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Ministry of Energy, Mines and
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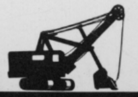
MINERAL RESOURCES DIVISION
Geological Survey Branch



WOLLASTONITE AND TREMOLITE OCCURRENCES IN BRITISH COLUMBIA

By Peter Fischl

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VICTORIA
BRITISH COLUMBIA
CANADA

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SUMMARY

Wollastonite, a calcium silicate pyroxenoid used in ceramics, paints, plastics and in asbestos replacements, occurs at several sites in British Columbia as a major component of skarn bodies of contact metamorphic and metasomatic origin. There is potential for wollastonite to occur in significant quantities in carbonatite deposits, although it has yet to be identified in the numerous carbonatites known within the province.

Tremolite, an amphibole of similar origin and with the potential for similar uses as wollastonite, is found in similar geologic environments throughout the province.

Mapping, sampling and a review of the MINFILE database has identified seven skarn occurrences containing significant wollastonite and two with significant tremolite. Of these occurrences, only Snake Bay (W1a) is in the advanced exploration stage with drill-indicated reserves.

Testing by CANMET of bulk samples from four of the wollastonite occurrences and one tremolite occurrence revealed that wollastonite and tremolite with only low to moderate aspect ratios could be produced using conventional grinding and beneficiation techniques. Of the five deposits tested, marketable wollastonite-tremolite concentrates (less than 1% Fe_2O_3 and ignition loss) could be produced from three of the occurrences with wet, high-intensity magnetic separation and reverse anionic flotation.

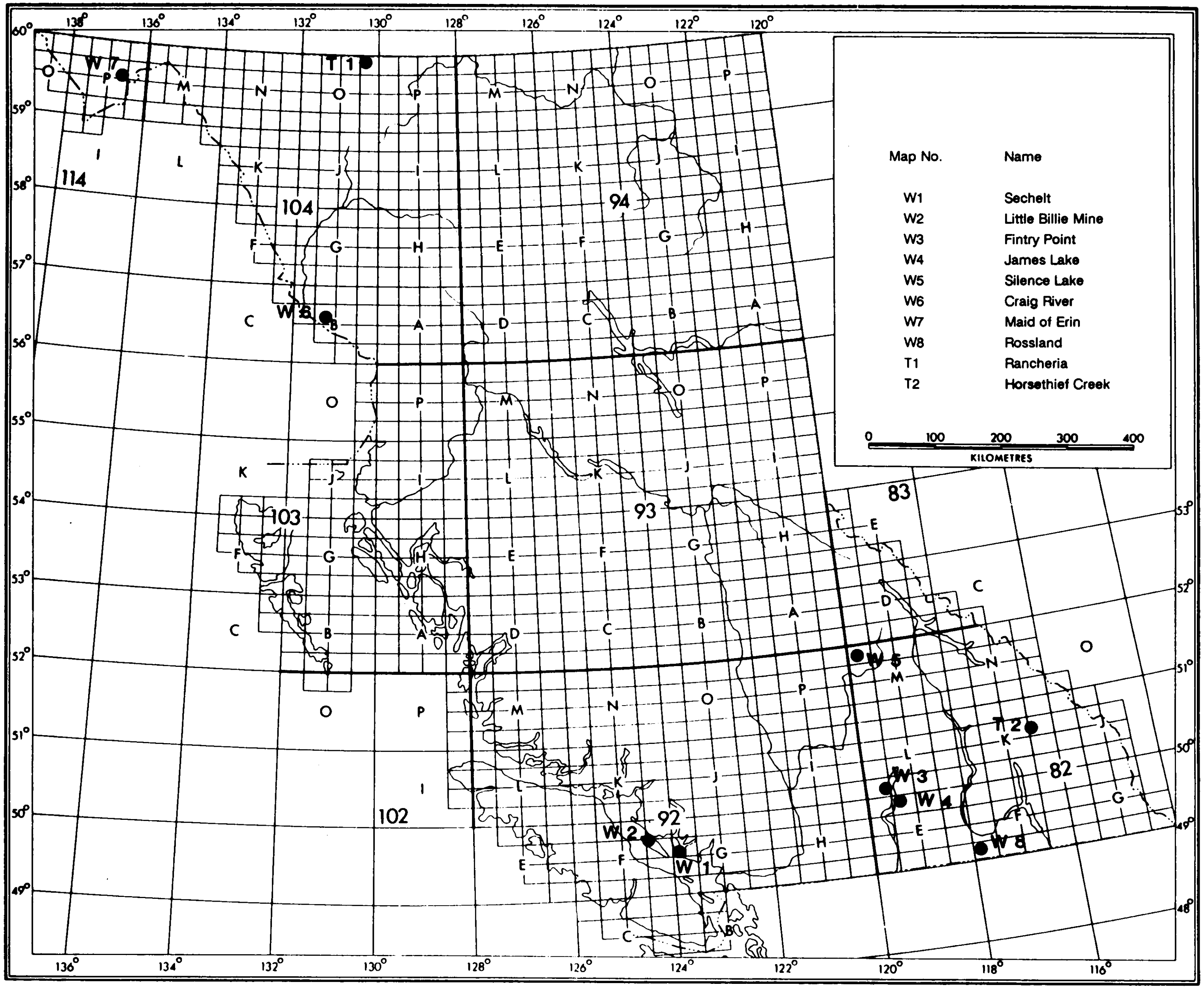

Figure 1. Map showing location of wollastonite occurrences described in this report.

INTRODUCTION

Wollastonite is one of the 'newer' industrial minerals and received comparatively little attention until the second half of this century. The mineral was discovered by, and named after the English chemist and mineralogist, William Hyde Wollaston (1766-1828). In the United States the mineral was first mined at Randsburg, California in 1933 for the manufacture of white mineral wool. The first large-scale industrial plant designed to process wollastonite for various end-uses was built in 1949 in New York State. Mining and processing began in a number of other countries during the 1960s and 1970s.

The ceramic industry quickly became a major consumer. By 1967 two-thirds of all ceramic tile companies in the United States used the mineral. Because of a variety of unique properties wollastonite is used in a number of other applications and shows potential for many more uses. Demand for the mineral is thus expected to increase steadily, especially in the field of performance fillers and asbestos replacements.

This report has been prepared to briefly evaluate the wollastonite potential of British Columbia by highlighting some of the more important occurrences. It is based on fieldwork carried out by the Geological Survey Branch and by corporations involved in the development of some of the deposits.

Even though the report is primarily concerned with wollastonite, several tremolite occurrences are also described, as tremolite has the potential for similar uses.

The author wishes to thank Danny Hora for initiating this project and reviewing the manuscript and Gary White, formerly of the Geological Survey Branch, for carrying out the fieldwork required for the completion of the project. The contribution made by numerous individuals and corporations involved in the production, exploration, sale and consumption of wollastonite is also gratefully acknowledged. The thorough edit by John Newell is much appreciated in improving this manuscript.

WOLLASTONITE - THE MINERAL

BASIC PROPERTIES OF WOLLASTONITE

Wollastonite is a calcium silicate of the pyroxenoid mineral group with a chemical formula of $CaSiO_3$ and a theoretical composition of 48.3 per cent CaO and 51.7 per cent SiO_2 by weight. Iron, manganese or magnesium may substitute for some of the calcium. Some naturally occurring iron wollastonites may contain up to 15 to 20 per cent $FeSiO_3$. The basic physical properties of the mineral are listed in Table 1 and some of its more useful characteristics are shown in Table 2.

The cleavage, and solubility of wollastonite in hydrochloric acid, help distinguish it from tremolite $[Ca_2Mg_5Si_8O_{22}(OH)_2]$, a metamorphic amphibole of similar appearance and origin. Both minerals tend to occur in coarsely bladed masses and both have similar hardness (wollastonite: 4.5 to 5, tremolite: 5 to 6). However, wollastonite has two perfect cleavages at 84°, while tremolite has two perfect cleavages at 56°. Wollastonite dissolves in concentrated hydrochloric acid while tremolite does not.

The two perfect cleavages enable wollastonite to be broken into lath-like particles of varying acicularity during crushing and grinding. This is one of its most important properties. The acicularity of the particles is characterized by their 'aspect ratio,' defined as the ratio of the length to width of individual particles, and it plays an important role in determining the suitability of wollastonite for particular applications. Low-aspect material (powder wollastonite) is characterized by aspect ratios of 3:1 to 5:1. It is limited to ceramic, metallurgical and simple (passive) filler applications. High-aspect wollastonite, with ratios of 15:1 to 20:1, is suitable for a much wider range of applications, including performance fillers and asbestos replacements. Not all wollastonite can be readily processed into the more valuable high-aspect filler grades. The two major producers of powder wollastonite, Partek Corporation in Finland and R.T. Vanderbilt Co. Inc. in New York, have recently begun resorting to special grinding techniques to produce fine grades of high-aspect wollastonite in order to compete with the two established producers, the NYCO Division of Processed Minerals Inc. of New York and Wolkem Private Ltd. of India.

The brightness (whiteness) of wollastonite is also important in determining its use for certain filler and ceramic applications.

Dry brightness is determined by measuring the reflectance of finely ground powder relative to a standard that is assigned a brightness of 100. The American Society for Testing and Materials specifies a surface coated with magnesium oxide as one standard (A.S.T.M. Standard E 97-55); barium sulphate is another commonly used standard. Brightness is reported in per cent. The colour of light used in measuring the brightness is usually also reported. 'G.E. brightness' is a term commonly used in North America and refers to brightness measured by a reflectometer that has been calibrated against the master reflectometer of the Massachusetts Institute of Technology. This particular instrument is a product of General Electric, hence the term G.E. brightness. For most filler applications wollastonite must have a brightness of at least 85 per cent. Its brightness can be affected during inversion to its high-temperature polymorph, pseudowollastonite. Thus, for most ceramic applications it is tested for undesirable discolorations that may occur at elevated temperatures.

TABLE 1. LIST OF THE BASIC PHYSICAL PROPERTIES OF WOLLASTONITE

Habit: triclinic
Hardness (Moh's Scale): 4.5 to 5
Colour: white, sometimes cream grey or very pale green
Streak: white
Lustre: vitreous to pearly
Cleavage: 2 perfect and 1 good
Specific gravity: 2.87 to 3.09
Melting point: 1540°C
Inversion temperature to pseudowollastonite (high-temperature polymorph): 112010°C

TABLE 2. USEFUL CHARACTERISTICS OF WOLLASTONITE

Hydrophyllic (readily wetted by water)
Low water absorption
Low oil absorption (20 to 26 millilitres/gram) (Andrews, 1970)
pH in 10 per cent slurry: 9.9 (Industrial Minerals Magazine, 1975)
G.E. brightness: 92 to 96 per cent (Ground to -325 mesh, using freshly precipitated MgO as a standard).
Chemically, largely inert, yet can be decomposed in concentrated hydrochloric acid
Loss on ignition (L.O.I.) of pure wollastonite: per cent

Ignition loss (L.O.I.) is another characteristic that must be taken into consideration. Ignition loss refers to the amount of volatile matter driven off when the mineral is heated to extreme temperatures. Such volatiles include carbon dioxide, water and organic materials. Most of the volatile matter is comprised of carbon dioxide derived from the thermal decay of calcite, a carbonate mineral often associated with wollastonite.

FORMATION AND GEOLOGICAL SETTING OF WOLLASTONITE

Wollastonite is formed by metamorphic or magmatic processes usually involving carbonate rocks. The mineral can be found in two distinct deposit types, skarn deposits (metamorphic and metasomatic) and carbonatites (magmatic).

Wollastonite-bearing skarns form by the thermal metamorphism of siliceous limestone during regional deformation or local igneous activity or by the metasomatism of limestone by silicious hydrothermal solutions developed along contacts with magma or channelled along faults and fractures. Wollastonite is formed by the following reaction:

$$SiO_2 + CaCO_3 = CaSiO_3 + CO_2$$

Silica + Calcite = Wollastonite + Carbon Dioxide

The presence of dolomite in metamorphosed or metasomatized carbonates can lead to the formation of tremolite by the following reaction:

$$5CaMg(CO_3)_2 + 8SiO_2 + H_2O = Ca_2Mg_5Si_8O_{22}(OH)_2 + 3CaCO_3 + 7CO_2$$

Dolomite + Silica + Water =
Tremolite + Calcite + Carbon dioxide

In skarn deposits wollastonite typically occurs with a number of other minerals such as:

diopside [$CaMgSi_2O_6$],
idocrase (vesuvianite)
[$Ca_{10}Al_4(MgFe)_2(Si_2O_7)_2(SiO_4)_5(OH)_4$],
grossular garnet [$Ca_3Al_2(SiO_4)_3$],
and andradite garnet [$Ca_3Fe_2(SiO_4)_3$].

All of the currently exploited and most of the potentially economic wollastonite deposits are skarns. All of the more important occurrences in British Columbia are also skarn deposits.

Wollastonite is also found in potentially economic concentrations in carbonatites; magmatic rocks comprised of calcium, magnesium and sodium carbonates with subordinate nepheline, feldspar, pyroxene, biotite-phlogopite and apatite. The rock tends to be enriched in various rare earth elements. Carbonatite deposits typically occur as near-surface intrusions associated with nephelinite or nepheline syenite in complexes of circular or elliptical outline. Wollastonite forms by crystallizing out of the carbonatite magma. Occurrences in carbonatites tend to be of lower grade but of significantly larger size than skarn deposits. A number of carbonatite occurrences have been documented in British Columbia (J. Pell, in preparation). So far wollastonite has not been found in any of them, but none have been evaluated for their wollastonite potential (J. Pell, 1990, personal communication).

WOLLASTONITE MARKETS

Wollastonite has many industrial applications, because of its various useful characteristics. Its acicularity is the most important factor that determines its suitability for particular applications. Low-aspect wollastonite is limited to uses involving ceramics, glazes, metallurgical fluxes and paints. Most of current production is consumed in such powder applications. High-aspect wollastonite is used as a performance filler in plastics, resins, rubber adhesives and in asbestos replacements. Markets requiring high-aspect wollastonite show the most potential for future growth.

LOW-ASPECT WOLLASTONITE

CERAMICS

Worldwide, the ceramics industry is the single largest user of wollastonite. In the United States and Europe 60 per cent of production is consumed in the manufacture of ceramics; it is also reported to be used widely in the U.S.S.R. Specific applications include wall and floor tiles, earthenware, whiteware and dinnerware, of which tile manufacture accounts for the bulk of consumption.

Some of the more important characteristics of wollastonite used in the manufacture of various ceramic articles are:

- increases bonding of ceramic materials before firing (*i.e.* improves green strength), enabling ceramic articles to retain their shape after molding and pressing;
- its low sintering temperature (991° to 1196°C) allows it to readily react (fuse) with other ceramic ingredients (clays, talc, feldspar, flint, *etc.*) during fast firing;
- improves resistance to heat shock, greatly reducing warping and cracking in rapidly fired materials, because of the low, straight-line expansion of ceramic mixes containing wollastonite;
- imparts high strength and high dimensional stability to ceramic articles after firing because of the strong bond formed with the other ceramic ingredients;
- promotes drying before and during firing by providing openings for the rapid passage of moisture through the ceramic material;
- reduces shrinkage during drying;
- reduces moisture absorption after firing;
- lacks water or carbonate, thereby reducing the liberation of gases, which can cause cracks and laminations.

Most of the listed advantages of wollastonite permit the use of shorter firing times at lower temperatures [*e.g.* 1030° to 1080°C for 30 minutes for tile bodies (O'Driscoll, 1990)], resulting in lower fuel and labour costs. Firing times are largely dependent on the concentration of wollastonite in raw ceramic mixes. A mixture containing more than 50 per cent wollastonite can reduce firing times from up to 70 hours to less than 2 hours (Andrews, 1970). Wollastonite used in the ceramics industry must contain less than 1 per cent Fe_2O_3 and have less than 1 per cent ignition loss. Inversion to pseudowollastonite, the high-temperature polymorph, during firing may result in undesirable volume and colour changes. Inversion may change white wollastonite to cream, various shades of tan to brown, or even dark red. However, the presence of a small amount of diopside raises the inversion temperature above the sintering temperature range.

The electrical insulating properties of wollastonite permit its use in the manufacture of ceramic insulators with low dielectric loss. Dielectric loss refers to the power loss through an insulator due to heating in a high-frequency alternating electric field. Dielectric losses of insulators containing wollastonite are typically 50 to 60 per cent less than conventional ceramic insulators. The addition of wollastonite also provides increased strength and thermal shock resistance with lower thermal expansion.

GLAZES

Wollastonite is also used by the ceramics industry in the production of glazes, the protective and decorative glass coatings applied to ceramic articles. They are usually nonporous to prevent the transmission of liquids and gases. Wollastonite glazes have a number of useful properties. They tend to have a low coefficient of expansion and are therefore in mild compression after being applied to a ceramic body, thus preventing crazing of the glaze. During firing, wollastonite glazes melt below the fusion (currying) temperature of the ceramic material to which they have been applied. They therefore flow and level smoothly without reacting chemically with the substrate. The lower viscosity imparts a more uniform gloss and texture with improved spraying characteristics. The low ignition loss (<1 per cent) ensures no gas emissions, which may disturb the glaze coating, are produced.

METALLURGICAL USES

Because it is a natural low-temperature fluxing material, wollastonite is used in a number of metallurgical applications. In Europe metallurgical fluxes are the second largest use of wollastonite after ceramics. It is used primarily in steel refining and casting and in welding powders. In steel refining it is used to draw alumina (Al_2O_3) out of molten steel. Fluxing formulations containing wollastonite are used in steel casting to protect bare metal surfaces from oxidation at high temperatures. They give a better surface finish to steel than those with silica and lime compositions. Wollastonite is favoured in welding powders because it improves burn characteristics, inhibits sparking and fuses readily. In most metallurgical applications wollastonite must be low in phosphorus and sulphur and free of carbonate to ensure low ignition loss (<1 per cent).

GLASS MANUFACTURING

Wollastonite is used to some extent in glass manufacture in both North America and Europe, this use is limited by the fact that conventional raw materials are cheap and abundant. Wollastonite deposits must therefore be favorably located with respect to glass plants, such as in Finland, in order to compete successfully with other raw materials. Most glasses are comprised of a supercooled mixture of calcium and sodium silicates produced by melting limestone (or lime), sand (silica) and soda ash together. Because it contains two of the three required ingredients, wollastonite can be fused with soda ash alone, to produce glass. There are a number of advantages to using wollastonite in glass making. It melts up to twice as fast and at lower temperatures with soda ash than a mixture of limestone, sand and soda ash, thus requiring less heat per kilogram of melt. It requires less than 500 kilocalories per kilogram of melt, while limestone and sand require over 850 kilocalories per kilogram; also, more glass is produced per kilogram of raw material. Only 100 kilograms of wollastonite, as opposed to 133 kilograms of limestone are required to produce 99 kilograms of glass melt (Industrial Minerals Magazine, 1975). Wollastonite also reduces the amount of 'scum' (unmelted layer of material floating on the surface of a glass melt) and the amount of 'seeds' (small gaseous inclusions) in glass. Overall, its use improves fuel economy and increases productivity. In order to be used for glass manufacture wollastonite must be low in iron (usually not exceeding 0.2 per cent Fe_2O_3). Excessive amounts of iron impart an unwanted pale green tint to glass.

PAINTS AND COATINGS

Wollastonite has also become an important raw material in the manufacture of paints and coatings. In the United States the paint industry is the second largest consumer, after ceramics. Various grades and concentrations are used in the manufacture of a number of different paints. Fine-ground wollastonite (1 micrometre) is used in gloss and semigloss finishes while 'ordinary sized' wollastonite (approximately 15 micrometres) is used in flat paints and polyvinyl acetate emulsions. In the United States white semigloss enamels contain 9 per cent wollastonite by weight, while primers and sealers contain nearly 13 per cent. Block fillers have approximately 12 per cent wollastonite by weight. The mineral is used most widely in exterior house coatings.

Wollastonite has gained wide acceptance in the paint and coatings industry for its various useful characteristics. Its high brightness permits lower pigment loadings in light-coloured paints. A smaller quantity of expensive binder can be used with wollastonite because of its low oil and water absorption. Its ease of wetting in oil and water and its ability to reduce viscosities allows paints to be prepared with higher pigment loadings. Wollastonite also helps pigments stay in suspension. It strengthens paint film, giving longer life, excellent opacity and tint retention and improved scrub resistance. The rust and weather resistance of exterior coatings is increased with the addition of wollastonite. Its alkaline nature makes it useful as a pH stabilizer in certain paints, such as polyvinyl acetate (PVA) paints, which decay over time to vinyl alcohol and acetic acid. The excess acidity may further degrade the paint and induce corrosion of metal paint containers and metal surfaces to which the paint is applied. The acidification of such paints can be controlled by the addition of 0.12 kilogram of wollastonite per litre of paint (0.25 lb/gallon) (E. Elevatorski, 1983). Wollastonite is also used as a pH stabilizer in acrylic latex paints. The addition of wollastonite to paints also reduces foaming during brushing and roller applications, and provides good levelling characteristics and a uniform film thickness. Its only major drawback is the fact that steel rollers cannot be used to grind paint-grade wollastonite because of possible contamination from the rollers spoiling its colour.

PAPER

Although wollastonite is commonly used as a filler in paints, its use as a filler and coater in paper is still quite limited, despite being thoroughly researched. It provides good brightness and improves the dimensional stability of paper, limiting its tendency to curl. It also reduces ink demand and strike through. The poor retention of wollastonite in paper, and its abrasiveness, has limited its use in the paper industry. However, ultrafine grades (1 to 2 micrometres) have better retention and abrasion qualities than standard-sized grades (15 to 17 micrometres). Various forms of less abrasive chemically altered wollastonite are reported to offer a greater potential than untreated wollastonite.

HIGH-ASPECT WOLLASTONITE

PLASTICS AND RESINS

Wollastonite is used extensively as a filler in plastics and resins. Twenty five to thirty per cent of consumption in the United States is used to reinforce plastics and thermal insulation boards. Approximately 16 million kilograms of wollastonite were used in plastics in the United States in 1987 (Dickson, 1987) and this market is expected to dominate consumption in the coming years. The mineral is used in both thermal plastics (*e.g.* polyvinyl chloride (PVC), nylon, polypropylene, liquid crystal polymers) and thermosetting resins (*e.g.* epoxy, phenolic, polyester, polyurethane), with loadings typically ranging from 10 to 40 per cent by weight. Its use as a functional filler in engineering and reinforced plastics accounts for most of the increase in demand by the plastics industry. This market currently represents about 10 to 15 per cent of the total U.S. plastics market (Dickson, 1987), and demand for wollastonite by the American plastics industry was recently reported to be growing at 10 to 12 per cent annually (Roskill Information Services Ltd., 1987). With the current slump in economic activity, especially in the construction and automobile industries this growth will be somewhat reduced.

The reinforcing ability of wollastonite depends largely on its acicularity; high-aspect wollastonite is therefore preferred. Its addition to plastics results in higher tensile strengths, increased dimensional stability and higher heat distortion temperatures. Its reinforcing ability is also dependent on the bond between the mineral particles and the enclosing plastic. Surface modifiers (surfactants), such as silanes, stearates and organometallics, are commonly used to improve bonding and to facilitate the dispersion of filler particles. The use of chemically modified fillers in the plastics industry was reported to be growing at an annual rate of 15 per cent, compared to a growth rate of 6 per cent annually for regular fillers (Harben, 1986). Silanes are ideally suited for improving bonding because they contain both organic and inorganic functional groups. They therefore react with both the filler and the surrounding plastic or resin, forming a strong bond. Chemically treated wollastonite is used in nylon and phenolic resins. It can replace more expensive glass fibre used in nylon and polypropylene, although with chemical treatment, wollastonite itself becomes somewhat more expensive.

As with paints and coatings, wollastonite is also used as a pH stabilizer in plastics. Halogenated polymers (*e.g.* polyvinyl chloride) slowly decompose in the presence of heat and light through the liberation of halogen acid (*e.g.* hydrochloric acid), leading to the further breakdown of the polymer. The buffering action of wollastonite helps neutralize the acid generated.

The use of wollastonite as a filler in plastics is desirable for a number of other reasons, including:

- its low oil and water absorption gives a high degree of stain resistance and reduces the tendency to swell;
- its hardness adds to wear and abrasion resistance, extending the life of plastic articles;
- its brightness makes it useful as a pigment in light-coloured plastics;
- it imparts good electrical insulating properties;
- its low cost relative to plastic makes it useful as a 'cheap filler', replacing more expensive material;
- it maintains low viscosities in molten plastic, even with high loadings (in excess of 30 per cent wollastonite).

RUBBER, GYPSUM AND ADHESIVES

Wollastonite is also used to a lesser extent as a reinforcer in rubber and gypsum products and adhesives. Its low water absorption, easy wettability, alkalinity and its effect on tensile strength and abrasion resistance make it useful in various rubber products and adhesives, such as skid-resistant tires, hot-melt adhesives, caulks and jointing compounds. In gypsum transverse rupture and tensile strengths are improved because of the strong bond formed with the gypsum matrix without additional surface treatment. Fire resistance of various gypsum products such as wallboard, plaster and stucco are also improved.

ASBESTOS SUBSTITUTES

The semifibrous nature of high-aspect wollastonite makes it useful as an asbestos replacement. Alternatives to asbestos fibre have been sought since the 1970s, because of the health hazard associated with its uncontrolled use. The search for substitutes will intensify with the almost complete banning of asbestos use in the United States by 1997. Only high-aspect wollastonite is suitable as a replacement. Even it is not perfect, because its fibres do not have the length and flexibility of asbestos fibres. However, the health risks and higher prices associated with asbestos make it a useful substitute in cements, heat containment applications and in vinyl asbestos systems.

Cements used in the manufacture of thin structures such as drain pipe, roofing tiles and siding, and in high-strength concrete structures needing resistance to salt and frost require a fibrous reinforcement. Such cements have traditionally used asbestos, but wollastonite has now been successfully used as a partial or complete replacement in such applications.

Because the melting temperature of wollastonite is comparable to that of asbestos, it can be substituted in some high-temperature applications. Wollastonite is currently used as a reinforcement filler in boards and panels employed in heat-containment applications. The mineral is also replacing asbestos in various frictional applications, such as brake linings, because of its extremely good heat-resistant properties.

Vinyl asbestos systems have also been subjected to increasing replacement. In the 1970s, when new laws governing the use of asbestos came in to effect in the United States, wollastonite began to replace asbestos in various vinyl asbestos systems, especially in caulking compounds, sealants, joint cements and roofing compounds. It is also being increasingly used in various ceiling and floor tiles as a reinforcer; its white colour makes it ideal for use in light-coloured tiles.

MISCELLANEOUS USES

A number of other uses and potential uses have been found for wollastonite. It has been used in inorganic foams for fire retardant insulation and for radar absorbers. Its chemical and thermal stability, coupled with its low vapor pressure over a broad temperature range, make it ideal for use in frosted coatings inside incandescent lamps. Because of its high resistance to thermal shock, it is also used in ceramic-bonded abrasives and abrasive wheels. Its hardness (4.5-5) and its acicular shape allows its use as a mild abrasive in dental pumice, paste hand-cleaners, scouring powders and porcelain enamel cleaners. Wollastonite has also found use in soil conditioners and in acid-resistant cement mortars, and potential use in antacids and in regulating pH in swimming pools, although the lower cost of limestone and dolomite has limited its use in horticulture and agriculture.

FUTURE DEMAND

Demand for wollastonite is expected to increase in a number of markets in the near future. Current research on its unique properties ensure the continued development of new uses for the mineral. With the advent of fast-firing and single firing in the manufacture of ceramics, consumption is expected to continue to increase in the ceramics industry. Markets for ceramics and paints are closely tied to the construction industry, and are therefore subject to its fluctuating state of activity. The metallurgical market shows some potential for growth, especially in welding-rod coatings and fluxes, and in metal-casting plasters.

The greatest potential growth in wollastonite consumption lies in the reinforcement of plastics and the replacement of asbestos. Plastic compounds subjected to mechanical stresses, such as in auto parts, will become increasingly in demand in the near future (Power, 1986). The outlook for surface-treated high-aspect wollastonite is quite bright, especially for use in nylon and polypropylene. With the eventual total ban of asbestos use in the United States, wollastonite will be an important substitute in various applications. As a relatively cheap performance filler it has extremely good potential as a replacement for other more expensive fibres, such as chopped and milled fibreglass.

America and western Europe will continue to dominate wollastonite consumption in the near future. The United States will see growth in demand for high-aspect wollastonite for use in performance fillers and asbestos replacements. European consumption, although largely restricted to powder wollastonite, is expected to eventually also increase in this area (Roskill Information Services Ltd., 1987).

MARKET SURVEY

A number of companies involved in the consumption and distribution of wollastonite and similar materials in the western United States and Canada (Alberta, British Columbia, Washington, Oregon, California) were contacted by telephone in order to evaluate the markets for the mineral and to gain familiarity with its uses. However, this survey is by no means complete and estimates of current total consumption in the surveyed areas have not been attempted.

Currently western North America is supplied with wollastonite by R.T. Vanderbilt and NYCO. Current demand is limited because of the cost of transporting the material across the continent. In addition, most of the major manufacturing plants in the fields of ceramics, paints and plastics are in eastern North America. Yet because of the high freight costs from New York, a 'window of opportunity' may exist for a wollastonite producer in the western United States or Canada to compete with the two established producers in New York, but results from the survey suggest that current demand in west may not be sufficient to absorb all the mine output from a western producer. However, any western producer located near tidewater would be in a position to take advantage of markets around the Pacific Rim, which may be sufficient to sustain mine output, together with the local markets.

Results of the market survey are summarized below, organized by application.

CERAMICS

None of the three ceramic manufacturers contacted in the Greater Vancouver area uses wollastonite. One manufacturer of glazes and electrical insulating porcelains in Medicine Hat, Alberta, currently not operating, is expected to consume 25 to 30 tonnes annually in the near future. A ceramics and pottery raw material supplier in the Greater Vancouver area reports selling, at most, some 230 kilograms per year, while one in Medicine Hat currently supplies about 5 tonnes per year.

Of two ceramic manufacturers in the Seattle-Tacoma area, neither reported using wollastonite, although two ceramic and pottery raw material suppliers located in this area both sell it. One in Tacoma reports sales of 2.5 to 3.5 tonnes per year, while the other, in Seattle, estimates its annual sales at about 1 tonne.

PAINTS AND COATINGS

Three of eleven paint and coating manufacturers contacted in Victoria and the Greater Vancouver area stated that they each use several tonnes of wollastonite per year, while one mentioned that it had used wollastonite in the past and two more reported they would consider using it if it was more readily available and lower priced. Of seven chemical and paint raw material suppliers in the Greater Vancouver area, one is a distributor of wollastonite. T. Jefferys of Cascade Chemicals Ltd. estimates that a total of 120 tonnes of wollastonite are consumed annually in the Greater Vancouver area in paints and pharmaceuticals.

Of sixteen paint manufacturers contacted in the western United States (nine in Washington, three in Oregon, four in California) four companies reported using the mineral. One Seattle-based manufacturer reported using about 400 kilograms per year, mostly in block filler. A manufacturer located in Portland uses up to 5 tonnes per year, also largely for block filler. One company in California consumes approximately 250 tonnes per year, while a manufacturer of special industrial coatings, also in California, uses about 1 tonne per year. A second manufacturer in Seattle stated that it used wollastonite once in the past for the preparation of traffic paint. A second Portland company reported that it once used wollastonite in latex paints but discontinued its use because of its high cost. This company is now using nepheline syenite (Minex brand) from Indusmin Ltd. of Ontario, Canada as a substitute. Of five chemical and paint raw material suppliers based in Seattle and one in Portland, three are distributors of wollastonite. One Seattle distributor supplies about 10 tonnes per year to local markets, while a second based in Portland reports annual sales of about 20 tonnes in Oregon and Washington. W. Cordano of Cordano Chemicals Co. Ltd. stated that wollastonite has the potential to displace some of the nepheline syenite consumption by the paint industry if it could be obtained at a lower price.

PLASTICS AND ADHESIVES

Of two plastic manufacturers, one in Washington and one in California, only the latter reports that it uses wollastonite in its plastics. This company consumes about 320 kilograms annually in the manufacture of engineering plastics. An adhesives manufacturer in Kent, Washington doesn't currently use the mineral but has investigated potential applications.

BRAKE LINING

No manufacturer of brake linings was identified in western Canada. In the United States all the major manufacturers are based in the east and currently use fibreglass or kevlar in their brake linings. However, of three manufacturers of special industrial friction products identified in Oregon, two report a combined consumption of about 17 tonnes of wollastonite annually.

CONCLUSIONS

This market survey has confirmed that wollastonite is consumed in the two westernmost Canadian provinces and the three westernmost American states. A breakdown of yearly consumption by province and state is given in Table 3.

TABLE 3. WOLLASTONITE CONSUMPTION IN WESTERN NORTH AMERICA

Alberta	up to 32 tonnes
B.C.	10 to 120 tonnes
Washington	25 tonnes
Oregon	at least 32 tonnes
California	at least 250 tonnes

It should be noted that not all manufacturers and raw material suppliers for ceramics, paints, plastics and polyvinyl chloride products in Oregon and California were contacted.

Clearly, this level of consumption will not support a wollastonite producer. However, a western producer would find a quickly expanding market for its product in western North America, because of lower freight costs and the resulting ability to lower prices and stimulate increased consumption. Yet, such a producer would probably require the additional support of Pacific Rim markets in order to become an economically viable supplier of wollastonite.

MINING AND PROCESSING OF WOLLASTONITE

Wollastonite is not an uncommon mineral, yet the number of wollastonite occurrences that can be economically exploited is quite small. Most mineable deposits worldwide contain at least 500 000 tonnes of reserves. If wollastonite is the only product, grades of at least 30 per cent are needed for a deposit to be potentially economic (Andrews, 1970), but deposits of lower grade can be economically mined if other commodities are recovered as a byproduct. In Finland, for example, Partek Corporation produces calcite of extreme purity suitable as a paper filler from low-grade wollastonite ore. Thus, minimum grade is in part dependent on the profitable extraction of accompanying minerals such as calcite and garnet from skarn deposits, and rare earths from carbonatites.

The narrow and steeply dipping character of most wollastonite deposits precludes conventional open pit mining. Near surface deposits are extracted by selective open-cut mining giving way to more conventional underground mining, provided the grade is high enough to justify the higher costs.

After mining, the ore is crushed and ground to liberate the wollastonite from unwanted minerals. Wet or dry high-intensity magnetic separation is used to separate wollastonite from weakly magnetic minerals such as garnet and diopside. Flotation may be required if carbonates and nonmagnetic silicates are present. Tests carried out by CANMET of Energy, Mines and Resources Canada indicate that most calcite and some quartz can be separated by reverse anionic flotation using sodium oleate (Andrews, 1989). The direct cationic flotation of calcite using Arquad T50 (a tertiary amine) has had limited success in separating calcite from wollastonite.

After separation the resulting concentrates are processed by further grinding and screening to produce a series of grades of differing sizes and acicularity. Most marketable concentrates contain at least 90 per cent wollastonite.

GLOBAL REVIEW OF WOLLASTONITE PRODUCTION AND EXPLORATION

The worldwide production of wollastonite has increased rapidly over the latter half of this century, in parallel with developments in processing and marketing. In 1969 worldwide production stood at 40 000 tonnes (Smith, 1981). In 1983 more than 125 000 tonnes of wollastonite were produced (Power, 1986). Production of natural wollastonite for 1990 is estimated at 355 800 tonnes, mostly from the United States, China, Finland, India and Mexico (Roskill, 1990). The only significant producer of synthetic wollastonite is Germany, where Rheinische Kalksteinwerke Gmbh produces 10 000 tonnes annually (Roskill, 1990). Yearly production for some of the more important producing countries is listed in Table 4.

NATIONS WITH CURRENT OR PAST PRODUCTION

UNITED STATES

America has always been the leading producer of wollastonite. In 1985, 66 per cent of the world production came from the United States (Power, 1986). Most of this production was consumed by the domestic ceramics industry. Current exports amount to 50 000 tonnes annually (Roskill, 1990). Of the 80 000 tonnes produced in 1981, 25 per cent was exported to Japan (Smith, 1981). The two major producers are the NYCO Division of NYCO Minerals Inc. (formerly Processed Minerals Inc.) and R.T Vanderbilt Co. Inc., both in New York State. A small amount of wollastonite was produced by Pfizer Inc. in California at one time.

In upstate New York a number of significant wollastonite deposits are contained in a belt of Precambrian limestones 10 kilometres long and 0.4 kilometre wide that have been contact metamorphosed and metasomatized by anorthositic intrusions, forming gneissic rocks containing bands of wollastonite, garnet and diopside. Mining began at the Fox Knoll mine in Essex County, 4 kilometres southwest of Willsboro, in 1943. In 1975 the deposit was reported to contain 7 million tonnes grading 55 to 65 per cent wollastonite (Industrial Minerals Magazine, 1975). NYCO was producing up to 95 000 tonnes of wollastonite per year shortly before the mine closed in December, 1982 (Smith, 1981). NYCO began mining a second deposit, the Seventy Mountain deposit, near Lewis in 1982. The mine is also located in Essex County, 22 kilometres southwest of Willsboro. Reserves were initially reported at 5 million tonnes grading 59 per cent wollastonite (Industrial Minerals Magazine, 1975) and currently stand at 6 million tonnes (Industrial Minerals Magazine, Nov. 1989, p. 17). NYCO is presently (1990) producing about 100 000 tonnes of wollastonite per year from this deposit,

TABLE 4. YEARLY WOLLASTONITE PRODUCTION BY COUNTRY
(Tonnes)

Year	U.S.A.	Finland	India	Mexico	Turkey	Kenya	Namibia	New Zealand
1989	N.A.	30 700	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
1988	N.A.	28 400	35 163	N.A.	5 800	N.A.	N.A.	N.A.
1987	72 000	21 300	31 021	10 993	N.A.	N.A.	N.A.	N.A.
1986	65 000	21 800	23 819	9 356	N.A.	N.A.	N.A.	N.A.
1985	72 000	16 917	26 040	13 512	N.A.	N.A.	N.A.	N.A.
1984	N.A.	15 100	27 008	9 251	N.A.	N.A.	N.A.	N.A.
1983	80 000	15 300	16 557	10 784	N.A.	N.A.	N.A.	N.A.
1982	82 000	15 600	20 724	15 000	N.A.	N.A.	N.A.	N.A.
1981	85 000	13 600	15 915	15 000	5 700	N.A.	N.A.	N.A.
1980	76 000	11 900	5 790	20 905	N.A.	N.A.	N.A.	N.A.
1979	74 000	10 576	3 794	11 892	N.A.	120	N.A.	N.A.
1978	70 000	7 950	1 928	5 653	N.A.	102	N.A.	N.A.
1977	65 000	8 904	3 329	692	5 000	300	N.A.	N.A.
1976	63 000	6 165	4 541	1 143	N.A.	120	N.A.	N.A.
1975	45 000	6 200	1 102	600	N.A.	N.A.	N.A.	N.A.
1974	55 000	8 137	954	2 000	N.A.	N.A.	N.A.	N.A.
1973	60 000	6 547	476	1 593	N.A.	55	N.A.	N.A.
1972	40 000	6 491	3 326	559	3 500	N.A.	N.A.	N.A.
1971	30 000	5 549	2 042	3 224	N.A.	N.A.	N.A.	N.A.
1970	30 000	6 051	576	6 562	N.A.	100	N.A.	N.A.
1969	30 000	5 200	448	4 567	N.A.	690	N.A.	N.A.
1968	N.A.	4 296	nil	68	N.A.	1 382	N.A.	N.A.
1967	N.A.	3 500	N.A.	700	N.A.	12 700	nil	
1966	N.A.	3 874	N.A.	N.A.	N.A.	nil	335	N.A.
1965	N.A.	3 048	N.A.	N.A.	N.A.	N.A.	208 54	
1964	N.A.	2 393	N.A.	15 553	N.A.	N.A.	116 14	
1963	N.A.	2 051	N.A.	N.A.	N.A.	N.A.	nil	9
1962	N.A.	2 420	N.A.	N.A.	N.A.	N.A.	N.A.	6
1961	N.A.	2 647	N.A.	N.A.	N.A.	N.A.	N.A.	nil
1960	N.A.	2 379	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Sources:
Andrews (1970)
Harben and Bates (1990)
Industrial Minerals Magazine, July, 1975
Power (1986)
Roskill (1990)
Smith (1981)

from ore containing 60 per cent wollastonite, 30 per cent garnet and 10 per cent diopside (Roskill, 1990). The garnet and diopside are removed by high-intensity dry magnetic separation. The garnet is separated from the diopside electrostatically to produce a garnet concentrate suitable for sand blasting and road treatment applications. Both powder and high-aspect (3:1 to 20:1) wollastonite are produced in sizes ranging from -325 to -1250 mesh. Concentrates typically contain 97 per cent wollastonite, 2.5 per cent garnet and 0.5 per cent diopside (R. Bauer, 1990, personal communication). A typical analysis is presented in Table 5.

By 1988 NYCO had outlined an additional 6 million tonnes of reserves at Oakhill, 5 kilometres from the Lewis mine (Industrial Minerals Magazine, Nov. 1989, p. 17). A second unmined deposit, the (high-aspect) Deerhead deposit, 8 kilometres north-northeast of the Lewis mine, contains 500 000 tonnes grading 58 per cent wollastonite (Industrial Minerals Magazine, 1975).

R.T. Vanderbilt Co. Inc. has been mining wollastonite from near Harrisville in the Governeur region of New York since 1977. The deposit lies in contact metamorphosed sedimentary rocks between two granitic intrusions. Wollastonite occurs in relatively pure, massive zones typically as fibres in excess of 30 centimetres long, with minor calcite, prehnite, graphite, magnetite and diopside. Reserves of 1.1 million tonnes contain 730 000 tonnes of recoverable wollastonite (D. Hodge, 1990, personal communication). Vanderbilt is currently producing approximately 40 000 tonnes of wollastonite annually by selective mining to avoid the need for beneficiation (O'Driscoll, 1990). Three grades of powder wollastonite are produced, -200, +325 and -325 mesh. A typical analysis is given in Table 5.

Until 1987 Pfizer Inc. was producing several hundred tonnes of wollastonite annually in Riverside County, southern California, to supply local ceramic markets. The orebody consisted of pods of wollastonite in Paleozoic limestone and underlying metamorphic rocks. Mining ceased because of excessive contamination by tremolite.

Although there is currently no wollastonite production in the state of Nevada, a promising deposit has been discovered. In October, 1989 Sikamin Gold Resources Ltd. of Toronto announced that it had discovered a high-grade wollastonite deposit in the Gilbert district of southern Nevada, while exploring a gold prospect. Mapping and drilling indicate at least three potential ore zones, the largest having a strike length of 900 metres, a width of 240 metres and a depth of at least 30 metres (Industrial Minerals Magazine, Nov. 1989, p. 19). Grades within this zone commonly exceeded 50 per cent wollastonite. Subsequent diamond and rotary drilling has indicated the potential for several million tonnes in open-pit reserves in an area 2100 metres by 260 metres to depths of up to 150 metres (Northern Miner, May 7, 1990, p. 6).

TABLE 5. TYPICAL ANALYSIS – NEW YORK WOLLASTONITE PRODUCTS

	NYCO[1]	R.T. Vanderbilt[2]
SiO_2	50.0	52.0
Al_2O_3	1.0	1.8
Fe_2O_3	0.5	0.34
CaO	47.0	42.0
MgO	0.3	1.5
MnO	0.1	0.03
Na_2O		0.27
TiO_2	0.05	
L.O.I.		2.04
Brightness (%G.E.)		88.0
NYAD 325	92	
NYAD 400	94	
NYAD 1250	95	
RG (high-aspect)	85	

[1] *NYCO, 1990, personal communication*

[2] *K. Rieger, 1990, personal communication*

CHINA

China has steadily increased its wollastonite production over the past decade to the point where it currently ranks second after the United States in terms of production. Total output for 1990 is predicted at 100 000 tonnes (Roskill, 1990). Three mines in the Jilin and Hubei provinces together produce at least 70 000 tonnes annually, of which 40 000 tonnes are exported to southeast Asia, Japan and Western Europe (O'Driscoll, 1990). At least three smaller producers are situated in Anhwei province.

Lishu Wollastonite Mining Corporation operates two mines, Dadingshan and Changweizi mines, in Jilin province near Panshi. The Dadingshan deposit comprises several ore zones hosted in marble containing 60 to 90 per cent wollastonite, as fibres typically 10 to 30 millimetres long, together with calcite, siliceous aggregates and minor diopside and garnet (O'Driscoll, 1990). The operation produces three lump sized grades, (10-30 mm's, 30-50 mm's and 50-150 mm's), two powder grades (10-20 microns and 20-150 microns) and various treated powder grades. Three micronized grades, with average sizes of 44, 20 and 10 microns are reported to have a whiteness of 90, 92 and 93 per cent respectively, with Fe_2O_3 contents of below 0.2 per cent (O'Driscoll, 1990). The deposit is mined by open pit methods, with a strip ratio of 3:1. Production has increased from 10 000 tonnes in 1985 to an estimated 50 000 tonnes for 1990.

A third mine, the Xiaoshuanpu mine, near Daye in Hubei province, was producing 20 000 tonnes of powder wollastonite annually in 1985. A deposit discovered in 1989 at Yengchong in Yunnan province is estimated to contain 100 million tonnes in reserves (O'Driscoll, 1990).

INDIA

India is now the third most important producer of wollastonite behind China. Wolkem Private Ltd., the only major Indian producer, currently mines the Belkappahar deposit in Rajasthan State.

The deposit is comprised of three main bands of wollastonite and calcite, interbedded with pyroxenites and garnet-bearing gneisses. The ore is reported to grade 96 to 97 per cent wollastonite with 3 to 4 per cent impurities (calcite, garnet, diopside and quartz). In 1975 proven reserves stood at 50 million tonnes with probable reserves of 200 million tonnes (Industrial Minerals Magazine, 1975). The deposit was discovered in 1969 and has been mined by Wolkem Private since 1972. Annual production is reported to have increased from 31 000 tonnes in 1987 to 35 000 tonnes in 1990 (Harben and Bates, 1990; O'Driscoll, 1990). About one third of this production is exported to western Europe, Japan, Australia and the U.S. Both powder and high aspect grades are produced, including the following four powder grades marketed under the Kemolit trade name; A-60 (60 mesh), S-1 (100 mesh), S-2 (200 mesh) and S-3 (300 mesh).

FINLAND

Finland currently ranks as the nation with the fourth largest wollastonite production. The mineral is mined by Partek Corporation at Lappeenranta in southern Finland. The deposit is hosted in an elliptical body of regionally metamorphosed carbonates, 3 kilometres long and 1 kilometre wide, enclosed in granite. The carbonates are variably altered to wollastonite, diopside or quartz. The orebody is a zone 650 metres long and 50 metres wide in the centre of the carbonate deposit. Grades average 18 to 20 per cent wollastonite but locally vary up to 60 per cent. Open-pit reserves stand at 4 million tonnes (Power, 1986). Garnet is reported to be completely absent in this deposit. Partek began mining here in 1957 and has is now producing at a level of about 83 per cent of its annual capacity for 40 000 tonnes. 75 per cent of this production (24 700 tonnes) is presently exported, mostly to western Europe (Roskill, 1990). A tonne of ore yields 200 to 250 kilograms of wollastonite and 500 to 600 kilograms of calcite. These minerals are separated by flotation, with the high-purity white calcite being sold for use in paper fillers and coaters. After flotation the wollastonite is purified by high-intensity magnetic separation to produce concentrates typically containing 90 per cent wollastonite, 3 per cent calcite, 2 per cent quartz and 5 per cent other silicates. Iron content is quite low at approximately 0.2 per cent Fe_2O_3. Powder wollastonite with aspect ratios of 3:1 to 4:1 is produced in 70, 200, 325, 400 and 635 mesh sizes. The company has recently begun using special milling techniques to produce wollastonite with high-aspect ratios of up to 20:1 in the 5 to 63 micrometre size range. Exploration by Partek on a second deposit 30 kilometres northwest of Lappeenranta up to 1986 has defined reserves of 20 million tonnes grading 25 to 30 per cent wollastonite (Roskill, 1990).

MEXICO

Mexico currently produces about 15 000 tonnes of wollastonite annually (O'Driscoll, 1990). The domestic ceramics industry is the main consumer of this production. In 1981, the most recent year for which figures are available, 71 per cent was used in wall and floor tiles, 25 per cent in pottery and 4 per cent in chinaware (Smith, 1981). A small amount is exported to Nicaragua and Ecuador. Wollastonite is known to occur in eight states: Chihuahua, Morelos, Puebla, Zacatecas, Chiapas, Tabasco, Durango and Sonora.

Wollastonita de Mexico had been mining wollastonite in the La Blanca district of Zacatecas by open-pit and underground methods since the 1960s. The mine was shut down in 1989 after being sold to Arcillas Industriales de Durango SA de CV. The deposit is comprised of tabular wollastonite bodies averaging 2.4 metres thick, conformably hosted in folded Cretaceous limestones adjacent to a granitic intrusion. Remaining reserves are estimated at 36 million tonnes (Harben and Bates, 1990), but good quality reserves are thought to be exhausted (O'Driscoll, 1990).

General de Minerales SA currently operates two mines in the La Blanca district of Zacatecas, one at Santa Fe near Noria Del Cerro, 35 kilometres southeast of Ojacaliente, with annual production capacity of 8000 tonnes, and a second near the town of Panfilo Natura, 50 kilometres from Guadalupe, with a capacity of approximately 7000 tonnes per year (Smith, 1981). Combined output from the two mines is estimated at 6000 tonnes for 1990 (O'Driscoll, 1990).

Compania Minera de Cerralvo produced some wollastonite as a byproduct of copper production from the Santa Fe mine, 40 kilometres south Pichucalco, 97 kilometres south-southwest of Villahermosa in northern Chiapas. During the 1970s some 1000 tonnes per year of wollastonite was produced from this deposit for the domestic paint industry. The deposit is comprised of an elliptical dome-shaped mass of wollastonite skarn 400 metres long, 120 metres wide and 100 metres thick containing copper mineralization. Reserves down to the third level are reported at 1 million tonnes, although most of the purer wollastonite contained in sulphide free pockets has been exhausted (Roskill, 1990).

Minerales y Maquilas del Norte SA operates a surface mine at La Blanca, 20 kilometres northeast of Ojacaliente in Zacatecas. Some 15 000 tonnes of raw ore are shipped to the company's processing plant at Santa Catarina to produce approximately 9000 tonnes of finished product annually. Four grades of high and low aspect wollastonite are produced (1.5 inch, 0.5 inch, 3%

+ 200 mesh, and 1% + 350 mesh), and sold primarily to domestic and American ceramic plants for the manufacture of floor and wall tiles.

Cia Minera Constelacion SA de CV, a subsidiary of Cominco Resources International Ltd., is developing a series of deposits 50 kilometres northwest of Hermosillo in Sonora. One zone of wollastonite-calcite-diopside marble, the South Zone, contains 700 000 tonnes grading 70 per cent wollastonite (O'Driscoll, 1990). Testing has indicated that both powder and acicular grades can be produced for ceramics, plastics and coatings. Production is expected to begin in the early to mid 1990s.

Gerle Gold Ltd. of Vancouver, B.C. is currently (1991) attempting to acquire an option on a property 50 kilometres north of Hermosillo near the previously described deposit. Wollastonite occurs in a series of bands and lenses in skarn altered limestone. Surface sampling has indicated a potential of 45 million tonnes in open pit reserves grading in excess of 70 per cent wollastonite (R. Hrkac, 1991, personal communication). Testing has indicated a high aspect product can be produced with a low iron content.

CHILE

Wollastonite is mined from a high quality deposit 60 kilometres northwest of Santiago, 50 kilometres from the port of Valparaiso. Some 500 tonnes are produced annually for domestic filler, paints and ceramic markets.

TURKEY

In Turkey wollastonite has been mined by various producers primarily for the domestic ceramic market. Production appears to have ceased, although an 1800 tonne per year operation is currently being planned in Bursa, near the coast south of Istanbul (Harben and Bates, 1990).

U.S.S.R.

Wollastonite is mined in Uzbekistan, 70 kilometres north of Samarkand. The deposit is comprised of calcsilicate hornfels containing 30 to 40 per cent wollastonite in middle Carboniferous argillaceous limestone adjacent to a Late Cretaceous granodiorite intrusion. The wollastonite contains 30 per cent calcite with minor feldspar, garnet and diopside. A second previously mined deposit of calcsilicate hornfels, 110 kilometres south of Samarkand, contains bands of wollastonite, pyroxene and garnet. The domestic ceramics industry is the major consumer of wollastonite in the U.S.S.R.

OTHER PRODUCERS

Other small-scale and sporadic production is reported from Kenya, New Zealand, Namibia and Japan.

POTENTIAL PRODUCERS

SOUTH AFRICA

By early 1991 South Africa will become a producing nation with the commencement of open pit mining operations at Modderfontein, 18 kilometres northeast of Garies in Namaqualand by Pella Refractory Ores. The deposit contains in excess of 2 million tonnes grading 50 to 60 per cent wollastonite, with aspect ratios of more than 20:1 (O'Driscoll, 1990). A wollastonite recovery plant is expected to produce 13 600 tonnes of finished product annually grading more than 90 per cent wollastonite, using electrostatic and high-intensity magnetic separation and flotation.

YUGOSLAVIA

With the mounting interest in wollastonite, exploration for the mineral has been increasing in a number of countries. In Yugoslavia large reserves of high-grade wollastonite located 200 kilometres south of Belgrade have been re-evaluated after being first examined in 1968. The deposits are reported to contain 60 to 70 per cent wollastonite with associated quartz and calcite (Industrial Minerals Magazine, June, 1986, p. 19). Flotation and electromagnetic separation tests have produced concentrates grading up to 90 per cent wollastonite, with less than 1 per cent calcite and up to 0.5 per cent Fe_2O_3.

AUSTRALIA

Of six known wollastonite deposits in Australia, one located in northeastern South Australia has been explored in detail since 1984. Preliminary diamond drilling has indicated a resource of 1 million tonnes grading 40 per cent wollastonite (Industrial Minerals Magazine, July, 1986, p. 19).

GREECE

Metallic & Industrial Minerals Mervior SA is developing a deposit in Kimmeria, near the Bulgarian border, with reserves of 300 000 tonnes averaging 60 to 70 per cent wollastonite (O'Driscoll, 1990). The deposit comprises a series of bands up to 8 metres thick, grading 50 to 80 per cent wollastonite (Power, 1986). Grossular garnet, diopside and specularite are associated with the wollastonite. Initial testing using wet high-intensity magnetic separation and flotation produced a concentrate with 0.3 per cent Fe_2O_3 (Ober *et al.*, 1989). The company is continuing drilling and plans to have completed a pilot plant by April 1991.

CANADA - ONTARIO

Outside British Columbia, exploration for wollastonite in Canada has been largely confined to Ontario. A significant deposit, the Deloro deposit, has been recently explored in Marmora Township, 190 kilometres east of Toronto. Skarn mineralization is developed in silicified marbles near a granitic intrusion in a sequence of Late Precambrian amphibolites, metawackes and carbonate metasediments. Drilling and mapping has defined a wollastonite zone with widths ranging from 1 to 100 metres. Associated minerals include calcite and minor pyrite. Preliminary reserves were estimated at 2 million tonnes grading 40 per cent wollastonite (Kretschmar, 1986). Subsequent work has defined four bodies of low to moderately acicular wollastonite of the following size and grades; 600 000 tonnes at 38 per cent wollastonite, 800 000 tonnes at 29 per cent, and two smaller zones with combined reserves of 500 000 tones grading 28 to 36 per cent (O'Driscoll, 1990).

Flotation and grinding tests produced aspect ratios of 2:1 to 4:1 in the -300 micrometer to +210 micrometre size range and 4:1 to 8:1 in the -210 micrometer to +150 micrometer size range (Andrews, 1988). Seventy per cent of the -325 mesh fraction has an aspect ratio of at least 3:1 (Kretschmar, 1986). Flotation of calcite from wollastonite using sodium oleate after magnetic separation produced concentrates grading 86 to 93 per cent wollastonite with 0.57 to 0.62 per cent Fe_2O_3, while flotation of wollastonite from calcite using Arquad T50 after magnetic separation produced concentrates containing 86 to 89 per cent wollastonite with 0.33 to 0.82 per cent Fe_2O_3 (Andrews, 1988). Preliminary mapping and sampling by Platinova Resources Ltd. in 1986 was followed by mapping, trenching, diamond drilling and beneficiation tests by Black Hawk Mining Inc. and Cominco Ltd. in 1987. Cominco and Platinova are continuing development of the deposit. Feasibility studies are currently (1991) being prepared by Cominco.

A second deposit is currently being evaluated at Mt. Grove, Olden Township in eastern Ontario by Ram Petroleums Ltd. Drilling has indicated a zone 35 metres wide and 75 metres deep containing 2.7 to 2.8 million tonnes grading 35 per cent wollastonite with calcite and minor diopside (O'Driscoll, 1990). Aspect ratios in sampled material have ranged from 10:1 to 12:1. By late 1990 the company had proceeded to the second stage of its drill program.

Another recently explored wollastonite deposit is situated at Prairie Lake, 48 kilometres northeast of Terrace Bay, Ontario. Wollastonite is hosted in a carbonatite complex with a nepheline-rich core. Diamond drilling in 1977 indicated 'tens of millions of tons' of ore averaging 25 per cent wollastonite, with some high-grade material grading up to 75 per cent (George Cross News Letter, Nov. 14, 1983). Diamond drilling was conducted by Nuinsco Resources Ltd. in 1983 to better define high-grade areas.

DEPOSIT DESCRIPTIONS

This section contains the detailed descriptions of nine wollastonite and two tremolite occurrences in British Columbia, five of which have been sampled by the Geological Survey Branch (Table 6). The mineral is known to occur in another 24 locations in association with other economic minerals. These occurrences are described in MINFILE (the Geological Survey Branch's computerized mineral occurrence database of over 10 000 metallic, coal and industrial mineral occurrences) and are listed in Appendix A.

Each occurrence is identified by a name, MINFILE number, and a map number referring to Figure 1. Names are usually derived from nearby physiographic features or population centres. If a second name is used in MINFILE it is given in parentheses following the first.

Each deposit is located by latitude and longitude, and by National Topographic System 1:50 000 map-sheet reference.

The location, geology, sampling data and previous work are described in detail for each occurrence. Bulk samples from occurrences W1a, W2, W3, W5 and T2 (ranging in size from 36.8 kilograms to 58.2 kilograms) were submitted to CANMET, Energy, Mines and Resources Canada for magnetic separation and flotation tests. Brightness and lightness of the raw feed and the various concentrates produced were measured using an Elrepho brightness meter, with barium sulphate as a standard. Chemical analyses for SiO_2, Al_2O_3, Fe_2O_3, MgO and loss on ignition were determined for the raw feed and the concentrates using x-ray fluorescence. Mineralogy and aspect ratios were determined by image analysis. Aspect ratios for the head samples and the wollastonite concentrates are shown in Table 7. Grinding of the raw feed was initially attempted using 1-kilogram charges in a laboratory ceramic-lined jar mill for 30 minutes using 15 millimetre burundum cylinders. The oversize was found to be to coarse for flotation test work, even though generally less than 5 per cent of the ground material was in the +420 micrometre fraction for the various samples. The grinding charge weight and the grinding time were therefore reduced to 500 grams for 20 minutes. A size analysis of the ground products for both procedures is shown in Table 8.

CANMET carried out dry magnetic separation tests with 1-kilogram portions of each sample ground for 30 minutes. The +420-micrometre and -53-micrometre size fractions were removed by wet screening before being processed by a Permroll dry magnetic separator. Visual observations indicated that significant concentrations of magnetic material were achieved only on the sample from occurrence W2. Results are shown in Table 9.

Wet magnetic separation tests were also conducted using three 500-gram charges per sample, each ground separately for 20 minutes, with the +420-micrometre size fraction removed. The middlings and nonmagnetic fractions were combined because of their similar visual appearance. Magnetic separation results are also shown in Table 9.

Flotation tests were carried out using 500-gram samples of raw feed ground for 20 minutes minus the 420-micrometre oversize. Flotation tests were also carried out on the middling-nonmagnetic fraction derived from the wet magnetic separation. The reverse anionic flotation of calcite and quartz was conducted using 300 to 400 grams per tonne of sodium oleate. Because Sample T2 contained only minor wollastonite, 400 grams per tonne Arquad T50 was used for the direct cationic flotation of wollastonite from calcite. Reagent concentration data are shown in Table 10 and results from the flotation tests are shown in Table 11.

The CANMET results are supplemented by analysis of grab samples collected by the Geological Survey Branch from the same five occurrences (W1, W2, W3, W5, T2) and by results of test work on occurrences W1 and W2 provided by several corporations. Ten major oxides and the loss on ignition were determined for the grab samples, using x-ray fluorescence. The mineralogical constituents of these samples were also determined by x-ray diffraction.

TABLE 6. LIST OF OCCURRENCES DESCRIBED IN REPORT

Sample No.	MINFILE No.	Name
W1a	092GNW052	Snake Bay
W1b	092GNW053	Wormy Lake
W2	092F 105	Little Billie Mine
W3	082LSW014	Fintry Point
W4	082ENW050	James Lake
W5	082M 123	Silence Lake
W6	104B 005	Craig River
W7	114P 007	Maid of Erin
T1	104O 034	Rancheria
W8	082FSW341	Rossland
T2	082KNE032	Horsethief Creek

Note: see Figure 1 for sample locations.

TABLE 7. ASPECT RATIO DETERMINATIONS[1]

Head Sample Material

Occurrence	Aspect Ratios	
	Range	Greatest Proportion
W1	1 to 6	2 to 3
W2	2 to 10	2 to 5
W3	2 to 10	2 to 4
W5	1 to 10	2 to 4
T2	1 to 7	2 to 3

Wollastonite Concentrates

Occurrence	Aspect Ratios	
	Range	Greatest Proportion
W1	2 to 6	2 to 5
W2	2 to 10	2 to 4
W3	2 to 10	2 to 4
W5	2 to 8	2 to 4
T2	--	

[1] *Andrews (1989)*

TABLE 8. GRINDING RESULTS[1]
(all values expressed as %)

30-minute grind of 1-kilogram charge

Size μm	Occurrence W1	W2	W3	W5	T2
+420	0.3	2.2	4.3	0.2	2.2
-420+210	0.2	1.5	3.9	0.3	2.7
-210+150	1.6	4.4	7.2	1.4	6.0
-150+100	5.3	6.6	8.1	3.7	7.2
-100+ 75	13.3	13.4	12.4	11.4	11.4
- 75+ 53	20.5	17.9	15.9	21.2	13.9
- 53	58.8	54.0	48.2	61.8	56.6
Total	100.0	100.0	100.0	100.0	100.0

20-minute grind of 0.5-kilogram charge

Size μm	Occurrence W1	W2	W3	W5	T2
+420	0.1	5.4	1.3	0.2	0.5
-420+210	0.2	6.2	1.9	0.1	5.7
-210+150	-	9.7	1.4	0.2	0.8
-150+100	1.2	9.2	9.5	3.0	8.1
-100 + 75	11.2	12.8	22.2	13.7	22.0
- 75 + 53	46.2	13.8	32.3	34.0	40.5
- 53	41.1	42.9	31.4	48.8	22.4
Total	100.0	100.0	100.0	100.0	100.0

[1] *Andrews (1989)*

SECHELT (W1)

SNAKE BAY (MINERAL HILL)

MINFILE No. 092GNW052	NTS 92G/12W
Map No. W1a	Latitude 49°30′56″
	Longitude 123°48′59″

LOCATION

The Snake Bay deposit is located on the Sechelt Peninsula, some 60 kilometres west-northwest of Vancouver and 1.5 kilometres west of Snake Bay on Sechelt Inlet.

GEOLOGY

The deposit is hosted by a roof pendant of calcareous metasediments, possibly of the Upper Triassic Vancouver Group (Quatsino or Karmutsen formations), within Jurassic diorite of the Coast plutonic complex. The following description is summarized from the work of Goldsmith and Logan (1987) and White (1989). The pendant trends northward for approximately 500 metres and varies up to 180 metres in width (Figure 2). The metasediments within it generally strike northeast and dip moderately to steeply west.

The roof pendant is comprised of variably intercalated limestone and banded skarn containing lesser amounts of garnetite, thinly laminated calcium silicate rock and andesitic dike rock. The limestone is commonly, light and dark grey, thinly bedded and fine to medium grained, but locally massive and coarse grained. Discontinuous bedding, in layers 1 to 5 centimetres thick, strikes east to northeast and dips 50° to 80° north. The limestone outcrops mostly in the northern half of the pendant. Siliceous layers containing calcite, garnet, quartz and wollastonite are commonly boudinaged or brecciated.

Variably striped, maroon, green, yellowish white and brown to black skarn containing garnet, diopside, epidote and wollastonite with minor pyrite, chalcopyrite and sphalerite outcrops throughout the pendant. The discontinuous, gently warped banding (remnant bedding ?) of the skarn strikes east to northeast and dips north or south at 50° to 85°. Crosscutting fractures contain wollastonite and calcite. Vitreous, dark purple, green or reddish brown garnetite, containing at least 85 per cent massive garnet with associated diopside, wollastonite, pyrite and calcite-filled fractures outcrops in the northern half of the roof pendant. Sparse outcrops of thinly laminated (1 millimetre to 5 centimetres), fine to medium grained, white to light greenish calcium silicate rock, containing less than 5 per cent garnet, occur sporadically throughout the pendant. Both the pendant and the enclosing diorite are cut by aphanitic, greenish black to black dikes, 0.5 to 3 metres wide, that strike mostly west to southwest and dip 65° to 90° northwest.

Wollastonite is developed near the eastern margin of the roof pendant along most of its length, occurring as:

- layers from 0.05 to 8 centimetres thick, alternating with garnet in banded skarn, where it replaces car-

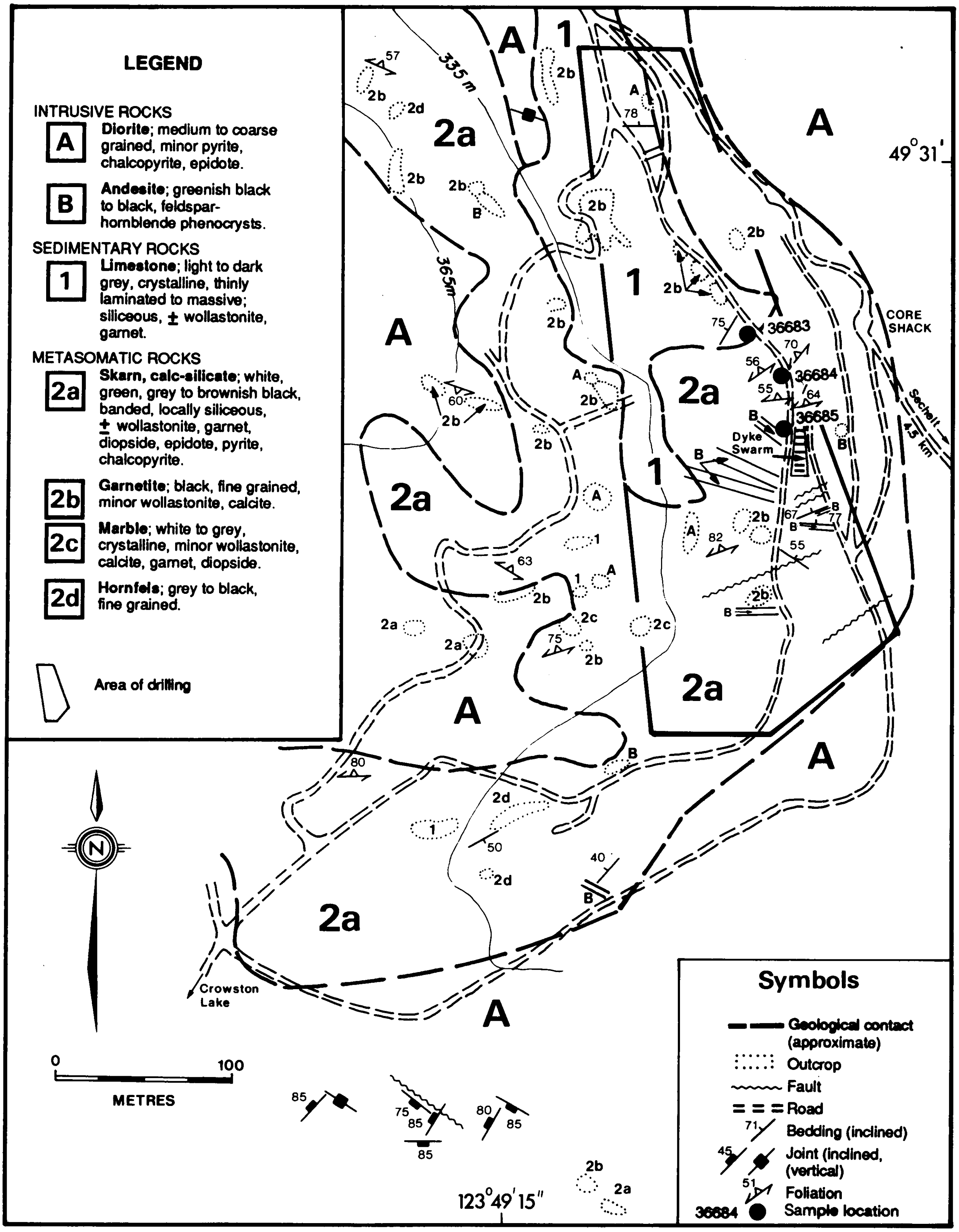

Figure 2. Geology of the Snake Bay roof pendant (W1a) (from White, 1989).

TABLE 9. MAGNETIC SEPARATION TEST RESULTS

Dry Magnetic Separation (Permroll Separator):

Site	Product	Wt %	Analyses				Distribution			
			Al_2O_3	Fe_2O_3	MgO	L.O.I.	Al_2O_3	Fe_2O_3	MgO	L.O.I.
W2	Magnetic	24.9	2.84	15.70	1.36	1.79	54.4	87.0	30.7	11.4
	Non-mag.	75.1	0.79	0.78	1.02	4.62	45.6	13.0	69.3	88.6
	Head	100.0	1.30	4.50	1.11	3.91	100.0	100.0	100.0	100.0

Wet Magnetic Separation (Jones Separator):

Site	Product	Wt %	Analyses				Distribution			
			Al_2O_3	Fe_2O_3	MgO	L.O.I.	Al_2O_3	Fe_2O_3	MgO	L.O.I.
W1	Magnetic	5.7	10.40	6.44	3.86	3.25	43.1	46.9	48.2	1.3
	Non-mag.	94.3	0.83	0.44	0.25	15.40	56.9	53.1	51.8	98.7
	Head	100.0	1.38	0.78	0.46	14.71	100.0	100.0	100.0	100.0
W2	Magnetic	15.6	3.15	16.60	2.69	0.67	26.5	65.5	33.0	1.8
	Non-mag.	84.4	1.61	1.61	1.01	6.74	73.5	34.5	67.0	98.2
	Head	100.0	1.85	3.95	1.27	5.79	100.0	100.0	100.0	100.0
W3	Magnetic	4.6	2.17	4.29	8.95	1.83	12.1	39.2	1.3	39.5
	Non-mag.	95.4	0.76	0.32	0.66	6.62	87.9	60.8	98.7	60.5
	Head	100.0	0.83	0.50	1.04	6.40	100.0	100.0	100.0	100.0
W5	Magnetic	10.3	11.60	7.41	3.83	0.47	52.4	55.2	55.6	0.9
	Non-mag.	89.7	1.21	0.69	0.35	5.81	47.6	44.8	44.4	99.1
	Head	100.0	2.28	1.38	0.71	5.26	100.0	100.0	100.0	100.0
T2	Magnetic	21.9	0.54	2.13	18.0	4.84	44.4	32.3	8.5	25.6
	Non-mag.	78.1	0.19	1.25	14.7	10.23	55.6	67.7	91.5	74.4
	Head	100.0	0.27	1.44	15.42	12.54	100.0	100.0	100.0	100.0

Note: Heads calculated from magnetic and non-magnetic products.

bonate with fibres up to 1 millimetre long. Grades are variable over very short distances (millimetres), from 5 to 75 per cent wollastonite.

- a very fine replacement of silica layers and inclusions in limestone. Grades vary up to 35 per cent wollastonite.
- coarsely crystalline and dense wollastonite and other calcium silicates, excluding garnet in thinly laminated calcium silicate rock. Grades locally vary up to 80 per cent wollastonite.

Wollastonite is also present to a lesser extent in garnetite and in calcite marble developed adjacent to dikes.

Drilling has defined a north-trending zone of wollastonite mineralization extending continuously for up to 150 metres along strike in the northern half of the roof pendant. The zone contains possible and probable reserves of approximately 291 000 tonnes of in situ wollastonite to a depth of 100 metres (Goldsmith and Kallock, 1988, p. 18). Diamond drilling south and southwest of this zone encountered high-grade wollastonite mineralization. Hole 88-12, collared 250 metres southwest of the zone intersected 14.6 metres averaging 85 per cent wollastonite, indicating the zone may continue to the south.

SAMPLING AND BENEFICIATION TESTS

Analyses of grab samples of raw mineralization collected from three sites on the property are given in Table 12.

Samples of raw wollastonite ore were also collected for beneficiation tests by B.C. Research Council and CANMET. These tests suggest a wollastonite concentrate can be produced suitable for most ceramic and filler applications; detailed results are presented in Appendix A. A 50-kilogram sample submitted to the B.C. Research Council was crushed and processed using a Permroll. high-intensity dry magnetic separator (McElroy, 1988). Crushing and sieve analyses of the raw feed revealed that garnet and diopside were not well liberated in particles greater than 0.5 millimetre in diameter (30 mesh). Results of a sieve analysis and a mineralogical examination of the resulting size fractions are presented in Table B1, Appendix B. Whole-rock analyses of the five size fractions shows that higher levels of alumina and iron occur in the coarser fractions. The +18 mesh material contained approximately 2.8 per cent Al_2O_3 and 1.2 per cent Fe_2O_3 compared to approximately 1.4 per cent Al_2O_3 and 0.96 per cent Fe_2O_3 in the -30 mesh fraction.

High-intensity dry magnetic separation of the five size fractions suggests that by crushing to a top size of 5 millimetres (4 mesh), 70 to 75 per cent of the raw feed can be concentrated with an Fe_2O_3 content of approximately 0.8 per cent. Chemical analyses of the magnetic and nonmagnetic components of the five size fractions are presented in Table B2, Appendix B. Because carbonate contents of the raw feed were initially low, the CO_2 contents in the non-magnetic fraction were also low

TABLE 10. REAGENT CONCENTRATION DATA[1]

Test	Site	Flotation Stage	Float Time (min)	pH	Collectors		Frother
					NaOL (g per t)	Arq. T50 (g per t)	D250 (g per t)
2	W3	Rougher	5	7.0	306.7	-	72.5
		Cleaner	3	7.0	51.1	-	-
3	W3	Rougher	5	7.0	407.9	-	23.6
		Cleaner	3	7.0	50.0	-	-
4	T2	Rougher	5	7.0	305.3	-	72.2
		Cleaner	3	7.0	50.5	-	-
5	W2	Rougher	5	7.0	303.1	-	95.5
		Cleaner	3	7.0	50.5	-	23.9
6	W5	Rougher	4	7.0	297.6	-	93.8
		Cleaner	2	7.0	49.6	-	-
7	W1	Rougher	5	7.0	307.6	-	96.9
		Cleaner	3	7.0	51.3	-	-
8	W2	Rougher	4	7.0	303.3	-	119.5
		Cleaner	3	7.0	50.6	-	-
9	T2	Rougher	5	7.0	337.6	-	79.8
		Cleaner	3	7.0	84.4	-	39.9
10	W5	Rougher	3	7.0	295.6	-	69.9
		Cleaner	2	7.0	49.3	-	-
11	W1	Rougher	5	7.0	331.2	-	58.7
		Cleaner	3	7.0	82.8	-	-
12	W1	Rougher	4	7.0	-	163.8	58.1
13	W3	Rougher	9	7.0	166.3	-	49.1
		Cleaner	4	7.0	41.6	-	-
14	T2	Rougher (2)	7	6.95	-	409.8	145.3

[1] *Andrews (1989)*

(Table B3). Brightness of the magnetically concentrated wollastonite (as measured by an Elrepho brightness meter using MgO as a standard) ranged from 80.5 to 82.6 per cent. The acicularity (aspect ratio) of wollastonite particles in various size fractions varies with the use of different grinding techniques with mean aspect ratios ranging from a high of 11.6 to a low of 1.51 (Table B4, Appendix B). Aspect ratios for most of the size fractions ranged from 3.18 to 6.70.

A 58.2 kilogram sample of raw wollastonite ore was submitted to CANMET for magnetic separation and flotation tests; major oxide analyses and mineralogy of the raw ore are presented in Table 12.

After grinding, 91.1 per cent of the 212 to 3.4 micrometre size-fraction was comprised of particles containing at least 70 per cent wollastonite.

Results of the wet, high-intensity magnetic separation of the -420-micrometre size-fraction are shown in Table 9. Fe_2O_3 was reduced to less than 1 per cent, but only slightly less than half of the iron was rejected. Most of the carbonate (98.7% of the L.O.I.) remained with the nonmagnetic fraction.

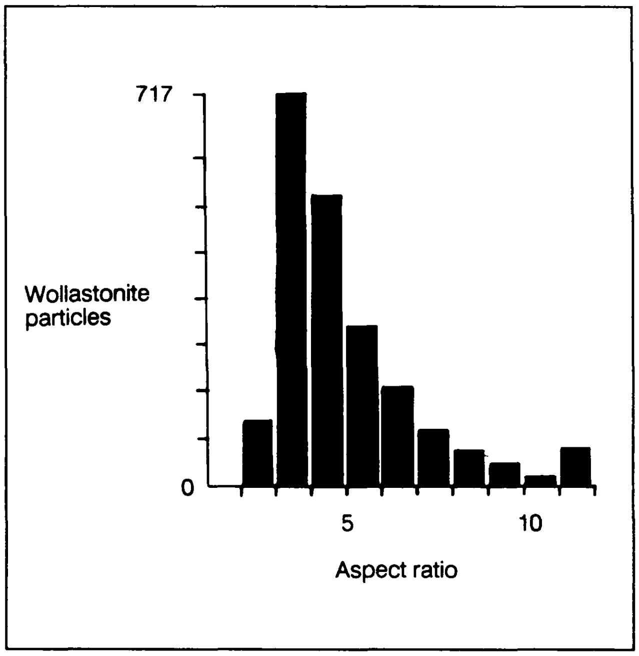

Figure 3. Histogram of number of wollastonite particles with a specific aspect ratio for Snake Bay (from Laustra *et al.*, 1989).

TABLE 11. FLOTATION RESULTS

Reverse flotation of raw feed:

Site	Test	Product	Bright.	Light.	Wt %	Analyses				Distribution			
						Al_2O_3	Fe_2O_3	MgO	L.O.I.	Al_2O_3	Fe_2O_3	MgO	L.O.I.
W1a	7	Final conc.	-	-	28.8	1.24	0.52	0.30	36.49	18.9	17.7	16.8	74.8
		1st cl. tails	-	-	7.8	2.19	0.99	0.33	27.53	9.0	9.1	5.1	15.3
		Rough tails	-	-	63.4	2.15	0.98	0.63	2.20	72.1	73.2	78.1	9.9
		Head (calc.)	-	-	100.0	1.89	0.85	0.51	14.05	100.0	100.0	100.0	100.0
W2	5	Final conc.	-	-	22.6	2.24	9.83	0.27	19.28	45.5	52.7	4.9	79.0
		1st cl. tails	-	-	5.4	1.35	6.85	1.37	6.66	6.6	8.8	6.0	6.5
		Rough tails	-	-	72.0	0.74	2.26	1.53	1.11	47.9	38.5	89.1	14.5
		Head (calc.)	-	-	100.0	1.11	4.22	1.24	5.52	100.0	100.0	100.0	100.0
W3	2	Final conc.	-	-	14.2	1.80	0.55	0.66	26.99	29.7	11.7	9.2	58.0
		1st cl. tails	-	-	13.0	1.80	0.83	1.28	12.52	27.2	16.2	16.2	24.6
		Rough tails	-	-	72.0	0.51	0.66	1.05	1.57	43.1	72.1	74.8	16.2
		Head (calc.)	-	-	100.0	0.86	0.66	1.02	6.60	100.0	100.0	100.0	100.0
W3	3	Final conc.	-	-	11.3	1.27	0.26	0.54	32.16	16.8	5.2	4.1	54.4
		1st cl. tails	-	-	11.6	2.04	0.69	1.21	12.01	27.6	14.4	9.4	20.9
		Rough tails	-	-	77.1	0.62	0.58	1.67	2.14	55.6	80.4	86.5	24.7
		Head (calc.)	-	-	100.0	0.86	0.56	1.49	6.68	100.0	100.0	100.0	100.0
W5	6	Final conc.	-	-	21.4	8.65	2.58	0.14	21.19	63.5	33.0	5.3	91.3
		1st cl. tails	-	-	5.6	6.72	2.38	0.59	3.55	12.9	8.0	5.8	4.0
		Rough tails	-	-	73.0	0.94	1.35	0.69	0.32	23.6	59.0	88.9	4.7
		Head (calc.)	-	-	100.0	2.91	1.67	0.58	4.97	100.0	100.0	100.0	100.0
T2	4	Final conc.	-	-	13.2	0.44	0.45	7.58	37.50	9.0	3.7	6.5	57.0
		1st cl. tails	-	-	8.1	0.57	1.45	15.00	13.82	7.1	7.3	7.8	12.9
		Rough tails	-	-	78.7	0.69	1.81	16.90	3.34	89.0	89.0	85.7	30.1
		Head (calc.)	-	-	100.0	0.65	1.60	15.52	8.70	100.0	100.0	100.0	100.0

Reverse flotation of non-magnetic fraction:

Site	Test	Product	Bright.	Light.	Wt %	Analyses				Distribution			
						Al_2O_3	Fe_2O_3	MgO	L.O.I.	Al_2O_3	Fe_2O_3	MgO	L.O.I.
W1a	11	Final conc.	72.92	87.75	30.6	0.39	0.24	0.16	38.21	7.9	9.7	11.7	86.8
		1st cl. tails	-	-	7.9	2.00	0.75	0.51	19.96	10.5	7.9	9.6	11.8
		Rough tails	71.84	87.38	55.8	1.04	0.48	0.23	0.03	35.5	38.5	30.5	0.1
		Head (calc.)	-	-	94.3	0.91	0.43	0.23	14.08	53.1	56.9	51.8	98.7
W2	8	Final conc.	63.05	80.94	15.4	0.78	3.52	0.21	28.71	13.0	13.8	3.5	78.5
		1st cl. tails	-	-	11.8	2.25	2.95	1.51	5.51	28.6	8.8	19.2	11.5
		Rough tails	73.82	87.69	57.2	0.52	0.82	0.72	0.81	31.9	11.9	44.3	8.2
		Head (calc.)	-	-	84.4	0.81	1.61	0.74	6.58	73.5	34.5	67.0	98.2
W3	13	Final conc.	71.61	87.85	19.2	1.72	0.29	0.50	24.68	34.6	10.2	8.3	73.4
		1st cl. tails	-	-	11.4	1.03	0.47	0.88	6.72	12.3	9.9	8.7	10.9
		Rough tails	76.84	89.52	64.8	0.78	0.34	0.77	1.43	53.0	40.7	43.5	14.4
		Head (calc.)	-	-	95.4	1.00	0.35	0.73	6.47	87.9	60.8	60.5	98.7
W5	10	Final conc.	72.27	88.29	16.2	5.37	1.23	0.36	27.93	36.8	15.1	9.1	90.9
		1st cl. tails	-	-	5.1	3.67	1.34	0.52	3.05	7.9	5.2	4.2	3.1
		Rough tails	81.20	91.37	68.4	0.10	0.47	0.29	0.37	2.9	24.5	31.1	5.1
		Head (calc.)	-	-	89.7	1.25	0.66	0.32	5.48	47.6	44.8	44.4	99.1
T2	9	Final conc.	78.07	90.16	14.8	0.10	0.49	8.05	34.89	3.7	4.8	7.5	60.6
		1st cl. tails	-	-	5.0	0.35	1.63	16.80	8.47	4.3	5.3	5.3	5.0
		Rough tails	74.50	88.11	58.3	0.33	1.50	16.70	3.78	47.6	57.6	61.6	25.9
		Head (calc.)	-	-	78.1	0.29	1.32	15.07	9.98	55.6	67.7	74.4	91.5

Direct Flotation:

Site	Test	Product	Bright.	Light.	Wt%	Analysis Distribution							
						Al_2O_3	Fe_2O_3	MgO	L.O.I.	Al_2O_3	Fe_2O_3	MgO	L.O.I.
W1a	12	Final conc.	-	-	6.3	1.47	0.76	0.49	16.89	6.9	6.1	6.2	7.3
		Rough tails	-	-	88.0	0.89	0.42	0.26	15.14	50.0	47.0	45.6	91.4
		Head (calc.)	-	-	94.3	0.94	0.44	0.28	15.26	56.9	53.1	51.8	98.7
T2	14	Rough float 1	-	-	5.7	0.58	1.57	16.40	9.36	3.9	5.9	5.9	6.7
		Rough float 2	-	-	8.5	0.75	1.56	15.70	6.35	7.6	8.8	8.5	6.8
		Rough tails	-	-	85.8	0.87	1.50	15.70	8.04	88.5	85.3	85.6	86.5
		Head (calc.)	-	-	100.0	0.84	1.51	15.74	7.98	100.0	100.0	100.0	100.0

TABLE 12. MAJOR OXIDE XRF ANALYSES SAMPLES FROM SNAKE BAY PROSPECT

	36683	36684	36685	CANMET[1]
SiO_2	37.31	46.55	13.95	35.5
Al_2O_3	12.91	1.10	1.94	19.6
Fe_2O_3	9.24	1.14	1.45	0.90
CaO	32.54	45.66	48.67	
$CaCO_3$				32.7
MgO	1.82	0.45	0.75	0.49
Na_2O	0.16	0.13	0.14	
K_2O	0.06	0.04	0.03	
TiO_2	2.76	0.08	0.04	
P_2O_5	0.52	0.25	0.62	
MnO	0.55	0.07	0.16	
BaO	<0.01	<0.01	0.01	
L.O.I.	0.26	3.97	29.02	15.09
Brightness				69.67
Lightness				85.99
Total	98.14	99.44	96.77	

Mineralogy (by XRD)

36683	Mixture of grossular and andradite, minor diopside, trace of quartz and calcite
36684	Wollastonite, calcite, quartz, grossular, feldspar (?)
36382	Calcite, wollastonite, trace of pyrite, diopside (?)

Mineralogy (by image analysis)[1]

CANMET	Wollastonite	61.4
	Quartz + minor feldspar	7.1
	Calcite + mafics + minor dolomite	0.4
	Ferruginous dolomite	12.3
	$CaSiO_3$ - lower Ca phase	4.9
	Iron oxides and sulphides	1.2
	Andradite	12.7
	Total	100.0

[1] *Andrews (1989)*

Flotation tests were carried out on the -420-micrometre size-fraction of the raw feed and of the nonmagnetic fraction. Results are shown in Table 12. Losses on ignition were substantially reduced in both the raw feed and the nonmagnetic fraction, while the already low iron content of the nonmagnetic fraction remained essentially the same after flotation. The floated nonmagnetic concentrate consisted of 88.8 per cent wollastonite, 6.2 per cent silicates and 5.0 per cent garnet by weight (Lastra *et al.*, 1989, p. 29). Aspect ratios for the raw wollastonite and wollastonite concentrated by magnetic separation and flotation are shown in Table 7. No significant increase in aspect ratios is apparent between the raw feed and concentrate. Figure 3 shows the distribution of aspect ratios of the floated, nonmagnetic concentrate.

These two bulk-sample tests indicate that wollastonite with low to moderate aspect ratios can be produced with Fe_2O_3 contents of less than 1 per cent. The unusually low carbonate content of the sample tested by B.C. Research Council is probably not typical of the whole deposit and flotation in addition to magnetic separation will probably be required to produce a marketable concentrate from most of the deposit.

PREVIOUS WORK

In 1987 and 1988 Tri-Sil Minerals Ltd. of Sechelt, British Columbia carried out geological mapping and 1720 metres of diamond drilling in 24 holes. The company has recently completed some stripping and is reported to be currently (1990) constructing a pilot plant (R. Riepe, 1990, personal communication).

WORMY LAKE

NTS 92G/12W
MINFILE No. 092GNW053 — Latitude 49°32′06″
Map No. W1b — Longitude 123°50′12″

LOCATION

The Wormy Lake wollastonite occurrence is located on the Sechelt Peninsula, 3.5 kilometres northwest of Snake Bay on Sechelt Inlet and approximately 2 kilometres northwest of the Snake Bay deposit (W1a).

GEOLOGY

The occurrence is hosted by calcareous metasediments in the northern part of the same roof pendant as the previously described Snake Bay deposit. Bedding in this locality strikes west to northwest and dips 30° to 81° north.

In the vicinity of Wormy Lake the roof pendant consists mostly of banded, white, green and grey to brownish black garnet-diopside-epidote skarn with minor pyrite and chalcopyrite (Figure 4). Black or brown, fine-grained garnetite and light to dark grey, thinly laminated to massive limestone occur to a lesser extent. Wollastonite is contained primarily in the banded skarn; only minor amounts are contained in the limestone and garnetite. Wollastonite bearing rocks outcrop intermittently over a distance of 600 metres in a zone trending east-northeast from the south end of Wormy Lake (White, 1989).

PREVIOUS WORK

Tri-Sil Minerals Inc. of Sechelt, British Columbia has carried out surveying, stripping and road construction in 1989.

TEXADA ISLAND

LITTLE BILLIE MINE

NTS 92F/15E
MINFILE No. 092F 105 — Latitude 49°45′29″
Map No. W2 — Longitude 124°32′44″

LOCATION

The Little Billie mine is located just outside the town of Vananda on the northeast coast of Texada Island, 120 kilometres northwest of Vancouver. The shaft collar is situated some 250 metres inland on Lots 521 and 522, 0.5 kilometre east-southeast of Vananda Cove.

GEOLOGY

The deposit occurs within a northwest-trending belt of Upper Triassic Quatsino limestone 13 kilometres long that has been intruded by stocks of the Middle Jurassic Island plutonic suite (Ettlinger and Ray, 1989; Webster and Ray, 1990a, b). The belt is flanked to the southwest and northeast by underlying basaltic volcanics of the Upper Triassic Karmutsen Formation.

Limestone, quartz diorite, greenstone and skarn are the four principal lithologies exposed in the Little Billie mine (Figure 5). The limestone is grey to white, fine to coarse grained, and usually low in magnesia (MgO). A few mottled and black beds of magnesian limestone up to 0.6 metre thick are exposed in the underground workings. Bedding in two limestone outcrops lying east and west of the collar shaft dips gently southwest. However, more continuous exposures in underground workings suggest the unit is gently folded into a north-trending anticline-syncline pair. A stock of medium-grained, light grey quartz diorite exposed for 700 metres along the coast intrudes the limestone north and east of the mine. The contact with the limestone generally strikes northwest and dips moderately southwest towards the mine. However, near the shaft an embayment of quartz diorite extends southwest from the stock, with contacts dipping vertically to steeply southeast. The embayment contains several fault bounded blocks of limestone and skarn. At the mine site several north trending quartz diorite dikes up to 30 metres wide extend vertically upward from the main quartz diorite mass. The limestone, quartz diorite and skarn are cut by two sets of greenstone dikes. Older, dark green northeast-trending dikes intrude limestone, while a younger set of easterly striking, hornblende-porphyritic dikes cut limestone, quartz diorite and skarn.

Three types of skarn mineralization are present in the Little Billie mine (Stevenson, 1945). Light tan to cinnamon-coloured grossularite garnet, with diopside, wollastonite and clusters of quartz, epidote and feldspar and minor molybdenite form zones of endoskarn adjacent to and within the quartz diorite. Light olive-green andradite garnet with wollastonite, diopside, bornite, chalcopyrite, gold and silver form zones of tough, dense exoskarn near the quartz diorite, where limestone is cut by the older greenstone dikes. Zones of coarse-grained, crumbly exoskarn containing dark brown to brown and green

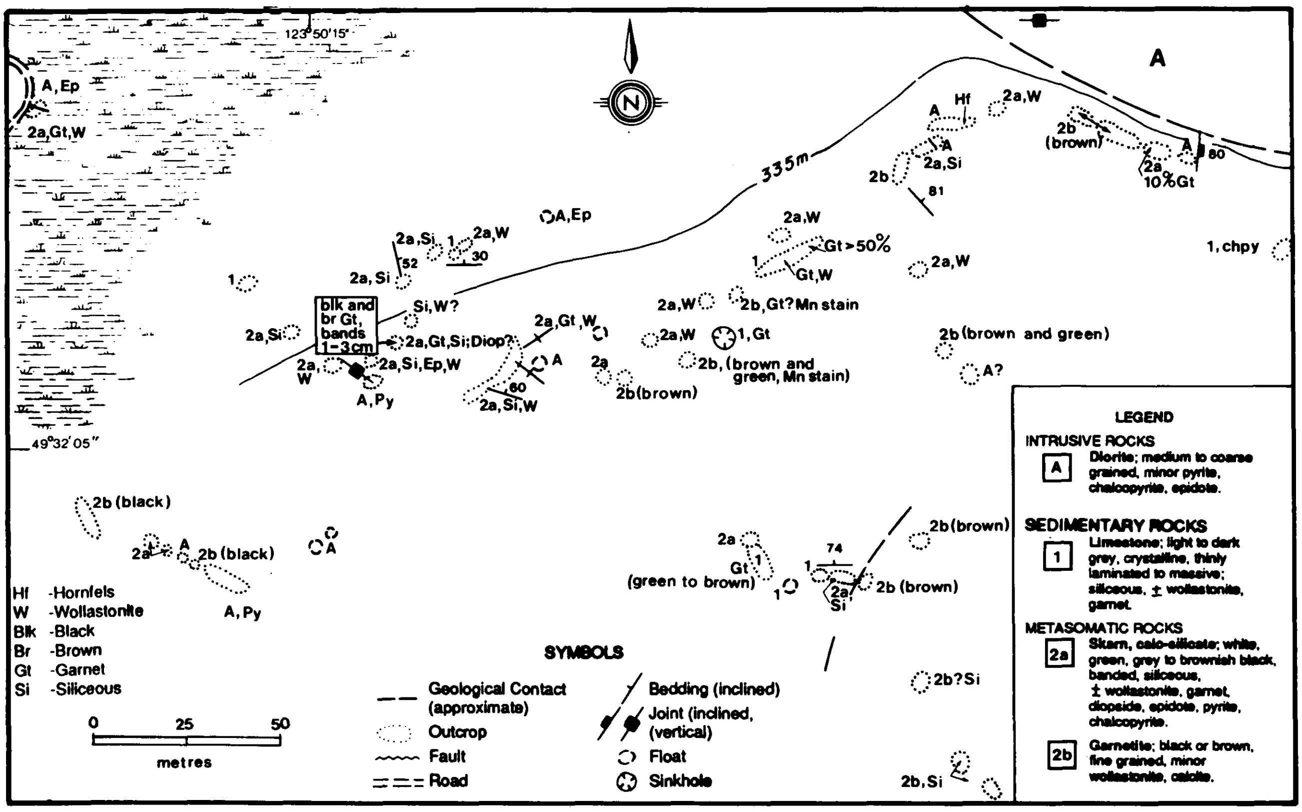

Figure 4. Geology of the Wormy Lake skarn (W1b) (from White, 1989).

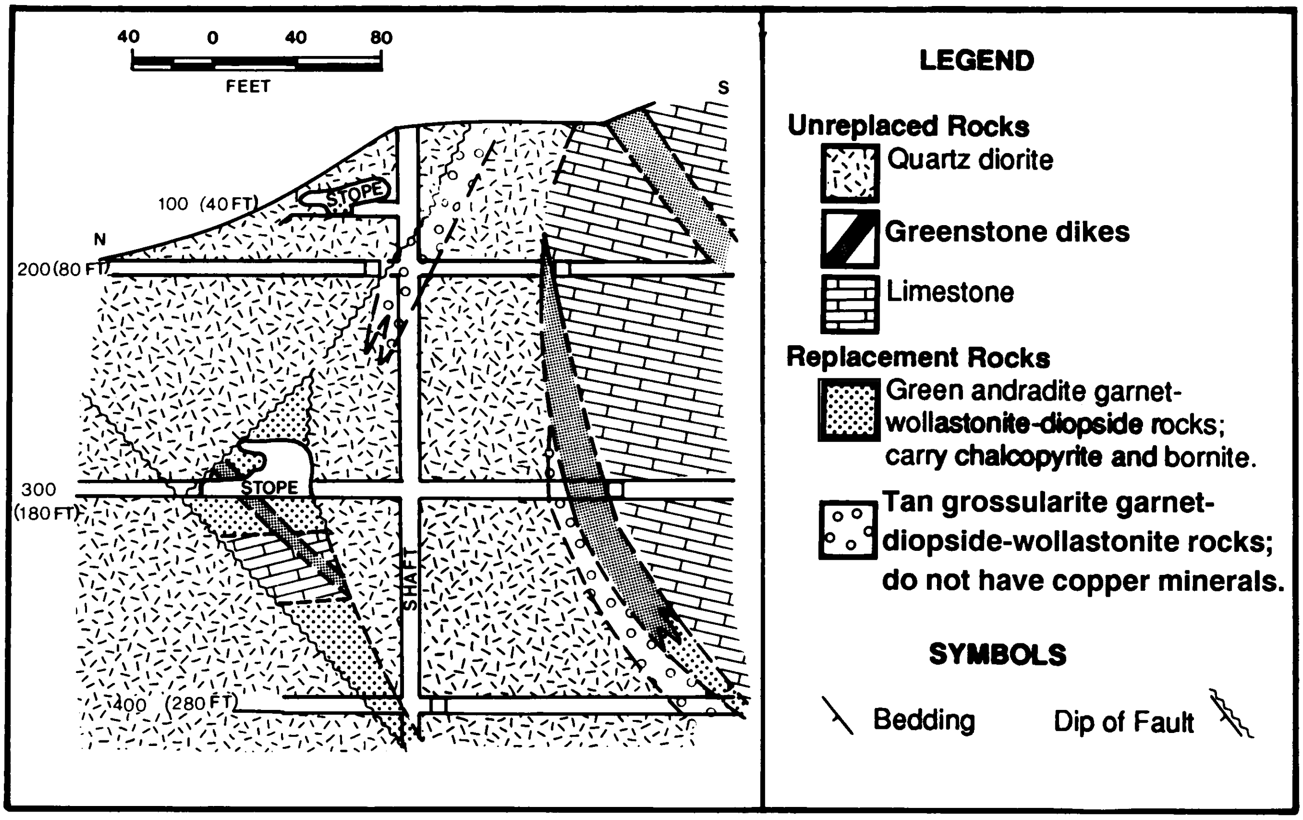

Figure 5. Typical north-south cross-section of the Little Billie mine (W2) (from Stevenson, 1945).

banded andradite garnet with magnetite, disseminated chalcopyrite and minor bornite also occur near the quartz diorite where limestone is intruded by dikes.

Wollastonite is confined to the first two skarn types. Of the two types, the green exoskarn appears to be more common and richer in wollastonite, which commonly occurs, together with green andradite, in layers from 0.6 to 5 centimetres thick.

The skarn alteration tends to be confined to steeply plunging tabular to pipe-like bodies along or near contacts between limestone and quartz diorite or limestone and greenstone. Typical dimensions of these bodies range from 3 x 16 x 24 metres to 4 x 25 x 150 metres. It is estimated that some 100 000 tonnes of andradite-wollastonite-diopside exoskarn are contained in such zones in the underground workings (White, 1989). One zone of precious metal mineralization recently outlined by diamond drilling is reported to be hosted by a zone of wollastonite-rich skarn containing several hundred thousand tonnes in reserves. Recent drilling has cut intercepts of up to 24 metres comprised essentially of wollastonite (S. Beale, 1990, personal communication).

SAMPLING AND BENEFICIATION TESTS

Analyses of two grab samples of wollastonite-bearing skarn collected from waste dumps at the mine site by Vananda Gold Ltd. (Jacobi, 1987) and by the Geological Survey Branch (Sample 36371) are presented in Table 13.

The VGL sample displayed high brightness, even on heating to approximately 1100°C (H. Jacobi, 1990, personal communication).

A 38.7 kilogram sample of massive, white wollastonite-rich skarn was sent to CANMET for processing by wet and dry magnetic separation and reverse flotation (Andrews, 1989; Lastra *et al.*, 1989). Major oxide analyses of the raw sample are presented in Table 13. Particles of the ground raw feed containing at least 70 per cent wollastonite comprised 95.7 per cent by volume of the 212 to 3.4 micrometre size fraction.

Dry and wet high-intensity magnetic separation results are shown in Table 9. Dry magnetic separation sufficiently concentrated the magnetic minerals to reduce the Fe_2O_3 content below 1 per cent. However, with wet magnetic separation the Fe_2O_3 content remained above 1 per cent even though 65.5 per cent of the total Fe_2O_3 was rejected.

Reverse flotation results are shown in Table 11. The Fe_2O_3 content and ignition loss remained above 1 per cent after flotation without magnetic separation, while Fe_2O_3 and ignition loss were reduced to less than 1 per cent with both flotation and magnetic separation. The final concentrate contained 77.5 per cent wollastonite, 4.7

TABLE 13. MAJOR OXIDE XRF ANALYSES OF GRAB SAMPLES FROM LITTLE BILLIE MINE

	VGL Sample[1]	GSB Sample	CANMET[2]
SiO_2	44.45	46.79	44.5
Al_2O_3	0.01	0.64	1.10
Fe_2O_3	1.81	3.88	4.21
CaO	37.09	42.16	
$CaCO_3$	-	-	14.3
MgO	2.28	1.29	1.20
Na_2O	0.01	0.14	
K_2O	0.03	0.07	
TiO_2	0.05	<0.01	
P_2O_5	0.07	0.07	
MnO	0.56	0.42	
BaO	-	0.06	
Ba	0.01	-	
L.O.I.	12.84	1.82	5.72
Brightness	-	-	62.78
Lightness	-	-	80.30
Total	99.22	97.35	

Mineralogy (by XRD)

VGL Sample[1]	Wollastonite (37.68%), calcite (29.18%), quartz (18.12%), diopside (11.68%), miscellaneous (0.18%)
GSB Sample	Wollastonite, diopside, calcite, hydrogrossular, goethite

Mineralogy (by image analysis)[2]

CANMET	Wollastonite	64.8
	Quartz + minor feldspar	10.1
	Calcite + mafics + minor dolomite	4.5
	Ferruginous dolomite	2.2
	$CaSiO_3$ - lower Ca phase	0.5
	Iron oxides and sulphides	0.7
	Andradite	17.2

[1] *Jacobi (1987)*
[2] *Andrews (1989)*

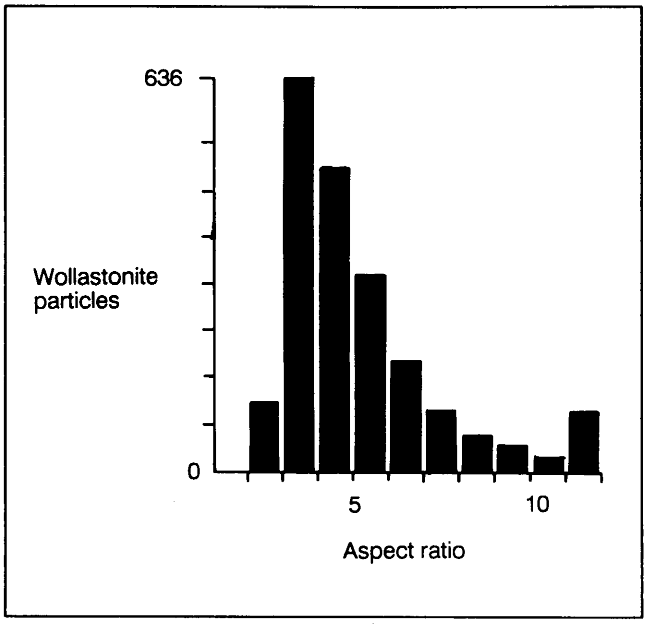

Figure 6. Histogram of number of wollastonite particles with a specific aspect ratio for Little Billie mine (from Laustra et *al.*, 1989).

per cent garnet and 17.8 per cent other silicates by weight (Lastra *et al.*, 1989, p. 29).

Reverse flotation in combination with wet magnetic separation produced a lower grade wollastonite concentrate of low to moderate acicularity. Wollastonite content was increased from 64.8 per cent in the raw feed to 77.5 per cent in the floated nonmagnetic concentrate. This increase may not be sufficient for most potential consumers of the product. Several stages of magnetic separation and/or flotation may be required to produce an acceptable concentrate. Brightness was increased from 62.78 to 73.82 per cent, while lightness was increased from 80.30 to 87.69 per cent. Aspect ratios of the raw feed and the final concentrate remained essentially the same as shown in Table 7. The distribution of aspect ratios for the floated nonmagnetic fraction is shown on Figure 6.

PREVIOUS WORK

The Little Billie Mine was operated periodically between 1896 and 1916, and continuously between 1948 and 1952, producing 363 168 grams of gold, 1198 kilograms of silver and 819 098 kilograms of copper from 63 711 tonnes of ore. Since 1986 Vananda Gold Ltd. and Freeport-McMoRan Gold Company have been exploring the property largely for precious metal bearing skarn zones. However, some test work has been carried out on the wollastonite by Cominco Engineering Services Ltd. on behalf of Vananda Gold.

OKANAGAN

FINTRY POINT

FINTRY POINT	**NTS 82L/04E**
MINFILE No. 082LSW014	Latitude 50°08'28"
Map No. W3	Longitude 119°34'07"

LOCATION

The Fintry Point occurrence is located 5.5 kilometres west of Fintry Point (Shorts Point) on Okanagan Lake, 25 kilometres southwest of Vernon and 35 kilometres north-northwest of Kelowna on Lots 5046, 5047 and 5049, just northeast of Shorts Creek.

GEOLOGY

The occurrence is hosted by a band of Harper Ranch Group sediments trending southwest from Ewing for 7 kilometres and varying from 0.8 to 2.5 kilometres in exposed width. These sediments were initially mapped as Cache Creek Group (Jones 1959) and subsequently assigned to the Thompson assemblage (Okulitch and Campbell, 1979) before being included with the Devonian to Triassic Harper Ranch Group (Meyers and Taylor, 1989). These sediments are flanked to the southeast by an intrusion of the Middle Jurassic Nelson plutonic suite and overlain to the west by up to 300 metres of Miocene plateau basalt.

Limestone and granite are the two main rock types outcropping in the vicinity of the deposit (White, 1989). The limestone is white to grey to black and fine to medium grained. Remnant bedding strikes northerly and dips east or west at 60° and 90°. Interbedded black argillite and fine-grained sandstone with a few lenses of conglomerate are exposed at lower elevations. The limestone is intruded on the east by a large body of fresh-looking, medium to coarse-grained granite and granodiorite. The intrusive contact strikes northeast and dips steeply southeast (Hallisey, 1963). A few sills of plagioclase porphyritic basalt have intruded the sediments along bedding planes.

Most of the wollastonite mineralization is confined to a zone 30 to 80 metres wide trending north-northeast for 850 metres, with a vertical extent of 500 metres (Figure 7). The zone lies 30 to 100 metres west of the granodiorite over most of its length, roughly paralleling the limestone-intrusive contact. The deposit is estimated to contain 20 to 30 per cent wollastonite, 60 to 70 per cent calcite and minor amounts of diopside and quartz (Hallisey, 1963).

A second zone of brown, fine-grained garnet-quartz skarn 0.6 to 2.0 metres wide and containing 65 per cent grossular garnet, 25 per cent quartz and 10 per cent diopside is developed along the limestone-intrusive contact. The diopside is largely altered to tremolite and actinolite (Hallisey, 1963).

Wollastonite commonly occurs as veins along bedding planes and crosscutting fractures and as massive, irregular lenses and random clumps in grey to black limestone close to the granodiorite and also as narrow alteration envelopes adjacent to quartz veinlets crosscutting bedding (White, 1989; Hallisey, 1963). Contacts between the wollastonite and the enclosing limestone host

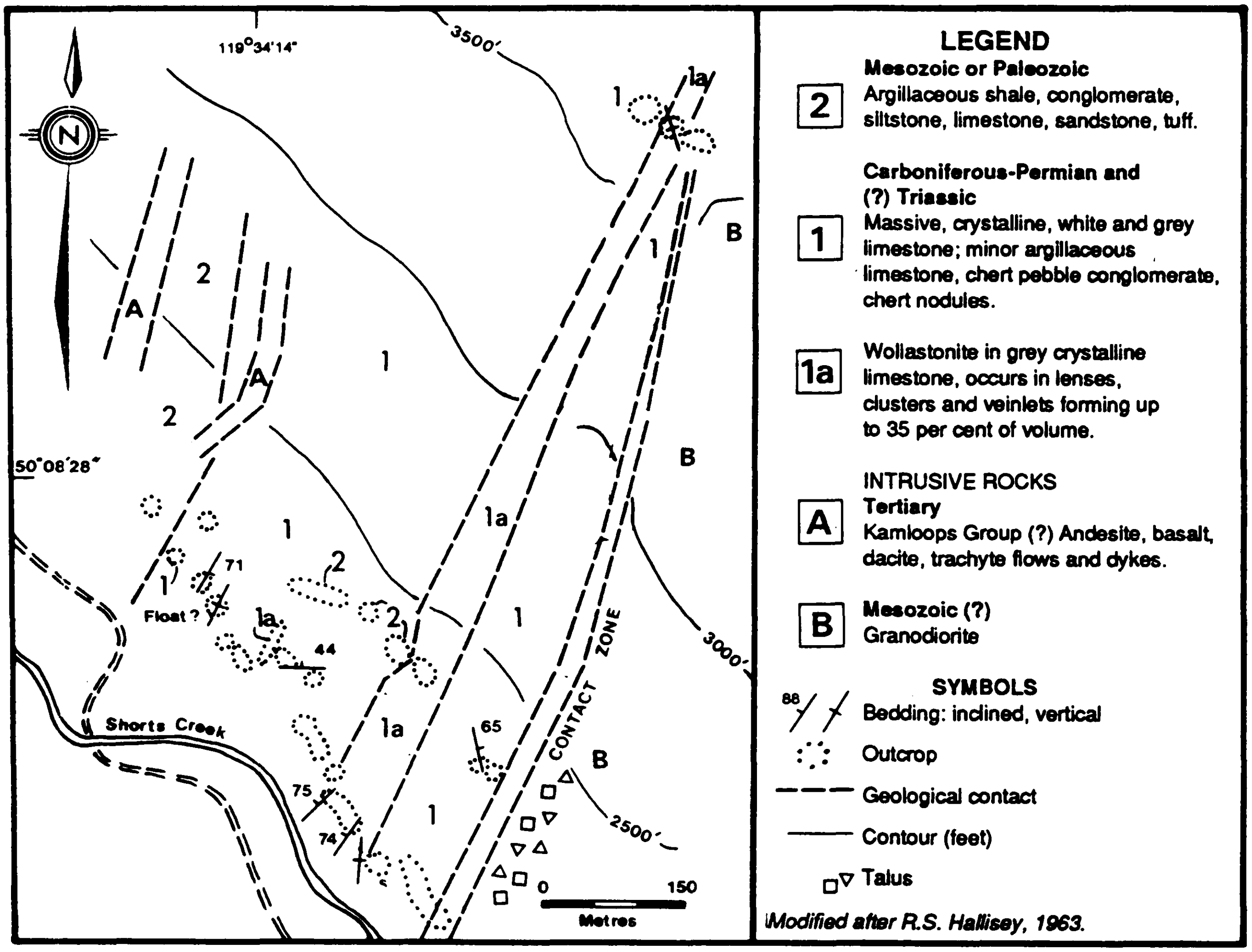

Figure 7. Geology of the Fintry Point wollastonite skarn (from White, 1989).

are sharp. It forms tough, massive aggregates of radial fibres, with fibre lengths of up to 12 centimetres, averaging 2 to 3 centimetres. Thin sections display fibrous aggregates of wollastonite randomly speckled with fine-grained diopside crystals. Minor amounts of diopside and fine-grained calcite, and minor crosscutting veinlets of prehnite, calcite and quartz are also present. Wollastonite mineralization appears to be the result of the movement of siliceous hydrothermal solutions along bedding planes, shear zones and faults. This hydrothermal metasomatism of the limestone is suggested by the lenticular and vein-like nature of the wollastonite bodies and the presence of quartz veins and lenses that typically display zones of wollastonite along their margins in the limestone.

TABLE 14. MAJOR OXIDE XRF ANALYSES OF SAMPLES FROM FINTRY POINT PROSPECT

	36376	36377	36382	CANMET[1]
SiO_2	41.33	58.13	43.96	52.0
Al_2O_3	0.09	3.09	0.22	0.93
Fe_2O_3	0.21	1.57	0.40	0.57
CaO	43.94	27.50	44.09	
$CaCO_3$	-	-	-	16.4
MgO	0.39	1.46	0.44	1.01
Na_2O	0.12	0.31	0.14	
K_2O	0.05	1.07	0.11	
TiO_2	<0.01	0.15	<0.01	
P_2O_5	<0.01	0.79	0.11	
MnO	<0.01	0.02	0.01	
BaO	0.01	0.01	0.02	
L.O.I.	10.56	5.85	9.21	6.57
Brightness				73.58
Lightness				88.16
Total	96.73	99.95	98.72	

Mineralogy (by XRD)

36376	Wollastonite, calcite
36377	Quartz, wollastonite, calcite
36382	Wollastonite, calcite

Mineralogy (by image analysis)[1]

CANMET	Wollastonite	44.4
	Quartz + minor feldspar	41.6
	Calcite + mafics + minor dolomite	10.8
	Ferruginous dolomite	2.0
	$CaSiO_3$ - lower Ca phase	0.7
	Iron oxides and sulphides	0.4
	Andradite	0.1

[1] *Andrews (1989)*

SAMPLING AND BENEFICIATION TESTS

Analyses of three selected grab samples collected by the Geological Survey Branch in 1988 are presented in Table 14, together with analyses of a 50.2 kilogram sample submitted to CANMET for magnetic separation and flotation tests (Andrews, 1989, Lastra, *et al.*, 1989).

Results for the wet magnetic separation of the -420 micrometre fraction are shown in Table 9. The already low Fe_2O_3 content (0.50 per cent) was reduced somewhat with the rejection of 39.2 per cent of Fe_2O_3.

Reverse flotation results for the raw feed and the nonmagnetic component of the -420-micrometre size-fraction are shown in Table 11. Two separate flotation tests on the raw feed failed to produce a concentrate with less than 1 per cent ignition loss, even though at least 75 per cent of the material lost on ignition was rejected in both cases. Reverse flotation of the nonmagnetic fraction produced similar results. The final concentrate (floated nonmagnetic fraction) contained 70.8 per cent wollastonite, 4.7 per cent garnet and 24.5 per cent other silicates (Lastra *et al.*, 1989, p. 29).

Reverse flotation and wet high-intensity magnetic separation produced a lower grade wollastonite concentrate with low to moderate acicularity and excessive ignition loss. The grade was increased from 44.4 per cent in the raw feed to 70.8 per cent in the final concentrate, but this would not be sufficient to meet most industry requirements. The lower grade is the result of the large amount of quartz present. The addition of calcium ions followed by the further addition of sodium oleate should reduce the level of quartz and therefore increase the concentrate

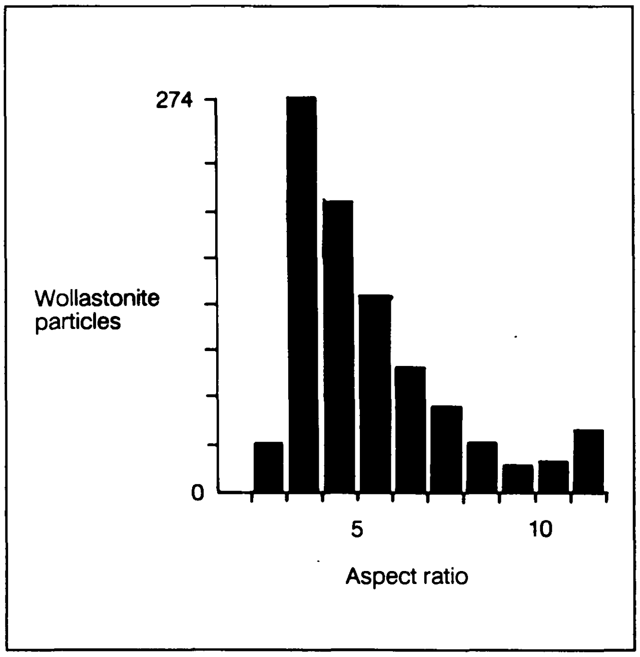

Figure 8. Histogram of number of wollastonite particles with a specific aspect ratio for Fintry Point (from Laustra *et al.*, 1989).

grade (Andrews, 1989). Aspect ratios of the raw feed and the final concentrate are shown in Table 7, they are essentially the same, while brightness and lightness increased slightly in the concentrate. Distribution of aspect ratios is illustrated by Figure 8.

PREVIOUS WORK

Previous exploration in this area west of Okanagan Lake has concentrated on precious metal bearing quartz veins. One quartz vein (White Elephant mine), lying 1 kilometre northwest of the wollastonite zone, was mined sporadically in the 1920s and 1950s for gold and silver. Exploration of the wollastonite zone is limited to some mapping and sampling by R. Hallisey (1963) and G. White (1989).

JAMES LAKE

MINFILE No. 082ENW050	NTS 82E/14W
Map No. W4	Latitude 49°57'27"
	Longitude 119°15'14"

LOCATION

This occurrence is situated 300 metres west of James Lake, some 18 kilometres northeast of Kelowna.

GEOLOGY

Flat-lying banded calcsilicate skarn is exposed for 340 metres along a northwest-trending road-cut (Z.D. Hora, 1989, personal communication; Yorke-Hardy, 1988). The deposit is overlain and underlain by gneissic rocks of the Okanagan gneiss complex.The skarn is comprised mostly of red, brown and green garnet, occasionally with fine-grained wollastonite and diopside.

Pyrite and chalcopyrite are sometimes evident within the skarn; the enclosing gneiss is pyritic in a few instances. Calcsilicate skarn also outcrops over a distance of 140 metres along a road-cut 680 metres southwest of the main exposure.

PREVIOUS WORK

This occurrence was sampled for precious and base metals in 1988 by prospectors W.D. Yorke-Hardy, R.G. Irving and J.H. Wright of Kelowna. It has yet to be evaluated for its wollastonite potential.

NORTH THOMPSON

SILENCE LAKE MINE

MINFILE No. 082M 123	NTS 82M/13E
Map No. W5	Latitude 51°50'00"
	Longitude 119°41'30"

LOCATION

The Silence Lake mine worked for tungsten during the period 1981-1982 is located 4 kilometres north of Silence Lake, 32 kilometres northeast of Clearwater. The open pit lies on the west side of Maxwell Creek, 3.5 kilometres northeast of its confluence with the Raft River.

GEOLOGY

The following description is summarized from White, (1989). The area immediately north of Silence Lake is underlain by northeastward-trending roof pendants in a granitic stock probably related to the Cretaceous Raft batholith, 14 kilometres to the south. The stock intrudes northwest-dipping metasediments of the Shuswap metamorphic complex (Monashee gneiss), that have been isoclinally folded and regionally metamorphosed to amphibolite facies.

The pendants are locally comprised of calcareous to noncalcareous biotite schist, biotite quartzite and skarn (Figure 9). The schist is medium grained, brown to grey in colour and comprised of 40 to 50 per cent quartz, 20 per cent feldspar and 20 per cent biotite. A well-developed foliation strikes northeast. The schistose rocks are commonly intercalated with massive, grey, medium-grained biotite quartzite. In the vicinity of the open pit two northeast-trending metasedimentary screens, the 'upper band' to the west and the 'lower band' to the east, are engulfed in medium-grained, equigranular, orange-brown-weathering biotite quartz monzonite and minor leucocratic quartz monzonite, granodiorite, quartz diorite and pegmatite. The intrusive lithologies outcrop more extensively south of the skarn zones.

Three types of skarn mineralization are developed in the metasediments (White, 1989; Cook, 1972; Dickinson, 1980; Falconer, 1986). Widespread siliceous garnet skarn forms massive, rough-surfaced, brown outcrops with indistinct layering in both upper and lower bands. It is comprised of coarse to very coarse-grained garnet (andradite-grossularite), diopside, idocrase, scheelite and quartz. Garnet occurs as clusters of medium-grained euhedral crystals or as coarse-grained subhedral crystals. This mineral assemblage appears to replace wollastonite skarn (Falconer, 1986). This skarn is host to economic scheelite mineralization in the 'upper band'. Pyroxene skarn, comprised of fine to medium-grained, iron and manganese-rich grossularite garnet, actinolite, idocrase, diopside, pyrrhotite and scheelite is confined to the 'lower band', where it also hosts economic scheelite mineralization. The rock is green to grey to black and massive or fine to medium banded.

A third skarn assemblage comprises medium to coarse-grained wollastonite, grossularite, diopside and calcite that forms chalky white, rough-surfaced outcrops, mostly in the 'upper band'. Red-brown garnet occurs as medium-grained, equigranular crystals clustered together in masses 1 to 5 centimetres in diameter that comprise 5 to 30 per cent of the rock. Massive, white wollastonite forms radiating aggregates growing outward from the garnet clusters with fibres up to 3 centimetres long in bands up to a metre in width. Calcite occurs in

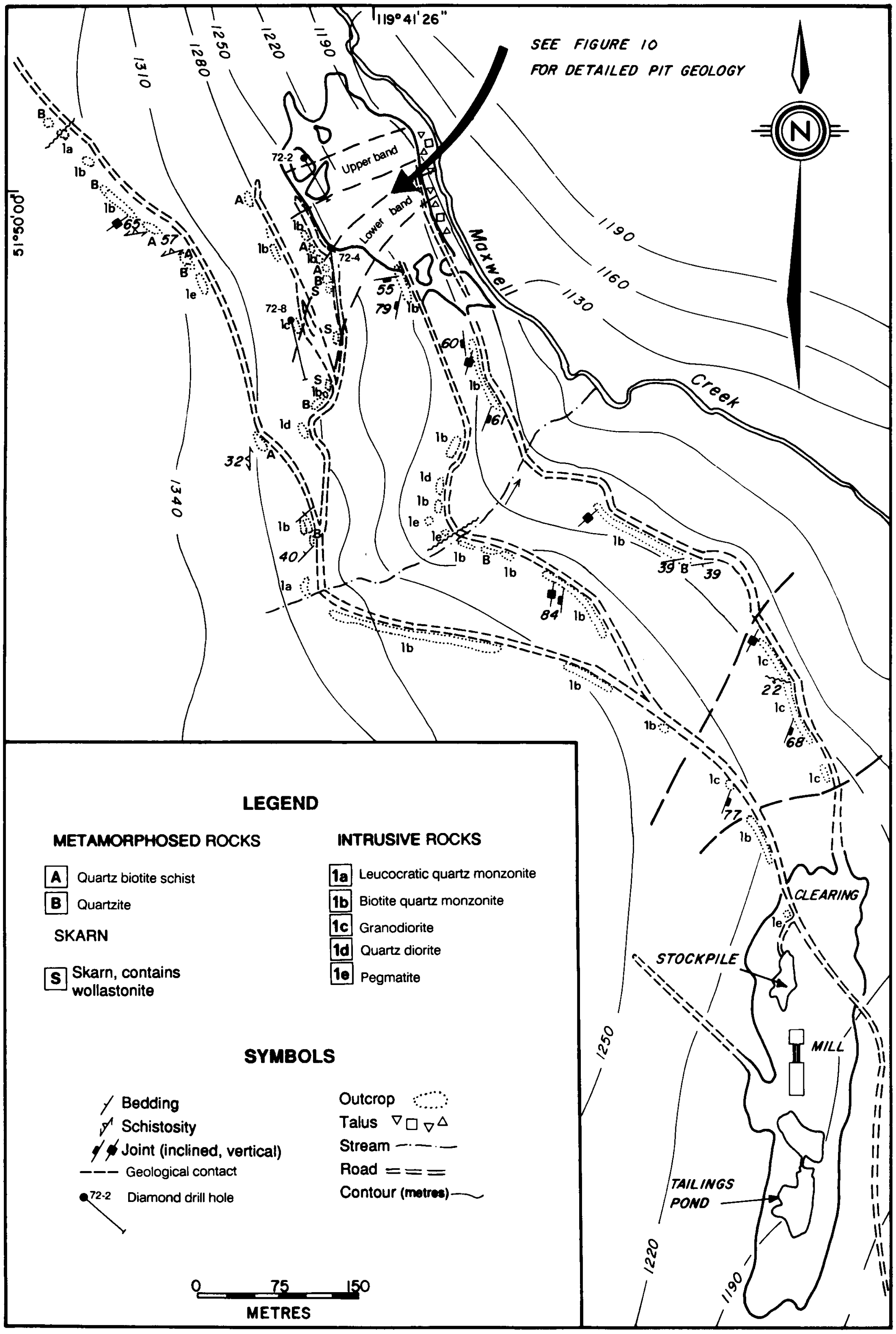

Figure 9. Geology of the Silence Lake mine (W5) (modified from White, 1989).

medium to coarse-grained masses that often outline indistinct layering. This third skarn type is occasionally intercalated with thin quartzite beds 0.1 to 1 metre thick.

The 'upper band' contains a significant zone of wollastonite-bearing skarn. The pit exposes a 15 to 20-metre section of this zone grading up to 35 per cent wollastonite (Figure 10). The zone strikes east-northeast and dips 60° to 70° northwest. An angled hole (DDH-72-2, bearing: 150°, inclination: -45°), collared approximately 35 metres west-southwest of the skarn exposures in the pit (Figure 9) cored 10 metres of wollastonite skarn at a depth of 17 and 27 metres. Two holes (DDH-72-4 and 72-8, bearings: 173° and 167° respectively, inclinations: both -45°), drilled 90 and 160 metres south-southwest of the pit exposure (Figure 9) encountered shorter intercepts (up to 5 metres) of wollastonite skarn within the 'lower band' (Falconer, 1986). Wollastonite skarn is exposed over widths of up to 6 metres in three outcrops 100 to 200 metres southeast of the two holes, also within the 'lower band' (Cook, 1972).

TABLE 15. MAJOR OXIDE XRF ANALYSES OF SAMPLES FROM SILENT LAKE MINE

	36372	36373	36374	36375	CANMET[1]
SiO_2	43.66	57.15	43.92	56.17	45.2
Al_2O_3	2.94	12.80	5.66	13.10	2.90
Fe_2O_3	1.99	4.09	2.44	4.34	1.60
CaO	40.07	15.17	35.89	15.51	
$CaCO_3$	-	-	-	-	12.7
MgO	0.82	2.04	0.96	2.16	0.56
Na_2O	0.23	1.14	0.15	0.15	
K_2O	0.04	1.08	0.04	1.21	
TiO_2	0.16	0.32	0.34	0.34	
P_2O_5	0.59	0.20	0.13	0.25	
MnO	0.09	0.43	0.09	0.48	
BaO	0.02	0.05	0.01	0.05	
L.O.I.	7.32	2.70	7.41	2.99	5.07
Brightness	-	-	-	-	76.05
Lightness	-	-	-	-	89.10
Total	97.93	97.17	97.03	97.77	

Mineralogy (by XRD)

36372	Wollastonite, calcite, grossular, diopside, quartz
36373	Quartz, plagioclase, grossular, calcite, muscovite, amphibole
36374	Wollastonite, quartz, calcite, grossular, diopside,
36375	Quartz, grossular, plagioclase, , calcite, muscovite, amphibole

Mineralogy (by image analysis)[1]

CANMET	Wollastonite	75.9
	Quartz + minor feldspar	10.2
	Calcite + mafics + minor dolomite	0.6
	Ferruginous dolomite	9.2
	$CaSiO_3$ - lower Ca phase	0.1
	Iron oxides and sulphides	0.2
	Andradite	3.8
	Total	100.0

[1] *Andrews (1989)*

SAMPLING AND TESTING

Major oxide analyses of two samples of wollastonite skarn (Samples 36372, 36374) and two samples of tailings (36373, 36375) are presented in Table 15.

A 59.4-kilogram sample of wollastonite-skarn was submitted to CANMET for magnetic separation and flotation tests (Andrews, 1989; Lastra *et al.*, 1989). Analytical results for a sample of the raw material are also presented in Table 15. Particles containing at least 70 per cent wollastonite comprised 97.5 per cent of the 212 to 3.4 micrometre size-fraction of the ground raw material.

Results of the magnetic separation of the -420 micrometre size-fraction are shown in Table 9. Wet magnetic separation successfully reduced the Fe_2O_3 content to less than 1 per cent by rejecting just over half of the iron.

Results for the reverse flotation of calcite and quartz from wollastonite for the -420 micrometre size-fraction are shown in Table 11. Reverse flotation of the raw feed reduced the ignition loss to less than 1 per cent with an Fe_2O_3 content of greater than 1 per cent, while reverse flotation of the nonmagnetic fraction produced a final concentrate containing less than 1 per cent Fe_2O_3 and with less than 1 per cent ignition loss. The final concentrate contained 88.14 per cent wollastonite, 0.4 per cent garnet and 11.3 per cent other silicates (Lastra *et al.*, 1989, p. 29).

Wet magnetic separation and reverse flotation produced a wollastonite concentrate of adequate grade with low to moderate acicularity and low Fe_2O_3 and ignition loss, acceptable for most ceramic and filler applications. Wollastonite content was increased from 75.9 to 88.14 per cent, brightness raised from 76.05 to 81.20 per cent and lightness increased from 89.10 to 91.37 per cent. The acicularity of the raw feed and the final concentrate remained essentially the same as shown in Table 7. A histogram of the distribution of the aspect ratios is shown on Figure 11.

PREVIOUS WORK

The deposit was initially explored for its tungsten content in 1972 by Union Carbide Exploration Corporation. The company carried out geological mapping and 540 metres of drilling in eight holes. An additional three holes were drilled in 1973 for a total of 438 metres.

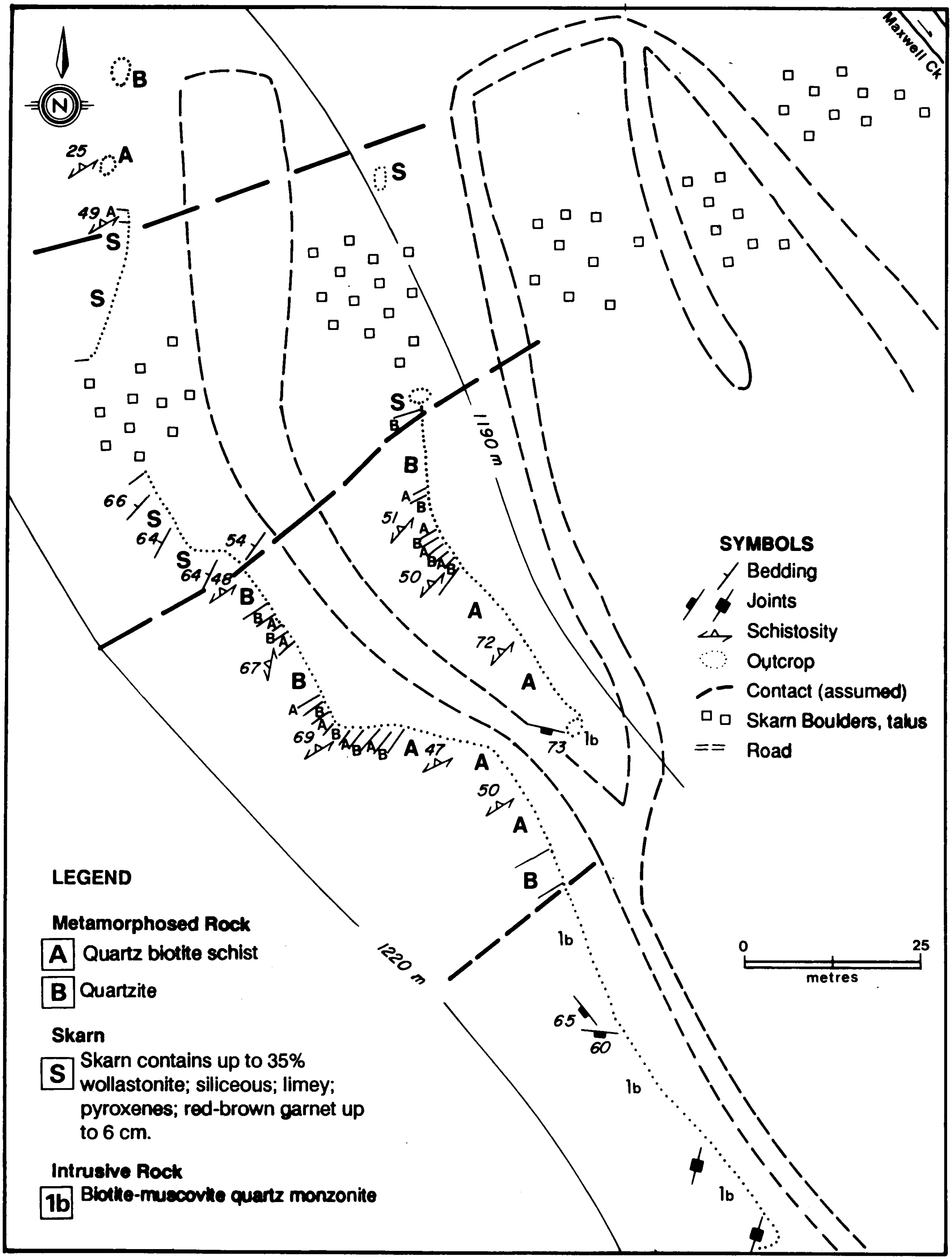

Figure 10. Geological sketch of the open pit area – Silence Lake mine (from White, 1989).

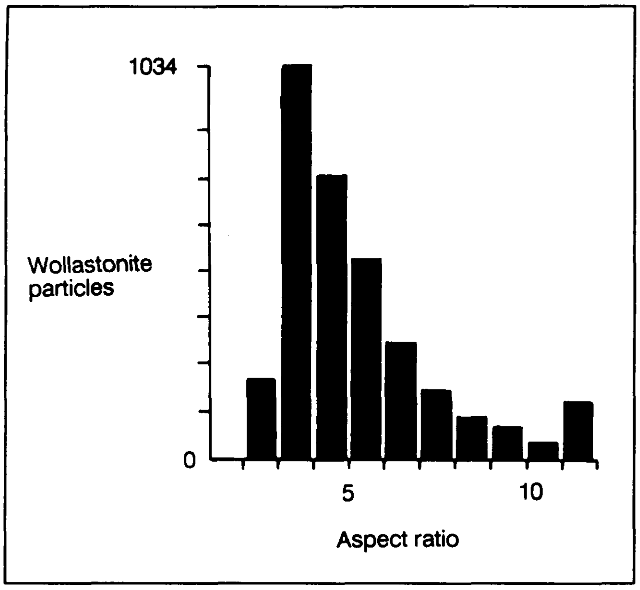

Figure 11. Histogram of number of wollastonite particles with a specific aspect ratio for Silence Lake (from Laustra *et al.*, 1989).

Between 1977 and 1979 United Mineral Services Ltd. defined several zones of scheelite-bearing skarn in the upper and lower bands by trenching and 287 metres of percussion drilling in eighteen holes. Dimac Resource Corporation, a subsidiary of United Mineral Services Ltd., became operator in 1979 and placed the property in production in October, 1981, after drilling 20 holes totalling 500 metres. A further 476 metres of diamond drilling and 609 metres of percussion drilling was carried out in the immediate vicinity of the pit. A total of 18350 tonnes of tungsten ore was produced to November, 1982, when rapidly declining tungsten prices forced mine closure. Dimac was placed in receivership in 1983 and the mine and 100 tonne per day mill were acquired by Troudor Resources Inc. Troudor evaluated the remaining tungsten reserves in 1986, but the wollastonite potential does not appear to have ever been evaluated.

NORTHWESTERN BRITISH COLUMBIA

CRAIG RIVER

CRAIG RIVER	**NTS 104B/11E**
MINFILE No.104B 005	Latitude 56°36'40"
Map No. W6	Longitude 131°10'12"

LOCATION

The Craig River occurrence is located south of the Iskut River, 13 kilometres up the Craig River valley. A wollastonite showing is reported on the southeast side of Seraphim Mountain, immediately west of the river.

GEOLOGY

Seraphim Mountain is underlain by an Early Tertiary granodiorite stock intrusive into a Permian to Lower Triassic sequence of limestones, siltstones, shales and volcanic rocks along the southeast flank of the mountain (Kerr, 1935, 1948). Kerr (1948) reported: "In Craig Valley, near the masses of hornblende granodiorite, the limestone is largely converted to wollastonite and silica." An unsuccessful attempt to find this occurrence was made in 1988 (White, 1989).

MAID OF ERIN

MAID OF ERIN	**NTS 114P/10E**
MINFILE No. 114P 007	Latitude 59°34'15"
Map No. W7	Longitude 136°35'05"

LOCATION

The Maid of Erin wollastonite occurrence is situated in the headwaters of the Klehini River, northwest of Rainy Hollow and 5 kilometres west of the Haines-Whitehorse Highway.

GEOLOGY

Skarn occurs in a roof pendant of argillite, quartzite and limestone, within Oligocene granite, quartz monzonite and diorite. The skarn zones are comprised of variable amounts of garnet, monticellite and idocrase, with sporadic pyrite, magnetite, sphalerite, galena, bornite and chalcopyrite. Drilling by Falconbridge Limited on the Maid of Erin Crown-granted claim (Lot 722) intersected a few narrow sections of wollastonite in four holes (Wilson, 1983). Drill-hole intercepts with sporadic veins and patches of wollastonite in skarn vary from centimetres to ten's of centimetres in length and more continuous sections up to 2 metres in length are reported. An examination of drill core and outcrops in 1988 failed to identify significant quantities of wollastonite (White, 1989).

PREVIOUS WORK

Falconbridge Limited carried out geological, geochemical and geophysical surveys between 1981 and 1982 and completed 1481 metres of diamond drilling in 20 holes in 1983, while exploring the property for base and precious metals.

RANCHERIA

RANCHERIA	**NTS 104O/16W**
MINFILE No. 104O 034	Latitude 59°58'20"
Map No. T1	Longitude 130°24'40"

LOCATION

The Rancheria tremolite-wollastonite occurrence is located 17 kilometres southeast of Rancheria, 3.5 kilometres south of the British Columbia - Yukon border. It outcrops between 1420 and 1700 metres elevation, approximately 3 kilometres northwest of the Tootsie River.

GEOLOGY

Calcsilicate skarn is developed along the east margin of the Cretaceous Cassiar batholith in northeast-trending sediments of Ordovician to Devonian age (Gabrielse, 1969).

The Rancheria property is underlain by black and grey limestones and light and dark quartzites dipping 40°

to 50° southeast. These beds are altered to biotite-carbonate hornfels and garnet-diopside skarn adjacent to quartz monzonite of the Cassiar batholith. The width of skarn alteration (exceeding 1 kilometre in places) suggests that the quartz monzonite dips southeastward under the sediments.

Tremolite and wollastonite mineralization outcrop 600 to 900 metres southeast of the quartz monzonite (MacArthur, 1979, 1980). A zone of tremolite-diopside-carbonate skarn outcrops over a strike length of 825 metres, varying up to 250 metres in width on surface. It is comprised mostly of tremolite with some outcrops of actinolite, diopside and wollastonite at the northern end. This skarn is interbedded with quartzite along its northwest edge and bounded to the southeast by a diabase dike. Wollastonite-bearing skarn outcrops over a strike length of 630 metres in a narrow zone along the southeast contact of the same dike.

A second zone of tremolite-diopside-carbonate skarn, 850 metres long, outcrops along strike 1500 metres southwest of the first zone. Surface widths vary up to 350 metres. Several westward-trending diabase dikes up to 35 metres wide cut this zone. The skarn is comprised mostly of tremolite with minor actinolite and diopside. It is interbedded with quartzite to the northwest and flanked by grey limestone to the southeast. Wollastonite is present in the limestone south of the skarn zone, adjacent to a diabase dike.

PREVIOUS WORK

Noranda Exploration Company Limited explored zones of molybdenite, scheelite and powellite mineralization up to 25 metres thick within the tremolite-diopside-carbonate skarn. The company conducted geological mapping and sampling in 1979 and 1980. The deposit was not assessed for its wollastonite or tremolite potential.

KOOTENAYS

ROSSLAND

ROSSLAND	**NTS 82F/04W**
MINFILE No. 082FSW341	Latitude 49°09'35"
Map No. W8	Longitude 117°50'00"

LOCATION

The deposit is exposed on the west slope of a hill adjacent to Highway 3B, 9.5 kilometres north-northwest of Rossland.

GEOLOGY

The showing is hosted in sediments of the Pennsylvanian to Permian Mount Roberts Formation which are intruded from the west by syenite and quartz monzonite of the Eocene Coryell Batholith (Little, 1982). Several mineralized outcrops comprise a zone trending 315° for approximately 150 metres along the northerly trending intrusive contact. The zone varies from 3 to 50 metres wide and dips 35° west (H. Klassen, 1991, personal communication).

Hand specimens show coarse, tabular, subparallel to subradial pearly white wollastonite, weathering light tan to light brown, with minor secondary calcite. Thin sections display coarse tabular prisms of wollastonite cut by thin irregular calcite veins, with traces of clinopyroxene (?) as high relief, moderately high birefringent grains and blebs (J.M. Huber Corp., 1990). Percentage estimates of the above constituents for two petrographic thin sections are given in Table 16.

TABLE 16. MINERALOGY OF TWO PETROGRAPHIC THIN SECTIONS FROM THE ROSSLAND OCCURRENCE[1]

	Section 1	Section 2
Wollastonite	95.5	94.5
Calcite	3.5	5.0
Diopside-hedenbergite	1.0	0.5
Total	100.0	100.0

[1] *J.M. Huber Corp. (1990)*

PREVIOUS WORK

The deposit was staked and sampled by Horst Klassen of Rossland. J.M. Huber Corporation analyzed some of the wollastonite samples in 1990.

HORSETHIEF CREEK

HORSETHIEF CREEK	**NTS 82K/09W**
MINFILE No. 082KNE032	Latitude 50°33'53"
Map No. T2	Longitude 116°24'50"

LOCATION

The Horsethief Creek tremolite-wollastonite occurrence is located west of the Rocky Mountain Trench, 28 kilometres west-northwest of Invermere. The principal outcrops are situated on the summit of a prominent hill on the south side of Horsethief Creek. It was discovered and staked by prospectors G. Plassmann and B. Bechtel in 1988.

GEOLOGY

The property is underlain by a northerly trending sequence of argillite, shale, dolomite, limestone and quartzite of the Helikian (Proterozoic) Dutch Creek and Mount Nelson formations (Reesor, 1973). The Horsethief Creek batholith, a large body of coarse-grained, quartz monzonite of Cretaceous age, outcrops a kilometre northwest of the occurrence.

The hill on the south side of Horsethief Creek is underlain by quartzite and dolomitic limestone of the Mount Nelson Formation (Figure 12; Bennett, 1986). Pale brown to light grey, massive and sometimes cherty quartzite extends northward along the east side of the hill toward Horsethief Creek. A large outcrop of limy quartzite is situated on the south side of the hill near its summit. Dark grey to black dolomitic limestone, striking north and dipping 30° to 65° west, outcrops along the west side of the hill.

Skarn mineralization is exposed over the north side of the hill, beginning at the summit and continuing downslope for at least 350 metres, over a vertical interval of 180 metres (White, 1989). Tremolite and wollastonite commonly occur in this zone as clusters of radiating fibres up to 10 centimetres long and as lenses and veins in siliceous dolomitic limestone. Several outcrops at the top of the hill, and along a cliff on the southwest face, contain northwest striking bands of massive, white to pale green calcium silicates, 15 to 20 centimetres wide intercalated with quartzite beds and cut by occasional calcite veins.

SAMPLING AND TESTING

Major oxide analyses of four grab samples of the skarn are presented in Table 17. A 36.8-kilogram bulk-sample was submitted to CANMET for magnetic separation and flotation tests (Andrews, 1989; Lastra *et al.*, 1989). The analysis of a sample of the raw material is also presented in Table 17. Aspect ratios of the raw material ranged from 1 to 7 with the greatest proportion lying between 2 and 3.

The -420-micrometre size-fraction of the ground raw feed was processed by wet high-intensity magnetic separation. Results are shown in Table 9. The Fe_2O_3 content remained above 1 per cent, with only 32.3 per cent of the iron being rejected.

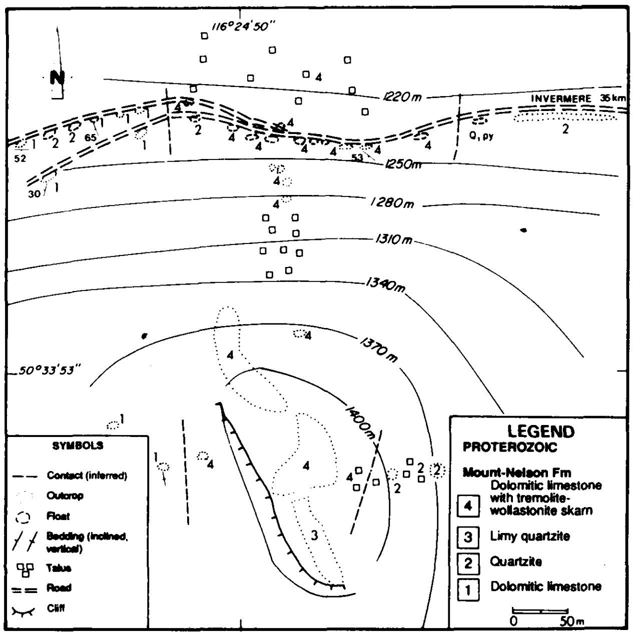

Figure 12. Geological sketch of the Horsethief Creek calcsilicate prospect (T2) (from White, 1989).

TABLE 17. MAJOR OXIDE XRF ANALYSES OF SAMPLES FROM THE HORSETHIEF CREEK OCCURRENCE

Sample Nos.	36378	36379	36380	36381	CANMET[1]
SiO_2	46.60	60.52	66.59	50.75	51.8
Al_2O_3	0.44	0.17	0.17	0.44	0.68
Fe_2O_3	1.46	0.88	1.00	1.73	1.58
CaO	20.86	16.96	14.72	20.56	
$CaCO_3$	-	-	-	-	20.8
MgO	19.45	12.94	12.70	17.48	14.6
Na_2O	0.19	0.16	0.17	0.19	
K_2O	0.08	0.06	0.06	0.11	
TiO_2	0.01	<0.01	<0.01	0.02	
P_2O_5	<0.01	0.04	<0.01	0.03	
MnO	0.03	0.02	0.04	0.05	
BaO	0.01	0.01	0.01	0.03	
L.O.I.	8.79	7.60	5.73	7.46	8.32
Brightness	-	-	-	-	75.85
Lightness	-	-	-	-	88.48
Total	97.93	99.37	101.20	98.85	

Mineralogy (by XRD)

36378	Tremolite, calcite
36379	Quartz, tremolite, calcite
36380	Quartz, tremolite, calcite
36381	Tremolite, calcite, quartz

Mineralogy (by image analysis)[1]

CANMET	Wollastonite	7.3
	Tremolite + minor feldspar	54.5
	Calcite + mafics + minor dolomite	37.5
	Ferruginous dolomite	0.4
	$CaSiO_3$ - lower Ca phase	0.1
	Iron oxides and sulphides	0.1
	Andradite	0.1

Note: Total tremolite content in raw material was later reported to be approximately 75 per cent (Andrews, 1989, personal communication).

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[1] *Andrews (1989)*

Reverse flotation of calcite and quartz from tremolite and wollastonite was carried out on the -420-micrometre size fraction for both the raw feed and the nonmagnetic fraction. Analyses of the various flotation products are shown in Table 11. In both cases the ignition loss remained above 3 per cent, while Fe_2O_3 remained above 1 per cent. The concentrate derived from the flotation of the raw feed contained approximately 90 per cent tremolite and 10 per cent wollastonite (Andrews, 1989, personal communication).

Magnetic separation and flotation produced a tremolite- wollastonite concentrate with excessive Fe_2O_3 and ignition loss. The tremolite grade was increased from 75 per cent in the raw feed to 90 per cent in the concentrate, while the wollastonite grade was increased from 7.3 to 10 per cent. Attempts to adequately separate the tremolite from wollastonite were unsuccessful. Brightness decreased from 75.85 to 74.50 per cent, while lightness decreased slightly from 88.48 to 88.11 per cent.

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APPENDIX A

LISTING OF WOLLASTONITE OCCURRENCES FROM MINFILE

Further information on the occurrences listed below can be obtained from MINFILE, Geological Survey Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources [553 Superior St. Victoria, B.C. (604) 356-2826].

MINFILE NO.	MAP NO.*	NAME	NTS SHEET	LATITUDE	LONGITUDE
082ENW050	W4	James Lake	082E/14W	49°57'27"	119°15'14"
082FSW001		Aspen,The Crunch, The Rock	082F/03E	49°11'08"	117°11'15"
082FSW006		Black Rock (L.14408)	082F/03E	49°08'20"	117°12'48"
082FSW097		War Eagle (L.680)	082F/04W	49°05'00"	117°48'29"
082FSW341	W8	Rossland Wollastonite	082F/04W	49°09'35"	117°50'00"
082KNE032	T2	Horsethief Creek	082K/09W	50°33'53"	116°24'50"
082LSW014	W3	Fintry Point	082L/04E	50°08'28"	119°34'07"
082M 123	W5	Silence Lake, Dimac, Gotcha	082M/13E	51°50'00"	119°41'30"
082M 188		TM 1	082M/13W	51°48'30"	119°47'25"
082M 189		TM 8	082M/13W	51°48'20"	119°50'40"
092E 064		Sat	092E/09W	49°30'40"	126°22'20"
092F 105	W2	Little Billie (L.522)	092F/15E	49°45'29"	124°32'44"
092GNW052	W1a	Snake Bay, Sechelt	092G/12W	49°30'56"	123°48'59"
092GNW053	W1b	Wormy Lake, Sechelt	092G/12W	49°32'06"	123°50'12"
092HSW003		Foundation Mines, Heart, BB	092H/03E	49°13'15"	121°05'15"
092HSW008		Empress (Lots 1804-1807)	092H/05W	49°16'57"	121°45'00"
092HSW012		Silver Bell, Della, D & J	092H/03E	49°11'46"	121°05'06"
092HSW042		Horseshoe, Rainbow, Big Ben	092H/03E	49°12'47"	121°04'32"
92HSW137		Bear	092H/03W	49°11'15"	121°15'40"
092JNE013		Bramoose, Peridot	092J/10E	50°43'25"	122°39'45"
092L 008		New Privateer, (L. 1040)	092L/02W	50°01'50"	126°49'03"
092L 130		Bluebird, Kodiack Blackbird	092L/02W	50°02'06"	126°49'52"
093E 102		Park	093E/06W	53°20'56"	127°21'00"
093L 186		GSC 1971 - 18	093L/12W	54°40'23"	127°48'27"
104B 005	W6	Craig River, Dundee, Rob	104B/11E	56°36'40"	131°10'12"
104B 109		Elbow Mountain	104B/12W	56°42'01"	131°49'55"
104B 331		Vanstates, Ian 8	104B/10W	56°42'15"	130°53'54"
104G 012		Devils Elbow, Stikine	104G/12E	57°34'13"	131°41'25"
104K 013		Mt. Ogden (Moly-Taku), Apex	104K/06W	58°26'19"	133°21'33"
104O 032		JCS	104O/16W	59°59'20"	130°23'30"
104O 032		Sue, JCS, Gunnar Berg	104O/16W	59°59'20"	130°23'30"
104O 034	T1	Rancheria, Root 1	104O/16W	59°58'20"	130°24'40"
104P 043		Mount Reed, Dome	104P/06W	59°18'10"	129°26'30"
114P 007	W7	Maid Of Erin (L.722)	114P/10E	59°34'15"	136°35'05"
114P 009		Victoria (L.903)	114P/10E	59°33'30"	136°33'20"
114P 010		Adams, Custer (L.727, 726)	114P/10E	59°33'40"	136°31'15"

**See Figure 1.*

APPENDIX B

RESULTS OF METALLURGICAL TESTING - SNAKE BAY DEPOSIT

TABLE B1. SIEVE ANALYSIS OF CRUSHED ORE SAMPLE: SNAKE BAY PROSPECT[1]

Size-fraction		Weight % Retained	Estimated Mineral Contents (%)			
mesh	millimetres		wollastonite	garnet	diopside	calcite
4 - 8	5.0 - 2.4	16.7	>80	<10	<5	~1
8 - 18	2.4 - 1.0	23.6	~90	~8	~1	~1
18 - 30	1.0 - 0.5	14.1	>90	~8	~1	~1
30 - 48	0.5 - 0.3	11.2	>90	~5	~3	~2
48 - 0	0.3 - 0.0	34.4	ND	ND	ND	ND

Notes:

4-8 and 8-18 mesh fractions: garnet mainly as unliberated small crystals or aggregates; diopside unliberated as crystals in wollastonite; calcite partly as grain cement 30-48 mesh fractions: at least 75% liberation of garnet and diopside 48-0 mesh fractions: remaining garnet clumps cemented by calcite.

[1] *McElroy (1988)*

TABLE B2. ANALYSES OF MAGNETIC AND NONMAGNETIC FRACTIONS OF CRUSHED AND SIZED SAMPLES: SNAKE BAY PROSPECT[1]

Fraction (mesh)	Test	Product	Wt%	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
4 - 8	1	Magnetic	15.92	43.0	7.31	2.78	39.4	0.82
		Non-mag.	84.08	48.5	2.16	0.94	49.0	0.35
4 - 8	2	Magnetic	27.25	43.0	7.13	2.32	40.1	0.74
		Non-mag.	72.75	47.8	2.53	1.00	48.6	0.38
8 - 18	1	Magnetic	17.83	42.0	8.06	3.55	37.6	1.10
		Non-mag.	82.17	48.8	1.53	0.89	49.2	0.29
8 - 18	2	Magnetic	28.86	43.6	5.45	2.09	42.3	0.84
		Non-mag.	71.14	49.7	1.41	0.75	49.5	0.28
18 - 30	1	Magnetic	23.08	42.7	6.62	3.07	40.6	1.31
		Non-mag.	76.92	49.4	1.32	0.66	50.1	0.22
18 - 30	2	Magnetic	34.26	45.1	4.59	1.83	43.1	0.72
		Non-mag.	65.74	49.5	1.12	0.60	50.0	0.21
30 - 48	1	Magnetic	19.03	46.0	4.60	2.73	45.0	1.28
		Non-mag.	80.97	50.0	0.91	0.56	50.0	0.18
30 - 48	2	Magnetic	28.20	46.0	4.01	2.23	46.0	1.05
		Non-mag.	71.80	49.8	0.78	0.67	48.4	0.16
48 - 0	1	Magnetic	23.06	33.7	3.19	2.24	31.7	0.96
		Non-mag.	76.94	49.5	0.99	0.86	48.5	0.17
48 - 0	2	Magnetic	16.88	45.0	3.45	2.63	44.1	1.24
		Non-mag.	83.12	48.8	1.16	0.65	48.3	0.18

Notes:

Feed rates (rates at which raw feed is passed through the magnetic separator) used in Tests 1 and 2 are as follows:

Test 1: ranged mostly from 4.7 to 6.7 tons per hour per metre for three passes, the exception being for the 48-0 mesh fraction, where 1.8 to 1.9 tons per hour per metre were used.

Test 2: most between 2.1 and 2.5 tons per hour per metre for three passes, the exception being for the 8-18 mesh fraction with feed rates of between 3.2 and 3.8 tons per hour per metre.

[1] *McElroy (1988)*

TABLE B3. CO_2 IN RAW ORE AND NONMAGNETIC FRACTION, SNAKE BAY PROSPECT[1] (WEIGHT %)

Size-fraction (mesh)	Raw Ore	Nonmagnetics	
		Test 1	Test 2
4 - 8	0.69	0.98	0.68
8 - 18	0.85	0.33	0.54
18 - 30	0.60	0.74	0.72
30 - 48	0.55	0.56	0.27
48 - 0	0.59	0.52	0.43

[1] *McElroy (1988)*

TABLE B4. ASPECT RATIOS OF WOLLASTONITE PARTICLES IN VARIOUS SIZE-FRACTIONS USING DIFFERENT GRINDING TECHNIQUES[1]

Preparation	Size-fraction		Average Dimensions (Microns)		Aspect Ratio (Mean)
	Mesh	Micron	Length	Width	
None (crushed raw ore)	30 - 48	500 - 298	940	260	4.12
	48 - 100	297 - 149	775	175	4.57
	100 - 200	149 - 80	465	55	9.55
Mortar & pestle (rubbing)	270 - 325	53 - 44	20.4	3.8	5.86
	325 - 400	44 - 37	10.5	3.5	5.70
	minus 400	37 - 0	6.5	1.1	6.70
Ceramic dry ball mill	270 - 325	53 - 44	15.8	3.9	4.00
	325 - 400	44 - 37	13.9	3.8	3.88
	minus 400	37 - 0	7.0	2.4	3.18
Ring pulverizer	325 - 400	44 - 37	11.0	2.1	11.6
	minus 400	37 - 0	6.8	2.0	3.53
Impact mill	270 - 325	53 - 44	16.5	3.7	4.63
	325 - 400	44 - 37	10.2	2.4	4.64
	minus 400	37 - 0	7.6	2.1	1.52

[1] *McElroy (1988)*