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ONTARIO GEOLOGICAL SURVEY

Open File Report 5715

Wollastonite in Southeastern Ontario

by

A. MacKinnon

1990

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V.G. Milne

V.G. Milne, Director
Ontario Geological Survey

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(Back Pocket)

Wollastonite occurrences associated with the Deloro Pluton, Southern Ontario

Scale 1:10,000

ABSTRACT

Wollastonite, an anhydrous calcium metasilicate ($CaSiO_3$), is undergoing rapid growth in demand as an industrial raw material. Its properties of high aspect ratio, brightness, chemical purity, and thermal shock resistance are important in various applications such as ceramics, metallurgical fluxes, and the filler industry. It is also used as an alternative to asbestos in some friction and heat containment applications.

Wollastonite is a common constituent of thermally metamorphosed impure limestone and may also occur as a product of metasomatism where silica is added to calcareous sediments or where calcareous sediments have been assimilated by igneous intrusive rocks. The primary requirements for its formation are: i) a source of calcite and silica, ii) a source of heat to cause reaction of the calcite with silica, forming wollastonite, and iii) a means of depleting CO_2 produced during the reaction, to allow the reaction to proceed. These conditions can also be met during high-grade regional metamorphism of calcareous quartzites or siliceous carbonates.

World demand for wollastonite is largely met by production from the United States, Finland, Mexico, and India. Canada does not presently produce wollastonite, although several occurrences are under investigation in Ontario, Quebec, British Columbia and Nova Scotia.

Precambrian carbonate belts of the Grenville Province in southeastern Ontario host numerous occurrences of wollastonite,

many of which were examined in detail during the course of this study. Particular attention was given to the Marmora Township study area, where eight wollastonite occurrences are associated with altered calcitic marbles along the western margin of the Deloro Pluton. Results of detailed geological, petrographic, and chemical studies suggest a common origin in terms of temperature, pressure, and chemistry, and the primary factor in their formation seems to have been original chemistry of the host rock. At least one of the Marmora Township occurrences (the Platinova-Cominco Property) appears to have sufficient size and grade potential for open pit development, based on field mapping, mineralogical studies and beneficiation tests.

Other areas considered to have good potential for wollastonite mineralization are the townships of Lake, Olden, and Glamorgan, and late to post-tectonic intrusions in contact with calcareous metasedimentary rocks in the Kingston, Gananoque, Westport, and Brockville areas of the Frontenac Axis. A recent discovery in the Gananoque area appears to be related to high-grade regional, rather than contact metamorphism, and indicates additional potential for wollastonite mineralization in areas of interlayered marbles and quartzites within the Frontenac Axis.

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The author would like to thank W.D. Hicks (formerly mineralogist, Ontario Geoscience Laboratories) and H. de Souza (Mineralogist, Ontario Geoscience Laboratories, Ontario Geological Survey) for providing X-ray diffraction identifications and microprobe analyses and descriptions. Beneficiation tests were preformed by P.R.A. Andrews (Mineral Engineer, Industrial Minerals Section, CANMET) under the supervision of R.K. Collings. D.A. Williams (Geologist, Ontario Ministry of Northern Development and Mines, Southeastern District, Tweed) provided valuable structural interpretations of the Marmora study area and informative discussions on the geology of the Paleozoic rocks. Capable field assistance was provided in the field by G. David (1986) and S. Cole (1987).

The co-operation of many local residents in providing access to their properties is appreciated. I would like to thank Noranda Incorporated for permitting examination of diamond drill core from their property, B. Sakrison (Manager Industrial Minerals, Cominco American Limited) and R. Gannicott (President, Platinova Resources Ltd.) for permitting access to their Marmora Township property, and R. Lortie (geologist Cominco Ltd., Toronto) for providing geological information on the Cominco/Platinova property near Gananoque. P.W. Kingston (Resident Geologist, Ontario Ministry of Northern Development and Mines, Southeastern District, Tweed) critically reviewed the contents and P.S. LeBaron (geologist, MNDM, Tweed) edited the final manuscript.

WOLLASTONITE IN SOUTHEASTERN ONTARIO

by: A. MacKinnon[1]

PART I

INTRODUCTION

Wollastonite, named after William Hyde Wollaston -- an English eighteenth century geochemist -- is an anhydrous calcium metasilicate, with a theoretical composition of 48.3% CaO and 51.7% SiO_2 (Elevatorski 1983).

The earliest reported production of wollastonite came from a deposit located near Code Siding, north of Randsburg, California, where small quantities were quarried during 1933-34 and 1938-41 and processed into mineral wool (Elevatorski 1983). Large-scale production did not materialize until the discovery of large high quality deposits in the 1950's, near Willsboro in New York State (Powers 1986). Canada does not presently produce wollastonite, although several occurrences are currently under investigation in Ontario, Quebec, British Columbia and Nova Scotia.

The demand for wollastonite is expected to grow at an annual rate of 10% (Plumpton et al 1987), as it is experiencing increased

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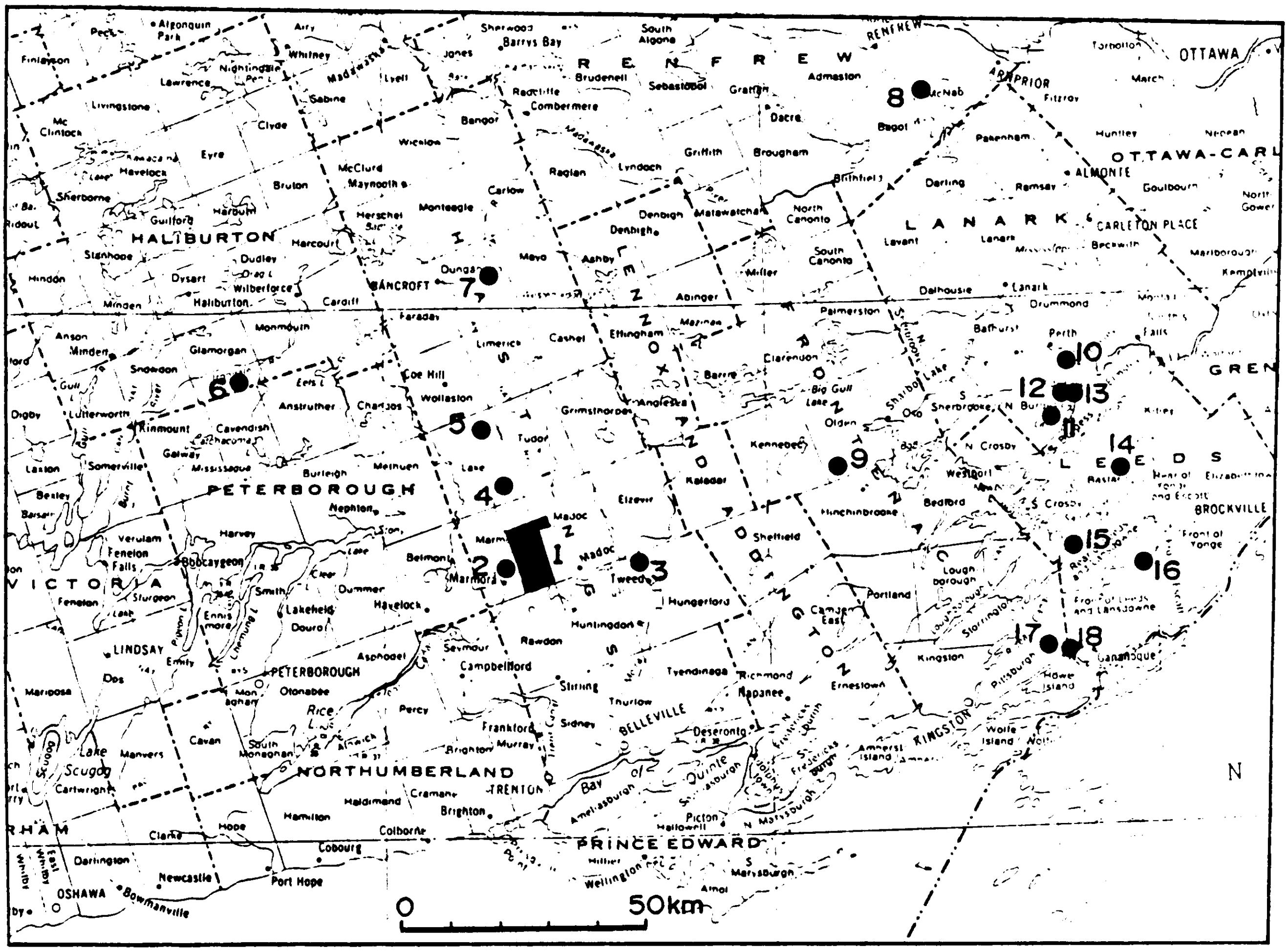
usage as a filler by the paint, plastic and ceramic industries. This report presents the results of a multi-year study of wollastonite occurrences in southeastern Ontario. Initially, a literature search was conducted to compile known occurrences of wollastonite. This work was followed by field investigations, and reconnaissance mapping to examine new areas considered to have potential for additional mineralization. The present survey examined numerous wollastonite occurrences throughout southeastern Ontario (Figure 1), but should not be considered an exhaustive report on the total potential of the area. The report includes a short summary of other Canadian occurrences, uses of wollastonite, world producers and the results of the benefication study completed by CANMET on two samples obtained from a deposit in Marmora Township, southeastern Ontario.

GEOLOGICAL SETTING OF WOLLASTONITE

Wollastonite is a common constituent of thermally metamorphosed impure limestone. It may also occur in contact altered calcareous sediments where the presence of silica is due to metasomatism, and also in igneous rocks contaminated with calcareous sediments (Deer et al 1978). Certain alkaline igneous rocks and carbonatites are also known to contain wollastonite. Examples are at Oka, Quebec and Alno, Sweden, in the urtite of the Prairie Lake complex, Ontario (Watkinson 1973), in the ijolitic alkaline rocks of Kenya (Pulfrey 1950) and Tanzania, and in wollastonite phonolites and related rocks (Deer et al 1978).



1. Marmora Study Area
2. Crowe Lake Occurrence
3. Tweed Marble Quarry
4. Lake of Islands Occurrence
5. Tudor Gabbro Occurrence
6. Glamorgan Township Occurrence
7. York River Tactite Occurrence
8. Burnstown Occurrence
9. Hawley Zinc Property
10. North Elmsley Township Occurrence
11. Silver Queen Mine
12. Lot 8 and 9, Concession 6, North Burgess Township
13. Lot 4, Concession 6, Lot 3, Concession 7, North Burgess Township
14. Bastard Township Occurrence
15. Deans Island Occurrence
16. Charleston Lake Occurrence
17. Brewers Mills Occurrence
18. Cominco County Line Road Occurrence

Figure 1. Approximate location of wollastonite occurrences in southeast Ontario

The formation of wollastonite may also result from regional metamorphism of impure calcareous sediments but only in exceptional cases where water from surrounding rocks was introduced into thin layers of carbonate rocks, thus diluting the CO_2 concentration of the fluid phase and allowing the reaction to go to completion forming wollastonite (Winkler 1976).

Worldwide, wollastonite mineralization is known to occur in skarn zones in close proximity to metallic mineral deposits. The majority of the world's economic skarn deposits occur in calcic exoskarns.* Einaudi and Burt (1982) distinguished five major classes of calcic skarn deposits (Fe, W, Cu, Zn-Pb, and Sn). Two notable examples are the Naica district in Mexico which was previously worked for zinc, and the Jilin and Anhui Provinces, in China which occur close to metallic mineral deposits, in particular Cu and Fe ore mines.

Copper, and iron skarns in particular commonly have wollastonite associated with them. An example of the association of iron skarn and wollastonite can be found within the study area (Kelly-Czerewko Property, Marmora Township).

Wollastonite may be found associated with Cu-Au and Au-Ag-Cu skarns along igneous-marble contacts i.e. Red Dome Gold Deposit, British Columbia (Ewers et al 1987). In general,the wollastonite zone tends to be barren of metallic ores (except locally, gold)

---

[*] Calcic exoskarn is used in the descriptive sense to denote a skarn in which the contact zone being replaced is carbonate in origin and contains a significant component of Ca or CaFe silicates such as garnet, pyroxenoids, or idocrase.

possibly because wollastonite tends to be incompatible with iron-rich ore-bearing solutions (Barnes 1979).

In Marmora Township there appears to be a spatial relationship between the occurrence of wollastonite and gold. Numerous small gold mines (i.e. Malone, Ackerman, Sovereign, Deloro, Campbell-Bloomfield, and Gillen occurrence) have operated intermittently on gold bearing-arsenopyrite-quartz veins in the felsic intrusive. This relationship is again evident at the Noranda property (occurrence 8, Figure 6) where a band of wollastonite-bearing marble is found associated with a small highly sericitized and sheared auriferous satellite body of the Deloro Pluton. This may indicate that both the wollastonite and gold are structurally controlled, restricted to areas which were highly fractured or faulted enabling the development of pervasive siliceous hydrothermal metasomatism.

CLASSIFICATION

Kuzvart (1984) classified wollastonite deposits into three types, on the basis of genesis:

Type I: contact metasomatic or skarn and contact metamorphic or skarnoid ie. Partek deposit (Finland), NYCO deposit (Willsboro, United States).

Type II: regional metamorphic i.e. California (United States), U.S.S.R.

Type III: carbonatitic i.e. Japan, India, Kenya, Mexico, Australia, U.S.S.R.

The present author advocates distinguishing between (i) contact metasomatic (skarn), (ii) contact metamorphic (reaction skarn) and (iii) skarnoid in Kuzvart (1984) classification Type I. Einaudi and Burt (1982) define skarns (alternate names secondary skarn, replacement skarn, skarn proper, ore skarn, and tactite) as coarse-grained bodies of calc-silicate in relatively pure carbonates formed by infiltration and diffusion of metasomatic fluids carrying exotic components. Where there is no introduction from outside the sedimentary section or only local exchange of components between the two rock types they refer to it as reaction skarn (alternate names exchange skarn, bimetasomatic diffussion skarn, and calc-silicate bands). Skarnoid refers to any skarn-like rocks of complex or uncertain origin.

Economically viable wollastonite deposits are rare and are generally restricted to impure limestones which have undergone shallow contact metamorphism by intrusive bodies of granite or other acidic rocks. The Marmora occurrences are of this type (type I), having formed in the thermal metamorphic aureole of the Deloro Pluton and its satellites. Most Ontario occurences are type I contact metasomatic/metamorphic and are rarely either type II or type III. The Platinova-Cominco County Line Road occurrence near Gananoque appears to be type II, based on the limited amount of information available from this relatively recent discovery. The best example in Ontario of type III in which significant wollastonite mineralization occurs is the Prairie Lake Carbonatitic Complex, located in northern Ontario.

The Burnstown occurrence, southeastern Ontario, has been suggested by Bartlett (1980) to be carbonatitic in origin.

WOLLASTONITE PRODUCERS -- WORLD

Figure 2 illustrates the location of the world's wollastonite reserves and producers. World demand is largely met by production from the United States, Finland, Mexico, and India. Choate (1989) estimated annual wollastonite production in 1988 at approximately 180 Kt (200,000 st).

United States

The United States is the largest producer of wollastonite in the world, with the bulk of production coming from New York State and California. Production in California is primarily as ornamental wollastonite, with a small quantity mined by Pfizer Inc. (trade name Wolcon) for the ceramic and coating industries.

The three main New York deposits (Fox Knoll, Lewis, Deerhead) owned by the Nyco division of PMI, are located on the northeast flank of the Adirondack Mountains, near the western side of Lake Champlain.

The geology of these deposits is described by Harben (1986) as follows:

> "The wollastonite forms part of a belt of contact-metamorphosed and metasomatised sediments. The Grenville limestone was injected by anorthosite yielding mixed gneisses containing wollastonite, garnet and diopside. Within the belt every stage of gradation from pure wollastonite to pure garnet is represented, although bands of pure wollastonite interbedded with garnetiferous zones are commercially the most significant."

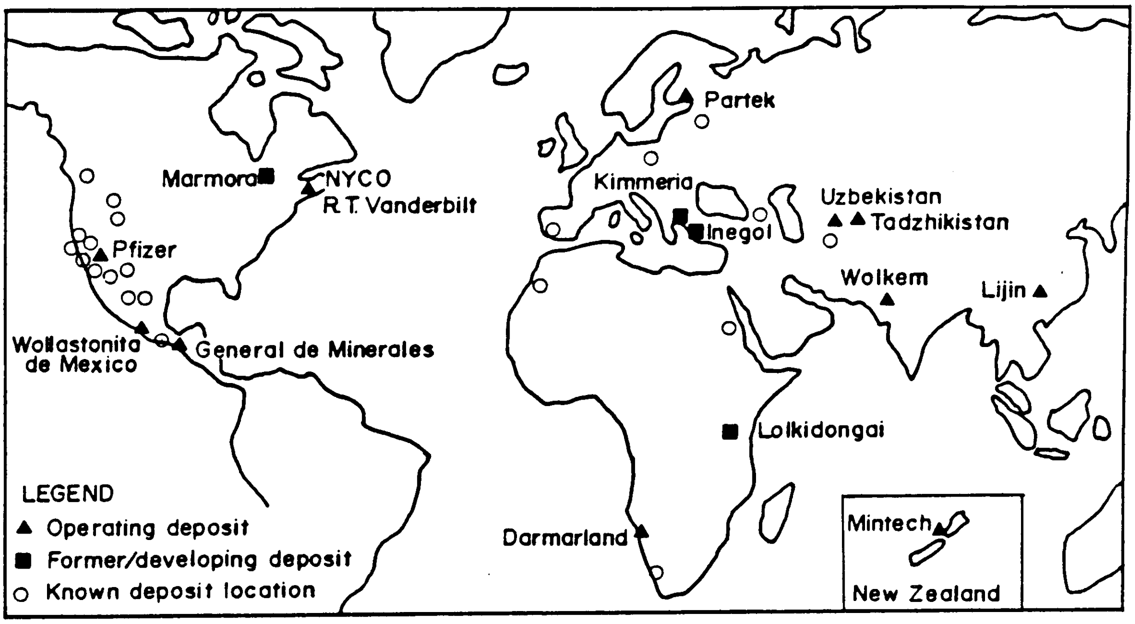


Figure 2. Locations of the world's wollastonite reserves and producers (from Power 1988).

The Fox Knoll deposit graded 60% wollastonite, 40% garnet and impurties, but is no longer operating because of depleted reserves. The Lewis and Deerhead deposits contain 6 million and 500,000 tons respectively, at 59% wollastonite.

NYCO'S production capacity is in excess of 100,000 short tpa. Choate (1988) reported 1987 production at 50,000 tpa of which 40% was exported to markets in Europe and Japan. NYCO produces a high aspect or "long grain" material suitable for use as an asbestos substitute or high performance filler, and some of this high aspect material is surface treated (trade name Wollastokup) to further enhance the material's properties for use as functional fillers in plastics and similar applications. Four main grades are produced, described by Harben (1986) as follows:

> NYAD FP wollastonite coarse grade which runs 100% - 10 mesh with a 70 brightness.
>
> NYAD G wollastonite has an aspect ratio of 20:1 and a whiteness of 85. Base grade for G Wollastokup surface modified wollastonite.
>
> NYAD 400 mesh wollastonite with an aspect ratio of 5:1 and a whiteness of 90. Base grade for 400 Wollastokup surface modified wollastonite.
>
> NYAD 1250 wollastonite fine particle size grade with an aspect ratio of 3:1 and a whiteness of 94. Base grade for 10 Wollastokup surface modified wollastonite.

Garnet is also produced as a by-product in 6 sizes for skid-proof paints, tumble millings, and sand blasting.

RT Vanderbilt Co. Inc. operates a deposit on the west side of the Adirondacks, near Gouverneur, New York State, with reported reserves of around 1 million short tons (Power 1986). The geology is similar to the NYCO Fox Knoll deposit except garnet is virtually absent (Harben and Bates 1984). Some phrenite occurs toward the inner core of the ore body which becomes a blue calcite with occasional small graphite flakes. The origin of this ore body is still undetermined but evidence is continuing to develop that mylonitization was likely a large influence on the formation of the minerals (G.E. Erdman, Vice President and General Manager, Gouverneur Talc Co. Inc., personal communication, 1988).

Choate (1989) estimated 1988 production to be 27 kt (30,000 st.) Currently the majority of production is used as a filler in ceramics, paint, and plastics with small tonnages shipped to welding rod manufacturers for use in flux formulas. Three products are marketed: Vansil W-10 (max. 4% retained on a 200 mesh), Vansil W-20 (max. 2.7% on 325 mesh), and Vansil W-30 (max. 0.08% on a 325 mesh). The coarser Vansil 10 is preferred by ceramic and plastic users (G.E. Erdman, Vice President and General Manager, Gouverneur Talc Co. Inc., personal communication 1988).

Finland

Wollastonite is a common constituent of many marbles in south and southwest Finland. Presently Oy Partek operates the only producing deposit at Ihalainen located near Lappeenranta in southeast Finland. Wollastonite is produced as a by-product from their calcite flotation process. Bowie et al (1978) describes the geology of the deposit near Lappeenranta as follows:

"The Ihalainen limestone deposit, the largest in southern Finland, is surrounded by a large massif of rapakivi granite. It contains intercalations of leptite, and is cut by veins of rapakivi granite, pegmatite, and amphibolite. Wollastonite occurs in association with calcite, quartz, grossularite, diopside, and serpentine in the central part of the limestone and at its contacts with the rapakivi pegmatites."

The main wollastonite zone is 50 metres (150 ft.) wide with at least a 610 metre (2,000 ft.) strike length; additional lower grade zones are also present. The wollastonite occurs predominantly in beds 1 mm to 1m in thickness, consisting of a dense mass of relatively short fibres (Andrews 1970). The grade averages 18-20% but locally reaches 60% (Andrews 1970). Ore reserves are estimated at 4 million tonnes; additional reserves of approximately 20 million tonnes, grading 25-30% wollastonite and 40 to 70% calcite, have been identified on a newly discovered deposit at Savitapale, twenty miles northwest of Lappeenranta (Power 1986, Roskill Information Services Ltd. 1987).

Partek's flotation capacity has recently been expanded to 40,000 stpa wollastonite and 100,000 stpa calcite. In 1988 production was reported at 27 kt (30,000 stpa), largely consumed by the European ceramic, and welding rod industries (Choate 1989). Four standard grades of wollastonite are produced: 70 mesh (FW70), 200 mesh (FW 200), 325 (FW325), and 425 (FW425). High aspect wollastonite is available in four grades: 5, 10, 40, and 63 micron top cut. Finnish wollastonite is characterised by its low iron content, which does not exceed 0.3% Fe_2O_3 (Bowie et al 1978). A typical mineral composition of Partek's product consists of wollastonite 90%, quartz 4%, calcite 4%, and other silicates (2%), iron content (Fe_2O_3) typically 0.2%.

The genesis of the wollastonite is contact metamorphism of siliceous limestone by the rapakivi granite (Andrews 1970, Bowie et al. 1978).

Mexico

Mexican production is largely consumed by the domestic ceramic industries with occasional exports to Nicaragua and Ecuador. Past production has been erratic, and although current annual production is running above 10,000 short tons, it has declined from a high in 1980 of 20,905 tons (Power 1986).

Three companies (General de Minerales, Wollastonita de Mexico, and Fernandez Fuentes Judith) are presently producing. General de Minerales SA is the largest and operates two mines, one at Santa Fe near Noria del Cerro, 65 km southeast of Guadalupe, and the other near the town of Panfilo Natura approximately 50 km from Guadalupe. Four grades of wollastonite are produced: 3", 1/2", 1/4", and 200 mesh, which typically have the following chemical composition: SiO_2 49.82%, Al_2O_3 5.34%, Fe2O3 0.96%, CaO 38.4%, K_2O 0.34%, TiO_2 0.14%, LOI 4.56% (Smith 1981). The large Santa Fe deposit in the State of Chiapas is at least 90 m (300 ft.) thick, 430 m (1,400 ft.) long, and 120 m (400 ft.) wide. It is elliptical and dome-shaped and contains less than 1% associated minerals. It is unusually pure and impurity free (garnet and calcite), however near the edge of the deposit it contains contaminants of bornite, chalcopyrite, and garnet (Elevatorski 1983). Wollastonita de Mexico operates a mine in the La Blanc District, State of Zacatecas about 30 miles east of

Ciudad Zacatecas. The geology as described by Andrews (1970) is as follows:

"The wollastonite occurs in folded Cretaceous limestones where they are intruded by granite, in outcrops protruding through a cover of Tertiary volcanic rocks and Quaternary alluvium. The limestone dips away from the granite contact and is invaded by small apophyses from the granite. Wollastonite rock forms irregular tabular bodies about 8 ft. thick, conformable with the recrystallised limestone which is dark and impure with thin, light-coloured bands. Adjacent to the granite contact is a dark grey wollastonite-bearing marble containing a series of thin layers of garnet. The wollastonite in its purest form is clear and very white. An analysis given by the company is: SiO_2 51.7 per cent., CaO 46.2 per cent., (Al_2O_3, $CaCO_3$) 2.1 per cent. Crystals are either acicular or occur as radial laminae; in certain deposits, such as the San Dario and Ampliacion de San Dario, the needles are very small. Less pure, grey, wollastonite is abundant and this might be processed with a suitable beneficiation plant."

Other occurrences include wollastonite-grossularite-idocrase skarns in the Naica area of Chihuahua, Magistral area of Llanos District north of Puebla and near Xalostoc, Sierra Tlayacac in the state of Morelos. The Naica district has previously been worked for ores of zinc and other metals (Andrews 1970, Elevatorski 1983).

China

Wollastonite deposits have been identified in at least six provinces (Jilin, Heilongjiang, Liaoning, Anhui, Jiangxi, and Hubei), but only the deposits in Jilin and Anhui are of sufficient quality to compete for international markets (Foundation 1986). The wollastonite in Heilongjiang, Liaoning, Jiangxi, and Hubei contains about 2% Fe_2O_3, is grey or grey-yellow in colour and has a granular habit, thus restricting its application to low cost domestic wall tiles.

Jilin Province is located in the far northeast of China, north of North Korea. The three main producing deposits are (i) Panshi County, Changwaizi and Caoming Mountain Mining Areas, (ii) Yanbian District, Xilin River Mines, and (iii) Siping District, Lishu County, Dading Hills Mining Area. The combined proven reserves of these deposits are 20 million tonnes with an additional 55 million tonnes of inferred reserves. Anhui Province located in central China has an additional 14 million tonnes of inferred reserves, with production derived from three main areas: Thunder Mountain in Huaining, Tongling, and Guangde (Foundation 1986).

The deposits in both Jilin and Anhui Provinces occur in close proximity to metallic mineral deposits, in particular copper and iron ore mines, and together with quartz and calcite.

Commonly the ore is hand cobbed and sorted into 4 grades: special grade, first grade, second grade and reject. The approximate specifications for the individual grades are listed in Table 1. The graded material is then crushed to 100, 200, and 325 mesh.

TABLE 1 CHEMICAL SPECIFICATIONS OF CHINESE WOLLASTONITE

	SiO_2%	CaO%	Fe_2O_3%	MgO%	Al_2O_3%	LOI%	Whiteness%
Special	46-53	43-50	0.1-0.2	0.2	0.3-0.4	1-3	86-90
Grade 1	44-53	43-50	0.2-0.5	---	-------	2-5	
Grade 2	44-53	43-50	0.3-0.8	---	-------	4-7	

During 1985, China produced approximately 61,500 tonnes of wollastonite from Jilin and Anhui Provinces. The majority of this production was consumed by local ceramic industries but a small quantity was exported. However, the supply and quality of Chinese wollastonite continues to be questionable (Choate 1988). The Chinese domestic markets are rapidly expanding as the use of wollastonite gains greater acceptance in pigments, fillers, as a source of silica and calcia in ceramics and porcelains, coatings for electrodes, bonding agents, and in steel making as a protective slag (Foundation 1986). China has large reserves of wollastonite but presently lack the beneficiation technology (flotation, magnetic separation) required to produce the processed and modified end-products of NYCO, Partek, or R.T. Vanderbilt. China is currently attempting to resolve this dilemma by openly inviting foreign enterprises to invest funds and provide advanced technology to exploit non-metallic mineral resources (Cheng Hai 1988).

India

Wolkem Pvt Ltd. operates the Belkapahar deposit, the only producing deposit in the country. The deposit is located near the village of Khila in the Jodpur division of Rajastham. Proven reserves are approximately 50 m tonnes and probable reserves are estimated at 200 million tonnes (Smith 1981).

The geology consists of three wollastonite zones interbedded with pyroxenites and garnet-bearing gneisses. Associated minerals include calcite, garnet, diopside, and quartz. The wollastonite is hand sorted, then crushed and milled to produce 4 main grades: minus 300, 200, 160, and 100 mesh sizes (Power 1986). Wolkem

Pvt Ltd. produces a "long grain" or high aspect ratio wollastonite suitable for asbestos replacement, and plastic reinforcement applications. Production in 1985 was a reported 35,000 tpa (Power 1986) and 25,000 tpa in 1987 (Choate 1988) which not only supplied domestic ceramic and paint markets but allowed about 50% to be exported to Europe, primarly as crude ore.

Other producers

Small quantities of wollastonite are produced in New Zealand, Japan, Namibia, Kenya, Turkey, and Greece; the U.S.S.R. has over 50 deposits but information on production figures was not available. Canada does not presently produce wollastonite, although several occurrences are currently under investigation in Ontario, Quebec, British Columbia, and Nova Scotia.

PROPERTIES AND USES OF WOLLASTONITE

There is an increasing demand for wollastonite, as it becomes more readily available and as the trend toward higher productivity places more stringent demands on raw materials. The demand for wollastonite is expected to grow at an annual rate of 10% (Plumpton et al 1987). Choate (1988, 1989) reported an increased demand for wollastonite worldwide; major growth occurred in Europe with emphasis in thermal wallboard applications. Estimated world wollastonite production in 1988 totalled 180 kt (200,000 st).

Wollastonite is marketed according to its degree of acicularity or length to width (aspect) ratio. Low aspect ratio (3:1 to 5:1) wollastonite is used for ceramics, metallurgical fluxes, and simple filler and coating applications. High aspect ratio or "long grain" (15:1 to 20:1) material is used as a semi-fibrous asbestos replacement, and as a functional filler in various plastic and resin systems. In addition to aspect ratio, other properties that are utilized include high brightness/whiteness, low loss on ignition, low thermal expansion, high chemical purity, low oil absorption, chemical inertness, high pH in an aqueous slurry, and high thermal shock resistance. The following section briefly outlines some of the uses of wollastonite. A more detailed explaination can be found in Sargent (1972), Roskill Information Services (1980, 1987), and Power (1986). A list of important chemical and physical characteristics of wollastonite is presented in Table 2.

Ceramic Industry

In recent years, the ceramic industry's need for a higher quality, more versatile ceramic raw material has enabled wollastonite to make significant gains over the more traditional ceramic materials (dolomite, talc, and feldspar) in wall tile and glaze applications. Primarily due to the trend toward faster-firing processes, materials are sought which are able to withstand greater thermal shock, increased mechanical handling and reduced evacuation of the gas phase evolved during firing (Power 1986).

The majority of wollastonite consumed by the ceramics industry is used in wall tile bodies, and coating-glaze applications,

TABLE 2 TYPICAL CHEMICAL AND PHYSICAL CHARACTERISTICS OF WOLLASTONITE

THEORETICAL FORMULA (1) $CaSiO_3$ calcium metasilicate
THEORETICAL COMPOSITION (1) CaO 48.37% SiO_2 51.73%
CRYSTAL HABIT (1) tabular or acicular
ASPECT RATIO (1) (length/width ratio) 3:1 to 30:1
SPECIFIC GRAVITY (2) 2.8-3.0
HARDNESS (1) (Mohs' scale) 4.5-5
COLOUR (6) brilliant white (pure)
grayish to brownish (impurties)
very pale green
BRIGHTNESS (G.E.) (1) 92-96%
LUSTRE (2) vitreous to pearly
REFRACTIVE INDEX (3) 1.616-1.631
MELTING POINT (1) 1540°C
WATER SOLUBILITY (1) 0.0095 g./100 ml (25°C)
POLYMORPHS wollastonite (low temperature)
parawollastonite (low temperature)
pseudowollastonite (high temperature)
COEFFICIENT OF EXPANSION (1) (25-800°C) 6.5×10^{-6} mm/mm/°C
(wollastonite)
(25-800°C) 11.8×10^{-6} mm/mm/°C
(pseudowollastonite)
INVERSION OF WOLLASTONITE TO PSEUDOWOLLASTONITE (1) 1120-1200°C*
PH (10% WATER SLURRY) (2) 9.9
CHEMICAL RESISTANCE (1) attacked by acids
FLUORESCENCE (2) yellow-orange to pink orange
may also phosphoresce
OTHER PROPERTIES
CHEMICALLY INERT (4)
LOW OIL ABSORPTION RATE (3,4) 20-26 ml/100g
LOW LOSS ON IGNITION (5) generally <1%
HIGH MODULUS OF RUPTURE (6)
HIGH THERMAL SHOCK RESISTANCE (6)
LOW MOISTURE ABSORPTION (2)
GOOD TENSILE, IMPACT PROPERTIES (2)
EXCELLENT ELECTRICAL INSULATION PROPERTIES (2)

SOURCES (1) SARGENT (1972)
(2) ELEVATORSKI (1983)
(3) SMITH (1981)
(4) ROSKILL INFORMATION SERVICES (1980)
(5) POWER (1986)
(6) LADOO (1960)

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* Andrews (1970) reported that there is some disagreement about the inversion temperature but the lower value seems acceptable as the true value.

however, smaller quantities are also used in earthenware, sanitary ware, and various specialized ceramic body applications.

Wollastonite's acicular habit, low thermal expansion, low loss on ignition, high chemical purity and whiteness, all contribute to the desirability of wollastonite as a ceramic raw material.

Paint Industry

Wollastonite has to compete with numerous cheaper materials (kaolin, nepheline syenite, calcium carbonate, talc, asbestos, barytes, mica, attapugite, diatomite, and silica) in simple filler applications. Therefore, its use is primarily restricted to speciality paints, such as anti-corrosive coatings, and textured paints. It is used in both water and oil-based paints, caulking compounds, traffic paints, acoustic tile coatings, as a replacement in asphalt-based coatings, semi-gloss enamels, polyvinyl acetate emulsions, primers, and sealers (Smith 1981).

Qualities of wollastonite that are utilitzed for paint applications include high brightness and whiteness, acicular shape, low oil absorption, and high pH (9.9). The high whiteness and very low oil absorption reduce pigment load and the volume of expensive binder that is required which reduces overall pigment costs. The acicular habit increases the durability of the paint and acts as a good flattening agent. In polyvinyl acetate paints (PVA), wollastonite acts as an anti-corrosive by maintaining the alkaline nature of the paint (Power 1986).

Plastics Industry

There is significant potential for growth in the use of wollastonite as a performance filler in resins/plastics, where it is used as a resin extender and reinforcing agent.

Wollastonite is primarily used where the performance of the product is more important than the relative cost.

Surface modification of the wollastonite with a coupling and/or wetting agent improves the compatability between filler and resin/plastic media and changes it from a utilitarian filler to a functional component of a polymer composite (NYCO pamplet). This results in a reduction in the volume of expensive media required and improves the physical, chemical, and electrical properties of the finished product (ie. improved flexural and tensile strength, good moisture repellent properties). Chemically-treated wollastonite is also more attractive to the producer because of its added-value. NYCO, because of the high aspect nature of its product, is currently directing the majority of its production toward this market (Power 1986).

Other Uses

Additional applications include use as an asbestos replacement, metallurgical flux, welding rod coatings, oil filters, plywood, matches, building stone, slag additive, and in the manufacture of glass, fibrated aluminum coatings, insulation, and paper (Sargent 1972, Roskill Information Services 1980, Smith 1981, Power 1986).

The increasing concern over potential health hazards associated with the use of asbestos has helped wollastonite gain greater acceptance as an asbestos alternative, particularly in asbestos short fibre markets. As a result, there is increased substitution of wollastonite for asbestos in some cement formulations in ceiling and floor tiling, friction applications (ie. brake linings) and as a semi-fibrous reinforcement filler in boards and panels in various heat containment applications.

Wollastonite is a natural low temperature fluxing material and has been reputed to produce better surface finishes to steel than those produced by silica and lime mixtures.

Substitution of wollastonite for limestone in the manufacture of glass results in faster melts and drawing rates and requires 33% less volume of raw material to produce an equivalent amount of melt (Roskill Information Services 1980). In addition, wollastonite has an added advantage in that it contributes both silica and lime to the melt. However, wollastonite is more expensive and generally cannot meet the low iron specifications of the more specialized glasses.

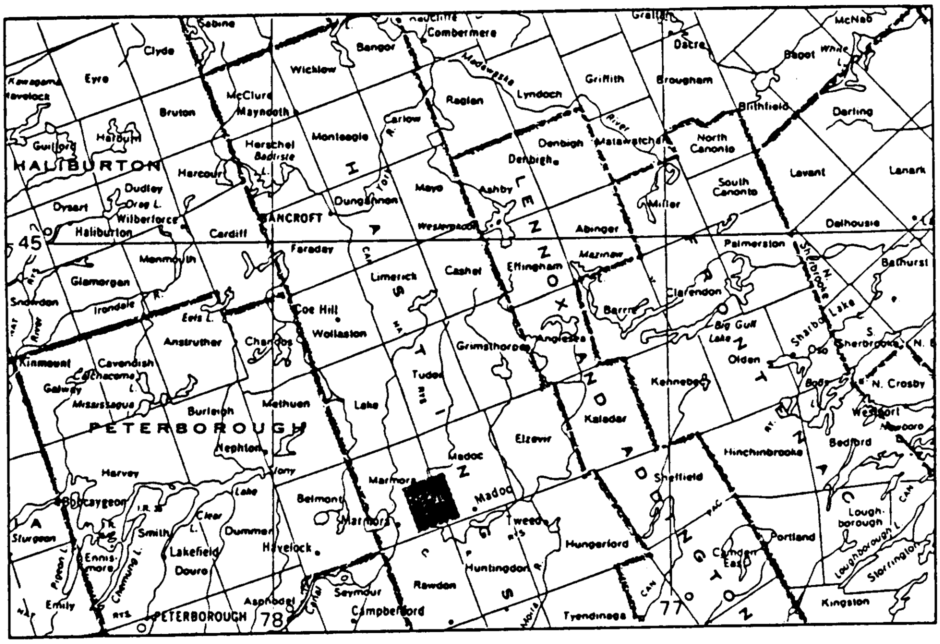
Wollastonite may also have application as a soil neutralizer because of its alkaline nature.

PART II

MARMORA STUDY AREA

LOCATION AND ACCESS

The Marmora Study area (Figure 3) lies about 175 km northeast of Toronto and 5 km east of the town of Marmora, Ontario. Highway 7 and the old Marmora-Madoc road traverse the southern part of the study area and County Road 11 provides access to the northern part. Farm and private roads, as well as an abandoned Canadian National Railroad right-of-way provide additional access in the northern region of the map area.



Scale: 1:1 584 000 or 1 inch to 25 miles

Figure 3. Location map, Marmora study area

PRESENT GEOLOGICAL SURVEY

Geological mapping of the Marmora study area commenced with reconnaissance mapping at a scale of 1:10,000 to identify wollastonite occurrences, followed by more detailed mapping of occurrences considered to have good potential for development. The preliminary reconnaissance encompassed an arcuate area, 1.0 to 1.5 km wide and extending 10 km along the western margin of the Deloro Pluton in Marmora and Madoc Townships.

Field data was plotted on 1:10,000 aerial photographs obtained from the Ministry of Natural Resources, Tweed Office and transferred to Forest Resources Inventory base maps of the same scale.

PREVIOUS GEOLOGICAL INVESTIGATIONS

Geological mapping in the Marmora Study area has been done by Coste (1886, 1:31,680 scale), Wilson (1940, 1:63,360 scale), and Bartlett and Moore (1983, 1:15,840 scale). In addition, the area is included in compilation maps by Hewitt and Satterly (1957), Lumbers (1964), Springer (1978), and Kingston et al (1985). The Paleozoic rocks of the area have been mapped by Carson (1980, 1:50,000 scale), and are currently being investigated by D.A. Williams (Geologist, Ontario Ministry of Northern Development and Mines, personal communication, 1989) at the same scale. Detailed studies of the Deloro Pluton have been made by Saha (1959), Kuehnbaum (1973), Wu (1984), Wu and Kerrich (1986), and Abdel-Rahman and Martin (1987). Bourque (1981, 1982) examined the carbonate rocks in Marmora and Belmont Townships in order to ascertain their paleoenvironments.

GENERAL GEOLOGY

The area is located near the southwestern boundary of the Central Metasedimentary Belt of the Grenville Province (Wynne-Edwards 1972). Hewitt (1956) refers to this area as the Hastings Basin while Lumbers (1967) prefers Hastings Region. The Hastings Basin is an area of middle greenschist regional metamorphism centered around Millbridge, Ontario (Figure 4). Supracrustal rocks within the Hastings Basin are believed to be the thickest in the Grenville Province (Wynne-Edwards 1967). Lumbers (1967) divided the supracrustal rocks into two conformable groups, the Mayo and Hermon groups. The Mayo group contains rocks primarily of metasedimentary origin while the underlying Hermon group consists predominantly of metavolcanic rocks.

Bartlett (1985, Figure 5) describes the stratigraphic succession in northern Marmora Township as becoming progressively younger from north to south with dark grey-green, homogeneous, fine-grained amphibolites of volcanic origin representing the oldest lithology in the township. Bedded tuff, breccia, and pillows may occur locally. These are succeeded to the south by quartzofeldspathic clastic metasediments, and intercalated fine-grained pyritic-biotite schists, which are in turn succeeded by impure to pure carbonate metasediments.

The carbonate metasediments are predominantly calcitic in composition, and may be interbedded with siliciclastic metasediments, and/or calc-silicated rocks. In contrast, the carbonate metasediments in Belmont Township are generally

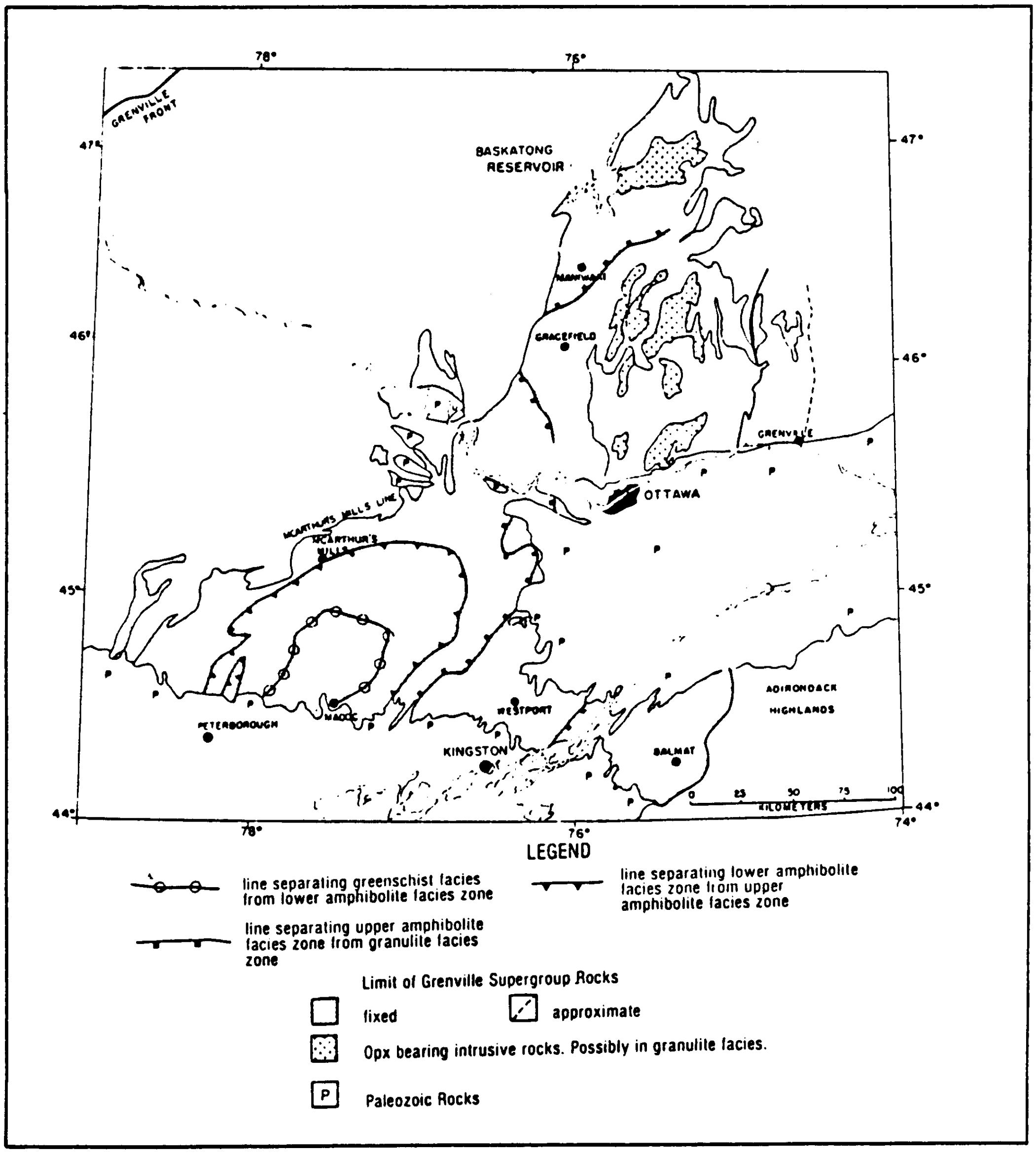


Figure 4. Distribution of metamorphic grade in rocks of the Grenville Supergroup (from Sangster and Bourne 1982).

relatively pure and dolomitic in composition.

Intruding the supracrustal rocks are mafic to felsic plutonic rocks which include the Cordova Gabbro, Twin Sister and Shanick diorites, Gawley Creek Syenite, Malone and Deloro granites, and numerous smaller bodies and dykes. Contact metamorphic aureoles have developed in the surrounding country rock. The aureoles may vary to an apparent width of 0.8 km and be metamorphosed to pyroxene-hornfels metamorphic facies.

Contact metasomatic magnetite skarns, and calc-silicate rocks have developed within marbles or near their contact with intrusive rocks. The magnetite deposits form small tabular to podiform bodies of massive to disseminated magnetite along the western and northern margins of the Deloro Pluton. The calc-silicate rocks may include the minerals tremolite, talc, quartz, wollastonite, diopside-hedenbergite, serpentine, scapolite, idocrase, andradite, and grossularite.

In addition, along the western contact of the Deloro granite is a north trending fracture system controlling auiferous arsenopyrite-quartz-carbonate veins and minor intrusions. Generally small and discontinuous, the veins lie both within the margin of the granite and within the greywacke and limestone (Sangster and Bourne 1982). Commonly associated minerals include arsenopyrite, chalcopyrite, pyrrhotite, pyrite, native gold, ankerite, biotite, muscovite, fluorite, zircon, hematite, magnetite, and tourmaline (Hurst 1927).

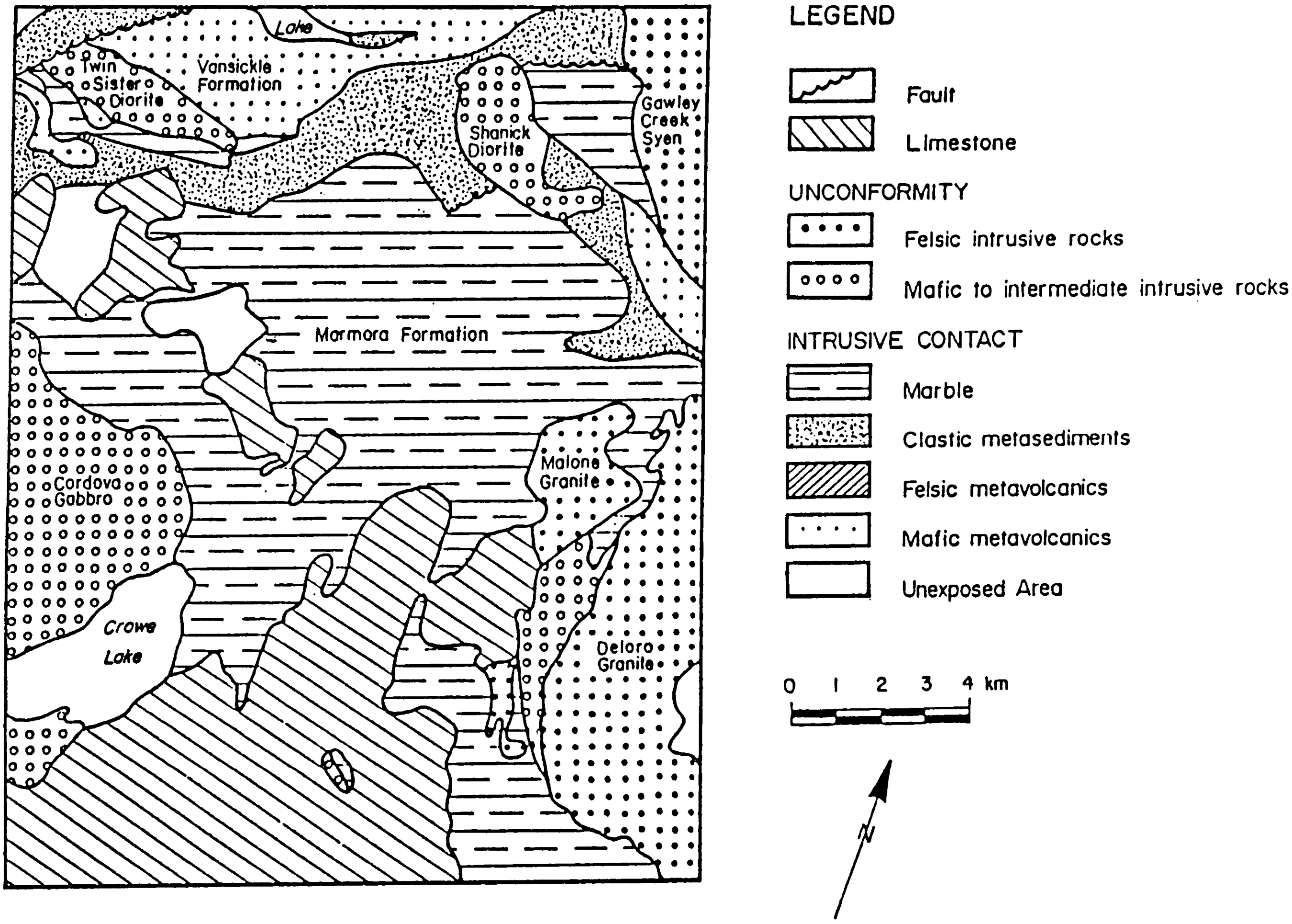


Figure 5. Marmora Township illustrating the distribution of the formations and major igneous intrusions (from Bartlett and Moore 1985).

Paleozoic sedimentary rocks unconformably overlie Precambrian rocks in the southwestern part of the township and occur as a series of northwest-trending outliers. The rocks are of middle Ordovician age and include the Shadow Lake, Gull River, and Bobcaygeon Formations.

Low temperature (75 - 150 degrees C) fluorite-barite-calcite veins believed to be genetically related to the faults of the Ottawa Valley graben system crosscut both Precambrian and Paleozoic cover rocks. The veins strike east to southeast, parallel to the faults. In Madoc Township, these have previously been mined, however, no significant concentrations have been identified in Marmora Township.

STRUCTURAL GEOLOGY

The Precambrian rocks were subjected to several periods of deformation and metamorphism beginning with the development of a homoclinal succession by isoclinal folding (D1) about a north-striking east-dipping axial surface. Regional metamorphism (M1) began during D1 and continued well into D2. Metamorphic overprinting of some of the plutonic bodies and the preservation of high-grade metamorphic mineral assemblages in their aureoles support this conclusion. A regional plutonic event (M2), (syn-D1 and pre-D2) commenced with the emplacement of mafic to intermediate plutons which differentiated to produce felsic derivatives. A later NW-SE compression (D2 and D3) produced closed to open folding (Bartlett 1985). The D2 fabric is best illustrated in the marbles which appear to wrap around the plutonic bodies.

Post-Flinton auriferous-arsenopyrite-quartz-carbonate-base metal-sulfide veins occur along the western contact of Grenvillian supracrustal rocks with the Deloro Pluton. Sangster and Bourne (1982) believed vein formation probably occurred during M2 when shearing related to ductility contrasts provided suitable sites for deposition of elements mobilized by steep thermal gradients related to the metamorphism.

The Precambrian-Paleozoic rocks have been transected by southeast to east trending normal faults (D4). In Marmora Township these faults frequently exhibit displacements of 50m or more (D. Williams, Geologist, Northern Development and Mines, personal communication, 1988). The faults are part of the Ottawa Valley graben system and are probably similar in age to mica-peridotite dykes at Picton and Varty Lake dated Jurassic-Cretaceous (Williams, in preparation). Fault exposure is generally poor and faults, because of their susceptibility to weathering, are commonly inferred from topographic linears. Williams and Thompson (1986) describe fault traces as normally gently curved but may be distinctly curved in the vicinity of fault junctions.

Fluorite-barite-calcite veins occur in tension fractures parallel to the faults of the Ottawa Valley graben system. The veins crosscut both Grenville and Paleozoic cover rocks and commonly have a left-lateral en-echlelon occurrence. Economic concentrations have previously been mined in Madoc Township close to fault junctions.

METAMORPHISM

The Marmora study area is located within the Hastings Basin, (Figure 4) an area of middle greenschist regional metamorphism centered around Millbridge, Ontario (Hewitt 1956).

Contact metamorphism of the adjacent sediments resulting from the intrusion of mafic to felsic plutonic rocks has developed exoskarns to varying degrees. Along the western margin of the Deloro Pluton the effects of contact metamorphism appear to extend up to 0.8 km into the adjacent country rock, however this may not represent the true width since the contact is dipping and the country rock has been folded about a NE axis. Faulting may have further enhanced the metamorphic effects by providing conduits for the movement of heat and fluids into the surrounding country rock.

Because the highest temperature of contact metamorphism occurs in the direct vicinity of the intruding magmatic body, zonation normally commences with a zone of highest temperature minerals close to the intrusive body followed by successive zones of assemblages of lower temperature minerals as distance from the intrusion increases. The sequence of reactions in the progressive metamorphism of siliceous dolomites (Bowen 1940) has been modified through experimentation (Harker and Tuttle 1956): the sequence progresses through talc, tremolite, diopside, forsterite, wollastonite, periclase, and monticellite. There is a progressive decarbonatization and dehydration with increasing temperature.

Wollastonite-bearing skarns are thought to have formed during the late stages of igneous activity in well defined zones at the igneous-marble contacts (Andrews 1970). The optimum temperature of formation of wollastonite and diopside from calcite and quartz and/or siliceous hydrothermal fluids is 500-700 degrees C. (Kalinin 1966a, 1966b; Kalinin and Lokhava 1966), although these minerals have been experimentally observed to form as low as 350-400 degrees C. (Kalinin 1967). Winkler (1976) reported that "wollastonite is never found in rocks metamorphosed at relatively low temperatures of 400 to 500°C, not even in contact metamorphic rocks formed at shallow depths corresponding to only a few hundred bars."

Wollastonite forms around 600 degrees C. in the contact aureoles around shallow-seated intrusions at a depth of 2 km (500 bars). The temperature of formation of wollastonite was determined to increase to 650-670 degrees C. at depths of 4 km, and to over 700 degrees C. at depths of 8 km or more (Winkler 1976).

The metamorphic grade within the inner contact zone of the Deloro Pluton reached pyroxene-hornfels facies (Turner 1968) with the development of wollastonite in the silica-rich calcitic assemblages and the development of calcite-forsterite-periclase and calcite-forsterite-diopside in the silica-deficient dolomitic marbles. These same assemblages may occasionally be developed under conditions of hornblende-hornfels facies where higher temperatures or lower PCO_2 than normal may be inferred. Therefore it becomes apparent that wollastonite is not a reliable temperature indicator if nothing is known about the composition of the fluid phase (at any given fluid pressure the equilibrium temperature increases with increasing XCO_2).

The formation of wollastonite and the dissociation of dolomite into periclase and calcite in the inner contact zones suggests the Deloro intrusion must have risen to shallow depths where the fluid pressure must have been very low, since wollastonite and periclase are not stable in the presence of excess CO_2. According to Wu and Kerrich (1986) the Deloro Pluton exhibits shallow explacement characteristics (<2.5 km), suggesting a temperature of wollastonite formation of about 600 degrees C.

The aforementioned assemblages in silica-poor dolomitic marbles may be produced by the following reactions or combination of reactions:

$$\underset{\text{dolomite}}{MgCa(CO_3)_2} = \underset{\text{calcite}}{CaCO_3} + \underset{\text{periclase}}{MgO} + \underset{\text{carbon dioxide}}{CO_2} \qquad (1)$$

$$\underset{\text{dolomite}}{MgCa(CO_3)_2} + \underset{\text{quartz}}{2SiO_2} = \underset{\text{diopside}}{CaMgSi_2O_6} + \underset{\text{carbon dioxide}}{2CO_2} \qquad (2)$$

$$\underset{\text{diopside}}{CaMgSi_2O_6} + \underset{\text{dolomite}}{3MgCa(CO_3)_2} = \underset{\text{calcite}}{4CaCO_3} + \underset{\text{forsterite}}{2Mg_2SiO_4} + \underset{\text{carbon dioxide}}{2CO_2} \qquad (3)$$

The formation of periclase through dissociation of dolomite was termed dedolomitisation by A. Harper (Mason 1978). The magnesium of the dolomite is all used in forming diopside or forsterite.

As is frequently the case in high grade magnesium assemblages, brucite pseudomorphs periclase; forsterite is replaced by serpentine; and diopside is partially to completely replaced by tremolite. These retrograde changes (reactions 4-6) are the expected consequence of a reaction with juvenile gas (PH_2O high compared with PCO_2) during post-metamorphic cooling (Turner 1968).

$$\underset{\text{periclase}}{MgO} + H_2O = \underset{\text{brucite}}{Mg(OH)_2} \qquad (4)$$

$$\underset{\text{forsterite}}{4Mg_2SiO4} + 6H_2O = \underset{\text{serpentine}}{2Mg_3Si_2O_5(OH)_4} + \underset{\text{brucite}}{2Mg(OH)_2} \qquad (5)$$

$$\underset{\text{diopside}}{5CaM_gSi_2O_6} + H_2O = \underset{\text{tremolite}}{Ca_2Mg_5Si_8O_{22}(OH)_2} + \underset{\text{calcite}}{3\ CaCO_3} + \underset{\text{silica}}{2SiO_2} \qquad (6)$$

As a result of hydration the observed assemblages in the field are: brucite-serpentine-calcite, brucite-calcite±dolomite ±graphite, serpentine-calcite, serpentine-diopside-calcite ±tremolite and calcite-serpentine-tremolite.

Talc was identified by x-ray diffraction techniques in some samples. On the Platinova-Cominco property talc was found in a fracture within the wollastonite zone, thus indicating late stage low grade hydrothermal activity during post-metamorphic cooling or overprinting by low grade regional metamorphism.

In the calcitic assemblages, primary silica in the limestone reacted with calcite in the limestone resulting in the following reaction to produce wollastonite:

$$\underset{\text{calcite}}{CaCO_3} + \underset{\text{quartz}}{SiO_2} = \underset{\text{wollastonite}}{CaSiO_3} + \underset{\text{carbon dioxide}}{CO_2} \qquad (7)$$

However, the wollastonite in the magnetite pit on the Kelly-Czerewko property is probably metasomatic in origin.

The main wollastonite assemblages observed in the field include: quartz-calcite-wollastonite-diopside, calcite-wollastonite-diopside, quartz-wollastonite-diopside ± garnet. The assemblage quartz-calcite-wollastonite-diopside implies the reaction occurs along the isobaric equilibrium curve, but may also occur where wollastonite selvages have prevented further reaction between calcite, and quartz. This assemblage was identified, as was quartz-wollastonite-diopside ± garnet on the Kelly-Cwerewko property. The assemblage diopside + calcite + quartz will be replaced with increasing metamorphic grade by either diopside + calcite + wollastonite or diopside + quartz + wollastonite depending on the bulk composition of the rock.

The paragenesis: quartz + grossularite + diopside + wollasonite + calcite was observed in a narrow reaction skarn on the west side of the Platinova-Cominco property and on the Rahm property. The paragenesis: quartz + grossularite + diopside + wollastonite is characteristic of the amphibole - hornfels metamorphic facies (Reverdatto 1973). The presence of calcite with the assemblage wollastonite + grossularite + quartz was reported to be extremely rare, and the formation of wollastonite + grossularite + quartz at temperatures less than 520^{o} C. to appear unlikely.

DESCRIPTION OF MAP UNITS

Outcrop designations were made on the basis of the predominant lithology (map located in back pocket).

MAP UNIT 1 - SILICEOUS METASEDIMENTS

Map Unit 1a -- Siliciclastic metasediments

At the northern end of the Malone Pluton the siliciclastic metasediments are predominantly calcareous wacke/siltstones and schists with subordinate calcitic marble, and millimetre to centimetre interlayered wacke and calcitic marble. Typically, these rocks are light to dark grey in colour, with a slatey to schistose texture. They are composed of fine-grained quartz, feldspar, chlorite, carbonate, sulfides, and hematite. The feldspar and quartz grains are generally subround and average <1 mm.

Calcitic, and minor dolomitic marble along the eastern border of the Deloro Pluton may be locally interlayered on a centimetre scale with subordinate siliciclastic metasediments.

Map Unit 1b -- Hornfels*

This rock is microcrystalline to fine-grained and dark grey to green and brown or reddish in colour. The texture varies from massive to thinly laminated (mm scale) to thickly banded, and locally brecciated. The bands reflect mineralogical differences in the rock and probably represent variations in the original chemistry. Bands vary in width from less than 1 mm to tens of centimetres, but are generally less than 30 cm. The mineral assemblage may include diopside, microcline, quartz,

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*The term hornfels is used in a descriptive sense for fine-grained metasomatically altered siliceous or aluminous rocks (Einaudi and Burt 1982).

clinozoisite, chlorite, grossularite, calcite, plagioclase, scapolite, epidote, idocrase, tremolite, mica, and minor amounts of apatite, magnetite, or hematite.

Previously this unit had been mapped as unsubdivided felsic intrusive, microgranite, and felsite by Bartlett and Moore (1983) and as clastic metasediments by Wilson (1940). The current investigation supports the clastic metasedimentary origin proposed by Wilson (1940) (wackes/siltstones/mudstone). In most cases, the original nature and mineralogy of the rock has largely been obscured because of the extreme fineness of grain size and the contact metasomatic/metamorphic effects produced by the intrusion of the Deloro Pluton which have largely converted the rock to skarn-type mineralogy. Mineralogical distinctions predominantly observed by x-ray diffraction and to a lesser extent thin section examination suggest that this unit may represent several rock types of varying origins which occur as a mappable unit because they have undergone similar metasomatism/metamorphism.

MAP UNIT 2 - CARBONATE METASEDIMENTS

Map Unit 2a -- Brucitic calcitic marble

This unit consists predominantly of white, fine-to medium-grained, calcitic and minor dolomitic marble. Accessory minerals include dolomite, brucite, serpentine, tremolite, and iron oxides. The weathered surface is grey to buff in colour with a finely pitted (<1 mm in diameter) granular texture, the result of brucite weathering out of the rock.

Brucite is a major constituent of this unit, comprising from 10 to 25% of the rock. Commonly, it occurs as fine-grained granules and fine-to medium-grained platelets. In addition coarse-grained brucite up to 30-40 cm in length was noted in the waste pile of a small Stoklosar quarry located between Malone and Deloro, suggesting that brucite has been dervied through several chemical reactions, firstly from hydration of periclase and secondly by alteration of dolomite along fractures. Thin section examination of these granules indicates that the periclase has been completely replaced by brucite.

Map Unit 2b -- Serpentinized calcitic marble

The marble varies from a microcrystalline rock, dark green to grey in colour, to a fine-to medium-grained, white, equigranular-textured marble similar in appearance to map unit 2d except that it contains blebs or veins of fine-grained serpentine up to 20 cm in thickness. The majority of the rock is composed of calcite and serpentine with lesser amounts of tremolite, dolomite, diopside, and pyrite. The green and grey variety frequently develop a soft, brown to rusty coloured weathering rind, several centimetres in thickness. The rock is massive to weakly foliated and composed of fine-grained xenoblastic calcite grains intergrown with laths of serpentine and chlorite. The marble is calcitic to slightly dolomitic in composition. Minor talc alteration of serpentine was observed in one thin section.

Map Unit 2c -- Siliceous calcitic marble

This rock is a siliceous variety of map unit 2d.

Map Unit 2d -- White, calcitic marble

This unit is a massive, fine-to medium-grained, crystalline marble. The marble is predominantly white and to a lesser extent grey-white in colour, with a granoblastic texture. It is composed essentially of calcite and may contain minor amounts of quartz, tremolite, phlogopite, and disseminated sulfides (pyrite). Locally, hematite has stained the rock pink in colour. It forms a continuous unit 800m long by 60 to 120m wide along the western edge of a tongue of Deloro granite on the Bonter property (Guillet 1985).

Map Unit 2e -- Grey, calcitic marble

The calcitic marble is typically fine-to medium-grained, grey or grey and white in colour, with well-developed layering on a millimetre to centimetre scale. Common accessory minerals include tremolite, quartz, sulfides, and hematite. Locally, the predominately calcitic marble may alternate with subordinate fine-to medium-grained, grey to buff weathered dolomitic marble and at a millimetre to centimetre scale with fine-to medium-grained siliciclastic units.

Rhythmic centimetre scale layering and fine vein networks of siliceous material in carbonate sediments was intrepreted by Bourque (1981) to represent stromatolites.

Map Unit 2f -- Diopsidic skarn

At several localities near the contact with the Deloro Pluton a diopside-rich skarn has developed, frequently adjacent to wollastonite mineralization (map unit 3). The skarn is typically massive, microcrystalline to fine-grained and light green in colour. The weathered surface is orangish to white in colour. The mineral assemblage consists predominantly of diopside with subordinate calcite, serpentine, and pyrite.

In thin section,the rock has a granular or hornfels texture with diopside occurring as fine-grained, equant, xenoblastic grains.

Map Unit 2g -- Talc-carbonate rock

Several outcrops of talc-carbonate rock were identified on the Bonter property, south of Malone. The rock appears massive, microcrystalline to fine-grained, and white to light green in colour. The majority of the rock consists of fine-grained talc and carbonate, with minor serpentine noted in some samples. It is similar in appearance to the microcrystalline, light green variety of map unit 2b (serpentinized calcitic marble) and map unit 2f (diopsidic skarn); map unit 2g is distinguished in the field based on hardness and non-reactivity to dilute HCl acid.

North of Hwy. 7, the mineralized zone of the Platinova-Cominco property contains several small (up to several centimeters) dark green to black veins. One sample consisted of fine, white bands of calcite interlayered with dark brown talc and in places with tiny, black aggregates of sphene. Several dykes at this locality have also been partially altered to talc.

Map Unit 3 -- Wollastonite-calcitic marble/calc-silicate rock/ skarn

Wollastonite mineralization is hosted by white, fine-to medium-grained, massive to foliated calcitic marble, calc-silicate rock, or skarn. The contacts between the calc-silicate rock and other metasedimentary units (marble, hornfels rock) are usually sharp but locally may grade into wollastonite-poor white-grey marble. The main constiuents of the rock are calcite, diopside-hedenbergite, wollastonite, and quartz in varying proportions. Locally, accessory minerals may include minor quantities of grossularite, tremolite, talc, barite, fluorite, apatite, and disseminated sulfides (pyrite). In addition, magnetite, andradite, and idocrase were found associated with wollastonite in a skarn zone on lot 16 concession 8, Marmora Township (Kelly-Czerewko property).

The wollastonite occurs as tabular to prismatic, medium-to coarse-grained crystals up to 6 cm in length or as fine-to medium-grained acicular clots and radial aggregates from 1-30 cm in diameter. The grade varies from 1-2% where it occurs as small isolated clots to at least 40-50% of the rock, and commonly averages 20-30%. The zones are usually small (<10m in width) and pod-like in appearance, and probably represent remnant roof pendants.

The texture varies from massive to strongly foliated and banded. Where massive, the wollastonite is commonly coarser-grained, more quartz-rich, friable and frequently fractures into fan-shaped fragments. South of Malone, on the Bonter property the wollastonite is commonly interbanded with fine-to medium-grained calcite, fine-grained light green diopside, and white to light grey quartz. Individual layers are generally .5 to 4 cm in thickness but may vary to tens of centimetres.

On lot 6, concession 8, between the Deloro West and Platinova-Cominco zones, the calc-silicate rock/skarn differs in appearance. Here, the rock is microcrystalline to fine-grained and white to greenish in colour. The characteristic pitted weathered appearance is not evident at this locality. The rock has a massive to banded texture. In thin section, the rock (based on 3 sections) contains wollastonite (35-45%), grossularite (15-20%), diopside (5-20%), quartz (5-15%), calcite (5-20%), and minor to trace amounts of apatite. The zone appears to be narrow (several metres) and may represent a reaction skarn betweed the hornfels unit and the marble.

The uncovered weathered surface is unique, and quite useful in indicating the presence of wollastonite in the rock. This surface is a mottled grey or black in colour, and has a pitted appearance, with the calcite standing out in relief and the wollastonite weathering low (Photo 1). However, this relationship is reversed, as might be expected, where overburden has prevented grain disintegration by weathering. This feature was particularly evident at the Platinova-Cominco property where it had been stripped north of Highway 7 (Photo 2).

Map Unit 4 -- MAFIC INTRUSIVE ROCKS

Most of the mafic intrusive rocks within the map area occur in a complex, heterogeneous zone of dioritic, gabbroic, syenitic and granitic rocks along the western margin of the Deloro Igneous Complex (Abdel-Rahman and Martin 1987), commonly referred to as the Deloro Pluton. However, there is a general progression eastward toward rocks more felsic in composition. East of Deloro, the progression is from hornblende-plagioclase gabbro at the margin near the Moira River, through diorite, to syenite, with a corresponding increase in perthite and decrease in plagioclase and hornblende (Bartlett and Moore 1985).

The criteria used to differentiate the mafic rocks in the field were primarily their colour index and grain size. Accordingly, three units were distinguished in the present mapping: medium-to coarse-grained gabbro (map unit 4a), fine-grained gabbro (map unit 4b), and diorite (map unit 4c).

The rocks are generally massive, phaneritic, medium-grained, and weather grey to white in colour. The colour index varies from 25-35 for diorite to 40-70 in the gabbros. The mineral assemblage consists predominantly of plagioclase and hornblende, and to a lesser extent actinolite and biotite. It may also contain pyroxene, quartz, carbonate, clinozoisite, epidote, sericite, chlorite, sphene, apatite, sulfides (pyrite), and hematite. Chlorite is usually more abundant in rocks where biotite is the major mafic constiuent. Pyroxene has been partially to completely altered to either hornblende, actinolite, biotite, or chlorite. Plagioclase phenocrysts are commonly either saussuritized to a fine-grained aggregate of epidote or sericitized and may be partially replaced by carbonate.

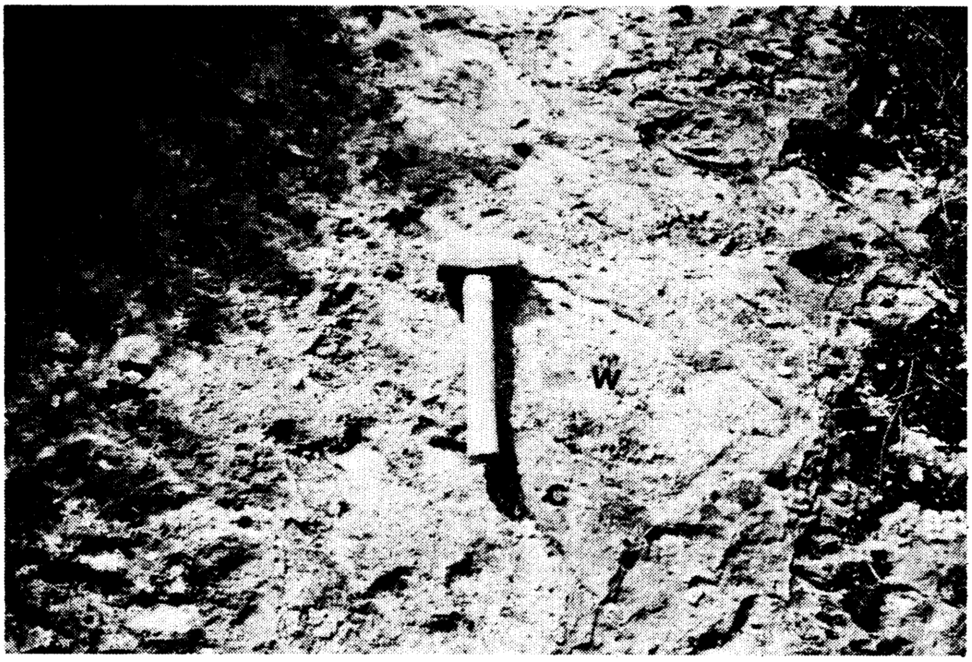


Photo 1. Uncovered weathered surface of wollastonite-bearing calc-silicate rock on the Platinova-Cominco property illustrating wollastonite weathering low and calcite high.

Photo 2. Overburden covered weathered surface of wollastonite rock showing wollastonite in high relief and calcite in lower relief.

Mafic to intermediate dykes up to 3.5 m in width frequently intrude the carbonate metasediments along the periphery of the Deloro Pluton. These dykes are probably hypabyssal in origin, a theory supported by Bartlett and Moore (1985). Typically they are massive, medium-grained and grey-green to black in colour. Fine-grained phases may represent a chilled phase of the intrusion. Commonly these dykes have been metamorphosed to medium-grained amphibolites, composed primarily of hornblende and plagioclase. These dykes predate the deformation event that deformed the marbles adjacent to the Deloro Pluton.

Skarn zones of varying widths have developed adjacent to these border rocks and shear-zones within them contain auriferous quartz-carbonate veins.

Map Unit 5 -- FELSIC INTRUSIVE ROCKS

Felsic intrusive rocks within the map area include the Deloro Igneous Complex, the Malone Pluton and numerous smaller bodies and dykes. These rocks intrude siliciclastic metasediments, calcitic marbles and minor dolomitic marbles of the Hastings Basin. Along the eastern margin of the Deloro Pluton felsic rocks intrude andesitic to rhyolitic metavolcanics.

Contact metamorphism and metasomatism resulting from the emplacement of the plutons have produced metamorphic aureoles up to 0.8 km in apparent width in which skarns and calc-silicate rocks have developed. Contact metasomatic iron occurrences in marble-rich metasediments are spatially related to the potassic granitic rocks of the Deloro Pluton.

The Deloro Igneous Complex occupies a crescent-shaped area of approximately 35 sq. km. in Marmora and Madoc Townships. Only the western edge of the pluton was examined during the course of this investigation. As previously mentioned, this area is a heterogeneous zone of dioritic, gabbroic, syenitic, and granitic rocks. Small bodies or xenoliths of diorite and gabbro are frequently enclosed by more felsic rocks of syenitic to granitic composition. The complex contains three intrusive phases, although not all are present within the study area. The intrusive is zoned oldest to youngest proceeding eastward from a calcic syenite to riebeckite-biotite hypersolvus granite and then to a fine-grained leucogranite with a granophyre texture (Saha 1959, Kuehnbaum 1973, Wu 1984).

The Malone Pluton is a small satellite pluton 3 km X 1.5 km and lying 0.5 km NW of the main Deloro Pluton. Bartlett and Moore (1985) describe the Malone Pluton as consisting ..." mainly of very fine-grained, porphyritic alkali-feldspar granite, with phenocrysts generally 0.5 -1 mm across of anhedral quartz and subhedral plagioclase and microcline and/or orthoclase and/or perthite." However within the study area it is primarily medium- to coarse-grained, similar in appearance to that of the Deloro felsic rocks.

A small (100-200 m X 900 m) auriferous granitic satellite intrusion occurs 0.7 km north of the Deloro Pluton. The intrusion is highly sheared (foliation strikes 50-67^{o}, dips 80^{o}NW to 80^{o} SE; and commonly strikes 60-62^{o} and dips 80^{o}NW to vertical) and transected by a series (4 or 5) of small northeast trending faults. Hematite and sericite alteration occurs along shear planes, locally with green muscovite. Quartz veining up to a foot in width can be observed but is generally only inches in width. Native gold has been found within the veins, but is primarily associated with sheared, altered granite. Noranda Inc. reports that development of this "high tonnage, low grade gold project...is currently on hold pending results of metallurgical tests." (Northern Miner, Vol. 75, No. 35, Nov. 6 1989).

The syenitic rocks are typically massive, phaneritic, medium-to coarse-grained and brown to pink in colour. The mineral assemblage consists predominantly of mesoperthite, and accessory minerals include quartz, biotite, calcic amphibole, chlorite, magnetite, sphene, and hematite. Abdel-Rahman and Martin (1987) also identified rare aenigmatite in clots of mafic minerals and the calcic amphibole as ferroactinolite to hastingsite. Locally, porphyritic syenite occurs containing subhedral phenocrysts up to 10 mm in length and magnetite (3-5%) up to 3 mm across. Mafic and quartz-rich phases occur locally. The hypersolvus syenite grades eastward into hypersolvus granite.

Generally the granite is massive, phaneritic, medium- to coarse-grained and pink in colour. The mineral assemblage consists of mesoperthite, quartz, and alkali amphibole (3-5%). Accessory minerals include zircon, chlorite, sericite, apatite, calcite, fluorite, hematite, and pyrite. Abdel-Rahman and Martin (1987) during their investigation also noted the presense of annite, ilmenite, and titanite.

A fine-grained to aphanitic phase was identified in the old Cameron gold occurrence workings on the Bonter property by Carter (1984). The rock is pink to dark green and grey in colour, and may exhibit compositional banding. Carter (1984) describes the rock as mainly consisting of saussuritized feldspar and minor quartz-carbonate veinlets. He suggested that it may represent a chilled phase of the intrusion. Rocks similar in appearance to these are exposed on the Platinova-Cominco and Deloro West Zone properties. These rocks are described as siliceous metasediments which have been subjected to contact metamorphism and largely converted to typical skarn mineralogy.

Paleozoic -- Middle Ordovician

Map Unit 6 -- Shadow Lake Formation

The formation is a fine-grained to conglomeratic, maroon to green, calcareous, feldspathic quartz sandstone, which is thinly- to medium-bedded. Quartz clasts up to 1.5 cm in diameter can be observed in some localities. Exposed thickness of the formation is generally 15 to 25 cm.

Map Unit 7 -- Gull River Formation

The formation is exposed in concession VIII, lots 10 and 11, Marmora Township, and in a small quarry at the northern end of the community of Deloro. It is a brownish-grey, fine- to medium-grained, microcrystalline limestone with abundant shaley partings

(D.A. Williams, Geologist, Ontario Ministry of Northern Development and Mines, Tweed, personal communication 1987).

Unit 8 -- Bobcaygeon Formation

The formation is a brownish grey, thinly to massively bedded, microcrystalline limestone with undulating shaley partings. It is exposed along a hillside and hilltop in concession VIII, lots 10 and 11, Marmora Township, in a small, down-faulted wedge at the western edge of the study area.

DESCRIPTION OF WOLLASTONITE OCCURRENCES WITHIN MARMORA STUDY AREA

MARMORA TOWNSHIP

PLATINOVA-COMINCO DEPOSIT

Location

The property is located on lots 5, 6, 7 and 8, concession VIII, Marmora Township, Hastings County, approximately 5 km east of the Town of Marmora. NTS 31 C/5, 31C/12 (Figure 6).

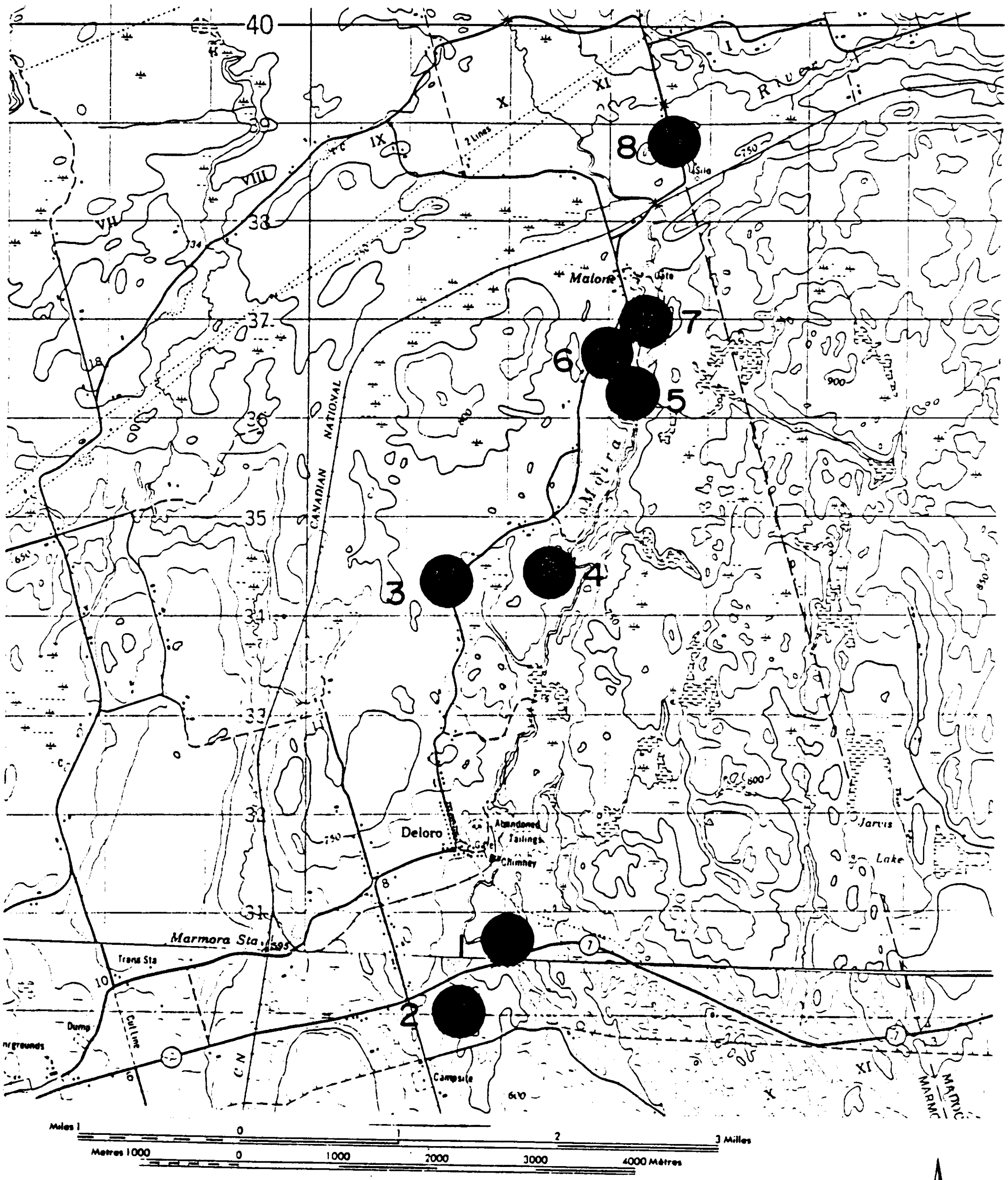
Access:

Access to the property is via Highway 7 and from the old Madoc-Marmora Road.

Geology

The stratigraphy in the immediate vicinity of the property consists of Grenvillian metasedimentary rocks intruded by later felsic intrusives and mafic dykes. These sediments have been subjected to regional and contact metamorphism and later deformation which has resulted in the development of skarn zones adjacent to the Deloro Pluton (Figure 7).

The wollastonite zone (map unit 1, Figure 7) trends northwesterly and dips moderately to steeply to the east. It appears to be



1. Platinova-Cominco Property
2. Deloro West Zone Property
3. Lot 13, Concession 9 Occurrence
4. Rahm Property
5. Moira River Conservation Authority Property
6. Kelly-Czerewko Property
7. Bonter Marble Quarry Property
8. Noranda Gold Property

Figure 6. Location map of the wollastonite occurrences in the Marmora study area.

continuous over a minimum strike length of 1,200 metres, but is highly variable in width, varying from a few metres to approximately 100 metres in the northern and central portions of the property. This unit is a fine-to medium-grained, wollastonite-bearing calcitic marble/calc-silicate rock and is white to light green in colour. The weathered surface (Photo 1) is a mottled grey or black in colour and has a pitted appearance with the calcite standing out in relief and the wollastonite weathering low. The reverse is true where overburden has prevented mechanical weathering of the wollastonite, this feature being evident in the stripped area north of Hwy. 7 (Photo 2). The mineral assemblage consists predominantly of wollastonite and calcite, with minor diopside-hedenbergite. Trace amounts of tremolite, quartz, talc, mica, and chlorite were also detected in some samples by X-ray diffraction. Minor fine-grained pyrite (<1%) and rare fluorite, garnet, and sphalerite were observed at several locations.

Kretschmar (1986) indicated that north of Hwy. 7 the wollastonite grade varies between 30.9-50.7% averaging 42.9±7.0%, whereas the south zone varies from 22.4-55.3% averaging 38.5±8.6%. Robert Gannicott (1988), the president of Platinova Resources Ltd., reported 450,000 tonnes of indicated open pit reserves grading 47% wollastonite in one zone and a further 680,000 tonnes of inferred ore at a grade of 39% wollastonite in a separate zone. He believes that this represents a minimum of 20 years production with considerable additional potential. Visual estimates of wollastonite abundance in outcrop can be difficult to make with

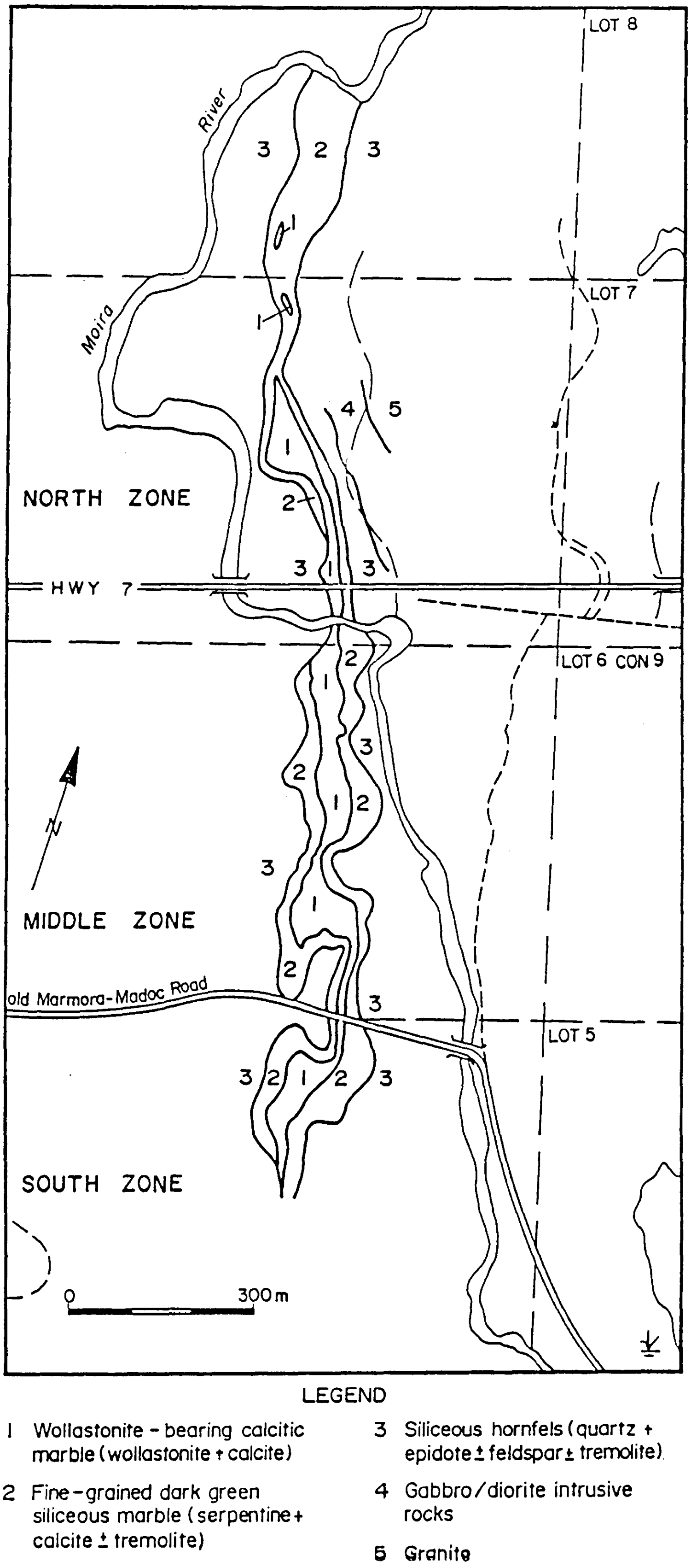


Figure 7 Simplified geological sketch map of the Platinova-Cominco property, Marmora Township (from MacKinnon et al 1987).

any degree of reliability due to the heterogeneous distribution and fine-grained nature of the wollastonite and calcite. However, visual estimates by Kretschmar (1986) are consistent with those of the author. The wollastonite occurs in nodular aggregates 1-30 cm in diameter or as blades and fibres in a fine- to medium-grained calcitic matrix. Individual blades up to 6 cm in length were identified in the mineralized zone south of the old Madoc-Marmora road.

Outcropping at several localities near the western margin of the property between the old Marmora-Madoc road and Hwy. 7 is a microcrystalline to fine-grained variety of the calc-silicate rock. This rock (Table 4) is finely laminated, white to greenish in colour and consists of layers (<1 mm in thickness) of wollastonite, grossularite, diopside, calcite, and quartz. The weathered surface is yellowish-brown to white in colour and locally quartz grains stand out in relief. Wollastonite mineralization occurs in what appears to be a narrow zone several metres in width (striking 252° and dipping 52-54°E) in contact with the hornfels unit. The zone may represent a reaction skarn between the hornfels unit and marble. Disseminated dark-brown to black blebs (<3 mm) were identified as sphalerite in a calcitic vein which crosscut the banding. Because of poor outcrop exposure further work is required to adequately assess the potential of this zone.

The variable thickness of the wollastonite zone may be due to structural deformation (NW-SE compression) in which the metasedimentary units behaved in a ductile manner relative to the rigid igneous body (Deloro Pluton). This deformation has resulted in the thickening and thinning observed in the field. Minor fold closure and the repetition of rock units suggest the possibility that the mineralized zone may be located in the hinge of a fold.

Several mafic and felsic dykes intrude the mineralized zone. The mafic dykes (amphibolite) are fine- to medium-grained, black to greenish in colour, and composed of amphibole, plagioclase, potassium feldspar, epidote, and sphene. The width varies from 0.5 to 2.0 metres and the dykes commonly exhibit near vertical dips. The dykes have been partially altered to a mixture of chlorite, calcite, plagioclase, and potassium feldspar.

Dissolution along fractures in the mineralized zone north of Hwy. 7 have produced small channels (up to 30 cm in width) and several of these contain veins of black to light green mixtures of calcite, dark brown talc, and tiny aggregates of sphene 0.5 mm in diameter (Photo 3). Serpentine was identified in one sample. Small brown bands (<3 cm) composed of fine-grained diopside, plagioclase and minor pyrite were noted within one sample taken from the mineralized zone. Near the western margin of the stripped area there is evidence of a post-Grenvillian pre-Paleozoic erosional event; large boulders (up to 5 m across) of marble lie unconformably on the bedrock surface. Trenches which contain highly weathered and hematitized rocks further suggest that the present surface lies just below the Precambrian-Paleozoic unconformity surface.

Photo 3 Dissolution along fractures in the mineralized zone on the Platinova-Cominco property north of Hwy. 7.

Frequently, in contact with the wollastonite-bearing unit is a fine-grained, dark-green, serpentine-bearing marble (map unit 2, Figure 7) commonly dipping to the east at 55-60 degrees. The marble is calcitic to slightly dolomitic in composition. The colour is predominantly light to dark-green, although locally a mottled grey-and-green, or grey marble was observed. The rock is massive to weakly foliated and composed of fine-grained (averaging 0.1 to 0.2 mm) xenoblastic calcite grains, intergrown with laths of serpentine, and chlorite. Accessory minerals may include tremolite, dolomite, mica, and occassionally disseminated pyrite and small siliceous veins. Mica defines the foliation which may reflect original bedding in the rock. Grouped within this unit is a banded and brecciated, white to grey calcitic marble which locally contains barite.

The hornfels unit (map-unit 3, Figure 7) is an aphanitic to fine-grained, siliceous-looking rock, frequently adjacent to the serpentine-bearing marble but which may occur in direct contact with the mineralized zone. The mineral assemblage may include diopside, clinozoisite, quartz, epidote, grossularite, idocrase, calcite, chlorite, tremolite, plagioclase, microcline, mica, and minor apatite, and sulfides. Texturally, map unit 3 varies from massive to finely laminated to thickly banded and in places brecciated. The coloured bands vary from a dark-grey to a mottled green and brown or beige to reddish. The weathered surface varies from white to orange; brown or beige bands frequently alter to grey. Several small veins (<3 mm) containing talc, chlorite, epidote, tremolite, quartz, or sulfides crosscut the unit locally, resulting in a brecciated appearance to the rock. The fractures or microfaults are moderately to steeply dipping and may displace bedding several centimetres. The original nature and mineralogy of the rock has been partly obscured because of the extreme fineness of grain size and the contact metasomatic/metamorphic effects produced by the intrusion of the Deloro Pluton which have largely converted the rock to skarn mineralogy. The laminated or banded nature probably represents relict primary textures and the compositional bands reflect original differences in the chemistry of the rock (siltstone, wacke).

The igneous assemblage consisting of the Deloro Pluton (map unit 5, Figure 7) and its attendant gabbroic to dioritic phases (map unit 4, Figure 7), occurs along the eastern edge of the property. The Deloro Pluton is a multiphase intrusive, compositionally zoned (from oldest to youngest) from a calcitic syenite to a riebeckite-biotite hypersolvus granite, and then to a fine-grained leucogranite with a granophyric texture (Saha 1959, Kuehnbaum 1973, and Wu 1984).

Chemistry and Petrology

Twelve thin sections and four polished sections were studied. The whole rock chemical composition (in percent) and trace element content (in ppm) of two samples of calc-silicate rock are presented (Table 3).

Sections 1-3 (Table 4) are thin sections of the microcrystalline variety of calc-silicate rock/skarn and sections 4-6 (Table 4) are of the hornfels rock from the western edge of the property. Section 7 (Table 4) is a thin section of serpentine-bearing calcitic marble and Sections 8-12 (Table 4) are of calc-silicate rock from the main mineralized zone.

Three polished sections (samples 3, 2-5-88, MA-5) were prepared of calc-silicate rock from north of highway 7 and another section (MA-3) from the area between Hwy 7 and old Marmora road.

Thin sections 1-3 consist of alternating fine-grained bands (<1mm) of grossularite, quartz, diopside, wollastonite and calcite.

TABLE 3 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) AND TRACE ELEMENT CONTENT (IN PPM) OF TWO SAMPLES OF CALC-SILICATE ROCK

	87-507	87-601		87-507	87-601
SiO_2	28.8	45.1	Rb	12	<10
Al_2O_3	0.19	0.15	Sr	1050	203
CaO	50.1	45.2	Y	<10	<10
MgO	0.91	0.67	Zr	<10	<10
Na_2O	0.46	0.37	Nb	<10	12
K_2O	0.11	<0.01	Ba	1510	45
Fe_2O_3	0.28	0.70			
MnO	<0.01	0.05			
TiO_2	<0.01	<0.01			
P_2O_5	0.04	0.03			
Cr_2O_3	<0.01	<0.01			
LOI	18.9	8.16			
Total	100.1	100.5			

87-507	calc-silicate rock - north of Hwy. 7
87-601	calc-silicate rock - south of old Madoc-Marmora Road

Thin section 4 is similar in mineralogy and texture but contains no wollastonite mineralization.

Thin section 5 is a fine-grained to aphanitic, massive to banded rock composed of clinozoisite, diopside, chlorite, sphene, and quartz. The sphene stands in high relief over the matrix and calcite occurs disseminated throughout the rock. A vein of tremolite was identified by X-ray diffraction techniques (XRD).

Thin section 6 is similar in appearance, and is composed of diopside, microcline, and quartz. Diopside occurs in a finely granular alignment producing a foliation in the rock. The extreme fineness of grain size, particularly in sections 5 and 6, caused difficulties in mineral identification even in thin section but x-ray diffraction analysis was of considerable assistance in determining the various constituents.

Thin section 7 consists of fine-grained calcite grains intergrown with laths of serpentine and chlorite. The calcite consists of xenoblastic grains averaging 0.1 to 0.2 mm. The rock is weakly foliated due to the alignment of phlogopite in the sample.

Thin section 8 consists of fine-grained wollastonite, clinopyroxene, calcite, and trace quartz and pyrite. The rock has a massive to weakly banded, granoblastic texture. The calcite occurs as xenoblastic grains averaging 0.3 - 0.5 mm intergrown with calcite and wollastonite. The diopside occurs as xenoblastic grains (0.3 - 0.5 mm) and aggregates (.05 - 0.1 mm) intergrown with wollastonite, and as blebs within calcite grains. The wollastonite occurs as radiating prismatic, hypidioblastic grains (averaging 0.1 - 0.3 mm) which commonly have aspect ratios of 2:1 to 4:1 but may reach an 8:1 ratio locally (Photo 4).

Thin section 9 is composed of intergrown wollastonite, diopside, calcite, and minor quartz and pyrite. Sections 10-12 are mineralogically and texturally similar to sections 8 and 9 but differ in their relative proportion of minerals present.

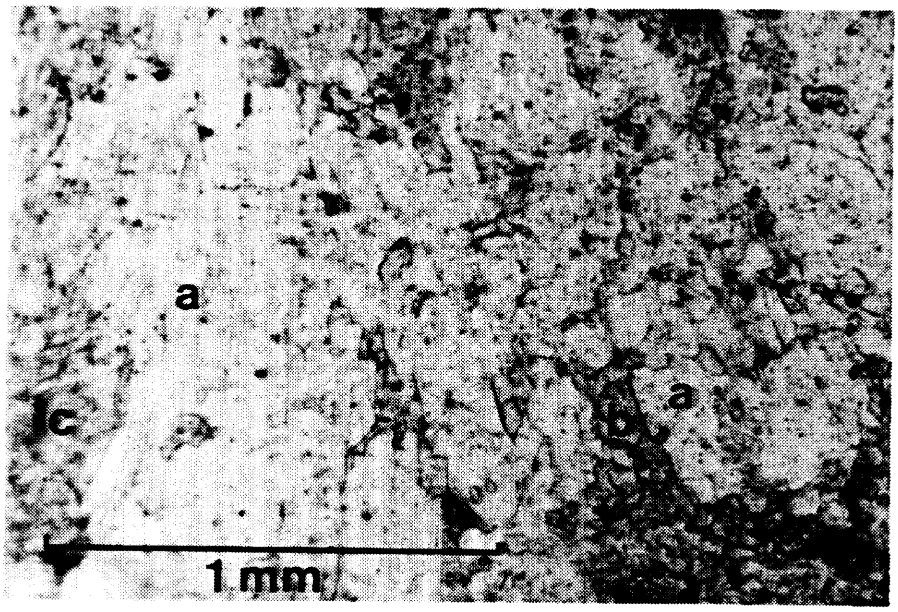


Photo 4: Photomicrograph (MA-5) in plane polarized transmitted light taken from Platinova-Cominco property, Marmora Township showing wollastonite (a), diopside (b) and calcite (c), Scale bar indicates 1 mm.

TABLE 4 ESTIMATED MODAL COMPOSITIONS (IN PERCENT) OF TWELVE THIN SECTIONS OF SELECTED ROCK TYPES

	1	2	3	4	5	6
grossularite	20	15	20	25	--	--
quartz	10	15	5	30	x	x
diopside	20	5	10	20	x	x
wollastonite	45	40	35	--	--	--
calcite	5	20	30	minor	--	--
serpentine	--	--	--	--	--	--
phlogopite	--	--	--	--	--	--
tremolite	--	--	--	--	x	--
apatite	--	<5	minor	minor	--	--
microcline	--	--	--	minor	--	x
idocrase	--	--	--	minor	--	--
clinozoisite	--	--	--	--	x	--
chlorite	--	--	--	--	x	--
magnetite	--	--	--	minor	--	--
pyrite	--	--	--	--	--	--
sphene	--	--	--	--	x	--

	7	8	9	10	11	12
grossularite	--	--	--	--	--	--
quartz	--	3	10	2	<1	2-3
diopside	--	2	5	15	15-20	20-25
wollastonite	--	70	25	29	20-25	35-40
calcite	82-87	25	60	54	60-65	30-35
serpentine	9-10	--	--	--	--	--
phlogopite	1-2	--	--	--	--	--

tremolite	3-4	--	--	--	--	--
apatite	--	--	--	--	--	--
microcline	--	--	--	--	--	--
idocrase	--	--	--	--	--	--
clinozoisite	--	--	--	--	--	--
chlorite	--	--	--	--	--	--
magnetite	--	--	--	--	--	--
pyrite	1-2	--	--	--	<1	1
sphene	--	--	--	--	--	--

X-presence identified by X-ray diffraction techniques

1-3. microcrystalline calc-silicate rock
4. hornfels rock (adjacent to microcrystalline calc-silicate rock
5-6. hornfels rock (south of the old Madoc-Marmora road, west of mineralized zone).
7. serpentine-bearing calcitic marble
8. calc-silicate rock (MA-5), north of Hwy. 7.
9. calc-silicate rock (MA-3), between the old-Madoc Marmora road and Hwy. 7.
10. calc-silicate rock (87-507)
11-12. calc-silicate rock

Polished section Sample 3 contains wollastonite, clinopyroxene, garnet, calcite and pyrite; wollastonite, diopside (centre of grain and grain boundary) and garnet (centre of grain and grain boundary) were analysed (Table 5). Several large garnet porphyroblasts were analysed in this section; the garnets become richer in iron and poorer in alumina and manganese toward the grain boundary. The diopside similarly becomes iron-enriched toward the grain boundary. The main inclusions within the section are minute grains of pyrite. Appendix 3 (Photo 1) shows wollastonite, diopside, calcite, and tiny inclusions of pyrite. Appendix 3 (Photo 2) shows a large garnet (top right) with a brighter rim due to an increase in iron, surrounded by wollastonite. Calcite and pyrite are also evident.

Polished section 2-8-88 is composed of wollastonite, diopside, quartz, and calcite; wollastonite and diopside were analysed (Table 5). The wollastonite contains inclusions of quartz, calcite, and the lighter inclusions are barian feldspar (Appendix 3, Photo 3).

Polished sections MA-3 and MA-5 are composed of wollastonite, diopside, calcite, and quartz; wollastonite was analysed (Table 6). Appendix 3 (Photo 4) shows tabular grains of wollastonite surrounded by calcite.

Beneficiation Study

Two samples of calc-silicate rock each weighing approximately 80 kg. were sent by the Ministry of Northern Development and Mines, southeastern district resident geologist office, Tweed to Canada

TABLE 5 ELECTRON MICROPROBE ANALYSES -- CHEMICAL COMPOSITION (IN PERCENT) OF MINERALS PRESENT IN SAMPLES (3, 2-8-88) OF CALC-SILICATE ROCK

	1	2	3	4	5	6
SiO_2	51.68	51.33	51.20	52.12	53.76	36.17
TiO_2	0.00	0.00	0.03	0.02	0.00	-----
Al_2O_3	0.00	0.00	0.08	0.34	0.25	4.51
Cr_2O_3	0.00	0.00	0.00	0.04	0.00	-----
FeO	0.20	0.25	0.18	14.05	9.15	24.69*
MnO	0.17	0.15	0.13	0.31	0.24	0.05
MgO	0.00	0.01	0.01	9.35	12.85	0.01
CaO	47.97	49.25	48.83	24.68	25.35	33.59
K_2O	0.02	0.00	0.04	0.02	0.00	-----
Na_2O	0.05	0.13	0.02	0.17	0.13	-----
Total	100.08	101.13	100.53	101.10	101.73	99.02

	7	8	9	10	11	12
SiO_2	36.53	36.61	36.90	37.76	51.53	54.24
TiO_2	-----	-----	-----	-----	0.00	0.00
Al_2O_3	4.35	10.04	5.51	9.34	0.04	0.09
Cr_2O_3	-----	-----	-----	------	0.00	0.00
FeO	25.27*	17.78*	24.83*	19.92*	0.15	4.99
MnO	0.11	0.23	0.09	0.19	0.06	0.09
MgO	0.02	0.09	0.01	0.07	0.02	15.26
CaO	33.56	34.70	34.24	34.11	48.59	25.25
K_2O	-----	-----	-----	-----	0.00	0.02
Na_2O	-----	-----	-----	-----	0.02	0.22
Total	99.85	99.44	101.57	101.39	100.40	100.16

1-3	wollastonite grains (sample 3)
4	diopside grain boundary (sample 3)
5	diopside grain centre (sample 3)
6-7	garnet grains (sample 3)
8	garnet grain centre (sample 3)
9	edge of garnet in 8 (sample 3)
10	garnet grain centre (sample 3)
11	wollastonite grain (sample 2-8-88)
12	diopside grain (sample 2-8-88)

*Total iron expressed as Fe2O3

TABLE 6 ELECTRON MICROPROBE ANALYSES-CHEMICAL COMPOSITION (IN PERCENT) OF WOLLASTONITE IN SAMPLES (MA-5, MA-3)

	1	2	3	4	5	6
SiO_2	51.38	51.72	51.70	50.31	51.29	49.92
TiO_2	0.00	0.06	0.00	0.12	0.05	0.00
Al_2O_3	0.58	0.00	0.11	0.00	0.17	0.12
Cr_2O_3	0.08	0.08	0.20	0.17	0.13	0.18
FeO	0.47	0.00	0.21	0.24	0.23	0.25
MnO	0.10	0.16	0.00	0.00	0.07	0.00
MgO	0.00	0.06	0.05	0.00	0.03	0.07
CaO	49.41	49.16	49.35	49.10	49.26	48.30
Na_2O	0.00	0.12	0.00	0.13	0.06	0.00
K_2O	0.06	0.03	0.00	0.00	0.02	0.05
TOTAL	102.08	101.42	101.02	100.07	101.30	98.89

	7	8	9	10
SIO_2	49.66	50.24	50.33	50.04
TiO_2	0.00	0.11	0.00	0.03
Al_2O_3	0.04	0.05	0.00	0.05
Cr_2O_3	0.18	0.00	0.08	0.11
FeO	0.34	0.25	0.25	0.27
MnO	0.00	0.00	0.00	0.00
MgO	0.39	0.00	0.00	0.12
CaO	47.84	48.61	48.84	48.40
Na_2O	0.00	0.00	0.12	0.03
K_2O	0.05	0.00	0.03	0.03
Total	98.50	99.26	99.65	99.08

1-4. grains of wollastonite calc-silicate rock (sample MA-5), north of Highway 2)
5. Average of grains 1-4
6-9. grains of wollastonite calc-silicate rock, (sample MA-3) between Hwy. 7 and Old Marmora-Madoc road)
10. average of grains 6-9

NOTE: Electron microprobe analysis was performed using Method 2 (Appendix 1).

Centre for Mineral and Energy Technology (CANMET) for beneficiation studies. These samples were collected from the main zone on the Platinova-Cominco property and were considered at the time to be representative of the mineralization. The grade obtained in the study may not be representative of the overall zone; results were based on samples from two sites. Andrews (1988) refers to these samples on the basis of colour (G-green, W-white) as Sample G (north of Hwy. 7), and Sample W (between Hwy. 7 and the old Madoc-Marmora road).

Sample G is a light green, fine-grained calcitic marble/calc-silicate rock containing wollastonite, calcite, diopside, and trace amounts of pyrite. The diopside (2%) occurs as finely dispersed encapsulated grains, 100 to 200 um in size, in the aggregate crystals of wollastonite thus imparting its characteristic greenish appearance (Andrews 1988). Sample W is a white-grey fine-grained calcitic marble/calc-silicate rock containing wollastonite, calcite, and trace amounts of pyrite.

(i) Preparation

A 20 kg. portion from each of the samples was crushed and sized to produce a head sample and a representative 200 g portion was examined microscopically to determine mineral associations and wollastonite liberation size. " The approximate composition of the head sample (G) was calcite (70%), wollastonite (25%), the remaining 5% accounting for diopside, other calc-silicates, trace amounts of pyrite and iron oxides. The approximate composition of head sample (W) was calcite 70%, and wollastonite (25-30%)

with trace amounts of pyrite and other iron oxide minerals." (Andrews 1988).

The optical examination indicated that the liberation size was 420 um. Each sample was stage-crushed to 420 um using a laboratory roll crusher and dry screened at 150 um.

(ii) Magnetic Separation

The sized products (-420 + 150 um, -150 um) of samples G and W were subjected to dry and wet magnetic separation to remove impurities (diopside and other iron oxide-containing minerals). Dry magnetic separation was conducted on the -420 + 150 um fraction, and wet magnetic separation on the -150 um portion. Results are reported in Appendix 4.

(iii) Flotation

Flotation to produce separate calcite and wollastonite concentrates was attempted by two methods: anionic sodium oleate flotation of calcite at pH 7 using between 205 and 310 g/t of collector, and cationic flotation of wollastonite at pH 9 using between 75 and 100g/t Arquad T50 (trimethyl tallow ammonium chloride).

Testing was conducted to determine the influence of varying grind size and collector concentrations on the different size fractions using each collector system. Table 7 summarizes the most promising results with each collector system for each sample at each size fraction. A comprehensive report of the work completed by CANMET is presented in Appendix 4 (Andrews 1988).

TABLE 7 PRELIMINARY BENEFICIATION STUDY - SUMMARY OF BEST FLOTATION RESULTS WITH EACH COLLECTOR SYSTEM FOR EACH SAMPLE AT EACH FRACTION TESTED (FROM ANDREWS 1988).

Sample	Size um	Collector system	Test No.	Calcite conc % $CaCO_3$	Wollastonite % Woll.	Conc % Fe_2O_3
G	+150	Oleate	7	97.5	93	0.62
G	-150	Oleate	17	95.4	93	0.14
G	+150	Arquad T 50	15	90.3	87	0.60
G	-150	Arquad T 50	26	91.0	89	0.33
W	+150	Oleate	28	93.7	86	0.57
W	-150	Oleate	41	95.5	88	0.51
W	+150	Arquad T 50	37	91.5	87	0.91
W	-150	Arquad T 50	49	94.7	86	0.82

Sample G- green phase, calc-silicate rock from mineralized zone located north of Hwy. 7.

Sample W- white phase, calc-silicate rock from mineralized zone located between Hwy. 7 and old Madoc-Marmora road.

History

In the 1960's, Stoklosar Marble Quarries Ltd. produced a small quantity of fine-grained serpentinized marble for terrazzo chips, from several small pits adjacent to the then-unrecognized wollastonite zone. Hewitt (1964) tested the physical properties of the wollastonite-bearing marble and obtained the following: compressive strength (p.s.i.) maximum 20750, minimum 14100, average 17366; absorption 0.07%; bulk specific gravity 2.80; weight per cubic foot 174.9 lbs.; abrasive hardness 51.6.

Three known gold occurrences (Ackerman Gold Mines, Campbell-Bloomfield Mine, and Gillen occurrence) are located just south of Hwy 7 near the eastern boundary of the property. The wollastonite-bearing unit was first identified on the property by Hewitt (1964) as white calcitic marble consisting of carbonate grains up to 2 mm in diameter intergrown with bladed wollastonite and was later recognized by Verschuren et al (1986) who examined and tested the material for building stone potential. Platinova Resources Ltd. obtained the property in the fall of 1986 and began preliminary channel sampling/benefecation testing. In early 1987, Platinova Resources Ltd. (49%) formed a partnership with Cominco Ltd. (51%) to develop the property. Exploration activity to date includes geological mapping, stripping, trenching, and diamond drilling (83 holes totalling 5023 m). Beneficiation studies were conducted on core samples, and a bulk sample was obtained from north of Highway 7. A small pilot plant study was initiated in June 1989.

Comments

Power (1986) reports that commercial wollastonite should be at least 90% wollastonite, with less then 1% L.O.I., and less than 1% Fe2O3. Preliminary testing by CANMET indicated that "in general, each variety of wollastonite (G and W) met the minimum wollastonite grade and iron oxide requirements, although the white variety was slightly below the 90% wollastonite specification; the L.O.I. analysis for each variety, however, was greater than 1%. Further processing including magnetic separation, and reverse flotation should reduce L.O.I. and Fe_2O_3 levels, and increase wollastonite grade" (Andrews 1988).

North (1985) reports that calcite fillers should have a brightness greater than 85% and a minimum of 92.5% $CaCO_3$ for dry ground and 95.9% for wet ground. Using the oleate flotation method, the calcite concentrate generally met chemical grade requirements but brightness was less than 85%. Andrews (1988) suggested that "further processing including magnetic separtion and ganque depressant addition should improve both grade and brightness."

Increasing the fineness of grind also significantly increased the brightness of both the wollastonite and calcite concentrates.

Testing conducted by Cominco American Inc. indicated that the wollastonite concentrate is suitable for ceramic applications (Sakrison, H., Manager Industrial Minerals, Cominco American Inc., personal communication 1989).

The green zone is more highly crystallized which is apparent when data obtained from x-ray diffraction of the white and green phase varieties are compared. A more pronounced peak with the green-phase variety indicates a higher degree of crystallization (Andrews 1988).

References

NTS 31C/12, 31C/5
Andrews (1988)
Assessment files, Tweed office MNDM
Bartlett and Moore (1983, 1985)
Hewitt (1964)
Kretschmar (1986)
MacKinnon (1986)
MacKinnon and Kingston (1987)
MacKinnon et al (1987, 1989)
North (1985)
Power (1986)
Verschuren et al (1986)

MARMORA TOWNSHIP
DELORO WEST ZONE PROPERTY

Location

The Deloro west zone is located on lots 6 and 7, concession VIII, Marmora Township, Hastings County, approximately 4.5 km east of the town of Marmora. NTS 31C/5 (Figure 6).

Access

Access to the property is via Highway 7 and the old Madoc-Marmora road.

Geology

The property is predominantly underlain by calcareous metasediments, and calc-silicate hornfels rocks (map in back pocket) and the geology is best illustrated at the roadcut on Hwy. 7 (Figure 8). The calc-silicate hornfels rock is microcrystalline to fine-grained and dark-grey to green and brown or reddish in colour. The colour of the weathered surface varies from white to orangish-brown. The mineral assemblage may include diopside, quartz, microcline, plagioclase, clinozoisite, chlorite, sphene, grossularite, carbonate, scapolite, and epidote. The mineralogy of the bands was determined by X-ray diffraction techniques and the results are presented in Table 9. The hornfels unit at the roadcut on Hwy. 7 contains a 3 metre section of easily recognizable bands which are generally less than 30 cm in thickness. Proceeding eastward the bands become thicker and more difficult to distinguish, until finally they are unrecognizable and the rock appears massive with a mottled colour. The rock is highly fractured (fracture sets

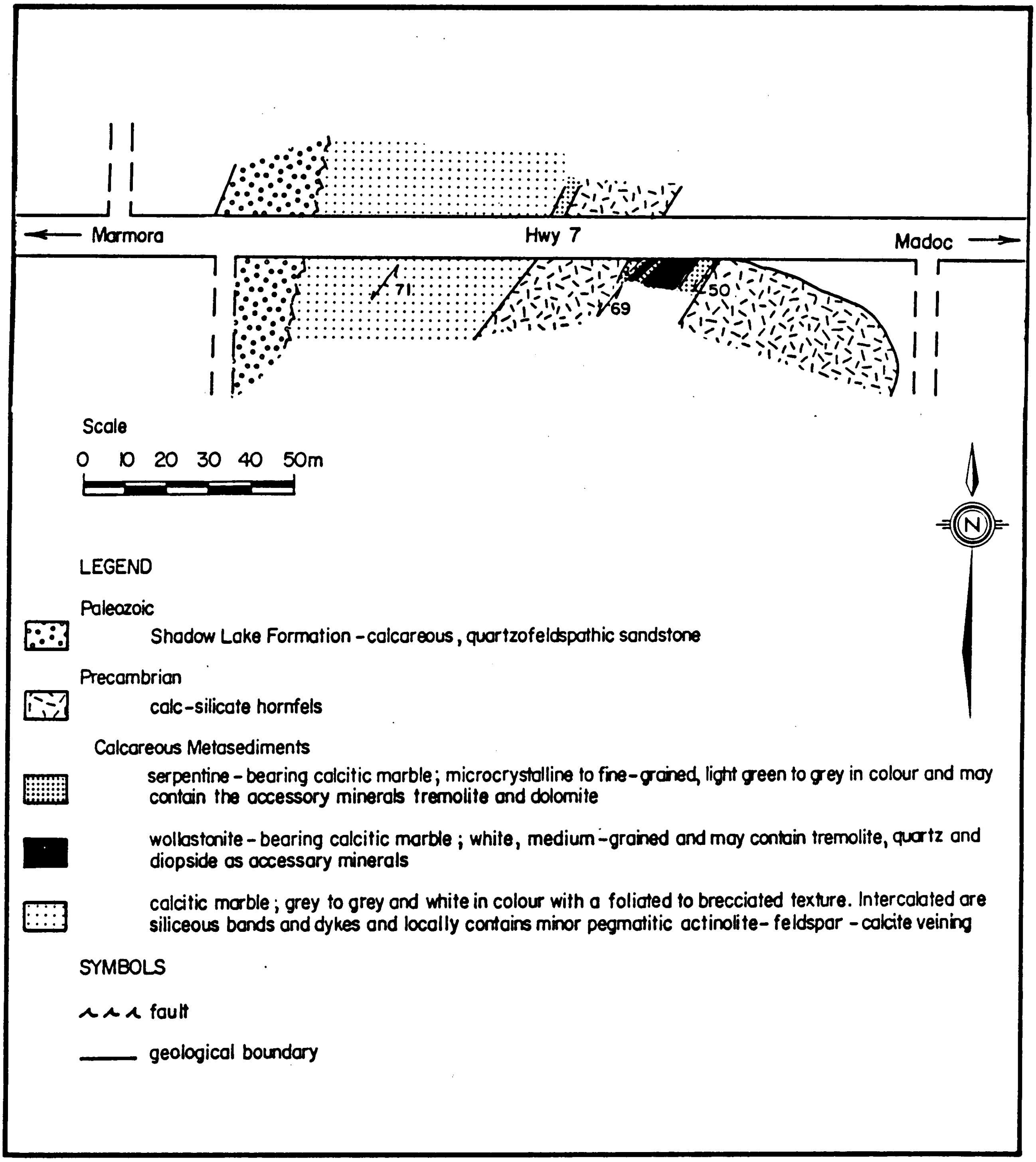


Figure 8. Geological sketch map of the Deloro West Zone roadcut.

striking 082°, dipping 79°NW and striking 003°, dipping 46-52°SE) with sulfides and calcite occassionally occurring along fracture planes. Several small (4-5 cm) veins containing coarse actinolite-feldspar-calcite-pyrrhotite were also noted. The calcareous metasediments consist of grey to grey and white, well-layered to brecciated calcitic marble, with lesser quantities of wollastonite-bearing calcitic marble/calc-silicate rock, serpentine-bearing calcitic marble, and finely intercalated clastic metasediments and marble.

The geology and mineralization at the Deloro west zone are similar to those of the Platinova-Cominco Property, but the mineralization is not as extensive and its width is highly variable, even over short distances. For example, in the roadcut on the northern side of Highway 7, the wollastonite zone is exposed in only one 0.7 m wide band, while on the southern side (Photo 5), there are three separate bands of wollastonite-bearing rock, 5.1, 1.1, and 1.5 m in width. The two more easterly bands appear to both strike 004°, with dips of 36°E and 26 - 36°E. The third band strikes 200° and varies in dip from 25°E to almost horizontal and appears to be offset by a small fault (striking 164° and dipping 51°W). It differs in appearance from the other two bands which contain aggregates of wollastonite and instead appears 'stromatolitic' or finely laminated, consisting of finely laminated white calcite intercalated with greyish layers of wollastonite, diopside, quartz, and plagioclase. Several small (<0.5-1 mm) pyrite cubes occur parallel to laminations and fine pyrite is disseminated throughout the rock. X-ray diffraction

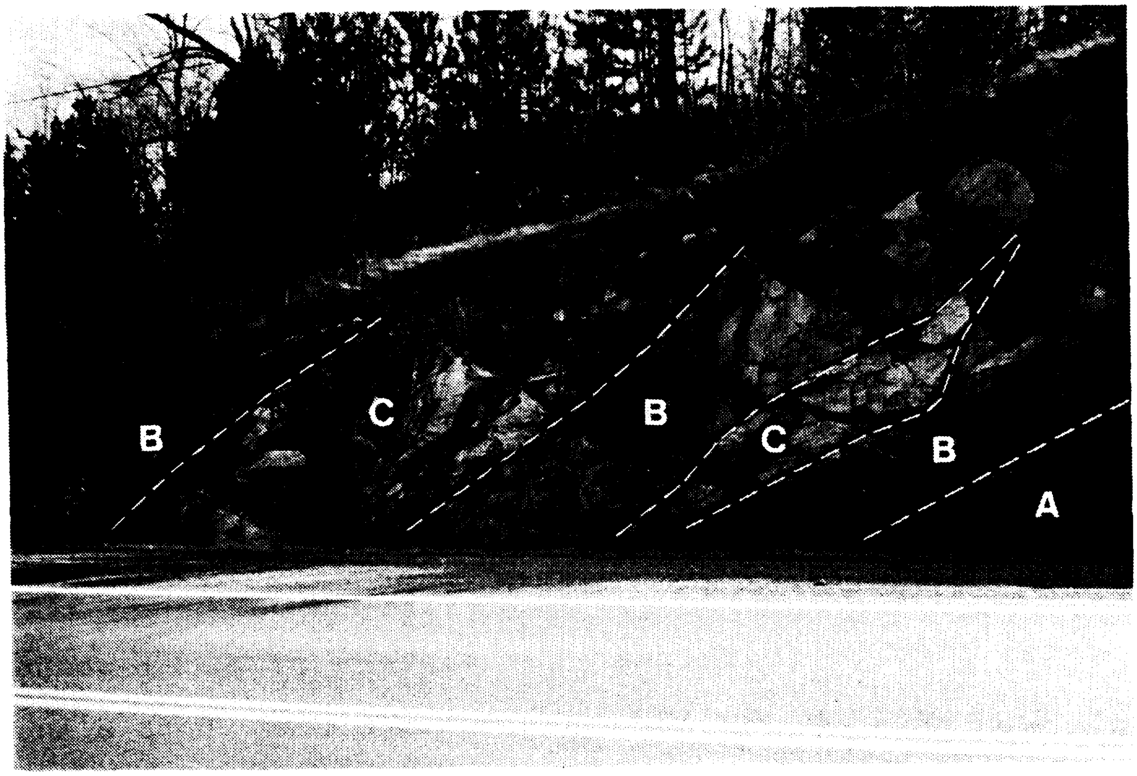


Photo 5 The Deloro West Zone roadcut (south side); A-hornfels rock, B-serpentine-bearing calcitic marble, C-calc-silicate rock.

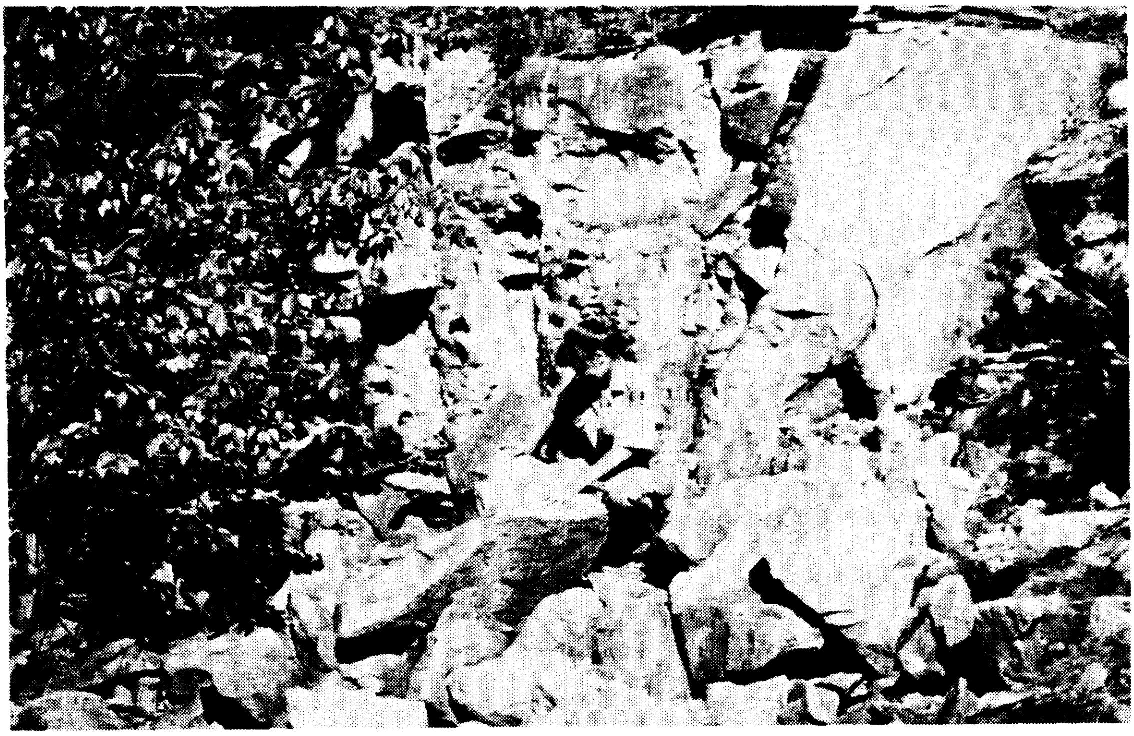


Photo 6 Small abandoned open cut in the mineralized zone of the Deloro West Zone property.

analysis detected the presence of minor amounts of apatite and magnetite. The marble is transected by a series of roughly parallel fractures, generally striking 146-154^{o} and dipping 46-60^{o} W, locally resulting in a brecciated appearance. The fractures may contain medium- to coarse-grained calcite and sulfides as veins which are up to 30 cm but usually less than 10 cm in thickness. Approximately 150 m south of highway 7 on lot 6, the wollastonite-bearing zone appears to dip 10 - 20^{o}E and plunge 21^{o}N. North of Highway 7 the mineralized zone is small and slab-like in appearance. The most extensive mineralization is located further south near the eastern property boundary between Highway 7 and the old Madoc-Marmora road where a 60 m X 100 m area is exposed containing areas of wollastonite mineralization.

Chemistry and Petrology

Five samples of the hornfels rock (87-108, 87-111, 87-112, 1-1-88, 1-2-88) and one sample of the wollastonite-bearing marble/calc-silicate rock (MA-6) were collected and subjected to chemical and/or petrological investigation.

Samples 87-108, 87-111, and 87-112 are from the area located north of the old Madoc-Marmora road between the Deloro West Zone and the Platinova-Cominco property. Samples 1-1-88 and 1-2-88 are from the roadcut on Hwy. 7. Sample MA-6 is from a small quarry located on lot 6, concession 8.

Thin sections were prepared from samples 87-108, 87-111, and 87-112. Whole rock analysis (Table 8) and x-ray diffraction were

TABLE 8 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) OF A SAMPLE (1-1-88) OF HORNFELS ROCK FROM THE DELORO WEST ZONE

SiO_2	70.8	CO2	0.70
Al_2O_3	6.84	S	0.01
Fe_2O_3	2.93	H2O+	0.66
FeO	2.40	H2O-	0.17
MgO	2.93	LOI	0.90
CaO	9.31	Total	99.60
Na_2O	0.42		
K_2O	1.92		
TiO_2	0.38		
P_2O_5	0.10		
MnO	0.11		

TABLE 9 MINERALOGICAL COMPOSITION OF A SAMPLE (1-2-88) OF BANDED HORNFELS ROCK TAKEN FROM HIGHWAY 7 ROADCUT (SOUTH SIDE) AS DETERMINED BY X-RAY DIFFRACTION ANALYSIS.

	1	2	3
Quartz	A	A	A
Plagioclase	B	A	B
K-feldspar	B	B	A
Diopside	B	-	B
Epidote	?	-	-
Serpentine	-	C	-

1 - green bands in hornfels rock
2 - black bands in hornfels rock
3 - beige or brown bands in hornfels rock

A-abundant B-moderate C-minor D-trace

performed on sample 1-1-88, and x-ray diffraction on sample 1-2-88 (Table 9). Microprobe work (Table 10) was performed on sample MA-6 and the wollastonite was analyzed. Additional x-ray diffraction analyses of selected rock types are presented in Appendix 2.

Thin section 87-108 is composed of fine-grained garnet, quartz, diopside, and carbonate (calcite). Diopside occurs as minute closely packed grains with interstitial fine granular aggregates of garnet. Quartz and carbonate are found in the ground mass where diopside granules are not closely spaced.

Thin section 87-111 is composed of fine-grained scapolite, diopside, garnet, epidote, and microcline. Relatively coarse-grained scapolite encloses minute grains of the other minerals. The rock has a foliated texture due to alignment of the fine-grained minerals.

Thin section 87-112 is composed of fine-grained scapolite, diopside, epidote, and microcline. The rock is extremely fine-grained and massive. Despite its mineralogical similarity to 87-111, this sample has textural features similar to that of an igneous rock.

Sample 1-1-88 is a massive aphanitic to fine-grained rock. The fresh surface is pink in colour and weathers white to orangish. The rock consists mainly of quartz, with lesser quantities of diopside, epidote, grossularite, calcite, plagioclase, and minor apatite, magnetite, and hematite. Tremolite, talc, and calcite are present in veins. The results of the whole rock analysis are presented in Table 8. Comparing the analysis with the analyses of syenitic and granitic specimens from the Deloro Pluton (Abel-Rahman and Martin 1987) indicates no co-relation. This indicates either that the hornfels rocks are not derived from igneous rocks associated with the Deloro Pluton, as the author suggests or metasomatism has altered the rocks to such a degree as to obliterate the original nature of the unit. Analysis of the trace-element distribution in the rocks may provide the additional information needed to resolve this problem.

Sample 1-2-88 is an aphanitic to fine-grained rock. The bands vary from green, brown or beige to grey in colour. The texture varies from fine laminations (<0.5 mm) to bands (1.2 cm in thickness). Fractures containing tremolite, quartz, sulfides, and epidote crosscut the laminations and occasionally offset them. The mineralogy is presented in Table 9.

Sample MA-6 is a massive to weakly foliated, fine-to medium-grained rock. The section is composed of intergrown xenoblastic grains of wollastonite, calcite, and minor diopside. The wollastonite itself appears to have a low aspect ratio and be relatively free of inclusions (Appendix 3, Photo 5). The results of the microprobe analysis (Table 10) indicate that the wollastonite grains are chemically fairly uniform and close to theoretical wollastonite in composition.

TABLE 10 ELECTRON MICROPROBE ANALYSES - CHEMICAL COMPOSITION (IN PERCENT) OF WOLLASTONITE PRESENT IN SAMPLE MA-6

	1	2	3	4	5
SiO_2	50.25	49.85	49.85	50.41	50.09
TiO_2	0.08	0.00	0.00	0.07	0.04
Al_2O_3	0.07	0.00	0.00	0.00	0.02
Cr_2O_3	0.00	0.14	0.14	0.08	0.09
FeO	0.27	0.20	0.15	0.27	0.22
MnO	0.11	0.00	0.00	0.00	0.03
MgO	0.00	0.00	0.00	0.00	0.00
CaO	48.29	48.55	48.37	48.49	48.43
Na_2O	0.00	0.00	0.00	0.00	0.00
K_2O	0.03	0.00	0.00	0.00	0.01
Total	99.10	98.74	98.51	99.32	98.92

1-4 wollastonite grains in calc-silicate rock, small quarry located on lot 6, concession 8.
5 average of grains 1-4

NOTE: Electron microprobe analysis was performed using Method 2 (Appendix 1).

History:

A small quarry (Photo 6) located in the mineralized zone on lot 6, concession 8, was probably sampled during the 1960's for terrazzo chips. Currently the property is being optioned by Easton Minerals Inc.

Comments

As previously mentioned, the geology and mineralization is similar to that of the Platinova-Cominco property, both in terms of mineralogy and chemistry. However, the mineralization appears to contain more siliceous impurities, which is more apparent on the weathered surface. The mineralization occurs in narrow bands and pods within other marble units, and adjacent to hornfels rocks. Further field work (stripping) is required to fully assess the potential of this zone; the area between Hwy. 7 and the old Madoc-Marmora road appears to have the most promise.

Repetition of the metasediments along the Hwy. 7 roadcut suggests folding and the two easterly bands may be one and the same. The roadcut proceeding eastward appears to become more highly altered resulting in primary structures being obliterated.

The most westerly wollastonite band appears laminated and may originally have been 'stromatolitic' in origin. The banded nature of the hornfels unit suggests a sedimentary origin, likely clastic metasediments (wackes, siltstones) and metamorphic effects produced by the Deloro Pluton have largely converted the original mineralogy to skarn.

References

NTS 31C/5
MacKinnon and Kingston (1987)

MARMORA TOWNSHIP
LOT 13, CONCESSION 9 OCCURRENCE

Location

The occurrence is located approximately 2.5 km north of the community of Deloro on Lot 13, Concession 9, Marmora Township, Hastings County. NTS 31C/12, UTM Co-ordinates 291400 mE, 4934250 mN, Zone 18 (Figure 6).

Access

Travel north 2.75 km from the Deloro General Store on County Road 11.

Geology

The property is situated within a small Precambrian inlier of carbonate metasediments, gabbro, and felsite. Figure 9 is a geological sketch map of the occurrence. The metasediments are fine-to medium-grained, white to grey calcitic marbles. Wollastonite (5-10%) was identified in a 1m wide band. Adjacent marble may also contain minor wollastonite.

The Paleozoic rocks (Shadow Lake Formation) consist of fine- to coarse-grained, green to maroon, calcareous feldspathic quartz sandstone, locally conglomeritic. The Precambrian-Paleozoic unconformity is exposed in the driveway and specular hematite was noted at the contact with the underlying Precambrian marble.

Comments

The textures and mineralogy of the band are similar to other zones of wollastonite mineralization in the area. The occurrence may not represent bedrock as it does not appear to be extensive and is rather slab-like in appearance. However, if it is a large boulder, it is probably derived from a nearby bedrock source.

References

NTS 31C/12
MacKinnon and Kingston (1987)

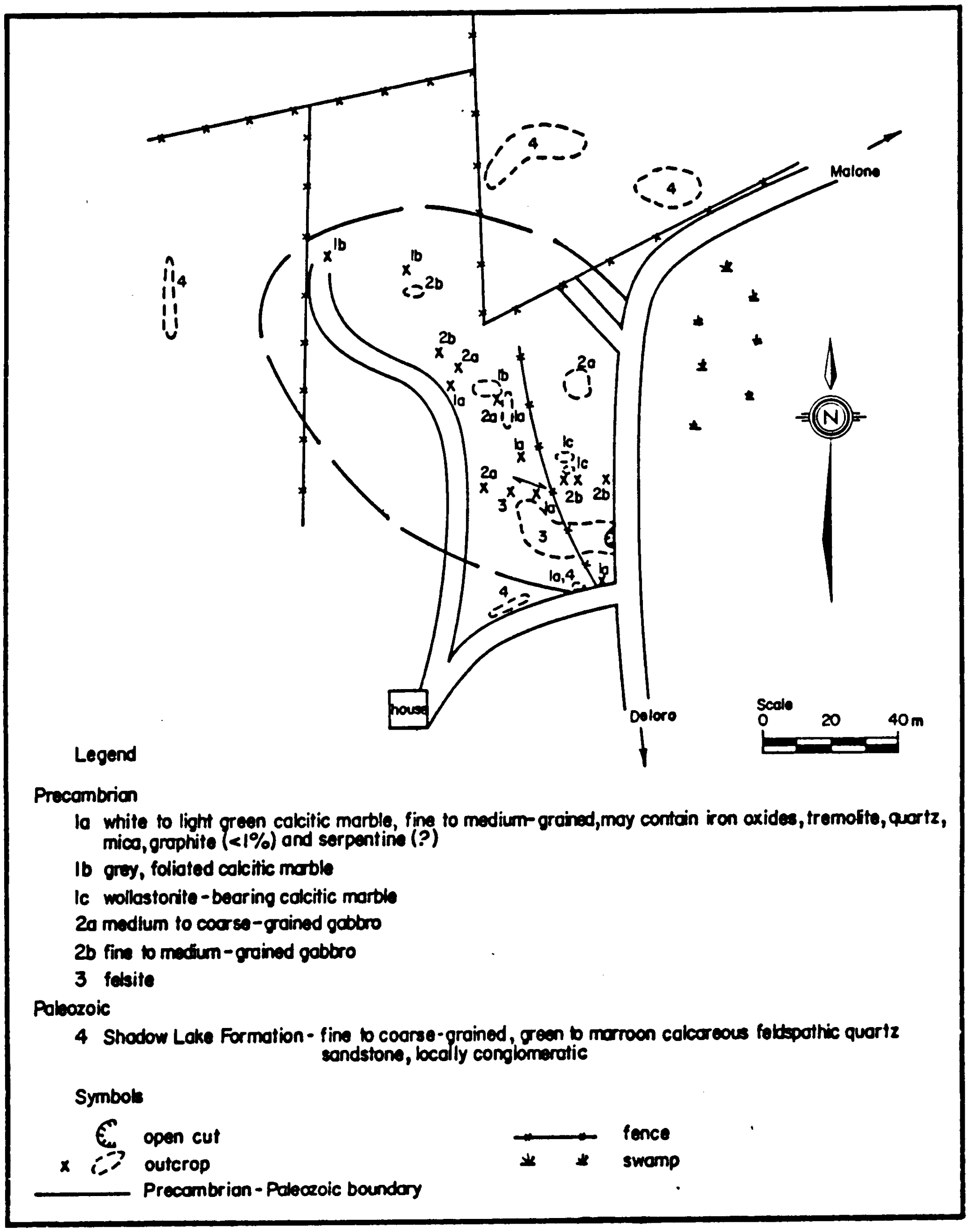


FIGURE 9, Geological sketch map of the wollastonite occurrence on lot 13, concession 9, Marmora Township.

MARMORA TOWNSHIP
RAHM PROPERTY

LOCATION

This showing is located in the northeastern corner of lot 12 and the southeastern corner of lot 13, concession 9, Marmora Township, Hastings County, approximately 5.5 km northeast of the community of Deloro. NTS 31C/12 (Figure 6).

Access

The property is accessible by a trail which connects with County Road 11, 2.7 km south of Malone.

Geology

The property is underlain by carbonate metasediments and younger mafic to felsic intrusive rocks. Figure 10 is a geological sketch map of the Rahm property. The metasediments (map unit 2) consist of fine- to medium- grained, white to grey and white, and dark green, calcitic marbles. Accessory minerals within the calcitic marbles include brucite, serpentine, tremolite, quartz, hematite, and sulfides.

Medium- to coarse-grained gabbro/diorite (map unit 4) border the marbles to the south, and massive, medium-to coarse-grained syenite, amphibolite syenite (in places porphyritic), and granite (map unit 5) lie to the west and east. Mafic and felsic dykes (generally <3 m in width) transect the carbonate rocks. Skarn rocks (garnet-diopside ± quartz ± calcite) and silicified metasediments (map unit 5c) frequently occur adjacent to the intrusive rocks.

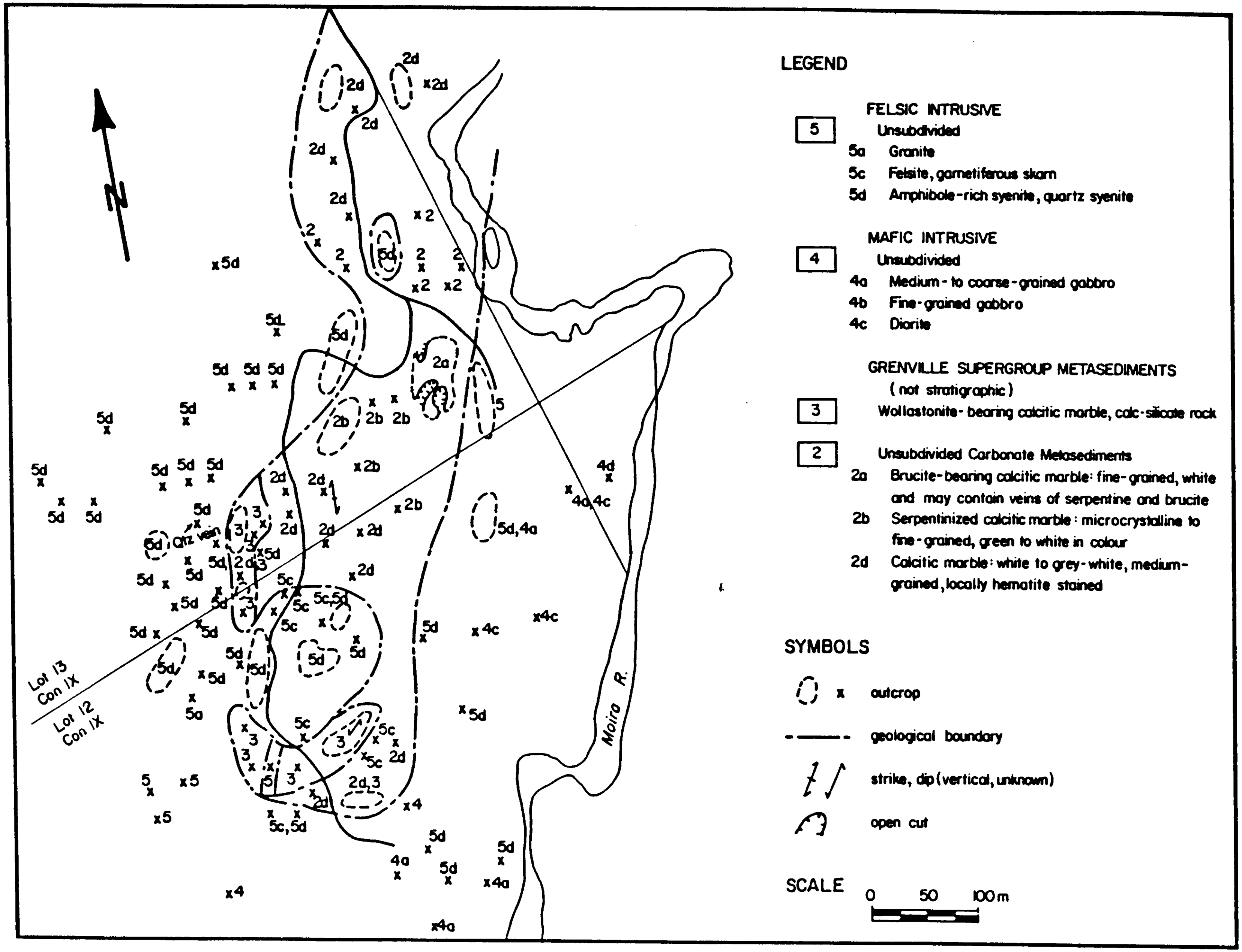


Figure 10. Geological sketch map of the Rahm property, Marmora Township.

Preliminary surface mapping identified two (possibly three) pod-like bodies containing wollastonite mineralization. The wollastonite-bearing units frequently grade into white medium-grained barren calcitic marble (map unit 2d) and occur interbedded with grey and white, laminated calcitic marble (map unit 2d, 2e). The southern pod is divided into several segments (2-3) by felsic dykes. The eastern portion is approximately 30 m wide and more than 60 m long, and contains up to 50 percent wollastonite, locally up to 80%. The western portion is predominantly low grade (<20%) and has surface dimensions of approximately 25 x 50 m. The host marble (map unit 3) is white, fine-to medium-grained, and composed of wollastonite, calcite, diopside, and minor quartz. Massive dark reddish-brown garnet (may contain inclusions of idocrase) was identified in the rubble near a small test pit, within nearby trenches, and in core, associated with wollastonite mineralization. The massive, fine-grained garnetiferous skarn occurs interbanded with wollastonite-bearing marble/calc-silicate rock.

The northern pod reaches a maximum width of 50 m and extends for 100 m. Siliceous impurities are more prevalent and wollastonite content more variable (less than 5% to greater than 30%) than in the southern pod. The wollastonite is fine- to coarse-grained, with both grain size and grade decreasing to the south. Minor amounts of disseminated sphalerite were identified in drill core. Photos 7 and 8 illustrate the wollastonite zone in the northern and southern pods, respectively.

Photo 7 Siliceous wollastonite-bearing calc-silicate rock in the northern mineralized zone, Rahm property, showing wollastonite and calcite (low relief) and quartz (high relief).

Photo 8. Small stripped area within the southern mineralized zone, Rahm Property, Marmora Township.

Chemistry and Petrology

Four samples of the mineralized calc-silicate rock (87-504, 87-504b, 87-506, 87-506b) were collected and subjected to chemical and/or petrological investigation.

Samples 87-504 and 87-504b are from the southern pod and samples 87-506 and 87-506b are from the northern pod.

Thin sections (Table 11) and whole rock analysis (Table 12) were performed on samples 87-504 and 87-506. Microprobe work (Table 13) was conducted on the wollastonite in samples 87-504b and 87-506b. Representative backscattered images of samples 87-504b and 87-506b are presented in Appendix 3. Additional x-ray diffraction analyses of selected rock types are presented in Appendix 2.

Sample 87-504 is weakly banded, fine- to medium-grained and composed of calcite, quartz, and minor wollastonite and diopside. Sample 87-506 is massive, medium- to coarse-grained and composed of calcite, diopside, wollastonite, and minor quartz. In thin section, the grains are predominantly xenoblastic in form, except for several hypidioblastic grains of wollasonite which occur intergrown with diopside. The modal analyses of thin sections 87-504 and 87-506 are presented in Table 11. The results do not appear to be representative of the mineralized zones or consistent with field observations. This may be due to the local variability of the constituent minerals, coarseness of grain size, or limited area examined within the sections.

Samples 87-504b and 87-506b are mineralogically and texturally similar to sample 87-504 and 87-506 except in the relative proportion of minerals present. The wollastonite content is higher and appears to be more consistent with field observations.

The chemistry of four wollastonite grains and one inclusion were analyzed in sample 87-504b (south pod) and three wollastonite grains in sample 87-506b (north pod); the results are listed in Table 13. The results indicate that the inclusion in sample 87-504b is hyalophane but the analytical total is slightly high (probably due to the barium). The other inclusions present in this sample are barite. Sample 87-504b consists of granoblastic wollastonite, and minor diopside, quartz, and barite (Appendix 3, Photo 6). Sample 87-506b consisted mainly of granoblastic wollastonite and minor calcite (Appendix 3, Photo 7).

History

In the fall of 1987, Cominco Ltd. optioned the property and conducted detailed geological mapping and trenching. In 1989, the company drilled 5 holes (totalling 252 m) to test the continuity of the mineralization found in outcrop and within the trenches.

Comments

A brief examination of the trenching done by Cominco during 1987 indicated that the northern pod may not be as extensive or continuous as preliminary surface mapping had suggested. Diamond drill results were generally poor and indicated that mineralization did not persist to depth in any significant width (maximum thickness 5-6 m but only obtained in 2 of 5 ddh's). Some short sections (20-60 cm) containing at least 80% wollastonite were identified.

The southern pod appeared to possess sufficient surface dimensions (approx. 30 m X 60 m) and economic concentrations (>40%) to sustain a small quarry operation. However, exploration to date indicates that such an operation is not warranted due to insufficient mineralization at depth.

The occurrence of wollastonite in the assemblages with garnet, diopside, quartz, and/or calcite (noted in ddh core) suggests wollastonite formed under conditions of the hornblende - hornfels facies metamorphism.

The mineralization appears pod-like and may possibly represent relict roof pendants.

References:

NTS 31C/12
MacKinnon and Kingston (1987)

TABLE 11 ESTIMATED MODAL COMPOSITIONS (IN PERCENT) OF TWO SAMPLES (87-506, 87-504) OF CALC-SILICATE ROCK FROM THE RAHM PROPERTY

	87-506	87-504
wollastonite	10-15	4
quartz	2-3	30
diopside	20-25	1
calcite	60-65	65

87-506 sample taken from north pod
87-504 sample taken from south pod

TABLE 12 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) AND TRACE ELEMENT CONTENT (IN PPM) OF TWO SAMPLES (87-504, 87-506) OF CALC-SILICATE ROCK

	87-506	87-504		87-506	87-504
SiO_2	26.2	15.2	Rb	12	<10
Al_2O_3	0.56	0.98	Sr	231	297
CaO	47.60	51.7	Y	<10	<10
MgO	2.25	0.79	Zr	<10	<10
Na_2O	0.46	0.43	Nb	17	<10
K_2O	0.09	0.14	Ba	145	227
Fe_2O_3	0.61	0.19			
MnO	0.07	0.03			
TiO_2	<0.01	0.05			
P_2O_5	0.02	0.05			
Cr_2O_3	<0.01	<0.01			
L.O.I	22.2	30.8			
Total	100.1	100.4			

TABLE 13 ELECTRON MICROPROBE ANALYSES-CHEMICAL COMPOSITION (IN PERCENT) OF WOLLASTONITE PRESENT IN SAMPLES (87-504b, 87-506b) OF CALC-SILICATE ROCK

%	1	2	3	4	5	6
SiO_2	50.59	51.66	51.69	51.18	51.28	59.07
TiO_2	0.00	0.00	0.00	0.00	0.00	0.26
Al_2O_3	0.02	0.00	0.00	0.01	0.01	20.86
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.15	0.11	0.03	0.18	0.12	0.12
MnO	0.00	0.08	0.05	0.06	0.05	0.01
MgO	0.00	0.02	0.02	0.02	0.02	0.00
CaO	49.43	48.31	48.42	49.00	48.79	0.22
K_2O	0.01	0.12	0.03	0.02	0.05	11.31
Na_2O	0.05	0.22	0.00	0.03	0.08	0.77
BaO						10.86
Total	100.25	100.52	100.25	100.49	100.4	103.49

%	7	8	9	10
SiO_2	51.22	51.70	51.95	51.62
TiO_2	0.04	0.00	0.00	0.01
Al_2O_3	0.04	0.04	0.04	0.04
Cr_2O_3	0.00	0.00	0.02	0.01
FeO	0.45	0.16	0.93	0.51
MaO	0.16	0.16	0.17	0.16
MgO	0.30	0.00	0.41	0.24
CaO	48.94	49.56	47.61	48.70
K_2O	0.03	0.02	0.03	0.03
Na_2O	0.02	0.02	0.04	0.03
Total	101.19	101.66	101.20	101.35

1-4 grains of wollastonite (sample 87-504b, South pod)
5 average of wollastonite grains 1-4
6 inclusions in wollastonite (sample 87-504b)
7-9 grains of wollastonite (sample 87-506b, North pod)
10 average of wollastonite grains 7-9

NOTE: Electron microprobe analysis was performed using Method I (Appendix 1).

MARMORA TOWNSHIP
MOIRA RIVER CONSERVATION AUTHORITY PROPERTY

Location

The occurrence is located approximately 1.2 km south of the community of Malone on the east side of the Moira River on lot 15, Concession 10, Marmora Township, Hastings County. NTS 31C/12, UTM Co-ordinates 293150 mE, 4936150 mN, Zone 18 (Figure 6).

Access

The area is reached from County Road 11, by following a dirt trail leading east from Malone to the Bonter marble quarries. Follow this trail to the most southerly quarry where the trail turns abruptly to the east. The mineralized outcrop is located approximately 300 m southeast, near the east bank of the Moira River.

Geology

The property (map in back pocket) is underlain by relatively pure, fine-to medium-grained, white to white-grey calcitic marbles and wollastonite-bearing calc-silicate rock. Intruding the marbles are plutonic rocks of syenitic to granitic composition. The mineralized zone occupies a 75 m long X 10 m wide area adjacent to a small tongue of syenite, near the east bank of the Moira River. The mineral assemblage consists predominantly of wollastonite (>30%) and calcite, with lesser quantities of diopside, quartz, and finely disseminated pyrite (1%). The host rock varies from fine- to coarse-grained with a massive to banded texture.

Bands vary in thickness from 10-30 cm, and consist essentially of intergrown, medium-to coarse-grained wollastonite, intercalated with white to greyish bands of fine-grained calcite and minor diopside. The wollastonite grains have a tabular to bladed to granular habit and average 2-3 mm in length. Banding is more pronounced towards the north, striking 043° and dipping 67°E. Photo 9, illustrates the banded nature at this locality. Where the rock is more massive-textured it is usually coarser-grained and contains a higher proportion of siliceous impurities (quartz and diopside).

Chemistry and Petrology

Two thin sections (Table 14) and one whole rock and trace element analysis (Table 15) were prepared from samples of calc-silicate rock collected by the writer. Sample 87-160 is from the north end and sample 87-161 is from the south end of the zone.

Thin section 87-160 is composed essentially of medium-grained, xenoblastic to hypidioblastic wollastonite intergrown with fine-grained calcite and minor diopside and quartz. Fine-grained pyrite occurs disseminated throughout the sample. There is a banded texture to the rock with wollastonite-rich bands alternating with carbonate-rich bands.

Sample 87-161 is massive, composed of intergrown wollastonite, calcite, diopside, and quartz; minor pyrite is also evident.

Photo 9. Intercalated wollastonite and calcite on the Moira River Conservation Authority property, Marmora Township

TABLE 14 ESTIMATED MODAL COMPOSITION (IN PERCENT) OF TWO SAMPLES (87-160, 87-161) OF CALC-SILICATE ROCK FROM THE MOIRA CONSERVATION AUTHORITY PROPERTY

	87-160	87-161
WOLLASTONITE	60-65	40-45
CALCITE	25-30	20-30
DIOPSIDE	4-6	10-15
QUARTZ	1-2	10-15
PYRITE	<1-1	1

TABLE 15 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) AND TRACE ELEMENT CONTENT (IN PPM) OF SAMPLE 87-160-161

SiO_2	35.1	Rb	<10
Al_2O_3	0.91	Sr	311
CaO	48.7	Y	<10
MgO	1.53	Zr	<10
Na_2O	0.32	Ba	1078
K_2O	0.07		
Fe_2O_3	0.25		
MnO	0.02		
TiO_2	0.04		
P_2O_5	0.07		
Cr_2O_3	<0.01		
L.O.I.	13.2		
Total	100.4		

Comments

This occurrence is one of a series of similar occurrences that extend along the periphery of the Deloro Pluton, within its thermal aureole. The mineralization at most of the occurrences is somewhat similar and often occurs as irregular pods, lenses, and layers (except Platinova-Cominco property). The wollastonite is hosted in massive to banded, medium- to coarse-grained calc-silicate rocks and calcitic marble.

References

NTS 31C/12
MacKinnon and Kingston (1987)

MARMORA TOWNSHIP
KELLY-CZEREWKO PROPERTY

Location

The occurrence is located on lot 16, concession 10, in Marmora Township, Hastings County, approximately 5 km north of the community of Deloro. NTS 31C/12, UTM Co-ordinates 293000 mE, 4936650 mN, Zone 18 (Figure 6).

Access

The property is reached by travelling north on County Road 11, 2.75 km from the Deloro General Store.

Geology

The Kelly-Czerewko property (Figure 11) occurs within a northeast trending sequence of marble and calc-silicate rocks between the Malone and Deloro Plutons. The marbles in the vicinity of the property are predominantly calcitic in composition and vary from

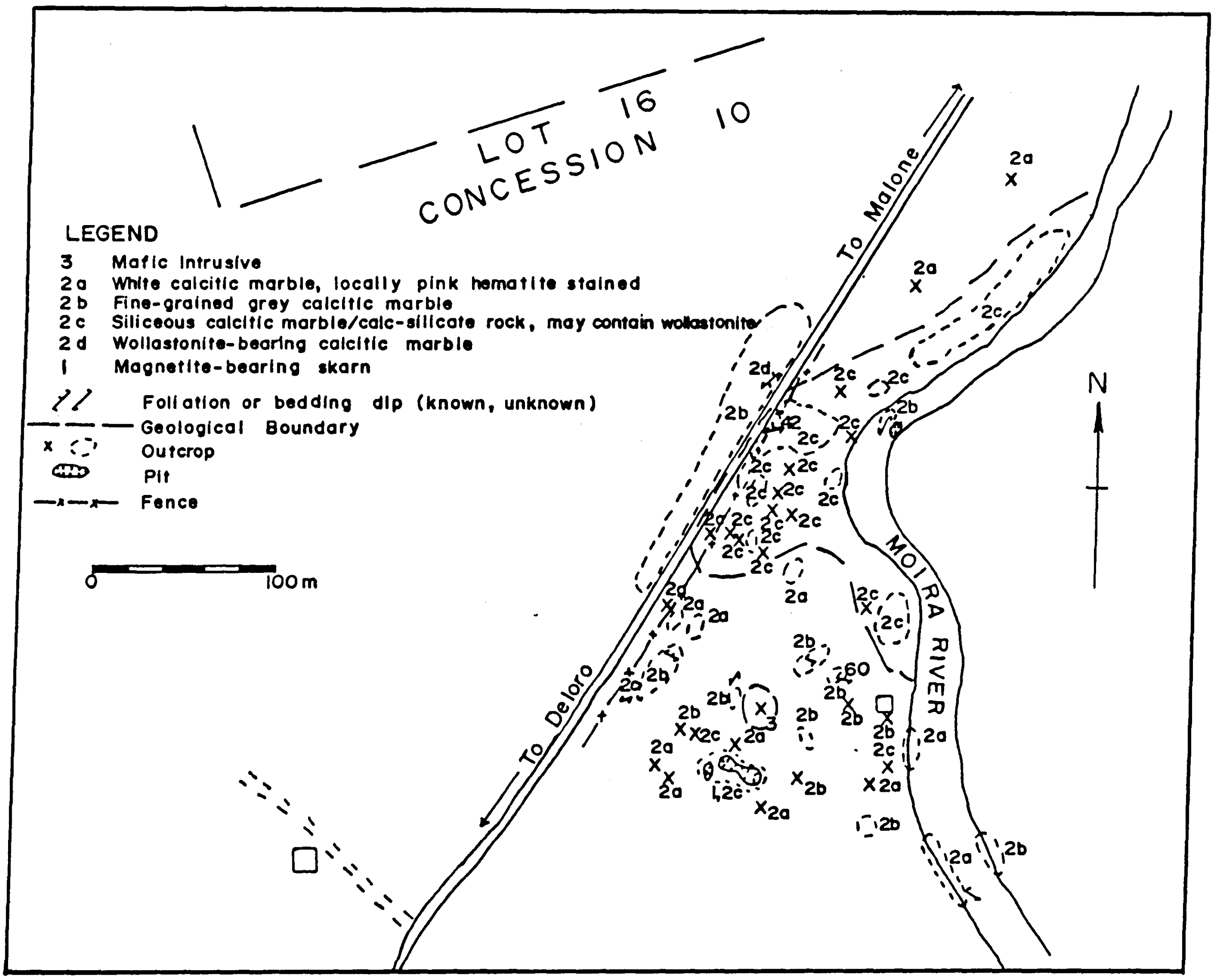


Figure 11. Geological sketch map of the Kelly-Czerewko property (From MacKinnon and Kingston 1987).

a white, medium-grained rock with a massive granoblastic texture to a well-layered, fine- to medium-grained, grey and white rock to a siliceous marble/calc-silicate rock. A small area of mafic intrusive rock outcrops near an old iron occurrence. The rock is fine-to medium-grained and composed essentially of plagioclase and amphibole.

Wollastonite mineralization is hosted both in calcitic marble (map unit 2d, Figure 11) and calc-silicate rocks (map unit 2c, Figure 11). The siliceous marble/calc-silicate rocks are white, massive, medium-to coarse-grained and composed essentially of quartz, wollastonite, calcite, and minor clinopyroxene. Local variations in the relative proportions of these constituents produce compositions varying from a siliceous calcitic marble to essentially quartz with minor quantities of calcite, wollastonite, diopside, and garnet. The wollastonite occurs as coarse-grained (up to 2 cm) prismatic to tabular crystals in aggregates with quartz and minor diopside. The grade varies from <10% to 25% and locally 85-90%, where it occurs primarily as reaction selvages between calcite and quartz. The wollastonite selvages are typically 1-2 cm in thickness and may be separated from the quartz and calcite reactants by thin (<0.5 mm) selvages of green diopside. Mineralization hosted by calcitic marble was identified in a roadcut on the west side of County Road 11. The marble is a white, fine-to medium-grained, foliated rock and is composed essentially of calcite. Accessory minerals include wollastonite (<15%), tremolite, quartz, and pyrite. The wollastonite occurs in aggregates elongated parallel to foliation (nematoblastic texture).

Magnetite-bearing skarn is exposed in a small pit located near the south end of the property (Photo 10). The iron occurrence classified under the scheme devised by Carter et al (1980) would be designated "1A. Stratabound, carbonate skarn-hosted deposits that occur at or near the contacts of igneous with carbonate rocks." Carter et al (1980) reported that these deposits typically have a low titanium content. A 0.5 m section of magnetite-bearing skarn rock is exposed in a small pit at the southern end of the property. The stratabound band strikes roughly NE-SW and dips 40-45°W.

The magnetite is fine-to medium-grained and is intimately intergrown with clinopyroxene (diopside-hedenbergite), garnet, quartz, and minor idocrase, tremolite, epidote, and calcite. The host rock is fine-grained, massive, and black and green in colour. The hanging wall contains a calc-silicate rock consisting essentially of quartz (up to 90%) and wollastonite, with minor calcite, garnet, and diopside. The wollastonite occurs intergrown with quartz, clinopyroxene, and garnet (grossularite and andradite). Separating these two units are areas of massive garnet and clinopyroxene.

Chemistry and Petrology

Five samples of the garnet-rich skarn (2-3-88, 2-4-88, 2-5-88, 2-6-88, 2-7-88) and two samples of the wollastonite-bearing calc-

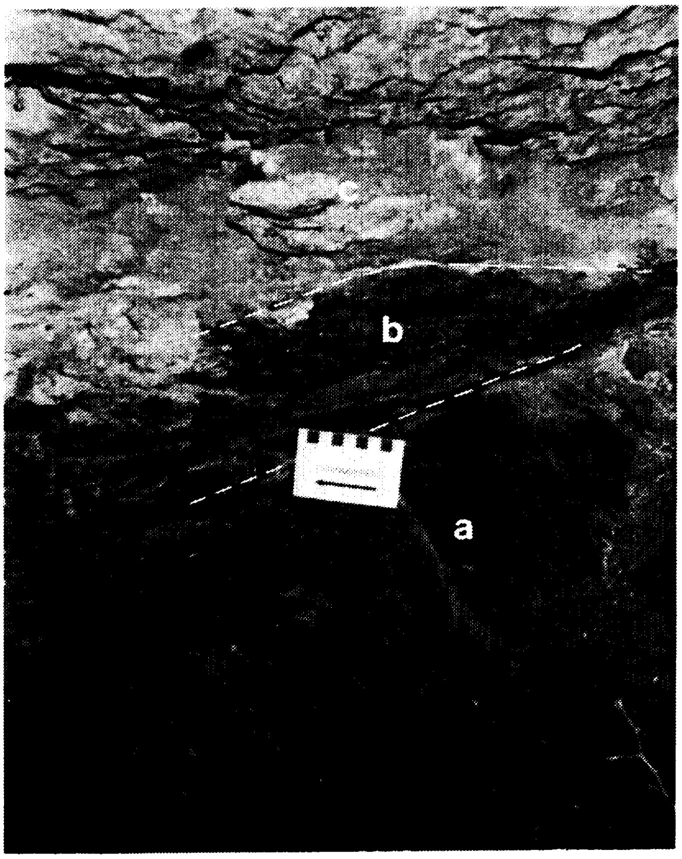


Photo 10. Hanging wall of magnetite pit illustrating magnetite (a) massive garnet (b) and quartz and wollastonite (c) Kelly-Czerewko property, Marmora Township.

silicate rock (MA-4, 2-8-88) were collected and subjected to chemical and/or petrological examination.

Samples (2-3-88, 2-4-88, 2-5-88, 2-6-88, 2-7-88) are from the pit area located at the south end of the property. Samples MA-4 and 2-8-88 are from the mineralized area on the east side of County Road 11.

Thin sections were prepared from samples 2-3-88, 2-7-88 and MA-4. Whole rock analysis (Table 16) was conducted on sample 2-8-88. Polished sections were prepared for microprobe analyses (Table 17-20) on samples (2-4-88, 2-5-88, 2-6-88, MA-4). Representative SEM backscattered images (BSE) are presented in Appendix 3. Additional x-ray diffraction analyses of selected rock types are presented in Appendix 2.

Thin section 2-3-88 consisted almost entirely of massive, andradite garnet, with occasional veins and pockets of greenish tremolite. Thin section 2-7-88 is composed mainly of grossularite, with minor inclusions of calcite and epidote. Pockets of idocrase, diopside, and minor apatite are also present. Thin section MA-4 contained wollastonite (85%), calcite (5%), quartz (5%), and minor diopside (5%).

Sample 2-8-88 is a white, massive, medium-to coarse-grained calc-silicate rock. The mineral assemblage consists predominantly of intergrown hypidioblastic to xenoblastic grains of wollastonite, and minor quartz, calcite, and diopside.

Polished section 2-4-88 contains garnet, clinopyroxene, quartz, and calcite; the large garnet prophyroblast and adjacent fibrous clinopyroxene were analysed (Table 17). The large garnet porphyroblast as well as clinopyroxene contains inclusions of xenoblastic quartz and calcite (Appendix 3, Photo 8). Several hypidoblastic garnets are apparent in hand specimen. The analysis indicates a zonation in the clinopyroxene from diopside in the central portion of the crystal grading to hedenbergite in the outer part (boundary) of the crystal. A significant increase in the Mn content in many of the pyroxene grains (2.17, 3.20%) was noted.

Polished section 2-5-88 consists mainly of massive, fine-grained dark brown to green garnet, intergrown with minor quantities of quartz, clinopyroxene (diopside-hedenbergite), apatite, and green prismatic veins of tremolite. The garnet, clinopyroxene, and amphibole were analysed (Table 18). The results again show a diopside-hedenbergite zonation, and in BSE photos 9 and 10 (Appendix 3) this zonation is apparent. The boundary between diopside and hedenbergite is often diffuse with many embayments, probably reflecting a gradual increase in iron content toward the edge of the crystal. The amphibole contains remnants of pyroxene and appears to represent a retrograde phase.

Polished section 2-6-88 consists of wollastonite, garnet, clinopyroxene, quartz, calcite, and minor sphalerite; wollastonite, garnet, and clinopyroxene were analysed (Table 19). The wollastonite is white to green, coarse-grained and consists of prismatic, hypidioblastic to xenoblastic grains, intergrown with white, medium-grained calcite and quartz, reddish-brown massive garnet, and green clinopyroxene. The analysis (Table 18) shows a clinopyroxene zonation from manganoan hedenbergite to more iron-rich compositions (Appendix 3, Photo 11).

Polished section MA-4 consists mainly of white, coarse-grained (up to 1 cm) intergrown crystals of prismatic to tabular wollastonite, and fine-grained white, massive granoblastic calcite; wollastonite was analysed (Table 20). In addition, minor quartz and clinopyroxene were also present. Bladed wollastonite is illustrated in Appendix 3 (Photo 12).

TABLE 16 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) AND TRACE ELEMENT CONTENT (IN PPM) A SAMPLE (2-8-88) OF CALC-SILICATE ROCK FROM THE KELLY-CZEREWKO PROPERTY.

SiO_2	55.3	Rb	<10
Al_2O_3	0.05	Sr	15
CaO	39.4	Y	<10
MgO	0.95	Zr	<10
Na_2O	0.27	Nb	<10
K_2O	0.02	Ba	<10
Fe_2O_3	0.94		
MnO	0.23		
TiO_2	<0.01		
P_2O_5	0.07		
Cr_2O_3	<0.01		
LOI	2.85		
Total	100.1		

TABLE 17 ELECTRON MICROPROBE ANALYSES - CHEMICAL COMPOSITIONS (IN PERCENT) OF MINERALS PRESENT IN SAMPLE 2-4-88

	1	2	3	4	5
SiO_2	34.78	35.31	50.90	50.22	49.61
TiO_2	-----	-----	0.00	0.00	0.00
Al_2O_3	0.73	0.55	0.03	0.03	0.00
Cr_2O_3	-----	-----	0.00	0.00	0.00
FeO	30.55*	30.62*	16.72	16.98	18.03
MnO	0.17	0.05	2.17	2.34	3.20
MgO	0.03	0.00	6.24	5.97	4.46
CaO	33.72	33.13	24.55	25.05	24.11
K_2O	-----	-----	0.00	0.01	0.02
Na_2O	-----	-----	0.12	0.04	0.09
Total	99.97	99.65	100.74	100.65	99.53

1-2 garnet grains from skarn in pit
3 manganoan hedenbergite grain
4 manganoan hedenbergite grain
5 salite - manganoan hedenbergite

* total iron as FE_2O_3

Note: that the pyroxene nomenclature followed by the Geoscience Laboratories, Toronto is that recommended recently by the International Mineralogical Association (I.M.A.). Most of the diopsides are called salite by Deer et al (1982) while ferrosalite is now hedenbergite.

Electron microprobe analyses were performed using Method 1 (Appendix 1).

TABLE 18 ELECTRON MICROPROBE ANALYSES - CHEMICAL COMPOSITIONS (IN PERCENT) OF MINERALS PRESENT IN SAMPLE 2-5-88

	1	2	3	4	5	6
SiO_2	35.39	51.04	48.86	51.55	49.41	51.79
TiO_2	-----	0.00	0.00	0.02	0.02	0.00
Al_2O_3	0.35	0.16	0.01	0.11	0.02	0.02
Cr_2O_3	-----	0.00	0.00	0.00	0.00	0.03
FeO	30.45*	15.90	27.02	14.74	27.27	18.21
MnO	0.12	0.41	0.75	0.35	0.47	1.87
MgO	0.02	8.38	1.05	9.24	1.45	6.16
CaO	33.15	24.09	23.24	24.54	22.44	24.31
K_2O	-----	0.02	0.01	0.00	0.04	0.02
Na_2O	-----	0.26	0.29	0.29	0.60	0.10
Total	99.49	100.26	101.23	100.82	101.71	102.51

	7	8	9	10	11	12
SiO_2	50.74	49.81	50.81	50.08	52.82	52.68
TiO_2	0.00	0.03	0.02	0.02	0.00	0.00
Al_2O_3	0.02	0.06	0.04	0.09	0.02	0.01
Cr_2O_3	0.00	0.01	0.00	0.01	0.00	0.00
FeO	17.09	34.19	33.78	34.26	12.10	9.60
MnO	2.10	0.42	0.33	0.38	0.70	0.70
MgO	6.30	2.29	2.80	2.10	10.81	11.95
CaO	24.62	11.75	11.72	11.43	25.08	24.96
K_2O	0.02	0.03	0.02	0.04	0.01	0.03
Na_2O	0.06	0.20	0.19	0.24	0.06	0.03
Total	100.96	98.77	99.70	98.65	101.61	99.95

1. garnet grain (boundary)
2. hedenbergite grain
3. grain boundary in analysis 2.
4. hedenbergite grain
5. grain boundary in analysis 4.

6-7. manganoan hedenbergite grains (iron-and manganese-rich edge)

8-10. amphibole grains

11-12. diopside grains

* total iron as Fe_2O_3

NOTE: Electron microprobe analyses were performed using Method 1 (Appendix 1).

TABLE 19 ELECTRON MICROPROBE ANALYSES - CHEMICAL COMPOSITIONS (IN PERCENT) OF MINERALS PRESENT IN SAMPLE 2-6-88

	1	2	3	4	5	6
SiO_2	35.91	36.05	51.45	49.56	51.04	51.26
TiO_2	0.02	0.00	0.00	0.00	0.00	0.00
Al_2O_3	1.08	0.24	0.00	0.00	0.02	0.04
Cr_2O_3	0.05	0.00	0.00	0.00	0.00	0.00
FeO	30.9*	28.03*	13.34	18.80	13.17	0.15
MnO	0.16	0.12	4.13	2.56	3.74	0.31
MgO	0.00	0.00	7.07	4.58	7.50	0.01
CaO	33.64	34.07	24.14	23.78	24.31	48.31
K_2O	0.02	0.03	0.02	0.02	0.02	0.03
Na_2O	0.03	0.00	0.05	0.08	0.05	0.04
Total	101.8	98.54	100.19	99.39	99.85	100.14

	7	8	9	10
SiO_2	51.80	52.06	51.34	51.62
TiO_2	0.00	0.00	0.00	0.00
Al_2O_3	0.02	0.09	0.06	0.05
Cr_2O_3	0.00	0.00	0.00	0.00
FeO	0.10	0.17	0.12	0.14
MnO	0.29	0.39	0.24	0.31
MgO	0.00	0.00	0.00	0.00
CaO	49.89	48.97	49.34	49.13
K_2O	0.03	0.04	0.04	0.04
Na_2O	0.01	0.04	0.02	0.03
TOTAL	102.14	101.78	101.16	101.31

1. andradite garnet porphyroblast
2. garnet grain
3-5. manganoan hedenbergite grains
6-9. wollastonite grains
10. wollastonite - average of grains 6-9.

* total iron as Fe_2O_3

NOTE: Electron microprobe analyses were performed using Method 1 (Appendix 1).

TABLE 20 ELECTRON MICROPROBE ANALYSIS - CHEMICAL COMPOSITION (IN PERCENT) OF WOLLASTONITE PRESENT IN SAMPLE MA-4

	1	2	3	4	5
SiO_2	48.65	50.80	50.38	50.39	50.06
TiO_2	0.00	0.00	0.10	0.06	0.04
Al_2O_3	0.14	0.00	0.00	0.00	0.04
Cr_2O_3	0.12	0.09	0.09	0.15	0.11
FeO	0.26	0.11	0.18	0.18	0.18
MnO	0.22	0.16	0.12	0.12	0.16
MgO	0.00	0.00	0.00	0.09	0.02
CaO	46.77	48.43	48.55	48.46	48.05
K_2O	0.07	0.12	0.00	0.10	0.07
Na_2O	0.00	0.00	0.00	0.00	0.00
Total	96.23	99.71	99.42	99.55	98.73

1-4. wollastonite grains from calc-silicate rock
5. wollastonite - average of grains 1-4.

NOTE: Electron microprobe analyses were performed using Method 2 (Appendix 1)

History

A small magnetite deposit (Nihil Mine) operated on the property during the late 19th century. Production figures were not available but could not have exceeded a few tens of tonnes. Workings consist of 2 small pits, the largest of which is 4 m wide, 18 m long and 1 - 4 m deep.

Comments

The geological setting and nature of the iron occurrence appears to indicate that it formed as a result of contact metasomatic effects of the mafic intrusive on the marble. The wollastonite mineralization appears to have formed primarily as a result of contact metamorphism produced by the Deloro and Malone Plutons intruding siliceous carbonate metasediments. However, in the vicinity of the pit metasomatism may have also influenced mineralization.

The results of the microprobe analysis noted a zonation (often diffuse) from diopside to hedenbergite, and from hedenbergite to more iron-rich compositions which suggest a gradual increase in iron as the reaction proceeded. The MnO content significantly increases toward the grain boundaries in many of the hedenbergite grains. The wollastonite occurs as prismatic to tabular, xenoblastic to hypidioblastic grains which have a low to moderate aspect ratio.

Marmora Township contains numerous small metasomatic iron occurrences and one notable past producer. Re-evaluating the skarn and calc-silicate rocks associated with these occurrences may result in the identification of additional wollastonite mineralization.

References

NTS 31C/12
Coste (1886)
MacKinnon and Kingston (1987)
Carter et al (1980)

MARMORA TOWNSHIP
BONTER PROPERTY

Location

This showing is located in the northwestern corner of lot 16 and the southwestern corner of lot 17, concession 11, and the northwestern corner of lot 16, concession 10, Marmora Township, Hastings County, southeast of the community of Malone. NTS 31C/12 (Figure 6).

Access

The property is reached via County Road 11 to Malone; turn east at Malone onto a private dirt road that crosses the Moira River.

Geology

The property (map in back pocket) lies in a northeast-trending band of carbonate metasediments, intruded generally by rocks of syenitic to granitic composition. This has resulted in the development of skarn zones between the Malone Pluton to the west and the Deloro Pluton to the east. The area examined in detail encompasses a 1.5 km X 600 m area along the eastern bank of the Moira River and includes both the Sovereign gold and Bonter marble properties.

The carbonate metasediments are essentially calcitic in composition, and are composed predominantly of fine-to medium-grained, white to grey crystalline marble and microcrystalline, light green to grey serpentinized marble. Accessory minerals include diopside, quartz, serpentine, talc, tremolite, dolomite, mica, and sulfides.

The wollastonite mineralization occurs in narrow lenses (typically 10 m wide X 30-50 m long) within other carbonate units. It is generally hosted by white, fine-to medium-grained, massive to foliated calcitic marble/calc-silicate rock. Accessory minerals include diopside, mica, quartz, sulfides (pyrite), and rarely, purple fluorite. However, wollastonite was also identified by x-ray diffraction techniques in a skarnoid rock containing, in addition to the characteristic mineral assemblage described above, light green garnets up to 3 mm in diameter.

The wollastonite occurs as tabular, medium-to coarse-grained crystals or as acicular clots or aggregates. The grade varies from 1 - 2% to 40 - 50%, commonly averaging 20 - 30%. It is interesting to note that where the rock is highly siliceous (quartz-rich) it usually possess a higher percentage of wollastonite.

Mineralization in an open area east of the main Bonter quarry consists of alternating bands of coarse wollastonite, fine-to medium-grained calcite, fine-grained light green diopside, and white to light grey quartz. The bands strike 93 degrees and appear to dip vertically. Individual layers are generally .5 to 4 cm in thickness but may vary to tens of centimetres. Locally, the alternating carbonate and silicate-rich layers suggest a stromatolitic texture and origin.

Flanking the wollastonite zone is a fine-grained, light green, massive rock composed predominantly of diopside, with minor quantities of calcite, serpentine, and pyrite. The weathered surface is orangish to white in colour. In thin section, the rock exhibits a granular or hornfels texture, with the majority of the rock consisting of fine, xenoblastic grains of diopside.

The granitic to syenitic intrusive rocks are generally pink, medium-grained, unaltered rocks with a massive, homogeneous texture. Carter (1984) while investigating the granitic rocks on the Sovereign Mine property, found them to be composed predominantly of orthoclase with little identifiable plagioclase, and minor biotite and chlorite (1 - 2%). He noted areas of the granite that were highly sericitized, resulting in quartz grains occurring in a fine-groundmass of sericite.

Field mapping by Carter (1984) and the present survey identified an aphanitic to fine-grained phase (map unit 4c) which is pink to dark-green and grey in colour and in places exhibits compositional banding. This unit is composed primarily of saussuritized feldspar, and contains minor quartz-carbonate veinlets. Carter (1984) suggested that this may represent a chilled phase of the intrusion, however it is somewhat similar in appearance to rocks believed by the author to be metasedimentary in origin.

Intruding the granite and marble are medium-grained dark green diabase and minor felsic dykes. The dykes rarely exceed 3 metres in thickness and commonly weather rusty brown. This feature is particularly evident on the east wall of the main Bonter quarry.

Chemistry and Petrology

Three samples of calc-silicate rock (87-508, 87-509, 87-509A) were collected and subjected to chemical and/or petrological investigation. Sample 87-508 is from an open area approximately 150 m west of the south end of the Bonter. Samples 87-509 and 87-509A are from an outcrop located near the Moira River.

Thin sections (Table 21) were prepared from samples 87-508, 87-509 and 87-509A and a whole rock analysis (Table 22) was performed on sample 87-508. Additional x-ray diffraction analysis of selected rock types are presented in Appendix 2.

Thin section 87-508 is a strongly foliated, white, medium-grained calcitic marble/calc-silicate rock. The mineral assemblage consists of bands of wollastonite and diopside alternating with quartz. The wollastonite occurs as xenoblastic to hypidioblastic grains up to 4 mm (commonly 1-1.5 mm) intergrown with xenoblastic grains of diopside. The diopside occurs as large crystals, as fine-grained aggregates, and as inclusions within wollastonite. The quartz-rich bands and augens consist essentially of xenoblastic grains of quartz (averaging 0.1-0.2 mm) which exhibit

TABLE 21 ESTIMATED MODAL COMPOSITION (IN PERCENT) OF THREE SAMPLES (87-508, 87-509, 87-509A) OF CALC-SILICATE ROCK FROM THE BONTER PROPERTY

	87-508	87-509	87-509A
Wollastonite	30-35	10-15	29
Diopside	40-45	10	3
Quartz	20-25	-	1
Calcite	<1	75-80	66
Feldspar	<1	-	-
Sphene	<1	-	-
Opaques	<1	-	-
Garnet	-	-	1

TABLE 22 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) AND TRACE ELEMENT CONTENT (IN PPM) OF A SAMPLE (87-508) OF CALC-SILICATE ROCK FROM THE BONTER PROPERTY

SiO_2	56.4	Rb	11
Al_2O_3	0.63	Sr	56
CaO	37.6	Y	<10
MgO	1.43	Zr	<10
Na_2O	0.41	Nb	<10
K_2O	0.36	Ba	120
Fe_2O_3	0.38		
MnO	0.11		
TiO_2	0.02		
P_2O_5	0.06		
Cr_2O_3	<0.01		
LOI	2.77		
Total	100.2		

a granular texture. The bands average 1-2 mm in thickness and the wollastonite-and diopside-rich bands are generally coarser-grained.

Thin section 87-509 is a weakly-foliated, white calcitic marble/calc-silicate rock. The rock has a granoblastic texture and is composed of xenoblastic grains of calcite (averaging 0.6 mm) intergrown with minor wollastonite and diopside. The wollastonite occurs as hypidioblastic, equant to prismatic grains up to 1.2 mm in length (averaging 0.3 - 0.4 mm). The grains are partially aligned and commonly exhibit an aspect ratio of 1:2 to 1:4. The wollastonite grains are relatively free of inclusions. Thin section 87-509A has a similar texture to 87-509 but contains a greater proportion of wollastonite.

History

The Bonter property is both a gold and marble past producer. Guillet (1985) summarizes the early history as follows:

" While the earliest mining activity has not been recorded, it is believed that the discovery of gold was made about 1866, and that until 1878 a number of people may have worked the site. In 1878 it is known that a D.E.K. Stewart was working a number of pits and shallow shafts under lease.

From 1890 to 1893 the site was worked by the Crescent Gold Mining Company of Marmora Limited. In addition to numerous pits, two shafts to depths of 20 m and 27 m (65 and 90 feet) were developed. The mine workings were connected by tramway to a ten-stamp mill housed in a 3-storey building and powered by a 90 hp steam boiler.

In 1903 the old pits and opening were being reworked by the Sovereign Gold Mining and Development Corporation of Ontario Limited.

As much as 1,000 ounces of gold may have been recovered overall, at an average ore grade of nearly 0.2 ounces of gold per ton (Gordon et al 1979).

W.R. Bonter and Company produced coarse marble blocks, chips, grit, and dust from six small quarries on the property. Production commenced in the 1930's and ceased by the 1970's. A small wooden mill was erected on site.

The property is currently optioned by R. Guillet, who has applied for a quarry permit to extract high calcium material suitable for filler applications.

Comments

The property contains numerous small lenses or pods of wollastonite mineralization. In general, the mineralization is low to medium grade, commonly containing >30% siliceous impurties (diopside and quartz). Additional work is required to determine the continuity of these zones both along strike and at depth.

References

NTS 31C/12
Carter (1984)
Gordon et al (1979)
Guillet (1985)
Northern Development and Mines, Southeastern District Resident Geologist's Office Assessment Files

MARMORA-MADOC TOWNSHIP
NORANDA PROPERTY

Location

The property is situated approximately 1 km north of the community of Malone, on lot 19, concession 11, Marmora Township and lot 19, concession 1, Madoc Township, Hastings County. NTS 31C/12, UTM co-ordinated 293600 mE, 4938950 mN, Zone 18 (Figure 6).

Access

The occurrence is located in a roadcut on County Road 11, along the Marmora-Madoc Township boundary.

Geology

The property (map in back pocket) is underlain by calcitic carbonate metasediments and intruded by highly sheared auriferous granite, and minor mafic intrusive. The carbonate metasediments consist mainly of fine-grained, grey, foliated calcitic marble with/without intercalated fine-grained calcareous schists.

A small band (5.1m) of wollastonite-bearing calcitic marble/calc-silicate rock (Photo 11) is exposed only in the vicinity of County Road 11, along the northern edge of the granite. The unit strikes 036° and dips 77 degrees NW and appears to plunge southwest. Mineralization occurs in aggregates or knots up to 30 cm in diameter, elongated parallel to the foliation. Micro-folding and isolated fragments of felsitic material occur within the unit, east of County Road 11. In addition to wollastonite and calcite, minor calc-siliates, diopside, and quartz were also noted. In contact with the mineralized zone is fine-grained bleached-looking felsite which may represent a reaction zone between the granite and the marble.

Examination of drill core obtained from Noranda's gold exploration program identified, in addition to the marbles observed at surface, a white to light green, massive to foliated marble and a grey banded and brecciated marble. The brecciated marble contains fragments of grey banded marble that have been rotated and displaced. X-ray diffraction of samples taken from the core identified the accessory minerals talc, serpentine, quartz, mica, dolomite, and amphibole. Diopside was observed in some hand samples.

The felsic intrusive rocks have been highly sheared (foliation strikes 050-067°, averages 60-62° and dips 80 NW to 80 SE but is generally 80 NW to vertical) and commonly exhibit hematite and sericite alteration along shearing planes. The intrusion is transected by a series of small northeast trending faults. Small quartz veins (commonly only cm in width, but may vary up to 0.5 m) can be observed. Native gold is occassionally found within these veins but generally is associated with a green muscovite alteration in the more strongly sheared parts of the intrusion.

Chemistry and Petrology

One thin section and one polished section were prepared from samples of the calc-silicate rock collected from the north side of the County Road 11 roadcut. A whole rock analysis of a sample of the calc-silicate rock is presented in Table 23.

Thin section MA-2 (Table 24) consists mainly of intergrown xenoblastic grains of fine-grained calcite, and prismatic to granular, coarser-grained wollastonite, with accessory minerals quartz, and diopside (Photo 12). The rock has a foliated texture, which is principally defined by grains of wollastonite.

The chemistry of the wollastonite grains is presented in Table 25.

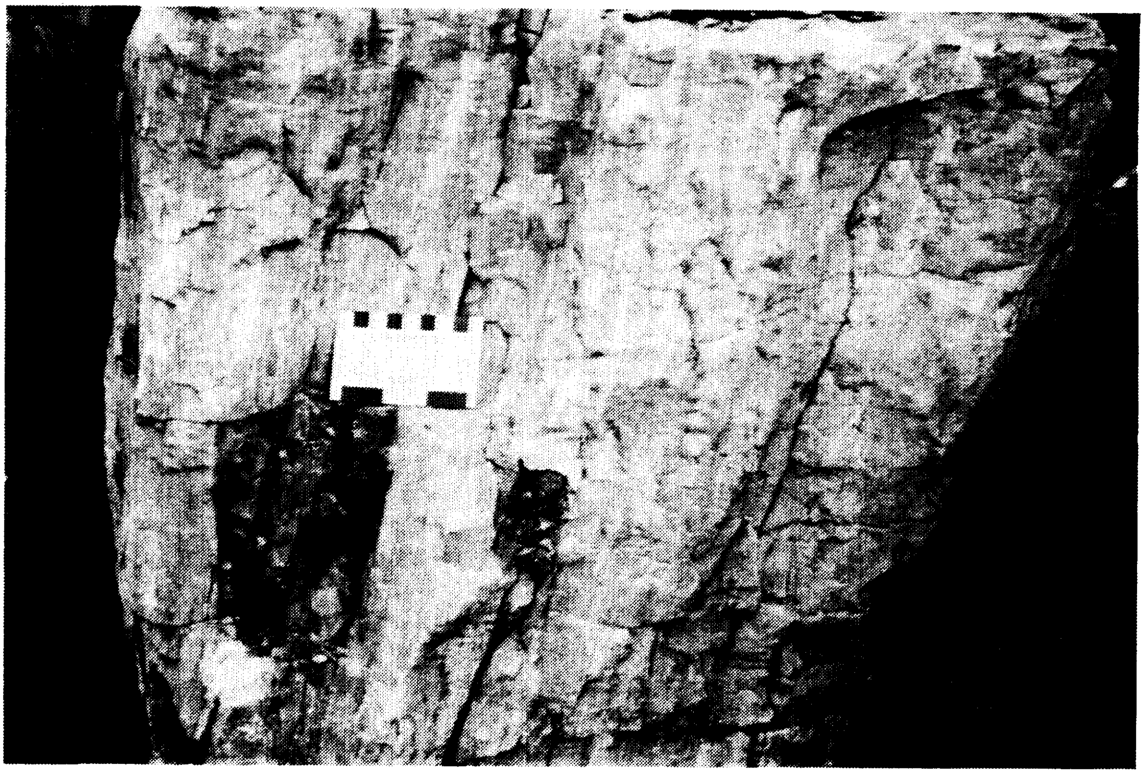


Photo 11. A small wollastonite-bearing calc-silicate band exposed along the northern edge of a small granite intrusion, Noranda Property, Marmora-Madoc Townships.

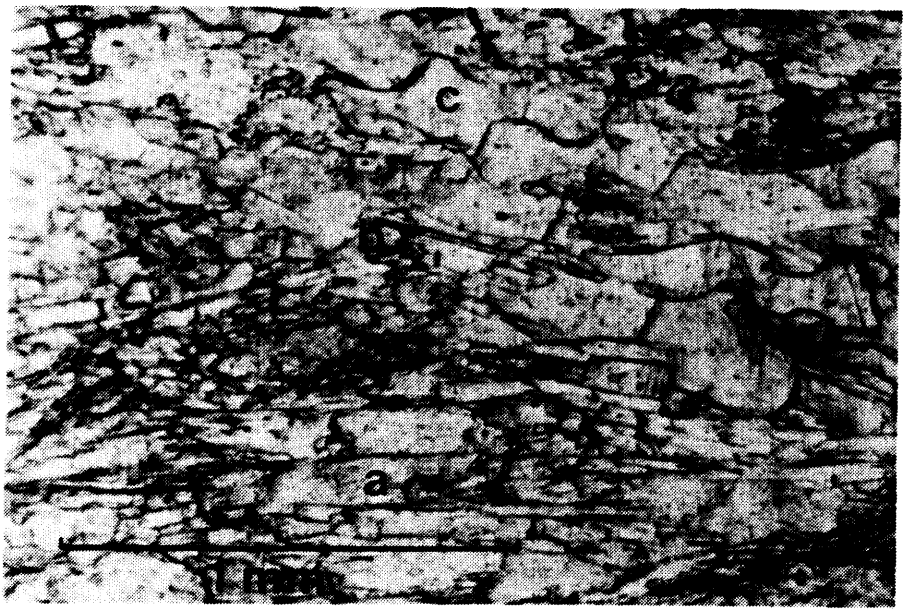


Photo 12. Photomicrograph (MA-2) in plane polarized transmitted light taken from the Noranda property, Marmora Township showing wollastonite (a), diopside (b) and calcite (c), banding. Scale bar indicated 1 mm.

TABLE 23 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) AND TRACE ELEMENT CONTENT (IN PPM) OF A SAMPLE OF CALC-SILICATE ROCK FROM THE NORANDA PROPERTY

SiO2	20.1	Rb	11
Al2O3	0.50	Sr	1390
CaO	46.3	Y	<10
MgO	1.85	Zr	<10
Na2O	0.41	Nb	<10
K2O	0.20	Ba	3748
Fe2O3	0.48		
MnO	0.04		
TiO2	0.01		
P2O5	0.05		
Cr2O3	<0.01		
LOI	28.9		
SUM	99.4		

TABLE 24 ESTIMATED MODAL COMPOSITION (IN PERCENT) OF A SAMPLE (MA-2) OF CALC-SILICATE ROCK

wollastonite	15-20
calcite	65-70
diopside	5-6
quartz	2-4
opaques	1-2

TABLE 25 ELECTRON MICROPROBE ANALYSES - CHEMICAL COMPOSITIONS (IN PERCENT) OF WOLLASTONITE PRESENT IN SAMPLE MA-2.

	1	2	3	4
SiO2	50.69	50.81	50.33	50.61
TiO2	0.00	0.00	0.05	0.02
Al2O3	0.06	0.00	0.05	0.04
Cr2O3	0.20	0.00	0.11	0.10
FeO	0.07	0.13	0.21	0.14
MnO	0.00	0.17	0.00	0.06
MgO	0.00	0.10	0.00	0.03
CaO	49.07	48.96	48.99	49.01
Na2O	0.00	0.16	0.00	0.05
K2O	0.00	0.00	0.00	0.00
TOTAL	100.09	100.33	99.74	100.05

1-3	wollastonite grains
4	average of grains 1-3

NOTE: Electron microprobe analysis was performed using Method 2 (Appendix 1)

History

In 1986 Noranda Inc. optioned the property as a gold prospect. Exploration work conducted to date includes geological mapping, geophysical surveys (magnetometer, VLF-EM), channel sampling, diamond drilling, and metallurgical testing.

Comments

The whole rock composition of the calc-silicate rock shows the highest value of Sr. (1390 ppm), and Ba (3748 ppm) of samples analyzed. The wollastonite mineralization is low grade (<20%) but is variable and outcrop exposure is limited. To date mineralization appears to be restricted to the north side of the granite close to County Road 11.

References

NTS 31C/12
MacKinnon and Kingston (1987)
MacKinnon et al (1989)

DISCUSSION AND CONCLUSIONS

Samples were taken from the 8 wollastonite occurrences within the study area. These samples showed a high degree of consistency in mineralogy, with few exceptions, as well as remarkable similarity in the chemistry of the wollastonite in particular. "Based on the detailed mineralogy and chemistry it is apparent that these deposits have a common origin in terms of temperature, pressure and chemistry of the host rocks. This would account for the unusual degree of chemical similarly, both in the mineral assemblage as a whole, and within the wollastonite itself" (MacKinnon et al 1989).

Deposits generally follow specific stratigraphic horizons because the composition of the original rocks was of major importance in determining the composition of the deposit (Lamey 1966). The most important criteria in the formation of wollastonite in the Marmora study area appears to be the original chemistry of the rock although textural and litholgical evidence indicates that the mineralized zones do not represent one specific horizon. The host rock appears to vary from a white to grey calcitic marble with quartz veining, to a white and grey siliceous calcitic marble with approximately 20% quartz grains distributed throughout, to interbanded marble and quartz-rich metasediments (quartz arenite), and finally to a finely laminated siliceous (possibly stromatolitic) marble.

The occurrences (excepting the magnetite pit on the Kelly-Czerewko property) formed as a result of contact metamophism (reaction skarns) which developed magnesian and calcitic exoskarns along the peripheries of the intrusions. Faulting may have further enhanced the metamorphic effects produced by the intrusion of the Deloro Pluton, by acting as conduits for heat and fluids into the surrounding country rocks.

Wollastonite is formed by the reaction $CaCO_3 + SiO_2$ -- $CaSiO_3 + CO_2$. The wollastonite textures observed in the field (acicular radiating aggregates and banded) can be explained on the basis of the reaction mechanism, which depends strongly on the composition of the fluid phase. Calcite is more soluble with increasing X_{CO2}, whereas quartz is more soluble with increasing X_{H2O}.

Vernon (1976) reported that "in experiments using a CO_2-H_2O fluid, wollastonite needles nucleated at specific centres (probably defect or impurity sites) on the surfaces of calcite grains and then grew outwards as rosettes, mainly parallel to the calcite surfaces, thereby forming a reaction rim. In the case of a pure CO_2 fluid phase, experimentation indicated the formation of granular wollastonite, not acicular, which formed rims on quartz". This is not a simple volume exchange of quartz for wollastonite due to Ca and Si gradients across the reaction rim which permits the diffusion of Ca and Si in opposite directions allowing wollastonite to grow on both the exterior and interior of the reaction rim (Vernon 1976). For this reason it is difficult to determine whether the calcite or quartz migrated in the banded texture. Where the mineralization occurs in aggregates i.e. Platinova-Cominco Property, the host rock did not originally have to consist of siliceous knots but rather quartz may have migrated from the surrounding marble into these aggregates to react. The mineralization at the Kelly-Czerewko property appears to be in part metasomatic in origin (magnetite-skarn in pit) and in part as reaction selvages between quartz veining and calcite in the rock. Microprobe analyses of the pyroxene and garnet indicated that the iron contents increased together, which is typical of iron and lead-zinc deposits formed in more intermediate or neutral conditions (Barnes 1979).

The Platinova-Cominco property in particular, appears by field mapping to possess grade, surface dimensions, and tonnages substantial enough for development by open pit methods.

Elsewhere the mineralization consists of narrow bands and what appear to be disseminated pods which may represent relict roof pendants. The grade varies from <20% to 40-50%, locally up to 80%. Further work is required to fully assess several of these occurrences i.e. Bonter Property.

Beneficiation studies on two samples of wollastonite from the Platinova-Cominco property indicate that liberation size is 420 microns. Preliminary testing (flotation) showed that in general, the wollastonite concentrate meets the minimum wollastonite grade and iron oxide requirements, but L.O.I. is greater than 1%. The calcite concentrate meets minimum chemical grade requirements but not the brightness requirements for high-quality filler material. Andrews (1988) suggested further processing should improve grade, brightness, and L.O.I. analysis of the wollastonite concentrate and the grade and brightness of the calcite concentrate.

PART III

SOUTHEASTERN ONTARIO WOLLASTONITE OCCURRENCES

MARMORA TOWNSHIP
CROWE LAKE OCCURRENCE

Location

The occurrence is located 3 km northeast of the junction of Hwy. 14 and Hwy. 7, on lot 11, concession 3, Marmora Township, Hastings County. NTS 31C/5, 31C/12, UTM co-ordinates 284310mE, 4930990mN, Zone 18 (Figure 12).

Access

The occurrence may be reached by boat on Crowe Lake or by township road, and the peninsula is traversed by several dirt and gravel cottage roads.

Previous geological work:

The area was first mapped by Coste (1886, 1:31,680 scale), and later by Wilson (1940, scale 1:63,360) and Bartlett and Moore (1983, 1:15,840 scale). Bartlett and Moore (1983) were the first to identify the presence of wollastonite at this locality.

Geology

Along the eastern shore of Crowe Lake, wollastonite was identified in reaction zones between calcite and quartz. This feature is described by Bartlett and Moore (1983, 1985) as follows:

"Occurring inland from the shore of Crowe Lake, and on an island in the lake is pure, white, fine- to medium-grained calcitic marble. Millimetre-scale cherty laminae, in part representing relict algal mat structures, are abundant locally; in one outcrop

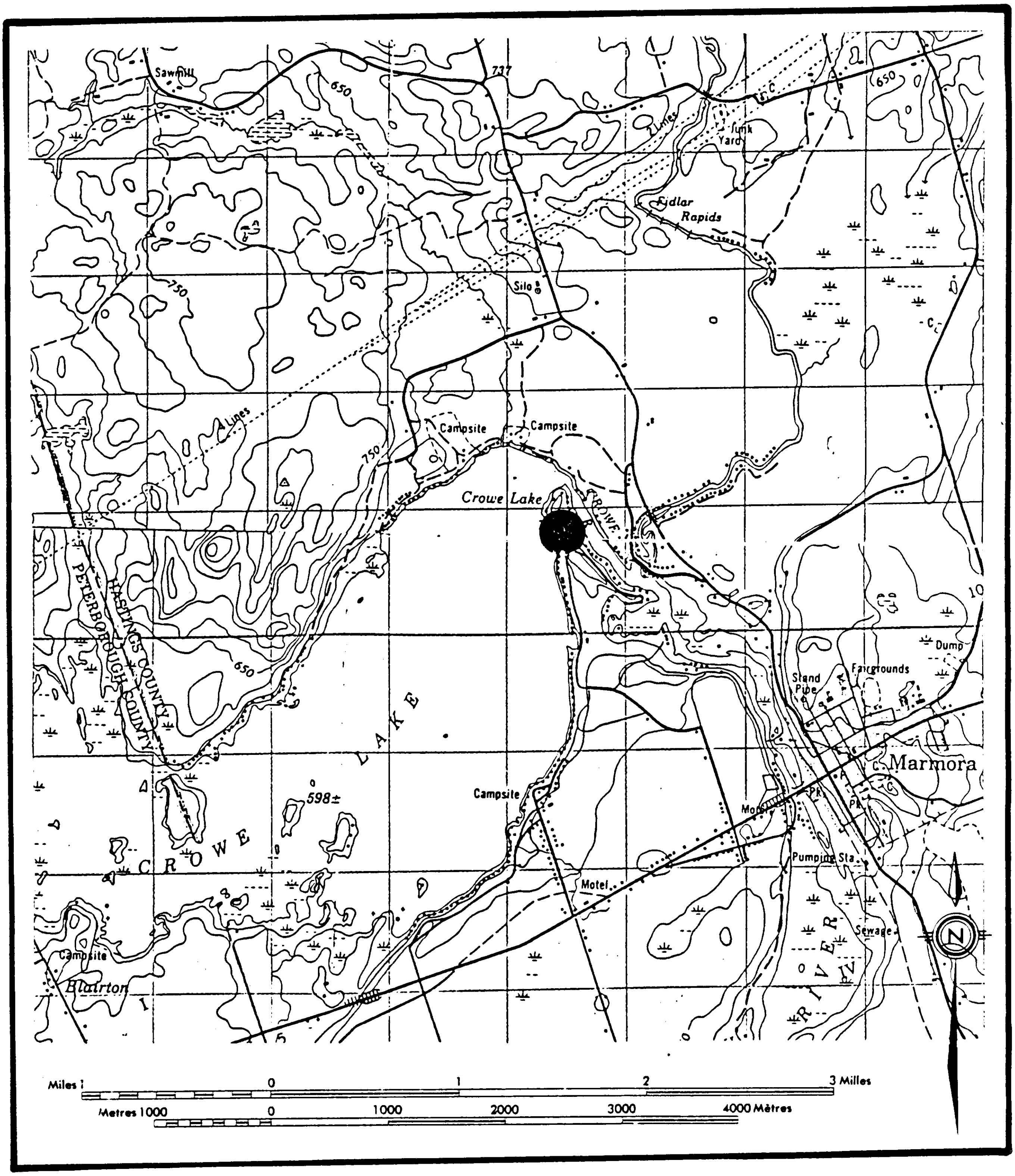


Figure 12. Location map of the Crowe Lake occurrence, Marmora Township.

displaying these features (UTM 284310mE/4930990mN), wollastonite separates quartz from calcite. Calcitic marble in the area east of Crowe Lake has been quarried in the past. Locally the marble has been converted to skarn."

The wollastonite is white to tan in colour, and has a fibrous to tabular habit. Hypidioblastic to idioblastic crystals of wollastonite up to several centimeters in length occur primarily as selvages (reaction rims) around siliceous veins and knots. The host rock is a fine- to medium-grained, white calcitic marble, commonly containing >20% siliceous impurities. The weathered surface is grey to white and locally yellowish in colour, with fragments and bands of siliceous material standing out in relief. Siliceous bands and fragments have a matted appearance and vary from less than 1 to 15 cm in thickness, generally averaging 1-2 cm (Photo 13). The mineral assemblage may include calcite, quartz, wollastonite, diopside, and tremolite. Locally, it may contain up to 35-40% diopside and tremolite, with little to no identifiable wollastonite (field identification).

Comments

Wollastonite mineralization appears to be more extensive than was reported by Bartlett and Moore (1983, 1985), both in terms of its distribution and relative abundance. The close proximity to houses and cottages on the peninsula limits or negates any potential for development should economic concentrations be identified. However, since the formation of wollastonite is due to contact metamorphism resulting from the intrusion of the

Cordova Gabbro, there exists good potential for further mineralization in the surrounding marbles and skarn zones.

References

NTS 31C/11
Bartlett and Moore (1983, 1985)
Coste (1886)
Wilson (1940)

Photo 13. Siliceous outcrop (possible stromatolite) containing wollastonite selvages, Crowe Lake Occurrence, Marmora Township.

HUNGERFORD TOWNSHIP
TWEED MARBLE QUARRY

Location

The property is located 5 km north of the town of Tweed, on lot 11, concession 14, Hungerford Township. NTS 31C/11, UTM co-ordinates 314400 mE, 4932900 mN, Zone 18 (Figure 13).

Access The quarry is located approximately .08 km south of the Hawkin's Bay Road (Elzevir-Hungerford Township boundary) along a gravel and dirt road on the west side of the Skootamatta River.

General Geology

The area is underlain by north-east trending supracrustal rocks (marbles, paragneisses, pelitic and psammo-pelitic schists and gneisses) of the Flinton and Mayo Groups, and metaplutonic granitic gneisses (Addington, Sheffield). Mafic metavolcanics of the Hermon Group (Tudor Formation) and the Elzevir granite occur to the north and the Clare River synform to the southeast. This is part of the area Hewitt (1956) defined as the Kaladar-Dalhousie Trough.

Previous Geological Work

The area was mapped by Burns (1951), and incorporated into Hewitt's (1964, 1:26,720 scale) Madoc Area compilation map. Thompson (1972) partially mapped the area during his investigation of the Flinton Group. Verschuren et al (1985, 1986) evaluated the quarry as part of a building stone survey of southeastern Ontario.

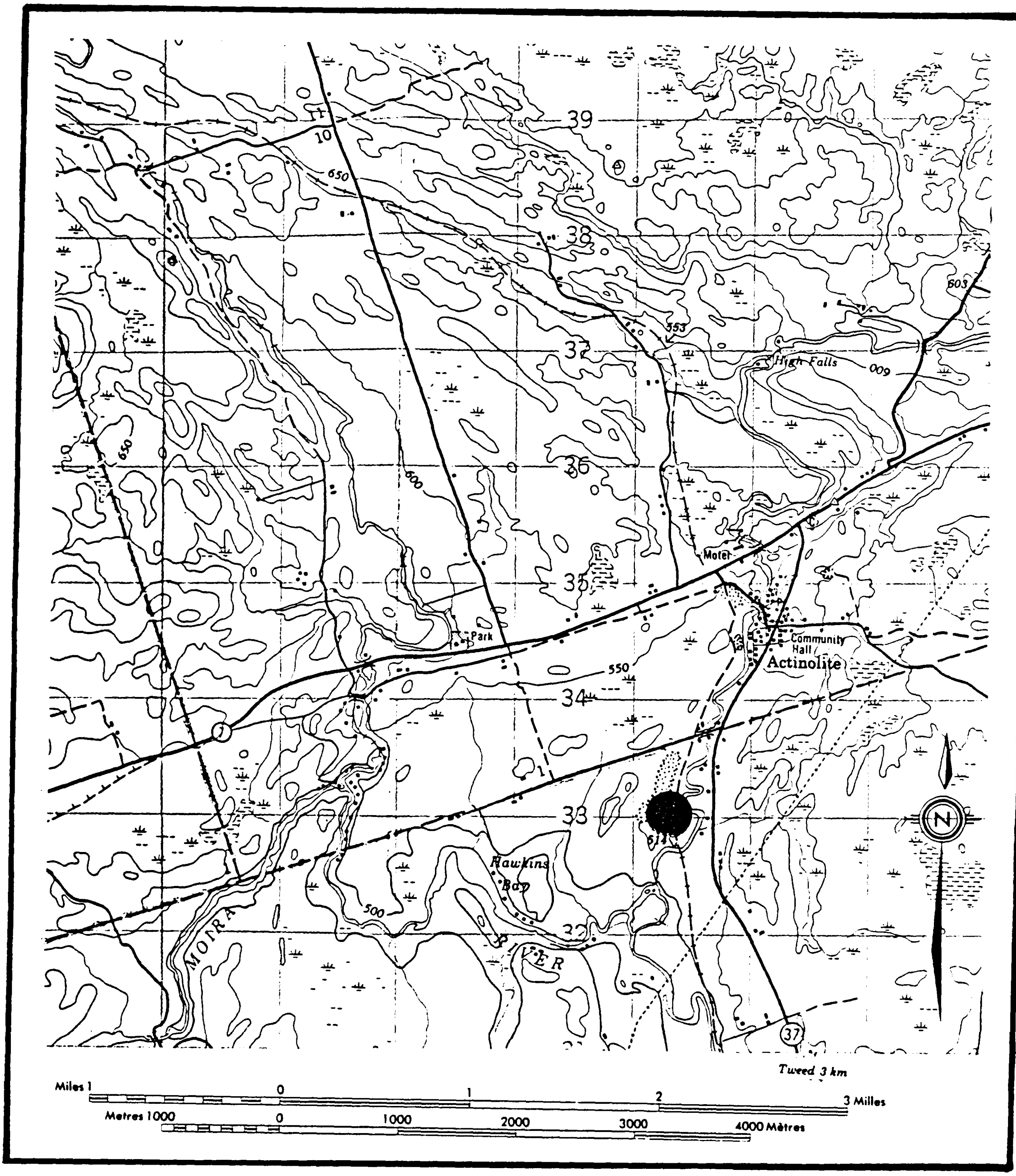


Figure 13. Location map of the Tweed Marble Quarry, Hungerford Township

Geology

The marble varies from predominantly dolomitic marble with thin, coarser, intercalated calcitic and tremolitic units, to a white, wollastonite-bearing calcitic marble/calc-silicate rock. Figure 14 illustrates the geology of the Tweed Marble Quarry. The dolomitic marble is fine-to medium grained, and white to cream and green in colour. Accessory minerals include tremolite, diopside, serpentine, quartz, pyrite (<1%), and local hematite staining. The rock is massive to foliated, striking 021-030 degrees and dipping southeast 73 degrees. Irregular, boudinaged amphibolite dykes up to 2 m in width intrude the marble in the vicinity of the quarry. Jointing in the quarry is regular to irregular, and limited to moderate in extent. Prominent joint sets are: strike 295°, dip vertical, spacing 1-2 m; strike 027, dip vertical, spacing 1-2 m; and horizontal, spaced 2-3.5 m apart (Verschuren et al 1986).

East of the quarry, field reconnaissance identified a 10-15 m wide band of wollastonite-bearing calcitic marble, averaging 5% to 10% wollastonite, and 10 to 15% locally. The band strikes 023 degrees and dips east 70 degrees. The weathered surface is a light grey to black in colour. The wollastonite occurs as white, fine to medium grained blades in aggregates up to 20 cm in diameter. These aggregates occur singly or in trains and probably represent the more siliceous-rich layers in the marble. Intercalated and boudinaged within the marble is a 15 cm thick siliceous band, and numerous inclusions of calc-silicates and quartz (Photo 14). Extensive Pleistocene cover (sand and

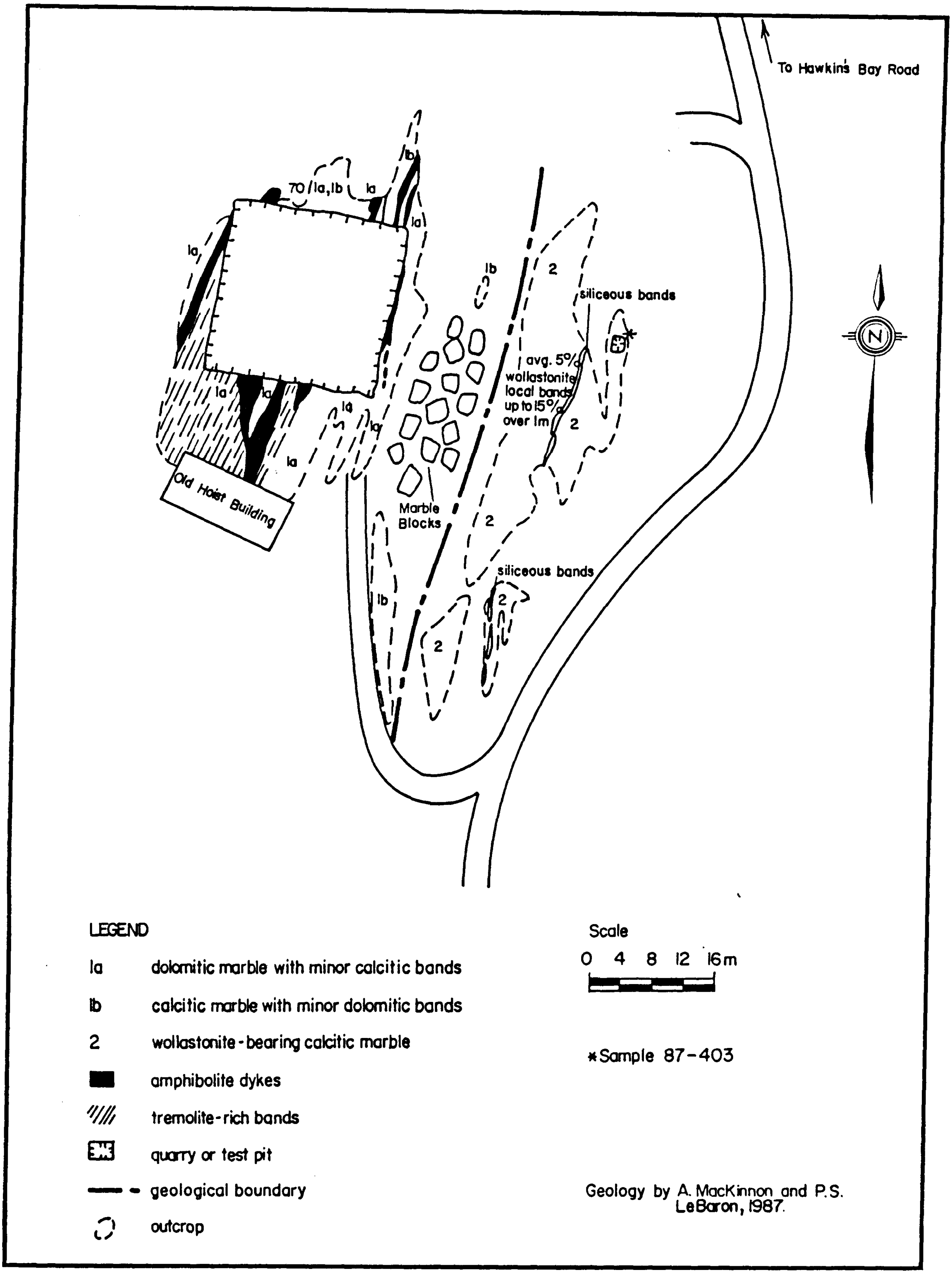


Figure 14. Geological sketch map of the Tweed Marble Quarry, Hungerford Township.

gravel) has resulted in generally poor outcrop exposure except where previously stripped in the vicinity of the quarry.

Chemistry

Papertzian and Kingston (1982) analyzed a sample (No. 736) of marble from the corner of the quarry as part of a marble reconnaissance of eastern Ontario. The results of this analysis and that of the present survey (Sample 87-403) taken from the wollastonite zone are presented in Table 26.

TABLE 26 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) OF SAMPLES OF SELECT ROCK TYPES FROM THE TWEED MARBLE QUARRY

	1	2
SiO_2	10.1	50.6
Al_2O_3	0.94	0.14
Fe_2O_3	0.10	0.18
MgO	0.81	2.56
CaO	47.9	42.8
Na_2O	0.00	0.37
K_2O	0.08	<0.01
TiO_2	0.01	<0.01
P_2O_5	0.00	0.02
MnO	0.03	<0.01
LOI	32.9	3.39
Total	92.9	100.1

1. calcitic marble, analysis taken from Papertzian and Kingston (1982) (Sample 736)

2. wollastonite-bearing calcitic marble/calc-silicate rock (sample 87-403)

Photo 14. Wollastonite marble containing a siliceous band and calc-silicate layers, Tweed Marble Quarry, Hungerford Township.

Two samples of calc-silicate rock from the wollastonite zone were analysed by X-ray diffraction techniques. The results indicate that the sample consists of wollastonite and calcite with minor quartz (Appendix 2).

History

The deposit was developed as a building stone quarry and was operated by Vermont Marble Company in the late 1960's. The property is currently held by U. Kretschmar.

Comments

The host marble is calcitic in composition and contains abundant knots and boudinaged bands of siliceous material. These siliceous impurties in combination with the extremely low grade (averaging 5-10%) renders this property impractical to mine for wollastonite. Although no economic concentrations of wollastonite were identified, its presence is significant since it implies conditions were suitable for the formation of wollastonite. The metamorphic grade in the Clare River synform is confined to amphibolite facies and increases northeast to southwest (Chappell 1978). Other calcitic marble units along the Sheffield and Addington Plutons may therefore prove to be useful exploration targets.

References

NTS 31C/11
Bain (1960)
Burns (1951)
Chappell (1978)
Hewitt (1956, 1964)
Papertzian and Kingston (1982)
Thompson (1943)
Verschuren et al (1985, 1986)

LAKE TOWNSHIP
LAKE OF ISLANDS OCCURRENCE

Location

The occurrence is located east of the south bay of Lake of Islands on lot 26, concession 9, Lake Township, Hastings County. NTS 31C/13, UTM Co-ordinates 283000 mE, 4960500 mN, Zone 18 (Figure 15).

Access

The area is reached by travelling on township roads to Dickey Lake and then traversing several kilometers either by foot or boat to the south-east shore of Lake of Islands.

General Geology

The geology of Lake Township is described by Laakso (1968) as follows:

> "The township lies wholly within the Hastings Basin structural subdivision of the Haliburton-Bancroft area of the Grenville province of the Canadian Shield.
>
> The bedrock is of Precambrian and Paleozoic age. The oldest Precambrian rocks are metasediments and metavolcanics of the Mayo Group. They consist of marble, paragneiss, para-amphibolite, schist, and basic and acid metavolcanic rocks. These metasediments and metavolcanics are intruded by gabbro, diorite, syenite, and granite. The largest gabbro bodies are the Lake metagabbro and Tudor gabbro in the southeastern part of the township. The principal granite plutons are the Copeway and Freen granites.
>
> In Paleozoic times, seas covered Lake township, and an outlier of Ordovician (Black River) rock is found at Vansickle.
>
> The area was highly folded during the Grenville orogeny, the main axes of folding being northeast-southwest, parallel to the regional folding. Crossfolding occurs along axes trending northwest-southeast."

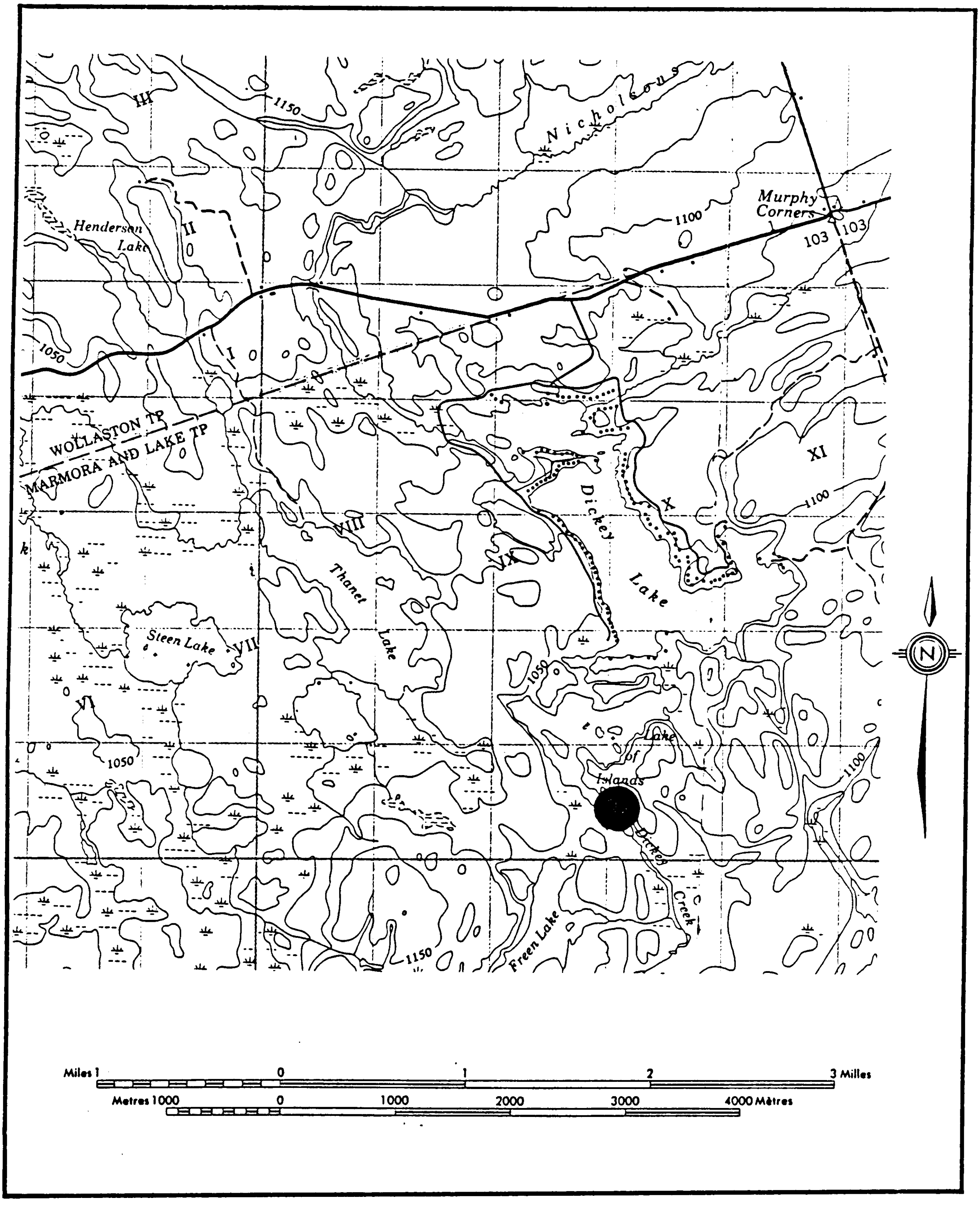


Figure 15. Location map of the Lake of Islands occurrence, Lake Township.

Previous Geological Work

Lake Township was first mapped by Adams and Barlow (1910, 1:2,534,450 scale), and later in more detail by Laakso (1966, 1968 1:31,680 scale). The area was included in mineral occurrence and compilation maps by Thomson (1943, 1:126,720 scale), Satterly (1943, 1:126,720 scale), and Kingston et al (1985, 1:125,000 scale). Carmichael (1970) and Walton (1978) have mapped parts of the township as part of their doctoral and masters dissertations, respectively.

Geology

The area (Figure 16) along the southeast shore of Lake of Islands is underlain by acidic and basic metavolcanics, pelitic schists (chloritoid schist), skarn, and interbanded marble, amphibolite, and hornblende schist. The metamorphic grade varies from greenshist to upper amphibolite facies.

The basic metavolcanics are dark green, fine-grained rocks with a massive to foliated texture. The acidic metavolcanic rocks are generally pinkish to blue in colour, aphanitic, and may locally contain acidic fragments.

Pelitic metasediments are light grey to green in colour, medium-grained, with a well-foliated texture and commonly contain chloritoid porphyroblasts.

Two small lenses of fine- to coarse-grained skarn were also noted. Walton (1978) examined these lenses and mapped the eastern lens in detail. During the investigation, he

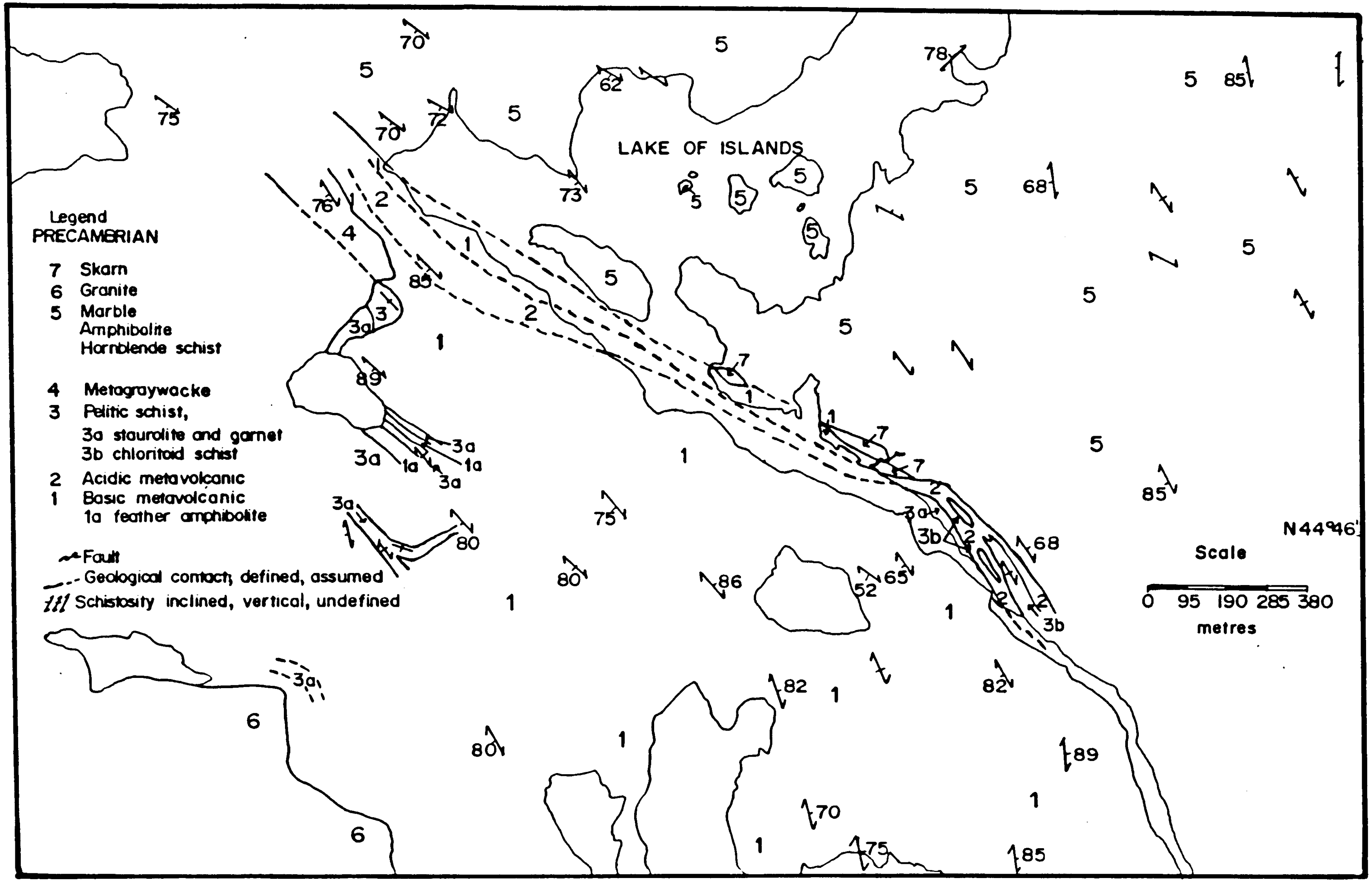


Figure 16. Geology sketch map of the Lake of Islands, Lake Township (from Walton 1978).

distinguished four symmetrical zones, each characterized by the presence or absence of the index minerals wollastonite, diopside, epidote, and actinolite. The mineralogy, maximum width, and relative placement of these zones are summarized in Table 27.

The metamorphic grade decreases outward from upper amphibolite in the central wollastonite zone through successive zones of diopside, epidote, and finally to actinolite.

The wollastonite zone consists predominantly of white, coarse-grained wollastonite with minor amounts of light green vesuvianite, light blue calcite, and colourless garnet. Walton (1978) mapped the zone along a 55 m strike length which varied in width from 0.9 - 5.5 m (generally > 3m).

A right lateral fault transects the skarn zone and Walton (1978) suggested a displacement of up to 15 metres.

Interbanded marble, amphibolite, and hornblende schist outcrop north and east of the skarn zone.

Comments

The isograds in the pelitic rocks indicate that regional metamorphism, in the area around the Lake of Islands, reached pressures of 4.8 Kb and temperatures of 525^{o}C. Walton (1978) cites the lack of overprinting of mineral assemblages in the outer zones of the skarn and the granoblastic texture (suggesting chemical equilibrium) found throughout the skarn to indicate that the skarn forming during regional metamorphism.

TABLE 27 MINERALOGICAL ZONATION OF A SKARN ZONE NEAR THE SOUTHEAST SHORE OF LAKE OF ISLANDS, LAKE TOWNSHIP

ZONE	MAXIMUM WIDTH (METRES)	MINERALOGY	REMARKS
Wollastonite	5.5 m	wollastonite, vesuvianite, garnet, calcite	white coarse-grained
Diopside	4 m	diopside, garnet, calcite, quartz, biotite, feldspar, fluorite	10% pale green diopside
Epidote	5 m	epidote, calcite, quartz, plagioclase, K-spar, garnet, biotite, fluorite	light green coloured, fine to medium-grained, granoblastic texture
Actinolite	7 m	actinolite, calcite, quartz, plagioclase, K-spar, biotite, fluorite	white and black colour, medium-grained

(after Walton 1978)

The zonation (wollastonite, diopside, epidote, actinolite proceeding outwards) may be explained as a consequence of changing fluid composition, with increasing CO_2. This may have resulted from water being channeled along fractures or a small fault, a hypothesis supported by Walton (1978). Dilution of CO_2 in the fluid phase is essential to the development of wollastonite formed during regional metamorphism.

<u>References</u>

NTS 31C/13
Adams and Barlow (1910)
Carmichael (1970)
Kingston et al (1985)

Laakso (1966, 1968)
Satterly (1943)
Thomson (1943)
Walton (1978)

LAKE TOWNSHIP
TUDOR GABBRO OCCURRENCE

Location

The occurrence is located approximately 6.5 km east of the community of Millbridge. The precise location is unknown, although it is known that it occurs in the area of lot 12 (W 1/2), concession 11, and lot 12 (E 1/2), concession 10, Lake Township, Hastings County. NTS 31C/12.

Access

Access is extremely poor, and involves a several kilometer walk either from Beaver Creek or from the road leading to Beaver Creek from the old Katherine lead mine.

Geology

Allen (1976) identified the presence of wollastonite in a calc-silicate xenolith of unknown size in the Tudor Gabbro.

Comments

The occurrence was not examined during the present investigation. Exploration of the silicified and impure marbles around the peripheries of the granitic and metagabbroic bodies in the southeastern part of the township may identify additional occurrences of wollastonite.

References

NTS 31C/12
Allen (1976)
Laasko (1966)

McNAB TOWNSHIP
BURNSTOWN OCCURRENCE

Location

The occurrence is located approximately 13 km southeast of the town of Renfrew on Lot 17, Concession 2, McNab Township. NTS 31F/7, UTM co-ordinates 376450 mE, 5026700 mN, Zone 18 (Figure 17).

Access

The wollastonite is exposed in a roadcut along Renfrew County Road No. 2 on Madawaska Hill, south of the Madawaska River.

General Geology

The occurrence lies within an east to northeast trending band of Grenvillian series supracrustal rocks consisting predominantly of interbedded calcitic and dolomitic marbles, with minor hornblende schist and gneiss. The band is situated between the Hurds Lake and White Lake trondhjemite-granodiorite bodies. These bodies are generally pink to pinkish-grey in colour, and fine- to medium-grained, with a foliated to massive texture. They may contain pegmatitic and syenitic phases. Several near vertical dipping, west- to northwest- trending faults (Mount St. Patrick, Shamrock and Pakenham) divide the area into fault blocks. These faults lie within the Ottawa Valley rift zone and predominantly exhibit dip-slip displacement (Williams, D.,

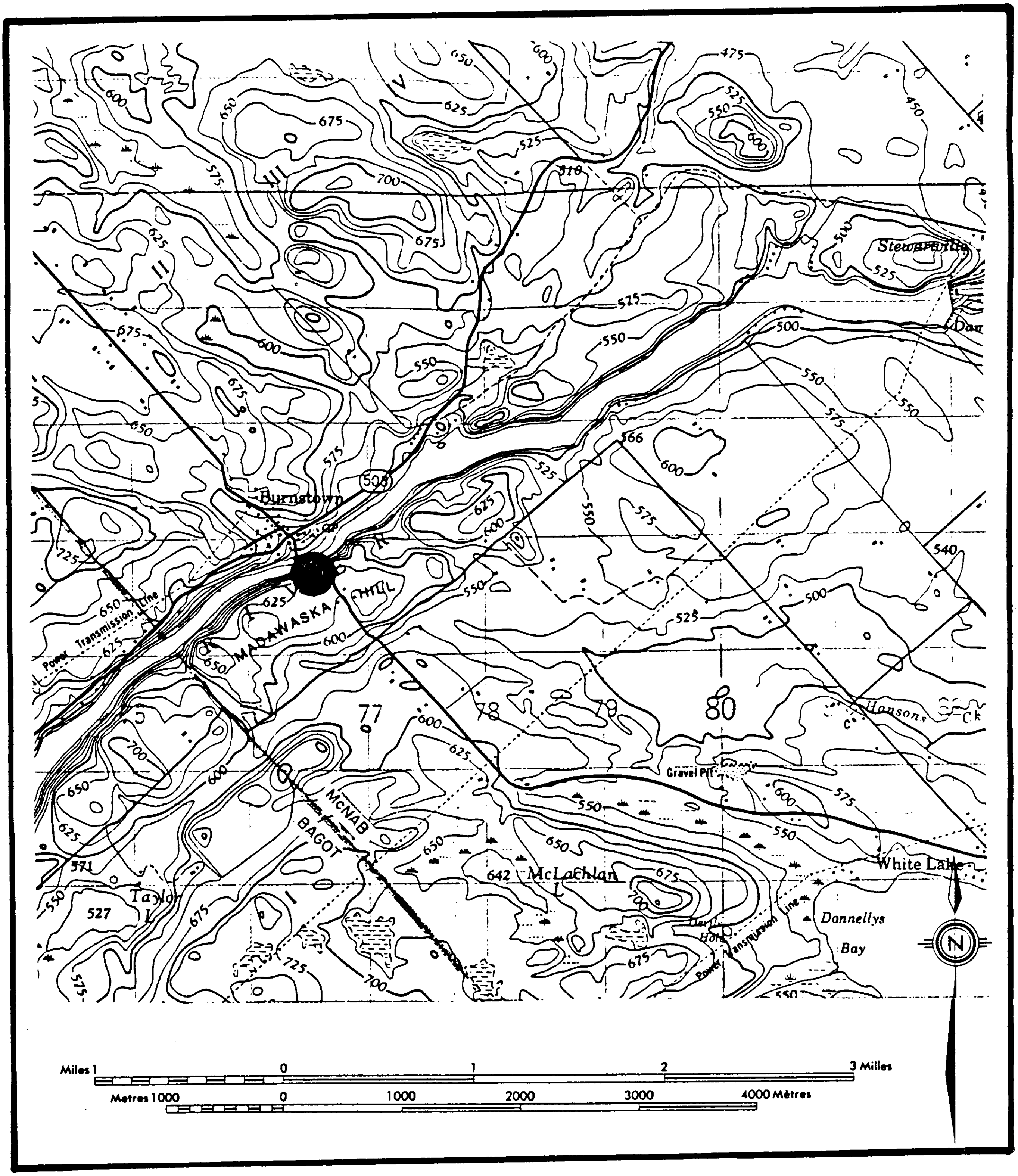


Figure 17. Location map of the Burnstown occurrence, McNab Township.

Geologist, Ministry of Northern Development and Mines, Tweed personal communication, 1988).

Previous Geological Work

The area has been mapped by Quinn (1952), Quinn et al (1956), and Lumbers and Vertolli (1979, 1980). In addition the area has been incorportated into numerous mineral studies by Carter et al (1979), Storey and Vos (1981b), Masson and Gordon (1981), and Lumbers (1982), and a detailed study of the marbles in the Pembroke-Renfrew Area was made by Storey and Vos (1981a). Bartlett (1980) examined the stratigraphy in the roadcut at Madawaska Hill.

Geology

Storey and Vos (1981) described the lithology of the rocks in the Madawaska Hill roadcut as follows:

> "The marble exposed in the Burnstown road cut is white to bluish calcite marble interlayered with calcareous amphibolite. Pyrite and tremolite are common particularly in and near the amphibolite. Tourmaline can be found in places near the amphibolite-marble contacts. The northern most 150 m of the cut are marbles, showing regular layering that is oriented N70 degrees E and dips 65 degrees S. The layering in the southern part of the cut is much more contorted and folded. Down-strike of these units to the east, scattered outcrops show a similar association of calcite marble and calcareous amphibolite."

Lumbers and Vertolli (1979) further described these rocks as a sequence of metamorphosed calcareous mudstone and sandstone commonly intercalated with thin units of siliceous marble, medium-to coarse-grained, light to dark green skarn, medium-to coarse-grained, white to greenish dolomitic marble containing siliceous impurities medium- to coarse-grained, gneissic, siliceous marble with thin intercalated units of amphibole-rich metasediments, and grey, gniessic, calcitic marble, locally containing thin intercalations of siliceous marble.

Bartlett (1980) proposed a carbonatitic origin for these rocks. During the investigation Bartlett (1980) identified a 9m thick band of wollastonite-bearing rock which he termed "Zebra Rock", due to its unique striped texture. These stripes consist of contorted, discordant bands of diopside up to several centimeters in thickness (Photo 15). The major constituents of this rock are wollastonite (65 to 70%), diopside (10 to 15%), scapolite (10%), microcline (5%), quartz (2 to 3%), and trace to accessory amounts of calcite.

Chemistry and Petrology

One thin section and one polished section were prepared from samples collected by the writer. The whole rock chemical composition and rare earth element content of one sample of calc-silicate rock from the Madawaska Hill roadcut is presented in Table 28.

Thin section MA-1 (Table 29) is composed of an inequigranular intergrowth of medium-grained wollastonite, diopside, scapolite, and minor amounts of microcline, quartz, and calcite (Photo 16). Most of the mineral grains are xenoblastic. Wollastonite occurs as xenoblastic to idioblastic, tabular to prismatic grains and typical aspect ratios are 1:4 to 1:6 but may vary to 1:8. Microcline grains exhibit the characteristic tartan twinning. The calcite occurs mainly in small veins (<1.5 mm) intergrown with scapolite.

Photo 15. Striped "zebra texture", consisting of contorted, discordant bands of diopside, Burnstown Occurrence, McNab Township.

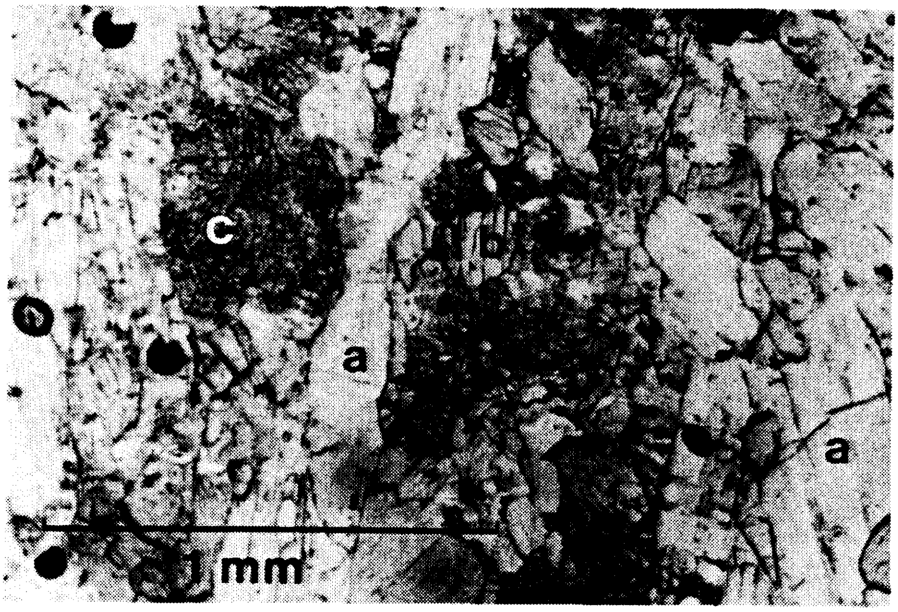


Photo 16. Photomicrograph (MA-1) in plane polarized transmitted light taken from the Burnstown occurrence, McNab Township, showing inequigranular intergrowth of wollastonite (a), diopside (b), and scapolite (c).

TABLE 28 WHOLE ROCK CHEMICAL COMPOSITION (IN PERCENT) AND TRACE ELEMENT CONTENT (IN PPM) OF A SAMPLE OF SKARN ROCK

SiO_2	50.9	Rb	<10
Al_2O_3	0.55	Sr	431
CaO	39.1	Y	16
MgO	3.94	Zr	<10
Na_2O	0.42	Nb	24
K_2O	0.37	Ba	67
Fe_2O_3	1.40		
MnO	0.06		
TiO_2	0.12		
P_2O_5	0.10		
Cr_2O_3	<0.01		
L.O.I.	3.00		
Total	100.00		

TABLE 29 ESTIMATED MODAL COMPOSITION (IN PERCENT) OF TWO SAMPLES OF SKARN ROCK TAKEN FROM THE MADAWASKA HILL ROADCUT

	1	2
Wollastonite	65-70	30-35
Diopside	10-15	40-45
Scapolite	10	20
Microcline	5	4-5
Quartz	2-3	1-2
Calcite	tr	tr

Sample 1	modal analysis taken from Bartlett (1980)
Sample 2	skarn rock (sample MA-1)

TABLE 30 ELECTRON MICROPROBE ANALYSES-CHEMICAL COMPOSITION (IN PERCENT) OF WOLLASTONITE PRESENT IN SAMPLE MA-1

	1	2	3	4	5
SiO_2	50.23	50.33	50.04	50.62	50.31
TiO_2	0.00	0.00	0.00	0.00	0.00
Al_2O_3	0.00	0.00	0.04	0.00	0.01
Cr_2O_3	0.00	0.06	0.17	0.00	0.06
FeO	0.26	0.28	0.23	0.14	0.23
MnO	0.13	0.00	0.00	0.00	0.03
MgO	0.06	0.06	0.00	0.00	0.03
CaO	48.32	48.27	48.06	48.74	48.35
Na_2O	0.00	0.00	0.00	0.00	0.00
K_2O	0.05	0.00	0.00	0.00	0.01
Total	99.05	99.00	98.54	99.50	99.02

1-4 wollastonite grains
5 average of grains 1-4

NOTE: Electron microprobe analysis was performed using Method 2 (Appendix 1).

Polished section MA-1 exhibits mineralogy similar to thin section MA-1; the wollastonite was analysed (Table 30).

Comments

A narrow zone (9 m) of skarnoid rock within the Madawaska Hill roadcut contains high grade concentrations of wollastonite (>60%). Generally, the wollastonite has a low aspect ratio but has sufficient purity and grain size to be of interest should economic quantities be identified.

Bartlett (1980) believes a 30 m section of buff-weathered dolomitic rock located near the south end of the roadcut, to have carbonatitic affinities, however his evidence appears to be inconclusive. The wollastonite may be related genetically (if conclusively proven to be a carbonatite dyke) or may be related to the Hurds Lake Trodhjemite intruded to the north. Further exploration should examine the carbonate rocks within (xenoliths) and perpherial to the Hurds Lake Trondhjemite, and along the margins of the White Lake Trondhjemite.

References

NTS 31 F/7
Bartlett (1980)
Carter et al (1979)
Lumbers (1982)
Lumbers and Vertolli (1979, 1980)
Masson and Gordon (1981)
MacKinnon et al (1987)
Quinn (1952)
Quinn et al (1956)
Satterly (1944)
Storey and Vos (1981a, 1981b)

PITTSBURGH TOWNSHIP
BREWERS MILLS OCCURRENCE

Location

The occurrence is situated approximately 6 km north of Joyceville on concession 8, lot 25, Pittsburgh Township, Frontenac County. NTS 31C/8, UTM co-ordinates 395760mE, 4918300mN, Zone 18 (Figure 18).

Access

The property may be reached via Hwy 15 and the Brewers Mills Road.

General Geology

The area is located within the Frontenac Axis, in an area of granulite facies regional metamorphism (Wynne-Edwards 1967).

Wynne-Edwards (1962) reported that the structure in the Ganonoque area is similar to the Westport area to the north except in general, the folds plunge gently southwest.

The geology consists of Grenvillian metasedimentary rocks (quartzite, paragneiss, marble, and calc-silicate rocks) which are intruded by gabbro, syenite, granite, diabase dykes, and white pegmatite. The Battersea granite lies to the north, and the Gananoque syenite to the southeast. Paleozoic (Nepean Formation) sandstone and conglomerate unconformably overly the Precambrian rocks west of the study area.

Previous Geological Work

The area was mapped by Wynne-Edwards (1962, scale 1:63,360), and

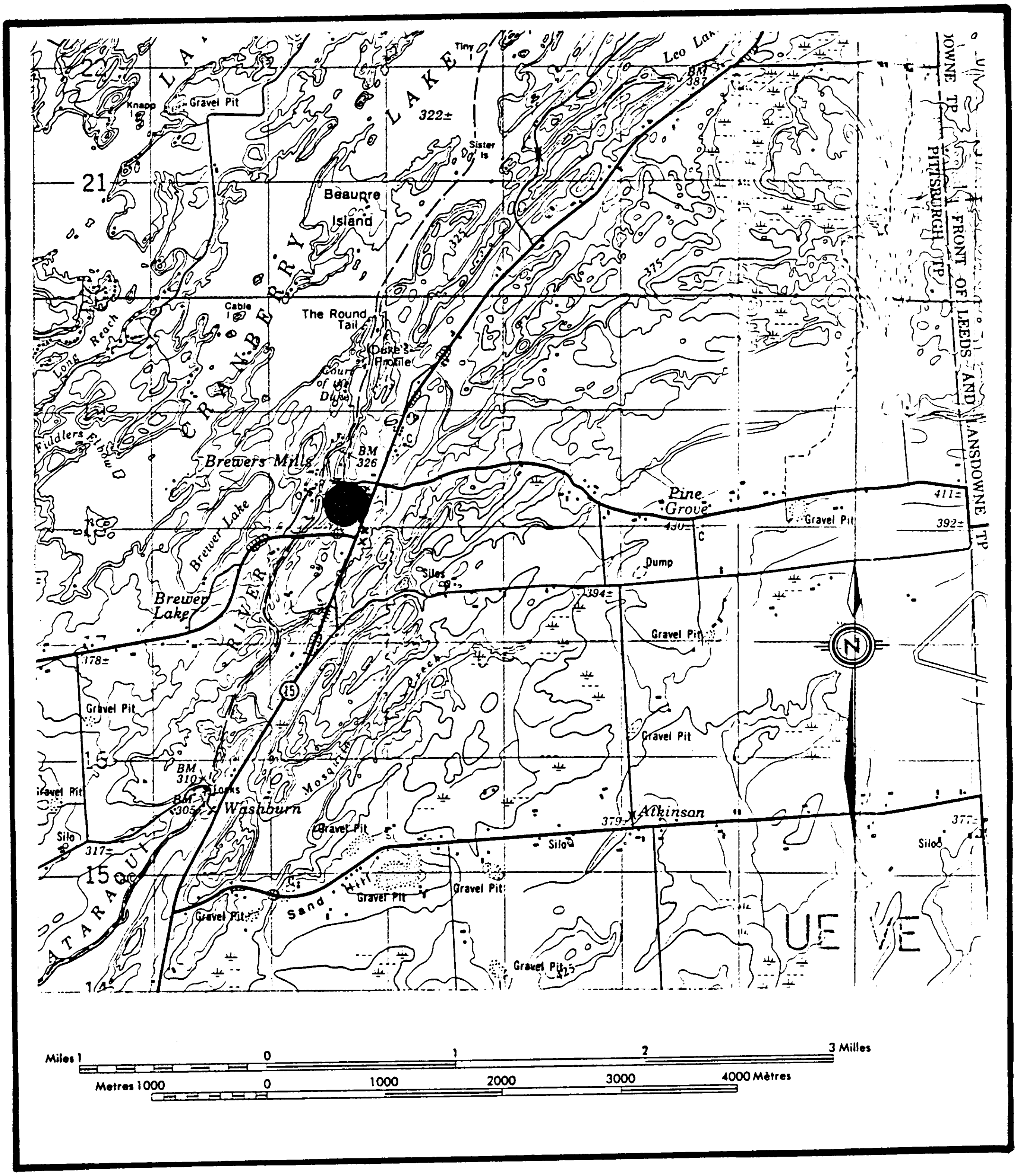


Figure 18. Location map of the Brewers Mills occurrence, Pittsburgh Township.

included in compilation maps by Hewitt (1964, scale 126,720), and Kingston et al (1985, scale 125,000).

Geology

The rocks within the study area (Figure 19) consist of metasedimentary rocks (units 1-4) intruded by diabase dykes (unit 5) and white pegmetite (unit 6).

Calcitic marble (Unit 1, Figure 19) is white in colour, medium-to coarse-grained, with a massive to weakly foliated, granoblastic texture. The weathered surface is light grey in colour. Accessory minerals may include calc-silicates, graphite and iron oxides. Disseminated flake graphite (up to 1 mm in diameter) comprises between 1 and 3% of the rock. A siliceous variety (unit 1a, Figure 19) may contain up to 5-10% quartz, 1-3% disseminated flake graphite and <1-2% pyrite. Other accessory minerals may include green diopside, feldspar, and minor wollastonite. The weathered surface has a friable texture and may be stained orangish in colour by iron oxides.

Fine-to coarse-grained calc-silicate rock (unit 2a, Figure 19) outcrops along the western edge of a scarp that extends southwest from the Brewers Mills road. The rock is white to greenish in colour, with a massive to banded, granoblastic texture. The mineral assemblage consists predominantly of wollastonite, calcite, and diopside in varying proportions, and accessory minerals may include graphite (≤1%), pyrrhotite, spinel, pyrite, magnetite and hematite. The wollastonite occurs as hypidioblastic, white to light green, tabular crystals up to 1.5

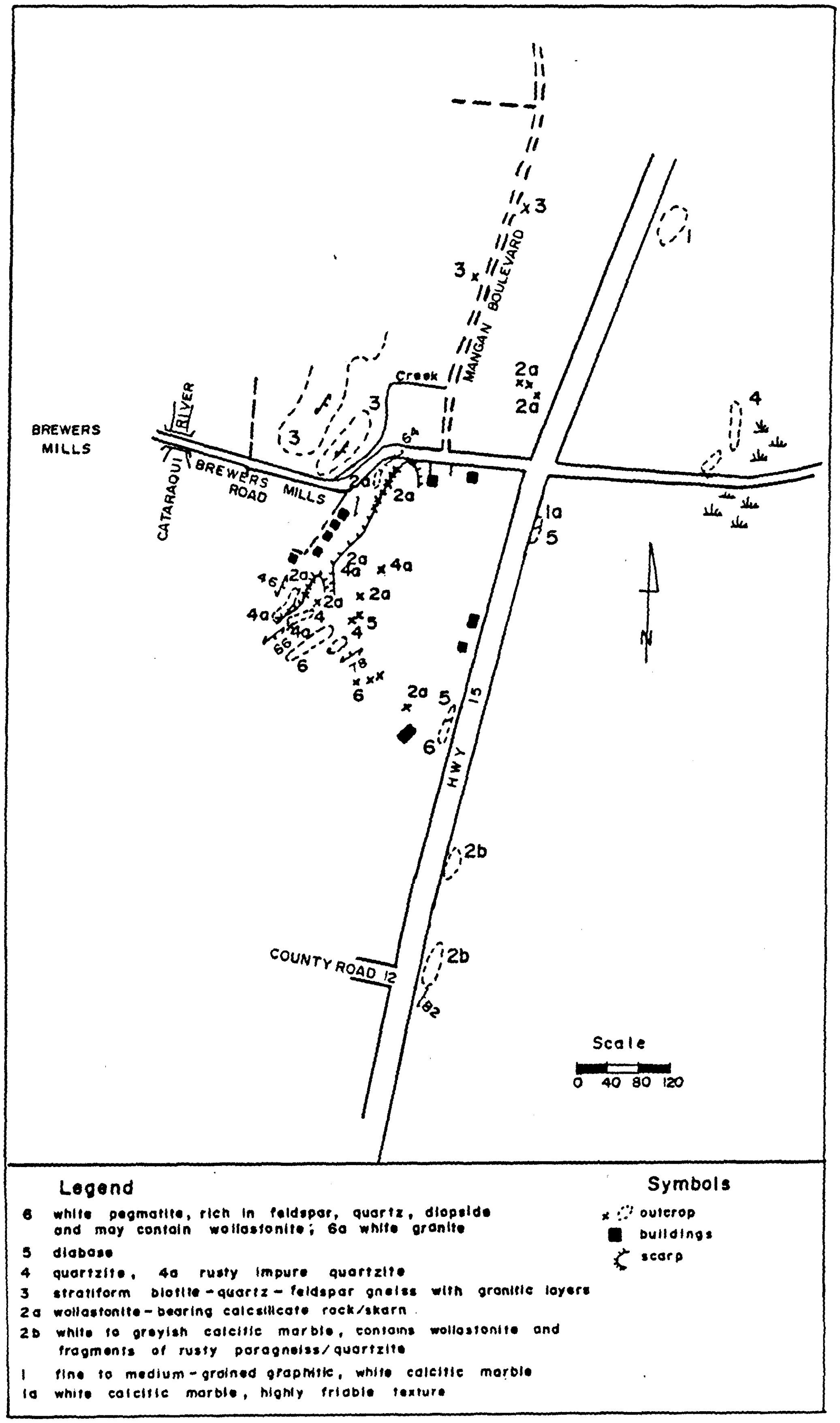


Figure 19. Geological sketch map of the Brewers Mills occurrence, Pittsburgh Township.

cm in length but generally averages 0.5 cm or less. The wollastonite content varies between 10-55%, and locally reaches 70-80%. Wollastonite mineralization consists of intergrown grains in bands or as disseminated crystals within a calcitic matrix. The weathered surface is white and green to orangish or yellowish in colour and where wollastonite and diopside content are high, the rock becomes friable and frequently fractures into fan-shaped fragments. The calcite occurs as white to grey, hypidioblastic to xenoblastic grains, averaging 1 mm in diameter. Diopside (up to 15%) occurs as light green, xenoblastic grains and blebs (averaging 1 mm in diameter) intergrown with calcite and wollastonite.

Along the western face of the scarp two horizontal bands of iron-stained impure quartzite were noted interbanded with the calc-silicate rock. These bands are greenish to black in colour and the origin presently remains uncertain, however they are somewhat similar in appearance to some of the dykes. The rock is iron-stained, weathered to a gossan, and partially altered to jarosite, goethite and gypsum. The upper band is 2-3 m in thickness and the lower 0.5-1 m, and the contacts are characterized by a zone of oxidation (hematite/limonite) up to 15-20 cm in thickness.

Fine- to medium-grained wollastonite-bearing calcitic marble (unit 2b, Figure 19) outcrops along Hwy. 15. The rock is white to grey in colour, with a massive to weakly foliated, granoblastic texture. The mineral assemblage consists predominantly of quartz and calcite, and accessory minerals include graphite, diopside, wollastonite, pyrrhotite, and chalcopyrite. Fragments and boudins of siliceous rusty quartzite/paragneiss within the marble have formed wollastonite selvages (reaction rims) up to 2-3 cm (Photo 17). The wollastonite occurs as stubby, tabular, hypidioblastic to idioblastic grains around siliceous fragments and in veins up to 3 cm thick within the marble. Fine-to medium-grained, xenoblastic grains of quartz and diopside occur within a calcitic matrix. Graphite (<1-2%) occurs as fine-grained (<0.5 mm) disseminated flakes which may be locally concentrated along boudin and fragment margins.

Quartzite (unit 3, Figure 19) is a fine-to medium-grained, white, massive rock. The weathered surface is orangish (rusty) to white and black in colour. The mineral assemblage consists predominantly of quartz and feldspar (plagioclase), and accessory iron oxides, sulfides, and graphite.

Map unit 4 (Figure 19) consists predominantly of medium- to coarse-grained biotite-quartz-feldspar gneiss with granitic interlayers. The layers consist predominantly of quartz, feldspar (plagioclase, K-spar), and biotite, and may contain chlorite, sulfides, calcite, iron oxides, cordierite and diopside as accessory constituents.

Late diabase dykes (unit 5, Figure 19) intrude all of the Precambrian rocks within the area. These dykes are believed to occupy tension fractures along the culmination of the Frontenac

Photo 17. Siliceous boudins in calcitic marble with wollastonite selvages, Brewers Mills Occurrence, Pittsburgh Township.

Axis (Wynne-Edwards 1962). Mineralogical examination by X-ray diffraction techniques indicated the presence of scapolite, diopside, amphibole, mica, potassium feldspar, and sulfides. The dykes are fine- to medium-grained with a black fresh surface which weathers a rusty colour.

White, pegmatitic rocks (unit 6 , Figure 19) occur as small bodies within the marble. The mineral assemblage consists mostly of diopside, quartz, and feldspar and accessory minerals may include calcite and sulfides. The rock is massive, coarse-grained to pegmatitic and is white to greenish in colour. The weathered surface is rusty to greenish in colour and is transected throughout by coarse veins containing calcite, quartz, and diopside. Diopside occurs as coarse, hypidioblastic to xenoblastic grains intergrown with white, fine- to coarse-grained, anhedral quartz and subhedral to anhedral feldspar. The calcite occurs as white, fine-to medium-sized grains or as coarse-grained veins, and as a minor accessory mineral within the pegmatitic rocks. Wollastonite may be present within smaller calcitic veins.

Comments

The wollastonite zone (calc-silicate rock) which occurs along the edge of a scarp dips steeply SE in what appears to be a synformal structure. The grade of wollastonite mineralization ranges between 10-55% and locally reaches 70-80%.

The formation of wollastonite is probably due to a contact metamorphic effect caused by the nearby syenite or gabbro. Other calc-silicate rocks and marbles in the area may therefore prove to be useful exploration targets for wollastonite.

References

NTS 31C/8
Hewitt (1964)
Kingston et al (1985)
Wynne-Edwards (1962, 1967)

PITTSBURGH AND FRONT OF LEEDS AND LANSDOWNE TOWNSHIPS
PLATINOVA-COMINCO COUNTY LINE ROAD PROPERTY

Location

The occurrence consists of a zone extending eastward from lot 37, concession 1, Pittsburgh Township (Frontenac County) through lot 1, concession 1, Front of Leeds and Lansdowne Township (Leeds and Grenville County). The extent of the property held jointly by Platinova Resources Ltd. and Cominco Ltd. is not known. Wollastonite can be observed in an outcrop on the west side of County Line Road, about 700 m north of Hwy. 2, NTS coordinates 401500 mE, 4908550 mN, Zone 18, NTS 31 C/8 (Figure 20).

Access

The property is reached via County Line Road which leads north from Hwy. 2 about 5 km west of Gananoque.

General Geology

The occurrence lies within the Frontenac Axis, in an area underlain predominantly by Precambrian siliciclastic rocks (quartzite, paragneiss, and calc-silicate rocks) which have been subjected to granulite facies metamorphism. Regional strike is

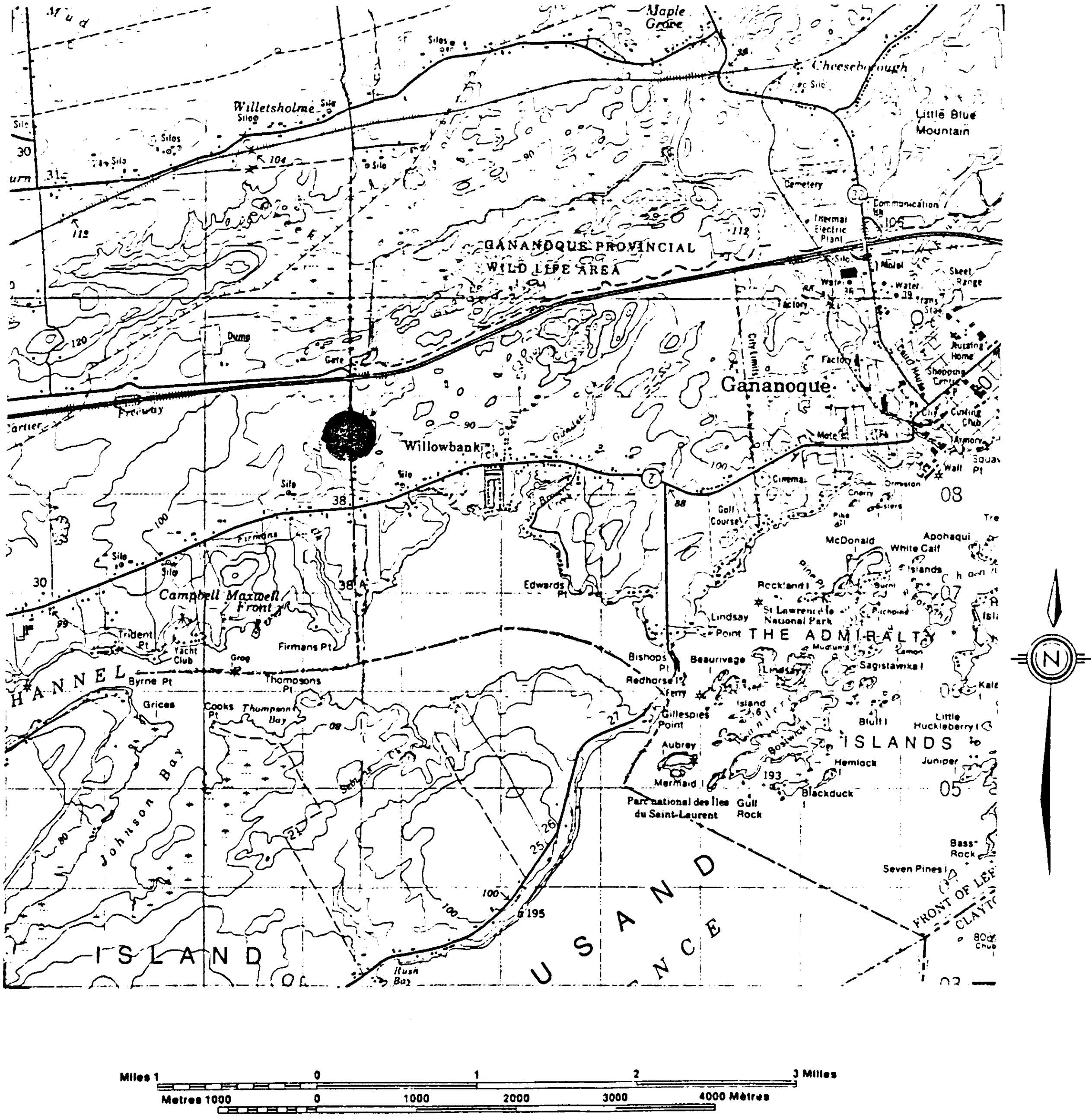


Figure 20. Location map of the Platinova-Cominco County Line Road occurrence, Pittsburgh and Front of Leeds & Lansdowne townships.

northeasterly and fold axes plunge gently northeast and southwest (Wynne-Edwards 1962).

The metasedimentary rocks have been intruded by pink, coarse-grained-granitic and syenitic bodies and by white pegmatites. Paleozoic sandstone and conglomerate outliers of the Nepean Formation locally overlie the Precambrian rocks.

Previous Geological Work

The Gananoque area was mapped by Wynne-Edwards (1962) and has been included in compilation maps by Hewitt (1964) and Kingston et al (1985).

Geology

The occurrence is situated within an area shown by Wynne-Edwards (1962) as a white pegmatite body occupying the core of a broad, domal anticline with axis plunging gently northeast and southwest and limbs dipping moderately northwest and southeast. The pegmatite is overlain successively by quartzite and paragneiss (biotite-quartz-feldspar ± hypersthene ± cordierite ± sillimanite). The wollastonite zone is exposed in an outcrop along County Line Road at the western end of the pegmatite body (Figure 21).

A brief examination of roadside outcrops along County Line Road between Hwy. 2 and Hwy. 401 confirmed the geology shown by Wynne-Edwards (1962) with the exception of the area shown as white pegmatite. This area actually contains at least three rock types: 1) pale, bluish-grey, medium-grained quartzite, 2) a massive, coarse-grained, white, granitic-textured rock consisting

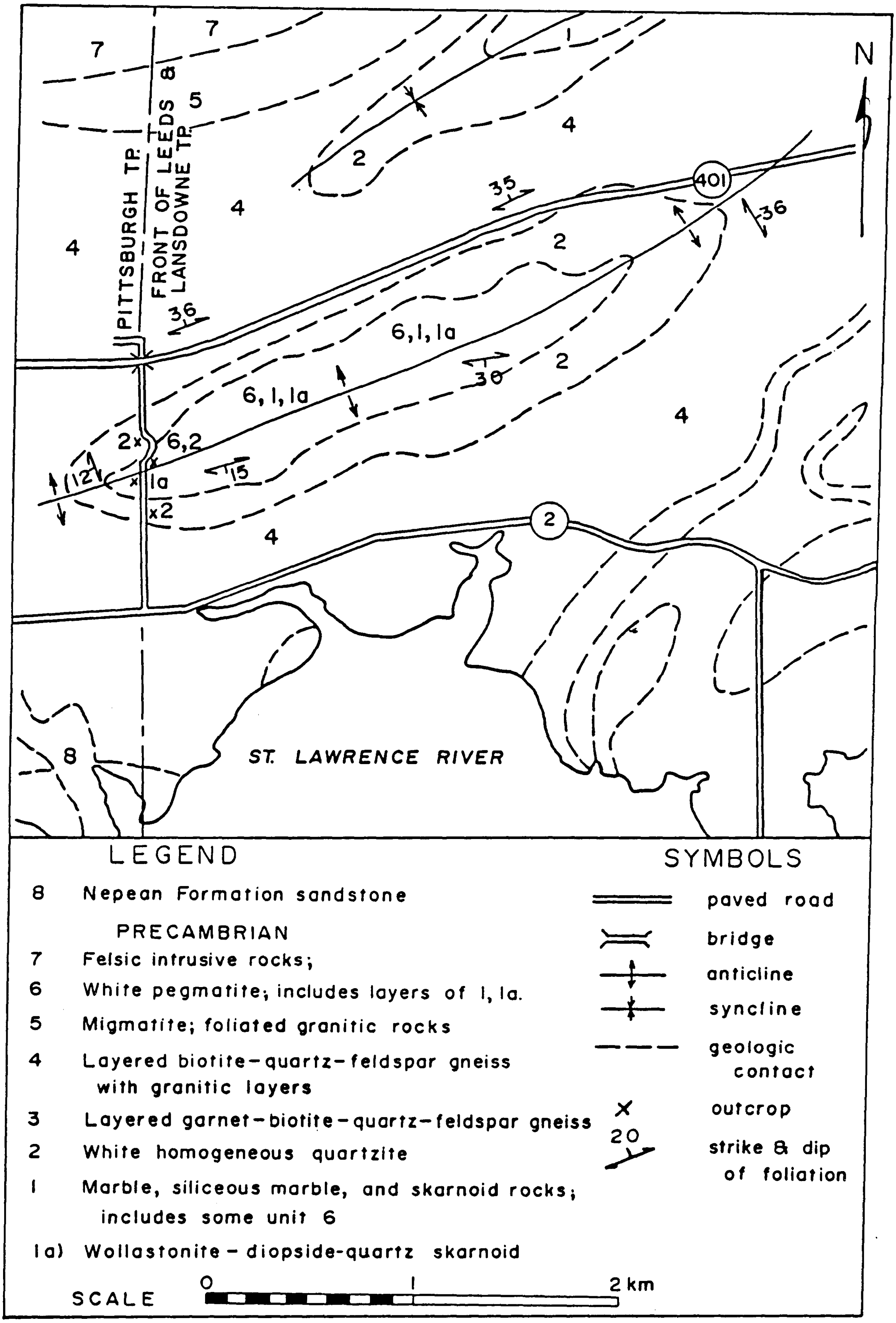


Figure 21. General geology of the Platinova-Cominco County Line Road occurrence, Pittsburgh and Front of Leeds & Lansdowne townships (modified after Wynne-Edwards 1962).

almost exclusively of quartz and white feldspar, and 3) a skarnoid rock composed of approximately equal proportions of fine to medium-grained quartz, diopside, and wollastonite with trace amounts of fine-grained pyrrhotite and sphene.

The following more detailed description is based upon information provided by Ralph Lortie (geologist, Cominco Ltd., Toronto, personal communication, 1989).

The wollastonite-bearing rocks occur along the axis of the anticline (Figure 21), forming a zone about 1400 m long and up to 350 m wide. Within this zone, impure quartzite layers, generally centimeters to tens of centimeters thick, are interbanded with skarnoid layers containing varying proportions of wollastonite, diopside, feldspar, quartz,pyrrhotite, and sphene. Calcite is present only in minor amounts (1-2%). Also present are granitic-textured layers consisting of quartz, feldspar (perthite), diopside, and sphene, possibly derived from metamorphism of arkosic sediments. The white pegmatite unit mapped by Wynne-Edwards (1962) in this area is tentatively interpreted as coarse-grained meta-arkosic rock forming conformable layers within the impure quartzite sequence.

The wollastonite-bearing layers locally contain up to 70% wollastonite in association with diopside ± quartz ± feldspar ± sphene. Adjacent biotitic/diopsidic quartzites may contain no wollastonite. The complex mineralogy of the impure quartzite sequence may present problems in average grade determination and in beneficiation of the wollastonite.

History

Wollastonite was discovered along County Line Road in 1986 by Mark Badham, then a student at Queen's University and currently curator of the Queen's mineral museum in Kingston.

In 1988, Ralph Lortie of Cominco Ltd. examined the discovery area in more detail and determined that the wollastonite-bearing zone was of sufficient size and grade to warrant an exploration program. Under a joint venture agreement with Platinova Resources Ltd., Cominco subsequently conducted a geological mapping program and drilled 12 diamond drill holes in 1989. Results of the drill program were not available at the time of writing this report.

Comments

The skarnoid wollastonite-bearing rocks in this area are probably the result of high-grade (upper amphibolite to granulite facies) metamorphism of calcareous, arenaceous sediments and represent a type II wollastonite occurrence, based on the classification of Kuzvart (1984).

The major difference between this occurrence and those of the Marmora study area is the proportion of quartz and carbonates in the host rocks. The County Line Road occurrence is hosted by a metasedimentary sequence dominated by quartzite which contains very little carbonate; the Marmora Township occurrences lie within carbonate-dominated metasediments. The original sedimentary rock at the County Line Road occurrence was probably a quartz sandstone containing calcitic/dolomitic cement and/or thin dolomitic beds (dolomite being the source of Mg now present in pyroxene), rather than a carbonate sediment containing disseminated quartz or quartz-rich laminae, as was probably the case in the Marmora area. Under high-grade metamorphic conditions, the quartz and carbonate reacted to form wollastonite and diopside, with excess quartz present in the County Line Road area, and excess calcite in the Marmora area.

A possible sedimentological model is that of calcareous sandstones deposited in a shallow (possibly intertidal) marine environment and subsequently overlain by more pure quartz sandstone (such as a beach deposit), represented now by the massive quartzite which caps the wollastonite-bearing zone (Ralph Lortie, geologist, Cominco Ltd., Toronto, personal communication 1989).

The widespread occurrence of interlayered marbles and quartzites which have been subjected to high grade metamorphism within the Frontenac Axis suggests that there is good potential for discovery of similar wollastonite occurrences in this region.

References

NTS 31C/8
Hewitt (1964)
Kingston et al (1985)
Wynne-Edwards (1962)

OLDEN TOWNSHIP
HAWLEY ZINC PROPERTY

Location

The Hawley Zinc property is located on lot 4, concession 3, Olden Township, Frontenac County, approximately 6 km SSE of the community of Mountain Grove. NTS 31C/10, UTM Co-ordinates 356200mE, 4949500mN, Zone 18 (Figure 22).

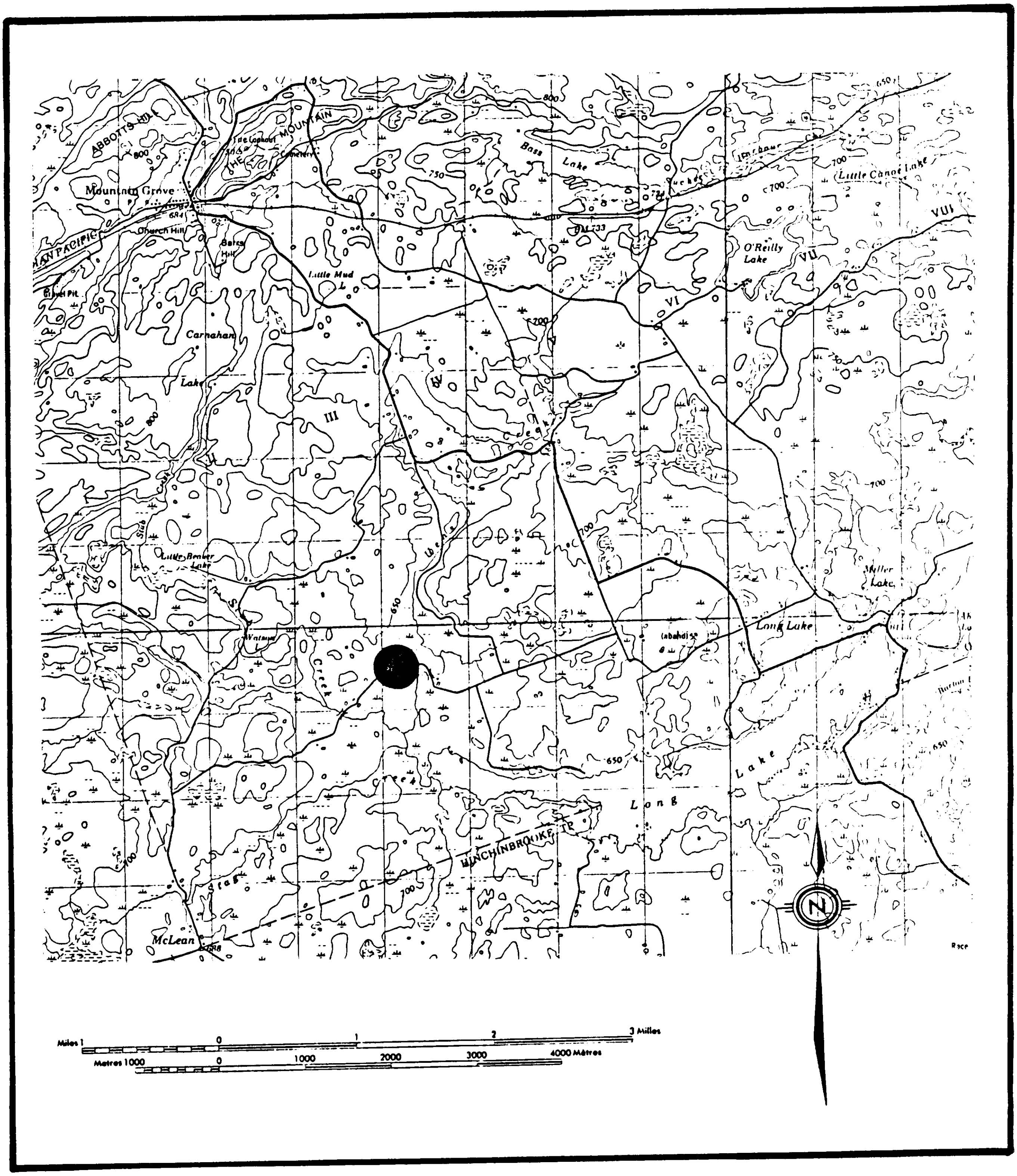


Figure 22. Location map of the Hawley Zinc Property, Olden Township.

Access

The property is accessible by travelling south approximately 4.4 km on the Long Lake Road (paved) from Mountain Grove to the Tom Fox Road (gravel), south to the Bobcock Road (gravel) and then proceeding west 1.5 km.

General Geology

The map-area lies within the Frontenac Axis segment of the Central Metasedimentary Belt (Wynne-Edwards 1972).

The oldest rocks in the area are mafic to intermediate metavolcanics and mafic to felsic gneisses and anatectites (high-grade equivalent). The metasediments are largely carbonate metasediments (predominantly calcitic), and clastic siliceous gneisses (quartzose wacke to feldspathic wacke). Hornblende-rich gneisses become prevalent to the east in the Clare River Synform. Carbonate metasediments occur along the western periphery and as large xenoliths within the Mountain Grove Intrusion.

The Robertson Lake mylonite zone (striking 045^o and dipping $30-50^oS$) passes through the village of Mountain Grove structurally subdividing the area into two strikingly different zones. The shear zone extends 80 km and typically ranges from 0.5 to 1.0 km in width. West of the shear zone rocks exhibit two periods of deformation and possibly a third whereas the structural geometry east of the shear zone becomes one of domal intrusions within the intra-limb zone of a broad synform plunging shallowly eastwards (Wolff 1982).

The intrusives east of the shear zone are late tectonic and consist of the Mountain Grove Mafic Intrusive and the McLean Granitic Pluton. The Mountain Grove Intrusion is the oldest and is compositionally a well-layered gabbro-anorthosite-syenite body.

The McLean Granite Pluton is intrusive to the Mountain Grove Intrusion and ranges in composition from trondhjemite to granite with minor syenitic phases and is generally massive.

Previous Geological Work

The area was mapped by Harding (1947, 1:63:360 scale) and later in more detail by Wolff and Smith (1979, 1:15,840 scale; 1981, 1:31,680 scale). The study area was included in the regional geological compilations by Hewitt (1964, 1:126,720 scale) and Kingston et al (1985, 1:125,000 scale).

Geology

The property (Figure 23) is underlain predominantly by medium-to very coarse-grained, white to grey calcitic marbles, calc-silicate rocks, and minor siliceous and dolomitic units. The metasediments of Late Precambrian age trend northwesterly and dip moderately to steeply north-east. These are intruded by anorthositic gabbro, gabbro, and felsic rocks of the Mountain Grove Intrusion. Located approximately 100 m west, a separate carbonate band 30 m wide and at least 200 m long, dipping steeply to the northeast consists entirely of sphalerite-bearing marble grading 2-4% ZnS (Bowdidge 1988).

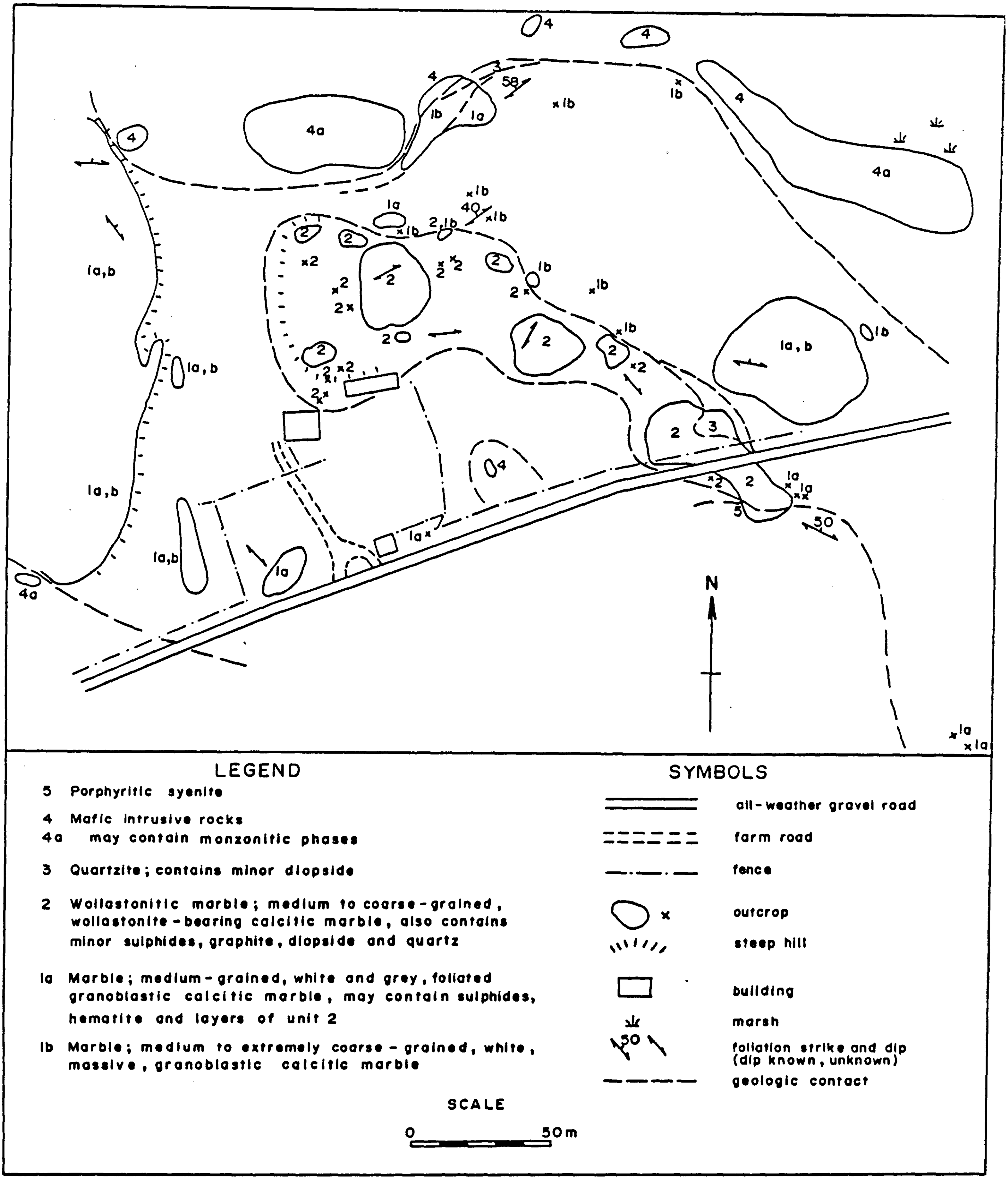


Figure 23. Geological sketch map of the Hawley Zinc Property, Olden Township.

Map unit 1a is a white and grey calcitic marble. The rock is predominantly medium-grained, with a massive to thinly laminated (0.5 - 2.0 cm thick) granoblastic texture. Accessory minerals may include fine-grained graphite (<1%), iron oxides (<1%), mica, chondrodite and minor quartz.

Map unit 1b is a white, medium-to very coarse-grained calcitic marble. The rock is massive with a granoblastic texture. Bedding, when present, is defined by a variation in grain size. The calcite rhombs are hypidioblastic in form and range up to 5 cm in length. Locally the unit occurs intercalated with white and grey calcitic marble (map unit 1a) and minor dolomitic rock.

Map unit 2 is a white to beige, medium-to coarse-grained calc-silicate rock. The rock is massive to strongly banded (0.1-1.0 cm) and foliated. The foliation is defined by grains of wollastonite which gives a nematoblastic texture to the rock. in the vicinity of the Bobcock Road, layering in the mineralized zone is highly deformed and small-scale folded (Photo 18). The mineral assemblage consists predominantly of intercalated wollastonite, calcite, and minor diopside and quartz. Accessory minerals include graphite (<1%), phlogopite, sulfides (pyrite), sea-green apatite, and local quartz veins and knots up to several centimeters in diameter.

The wollastonite occurs as white to beige, fine-to coarse-grained, short prismatic to bladed crystals, typically 1-3 mm in length. The mineralized zone has been traced along strike 200 m and ranges in width from 15 to 50 m. The grade varies from 20

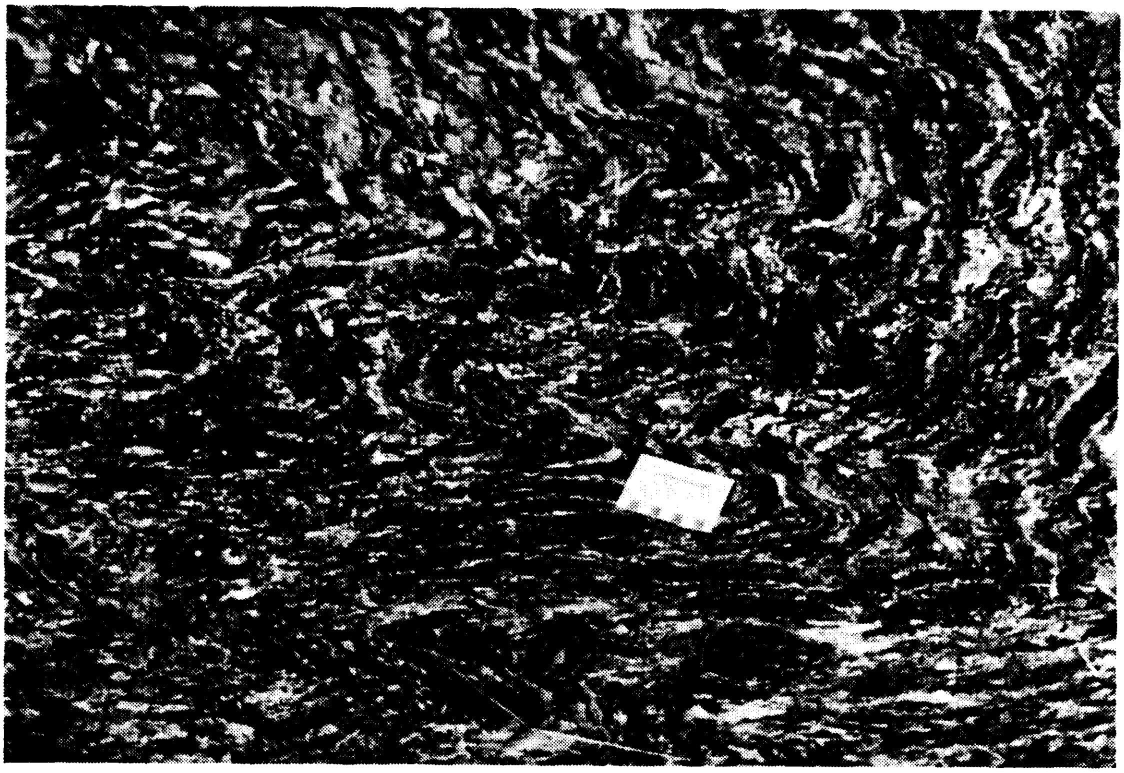


Photo 18. Small-scale folding of intercalated wollastonite and coarse-grained calcite, Hawley Zinc Property, Olden Township.

to 45%, averaging 30-35%. The unit is gradational to coarse-grained white calcitic marble (map unit 1b). Small apatite crystals (<0.5 mm) occur as inclusions within and intergrown with calcite. The wollastonite lenses/layers are brownish at the edges where in contact with the calcite layers.

Map unit 3 is a white and green, fine-to medium-grained siliceous rock (quartzite ?). The author suggests a metasedimentary origin for this unit on the basis of its granular texture. The rock is composed essentially of quartz and diopside. The quartz grains are white to colourless, subangular to subround in form and appear to be moderately to well-sorted, averaging 0.5 - 1.0 mm in diameter. The diopside (20-25%) occurs as fine-grained light green grains which locally appear to define a weak banding. The unit is extremely porous and may locally be stained orangish by iron oxides. The exposure is limited to a pod-like area (10 X 15 m) near the Bobcock Road and to a small area at the north end of the map area where the rock is in contact with mafic intrusive and exhibits a granitic texture.

Map unit 4 represents the Mountain Grove Mafic Intrusion. Compositionally the body varies from gabbro to anorthositic gabbro, monzonite and syenite within the study area.

The gabbro (colour index >30) and anorthositic gabbro (colour index 10-30) are massive, phaneritic, and weather a greyish colour. Typical grain sizes are fine-to medium-grained (0.5 -2.0 mm), although occassionally plagioclase phenocrysts up to 6 mm were identified. Field identifications were based on the colour index of the rock. In hand specimen, the rock consists of plagioclase, hornblende, biotite, and accessory magnetite. Locally, fine-grained and medium- to coarse-grained monzonitic phases occur within the gabbroic rocks. The contacts are usually sharp, irregular and more than one phase may be present within an individual outcrop.

The monzonite is massive, phaneritic, and granular textured. The rock weathers a greyish colour somewhat similar to the mafic rocks, and locally is pinkish. Typical feldspar grains are subhedral and range from 1.0 - 6.0 mm. The pyroxene grains are fine-grained (<1 mm) light to dark green in colour and appear to be highly altered. Fine-grained biotite, and magnetite (<1%) occur interstital to grains of feldspar.

Map unit 5 is a pink, coarse-grained porphyritic syenite. The rock is massive, phaneritic and composed largely of feldspar phenocrysts and sub-ordinate pyroxene (5%), biotite, and opaques. Typical grain size of feldspars ranges from 2 to 7 mm. Exposure is limited to a small outcrop intruding the mineralized zone, south of the Bobcock Road. The intrusion may possibly be associated with the McLean Granitic Pluton located to the southwest.

History

In 1972-1973 Lynx-Canada Explorations Ltd. conducted a soil geochemistry survey of the property which showed background Zn values of 200 ppm and a few scattered anomalously higher values. Two small (0.25 m) occurrences of massive sphalerite mineralization were found on the property. In 1988, the property was staked and geologically mapped by Ram Petroleum Ltd.

Comments

Preliminary field work indicates that wollastonite mineralization outcrops in a 200 X 15-50 m wide zone adjacent to mafic intrusive rocks of the Mountain Grove Intrusive (late tectonic). The zone trends northwest to southeast, dips moderately to steeply to the north-northeast, and averages 30-35% wollastonite.

The banded nature of the mineralization suggests the calc-silicate unit may originally be representative of intercalated cherty or quartz-rich metasediments (quartzite?) and carbonate units.

The Mountain Grove Mafic Intrusion contains numerous highly deformed inclusions of carbonate material, one of which hosted the nearby Long Lake zinc mine. Exploration of these xenoliths and the marble along the western margin of the intrusion hold good potential for locating additional mineralization.

References

NTS 31C/10
Harding (1947)
Hewitt (1964)
Kingston et al (1985)
Wolff (1982)
Wolff and Smith (1979, 1981)

NORTH BURGESS TOWNSHIP
SILVER QUEEN MINE

Location

The occurrence is located approximately 13.8 km south of the town of Perth on lot 13 (E 1/2), concession 5, North Burgess Township, Lanark County. NTS 31C/16, UTM co-ordinates 341100 E, 4958300 mN, Zone 18 (Figure 24).

Access

Travel south on County Road 14 to Lally Drive (road to Murphy's Point Provincial Park), and proceed east approximately 2.7 km.

General Geology

Grenvillian metasedimentary rocks consist of crystalline limestones and dolomites, meta-pyroxenites, paragneisses, and to a lesser extent quartzites. The marbles are generally granular, coarsely crystalline and commonly contain as accessory minerals phlogopite, diopside, and graphite. Sedimentary gneisses include biotite-garnet gneiss, biotite gneiss, feldspar-biotite gneiss, biotite-hornblende gneiss, and granitized gneisses. Within the study area, biotite-garnet gneiss is abundant and frequently occurs interbanded with thin marble units and quartzite.

Migmatitic rocks of mixed origin occupy extensive areas within the township. These rocks represent a transition between sedimentary and granitic rocks. Dugas and Wilson (1961) observed a transition through massive plutonic rock, syenite gneiss, syenite migmatite, to garnet gneiss. They believed these syenite-migmatite complexes were a consequence of the

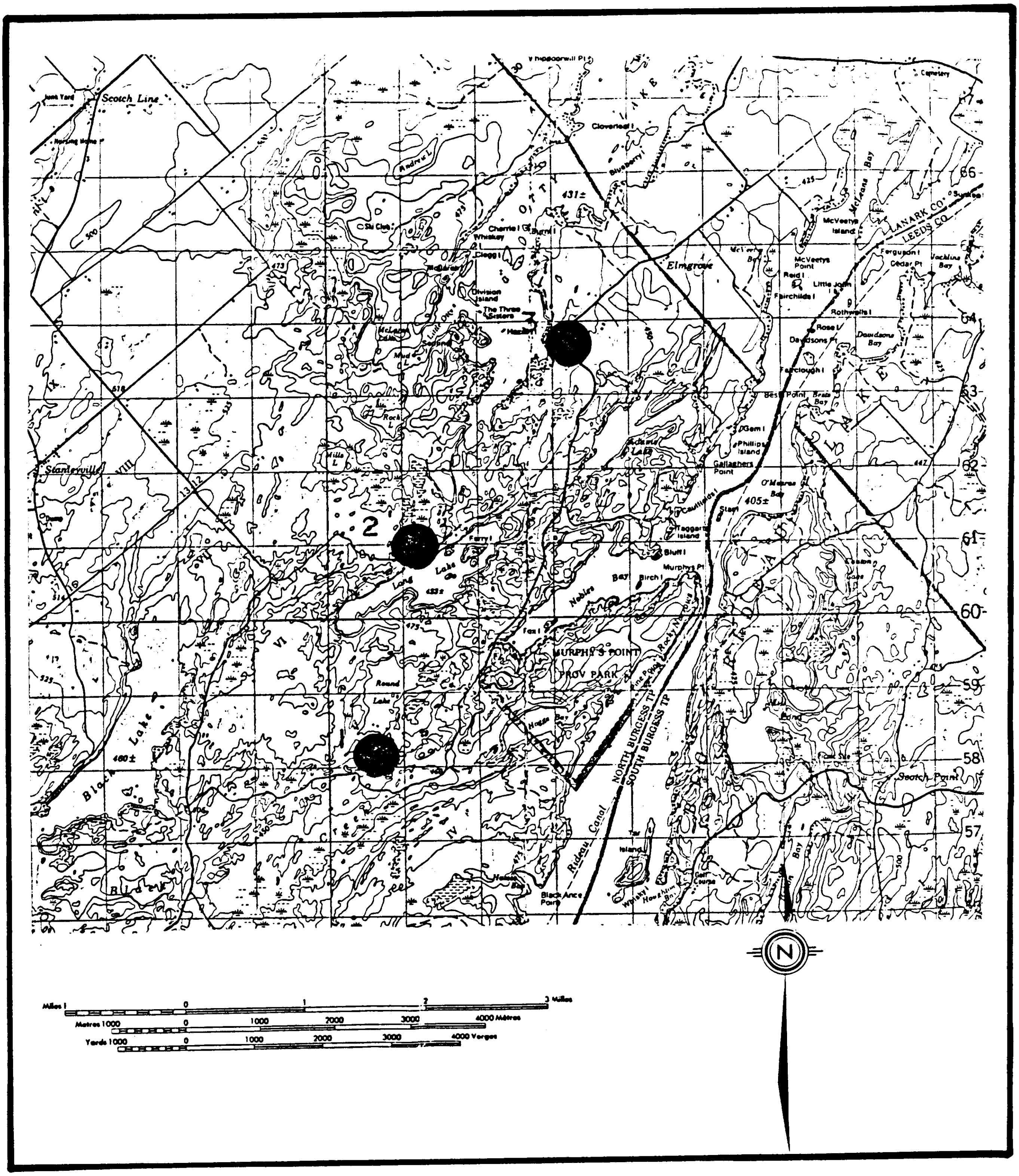


Figure 24. Location map of the wollastonite occurrence in North Burgess Township; shaded areas represent approximate area. 1-Silver Queen Mines, 2-lots 8 and 9, concession 6, 3-lot 4, concession 6; lot 3, concession 7.

granitization process which transformed quartzite into granite, and garnet gneiss into syenite.

The intrusive rocks are predominantly syenite and quartz syenite although, small bodies of granite and diorite were also noted. Small pegmatitic and lamprophyre dykes crosscut other rock types throughout the area.

The Paleozoic Nepean Formation unconformably overlies the Precambrian rocks in the northern and south-eastern parts of the township. The Nepean Formation consists primarily of medium-grained, well-sorted quartz sandstone with minor thin interbeds of quartz-pebble conglomerate (Williams and Wolf 1984).

The majority of Precambrian rocks are northeast trending, however, locally may be structurally complex. A major northeast trending fault zone (Rideau Lake Fault Zone) underlies Rideau Lake, about 3.5 km east of the wollastonite occurrences shown on Figure 24.

Previous Geological Work

H.G. Vennor (1870-1876) and R.W. Ellis (1905) worked in the general area of Frontenac, Leeds, and Lanark Counties. The Precambrian geology was examined by Dugas (1950) and Dugas and Wilson (1961, 1:63,630 scale) and incorporated into compilation maps by Hewitt (1964, 1:126,720 scale), and Kingston et al (1985, 1:125,000 scale). The Paleozoic geology was mapped by Williams and Wolf (1984, 1:50,000 scale). The Silver Queen Mine has been included in numerous mineral studies made by de Schmidt (1912, 1916), Spence (1920), Satterly (1944), Sabina (1967) and

Papertzian and Kingston (1985). Hunt (1866) first identified the presence of wollastonite in North Burgess Township.

Geology

The following description is from de Schmidt (1912):

> "The deposit, which occurs along the contact of a pyroxenite dyke with gneiss and crystalline limestone and has a direction of N 30 degrees E. with a dip to N.W., has been mined by means of three pits.....
>
> The mica and phosphate occur in large pockety masses along the contact, which extends a considerable distance and the occurrence somewhat resembles the Blackburn mine in Templeton tonwship, Que., though on a smaller scale.
>
> Much of the mica is crushed and twisted, as is often the case in shallow workings where large quantities of phosphate are present, but experience shows that with depth this crushing of the mica tends to disppear, the crystals becoming more firm and solid.
>
> An interesting feature is the occurrence on crevices in the sugar-phosphate of sheets of white hornblende-asbestos or "mountain-leather." Long prismatic crystals of dark-green actinolite penetrating pink calcite were found on the dump, and small quantities of scapolite were noticed. The pyroxenite varies from a dark-green to a light-grey rock, the pyroxene often possessing highly-developed cleavage in three directions. The crystalline limestone adjacent to the contact with the pyroxenite dyke is remarkable both on account of its colour, which is a light blue, and for its property of liberating sulphuretted hydrogen in considerable quantities when crushed or struck with the hammer. The rock also contains a large amount of phlogopite in minute crystals, as well as pyrites, diopside, garnet, tremolite, and graphite."

In addition to these minerals described by de Schmidt (1912), Sabina (1967) identified small quantities of wollastonite, zircon, serpentine, hematite, barite, tourmaline, quartz (crystals), marcasite, and pyrrhotite in a small pit near the main mica-apatite opening.

History

The Silver Queen Mine property contains two mines, an apatite-mica mine and a feldspar mine. It was initially opened in 1903 by Mr. R. Connell of Ottawa as a mica mine. In 1905, Dominion Improvement and Development Co. obtained the property and leased it for a year to Mr. C. Ellsner. The mine operated between 1905 and 1947, producing large quantities of high grade apatite and to a lesser extent mica. The feldspar mine operated on an intermittent basis between 1911 and 1914, and produced a small quantity of spar (2,990 tons). Workings on the property consist of a shaft and several pits (Satterly 1944, Spence 1920, de Schmidt 1912).

Comments

The North Burgess Township wollastonite occurrences are associated with pyroxenitic rocks and mica-apatite veins. The mineralization is hosted by crystalline limestone and veins crosscutting the pyroxenites. Based on the literature, the grade appears to be low but no quantitive figures were available.

Throughout the township there are numerous mica-apatite and mica veins associated with pyroxenitic rocks and crystalline limestones. Examination of these occurrences may identify additional mineralization but the likelihood of finding economic concentrations appears to be poor. The North Burgess occurrences were not examined in the field and conclusions were solely based on limited information found within the literature.

References

NTS 31C/16
de Schmidt (1912, 1916)
Dugas (1950)
Dugas and Wilson (1961)
Hewitt (1964)

Hunt (1866)
Kingston et al (1985)
Papertzian and Kingston (1985)
Sabina (1967)
Satterly (1944)
Spence (1920)
Williams and Wolf (1984)

NORTH BURGESS TOWNSHIP
LOT 8 AND 9, CONCESSION 6

Location

The occurrence is located approximately 10 km south of the town of Perth, on lots 8 and 9, concession 6, North Burgess Township, Lanark County. NTS 31C/16, UTM co-ordinates 401300-402500 mE, 4960800-4961700 mN, Zone 18 (Figure 24).

Access

Access can be obtained either via boat on Long Lake or by proceeding east approximately 2.6 km from County Road 14 along a private road leading to the southwest shore of Otty Lake.

Geology

Hunt (1866) described the geology as follows:

".... along the shores of Long Lake, the pyroxenite rocks are well seen, alternating with a reddish feldspathic gneiss, consisting of quartz and orthoclase; the latter often coarsely crystalline, and giving a granite aspect to the pyroxene rock, forming large interstratified beds, or smaller masses lenticular in shape, is interstratified with the reddish gneiss, and presents great variations in its character; sometimes it consists of a granitoid aggregate of pale grayish-green pyroxene with small plates of black mica, at other times, from the predominance of the latter mineral, there results a dark, brown micaceous pyroxenic schist, apparently cleaving with the stratification. These varieties of rock are repeatedly seen in the section, alternating with the orthoclase gneiss, and sometimes forming small interrupted masses, not more than a foot or two in diameter, imbedded in it. Darker green patches of hornblende occasionally occur in the granular pyroxene rock, some beds of which are green in colour and include white orthoclase and white quartz, with small crystals of clove-brown sphene. In one case a bed of a granular mixture of white feldspar and dark green hornblende, with sphene, is met with, cut with small veins of quartz, and passing on one side, by a disappearance of the hornblende, into a nearly pure white orthoclase rock, still holding sphene. Small veins of a fine grained white granite cut the whole of these strata. In the immediate vicinity of the beds just described, the gneiss becomes finer grained and highly quartzose, and beds of limestone make their appearance; one fine-grained and mingled with masses of pale green serpentine, and in an outcrop, near by, another, coarse-grained, but distinctly stratified, and conforming in direction with the preceding rocks. This coarsely crystalline limestone contains small plates of mica, and in some parts includes an abundance of green pyroxene in small prisms, together with crystalline grains of apatite, generally small, but sometimes half an inch in diameter."

In addition, Hunt (1866) noted numerous northwest trending veins cross-cutting the gneiss and pyroxenite near the shore of Long Lake. Minerals found within these veins include pyroxene, apatite, mica, pink calcareous spar and wollastonite.

Comments

No mention of the extent of mineralization was found within the literature. The occurrence could not be located by the author.

Reference

NTS 31C/16
Dugas and Wilson (1961)
Hunt (1866)

NORTH BURGESS TOWNSHIP
LOT 4, CONCESSION 6
LOT 3, CONCESSION 7

Location

The occurrence is situated approximately 8 km southwest of the town of Perth on lot 4, concession 6, and lot 3, concession 7, North Burgess Township, Lanark County. NTS 31C/16 (Figure 24).

Access

Proceed west on the Murphy Point road 1.7 km from the community of Elmgrove .

Geology

The geology is similar to that described on lots 8 and 9, concession 6, North Burgess Township. The stratigraphy is further described by Hunt (1866) as follows:

> " Here is seen a great development of pyroxenitic strata, having a north-east strike, generally grayish-green, granular, with but little mica, and including beds and interrupted masses of a mixture of white quartz and wollastonite. Disseminated grains of apatite are frequent in the pyroxenic rock, which is also cut by numerous veins carrying this mineral...
> In the immediate vicinity of these pyroxenites, is an exposure of crystalline limestone, covering many acres, and containing in some parts, grains of pyroxene, wollastonite and apatite, the later two, however, sparsely distributed. The limestone is here cut by a vein of white lamellar heavy-spar, whose course is magnetic north.
>
> These same limestones appear again on the strike, on the third lot of the seventh range of North Burgess, where they are also seen over several acres, scarcely covered with soil, and are white and coarsely lamellar. As before, green pyroxene, apatite, and more rarely, wollastonite and brown mica, all in small grains or crystals, are present."

References

NTS 31C/16
Dugas and Wilson (1961)
Hunt (1866)

FRONT OR REAR OF LEEDS AND LANSDOWNE TOWNSHIPS
CHARLESTON LAKE OCCURRENCE

Location

Exact location unknown, except that it occurs around Outlet Post in Lansdowne Township at the south end of Charleston Lake. NTS 31C/8 (Figure 25).

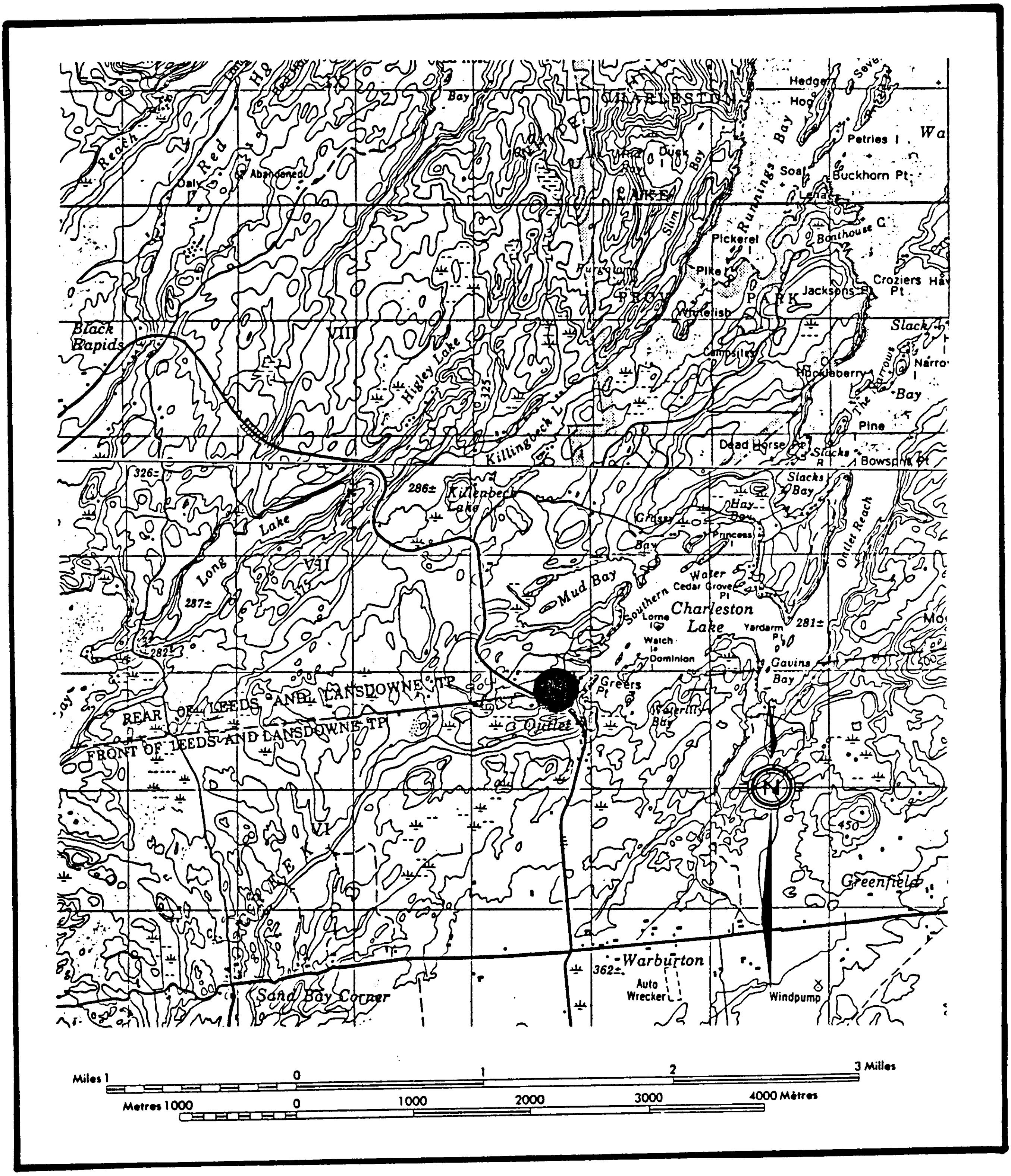


Figure 25. Location map of the Charleston Lake area, Front of Leeds and Lansdowne and Rear of Leeds and Lansdowne Townships.

Access

Outlet is accessed via County Road 3.

General Geology

The occurrence is located on the eastern edge of the Frontenac Axis, in an area of amphibolite to granulite facies regional metamorphism. The area is underlain by crystalline limestones, quartzites, well-layered, biotite-quartz-feldspar gneisses and migmatite. The crystalline limestones may contain small masses of white pegmatite and diorite, diopsidic skarn, rusty paragneiss and calc-silicate inclusions. The quartzites vary from massive, pure quartz to thinly interbedded quartzite and marble. Sillimanite, cordierite, hypersthene, and garnet are common constituents of the biotite-quartz-feldspar gneisses. The migmatites are poorly foliated and consist of intermixed granitic and metamorphic rocks.

Frontenac-type quartz monzonite at Charleston Lake is crosscutting and post-dates Rockport-type to the south (Wynne-Edwards, 1962).

Flat lying Paleozoic strata (Nepean Formation) unconformably overlie Precambrian rocks to the north of Charleston Lake and occur as isolated outliers within and around Charleston Lake.

Previous Geological Work

The Precambrian geology of the Charleston Lake Area was reconnaissance mapped by Barker (1922, 1:126,720 scale), and later in more detail by Wynne-Edwards (1962, 1963, 1967, 1:63,360 scale). Hewitt (1964, 1:126,720 scale), and Kingston et al (1985, 1:125,000 scale) have assimilated the area into their complilation maps. The Paleozoic geology was mapped in part by Carson (1981, 1982, 1:50,000 scale), and in part by Williams and Wolf (1984, 1:50,000 scale). Vennor (1872) traversed the Counties of Leeds and Frontenac and published a general description of the rocks and minerals.

Comments

Traill (1980) reported that wollastonite occurs at Outlet Post in Lansdowne Township. A sample of the wollastonite was donated by J.H. Slack (1913) to the National Mineral Collection in Ottawa. However, the occurrence could not be located during the present investigation.

References

Barker (1922)
Carson (1981, 1982)
Hewitt (1964)
Kingston et al (1985)
Traill (1980)
Vennor (1872)
Williams and Wolf (1984)
Wynne-Edwards (1962, 1963, 1967)

Dungannon Township
York River Tactite Occurrence

Location

The occurrence is situated approximately 300 m north of the East Road (Highway 500) on the east bank of the York River, on lot 11, concession 11, Dungannon Township, Hastings County. NTS 31F/4, UTM co-ordinates 284850mE, 4994100mN, Zone 18 (Figure 26).

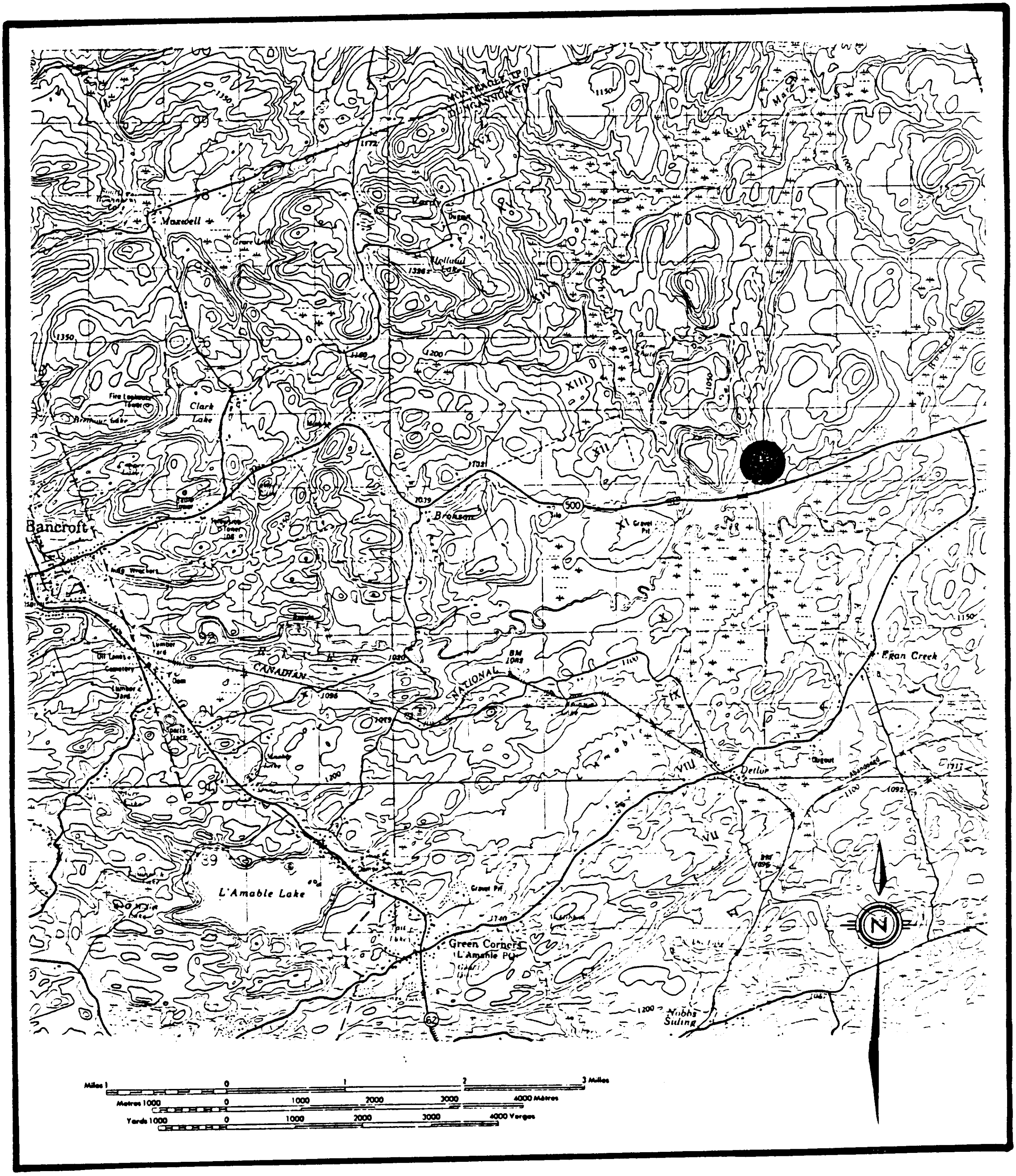


Figure 26. Location map of the York River Tactite occurrence, Dungannon Township.

Access

The area is reached by travelling east on Highway 500 across the York River bridge to a single lane road on the left. Proceed north along lane to a small pit.

General Geology

"The oldest rocks in the area are amphibole, paragneiss, and marble, all of which may have been replaced in part by nepheline syenite, syenite, granite, and gabbro. The Mallard Lake Metagabbro is interpreted to be the oldest intrusion. Later intrusions include nepheline rocks, syenites, and granites" (Hewitt and James 1956).

Nepheline syenite gneiss occurs mainly in a narrow northeast trending band (200-400 m in width) flanked on the east and west by marble. The band contains numerous zones of nepheline-albite pegmatite. Amphibole occurs in narrow zones within the nepheline gneisses, marbles, and adjacent to the gabbroic bodies. The Mallard Lake Metagabbro bounds the study area to the east and the Great Bend Granite to the west. The Great Bend Granite contains numerous xenoliths of marble, ranging in size from a few to several hundred metres (Grant 1988).

Previous Geological Work

The area was mapped by Hewitt and James (1956, 1:31,680 scale), and in part by Morse (1983, 1:2400 scale), Miller (1985, 1:1200 scale) and Grant (1988, 1:2500 scale). The nepheline-bearing rocks have been included in studies by Baragar (1953), Hewitt

(1961), Reeve and Anderson (1976), and Sylvester and Anderson (1976).

Geology

The geology (Figure 27) of the York River tactite is briefly described by Hewitt and James (1956) as follows:

> ". . . in the roadcut just east of the York River bridge on the East road. Two hundred yards north of the East road on the east bank of the York River there is a small pit in the marble that exposes a skarn zone in which grossularite, diopside, vesuvianite, wollastonite, zircon, spinel, forsterite, and chlorite, as well as calcite and feldspar, have been identified by Louis Moyd. The skarn zone in the marble overlies the nepheline gneiss band and may be associated genetically with the alkaline gneisses.
>
> The crystalline limestone and dolomite consist of medium-grained aggregates of calcite and dolomite up to 1/4 inch in size. In the silicated or impure varieties of marble the following minerals are common: diopside, tremolite, phlogopite. graphite, scapolite, vesuvianite, garnet, quartz, feldspar, pyrite, pyrrhotite, and apatite. Most of the marbles are either calcitic or dolomitic limestone. Near the nepheline gneiss bands, nepheline occasionally occurs in the marble, replacing calcite. Hastingsite and alkaline pyroxene may also occur with nepheline in the marble contact zone. Forsterite, spinel, brucite, diopside, wollastonite, pectolite, vesuvianite, grossularite, chondrodite, and clinohumite were identified in marbles of the York River area by C.E. Tilley."

Wollastonite occurs in a dolomitic skarn zone containing about thirty mineral species (Sabina 1986). A sample of the wollastonite is located in the national mineral collection in Ottawa (catalogue number 061/26). A sample collected by the writer from the cliff on the east side of the York River, opposite the Golding-Keene quarry contains wollastonite, diopside, scapolite, and minor calcite and pyrrhotite. The skarn rock is white and green in colour and composed predominantly of wollastonite and light green xenoblastic grains of diopside (50-60%). The wollastonite occurs as white tabular hypidioblastic

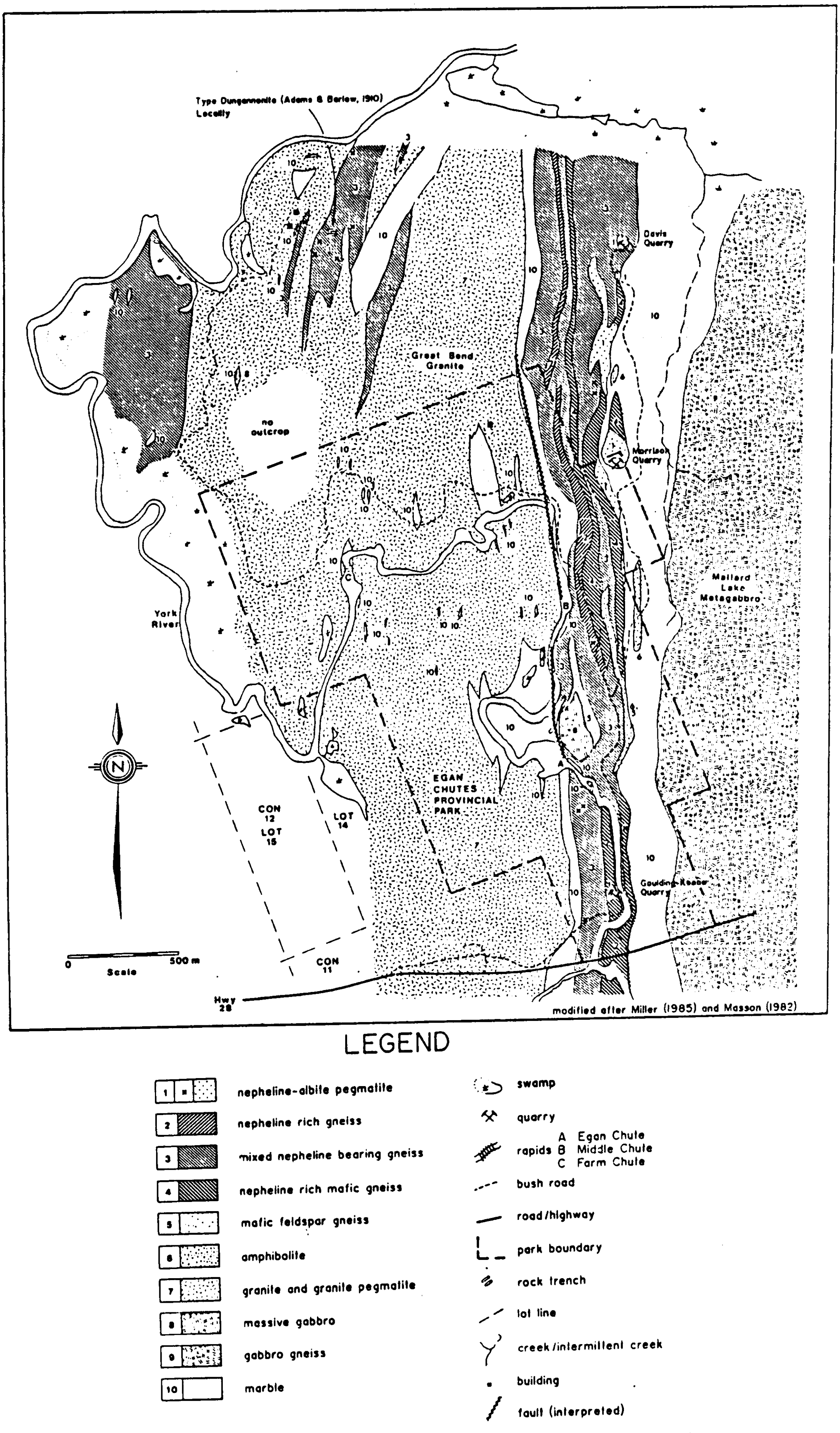


Figure 27. Geological map of the York River Tactite occurrence and adjacent areas, Dungannon Township (from Grant 1988).

grains, averaging 2-5 mm in length and locally up to 1 cm in length. A second sample of skarn contained colourless cancrinite with veins of calcite. Wollastonite was identified in a small outcrop (1-2 sq. metres) of skarn located 400 m southeast of the Morrison quarry (Grant, W.T., Bancroft Drill Core Library Geologist, Ministry of Northern Development and Mines, personal communication 1988). A sample of the skarn rock consists of finely banded (<1 cm in thickness) intergrown garnet, calcite, wollastonite, and dark green clinopyroxene (1-2%). The garnet (25-30%) occurs as finely disseminated reddish-brown grains, averaging <0.5 mm in diameter. The wollastonite (<10%) occurs as white prismatic crystals (<1 cm in length). Presently the extent of mineralization remains uncertain due to poor outcrop exposure.

History

The map area (Figure 27) contains three past producing quarries (Goulding-Keene, Morrison, and Davis quarries) of nepheline pegmatite. The material produced was used by the glass and pottery industries. The Goulding-Keene quarry operated from 1937 to 1939, the Davis quarry 1939-1942, and the Morrison quarry 1939-1940, producing 10,000, 1694, and 1663 tons of material, respectively (Hewitt 1961). The occurrence is part of the recently created Egan Chutes Provincial Park (340 ha) situated along the York River.

Comment

Wollastonite was identified at two localities within the Egan Chutes Provincial Park. Exploration should concentrate in the marbles peripheral to the Mallard Lake Metagabbro outside park boundaries since the park precludes any potential development of the known occurrences. The likelihood of delinating economic concentrations of wollastonite is poor due to the nature of the mineralization, which is within a multi-mineralic skarn zone.

References

NTS 31F/4
Baragar (1953)
Grant (1988)
Hewitt (1961)
Hewitt and James (1956)
Miller (1985)
Morse (1983)
Reeve and Anderson (1976)
Sabina (1986)
Sylvestor and Anderson (1976)

South Crosby Township
Deans Island Occurrence

Wynne-Edwards (1967) and Currie and Ermanovics (1971) noted needles of wollastonite in a skarn at the south end of Dean's Island (Figure 28), approximately 2.7 km southwest of the community of Morton (NTS 31C/9). While no economic concentrations were found it does provide an indication of the metamorphic grade and suggests the possiblity that such concentrations may exist in as yet undiscoverd occurrences.

Bastard Township Occurrence

Logan et al (1863) reported the occurrences of a pale green wollastonite-bearing rock, with quartz and small scales of brown mica. The location of this occurrence is unknown, as are the extent and grade of the mineralization.

North Elmsley Township Occurrence

Small masses of white, fibrous wollastonite and a few crystals of zircon were observed in a vein with pink lamellar calcite on lot 25, concession 8 (Figure 29). The veins are associated with pyroxene-apatite skarn zones hosted in white, coarse-grained orthoclase gneisses (Hunt 1866). Hunt (1866) suggested that a mass of limestone on Lot 25 that was described as a bed ten feet in width of wollastonite-bearing rock, enclosing three feet of nearly pure, sea-green apatite was probably only a large calcareous vein containing some wollastonite. The occurrence was not located during this study.

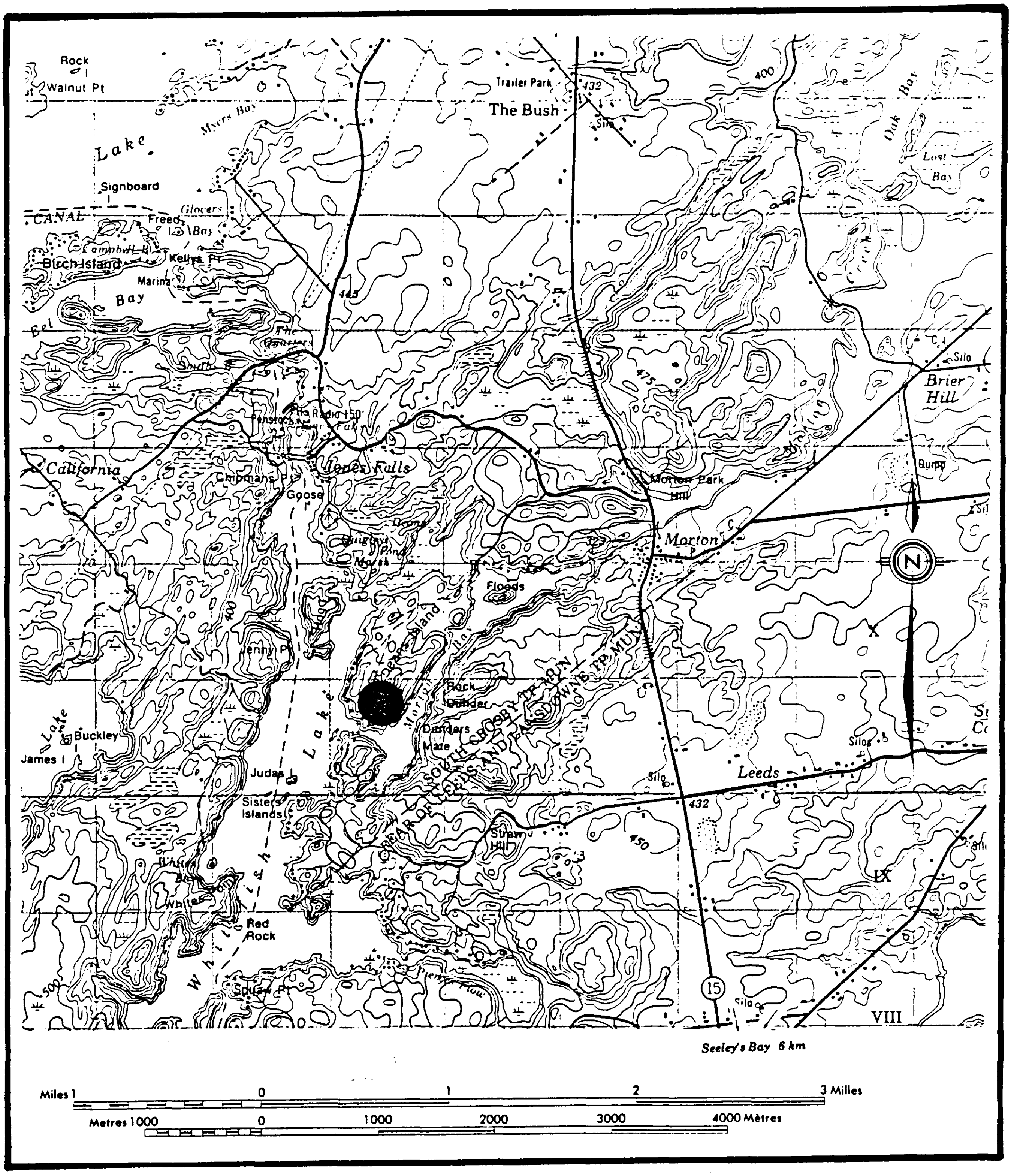


Figure 28. Location map of the Deans Island occurrence, South Crosby Township.

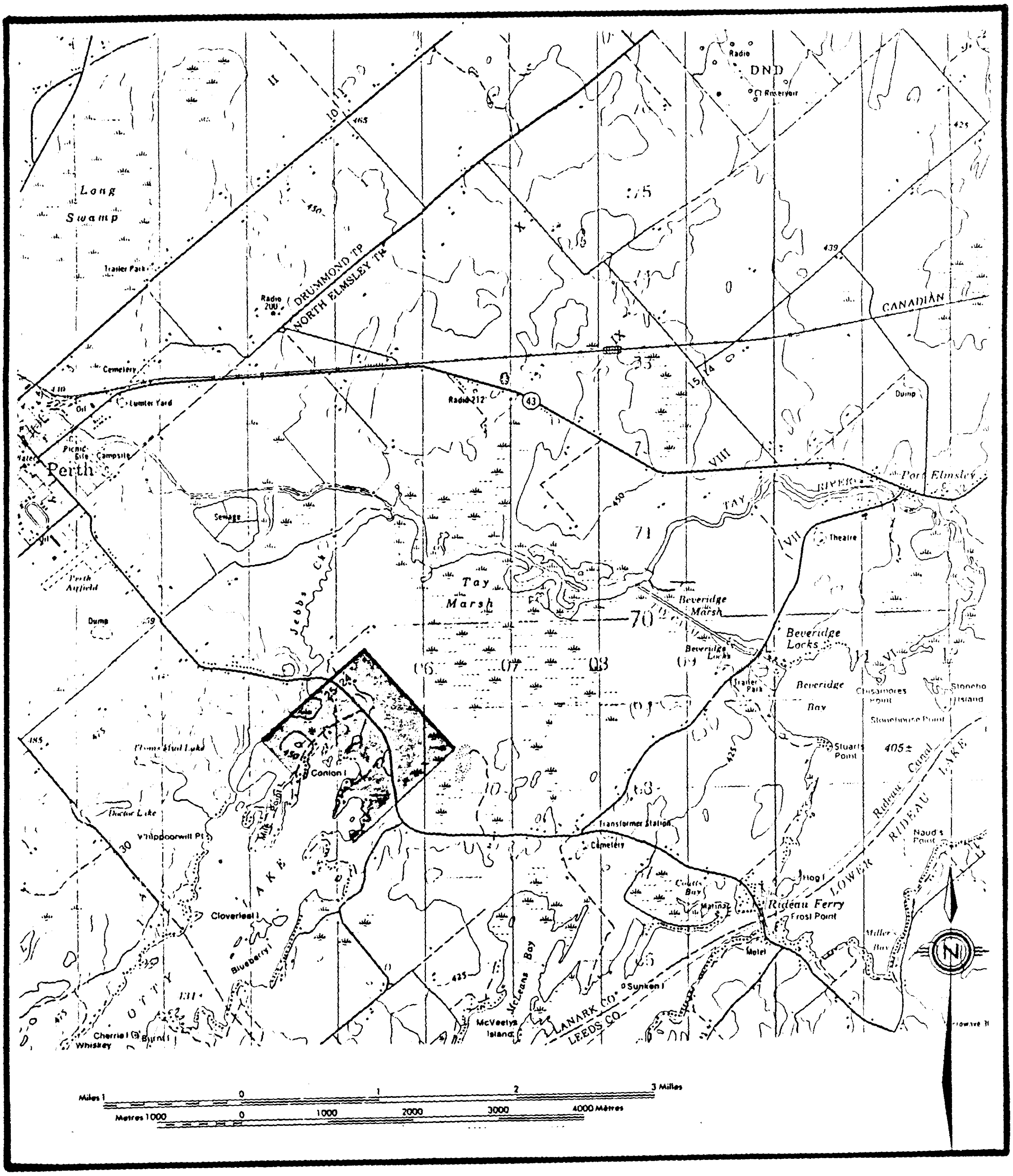


Figure 29. Location map of the North Elmsley Township occurrence.

Glamorgan Township
Glamorgan Gabbro Occurrence

The area is underlain by igneous-textured gabbro and metagabbro, surrounded by marble, skarn, and near the margins of the intrusion by pyroxenite. Gittens and Lumbers (1972) noted a prominent skarn zone up to 60 m in width adjacent to the Glamorgan Gabbro, approximately 1.5 km south of Gooderham (Figure 30). The skarn was reported to be composed essentially of garnet and clinopyroxene, and in places contains vesuvianite and/or wollastonite.

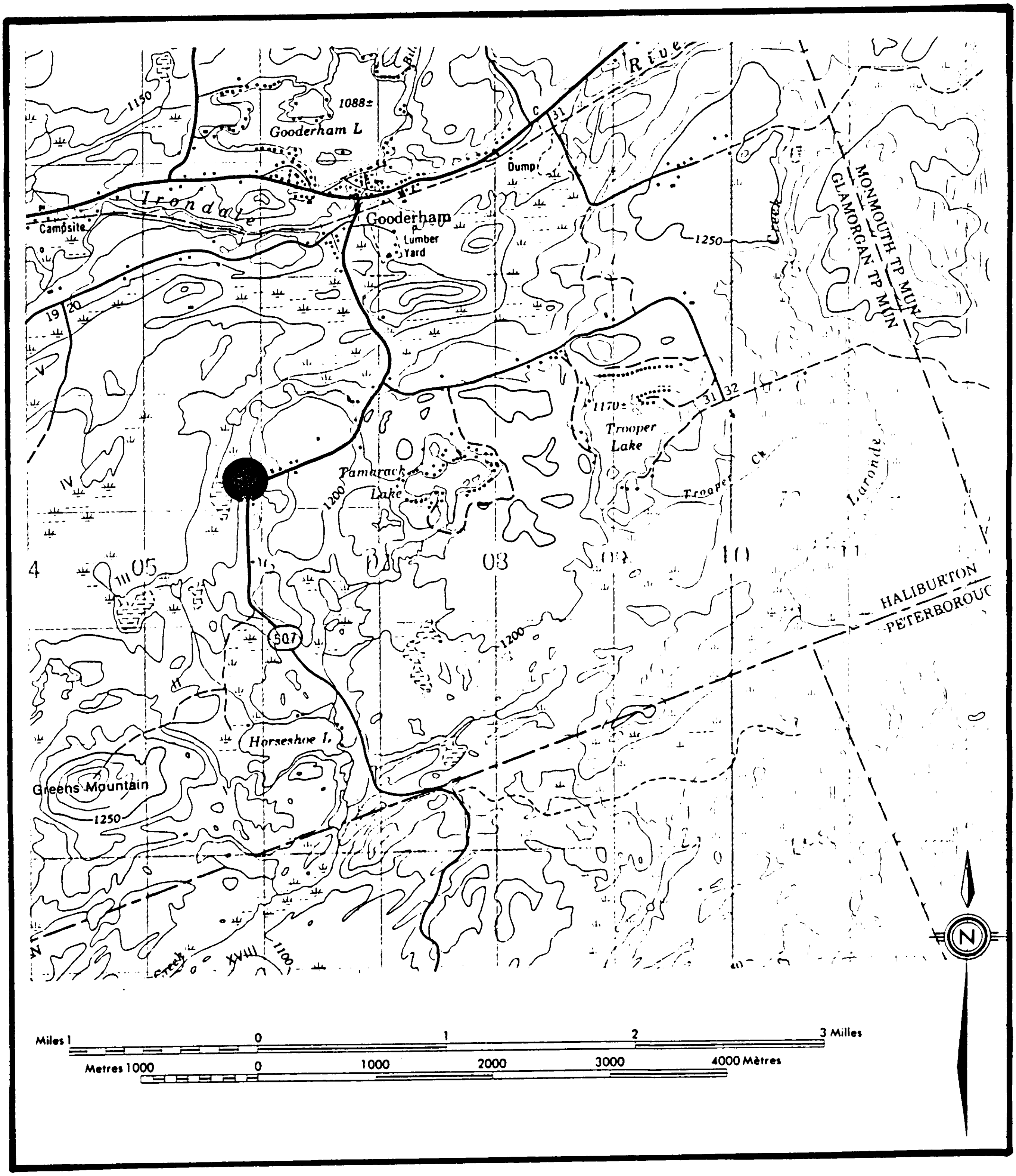


Figure 30. Location map of the Glamorgan Gabbro Occurrence.

PART IV

NORTHERN ONTARIO WOLLASTONITE OCCURRENCES

DISTRICT OF THUNDER BAY
PRAIRIE LAKE CARBONATITE COMPLEX

Location

The Prairie Lake complex is located at 49° 02′ N latitude and 86° 43′ W longitude, about 45 km northwest of Marathon, Ontario (Figure 31).

Access

Access may be either via float aircraft from Geraldton or Pays Plat to Prairie Lake or by the Dead Horse Creek forest access road, skid roads and 8 km of abandoned tractor road constructed in 1975-1976 by the International Minerals and Chemical Corporation.

Geology

The Prairie Lake Carbonatite complex (Figure 32) is situated within the Quetico Subprovince of the Superior Province of the Canadian Shield (Ayres et al. 1971). Bell and Blenkinsop (1980) dated the complex at 1033±59 Ma using the Rb-Sr isochron method.

Sage (1987) summarizes the geology as follows:

"The Prairie Lake complex forms a circular topographic high west of Prairie Lake. The complex consists of a complexly interfingered sequence of arcuate to curvilinear bands of carbonatite and of pyroxene-nepheline rocks of the melteigite-urtite series collectively referred to as ijolite. The ijolitic rocks are, by far, the dominant rock in the core of Prairie Lake complex. The carbonatite rocks are more abundant towards the periphery of the intrusion. The complex occurs on fractures parallel and subsidiary to the Big Bay -- Ashburton Bay Fault which has served as a major site of alkalic rock -- carbonatite intrusive activity northeast of the Lake Superior basin."

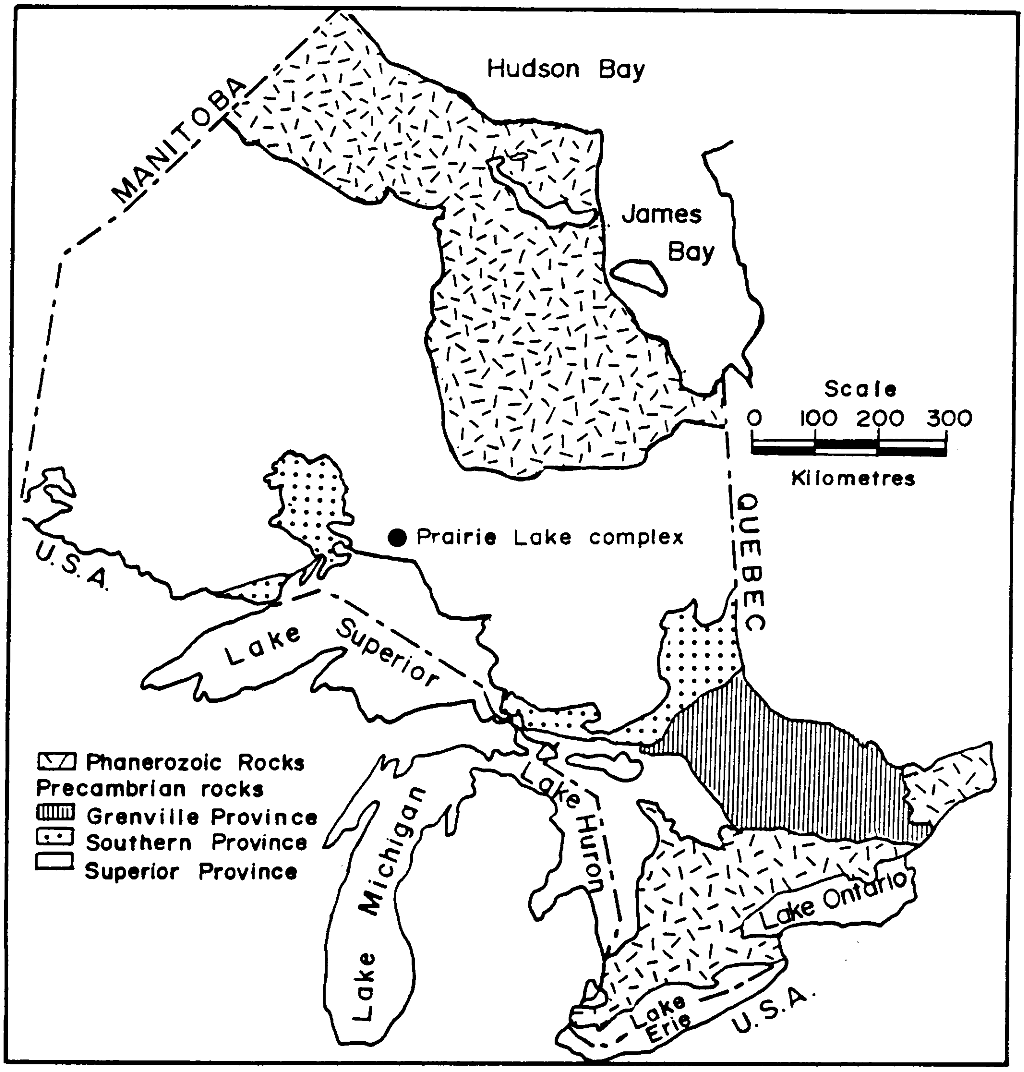


Figure 31. Location map of the Prairie Lake Carbonatite Complex, District of Thunder Bay.

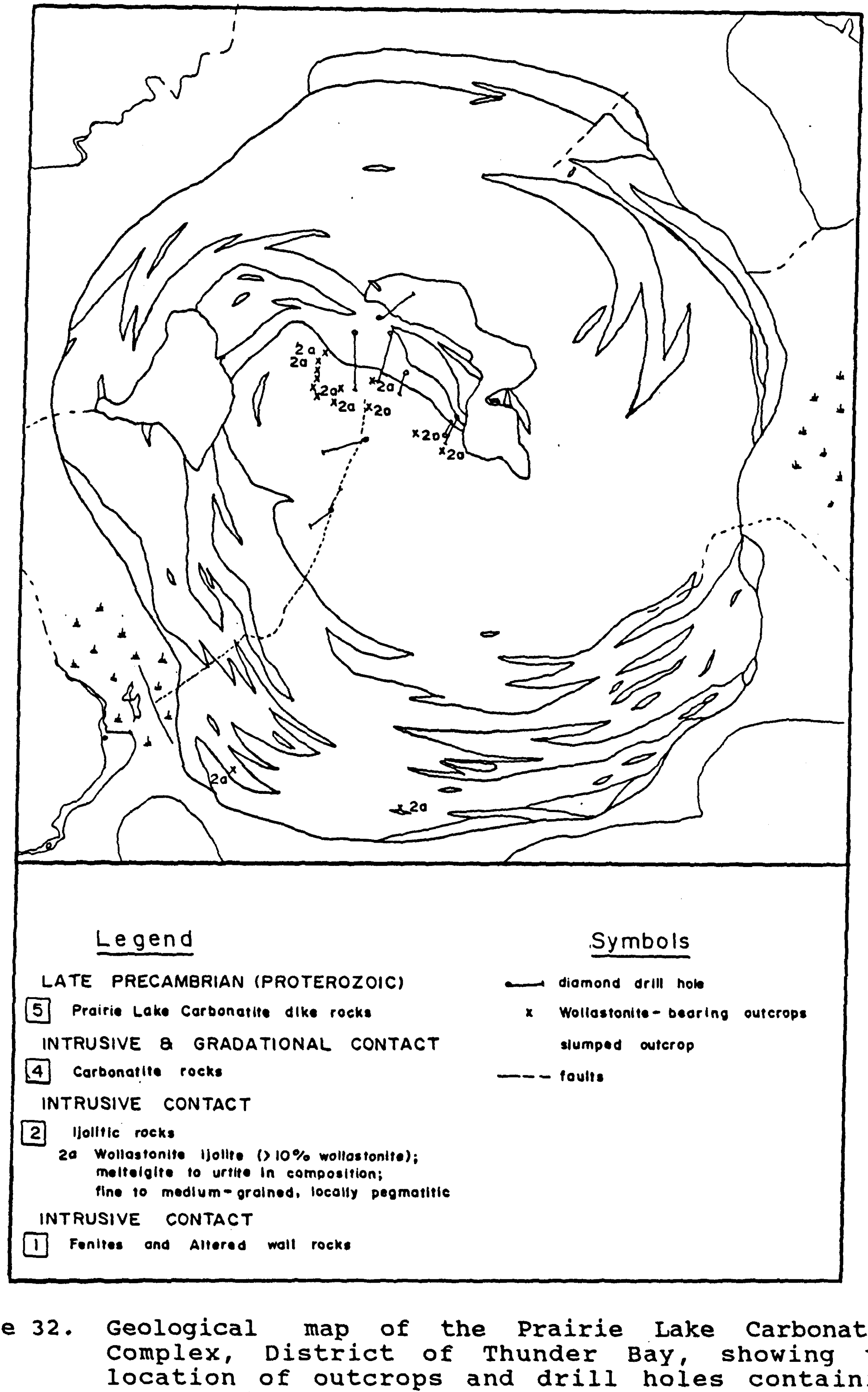


Figure 32. Geological map of the Prairie Lake Carbonatite Complex, District of Thunder Bay, showing the location of outcrops and drill holes containing wollastonite mineralization.

The complex was originally explored because of its uranium and niobium potential but during the course of the investigation significant concentrations of apatite, vermiculite, and wollastonite were encountered.

The wollastonite occurs as clusters of prismatic crystals within massive, fine to coarse-grained ijolites, and nepheline-rich, coarse-grained pegmatitic segretions within the finer phases. The wollastonite-rich rocks are principlly in the north-central area of the complex, west of Centre Lake. Outcrops and drill holes which contain wollastonite concentrations of greater than 10% are shown on Figure 32. The pegmatitic segregations may contain up to 50% wollastonite and are composed almost exclusively of nepheline and wollastonite. Black garnet, biotite, and calcite are common accessory minerals in this ijolitic group (Sage 1987). Concentrations of 30-75% wollastonite were found in thin sections of drill core from the 1983 Nuinsco exploration programme (Kretschmar 1984).

History

The complex was first worked in 1968 by J. Gareau (Newmont Mining Corporation of Canada Ltd.). The company trenched (419 m), diamond drilled (531 m, Winkie drill), and conducted geophysical and geological surveys on radioactive showings. In 1975, the International Minerals and Chemical Corporation (Canada) Ltd. restaked the former claims and optioned two claims to New Insco Mines Ltd. In 1975, New Insco Mines Ltd. later optioned the 39 claims of International Minerals and Chemical Corporation Ltd. and drilled 15 holes (1546.2 m) for uranium. In 1976, the company completed radiometric surveys, 131 auger holes, geological mapping, and limited trenching and pitting. Additional diamond drilling was conducted in 1977 (1570 m) and in 1978 conducted a ground geophysical survey for U, Nb, and P. The company changed its name in 1979 to Nuinsco Resources Ltd. and in 1983 an additional 1730 m of drilling were completed to evaluate the wollastonite potential of the complex (Sage 1987).

Comments

The extensive development of wollastonite ijolite in the Prairie Lake complex is unique to carbonatite complexes in Ontario or North America. The Lackner Lake (Parsons 1961) and Oka (Gold 1969) carbonatite complexes have reported wollastonite-bearing phases of minor extent. Sage (1987) suggested that the carbonatite-ijolite complex at Ottoma Bay in western Kenya (Pulfrey 1950) appears to be closely analogous to the Prairie Lake complex except Pulfrey (1950) reported the occurrence of cancrinite and pectolite which were not identified in the rocks of the Prairie Lake area. Sage (1987) reported that due to poor outcrop exposure, systematic cross-sectional drilling is required to determine the presence or absence of economic concentrations of minerals.

References

Ayres et al (1971)
Bell and Blenkinsop (1980)
Gold (1969)
Kretschmar (1984)
Melnik (1984)
Parsons (1961)
Pulfrey (1950)
Sage (1987)

Satterly (1968)
Watkinson (1976)

THUNDER BAY DISTRICT
PIJITAWABIK BAY AREA

Kennedy and Sherlock (1989) reported that wollastonite has been identified in the Pijitawabik Bay area, Lake Nipigon, and recommended the area for further exploration.

References

Kennedy and Sherlock (1989)

RECOMMENDATIONS FOR EXPLORATION

While exploring for wollastonite three basic requirements necessary for the formation of wollastonite should be kept in mind: (i) a source of calcite and silica to react to produce wollastonite, (ii) a source of heat for the reaction to proceed and (iii) a means of depleting CO_2 during the reaction. Exploration should concentrate on areas which can meet these three basic criteria.

The calcite is provided by the host marble while the silica may be derived through a variety of sources, such as host sediment, adjacent siliceous sediments (reaction skarn), or an external source (intrusion). The original chemistry (primary silica) of the rock appears to be the source in the majority of the occurrences studied which were found to contain significant concentrations of wollastonite mineralization.

Therefore, areas where carbonate and siliceous sediments commonly co-exist, ie. basin margin (intertidal environment), are favourable areas to explore. On the basis of textural and rock relationships observed in the field, possible host rocks include: sandy or cherty limestones, calcareous sandstones, interbedded arenites and limestones, and possibly stromatolites.

The original chemistry (thus position in the basin) is less important in metasomatic deposits where wollastonite formed as a result of silica introduced from outside the system.

The extent of the various zones of the contact aureole depends on the heat content, i.e. on the size (thickness) of the intrusion. The temperature rise of the country rock depends on the temperature of the intruding magma which varies with composition, i.e. granitic 700-800°C, syenitic 900°C, and gabbroic 1200°C (Winkler 1976). The temperature at various distances from the contact is also influenced by the temperature of the country rock prior to intrusion of the magma.

Winkler (1976) reported that the width of the zone of each metamorphic grade is increased by (a) increasing temperature of the magma, (b) increasing thickness (or diameter) of the intrusion and (c) increasing depth of the intrusion. The zone of high-grade metamorphism is considerably more extensive around gabbroic intrusions as compared with syenitic or granitic intrusions.

Therefore exploration around medium-to large-sized intrusions increases the likelihood of finding large concentrations of wollastonite mineralization. Deposits formed as a result of metasomatism are restricted to the more acidic intrusions, except in cases where the mafic intrusion is associated with felsic rocks.

The formation of wollastonite is a decarbonatization reaction (produces CO_2) and since wollastonite is not stable in excess CO_2, a means of depleting the CO_2 is necessary for the reaction to proceed. This may be accomplished either by maintaining a low fluid pressure (shallow contact metamorphism) or, in the case where wollastonite forms due to regional metamorphism, by dilution of the CO_2 phase by H_2O.

In areas of low to medium grade regional metamorphism exploration should concentrate along the margins of and within xenoliths in medium-to large-sized shallow intrusions. Wollastonite may form around deeper-seated intrusions where structures provided passageways or conduits for the dilution of the fluid phase with H_2O or permitted the escape of CO_2.

In areas of high grade regional metamorphism preference should be given to late tectonic and post-tectonic intrusions and areas where structure or lithology has permitted the introduction of water. The timing of the intrusion is not nearly as important when regional metamorphism is low grade.

Areas of good potential examined in the study include the Marmora-Lake Townships area, Olden Township (Mountain Grove Mafic Intrusion and McLean Granitic Intrusion), Pittsburgh Township, Front of Leeds and Lansdowne Township, and Glamorgan Township.

Exposed extensively throughout the Kingston, Gananoque, Westport and Brockville areas of the Frontenac Axis are late-to post-tectonic intrusives which were developed through the process of granitization and subsequent emplacement at structurally favourable sites such as dilatant low pressure zones (Wynne-Edwards 1967). These areas hold good potential for locating wollastonite mineralization. Also within the high-grade metamorphic terrain of the Frontenac Axis, interlayered marbles and quartzites representing transition zones from carbonate to siliciclastic sedimentation are favourable target areas, particularly where they exhibit structural features such as faults or fold hinges.

A re-evaluation of the calc-silicate rocks associated with metallic mineral deposits, in particular iron and copper, may delineate additional deposits.

Since all significant wollastonite occurrences are found in calcitic marbles/calc-silicate rocks, a good rule of thumb when exploring for wollastonite is that if the rock is dolomitic or has a significant dolomitic component then it probably does not contain wollastonite. The minerals present instead are usually tremolite and diopside, and less frequently scapolite.

SUMMARY

1. Based on the detailed mineralogy and chemistry from 8 wollastonite occurrences within the Marmora study area it is apparent that these deposits have a common origin in terms of temperature, pressure and chemistry of host rocks, with few exceptions, thus accounting for the high degree of chemical similarity both in the mineral assemblage as a whole, and within the wollastonite itself.

2. Textural and lithological evidence within the Marmora study area suggests that the mineralized zones do not represent one specific horizon but rather a particular chemistry of rock.

3. The metamorphic grade within the inner contact zone of the Deloro Pluton reached pyroxene-hornfels facies with the development of wollastonite in the silica-rich calcitic assemblages and of calcite-forsterite-periclase and calcite-forsterite-diopside in the silica-deficient dolomitic marbles.

4. Wollastonite mineralization within Marmora Township is hosted by white, fine- to medium-grained, calcitic marbles and calc-silicate rocks. The grade varies from 1-2% where it occurs as isolated knots to at least 40-50%, commonly 20-30%. The zones are usually small (<10m in width) and pod-like in appearance, and probably represent remnant roof pendants.

5. The Marmora Township Platinova-Cominco property in particular, appears by field mapping to possess grade, surface dimensions, and tonnages substantial enough for development by open pit methods. Preliminary beneficiation studies indicate liberation at 420 microns and that in general the wollastonite concentrate meets the minimum wollastonite grade and iron oxide requirements but L.O.I. is greater than 1%. The calcite meets minimum chemical grade requirements but not the brightness requirements of a high-quality filler. However, further processing should improve grade, brightness, and L.O.I. analysis.

6. Exploration around medium-to large-sized intrusions, particularly felsic intrusions, increases the likelihood of finding economic concentrations of wollastonite mineralization.

7. Areas examined within the study showing good potential for wollastonite mineralization include Marmora-Lake Townships, Olden Township, Pittsburgh Township, Front of Leeds and Lansdowne Township, and Glamorgan Township. In addition, late to post-tectonic intrusions in the Kingston, Gananoque, Westport,and Brockville areas possess good potential.

8. There is potential for additional occurrences of wollastonite, similar to the Platinova-Cominco County Line

Road occurrence near Gananoque, in the Frontenac Axis where calcareous sandstones or siliceous carbonates have been subjected to high-grade metamorphism in structurally favourable sites such as fault zones or fold hinges.

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APPENDIX 1. ANALYTICAL TECHNIQUES

X-ray Diffraction Analysis

Each sample was ground to -200 mesh and mounted on a glass slide for x-ray diffraction which was performed by the Geoscience Laboratory of the Ontario Geological Survey using a Phillips PW-730 diffractometer.

Electron Microbeam Analysis

METHOD 1

Electron microprobe analysis was carried out by H. de Souza (Mineralogist, Geoscience Laboratories, Toronto) using a JEOL 8600 Superprobe, located at the University of Western Ontario. The analytical conditions used were 10 nA beam current at 15 kV accelerating voltage and a 40 degree take-off angle. Wavelength - dispersive spectrometers were used to measure the x-ray signals and the standard Tracor-Northern ZAF correction program was used to convert the K-ratios obtained into weight percent. Backscattered electron photographs were taken on a JEOL 840 scanning electron microscope located at the University of Toronto.

NOTE: that the pyroxene nomenclature followed by the Geoscience Laboratories, Toronto is that recommended recently by the IMA. Most of the diopsides are called salite by Deer et al (1982) while ferrosalite is now hedenbergite.

METHOD 2

In order to obtain both qualitative and quantitative analyses of the wollastonite occurrences of interest, a polished section was prepared containing selected grains from each field sample. The section was ground and polished through 0.05 um Al_2O_3 using standard metallographic techniques, and was carbon-coated to provide a conducting surface.

The qualitative analysis, for the purpose of locating the wollastonite grains, was performed by W.F. Caley and P.W. Kingston using a JEOL JSM-840 scanning electron microscope with Tractor Northern automation; the instrument is located in the Department of Metallurgical Engineering, Queen's University, Kingston, Ontario. Representative photomicrographs were taken using backscattered electrons, compositional mode.

Quantitative analyses of selected wollastonite grains from each occurrence were performed using an ARL SEMQ scanning electron microscope quantometer, equipped with Tracor Northern automation; this instrument is located in the Department of Geology, Queen's University, Kingston, Ontario. Counting times were 200 sec/at 15 KV and an emission current of 100 microamps; standards consisted of the pure oxide of each element of interest.

APPENDIX 2. X-RAY DIFFRACTION MINERALOGY RESULTS

TABLE 1 MINERAL IDENTIFICATION OF SELECT ROCK SAMPLES FROM THE PLATINOVA-COMINCO PROPERTY AS DETERMINED BY X-RAY DIFFRACTION TECHNIQUES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wollastonite	-	-	-	-	-	-	-	-	-	-	-	B	A	B	D
Calcite	A	C	B	A	A	A	A	A	A	C	A	A	C	A	A
Diopside	-	-	-	-	-	-	-	-	-	A	-	-	-	-	D
Quartz	-	-	-	-	-	D	-	-	-	D	-	-	-	-	-
Amphibole	-	A	-	-	D	D	C	D	BC	D	D	-	-	-	-
Talc	-	-	-	-	D	D	D	D	D	D	D	-	-	-	-
Mica	-	-	-	-	-	-	D	-	D	D	-	-	-	-	-
Serpentine	B	B	A	A	AB	AB	-	B	-	D	A	-	-	-	-
Chlorite	-	-	-	-	-	-	B	-	C	-	-	-	-	-	-
Dolomite	-	-	?	-	-	-	B	-	-	-	C	-	-	-	-

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Wollastonite	C	C	BC	A	A	B	AB	-	-	-	-	-	-	-	-
Calcite	A	A	A	A	A	A	A	-	-	X	-	C	C	-	-
Diopside	D	-	-	-	-	-	-	-	-	-	-	-	C	A	-
Quartz	-	-	-	-	-	-	-	X	X	X	-	A	A	-	-
Amphibole	-	-	D	D	D	D	D	-	X	X	-	C	-	-	A
Talc	-	-	D	D	D	D	D	-	-	-	-	D	-	-	-
Mica	-	-	D	D	D	D	-	-	-	-	-	C	-	-	-
Serpentine	-	-	-	-	-	-	-	-	-	-	-	D	-	-	-
Chlorite	-	-	-	D	D	D	-	-	-	-	-	-	-	-	-
Dolomite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	-	-	-	-	-	-	-	X	X	X	X	-	C	-	C
Feldspar	-	-	-	-	-	-	-	-	-	-	X	B	C	-	-

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Grossularite	-	-	-	-	-	-	-	-	-	-	-	-	C	-	-
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	D	-	-
Opaques	-	-	-	-	-	-	-	-	-	-	-	-	D	-	-
K-feldspar	-	-	-	-	-	-	-	-	-	-	-	-	-	A	B
Plagioclase	-	-	-	-	-	-	-	-	-	-	-	-	-	A	B
Sphene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D

1-11	serpentine-bearing calcitic marble
12-22	wollastonite-bearing calcitic marble/calc-silicate rock
23-29	hornfels
30	mafic dyke

A-Abundant B-Moderate C-Minor D-Trace or Detectable
X-Mineral present

TABLE 2 MINERAL IDENTIFICATION OF SELECT ROCK SAMPLES FROM THE DELORO WEST ZONE AS DETERMINED BY X-RAY DIFFRACTION TECHNIQUES

	1	2	3	4	5	6	7	8	9
Calcite	A	A	A	A	A	D	-	-	-
Wollastonite	B	D	B	-	-	-	-	-	-
Diopside	-	-	-	-	-	A	B	B	B
Quartz	-	C	D	-	-	D	A	A	A
Tremolite	-	-	-	D	-	D	-	-	-
Mica	-	-	-	D	-	D	-	-	-
Epidote	-	-	-	-	-	-	?	-	-
K-feldspar	-	-	-	-	-	-	B	-	A
Plagioclase	-	-	-	-	-	-	B	A	B
Serpentine	-	-	-	-	-	-	-	C	-

1-3 wollastonite-bearing calcitic marble/calc-silicate rock
4-5 calcitic marble
6 diopsidic skarn
7-9 bands in the hornfels unit at Hwy. 7 roadcut; green band (7), black band (8), beigh band (9)

A-Abundant B-Moderate C-Minor D-Trace or Detectable

TABLE 3 MINERAL IDENTIFICATION OF SELECT ROCK SAMPLES FROM THE RAHM PROPERTY AS DETERMINED BY X-RAY DIFFRACTION TECHNIQUES

	1	2	3	4	5	6	7
Calcite	A	A	A	A	A	A	B
Dolomite	C	B	-	-	-	-	-
Brucite	B	B	-	-	-	B	B
Wollastonite	-	-	D	-	-	-	-
Diopside	-	-	-	D	-	-	-
Serpentine	-	-	-	-	-	A	-
Graphite	-	D	-	-	-	-	-

1-2	brucite-bearing marble
3-4	wollastonite-bearing calcitic marble
5	white calcitic marble
6-7	brucite-bearing marble, samples taken from north of the Rahm property

A-Abundant B-Moderate C-Minor D-Trace or Detectable

TABLE 4 MINERAL IDENTIFICATION OF SELECT ROCK SAMPLES FROM THE KELLY-CZEREWKO AND BONTER PROPERTIES AS DETERMINED BY X-RAY DIFFRACTION TECHNIQUES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Calcite	B	B	B	A	A	A	A	A	A	B	A	A	B	A	C	B	A	-	D
Wollastonite	C	-	-	-	-	CD	D	D	-	-	-	-	-	-	-	-	-	-	-
Quartz	C	-	A	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-
Diopside	-	A	D	D	D	-	D	-	-	-	-	-	A	-	-	A	-	A	A
Grossularite	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	-	-	-	-	D	-	-	-	D	-	-	-	-	-	-	-	-	-	-
Serpentine	-	-	-	-	-	C	-	-	D	A	B	B	B	B	-	-	-	-	-
Talc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	B	-	-	-

1. calc-silicate rock in pit, Kelly-Czerewko property
2. skarn rock in pit, Kelly-Czerewko property
3-5. diopside-bearing calcitic marble, Bonter property
6-8. wollastonite-bearing calcitic marble/calc-silicate rock, Bonter property
9-14. serpentine-bearing calcitic marble, Bonter property
15-16. talc-carbonate rock, Bonter property
17. white calcitic marble, Bonter property
18-19. diopsidic skarn, Bonter property

A-Abundant B-Moderate C-Minor D-Trace or Detectable

TABLE 5 MINERAL IDENTIFICATION OF SELECT ROCK SAMPLES FROM THE NORANDA GOLD PROPERTIES AS DETERMINED BY X-RAY DIFFRACTION TECHNIQUES

	1	2	3	4	5	6	7	8	9	10	11	12	13
Calcite	A	A	A	A	A	A	A	A	A	-	C	-	-
Talc	D	-	-	-	-	-	-	-	-	-	-	-	-
Serpentine	D	-	-	-	-	-	-	A	-	-	-	-	-
Quartz	-	B	C	C	-	B	-	-	-	-	-	-	-
Mica	-	C	-	-	C	-	-	-	-	B	-	-	-
Dolomite	-	D	-	-	C	-	-	-	-	-	-	-	-
Amphibole	-	-	D	D	D	-	-	C	B	A	-	B	A
Wollastonite	-	-	-	-	-	D	B	-	-	-	-	-	-
Diopside	-	-	-	-	-	D	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	B	C	-	A	-	B
Chlorite	-	-	-	-	-	-	-	-	C	-	C	D	-
Epidote	-	-	-	-	-	-	-	-	-	C	-	-	C
Plagioclase	-	-	-	-	-	-	-	-	-	A	A	A	B
Sphene	-	-	-	-	-	-	-	-	-	-	-	-	D

1. serpentine-bearing calcitic marble
2-4. light green to white calcitic marble
5. foliated grey calcitic marble
6-7. wollastonite-bearing calcitic marble
8-13. mafic intrusive on lot 19, concession 1, Madoc Township

A-Abundant B-Moderate C-Minor D-Trace or Detectable

TABLE 6 MINERAL IDENTIFICATION OF SELECT ROCK SAMPLES AS DETERMINED BY X-RAY DIFFRACTION TECHNIQUES

	1	2	3	4	5	6	7	8	9	10	11	12
Wollastonite	B	A	B	A	A	A	A	A	B	B	A	A
Calcite	A	B	C	-	A	A	A	B	A	A	B	A
Quartz	C	D	A	-	-	-	-	-	-	-	-	-
Diopside	-	-	D	D	-	A	C	-	-	B	-	B
Graphite	-	-	-	-	C	-	-	-	-	C	-	D
Spinel	-	-	-	-	-	-	-	-	-	-	C	-
Pyrrhotite	-	-	-	-	-	-	-	-	-	-	D	D
Magnetite	-	-	-	-	-	-	-	D	D	-	-	-

1-2 calc-silicate rock, Tweed Marble Quarry
3-4 wollastonite-bearing skarn, Burnstown Occurrence
5-12 wollastonite-bearing calc-silicate rock, Brewers Mills Occurrence

A-Abundant B-Moderate C-Minor D-Trace or Detectable

APPENDIX 3. SEM BACKSCATTERED IMAGES

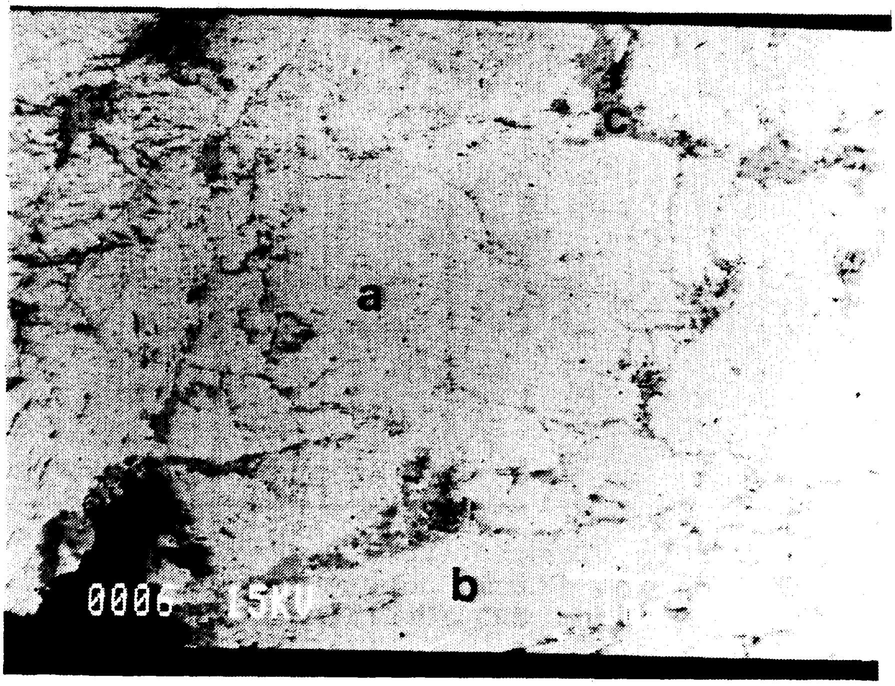

PHOTO 1. SEM backscattered images (sample 3) of wollastonite (a), diopside (b), calcite (c), and tiny inclusions of pyrite, Platinova-Cominco property, north of Hwy. 7, Marmora Township. Scale bar indicates 1 mm.

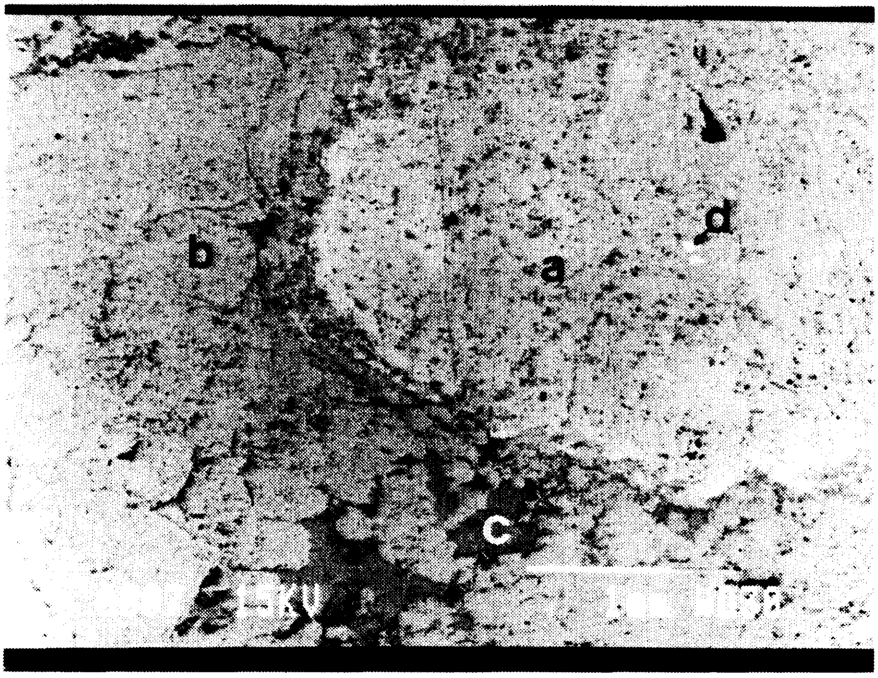

PHOTO 2. SEM backscattered images (sample 3) of a large garnet (a) (top right) with a brighter rim due to an increase in iron, surrounded by wollastonite (b). Calcite (c) and pyrite (d) are also present; Platinova - Cominco property, Marmora Township. Scale bar indicates 1 mm.

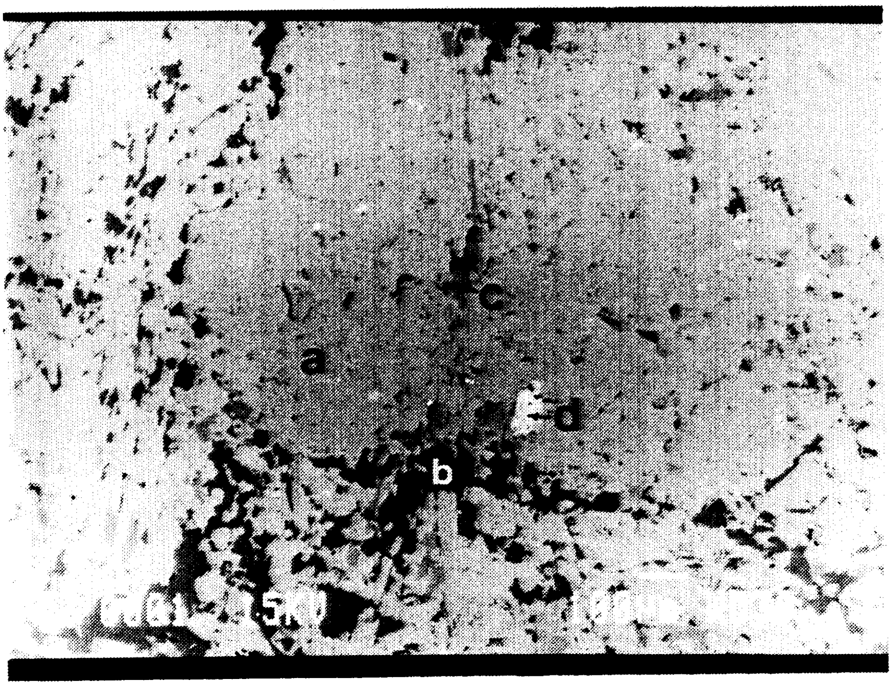

PHOTO 3. SEM backscattered image (sample 2-8-88) illustrating wollastonite (a), quartz (b), calcite (c) and barian feldspar inclusions (d), Platinova-Cominco property, Marmora Township. Scale bar indicates 100 um.

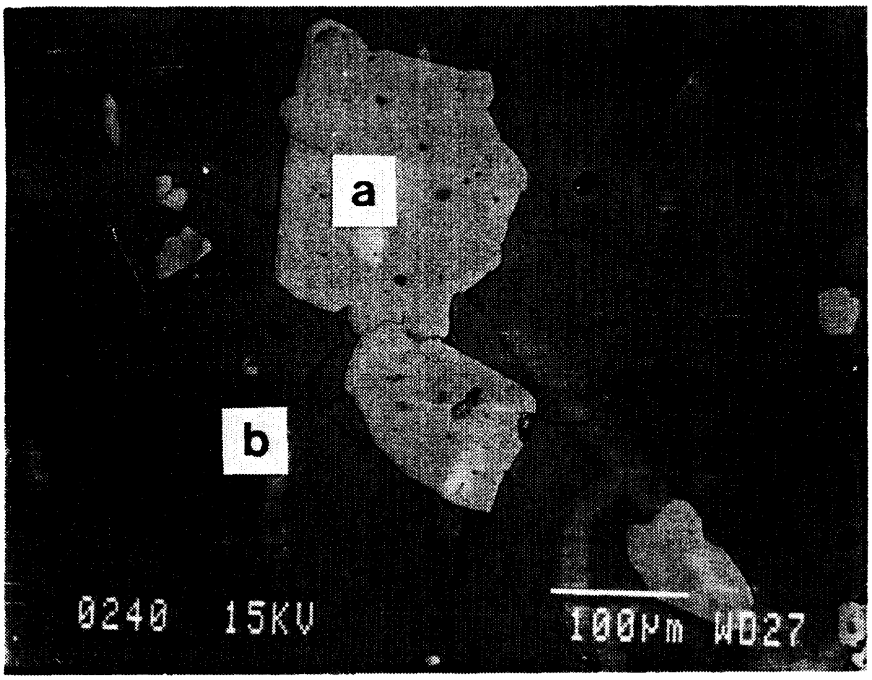

PHOTO 4. SEM backscattered electron images (sample MA-5) of wollastonite (a) and calcite (b) from the Platinova-Cominco property, Marmora Township. Scale bar indicates 100 um.

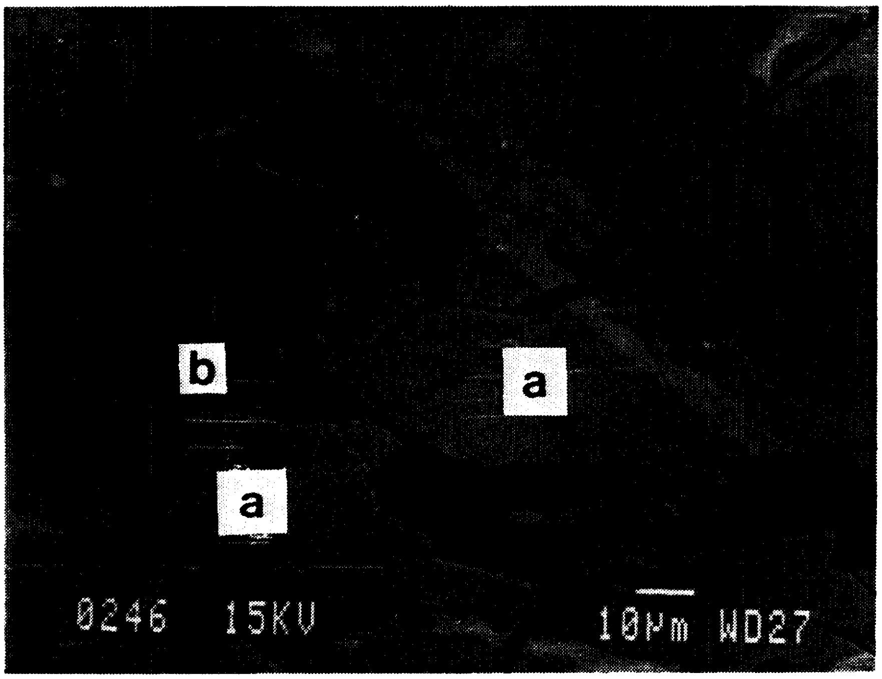

PHOTO 5. SEM backscattered electron images (sample MA-6) of wollastonite (a) and calcite (b) from the Deloro west zone, Marmora Township. Scale bar indicates 10 um.

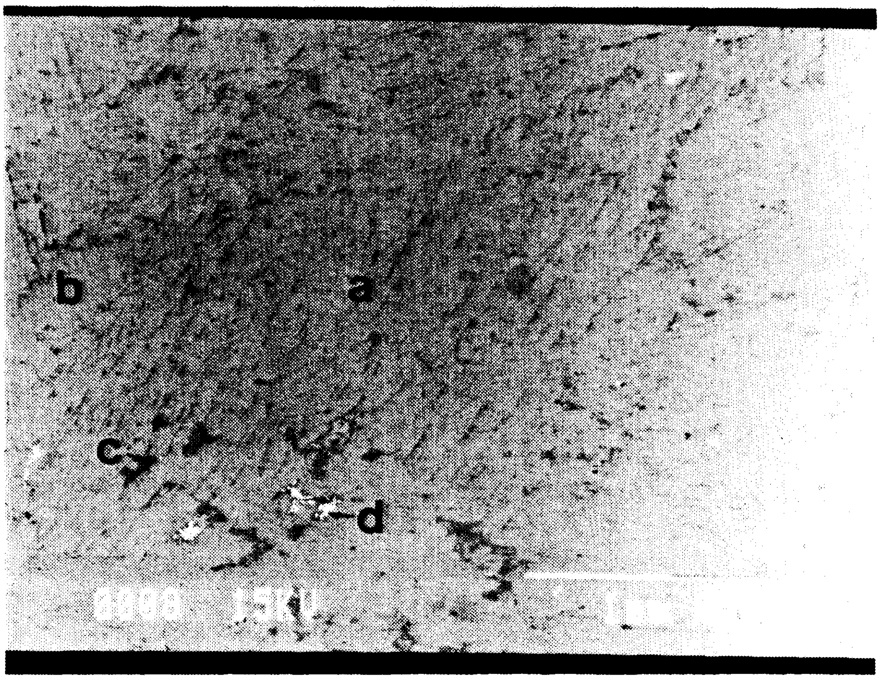

PHOTO 6. SEM backscattered images (sample 87-504b) of granoblastic wollastonite (a), minor diopside (b), quartz (c) and barite (d), Rahm property, Marmora Township. Scale bar indicates 1 mm.

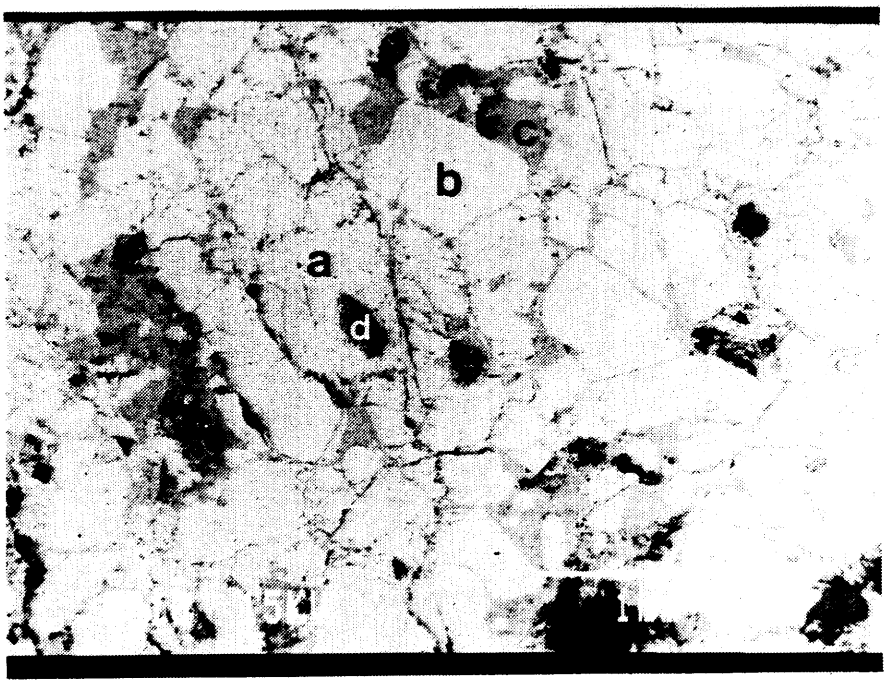

PHOTO 7. SEM backscattered image (sample 87-506b) illustrating granoblastic wollastonite (a), calcite (b), quartz (c) and diopside (d), Rahm property, Marmora Township. Scale bar indicates 1 mm.

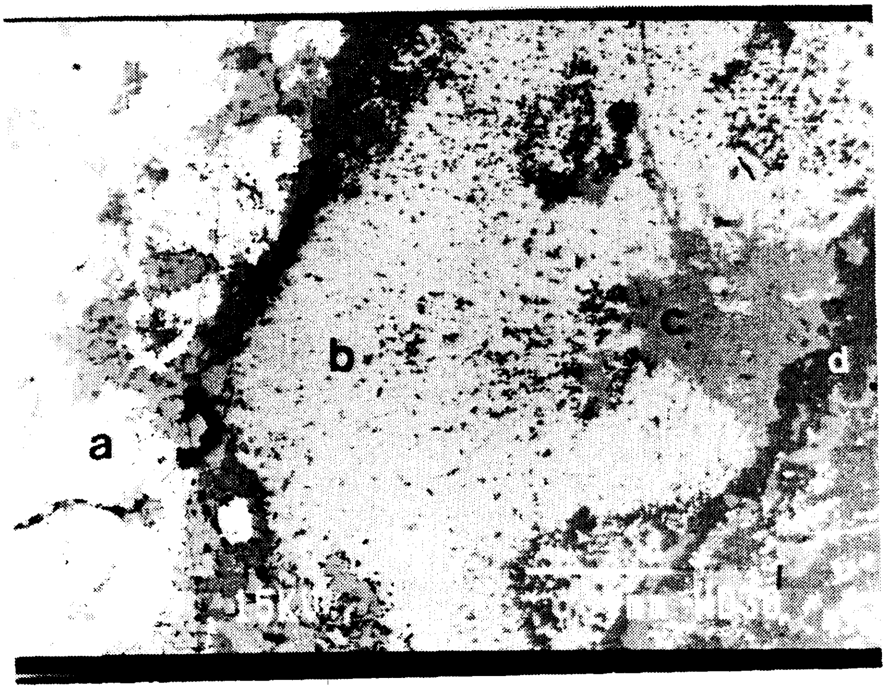

PHOTO 8. SEM backscattered image (sample 2-4-88) illustrating garnet (a) and clinopyroxene (b) containing quartz (c) and calcite (d) inclusions Kelly-Czerewko property, Marmora Township. Scale bar indicates 1 mm.

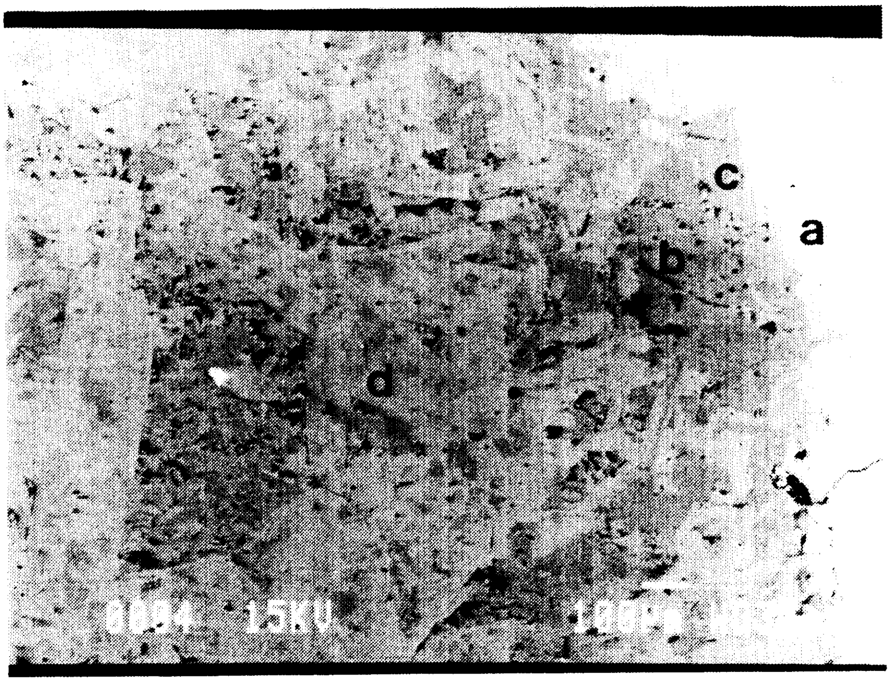

PHOTO 9. SEM backscattered image (sample 2-5-88) of garnet (a) at right, with diopside (b) rimmed to hedenbergite (c). The large prismatic crystals in the centre are amphiboles (d) and minor quartz (e) is also present, Kelly-Czerewko property, Marmora Township. Scale bar indicates 100 um.

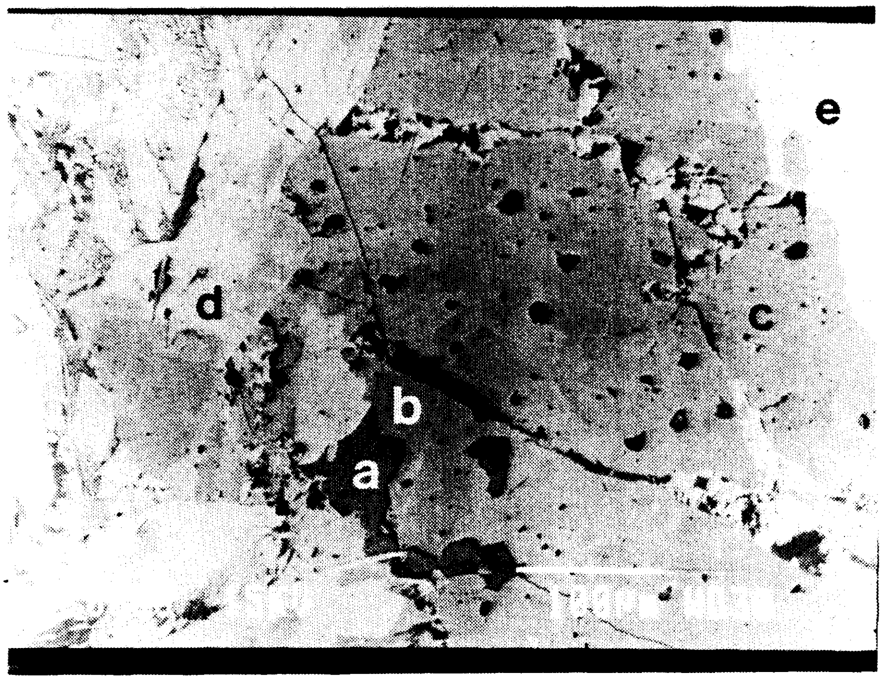

PHOTO 10. Close up of photo 9, and better illustrates the relationship of the pyroxenes which is not evident optically. The minerals present in order of increasing brightness are quartz (a), hedenbergite (b), diopside (c), amphibole (d) and garnet (e). This shows that the clinopyroxene consists of salite cores surrounded by hedenbergite rims but the boundary between diopside and hedenbergite is diffuse with many embayments, probably reflecting a gradual increase in iron content towards the edge of the crystal. The amphibole appears to be a retrograde phase containing remnants of the pyroxene which it is replacing. Scale bar indicates 100 um.

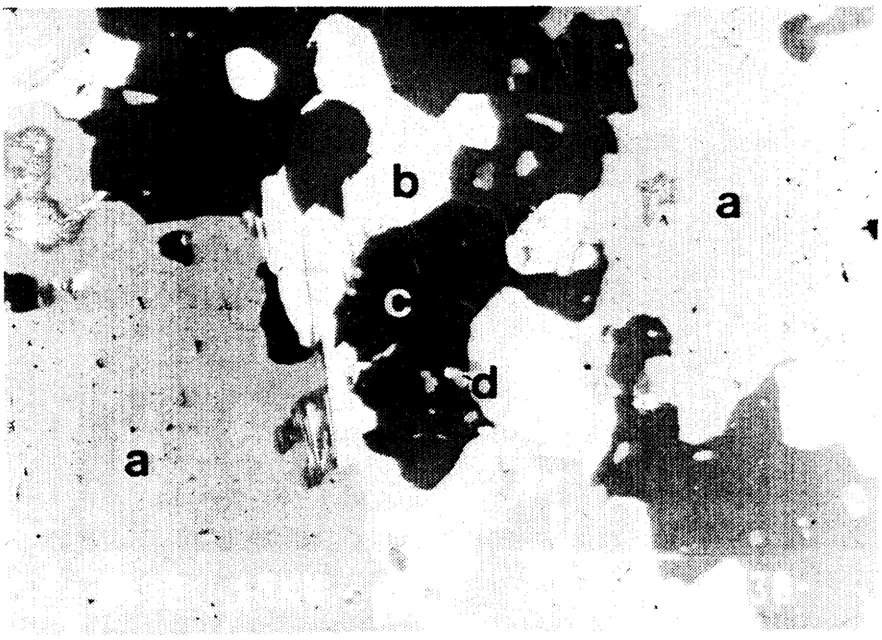

PHOTO 11. SEM backscattered image (sample 2-6-88) of manganoan hedenbergite zoned to more Fe-rich compositions (a), sphalerite (b), quartz (c), and calcite (d), Kelly-Czerewko property, Marmora Township. Scale bar indicates 100 um.

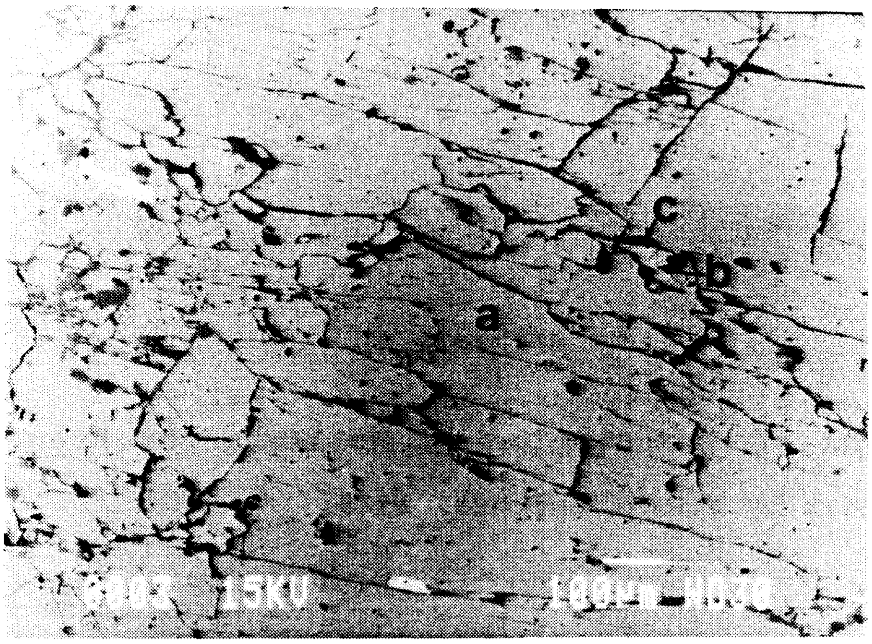

PHOTO 12. SEM backscattered image (sample MA-4) illustrating bladed wollastonite (a), minor diopside (b) and quartz (c), Kelly-Czerewko property, Marmora Township. Scale bar indicates 100 um.

APPENDIX 4

Beneficiation of Two Samples of Wollastonite From Marmora, Ontario; Report by P.R.A. Andrews, 1988.

Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

BENEFICIATION OF TWO SAMPLES OF WOLLASTONITE FROM MARMORA, ONTARIO

P.R.A. Andrews
Mineral Processing Laboratory

September 1988

Project: 30.21.02
Beneficiation of Industrial Minerals

MINERAL SCIENCES LABORATORIES
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BENEFICIATION OF TWO SAMPLES OF WOLLASTONITE FROM MARMORA, ONTARIO

by

P.R.A. Andrews*

ABSTRACT

Two samples of calcitic wollastonite analysing approximately 25% wollastonite and 70% calcite were beneficiated to produce separate calcite and wollastonite concentrates. One sample, which contained diopside was characterized by a greenish colour; the other, though white in appearance contained trace amounts of pyrite. Processing included wet and dry magnetic separation to remove diopside and other iron-oxide containing minerals. Flotation to produce separate calcite and wollastonite concentrates was attempted by two methods. Anionic sodium oleate flotation of calcite at pH 7 using between 205 and 310 g/t of collector successfully concentrated calcite to 93.7-97.5% $CaCO_3$. Concentration of wollastonite in the rougher tails was to 86-93% with 0.57-0.62% Fe_2O_3. Cationic flotation using between 75 and 100 g/t Arquad T 50 (trimethyl tallow ammonium chloride), a tertiary amine, at pH 9 successfully concentrated wollastonite to 86-89% $CaSiO_3$ with 0.33-0.82% Fe_2O_3. Further processing employing gangue depressants and reverse flotation of remaining silicates should further concentrate calcite and wollastonite.

Keywords: Calcite, wollastonite, magnetic separation, anionic and cationic flotation

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ENRICHISSEMENT DE DEUX ECHANTILLONS DE WOLLASTONITE DE MARMORA, ONTARIO

par

P.R.A. Andrews*

RESUME

Deux échantillons de wollastonite calcitique titrant environ 25 % de wollastonite et 70 % de calcite ont été enrichis en concentrés séparés de calcite et de wollastonite. Un échantillon contenant de la diopside était caractérisé par une couleur verdâtre: l'autre, quoique blanc en apparence, contenait des traces de pyrite. Le traitement a consisté en une séparation magnétique en milieux sec et humide visant à éliminer la diopside et d'autres minéraux contenant des oxydes de fer. On a essayé deux méthodes de flottation pour produire des concentrés séparés de calcite et de wollastonite. La flottation anionique à l'oléate de sodium de la calcite, à ph 7, avec des teneurs en collecteur de 205 à 310 g/t a permis de réaliser un concentré de calcite contenant entre 93,7 et 97,5 % de $CaCO_3$. La wollastonite dans les produits de queue des cellules dégrossisseuses avait une concentration de 86 à 93 % avec de 0,57 à 0,62 % de Fe_2O_3. La flottation cationique à raison de 75 à 100 g/t d'Arquad T 50 (chlorure de triméthylammonium suifeux), une amine tertiaire, à pH 9, a permis de concentrer la wollastonite à 86-89 % de $CaSiO_3$ avec de 0,33 à 0,83 % de Fe_2O_3. Un traitement additionnel avec des déprimants de gangue et une flottation inverse des silicates résiduels devraient permettre de concentrer davantage la calcite et la wollastonite.

Mots clés: calcite, wollastonite, séparation magnétique, flottation anionique et cationique

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INTRODUCTION

In February 1987 two samples of calcitic wollastonite-bearing marble, each weighing approximately 80 kg, were received from the Ministry of Northern Development and Mines. These samples, white and green in appearance, were collected from two distinct geological zones and are considered to be representative of the deposit. The location of the deposit is 5 km east of Marmora, Ontario. Each variety of wollastonite is referred to by the colour phase, but to avoid unnecessary repetition each variety is also referred to by the colour letter.

e.g., Green-phase wollastonite - Sample G
White-phase wollastonite - Sample W.

SAMPLE DESCRIPTION

White-Phase Wollastonite

Sample W is a white-grey fine-grained calcitic marble containing fine-grained subhedral nematoblastic crystals of white wollastonite. Trace amounts of sulphides, principally pyrite, are disseminated throughout the skarn.

Green-Phase Wollastonite

Sample G is a light green fine-grained calcitic wollastonite bearing marble containing fine-grained subhedral nematoblastic crystals of white wollastonite. Minor associated mineralization includes trace amounts of sulphides, principally pyrite, disseminated throughout the sample with preferred association within calcitic grains.

The presence of approximately 2% diopside as finely dispersed encapsulated grains, 100 to 200 µm in size, in the aggregate crystals of wollastonite imparts the greenish appearance. The green zone also is more highly crystallized, which is apparent when data obtained from X-ray diffraction of the white and green-phase varieties are compared. A more pronounced peak with the green-phase variety indicates a higher degree of crystallization.

SIZE REDUCTION

Both Sample G and W were stage-crushed using a combination of large and small jaw crushers to approximately 6 mm. Further comminution was conducted on a 20 kg riffled portion of each sample; the remaining portion of each was stored. After reduction to 2.4 mm using a laboratory roll crusher a head sample was prepared from Sample G and W crushed material.

HEAD SAMPLE

White-Phase Wollastonite

A representative 200 g portion for size analysis was wet and dry screened and results are reported in Table 1. Each size fraction was examined by optical microscopy to determine mineral association and wollastonite liberation size; results are reported in Table 2. The approximate mineral composition was calcite 70% and wollastonite 25-30% with trace amounts of pyrite and iron oxide minerals.

Green-Phase Wollastonite

A representative 200 g portion for size analysis was wet and dry screened and results are reported in Table 1. Each size fraction was examined by optical microscopy to determine mineral association and wollastonite liberation size; results are reported in Table 3. The approximate mineral composition was calcite 70%, wollastonite 25%, the remaining 5% accounting for diopside, other silicate minerals, trace amounts of pyrite and iron oxide minerals.

PROCESSING

Secondary Crushing

The results of optical microscopy on each phase variety of wollastonite indicated that the liberation size was 420 μm, so that each 20 kg portion was stage-crushed to 420 μm using a laboratory roll crusher. After crushing, each sample was dry screened at 150 μm.

Magnetic Separation

Wet and dry magnetic separation to remove diopside, etc., was conducted on Sample G and W sized products (-420 +150 µm and -150 µm). Dry magnetic separation was conducted on -420 +150 µm material using a perm-roll separator, and wet magnetic separation on -150 µm material using a Jones high intensity separator; results are reported in Table 4.

Flotation

Wollastonite was concentrated by two techniques: flotation of calcite from wollastonite and other silicates, and flotation of wollastonite from calcite and other silicates. The former method employed sodium oleate as a collector for calcite, and the latter method the quarternary amine collector Arquad T 50 (trimethyl tallow ammonium chloride) as collector for wollastonite.

Preliminary testwork to establish optimum parameter conditions was conducted with the -420 +150 µm fraction of Sample G using the calcite flotation technique. Flotation was initially conducted on unground -420 +150 µm material; results are reported in Table 5. The influence of variable grind size on flotation performance at constant pH and collector concentration is summarized by the results in Table 6. The results of the combined effect of variable grind size and collector concentration at constant pH are presented in Table 7. Two further series of tests were conducted using the wollastonite flotation method. The results in Table 8 demonstrate the influence of variable collector concentration on wollastonite flotation performance at constant pH and grind size, and the results in Table 9 investigated the influence of variable grind size at constant pH and collector concentration.

The -150 µm portion of Sample G was treated separately and the results of testwork using the calcite flotation technique are reported in Tables 10 to 12. The results in Table 10 indicate the influence of variable collector concentration at constant pH and grind size. The results in Table 11 indicate the influence of variable pH at constant collector concentration and grind size. The results in Table 12 indicate the effect of variable grind size at constant pH and collector concentration. Two series of tests were conducted using the Arquad T 50 method. The results in

Table 13 indicate the influence of variable collector concentration at constant pH and grind size. The results in Table 14 indicate the influence of variable grind size at constant pH and collector concentration.

Remaining testwork was conducted with Sample W. The influence of variable collector concentration at constant pH and grind size using -420 +150 µm material was investigated by the calcite flotation method with results reported in Table 15, and by the wollastonite flotation method with results reported in Table 16. The influence of variable grind size at constant pH and collector concentration also was investigated by each flotation method. Results obtained with the sodium oleate method are reported in Table 17 and with the Arquad T 50 method in Table 18.

The -150 µm portion of Sample W was treated separately. The effect of variable collector concentration at constant pH and grind size was investigated using each collector system. The results obtained with sodium oleate are reported in Table 19, and the results with Arquad T 50 in Table 20. The influence of variable grind size at constant pH and collector concentration was also investigated for each collector system. The results obtained with sodium oleate are reported in Table 21, and the results obtained with Arquad T 50, in Table 22. Flotation parameter and reagent concentration data for each sample at each size fraction are presented in Tables 23 to 26.

RESULTS

Evaluation of testwork results was based on analytical data, specifically Fe_2O_3, LOI and acid soluble. The acid soluble analysis was interpreted as per cent calcite, since calcite was the only carbonate mineral detected. The acid soluble analyses for products high in wollastonite were omitted because of suspected interference from decomposed wollastonite giving erroneously high acid soluble analyses. The acid soluble technique involved heating products with concentrated HCl prior to dilution, and it is known that wollastonite gelatinises in concentrated HCl.

The grade of wollastonite was inferred from the LOI analysis. Selected high-grade wollastonite concentrates were subjected to a staining technique using alizarin red dye which preferentially stains calcite pink leaving wollastonite unstained. The estimated calcite content of wollastonite concentrates approximately equalled the LOI analysis as indicated by the following results.

Product	% Wollastonite	% Calcite	% LOI
Test 10 final concentrate	85 to 90	10 to 15	4.44
Test 12 final concentrate	80 to 85	15 to 20	8.33

Magnetic Separation

The iron oxide rejection for Sample G was approximately 50% in the -420 +150 µm fraction, and correspondingly higher at approximately 80% in the -150 µm fraction. When considering Sample W, the iron oxide rejection was less efficient; for the -420 +150 µm fraction only 3.1% was rejected and for the -150 µm fraction only 21.4% was rejected. These results are consistent with the more efficient removal of diopside from Sample G than the removal of non-magnetic pyrite from Sample W.

Flotation

Sample G: -420 +150 µm

The results of Tests 1 to 3 in Table 5 demonstrate that high-grade calcite, >94% $CaCO_3$ can be obtained on unground material at pH 7.0 using between 305 and 410 g/t sodium oleate. Wollastonite was concentrated in the rougher tailings up to approximately 85% in Tests 1 and 2.

The influence of increasing fineness of grind on flotation performance was demonstrated by the results in Table 6. By increasing the -75 µm portion from 13.5% to 43.5% by weight, and maintaining the pH at 7.0 and sodium oleate concentration at 310 g/t, the grade of calcite concentrate was increased from 94.52% $CaCO_3$ in Test 4 to 97.51% $CaCO_3$ in Test 7. Brightness values increased correspondingly from 67.2% in Test 4 to 77.9% in Test 7. Wollastonite grade was similarly increased, by increasing the fineness of grind, from approximately 85% in Test 4 to 93% in Test 7 as indicated by the LOI analyses. Brightness values were similarly increased from 62.7% in Test 4 to 68.5% in Test 7. Weight recovery of both calcite at approximately

65% and wollastonite at approximately 26% appears to be independent of fineness of grind.

The results in Table 7 demonstrate the influence of increasing collector concentration at two different levels of fineness of grind. By maintaining a grind of 19.0% -75 µm by weight, pH constant at 7.0, and increasing the sodium oleate concentration from 310 to 420 g/t, there was a slight increase in calcite concentrate grade from 92.3% $CaCO_3$ in Test 5 to 93.6% $CaCO_3$ in Test 8. The wollastonite grade in the rougher tails was increased from approximately 85% in Test 5 to 89% in Test 8 as indicated by LOI analyses. At a finer grind of 43.5% -75 µm by weight and repeating the same test conditions, a decrease in calcite grade from 97.5% $CaCO_3$ for Test 7 to 95.0% $CaCO_3$ for Test 9 was noted. The wollastonite grade in the rougher tails of Tests 7 and 9 remained virtually unchanged. By increasing the collector concentration, at each grind size, there was a slight increase in weight recovery of calcite and a slight decrease in weight recovery of wollastonite.

Preliminary testwork with the quarternary amine collector Arquad T 50 indicated that wollastonite could be floated from calcite. The results in Table 8 demonstrate the influence of increasing collector concentration from 50 g/t to 100 g/t at pH 9.0 and a grind of 13.5% -75 µm. The best grade of wollastonite concentrate at approximately 88% was obtained in Test 10 which employed the least amount of collector. In Test 12 calcite concentration to >93% $CaCO_3$ was obtained in the rougher tails. Weight recovery of wollastonite increased and weight recovery of calcite decreased with increasing collector concentration. The results in Table 9 demonstrate the effect of increasing grind size from 13.5% -75 µm to 43.5% -75 µm on wollastonite grade, at pH 9.0 with 75 g/t of collector. Wollastonite grade increased from approximately 83% in Test 11 to approximately 87% in Test 15. Increased grind size had very little effect on calcite grade but calcite (LOI) recovery increased from 87.1% in Test 11 to 92.7% in Test 15. Increasing the fineness of grind also significantly increased the brightness of both wollastonite and calcite concentrates.

Sample G: -150 µm

Two series of tests were conducted using sodium oleate collector: variable collector concentration at constant pH and grind size, and variable pH at constant collector concentration and grind size. The results in Table 10 indicate that by increasing collector concentration calcite concentrate grade is slightly decreased, although weight recovery remains independent of increasing collector concentration between 310 and 420 g/t. Wollastonite concentration appears best at 365 g/t (Test 17) where approximately 93% wollastonite was obtained at a weight recovery of 31%. Brightness values for both calcite and wollastonite concentrates regardless of test conditions were approximately equal at 73%.

The influence of variable pH (Table 11) on flotation of calcite, between pH 7 and 9 at a sodium oleate concentration of 310 g/t results in a slight decrease in calcite grade with increasing pH. Weight recovery remained unchanged with increasing pH. Wollastonite recovery is more influenced by an increase in pH such that the weight recovery decreases from 33.4% at pH 7 (Test 16) to 23.5% at pH 9 (Test 20). Conversely the grade increased from approximately 92% in Test 16 to approximately 94% for Test 20. Brightness values for each mineral were approximately equal at 73%, although there was a very slight increase in brightness for both calcite and wollastonite concentrates with increasing pH. The effect of increasing grind size (Table 12) indicates a negative effect on wollastonite grade and calcite recovery. Calcite grade and brightness values were, however, significantly increased from 96.4% $CaCO_3$ and brightness 73% in Test 16 to 99.0% $CaCO_3$ and brightness 86.2% in Test 22.

When using Arquad T 50, the results in Table 13 show the effect of increasing collector concentration while maintaining pH and grind size constant. Weight recovery of wollastonite increased from 27.9% for 75 g/t of collector (Test 23) to 38.3% for 130 g/t of collector (Test 25); there was a corresponding decrease in grade from approximately 90% to 86%. Conversely calcite weight recovery in the rougher tails decreased from 65.1% in Test 23 to 52.9% in Test 25. At the same time calcite grade increased from 84.4% $CaCO_3$ in Test 23 to 96.4% $CaCO_3$ in Test 25. Brightness values for both calcite and wollastonite concentrates regardless of test conditions were approximately 70% for wollastonite and 74% for calcite. The influence of increasing fineness of grind (Table 14) indicated a negative effect on both calcite and wollastonite grade; weight recovery of each was independent of increasing fineness of grind.

Sample W: -420 +150 µm

Four tests were conducted using variable additions of sodium oleate at pH 7 and a grind of 23.4% -75 µm. The results of these tests in Table 15 indicate that the best results for both calcite and wollastonite concentration were obtained with the least quantity of collector, 205 g/t. When using 205 g/t sodium oleate (Test 28), a calcite concentrate with a 64.6% weight recovery and 93.66% $CaCO_3$ grade was obtained. Increasing the quantity of collector above 205 g/t had a detrimental effect on calcite weight recovery and wollastonite grade. The concentration of wollastonite in the rougher tails was approximately 86% when using 205 g/t collector. Brightness values for Test 28 were 83.5% for the calcite concentrate and 72.5% for the wollastonite concentrate.

Testwork was conducted with variable additions of Arquad T 50 collector at a grind of 23.4% -75 µm and a pH of 7.0. In Table 16 the best results for calcite and wollastonite flotation were obtained using 75 g/t of collector (Test 33). The wollastonite concentrate analyzed approximately 86% with a weight recovery of 23%, and the concentration of calcite in the rougher tails was 91.3% $CaCO_3$ for a weight recovery of 67.2%. Brightness values for Test 33 were 83.6% for the calcite concentrate and 70.7% for the wollastonite concentrate.

The effect of increasing fineness of grind on calcite and wollastonite flotation performance, using sodium oleate collector, is shown by the results in Table 17. By increasing the fineness of grind from 23.4% -75 µm in Test 28 to 38.3% -75 µm in Test 36, calcite grade was increased from 93.66% $CaCO_3$ to 97.24% $CaCO_3$. Weight recovery decreased from 64.6% to 49.6%. Wollastonite concentration decreased with increasing fineness of grind from approximately 86% in Test 28 to approximately 78% in Test 36. When using Arquad T 50 collector, the effect of increasing fineness on calcite and wollastonite flotation (Table 18) was not significant for either grade or weight recovery.

Sample W: -150 µm

Testwork conducted with variable concentration levels of sodium oleate at pH 7.0 indicated that 305 g/t of collector (Test 41) gave the best results. The product balance of Test 41 in Table 19 indicated that a calcite concentrate analyzing 95.48% $CaCO_3$ with a weight recovery of 73.2% and brightness value of 76.9% could be obtained. The concentration of wollastonite in the rougher tails was approximately 88% wollastonite with a weight recovery of 23.2% and a brightness value of 71.3%.

When assessing the effect of variable concentration of Arquad T 50 at pH 7.0 on calcite and wollastonite flotation, the results in Table 20 suggest that Test 43 conditions were the best compromise between weight recovery and grade of wollastonite. A grade of approximately 80% wollastonite with a 29.2% weight recovery and a brightness value of 68.9% was obtained. The concentration of calcite in the rougher tails of Test 43 was 97.22% $CaCO_3$, with a weight recovery of 60.4% and a brightness value of 84.2%. Although Test 42 produced the highest grade of wollastonite at approximately 92%, the lowest weight recovery was obtained. Similarly, Test 44 produced the lowest grade but the highest weight recovery.

The effect of increasing fineness of grind on calcite and wollastonite flotation performance using sodium oleate collector is shown by the results in Table 21. The best grade and weight recovery combination for calcite was Test 45, where a concentrate analyzing 98.29% $CaCO_3$ at 64.5% weight recovery and brightness value of 82.6% was obtained. Increasing fineness of grind above 75.9% -75 µm resulted in a detrimental effect on calcite flotation. The best results for wollastonite flotation were obtained at a coarser grind of 64.9% -75 µm, Test 41, where wollastonite grade in the rougher tails was approximately 89% and brightness 71.3%. When using Arquad T 50 collector, wollastonite grade increased from approximately 80% in Test 43 at 64.9% -75 µm to approximately 86% in Test 50 at 90.1% -75 µm (Table 22). Weight recovery decreased from 29.2% in Test 43 to 19.6% in Test 50. Increasing fineness of grind reduced calcite grade from 97.22% $CaCO_3$ in Test 43 to 90.44% $CaCO_3$ in Test 50. Brightness values for wollastonite and calcite concentrates were not significantly altered by increasing fineness of grind.

COMMENTS

Wollastonite as a commercial product for ceramic, metallurgical flux, filler and coating applications should be at least 90% wollastonite with less than 1% LOI and less than 1% Fe_2O_3 (Power, 1980). In general, each variety of wollastonite met the minimum wollastonite grade and iron oxide requirements, although the white variety was slightly below the 90% wollastonite specification; the LOI analysis for each variety, however, was greater than 1%. Further processing including magnetic separation and reverse flotation of the remaining silicate minerals should reduce the LOI and Fe_2O_3 levels and increase the wollastonite grade.

Calcite is used mainly in paper, plastics and paint where the criteria for use is brightness, which should be 85% or more. Chemical analysis reports a minimum of 92.5% $CaCO_3$ for dry ground and 95.9% for wet ground calcite (North, 1983). Calcite produced by the oleate flotation technique generally met chemical grade requirements but brightness was less than 85%. Further processing including magnetic separation and gangue depressant addition in flotation should improve both grade and brightness.

PHYSICO-CHEMICAL CONSIDERATIONS

Surface Charge

Calcite is classified as a salt-type mineral and as such surface dissolution occurs as hydrolysis and complex formation reactions. A number of chemical species are produced, some of which according to Samasundaran and Agar (1967) are potential determining: H_2CO_3, HCO_3^-, CO_3^{2-}, Ca^{2+}, $CaHCO_3^+$, $CaOH^+$ and $Ca(OH)_2(aq.)$. Consequently, when calcite is in equilibrium with an aqueous phase at high pH values HCO_3^- and CO_3^{2-} will exist whereas, at lower pH values Ca^{2+}, $CaHCO_3^+$ and $CaOH^+$ species will occur. The point of zero charge of calcite at 8.2 was obtained by the same investigators, and zeta potential was observed to increase in magnitude on each side of the z.p.c.

Wollastonite, $CaSiO_3$ or calcium metasilicate, is classified as a pyroxene typified by the metasilicate single chain. Very little information is available concerning the electrokinetic behaviour of wollastonite and the z.p.c. is not reported in the chemical literature. It is reasonable to suppose that wollastonite would be chemically similar to other pyroxene minerals, such as enstatite, diopside and augite; the z.p.c.'s of these minerals being in the range 2.8 to 3.8 (Fuerstenau, D.W. and Fuerstenau, M.C., 1982). Further evidence that the z.p.c. of wollastonite might be in this range is indicated by the very large flotation area between pH 3 to 12 when using the cationic collector dodecylamine, and the absence of flotation when using anionic sodium oleate collector (Manser, 1973). Such response to flotation by a cationic collector could be explained by electrostatic attraction in an area of negative surface charge. The mechanism by which wollastonite acquires a surface charge would be by ionization of surface Ca^{2+} ions and hydrolysis of exposed Si ions. In aqueous media, exposed silicon ions can be considered as forming a surface silicic acid, the dissociation of which results in a negative surface charge.

Adsorption

Data obtained by Klassen and Mokrousov, 1963 indicates that there is no direct correlation between the solubility of calcite and calcium oleate, and the amount of adsorbed oleate on calcite surfaces. Such observations indicates that oleate adsorption is more complex than simple ion-exchange mechanisms. The adsorption of oleate on calcite is suggested to be by electrostatic forces below the z.p.c. where calcite is positively charged, and by the chemical forces above the z.p.c. where calcite is negatively charged (Samasundaran, 1969; Mishra, 1982).

Adsorption data for wollastonite is limited and can only be inferred from experimental observations. Thus, the absence of flotation using sodium oleate collector (Manser, 1973) is anomalous; it would be expected to be self-activating in anionic flotation because of the relatively large portion of calcium ions present. Electrostatic or Coulombic forces are suspected because of the larger pH range over which flotation is obtained using cationic dodecylamine collector.

Calcite-Wollastonite Separation

The selective flotation of calcite from wollastonite using anionic sodium oleate can be explained in terms of surface potentials. At pH 7 oleate ions are adsorbed on positively charged calcite surfaces, rather than negatively charged wollastonite surfaces. It is interesting to note that possible ionized silicic acid from wollastonite does not depress calcite. Mishra (1982) found that at pH 8 sodium metasilicate did not depress calcite whereas electrokinetic data indicated adsorption of silicate species on calcite. This behaviour was attributed to the preferential adsorption of oleate ions at the positively charged calcite surface.

Wollastonite flotation at pH 9 can similarly be explained by surface potentials; cationic flotation of wollastonite with Arquad T 50 occurred in a region of negative surface charge for wollastonite. Calcite is unresponsive to quarternary amines thus, wollastonite can be selectively floated from calcite.

CONCLUSIONS

Calcite and wollastonite were successfully concentrated by each flotation technique: anionic sodium oleate flotation of calcite from wollastonite, and cationic Arquad T 50 flotation of wollastonite from calcite.

The best results with each collector system for each sample at each size fraction tested are summarized as follows:

Sample	Size µm	Collector system	Test No.	Calcite conc % $CaCO_3$	Wollastonite % Woll.	Conc % Fe_2O_3
G	+150	Oleate	7	97.5	93	0.62
G	-150	Oleate	17	95.4	93	0.14
G	+150	Arquad T 50	15	90.3	87	0.60
G	-150	Arquad T 50	26	91.0	89	0.33
W	+150	Oleate	28	93.7	86	0.57
W	-150	Oleate	41	95.5	88	0.51
W	+150	Arquad T 50	37	91.5	87	0.91
W	-150	Arquad T 50	49	94.7	86	0.82

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Table 1. Head sieve analyses

Size fraction µm	White phase % wt	Green phase % wt
+2400	0.1	-
-2400 +1200	6.0	16.4
-1200 +600	27.0	25.4
-600 +300	21.4	18.2
-300 +210	9.6	8.2
-210 +150	7.3	6.2
-150	28.6	25.6
TOTAL	100.0	100.0

Table 2. Optical examination of sized fractions of white-phase wollastonite

Size fraction µm	Description
-2400 +1200	- bladed wollastonite occurs as an assemblage with calcite - no separation or concentration - disseminated sulphides occur in trace amounts and are most commonly associated with the calcite
-1200 +600	- essentially the same as -2400 +1200 µm
-600 +300	- wollastonite occurs as bladed blocky subhedral crystals with encapsulated calcite grains - partial liberation - approximately 25% of the size fraction as wollastonite - low aspect ratio 2:1 to 4:1 - disseminated sulphides (pyrite) occur in trace amounts
-300 +210	- liberation was achieved; encapsulated grains of calcite, however, found in the bladed crystals of wollastonite - low aspect ratio 4:1 - approximately 25% of the size fraction as wollastonite - disseminated sulphides (pyrite) occur in trace amounts
-210 +150	- minor amounts of encapsulated grains of calcite are still present in the wollastonite crystals - blocky aggregates of the wollastonite are for the most part broken down thereby yielding a higher aspect ratio of between 8:1 and 4:1 - disseminated sulphides (pyrite) occur in trace amounts - approximately 30% of the size fraction as wollastonite
-150	- wollastonite crystals are essentially free from the calcite grains - disseminated sulphides (pyrite) occur in trace amounts - approximately 30% of the size fraction as wollastonite - aspect ratio is higher at 8:1

Table 3. Optical examination of sized fractions of green-phase wollastonite

Size fraction µm	Description
-2400 +1200	- bladed wollastonite occurs as an assemblage with calcite - coloured silicates are found throughout the sample encapsulated both in the wollastonite and calcite - disseminated sulphides (pyrite) occur in trace amounts and are most commonly associated with the calcite - encapsulated calcite may be found in the wollastonite crystals
-1200 +600	- essentially the same as -2400 +1200 µm - pyrite occurring in subhedral-euhedral modified octohedran cubes in trace amounts - approximately 15% of the size fraction as wollastonite
-600 +300	- wollastonite is partially liberated from the calcitic matrix however, there are still encapsulated diopside grains in aggregates of wollastonite - sulphide (pyrite) is liberated and found finely dispersed throughout the size fraction in trace amounts - approximately 15 to 20% of the size fraction as wollastonite
-300 +210	- liberation is essentially complete; diopside is approximately 90% liberated from the wollastonite aggregate - wollastonite aspect ratio is low between 4:1 and 2:1 - some encapsulated calcite still remains associated with the wollastonite - approximately 20 to 25% of the size fraction as wollastonite
-210 +150	- minor amounts of encapsulated grains of calcite are still present in the wollastonite crystals - blocky aggregates of the wollastonite are essentially broken down thus, resulting in a higher aspect ratio of between 8:1 and 4:1 - disseminated sulphides (pyrite) occur in trace amounts - approximately 25% of the size fraction as wollastonite
-150	- wollastonite crystals are essentially 98% liberated from any entrained calcite or diopside - aspect ratio is higher at >8:1 - disseminated sulphides are present throughout the size fraction in trace amounts - approximately 25 to 30% of the size fraction as wollastonite

Table 4. Magnetic separation test results for each wollastonite sample

Size range	Products	Wt %	Analysis %				Distribution %			
			Fe_2O_3	Al_2O_3	MgO	LOI	Fe_2O_3	Al_2O_3	MgO	LOI
-420 +150 Green phase	Magnetics	11.0	1.46	0.32	2.21	20.0	47.5	26.3	49.4	7.0
	Non magnetics	89.0	0.20	0.11	0.28	32.6	52.5	73.7	50.6	93.0
	Head (calculated)	100.0	0.34	0.13	0.49	31.2	100.0	100.0	100.0	100.0
-150 Green phase	Magnetics	8.9	4.17	0.92	9.10	7.3	74.3	33.9	90.0	2.8
	Middlings	7.1	0.38	0.24	0.44	19.8	5.5	7.0	3.4	6.0
	Non magnetics	84.0	0.12	0.17	0.07	25.5	20.2	59.1	6.6	91.2
	Head (calculated)	100.0	0.50	0.24	0.90	23.5	100.0	100.0	100.0	100.0
-420 +150 White phase	Magnetics	1.3	1.00	0.86	3.31	17.4	3.1	2.9	6.6	0.8
	Non magnetics	98.7	0.32	0.38	0.62	28.8	96.9	97.1	93.4	99.2
	Head (calculated)	100.0	0.33	0.39	0.65	28.7	100.0	100.0	100.0	100.0
-150 White phase	Magnetics	5.2	1.35	1.00	4.29	5.1	15.8	10.3	34.1	0.9
	Middlings	3.3	0.75	0.65	1.41	28.6	5.6	4.2	7.2	3.3
	Non magnetics	91.5	0.38	0.47	0.42	30.4	78.6	85.5	58.7	95.8
	Head (calculated)	100.0	0.44	0.59	1.01	29.0	100.0	100.0	100.0	100.0

Table 5. Product balances for unground green-phase wollastonite at constant pH using variable sodium oleate concentration: -420 +150 µm

Test No.	Products	Bright %	Wt %	Analysis %			Distribution %	
				Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
1	1st Rgh. float	66.9	2.9	0.13	41.3	96.3	1.8	3.8
	2nd Rgh. float	68.2	1.3	0.13	40.2	94.5	0.9	1.7
	3rd Rgh. float	63.8	3.4	0.13	41.1	95.4	1.8	4.5
	4th Rgh. float	68.3	11.4	0.13	41.1	95.6	6.7	15.1
	5th Rgh. float	65.2	16.4	0.14	39.4	94.4	10.4	20.8
	6th Rgh. float	61.9	18.4	0.21	39.0	92.9	17.6	23.0
	7th Rgh. float	59.0	17.6	0.27	35.8	88.7	21.6	20.2
	8th Rgh. float	55.7	6.0	0.40	32.8	-	10.8	6.3
	Rgh. tails	59.3	22.6	0.28	6.4	-	28.4	4.6
	Head (calculated)	-	100.0	0.22	31.1	74.1	100.0	100.0
2	Final conc.	62.9	68.9	0.20	39.9	94.1	58.5	90.8
	2nd cleaner tails	-	6.0	0.30	15.0	-	7.6	3.0
	1st cleaner tails	-	5.1	0.28	14.0	-	5.9	2.4
	Rgh. tails	59.4	20.0	0.33	5.8	-	28.0	3.8
	Head (calculated)	-	100.0	0.24	30.3	72.0	100.0	100.0
3	Final conc.	64.9	48.5	0.14	40.7	95.9	30.6	67.3
	2nd cleaner tails	-	10.3	0.20	37.6	92.2	9.5	13.2
	1st cleaner tails	-	12.5	0.24	20.0	-	13.5	8.5
	Rgh. tails	58.8	28.7	0.36	11.2	-	46.4	11.0
	Head (calculated)	-	100.0	0.22	29.3	69.8	100.0	100.0

Table 6. Product balances for green-phase wollastonite ground to different sizes with constant pH and sodium oleate collector concentration: -420 +150 µm

Test No.	Products	Size % -75 µm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
4	Final conc.	13.5	67.2	65.9	0.19	39.4	94.5	51.2	88.5
	2nd Cleaner tails		-	2.7	0.25	30.6	-	2.9	2.8
	1st Cleaner tails		-	3.8	0.33	20.6	-	5.3	2.7
	Rgh. tails		62.7	27.6	0.36	6.4	-	40.6	6.0
	Head (calculated)		-	100.0	0.24	29.4	71.8	100.0	100.0
5	Final conc.	19.0	71.0	66.6	0.14	38.8	92.3	33.9	91.2
	2nd Cleaner tails		-	2.5	0.47	14.9	-	4.4	1.3
	1st Cleaner tails		-	2.6	0.42	18.0	-	4.0	1.7
	Rgh. tails		64.0	28.3	0.56	5.8	-	57.7	5.8
	Head (calculated)		-	100.0	0.27	28.3	67.4	100.0	100.0
6	Final conc.	28.3	74.0	65.9	0.10	41.3	96.2	26.3	91.4
	2nd Cleaner tails		-	1.1	0.30	20.1	-	1.2	0.7
	1st Cleaner tails		-	6.3	0.51	18.2	-	12.7	3.9
	Rgh. tails		65.0	26.7	0.56	4.4	-	59.8	4.0
	Head (calculated)		-	100.0	0.25	29.8	70.8	100.0	100.0
7	Final conc.	43.5	77.9	62.2	0.08	41.9	97.5	19.6	87.2
	2nd Cleaner tails		-	2.2	0.29	31.3	-	2.4	2.3
	1st Cleaner tails		-	11.1	0.42	24.3	-	18.4	9.0
	Rgh. tails		68.5	24.5	0.62	1.9	-	59.6	1.5
	Head (calculated)		-	100.0	0.26	29.9	71.1	100.0	100.0

Table 7. Product balances for ground green-phase wollastonite indicating the influence of variable size and sodium oleate collector concentration at constant pH: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
5	Final conc.	19.0	71.0	66.6	0.14	38.8	92.3	33.9	91.2
	2nd Cleaner tails		-	2.5	0.47	14.9	-	4.4	1.3
	1st Cleaner tails		-	2.6	0.42	18.0	-	4.0	1.7
	Rgh. tails		64.0	28.3	0.56	5.8	-	57.7	5.8
	Head (calculated)		-	100.0	0.27	28.3	67.4	100.0	100.0
8	Final conc.	19.0	73.3	69.1	0.16	40.2	93.6	46.3	91.9
	2nd Cleaner tails		-	2.8	0.27	23.9	-	3.3	2.2
	1st Cleaner tails		-	6.9	0.40	15.6	-	11.7	3.6
	Rgh. tails		67.0	21.2	0.44	3.3	-	38.7	2.3
	Head (calculated)		-	100.0	0.24	30.2	72.0	100.0	100.0
7	Final conc.	43.5	77.9	62.2	0.08	41.9	97.5	19.6	87.2
	2nd Cleaner tails		-	2.2	0.29	31.3	-	2.4	2.3
	1st Cleaner tails		-	11.1	0.42	24.3	-	18.4	9.0
	Rgh. tails		68.5	24.5	0.62	1.9	-	59.6	1.5
	Head (calculated)		-	100.0	0.26	29.9	71.1	100.0	100.0
9	Final conc.	43.5	77.3	70.3	0.13	40.8	95.0	34.6	95.3
	2nd Cleaner tails		-	3.3	0.54	14.2	-	6.9	1.6
	1st Cleaner tails		-	4.7	0.50	9.8	-	9.1	1.5
	Rgh. tails		69.2	21.7	0.60	2.3	-	49.4	1.6
	Head (calculated)		-	100.0	0.26	30.1	71.6	100.0	100.0

Table 8. Product balances for ground green-phase wollastonite at variable Arquad T 50 concentration while maintaining constant pH and grind size: -420 +150 µm

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
10	Final conc.	50	63.4	12.7	0.46	4.4	-	19.9	1.9
	1st Cleaner tails		-	5.7	0.38	16.1	-	7.5	3.0
	Rgh. tails		69.2	81.6	0.26	35.3	84.0	72.6	95.1
	Head (calculated)		-	100.0	0.29	30.3	72.1	100.0	100.0
11	Final conc.	75	62.6	17.7	0.46	8.1	-	33.9	4.7
	1st Cleaner tails		-	12.2	0.32	20.2	-	16.3	8.2
	Rgh. tails		68.7	70.1	0.17	37.5	89.9	49.8	87.1
	Head (calculated)		-	100.0	0.24	30.1	71.7	100.0	100.0
12	Final conc.	100	61.8	19.8	0.44	8.3	-	37.2	5.6
	1st Cleaner tails		-	14.0	0.38	18.6	-	22.8	8.6
	Rgh. tails		69.0	66.2	0.14	39.0	94.3	39.9	85.8
	Head (calculated)		-	100.0	0.23	30.0	71.5	100.0	100.0

Table 9. Product balances for ground green-phase wollastonite indicating the effect of variable grind size at constant Arquad T 50 concentration and pH: -420 +150 µm

Test No.	Products	Size % -75 µm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
11	Final conc.	13.5	62.6	17.7	0.46	8.1	-	33.9	4.7
	1st Cleaner tails		-	12.2	0.32	20.2	-	16.3	8.2
	Rgh. tails		68.7	70.1	0.17	37.5	89.9	49.8	87.1
	Head (calculated)		-	100.0	0.24	30.1	71.7	100.0	100.0
13	Final conc.	19.0	75.2	24.1	0.52	7.2	-	47.0	5.8
	1st Cleaner tails		-	3.3	0.30	23.9	-	3.8	2.7
	Rgh. tails		83.8	72.6	0.18	37.6	89.6	49.2	91.5
	Head (calculated)		-	100.0	0.27	29.8	71.0	100.0	100.0
14	Final conc.	28.3	76.3	23.7	0.55	6.5	-	49.0	5.2
	1st Cleaner tails		-	6.8	0.36	19.7	-	9.1	4.5
	Rgh. tails		84.3	69.5	0.16	38.8	92.3	41.9	90.3
	Head (calculated)		-	100.0	0.27	29.8	71.0	100.0	100.0
15	Final conc.	43.5	72.4	20.6	0.60	4.8	-	47.3	3.3
	1st Cleaner tails		-	5.5	0.36	22.1	-	7.6	4.0
	Rgh. tails		83.4	73.9	0.16	37.9	90.3	45.1	92.7
	Head (calculated)		-	100.0	0.26	30.2	72.0	100.0	100.0

Table 10. Product balances for unground (-150 µm) green-phase wollastonite indicating the influence of variable sodium oleate concentration at constant pH

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
16	Final conc.	310	73.0	59.7	0.11	41.2	96.4	50.0	93.9
	2nd Cleaner tails		-	1.8	0.30	13.9	-	3.8	1.0
	1st Cleaner tails		-	5.1	0.22	11.0	-	8.3	2.1
	Rgh. tails		72.2	33.4	0.15	2.3	-	37.9	3.0
	Head (calculated)		-	100.0	0.13	26.2	62.3	100.0	100.0
17	Final conc.	365	73.3	60.7	0.10	41.0	95.9	50.0	94.7
	2nd Cleaner tails		-	2.3	0.21	19.5	-	4.1	1.7
	1st Cleaner tails		-	5.8	0.21	6.9	-	9.8	1.5
	Rgh. tails		73.0	31.2	0.14	1.8	-	36.1	2.1
	Head (calculated)		-	100.0	0.12	26.3	62.5	100.0	100.0
18	Final conc.	420	72.4	61.3	0.11	40.3	95.1	52.8	95.0
	2nd Cleaner tails		-	2.0	0.23	12.9	-	3.9	1.0
	1st Cleaner tails		-	6.7	0.19	7.6	-	10.2	2.0
	Rgh. tails		72.7	30.0	0.14	1.8	-	33.1	2.0
	Head (calculated)		-	100.0	0.13	26.0	61.9	100.0	100.0

Table 11. Product balances for unground (-150 µm) green-phase wollastonite indicating the influence of variable pH at constant sodium oleate concentration

Test No.	Products	pH	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
16	Final conc.	7.0	73.0	59.7	0.11	41.2	96.4	50.0	93.9
	2nd Cleaner tails		-	1.8	0.30	13.9	-	3.8	1.0
	1st Cleaner tails		-	5.1	0.22	11.0	-	8.3	2.1
	Rgh. tails		72.2	33.4	0.15	2.3	-	37.9	3.0
	Head (calculated)		-	100.0	0.13	26.2	62.3	100.0	100.0
19	Final conc.	8.0	74.3	61.2	0.11	40.0	95.3	54.0	92.3
	2nd Cleaner tails		-	4.2	0.19	19.5	-	6.5	3.1
	1st Cleaner tails		-	8.4	0.18	7.3	-	12.1	2.3
	Rgh. tails		72.9	26.2	0.13	2.3	-	27.4	2.3
	Head (calculated)		-	100.0	0.12	26.5	63.1	100.0	100.0
20	Final conc.	9.0	74.0	60.3	0.10	39.5	95.1	44.8	92.0
	2nd Cleaner tails		-	5.6	0.24	14.1	-	9.7	3.1
	1st Cleaner tails		-	10.6	0.15	8.5	-	11.9	3.5
	Rgh. tails		73.2	23.5	0.19	1.6	-	33.6	1.4
	Head (calculated)		-	100.0	0.13	25.9	61.6	100.0	100.0

Table 12. Product balance for ground (-150 μm) green-phase wollastonite indicating the effect of variable grind size at constant sodium oleate concentration and pH

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
16	Final conc.	64.2	73.0	59.7	0.11	41.2	96.4	50.0	93.9
	2nd Cleaner tails		-	1.8	0.30	13.9	-	3.8	1.0
	1st Cleaner tails		-	5.1	0.22	11.0	-	8.3	2.1
	Rgh. tails		72.2	33.4	0.15	2.3	-	37.9	3.0
	Head (calculated)		-	100.0	0.13	26.2	62.3	100.0	100.0
21	Final conc.	75.0	84.3	46.4	0.08	42.2	98.8	18.2	76.5
	2nd Cleaner tails		-	4.8	0.14	52.5	-	3.5	9.8
	1st Cleaner tails		-	9.3	0.23	25.1	-	10.3	9.1
	Rgh. tails		72.5	39.5	0.35	2.9	-	68.0	4.6
	Head (calculated)		-	100.0	0.20	25.6	60.9	100.0	100.0
22	Final conc.	83.8	86.2	32.9	0.06	42.3	99.0	9.4	55.2
	2nd Cleaner tails		-	9.6	0.09	50.8	-	4.2	19.4
	1st Cleaner tails		-	13.8	0.25	28.3	-	16.4	15.5
	Rgh. tails		73.0	43.7	0.34	5.7	-	70.0	9.9
	Head (calculated)		-	100.0	0.21	25.2	59.9	100.0	100.0

Table 13. Product balance for unground (-150 μm) green-phase wollastonite at constant pH and variable Arquad T 50 concentration

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
23	Final conc.	75	70.0	27.9	0.26	2.9	-	53.2	3.3
	1st Cleaner tails		-	7.0	0.17	18.3	-	8.8	5.1
	Rgh. tails		73.8	65.1	0.08	35.5	84.4	38.0	91.6
	Head (calculated)		-	100.0	0.14	25.2	60.0	100.0	100.0
24	Final conc.	100	70.6	28.3	0.22	3.3	-	47.6	3.6
	1st Cleaner tails		-	10.3	0.18	18.9	-	14.7	7.5
	Rgh. tails		73.5	61.4	0.08	37.2	88.6	37.7	88.9
	Head (calculated)		-	100.0	0.13	25.7	61.2	100.0	100.0
25	Final conc.	130	70.0	38.3	0.27	5.5	-	69.1	8.3
	1st Cleaner tails		-	8.8	0.16	26.3	-	9.4	9.1
	Rgh. tails		73.3	52.9	0.06	39.8	96.4	21.5	82.6
	Head (calculated)		-	100.0	0.15	25.5	60.6	100.0	100.0

Table 14. Product balance for ground (-150 µm) green-phase wollastonite indicating the effect of variable grind size at constant Arquad T 50 concentration and pH

Test No.	Products	Size % -75 µm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
24	Final conc.	64.2	70.6	28.3	0.22	3.3	-	47.6	3.6
	1st Cleaner tails		-	10.3	0.18	18.9	-	14.7	7.5
	Rgh. tails		73.5	61.4	0.08	37.2	88.6	37.7	88.9
	Head (calculated)		-	100.0	0.13	25.7	61.2	100.0	100.0
26	Final conc.	75.0	74.3	33.0	0.33	3.8	-	54.5	5.3
	1st Cleaner tails		-	18.4	0.28	21.4	-	26.0	16.6
	Rgh. tails		79.3	48.6	0.08	38.2	91.0	19.5	78.1
	Head (calculated)		-	100.0	0.20	23.8	56.6	100.0	100.0
27	Final conc.	83.8	75.2	26.7	0.23	4.8	-	36.5	5.0
	1st Cleaner tails		-	12.9	0.26	18.4	-	20.4	9.2
	Rgh. tails		74.3	60.4	0.12	36.7	87.4	43.1	85.8
	Head (calculated)		-	100.0	0.17	25.8	61.5	100.0	100.0

Table 15. Product balance for ground white-phase wollastonite at variable sodium oleate concentration while maintaining constant pH and grind size: -420 +150 µm

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
28	Final conc.	205	83.5	64.6	0.26	39.7	93.7	47.2	90.9
	1st Cleaner tails		-	5.4	0.32	16.0	-	4.8	3.1
	Rgh. tails		72.5	30.0	0.57	5.7	-	48.0	6.0
	Head (calculated)		-	100.0	0.36	28.2	67.1	100.0	100.0
29	Final conc.	260	79.8	59.5	0.29	39.4	93.8	51.6	86.2
	1st Cleaner tails		-	8.6	0.32	20.7	-	8.4	6.6
	Rgh. tails		75.8	31.9	0.42	6.1	-	40.0	7.2
	Head (calculated)		-	100.0	0.34	27.2	64.7	100.0	100.0
30	Final conc.	305	79.0	29.7	0.14	40.8	97.1	12.9	54.6
	1st Cleaner tails		-	3.1	0.24	22.6	-	2.2	3.2
	Rgh. tails		70.1	67.2	0.41	14.0	-	84.9	42.2
	Head (calculated)		-	100.0	0.32	22.2	52.8	100.0	100.0
31	Final conc.	360	82.5	48.1	0.25	40.4	96.2	32.4	76.9
	1st Cleaner tails		-	7.0	0.35	22.1	-	6.8	6.1
	Rgh. tails		75.0	44.9	0.50	9.6	-	60.8	17.0
	Head (calculated)		-	100.0	0.37	25.3	60.2	100.0	100.0

Table 16. Product balance for ground white-phase wollastonite at constant pH and grind size with variable Arquad T 50 concentration: -420 +150 μm

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
32	Final conc.	50	63.6	11.5	1.35	2.7	-	48.0	1.0
	1st Cleaner tails		-	2.9	0.49	14.2	-	4.3	1.5
	Rgh. tails		83.2	85.6	0.18	32.2	76.6	47.7	97.5
	Head (calculated)		-	100.0	0.33	28.3	67.3	100.0	100.0
33	Final conc.	75	70.7	23.0	0.84	5.8	-	63.1	4.8
	1st Cleaner tails		-	9.8	0.40	14.3	-	12.7	4.9
	Rgh. tails		83.6	67.2	0.11	37.9	91.3	24.2	90.3
	Head (calculated)		-	100.0	0.31	28.2	67.1	100.0	100.0
34	Final conc.	100	72.5	23.4	0.79	6.2	-	47.4	5.2
	1st Cleaner tails		-	8.8	0.47	13.8	-	28.2	4.3
	Rgh. tails		83.5	67.8	0.14	37.4	89.8	24.4	90.5
	Head (calculated)		-	100.0	0.39	28.0	66.7	100.0	100.0

Table 17. Product balance for ground white-phase wollastonite indicating the effect of variable grind size at constant sodium oleate concentration and pH: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
28	Final conc.	23.4	83.5	64.6	0.26	39.7	93.7	47.2	90.9
	1st Cleaner tails		-	5.4	0.32	16.0	-	4.8	3.1
	Rgh. tails		72.5	30.0	0.57	5.7	-	48.0	6.0
	Head (calculated)		-	100.0	0.36	28.2	67.2	100.0	100.0
35	Final conc.	29.1	87.2	60.7	0.13	40.6	96.2	24.1	86.4
	1st Cleaner tails		-	6.6	0.35	23.6	-	7.0	5.5
	Rgh. tails		69.3	32.7	0.69	7.1	-	68.9	8.1
	Head (calculated)		-	100.0	0.33	28.5	67.9	100.0	100.0
36	Final conc.	38.3	85.2	49.6	0.08	41.0	97.2	12.2	71.2
	1st Cleaner tails		-	8.3	0.22	33.2	-	5.5	9.7
	Rgh. tails		71.9	42.1	0.64	13.0	-	82.3	19.1
	Head (calculated)		-	100.0	0.33	28.6	68.0	100.0	100.0

Table 18. Product balance for ground white-phase wollastonite indicating the effect of variable pH and grind size at constant Arquad T 50 concentration: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
33	Final conc.	23.4	70.7	23.0	0.84	5.8	-	63.5	4.8
	1st Cleaner tails		-	9.8	0.40	14.3	-	12.8	4.9
	Rgh. tails		83.6	67.2	0.11	37.9	91.3	23.7	90.3
	Head (calculated)		-	100.0	0.31	28.2	67.1	100.0	100.0
37	Final conc.	29.1	70.0	23.1	0.91	4.7	-	64.0	3.8
	1st Cleaner tails		-	8.1	0.43	16.2	-	10.7	4.5
	Rgh. tails		86.0	68.8	0.12	38.4	91.4	25.3	91.7
	Head (calculated)		-	100.0	0.33	28.9	68.7	100.0	100.0
38	Final conc.	38.3	73.0	25.6	0.84	5.1	-	67.8	4.7
	1st Cleaner tails		-	7.4	0.47	17.7	-	11.1	4.8
	Rgh. tails		86.2	67.0	0.10	37.2	88.5	21.1	90.5
	Head (calculated)		-	100.0	0.32	27.5	65.5	100.0	100.0

Table 19. Product balance for unground (-150 μm) white-phase wollastonite indicating the influence of variable sodium oleate concentration at constant pH

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
39	Final conc.	200	80.3	64.5	0.21	40.3	95.9	34.6	86.1
	1st Cleaner tails		-	4.4	0.58	21.3	-	6.6	3.1
	Rgh. tails		70.7	31.1	0.74	10.5	-	58.8	10.8
	Head (calculated)		-	100.0	0.39	30.2	71.9	100.0	100.0
40	Final conc.	255	79.8	68.2	0.27	40.6	95.8	46.2	90.5
	1st Cleaner tails		-	5.9	0.78	21.5	-	11.6	4.2
	Rgh. tails		71.1	25.9	0.65	6.3	-	42.2	5.3
	Head (calculated)		-	100.0	0.40	30.6	72.8	100.0	100.0
41	Final conc.	305	76.9	73.2	0.39	40.1	95.5	67.9	95.8
	1st Cleaner tails		-	3.6	0.46	11.5	-	4.0	1.3
	Rgh. tails		71.3	23.2	0.51	3.8	-	28.1	2.9
	Head (calculated)		-	100.0	0.42	30.7	72.1	100.0	100.0

Table 20. Product balance for unground (-150 μm) white-phase wollastonite at constant pH and variable Arquad T 50 concentration

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
42	Final conc.	50	60.7	12.1	2.07	2.1	-	66.5	0.8
	1st Cleaner tails		-	7.5	0.40	18.1	-	8.0	4.5
	Rgh. tails		81.0	80.4	0.12	35.7	89.1	25.5	94.7
	Head (calculated)		-	100.0	0.38	30.3	72.1	100.0	100.0
43	Final conc.	75	68.9	29.2	1.07	9.6	-	78.0	9.1
	1st Cleaner tails		-	10.4	0.33	31.6	-	8.5	10.7
	Rgh. tails		84.2	60.4	0.09	40.9	97.2	13.5	80.2
	Head (calculated)		-	100.0	0.40	30.6	73.2	100.0	100.0
44	Final conc.	100	71.4	37.3	0.83	15.8	-	69.8	19.8
	1st Cleaner tails		-	11.4	0.73	27.5	-	18.7	10.5
	Rgh. tails		82.4	51.3	0.10	40.5	96.3	11.5	69.7
	Head (calculated)		-	100.0	0.44	29.8	70.9	100.0	100.0

Table 21. Product balance for ground (-150 μm) white-phase wollastonite indicating the effect of variable grind size at constant sodium oleate concentration and pH

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
41	Final conc.	64.9	76.9	73.2	0.39	40.1	95.5	67.9	95.8
	1st Cleaner tails		-	3.6	0.46	11.5	-	4.0	1.3
	Rgh. tails		71.3	23.2	0.51	3.8	-	28.1	2.9
	Head (calculated)		-	100.0	0.42	30.7	72.1	100.0	100.0
45	Final conc.	75.9	82.6	64.5	0.15	41.3	98.3	25.9	86.7
	1st Cleaner tails		-	4.0	0.50	21.1	-	5.3	2.7
	Rgh. tails		70.3	31.5	0.82	10.3	-	68.8	10.6
	Head (calculated)		-	100.0	0.38	30.7	73.1	100.0	100.0
46	Final conc.	84.8	82.2	61.3	0.10	41.5	98.8	16.4	83.4
	1st Cleaner tails		-	3.7	0.55	18.6	-	5.4	2.3
	Rgh. tails		69.9	35.0	0.83	12.5	-	78.2	14.3
	Head (calculated)		-	100.0	0.37	30.5	72.6	100.0	100.0
47	Final conc.	90.1	80.7	47.7	0.09	42.0	99.2	9.9	64.8
	1st Cleaner tails		-	6.2	0.36	30.2	-	5.2	6.1
	Rgh. tails		70.1	46.1	0.78	19.5	-	84.9	29.1
	Head (calculated)		-	100.0	0.42	30.9	73.5	100.0	100.0

Table 22. Product balance for ground (-150 µm) white-phase wollastonite indicating the effect of variable grind size at constant Arquad T 50 concentration and pH

Test No.	Products	Size % -75 µm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
43	Final conc.	64.9	68.9	29.2	1.07	9.6	-	78.0	9.1
	1st Cleaner tails		-	10.4	0.33	31.6	-	8.5	10.7
	Rgh. tails		84.2	60.4	0.09	40.9	97.2	13.5	80.2
	Head (calculated)		-	100.0	0.40	30.8	73.2	100.0	100.0
48	Final conc.	75.9	70.9	24.6	0.84	6.6	-	61.6	5.4
	1st Cleaner tails		-	9.7	0.38	29.1	-	11.0	9.4
	Rgh. tails		80.7	65.7	0.14	39.1	93.1	27.4	85.2
	Head (calculated)		-	100.0	0.34	30.1	75.6	100.0	100.0
49	Final conc.	84.8	69.0	22.5	0.82	5.7	-	44.5	4.1
	1st Cleaner tails		-	9.7	0.42	28.4	-	9.8	8.9
	Rgh. tails		81.3	67.8	0.28	39.8	94.7	45.7	87.0
	Head (calculated)		-	100.0	0.42	31.0	73.8	100.0	100.0
50	Final conc.	90.1	69.0	19.6	0.84	5.6	-	47.8	3.6
	1st Cleaner tails		-	8.8	0.42	27.7	-	10.7	7.9
	Rgh. tails		81.0	71.6	0.20	38.0	90.4	41.5	88.5
	Head (calculated)		-	100.0	0.35	30.8	73.2	100.0	100.0

Table 23. Flotation parameter and reagent concentration data for -420 +150 μm green-phase wollastonite

Test No.	Flotation stage	Float time min	Grind time min	pH	Collector		Frother
					Sodium oleate g/t	Arquad T 50 g/t	M.I.B.C. g/t
1	Rougher	28	-	7.0	410	-	200
2	Rougher	4	-	7.0	405	-	55
	Cleaner	8	-	7.0	75	-	55
3	Rougher	3	-	7.0	305	-	20
	Cleaner	6	-	7.0	100	-	40
4	Rougher	3	3	7.0	310	-	40
	Cleaner	6	-	7.0	105	-	75
5	Rougher	3	5	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	40
6	Rougher	4	10	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	40
7	Rougher	4	15	7.0	310	-	40
	Cleaner	8	-	7.0	105	-	40
8	Rougher	3	5	7.0	420	-	40
	Cleaner	6	-	7.0	155	-	40
9	Rougher	3	15	7.0	420	-	40
	Cleaner	5	-	7.0	155	-	40
10	Rougher	2	3	9.0	-	50	20
	Cleaner	1	-	8.9	-	15	20
11	Rougher	2	3	9.1	-	75	20
	Cleaner	2	-	9.1	-	25	-
12	Rougher	2	3	9.2	-	100	20
	Cleaner	2	-	9.0	-	35	20
13	Rougher	2	5	9.4	-	75	20
	Cleaner	2	-	9.2	-	25	-
14	Rougher	3	10	9.4	-	75	20
	Cleaner	2	-	9.1	-	25	-
15	Rougher	3	15	9.5	-	75	20
	Cleaner	2	-	9.1	-	25	-

Table 24. Flotation parameter and reagent concentration data for -150 μm green-phase wollastonite

					Collector		Frother
Test No.	Flotation stage	Float time min	Grind time min	pH	Sodium oleate g/t	Arquad T 50 g/t	M.I.B.C. g/t
16	Rougher	1	-	7.0	310	-	75
	Cleaner	3	-	7.1	105	-	75
17	Rougher	2	-	7.0	365	-	75
	Cleaner	4	-	7.0	105	-	75
18	Rougher	2	-	7.0	420	-	75
	Cleaner	4	-	7.0	155	-	75
19	Rougher	2	-	7.8	310	-	75
	Cleaner	4	-	8.0	105	-	75
20	Rougher	3	-	9.0	310	-	75
	Cleaner	5	-	9.0	105	-	75
21	Rougher	4	5	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	-
22	Rougher	4	10	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	-
23	Rougher	2	-	8.8	-	75	40
	Cleaner	1	-	8.8	-	40	40
24	Rougher	2	-	9.0	-	100	40
	Cleaner	1	-	9.0	-	35	40
25	Rougher	2	-	8.9	-	130	40
	Cleaner	2	-	8.9	-	50	40
26	Rougher	6	5	9.2	-	100	40
	Cleaner	2	-	9.1	-	35	-
27	Rougher	3	10	9.4	-	100	40
	Cleaner	2	-	9.2	-	35	-

Table 25. Flotation parameter and reagent concentration data for -420 +150 µm white-phase wollastonite

Test No.	Flotation stage	Float time min	Grind time min	pH	Collector: Sodium oleate g/t	Collector: Arquad T 50 g/t	Frother: M.I.B.C. g/t
28	Rougher	3	5	7.0	205	-	20
	Cleaner	2	-	7.0	65	-	-
29	Rougher	2	5	7.0	260	-	20
	Cleaner	1	-	7.0	85	-	20
30	Rougher	2	5	7.0	305	-	-
	Cleaner	1	-	7.0	100	-	-
31	Rougher	2	5	7.0	360	-	-
	Cleaner	1	-	7.0	120	-	-
32	Rougher	2	5	7.0	-	50	20
	Cleaner	1	-	7.0	-	15	-
33	Rougher	2	5	7.0	-	75	-
	Cleaner	2	-	7.0	-	25	-
34	Rougher	2	5	7.0	-	100	20
	Cleaner	1	-	7.0	-	40	-
35	Rougher	3	10	7.0	205	-	20
	Cleaner	2	-	7.0	65	-	-
36	Rougher	3	15	7.0	205	-	20
	Cleaner	3	-	7.0	65	-	-
37	Rougher	2	10	9.3	-	75	-
	Cleaner	2	-	9.1	-	25	-
38	Rougher	2	15	9.3	-	75	-
	Cleaner	2	-	9.0	-	25	-

Table 26. Flotation parameter and reagent concentration data for -150 µm white-phase wollastonite

Test No.	Flotation stage	Cond. time min	Float time min	Grind time min	pH	Collector		Frother
						Sodium oleate g/t	Arquad T 50 g/t	M.I.B.C. g/t
39	Rougher	4	4	-	7.0	200	-	-
	Cleaner	4	3	-	7.0	65	-	-
40	Rougher	4	3	-	7.0	255	-	-
	Cleaner	4	2	-	7.0	80	-	-
41	Rougher	4	3	-	7.0	305	-	-
	Cleaner	4	2	-	7.0	100	-	-
42	Rougher	4	3	-	7.0	-	50	20
	Cleaner	4	1	-	7.0	-	15	-
43	Rougher	4	2	-	7.0	-	75	20
	Cleaner	4	2	-	6.9	-	25	-
44	Rougher	4	2	-	7.0	-	100	20
	Cleaner	4	2	-	7.0	-	40	-
45	Rougher	-	4	5	7.0	305	-	-
	Cleaner	-	3	-	7.0	100	-	-
46	Rougher	-	4	10	7.0	305	-	-
	Cleaner	-	3	-	7.0	100	-	-
47	Rougher	-	4	15	7.0	305	-	-
	Cleaner	-	3	-	7.0	100	-	-
48	Rougher	-	3	5	9.1	-	75	20
	Cleaner	-	2	-	9.0	-	25	-
49	Rougher	-	3	10	9.0	-	75	20
	Cleaner	-	2	-	8.9	-	25	-
50	Rougher	-	3	15	9.1	-	75	20
	Cleaner	-	2	-	8.9	-	25	-

APPENDIX 5. **Wollastonite Occurrences - Canada**

This section presents the occurrences of wollastonite listed in the Catalogue of Canadian Minerals, Geological Survey of Canada as described by Traill (1980). Ettlinger and Ray (1987) and White (1989) provided additional information on the British Columbia occurrences, and Justino and Sangster (1987) and Pegg (1987) on the Lime Hill occurrence in Nova Scotia. Sabina (1969, 1986) and Hogarth et al (1983) supplemented the information by Traill (1980) on the Ontario occurrences. This listing should not be considered an exhaustive report of all wollastonite occurrences in Canada as several provinces are presently evaluating their resources.

British Columbia

Sechelt Peninsula (92G/12/W), (Snake Bay; Wormy Lake) mineral inventory number 092G-52, 53. A wollastonite skarn is located near Snake Bay (Figure 1), 5 km north of Sechelt. The mineralized zone is 150 m wide and up to 100 m in depth, along a 450 m strike length. Possible and probable drill-indicated reserves are 291,000 tonnes of wollastonite. The Wormy Lake occurrence (Figure 2), 2.5 km north-northwest of Snake Bay contains sporadic wollastonite outcrops over a distance of 600 m. Both occurrences are hosted in a north-trending limestone belt (Karmutsen Formation) in a roof pendant within the Coast plutonic complex. Associated minerals include wollastonite, garnet, diopside, epidote, quartz, calcite, and occassionally pyrite and chalopyrite (White 1989).

Little Billy Mine, mineral inventory number 092F-105 (Figure 3). Coarse-bladed wollastonite and garnet-diopside skarns contain bornite, chalcopyrite, pyrite, molybdenite, magnetite, sphalerite, galena, scheelite, gold, and silver at the Little Billy Mine on Northern Texada Island. The wollastonite is associated with copper-gold skarns which have developed where limestones where intruded by Mesozoic (?) felsic granodiorites and quartz monzonites (Ettlinger and Ray 1987). Reserve estimates indicate approximately 100,000 tonnes of wollastonite-rich skarn are present in the old workings (Stevenson 1944, White 1989).

Fintry Point, mineral inventory number 0822-014 (Figure 4). Wollastonite skarn outcrops 6 km west of Fintry point on the west shore of Okanogan Lake. It is hosted in Permo-Carboniferous limestone of the Thompson assemblage, along a zone 30-80 m wide having a strike length of 850 m and an exposed vertical extent of 500 m. The grade ranges up to 35% and associated minerals include calcite, quartz, and minor garnet and diopside (White 1989).

Silence Lake Mine, mineral inventory number 082M-123 (Figure 5). Wollastonite skarn outcrops at the Dimac Resource Corp. Tungsten mine, located approximately 30 km northeast of Clearwater. A 15-

20 m zone of siliceous skarn grading 35% wollastonite was exposed by past mining operations. Similar mineralization outcrops 170 m south-southeast of the main showing. Associated minerals include wollastonite, garnet, diopside, and relict calcite. Intercalated thin quartzite beds are common (White 1989).

At the Victory Tungsten property near Salmo, on the south side of Sheep Creek 4.8 km east of its confluence with the Salmo River, the ore occupies a contact metamorphic zone which includes pyrrhotite, pyrite, molybdenite, sphalerite, scheelite, garnet, actinolite, calcite, quartz, and wollastonite (Greenwood 1967, Traill 1980).

White splintery wollastonite, associated with diopside, garnet, epidote, chalcopyrite, bornite, native silver, and molybdenite occurs at the Marble Bay Mine on Texada Island. A chemical analysis of the wollastonite yielded: SiO_2 51.60, Al_2O_3 1.82, Fe_2O_3 0.32, FeO 0.13, MgO 0.28, CaO 44.50, MnO 0.08, Na_2O 0.52, K_2O 0.32, H_2O 0.31, CO_2 0.30, total 100.18; S.G. 2.924 (Traill 1980).

At Nanaimo Lakes on Vancouver Island, Jurassic quartz diorite contains epidote-amphibole endoskarn at surface and is associated with massive garnet wollastonite skarn replacing limestone at depth. The wollastonite is fine-grained and forms the matrix surrounding garnet (Ettlinger and Ray 1987).

Wollastonite occurs in a zoned skarn adjacent to diorite on the Oka property located along Greata Creek, approximately 15 km west-northwest of Peachland. The zone consists of fine-grained wollastonite and light brown garnet (Ettlinger and Ray 1987).

Wollastonite is found on the Oregon property between Sixteen Mile and Eighteen Mile creeks and 4.8 km east of Hedley in the Osoyoos mining division (Traill 1980).

Wollastonite occurs in skarns associated with tremolite, quartz, epidote, and diopside at the Nickel Plate Mine in the Hedley camp. Minor wollastonite is generally associated with diopside adjacent to garnet stringers (Ettlinger and Ray 1987).

Wollastonite occurs at Nootka Sound in the Clayoquot mining division (Traill 1980).

Northwest Territories

Pale yellow lineated megacrysts of wollastonite occur in lime-silicate rock at Narrow Bay, Freshwater Lake, on Baffin Island (Traill 1980).

Yukon

Wollastonite is associated with andradite, pyroxene, calcite, quartz, and bornite in a number of test pits and trenches between Cowley Creek and Dugdale Station at the southern end of the Whitehorse copper belt. Masses of snow white wollastonite up to 30 cm in diameter were noted (Traill 1980).

Wollastonite-rich skarn occurs at the Anaconda, Rabbit-foot, and War-Eagle copper deposits, located 3 to 5 km northwest of Whitehorse (Traill 1980).

Quebec

White fibrous wollastonite, white to greenish-white prehnite, pink garnet, transparent vesuvianite, and grass-green diopside occur at the Jeffrey Asbestos Mines, at the contact of peridotite with granitic rock (Traill 1980).

Wollastonite with fine-grained recrystallized quartz of a white to light blue colour, was found on Needle Mountain, Holland Township, Gaspe-North County (Traill 1980).

Silky green platy crystals of wollastonite up to 10 cm in length occur with nepheline, sodian augite and melanite garnet in ijolite rock within the Oka Complex, located 32 km west of Montreal on the north shore of the Lake of Two Mountains. Chemical analysis by H. Ulk of wollastonite from DDH G15, at 330 feet: SiO_2 50.15, Al_2O_3 0.14, Fe_2O_3 0.04, FeO 0.60, MnO 0.96, CaO 46.97, Na_2O 0.35, K_2O 0.05, H_2O+ 0.38, CO_2 0.45, total 100.09, S.G. 2.859 (Traill 1980).

Coarsely crystalline wollastonite is associated with green diopside, feldspar, quartz, calcite, and massive graphite at the Miller (Keystone) Mine (Sabina 1986, Traill 1980).

The gangue material of a graphite deposit in lot 10, range V, Grenville Township, Argenteuil County, contains wollastonite. Chemical analysis of wollastonite from Grenville: SiO_2 53.05, CaO 45.74, FeO 1.20, total 99.99; S.G. 2.89-2.92 (Traill 1980).

An association of wollastonite with blue calcite is reported in range I, lot 7, of Wakefield Township, Gatineau County (Traill 1980).

Roadcuts on Highway 35 north of Notre-Dame-de-la-Salette contain wollastonite as white bladed aggregates (Sabina 1969, Traill 1980).

Wollastonite occurs at St. Jerome, Morin, in Terrebonne County (Traill 1980).

Wollastonite has been identified from Mont St-Hilaire (Traill 1980).

Specimens of wollastonite have been collected from range VI, lot 17, and range II, lot 16, in Amherst Township, Papineau County

(National Mineral Collection, Traill 1980).

At the Stephen Cross quarry (Figure 6), west of the Gatineau River Road near Wakefield, wollastonite occurs in association with diopside and calcite or diopside and graphite with/without grossularite. The wollastonite skarn occurs interlayered with brucitic marble and at the contact of marble with syenitic and monzonitic rocks of the Wakefield Batholith (Hogarth et al 1983).

Near the Chenaux rapids Dam, on Limerick Island (Figure 7), about 80 km upstream from Ottawa, wollastonite and diopside, with/without vesuvianite, pyrrhotite and feldspar occur as grey bands interlayered with fine-to medium-grained marble containing calcite, diopside, graphite, and rarely titanite, phlogopite, and tremolite. A contact with marble at the south end of Limerick Island contains coarse parawollastonite poikilitically enclosing diopside (Hogarth et al 1983).

Wollastonite, diopside, titanite, hornblende, garnet, vesuvianite, scapolite, fluorite, and molybdenite occur with graphite in crystalline limestone at its contact with pegmatite. The quarry is located in a graphite mine on the west side of the South Stakely-Lawrenceville road at a point 1 1/4 miles north of South Stakely (Sabina 1969).

Nova Scotia

Wollastonite occurs on the Lime Hill zinc property (Figure 8), Inverness County Cape Breton Island, some 26 km NE of Port Hawkesbury. The property is currently held by Blue Stack Resources Limited.

The wollastonite typically occurs as thin white bands composed of aggregates of fine needles. The bands vary from 2 to 10 mm in thickness and are enclosed within grey calcite marble often with a white to pale green mineral (diopside). Mineralization occurs in three zones (grading on average 25-30% wollastonite) with each zone consisting of between 1 and 4 separate bands (typically 0.3 - 1.0 m in thickness) (Pegg 1987). Chatterjee (1980) described the marbles in the vicinity of Lime Hill as roof pendants of the George River Group in siliceous intrusions.

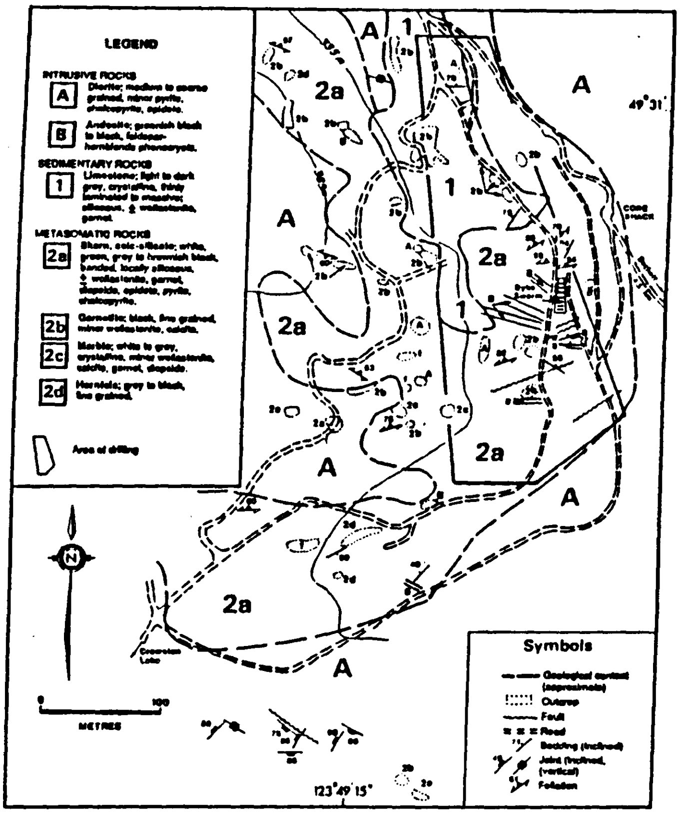


Figure 1. Snake Bay wollastonite-garnet skarn (from White 1989).

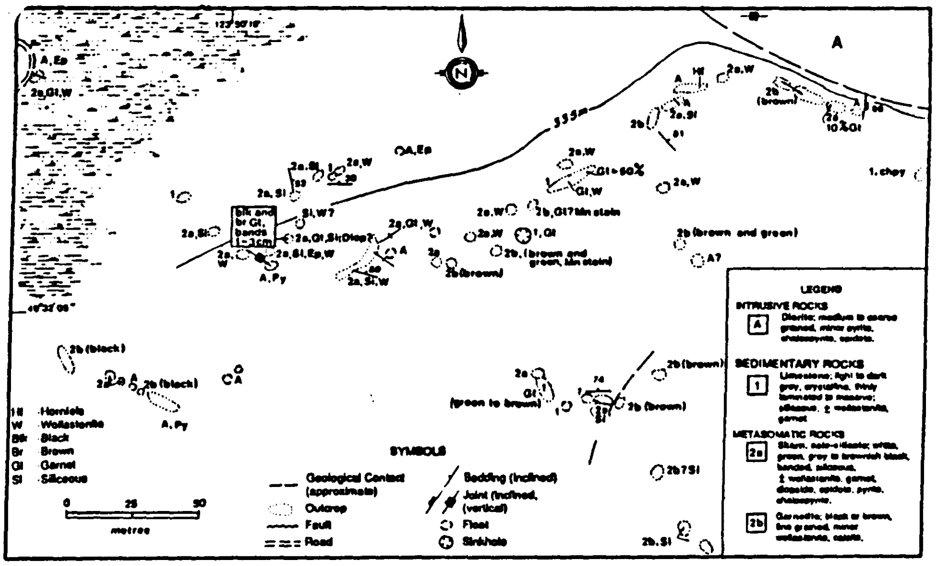
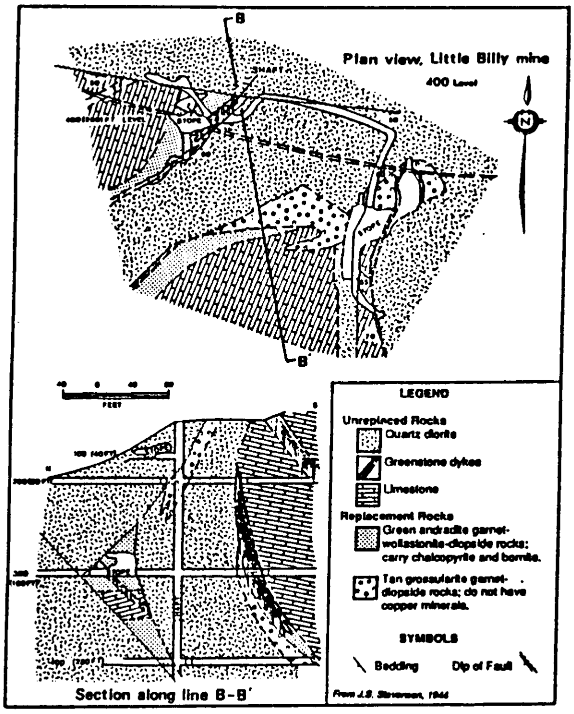


Figure 2. Location map of Wormy Lake - geological outcrop map (from White 1989).



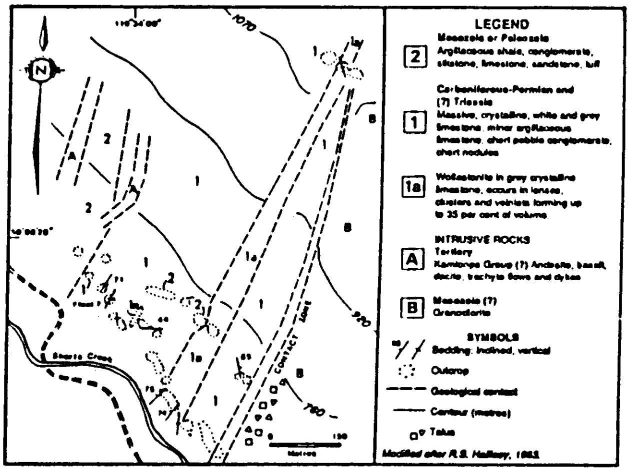
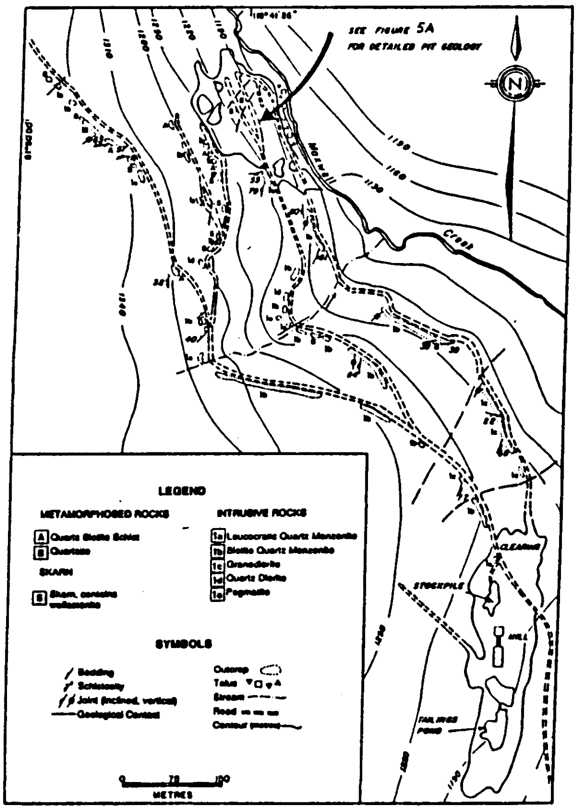


Figure 4. Fintry Point wollastonite skarn (from White 1989).

Figure 3 . Little Billy mine - wollastonite occurs in replacement rocks (from White 1989).



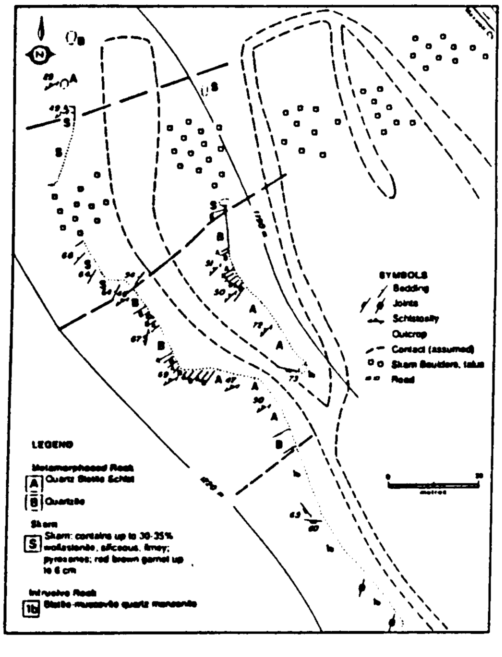


Figure 5a. Open pit area

Figure 5. Geological outcrop map - Silence Lake mine (from White 1989).

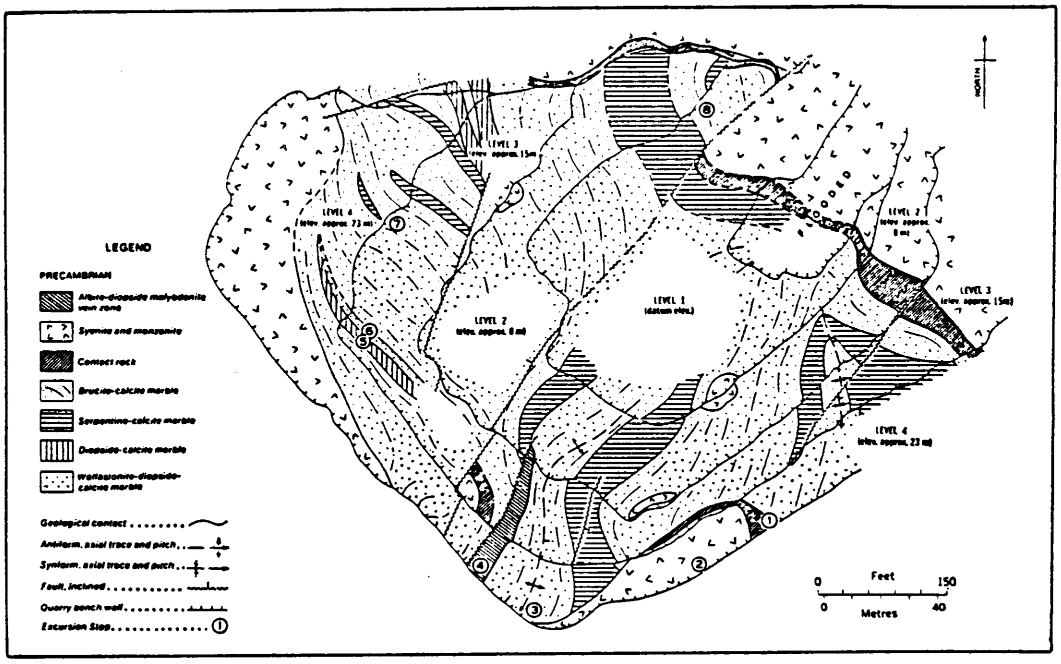


Figure 6. Geological map of the Stephen Cross quarry, Wakefield, Quebec (from Hogarth et al 1983).

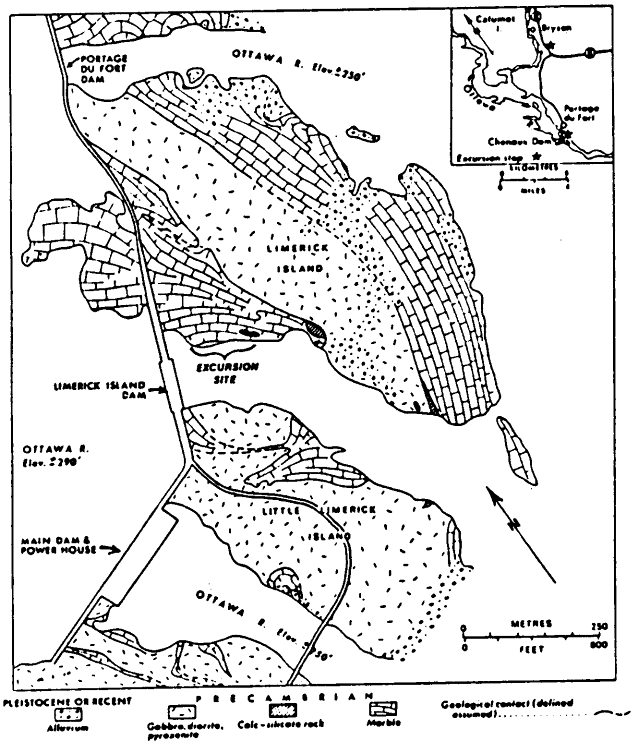


Figure 7. Geology of the Chenaux Dam Site, Portage-du-Fort, Quebec (from Hogarth et al 1983).

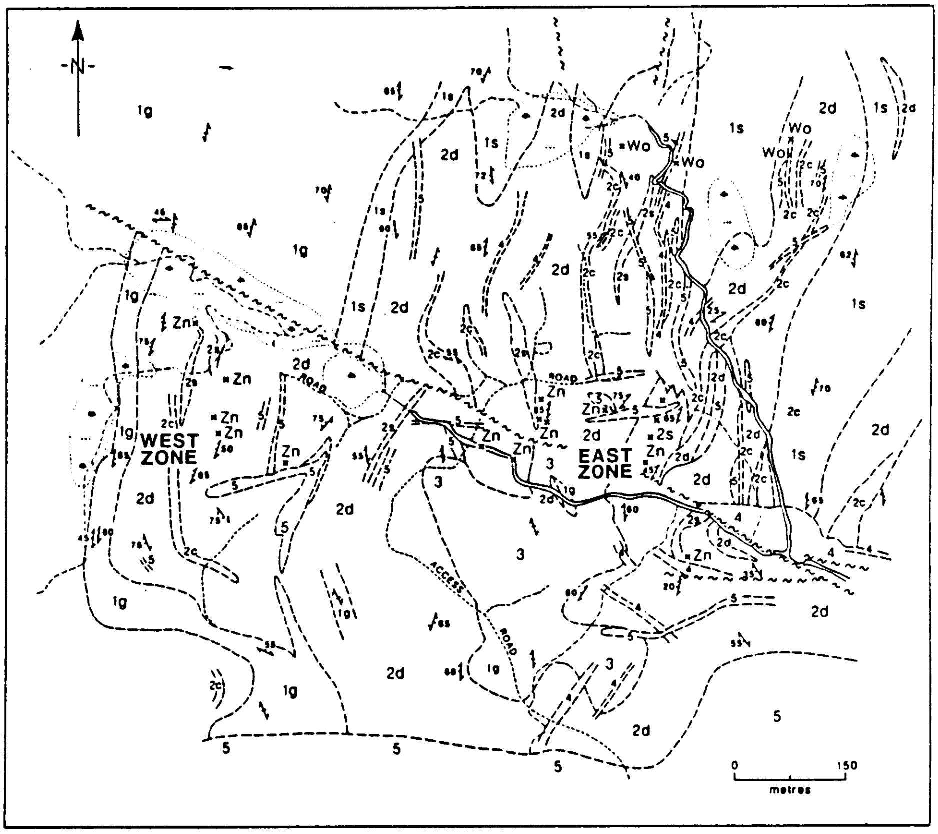


Figure 8. Geology of the Lime Hill Zn occurrence. Legend: 1. Biotite-quartz-feldspar gneiss; (1g) + cordierite + sillimanite + garnet; (1s) more mica-rich; 2. Marble; (2a) calcareous marble; (2b) dolomitic marble; (2s) serpentine marble (<15% serpentine); 3. Granitic orthogneiss; 4. Foliated amphibolite dykes, includes some post-granite dyke diorite porphry; 5. Late granitic dykes of several ages, including white to pink biotite and/or amphibole-bearing syenite, granite, monzodiorite, leucogranite and spare pegmatite; Wo = wollastonite; Zn = Sphalerite; 20 = strike and dip of foliation;~~~~= fault. (from Justino and Sangster 1987)

LEGEND

PHANEROZOIC
CENOZOIC
QUATERNARY
PLEISTOCENE AND RECENT
Sand, gravel, clay
UNCONFORMITY

PALEOZOIC
ORDOVICIAN
MIDDLE ORDOVICIAN

8 Bobcaygeon Formation: thinly-to massively bedded microcrystalline limestone with undulating shaley partings, brownish-grey in colour.

7 Gull River Formation: microcrystalline to fine-grained limestone with abundant shaley partings, brownish-grey in colour.

6 Shadow Lake Formation: fine-grained to conglomeratic, thinly-bedded, calcareous feldspathic quartz sandstone, maroon to green in colour.

UNCONFORMITY

PRECAMBRIAN
LATE PRECAMBRIAN
FELSIC INTRUSIVE ROCKS

5 Unsubdivided
- 5a Granite: medium-to coarse-grained, pink, consisting of mesoperthite, quartz and 3-5 % amphibole.
- 5b Pegmatite.
- 5c Felsite, microgranite: microcrystalline, pink and may contain garnetiferous skarn.
- 5d Amphibole-syenite, quartz-syenite: medium to coarse-grained, pink, consisting of mesoperthite with clots of amphibole / biotite / chlorite.
- 5e Leucogranite: medium-to coarse-grained, white, consisting of feldspar, quartz and minor amphibole.
- 5f Gossan-stained syenite.

EARLY MAFIC INTRUSIVE ROCKS

4
- 4a Medium-to coarse-grained gabbro-predominantly hornblende and plagioclase; colour index 40-70.
- 4b Fine-grained gabbro-massive, grey-green to black.
- 4c Diorite-plagioclase and hornblende; colour index 25-35.

GRENVILLE SUPERGROUP METASEDIMENTS
(not stratigraphic)

3 Wollastonite-bearing calcitic marble / calc-silicate rock / skarn: varying proportions of calcite, diopside-hedenbergite, wollastonite and quartz; wollastonite forms crystals up to 6cm long or acicular clots and radial aggregates 1 to 30cm in diameter, comprising up to 50 % of the rock; weathered surface is pitted, with calcite in high relief and wollastonite low; fine-to medium-grained, massive to foliated; white to pale green in colour.

2 Carbonate Metasediments
- 2a Brucite-bearing calcitic marble: calcitic with minor dolomite, fine-to medium-grained, white; accessory brucite, serpentine, tremolite and iron oxides.
- 2b Serpentinized calcitic marble: fine-grained calcite intergrown with laths of serpentine and chlorite; also clots and veins of serpentine up to 20 cm wide; dark green to white.
- 2c Siliceous calcitic marble: siliceous variety of map unit 2d.
- 2d White calcitic marble: fine-to medium-grained, massive, white crystalline marble; minor quartz, tremolite, phlogopite, pyrite and local hematite.
- 2e Grey calcitic marble: laminated grey to grey/white calcitic marble, locally containing millimeter to centimeter scale dolomitic and siliciclastic layers; possibly locally stromatolitic.
- 2f Diopsidic skarn: diopside with subordinate calcite, serpentine and pyrite; fine-grained to microcrystalline, pale green.
- 2g Talc-carbonate rock: similar in appearance to 2b and 2f, but contains fine-grained talc, carbonate and minor serpentine.

1 Siliceous Metasediments
- 1a Siliciclastic metasediments: calcareous wacke/siltstone, pale to dark grey, slatey to schistose.
- 1b Hornfels: metasomatized wacke/siltstone (skarn), microcrystalline, laminated to thickly banded; grey, green, brown and reddish bands.

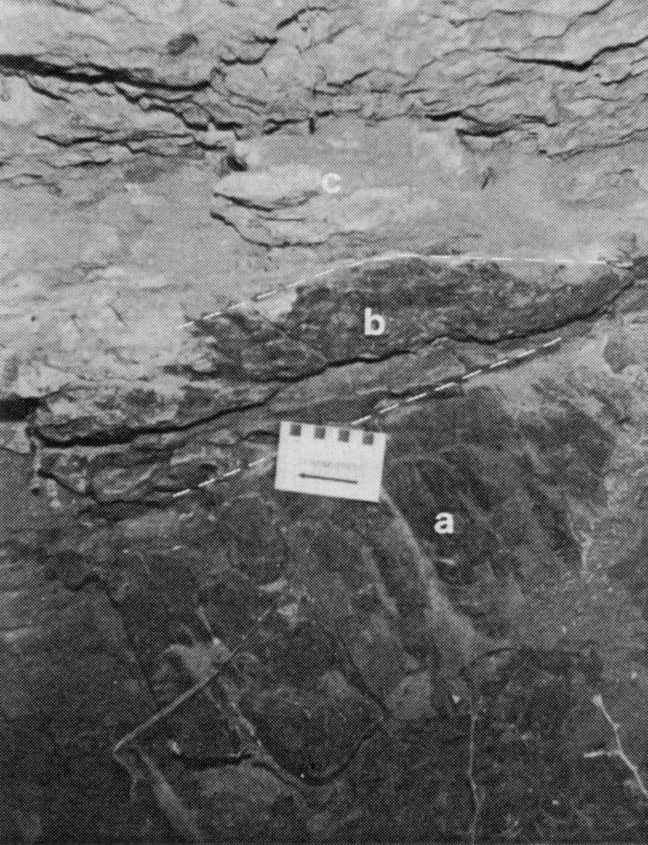
SYMBOLS

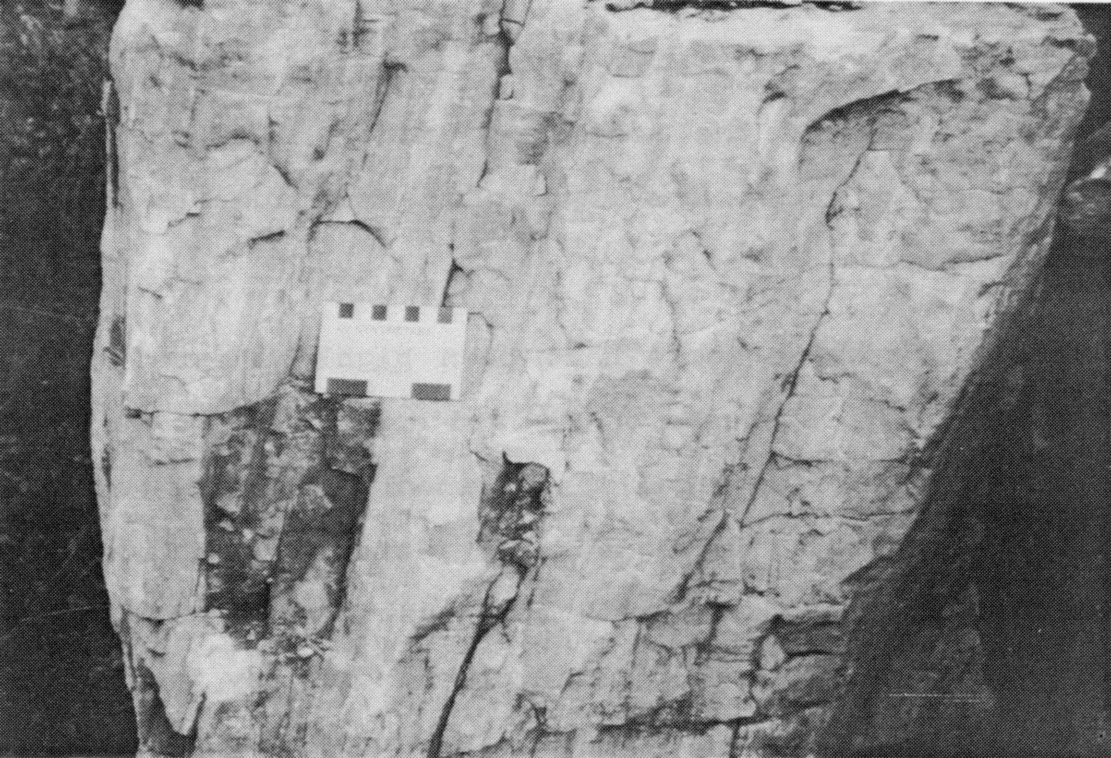
x Outcrop
Geological boundary
Fault
Strike dip (inclined, unknown)
Quarry

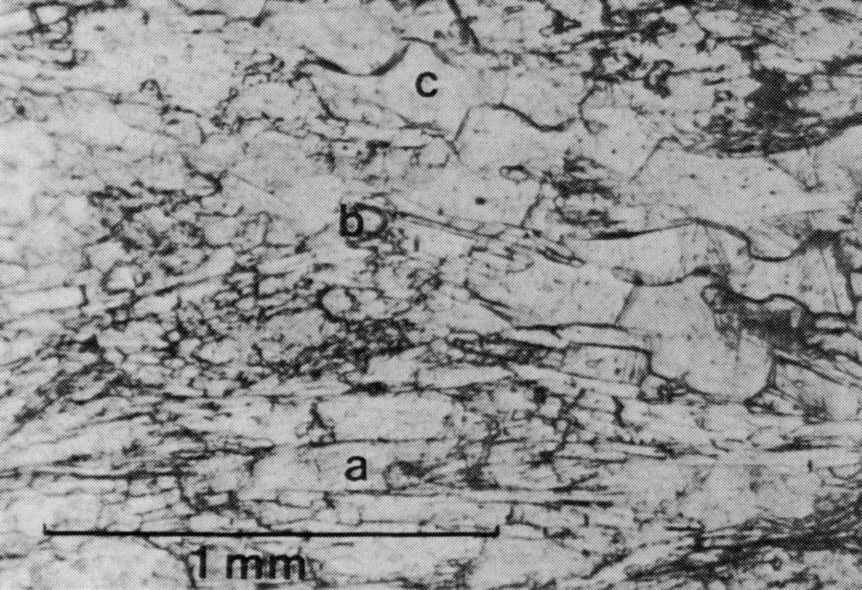
WOLLASTONITE OCCURRENCES ASSOCIATED WITH THE DELORO PLUTON, SOUTHERN ONTARIO

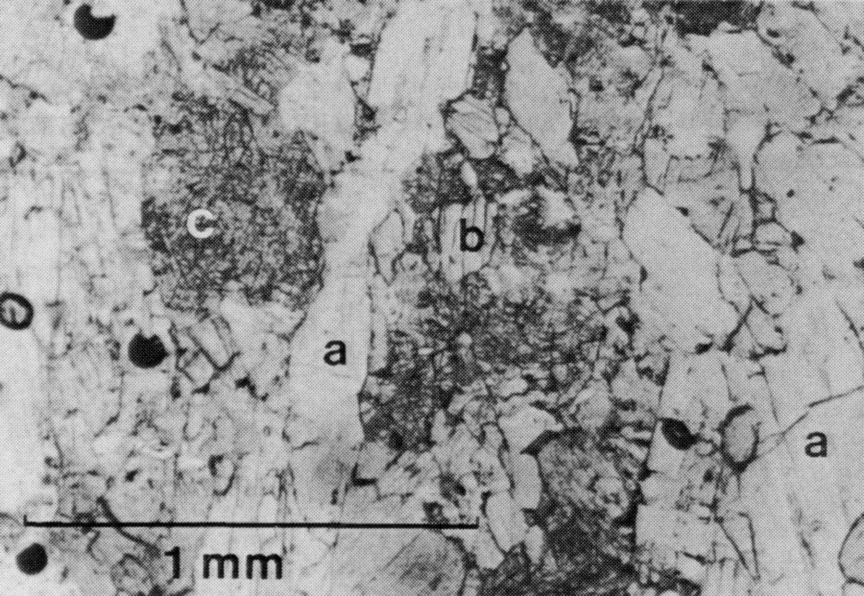
Scale 1:10000
500 0 500 1000 m
1000 0 1000 2000 3000 4000 5000 ft

Geology by Alistair MacKinnon 1987, 1988.

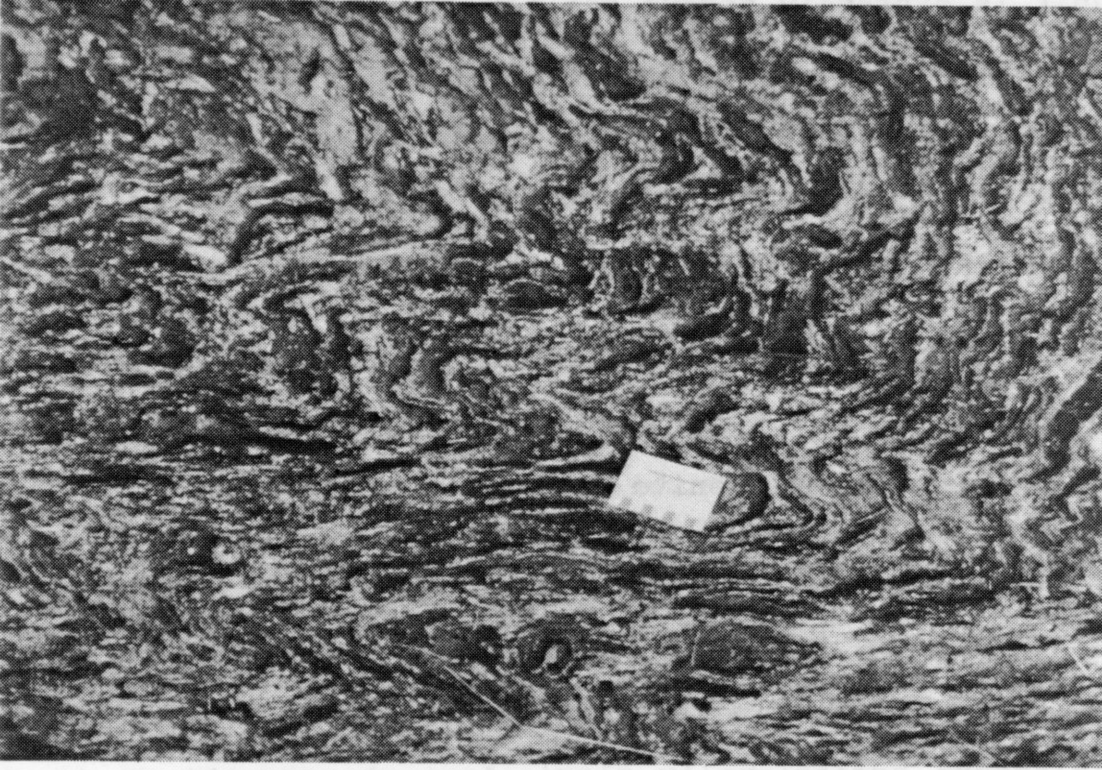

c
b
a

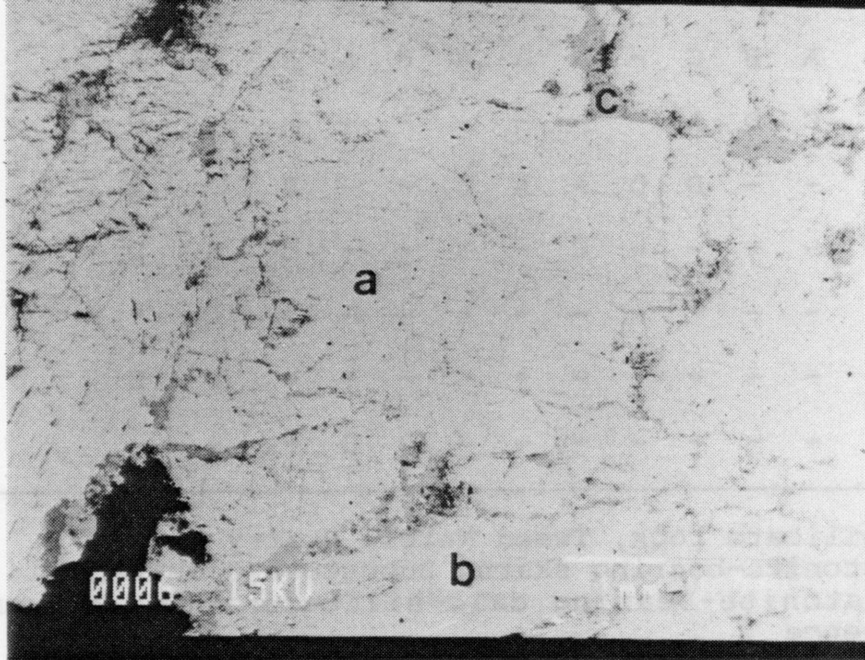



c
b
a
1 mm


c
b
a
a
1 mm


CENTIMETRES

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a
b
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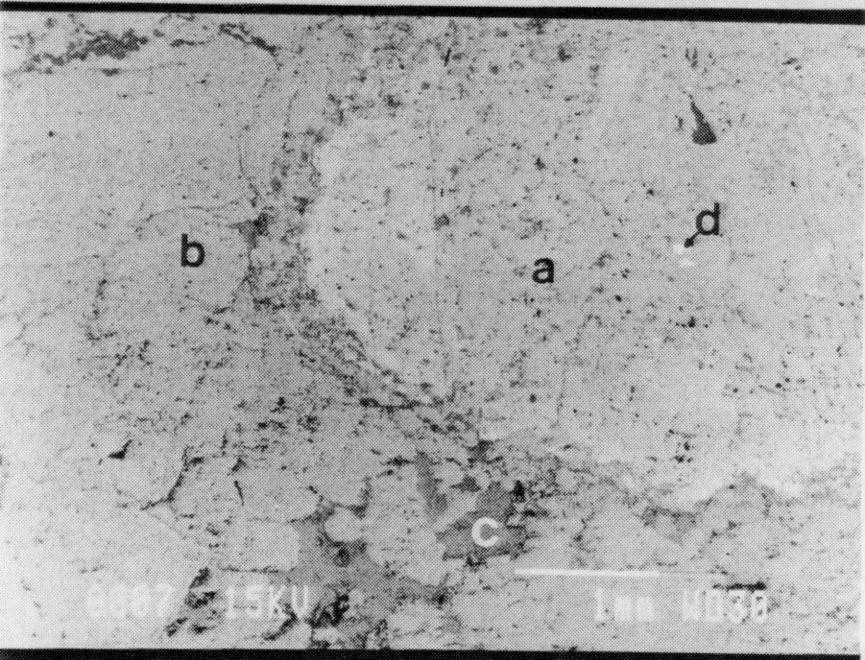
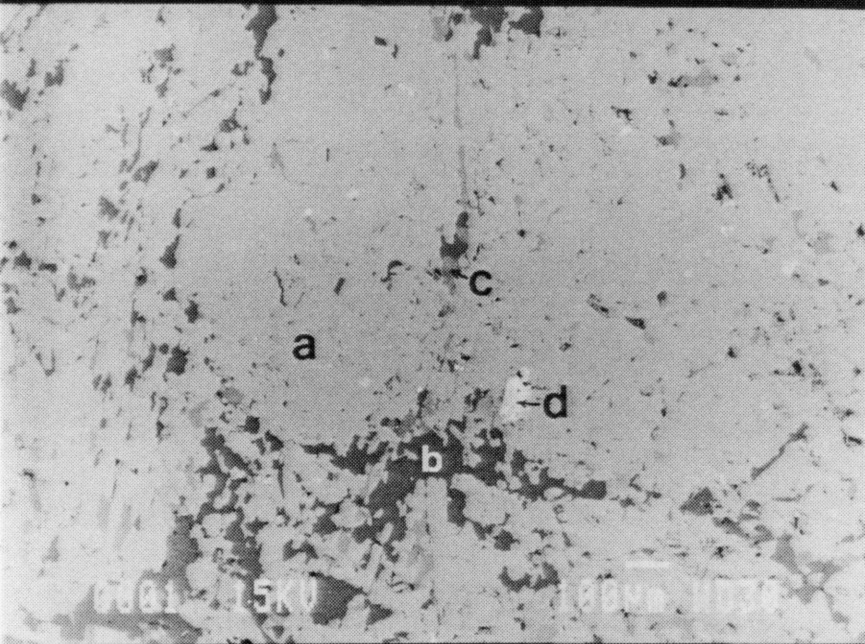
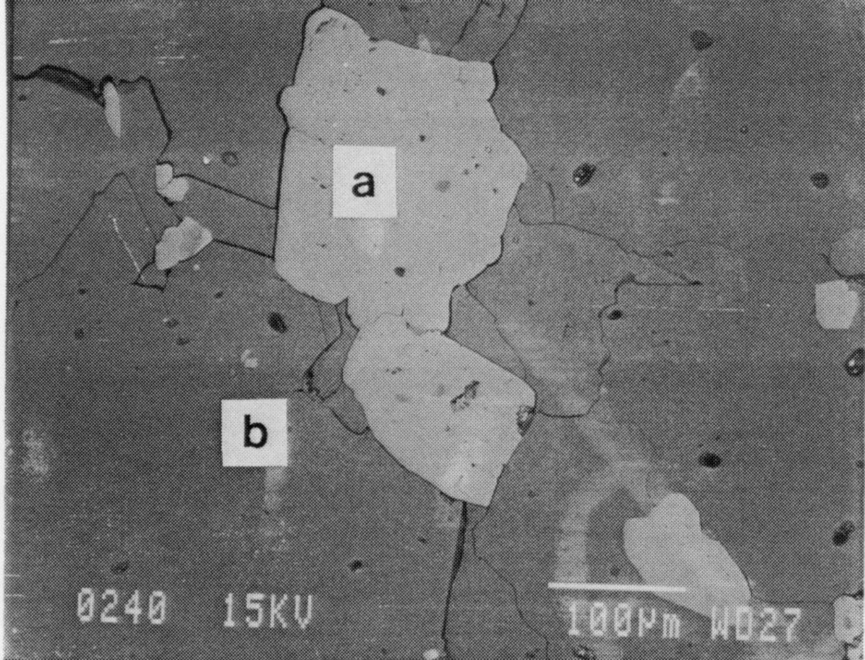
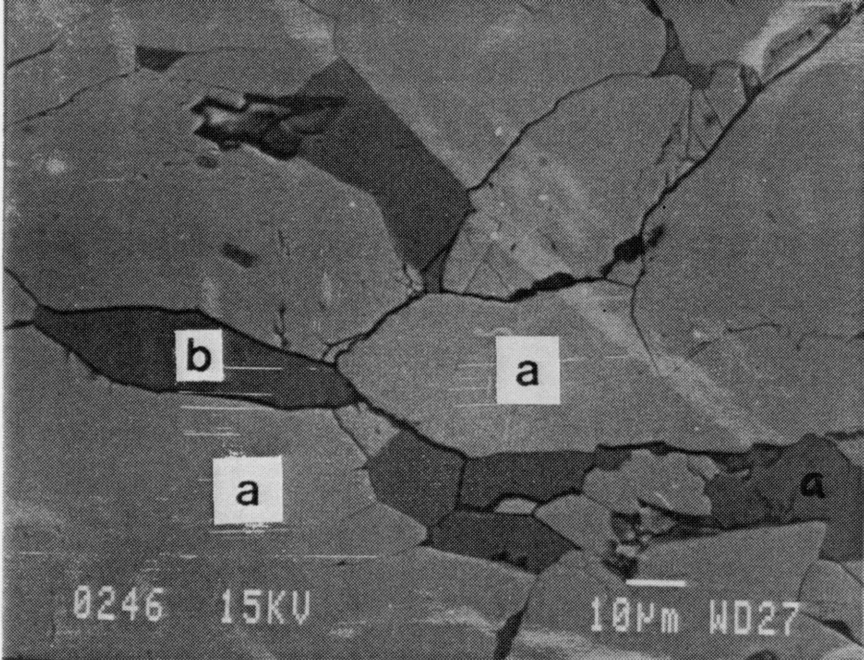
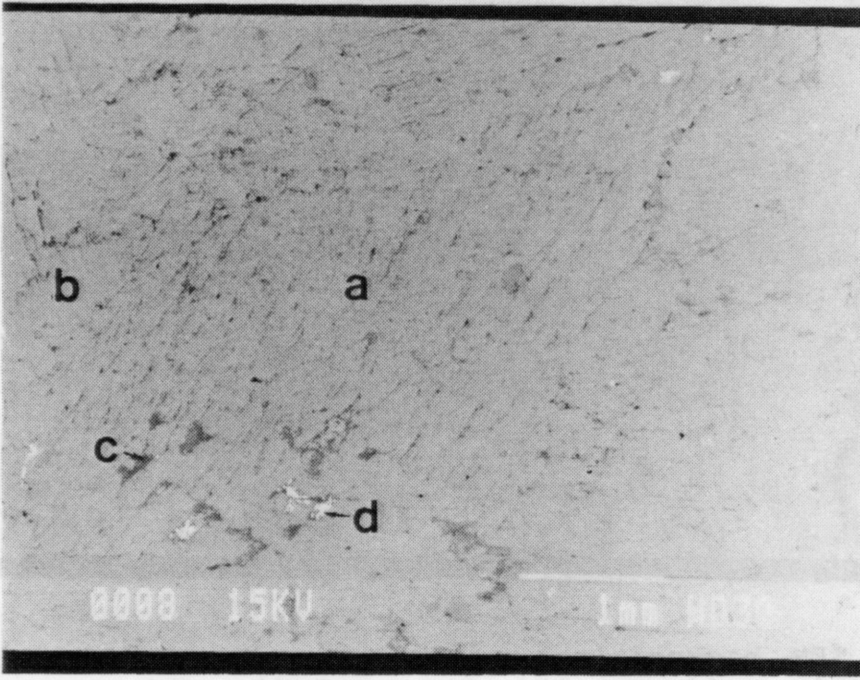
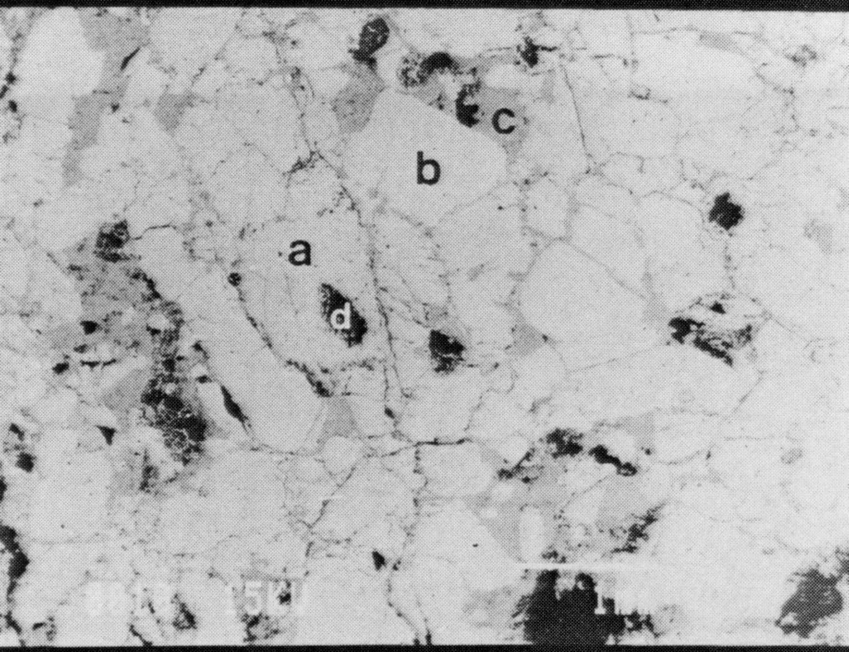

b
a
d
c
0007 15KV
1mm WD30


c
a
d
b
0001 15KV
100Pm

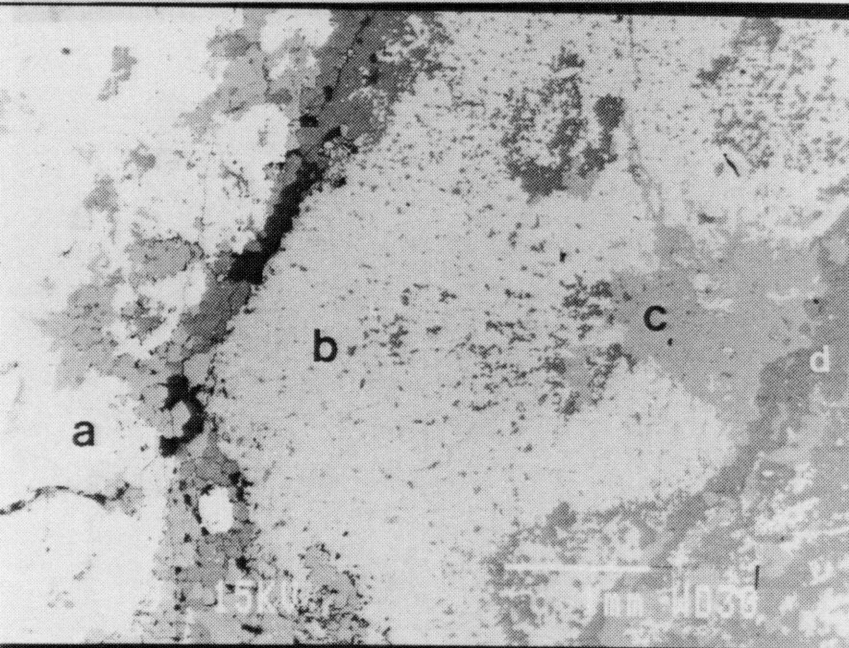

a
b
0240 15KV
100Pm WD27

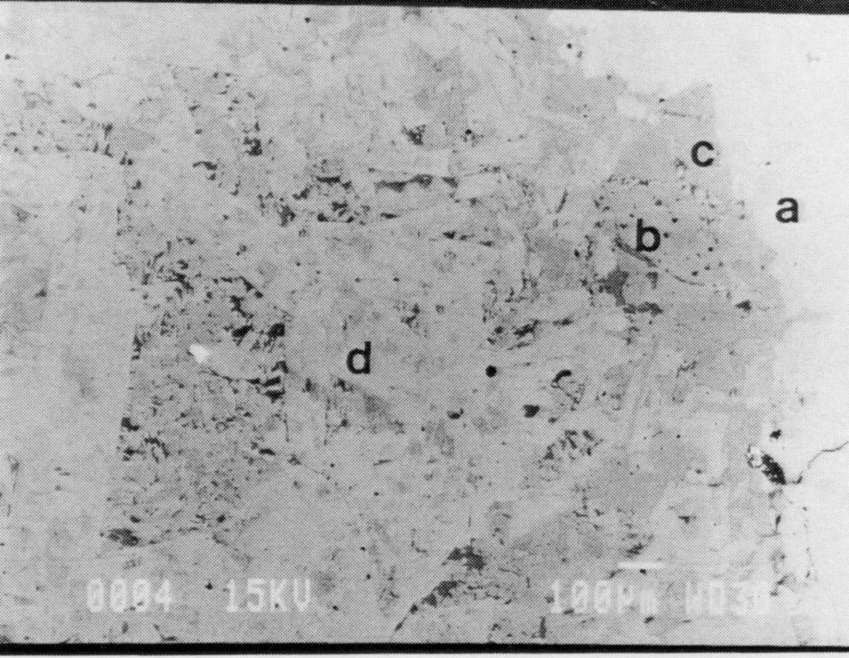

b
a
a
a
0246 15KV
10μm WD27

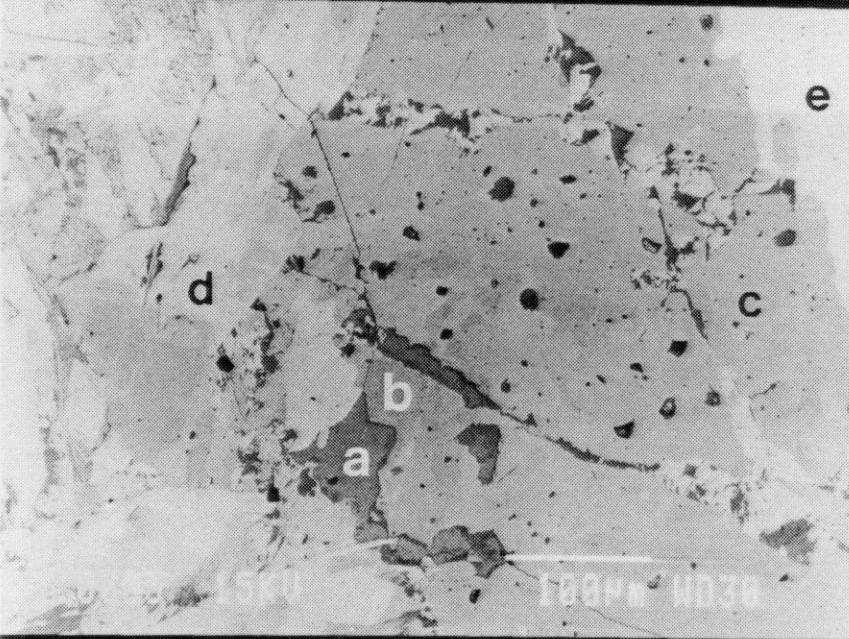

b
a
c
d
0008 15KV
1mm

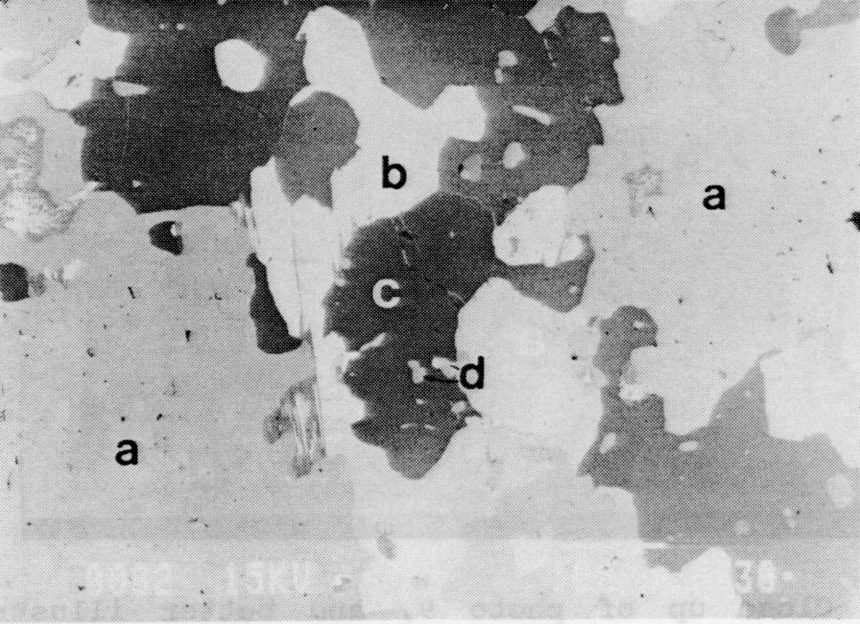


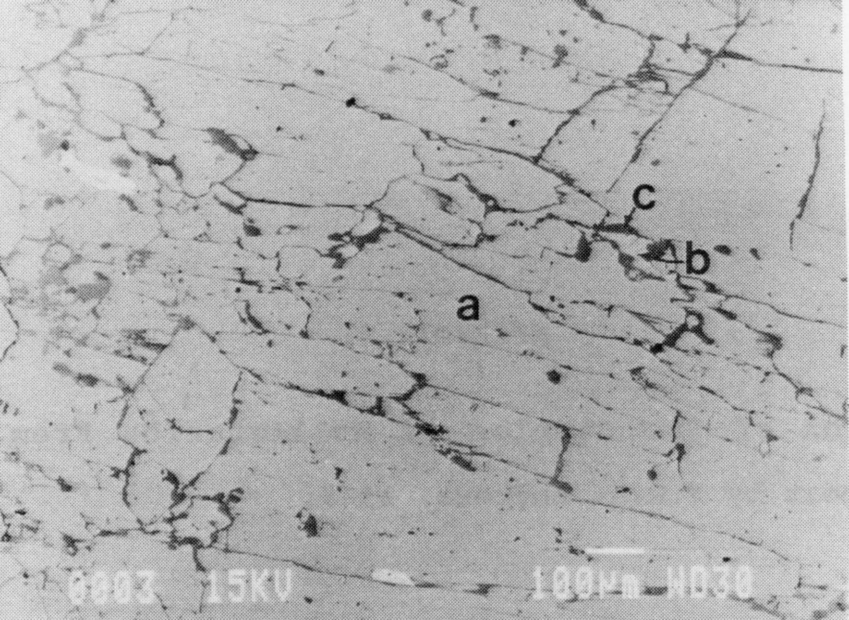
c
b
a
d

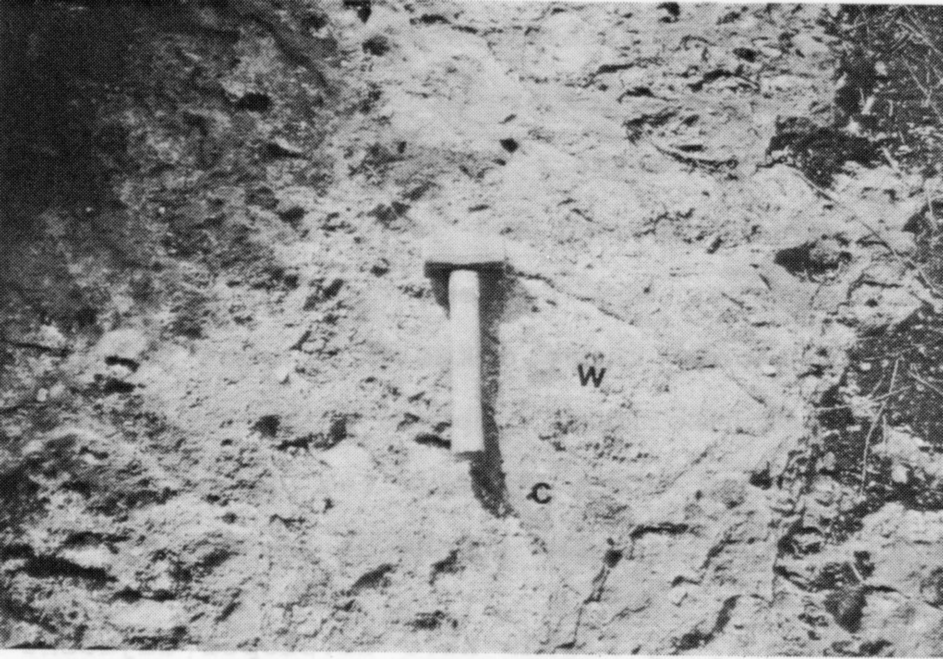

a
b
c
d
15KV
1mm WD36


c
a
b
d
0004 15KV 100µm WD3

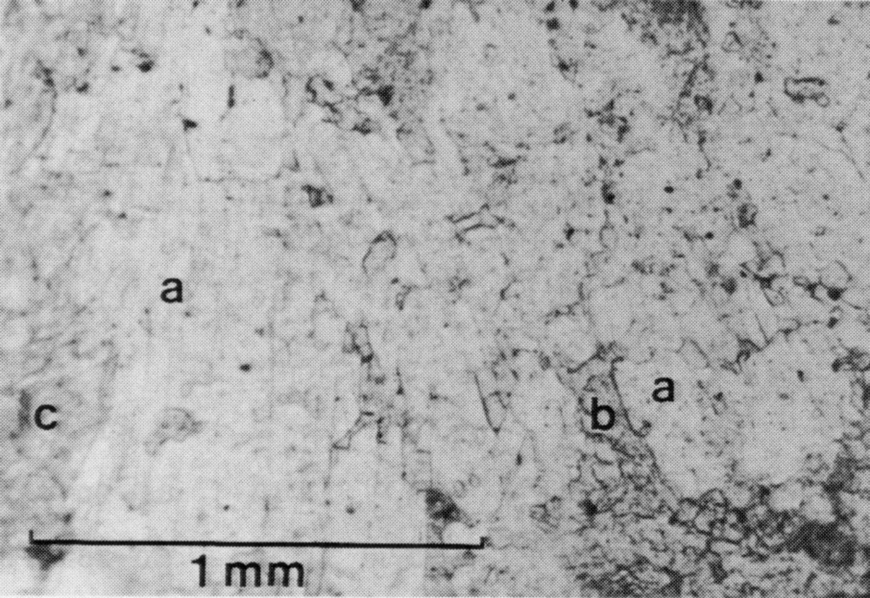

e
d
c
b
a
15KV
100μm WD30

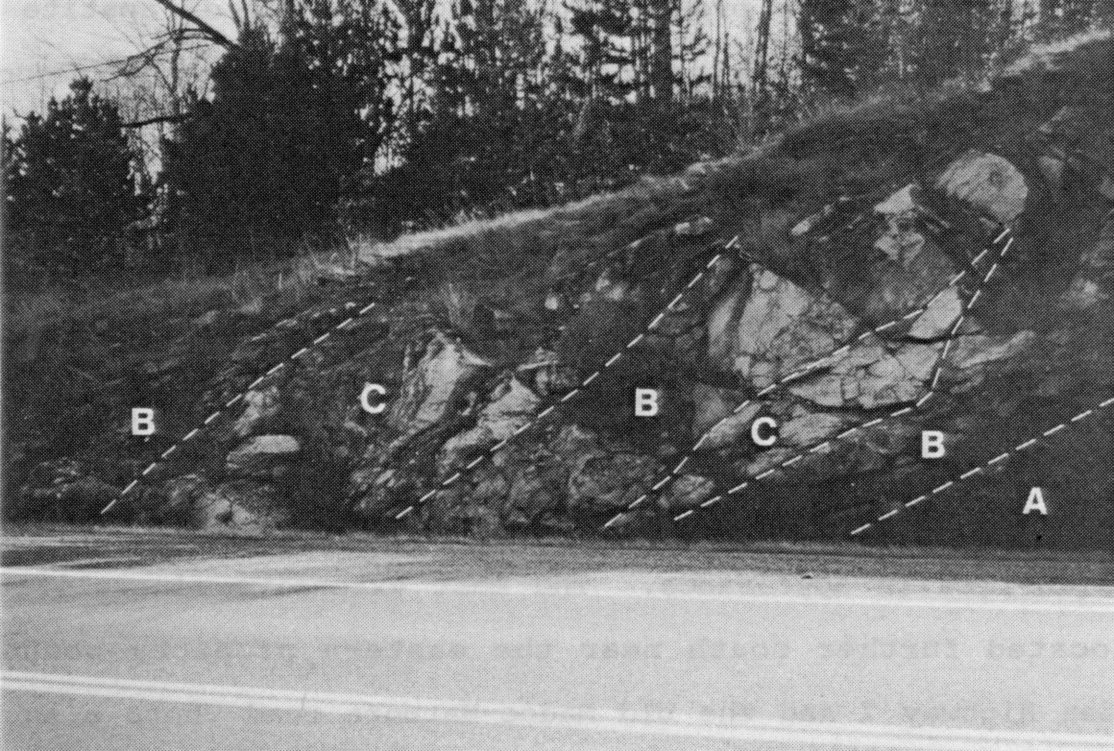

b
a
c
d
a
0092 15KV
30


c
b
a
0003 15KV 100µm WD30


W
C


W
C


a
c
b
a
1 mm


B
C
B
C
B
A