic Factors: Chief consumers of
silica sand in British Columbia are steel foundries.
Small amounts are also used for sand-blasting, special
plasters, etc. None is produced locally. Imports in
1940 totalled nearly 2,000 tons from the United States,
largely from Illinois and California. Delivered prices
ranged from $10 to $14 per ton. Prior to the war,
Belgium was the chief source of supply, sand coming in
as ballast and selling for $6. to $8. per ton.

The market for silica sand in Alberta is
relatively large, mainly for use in the manufacture of
glass. Here again the source of supply is the United
States. Delivered prices are slightly less than those
for British Columbia, owing to shorter rail haul from
producers in Illinois and Minnesota. Washington also
consumes a fairly large quantity of silica sand but
none is produced in the State.

The economic feasibility of processing impure
sands to meet the above markets cannot be accurately
judged from the test-work done. The following illus-
trative example, based on results with Qualicum Beach
sand, is intended to clarify further discussion and not
to be accepted as a final estimate of practical costs:

Example:

Assumptions - mining cost - 25 cents per ton.
             overall recovery of silica sand -
                       10 per cent. of crude
             sand.
             capacity of plant - 100 tons crude
                       sand per day.

Items	Tons Treated	Cost Per Ton	Total Cost	Waste Products
Mining	100	$0.25	$25.00	----
Washing, sizing and gravity-tabling	100	0.20	20.00	Mica-shell concentrate 5 tons high-iron concentrate - 25 tons.
Conditioning and Agglomerate-tabling	70	0.15	10.00	Low-silica tailing- 45 tons.
De-agglomeration and Agglomerate-tabling	25	0.25	6.00	High-iron agglomerate product - 2 tons
Conditioning and Agglomerate-tabling	23	1.00	23.00	High-feldspar production - 10 tons.

Direct treatment cost, less labour $84.00 for 100 tons crude.
Labour   15.00
Indirect costs   15.00

Total costs $ 114.00

Cost per ton silica sand   11.40

To the above must be added cost of drying, magnetic separation and handling, as well as profit. On this basis, $14. to $15. per ton would be a minimum selling price.

Critical analysis of the foregoing example, however, brings out the following factors:

(a)   Mining cost is the largest item affect-
ing selling price of the sand. A reduction from 25
cents to 15 cents at this point would represent a saving
of $1.00 per ton on the final product.

(b)   In the treatment of certain sands
gravity-tabling might well be eliminated without
adversely affecting processing efficiency. This would
save roughly 10 cents per ton on crude feed or $1.00 per
ton on silica sand.

(c)   Reagents necessary for the separation
of feldspar and quartz are expensive. There is a
possibility that sodium fluoride or sodium silico-
fluoride and sulphuric acid may be substituted for
hydrofluoric acid in this stage. By so doing a saving
of 40 to 50 cents per ton silica sand might be effected.

(d)   Other items of direct cost show little
promise of reduction.

Even should the above-mentioned economics be
possible, the selling price of silica sand would still
be $12. to $13. per ton. On the basis of the above
example, therefore, the beneficiation of impure sands
to yield silica sand would appear definitely uneconomic.
Before dismissing the subject, however, it must be
remembered that in the present example all expenses are
charged against a final product representing only 10
per cent. of initial feed. This being the case either
higher recovery or sale of "waste" products will improve
the picture materially.

In the above example an increase in recovery
from 10 per cent. to 20 per cent. would decrease costs
from $11.40 to $7.60 per ton of silica sand. Further
increase to 50 per cent. would reduce production cost
to $3.00 to $4.00 per ton with the above flow sheet, or
to a considerably lower figure with simpler processing.

The group of sand deposits considered in the
present report are essentially low in silica. Recoveries
exceeding 15 per cent. of feed are not to be anticipated
even under optimum conditions. Hope of economic treatment,
therefore, depends upon the possibility of selling
"waste products."

Reverting to the illustrative example, the following points are worthy of discussion:

(a) A "high-iron" concentrate of 25 tons is removed by gravity-tabling. About 5 tons of this is black sand, composed of magnetite, ilmenite, epidote, garnet, etc., the remainder being a mixture of quartz, feldspar, hornblende, etc. No specific use can be suggested for the former at present, but the latter would be suitable for plaster or concrete.

(b) The "light" product from gravity-tabling contains mica. The proportion would be small for Qualicum Beach sand, but up to 25 per cent. for certain others, including Savary Is., Harwood Is., etc. This mica can be readily separated from gangue by agglomerate-tabling with cationic reagents and suitable modifiers. From some sands as much as 1 or 2 tons per hundred tons would be recoverable and would be suitable for manufacture of asphalt roofing after de-oiling.

(c) From the first stage of agglomerate-tabling about 45 tons of low-silica tailing results. This material would compare favourably with many plaster and concrete sands sold in British Columbia.

(d) The final separation yields about 10 tons of high-feldspar product. This would have the following approximate composition after de-agglomeration, tabling and magnetic separation:

SiO_2, 63 per cent.; Al_2O_3, 23 per cent.; Fe_2O_3, 0.08 per cent.; CaO, 8 per cent.; Na_2O, 5 per cent. and K_2O, 1 per cent.

Such a product would be a substitute for nepheline syenite and feldspar in glass manufacture. It could also replace silica sand as an ingredient of special plasters, etc. where white colour is the essential requirement.

If situated sufficiently close to consuming centres, a plant might sell the following materials in addition to silica sand:

Plaster and concrete sand - 70 tons at 50 cents

		$35.00
Feldspar	- 10 tons at $3.	30.00
	Total	$65.00

Overall costs per 100 tons	$ 114.00	
Sale of waste products	65.00	
	Balance	$ 49.00

Cost per ton charged against
   silica sand   4.90 per ton

     Should the production and sale of mica prove possible, costs would be further reduced as follows:

|	
1 ton mica at $25. per ton	$ 25.00
Balance chargeable to silica sand	24.00
Cost per ton silica sand	2.40

     That the above cost data can only be accepted as illustrative of the factors involved, must be re-emphasized. They also serve, however, to indicate the kind and degree of expenses connected with an operation of this sort.

References

1. Conditioning Surfaces for Froth Flotation - J.E. Norman and O.C. Ralston - TP 1074, A.I.M.E., 1939.

2. New Methods of Cleaning Glass Sands - J. Dasher and O.C. Ralston - Bull. Amer. Cer. Soc., June,1941.

3. Progress Report - Metallurgical Division - Ore-Dressing Studies - R.I. 3484, U.S.B.M., Jan, 1940, p. 24.

4. Process for Preparation of Silica for Glass Batches - U.S. Patent 2052227, 1936; Br. Patent 462213, 1937, Fr. Patent 805111, 1936.

5. Mineral Froth Flotation - U.S. Patent 1492904, 1924.

6. Conditioning of Glass Sands and Dressing by Froth Flotation - Br. Patent 510323.

7. Elimination of Iron from Sandstone from East Templeton, Que. - Investigations in Ore Dressing and Metallurgy, Dept. of Mines, Mines Branch, Ottawa 1927, p.134.

8. Grinding and Washing of Sand from Guiges Township, Que. - Investigations in Ore Dressing and Metallurgy, Dept. of Mines, Mines Branch, Ottawa, 1929, p. 161.

9. Preparation of Silica Sand from the River Denys Sand and Clay Co. Ltd. Melford, Cape Breton, N.S. - Investigations in Ore Dressing and Metallurgy, Dept. of Mines, Mines Branch, Ottawa, 1931, p. 112.

10. Testing of Silica Sand and Sandstone from Beauharnois Power Corporation, Ltd., Beauharnois, Quebec - Investigations in Ore Dressing and Metallurgy, Dept. of Mines, Mines Branch, Ottawa, 1931, p. 121.

11. The Testing of Quartz from Larouche, Chicoutimi County, Que. - Investigations in Ore Dressing and Metallurgy, Dept. of Mines, Mines Branch, Ottawa, 1932, p. 228.

12. The Crushing and Washing of Sandstone from St. Canute, Que. - Investigations in Ore Dressing and Metallurgy, Dept. of Mines, Mines Branch, Ottawa, 1932, p. 230.

13. Experimental Tests on Quartz and China Clay from
    Lac Remi, Que. - Investigations in Ore Dressing
    and Metallurgy, Dept. of Mines, Mines Branch,
    Ottawa, 1932, p. 240.

14. Flotation and Agglomerate Concentration of Non-
    metallic Minerals. O.C. Ralston - R.I. 3397,
    U.S.B.M. May, 1938.

15. Concentration of Felspathic Waste from a Titanium
    Mine near Roseland Va. D.I. Smith, R.G. O'Meara
    and T.N. McVay - Journ. Am. Cer. Soc., Nov., 1940.

16. Froth Flotation and Agglomerate Tabling of Micas -
    J.E. Norman and R.G. O'Meara - R.I. 3558, U.S.B.M.
    Feb., 1941.

17. High Intensity Magnetic Separation of Industrial
    Minerals - D.M. Ramsay - Trans. C.I.M.M., Vol.
    XL, 1937, p. 730.

18. Special Methods for Concentrating and Purifying
    Industrial Minerals - G.W. Jarman - TP 959,
    A.I.M.E., 1938.

19. Dry Separation of Minerals - T. Kipp - Bull. C.I.
    M.M., Oct. 1940.

20. Separation of Felspar from Quartz - H.G. Iverson -
    Eng. and Min. Jour., Vol. 133, 1932, pp. 227-229.

21. Froth Flotation and Agglomerate Tabling of Felspars -
    R.G. O'Meara, J.E. Norman and W.E. Hammond -
    Bull. Am. Cer. Soc., Aug., 1939.

22. Principles of Mineral Dressing - A.M. Gaudin - McGraw-
    Hill, 1939.

23. Oil-Air Separation of Nonsulphide and Nonmetal
    Minerals - A.F. Taggart, G.R.M. Del Giudice, A.M.
    Sadler, and M. Hassialis - TP 838, A.I.M.E., 1937.

24. Flotation and Depression of Nonsulphides - J.B.
    Clemmer and R.G. O'Meara - R.I. 3239, U.S.B.M.,
    1934.

25. Soap Flotation of the Nonsulphides - W.H. Coghill
    and J.B. Clemmer - TP 445, A.I.M.E., 1932.

26. Selective Oiling and Table Concentration of Phosphate
    Sands in the Land - Pebble District of Florida -
    R.G. O'Meara and J.W. Pamplin - RI 3195, U.S.B.M.,
    1932.

27. Beneficiating Cement Raw Materials by Agglomeration and Tabling - F.P. Diener, J.B. Clemmer and S.R.B. Cooke - RI 3247, U.S.B.M., 1935.

28. Concentration of Potash Ores of Carlsbad, New Mexico by Ore Dressing Methods - RI 3271, U.S.B.M., 1935.
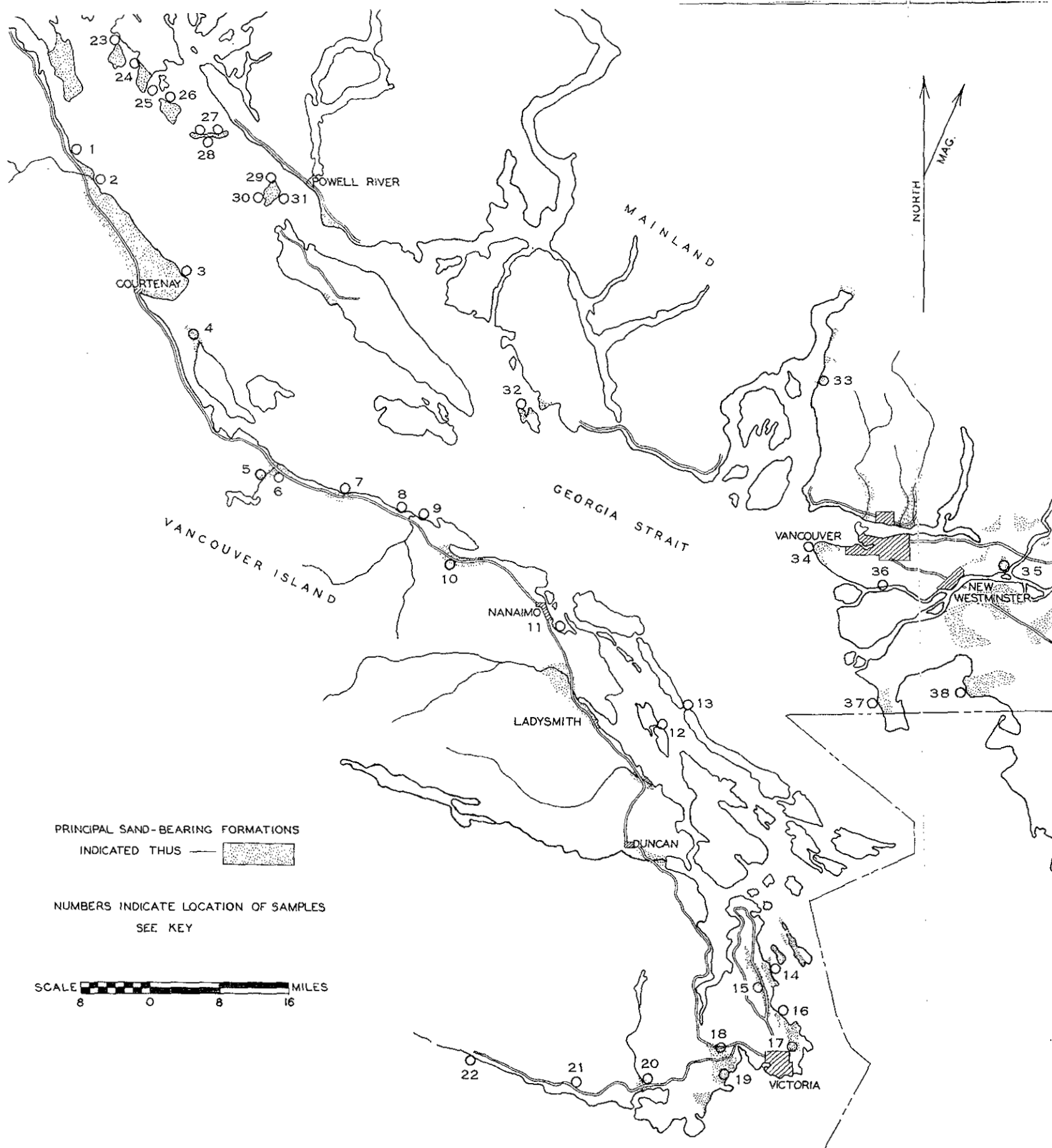
KEY MAP

Showing Distribution of More Important Sand Deposits in the
Southern Coastal Area of British Columbia

PRINCIPAL SAND-BEARING FORMATIONS
INDICATED THUS —

NUMBERS INDICATE LOCATION OF SAMPLES
SEE KEY

SCALE ▨▨▨▨▨ MILES
8   0   8   16