1. ECONOMICS

Silica applications range from traditional foundry sand to high technology uses such as synthetic quartz crystals. Some markets are saturated and dominated by big players at the regional scale, whereas others are controlled by developing nations. On a positive note, many new and promising applications may require additional production capacity in the near future.

The most promising applications for new producers in Quebec would be in the technology sector (i.e., cultured quartz crystals and specialty silica). Such high-value products are derived from lascas, a high-purity form of lump quartz. Applications for specialty silica products include paints, rubbers, catalysts, adhesives, fiber optics, chemicals, refractory products, inks, batteries, pharmaceutical products, cosmetics, etc.

Silica products: prices, production and market outlook

Product	**World production (2001)**	**Current prices ($US/t)**	**Dominant producers**	**Trends/outlook**
1. Saturated markets				
Silica sand - foundry - glass	97 Mt, (~30 Mt in North America)	11.5-25	A few large producers at the regional scale (e.g. Unimin in North America: 40 quarries and plants)	- Competition from U.S.A. - Foundries: stable or decreasing demand due to recycling - Decreasing production of glass containers due to recycling - Increasing demand for housing construction? (fiberglass, flat glass)
2. Stable or slowly expanding markets				
Metals and alloys - silicon metal - ferrosilicon	34 Mt (~4/5 represents ferrosilicon)	~1,100 ~900	China, former USSR, Norway, U.S.A	From 1996 to September 2001, prices per kilogram dropped from >$1.30 US to $0.88-0.95 US for ferrosilicon (50% Si) and from $2.00 US to $1.08-1.15 US for silicon metal due to low-cost Chinese imports. Western plants are now concentrating on the more profitable silicon metal market. Total consumption is related to the health of the steel industry.
Silicon carbide (as abrasive)	~ 1 Mt	585	China, Eastern Europe, India, Korea, South America	Last Canadian producer closed in June 2001 (China dominates market: 82% of 1997-2000 U.S.A. imports).
Tripoli	80 Kt	221	U.S.A.	Stable consumption; no new application anticipated.
3. Expanding markets				
Lascas	N.A.	1,200	Brazil, Germany, Madagascar	Used for making synthetic quartz crystals and fused silica. Price per kilogram moved from $0.85 US in 1991 to $1.20 US in 1997.
Synthetic quartz crystals	2 Kt	461,000	China, Japan, Russia, U.S.A.	Depends on need for electronic applications (probable growth within the next few years).
Specialty silica (including fused silica)	N.A.	~90 to 4,200	U.S.A., others?	Anticipated annual growth of 5.2% in U.S.A.

Source of data: see web site (www.sidex.ca)

2. ECONOMIC GEOLOGY

Quartz deposits include silica sands, orthoquartzites, quartzites and massive quartz deposits (veins and pegmatites). Some deposit types are better suited than others because their properties more readily meet industry specifications for certain silica products.

Silica sands of economic value are those with very high silica content, good sorting, and rounded to sub-rounded particles; these sands can be washed, screened and purified at low cost to meet consumer specifications.

Very pure sandstone, or **orthoquartzite**, is produced by long periods of erosion and sedimentary transport that progressively eliminate all minerals except quartz. Source rocks were probably other sandstones. Although orthoquartzite can be found on all continents and from every geological age, it is rarely pure enough to mine. Rocks with weak cement are preferable for silica sand production (which involves crushing, screening and sometimes magnetic separation), whereas a strong cement is required to produce lump quartz. Size of deposits: a few million metric tons.

Quartzite represents metamorphosed orthoquartzite, and is made of recrystallized and well-cemented quartz particles. Hydrothermal alteration may increase the silica content of the original sandstone, but could also produce kaolin (a clay mineral). Recrystallization destroys the rounded shape of quartz particles, resulting in angular shapes during crushing. This feature excludes quartzite as a source of foundry sand. Some quartzite units are a good source of lump quartz for ferrosilicon and silicon metal production. Size of deposits: a few million metric tons.

Massive quartz deposits include unmineralized hydrothermal veins or lenses, and magmatic segregations in granitic pegmatites. Lump quartz for ferrosilicon and silicon metal production can be derived from these deposits. Vein quartz containing numerous fluid inclusions is not suitable for

General specifications for different uses of silica

Uses	Min. SiO_2 (wt%)	Max. Al_2O_3 (wt%)	Max. Fe_2O_3 (wt%)	Max. TiO_2 (wt%)	Particle size	Notes
Glass sand - containers: colored clear - flat glass	 98.9 99.5 99.5	 0.15 0.10 0.20	 0.15 0.035 0.007	 0.10 0.02 0.02	 0.1-0.5 mm	Other major elements need to be checked as well; <2 ppm Cr or Co for flat glass; avoid Cu and Ni
Foundry sand	88.0-99.0		Variable		0.08-0.85 mm	Highest SiO_2 content possible; particle shape sub-angular to rounded
Flux agent in smelting	90-95	1.5	1.5		2-5 cm	<0.2 wt% CaO+MgO
Hydraulic frac					0.4-0.85 mm	Rounded particle shapes
Silicon carbide (SiC)	99.3 99.7	0.08-0.25	0.03-0.20		0.15 mm	Specifications vary according to black or green product; <0.01 wt% CaO, <5% moisture
Silicon: - metal - chemical	 99.5 99.8	 0.20 0.10	 0.10 0.05	 0.006 0.005	0.17-1.7 mm [1] or >2.5 cm [2]	Resistance to thermal shock essential; completely avoid P and As; <0.2 wt% CaO & MgO
Ferrosilicon	98.7	0.60	0.30	0.05	0.17-1.7 mm [1] or 2-12 cm [2]	Resistance to thermal shock essential; <0.2 wt% CaO & MgO, <0.1 wt% P_2O_5
Fiberglass: - insulation - fabrics	 98.1 99.2	 0.52 0.60	 0.50 0.04	 0.05	~ 0.1-0.4 mm	 CaO+MgO <0.16 wt% CaO+MgO <0.20 wt%
Sodium silicate	99.4	0.20	0.05	0.05	0-6 mm	CaO+MgO <0.05 wt%
Lascas		<100 ppm Al	<100 ppm Fe		A few cm	Fe, Al, transition elements and alkaline elements <100 ppm, but preferably <10 ppm

glass-making, unless the inclusions have been destroyed during metamorphism. Hand-sorted, crushed and washed hydrothermal quartz can be sold as lascas. Size of deposits: a few hundred thousand metric tons.

Quartz deposits generally need to be proximal to their intended markets in order to be profitable: transport of bulk quartz proceeds only at a regional scale. In the case of silica sand destined for foundries and the glass-making industry, the producer is ideally located immediately adjacent to the consumer. Lascas constitutes a notable exception, as it is exported from Brazil, Madagascar and Germany to the United States. For this reason, Quebec is favorably positioned to produce lascas destined for the fused silica and cultured quartz industries south of the border.

3. EXPLORATION

In almost all cases, silica mining operations must be located near the consumers. It is therefore recommended that markets be investigated prior to prospecting for ore deposits. The work that will need to be done during mineral exploration and deposit evaluation will vary according to the deposit type and the product's end-use.

Once a geographical area and potential clients have been identified, mineral exploration can begin. The first step is typically a bibliographic search accompanied by the examination of geological maps. This will permit known deposits and high potential areas to be identified (see following section).

For **silica sand deposits**, it is necessary to conduct chemical analyses for major elements and some trace metals, and to determine particle size distribution. Roundness, sorting and uniformity will also have to be evaluated. Sand thickness and depth to the water table should be measured using trenches for shallow deposits (< 9 m deep), and by auger-drilling for deeper deposits.

In **orthoquartzite-** and **quartzite-type deposits**, the difficulty lies in identifying a horizon that is pure enough and thick enough for mining. Despite the fact that quartzite tends to produce large outcrops with positive topographic relief, stripping and trenching may be necessary. To locate a high-purity zone, visual inspection should be followed by petrography or geochemistry. Promising analyses will lead to bulk sampling in order to determine the appropriate processing procedure so that the product will meet the desired physical and chemical specifications (specifications vary according to the application for the product). Decrepitation tests are mandatory for silicon metal or ferrosilicon. Finally, diamond drilling will help define grade continuity and deposit size.

For **massive quartz deposits** intended for lascas production, precise chemical analyses (ppm for all elements except Si) are necessary to determine if the quartz meets strict criteria. Other than that, exploration methods are similar to those mentioned for quartzite and orthoquartzite.

Natural **quartz crystal deposits** are worked from surface findings; exploratory drilling is not practical and it is not possible to calculate reserves.

4. QUEBEC'S POTENTIAL

Quebec has been a major player in Canadian silica mining since 1990, with a production of 500,000 to 600,000 metric tons per year. To emerge, any new exploitation would need to be of exceptional purity and intended for promising applications. Lascas produced from hydrothermal quartz possibly constitutes such an example.

Numerous silica deposits are found in orthoquartzite sequences throughout Quebec. The Cairnside Formation (Montreal area), the Guigues Formation (Témiscamingue), and the Val Brillant and Kamouraska formations (Gaspésie) are currently exploited and indicate the potential for developing other quarries. Among the large number of quartzite lenses known in the Grenville Province, several have been investigated and some of these show potential for exploitation. The geological map shows 44 of these deposits and the table below summarizes their relevant features.

Massive quartz deposits, including hydrothermal veins and pegmatites, are relatively numerous in Quebec. Good-sized lenses and veins have been found in the Appalachians, as well as the Grenville and Superior provinces. Some have been exploited, with very high silica grades and relatively few impurities (often >99.5 wt% SiO_2). These deposits are considered to be well suited for high-purity lump quartz applications, but their tonnages are significantly lower than those for quartzite and orthoquartzite deposits. The following table briefly describes the 31 silica deposits of this type shown on the geologic map.

Quartzites and orthoquartzites

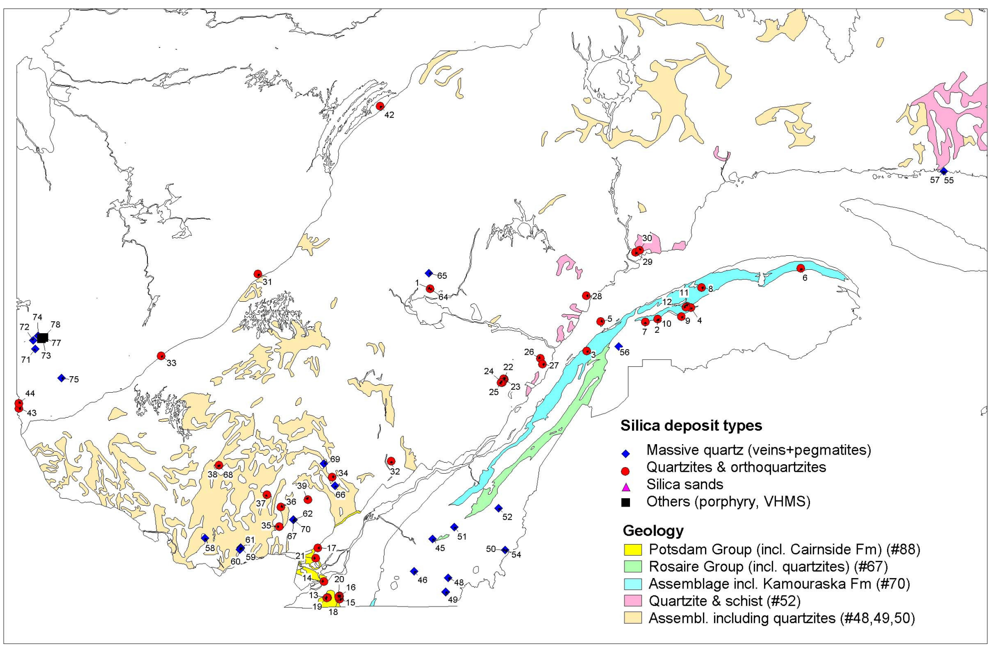
1	Lac Moreau
2	Awantjish
3	Carrière G. Dubé
4	Colline de La Tortue
5	Fleuriau
6	Mine de Grande-Vallée
7	Lac Rigo-No
8	Saint-Jean-de-Cherbourg
9	Saint-Tharcisius
10	Silice de Val-Brillant
11	Tessier
12	Uniquartz
13	Carrière Arcoïte
14	Carrière Chromasco (Melocheville)
15	Car. Montpetit
16	Carrière Radius Exploration
17	Carrière Saint-Canut / Unimin
18	Carrière de Ste-Clotilde (Les Sables Silco)
19	Carrière Schink
20	Propriété En-Ola
21	Sainte-Scholastique
22	Carrière Silicium Gex
23	Carrière SKW Canada
24	Lac Profond
25	Saint-Urbain (Leeds Metals/Lac de la Tour)
26	Lac Druillettes
27	Lac Port-aux-Quilles
28	Forestville
29	Lac Croche/Laflèche
30	Lac La Chesnaye
31	Lac Trompeur
32	Lac Clair
33	Lac Ha! Ha!
34	Silice Supérieure-2
35	Carrière Saint-Rémi-d'Amerst
36	Clyde (Dominion Silica)
37	Loranger
38	Mine Baskatong (Lac Baskatong)
39	Mine St-Donat (Unimin)
40	Lac Daigle
41	Lac Moiré
42	Colline Blanche
43	Carrière de la Baie Joannes
44	Saint-Bruno-de-Guigues

Massif quartz (veins, pegmatites)

45	Claims Turgeon
46	Kébec Cristal (Adam)
47	Ménard
48	Mine Beaudoin
49	Mine Bourque
50	Mine Dupuis-Veilleux
51	Propriété Bouffard
52	Rapides du diable
53	Sainte-Edwidge
54	Saint-Ludger
55	Colline Watshishou
56	Île à la Mine
57	Mont Blanc
58	Gendron (Gendron Quartz)
59	Mine Black
60	Mine Parcher
61	Mine Pedneau
62	Mine Templeton
63	Lac Bouchette
64	Lac Moreau
65	Lac Noir (Quebec Silica)
66	L. Champagne
67	Lac Cordon
68	Lac Baskatong
69	Silice Supérieure-1
70	Ste-Agathe-des-Monts
71	Mine Beaudry
72	Macanda (Macanda Copper)
73	Mine Powell-Rouyn
74	Mine Peel-Elder
75	Clerion

Other types

76	Mine Silice Madeleine (Sandy Hook)
77	Mine Joliet Quebec
78	Mine Don Rouyn



Map of southern Quebec (modified from report DV 2001-07) showing rock assemblages containing quartzite and orthoquartzite (numbers correspond to those used in the legend), and the location of known silica deposits (numbers refer to the above tables). The Val Brillant Formation in the Appalachians and the Guigues Formation in Témiscamingue could not be shown since they do not appear in the legend of the report. Assemblage #70 includes the Trois-Pistoles Group that contains formations of sandstone, mudrock, conglomerate and limestone, capped by the Kamouraska Formation.