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Graphite Occurrences of the Frontenac Axis, Eastern Ontario

Ontario Geological Survey
Mineral Deposits Circular 33

A. MacKinnon and P.S. LeBaron

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Foreword

Graphite mining in eastern Ontario began in the late 1800s and continued until the closure of Canada's largest graphite producer, the Black Donald Mine, in 1954. Recent increases in flake graphite prices have revived interest in eastern Ontario graphite occurrences. Four of the 6 major graphite occurrences described in this report have been the focus of detailed exploration programs. Significant reserves of high-quality flake graphite have been delineated on two of the properties; the Kirkham property of Stewart Lake Resources Inc. and the Cornell property of Victoria Graphite Inc., both of which are being considered for production.

The descriptions contained in this report will be useful in the development of exploration programs for graphite occurrences within the Frontenac Axis of eastern Ontario and in other similar geological environments.

V.G. Milne

Director
Ontario Geological Survey

Abstract

Precambrian metasediments of the Frontenac Axis, an area of high-grade metamorphism within the Grenville Province of southeastern Ontario, host significant occurrences of flake graphite. Of 6 major occurrences examined in the course of this study, 4 are undergoing active exploration. Two of these—the Kirkham property of Stewart Lake Resources Inc. and the Cornell property of Victoria Graphite Inc., with production still pending, reported reserves of 1.5 million tonnes (Mt) at 9.5% graphite and 300 000 t at 6% graphite, respectively.

The occurrences consist of flake graphite disseminated in marble. Features common to these occurrences include proximity to a major fault, association with paragneiss units interlayered with the host marble and the presence of pegmatite bodies. Most occurrences show strong deformation and are highly variable in dimensions and attitude. They exhibit features which suggest that the graphite has formed from organic matter in the original sediment (disseminated flakes) and that some remobilization and local concentration (graphite-rich pods and lenses) has occurred, possibly the result of contact metasomatism and/or ductile deformation.

The major consumers of flake graphite are foundries and manufacturers of refractories and crucibles. Other applications include lubricants, brake linings and pencil leads.

The recent discovery of substantial reserves of high-quality flake graphite within previously known occurrences suggests that there is good potential for additional discoveries within the Frontenac Axis.

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Résumé

On trouve d'importants gisements de graphite en paillette dans les roches métasédimentaires précambriennes de l'axe de Frontenac qui représente une zone de métamorphisme élevé au sein de la Province de Grenville dans le sud-est de l'Ontario. Sur les 6 gisements majeurs examinés au cours de cette étude, 4 sont actuellement l'objet d'exploration. Deux de ces gisements, la propriété Kirkham de Stewart Lake Resources Inc. et la propriété Cornell de Victoria Graphite Inc. dont les réserves respectives sont de 1,5 millions de tonnes (Mt) avec une teneur en graphite de 9,5% et 300 000 t avec 6% de graphite, auraient dû commencer à produire en 1991.

Les gisements sont constitués de graphite sous forme de paillettes disséminées dans du marbre. Plusieurs caractéristiques sont communes à ces gisements comme la proximité d'une faille majeure, l'association avec des unités paragneissiques intercalées avec le marbre encaissant et la présence de masses pegmatitiques. La plupart de ces gisements montrent une déformation importante et sont très variables en taille et disposition. Ils montrent des traits qui suggèrent que le graphite s'est formé à partir de matière organique dans les sédiments d'origine (paillettes disséminées) et qu'une certaine remobilisation et concentration locale (amas et lentilles riches en graphite) se soient produites, peut-être à la suite de métasomatisme de contact et/ou de déformation ductile. Les principaux consommateurs de graphite en paillette sont les fonderies et manufactures de produits réfractaires et de creusets. D'autres applications comprennent les lubrifiants, garnitures de freins et mines de crayons.

La découverte récente de réserves importantes de graphite en paillette de très bonne qualité dans des gisements déjà connus laisse supposer qu'il existe des possibilités de découvertes supplémentaires dans l'axe de Frontenac.

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Graphite Occurrences of the Frontenac Axis, Eastern Ontario

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Introduction

Several of Ontario's major flake graphite occurrences are located in eastern Ontario within an area of granulite facies metamorphic rocks known as the Frontenac Axis, a subdivision of the Central Metasedimentary Belt of the Grenville Province. These occurrences are all located within 5 km of the Rideau Lake fault, a major northeasterly trending structure that transects the Frontenac Axis about 50 km north of Kingston (Wynne-Edwards 1967); all are hosted by crystalline marble which is interlayered with paragneiss and intruded by pegmatite bodies; and most have undergone complex folding and faulting which has produced graphitic zones of highly variable thicknesses and attitudes.

Six major occurrences are described in detail in this report. Descriptions are based upon geological field work performed in 1988 by Stephen Black (Consultant Geologist, Sharbot Lake, Ontario) and Alistair MacKinnon, and previously published reports, assessment files and unpublished company reports. Other graphite occurrences within eastern Ontario are listed in the "Appendix".

The recent high level of exploration activity for graphite in Canada has been generated by high prices and new market opportunities resulting from a decrease in exports from China, the world's largest producer and exporter of graphite (Russell 1988). At the time of writing, Canada produced graphite from a mine operated by Stratmin Graphite Inc. near Mont-Laurier, Quebec, and from the Graphite Lake Mine near Huntsville, Ontario, operated by Cal Graphite Corporation. However, several properties which are under development by various companies in Ontario and Quebec were to have begun production in 1991.

The descriptions of graphite occurrences are preceded by an introductory section on graphite as an industrial commodity, which includes information on world production and consumption, uses, prices and market outlook. It is hoped that this report will encourage and assist the reader in developing exploration programs for graphite within the study area and in other similar geological environments.

ACKNOWLEDGMENTS

Considerable information in this report was obtained from unpublished reports prepared by various companies engaged in active exploration within the study area. In particular, the authors would like to thank R.G. Hawley (President, Oso Exploration Services Ltd. and Field Manager for Lodi Metals Inc.), A. Menard (Geologist, Stewart Lake Resources Inc.) and Dr. A.H. Klein (President, Victoria Graphite Inc.) for providing access to their properties and company information.

Geological mapping of the graphite properties was done by Stephen Black (Consultant Geologist, Sharbot Lake) during the 1988 field season.

P.W. Kingston (Resident Geologist, Southeastern District, Tweed) initiated the study and reviewed the final manuscript.

LOCATION OF THE STUDY AREA

The study area is located about 40 km north of Kingston, from lat. 44°30′ to 44°55′N and long. 76°05′ to 76°40′W, covering parts of Frontenac, Leeds and Lanark counties. Figure 1 shows the townships which host the major graphite occurrences within the study area.

Access to the general area is via highways 38 and 15. A network of county roads, concession roads and cottage roads provide good access within the study area.

WORLD PRODUCTION AND CONSUMPTION

The world production of graphite can be divided into 2 categories; natural crystalline and amorphous. The former can be further subdivided into flake, vein and powder. This classification scheme reflects the various modes of occurrence of graphite, which account for the differences in its physical properties and appearance. Major world producers are listed by type in descending order of importance: flake graphite—China, Brazil, India, USSR, Madagascar, West Germany and Norway; microcrystalline or amorphous graphite—China, South Korea, Mexico, Czechoslovakia, Austria, USSR, North Korea and Zimbabwe; and lump graphite—Sri Lanka (Boucher 1989). Table 1 lists the combined production of all types of graphite by country.

In 1988, world production of graphite totalled 703 000 t (Taylor 1989), of which approximately 40% was flake graphite (Boucher 1989). The 3 largest producers are China, South Korea and the USSR. China has the greatest influence on world markets, being the largest producer and exporter of graphite in the world, with totals of 185 000 and 80 000 t, respectively, in 1988 (Boucher 1989). Other major exporters and importers are listed in Table 2.

Most graphite producers are net exporters to varying degrees, with the exception of the Eastern Bloc countries, where the majority of production is consumed domestically. Japan, the United States, West Germany and the United Kingdom are the main importers of graphite, with total imports in 1987 of 94 268, 43 335, 30 504 and 19 729 t, respectively (Boucher 1989).

Boucher (1989, p.31.5) reported: "The largest consumers of graphite are the large producers of iron and steel, base metals and precious metals. Together they consume about 50% of all graphite and they are the largest users of flake graphite. The largest consumers are: U.S.S.R., Japan, United States, China, West Germany, United Kingdom, Italy, France and Brazil."

The United States relies primarily upon production from foreign sources for its supply of natural graphite,

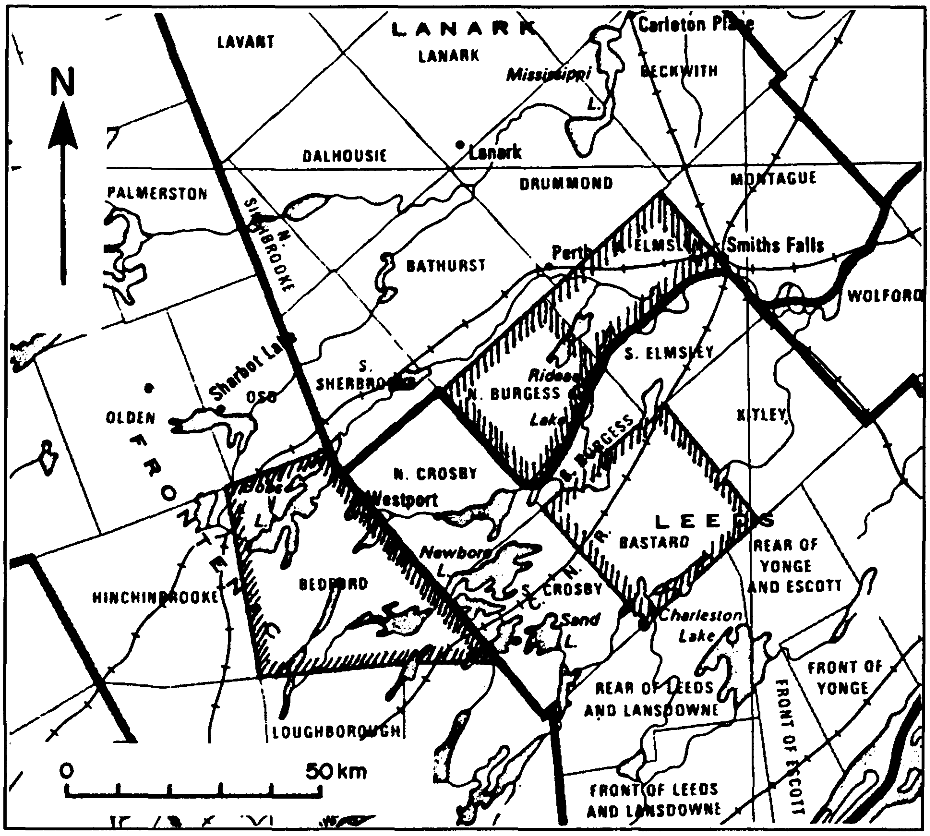


Figure 1. Location map of the study area, showing the townships which host major graphite occurrences.

Table 1. World production of graphite, 1987 (*modified from* Russell 1988).

Country	Production (tonnes)	% of World Production
China	185 000	28.8
South Korea	99 765	15.5
USSR	84 000	13.1
Brazil*	47 000	7.3
Austria	39 391	6.1
Mexico	37 000	5.8
India	26 864	4.2
Czechoslovakia*	25 254	3.9
North Korea	25 000	3.9
West Germany	13 600	2.1
Zimbabwe	13 530	2.1
Madagascar	13 168	2.0
Romania	12 000	1.9
Turkey	11 760	1.8
Sri Lanka	9 400	1.5
World Total	642 732	

* *1986 figures*

Table 2. Major exporters and importers of graphite in recent years (*modified from* Boucher 1989).

	Exports (000 t/y)		Imports (000 t/y)
China	70–80	Japan	70–90
South Korea	35–45	United States	40–47
Mexico	20	West Germany	30–35
Madagascar	15	United Kingdom	20–22
Zimbabwe	13	Taiwan	8
Austria	10	Italy	6
West Germany	10	France	5
Brazil	9	Austria	4
Norway (when exports resume)	5–7		

some of which is in turn exported. In 1988, imports for USA consumption were estimated to total 58 000 t (Taylor 1989) and exports to Canada were valued at $3 021 000 (Boucher 1989). The major import sources (1984–1987) are Mexico (44%), China (26%), Brazil (10%) and Madagascar (6%). Graphite was produced in the USA in 1988, but production figures were not released (Taylor 1989).

Canada produces no amorphous graphite and until recently, it produced only a small quantity of flake graphite on an intermittent basis from a mine and plant operated by Asbury Graphite Quebec Inc., located near Notre-Dame-du-Laus, Quebec. The majority of this production was exported to its parent company, Asbury

Graphite Mills Inc. of Asbury, New Jersey, in the United States. Since 1989, 2 new mines have come into production and the Asbury mine has been closed. The Lac des Iles Mine of Stratmin Graphite Inc. in Quebec and the Graphite Lake Mine of Cal Graphite Corporation in Ontario are both expected to produce 20 000 tpa of flake graphite concentrate (Russell 1991). Canadian consumption of crude graphite, which totalled 14 217 t in 1987, is dominated by Ontario (70%) and Quebec (15%) (Boucher 1989).

WORLD RESOURCES

The U.S. Bureau of Mines estimates that economic reserves of graphite total 29 million tonnes (Mt) and the reserve base, including demonstrated reserves, marginally economic and subeconomic resources, is estimated at 151 Mt. Total world resources are estimated at almost 1350 Mt, divided between flake (40%), vein (5%) and amorphous (55%) varieties (Roskill Information Services 1987).

USES

This section describes the major applications of graphite, the type of graphite that is typically used and its contribution to the product.

In the United States, the main uses of graphite are in refractories (26%), dressings and moulds in foundry operations (15%), lubricants (14%), brake linings (13%), pencils (7%), steel making (5%) and other applications (20%; Taylor 1989). Consumption by Canadian manufacturing plants in 1987 was distributed among foundry facings (70%), ferro-alloys and primary steel (7%), refractories (5%) and other applications (18%), which include use in brake linings, chemicals, abrasives and batteries (Boucher 1989).

These products utilize one or more of the inherent qualities of graphite such as high thermal and electrical conductivity, non-wettability, thermal and chemical resistance, unctuousness, softness, low coefficient of friction, high strength to weight ratio, and its purity as a source of carbon.

Refractories

The largest consumer of graphite is the refractories industry, which uses both crystalline flake and amorphous varieties. The most common refractory products include crucibles, refractory brick and plastics, stopper heads, nozzles, retorts, shrouds, continuous casting powders, core and mould washes, and hot top compounds.

Approximately 40% of flake graphite is used in the manufacture of crucibles for the steel, nonferrous and precious metals industries (Russell 1988). Flake graphite is preferred to microcrystalline graphite for this application because it burns more slowly, has a high attrition resistance and imparts structural strength (Boucher 1989). The anisotropic quality (exhibits different characteristics when measured along the different axes) of the flake makes it extremely resistant to chemical reaction and oxidation when properly aligned, a feature which also improves thermal conductivity and other characteristics desirable in the crucible (Hand 1986).

The addition of graphite improves thermal shock and corrosion resistance in refractory bricks and plastics. These refractories, such as magnesia-carbon bricks, are used in areas of high intensity heat and corrosion. High thermal shock resistance, particularly essential in the continuous casting process, is provided by graphitized alumina refractories which are used to control and protect the metal flowing from the ladle to the water-cooled mould. The refractories are subjected to molten steel at temperatures up to 1600°C with little or no preheat (Robbins 1984). Other reasons graphite is used include thermal conductivity, non-wettability, compressibility (malleability) shrinkage resistance and lubrication (helps reduce die wear).

Both flake and amorphous graphite are used in refractory brick and plastics. The higher quality bricks and plastics generally use flake graphite, which is typically higher in carbon content and has better thermal and chemical characteristics than amorphous grades. The flake ranges in carbon content from 90 to 97% and in particle size from + 80 mesh to + 100 mesh. The amorphous graphite ranges in carbon content from 70 to 80% and in size from less than 0.75 inch to -30 mesh (Hand 1986).

In continuous casting powders, graphite is used to provide thermal insulation and to vary melting rates. Hand (1986, p.23) reported: "The continuous casting powder is added under the tundish and on top of the mould. Once the mould powder becomes a liquid, the graphite is freed to rise above the molten material and provide insulation in the form of a metal cover." Crystalline flake is usually used, typically with carbon content ranging from 80 to 95%. The particle size is generally -70 mesh.

Core and Mould Washes

Graphite is used in core and mould washes because it is not wetted by metal, therefore, it promotes separation of the casting from the mould; it combines with oxygen, keeping the oxygen from the casting; and it provides a smooth surface, which reduces machining costs. Either flake or amorphous types can be used, with carbon content ranging from 80 to 90% for flake graphite and 70 to 80% for amorphous graphite. Particle size for both types is commonly + 220 mesh (Hand 1986).

Lubricants

Graphite's softness, low coefficient of friction, inertness and heat resistance make it ideal as a dry lubricant and a lowercost alternative to molybdenum disulphide (Garland 1987). The graphite typically used is high carbon (96 to 99%), fine crystalline and less than 1 micron in size.

Brake Linings

The use of graphite moulded in resin for brake and clutch linings reduces the rate of wear and the coefficient of friction by acting as a lubricant. Boucher (1989, p.31.4) reported: "High carbon fine crystalline graphite, below 75 microns, is used with a minimum carbon content of 98%, although a concentrate of 90% can be used if abrasive impurties such as silica are at a low level." Blends of natural and synthetic graphite at a ratio of 60:40 (natural, synthetic) are often used, premixed to the manufacturer's particular specifications (Robbins 1984).

Pencil Leads

Pencil lead is perhaps the most widely known application of graphite, but it represents only a small portion of the total market (7%). This application utilizes the ability of natural graphite to mark. The degree of hardness of a pencil is determined by the ratio of clay to graphite within the lead. The type of graphite used is finely ground, microcrystalline with carbon content generally greater than 90%, but cheaper grades may require only 80 to 82% C (Robbins 1984).

Powder Metallurgy

In powder metallurgy (sintering), high purity graphite is mixed with metal powder in dry form, heated and formed into specific shapes (i.e., cogs in gears). The graphite acts as a lubricant and as a source of carbon to strengthen the metal. The carbon content must be between 96 and 99% and particle size should average 5 microns (Boucher 1989).

Recarburizer

Amorphous or synthetic graphite is used as a recarburizer to increase the carbon content of iron melted in electric furnaces charged with large proportions of scrap. Flake graphite is not used due to its softness and lubricating nature, which may cause weakness and cracking in the steel (Robbins 1984).

Exfoliated Graphite

Exfoliated graphite is an expanded form of graphite produced by vaporization of a chemical substance which has been introduced into the lamellar structure of the graphite crystal by various treatments, such as the reaction of graphite with a mixture of sulphuric and nitric acids. The exfoliated product exhibits very low density and high temperature resistance and can be compressed into a material with high lubricity and flexibility. Potential applications for exfoliated graphite include high temperature gaskets, seals, packing material, fire extinguisher agent, thermal insulator and conductive resin composites (Hawley 1988).

Other Uses

Additional applications include batteries, brushes in electric motors, alternators and generators, engineering components, conductive coatings and paints, polishes, rubber products and explosives.

SPECIFICATIONS

Flake graphite is classified into concentrates as large, medium and fine flake; vein graphite into lump sizes; and amorphous graphite as amorphous or powdered. Flake size describes a specific percentage of concentrate which is retained on or passes through a specified mesh size (i.e., 75% on +40 mesh, or 425 microns). Further distinctions are made on the basis of the minimum carbon content, expressed as % carbon. Table 3 presents graphite specifications from several of the major producing countries.

In addition to flake size and carbon content, the types of impurities are important to the consumer, since they may have a direct influence on the quality of the finished product. For example, the crucible industry can accept graphite with a carbon content as low as 80%, provided that the alkali content of the impurities is less than 2%, since graphite containing an alkaline ash cannot withstand the high temperatures to which the crucibles are exposed. Thus, the quantity of ash within the graphite is not as important as its composition. The manufacturers of alkaline-manganese batteries require graphite free of metallic impurities such as arsenic, cobalt, copper, antimony, etc. The powder manufacturers require low abrasive type (silica) ash content, whereas a high silica or silicate ash content is desirable in low-grade graphite applications. The amount of ash is not important for most low-grade applications. Sulphides accelerate the decomposition of a coating or paint and are, therefore, undesirable (Fogg and Boyle 1987). Specifications for a variety of applications are shown in Table 4.

It should be noted that different sizing practices are employed at different operations and that the size designation as large, medium or fine implies parameters (particle size distribution and carbon content), which vary according to the producer and type of graphite (flake, vein or amorphous varieties). The consumer must, therefore, select the product which best suits his requirements. This lack of standardization is a consequence of the nature of the graphite industry itself, which has for many years sold graphite as a specialized item with the specifications agreed upon by the supplier and customer. Russell (1988, p.24) reported: "Now in a few major applications, particularly in the area of refractories, it has become a commodity item, where deviations in the price are frequently associated with deviations in quality and customers constantly switch between suppliers in attempts to secure the best deals."

Table 3. Specifications for major crystalline graphite producers (*modified from* Robbins 1984).

Crystal size		% Carbon content	Price/tonne
Madagascar			
Large flake:	75% on 40 mesh 97% on 60 mesh	85–89.5% to 92–94%	US$850 to US$1140
Medium flake:	25% on 40 mesh 97% on 80 mesh	80–84.9% to 90–92.5%	US$750 to US$978
Fine flake:	25% on 40 mesh and 75% on 60 mesh (maximum), 95% on 80 mesh (minimum)	75–80% to 89–92.5%	US$636 to US$886
Extra fine flake:		70–75% to 85–90%	US$407 to US$494 Prices FOB* Madagascar, June 1984
Brazil			
Large flake:	60% on 60 mesh 90% on 80 mesh 3% through 200 mesh	85–89%, Ash content 13%. Equivalent to Chinese V85 grade	US$700 Prices FOB* Santos, March 1984
Fine flake:		85–99.6%	US$420 to US$2250 Price FOB* Santos, June 1984
China			
Large flake:	80% on 50 mesh	85% to 90%	450 to 550 pounds
Medium flake:	80% on 80 mesh	85% to 90%	350 to 450 pounds
Small flake:	50% on 80 mesh	80% to 90%	200 to 275 pounds Prices UK CIF**. NB: UK foundry users reporting 125 pounds for 80% carbon amorphous
Norway			
Large flake:	Above 100 mesh	85% to 95%	450 to 700 pounds
Medium flake:	150+ mesh	85% to 95%	400 to 600 pounds
Powder:	Below 200 mesh	80% to 95%	200 to 400 pounds Prices UK CIF**, June 1984. NB: Norweigian prices fall within the above general range
Sri Lanka			
Large lump/lump:	+10 mm	92% to 99%	US$550 to US$1100
Chippy dust:	-5 mm	80% to 99%	US$205 to US$1100
Powders:	Below 200 mesh	70% to 99%	US$180 to US$1250 Prices FOB* Colombo, June 1984
West Germany			
Powders:	N/A	50% to 99.99%	DM600 to DM20 000. Prices ex-works, June 1984. Average price DM1900 to DM2000
Zimbabwe (Lynx mine)			
Flake:	50% on 315 microns 85% to 160 microns	90% to 92%	Subsidiary of West German company Graphitwenk Kropfmürl A.G. Produchon 13 000–15 000 tpa

* *FOB – free on board*

** *CIF – cost, insurance, freight*

SUBSTITUTE MATERIALS

Natural graphite has few substitutes because alternative materials are usually either more costly or do not perform as well.

In steel making, anthracite coal, petroleum coke and used carbon electrodes are commonly used alternatives to graphite. Calcined coke and other carbon materials are satisfactory substitutes in certain foundry core and mold washer applications. Molybdenum disulphide

Table 4. Specifications for graphite for various applications (*modified from* Russell 1988).

Application	Average carbon content %	Average flake size	Comments
Foundries (Amorphous)	40–70	Mesh size BSS* 200 to 300	Sulphides deleterious, quartz and mica advantageous.
Crucibles	80–90	+100 BSS mesh	Primarily crystalline flakes, large flake size. Varies – can be typically 75% +30 mesh, 75% +40 mesh or 75% +50 mesh.
Refractory bricks – amorphous	70–80	–0.75 inch and –30 mesh	
– flake (higher quality bricks)	90–97	+80 mesh to +100 mesh (sometimes up to +200 mesh)	Over the last few years a trend towards using finer sizes and higher carbon materials has developed.
Magnesia–carbon bricks	min 85 optimum 87–90	+150µm to –710µm or 70% on No 210 BSS mesh	Flake graphite used. Aspect ratio should be 20:1 (i.e., flake length to width). Ash content < 2%, but up to 10% sometimes used.
Alumina graphite refractories	min 85	–30 BSS mesh to +100 BSS mesh	
Expandable graphite	min 90	–10 to +60 BSS mesh	
Brake linings	min 98	–200 BSS mesh	Blends of 60:40 (natural, synthetic) are sometimes used.
Batteries Dry cell	min 88	85% passing. No 200 BSS mesh	Usually ground natural graphite.
Alkaline	min 98	–200 BSS mesh – can be to sizes as low as 5µm	Pure natural graphite or synthetic. Requires no impurities such as Cu, Co, Sb, As.
Brushes	95% – more usually 99	ground to a min –100 mesh, usually passes through a No 300 mesh	Usually 99% C as application cannot stand more than a 1% silica and ash impurity.
Sintering	98–99	Average particle size 5µm	Can be natural or synthetic.
Lubricants	98–99	No 150–300 BSS mesh	
Conductive coatings (amorphous)	50–55		May contain 20–25% silica.
Core and mold washes			
flake	80–90	particle size	
amorphous	70–80	200 mesh	
Pencils**	80–82		Cheaper leads
	min 90		Better pencils
			Amorphous graphite containing no abrasives or silica.

** BSS – British Standard Sieve*

*** modified from Garland (1987)*

(MoS_2) could replace graphite as a dry lubricant, but is more sensitive to oxidative conditions (Taylor 1989). Silicides, nitrides, borides and other high temperature refractories could also substitute for graphite in these uses, but at a greater expense. Substitutes for graphite used as a recarburizer include synthetic graphite, petroleum coke and metallurgical coke.

MARKET OUTLOOK

Taylor (1989) reported that the availability of graphite was satisfactory during 1988. However, industry analysts predicted supply shortages in 1989 of between 30 000 and 40 000 t because of declining Chinese exports. The decline in exports is the result of increased domestic consumption, closing of marginal mines, and drought within the country (Russell 1988). This has caused increased prices and may result in temporary shortages which should, however, be alleviated by increased production from established producers with new projects in Norway, Brazil and Canada. The recent political instability in China may also create market opportunities in countries that rely on China as a major source of graphite.

The refractories manufacturers have recently expressed concern over China's impending centralization policy for the sale of graphite, under which the various grades and sizes of graphite would be purchased from a central agency, rather than from a specific deposit as is currently the practice. Often, graphite from different deposits will differ in shape, chemical impurities and other parameters that may have a direct influence on the quality of the product. However, this should not create the problems it may have in the past when recipes were based on graphite obtained from a single source, because in recent years, the trend has been toward blended grades in refractory manufacture (Russell 1988).

Russell (1988, p.24) reported:

> Continuous casting and other refractory applications have increased steadily the amount of natural graphite consumed over the last few years. Other major growth areas, particularly in the USA, have been in non-asbestos and metallic brake linings, and gasket materials as replacements for asbestos and carbon composites. In comparsion with these growth areas, lost markets for graphite have been minimal.
>
> There also have been some new developments for graphite in ceramics, fire retardant products, and as a filler in high density mouldings. In ceramics graphite is used as a filler to assist increases in density, mostly in carbon composites. Another potential growth area is the use of expanded graphite as a fire-retardant, eg. in foam-filled furniture which combusts easily and gives off toxic fumes when alight.
>
> Another developing use of graphite is in high density mouldings, such as those used in defence systems and aerospace applications.

PRICES

Prices vary according to carbon content, flake size and distribution, and the ash content (type and amount), with price often negotiated between the buyer and seller. The value of the product increases with purity (high carbon content) and flake size (higher proportion of large flake size). Crystalline flake varieties will generally command a higher price than amorphous graphite. Two types of price listings are shown in tables 5 and 6.

Prices in *Industrial Minerals* are quoted, irrespective of the source, in US dollars per metric ton on cif (cost, insurance, freight) United Kingdom port basis (*see* Table 5). The wide price variations emphasize graphite's extensive range of specifications and applications. Currently, there are 500 to 600 grades on the market. The prices range, according to size and carbon content, from $540 to $1500 per tonne for flake graphite and from $325 to $1300 per tonne for powder (-200 mesh).

Table 5. *Industrial Minerals* pricing quotation, cif*, United Kingdom port, US$ per tonne (*from Industrial Minerals*, December 1988).

Crystalline lump, 92/99% C	$750–1500
Crystalline large flake, 85/90% C	$820–1300
Crystalline medium flake, 85/90% C	$770–1120
Crystalline small flake, 80/95% C	$540–900
Powder (200 mesh), 80/85% C	$325–360
90/92% C	$520–600
95/97% C	$770–1000
97/99% C	$1000–1300
Amorphous powder, 80/85% C	$220–440

**cif – cost, insurance, freight*

Table 6. *Chemical Marketing Reporter* pricing quotation, New York, USA basis, bags, drums, US$ per pound (*from Chemical Marketing Reporter*, December 1988).

Crystalline, powder,	88–90%	.30 – .60
	90–92%	.40 – .75
	95–96%	.60 – .90
	97% and up	.80 –1.20
Flake, No. 1 (large),	90–95%	.65 – .75
No. 2 (medium),	90–95%	.65 – .75
No. 3 (small),	90–95%	.65 – .75
Amorphous, powder		.16 – .40
powder, 97% and up,		.80 –1.20

The *Chemical Marketing Reporter* lists products purchased ex-warehouse from suppliers in the New York area (*see* Table 6). The higher prices listed are believed to reflect a degree of added processing (Fogg and Boyle 1987).

In 1988, the world market experienced major price increases of up to 40% and approximately 25% overall. Even the lowest grades of flake material rose by approximately US$100.00 (Russell 1988).

CANADIAN DEVELOPMENT AND EXPLORATION ACTIVITY

There are currently only 2 producers of natural graphite in Canada—the Lac des Iles Mine of Stratmin Graphite Inc. near Mont-Laurier, Quebec, and the Graphite Lake Mine of Cal Graphite Corporation near Huntsville, Ontario. The former began production in 1989 and the latter in 1990. Recent exploration for graphite, primarily in Ontario and Quebec, has produced a number of promising prospects, 4 of which (Mazarin Mining Exploration Inc. in Quebec; Canadian Graphite Ltd.-Northcoast Industries Ltd., Stewart Lake Resources Inc. and Victoria Graphite Inc. in Ontario) have completed feasibility studies.

A small, open pit mine owned by Asbury Graphite Quebec Inc. at Notre-Dame-du-Laus, Quebec, was operated intermittently during the 1980s, but has recently been closed. The Asbury Graphite deposit contains open pit reserves estimated at 300 000 t averaging 8% graphite. The ore consists of disseminated graphite flakes within marble associated with biotitic quartzite (Boucher 1989).

Stratmin Inc. of Montreal, Quebec, signed an agreement in 1989 to lease the Asbury Graphite Quebec Inc. 9000 t/y Notre-Dame-du-Laus milling facilities for 15 years, with options for additional five-year renewals. However, Stratmin announced a four-month closure of the mill in January 1991 (*The Northern Miner*, January 21, 1991, p.23). A new mill with a 20 000 t/y capacity built at the Lac des Iles minesite will continue to operate. Asbury is committed to purchase 5000 t from this new facility, and C.ITOH Ceramics Corp. of Japan has agreed in principle to purchase an additional 5000 t/y for 5 years. Estimated reserves at the Lac-des-Iles properties are 23.7 Mt, grading 7.5% graphitic carbon (Boucher 1989).

Mazarin Mining Exploration Inc., Quebec, is conducting exploration on 2 properties in northern Quebec: the Lac Knife and Lac Carheill properties. Preliminary metallurgical tests at the Lac Knife deposit indicated total recovery of 96%, and a size distribution as follows: +48 mesh fraction (18%), -48 +100 mesh (46.9%), -100 +325 mesh (23.3%) and -325 mesh (7.8%). The carbon content grades 98.5, 95.5, 95.6 and 78.9%, respectively (*The Northern Miner*, April 17, 1989, p.6). The deposit consists of 3 zones of graphite and sulphide-bearing quartz-feldspar gneisses with total reserves estimated at 8.75 Mt grading 14.2% graphite (*The Northern Miner*, December 4, 1989, p.14). A feasibility study was completed in 1989 and a production decision was to have been made in 1991. The anticipated annual output is 23 000 t of 95% carbon graphite concentrate (Russell 1991).

Two of the graphite properties under development in Ontario lie within the Central Gneiss Belt of the Grenville Province (Canadian Graphite Ltd.-Northcoast Industries Ltd. and Cal Graphite Corporation).

Canadian Graphite Ltd. (formerly known as Princeton Resources Corporation) and Northcoast Industries Ltd., under a joint venture agreement, are developing a flake graphite deposit near Bissett Creek in Maria Township, Ontario. The deposit is hosted by biotite-amphibole-quartzofeldspathic gneiss, and contains in excess of 16 Mt grading 3.2% graphite. A feasibility study prepared by KHD Canada Ltd. proposed a 1800 t/d mill with an expected annual production of 15 000 to 20 000 t of concentrate grading 90 to 92% C.

In 1990, Cal Graphite Corporation of Lively, Ontario, began production from a flake graphite deposit located in Butt Township near Huntsville, Ontario. The Graphite Lake deposit is hosted by mafic gneiss and paragneiss with reserves of 60 Mt grading almost 3% graphitic carbon. A 5000 t/d mill has been constructed on site, with production expected to be 20 000 t/y by 1992. A refinery to produce higher grade (greater than 94% C) concentrate at Sudbury is expected to be operational by mid-1992 (Russell 1991).

The other 2 advanced-stage, Ontario graphite properties (Stewart Lake Resources Inc. and Victoria Graphite Inc.) lie within the Frontenac Axis, a subdivision of the Central Metasedimentary Belt of the Grenville Province.

A feasibility study on the Kirkham graphite property of Stewart Lake Resources Inc. in Bedford Township reported geological reserves (proven and probable) totalling 1.5 Mt grading 9.49% graphite. Of this total, diluted mineable reserves have been calculated at 930 000 t grading 8.61% graphite (Kilborn Limited 1989). The company is awaiting environmental clearance for production (*The Northern Miner*, September 9, 1991, p.3).

A preliminary feasibility study on the Portland graphite property of Victoria Graphite Inc. in Bastard Township indicates a total of 295 000 t (possible and probable reserves) grading 6% graphite to a depth of 20 m (Elliott 1989). The company reported potential reserves of 1.6 Mt to a depth of 150 m. An existing mill has been refurbished, all pre-production testing has been completed, and environmental approval has been obtained. The company is attempting to secure financing for production start-up in 1992 (A. Klein, Victoria Graphite Inc., Gloucester, personal communication, 1991).

Four additional graphite prospects in the Frontenac Axis are currently being explored or have been examined in recent years. These prospects—the Burridge and Bawden properties in Bedford Township, the Timmins property in North Burgess Township and the Globe property in North Elmsley Township—together with the Kirkham (Stewart Lake Resources Inc.) and Portland (Victoria Graphite Inc.) properties, represent the major known graphite occurrences in the Frontenac Axis and are the primary focus of this study.

CLASSIFICATION OF GRAPHITE DEPOSITS

A common classification scheme for graphite deposits is that of Cameron (1960), who lists the following 5 major deposit types:

1. disseminated flake graphite in silica-rich metasediments
2. disseminated flake graphite in marble
3. metamorphosed coal and carbonaceous sediments
4. veins
5. contact metasomatic or hydrothermal deposits in metamorphosed calcareous sediments or marble

The graphite occurrences within the Frontenac Axis are of type 2 and type 5. These are briefly described below. For detailed descriptions of all graphite deposit types, the reader is referred to Garland (1987).

Disseminated Flake Graphite Deposits in Marble

Flake graphite occurs in metasediments as the result of conversion of organic matter in the original sediment to graphite by regional or contact metamorphism. Carbonaceous material in the sediment changes to amorphous graphite under zeolite facies metamorphism and to crystalline graphite in the amphibolite facies (Harben and Bates 1984). The distribution and amount of graphite in the rock generally reflects the amount of original carbon in the rock. However, there is clear evidence of epigenetic deposition in the form of crosscutting veins, replacement deposits and metamorphic segregations, which presents problems involving the mechanisms of mobilization, transportation and redeposition of the graphite. Various possible solutions to these problems, one of which involves the reduction of carbon from carbonate, are presented in Harben and Bates (1984).

Graphite is a common accessory mineral in marbles, generally comprising less than 1 weight % of the rock. Many blue- or grey-tinted marbles derive their colour from very minor amounts of disseminated, microcrystalline graphite.

Less commonly, graphite occurs as flakes disseminated throughout a marble unit in concentrations ranging from 2 to greater than 20%, usually defining a foliation and ranging in grain size from less than 1 mm to greater than 1 cm. These deposits are similar to disseminated flake graphite deposits in silica-rich metasediments (type 1), but are generally more variable in grade, structure and mineralogy because of the greater ductility of the marble host rocks. They are, therefore, generally smaller deposits and, with respect to current world production, are of considerably less economic importance than are the type 1 deposits (Graffin 1983).

Contact Metasomatic or Hydrothermal Deposits in Marble

These deposits occur in skarn or altered marbles and exhibit characteristics grading from the disseminated flake type to the vein type of graphite. They are generally higher in grade but of lower tonnage than the disseminated flake type, commonly consisting of massive, graphite-rich pods and lenses in the marble host rock. The Black Donald Mine, Canada's largest graphite mine, having produced 85 164 tons of graphite from 1896 to its closing in 1954, was classified as a metasomatic deposit (Hewitt 1965).

REGIONAL GEOLOGY

The study area is underlain by Precambrian rocks of the Grenville Province, which are locally overlain by Paleozoic sedimentary rocks. The following description of regional geology is summarized from Wynne-Edwards (1972).

The Grenville Province in eastern Ontario has been subdivided into the Central Metasedimentary Belt and the Ontario Gneiss Segment of the Central Gneiss Belt (Figure 2).

The Ontario Gneiss Segment is dominated by quartzofeldspathic gneisses with local areas of marble, quartzite and paragneiss of the Grenville Supergroup. Metamorphic grade is generally upper amphibolite facies. The gneisses are intruded by a variety of mafic to felsic plutonic rocks.

The Central Metasedimentary Belt hosts the rocks of the Grenville Supergroup—a suite of metamorphic carbonates, calc-silicates, quartzites, paragneisses, amphibolites and metavolcanics. These have been intruded by mafic to felsic plutonic rocks. Metamorphic grade is amphibolite facies at the northwestern margin of the belt, descreasing to greenschist facies at the centre of the belt (the Hastings Basin), and increasing to amphibolite and granulite facies in the southeast (the Frontenac Axis).

More detailed geological descriptions of the Central Metasedimentary Belt are presented in Wynne-Edwards (1967, 1972) and Carter (1984).

PREVIOUS GEOLOGICAL WORK

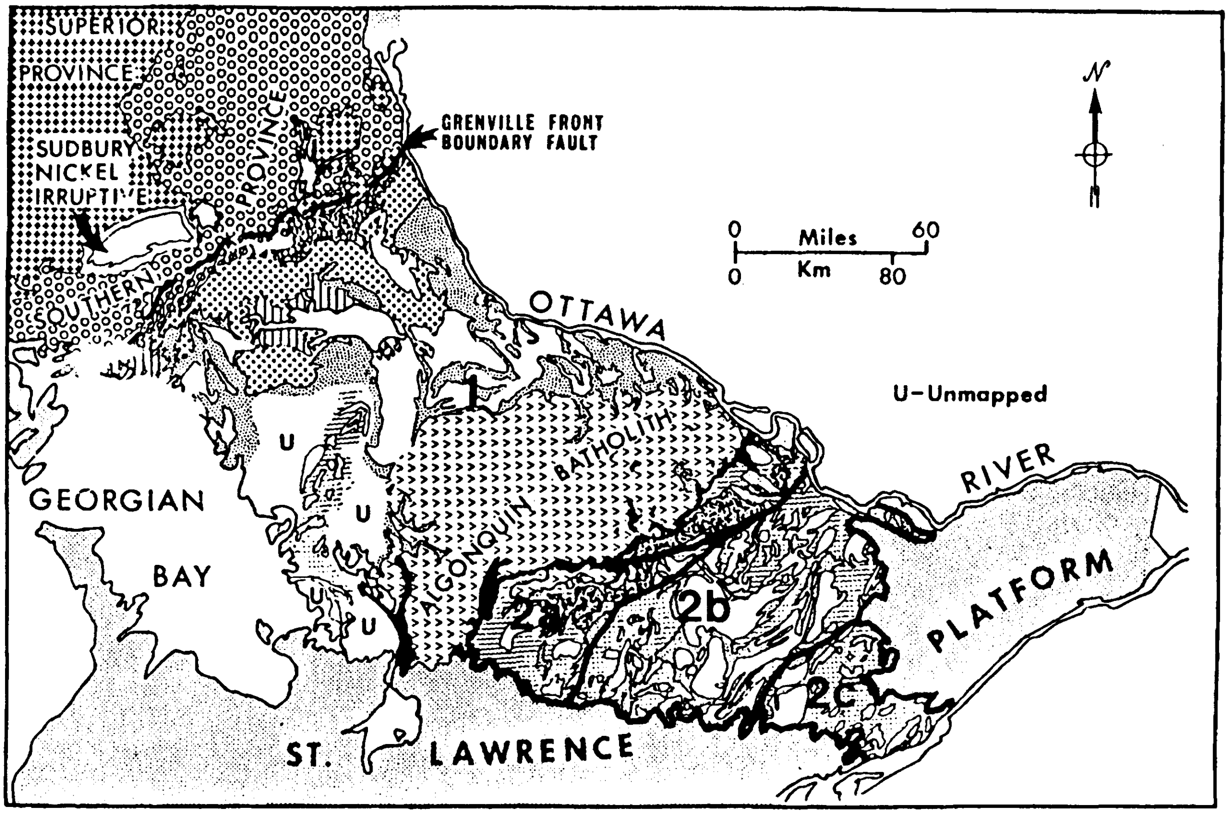
Geological mapping within the study area was done by Baker (1923), Wilson (1946), Harding (1951), Wilson and Dugas (1961), Wynne-Edwards (1965, 1967) and Williams and Wolf (1984a, 1984b). The geology of the area is also shown on compilation maps by Hewitt (1964) and Kingston et al. (1985).

The graphite occurrences of eastern Ontario are described in reports by Spence (1920), Hewitt (1965) and Papertzian and Kingston (1982). Some of the occurrences are also described in less detail by Wilson (1917), Bell (1942) and Satterly (1944).

GEOLOGICAL SETTING OF THE FRONTENAC AXIS GRAPHITE OCCURRENCES

The graphite occurrences of the Frontenac Axis lie within an area dominated by highly metamorphosed (granulite facies) sedimentary rocks and younger granitic intrusive rocks (Figure 3). The metasedimentary sequence consists primarily of calcitic marble interlayered with paragneiss. Bordering the marble belts are granite and/or granitic gneiss complexes, much of which may be of metasedimentary origin (Hewitt 1964).

The occurrences described in the following section are all located within 5 km of the Rideau Lake fault, a major transcurrent fault which trends northeasterly across the Frontenac Axis for a distance of at least 160 km. It forms a shear zone at least 500 m wide in the Precambrian rocks, and can be traced northeastward and southwestward through Paleozoic rocks as a prominent lineament (Wynne-Edwards 1967). Within the



LEGEND

PHANEROZOIC

- Unsubdivided Paleozoic sedimentary rocks

PRECAMBRIAN

GRENVILLE PROVINCE

Late Proterozoic

- Alkalic plutonic rocks
- Unsubdivided plutonic rocks
- Metavolcanics
- Carbonate and other metasediments
- Coarse clastic sequence

UNCONFORMITY

- Algonquin batholith (unsubdivided)

Early Proterozoic

- Unsubdivided plutonic rocks
- Shallow to deep water metasandstone and other metasediments
- Deep water turbidite deposits (mainly greywacke-siltstone)
- Gneissic metasediments derived from the Huronian Supergroup
- Coarse clastic sequence

UNCONFORMITY

Archean

- Gneissic Archean plutonic and supracrustal rocks

GRENVILLE AND SUPERIOR PROVINCES

- Unsubdivided early Proterozoic rocks of the Southern Province
- Unsubdivided Archean rocks of the Superior Province

GRENVILLE PROVINCE SUBDIVISIONS

1 Ontario Gneiss Segment
2 Central Metasedimentary Belt
  a. Glamorgan-Cardiff Belt
  b. Hastings Basin
  c. Frontenac Axis

Figure 2. Generalized geology (*modified from* Sims et al. 1981) and subdivisions of the Grenville Province, Ontario (*modified from* Wynne-Edwards 1972).

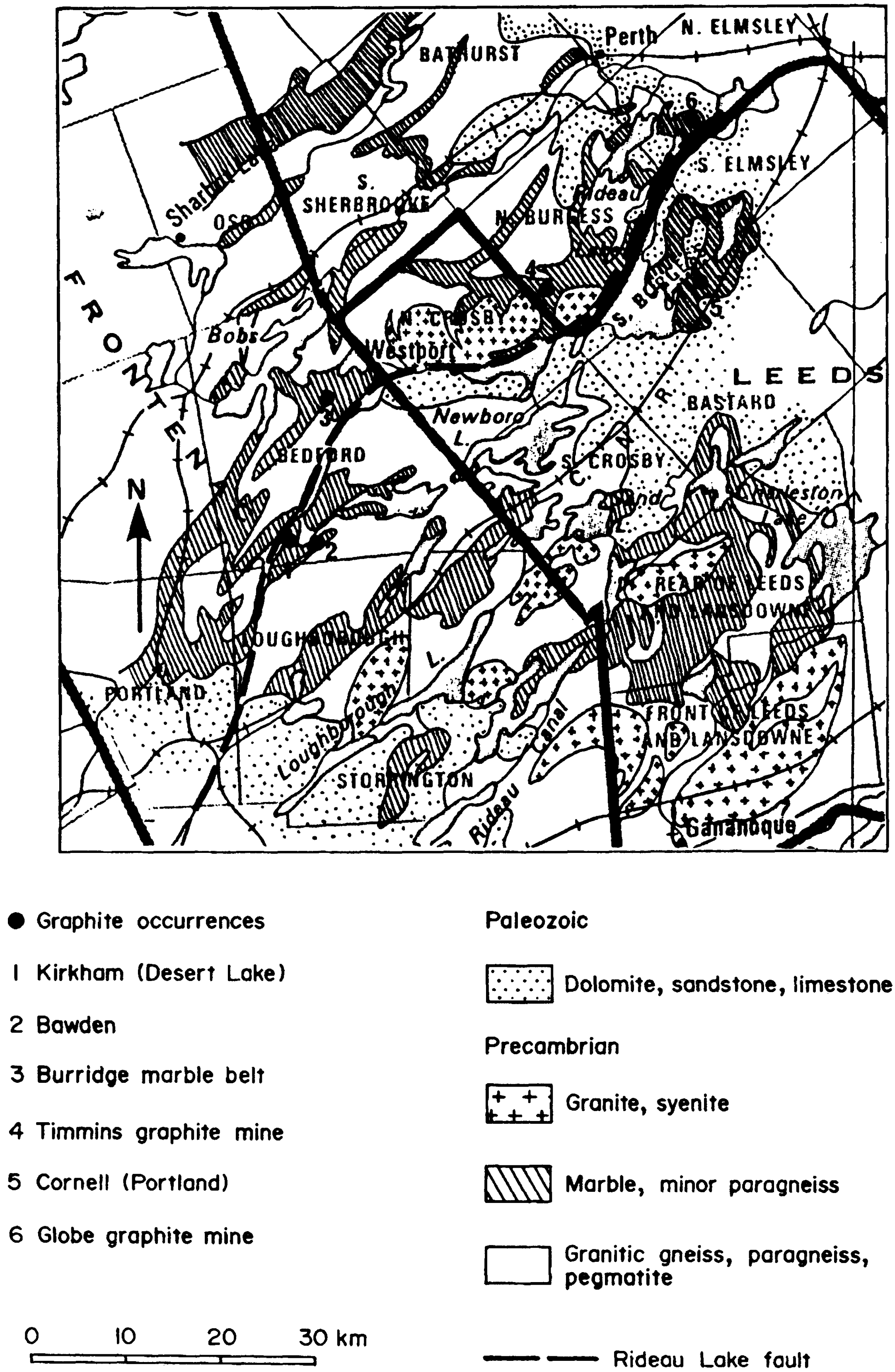
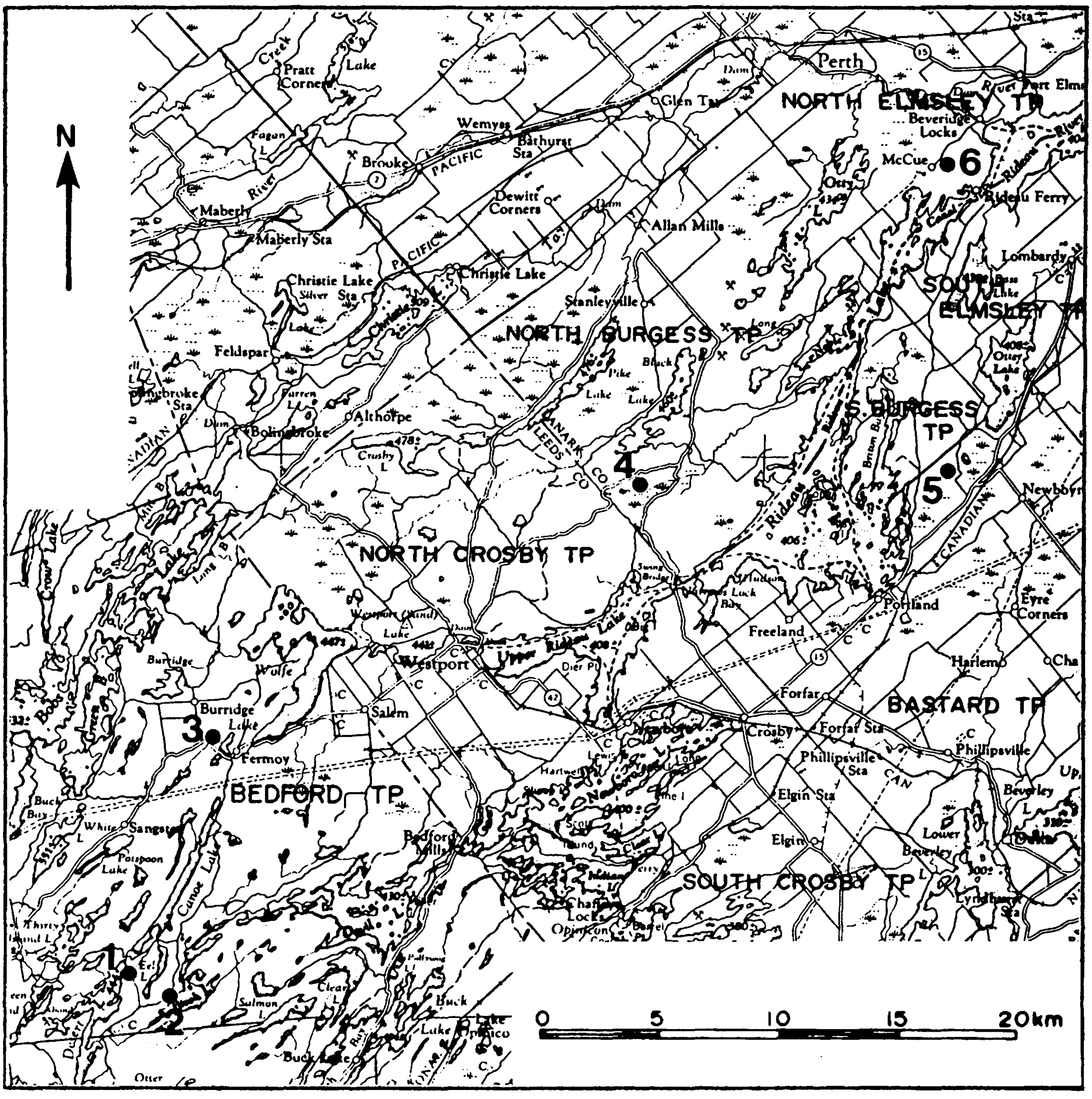


Figure 3. Generalized geology in the area of the Frontenac Axis graphite occurrences (*modified from* Hewitt 1964).

study area, the structure is also known as the Canoe Lake fault, extending through Desert Lake, Canoe Lake, Wolfe Lake, Westport Lake and into Rideau Lake.

All of the occurrences consist of flake graphite hosted by crystalline marble. Other associations common to the occurrences include the presence of paragneiss units interlayered with the marbles and the presence of pegmatite intrusions. The distinction between type 2 (flake graphite disseminated in marble) and type 5 (metasomatic or hydrothermal deposits in marble) is difficult because of the high metamorphic grade and the presence of pegmatites and calc-silicate minerals in all cases. However, some differences are apparent with respect to style of mineralization and



Graphite Occurrences

1.	Kirkham (Desert Lake)	4.	Timmins graphite mine
2.	Bawden	5.	Cornell (Portland)
3.	Burridge marble belt	6.	Globe graphite mine

Figure 4. Location map of the major graphite occurrences studied.

structural setting, described by Black and MacKinnon (1988, p.362) as follows:

> The Timmins, Burridge, Desert Lake, and Bawden occurrences all contain significant quantities of flake graphite hosted in crystalline marble and calc-silicates. The Globe and Cornell properties are hosted in siliceous marbles, and have appreciable quantities of "needle" graphite as well as equidimensional flake. The structural styles of the deposits differ markedly. The Globe, Bawden, and Desert Lake deposits are found in close association with tightly folded (synformal) structures. The Cornell and Burridge properties are found within a large series of parallel marble bands. The Timmins property is unique in that it is close to two major plutons.

Figure 4 shows the locations of the 6 major graphite occurrences described in the following pages.

Descriptions of Major Graphite Occurrences

KIRKHAM PROPERTY (DESERT LAKE PROPERTY)

Property Status

Active prospect (Stewart Lake Resources Inc.)

Location

The property, which consists of 59 mining claims, 9 of which are patented, is situated in the southwestern part of Bedford Township, about 40 km north of Kingston and 18 km northeast of Verona. The graphite occurrence lies within Lot 4, concessions IV and V, Bedford Township, Frontenac County (*see* Figure 4); lat. 44°33′40″N, long. 76°34′15″W; UTM co-ordinates 374950E, 4935050N, zone 18; NTS 31 C/10.

Access

Access to the property is obtained via Highway 38 to County Road 8 east from Godfrey, and south by cottage roads to the area between Canoe and Desert lakes.

History

In 1919, Mining Corporation of Canada Limited performed trenching, test pitting and diamond drilling (5 holes totalling 488 m) on a flake graphite occurrence on the shore of Desert Lake (Guillet 1989). In 1952, Frobisher Ltd. drilled 30 diamond-drill holes totalling 3006 m and established the presence of 2 lenses of graphite ore. The eastern lens was stripped for a length of 30 m along the shore of Desert Lake and a 270 t bulk sample was shipped to the Black Donald graphite mine near Calabogie for milling. The same company performed an electromagnetic survey in 1953, which indicated a potential strike length of over 1200 m for the graphite zone (Hewitt 1965). The following record of work done by Stewart Lake Resources Inc. is summarized from Guillet (1989).

In 1986, Stewart Lake Resources Inc. acquired 9 patented claims covering the graphite occurrence through an option from Falconbridge Limited, after having staked 12 claims along strike of the occurrence in 1985. A total of 38 additional claims were staked in 1987. Geological mapping was done in 1986, followed by a series of diamond drilling programs completed between April 1987 and March 1989. A total of about 27 000 m were drilled in 217 holes.

An airborne geophysical survey (magnetometer and VLF-EM (very low frequency-electromagnetic) was performed by Aerodat Ltd. for Stewart Lake Resources Inc. in 1987, followed by ground VLF-EM and IP (induced polarization) surveys.

Underground exploration commenced in 1988 with the construction of a decline to a vertical depth of 100 feet. Levels were established at 50 feet and 100 feet, with exploratory drifting on these levels totalling 295 and 155 feet, respectively. About 3000 tons of graphite-rich rock from this program is stockpiled on surface.

Also in 1988, 200 tons of graphite-bearing rock were shipped to the Ontario Research Foundation for pilot plant milling tests.

In 1989, a feasibility study was prepared by Kilborn Limited for Stewart Lake Resources Inc. The study reports reserves of 1.6 million tons grading 9.5% graphite in 2 separate zones and proposes a mine and mill construction schedule leading to production in November 1990. The ore is to be mined by open pit for the first 2.5 years, followed by underground mining, and processed at a rate of 250 tons per day (Kilborn Limited 1989). Additional diamond drilling is also proposed on a third, parallel graphite-bearing zone.

Geology

Figure 5 (back pocket) shows the general geology in the area of the Kirkham and Bawden graphite occurrences. Calcitic marble is intercalated with narrow units of paragneiss and wide bands of granitic gneiss. The rocks are tightly folded, with fold axes plunging northeastward. The Canoe Lake (Rideau Lake) fault forms the contact between granite and granitic gneiss to the northwest and the main marble belt to the southeast. The fault lies within about 100 m of the Kirkham graphite occurrence.

Graphite mineralization at the Kirkham property, in the area between Canoe and Desert lakes, occurs within siliceous marble as a series of northeasterly trending lenses. The lenses lie along the contact between marble and quartzitic paragneiss on both limbs of an overturned synclinal structure (Figure 6). The syncline plunges northeastward at about 25° and the west and east limbs dip eastward at about 45 and 70°, respectively (Hewitt 1965).

Stewart Lake Resources Inc. identified 3 separate graphitic zones. Zone 1 consists of the 2 lenses shown in Figure 6, and zones 2 and 3 (*see* Figure 5, back pocket), situated about 300 and 1000 m to the east, respectively, are believed to represent the same stratigraphic succession, offset from the main zone by drag folding and faulting (Guillet 1989).

Alteration of the marble along the quartzite contact to a granular aggregate of diopside, serpentine, carbonate and graphite is interpreted by Hewitt (1965) as a metasomatic replacement associated with hydrothermal solutions derived from the nearby granite.

The graphite occurs as thin flakes up to 3 mm in diameter, disseminated throughout the marble or in layers, in concentrations ranging from 2 to 20%. The graphitic lenses are highly folded and contorted, exhibiting

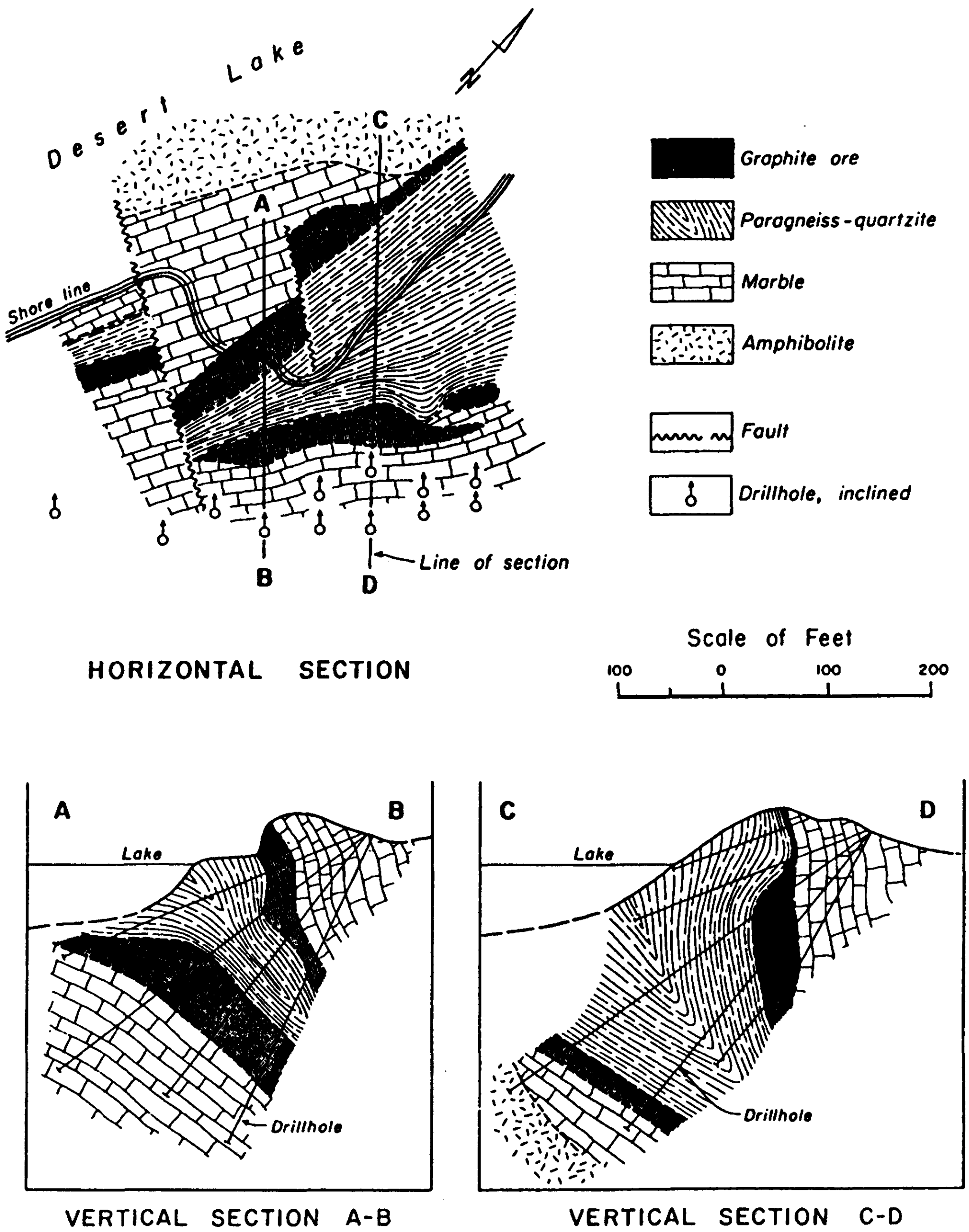


Figure 6. Structure of the Kirkham graphite occurrence (*modified from* Hewitt 1965).

large variations in dimensions and attitude over short distances. Maximum widths are in the order of 15 m, but widths of 2 to 5 m are much more common.

Total reserves of proven and probable ore in zones 1 and 2 have been calculated as 1.63 million tons grading 9.49% graphite, based on a cutoff grade of 5% C over a minimum thickness of 4 feet. Pilot plant tests indicate that the following results can be expected from the mill (Kilborn Limited 1989):

Coarse concentrate (+100 mesh)	90% graphite; 60% recovery
Fine concentrate (-100 mesh)	80% graphite; 30% recovery
Mill feed grade	8.61% graphite (average)

Various graphite products will be produced from these 2 concentrates, depending on market requirements for flake size and carbon content.

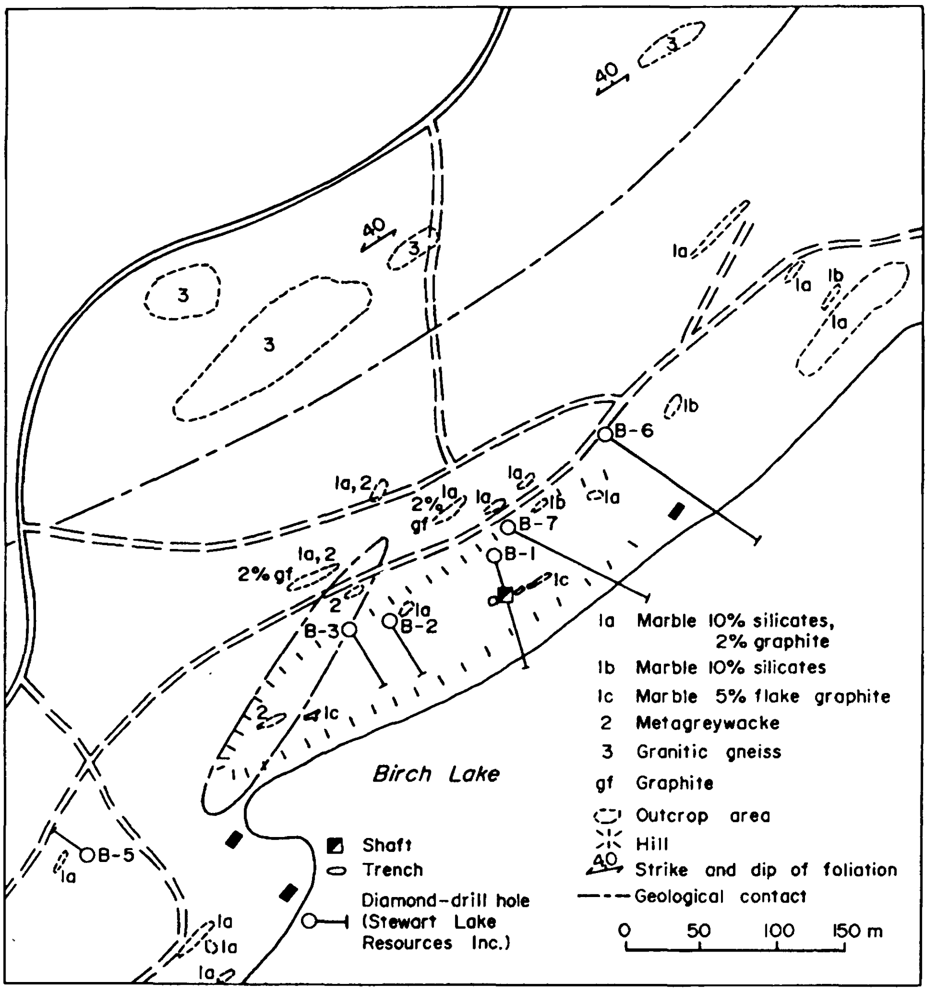


Figure 7. Geology of the Bawden graphite occurrence (*modified from* Menard 1988; Papertzian and Kingston 1982).

Comments

Stewart Lake Resources Inc. has outlined a significant graphite deposit consisting of 2 parallel zones. A third graphite zone has been identified and 12 other geophysical anomalies, which may represent graphite mineralization, remain untested. The highly variable nature of the graphitic zones with respect to dimensions and attitude suggests that detailed follow-up work in the vicinity of small surface exposures of graphite or minor geophysical electromagnetic anomalies may lead to the discovery of more extensive graphite mineralization in this area.

BAWDEN PROPERTY

Property Status

Prospect

Location

The graphite zone is exposed near the northwest shore of Birch Lake on Lot 2, Concession VI, Bedford Township, Frontenac County (*see* Figure 4); lat. 44°33′00″N, long. 76°32′55″W; UTM co-ordinates 377000E, 4933850N, zone 18; NTS 31 C/10.

Access

The Birch Lake area can be reached by cottage roads that lead around the north end of Desert and Eel lakes from County Road 8, which intersects Highway 38 at Godfrey. A bush road leads northeastward from a private cottage road directly to the showing (Figure 7).

History

Prior to 1890, Joseph Bawden of Kingston sunk a shaft to a depth of about 9 m and carried out a few metres of drifting on a graphite showing near the northwest shore of Birch Lake. It was reported that 100 barrels of graphite ore were produced and shipped to the United States (Harding 1951).

There is no record of further work until 1987 when Stewart Lake Resources Inc. carried out geological mapping, geophysical surveys and a small program of diamond drilling. Of 4 holes drilled in the area of the old shaft (*see* Figure 7) and 3 holes drilled along strike on geophysical targets, only 1 hole intersected significant graphite mineralization (1.5 m grading about 10% graphite). No further work is planned on this occurrence by Stewart Lake Resources Inc. (A. Menard, Stewart Lake Resources Inc., personal communication, 1990).

Geology

The Bawden occurrence appears to be situated in the same stratigraphic setting as that of the Kirkham occurrence, particularly that of the Stewart Lake Resources No.3 Zone. These 2 graphite zones occur on opposite limbs of a large, northeasterly plunging synclinal structure, within calcitic marble interlayered with paragneiss, close to the contact with a wide band of granitic gneiss (*see* Figure 5, back pocket).

Papertzian and Kingston (1982) examined the shaft and nearby trenches, located at the top of a marble ridge within 50 m of the shore of Birch Lake (*see* Figure 7), and reported that the showing consists of a narrow zone (less than 1.5 m wide) containing up to 5% graphite as disseminated flakes and occasional lenses and pods (1 to 2.5 cm wide) grading 15 to 20% graphite. The host marble contains traces of pyrite and 5 to 10% diopside.

Comments

The results of diamond drilling by Stewart Lake Resources Inc. indicate that graphite mineralization is not extensive. The Bawden occurrence and zones 1, 2 and 3 of the Kirkham property to the west may all represent folded and/or faulted extensions of the same graphitic unit. Therefore, although the Bawden occurrence appears to have little potential for development, it indicates the presence of a favourable stratigraphic unit which warrants further investigation, particularly in the area of the fold closure at the southwestern end of Eel Lake where structural thickening of the favourable unit may have occurred (*see* Figure 5, back pocket).

BURRIDGE MARBLE BELT

Property Status

Active prospect (Houston Management Corporation Ltd.)

Location

The property consists of 49 unpatented mining claims in central Bedford Township, Frontenac County, situated approximately 15 km northeast of Godfrey and 10 km west of Westport (*see* Figure 4); lat. 44°38′30″N, long. 76°32′55″W; UTM co-ordinates 377000E, 4944000N, zone 18; NTS 31 C/10.

Access

Access to the claims is via the Burridge Road and New Road (gravel) from County Road 8 (paved), which connects with Highway 38 at Godfrey.

History

Prior to about 1915, the area was extensively mined for galena within late-stage fault-related calcite-barite veins; production reached several million pounds of lead (King 1989). Numerous pits, trenches and shafts are located throughout the area.

The only documented occurrence of graphite within the claim group is located on Lot 18, Concession VIII, Bedford Township. Harding (1951, p.71) described this occurrence as follows:

> A prospect pit more than 15 feet deep was sunk many years ago in coarse-textured white crystalline limestone about 14 chains west of the Burridge-Fermoy road on part of lot 18, concession VIII, Bedford township. When the pit was examined in 1944, the lot was owned by George Butterill, of Fermoy. During most of the year the bottom of the pit is covered with water, which flows in from a small creek about 25 feet away. The pit was partly filled with water and debris at the time of the writer's visit, and the actual depth of the working was not obtained. The rocks in the pit and the fragments on the dump were largely obscured by vegetation. A narrow vein was visible on the north wall of the excavation. Vein minerals include barite, calcite, and a few small crystals of galena. The limestones in the pit contain abundant disseminated flakes of graphite.

In 1988, Houston Management Corporation Ltd., through staking and option agreements, acquired 49 claims. Exploration to date has consisted of preliminary field examination and sampling of accessible mineralized areas.

Geology

The Burridge marble belt is an area of crystalline marble located in the central part of Bedford Township, approximately 15 km northeast of Godfrey and 10 km west of Westport. The present investigation involved geological reconnaissance mapping of a part of the southern half of the belt, an area approximately 5 km long by 0.5 to 1.5 km wide (Figure 8, back pocket).

The area is characterized by a relatively clean, coarse-grained crystalline calcitic marble with a low graphitic content, commonly less than 1%. Calcite grains exceed 3 cm at several locations. The rock is massive, generally exhibiting a granoblastic texture, but a preferred orientation of calcite grains and a weak colour layering from white to grey is evident locally. The marbles generally strike northeast and dip 30 to 80° to the southwest.

Rusty graphitic gneiss occurs as conformable interlayers and as contorted fragments within the marble units. The gneisses are variable in composition and consist of alternating white, pink and grey bands. Individual bands are relatively homogeneous and up to 1 m, but generally 2 to 10 cm in thickness. The mineral assemblage may include quartz, diopside, scapolite, phlogopite, biotite, graphite, feldspar, garnet and pyrite.

The Grenville marbles have been intruded by granitic gneiss and remobilized granitic basement rocks (including pegmatite). The banding in the gneisses generally strikes northeasterly and conforms roughly to the strike of the metasediments. Small remnants of sediments are recognizable within the gneissic rocks. Harding (1951) reported: "Garnetiferous pink and grey gneisses, which are composed largely of quartz and feldspar, cover most of the section that lies between White Lake and Canoe Lake."

Mineralization consists of several small lenses or discontinuous conformable bands of graphite-enriched marble and paragneiss, commonly grading 2 to 5% and locally up to 10% graphite. A grab sample (GR–08–89) of calcitic marble obtained near a galena pit by the authors assayed 4.35% graphite. The graphite occurs as medium- to coarse-grained disseminated flakes, which frequently reach 3 to 5 mm in diameter.

Exploration by Houston Management Corporation Ltd. in 1988 identified an interesting graphitic zone on lots 15 and 16, Concession V, where a roughly north-trending series of graphitic marble and rusty paragneiss units host medium to coarse flake graphite. The enriched zones occur intermittently across a width of 100 m within an area of low-grade calcitic marble containing less than 1% graphitic carbon. King (1989) reported that because of limited outcrop exposure, the bands of graphitic paragneiss could only be traced for tens of metres. The bands vary in width from 3 to 5 m. Near the boundary between claims 1037728 and 1037717 (the NW 1/4 and NE 1/4 of Lot 16, Concession V), a steeply dipping band of graphitic paragneiss assayed 8.25, 11.8 and 10.7% graphite. This zone was traced along strike for 75 m. In addition, intermittent exposures of graphitic marble and rusty paragneiss grading 4 to 10% graphite across 1 to 10 m widths were reported to the south near the southern boundary of claim 1037726 (NW 1/4, Lot 15, Concession V), suggesting a possible strike length close to 700 m for the mineralized zone (King 1989).

Comments

Several occurrences of medium to large equidimensional flake, up to 6 to 8 mm in diameter were observed within the study area. The host rocks are calcitic marble and paragneiss, which commonly grade 2 to 5% graphite and locally up to 10% across 1 to 10 m widths.

The ubiquitous presence of graphite at calcite grain boundaries within the marble suggests that the formation of graphite is due to regional metamorphism and that zones of enrichment probably represent rocks originally richer in carbon.

Additional work is required to fully assess the graphite potential of the area; however, the presence of enriched zones of coarse flake appears promising.

TIMMINS GRAPHITE MINE

Property Status

Past producer, active prospect (Lodi Metals Inc.-Black Hawk Mining Inc.)

Location

The property consists of 39 unpatented mining claims, on N 1/2 lots 24 and 25, Concession IV, N 3/4 Lot 21 and lots 23–26, Concession V; and S 1/2 lots 18–25, Concession VI, North Burgess Township, Lanark County. It is located approximately 10 km northeast of Westport and 23 km south of Perth (*see* Figure 4); lat. 44°44′24″N, long. 76°18′36″W; UTM co-ordinates 396283E, 4954684N, zone 18; NTS 31 C/9, 16.

Access

The area is reached by travelling west from Perth on County Road 10, then proceeding south on North Burgess Road 3 approximately 12.5 km to the property. North Burgess Road 3 traverses the northern part of the claim group; the southern part is traversed by County Road 14 (Narrow Lock road); and the western part by a road running south along the township boundary between North Burgess Road 3 and County Road 14.

History

Frank Hines first discovered graphite in 1917 on lots 24 and 25, Concession V, North Burgess Township. In 1918, N.A. Timmins began development of the property, which continued intermittently until 1923. During this period, exploration work consisted of surface trenching and stripping, diamond drilling (6 diamond-drill holes), and in 1919, a flotation mill was erected, consisting of 2 concentrating units. Hawley (1988) reported that in 1919, 2776 tons of ore were processed, producing 150 tons of graphite concentrate, indicating an average grade of 18.5% graphite.

The property was again examined in 1942 by Charles Spearman, who submitted samples to the U.S. Department of the Interior, however, no further work resulted.

In 1951, Frobisher Ltd. drilled 20 holes (totalling 4040 feet) on 2 graphitic lenses (East and Central zones), 300 feet and 450 feet long, averaging 11.1 feet at 7.6% C and 12.7 feet at 8.4% C, respectively (Hewitt 1965). At that time, indicated reserves were estimated at 250 000 tons of 8% graphite, with an additional 750 000 tons of probable reserves (R.G. Hawley, Lodi Metals Inc., personal communication, 1988). A mill test at the Black Donald mill in Brougham Township was conducted on 150 tons of ore taken from the East zone.

Orwell Energy Corporation Ltd. obtained the property in 1981 and sent a 200-pound sample from the east and central pits to the Mineral Exploration Research Institute in Montreal, Quebec. In 1983, the company's exploration program consisted of geological mapping, diamond drilling (2 diamond-drill holes totalling 602 feet) and a double dipole electromagnetic survey (Miggliacci and Lee 1983).

Orwell allowed the claims to lapse and in 1985, 14 claims were restaked by C. Kehoe and D. Riddell. In April 1987, they optioned the property to Murcielago Corp. Ltd. The company cut a grid and conducted preliminary geological mapping in the immediate vicinity of the old mine workings.

Lodi Metals Inc. optioned the property from Murcielago Corp. Ltd. in November 1987, and in 1988 conducted geological mapping and an IP survey. Samples were sent to Lakefield Research Ltd. and Recherches Minerales in St. Foy, Quebec, for metallurgical testing.

Black Hawk Mining Inc. and Lodi Metals Inc. entered into a joint venture partnership in October 1988 to explore the property. Work completed to date consists of detailed geological mapping, SP (self-potential) and IP surveys, diamond drilling (46 diamond-drill holes totalling 4115 m), trenching (69 trenches) and stripping (R.G. Hawley, Lodi Metals Inc., personal communication, 1988).

Geology

The property is underlain predominantly by Grenvillian metasediments (marble and quartz-biotite-feldspar gneisses with minor calc-silicate rock, para-amphibolite and quartzite) which are cut by granite and granite pegmatite (Figure 9, back pocket). The metasediments are bounded to the east and west by 2 large granitic bodies, the Rideau Lake and Westport plutons, respectively. To the north lies a large area of ultrabasic migmatitic gneisses, indicative of the high regional temperatures (granulite facies) attained in the rocks of this region (Black and MacKinnon 1988).

The Westport and Rideau Lake plutons are homogeneous, subcircular bodies of red monzonite which are structurally concordant with the metamorphic rocks that enclose them. Wynne-Edwards (1967) suggested that they were emplaced in dilatant zones created at a late stage of regional deformation. The monzonite is usually coarse grained and massive. The rock is composed mainly of intergrown albite and microcline (perthite), but may contain biotite-, hornblende- and pyroxene-rich varieties. Accessory minerals include apatite, ilmenite, magnetite, sphene, zircon, pyrite and quartz (Wynne-Edwards 1967). Near the contact with marble, the pink feldspars may be bleached white. Throughout the property, particularly in the western part, small tectonic slices of this granitic material are found in close association with the graphite-rich zones.

The metasediments have been deformed around these plutons, generally exhibiting a southerly dip of 20 to 70°toward the plutons.

The marbles, in part dolomitic, are medium to coarse grained and white to tan in colour. Outcrops form low ridges or mounds and commonly weather to a coarse calcite gravel. Accessory minerals commonly include phlogopite (averaging 2 mm in diameter) and graphite. Generally, no more than 1 to 2% graphite is present in the coarsely crystalline marbles, but local concentrations may be as high as 15%.

Biotite-quartz-feldspar gneiss is distributed throughout the property and frequently occurs interlayered with the crystalline marbles. Foliation within this unit is defined by mineralogical layering. The weathered surface is often rusty to black in colour due to the presence of sulphides (pyrite). High concentrations of graphite have also been found within these rusty, pyritic paragneisses. Locally, pelitic gneisses occur interlayered with the marbles.

These gneisses consist of various assemblages of quartz, plagioclase, biotite, potassium feldspar, garnet, cordierite and sillimanite (Miggliacci and Lee 1983). A few scattered outcrops of clean quartzite were noted on the western part of the property.

The calc-silicate rock is frequently interlayered with the biotite-quartz-feldspar gneiss. Hawley (1988, p.18) reported: "quartz and calcite are ubiquitous with minor diopside, serpentine, talc, pyrite, apatite, and phlogopite. Up to 10% graphite in visual estimate is also found in this unit." A sample taken from a trench during the present investigation contained, in addition to abundant calcite, grey scapolite, light green amphibole, minor yellow and green tourmaline, dark purplish sphene, graphite and pyrrhotite.

The mineralization is hosted in both crystalline calcitic and dolomitic marbles, as well as in small areas of calc-silicate gneisses and pyritic micaceous paragneisses (Black and MacKinnon 1988). The graphite-rich zones consist predominantly of flake graphite disseminated in crystalline dolomitic marbles. Hawley (1988, p.23) described this graphite as: "commonly a good quality large flake, usually at least 2 mm in diameter and commonly up to 4 mm in diameter. The percentage of graphite found within the dolomitic marbles is usually between 4 and 8%. There are however numerous occurrences where the percentage graphite is considerably higher, ie. 10-12%."

Small lenses of calc-silicate rock containing 15% graphite are not uncommon on this property, however, flake size is considerably finer than the disseminated type, averaging 1 mm in diameter. These high-grade lenses, whether hosted in the crystalline marble or the micaceous schists, are almost always found in association with hornblende amphibolites, which vary in texture from gneissic to massive and may be intrusive in origin.

Recent mapping by Lodi Metals Inc. has identified several parallel units of graphitic marble, both south and north of the previously known deposit, and has extended the graphitic zone a considerable distance to the east (Hawley 1988). The strike length of the zone now totals at least 10 000 feet, comprised of several individual zones up to 2000 feet in length. The true width of the zone, including country rock separating graphite units, is at least 4000 feet. The zones of graphite-enriched marble are commonly 25 to 50 feet wide, and usually have a vertical or near vertical dip. The western part of the property contains numerous short graphite-rich zones averaging 100 feet in length. These zones are at various attitudes, interlayered with a series of tectonic slivers of granitic gneiss that are common in the western part of the property. Lodi Metals Inc. is attempting to locate an area in which a number of these zones are sufficiently closely spaced to allow development by open pit mining.

Other zones within the central and eastern parts of the property follow the regional structural trend more closely and may be developed as separate pits. One such area is currently being delineated in the eastern part of the property on lots 23 and 25, Concession V, where trenching exposed a 38-foot wide graphitic zone averaging 13% graphite. Drilling across the zone indicates that mineralization continues to a depth of at least 100 feet. At the time of writing, preliminary work suggested a strike length of between 400 feet and 600 feet, and a consistent width of approximately 40 feet, representing a deposit that would be amenable to open pit extraction. This property may contain a higher tonnage than was originally estimated by Frobisher Ltd. However, confirmation of this requires additional drilling.

Comments

The metamorphic rocks of the Rideau Lakes area crystallized under conditions of granulite facies regional metamorphism and later underwent partial readjustment to amphibolite facies, due to the contact metamorphic effects produced by the emplacement of the Westport and Rideau Lake plutons (Wynne-Edwards 1967). The high degree of metamorphism resulted in the recrystallization of the marbles to coarser varieties and may have caused mobilization of carbon atoms out of the carbonate, forming well-defined graphite flakes along the carbonate crystal boundaries. However, this mechanism for the formation of graphite was probably not responsible for the accumulation of graphite in the higher grade lenses. It is more likely that these were formed from material that originally had a high organic carbon content.

The property is located within 3 km of the Rideau Lake fault, which is a major structural feature at least 160 km long and at least 460 m wide. Although normal displacement took place on the fault after the Paleozoic sediments were deposited, the shear zone represents a Precambrian wrench (transcurrent) fault of major proportions (Wynne-Edwards 1967). Both the major fault and the granitic intrusions may have influenced graphite mineralization in this area.

Beneficiation problems related to the presence of mica were reported by Frobisher Ltd. in 1951, when samples of the Timmins ore were sent to the Black Donald mill for testing (Hewitt 1965). These reports were not substantiated in subsequent testing by Orwell Energy Corporation Ltd. in 1982 and Lodi Metals Inc. in 1988. Testing completed by Lodi Metals Inc. showed that no complicating factors such as mica are present in the graphite ore (Hawley 1988). Discrepancies in the test results may be due to recent advances made in the beneficiation processes used, and to Frobisher's use of the Black Donald mill, which was designed for an ore type significantly different from that of the Timmins property. Although the Black Donald ore contained a much higher percentage of graphite, it also contained a much higher percentage of fine graphitic material than the Timmins ore. The Timmins ore is characterized by a high percentage of medium to coarse flake graphite. This difference in ore type would require major differences in grinding and flotation techniques in order to liberate the graphite.

The Timmins deposit is certainly worthy of further work, as it appears that a substantial deposit may be present.

CORNELL PROPERTY (PORTLAND PROPERTY)

Property Status

Active prospect (Victoria Graphite Inc.)

Location

The occurrence is located on Lot 10, Concession I, Bastard Township, Leeds County, 5.5 km northeast of the community of Portland, Ontario (*see* Figure 4); lat. 44°44′35″N, long. 76°09′50″W; UTM co-ordinates 408324E, 4954946N, zone 18; NTS 31 C/9.

Access

The area is reached by proceeding 5.5 km north on Highway 15 from the community of Portland, then proceeding northwest 0.8 km on the Portland Graphite road to a farm house. The showing is located approximately 0.8 km northeast of the farm house.

History

J.C. Cornell first discovered the occurrence in 1934 and in 1957 acquired the property. The Joseph Dixon Crucible Company of Jersey City optioned the property from June to September 1959. Workings consisted of 4 small quarries or trenches, the largest measuring approximately 12 by 6 by 3.6 m deep. In 1959, a 700-pound bulk sample was taken and sent to the Mines Branch laboratories in Ottawa for beneficiation testing. Stone (1960, p.i) reported: "by differential stage grinding and removal of minus 325 mesh material at each stage, a concentrate assaying 90.1 percent carbon for a 72.3 percent recovery was obtained. Similar results were obtained with a combination of flotation and differential grinding. An increase in recovery to 78.5 percent resulted in a drop of grade to 60 percent carbon. Fractions as high as 98.1 percent carbon were obtained. Beneficiation of minus 325 mesh material was not successful."

In the mid–1960s, A. Holland erected a mill and extracted some ore from an open pit about 15 by 15 by 4 m deep. Victoria Graphite Inc. optioned the property in 1986 and have recently completed an exploration program of geological and geophysical surveys, trenching and diamond drilling totalling 5884 m in 73 holes. A preliminary feasibility study completed in December 1989 reported total probable reserves of 295 000 t grading slightly above 6% graphite to a depth of 20 m in 2 zones and recommended development of an open pit mine and construction of a 100 t/d pilot plant (Elliott 1989).

Geology

The property is situated within a small area of Grenville metasediments (about 10 km in diameter) bounded to the west by the Rideau Lake fault and overlain to the north, east and south by Paleozoic sandstone and dolostone of the Nepean and March formations. The metasediments consist predominantly of marble interlayered with minor rusty paragneiss and quartzite, all of which are intruded by white granitic pegmatite.

The following description of graphite zones on the Cornell property is summarized from Elliott (1989).

The graphite deposits occur in 3 zones, all within siliceous marble. The 3 zones (D, G and I) strike north-northeasterly and dip steeply to the west (Figure 10), with strike lengths of about 750, 650 and 300 m, respectively. Each shows graphite mineralization over widths of up to 75 m, but ore-grade material is confined to narrow lenses within the broad graphitic zones. Diamond drilling has been concentrated on the D and I zones; only 7 holes have tested the G zone.

A 250 m length of the D zone contains an estimated 146 429 t grading 5.62% graphite to a depth of 20 m. Within this zone, grades range from 1 to 13% graphite over true widths of 1 to 8 m. It is well exposed as a 5 m high, southeast-facing ridge and is, therefore, amenable to open pit development.

The I zone is estimated to contain 147 260 t grading 6.41% graphite to a depth of 20 m. Grades and widths in this zone range from 3 to 13% graphite and 0.3 to 7 m (true width).

A bulk sample of 34 t, taken from the proposed open pit location on the D zone, was shipped to Lakefield Research Ltd. for pilot plant testing in 1989. The results of the tests indicate recoveries of 87 to 95% of the graphite for ore ground to -10 mesh; flotation concentrates grading 80 to 85%, which can be upgraded to 91 to 93% by heavy liquid separation; and a coarse flake (+48 mesh) content of about 66% in the concentrate.

Hewitt (1965) reported that the graphite occurs as disseminated flakes averaging 1/8 inch in diameter. Black and MacKinnon (1988, p.361) stated: "Some of this flake has a high aspect ratio, ie. 4:1; however, it appears that this will readily break down to a finer equidimensional flake during milling."

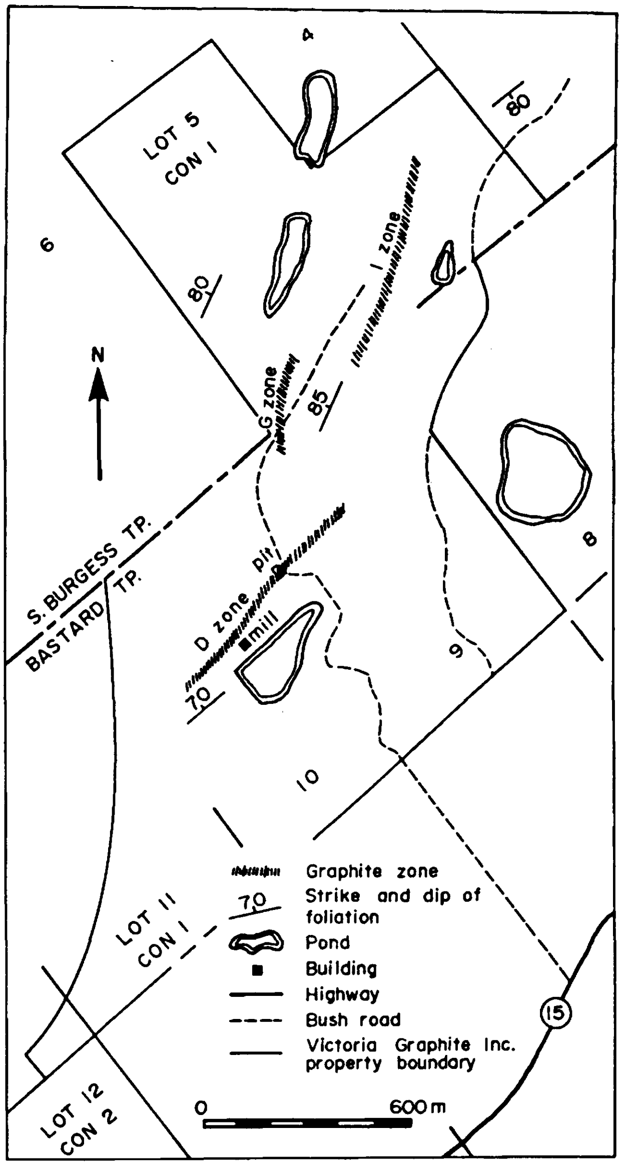


Figure 10. Sketch map of the Cornell occurrence, showing graphite zones outlined by Victoria Graphite Inc. (*modified from* Elliott 1989).

Papertzian and Kingston (1982) indicated the presence of granite pegmatite adjacent to the Victoria Graphite zone D.

Comments

This occurrence differs from the other 5 occurrences described in this section in the apparent absence of major granitic intrusions and granitic gneiss bands. However, features in common with the other occurrences are proximity to the Rideau Lake fault on a regional scale and proximity to pegmatite bodies on a property scale.

The presence of several additional graphite occurrences within the same area of marble in South Burgess and Bastard townships (Hewitt 1964) suggests that this area represents a favourable exploration target for flake graphite deposits.

GLOBE GRAPHITE MINE

Property Status

Past producer

Location

The property consists of 3 unpatented mining claims: numbers EO581432, EO581433 and EO581434 on part of lots 21 and 22, Concession VI, North Elmsley Township, Lanark County, located approximately 8 km southeast of Perth and 12 km west of Smiths Falls (*see* Figure 4); lat. 44°51′32″N, long. 76°09′40″W; UTM co-ordinates 408269E, 4967725N, zone 18; NTS 31 C/16.

Access

The area is reached by travelling west on Highway 43 from Smiths Falls to Port Elmsley, then proceeding southwest on Lanark County Road 2 approximately 4.8 km to the property. The road from Rideau Ferry to Port Elmsley forms the northern boundary of the property.

History

The Globe Mine is the earliest recorded producing graphite mine in Ontario. The property was initially worked from 1870 to 1875 by the International Mining Company of New York. Ore was processed in a mill at Oliver's Ferry on the Rideau Canal. In 1893, National Graphite Company drilled 8 holes, ranging from 50 to 100 feet in depth. In 1901, further drilling (4 diamond-drill holes) was carried out by R.A. Pyne and in 1902, Rinaldo McConnell resumed mining and established a 20-ton mill at Port Elmsley (Spence 1920). Production ceased between 1903 and 1908, but the mine was operated from 1908 to 1911 by the Globe Refining Company, and from 1915 to 1919 by the Globe Graphite Mining and Refining Company, who last operated the mine (Hewitt 1965). Several companies have since completed exploratory work, the last being Black Gregor Explorations Inc., which carried out geological mapping, geophysical surveys (magnetic, VLF-EM and horizontal loop EM) and diamond drilling (7 diamond-drill holes) (Bowdidge 1984).

Workings consist of 2 shafts and 3 pits. The main pit (Pit No.1, Figure 11) is 400 feet long by 10 to 30 feet wide, trending 065°. At the northeast end of the pit, a shaft was sunk to follow the ore to depth. Initially, the shaft was inclined at 60° to the northwest, but was steepened to vertical with depth (Hewitt 1965). The shaft extends to a vertical depth of 170 feet (250 feet measured on the incline of the shaft) with 4 levels at 100, 150, 200 and 250 feet. The first 3 levels were developed in both directions from the shaft for about 200 feet along the strike of the orebody, while the last was developed only in an easterly direction (Spence 1920). A second shaft located 400 feet north of the mine pit was sunk to a depth of 106 feet with 40-foot drifts towards the north at the 50- and 100-foot level. Shaft No.2 was not located during the present investigation.

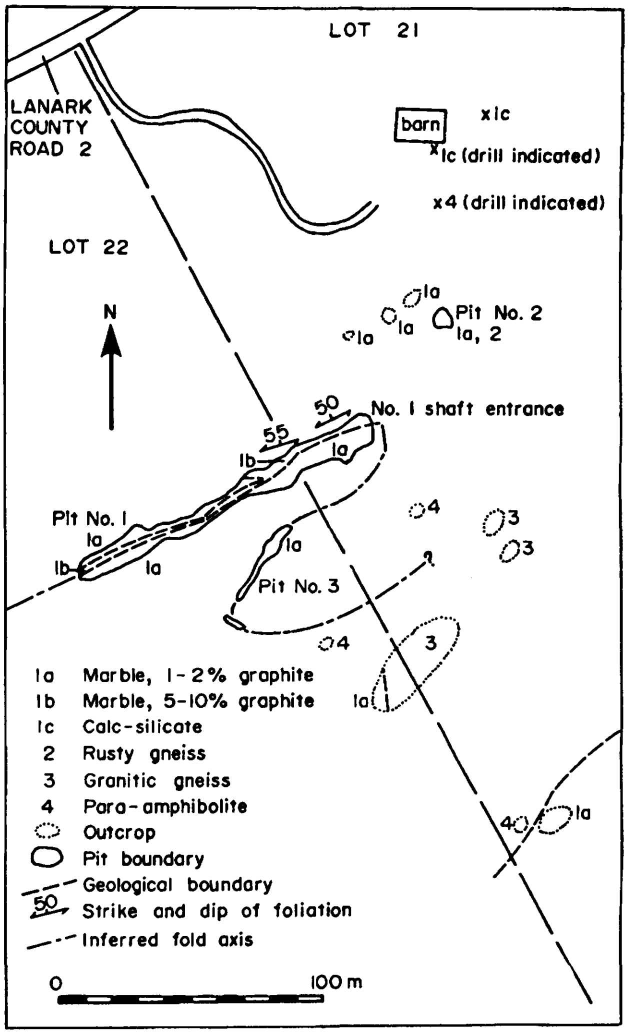


Figure 11. Geological sketch map of the Globe graphite mine (*modified from* Hewitt 1965; Bowdidge 1984).

Bell (1942) suggested that no more than 20 000 tons of graphite ore was mined from this deposit. Spence (1920) quoted the average graphite content of the ore milled from 1915 to 1918 as 8%.

Geology

The property is located within an inlier of Grenville Supergroup rocks surrounded by flat lying, Paleozoic (Nepean Formation) sandstone (Wilson and Dugas 1961).

The deposit is hosted in crystalline marble and calc-silicate rocks in proximity to quartzofeldspathic gneisses and granite (*see* Figure 11). The marble is generally well banded, medium to coarse grained and grey to white in colour. Common accessory minerals include graphite, phlogopite and pyroxene. The calc-silicate rocks vary from diopside-pyroxenite to diopside- and calcite-bearing feldspathic gneisses (Bowdidge 1984). Mineralogically, the rocks consist primarily of diopside, but may contain as accessory minerals calcite, scapolite, orthoclase feldspar, mica, quartz, serpentine, pyrite and titanite.

Spence (1920, p.29) described the graphite orebody as: "a saddle-shaped mass in highly silicated Grenville limestone intruded by masses of pegmatitic rock. The latter ranges in composition from a gabbro to a syenite and commonly contains pyroxene and biotite." Spence further noted that the graphite content increased in proportion to the degree of silicification. During the present investigation, much of the workings could not be examined because of poor exposure due to flooding and heavy soil infilling. Bell (1942) described the surface mineralization as being associated primarily with siliceous zones within the marble, with the higher grade portions forming 2 lens-like bodies. The east lens has a strike length of 250 feet and an average width of about 7.5 feet. The greatest exposed width was 10 feet, with the exception of a nearly 40-foot thick intersection at the crest of an easterly plunging (30°NE) antiform at the east end of the pit. To the west, the zone narrowed to about 4 feet for a distance of 70 feet, and then bulged to 8 feet for a distance of 90 feet. The graphite zone within the main pit (Pit No.1) strikes roughly east-northeast, with an average dip of 55°N. The zone south of the pit is structurally complex, and at present remains poorly understood.

The graphite occurs predominantly as equidimensional flake, averaging between 0.5 and 1.0 mm in diameter and as small bodies of "needle flake", wherein the length of each "needle" may be 5 to 6 times its width. In thin section, Wilson (1917) reported an anastomosing structure to the graphite, with the interstices between the flakes filled with quartz crystals transverely disposed. The mineralization is divided between 4 zones (Bowdidge 1984). Graphite-rich zones containing up to 20% graphite are separated by medium- to low-grade marble bands. Two grab samples (GR-6-89 and GR-7-89) taken by the authors from the northeast end of Pit No.1 assayed 8.14 and 13.85% graphitic carbon, respectively. Drilling on the downplunge extension of the main graphite zone by Black Gregor Explorations Inc. confirmed that mineralization extends to a vertical depth of at least 300 feet. However, the thickness, strike length and grade appear to be somewhat less than that at surface, where up to 40 feet of 15% graphite was reported from the old workings. As a result, Bowdidge (1984) estimated that approximately 50 000 tons of approximately 7% graphite remain in the deposit below the mined-out portion, to the 300-foot level. He suggested that if it were extended to the 1000-foot level, an economic deposit might be proved.

Geophysical work suggests the possibility of additional zones near the existing site. Drilling of a geophysical anomaly a short distance to the south of the old workings confirmed the presence of several narrow graphite-bearing zones, however, they appear to have little economic value (Bowdidge 1984).

Comments

The silicated zones probably represent a contact metamorphic product formed along the borders of the pegmatitic rocks. Since the graphite content increases in proportion to the degree of silicification, the graphite is likely metasomatic in origin, a conclusion supported by Wilson (1917) and others.

Although the property contains appreciable quantities of disseminated flake and "needle flake" graphite, further exploration work is needed to gain a greater understanding of the structure and to delineate additional reserves. A significant increase in reserves is required before this property can be considered a viable prospect.

Conclusions

The 6 graphite occurrences examined in this study exhibit a number of similar characteristics:

1. The occurrences show a spatial association, on a regional scale, with a major transcurrent fault. Each occurrence lies within 5 km of the Rideau Lake fault.
2. Graphite mineralization is hosted by crystalline marble, most commonly calcitic, but locally dolomitic (Timmins property).
3. The host marble is interlayered with paragneiss, generally granitic to quartzitic in composition. Significant graphite mineralization is usually confined to the marbles, but at the Burridge and Timmins properties, rusty, pyritic-micaceous paragneiss units locally contain up to 10% graphite.
4. Granitic pegmatites occur close to the graphite zones on all properties, with the exception of the Globe graphite mine. This association is also common within the occurrences listed in the "Appendix".
5. The graphite occurs primarily as disseminated flakes in marble, averaging about 3 mm in diameter. Grades range from 3 to 20% graphite, averaging between 5 to 10%. Associated minerals include diopside and lesser amounts of serpentine and phlogopite.

The occurrences show some differences in mineralization and structure. The Globe and Cornell properties contain significant quantities of "needle" graphite (length to width ratio of about 4:1). The Kirkham, Bawden and Globe graphite zones occur within tightly folded marbles, in contrast to the Cornell and Burridge zones, which lie within a series of parallel marble bands. The Timmins property is unique in its proximity to 2 major plutons.

Four of the 6 occurrences are currently undergoing active exploration. The results of work to date indicate that deposits in the order of 1 to 2 Mt grading between 5 and 10% graphite are present and will yield a flake graphite product with particle size and carbon content acceptable to the graphite industry.

In the development of an exploration program for graphite deposits of the type described in this report, the following guidelines should be considered:

1. The presence of a major fault, high regional metamorphic grade, complex structure and major igneous intrusions may have influenced the formation and/or concentration of graphite.
2. The presence of interlayered marbles and paragneisses indicates a shallow, nearshore marine environment favourable for the accumulation of organic material, which is the most probable source of carbon in these deposits.
3. The high ductility of marbles, particularly graphitic marbles, may result in deposits of extremely irregular dimensions and attitudes. Therefore, detailed sampling, mapping and structural analysis are required to properly evaluate a prospect.

Appendix. Graphite occurrences of the Central Metasedimentary Belt, eastern Ontario (excluding those within the Frontenac Axis).[1]

Location	Description
FRONTENAC COUNTY	
Kennebec Tp., Conc. VI, Lot 8	3 pits on graphitic pegmatite which cuts graphitic paragneiss
Oso Tp., Conc. I, Lot 3, E 1/2	Disseminated graphite in marble, pegmatite and granite
Oso Tp., Conc. IV, Lot 19	2 pits in amphibolite containing small veins of graphite
HALIBURTON COUNTY	
Cardiff Tp., Conc. XIV, Lot 18	1 pit in rusty biotite amphibolite containing 10% coarse flake graphite in a 0.6 m wide zone
Cardiff Tp., Conc. XV, Lot 18	Open cut in a graphitic paragneiss band 1.1 m wide containing 8 to 10% coarse graphite flakes
Cardiff Tp., Conc. XIV, Lot A	1 pit in coarse crystalline white marble containing a 1 m band averaging 25% very coarse graphite flakes; no rock is exposed around the pit
Cardiff Tp., Conc. XX, Lot A	4 separate occurrences: 2 in marble and 1 in syenite at a marble contact contain 2 to 3% flake graphite; the fourth contains 5 to 8% coarse flake graphite and has been worked via a shaft at least 25 m deep
Cardiff Tp., Conc. XXII, Lot 4	Small pit in white marble containing less than 5% graphite
Cardiff Tp., Conc. XXII, Lot 11 (National Graphite Property)	Small open pit mined intermittently from 1912–1915; diamond drilling by Frobisher Ltd. in 1951 indicated a zone 365 m long and 18 m wide containing 1.3 Mt grading 4.1% C; within this is a zone of 728 000 t grading 5% C; flake graphite up to 3 mm occurs in calcareous paragneiss
Cardiff Tp., Conc. XXII, Lot 24	2 pits in graphitic syenite pegmatite containing from 5 to 20% coarse graphite over a 1 m width at contact with marble and paragneiss
Monmouth Tp., Conc. XIII, Lot 32	Pit in white marble containing 0.5 to 1% graphite, locally up to 10%
Monmouth Tp., Conc. XIV, Lot 35, N 1/2	2 pits expose weakly graphitic marble
Monmouth Tp., Conc. XIV, Lot 35, S 1/2	Graphitic zone traced by outcrop and float
Monmouth Tp., Conc. XV, Lot 35, S 1/2	2 pits in graphitic marble, generally low grade but locally up to 10%
Monmouth Tp., Conc. XVI, Lots 34–35	Inclined adit 2.5 by 4.5 by 30 m long on Lot 34 in a hill of marble interbedded with paragneiss; up to 10% disseminated flake graphite; 4 pits in marble averaging about 5% graphite on Lot 35
HASTINGS COUNTY	
Carlow Tp., Conc. VIII, Lot 10	Pit in interbanded amphibolite and marble cut by granite pegmatite; graphite flakes, seams and lenses are confined to the amphibolite; poor quality and grade

Location	Description
Faraday Tp., Conc. I, Lot 12	Pit exposed a small pod (0.5 by 1 m) of graphite veinlets
Herschel Tp., Conc. VIII, Lot 16, S 1/2	2 bands of graphitic gneiss 1.1 m thick, traced about 15 m, interlayered with marble and cut by pegmatites; low grade, coarse flake
Herschel Tp., Conc. X–XI, Lots 24–25	Several shallow pits in graphitic granitic gneiss; samples assayed 5.3 and 6.4% graphite
Herschel Tp., Conc. XI, Lots 17–18	6 pits in rusty graphitic gneiss, 2 to 4% graphite
Monteagle Tp., Conc. V, Lot 16	Coarse flake graphite in marble intruded by granite gneiss and pegmatite; sample assayed 1.97% graphite
Monteagle Tp., Conc. XIII, Lots 23–24 (Tonkin-Dupont Mine and National Graphite Mine)	323 t of refined graphite was produced from this deposit from 1912–1916; diamond drilling in 1952 (335 m) and 1962 (701 m); average of 7% graphite flakes 1.5 to 3 mm, locally 15 to 20%; host rocks are marble, pyroxenite, paragniess, amphibolite and pegmatite; graphite is mainly confined to marbles and occurs in at least 2 bands; workings consist of several large pits up to 45 m deep
Monteagle Tp., Conc. XIV, Lots 13–14	Rusty, graphitic paragneiss 3 m wide has been traced for 100 m; flakes average 3 mm; a 3 m channel sample assayed 2.97% graphite; the gneiss is underlain by marble
Tudor Tp., Conc. IX, Lot 21	Veins and pockets of amorphous graphite reported in marble
LANARK COUNTY	
Darling Tp., Conc. VII–VIII, Lot 9	High-grade flake and amorphous graphite zone in marble adjacent to pegmatite dike; exposed over a strike length of 18 m and width of 3 to 4.5 m; channel samples by Black (1989) assayed 16.6% graphite across 2.4 m and 30.5% graphite across 0.9 m
LENNOX AND ADDINGTON COUNTY	
Ashby Tp., Conc. VIII, Lot 1	Amorphous graphite is reported, probably an extension of the zone in Denbigh Tp., Conc. VIII, Lot 34 (Spence 1920, p.39)
Denbigh Tp., Conc. VIII, Lot 34	Disseminated flake graphite and amorphous graphite seams in marble intruded by syenite and pegmatite; shaft 15 m deep and 2 pits
PETERBOROUGH COUNTY	
Anstruther Tp., Conc. I, Lot 38	11 m deep shaft on a graphitic pegmatite dike in marble
RENFREW COUNTY	
Blithfield Tp., Conc. IV, Lots 13–14	Small occurrence of graphite in rusty paragneiss near Madawaska River
Blithfield Tp., Conc. V, Lot 25	Graphitic gneiss 0.5 m wide interbedded with marble
Brougham Tp., Conc. III, Lots 17–18 (Black Donald Graphite Mine)	Operated intermittently from 1896–1954; produced 77 500 t of graphite; graphite hosted by marble in a marble–quartzite–paragneiss sequence (*see* Hewitt 1965 for detailed description)
Brougham Tp., Conc. VI, Lot 1	Small, lenticular graphite zones in marble; 3 pits
Brougham Tp., Conc. VI, Lot 17	Small flake graphite occurrence in diopside-rich rock interbedded with marble and mica schist

Location	Description
Brougham Tp., Conc. VIII, Lot 6	0.5 m wide zone of disseminated graphite in scapolite gneiss at contact between marble and pegmatite
Brougham Tp., Conc. X, Lot 13	1% graphite in marble; pit and trench
Griffith Tp., Conc. XIV, Lot 26	Pit on graphite-rich lens 15 to 60 cm wide, 2.5 m long; 30% graphite in hornblende gneiss
Lyndoch Tp., Conc. II, Lots 1-2	Graphite flakes in marble; several pits and shafts over a 580 m strike length; generally narrow, high-grade bands in a zone averaging up to 10% graphite over a 1.5 m width
Lyndoch Tp., Conc. XV, Lot 24	Small pit in graphitic marble; 5 to 10% graphite flakes up to 3 mm over a width of up to 0.6 m
Ross Tp., Conc. X, Lot 9	Minor occurrence of graphitic marble exposed in a pit

[1] *Source of information: Hewitt 1965, unless otherwise noted.*

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CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm²	0.155 0	square inches	1 square inch	**6.451 6**	cm²
1 m²	10.763 9	square feet	1 square foot	**0.092 903 04**	m²
1 km²	0.386 10	square miles	1 square mile	2.589 988	km²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm³	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm³
1 m³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m³
1 m³	1.308 0	cubic yards	1 cubic yard	0.764 555	m³
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

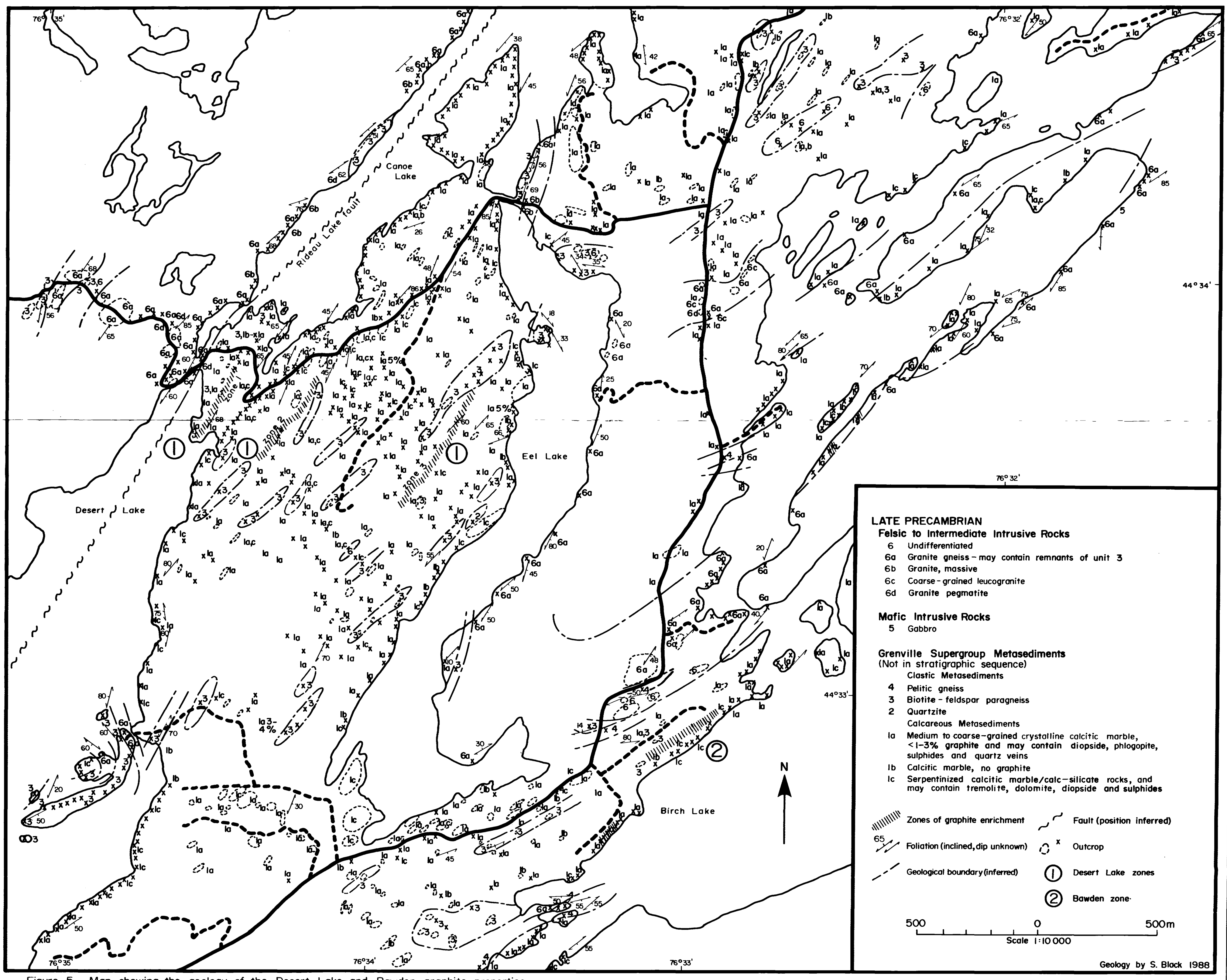

Figure 5. Map showing the geology of the Desert Lake and Bawden graphite properties.

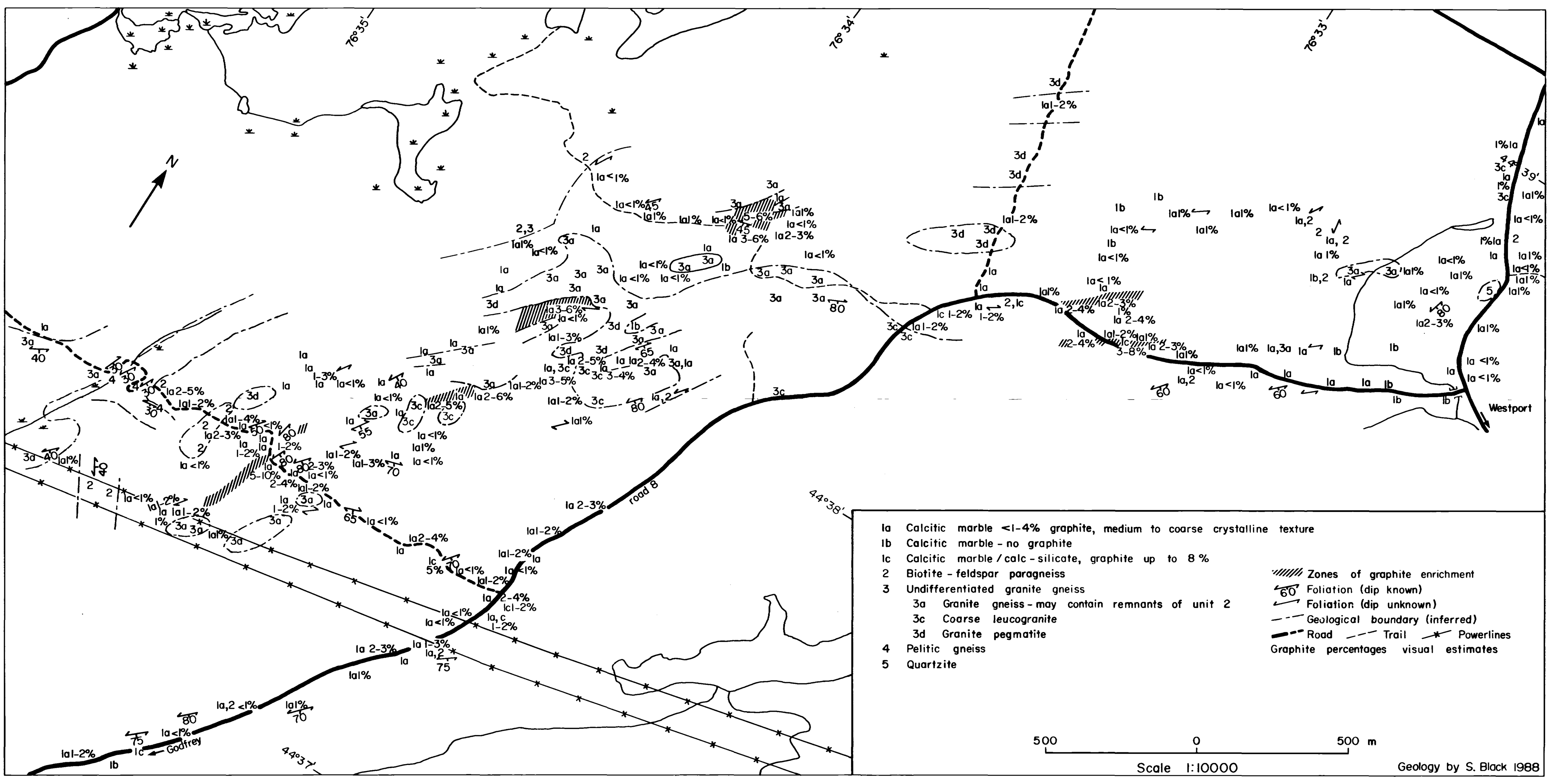

Figure 8. Map showing the geology of the Burridge marble belt graphite occurrences.

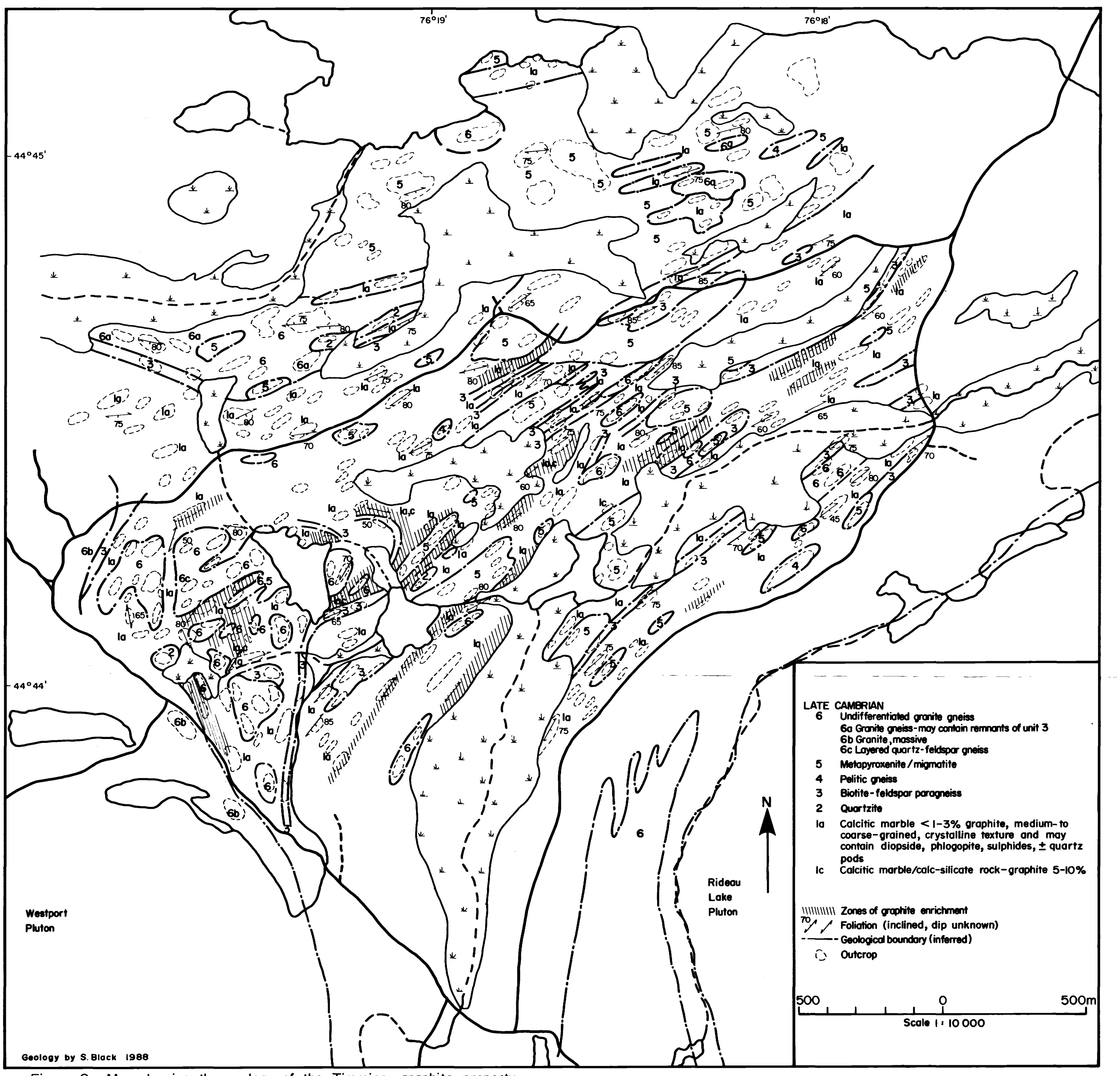

Figure 9. Map showing the geology of the Timmins graphite property.