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Graphite in the Central Gneiss Belt of the Grenville Province of Ontario

by

M.I. Garland

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V.G. Milne

V.G. Milne, Director
Ontario Geological Survey

FOREWORD

This report presents the results of a three year study of the potential of the Central Gneiss Belt of the Grenville Province of Ontario to host graphite deposits. The project included extensive field and laboratory examinations of known graphite occurrences in the Central Gneiss Belt, and a thorough review of the applications of graphite in industry. Flake graphite is widely used as a refractory; amorphous graphite finds uses as powders for such products as brake linings, lubricants and batteries.

Graphite has been produced in Ontario from deposits within marbles of the Central Metasedimentary Belt of the Grenville Province, and is known to occur with gold and base metal deposits in carbonaceous metasedimentary rocks and shear zones in the Superior Province. This study examines deposits in siliceous metasedimentary rocks of the Central Gneiss Belt. Although detailed exploration of these deposits is limited, they seem to offer possibilities of open pit mining of a large, low grade resource.

The descriptions and conclusions of this report will be of special interest to the minerals industry and to prospectors considering graphite as an exploration and development target.

V.G. Milne
Director, Ontario Geological Survey
12 May 1987

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CONTENTS

APPENDICES

LIST OF MAPS

		SCALE
1.	Graphite Occurrences in the Algonquin Region/Structural Domains andPelitic Gneiss Units from A. Davidson	1:1,000,000
2.	Lithotectonic Subdomains of the Central Gneiss Belt and the Pelitic Gneiss units	1:250,000
3.	Laurier Township Geology	1:2500
4.	Laurier Township Graphitic Zone	1:2500
5.	Butt Township Geology	1:2500
6.	Ryerson Township Geology	1:2500

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report presents the results of a three year study to evaluate the potential for graphite in the Central Gneiss Belt. Field work was performed in the summers of 1983, 1984, 1985, and part of 1986, and consisted of checking occurrences identified in the literature, mapping in detail two of the deposits, mapping on a larger scale one other deposit, and sampling the trenches of a fourth deposit. The background research consisted of a literature study on the properties and uses of graphite, and attempts to solve the riddle of what makes a graphite deposit economic. Since, for the finer grained types of graphite, current supply can now meet demand, it is important for a potential producer to establish a market strategy. To do this it is essential to have an understanding of what type of graphite commands the best prices, how it is used, who would buy it, and how and where that type of graphite is found. REE determinations of some of the graphites and their corresponding host rock, and carbon isotope determinations on two samples were performed to collect data on the graphite itself.

GRAPHITE IN THE CENTRAL GNEISS BELT
OF THE GRENVILLE PROVINCE OF ONTARIO

by

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1.0 SUMMARY

Graphite has been used for centuries as a writing medium, and for the past hundred years commercially. This commercial use continues. The many unique properties of graphite that make the mineral so important industrially are directly related to its crystalline structure.

Although geographically widely distributed, graphite is for the most part geologically restricted to Precambrian or lower Paleozoic rocks, usually in metamorphic terrains. The classification scheme most widely accepted for graphite deposits is that introduced by Cameron (1960). The five types of deposits are: disseminated flake graphite in siliceous metasediments; disseminated flake graphite in marbles; metamorphosed coal seams; vein deposits; and contact metasommatic or hydrothermal deposits. The geology of each type is different. Economic deposits today are of the first, third and fourth type.

The key for successful development of a graphite deposit is in the marketing. Each graphite product requires graphite with very particular specifications, and to complicate the issue there are no accepted standard, or dependable, specifications against which to gauge graphite from a new deposit. It is also difficult to break into an already established group of suppliers from Sri Lanka, The Malagasy Republic, Mexico and Korea.

The main uses for graphite flake are in crucibles and other refractory products, particularly for the various parts used in the continuous casting process of steel. Large flake, natural graphite, which has highly specialized properties, is in demand for these applications and commands the better prices because of its rarity. Amorphous graphite, which is more abundant and lower priced, is used in graphite powders for such applications as brake and clutch linings, batteries, lubricants, moulded graphite products and recarburizing steel.

In Ontario graphite occurs in both the Superior and Grenville structural provinces. In the Superior Province it is associated with gold and base metal deposits occurring in carbonaceous sediments and shear zones. In the Grenville Province, graphite occurs within both the Central Gneiss Belt (CGB) and Central Metasedimentary Belt (CMB). Prior production from Ontario has come from graphite deposits within the marbles of the CMB which are locally of higher grade. Economic deposits now are being found in the siliceous metasediments of the CGB. The lower grade of deposits in the CGB is offset by their larger size and amenability to open pit mining.

Until recently, the geology of the Central Gneiss Belt of the Grenville province had not been well documented. Davidson et al (1981-1986) have recognized three thrust sheets composed of distinct structural sub-domains. The graphitic horizons, confined to rocks of the first or relatively older thrust sheet, are part of a series of metasediments now consisting of quartzites and quartzo-feldspathic gneisses. Where graphitic, the sediments also contain pyrite, giving the unit a characteristic rusty weathering signature. Of the many known occurrences of graphite within the Central Gneiss Belt, four deposits of economic interest were chosen for a more detailed study.

The four deposits, one each in Laurier, Butt, Ryerson and Maria Townships, consist of a series of gneisses and paragneisses. The graphite-bearing unit is a quartz-feldspar-biotite schist which can be garnetiferous. The graphite flake varies in diameter from less than 0.5 millimetre to 1 centimetre, and in grade from 1 weight percent to 5 weight percent. The graphitic unit, especially in Ryerson and Butt townships, appears to be a ductile shear zone as evidenced by the drag folds and contorted foliation. The Ryerson and Butt township deposits appear to be on a single stratigraphic horizon that has been traced almost as far as Maria Township.

The limited chemistry done on rocks from the deposits studied consists of REE and trace element determinations by neutron activation and carbon isotope work.

In conclusion, the graphite occurrences in the four townships are situated in similar rocks. The graphite occurs disseminated throughout the unit and the grade varies with lithology. They appear to represent a particular sedimentary facies that collected organic debris. Since then they have undergone metamorphism and suffered considerable elongation.The graphite units are restricted to one thrust sheet, and are probably now much longer and thinner than they were originally.

2.0 SUMMARY OF RESULTS

1. In each occurrence, the host rock to the graphite is a quartz-feldspar schist, grading in one occurrence to a gneiss. The graphitic units in Butt Township are comprised of a quartzite and a quartz-feldspar-biotite-garnet schist; in Laurier Township the graphitic unit is a quartz-biotite-muscovite schist; in Ryerson Township the unit is a quartz-feldspar-biotite schist; and in Maria Township the unit is a quartz-feldspar-biotite-garnet gneiss.
2. In both the Butt and Ryerson township occurrences, the graphitic units have undergone extensive ductile deformation.
3. The siliceous metasedimentary graphitic units only occur in stack 1 of Davidson's (1981 to 1986) interpretation of the Central Gneiss Belt.
4. The carbon isotopes are similar to those from other biogenic carbon.
5. The REE patterns of the graphite separates are similar to the parent rock, which has patterns similar to those for greywackes.
6. The disseminated nature of the graphite; the restriction to a particular type of metasedimentary horizon; the restriction of this type of horizon to subdomains of Davidson's stack 1; the light carbon isotopes; and the REE patterns similar to other metasediments indicate that the graphite has formed in place from organic debris deposited with the sediment. The distribution of the graphite within

the metasedimentary unit reflects a primary distribution of carbonaceous material within the original sediment.

3.0 INTRODUCTION

The objectives of this report are to evaluate the potential for graphite as an economic commodity in the Central Gneiss Belt (CGB), to substantiate the earlier literature surveys on graphite occurrences within the CGB, to provide an aid to and encourage exploration for graphite in the CGB, and to ultimately derive a geological understanding of graphite in the CGB.

The CGB has not had the scope of regional mapping afforded other areas in Ontario, and the result is an irregular patchwork database composed of various maps, at various scales. Graphite occurrences have been documented throughout the literature (section 5.3), but subsequent field work could not expand past reiterating previous work without a coherent database. for this study, four occurrences were examined: two were mapped in detail, one was mapped on a broad scale, and one was sampled.

The most important use for graphite is in the steel and metal refining industries. The economics of graphite are therefore tied directly to the health of these, and since both steelmaking and refining have been recovering from the recession in the early 1980's, the graphite industry has also been experiencing improved demand. The political instability of many of the major producing nations has caused a shift in graphite exploration to countries noted for political stability, sacrificing less expensive labour and shipping.

The CGB of Ontario has benefited from the increased exploration for graphite. In order to provide a stimulus and an aid to exploration, this study on graphite has incorporated research on the properties and uses of graphite, processing considerations, production statistics from the major producing countries, and marketing considerations. A discussion of current prices and specifications was included since the graphite industry has traditionally worked on the basis of a close relationship between buyer and seller, excluding any world-wide standards.

The inertness of graphite, which makes it useful to industry, also makes it very difficult to analyze. Preliminary analytical work was done in this study on the rare earth elements (REE) and some trace elements contained in graphite. Apart from the academic considerations, there has been growing interest in the role of carbon, as graphite, in the formation of ore deposits (Wilson 1985; Wilson and Ruckledge 1986; Springer 1985) and there exists some potential forthe development of graphite deposits in this respect.

The mapping by Davidson et al. (1981 to 1986) has provided the area with a structural overview, and it is possible to relate the graphitic horizons to this overview

(Map 2). As work continues, it may become possible to provide some very good data to exploration companies on location, strike extent, size and potential of graphite deposits in the CGB of Ontario.

4.0 GRAPHITE IN INDUSTRY

4.1 INTRODUCTION

This section provides some background to the graphite industry, beginning with a brief discussion of some of the terms used. As in any specialized industry, the terminology has developed to fit the needs of that particular trade, and it is necessary to be familiar with the meaning in order to understand the industry.

The numerous and very unique physical properties of graphite are important, as they directly influence the many and varied uses of graphite. Some of the properties offer graphite as a suitable substitute for commodities being phased out for health or availability reasons, and other properties render graphite as the best for a particular purpose, for which any substitute would be sub-standard.

Graphite is produced in only a few countries, most of them in Asia, Africa, or Europe. On a world-wide scale, supplies are still sufficient to meet demand; on a local scale there is demand for specialty products requiring a particular type or blend of graphite. The major importers of graphite are situated in the industrialized countries, primarily the United States and Japan, and the health of the graphite industry has paralleled that of the steel industry within these countries. New producers of graphite may find it difficult to break into a traditional market tied to specific buyers. The recent trend of blending graphite from various sources and selling through a distributer, coupled with the political and national insecurity within several of the major producing nations, has provided impetus for new producers.

Theoretically, the separation of graphite from its host is a simple procedure: graphite floats and can be trapped on the surface with the use of a frothing agent. Problems arise with the crushing and grinding of the rock. The value of a graphite flake increases with its size, and any amount of grinding reduces the flake size and the resulting value of the concentrate. A further complication in assessing the value of a concentrate, or even a potential graphite deposit, is the general lack of standard specifications for grade, type of graphite and price. These items are usually negotiated between the buyer and seller and are based on a wide spectrum of specifications. Some of these, along with some of the inherent problems, are described in this section.

It is important for a potential producer of graphite to be aware of the great number of uses for graphite and the possibilities open to him for marketing his product. Some of the major uses and the type of graphite preferred are outlined. It is important to note that the graphite industry is open to technological changes and graphite is finding its way into the ceramics, plastics, aerospace, and automotive industries, opening new markets for an industry which has traditionally been tied to the steel industry.

4.2 OVERVIEW OF THE ELEMENT CARBON IN NATURE

4.2.1 Carbon

Carbon is one of the most important terrestrial elements amongst the first six in terms of cosmic abundance. It is non-metallic, with a small mass. Its atomic weight is 12.01, and its atomic number is 6. In the global geochemical cycle carbon is the third most abundant gas in the atmosphere. It occurs in solid forms combined with oxygen to form the carbonate minerals; alone as graphite or diamond; or in the amorphous form as a constituent of coal, petroleum and other organic compounds (A.G.I. 1973).

Carbon occurs most commonly and diversely in organic combinations known as biogenic carbon, all of which are recycled by living organisms. Coal, for example, is a combustible meterial containing over 50% by weight carbonaceous material of biogenic origin (A.G.I. 1973). Carbon may also be a part of inorganic systems related to magmatic activity, and is a constituent of carbonates, which may be both organic and inorganic in origin.

Mineral carbon occurs as two minerals formed entirely of carbon: graphite and diamond. In diamond the carbon atoms are arranged at the corners and face centres of cubes forming a face-centred cubic isometric structure. Carbon atoms are also situated along the diagonals of the cube in such a way that each carbon atom has four neighbours (Harben and Bates 1984). This structure is very strong, giving diamond its unique hardness. Graphite is a hexagonal, naturally occurring crystalline form of carbon, dimorphous with diamond. In contrast to diamond, it has carbon atoms at the corners of stacked hexagonal rings, forming plates which are weakly bonded together. Graphite can be converted to synthetic diamond by being subjected to high heat and pressure in the presence of a metal catalyst (Harben and Bates 1984).

4.2.2 Commercial Nomenclature

In order to understand the graphite trade it is necessary to know the terms that are commonly used in specifications.

The commercial or industrial terms used to describe graphite are confusing as every producer of graphite has a different classification scheme for their product, and these classification schemes are based on physical appearance of the graphite rather than mineralogy. Graphite is usually described in the industry as crystalline flake, vein, or amorphous. Crystalline flake is the term used for any flake graphite, particularly for graphite from disseminated flake graphite deposits. Vein is the term used for large crystals of graphite found in veins or pegmatites, and amorphous graphite is used for fine-grained, black graphite, usually formed by the metamorphism of coal seams but also found in shear zones and in veins. The mineral graphite is always crystalline and occurs as flakes by nature of the crystal habit. Crystalline flake graphite consists of flakes usually within the size range of less than a millimetre to over a centimetre; vein graphite can consist of large flakes, several centimetres in diameter, or agglomerations of very fine flakes; and amorphous graphite is actually microcrystalline flake graphite. Some of the industrial terms used to describe different types of graphite are: disseminated flake, microcrystalline aggregates, lump, chip, needle, amorphous, dust, number one flake and number two flake. Despite the variety that the many different names implies, the different types of graphite are all crystalline and all exhibit a flake habit on some scale, be it microscopic or macroscopic.

Another confusing feature of graphite nomenclature is the synthetic or artificial graphite, made from petroleum coke in high-temperature furnaces (2200oC). Synthetic graphite is very pure, but is finer grained and less dense than natural graphite. Fibres of carbon and graphite are produced by pyrolization of threads spun from rayon, polyacrylonitrile, or pitch materials. These are not natural graphite. They are used in the form of yarn, filament, felt or whiskers to reinforce plastic, metal, epoxy and other composite materials, giving added strength and rigidity and reducing weight. Man-made graphite fibres are impervious to electromagnetic radiation and are used as coatings to protect parts and housings from electromagnetic interference. Material made with carbon fibres is used on aircraft, ships, and other military vehicles to offer invisibility from radar detection. Carbon and graphite fibre textiles are used as an asbestos substitute.

4.3 PROPERTIES OF GRAPHITE

Graphite exists most commonly in the hexagonal form, occasionally in the rhombohedral form, and new work with high resolution transmission electron microscopy has revealed a rare monoclinic form (Barry and Buseck 1986). In habit, the mineral is thinly tabular with the C axis compressed making (0001) the broadest face. Internally the carbon atoms in graphite are arranged in parallel layers, each layer or sheet being a system of hexagonal rings that contain six carbon atoms. The distance between the layers is approximately twice the atomic spacing of the carbon atoms within the layer. This accounts for the foliated structure and good basal cleavage of the mineral (Reynolds 1968). A schematic diagram of the graphite flake is shown in figure 4.1.

The physical properties of graphite which reflect its internal structure are:

1. Parallel to the layers, the mineral is soft (1 to 2 on the Mohs hardness scale), yet sectile and flexible enough to resist destruction by grinding. The mineral has low surface friction and can be used alone or in oil suspension as a lubricating agent. As a dry lubricant, it is valuable because it cleaves into finer layers, coating the surfaces involved.

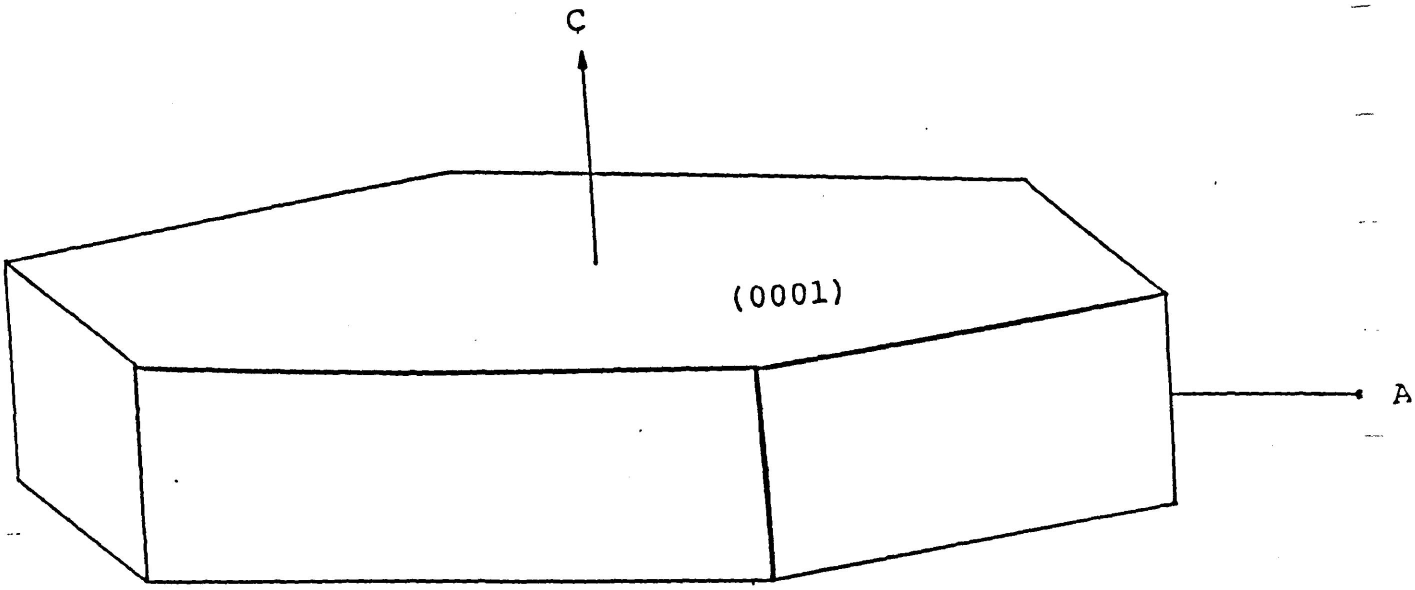


Figure 4.1: Schematic diagram of the graphite flake.

2. The mineral is strongly anisotropic with respect to thermal expansion and conductivity. Thermal expansion, relatively low, is 100 times greater along the C axis or through the crystal than along the A axis or along the crystal. Thermal conductivity is 200 times greater along the crystal than through it. Thermal conductivity also increases with rising temperature (Leinhos 1983). These properties are central to graphite's importance in the refractory product industry.

3. Graphite conducts electricity, also anisotropically. Conduction is slightly better along the crystal than through it (Leinhos 1983). It maintains the ability to conduct electricity even in very thin coatings.

4. Graphite melts at 3650oC, higher than most metals refined today (Graffin 1983; Harben and Bates 1984). The mineral can withstand temperatures in excess of those required in the refinery industry without any apparent damage to itself. As temperature increases, graphite increases in strength (Leinhos 1983). At4500oC it vapourizes.

5. Graphite oxidizes to CO2 in the presence of oxygen at temperatures around 600oC (Harben and Bates 1984; Weis 1973). Oxidation takes place at the edges of the flake, not through the plane of the flake. Studies by Heindl and Mohler (1953) showed that finer flakes oxidize more rapidly than coarser

flakes which is a reflection of the edge surface area exposed to oxidation. Similarly purer flakes oxidize faster than those of the same type with a higher ash content (Heindl and Mohler 1953). Amorphous or cryptocrystalline graphites oxidize at slightly lower temperatures than their flaky counterparts, and at a higher rate (Leinhos 1983).

6. Graphite, with a specific gravity of 2.00 to 2.25, is relatively light. Combined with the toughness of the flakes, graphite has a strength to weight ratio six times that of steel (Graffin 1983). This feature makes graphite fibre valuable in, for example, the aircraft industry.

7. Graphite is soluble in molten steel (Seeley 1964).

8. Graphite is a shiny grey metallic colour in flake form and a black sooty colour when massive or cryptocrystalline. It is completely opaque even when in very thin coatings or layers.

The uses of graphite are directly related to its properties:

1. Graphite is used as a dry lubricant, particularly in applications where oil or grease would be detrimental (Cameron 1960, Robbins 1984).

2. The low thermal expansion and high thermal conductivity contribute to the thermal shock resistance in the mineral. The anisotropic nature of these properties are important considerations during the manufacture of crucibles and refractory bricks to reduce thermal gradients within the products and to reduce power and fuel requirements within the refining industry (Leinhos 1983).

3. The ability to conduct electricity and lubricate at the same time makes graphite useful for motor and generator brushes (Cameron 1960, Robbins 1984).

4. & 5. The most important industrial application of graphite is in the refractory industry, where the very high melting temperature and the good thermal shock characteristics make the mineral well suited for the industry. In reducing conditions such as those found inside the continuous casting process for steel, graphite refractories suffer almost no damage on exposure to a very hostile environment. In

oxidizing conditions such as those found at the slag-line of a furnace or ladle exposed to oxygen, the graphite will oxidize, and refractories used in these environments are treated with additional refractory products to reduce oxidation (Heindl and Mohler 1955, Innace 1982, Leinhos 1983, Robbins 1984).

6. The high strength to weight ratio of graphite makes the mineral suited for applications where strength is required but weight must be kept to a minimum, such as camera parts, engine blocks and aircraft parts (Bell 1984).

7. Graphite is soluble in molten steel and is used to increase the carbon content of steel and steel alloys (Robbins 1984). Graphite is nonwettable with respect to most molten metals, and is used to line moulds and foundry facings to prevent sticking (Leinhos 1983, Innace 1982).

8. The opaqueness and black colour of graphite enable the mineral to be used for coatings and in paints, and in pencil leads. The conductive nature of the coatings makes graphite useful in areas where coating must be thin but still conductive, such as in electron microbeam work (Robbins 1984).

4.4 PROCESSING OF GRAPHITE

As most graphite does not command an excessively high price on the world market (see section 4.6), the processing required to prepare a concentrate must be cost effective. Beneficiation of graphite ore has traditionally been technologically simple: in the 19th century and in some countries today processing consists of hand sorting the graphite from the gangue and separating it into crude size fractions (Cameron 1960). This technique was most effective for the massive or vein type of graphite. Flake graphite deposits exploited in the 19th and early 20th century were usually highly weathered, to the point of being completely friable and hence requiring only cursory grinding to release the graphite. By the early 20th century, froth flotation and screening were employed to separate the graphite from the ground ore and divide it into size factions. Since most of the highly weathered graphite deposits have been exploited, the graphite deposits currently under consideration or being mined at the present time are not as highly weathered and releasing the graphite from the gangue can present problems. The major consideration is to release as much graphite as possible with little or no damage to the flakes as a result of the grinding.

Flake graphite is floated to separate it from the host rock. Various agents are added to the water to assist the separation procedure, the most common being a frothing agent such as pine oil. The ground ore is agitated in the water and pine oil and then allowed to settle. The gangue minerals sink and the graphite is concentrated on the surface (E. Blanchard, president, Erana Mines Ltd., Sudbury, personal communication, 1985). An Archimedes' screw device can also be used to lift the graphite concentrated in the water to the surface, similar to but the reverse of gold panning.

As purity and carbon content are important considerations for marketing, impurities must be carefully removed. Carbon content required of the graphite concentrate is product dependent, as are the types and amounts of impurities. A carbon content of 80% is the accepted minimum for most graphite concentrates (E. Weed, research engineer, Vesuvius Crucible Ltd., Pittsburg, Pa., personal communication, 1984). Higher carbon contents usually fetch higher prices, but there is a demand for concentrates of all carbon contents from 80% and higher.

Mica has a similar crystal structure to that of graphite and presents a problem by interlayering with the graphite, commonly becoming difficult to separate. Its flaky habit causes the mica to float, concentrating it with the graphite and increasing the percentage of impurities in the final concentrate. Quartz and feldspar can be wedged between the graphite layers and cannot be separated without repeated grinding, which reduces the quality and value of the flake.

Excessive grinding destroys the graphite flake by smearing or breaking the flakes into successively smaller pieces. Ideally a single grind should produce on separation a graphite concentrate of 80% carbon or higher to meet market requirements (E. Weed, research engineer, Vesuvius Crucible Ltd., Pittsburg, Pa., personal communication, 1984). If further grinding is required to increase the carbon content, there is a good chance that a high percentage of the flake will be too small to command a good price. Large flake sizes, greater than 425 um, command the highest prices on a per tonne basis, although there is an industrial demand for graphite flake of all sizes (Prud'homme 1985; Robbins 1984).

The final required flake size or flake size distribution is not standard for all parts of the user industry. After the concentration stage, a producer generally tailors his product to the needs of the manufacturer. Each product manufactured has very specific requirements for the graphite used (see section 4.7), including flake size. Flake graphite concentrates are separated into coarse, medium and fine fractions with percentages of certain sieve sizes. For example, Malagasy large flake is classified as 75% on the 40 mesh screen (425 um) and 97% on the 60 mesh screen (250 um) (Robbins 1984). Bagged large flake graphite will contain a high percentage of coarse flake and the rest would be made up of finer flake of varying sizes. Vein graphite is divided into a number of grades according to the size of the pieces of graphite: lump graphite ranges from pea to walnut size, chip graphite ranges from pea to wheat grain size and dust is finer than 250 um (Taylor 1980). Amorphous graphite is graded primarily on graphitic carbon content.

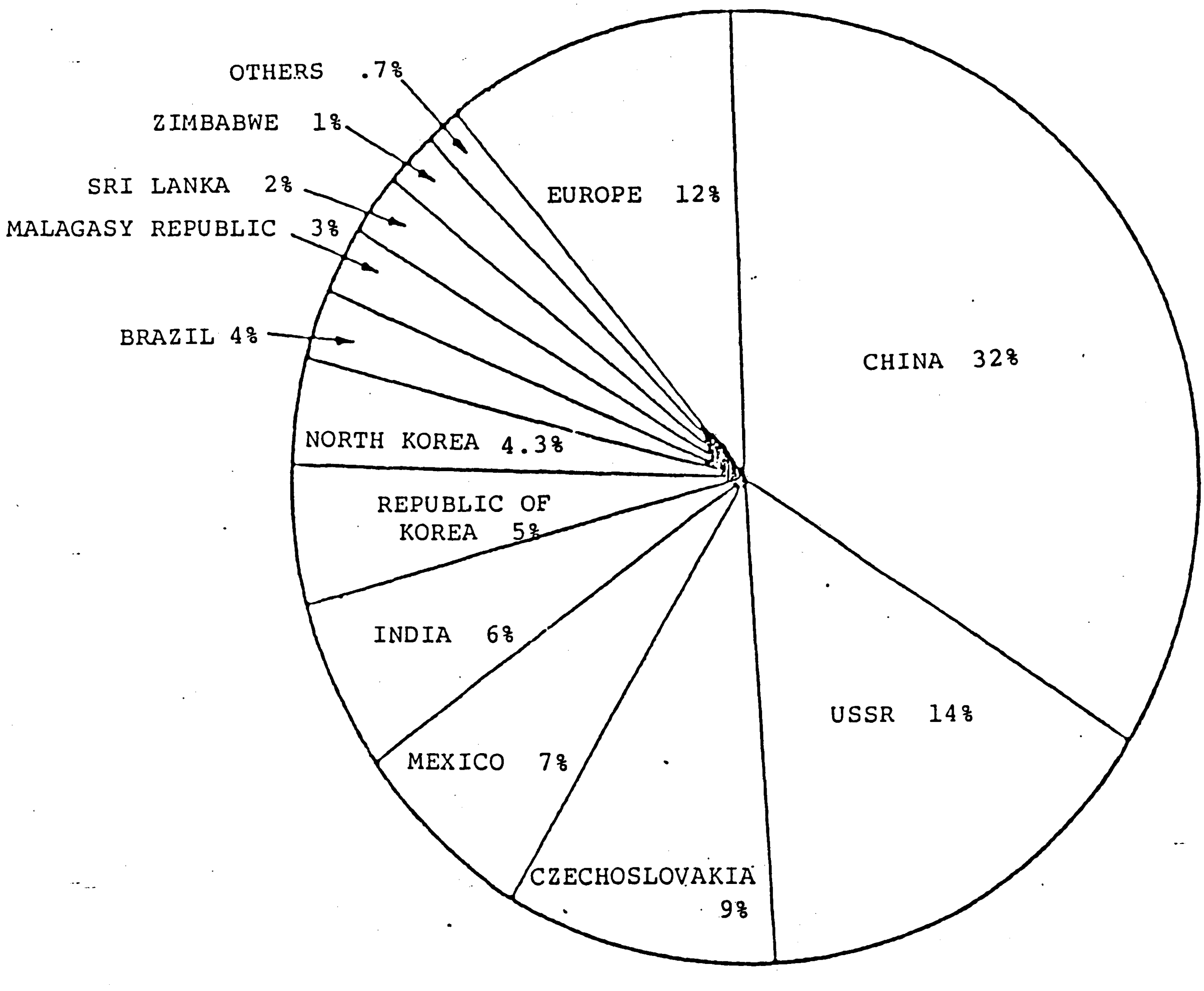
As grinding destroys the flake size and value, for maximum efficiency the maximum carbon content should be obtained with the minimum of grinding. This can be a particular problem where graphite is found in high grade, siliceous, metamorphic rocks as the host minerals - quartz, feldspar, and garnet - are much harder than the graphite. In an attempt to overcome this, the CANMET Extractive Metallurgical Laboratory in Ottawa experimented with a bioleaching process to release the graphite non-destructively from some Canadian graphite deposits. This was an attempt to disaggregate the rock by selectively decomposing sulphide minerals in the rock fabric. This process tried to imitate and intensify the natural weathering process. CANMET found that organic compounds leached from the graphitic component of the rock promoted fungal growth in the test leach. This trapped ferric hydroxide precipitates, effectively plugging the system. It was also found that the organic leachates were toxic to the bacteria responsible for the leaching. CANMET believed that further work would solve both these initial problems and recommended further studies to asses the viability of heap leaching graphite (CANMET Extractive Metallurgical Laboratory, Ottawa, personal communication, 1985).

4.5 PRODUCTION

Graphite is produced in only a few countries and production is usually limited to one major category of use. Occurrences and potential deposits of graphite commonly remain undeveloped due to the relatively small volume of graphite used by producers and the already well established supply. Graphite demand is linked to the metallurgical industries and the slow recovery of these industries is reflected in the increased demand for graphite as of 1985 (Prud'homme 1985). World supplies are still sufficient to meet demand, especially for low grade, fine grained natural graphite powders. The rarity of large flake graphite and the unique properties that graphite exhibits mean that deposits of this type are of particular interest, and graphite is a mineral of strategic importance to all steel-making nations.

In 1984, world production of all types of graphite was derived as: 32% from China, 21% from Europe, including Norway, 16% from India, South and North Korea, 14% from the U.S.S.R., 7% from Mexico, 4% from Brazil, 3% from the Malagasy Republic, and 2% from Sri Lanka (Figure 4.2).

North America is largely dependent on foreign sources for graphite, particularly crystalline flake. The United States imported almost 53,000 tonnes of graphite in 1984, 50% from Mexico, and the rest mainly from China, Brazil, and the



TOTAL = 562330 TONNES

Figure 4.2: World production of graphite in 1984. (Adapted from: Prud'homme 1985)

Malagasy Republic (Prud'homme 1985). As foreign policies of the governments of the supplying countries might endanger the availability of high-grade graphite there is always interest in stimulating development of alternate sources of graphite.

Graphite production of the major producing countries from around the world is summarized below:

a) Sri Lanka: The three major graphite mines are the Bogala, Kahatagaha and the Kolongaha, all operated by the state Graphite Corporation of Ceylon since 1971. The 1980 production figure for Sri Lanka was around 10,000 tonnes (Pettifer 1980); in 1984, it was 9,000 tonnes(Prud'homme 1985). In 1984, Sri Lanka exported 7,000 tonnes, primarily to Britain and Japan. Sri Lanka has been experiencing environmental and political problems which have influenced production and caused buyers to look for a more stable source of supply.

b) Malagasy Republic: Graphite from the Malagasy Republic is of such a high quality due to its large flake size, carbon content and uniformity that is has become the standard for comparison worldwide. It has the natural advantage that the ore is deeply weathered and can be mined with earth-moving equipment. Antiquated equipment and mining methods are now hampering production, reducing it below the 20,000 tonne mark common in the 1970's, to around 13,500 tonnes in 1984. Of the 11,000 tonnes exported in 1984, half went to Britain, and almost a third went to the United States (Prud'homme 1985).

c) Mexico: Mexico is one of the most important producers of amorphous graphite. The largest single producer is Grafitos Mexicanos SA which mines 30,000 TPA. (This is almost half of Mexico's 1980 production (Pettifer 1980)). The 1984 production was 40,000 tonnes (Prud'homme 1985). Around 85% of Graphitos' production is sold to Asbury Graphite Mills, Inc. of New Jersey, while the remainder is used domestically. Grafitos blends the high carbon graphite with lower quality graphite to produce a product between 80% and 82% C. In 1980 a subsidiary of the Mexican Government opened a new mine in southern Mexico, producing a graphite flake concentrate with a 95.5% carbon content. Mexico exported 25,273 tonnes in 1984, all to the United States (Prud'homme 1985).

d) U.S.A.: The last producer of flake graphite in the U.S., the Southwestern Graphite Co., owned by The Joseph Dixon Crucible Co., closed its Texas mine in 1979. The flake graphite was mined from the Packsaddle Schist, with an average graphite content of 4.5% to 5.0% by weight. Concentrate containing 96% to 97% carbon was produced. International Carbon and Minerals Corp. (IMC) of Missouri have been considering re-opening the Clay County, Alabama flake graphite deposit, formerly owned and operated by the Alabama Flake

Graphite Co. and the General Graphite Co. (Pettifer 1980). Only one amorphous graphite mine is in operation: the United Minerals Company has operated on an intermittent basis, since 1982, its open-pit mine in Montana. The graphite is a low grade amorphous type, averaging about 25% carbon (Prud'homme 1985) which is sold for steel refineries in the United States rather than exported.

e) <u>China:</u> China suppplies almost a third of the world demand for flake graphite. Estimated reserves are 615 million tonnes averaging 12% graphite, giving China the potential to meet the total world requirements for flake graphite (Prud'homme 1985).

f) <u>Europe:</u> The graphite-producing countries of Europe are: Czechoslovakia, Austria, West Germany and Norway. In 1984, their combined production was 21% of the total world production. The main European importing countries are Austria, West Germany and Britain, which buy 6,000, 28,000, and 19,000 tonnes, respectively (Prud'homme 1985). The Austrian and Czechoslovakian graphite is of the amorphous variety. The Norwegian graphite is of the flake variety, mined from a deposit near Tromso. The mill is designed to operate at 10,500 tonnes per year (Oxford 1984). Graphitwerk Kropfmuhl of Munich operates the Kropfmuhl mine in West Germany, producing a flake graphite concentrate as well as accepting concentrates from other sources for carbon content upgrading. West Germany also imports most of the graphite produced in Zimbabwe, for processing and distribution.

g) Republic of Korea and India: The Republic of Korea produces both amorphous and flake graphite, exporting approximately 30,000 tonnes per year, mainly to Japan (Oxford 1984, Prud'homme 1985). India produces around 35,000 tonnes of flake graphite (Prud'homme 1985), but their industry is hampered by labour-intensive extraction techniques and crude processing plants.

h) Brazil: Brazil operates two flake graphite mines in the Minas Gerais area. This is deeply weathered terrain, allowing open-pit mining by loader-truck operations. Concentration of the graphite is by flotation. Production in 1984 was 20,000 tonnes (Prud'homme 1985), 35% of which was sold domestically (Oxford 1984). The United States imports a small amount of flake graphite from Brazil.

i) U.S.S.R.: The U.S.S.R. produced 80,000 tonnes of flake and amorphous graphite in 1984 (Prud'homme 1985), most of which was used internally.

j) Canada: Since 1980, Asbury Graphite Quebec Incorporated has been operating, on an intermittent basis, a flake graphite deposit located east of Ottawa. Reserves are estimated at 500,000 tonnes, with an average grade of 10%

graphite. Production rate at the mill is 350 tonnes per day. Most of the concentrate is shipped to Asbury Carbons Incorporated in New Jersey (Prud'homme 1985).

4.6 PRICES AND SPECIFICATIONS

The price structure of the graphite market is complicated by the many different grades available and a general lack of standard specifications. Published prices represent a range; actual prices are negotiated between buyer and seller and are based on a wide spectrum of specifications. This point highlights one of the major problems in dealing in the graphite market: there are as many different specifications for graphite as there are producers and users of graphite.

Graphite producers classify flake graphite into concentrates consisting of large, medium, and fine flake; vein graphite into different lump sizes; and amorphous graphite as amorphous or powdered graphite. These subdivisions are further classified according to size of the flake, lumps, or granules, and to the minimum required carbon content. Graphite producers do not specify impurity or ash tolerances since ash requirements are primarily a concern of the manufacturers. Flake size is specified as a certain percentage of the concentrate which passes or is retained by a particular mesh. For example, a large-flake concentrate described as 75% on 40 mesh (425 um) and 97% on 60 mesh (250 um) means that at least 75% of the concentrate consists of graphite flakes larger than 425 um, and that at least 97% of the concentrate consists of graphite flakes larger than 250 um. Vein graphite is specified as lumps of various size fractions and powder. Amorphous graphite is specified as powder, usually passing a 200 mesh (75 um).

Each type of graphite concentrate has a specified minimum required carbon content, expressed as percent carbon. Graphite is rarely 100% carbon due to the presence of impurities such as mica, feldspar, pyrite, and quartz lodged between the layers. Grinding releases only some of these impurities, resulting in carbon contents less than 100%.

Complications arise when each different producer of graphite puts different specifications on the established graphite subdivisions. Large flake graphite has different requirements for size and carbon content depending on its source; the Malagasy Republic, Brazil, or any other flake producing area. The same holds true for the vein and amorphous varieties, necessitating the need for a prospective buyer to search out a source of graphite which specifically meets the requirements for his product.

Table I summarizes some of the graphite specifications from major producing countries. Size restrictions and carbon contents are different for each type of concentrate. The coarser flake concentrates command the higher prices as do the higher carbon contents within each type. The 1987 prices quoted from Industrial Minerals (February 1987) are listed below:

CIF UK port		US$/tonne
Crystalline lump, 92/97% C		$550-$1,100
Crystalline large flake, 85/90% C		$630-$1,000
Crystalline medium flake, 85/90% C		$490-$860
Crystalline small flake, 80/95% C		$300-$800
Powder (200 mesh),	80/85% C	$250-$275
	90/92% C	$410-$460
	95/97% C	$550-$750
	97/99% C	$750-$1,000
Amorphous powder,	80/85% C	$175-$350

Graphite users also have specifications with respect to flake size and carbon content, but because their specifications are set for individual products it becomes very difficult to generalize. The amount and type of impurities are important since they could have a direct effect on the quality of the product. For example, the specifications for a graphite concentrate to be used in the manufacture of crucibles depends on the type of crucible: clay/graphite crucibles require 45% of the graphite flake to be larger than 250 um, a carbon content of at least 90%, and the ash must be non-alkaline. Silicon carbide/graphite crucibles require 30% of the flake to be larger than 150 um, a carbon content of 80%, and a more easily fusible ash. For any product, whether it uses flake, vein, amorphous, or synthetic graphite, the specifications depend on the technology involved in the manufacturing process and vary with each different product and with each different manufacturer. Specifications for a variety of products are summarized in Table II.

TABLE I: SPECIFICATIONS USED BY MAJOR CRYSTALLINE GRAPHITE PRODUCERS

	Crystal Size	% Carbon Content	Price/Tonne (US$)
Malagasy Republic			
Large flake	75% > 425 um 97% > 250 um	85-89.5% to 92-94%	$850 to $1,140
Medium flake	25% > 425 um 97% > 180 um	80-84.9% to 90-92%	$750 to $978
Fine flake	25% > 425 um and 75% > 250 um (maximum); 95% > 180 um (minimum)	75-80% to 89-92.5%	$636 to $886
Extra fine flake		70-75% to 85-90%	$407 to $494 Prices FOB Malagasy Republic. June 1984
Brazil			
Large flake	60% > 250 um 90% > 180 um 3% < 75 um	85-89% Ash content 13%. Equivalent to Chinese V85 grade	$700. Prices FOB Santos. March 1984
Fine flake		85-99.6%	$420 to $2,250 Price FOB Santos. June 1984
China			
Large flake	85% > 300 um	85% to 90%	$600 to $740
Medium flake	80% > 170 um	85% to 90%	$470 to $600
Small flake	50% > 180 um	80% to 90%	$270 to $370.
Norway			
Large flake	Above 150 um	85% to 95%	$600 to $940
Medium flake	Above 110 um	85% to 95%	$540 to $800
Powder	Below 75 um	80% to 95%	$270 to $540. Prices as of June 1984.
Sri Lanka			
Large lump lump	+10 mm	92% to 99%	$550 to $1,100
Chippy dust	-5 mm	80% to 99%	$205 to $1,100
Powders	Below 75 um	70% to 99%	$180 to $1,250
West Germany			
Powders	N/A	50% to 99.99%	$670 to $700 Average price June, 1984
Zimbabwe (Lynx Mine)			
Flake	50% to 315 um 85% to 150 um	90% to 92%	Subsidiary of West German company Graphitwenk Kropfmurl AG. Produchon 13,000-15,000 tpa

Adapted From: Robbins, J. (July 1984.)

TABLE II: SPECIFICATIONS FOR GRAPHITE PRODUCTS

USE	Size & Type	Carbon Content	Ash
REFRACTORIES			
Crucibles			
a) Clay/Graphite	-flake -45% must be flake larger than 250 um	90% C	-must be non-alkaline
b) Silicon-carbide/ Graphite	-flake -30% must be medium-large flake -larger than 150 um	80% C	-Ash with lower PCE* tolerated -depends on bonding agents
Mag-Carbon Bricks	-flake -medium-large -150 um - 170 um -aspect ratio 20:1	87%-90% C	-Ash below 10% -Silica, alumina and iron are detrimental.
Alumina-Carbon	-flake -larger than 420 um	85% C	-10% - 20% SiO2 forms part of the bonding agent

* PCE - Pyrometric Cone Equivalent (see ASTM Part 17, 1978)

SPECIFICATIONS FOR GRAPHITE PRODUCTS (cont.)

USE	Size & Type	Carbon Content	Ash
POWDERS			
Brake Linings	-flake, vein, synthetic -often blended 60:40 natural to synthetic ratio -flake smaller than 75 um -synthetic granules 1 mm	98% C (90% C if abrasives very low	-no silica in ash
Batteries			
a) Dry Cell zinc/carbon	-ground natural graphite -smaller than 75 um	88% C	-impurity tolerant -should be free of metals
b) Alkaline	-ground natural graphite or synthetic -5-75 um	98% C	-no metallic impurities
Brushes	-fine powdered graphite -natural (vein or amorphous) or synthetic -150 um or less -prefer finer than 50 um	95%-99% C	-silica must be less than 1%

SPECIFICATIONS FOR GRAPHITE PRODUCTS (cont.)

USE	Size & Type	Carbon Content	Ash
Powder Metallurgy (Sintering)	-fine powdered graphite -natural or synthetic -average particle size 5 um	96%-99% C (98%-99% preferred)	-no abrasives
Lubricants	-fine natural flake -50-150 um	96%-99% C used, 98%-99% preferred	-no abrasives
Paints and Conductive Coatings	-amorphous -powdered flake -very finely ground	50% C (amor.) 70% C (powd. flake)	-no pyrite (weathers to H2SO4) -no mica (causes flaking)
Pencils	-amorphous	80%-82% for cheaper leads 90%+ for better pencils	-no silica -no abrasives

SPECIFICATIONS FOR GRAPHITE PRODUCTS (cont.)

USE	Size & Type	Carbon Content	Ash
Foundries			
a) Facings	-vein or amorphous -dust from refining mills -reground rejected graphites -50-75 um	40%-70% C	-fusible material unacceptable ie. sulphides
b) Recarburising Steel	-synthetic, amorphous, & petroleum coke (depends on availability)	-high purity desirable	-compounds that react with steel i.e. pyrite--contaminates the steel
Mechanical Engineering Components	-amorphous (temp <300oC) -electrographitized material (>300oC)	-purity depends on product	-ash tolerance depends on product
Insulating Agents	-flake graphite treated chemically (Dow Chemical pat.) -weakens bonds between plates -allows graphite to expand when heated -1.8mm to 250um	85% C min.	

4.7 USES

The main uses of graphite are: refractories, foundry facings, steelmaking, lubricants, batteries, brake and clutch linings, and pencils. These products take advantage of such properties of graphite as the high thermal conductivity, the increase in strength with temperature, anisotropic conduction of heat and electicity, resistance to oxidation, inertness to most chemicals, non-wettability, unctuousness, and high thermal shock tolerance. Each particular use has a requirement or set of requirements met by a particular kind of graphite. The following subsections discuss the individual products, specifications, and properties of graphite required.

4.7.1 Refractory Products

There are many different kinds of refractory products, all used in applications where a resistance to heat is required. The common refractory products are crucibles, bricks for ladle and furnace linings, shrouds, nozzles, stopper heads and retorts. The major applications are for use in the metal refining industry.

a) Crucibles

Crucibles, shrouds and stopper heads account for 6% of the U.S. demand for graphite (Taylor 1980). Graphite is used in crucibles because of its high heat conductivity, which allows rapid melting of the charge; its low thermal expansion, which gives the product resistance to thermal shock; and its refractoriness, which allows for continued use at elevated temperatures without fusion or porosity change. It has the ability to remain flexible and strong at high temperatures and it is resistant to corrosion from both metals and fluxes.

Traditionally, the graphite used in crucibles has been large flake, greater than 300 microns (Springer 1983), supplied from the Malagasy Republic. In general the specifications for flake size for crucibles are: 30% greater than 600 microns, 90% greater than 250 microns and 100% greater than 150 microns (Springer 1983). Large flake size is necessary in crucible manufacture to facilitate bonding with clay and other materials in the mixture. The larger flake is also more resistant to oxidation (Heindl and Mohler 1955). Crucibles have been made traditionally by spinning, similar to pottery manufacture, or ramming (E. Weed, research engineer, Vesuvius Crucible Ltd., Pittsburg, Pa., personal communication, 1984). Flake orientation by these methods is parallel to the crucible wall, presenting the flat surface to the hot metal and the C axis normal to the heat flow. This orientation does not take best advantage of the lower thermal expansion or higher thermal conductivity parallel to the A and B axes along the flake. Isostatically pressed crucibles align the flakes perpendicular to the walls to take better advantage of the anisotropic properties (Leinhos 1983)(figure 4.3).

The preferred type of graphite for crucibles is flaky, with a high aspect ratio, and the flakes should pack normal to layering with a 50 to 60% volume decrease (J. Springer, industrial minerals policy advisor, Ministry of Northern Development and Mines, Sudbury, personal communication, 1983; E. Weed, research engineer, Vesuvius Crucible Ltd., Pittsburg, Pa., personal communication, 1984). Since oxidation and burning preferentially attack the edge rather than the face of the flake, a high aspect ratio yields a graphite with a low burning rate which prolongs crucible life, and a low bulk density (50 g./100 ml.) which reduces shrinkage on drying.

Carbon content required of the flake depends on whether the crucible is made of the traditional clay-graphite mixture using clays similar to those used in china and porcelain, or whether the newer silicon carbide/graphite mixture is used. In the clay-graphite crucibles, 45% of the mixture must be large flake graphite with a carbon content of at least 90% (Robbins 1984). Crucibles made from silicon carbide/graphite do not have such stringent flake size requirements and companies now blend the graphite using flake from many different sources for these products.

The amount of impurities is not as important as is the type of impurity. Graphite with a carbon content of 80% is

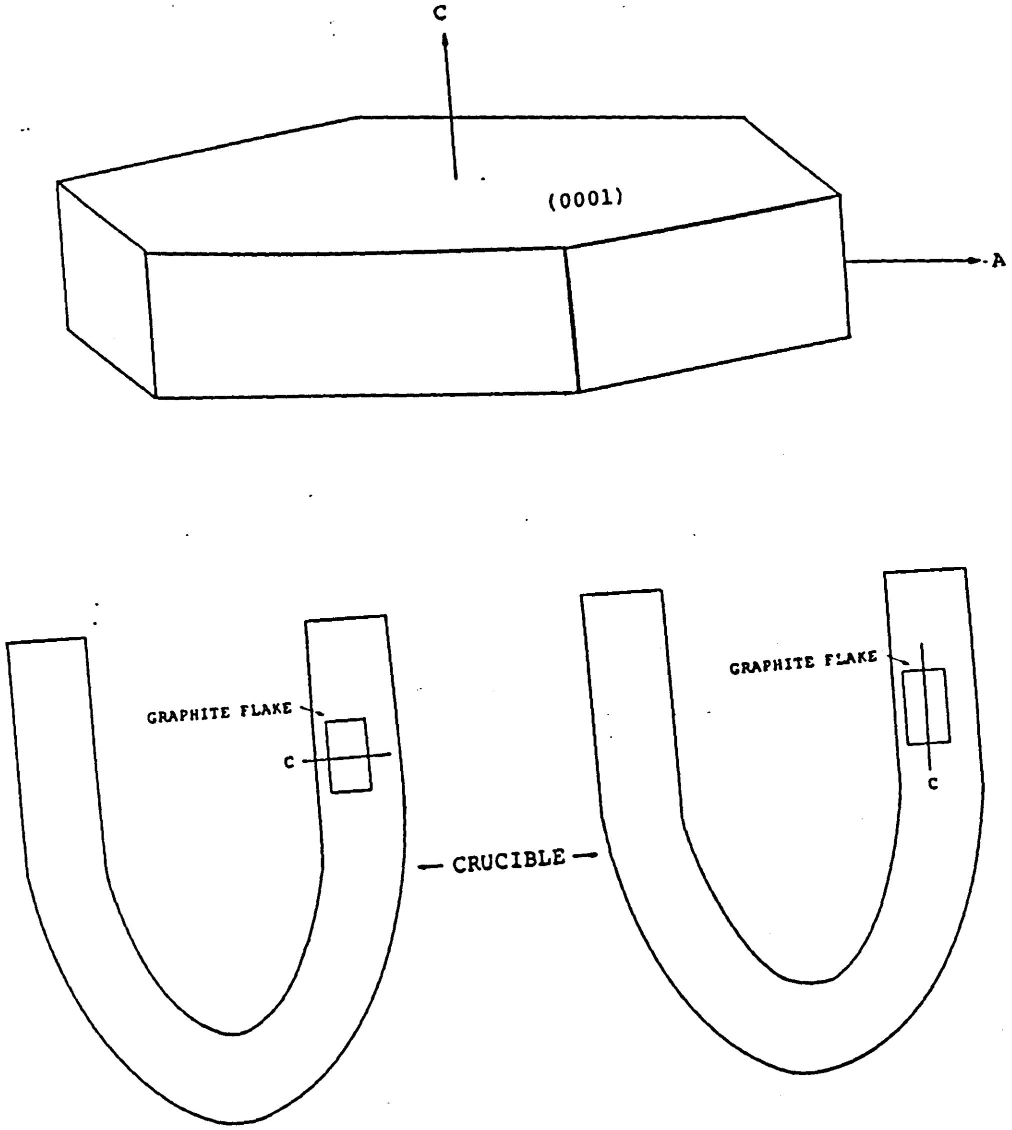


Figure 4.3: Schematic diagram showing the graphite flake and orientation with the C axis perpendicular and parallel to the crucible wall.

quite acceptable for crucibles if the impurities are not too alkaline. Alkalis produce low temperature melting flux mixtures and lower the heat strength of the refractory product. They must therefore be less than 2%. Other impurities, such as mica or pyrite, which are prone to rapid oxidation give pinehole faults in the crucible wall and must also be avoided.

In the silicon carbide/graphite crucibles the ash component is beneficial. It can contribute to the formation of a glaze which acts to protect the crucible from oxidation. Therefore, a less refractory, more alkaline ash component is tolerated than that generally required for clay/graphite crucibles (Leinhos 1983).

The introduction of isostatic pressing to improve flake orientation, the increased use of finer and blended graphites and the increased impurity tolerance has led to increasing demand for silicon carbide/graphite crucibles over the more traditional clay/graphite crucibles.

b) Mag-Carbon Bricks

Mag-carbon bricks traditionally were used by steel manufacturers in furnace linings. The older style magnesia bricks are ceramically bonded; the newer style are resin bonded to produce a more durable brick and a more effective refractory. With the advent of electric-arc furnaces, and the production of stainless steel which requires temperatures of approximately 2000oC, all large electric-arc furnaces now use at least some mag-carbon bricks to line the walls (figure 4.4). The increased use of water-cooling technology for the electric-arc furnace has increased the use of mag-carbon bricks for their conductivity. (Leinhos 1983; Robbins 1984). They are also used in the trunnion areas of basic oxygen furnaces (figure 4.5). Benefits are less thermal shock and reduced slag penetration, resulting in a longer service life (Leinhos 1983). Brick life is typically five hundred casts, and can be improved to a thousand casts by increasing the carbon content from 15-20% to 20-25%. Basic oxygen furnaces (BOF) also employ mag-carbon bricks in the furnace lining, with a brick life of seven hundred casts. Mag-carbon linings have also been implemented in the linings of ladles to compensate for the corrosive slag line produced by reagents added to the steel. The highly oxidizing environment of the slag line reduces ladle life to fifty casts.

The graphite first used for mag-carbon bricks was synthetic, from ground electrodes. Natural flake was soon proven to have superior thermal shock characteristics and replaced the artificial graphite. A high carbon content (87-90%) is required, and is obtained by blending a variety of high carbon, smaller-flaked graphite from several sources, most notably China (Robbins 1984). Ideal flake size is in the 150 to 710 micron range, since larger flakes may cause cracking and bending problems (Robbins 1984). An aspect ratio of at least 20:1 is recommended to reduce

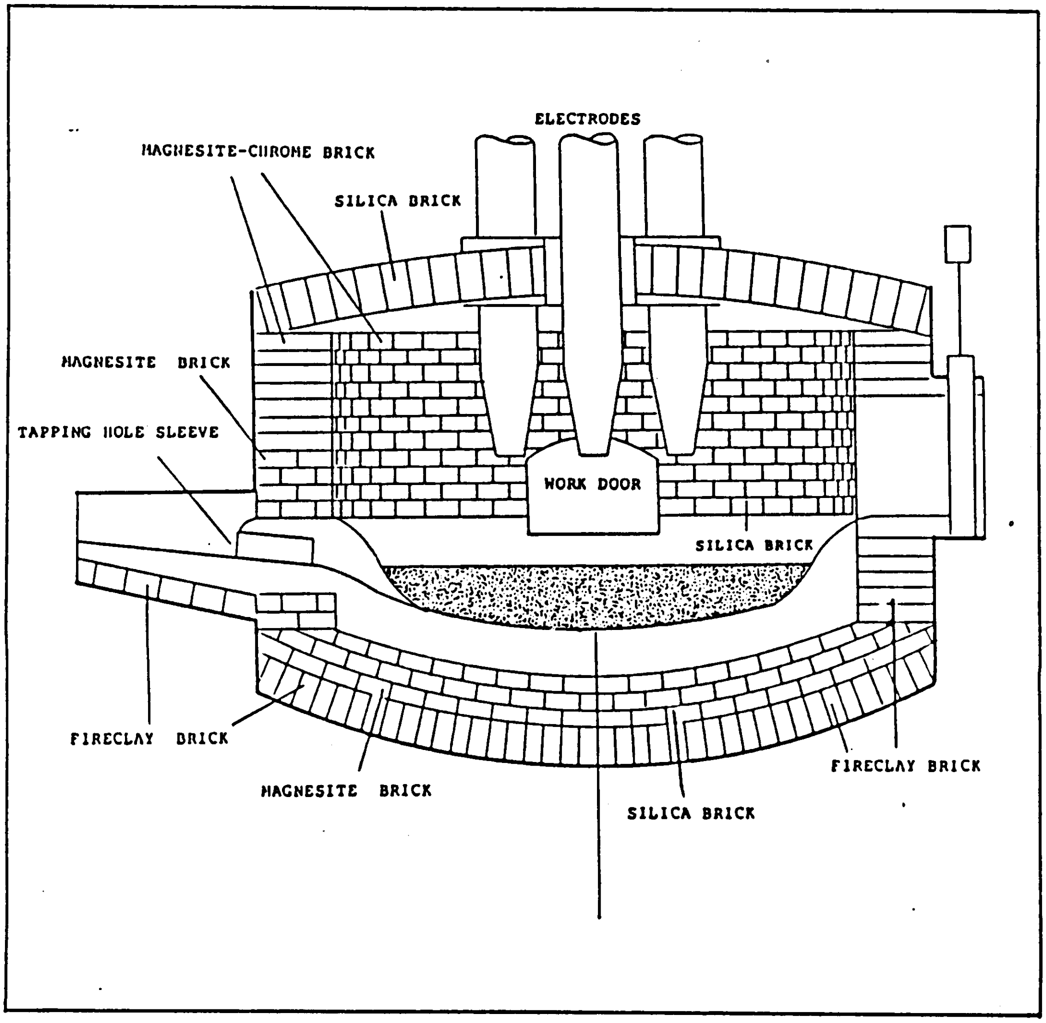


Figure 4.4: Electric-arc furnace used in steelmaking. Electric arcs are struck from the electrodes to the scrap in the furnace then back to the electrodes, melting the steel.
(Adapted from: Miller 1984)

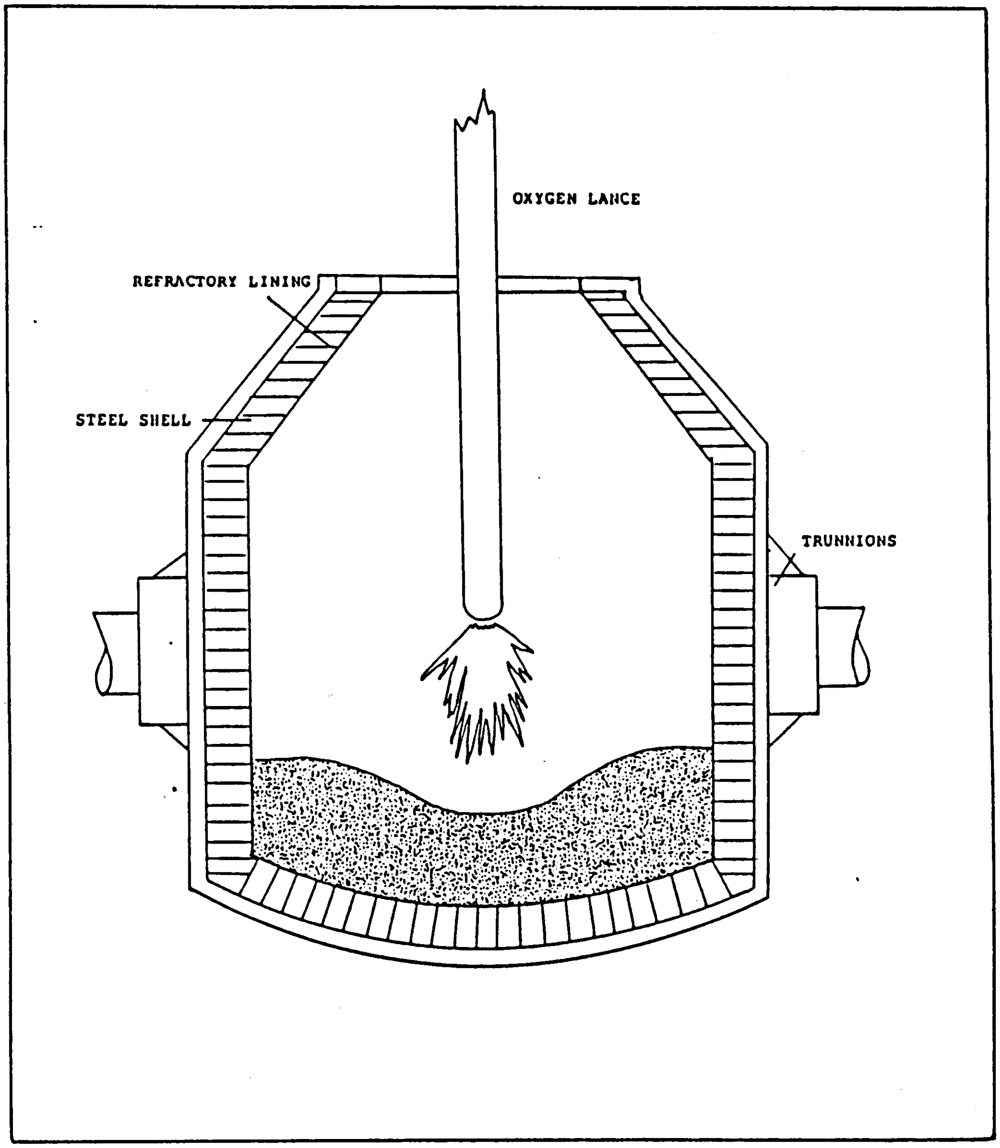


Figure 4.5: Schematic diagram of the basic oxygen furnace.

the amount of flake edge exposed to oxidation.

The ash content should be less than two percent although ten percent is acceptable for some applications. Detrimental components are silica, alumina and iron, as they combine with the magnesia to form low-melting, non-refractory compounds.

c) Graphitized Alumina Refractory Products

Graphitized alumina refractory products are used to control the flow of molten metal from the ladle to the tundish or mould. Ladles pour from the bottom, like a bath tub, and the refractory prevents oxidation as the molten metal pours into the tundish. The graphite nozzle fitted into the ladle guides the metal and the stopper meters the amount poured (figure 4.6). Since the refractory products are suddenly introduced to temperatures around 1600oC good thermal shock and corrosion resistance qualities are required. The graphite must also be strong, non-wettable, and a good conductor of heat.

The alumina graphite mixture generally contains between 10% and 20% SiO_2 (which aids in the bonding of the components) and 25-30% graphite, but the actual amounts and proportions vary according to individual manufacturer's specifications (Robbins 1984, Leinhos 1983). Although carbon content must be at least 85%, flake size is the critical parameter, ideally falling in the 150 um to 500 um size (Robbins 1984, Heindle and Mohler 1955) in order to better withstand the oxidizing conditions. These

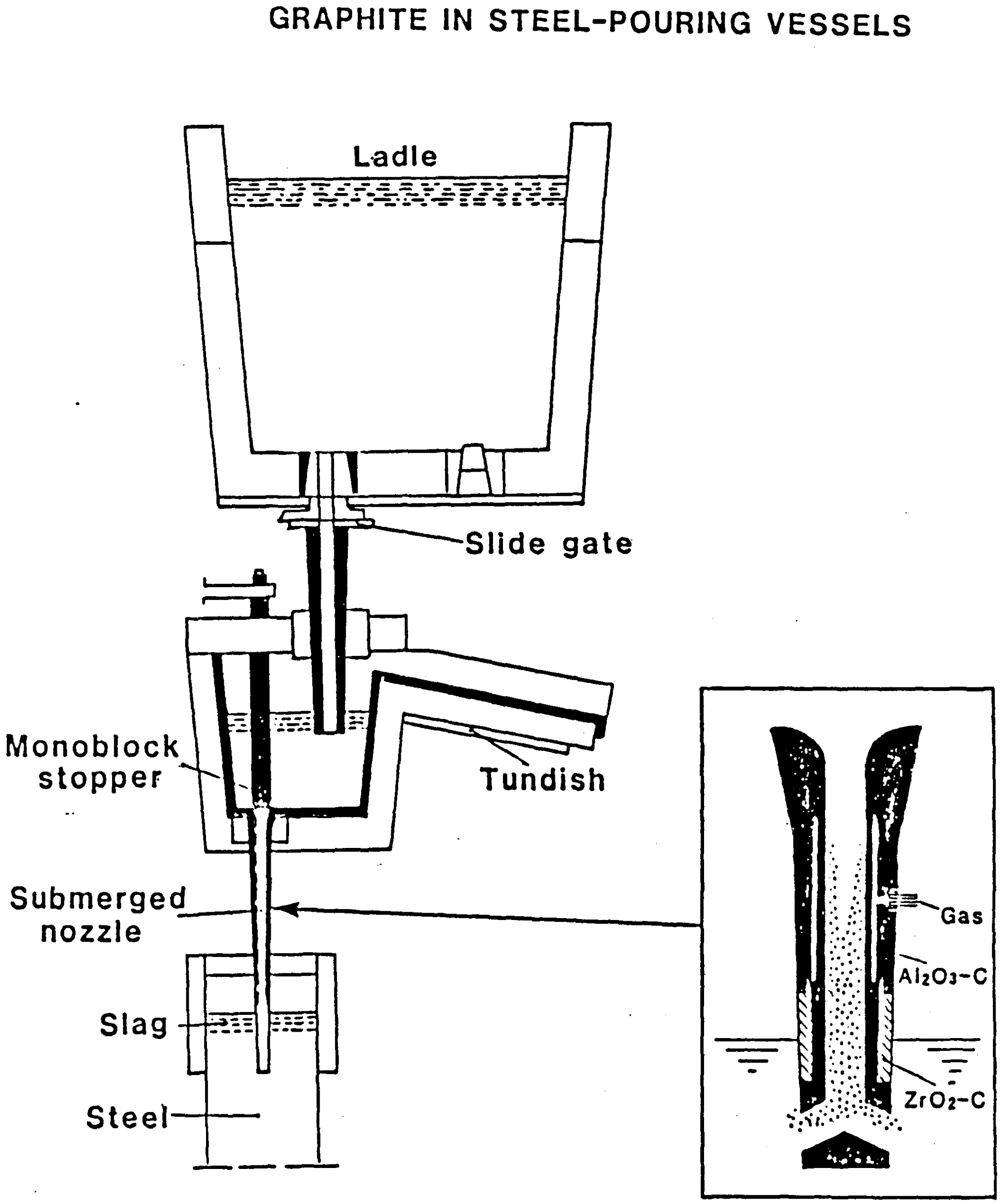


Figure 4.6: Graphitized alumina refractory products used in the continuous casting process of steelmaking.

refractory products can be made by either isostatic pressing or vacuum extrusion. Some refractory products, such as nozzles, require a lower thermal conductance. The heat must be contained inside the nozzle to prevent cooling and clogging. Stoppers require excellent shock resistance. They are isostatically pressed for optimum flake orientation as well as containing compounds such as zirconia or corundum to raise thermal shock resistance and prevent breakage (Innace 1982).

4.7.2 Brake Linings

The decline in the use of asbestos, which was the prime component in brake linings, has increased the use of graphite moulded in resin for use in brake and clutch linings. The U.S. demand for graphite for this purpose is 3% (Taylor 1980). The graphite smears on the brake-drum or disc, reducing friction and decreasing the rate of wear of the linings themselves.

The graphite for linings is usually a blend of natural flake and synthetic graphite with the carbon content 90% or higher and 95% of the powder finer than 75 um. The fineness of the powder ensures uniformity and more even wear of the moulded product. Some impurities can be tolerated if they are non-abrasive. Where strength is a prime concern, manufacturers can now produce a stronger product by using a granular synthetic graphite with superior bonding capacity to the resin.

4.7.3 Batteries

The quality of the graphite used in battery electrodes affects the performance of the battery to such an extent that the requirements for the graphite are strict. Carbon content, structure and orientation of the flakes, and flake size all influence the cell performance. Natural flake graphite, ground and blended, is used for dry cells and untreated natural flake is used for alkaline cells. The carbon content must be 88% or higher, especially for alkaline batteries, and the impurities must be non-metallic (Robbins 1984). Consumption of graphite for batteries accounts for three percent of U.S. total consumption (Taylor 1980).

4.7.4 Brushes

Brushes are used in electric motors, alternators and generators. Various combinations of natural and synthetic graphite are used depending on the use of the brush. In general a mixture of graphite and a binder, either a coal tar pitch or a synthetic resin, are compressed into blocks and heat treated to at least 600oC. The main parameter for this type of graphite is the amount of "spring back", or how much the graphite expands after compression and release. Low spring back is required or the brush will disintegrate with use. Sri Lankan and Bavarian graphite have the lowest spring back, while most synthetic graphites have high spring back. The flake must be fine-grained or finely ground, to a 50 um. maximum size, have a carbon content of 95-98%, and contain less than one percent silica ash (Robbins, 1984; Prud'homme, 1985).

4.7.5 Powder Metallurgy (Sintering)

Sintering is the technology of mixing high purity graphite with metal powders in dry form and heating this mixture to form specific shapes, such as cogs in gears and motor parts. The carbon is used to strengthen the metal. Carbon content is extremely variable, depending on the product, and most impurities with the exception of sulphides and other readily fusible materials are tolerated. Both natural and synthetic graphite can be used, once again dependent on the type of product being made.

4.7.6. Lubricants

The use of the popular dry lubricant, molybdenum disulphide, is currently declining due to its high cost. The softness, low coefficient of friction, inertness, heat resistance and lower cost make graphite an ideal substitute as a dry lubricant. Natural flake graphite is preferred, in the 105 um. to 50 um. size range, with a carbon content of 90% or higher (Robbins, 1984). Graphite for lubricants and special packings consumes approximately 6% of the U.S. demand (Taylor, 1980).

4.7.7. Conductive Coatings and Paints

Conductive coatings are used for protection and colour for electrical screen prints, anti-static floor coverings, and any other substrates that require a light-stable, chemical or heat resistant covering. Graphite coatings also absorb radioactivity, specifically neutrons.

Either the very fine or 'amorphous' graphite or powdered flake is used, with carbon contents once again dependent on the end product. Impurity tolerances also vary depending on the product, although for most uses pyrite causes decomposition and mica causes flaking.

4.7.8. Expandable Graphites and Foundry Graphites

Expandable graphite is used to prevent the adhesion of metals to moulds, and as an insulating agent in casting processes. The graphite is mixed with a bonding agent such as refractory clay, talc, sand, or mica to provide a smooth finish to the interior of the mould. The graphite used for this process can be either low grade, fine grained graphite, graphite rejected for other uses, or fine flake graphite. These are treated chemically to weaken the bonds between the flakes, allowing expansion of the graphite on heating to form a light weight insulating blanket (Leinhos, 1983). Dow Chemical has a patent on the process, but other companies have used chromic and sulphuric acid (Robbins, 1984) and sulphuric and nitric acid (Leinhos, 1983) to weaken the bonds.

Foundry graphite is used to provide a smooth finish to the inside surface of the foundry moulds to expedite removal of the cooled metal. The graphite used for this is either low grade graphite dust, finely ground microcrystalline graphite, or re-ground graphite rejected from other uses. Foundry facings account for 16% of the U.S. demand for graphite (Taylor, 1980).

4.7.9. Recarburizing

The graphite used to increase the carbon content of steel is usually amorphous or synthetic, obtained by grinding discarded electrodes. Natural flake graphite is usually too soft and the flakes cause weaknesses and cracking in the steel. The U.S. and Japan use readily available amorphous graphite from Mexico and South Korea (Robbins, 1984). Approximately 27% of the total U.S. demand is for recarburizing steel (Taylor, 1980).

4.8 MARKETING

Graphite has traditionally been a commodity that has exhibited firm linkages between customers and sources. Once a consumer found a suitable grade and type of graphite for a particular product, that source tended to be the only one used. Technological evolution of a product eventually developed around a particular type of graphite. This idea was strengthened by the belief that graphite from each different deposit displayed unique characteristics, suitable for a consumer's particular application. Graphite is also a commodity that has been traditionally tied to the steel and metal refining industries. The recent slump and ongoing re-organization of the steel industry world-wide has affected the demand and price of graphite and graphite products.

The infrastructure of the graphite industry is currently changing. Japan has increased imports of natural graphite (Robbins 1984) and Sri Lanka is experiencing equipment and political problems (Fogg and Boyle 1987), causing concern among importing countries about the stability of some of the long-established sources of graphite. Exhaustion of reserves and operational problems are adversely affecting production in other traditional producing countries. Consumers are starting to blend graphite from different sources, reducing their dependance on one particular source and increasing the market for graphite concentrates. The slow recovery in the metallurgical industries, as well as the continuing development of new products, is benefitting the graphite producers and providing a stimulus to potential producers.

The major markets for graphite are the industrialized countries. In 1984 Japan imported 85,009 tonnes of graphite, the United States imported 52,826 tonnes, West Germany imported 27,604 tonnes, the United Kingdom imported 19,539 tonnes, and Austria imported 6,075 tonnes (Prud'homme, 1985) (figures 4.7 and 4.8a). Prud`homme (1985) reports the total world production in 1984 as 562,330 tonnes, in which case Japan's imports represent 15%, the United States 9%, West Germany 5%, the United Kingdom 4%, and Austria 1%, a total of 34% of the world production. These numbers imply that supply of natural graphite greatly exceeds demand, and this is true, particularly for the finer-grained concentrates and the amorphous graphite. Coarser flake graphite, used in refractory products, has been difficult to obtain in the past (Pettifer, 1980) prompting consumers to branch out into different source areas. Of the 52,826 tonnes of graphite imported by the United States in 1984, 44% went towards refractory products and had to be refractory grade. Of the rest, 26% was consumed by the steel industry and the remaining 30% was used in all the other assorted graphite products (Taylor 1980) (figure 4.8b). It is important to note that the refractory industry consumes almost half the United States' demand for graphite and it is this industry that requires the

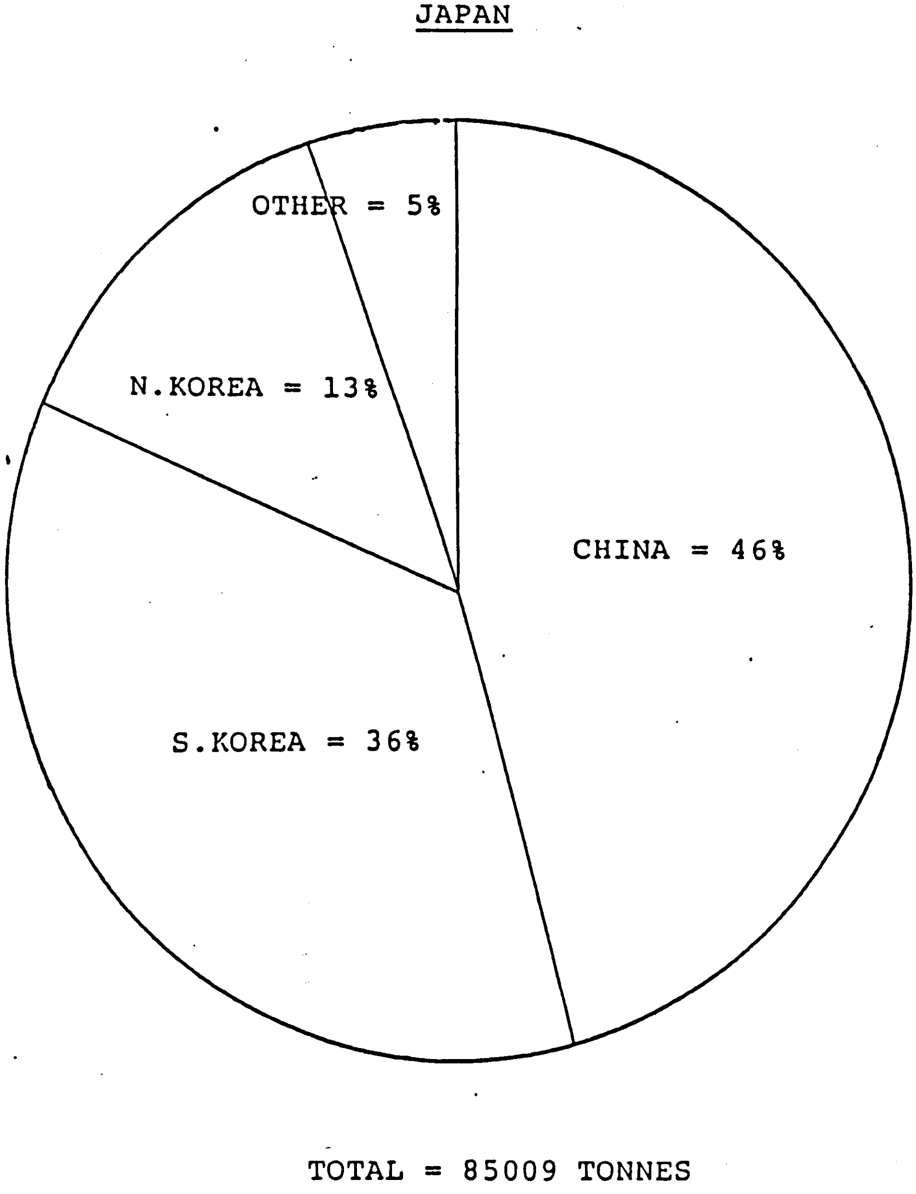


Figure 4.7: Graphite imported into Japan in 1984. "Other" consists of Brazil, West Germany, Malagasy Republic and Sri Lanka.
(Prud'homme 1985)

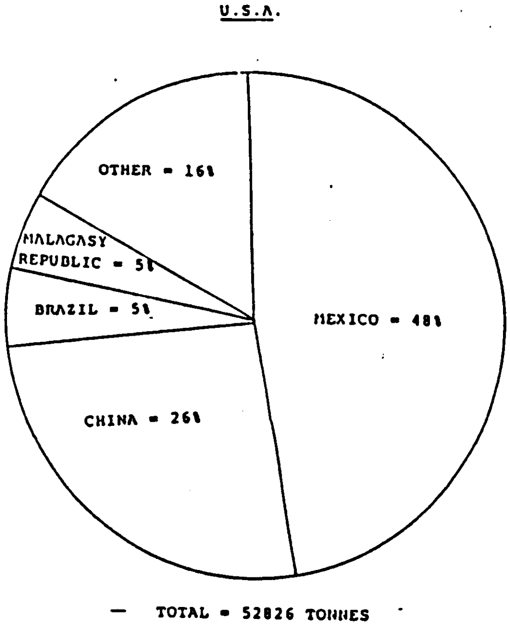


Figure 4.8a: Graphite imported into the USA in 1984. "Other" consists of West Germany and Sri Lanka. (Prud'homme 1985)

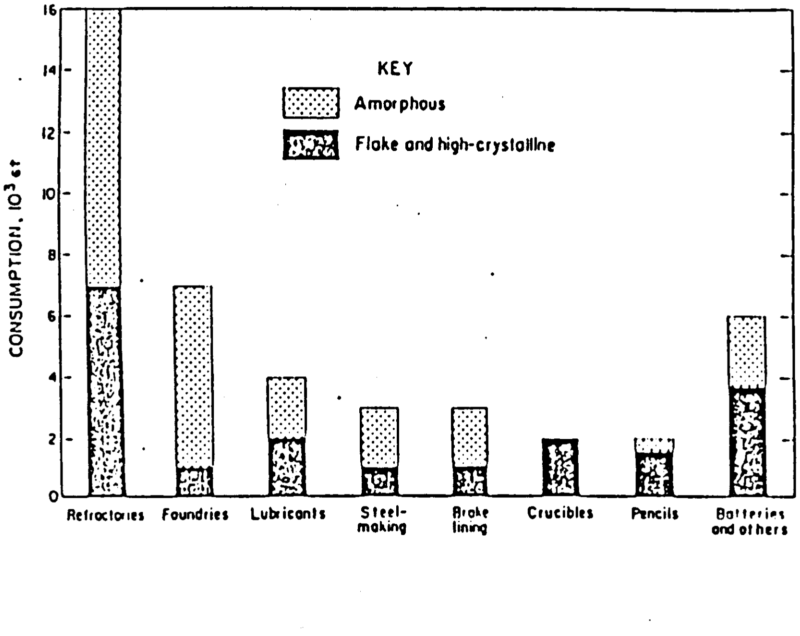


Figure 4.8b: Consumption of natural graphite by the USA in 1983.
(From: Fogg and Boyle 1987)

coarse-flake, higher priced graphite.

Recent trends in the industry indicate that the marketing of graphite concentrates is handled by groups or agents representing the graphite producers (Pettifer 1980). It is also becoming a common practice for graphite to be sold through a distributer, and it is the distributer who organizes exports or imports according to consumer specifications. This takes the onus off the producer to find all available markets for his graphite and maximizes the sales of all grades produced.

Like most industrial minerals, the price structure of graphite is such that labour and shipping costs are important factors of a competitive operation. Labour costs tend to be high in Western Europe and North America (excluding Mexico) but this factor is compensated by a stable political environment and quality control. Shipping costs also are higher in countries in North America and Western Europe, but a graphite producer in these countries is comparatively closer to markets. As purity of product is a major concern, graphite is usually shipped in bags, preferably plastic wrapped (E. Weed, research engineer, Vesuvius Crucible Ltd., Pittsburg, Pa., personal communication, 1984). Desirable characteristics which influence the buyer's choice are consistency of the product in the bag and the absence of deletrious materials due to improper bagging techniques (E. Weed, research engineer, Vesuvius Crucible Ltd., Pittsburg, Pa., personal communication, 1984).

5.0 GEOLOGY OF GRAPHITE

5.1 OVERVIEW OF CARBON AS GRAPHITE

Graphite forms as a result of metamorphism of carbonaceous material. The perfection of crystallinity varies directly with metamorphic grade; progressing from a virtually amorphous carbonaceous material, through development of unoriented carbon lattice layers, to reduction of the layer spacing, and finally to ordering of the carbon layers, which is diagnostic of fully ordered graphite (Landis 1970, Donnet 1981). Fully ordered graphite first appears in upper greenschist facies to lower amphibolite facies metamorphic rocks, between pressures of two to six kilobars and above temperatures of 400oC (Landis 1970). Landis (1970) also concluded that of the two variables, pressure and temperature, the crystallization of graphite is most dependant upon temperature.

Flake graphite occurs in sediments which have been metamorphosed, usually by regional metamorphism, to amphibolite grade (Landis 1971). Host rocks tend to be quartz-mica schists and/or gneisses, micaceous quartzites, or marbles. The distribution and amount of graphite in the rock appears to be a reflection of the amount of original carbon in the rock.

Amorphous graphite is derived mainly from the metamorphism of coal beds or very carbonaceous sediments. Heat required for formation of graphite can be due to either regional or contact metamorphism. The formation of vein graphite differs from the other two types in that there is no requirement for pre-existing carbon to be metamorphosed. There are many different explanations for the formation of vein graphite (Seeley 1964). The most popular hypothesis involves carbonate breakdown to methane, then formation of graphite (Salotti 1971, 1972). The relationship that some vein graphite has with pegmatites indicated magmatically mobilized graphite (Wifayananda and Jayawardena 1983), but biogenic/abiogenic origins are still under contention (Reimer 1984, Jedwab and Boulegue 1984).

5.2 CLASSIFICATION OF GRAPHITE DEPOSITS

Cameron (1960) classified known graphite deposits into five categories reflecting the different types of graphite. This classification scheme is the most common one seen in the literature. The five types of graphite deposits, or occurrences, are:

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

Deposits of category 1 or 2 are usually disseminated flake graphite and those of category 3 and 5 consist of micro-crystalline or amorphous graphite. Economic deposits in the 19th and early 20th century were of types 1 and 5. Deposits of greatest economic importance today are of types 1 and 3. The general geological settings of the five types, and disposition of the graphitein each, differ as outlined in the descriptions that follow.

5.2.1 Disseminated Flake Graphite in Silica-Rich Metasediments.

Crystalline flake graphite disseminated in silica-rich metasediments is usually associated with older rocks, notably those of Precambrian age, which have undergone a high degree of regional metamorphism. It is not uncommon, therefore, to find deposits of this type in rocks such as gneisses, schists, and quartzites. The host rocks vary from quartz-mica schists, to quartz-feldspar-biotite gneisses with and without garnet, to semi-pelitic schists. The original character of the host rock in most cases has been obliterated by the metamorphism involved. The overall composition, mineralogy and geological setting indicate a sedimentary rock, usually quartz-rich, as the host (Seeley 1964).

The graphite occurs as flakes disseminated throughout the unit, usually defining the foliation. Flake size reflects the grain size of the host rock, and varies from finer than a millimetre to over a centimetre in width (Harben and Bates 1984).

If mica is present, the mica and graphite are frequently interlayered. The grade of this type of deposit varies from one to two weight percent to upwards of ten weight percent in deposits such as those in the Malagasy Republic.

Impurities in flake graphite are usually the common minerals of the host rock, particularly quartz, feldspar, mica, amphibole and garnet. With the exception of the mica, most of these minerals are easily separated.

The strike length of the host unit is usually in the range of hundreds of metres up to several kilometres. Concentrations of graphite tend to occur along the host unit, and these graphitic sections themselves can be several hundreds of metres in strike length. Their width, however, is variable.

Some of the world's major graphite producers and past producers are from deposits of this type. Probably the best known flake graphite deposits are those in the Malagasy Republic. These occur in belts of a micaceous gneiss continuing over a distance of seven hundred kilometres along strike. Mining is restricted to the extensively weathered upper levels, removing any need for grinding the ore. Graphite from the Malagasy Republic has a high proportion of good-quality coarse-grained flake, and the companies are noted for the care and consistency taken in preparing the product for export, thus setting the world standard for high-quality flake graphite. Figure 5.1 illustrates the three major graphite mining areas on the island: the Manampotsy District, the Ambatolampy District, and the Ampanihy District. The most significant is the Manampotsy District. The many graphite

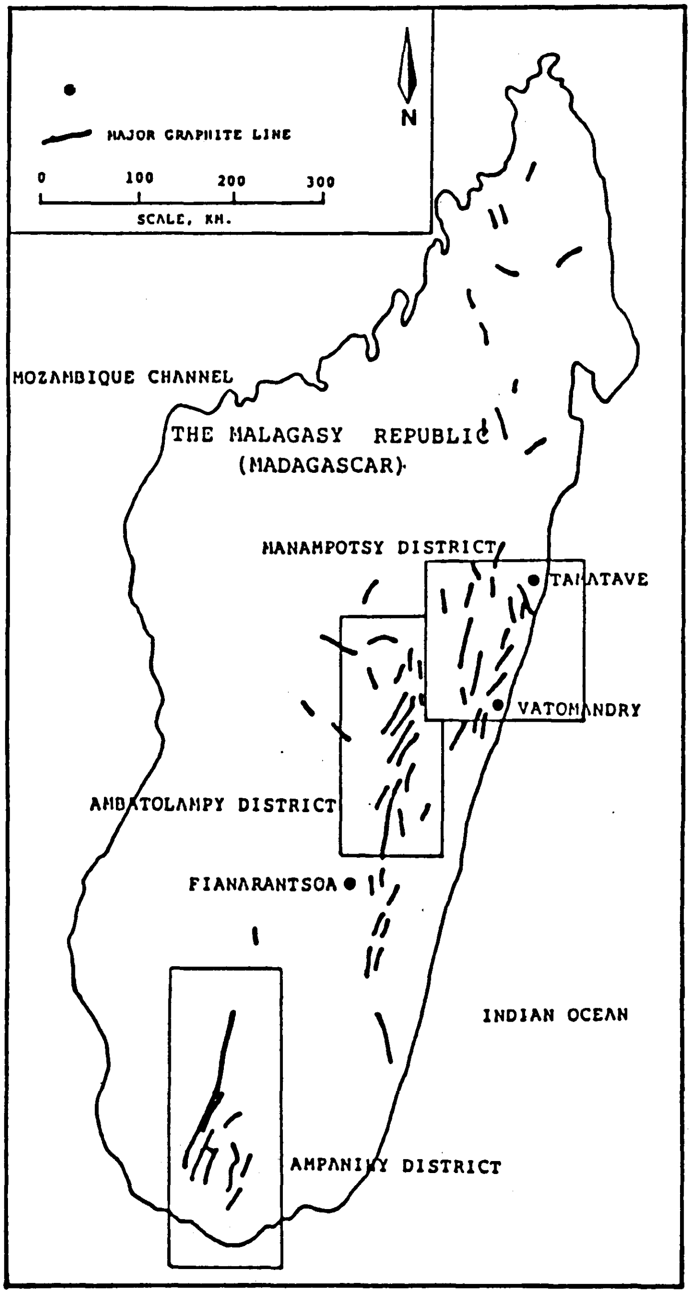


Figure 5.1: Location of the major graphite districts and graphite lines in the Malagasy Republic. (Adapted from: Fogg and Boyle 1987)

workings and pits are shown as "graphite lines" on the diagram.

Flake graphite deposits are found in India, occurring as disseminated flakes in schists and gneisses, averaging less than 20% by weight graphite (Fogg and Boyle 1987). The graphite occurrences form two broad belts, as seen in figure 5.2.

Flake graphite of this type is also mined from deposits in Brazil, Norway, China, and the Soviet Union. Although the United States now imports all of its flake graphite, between 1850 and 1950 there was a well-established American flake-graphite industry from New York, New Jersey, Alabama, Pennsylvania, Michigan, Texas, California, Nevada and Rhode Island. The longest producing deposits were those in Texas and Alabama. Alabama graphite production reached a peak during World War I, and ended after the Korean War. Alabama flake graphite, which once set the standard for crucible grade graphite, was superceded by Madagascar flake by the 1940's (Cameron and Weis 1960).

The deposits in Texas occur in the Precambrian Packsaddle schist and were exploited at the turn of the century. The most recent producer, the Southwest Graphite Company, operated its Burnet County deposit from 1955 unit the mid-1970s. Figures 5.3 and 5.4 illustrate the graphite deposits,

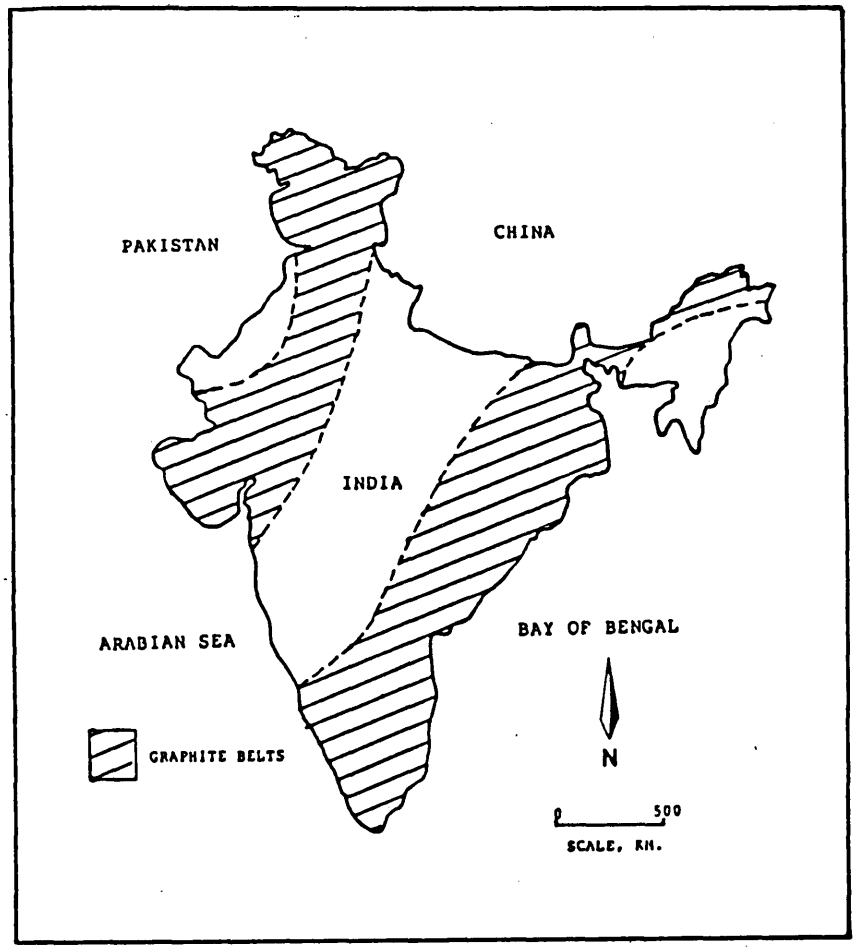
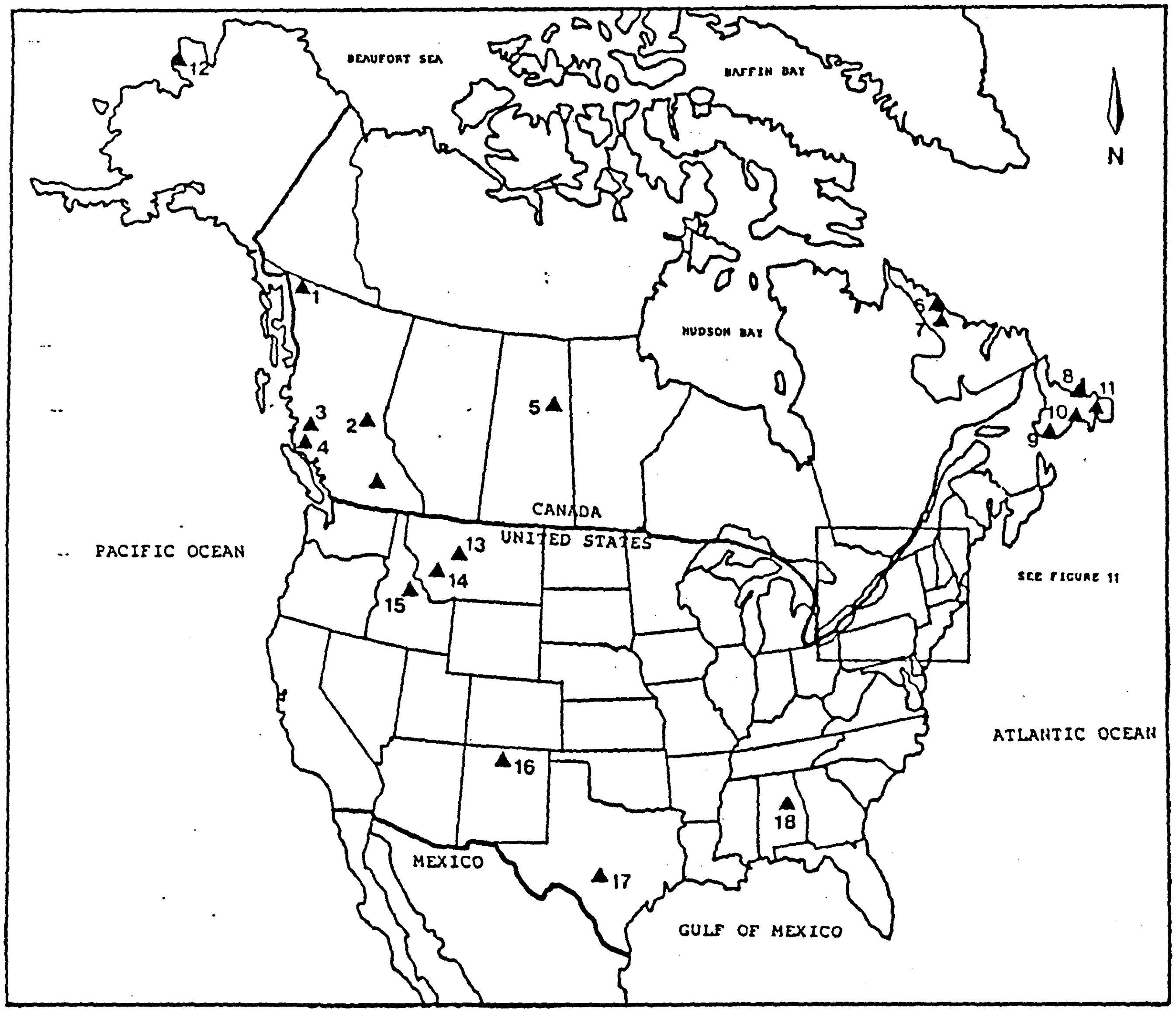


Figure 5.2: Location of the graphite belts in India. (From: Fogg and Boyle 1987)

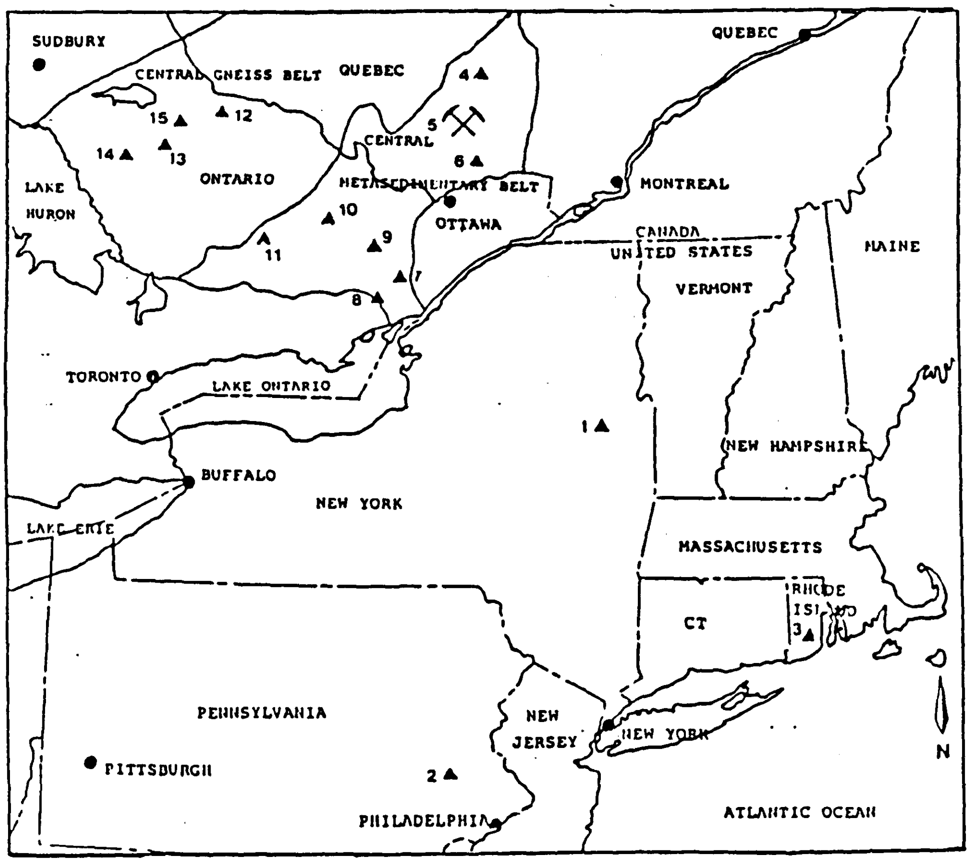


LEGEND

▲ GRAPHITE DEPOSIT

Figure 5.3: Location of graphite deposits in Canada and the USA. (Adapted from: Fogg and Boyle 1987)

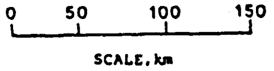
DEPOSIT LOCATION AND NAME	MAP NUMBER	PRODUCTION STATUS
CANADA:		
BRITISH COLUMBIA:		
RED CAP-TAKU RIVER	1	DEPOSIT
WILLOW RIVER	2	DEPOSIT
BENTINCK RIVER	3	DEPOSIT
RIVERS INLET	4	DEPOSIT
SASKATCHEWAN: DEEP BAY	5	DEPOSIT
NEWFOUNDLAND:		
NACHVAK	6	DEPOSIT
SAGLEK BAY	7	DEPOSIT
BAIE VERTE	8	DEPOSIT
LONG RANGE	9	DEPOSIT
BAIE d'ESPOIR	10	DEPOSIT
FAIR AND FALSE BAY	11	DEPOSIT
UNITED STATES:		
ALASKA: KIGLUAIK MOUNTAINS-IMURUK BASIN	12	PAST PRODUCER
MONTANA:		
BLACK DIAMOND CARBON MINE	13	PRODUCER
DILLON	14	DEPOSIT
IDAHO: SHORTY CLAIMS	15	DEPOSIT
NEW MEXICO: RATON	16	DEPOSIT
TEXAS: SOUTHWESTERN GRAPHITE MINE	17	PAST PRODUCER



LEGEND

⚒ PRODUCER

▲ GRAPHITE DEPOSIT



DEPOSIT LOCATION AND NAME	MAP NUMBER	PRODUCTION STATUS
UNITED STATES:		
ADIRONDACK MOUNTAINS, NEW YORK	1	PAST PRODUCER
CHESTER-ALLENTOWN AREA, PENNSYLVANIA	2	PAST PRODUCER
RHODE ISLAND	3	DEPOSIT
CANADA:		
BOUTHILLER-ORWELL	4	DEPOSIT
NOTRE DAME DU LAUS	5	PRODUCER
BELL MINE	6	PAST PRODUCER
CORNELL	7	PAST PRODUCER
KIRKHAM-DESERT LAKE	8	PAST PRODUCER
GLOBE	9	PAST PRODUCER
BEIDELMAN-LYELLAND CARTER LAKE	10	PAST PRODUCER
NATIONAL CARDIFF	11	PAST PRODUCER
BISSETT CREEK	12	DEPOSIT
BUTT TOWNSHIP	13	DEPOSIT
PIERSON TOWNSHIP	14	DEPOSIT
LAURIER TOWNSHIP	15	DEPOSIT

Figure 5.4: Location of graphite deposits in SE. Ontario, S. Quebec, New York, Pennsylvania, and Rhode Island.
(Adapted from: Fogg and Boyle 1987)

occurrences, producers, and past producers in the United States and Canada.

5.2.2 Disseminated Flake Graphite Deposits in Marble

Just as graphite occurs disseminated in siliceous metasediments it also occurs disseminated in marbles. The graphite content is commonly less than one weight percent, but may locally grade higher. This type of deposit may also be associated with contact metasomatic deposits which are much higher in grade, but small in tonnage. Where the two types are associated, flake graphite can be seen to coexist with lenses and pods of graphite in an impure skarn-type marble, making it difficult to differentiate between the two types. It is possible that disseminated flake in marble differs from the metasomatic type of graphite only on a matter of scale; the metasomatic type being more massive. The association led to early exploration of the marbles for graphite since the small, high grade plugs of graphite were easily mined and treated for export.

In the marbles of the Central Metasedimentary Belt of the Grenville in Ontario, there are many graphite occurrences, a few of which have produced flake graphite (Hewitt 1965). None was large enough to compete with graphite from foreign sources and it was found that the disseminated flake deposits were far too variable in grade, structure and mineralogy over a small strike length to be mined.

5.2.3 Metamorphosed Coal and Carbonaceous Sediments

Deposits of this type furnish most of the world's supply of microcrystalline or amorphous graphite. They are formed from coal beds and seams or highly carbonaceous sediments which have undergone thermal metamorphism. It is particularly apparent in deposits of this type that the degree of graphitization, and hence the grade of the deposit, are related to the grade of metamorphism. Because thermal metamorphism is usually not as uniform as regional metamorphism, this type of deposit commonly has gradations from unmetamorphosed carbonaceous material through partially crystallized graphite, to fully crystallized graphite. The age of this type of graphite varies with the age of the original sediments and the thermal history. Deposits date from the Precambrian throughout the Paleozoic to the Mesozoic era. The bigger deposits that are producing amorphous and microcrystalline graphite are metamorphosed coal beds that date from well-known coal-forming periods such as the Cretaceous or Jurassic.

To be economic, such a deposit must contain seventy to eighty weight percent graphite, as compared with under ten in the flake deposits. The associated minerals depend on the original sediment and are usually mica, tourmaline, iron oxides and sulphides, and rutile. The dense fine-grained graphite ore of these deposits does not lend itself to flotation techniques, consequently beneficiation consists of handpicking of the deleterious material. If required, further quality improvement is achieved by grinding and size separation (Seeley 1964).

The two most important suppliers of amorphous graphite are Mexico and the Republic of Korea. Mexico exports approximately 85% of its graphite to the United States (Pettifer 1980) and the Republic of Korea exports almost exclusively to Japan. The Mexican deposits, in the State of Sonora, were discovered in 1867 and first exploited in 1891. Sonora is in the basin-and-range physiographic province, characterized by north-trending mountain ranges consisting of tilted fault blocks which reveal a variety of rocks including the Barranca Formation comprising Upper Triassic and Lower Jurassic sedimentary rocks (Weis 1978). Carbonaceous slate, conglomerate, and coal, mixed with quartzites form the middle unit of the Barranca Formation. Individual coal beds are usually less than two metres thick, but can extend for tens to hundreds of metres along strike and down dip. Metamorphism due to folding has upgraded the coal to anthracite and subsequent thermal metamorphism from igneous activity produced graphite from the anthracite. Most of the graphite contains

85% carbon (Weis 1978) but is blended to produce a concentrate of 80-82% carbon (Pettifer 1980). Beneficiation involves grinding, blending and bagging.

The amorphous graphite from the Republic of Korea is associated with anthracite coal in schists and phyllites (Pettifer 1980, Harben and Bates 1984). Estimated reserves of amorphous graphite are between 1.1 and 1.5 million tonnes averaging 75% carbon (Pettifer 1980). The less graphitized material is sold as a high quality anthracite. The graphite area in the Republic of Korea is shown in figure 5.5.

Apart from the U.S.S.R., the largest amorphous graphite producer in Europe is Austria (Harben and Bates 1984). Graphite is mined in two areas, the Styrian Alps and Lower Austria. The Styrian deposits occur within folded slates and limestones, and were formed by the metamorphism of coal seams. Most of the graphite concentrate produced has a carbon content of 40-88%, and is sold for foundry facings. Fine powders, carbon content 90-92%, are produced for special uses. Graphite deposits, situated near the Danube in Lower Austria, occur in a belt of highly metamorphosed schists and associated with marble. Both flake and amorphous graphite are mined, producing a concentrate with a carbon content of 45-50% (Industrial Minerals 1976).

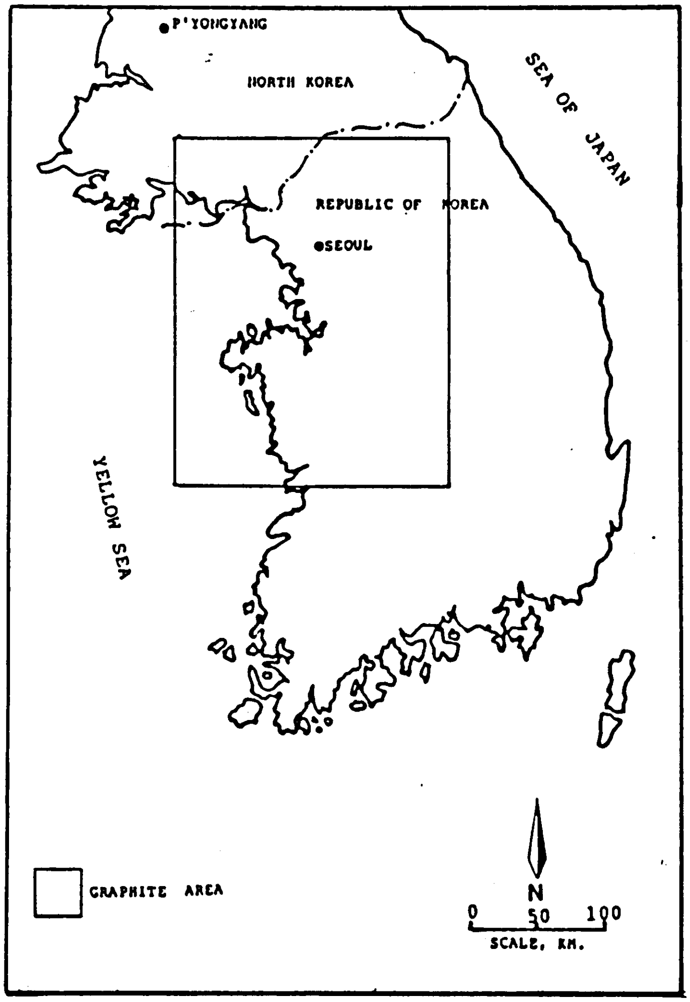


Figure 5.5: Outline of the area with graphite deposits in the Republic of Korea. (From: Fogg and Boyle 1987)

Italy is a small scale producer of amorphous graphite from deposits near Turin. The graphite content of the deposits varies from 40% to 70%, but a concentrate of 80-85% carbon can be produced (Pettifer 1980).

The best known amorphous graphite occurrences within the United States are the coal fields of Raton, New Mexico, and the graphitic anthracite deposits of the Narragansett basin of Rhode Island (Cameron and Weis 1960).

5.2.4 Vein Deposits

Vein deposits occur in Siberia near Irkutsk in a nepheline syenite (Clark 1921); at Dillon, Montana associated with pegmatites (Ford 1954); in Sri Lanka within graphitic schists and high-grade gneisses (Erdosh 1980); and at Borrowdale, England, associated with a diabase intrusive into volcanic rocks (Strens 1965). Vein deposits consist of graphite plates or needles, which are actually very large crystals, often oriented perpendicular to the walls at the edge of the vein and parallel to the walls in the middle of the vein. In Sri Lanka, graphite veins are composed of several sheets of graphite parallel to the vein wall. The sheets range in thickness from 1 mm to 150 mm and are made up of medium to coarse grained graphite crystals oriented perpendicular to the sheet. Between the sheets are fine graphite crystals parallel to the sheet. Figure 5.6 shows the location of graphite mines in Sri Lanka.

The origin of vein graphite has been disputed over the years; Clark (1921) amd Winchell (1911) concluded that the graphite was formed by the reduction of CO2 derived from either juvenile sources or from silicification of limestone. Bastin (1912) believed the graphite precipitated from gaseous solutions or pegmatitic liquids. In general the popular explanations envisage the carbon being mobilized from nearby sediments and redeposited during metamorphism, or reduced from CO2 (Erdosh 1970), although the mechanics and chemistry of these reactions are not often adequately explained or supported by reliable geological or experimental evidence.

Erdosh (1970) proposed that the graphite from graphitic sediments moved in the solid phase towards areas of lower pressure. Salotti et al. (1972) pointed out that graphite veins are not restricted to areas of high metamorphism such as those in Montana, and that graphite ruptures under pressure rather than undergoing plastic flow, negating Erdosh's theory of migration under pressure. They proposed instead that the carbon was released by methanation of pre-existing carbonate minerals. Subsequent pyrolysis of the resulting methane caused carbon to precipitate.

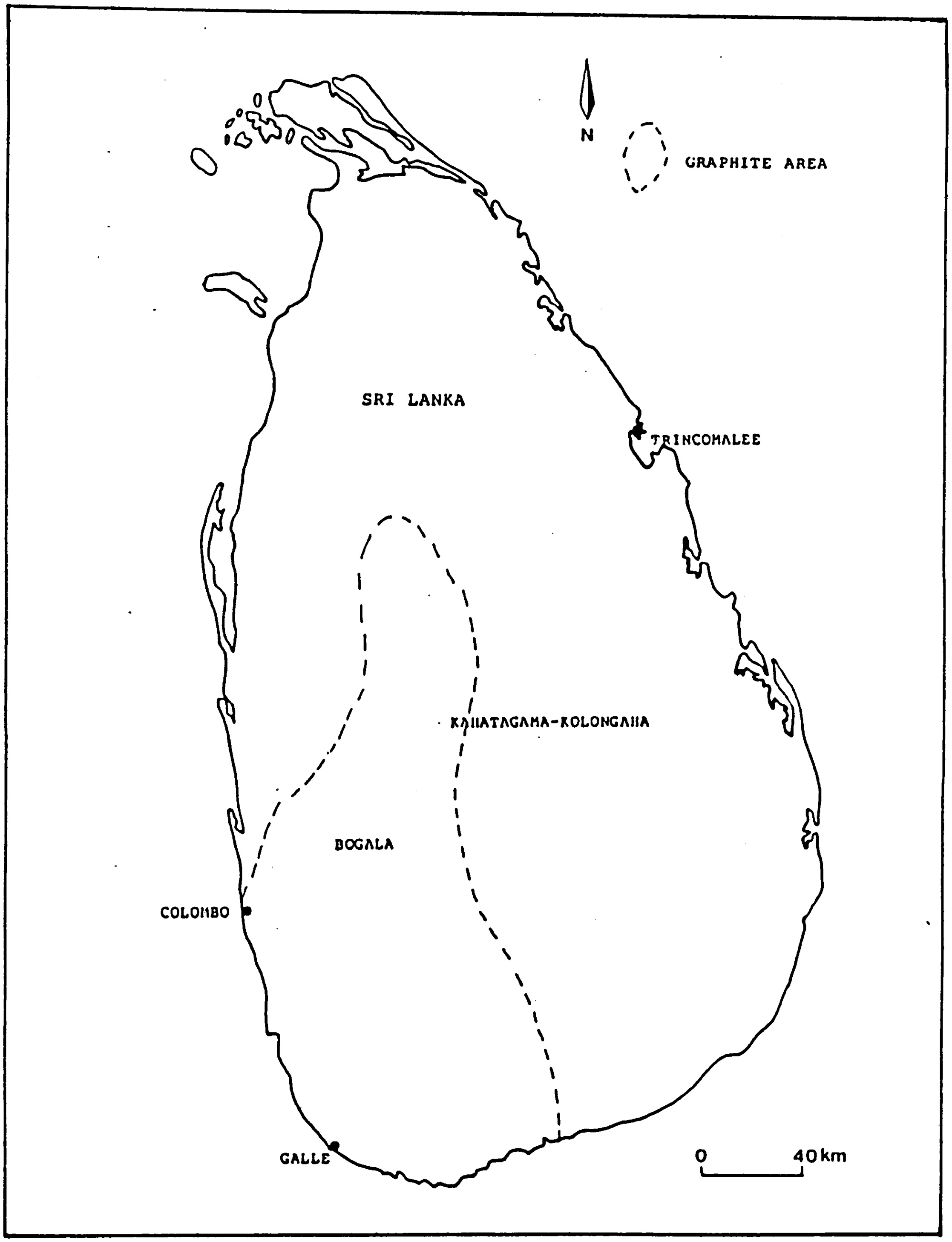


Figure 5.6: Location of the graphite mines in Sri Lanka. (Adapted from: Dissanayake 1981)

The graphite in vein deposits is remarkably pure, up to 98% carbon. As it could be mined and separated by hand, these deposits were easily accessible to people 100-180 years ago.

5.2.5 Contact-Metasomatic or Hydrothermal Deposits in Marble

Graphite occurrences of this type are actually of a varied nature and vaguely defined. They show gradations from the disseminated flake type to the vein type of graphite. Found in skarn or altered marbles, they can consist of a graphite occurring as disseminated flakes, patches, blebs, lenses and/or veins. The erratic distribution of the graphite and the small tonnage have frustrated most attempts at exploitation. In North America, exceptions were the Black Donald mine at Calabogie (Hewitt 1967) and the small mines near Ticonderoga, New York, (Bastin 1910, Cameron and Weis 1960).

5.3 GRAPHITE IN ONTARIO

5.3.1 Distribution

Globally, carbon occurs in crustal rocks of all ages, 93% in sedimentary and metamorphic rocks and 7% in igneous rocks (Ohmoto and Rye 1979). Of the non-igneous carbon, 22% is organic material and graphite, and 78% is carbonate carbon (Wilson 1985). On a worldwide basis Archean rocks contain an average of 0.77% carbon, Aphebian rocks contain 1.68% carbon and Phanerozoic rocks contain 0.83% to 0.87% carbon (Cameron and Garrels 1980). It is not surprising to find some form of carbon, either as a carbonaceous sediment or graphite, within each of the three structural Provinces in Ontario, most notably in the Superior and Grenville Provinces.

In the Archean rocks of the Superior Province, carbonaceous material is found within the greenstone belts, particularly as an integral part of the sediments, and in shear zones. Carbonaceous sediments consist of argillites coloured black by finely dispersed carbon. Locally these grade into graphitic schists (Springer 1985). Graphite is also concentrated within shear zones cutting the carbonaceous sediments where it is believed to play a part in the fixation of gold in some gold deposits in the Archean (Springer 1985, Wilson 1984, Wilson and Rucklidge 1986). Here graphite is viewed as an indicator for gold or some other metal, rather than a commodity itself. This is due in part to the small size of the graphite occurrences and to the stronger interest in gold. In areas characterized by higher metamorphic grade, graphite occurs as flakes disseminated throughout siliceous metasediments, similar to graphitic rocks found in the Central Gneiss Belt of the Grenville Province.

The more important graphite deposits of Ontario have been found historically in the Grenville Province. In Ontario the Grenville Province is divided into three subdivisions; the Grenville Front Tectonic Zone, the Central Gneiss Belt and the Central Metasedimentary Belt (figure 5.7). The boundary between the east-trending, steeply folded Huronian sediments and the northeast-trending, southeast-dipping gneissic rocks, known as the Grenville Front, is generally accepted as the focus of thrust faulting (Davidson et al. 1985). This thrust faulting becomes increasingly penetrative to the southeast and is associated with parallel zones of intense shearing and mylonitization. The Grenville Front Tectonic Zone is up to thirty kilometres wide (Lumbers 1978) and consists of a series of granitoid units (the Grenville Front Granites, Davidson et al. 1985) and gneisses with a strong northeast-trending foliation (Wynn-Edwards 1972). Graphite occurrences have not been documented from this zone.

The Central Gneiss Belt, situated between the Grenville

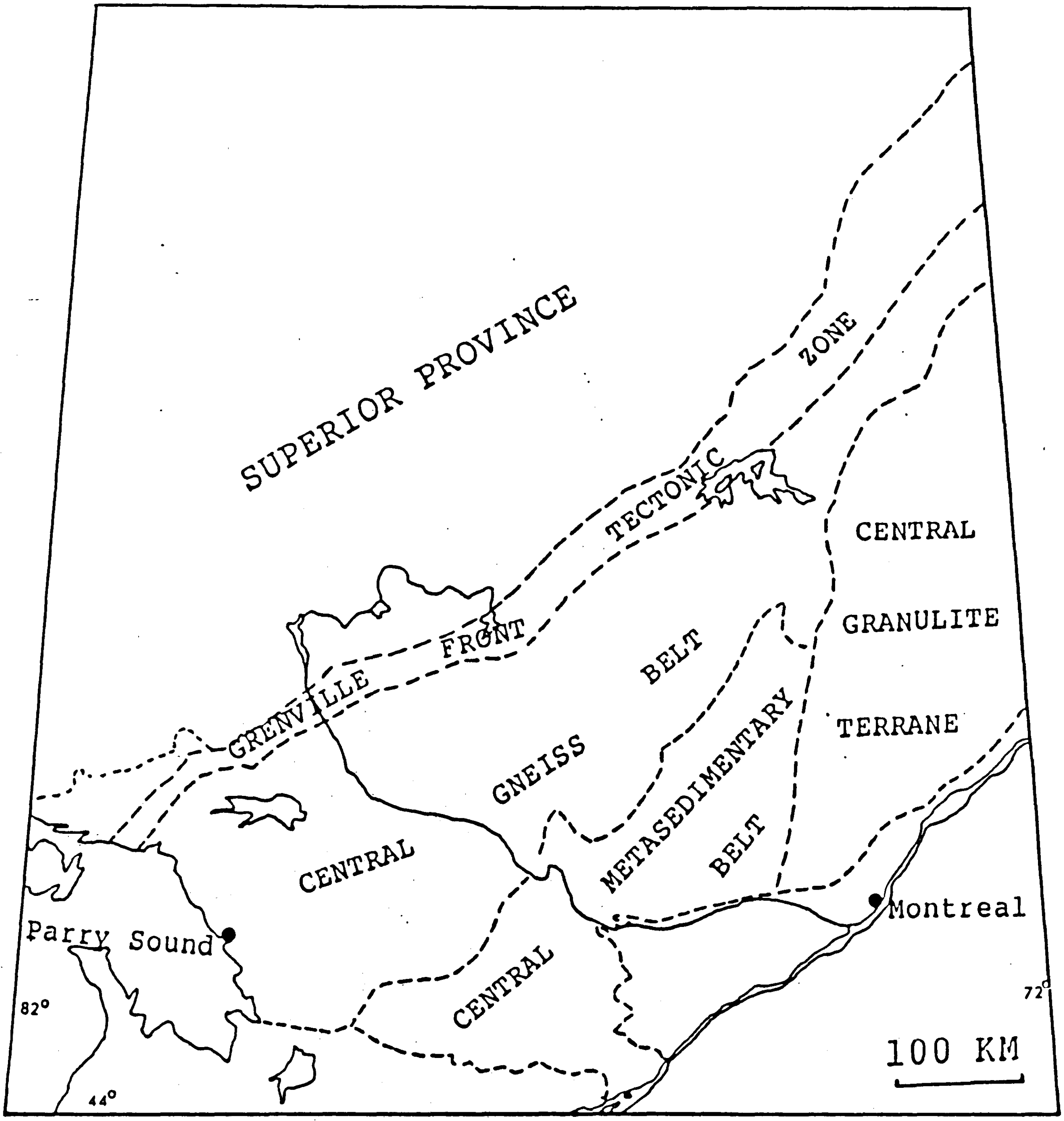


Figure 5.7: Sketch map showing the internal subdivisions of the Ontario portion of the Grenville Province. (Modified after: Wynne-Edwards 1972)

Front Tectonic Zone and the Central Metasedimentary Belt, comprises high-grade paragneisses and orthogneisses of upper amphibolite to granulite grade. The igneous rocks range from granite to anorthosite in composition, and display various degrees of conformability with their surrounding rocks (Davidson et al. 1981, 1985, 1986). Graphite occurs as crystalline flake disseminated within siliceous metasedimentary units of considerable strike length and within the marble tectonite units which have a more restricted strike length.

The Central Metasedimentary Belt, bounded on its southern margin by Paleozoic rocks, consists of lower grade volcanic and metasedimentary rocks, and a variety of igneous intrusions. Graphite occurs as disseminated flake and replacement-type deposits within the marble units. Historically, Ontario graphite production has come from the Central Metasedimentary Belt; the most notable deposit is the Black Donald Mine.

5.3.2 Brief History of Graphite Mining in the Central Gneiss Belt

Of the many graphite occurrences and deposits in the Central Metasedimentary Belt, several achieved commercial production, and four of these are in the study area (Map 1).

The most noted is the Black Donald Mine at Calabogie. A detailed description of many of the occurrences can be found in Papertzian and Kingston (1982) and Hewitt (1965).

The Black Donald Mine in Brougham Township was located on the south side of Black Donald Lake. From when it opened in 1896 until it closed in 1954, a total of 85,164 tons of graphite was produced. Opened originally by the Ontario Graphite Company, the property was leased in 1908 by the Black Donald Graphite Company. In 1942 Frobisher Limited bought the property and continued mining until 1954 (Hewitt 1965).

The graphite zone occurs as a lens in a marble and siliceous gneiss-hornblende gneiss sequence. The zone had an average width at surface of twenty feet, and graded 65% to 80% carbon with calcite the chief impurity. Although described as "amorphous", the graphite is actually an agglomeration of fine-grained flake, coarse-grained flake and needles. The graphite and surrounding metasediments form an antiform with amplitude of 350 feet and a plunge of 20o to the northeast. The graphite is believed to have been formed by replacement of the marble, evidenced by brecciated textures in the graphite (Hewitt, 1965). This is impossible to substantiate as the workings are now flooded.

The other graphite occurrences that were at one time mined are similar in geology to the Black Donald deposit, although not as rich in grade. The host rocks are a series of marbles, siliceous marbles, and metasedimentary gneisses, the graphite occurring as disseminated flakes, agglomerations of large flakes, or lenses, predominately within the marbles. The deposits were originally developed between 1910 and 1920, and again in the 1940s during the world wars, reflecting the economic situation in the United States and Korea and the designation of graphite by the USA as a strategic mineral. Interest waned in the 1950's after the Korean War.

The National Graphite property in Cardiff Township was originally developed in 1912 by the New York Graphite Company which merged with the National Graphite Company in 1915. The latter company built a mill on the property which later processed ore from the nearby Tonkin-Dupont Mine after mining stopped at the National property. In 1951 the Black Donald division of Frobisher Limited outlined a flake graphite zone 1200 feet in strike length, 60 feet in width, and totalling 1,440,000 tons of ore grading 4.1% carbon (Hewitt 1965).

The Tonkin-Dupont Mine in Monteagle Township produced approximately 200 tons of graphite concentrate in 1913 and 1914. In 1915 the National Graphite Company developed the continuation of the ore body and produced concentrate until 1917. Since then, S.H. Law of Toronto, McKenzie Red Lake Gold Mines, and Canada Graphite Mines Limited have each explored the property by diamond drilling. The graphite occurs as large flakes in a calc-silicate marble interbedded with a rusty metasedimentary gneiss.

What is now known as the Beidelman-Lyall property in Lyndoch Township was actually discovered by Dan Moriarty in 1880, and it was Messrs Beidelman and Lyall who ultimately developed the property in 1917. They put down two shallow shafts and several trenches which exposed graphitic lenses and large flakes (2-3 cm) in a phlogopitic marble. The trenches are still relatively well exposed.

There are several other mines and prospects throughout the Central Metasedimentary Belt outside the study region, most notably the Timmins Mine in North Burgess Township, the Kirkham Property in Bedford Township and the Globe Graphite Mine in North Elmsley Township. A comprehensive description of these and other graphite occurrences can be found in Papertzian and Kingston (1982) and Hewitt (1965).

5.4 GRAPHITE OCCURRENCES IN THE CENTRAL GNEISS BELT

5.4.1 Previous Geological Work

The Central Gneiss Belt (CGB) has been mapped by various individuals and agencies who have looked at specific areas or commodities. The Geological Survey of Canada mapped the Haliburton and Bancroft areas in 1910 (Adams and Barlow 1910). Lumbers (1971, 1978) describes in detail the lithology of the North Bay area with a map at a scale of one inch to two miles. Satterly (1956) mapped Lount Township, Quirk (1930) mapped the Key Harbour area, and Lacy (1960) mapped an area near Dunchurch. More recent work comprises preliminary maps of the Moon River area by Van Berkel and Schwerdtner (1986) and of the Dunchurch area by Bright (1987).

The Provincial Government report by Satterly (1942) is the first in-depth account of all the exploration work to that date. Hewitt (1967) gives a detailed account of all known commodities in the Parry Sound-Huntsville area, including industrial as well as metallic mineral occurrences. Martin (1983) catalogued industrial minerals, Davidson (1982) described on a reconnaissance scale the graphitic pelitic gneisses, and Villard et al. (1984) sampled some of the gold showings in the Parry Sound-Huntsville area. Verschuren et al. (1986) have evaluated the building stone potential of an area including part of the CGB, and in 1986 Marmont and Johnston began an in-depth study of the economic potential of the marbles, pegmatites, and anorthosites of part of the Muskoka-Parry Sound area (Marmont and Johnston 1987).

The Geological Survey of Canada is continuing an extensive mapping program which began in 1980 to decipher the structure of the Central Gneiss Belt (Davidson et al. 1981, 1982, 1985, 1986, Culshaw et al. 1983, Hanmer 1984, and Hanmer et al. 1985). This reconnaissance structural mapping is the first overall published synthesis of the geology of the CGB. Several universities are also conducting research projects in the CGB. A listing of these projects and current work in the CGB can be found in Marmont and Johnston (1987).

5.4.2 Geological Synopsis of the Central Gneiss Belt

The mapping by Davidson and co-workers (Davidson and Morgan 1981; Davidson et al. 1982, Culshaw et al. 1983, Davidson 1984, Davidson et al. 1986) has defined several lithotectonic domains on the basis of lithology, structure, and grade of metamorphism. Narrow zones of highly tectonized rocks, mylonites, and ductile shears separate domains from each other. The attitudes of the tectonite zones and differences of lithology and metamorphic grade led Davidson and his colleagues to conclude that some domains have been structurally emplaced above others. They propose that the domains represent a stack of thrust layers pushed to the northwest. This idea has been substantiated by the results of the Lithoprobe traverse in Lake Huron which crossed part of the Grenville Province and the Grenville Front revealing a series of southward-dipping thrust faults within the Grenville (G.D. Garland, chairman, Lithoprobe Steering Committee, University of Toronto, personal communication, 1987).

Figure 5.8 diagrammatically illustrates the subdivisions and the stacking order of the various domains. The first thrust sheet or bottom stack comprises the Britt, Kiosk, Rosseau, Go Home, Ahmic, and Algonquin Domains, the second stack consists of the Parry Sound Domain and the third stack consists of the Muskoka, Moon River and Seguin Domains

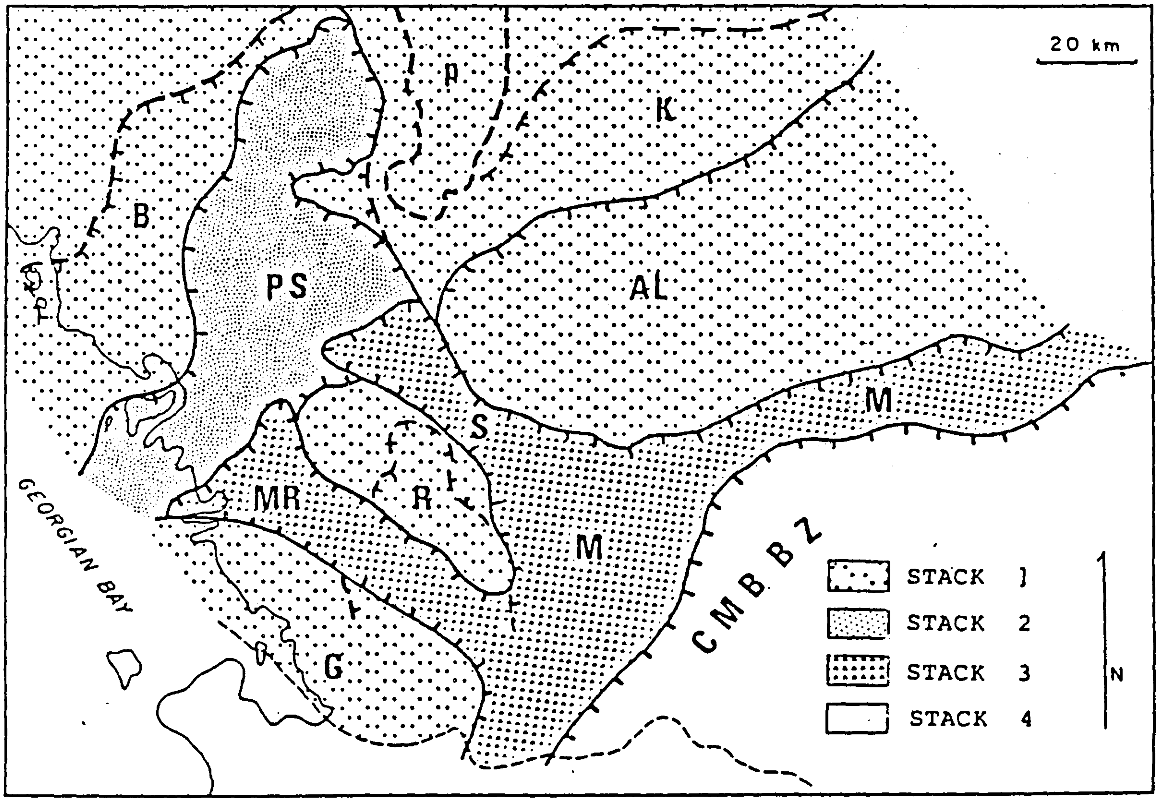


Figure 5.8: Lithotectonic subdivisions of the Central Gneiss Belt east of Georgian Bay.
Stack 1: B-Britt, K-Kiosk, R-Rosseau, G-Go Home, Al-Algonquin

Stack 2: PS-Parry Sound

Stack 3: M-Muskoka, Mr-Moon River, S-Seguin

Stack 4: CMBBZ-Central Metasedimentary Belt Boundary Zone

P: Powassan Batholith
(Adapted from: Davidson and Grant 1986)

(Culshaw et al. 1983). The rocks of the Central Metasedimentary Belt constitute the fourth layer in the sequence (Culshaw et al. 1983). A more detailed geological description of the domains can be found in Marmont and Johnston (1987) and in the original papers.

Graphitic occurrences within the semi-pelitic or quartzo-feldspathic gneisses occur only in stack one, as thin units of considerable strike length. These units occur in every domain that comprises the lowest stack, within sequences of highly deformed paragneisses, orthogneisses and migmatites of upper amphibolite to granulite grade (Map 2).

Graphite also occurs within the Parry Sound Domain, stack two, as pods of disseminated flake in the marble units (Satterly 1955), but the occurrences have been too small to warrant exploration work. The significance of the restriction of the siliceous flake graphite deposits to the first stack has yet to be determined, although it presumably reflects the structural history and the provenance of this member.

5.4.3 Geological setting of graphite deposits in the Central Gneiss Belt

Within the Central Gneiss Belt graphite occurrences are restricted to pelitic and semipelitic gneisses (Davidson 1980), or quartz-biotite gneisses whose dominant lithology is quartz, feldspar, biotite, plus or minus garnet. Mineralogically, the unit averages between 50 to 60% quartz in petrographical examinations, a modal amount typical of sediments (Taylor and McLennon 1985). Texturally, it is schistose to almost gneissic, and fine grained, with pods and lenses of coarser grained material throughout. The rocks appear mineralogically and texturally to be metasediments.

Graphite seems to be more abundant when the mineralogy is simply quartz and biotite. Rusty alteration due to pyrite is associated with the metasediment as a whole, and although a useful indicator for tracing the host unit, it is not positively correlated with the presence of graphite. Graphite does not occur continuously along or within the units, but is usually located either as horizons of disseminated flake or as accumulations of flake sometimes resembling veinlets. The grade varies from <1 to 3 or 4 weight percent graphite, averaging around 1.5 to 2 weight percent. Flake size averages 1-1.5 mm in diameter.

In the Central Gneiss Belt graphite is also found as very coarse-grained flakes in some of the marble bands, but these occurrences tend to be restricted in size and of limited extent along strike.

6.0 FIELD INVESTIGATIONS OF FOUR GRAPHITE OCCURRENCES WITHIN THE CENTRAL GNEISS BELT

In the inception stages of this project, there was interest in graphite occurrences in Laurier Township, Butt Township, Ryerson Township and Maria Township. The general lack of a coherent data base frustrated many exploration attempts and it was felt that a project which provided some detail on the extent and geology of the graphitic units would be beneficial to the exploration community. The particular graphite occurrences studied in the project were chosen because of their size relative to the usual showing, and because of the interest already shown by various agencies in these occurrences. Figure 6.1 depicts the Muskoka-Parry Sound-Renfrew area and shows the four townships involved in the study.

6.1 BUTT TOWNSHIP

6.1.1 Location & Access

Butt Township is situated approximately 15 kilometres east of the town of Burk's Falls and straddles the western boundary of Algonquin Park. The area of interest is located near Graphite Lake, situated in the unsurveyed northwestern

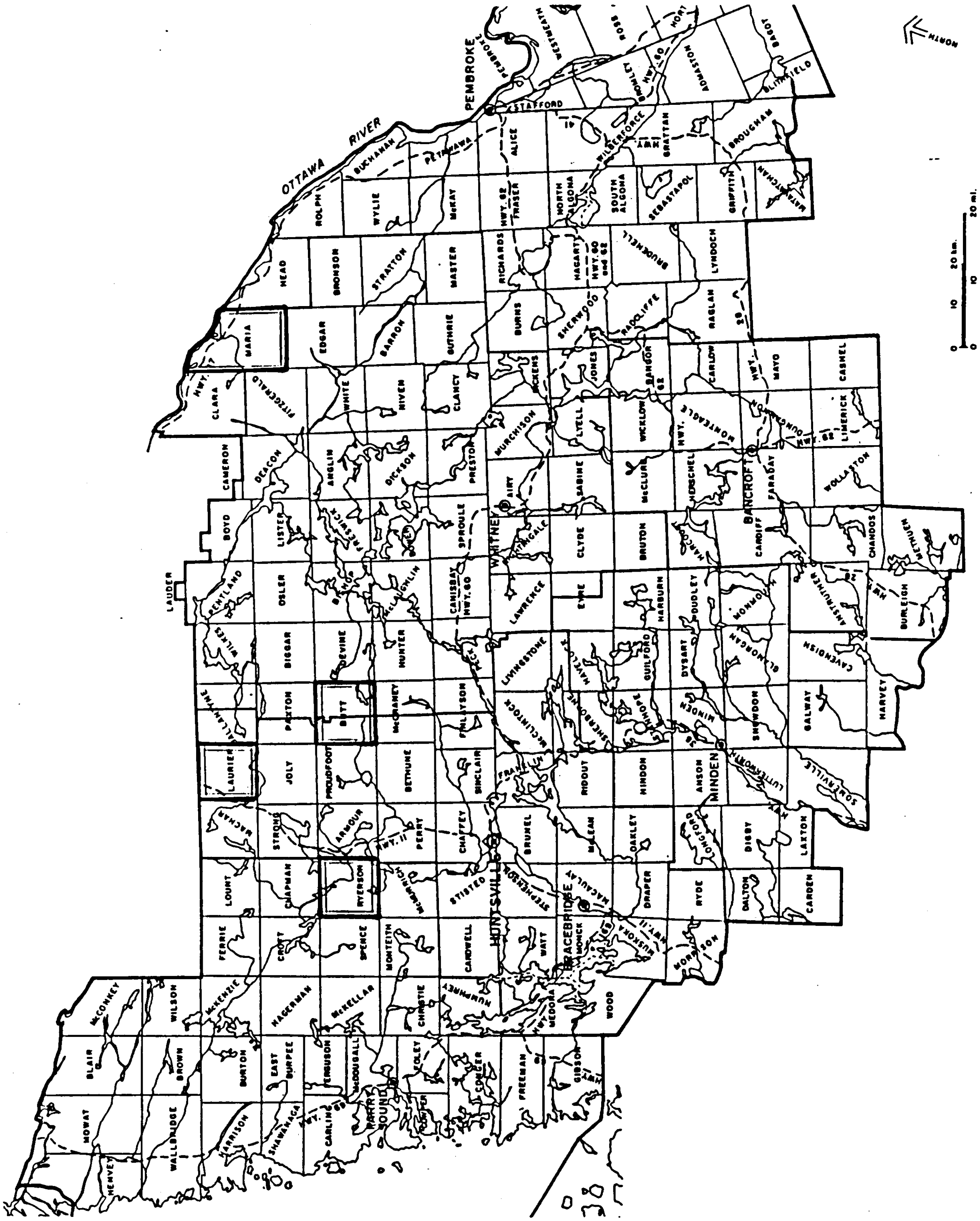


Figure 6.1: Location of the study area. The four townships involved in the study are outlined.

corner of the township (figure 6.2). Graphite Lake is reached via the Tim River access road, a section of a gravel forest access road from Highway 518 west, past Kearney and Sand Lake. The road serves as entry to Algonquin Park, both for tourists and lumber trucks, and could be all-weather if snow removal was undertaken during the winter.

6.1.2 Previous Work

The property was first staked for graphite in 1917, (V. Sheehan, prospector, Kearney, personal communication, 1986), a result of a declaration by the United States that graphite was a strategic mineral during World War I. Graphite was again declared a strategic mineral during World War II, causing renewed interest in the commodity.

In response to the war time markets in the U.S., Noranda Exploration acquired the mineral rights for the Butt Township graphite occurrence in 1940 (E. Gallo, consulting geologist, Islington, Ontario, personal communication, 1986). Records from this work are not on file in the Resident Geologist Office in Dorset, but might be available from the Timmins office of Noranda Exploration Ltd. (E. Gallo, consulting geologist, Islington, Ontario, personal communication, 1986).

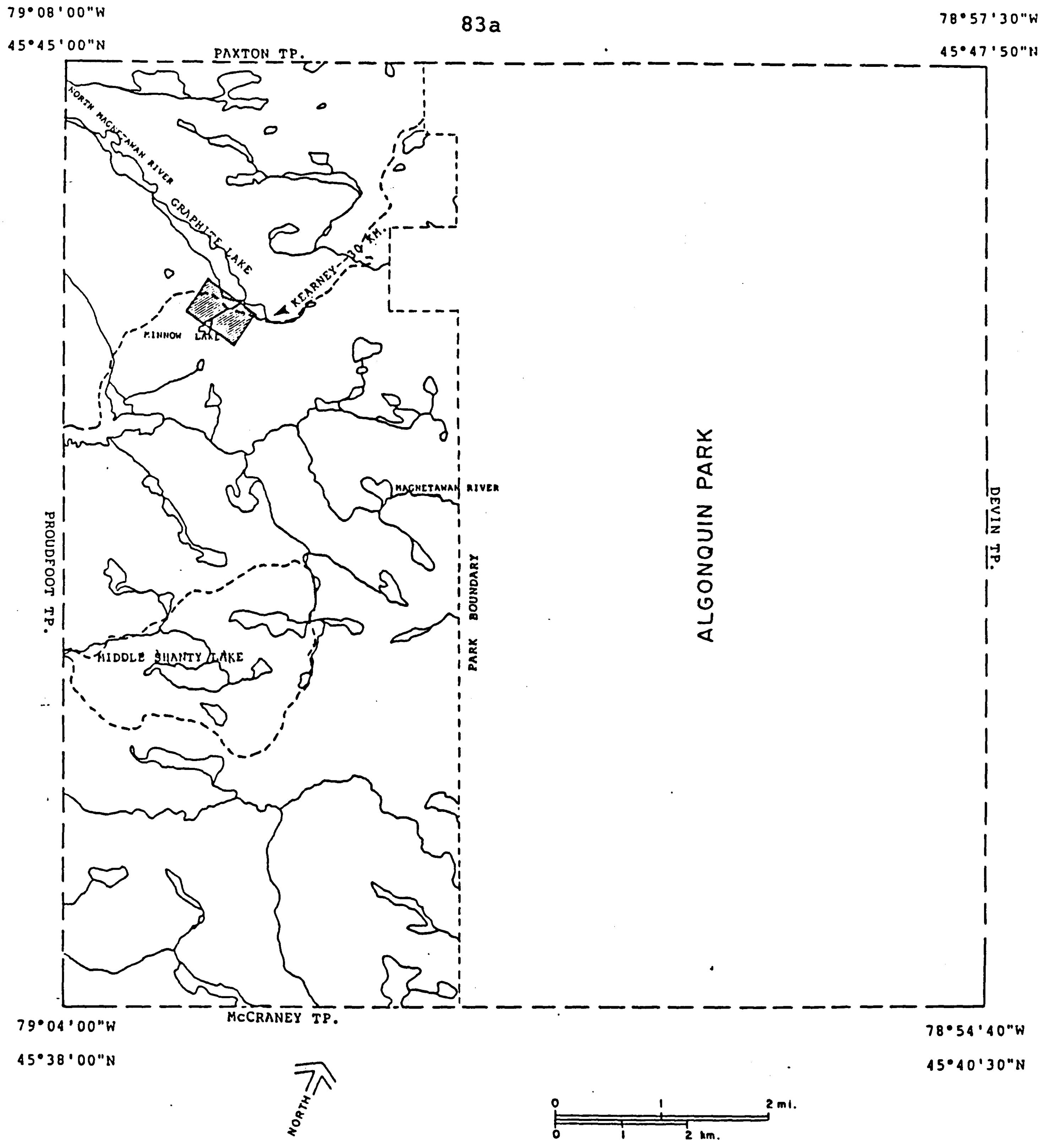


Figure 6.2: Butt Township and the location of the graphite deposit (shaded area).

In 1973 Noranda again acquired the mineral rights via ten unpatented claims over the graphite zone. These records are on file in the Resident Geologist's office in Dorset. Noranda carried out induced polarization (I.P.) and vertical loop electromagnetic surveys and produced a geology map. The disseminated nature of the graphite lends itself to the I.P. technique, and not surprisingly this survey appears to have been the most useful in delineating the graphitic horizon's strike length and width. Noranda found an anomalous zone 2500 metres in length, with a maximum width of three hundred metres at the south end of Graphite Lake. The vertical loop survey was not successful, failing to yield any definite crossovers. The geological mapping described two rock types: paragneiss and quartzite. Noranda decided that the grade was uneconomic and dropped the claims. C.P. Gris and Sons mapped one claim on the west side of Graphite Lake in 1976-77.

In 1980, Dravo Corporation of Pittsburgh obtained the mineral rights, had the property mapped, and recommended that diamond drilling and trenching should be done. Vesuvius Crucible Ltd. of Pittsburgh, Pennsylvania acquired an interest in the property and in 1981, twenty diamond drill holes were drilled for a total of 4095 feet. The logs are on file in the Resident Geologist's Office in Dorset. Vesuvius Crucible ceased exploration in 1983.

In 1985 sixteen claims were recorded and sold to Cal-Graphite Corporation of Burlington. As of January 1987, 56 diamond drill holes had been completed, totalling 7,000 metres (Constable and Dunks 1986). In addition, stripping of the overburden from the graphitic zone was completed by the fall of 1986. Cal-Graphite has defined a graphitic unit at least 900 metres along strike, dipping about 40o southeast and open along strike and down dip. Indicated true width varies from 15 to 80 metres. The average grade is 3.71 weight percent graphite, and 90% of the flake in concentrate is +100 mesh. Carbon content of the concentrate is 80 to 85% and can be upgraded to 99% with multiple flotations. (D. Constable, president, Constable Consulting Inc., Sudbury, personal communication, 1986). Estimated reserves as of a 1986 feasibility study are approximately 25 million tonnes at 3.75 weight percent graphite (Constable and Dunks 1986).

6.1.3 Regional Geological Setting

The Butt Township graphite occurrence lies in the Kiosk Domain as defined by Davidson (1986) in the broad east-northeast-trending linear belt of gneisses characteristic of the southern Kiosk Domain (see figure 5.8 and Map 2). The gneisses are a series of mafic, quartzofeldspathic, and pelitic units. The last contains the graphitic horizons and can be traced east-northeast through Algonquin Park, and may continue as far as Maria Township where another graphite deposit is under exploration (Davidson and Grant 1986).

6.1.4 Local Stratigraphy

The Butt Township occurrence was mapped in detail by the author as part of this study. A chained and flagged baseline with azimuth 035o was established during the summer of 1984. The baseline was flagged to 1500 metres south and 600 metres north from the road. Cross lines were flagged by pace and compass to 400 metres east and west, effectively covering the area between Graphite Lake and Minnow Lake. The area between the two lakes was mapped (Map 5 in pocket).

The rocks in the study area are a series of gneisses, primarily variations of quartz-feldspar-biotite gneiss and quartz-biotite schist. For the most part the gneisses have been differentiated on the basis of subtle differences in mineralogy, which may reflect primary compositional differences or slightly different metamorphic conditions. Generally the gneisses are quartz-feldspar-dominated combinations, exhibiting the fine-grained, recrystallized texture typical of granulite metamorphism. Units 2b and 2d (Map 5) differ primarily in the appearance of clinopyroxene in unit 2b and the predominant quartz rodding in unit 2d. On the eastern side of the map area, unit 2b forms a rim around unit

2d, which has amphibole but no pyroxene. The graphite occurs only in the metaquartzite (units 1a,b) and quartz biotite schist (unit 1d).

6.1.5 Description of Map Units

Map unit 1(a, b) is a metaquartzite(1b is 1a with biotite) containing 75%-90% quartz with feldspar, biotite and graphite. In outcrop it is a sugary, fine grained, grey, massive rock that weathers to a rusty yellow colour, becoming very friable. The graphite flakes are not affected by weathering and tend to concentrate in the soil.

In thin section, the quartz appears as large fractured grains, with smaller grains and broken pieces around them, as if they had been crushed. Iron stain surrounds the quartz grains and fills fractures. Sodic plagioclase is a minor constituent. Biotite, in amounts of up to 10%, defines the foliation. The more biotitic varieties of quartzite, > 5% biotite, are designated unit 1b on Map 5. Graphite is disseminated throughout the unit in association with the biotite, with which it may be interlayered or interlaminated. The flake size is estimated to average 1.0 to 1.5 mm. in diameter. The grade, quoted as weight percent graphite, averages 3.5% to 3.7%. The metaquartzite unit is bounded by well developed gneisses on the east and west (Map units 2a, 2b, and 2d).

Quartz-feldspar-biotite schist with graphite occurs as isolated outcrops within the quartzite unit and appears to be a local variation. It is characterized by a variable texture due to pods of coarser quartz, feldspar and biotite material within the finer-grained quartz-feldspar-biotite schist. Like the quartzite, the unit contains graphite flake, up to 5 percent by volume. Petrographic study reveals an inequigranular texture; large, fractured quartz grains with undulatory extinction are surrounded by smaller quartz and microcline grains. Biotite, graphite and ribbons of quartz define the foliation, with the biotite and graphite intergrown as in the quartzite. In outcrop the pods of coarser quartz, feldspar and biotite have sharp contacts with the finer material, but are poorly defined in strike extent. They may be sections that have partially melted and recrystallized. Graphite, of slightly larger flake size (2-3 mm.), is found in these pods, but the grade is lower, 3% by volume rather than the 5 to 7% in the finer material.

Map unit 1d is a quartz-feldspar-biotite-garnet schist similar to the quartz-feldspar-biotite schist. The unit is fine-to medium-grained, foliated but not gneissic, and contains pink to red garnets. Mafic minerals form clots where the grain size is coarser. Weathering of the unit results in a rusty coloured friable rock. Prior to 1986, outcrops of this unit were small, with usually flat exposures. The increased exposure due to stripping has revealed a very complex structure indicative of a ductile shear zone. Incorporated into the unit are large (10 m. by 10 m.) blocks of a spotted rock mapped originally as a plagioclase amphibolite. The slight foliation within these blocks is at angles to neighbouring blocks and to the surrounding quartz-feldspar-biotite schist, suggesting rotation. Graphite is disseminated throughout the quartz-feldspar-biotite schist but does not occur within the blocks. The graphite flake tends to be coarser and more concentrated in the noses of folds and along the margins of pegmatites suggesting some remobilization.

Petrographic study shows that unit 1d is composed largely of quartz and plagioclase. The quartz occurs as large fractured grains, as inclusions in the plagioclase, or as small interstitial grains. The garnets are large (3-4 mm.), contain abundant quartz inclusions, and are associated with biotite. The mafic clots consist of hornblende and biotite, with chlorite alteration. Sphene and apatite are accessories. Graphite occurs towards the outer edges of this unit: the centre part is barren. Surface mapping delineated a horseshoe-shaped unit, and foliations indicate a fold with an axis trending about 075o. (Map 5).

Quartz-feldspar-biotite gneiss (unit 2a) occurs in a few outcrops within unit 2b. It may be a separate rock type but is dispersed so randomly throughout the more widespread quartz-biotite-garnet gneiss that it was considered a part of this unit. The quartz-feldspar-biotite gneiss is finely banded, pink, and medium- to fine-grained. In thin section, it is seen to consist almost entirely of quartz, potassium feldspar and perthite in alternating, centimetre-wide bands of fine-grained and coarse-grained material. The coarse-grained bands consist of long quartz rods showing undulatory extinction. Large (1mm.) crystals of microcline showing the distinctive tartan twinning, plagioclase, and perthite occur between the quartz rods. The fine-grained bands consist of plagioclase, untwinned potassium feldspar and quartz. The quartz is of various grain sizes with irregular outlines, giving the appearance of having been crushed. Biotite occurs in the fine-grained bands and is moderately oriented. Opaque minerals fill the fractures and spaces between the long quartz rods.

Quartz-biotite-red garnet gneiss (unit 2b) is a unit which occurs on the western edge of the map area and appears to be a wide band of fine-grained pink gneiss. It also occurs as a twenty-five metre wide band to the eastern side of the graphitic unit. The gneiss is in contact with the graphite-bearing metaquartzite. Where exposed, the contact is sharp, with rust but not graphite pervasive across the contact. In outcrop the rock consists of quartz and feldspar with biotite and red garnets which can be as large as one centimeter in diameter. The quartz is commonly rodded. Petrographic study shows mostly feldspar, both plagioclase and potassium feldspar, with between 10 and 20% quartz. Biotite, garnet, and clinopyroxene (augite) are also present. Locally hornblende is evident, usually rimming the pyroxene.

The quartz-feldspar-biotite gneiss with quartz rods (unit 2d) appears on the eastern edge of the map area, and although treated as a separate unit from 2b, the two units are probably equivalent, exhibiting differences due to metamorphism. Unit 2d is a very fine-grained and finely banded pink-grey gneiss consisting mostly of quartz, feldspar and biotite with very predominant quartz stringers parallel to the banding. Petrographic study reveals mostly feldspar, both sodic plagioclase and orthoclase, and large rodded quartz grains. The 2d unit contains hornblende and biotite but differs from the 2b unit in having no clinopyroxene.

Plagioclase-amphibolite (unit 3a), a non-foliated, spotted rock, occurs in a few small outcrops, forming an ellipse within the graphitic metaquartzite unit. The rocks may originally have been intrusive, since the one visible contact with the metaquartzite is very sharp. The major constituents are feldspar, quartz and hornblende, and the rock is very distinctive in its massive nature and spotted appearance due to the clumps of mafic minerals. There is no graphite within unit 3a.

6.1.6 Structure

The area between Graphite Lake and Minnow Lake was stripped to bedrock late in 1986 and a preliminary examination of the property revealed many complicated structures within the meta- quartzite unit: sheath folds, drag folds, and rootless folds are evident in the foliation; mafic lenses have been folded and boudinaged; pegmatic material can be seen to thin out, finally becoming disaggregated into porphyroclasts; and anastomosing shears are present. What were thought to be dioritic intrusive bodies, identified as plagioclase amphibolites on the map, are actually large blocks (up to thirty metres in diameter) that have been incorporated into the metaquartzite unit by shearing.

The metaquartzite is now seen as the locus of a ductile shear zone which is five hundred metres wide in the area between the two lakes. This poses the problem of whether the graphite is now present in a pre-existing shear zone, or whether the graphite unit with its plastic nature has concentrated the shearing forces and become a shear zone. Although there is some minor graphite concentration (approximately five volume percent) associated with pegmatitic material at the contact between the graphitic metaquartzite and the rafts of barren material, the graphite is disseminated throughout the unit with the higher grades within the quartz-rich phases. There are no veinlets or graphite shears, indicating mobilization under stress. The simplest explanation is still that the graphite flake represents primary distribution of originally organic carbon. This is substantiated by carbon isotope work described in section 7.0.

6.1.7 Mineralization

The graphite is restricted to the meta-quartzite (units 1a,b) and the quartz-feldspar-hornblende-biotite-garnet schist (unit 1d) (Map 5). Graphite does not occur in the gneissic or in the dioritic (plagioclase amphibolite) units. In light of the preliminary work on the stripped area it appears that the graphite occurs within the more ductile, quartz-rich units and not within the incorporated blocks of dioritic material. Flake sizes and graphite concentrations increase slightly in fold noses and along contacts with pegmatites, but there is no evidence of graphite remobilized into shear zones or veins.

Flake size in hand sample or in outcrop appears to average a millimeter in diameter. Screen tests conducted on graphite concentrates for the Cal-graphite feasibility study yielded between 70% and 90% graphite larger than 150 um.

(Constable and Dunks 1986). Reserve estimation from the 1985 diamond drill data showed that the highest grade of graphite (3.90% to 4.00%, Constable 1986) occurrs in the meta-quartzite unit, towards the northern end of the Cal-graphite property. Estimated reserves according to the feasibility study (Constable and Dunks, 1986) are 26,774,400 tonnes of graphite ore with an average grade of 2.42% by weight graphite.

The graphite concentrate assayed an average carbon content of 85% (Constable and Dunks 1986). The major impurities are quartz and biotite which can be released to some extent through grinding and flotation. The biotite is commonly interlayered with the graphite. Removing the biotite entirely would sacrifice flake size and reduce the market value of the concentrate.

6.1.8 Summary

The Butt Township graphite occurs within a metasedimentary horizon in a series of gneisses located in the Kiosk Domain. The metasediment hosting the graphite is a metaquartzite. It has undergone intense shearing, manifested by the number of complicated structures. The horizon is long, traceable through Algonquin Park, and could be the same series of rocks that host the Maria Township graphite.

The Cal-Graphite property is under exploration at the present time; further work will depend on the production decision of the company.

A detailed map and report of the stripped area between Graphite and Minnow Lakes is planned as a separate publication, to be released in the fall of 1987.

6.2 LAURIER TOWNSHIP

6.2.1 Location and Access

Laurier Township is located on the east side of Highway 11 near the town of Trout Creek (figure 6.3). The area of interest lies within the north-central part of the township. The area mapped is on the north side of Sausage Lake, but exploration work has extended up to two miles south of the lake. The three patented mining claims are situated in concession XIII, lots 21 and 22 and concession XIV, lot 22.

The claims are reached by a forest access road from the main street of the town of Trout Creek. The cottage road into the claims is approximately 5 km from Trout Creek.

6.2.2 Previous Work

On the basis of one sample, assayed in 1924 by Milton Hersey Co. Ltd. of Montreal, that returned 1.36 oz/ton gold and 2.3 oz/ton silver, the Serra S. Bruno Mining Company Limited sold shares on the Toronto Stock Exchange. In 1982 twenty-two continuous claims were staked, and exploration work consisted of three trenches and two diamond drill holes. By 1984 Copconda-York, a Unionville, Ontario based company, held an option agreement for the three mining leased claims.

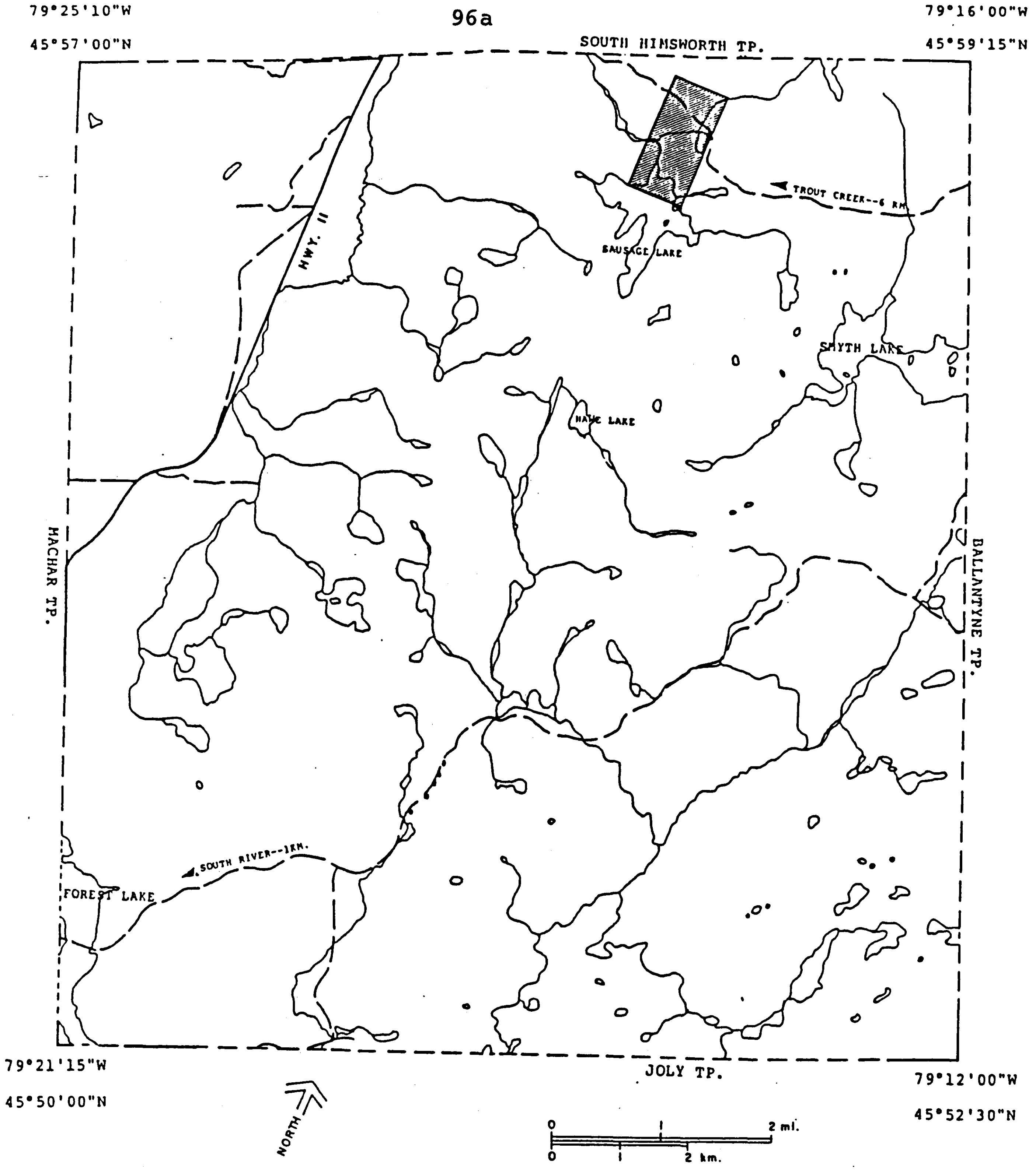


Figure 6.3: Laurier Township showing the location of the graphite deposit (shaded area).

Exploration work consisted of two diamond drill holes.

6.2.3 Regional Setting

The Laurier Graphite Property is situated in the northern part of the Kiosk Domain (Davidson and Grant 1986), more specifically in a narrow band of north-south trending paragneisses forming a septum in the Powassan Batholith. It is possible that the granitic intrusion on the Laurier Property is related to the Powassan Batholith or to one of the smaller, more deformed metaplutonic masses with phases similar to the Powassan Batholith that are characteristic of the Kiosk Domain. The gneiss assemblage in the northern part of the Kiosk Domain includes quartzite and quartzofeldspathic paragneisses as well as more highly deformed metaplutonic rocks which are now orthogneisses.

The gneisses hosting the Laurier graphite occurrence trend north out of the map area, and continue to the south almost as far as Burks Falls. The graphitic horizon has been traced north to the township boundary and to the south for approximately 6 kilometres.

6.2.4 Local Stratigraphy

The property was mapped by the author for this study at a scale of 1:2500. A flagged grid was erected on the property, approximately 1300 metres by 600 metres, set with the baseline at azimuth 355o (Map 2).

Four different lithological units have been defined by mapping: a feldspar-quartz-biotite schist, a quartz-feldspar-biotite-graphite schist, a granitic intrusive rock, and a series of quartz-feldspar-biotite-garnet gneisses. The strike of the foliation varies from 355o to 020o, parallelling the contacts of the units themselves. The units are thin, from 25 metres to 250 metres wide on the surface, and have been traced for a distance of 2 kilometres along strike. They extend beyond the limits of mapping to the north and to the south.

The quartz-feldspar-biotite-garnet gneiss outcrops on the west side of the mapped area, but has been noted on reconnaissance traverses to occur to the north and to the south for several kilometres. The quartz-feldspar-biotite-graphite schist and the feldspar-quartz-biotite schist are separated from the gneisses and each other by thin bands of the granitic intrusive rock. More of the intrusive rock was noted to the east of the map area during a preliminary reconnaissance survey. The map area lies between two lobes of the Powassan Batholith and it is possible that the granitic units are related to this batholith.

The two schist units, the quartz-feldspar-biotite-graphite schist and the feldspar-quartz-biotite schist appear to be of sedimentary origin, but only the one is graphitic. They extend for at least three kilometres to the south as determined by reconnaissance mapping, but the graphitic zone appears to be of the highest grade to the northern side of Sausage Lake.

6.2.5 Description of Map Units

The feldspar-quartz-biotite schist (unit la) is a very fine grained, sugary-textured, grey-pink rock consisting of feldspar and quartz with biotite. It is usually foliated, and is schistose but not gneissic. The unit can be rusty on outcrop surfaces but does not contain graphite. Petrographic study reveals that rock is equigranular and fine-grained, and appears to be recrystallized. It is mainly feldspar and quartz with discrete laths of hornblende and biotite. The feldspar consists of microcline and plagioclase, of which the plagioclase is highly sericitized. Small grains of myrmekite are interstitial to the larger quartz and feldspar grains. Obvious in thin section, but not in hand sample, are round, pink garnets, larger than the other minerals,and poikilitically enclosing small inclusions of feldspar and quartz. Sulphide occur in small grains disseminated throughout the rock.

The quartz-feldspar-biotite-graphite schist (unit 1b) is a very fine grained, rusty, friable when weathered, dark grey rock that tends to be schistose. This is the graphite-bearing unit, with fine-grained (1 mm) flakes of graphite disseminated throughout the rock. In thin section, the rock is seen to be predominantly fine-grained, equigranular quartz and highly sericitized plagioclase. Graphite, muscovite, and biotite are disseminated throughout and define the foliation. Muscovite is predominant close to the contact with the granitic intrusive rock and appears to be a result of the alteration of the feldspar. The graphite and mica, especially the biotite, are associated to the point of being inter-layered. Generally the quartz is fine-grained and equigranular, showing triple point junctions indicative of recrystallization. There are coarser grained areas, mostly in the form of narrow, centimetre-wide stringers, with large (5 mm) fractured quartz and feldspar grains. Graphite is most abundant and evenly disseminated within the finer grained, equigranular parts of the unit. Locally some hornblende is present as well as clinopyroxene (augite) and retrograde chlorite. This unit looks somewhat similar to unit 1a, but contains graphite and lacks garnet. On a fresh surface sulphides are visible; they give the weathered surface the very distinctive rusty gossan.

The granitic intrusion (units 2 and 2a) outcrops as hummocks and ridges, forming narrow bands that are interfingered with the two metasedimentary units (la and lb). Unit 2, the megacrystic granite, consists of light blue potassium feldspar and plagioclase (albite) augen, from 0.5 to 1.0 cm. in diameter. They are surrounded by a finer grained matrix of sericitized orthoclase, quartz, myrmekite, garnet hornblende, biotite, the occasional crystal of sphene, and some chlorite.

Although this unit of the granitic intrusion is not gneissic, foliation is evident by the slight elongation of the feldspar augen and the tendency for the quartz to form ribbons interstitial to the feldspar.

Unit 2a, the granitic gneiss, is unit 2 material in which a higher level of penetrative deformation has developed colour banding and a lineation plunging 40o to the south. The gneissic section occurs on the eastern side of the granitic units into which it grades sharply. It consists of elongated, large quartz grains with inclusions of muscovite and feldspar. They are aligned parallel with the foliation, and alternate with bands of fine grained microcline, quartz, sericitized albite, garnet, augite, and chlorite. The latter bands appear to be the remains of highly stretched and recrystallized feldspar augen. This granitic intrusion has sharp contacts with the metasediments, and although there is usually some rust along the contact that extends into the granite for a metre or so, there is never any graphite in the granite or concentrated at the contact, except in a single graphite vein, which is discussed below.

Unit 3b on the map is a quartz-feldspar-biotite-garnet gneiss; unmistakable due to the distinct, alternating light and dark bands of quartz-feldspar and biotite-hornblende-garnet, respectively. Knobby stringers of quartz-feldspar parallel the bands. The garnets are a pink-mauve colour.

6.2.6 Mineralization

The graphite in Laurier Township occurs both as disseminated flake within a silica-rich metasediment and as a vein approximately one to two metres wide. The disseminated graphite occurs only within one of the metasedimentary units; the quartz-feldspar-biotite-graphite schist. It does not occur within the gneisses nor within the feldspar-quartz-biotite schist or the granitic intrusive rock. The graphite flake within the metasediment tends to be fine-grained, on average a millimetre in diameter. No tests were done to evaluate the sieve fractions of a graphite concentrate, which would determine flake size after grinding and flotation. Outcrop of the graphitic unit is sporadic but the distribution of the graphite appears to be uniform within it. The average weight percent grade is approximately 2.0% graphite.

Between the western boundary of the graphitic unit and the granitic intrusion there is a zone approximately 2 metres wide, paralleling the contact. The zone is harder than the surrounding rock and is a dark rusty red in colour. Within this zone there is a graphite vein about 1 metre wide. The graphite appears massive and black in hand sample, but assays only 25% carbon on average. Petrographic analysis revealed graphite flakes about 1 millimetre in the long direction and tending to be wavy or curved. Between the graphite flakes are quartz grains showing signs of recrystallization, biotite, up to 5% carbonate, pyrite and iron oxides. G. Wilson (consultant, Turnstone Geological Services Ltd., Toronto, Ontario, personal communication, 1987) noted in one polished thin section the presence of biotite speroids 3 millimetres in diameter rimmed by graphite. The source of the graphite within this zone is an enigma. In outcrop the distribution and appearance of the graphite are indicative of a shear zone. The secondary minerals (carbonate, biotite) and the iron staining imply alteration. The topography of the area, a cliff edge leading into a swamp, indicates the possibility of a fault zone. On air and satellite photos, this fault zone can be traced as a lineament for several kilometres to the south. Earlier gold exploration in the area took place along this zone, both north and south of the lake. It seems probable that the graphitic zone is a result of alteration along a fault zone, but further work is required to determine the source of the graphite.

6.2.7 Summary

The Laurier graphite occurrence consists of a thin band of a quartz-rich metasediment that is part of a series of paragneisses in the Kiosk Domain (Map 2). These gneisses form a septum in the Powassan Batholith. The graphite occurs in two forms: as fine-grained flakes that constitute on average 2 weight percent of a quartz-feldspar-muscovite schist, and as a graphitic vein that has formed at the contact between a granitic intrusion and the graphitic quartz-feldspar-muscovite schist. The graphite vein averages twenty-five weight percent carbon.

The host units of the graphite appear to extend along strike to Lake Bernard and have neither been mapped nor prospected sufficiently to warrant an estimate of the graphite potential, or, for that matter, the gold potential.

6.3 RYERSON TOWNSHIP

6.3.1 Location and Access

Ryerson Township is located just west of the town of Burk's Falls, easily accessible from Highway 11 by either Highway 520 West or a gravel road leading to Doe and Rainy Lakes (figure 6.4). There are two separate graphite properties of interest in the township, one near the old town of Midlothian, and the other bordering the Royston Road.

The northern graphite occurrence is located on concession X, lots 20, 22, and 23, and concession IX, lots 20, 22, 23, and lot 21, and Concession VIII, lots 18, 19 and 20. The property is reached by a gravel road from Highway 520 West heading to Midlothian, approximately six km from Burks Falls. The southern property is located on concession V lots 11, 12, and 13, and is reached by the Royston Road, which turns east off the Doe Lake Road approximately three kilometres from Highway 11.

6.3.2 Previous Work

The Ryerson Graphite Project, a privately financed syndicate, was formed in 1982 and acquired the mineral rights to

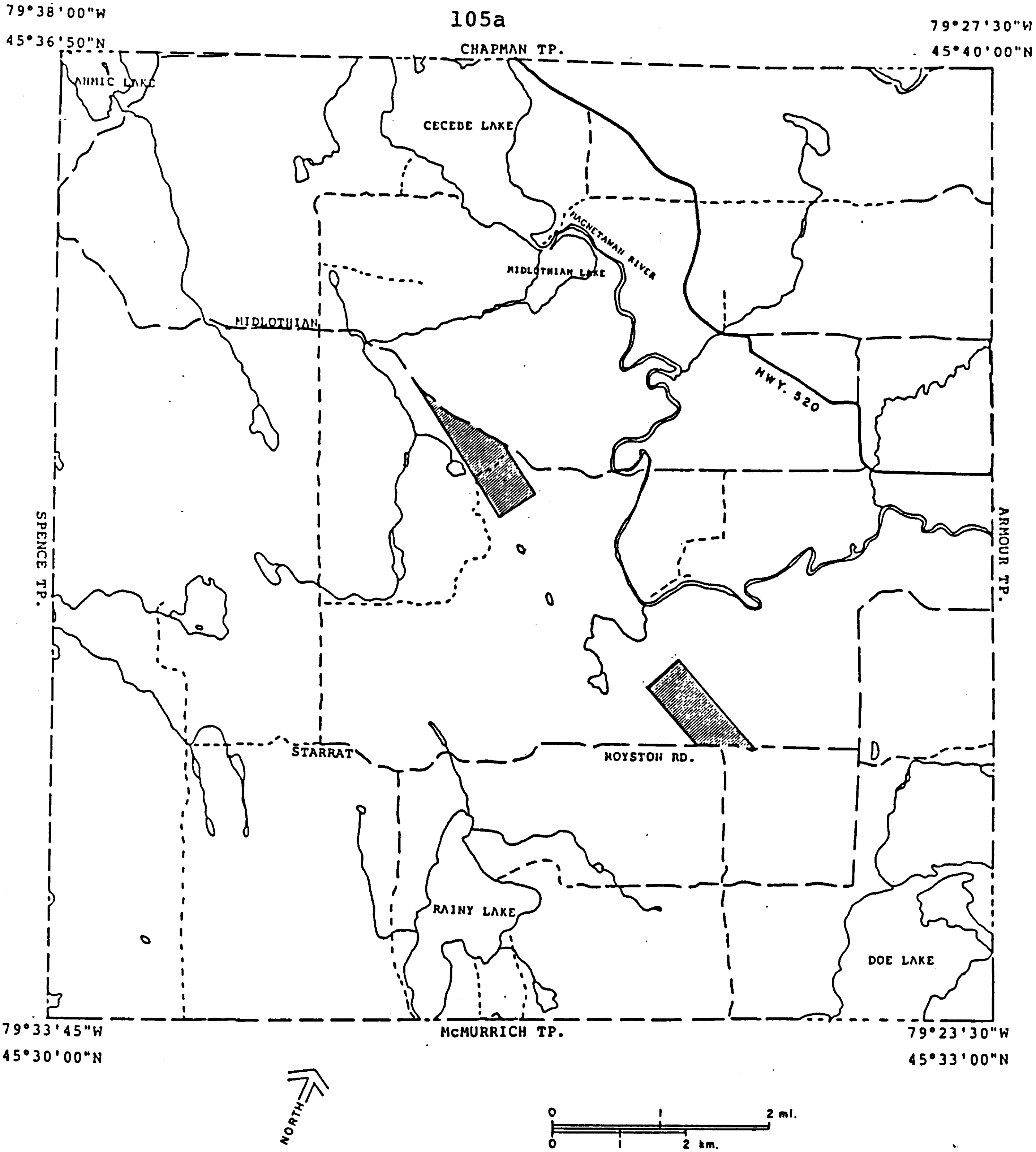


Figure 6.4: Ryerson Township showing the location of the graphite deposits (shaded areas).

the patented land in concessions X and IX. By 1983 7 diamond drill holes totalling 2,842 feet were completed as well as 4 trenches and 1 pit. A bulk sample of 500 pounds of graphite concentrate was sent to Asbury Graphite in New Jersey, and another to Mineral Research at Michigan Technological University in Houghton, Michigan for testing of the flake.

The southeastern part of this occurrence consists of the south half of lot 20, concession IX and lots 18, 19, and 20 of concession VIII. The mineral rights have been acquired by Copconda-York of Unionville, Ontario. Geosphere Consulting Limited completed geological and geophysical surveys, magnetometer, VLF, and Max Min II on both properties in 1982. Copconda-York had 3 trenches blasted and sampled, producing carbon assays that varied from 0.53% carbon to 2.65% carbon (Assessment Files, Resident Geologist's Office, MNDM, Dorset). No further work has been done on either of these properties.

The exploration program for the graphite occurrence on Royston Road was under the direction of Murwa Investments Limited, and by June 1982 they had mapped and trenched the graphitic horizons. By September, 1982, a new company, the Ryerson Graphite Property Incorporated, was formed, and undertook the excavation of 10 more trenches along the graphite horizon. By late fall of that same year Erana Mines of Sudbury, Ontario had made an agreement with Ryerson Graphite Property Inc. for the mineral rights and were in the process of testing 500 pounds of graphitic ore from one of the higher grade sections. Erana Mines felt that the results of the bulk sample warranted a 25 ton bulk sample to be tested, and a feasibility study to be done on the property. Graphite Corporation of Canada, incorporated in 1982, bought the land outright, acquiring the mineral rights. By 1983, they had drilled 8 holes totalling 600 metres and had resampled the trenches. Porto Metal Mills of Sudbury did the graphite separations. Average assays were around 4 weight percent carbon for the rock and 88 weight percent carbon for the concentrate.

By the end of 1986, 12 more diamond drill holes had been completed totalling 1359 metres (J. Goodwin, consulting geologist, Callandar, Ontario, personal communication, 1987), and a self potential survey had been completed over the graphite horizon.

6.3.3 Regional Setting

The Ryerson Graphite occurrences are hosted by a paragneissic unit which seems to follow the structural trend within the Kiosk Domain around the north part of the Parry Sound Domain (Map 2). It is possible that this sequence continues in the Britt Domain (Davidson et al. 1982) (Map 2). Graphite occurs within the unit at enough locations (Martin 1983) to warrant exploration of the continuation of the paragneiss.

Drag folding and rootless folds are evident within the graphite-bearing, quartz-feldspar-biotite schist where it is exposed, and it is possible that this unit has undergone ductile shearing accompanied by stretching and thinning similar to the Butt Township graphitic unit.

6.3.5 Description of Map Units

The quartz-feldspar-hornblende-garnet gneiss (unit 1b) occurs in a broad band on the northern edge of the area mapped (Map 6). The gneiss is finely banded white and black rock with bands 1 to 2 centimetres wide. The bands are straight and continuous, showing no contortions or folding. The mafic mineral appears to be primarily hornblende, often occurring as clots and associated with the garnets, which are a dark red and comprise from three to seven percent of the rock.

The quartz-feldspar-biotite-garnet gneiss (unit 1d) differs from the above unit in having more biotite than hornblende. The rock consists of grey and pink bands, with quartz stringers both cross-cutting and paralleling the gneissosity. The bands are not as continuous as in unit 1b; the biotite and garnet tend to occur in patches, forming irregular bands and blobs. This unit occurs on the southern edge of the map area and does exhibit some folding and warping.

The quartz-feldspar-biotite gneiss (unit le) is also a finely banded sugary-textured rock, similar to unit ld, but does not contain garnet. There is some quartz veining parallel to the gneissosity and a high degree of stretching is indicated by feldspar clots that are elongated about 30:1. This unit occurs as relatively narrow bands within unit ld.

The quartz-feldspar-biotite schist (unit lf) is a rusty, friable, quartz-rich rock. It is not gneissic, but does exhibit some foliation due to alignment of the biotite and graphite. This is the only unit that contains graphite, which occurs as flakes defining the foliation and associated with the mica. Average grades of the graphite vary form 1 to 3 weight percent. Mats of coarse-grained tremolite and radiating clusters of fine sillimanite occur in minor amounts within the unit. Garnet is rare, and is pink to light red in colour. As a general rule, as the biotite content increases, garnet begins to appear, and the graphite content decreases. This unit occurs as a band interpreted to be in the range of 2 to 4 hundred metres thick and conformable with the surrounding gneisses. Within the unit there are lenses of coarser grained, quartzo-feldspathic material which have been drag-folded. The graphite properties lie on strike with each other and have been interpreted to be parts of the same unit, but there is no outcrop between to substantiate this interpretation.

The mafic rocks (units 1c and 2) occur along the south boundary of the map area. Unit 2 appears to be a mafic intrusive rock, forming discrete outcrops. In one outcrop a sharp contact with the gneisses could be seen. These intrusions are not foliated except near the contact. They consist of an amphibole (hornblende) in a plagioclase matrix, with the feldspar content higher toward the contact. On the weathered surface the rock resembles a diorite. Unit 1c is a hornblende-feldspar-quartz gneiss with garnet and pyroxene in the mafic bands. Only one outcrop of this unit was observed.

6.3.6 Mineralization

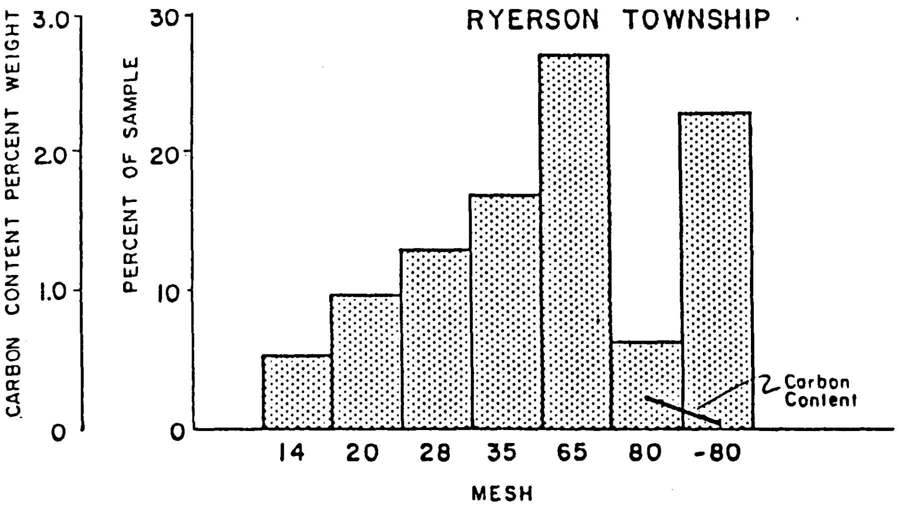
The graphite from the Ryerson Township occurrences is a flake approximately 1.0 to 1.5 mm. in diameter by visual estimation. The graphite occurs only within one unit, the quartz-feldspar-biotite schist (1f). Average grade from the northern part of the unit is 2.0% by weight (Assessment Files, Resident Geologist's Office, MNDM, Dorset) and 2.5% by weight (J. Goodwin, consulting geologist, Callandar, Ontario, personal communication, 1986) from the southern part. The graphitic unit has been examined in detail for approximately

1000 metres at both its northern and southern ends as displayed on Map 6. There is a possibility that the graphite continues between the two separate properties, but lack of outcrop makes this difficult to determine.

A bulk sample was taken from the northern property. The results, from Asbury Graphite, are plotted in figure 6.5. Carbon content and percent weight of the sample are plotted against the mesh size. The 14 mesh corresponds to 1.4 mm, the 35 mesh to 500 um, and the 80 mesh to 180 um. The bulk of the concentrate is larger than 250 um. The optimum carbon content seems to be associated with flakes at the 500 um size. This could be related to the manner in which impurities are trapped within the flakes; large flakes could possibly contain more impurities per unit area, while smaller flakes may have fewer impurities.

6.3.7 Summary

The Ryerson graphitic unit has been explored in two places: at the northwestern and southeastern parts of the map area. Exploration work is still in progress on the southern occurrence. The graphite is contained within a quartz-feldspar-biotite schist, a rusty quartz-rich rock with local patches of tremolite and sillimanite. The graphite unit is part of a series of gneisses that trend to the northwest,



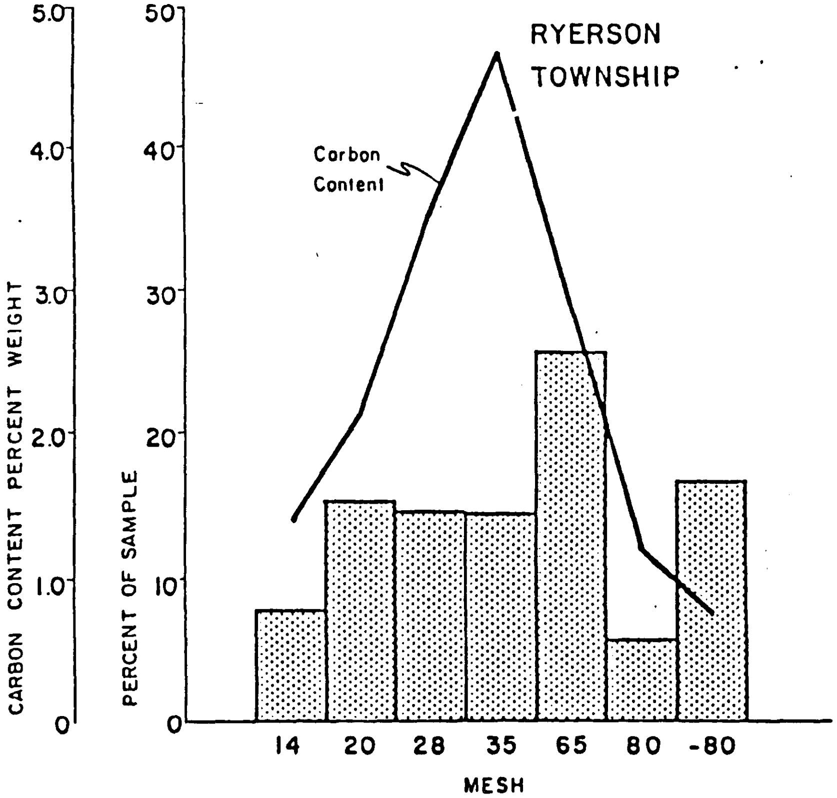


Figure 6.5: Percent carbon versus flake size for the graphite bulk sample from the northern property, Ryerson Township. Data from Asbury Graphite Inc.

ultimately following the edge of the Parry Sound Domain (Map 2).

6.4 MARIA TOWNSHIP

6.4.1 Location and Access

The Maria Township graphite occurrence, also known as the Bissett Creek graphite occurrence, is located east of Deux Rivieres, just south of Highway 17 (figure 6.6). The area of interest lies within concessions III, IV, V, and VI, lots 20 to 28. Access is good, via the Bissett Creek haulage road that exits Highway 17, 1 kilometre east of the Town of Bissett Creek. A good secondary haulage road leads east into the property 14 km south on the Bissett Creek road.

6.4.2 Previous Work

Maria Township lies within the area mapped by Lumbers (1976). Early work on the graphitic horizon consisted of some trenching and 1 diamond drill hole, done for assessment work. Westcoast Charters of Vancouver did more trenching in 1982, and Princeton Resources continued with an extensive diamond drilling program from 1983 until 1986. A pilot mill was established on site and during the winter of 1987 a bulk sample was produced and the graphite tested (Princeton Resources Corporation, Vancouver, B.C., personal communication, 1987).

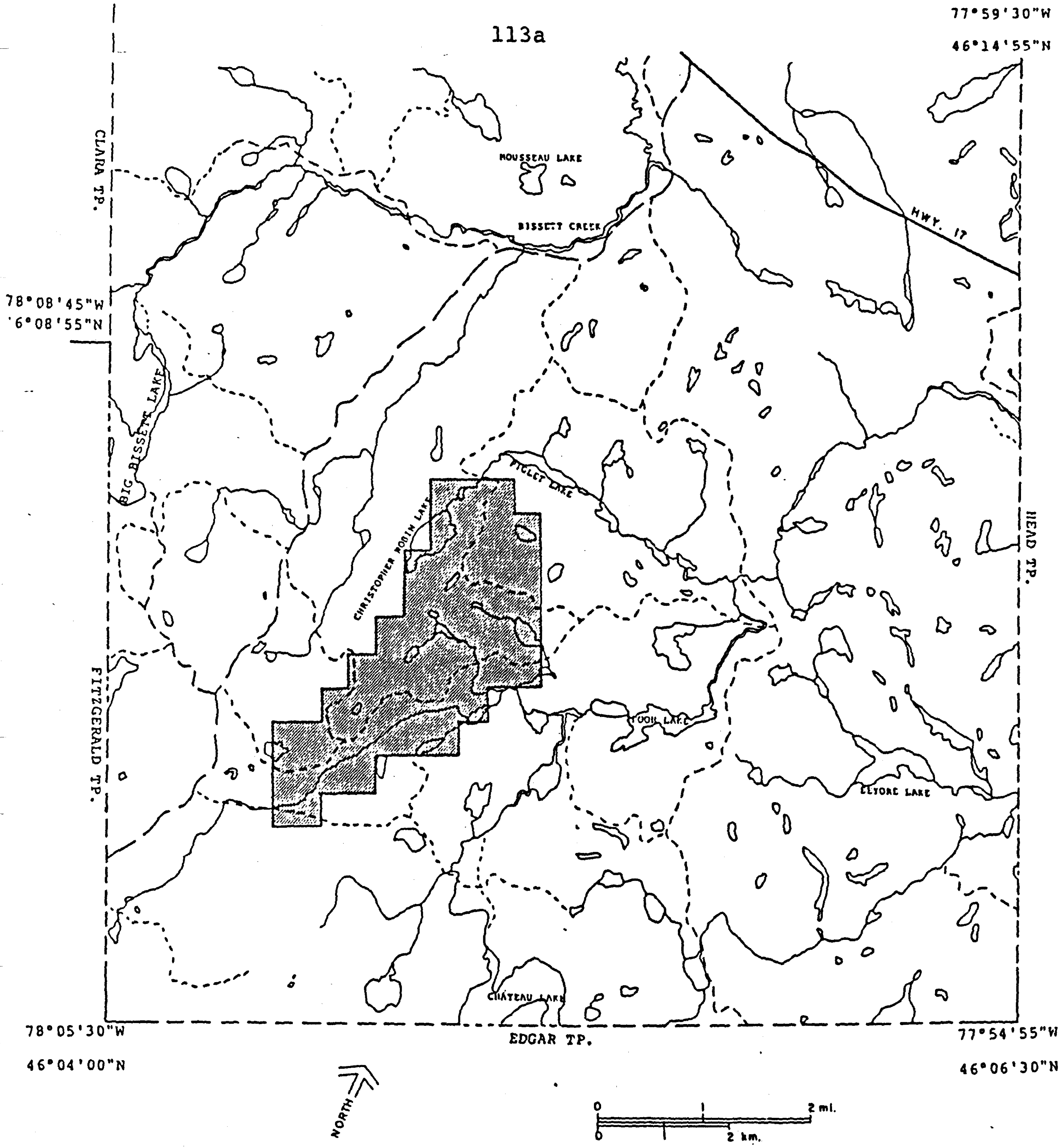


Figure 6.6: Maria Township showing the location of the graphite deposit (shaded area).

6.4.3 Regional Setting

The paragneiss assemblage hosting the Butt Township graphite occurrence has been traced by reconnaissance work through Algonquin Park to Radiant Lake (Davidson and Grant 1986) and may be the same series of rocks that host the Maria Township graphite.

6.4.4 Local Stratigraphy

This property was not mapped during this study, due to lack of good exposure in comparison with the other properties. However, the trenches were examined and sampled.

The host rock is a quartz-feldspar unit with pink garnets, biotite, and some sillimanite (Innes 1982). Foliations dip within 15o of the horizontal, generally to the northeast. Lumbers (1976) did not differentiate units within the map area, calling the rocks migmatitic biotite gneiss and biotite gneiss. The quartz-feldspar-biotite-garnet rock varies in texture from a schist to a gneiss. The unit weathers very rapidly: a rusty gossan covers trenches only 1 year old, and the sandy soil is full of weathered-out graphite flakes. In coarser grained garnet-biotite segregations, the graphite flakes are also coarser, but grade is lower.

6.4.5 Mineralization

The graphite in hand sample appears to be 1.5 to 2.0 mm. in diameter on average. The grade on surface exposures appears to vary from 5% to 10% percent by volume. The graphite appears to be restricted to the quartz-feldspar-biotite-garnet gneiss. As the amount of garnet and biotite increases, the amount of graphite decreases.

Princeton Resources Corporation outlined three zones of graphite mineralization by diamond drilling. Each zone contains disseminated graphite at various depths from surface to 265 feet (Princeton Resources Corporation, News Release, 1985). Outlined reserves are 3,800,000 tonnes grading 3.05% graphite by weight. Testing on the graphite concentrate revealed that 51% of the concentrate consists of flakes larger than 500 um. The first flotation concentrate was 78% carbon by weight, which could be upgraded to 91% carbon by weight by regrinding and floating (Princeton Resources Corporation, News Release, 1985).

6.4.6 Summary

The Maria Township graphite deposit, currently under investigation by Princeton Resources Corporation, is located southeast of the Town of Bissett Creek. The graphite flake occurs in a quartz-feldspar-biotite-garnet gneiss, with an average grade of 3.0% by weight. Princeton Resources Corporation have built a mill on the property and plan to process a bulk sample early in 1987.

6.5 COMPARISON AND INTERPRETATION

The graphite in the four occurrences in Butt, Laurier, Ryerson, and Maria townships is flake graphite. In Laurier Township a graphite vein also occurs. The flakes are consistently 0.5 to 2.0 mm. in size, and are in all cases disseminated throughout the host, with minor accumulations in fold noses and along pegmatite margins seen in Butt and Ryerson townships. The vein graphite in Laurier Township is composed of millimetre-sized flakes, usually wavy or curved, interstitial quartz, biotite, and carbonate. Graphitic carbon in this case assays on average 25% by weight.

The Butt Township occurrence has calculated reserves of 25 million tonnes grading 3.75% weight graphite (Constable and Dunks 1986). The Maria Township occurrence has reserves of approximately 13 million tonnes grading 2.72% weight graphite (Industrial Minerals, March 1987). The Ryerson and Laurier township occurrences have no tonnage estimates or feasibility studies conducted as yet.

In all four occurrences, the host rock is a quartz-rich schist which petrographically and physically appears to be a metasediment. In all cases, the rock weathers to a rusty gossan, so characteristic that it can be used as an exploration tool. Biotite is present in each occurrence, defining the foliation and commonly interlayered with the graphite. Feldspar, usually plagioclase, is also present in all cases. The graphite units in Laurier and Butt townships are quartz-feldspar-biotite schists, and in Butt Township a metaquartzite is host as well. The host unit in Laurier Township is finer grained than the one in Butt Township, and is a dark green to grey colour on the fresh surface, possibly due to chloritic and sericitic alteration. The metaquartzite in Butt Township is fine-grained, but coarser than in Laurier Township, and has a grey colour on the fresh surface. The quartz-feldspar-biotite schist is similar to the metaquartzite but has enough biotite to define a foliation and to give a schistose appearance. The graphite unit in Ryerson Township, also a quartz-feldspar-biotite schist, grades locally into an incipient gneiss with the development of light and dark coloured bands. The Maria Township unit is similar in appearance to that of in Ryerson Township, tending to be gneissic. Both units are fine- to medium- grained, grey, quartz-rich rocks with a schistosity due to biotite and graphite. Sillimanite has been reported from both units, and was seen in Ryerson Township as radiating clusters of fine needles on foliation planes. Tremolite was seen at the Ryerson Township occurrences as felted masses of coarse (3 cm) needles in a lens within the quartz-feldspar-biotite schist. The only carbonate minerals observed were in the graphite vein in Laurier Township, forming grains interstitial to the graphite flakes.

It is evident from the work by Davidson et al.(1981, 1982, 1986) that the particular series of gneisses hosting the graphitic metasediment continues for several kilometres, following and/or defining structural trends (Map 2). Small graphite showings are dotted along the strike of the metasedimentary unit, although concentrations of graphite occur in fewer places. The graphite in Butt Township appears to be in a unit on the same structural trend as the graphite-hosting unit in Ryerson Township, which may continue into Maria Township (Davidson and Grant 1986). There are graphite showings along the strike extent (Martin 1983) but known concentrations are the two in Ryerson Township, the one in Butt Township, and the one in Maria Township. The host unit is generally similar (quartz-feldspar-biotite schist) but in Ryerson Township there is sillimanite and tremolite; in Maria Township, garnet is more prominent, and the host unit contains tremolite and relatively high amounts of sphene. The unit in Ryerson and Maria Townships tends to be more gneissic than at the Butt Township occurrence. Ductile deformation is very evident at the Butt Township occurrence and is also present at the Ryerson Township occurrence. In Maria Township, poor exposure of the almost horizontal unit may mask any evidence of deformation. In Laurier Township, the unit is visibly different; it is finer-grained than at the other occurrences, and the presence of muscovite and chlorite suggests subsequent hydrothermal effects.

The differences in mineralogy between the metasediments in the Maria, Butt, and Ryerson township occurrences may be a reflection of depositional differences in the original sediments, superimposed by differences in metamorphism. For example, a higher initial clay fraction will yield sillimanite under certain metamorphic conditions, while sediments with a higher feldspar fraction will yield garnet or amphibole depending on the metamorphic conditions. The structures in the rocks indicate ductile deformation in at least Butt and Ryerson Townships, resulting in stretching and consequent thinning of the units. What now appear to be inconsistent differences along the same unit could represent different facies environments of a particular sedimentary horizon. Factors such as water depth, river outlets, and wave action on a beach could yield a metasediment with gross similarities, yet with differences in mineralogy such as high clay content from deeper water environments, or quartz- and feldspar-rich rocks from shallow or beach environments. Each environment would be capable of trapping and containing carbonaceous debris such as plant or animal remains in the water. At amphibolite grade or higher, graphite will form from such carbonaceous material (Landis 1971). From the work to date, it appears that concentration of graphite relates directly to the original concentration of carbonaceous material. Subsequent concentration of graphite in fold noses and along pegmatitic margins as seen in Butt and Ryerson townships, is on a minor scale and has not affected the graphite distribution over areas larger than the immediate vicinity. The vein in Laurier Township is an enigma: there appears to be no graphite concentration gradient or flake size gradient within the graphitic schist next to the vein, as would be expected if the graphite were mobilized from the metasediment into the vein. Further work along the strike of this vein is needed to answer questions regarding the extent of graphite within the zone, whether there is gold associated with the graphite in areas not yet tested, and how the graphite was emplaced.

7.0 PETROGRAPHY, CARBON ISOTOPE, AND RARE EARTH ELEMENT ANALYSES OF THE GRAPHITIC HORIZONS

7.1 PETROGRAPHY OF THE GRAPHITIC UNITS

7.1.1 Butt Township

The graphitic units in Butt Township appear on Map 5 as unit 1a/b, (quartzite and quartzite with biotite), and unit 1d, (quartz-feldspar-biotite-garnet schist). The petrography of the quartzite will be discussed first.

a. Quartzite (Unit 1a,b)

Quartz occurs in large fractured grains and rods, 1 to 2 mm. wide. It also occurs in smaller grains,(0.05 mm. in diameter) showing 120o recrystallization boundaries. In both populations, the quartz is fractured and shows strained extinction. Ilmenite has stained the grain boundaries and occurs in fractures cross-cutting grain boundaries and penetrating other minerals. Quartz accounts for 65 to 75% of the quartzite. The field term, quartzite, has been retained as the name of this unit to avoid confusion, although technically a quartzite should have a quartz component of 95% or more (Pettijohn 1975).

Plagioclase feldspar has compositions ranging from An40 to An50, as determined by the Michel-Levy method. Most exhibits albite twinning but it also occurs untwinned. It occurs in grains 0.05 to .1 millimetres in size, distributed in feldspar-rich bands that alternate with quartz-rich bands. The feldspar is always altered, from a dusty to an intense kaolinization, with flakes of sericite and some chlorite. Potassium feldspar occurs as microcline in grains 0.05 to 0.1 millimetres wide between the larger quartz grains and usually associated with small blebs of quartz and biotite. In areas devoid of the larger quartz grains, potassium feldspar is not found with the finer grained quartz-plagioclase mixture. The total amount of feldspar in this unit is approximately 10%.

Mica occurs as biotite in small, stubby laths, 0.05 to 0.1 millimetres long, interlayered with flakes of graphite. It exhibits a pale yellow to red-brown pleochroism. If ilmenite and hematite are present, the biotite is associated, forming concentrations in fractures with iron oxides.

Garnet occurs only in the parts of the unit with more than 5% biotite and is associated with it. When present, it is in small rounded, highly fractured grains and usually only in amounts less than 1%. Apatite occurs in small grains (less than .02 millimetres) and is distributed throughout the rock.

Graphite occurs in amounts from 3% to 10% by volume, in laths > 0.75 millimetres long by 0.05 millimetres wide. It is disseminated throughout the quartz-feldspar part of the unit, but is not as plentiful in the bands of coarse-grained quartz rods, and is usually not found interstitial to the large quartz grains. As mentioned above, the graphite is commonly interlayered with the biotite, and mimics its grain size.

b. Quartz-feldspar-biotite-garnet schist (Unit 1d)

The unit 1d is different from unit 1a,b by having less quartz, more feldspar, and a greater variety of accessory minerals. Quartz occurs as large rutilated grains, 1.0 to 1.5 millimetres in diameter. It also occurs as fine blebs interstitial to other minerals and as recrystallized grains 0.02 to 0.05 millimetres wide. Large grains of quartz are fractured, show strained extinction, and are stained by ilmenite. Quartz constitutes approximately 30 to 40% of the rock.

The feldspar is plagioclase (An50 to An60), either untwinned or albite-twinned in grains 0.2 to 0.5 millimetres wide. The feldspar is not as highly altered as in the biotite quartzite unit (1a,b) but shows alteration along cleavages. Feldspar comprises approximately 40% of the rock.

The mica, as in unit 1a,b, appears to be biotite, is usually 5% or less of the rock, and is commonly interlyered with the graphite. Accessory minerals consist of chlorite, ilmenite and hematite, garnet, and sphene. The chlorite appears to be altering from a clinopyroxene, but the chloritization has masked the clinopyroxene, precluding a positive identification. This is illustrated in figure 7.1. The ilmenite and hematite, associated with the biotite and the graphite, fill fractures and rim quartz grains. Graphite occurs in lesser amounts than in the quartzite (unit 1a,b), approximately 1% to 3% by volume. It occurs as laths or flakes 1 to 2 millimetres long and is interlayered with the mica.

The graphitic horizon (units 1a,b and 1d) in Butt Township is deceptively mineralogically simple, consisting of varying amounts of quartz, feldspar, and biotite with graphite. Questions to consider are: the absence of potassium feldspar, the two populations of quartz, the fracturing and infilling with iron oxides, the alteration of the plagioclase, and the probable presence and subsequent alteration of a clinopyroxene, and the association of the graphite with the mica and the iron oxides. The only occurrence of potassium feldspar is interstitial to the large quartz grains. Original potassium feldspar, if present at one time, has been broken down, and may have contributed to the formation of mica. Quartz occurs as rods in a response to stress and appears to have been recrystallized from the large quartz grains. Extinction shadows and subdomains are still visible within individual large grains, indicating strain within the crystal lattice. The quartz commonly includes other grains of quartz and feldspar. At the edges of these

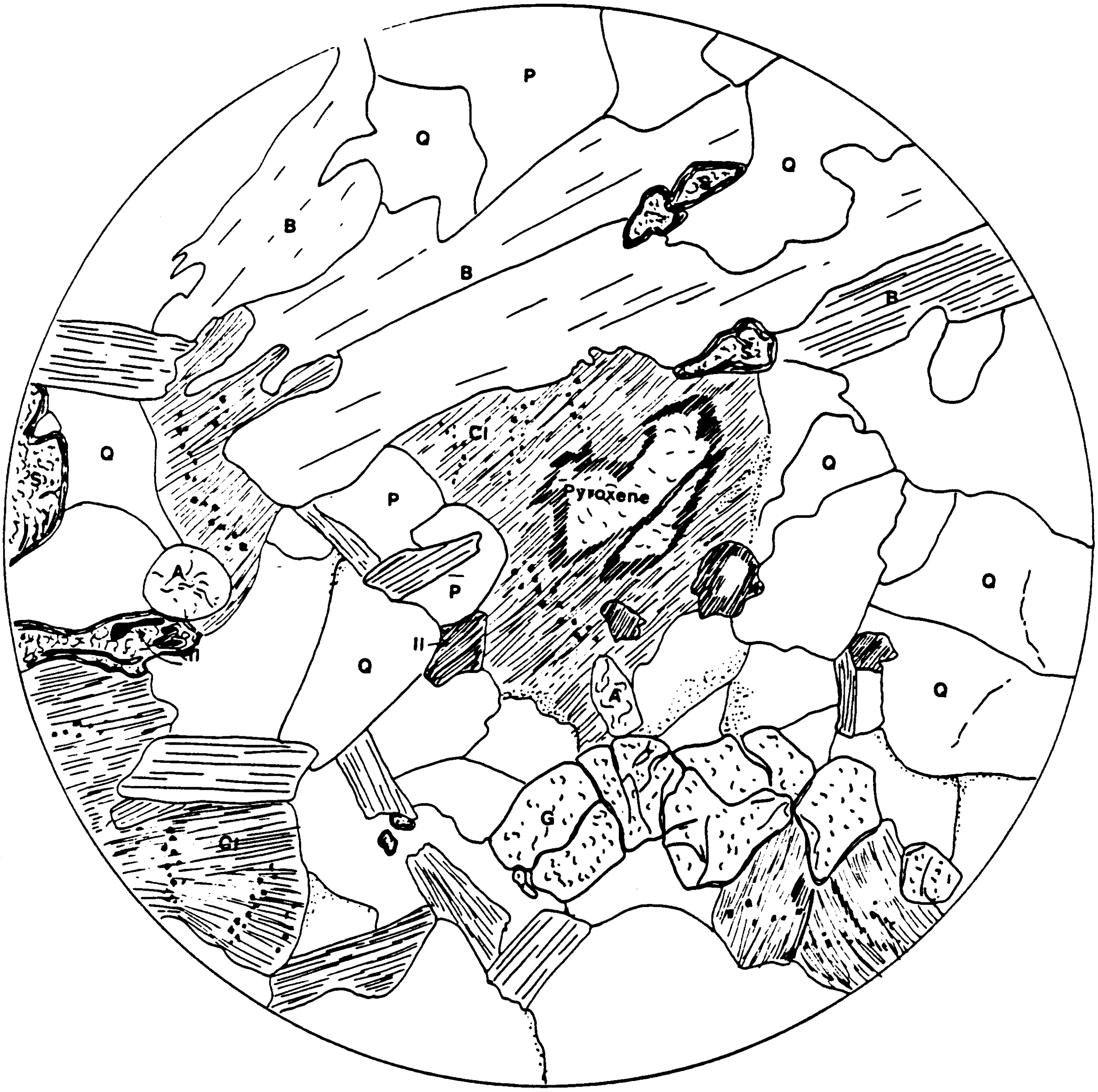


Figure 7.1: Sketch of a photomicrograph showing chlorite after clinpyroxene. Sample: B-34, Butt Township.
Diameter: 2 mm. Q-quartz, P-plagioclase, A-apatite, S-sphene, B-biotite, Il-ilmenite, G-garnet.

large grains are smaller grains of feldspar and quartz which have undergone some crushing. The finer quartz grains appear to have been recrystallized from existing quartz but have formed equidimensional grains in a matrix with feldspar, biotite and graphite.

Fracturing is evident on a microscopic, as well as macroscopic, scale. Fracturing appears to have taken place after the recrystallization of the quartz, including the formation of the quartz rods, and after the crystallization of the graphite; networks of fractures cut through the large quartz grains, cut across grain boundaries into other minerals, and have provided a pathway for the mobilization of ilmenite, biotite, and to some extent graphite (figure 7.2). Concentrations of iron oxides, ilmenite and probably hematite, form anastomosing veinlets which cross the entire matrix of the thin section. Biotite tends to be concentrated along the edges of these veinlets and graphite is present both in higher concentrations and in larger flake size, and is still interlayered with the mica.

Pyroxene, when present, and plagioclase have been intensely altered to chlorite and kaolinite-sericite. The mineral assemblage - quartz-feldspar-clinopyroxene-garnet-indicate granulite grade metamorphic conditions (Winkler 1984). The presence of chlorite and kaolinite indicates a second process which produced these lower temperature

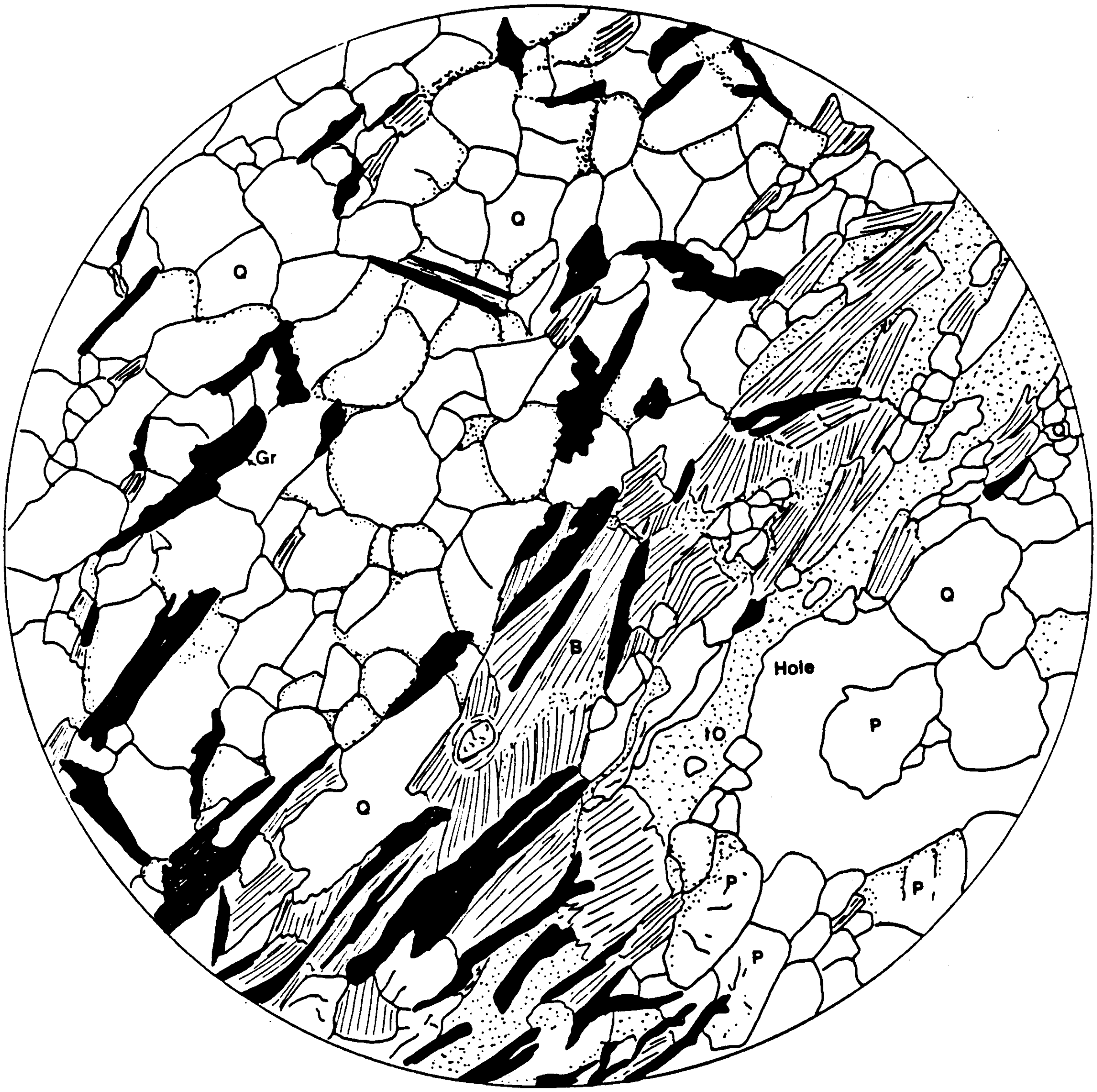


Figure 7.2: Sketch of a photomicrograph showing the concentration of iron oxides and graphite in a fracture. Sample: B-3, Butt Township. Diameter: 5 mm. Q-quartz, P-plagioclase, IO-iron oxides, Gr-graphite.

minerals.

7.1.2 Laurier Township

The graphitic horizon in Laurier Township is within unit lb, the quartz-feldspar-muscovite schist. It is similar mineralogically to the graphitic unit in Butt Township. Quartz, comprising at least 50% of the rock, occurs in either a fine-grain size, up to 0.07 millimetres in diameter, and in coarse-grain sizes of 1 millimetre or more. The larger size fraction tends to form rods, defining the foliation. The coarser grains also form bands. Interstitial to the large grains in these bands are fine (< 0.05 mm.) blebs of quartz. Except for the tiny blebs, the quartz grains are amoeboid to polygonal in shape, are fractured and show strained extinction.

Feldspar, 30% to 35% of the rock by volume, is mostly plagioclase, untwinned or exhibiting albite twinning. Composition is in the range An40 to An60. Potassium feldspar is rare, occurring as microcline in large grains, approximately one millimetre in diameter, in a matrix of finer grained quartz and plagioclase. The plagioclase, but not the microcline, is intensely altered, more so than in Butt Township, to dusty kaolinite, flaky sericite and chlorite to the point of complete obliteration of the original mineral. In some thin sections the altered feldspars are stretched to ribbons, interstitial to the quartz.

There are two types of mica present, biotite and muscovite. Biotite constitutes 2% or 3% but can be up to 10% of the rock by volume, and exhibits distinctive light-yellow to red-brown pleochroism. It occurs in laths, 0.05 to 0.1 millimetre long, disseminated throughout the quartz-feldspar matrix, and interlayered with the graphite. Muscovite occurs in amounts of 2% to 4%. It is associated with quartz and is also interlayered with the graphite. It forms laths and can be up to 0.5 millimetre long.

The clinopyroxene, augite, is biaxial positive, occurs as short, stubby laths, and comprises from 1% to 20% by volume of the rock. It is dispersed through the non-foliated, equigranular, quartz-feldspar bands or in the material interstitial to the bands comprised of the large quartz grains. The augite has been altered in part to chlorite and in places to a colourless amphibole (tremolite).

Silliminite is present in two thin sections as skeletal grains and needles. In the one thin section, it occurs as skeletal crystals, approximately 0.05 millimetres long, selectively in a band three to four millimetres wide containing plagioclase, up to 45% biotite, and no graphite. The graphitic band, approximately the same width, contains at least 60% quartz, plus graphite, plagioclase and biotite, but no silliminite (figure 7.3). In the other thin section sillimanite occurs as needles less than 0.05 millimetres long, associated with muscovite, and constitutes 5% of the rock by volume. Scapolite, in grains less than 0.05 millimetres in diameter, and in amounts less than 2%, was observed interstitial to polygonal quartz grains in one section. Apatite, in small round grains, occurs throughout in concentrations close to 1%.

The graphite, in amounts up to 10% by volume, occurs disseminated throughout the quartz-rich parts of the rock. Areas rich in iron oxide stain and ilmenite tend to have more graphite. Flakes can be anywhere from 0.05 to 1.5 millimetres in diameter, usually reflecting the size of the surrounding minerals. The flakes delineate the foliation. When the rock consists of fine-grained and coarse-grained bands of quartz-feldspar, the graphite occurs in the fine-grained bands but penetrates into the coarse-grained bands at the contact.

There are some differences between this unit and the analagous one in Butt Township: there are no garnets in this unit, but there are other high alumina minerals, such as silliminite and scapolite. There is more clinopyroxene, and both the pyroxene and the plagioclase are more intensely altered. Mica consists of well developed muscovite as well as biotite. The similarities between the units are the type and

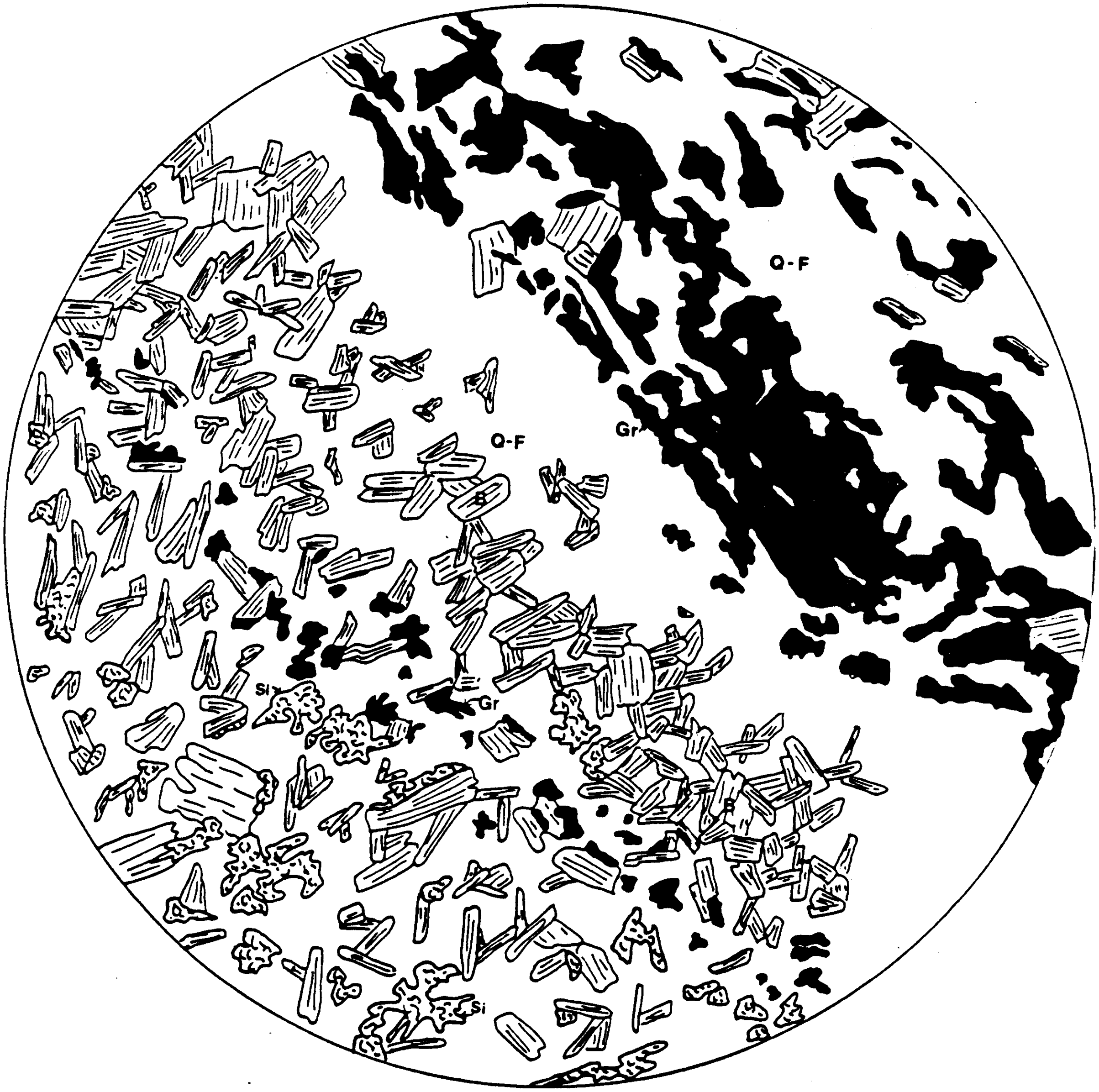


Figure 7.3: Sketch of a photomicrograph showing the bands with sillimanite, biotite, graphite. Sample: 83-10-6, Laurier Township. Diameter: 5 mm. Si-sillimanite, B-biotite, Gr-graphite, Q-F-quartz-feldspar background.

amount of quartz and feldspar, and the grain size variation of the quartz. There is fracturing and iron oxide stain in the fractures and surrounding mineral grains, and the graphite and biotite tend to concentrate with the iron oxides. In both units the graphite occurs with the equigranular quartz-feldspar, and is interlayered with the biotite and muscovite.

In both units there is evidence of fracturing which occurred after the high-grade metamorphic mineral assemblage was established. There is also evidence for alteration of some of the minerals from this assemblage, particularly the plagioclase and the pyroxene, but in Laurier Township the plagioclase has been deformed subsequent to alteration, and in fact the two events could have progressed in part simultaneously.

7.1.3 Maria Township

The graphitic unit in Maria Township is a quartz-feldspar-biotite-garnet gneiss, with a tendency to be schistose rather than gneissic. Quartz occurs in amounts varying from 45% to almost 80%. As in the graphitic units in the other two townships, the quartz occurs in two sizes: large fractured and moderately strained grains, up to three millimetres in diameter, and in finer polygonal grains comprising most of the rock. The larger grains show a tendency to form rods, and the smaller grains, especially those interstitial to the large quartz grains, are ragged and disaggregated, having a crushed appearance.

Feldspar consists of both microcline and a sodic plagioclase. Microcline is the more abundant phase, approaching 40% by volume. It forms large grains, from 1 to 2 millimetres in size, and displays prominent tartan twinning with only minor patches of kaolinitic alteration. The microcline may carry small round inclusions of quartz and may have myrmekitic intergrowths near the margins. Plagioclase feldspar occurs in amounts from 5% to 10%, in grains up to one millimetre in size. It exhibits abundant albite twinning and has negative relief next to quartz, indicating a sodic compostition. The plagioclase shows some alteration to kaolinite and flaky sericite.

Biotite, length slow, has pale yellow to red-brown pleochroism, and straight extinction. It occurs in amounts from 1% to 8%, as stubby laths approximately one millimetre long. Graphite is interlayered with the biotite, but not to the same extent as in the other townships. Biotite is associated with the iron oxides in fractures.

Tremolite, colourless, length-slow on prismatic pieces, with a diffuse biaxial negative figure, occurs in large ragged crystals up to 5 millimetres long by 1 millimetre wide. It is not uniformly distributed, but occurs in clumps of radiating crystals, and contains quartz inclusions (figure 7.4).

Augite occurs in small grains, 0.1 to 0.3 millimetres in diameter disseminated throughout the matrix. Sphene occurs as small grains from 0.05 to 0.1 millimetres in size. Interference figures are difficult to obtain due to the extreme relief and dark colour, but the sphene appears to be biaxial positive. The small ovoid grains occur with the biotite and the graphite as well as separately. Iron oxides, ilmenite and goethite, fill fractures and form veinlets parallel to the foliation.

Graphite occurs in concentrations up to 5% by volume, in laths which are actually flakes with perfect basal cleavage. The maximum size is 2.5 millimetres by 0.08 millimetres. The flakes may bifurcate or show kinking. Graphite occurs disseminated throughout the rock and has a tendency to concentrate in fractures with biotite and the iron oxides. There is some interlayering with the biotite but not to the same extent as in the other townships.

7.1.4 Ryerson Township

The graphitic unit in Ryerson Township, labelled 1f on

Figure 7.4: Sketch of a photomicrograph showing the large tremolite crystals. Sample: 1025-7d, Maria Township. Diameter: 5 mm.
T-tremolite, P-plagioclase, M-microcline, Q-quartz, B-biotite, Gr-graphite, S-sphene.

Map 6, is a quartz-feldspar-biotite schist. This was the only unit from this occurrence studied petrographically. Quartz, 45% of the rock, occurs in two forms: as large anhedral grains up to 5 millimetres long exhibiting variable strained extinction, and as smaller inclusions within large microcline crystals. The inclusions do not exhibit the strained extinction.

Feldspar consists of both microcline and a sodic plagioclase. Microcline is the more abundant feldspar, comprising approximately 40% of the rock, and occurs in very large, fresh, tartan-twinned crystals up to 7 millimetres in diameter, with quartz inclusions. The plagioclase feldspar occurs in grains up to 3 millimetres in diameter, in amounts up to 10%. It has abundant albite twinning and lower relief than quartz, and appears to be An20 to An30 in composition. There is minor kaolinitic and sericitic alteration.

Biotite occurs in laths up to 1.5 millimetres long and exhibits dark brown pleochroism. It occurs in amounts up to 10% interlayered with the graphite. Muscovite occurs in trace amounts intergrown with the biotite.

Graphite occurs as thin flakes in amounts up to 10% by volume, but on average 3% to 5%. Maximum flake size is 1.4 by 0.07 millimetres. The graphite can exhibit aspect ratios of 25:1 in the plane of the section. It occurs disseminated throughout the quartz-feldspar matrix, but not in the coarse-grained quartz-feldspar lenses.

Accessory minerals consist of both iron oxides, mostly magnetite, the iron sulphides pyrite and chalcopyrite, and sphene.

7.2 CARBON ISOTOPES

Early work on carbon isotopes concluded that there is considerable variation in the stable isotopes 12C and 13C from carbon of various sources (Nier and Gulbransen 1939, Gavelin 1957). Since then, researchers have been working to acquire data to enable them to distinguish the origin of carbon on the basis of its isotopic composition. Organic carbon is isotopically light, being richer in 12C; and carbonate carbon tends to be isotopically heavier, being richer in 13C. Problems arise when organic carbon and carbonate carbon coexist: the two isotopes equilibrate between coexisting species with increasing temperature (Weis 1981, Kreulen and van Beek 1983, Chukhrov et al. 1983). The formation of graphite requires temperatures high enough to allow this equilibration (Chukhrov et al. 1983, Kreulen and van Beek 1983). Only if there is no carbonate component associated with the graphite will the carbon isotopes of the graphite reflect the isotopes of the original carbon (Weis 1981). Organic carbon, as documented in coal, petroleum and graphite has d13C values between -15 and -35 (Barnes 1979, Nier and Gulbransen 1939). It has also been shown that the biological enrichment of 12C is due to photosynthetic fractionation and has been virtually constant since the Precambrian (Eichmann and Schidlowski 1975, McKirdy and Powell 1974, Nagy et al. 1974, Hoefs and Schidlowski 1967).

Two samples, one from each of the Butt Township and Maria Township occurrences, were submitted to the Environmental Isotope Laboratory at the University of Waterloo. These have d13C values of -25.9 per mil for the Butt Township sample; -15.58 per mil for the Maria Township sample. The results fall into the range of carbon isotope values for carbon from an organic source. More results are required prior to drawing any definitive conclusions regarding the source of the carbon, and it would be interesting to have carbon isotopes from the vein in Laurier Township in order to compare the carbon isotopic composition to that of the flake graphite.

7.3 NEUTRON ACTIVATION

Neutron activation, at the Slowpoke reactor at the University of Toronto (U of T), was the method used to analyze

21 samples for rare earth (REE) and trace elements. This work forms the backbone of the author's Master's thesis with the University, and the interested reader is referred to this work for more detail pertaining to the neutron activation (INAA) analyses. The procedure for sample preparation and counting is documented in Wilson and Garland (1987). The 21 samples are listed in Table III.

TABLE III. Samples submitted for INAA

SAMPLE NUMBER	LOCATION	DESCRIPTION
1025-3bg	Maria	graphite
1025-3bs	Maria	sediments
1025-3br	Maria	whole rock
1025-9	Maria	graphite
RY-ACK	Ryerson	graphite
Ry-1g	Ryerson	graphite
Ry-1s	Ryerson	sediments
Ry-1r	Ryerson	whole rock
85-B6	Butt	graphite
85-B1g	Butt	graphite
85-B1s	Butt	sediments
83-10-2g	Laurier	graphite
83-10-2s	Laurier	sediments
83-10-7g	Laurier	graphite
83-10-5	Laurier	graphite
UTB-1	U of T	standard
83-10-4	Laurier	graphite
B-1-16	Butt	graphite
1025-7d-16	Maria	graphite
1025-7d-8	Maria	graphite
1025-6a-8	Maria	graphite

The designations "graphite" "sediments" and "whole rock" refer to the part of the separated material that was used as the sample. "Graphite" refers to the graphite separated from the ground rock, "sediment" refers to the fraction left after the graphite was removed, and "whole rock" refers to the crushed rock itself. For those samples from Butt and Laurier townships, the sample locations are plotted of the geology maps in the back pocket. The samples from Maria Township are from the original trenches, which have been obliterated by the new access road. Sample RY-ACK is from the northwestern graphite occurrence in Ryerson Township, and sample Ry-1 is a grab sample from the long trench on the southeastern occurrence in Ryerson Township.

In each township the samples are from the graphitic horizon, which is a quartz-rich metasediment. The final geochemical signature of a metasediment is affected by the erosion and transport of the original material, deposition and diagenesis, and metamorphism of the original sediment (Sawyer 1986). Previous studies of REE/chondrite plots of sediments of various ages and origins have indicated that mixing and sorting of the clastic components of the sediments, rather than complex interactions with the hydrosphere, are the dominant mechanisms responsible for the observed REE patterns (Nance and Taylor 1976). Transport of the REE is mechanical rather than chemical (Taylor and McLennan 1985), particularly via minerals that concentrate the REE but resist weathering. Sediments with higher quartz, feldspar, and heavy mineral components are enriched in the light rare earth elements (LREE) relative to the finer grained, clay-rich metapelites, which are enriched in the heavy rare earth elements (HREE)

(Sawyer 1986). It has also been noted that diagenesis and metamorphism appear to have little effect on the fractionation of the REE of the sediment (Nance and Taylor 1976).

Most REE data is presented as a plot of the chondrite-normalized rock to the element in question. Piper (1974) recognized that using a chondrite standard to normalize sediments with REE concentrations extremely different from those of chondrites precludes any comparison of REE patterns in different sediments. He found that picking a standard with REE concentrations similar to the sample yielded more coherent data. For purpose of comparison, chondrite-normalized plots of REE patterns for Archean greywackes and Recent sands are included and displayed in figure 7.5. The major difference between the REE patterns of the Archean and the younger sediments is the lack of the negative europium anomaly in the Archean samples. This is thought to be the result of a higher component of volcanogenic, particularly andesitic, debris in the Archean greywackes (Taylor and McLennan 1985).

The REE results for the samples analysed in this study are listed in Table IV. The samples from each of the four occurrences, the graphite and sediment separates from all the occurrences, and the four samples from the Maria and Butt township occurrences analysed run in the first of the two batches are displayed as chondrite-normalized plots using

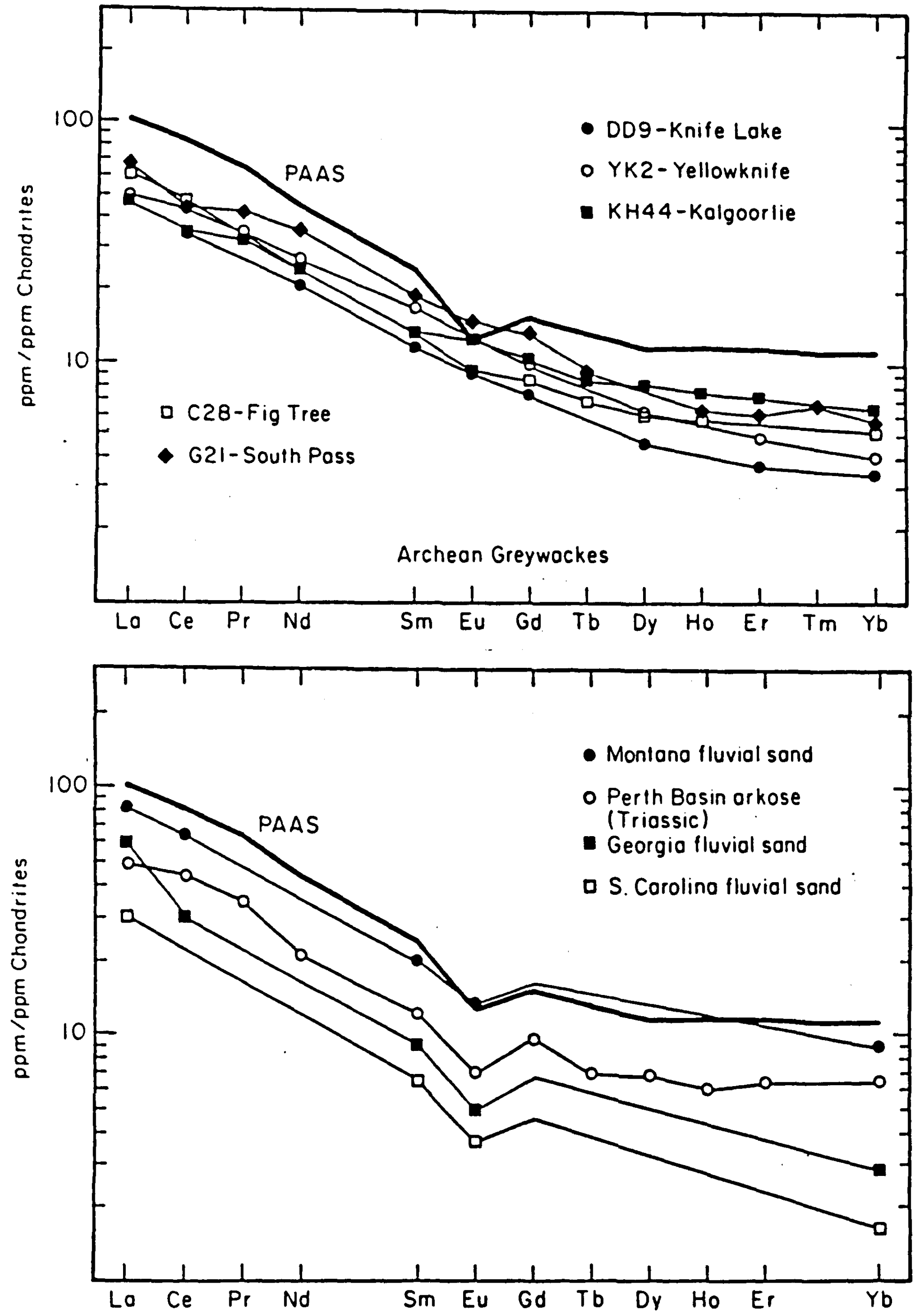


Figure 7.5: Chondrite-normalized REE plot of selected Archean greywackes and Holocene river sands. (From: Taylor and McLennan 1985)

chondrite values of Taylor and Gorton (1977) (figures 7.6 to 7.10). The two samples consisting of the rock, plus sediment and graphite separates were plotted using the REE concentrations in the rock as a standard, as suggested by the work of Piper (1974) (figure 7.11).

The samples were activated in two batches. The first or preliminary run consisted of 4 graphite separates, 1 from Butt Township and 3 from Maria Township. The results are displayed as chondrite-normalized REE plots in figure 7.6. A moderate LREE enrichment in the sample suite is apparent on the upper plot in Figure 7.6. The La/Yb ratio averages 17, somewhat more fracyionated than the 12 mean value for shales (Piper 1974). The patterns are similar to those for Archean greywackes with two major differences: in two samples, there is a cerium value just over 100 times that of chondrite, and the overall values, LREE to HREE, are 10 to 2 times chondrite as opposed to 100 to 10 for the Archean greywackes. These samples are graphite separates: two samples (1025-7d) are different size fractions of the same separate. The lower plot in Figure 7.6 depicts just the Maria samples. The two size fractions from the same sample give identical plots, both with the Ce anomaly. This high value for Ce will be discussed further in the section.

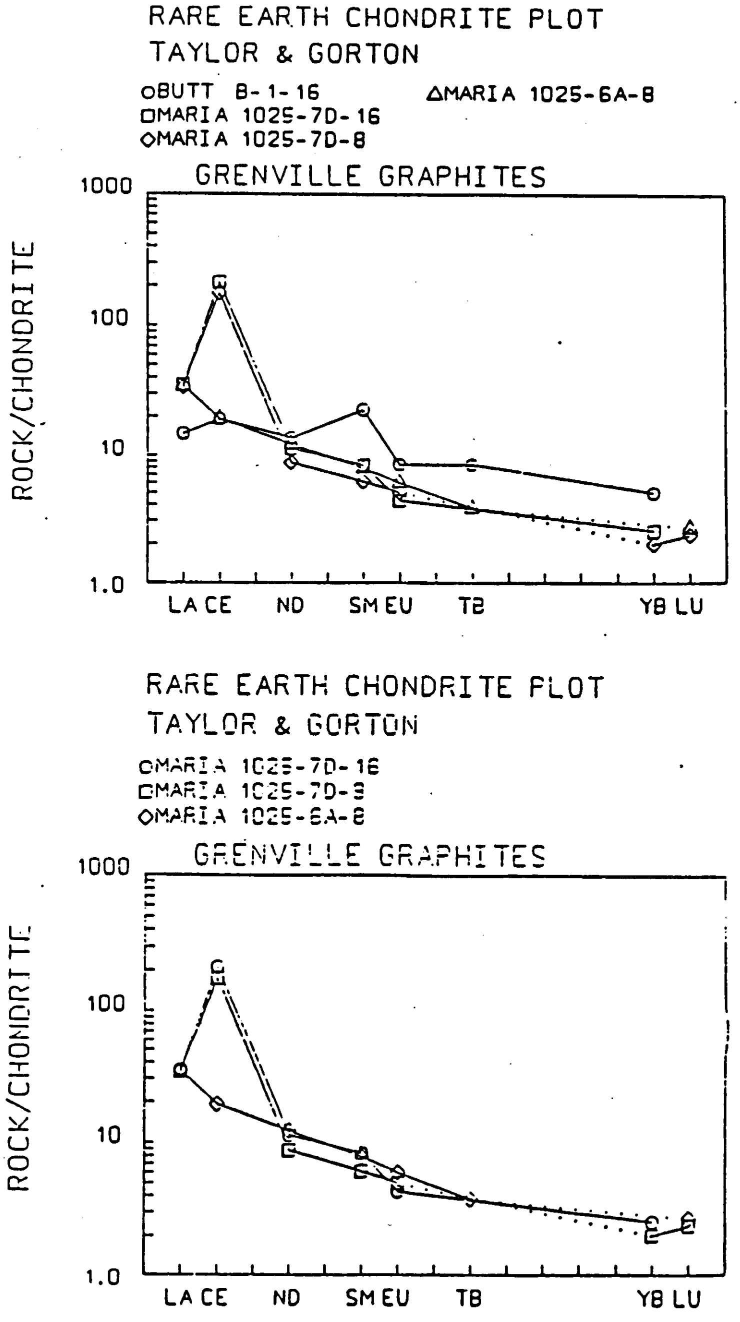


Figure 7.6: The upper plot depicts the four analysed graphite samples from the first suite. The lower plot contrasts the samples from Maria Township.

TABLE IV: INAA DATA FOR 18 SAMPLES OF GRENVILLE GRAPHITES (concentrations in ppm)

```
ASCII DUMP   INAA DATA FOR GRENVILLE GRAPHITES                      PAGE  1
NSAMPL = 18    NELEMT = 15    VERFIL = 1.00         C. DATE = 5-Apr-87
                                         SAMPLE NUMBER

ELEMENT                  1           2           3           4           5
---------------------------------------------------------------------------

LA                   9.010      16.990      19.330      22.400      25.050
CE                  17.320      39.610      40.950      33.410      48.290
ND                   6.660      17.630      18.670      12.990      20.430
SM                   1.230       3.310       3.530       2.110       3.660
EU                   0.180       0.590       0.810       0.580       0.780
TB                   0.170       0.550       0.420       0.290       0.330
YB                   0.330       1.220       1.200       0.830       1.430
LU                   0.080       0.220       0.240       0.170       0.260

---------------------------------------------------------------------------

SAMPLE  1      253bg
SAMPLE  2      253bs
SAMPLE  3      253br
SAMPLE  4      ry1g
SAMPLE  5      ry1s

ASCII DUMP - INAA DATA FOR GRENVILLE GRAPHITES
NSAMPL = 18    NELEMT = 15    VERFIL = 1.00         C. DATE = 5-Apr-87
                                         SAMPLE NUMBER

ELEMENT                  6           7           8           9          10
---------------------------------------------------------------------------

LA                  58.200      33.370      27.840       4.510       5.220
CE                 139.350      72.400      55.840       8.810       7.390
ND                  70.300      23.600      27.350       3.410       4.540
SM                  12.790       2.800       4.540       1.160       1.280
EU                   2.130       0.690       1.850       0.270       0.330
TB                   1.360      n.a.         0.710       0.180       0.220
YB                   4.730       0.620       1.850       1.100       1.510
LU                   0.820       0.130       0.320       0.220       0.660

---------------------------------------------------------------------------

SAMPLE  6      ry1r
SAMPLE  7      85b1g
SAMPLE  8      85b1s
SAMPLE  9      83102g
SAMPLE 10      83102s
                                         SAMPLE NUMBER

ELEMENT                 11          12          13          14          15
---------------------------------------------------------------------------

LA                   6.210      15.780      11.080      21.470       4.260
CE                  12.200      31.270      18.950      49.950       9.710
ND                   4.580      16.050       7.320      19.720       2.920
SM                   1.110       3.140       1.360       4.160       0.760
EU                   0.420       0.350       0.190       1.100       0.300
TB                   0.140       0.370       0.200       0.920       0.190
YB                   0.420       1.140       0.990       2.690       2.300
LU                   0.120       0.240       0.220       0.450       0.430

---------------------------------------------------------------------------

SAMPLE 11      10259
SAMPLE 12      ryack
SAMPLE 13      85b6
SAMPLE 14      83107g
SAMPLE 15      83105g

ASCII DUMP - INAA DATA FOR GRENVILLE GRAPHITES                      PAGE  4
NSAMPL = 18    NELEMT = 15    VERFIL = 1.00         C. DATE = 5-Apr-87
                                         SAMPLE NUMBER

ELEMENT                 16          17          18
---------------------------------------------------------------------------

LA                  38.510      25.190      26.550
CE                  70.440      58.540      61.440
ND                  36.940      32.090      34.190
SM                   6.860       7.580       7.930
EU                   1.750       2.300       2.510
TB                   0.910       1.090       1.170
YB                   4.010       3.980       4.110
LU                   0.770       0.540       0.620

---------------------------------------------------------------------------

SAMPLE 16      83104g
SAMPLE 17      utb1/1
SAMPLE 18      utb1/2
---------------------------------------------------------------------------
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The second set of samples analysed included all other samples in Table III. Figure 7.7 depicts the results for samples from the Butt Township occurrence. Samples 85b6 and 85b1g are graphite separates, and sample 85b1s is the sediment remains. The patterns are similar to those of Archean greywackes, except for the Eu depletion in the pattern for 85b6. This could be due to the amount of mica, which is Eu deficient, with the graphite. The results of analyses of samples from Laurier Township are depicted in figure 7.8. Samples 83-10-5g and 83-10-7g are from two places on the graphite vein, 83-10-5g and 83-10-2g are graphite separates from unit 1b, and 83-10-2s is the sediment remains from sample 83-10-2g. The patterns form two groupings with the concentration of the LREE significantly higher for samples 83-10-4g and 83-10-7g. The samples of the less rich-LREE group are chloritized, which could have affected the LREE. Analyses of samples from the Ryerson Township occurrences are shown in figure 7.9. This suite contains a pattern for the rock as well as the separates, and it is interesting to note that the REE pattern for the rock (sample RY-1r) is similar to, but higher than, that of the graphite and sediment separates (Ry-1g and Ry-1s). A slight negative europium anomaly is visible for samples Ry-1r and Ry-1s, and also for RYACK, a graphite separate, and may be a reflection of the mica content of the graphite. The samples from Maria Township, in figure 7.10, consist of the graphite and sediment separates, plus the rock of 1025-3b and the graphite separate of 1025-9. The patterns for the rock and sediment of 1025-3b (253br, 253bs) mimic each other, as does the pattern for the graphite separate (253bg), but with lower concentrations. All three show a negative europium anomaly. The pattern for the graphite separate from 1025-9 is in the same concentration range as that of 253bg, but has a slightly positive europium anomaly.

The graphite and sediment separates from the two samples with REE data for the rock, Ry-1 and 1025-3b, were normalized with respect to the rock. This allows interpretation of the REE concentrations within the separates as compared to the concentrations within the parent rock. The patterns for Ry-1 and 253b (figure 7.11) show that the sediment separates generally have higher concentrations than the graphite separates, and both usually have lower concentrations than the rock. The graphite separate for Ry-1 is low in most of the REE, except europium, which may be due to feldspar trapped in the flakes.

The preliminary conclusions for the REE study of the graphitic units are:

1. The REE patterns of sediment separates and whole rocks resemble those of Archean greywackes as published by Nance and Taylor (1976) and Taylor and McLennan (1985).

2. The REE patterns of the graphite separates also resemble

those of Archean greywackes, but exhibit lower overall concentrations.

3. The occasional anomalous results, such as the high cerium anomaly for sample 1025-7d and the fluctuating europium anomalies, are thought to be due to the difficulty in obtaining pure graphite separates. The contaminant minerals mixed with the graphite yield patterns characteristic of themselves. For example, the Maria samples have several percent sphene (as determined by petrography), and any sphene caught in the graphite would cause a higher than normal cerium value (Taylor and McLennan 1985).

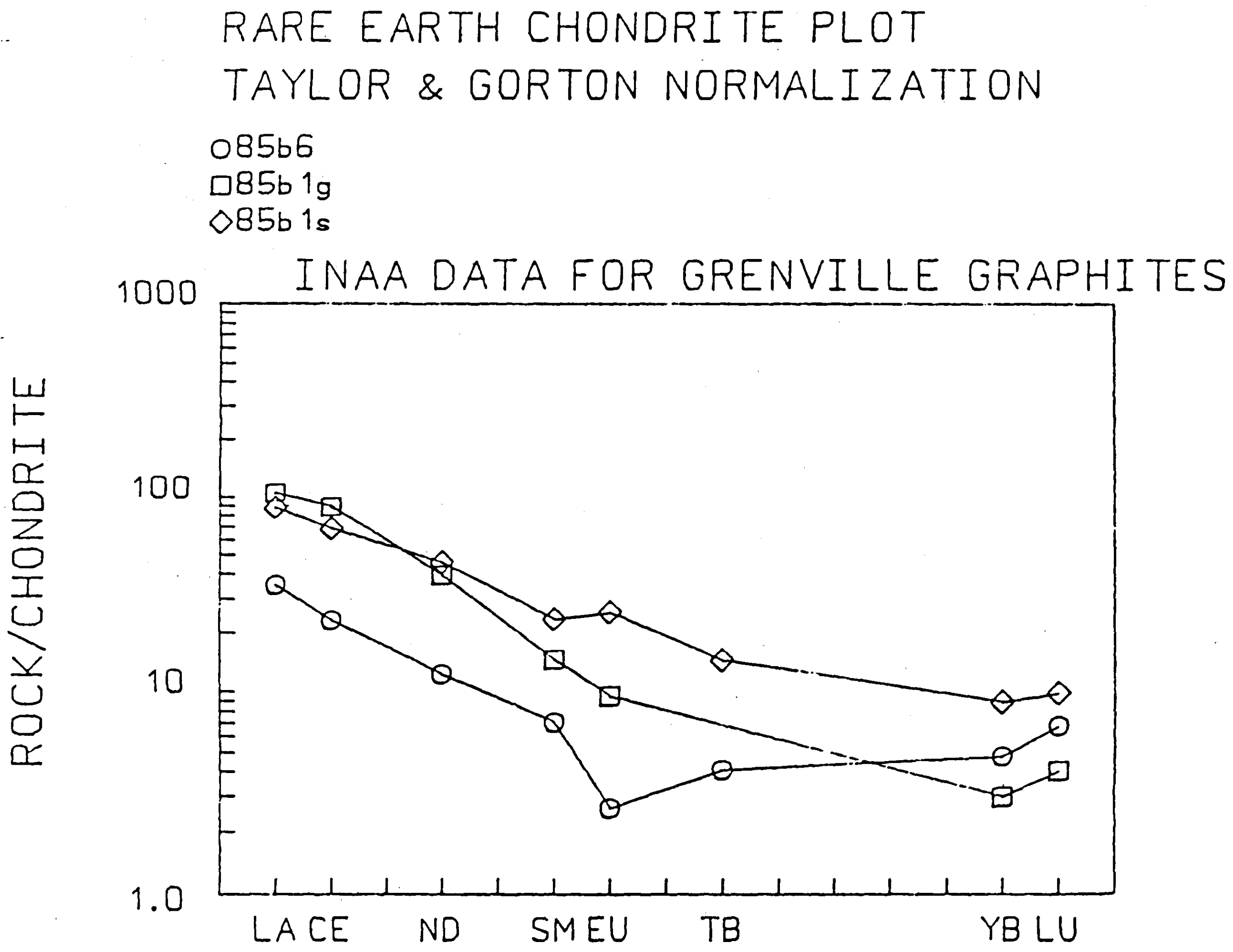

Figure 7.7: Chondrite normalized REE plot of the samples from Butt Township.

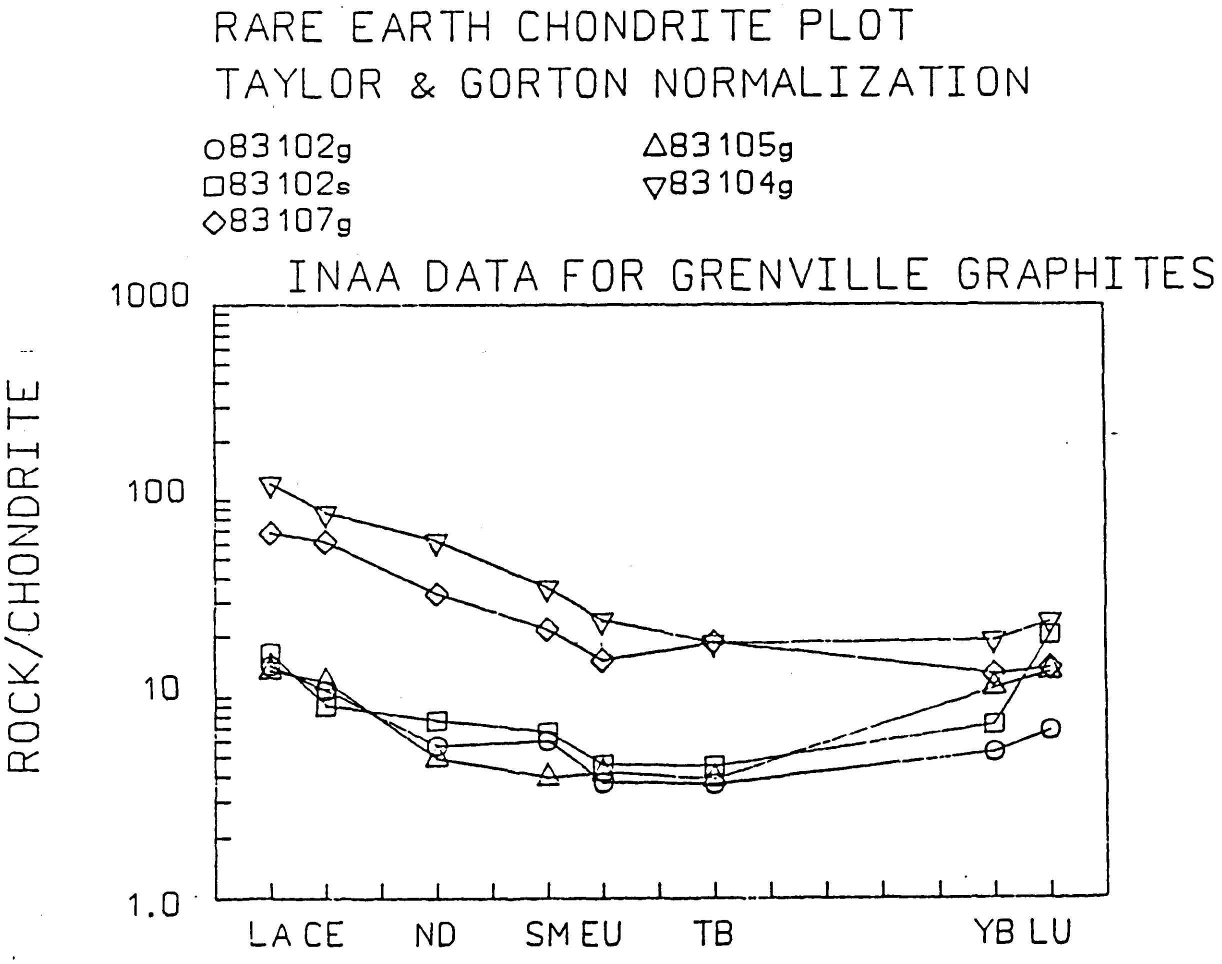

Figure 7.8: Chondrite normalized REE plot for the samples from Laurier Township.

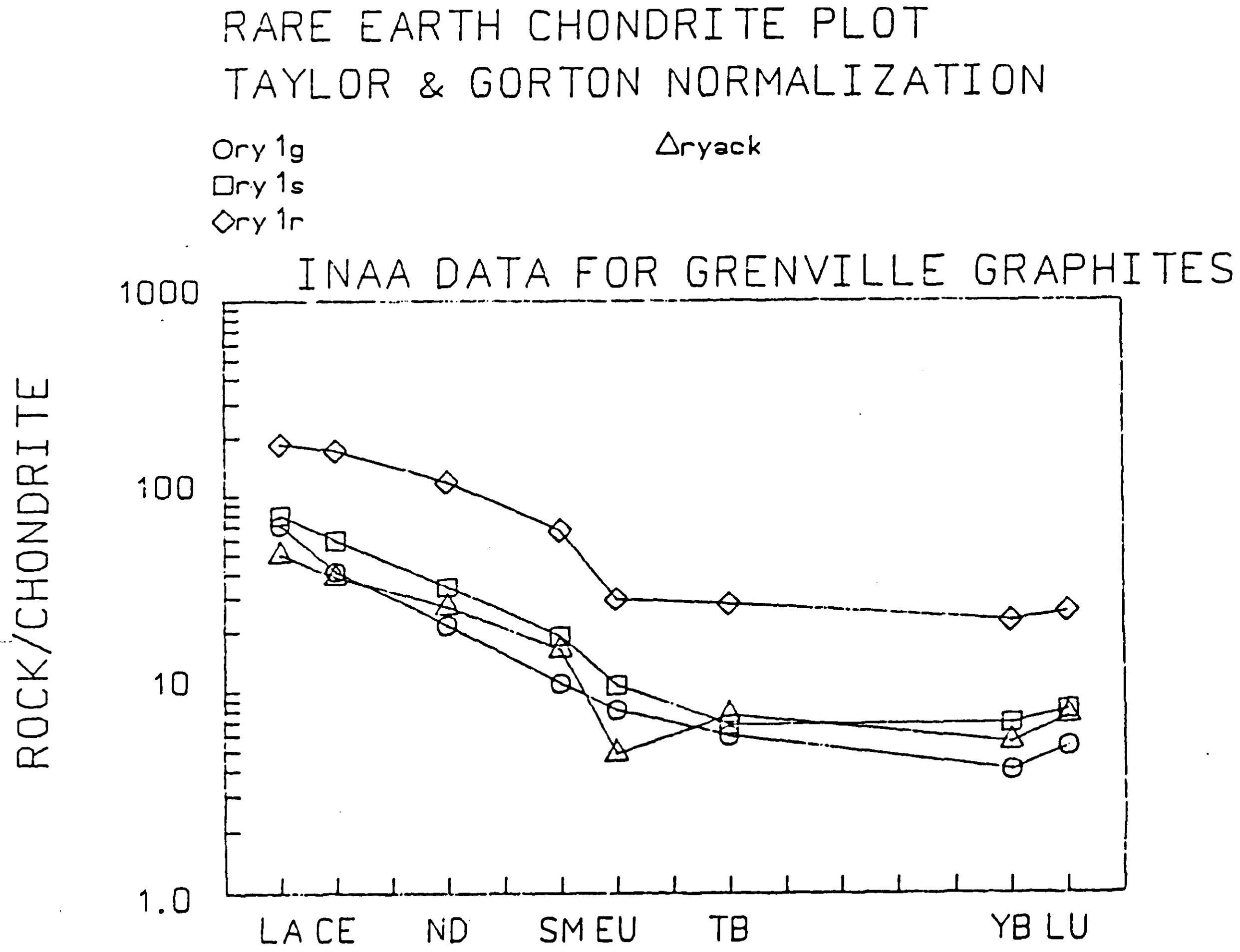

Figure 7.9: Chondrite normalized REE plot for the samples from Ryerson Township.

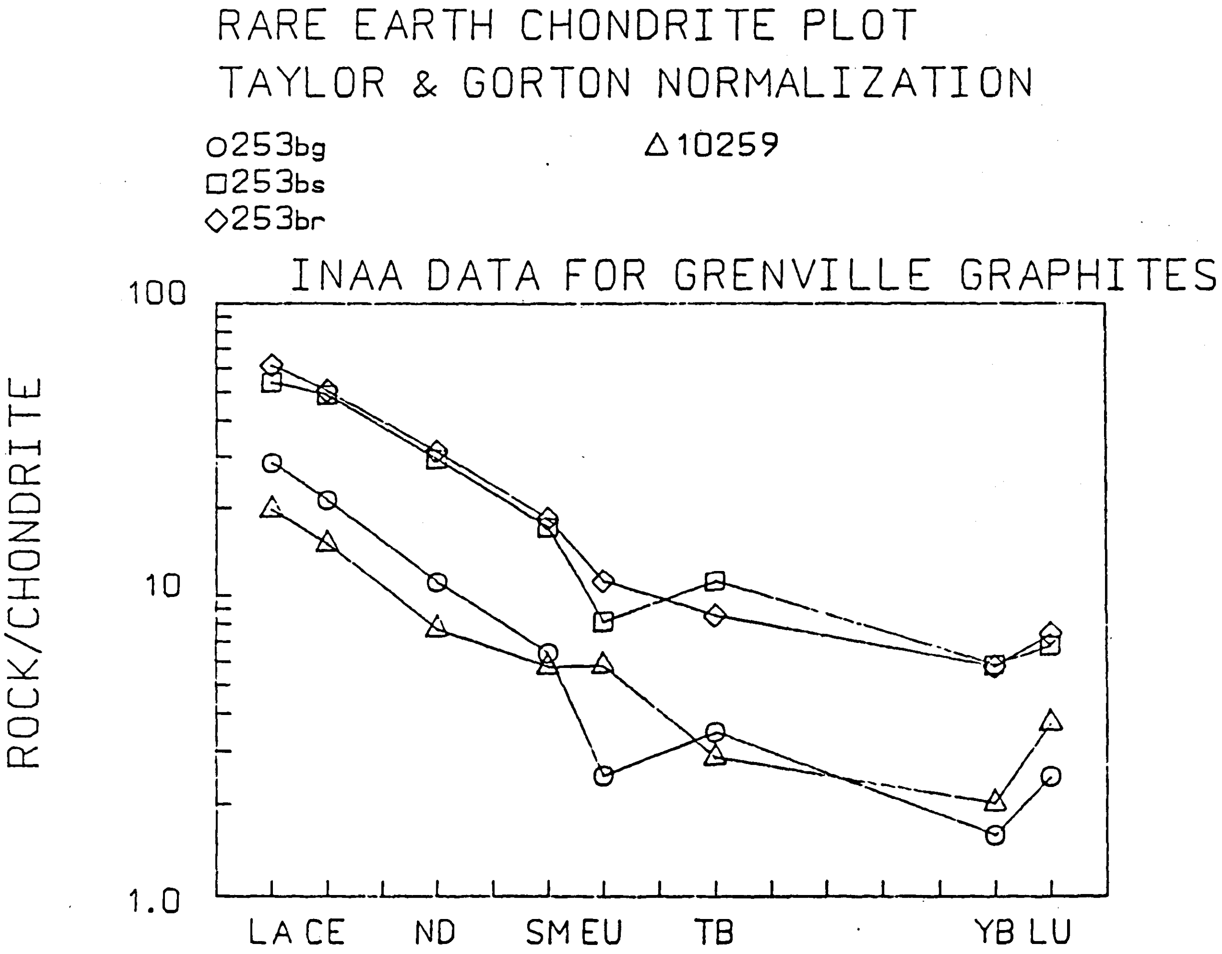

Figure 7.10: Chondrite normalized REE plot for the samples from Maria Township.

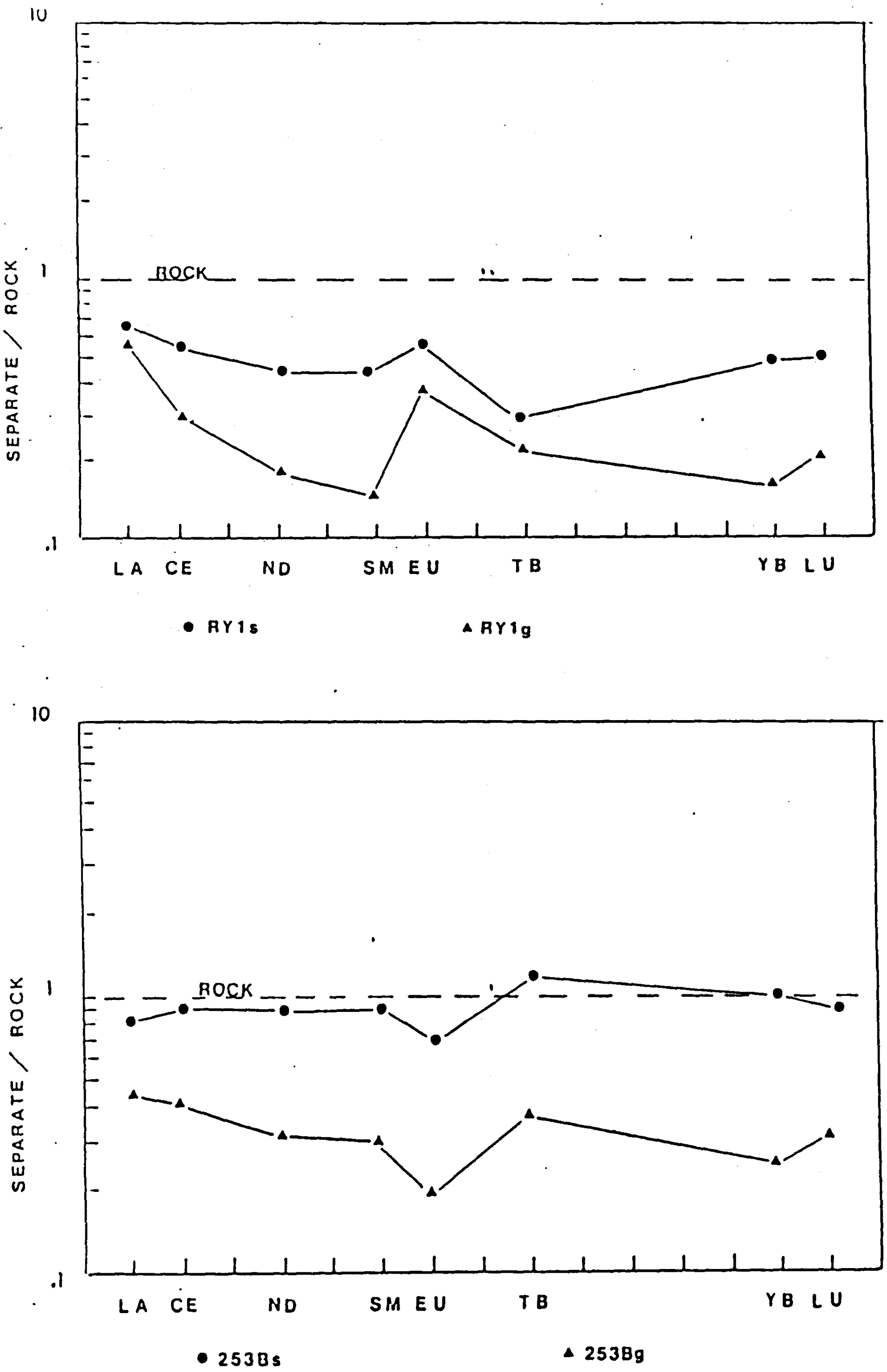

Figure 7.11: Parent rock normalized REE plots for samples 253b and Ry-1.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

1. The graphite is of the crystalline flake type, occurring as discrete flakes disseminated throughout a quartz-feldspar metasediment. The average amount of graphite varies from 2% to 4% by weight in the areas currently undergoing exploration. The size of the flakes ranges from 0.5 to 1.5 millimetres. In one occurrence, in Laurier Township, the graphite also occurs in a vein, and consists of graphite flakes in the same size range as the disseminated flake. The origin of the vein is still unknown.

2. Graphite concentrates from Ryerson, Maria and Butt townships, separated by flotation methods, have yielded size fractions and carbon contents acceptable to the graphite industry.

3. The host rock to the graphite is in each occurrence a quartz-feldspar schist, grading in one to a gneiss. The graphite-bearing units in Butt Township consist of a quartzite and a quartz-feldspar-biotite-garnet schist. In Laurier Township the graphitic unit is a quartz-biotite-muscovite schist, in Ryerson Township it is a quartz-feldspar-biotite schist, and in Maria Township it is a quartz-feldspar-biotite-garnet gneiss. In outcrop the units appear similar in colour and texture; it is in thin section that differences are apparent. These differences probably represent subtle

differences in original mineralogy and in metamorphism.

4. The graphitic units have undergone extensive ductile metamorphism in both Butt and Ryerson townships. This feature was not observed in Laurier or Maria townships, but this could be due to the poor outcrop exposure.

5. The graphitic units all occur in stack one of Davidson's (1981-1986) interpretation of the CGB. Graphite occurs associated with marble units in the Parry Sound Domain of stack two, but the siliceous measedimentary occurrences are restricted to stack one, and occur in every domain of stack one. There is a distinct possibility that the many small graphite occurrences are actually part of the same metasedimentary unit, especially if the unit has undergone stretching and thinning associated with ductile deformation.

6. The carbon isotopes are similar to those from other biogenic carbon.

7. The REE patterns of the graphite separates mimic those of the parent rock and the associated sediment separates. The REE patterns of the vein graphite are not significantly different. The parent rock patterns are typical of Archean greywackes. It is also apparent that any detrital mineral caught in with the graphite will influence the pattern. The trace element and base metal results are prelimimary only, and are for interest. They do indicate that the graphite does attract these elements, and there appears to be potential for graphite as an accumulating agent.

8. The disseminated nature of the graphite, the

restriction of the graphite to a quartz-rich metasediment, the restriction of this quartz-rich, graphitic metasedimentary unit to one of the thrusts sheets, the light carbon isotopes, and the REE patterns similar to greywacke patterns all indicate that the graphite has formed in place from organic debris originally deposited with the sediments. There has been minor mobilization as seen by graphite accumlations in fold noses and in pegmatite margins, but there is no evidence for large scale mobilization.

8.2 RECOMMENDATIONS

1. The graphite deposits in the CGB are potentially economic but require very careful marketing. Traditional ties between existing producers and buyers are difficult to overcome. It is recommended that a potential producer identify a market prior to developmental stages of a deposit.

2. The geology of graphite occurrences in the CGB is more complex than is often evident. Careful mapping and sampling are necessary to understand the deposit, and to alleviate future costs.

3. The mineralogy of the graphite requires consideration when trying to separate and refine the concentrate. Graphite is relatively easy to separate but difficult to refine further without damage to the flake and consequent reduced quality.

4. Exploration on a broad scale in the CGB will benefit from the work by Davidson et al (1981-1986). The horizons

which can be graphitic are restricted in occurrence and appear to be contiuous for several kilometres along strike. Further work incorporating the many small occurrences along these horizons may reveal graphite deposits of the same scale as those currently undergoing exploration.

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APPENDIX I

REPORT ON TRIP TO VESUVIUS CRUCIBLE

OCTOBER 29-31, 1984

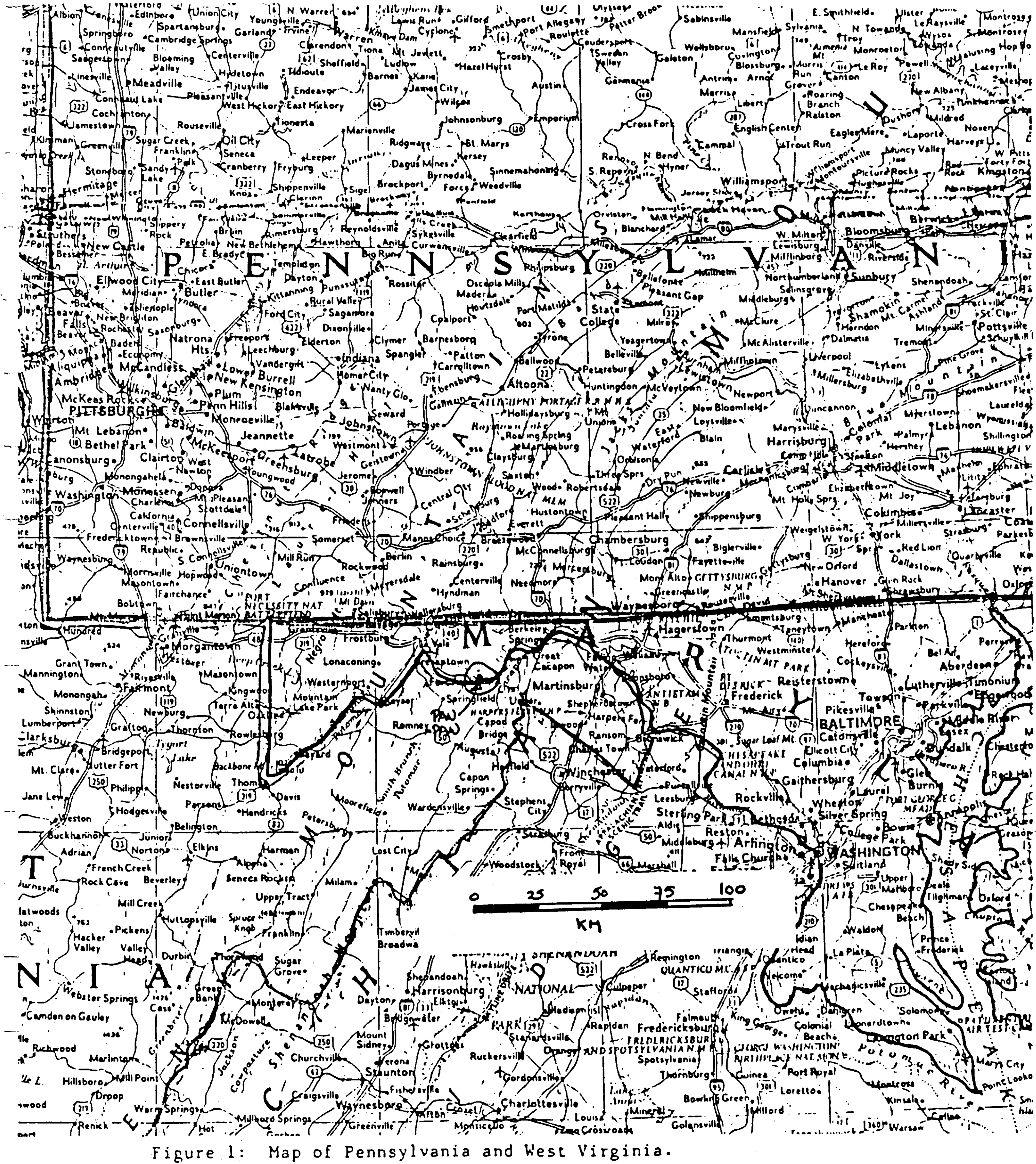


Figure 1: Map of Pennsylvania and West Virginia.

COMPANY HISTORY:

Vesuvius Crucible originated at the turn of the century as a manufacturer of graphite crucibles. The company started with one plant in Swissvale near Pittsburgh, Pennsylvania (Figure 1). Graphite imported from Madagascar was the chief source of carbon. After the first World War graphite mined locally from Alabama and Texas was used, and the company expanded to include plants in West Virginia, Illinois, Belgium, Germany, Scotland and Italy. The company now has a research facility and participates actively in engineering new designs and mixes for crucibles and refractory products.

PURPOSE OF M.N.R. TRIP:

Since the Algonquin Region is currently working on a graphite project to promote Ontario graphite it is important to understand the graphite market in North America: who the potential buyers are and what they want in a graphite property and what the requirements are for flake graphite. Since our office had been in communication with Vesuvius Crucible due to their involvement with the Butt Township graphite, Vesuvius extended an invitation to visit their Paw Paw, West Virginia plant to see how they used graphite.

OUTLINE OF VISIT:

Paw Paw, West Virginia, population approximately 1,000, is situated on the Potomac River in the apple growing part of the central Appalachians (Plate 1). The terrain is rugged consisting of hardwood forested hills to 3,000 feet ASL, with the apple orchards planted along the sides of the hills (Plates 2 and 3). Before Vesuvius Crucible, the main industry in Paw Paw was the apple packing plant and the tanning factory. The apple plant is still going strong; Vesuvius Crucible have taken over the old tanning factory buildings. The graphite plant consists of the two large buildings from the original factory where the graphite products are made, a new warehouse building, a laboratory and an office trailer (Plate 4). The plant is connected directly to the main rail line by a siding, and to the interstate highway system via good all weather roads (Plate 5)

Plate 1: Potomac River, West Virginia.

Plate 2: Eastern view towards the Central Appalachians.

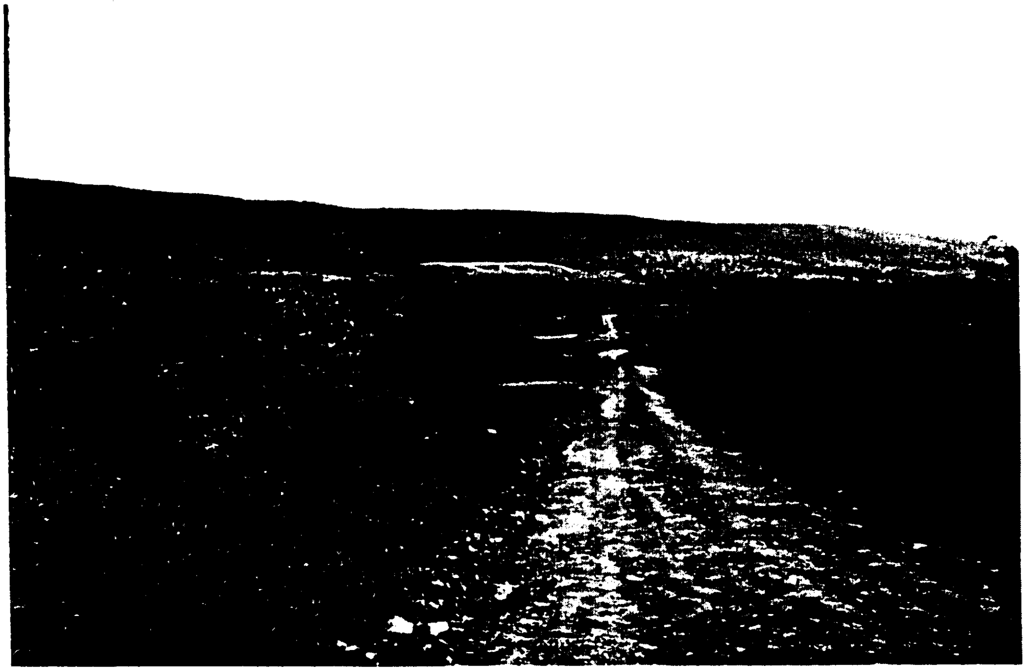


Plate 3: Apple orchards in the Appalachians.

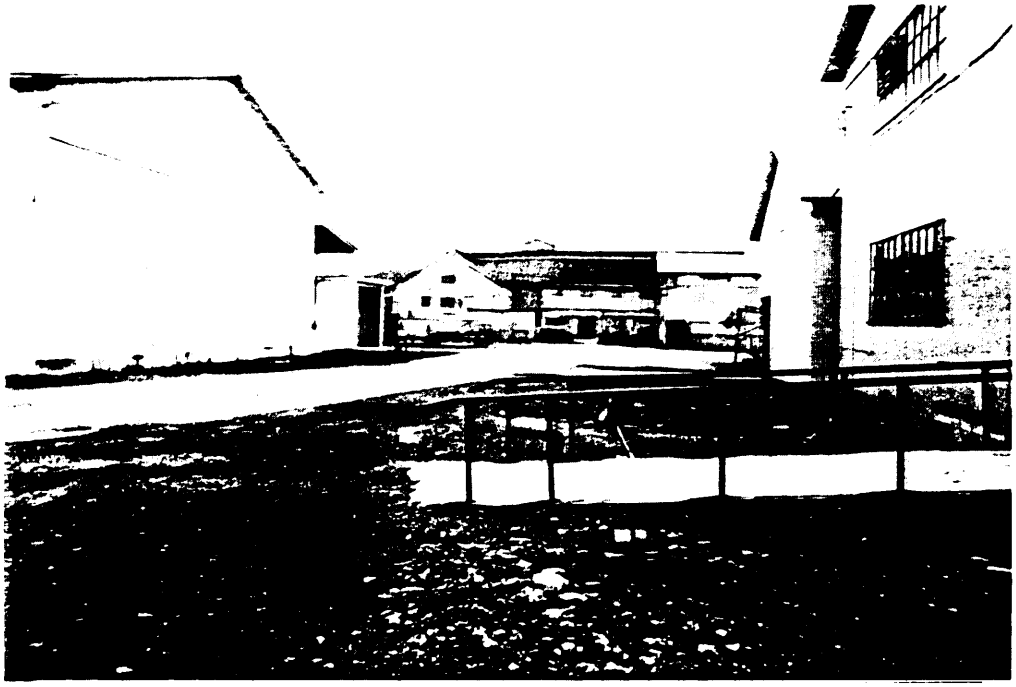


Plate 4: Vesuvius Crucible, with the original tanning factory buildings on the right and the newer warehouse on the left.

Plate 5: The rail siding and warehouse, with the old factory building in the background.

Each Vesuvius factory specializes in one product or family of products. The West Virgina factory manufactures stoppers of all types, although they make crucibles and saggers for their own use and some immersion bells for the steel industry.

MIXING:

The mixing, the vacuum extruding, the forming, drying and firing are all in the same building, and are all on a small scale. All the mixtures for the various items are recorded on recipes and are confidential information. Each batch mixed has a lot number which is carried through to the final stage for reference if something appears wrong at any time in the production line.

Large bins for the various constituents are filled from above. The bins feed onto a scale where the clay-graphite product is mixed by weight (Plate 6). The powder is added with water into a mixing machine until it is the proper consistency, then stored in 1 m x 1 m x 2 m blocks. The clay-graphite is similar to modelling clay and must be kept damp and stored in plastic (Plate 7). The amount of moisture in the mixture depends on the final product and how stiff the clay has to be.

EXTRUSION:

The blocks of clay-graphite are fed into a vacuum extrusion machine which forces the mixture through a die of a particular diameter and cuts the ensuing cylinder into prescribed lengths. The plugs are stacked on dollies, still with their lot number and are sent either to be made into stoppers or crucibles.

It is important in refractory products to have the graphite flakes aligned in certain directions to maximize conductivity and life of the product. Graphite flakes align perpendicular to applied stress. The vacuum extrusion partially aligns the flakes then the pressing or jigging further aligns the flakes.

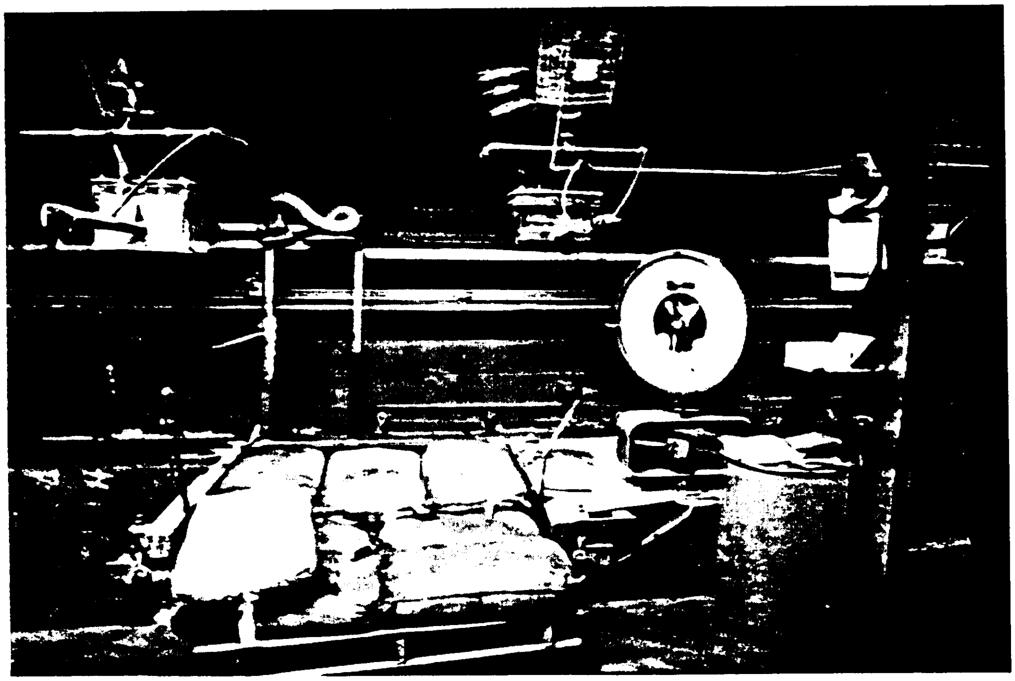


Plate 6: The weighing scale where the clay and graphite flake is mixed by weight.

Plate 7: The mixing machine to the right, and large blocks of mixed clay-graphite covered in green plastic.

Another method to pre-align the flakes is the "drop ball" method, where a ball of clay-graphite mix is dropped from a height of 20 feet. The impact aligns the flakes.

CRUCIBLES:

The crucibles in the Paw Paw plant are made for company use or exported for immersion bells. Immersion bells have holes in the side through which magnesium is added to molten steel. The crucible clay-graphite mixture has about 25% moisture, and is moldable or pliable. The crucible plugs from the extrusion machine are put into plaster molds (Plate 8), and the inside of the plug is tooled out by a die as the plug spins on the jig, much like a potter's wheel (Plate 9). The precision is in the thickness of the crucible wall and the inside dimensions, and is set by the operator on the die. The crucible is dried in hot air for 14 days, and the residual moisture is reduced to 1%. The crucibles are then fired. Crucibles that spall or crack are rejected, and are rarely reused in crucible mix since regrinding damages the flakes.

Saggers are large crucibles used by the company to hold the products while being fired, and prevent oxidation during the firing process. Too large to use extruded plugs, they are made directly from the clay-graphite mix fitted inside a plaster mold by hand and the inside tooled on a rotating jig. The lids are also molded by hand.

STOPPERS:

Stoppers are used to control the flow of molten steel from the ladle to the tundish and are required to go from room temperature to 2,000 C in seconds (Figure 2). One stopper usually only lasts for one ladle of molten metal, ensuring a constant demand for the product.

Stoppers are threaded on the inside and bullet shaped on the outside. The thread dimensions are criticial and are pressed on a machine, while the outside is shaped by pounding the plug onto a reverse-bullet shaped mold. Quite often the exterior dimensions are machined by the client to

Plate 8: Plastic molds for making crucibles.

Plate 9: "Jigging" crucibles.

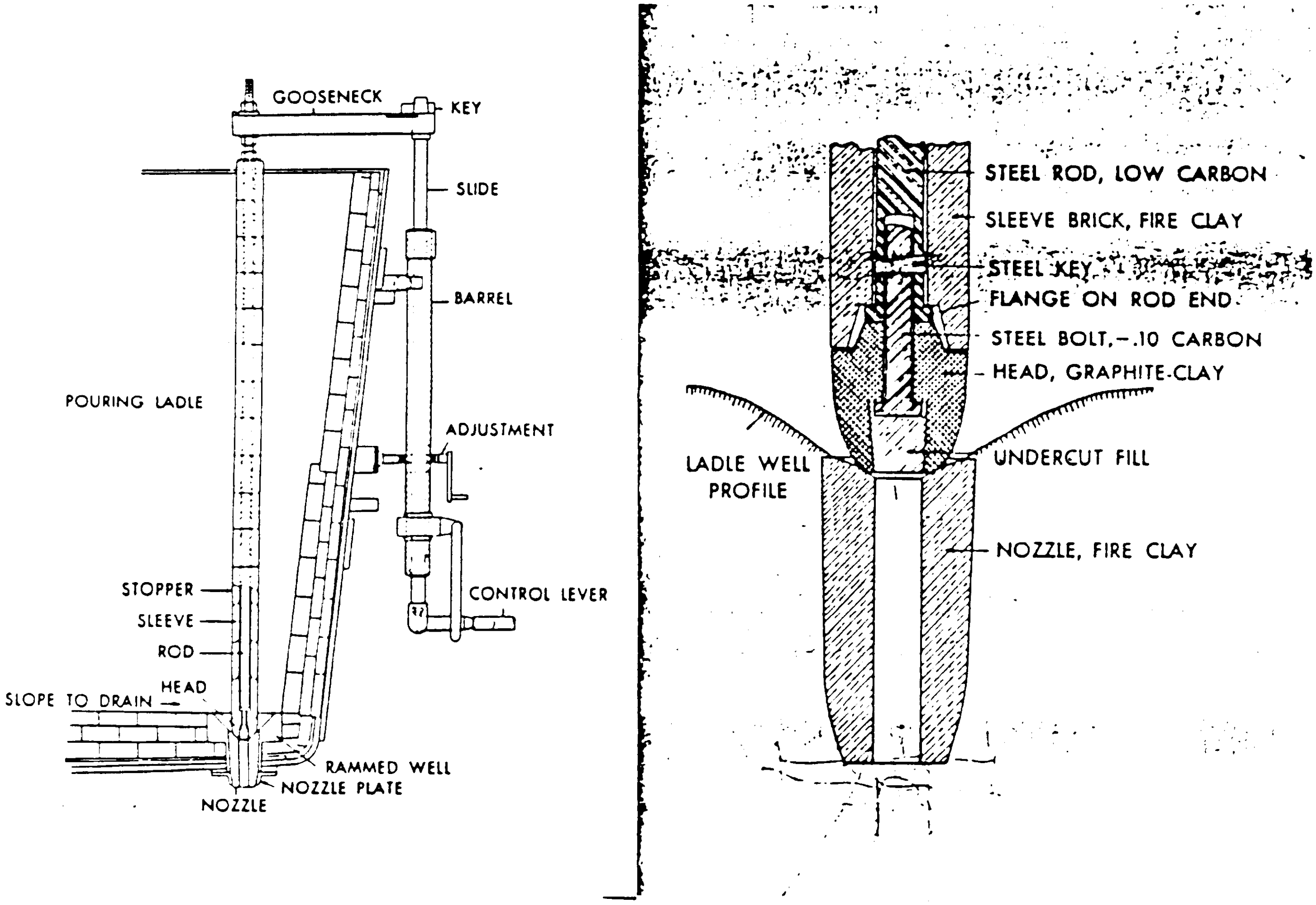


Figure 2: Section of typical bottom pour steel ladle and details of a graphite stopper assembly (courtesy Vesuvius Crucible).

their own specifications and precision requirements. The clay-graphite mix is stiffer with less water and less graphite in the mix. The stoppers are each stamped with a coded identification mark, and set on racks to dry for 2 weeks. Any cracked or broken stoppers are discarded (Plate 10).

FIRING:

There are two types of kilns, both propane fueled. One is a stationary, slow furnace, and the other is a continuously moving hotter and faster furnace. The crucibles are fired in the stationary furnace at 1,100° F. The slower rate of firing prevents oxidizing due to their higher graphite content. The crucibles and stoppers are then loaded into saggers, sealed with silica sand to avoid oxidation, and fed slowly through the moving kiln for 33 hours at 2,500° F (Plate 11). Prior to each batch being fired, three items per lot are fired to check for shrinkage. Three out of every 1,000 are sampled for porosity, density, and thermal shock.

Saggers and crucibles exposed to continuous firing are glazed to cut down on oxidation. Stoppers are not glazed as they are made for their thermal shock abilities.

LABORATORY:

Testing on the plant site is done to ensure continuity of quality of the products and to check on new research techniques. A porosity test is run on samples of the various clay graphite mixes from each lot number to ensure the porosity is under the maxiumum 24% set by the steel mills. The test is usually conducted by boiling the sample in water for two hours and noting the weight difference. The amount and type of ash is monitored by loss on ignition (LOI) tests. Two samples from each batch are used: one is heated in a normal oven and checked for LOI water, and the other is heated in a furnace to 1800° C for LOI carbon. The ash that is left is checked and weighed. The graphite flakes themselves are

Plate 10: Boxes of discards stored in the warehouse.

Plate 11: The continuous firing kiln with a sagger just exiting on the conveyor belt. Already fired saggers are to the right and a bin of discards is in the foreground.

checked for quality control. One sample per fifteen bags is taken and a handful of flakes are dropped into a standard 1 litre graduated cylinder. The cylinder is tapped on the table until the flakes are settled as much as they will, and the volume difference is calculated and converted to a density unit. Although subjective, this test gives an indication of flake thickness, which determines the flake's susceptibility to oxidation. Since flakes oxidize from the ends, thin flakes are more desirable. The rest of the graphite flakes from the sample are seived for average particle diameter which is calculated by weight percent times the mean diameter of the flakes on the sieves.

WAREHOUSE AND SHIPPING:

Vesuvius Crucible imports graphite from Madagascar, Sri Lanka, Brazil, China and Norway, as well as graphite from American sources. They have found that flake graphite exhibits the same properties regardless of origin as long as the graphite is the same degree of crystallinity. The only constraints they have on graphite importation is consistency and quality of shipments, which are met by the Madagascar companies (Plate 12).

Vesuvius Crucible also stores zircon sand for use as a sure flour to assist molten steel flowage and they resell it to American steel mills. Silica sand is stored for use as a sealer and ramming mix in the pocket blocks of the ladles. Clay powder is imported from England as well as from local sources. Norwegian fine graphite is imported for use as a lubricant in the stopper-making process.

The shipping area is part of the warehouse. Some products are coated in magnesium oxide or plaster at customer's request before they are shipped. The products are inspected, packed in crates and loaded onto trucks or railcars (Plate 13).

CONCLUSIONS:

The trip to West Virginia to see an actual graphite plant was in retrospect a necessary part of the graphite project:

Plate 12: Graphite flakes in bags in the warehouse.

Plate 13: Products inspected and boxed for shipping.

1) The refractory and crucible industry employs what the Vesuvius enginner terms "Early Egyptian Technology". Crucible and stopper making is almost an art relying on the worker's manual skills rather than automation. Knowledge and technique are passed along via word of mouth and apprenticeship.

2) Vesuvius Crucible alone uses 6 M.T. of graphite flake a year in all their plants. Graphite flake from various sources is blended in the various recipes. It is not the flake characteristics that determine from which source the graphite is imported, rather it is the reliability and consistency in shipping.

3) Vesuvius Crucible would be interested in a Canadian flake graphite source as long as the deposit averages 4% by weight graphite and an 85% carbon content in the concentrate. Unfortunately as yet, the known Ontario deposits haven't met this requirement.

4) Natural flake graphite will always be required for refractories in the molten metal industry, and continuing research is finding more and varied applications for natural graphite. Synthetic and non-crystalline carbon does not exhibit the same unique properties of natural graphite. There are North American and European markets for Canadian flake graphite, should a deposit go into production.

APPENDIX II
GRAPHITE ANALYSIS

Carbon analytical data is presented in three forms: total carbon, which is determined by the Leco-IR method, carbonate carbon which is determined coulometrically and non-carbonate carbon which is calculated as the difference between total carbon and carbonate carbon.

Briefly, to determine total carbon content of a rock, the sample is combusted in a stream of oxygen in a Leco induction furnace and the resulting CO2 and CO are measured by separate infrared absorption detectors. The outputs are added electronically and report total carbon as CO2. Carbonate carbon is determined by heating a sample in perchloric acid. Only CO2 from carbonate is released in this process, since graphite is insoluble in the acid. The non-carbonate carbon result cannot identify the form in which the non-carbonate carbon occurs, since it is merely the difference between total carbon and carbonate carbon, and could be due to organic matter, hydrocarbons, graphite or diamond. C. Ackerley (C. Ackerley, research assistant, University of Guelph, Ontario, personal communication, 1984), of the University of Guelph, has researched graphite analysis involving volume determination with the scanning electron microscope. This method is complex, expensive, and labour intensive. For most practical purposes the Leco method is accepted as being consistent and reliable.

The easiest method to separate graphite from the surrounding rock is first to release the flakes by grinding as necessary, and then to float the graphite. The flake crystal habit and low specific gravity of the flakes make them suitable for floating in plain water, although most commercial operations use additives, such as pine oil, to reduce the surface tension of the water, thereby forcing more of the flaky impurities (mica) to sink, and a frothing agent such as kerosene to form an immiscible froth on top, making it easier to skim off the graphite. Although both substances would evaporate during assay and not affect the carbon results to any great degree, there may be residues left on the flakes which could affect trace element analyses. The one problem with this method is that the graphite is frequently interlayered with mica flakes which also float. Mica responds well to magnetic separation techniques, and if there is a lot of mica in the deposit, or if petrography reveals mica and graphite interlayering, then the concentrate should be run through a magnetic separator before bagging for use.

Grinding the rock causes some concern for the integrity of the graphite flake. Overgrinding eventually reduces flake size and can destroy the flake. The highly weathered deposits of the Malagasy Republic have the advantage in that the graphite has already been released from the host rock by weathering processes and the large flake can be preserved intact.

The CANMET Extractive Metallurgy Laboratory tried an experiment involving heap leaching of some graphite ore from Maria Township (see section 4.4). They found that the leaching did not work, as the solution leached organic compounds from the graphitic component of the ore, and with recirculation to the leach solution, these compounds accumulated and promoted fungal growth which clogged the works. It appeared that the organic leachates were toxic to the autotrophic organisms required to break down the rock (CANMET 1985). It is interesting to note that there exist organic compounds in the rock besides the graphite that may be precursors to the graphite, despite the metamorphic grade.

The best way to evaluate a carbon concentrate is to have it tested by a company in the graphite business. Figure 9 shows two plots of flake size versus carbon content obtained from Asbury Graphite's data on the Ryerson Township flake graphite. The most abundant fraction of the flake falls in the 35 to 65 US sieve size, but the carbon content is not highest in the largest flakes nor in the most abundant flake section. This must be related to the manner in which the impurities are trapped between the flakes; large flakes could possibly contain more impurities per unit area, while small flakes may have fewer flakes per impurity. The optimum carbon content seems to be associated with flakes in the 35 mesh range.

APPENDIX III

TRACE ELEMENT CHEMISTRY

Trace elements were determined for the 18 samples in the second SUITE. The results are summarized in Table V.

TABLE V: Trace Element Data for the Graphitic Units

ELEMENT	1	2	3	4	5
U	.79	3.88	3.74	1.33	2.80
Th	3.36	9.69	6.93	2.72	4.69
Cr	15.90	56.75	47.56	62.08	86.85
Ni	2.43	105.53	120.51	128.28	91.19
Mo	40.55	7.53	20.46	13.67	2.67
Au	1.10	0.60	0.19	1.15	0.69
Zn	27.25	81.78	85.40	84.25	93.82
Co	1.74	7.44	9.38	11.27	14.57

sample 1	253bg Maria, graphite
sample 2	253bs Maria, sediment
sample 3	253br Maria, rock
sample 4	rylg Ryerson, graphite
sample 5	ryls Ryerson, sediment

ELEMENT	6	7	8	9	10
U	7.43	0.40	1.04	3.85	43.41
Th	16.84	10.90	9.97	2.68	6.33
Cr	111.34	7.09	10.57	27.44	22.2
Ni	108.21	6.58	14.37	170.49	190.04
Mo	4.38	21.35	6.95	41.29	50.89
Au	0.14	4.18	0.98	1.28	1.44
Zn	89.64	167.43	155.69	46.93	58.74
Co	14.87	6.47	7.82	8.17	8.46

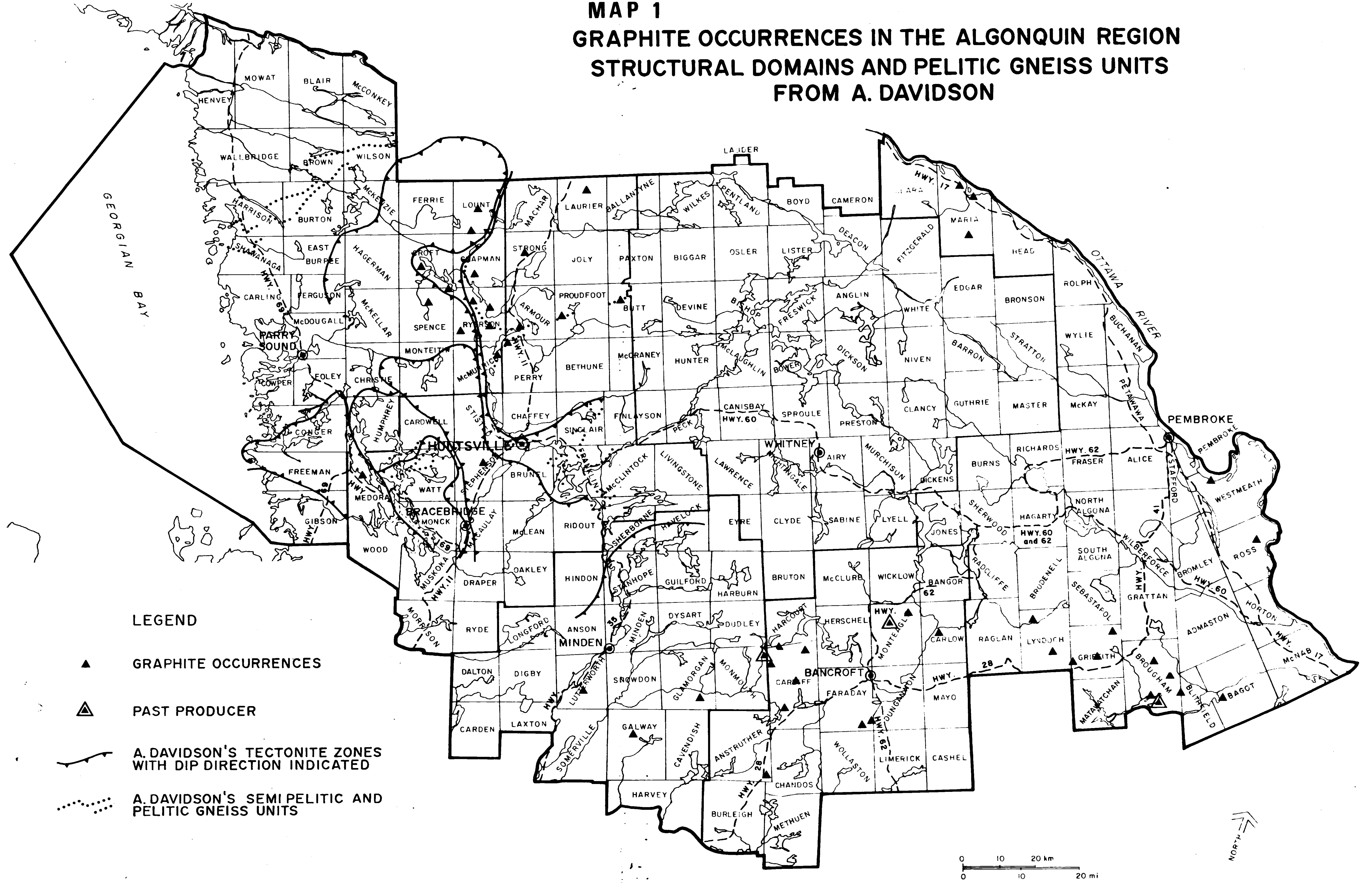
sample 6	rylr Ryerson, rock
sample 7	85blg Butt, graphite
sample 8	85bls Butt, sediment
sample 9	83102g Laurier, graphite
sample 10	83102s Laurier, sediment

ELEMENT	11	12	13	14	15	16
U	1.61	4.42	3.95	5.58	8.31	12.31
Th	2.44	1.78	2.44	5.50	4.50	7.67
Cr	19.50	47.95	21.08	22.28	19.11	33.58
Ni	3.99	3.39	1.51	10.56	88.49	164.4
Mo	48.19	268.30	24.87	5.16	16.36	5.69
Au	0.82	2.83	2.42	1.27	0.80	0.96
Zn	22.08	1336.97	52.10	41.39	29.92	19.47
Co	13.05	5.41	1.83	4.33	3.00	6.66

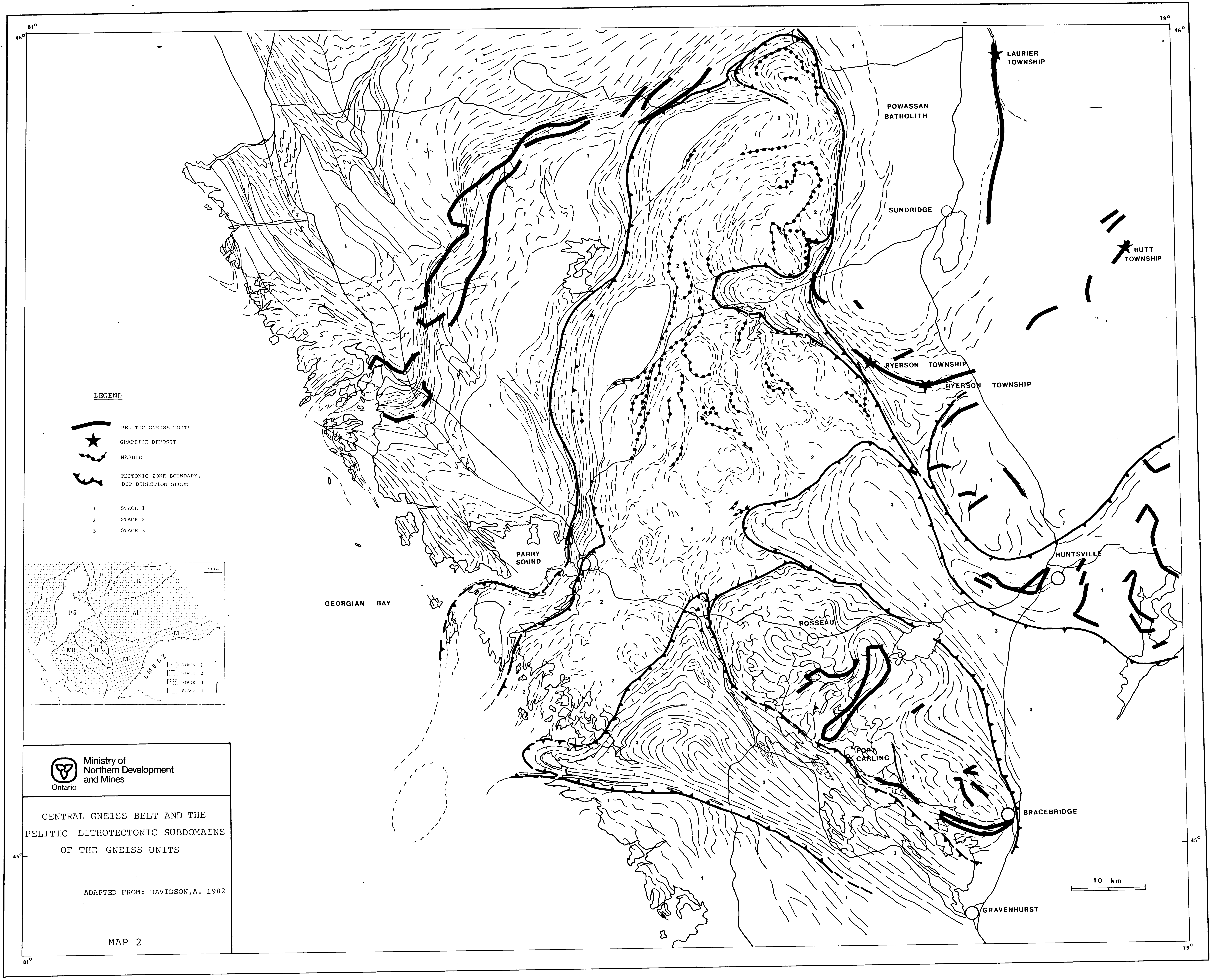
sample 11	10259 Maria, graphite
sample 12	ryack Ryerson, graphite
sample 13	85b6 Butt, graphite
sample 14	83107g Laurier, graphite
sample 15	83105g Laurier, graphite
sample 16	83104g Laurier, graphite

samples 17 and 18 are utbl/1 and utbl/2 (standards)

MAP 1
GRAPHITE OCCURRENCES IN THE ALGONQUIN REGION STRUCTURAL DOMAINS AND PELITIC GNEISS UNITS FROM A. DAVIDSON



SOURCES: (1.) MARTIN, W., 1982, O.G.S., OPEN FILE REPORT 5425. (2.) DAVIDSON, A. et al, 1982, G.S.C. PAPER 82-1A. (3.) DAVIDSON, A., 1982, G.S.C. OPEN FILE REPORT 870.



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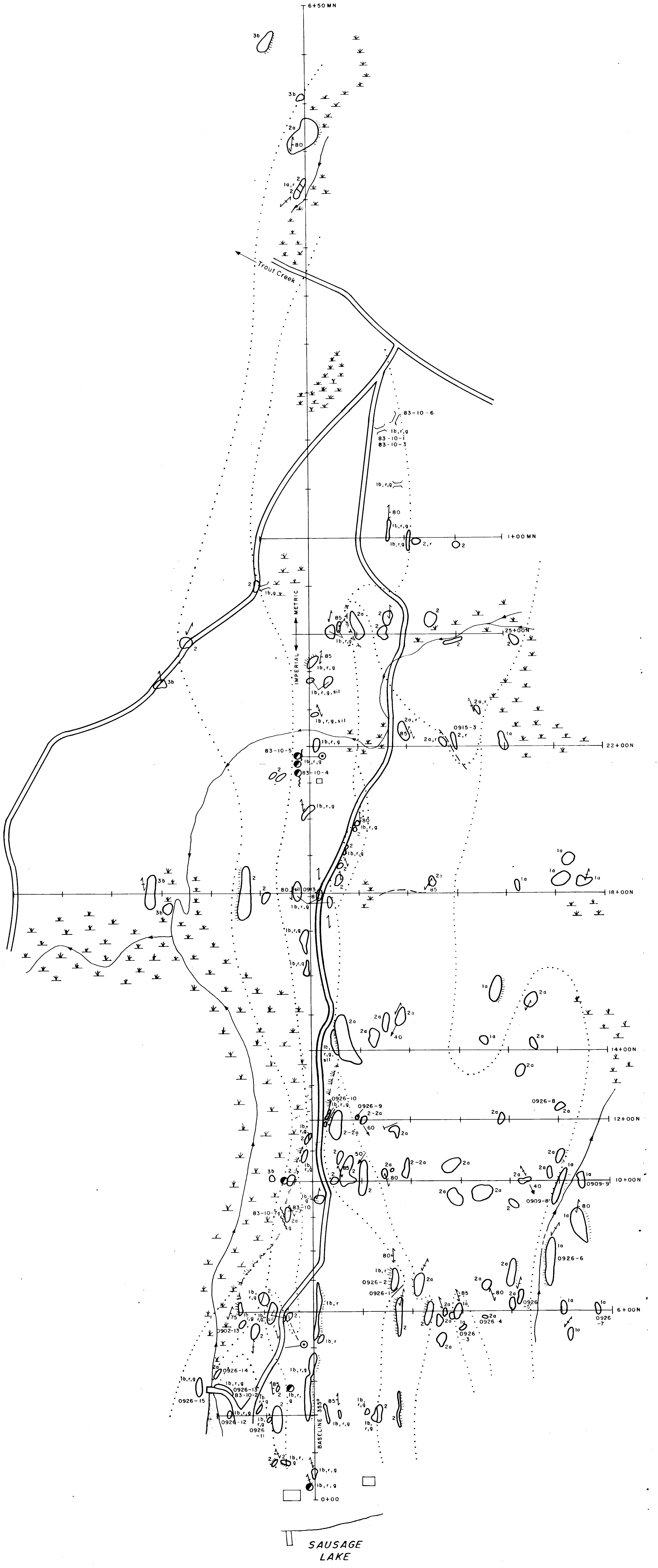
CENTRAL GNEISS BELT AND THE PELITIC LITHOTECTONIC SUBDOMAINS OF THE GNEISS UNITS

ADAPTED FROM: DAVIDSON,A. 1982

MAP 2



LEGEND

1a	FELDSPAR-QUARTZ-BIOTITE SCHIST
1b	QUARTZ-FELDSPAR-MUSCOVITE SCHIST
2	GRANITIC INTRUSIVE / WITH FELDSPAR AUGENS
2a	GRANITIC INTRUSIVE / GNEISSIC, FELDSPAR AUGENS STRETCHED AND RECRYSTALLIZED
3b	QUARTZ-FELDSPAR-BIOTITE-GARNET GNEISS
r	RUSTY
g	GRAPHITE
sil	SILICEOUS

SYMBOLS

	ROADS / TRAILS
☐	BUILDING
	SWAMP
	CLIFF
	OUTCROP
	GEOLOGICAL CONTACT - OBSERVED
	GEOLOGICAL CONTACT - INTERPRETED
70	STRIKE AND DIP OF FOLIATION
60	TREND AND PLUNGE OF LINEATION
	STRIKE AND DIP OF JOINTS
	SHEAR ZONE
—⊙	DIAMOND DRILL HOLE
●	PIT OR SHAFT
	TRENCH
0926-6	SAMPLE LOCATION

NORTH

0 50 100 metres

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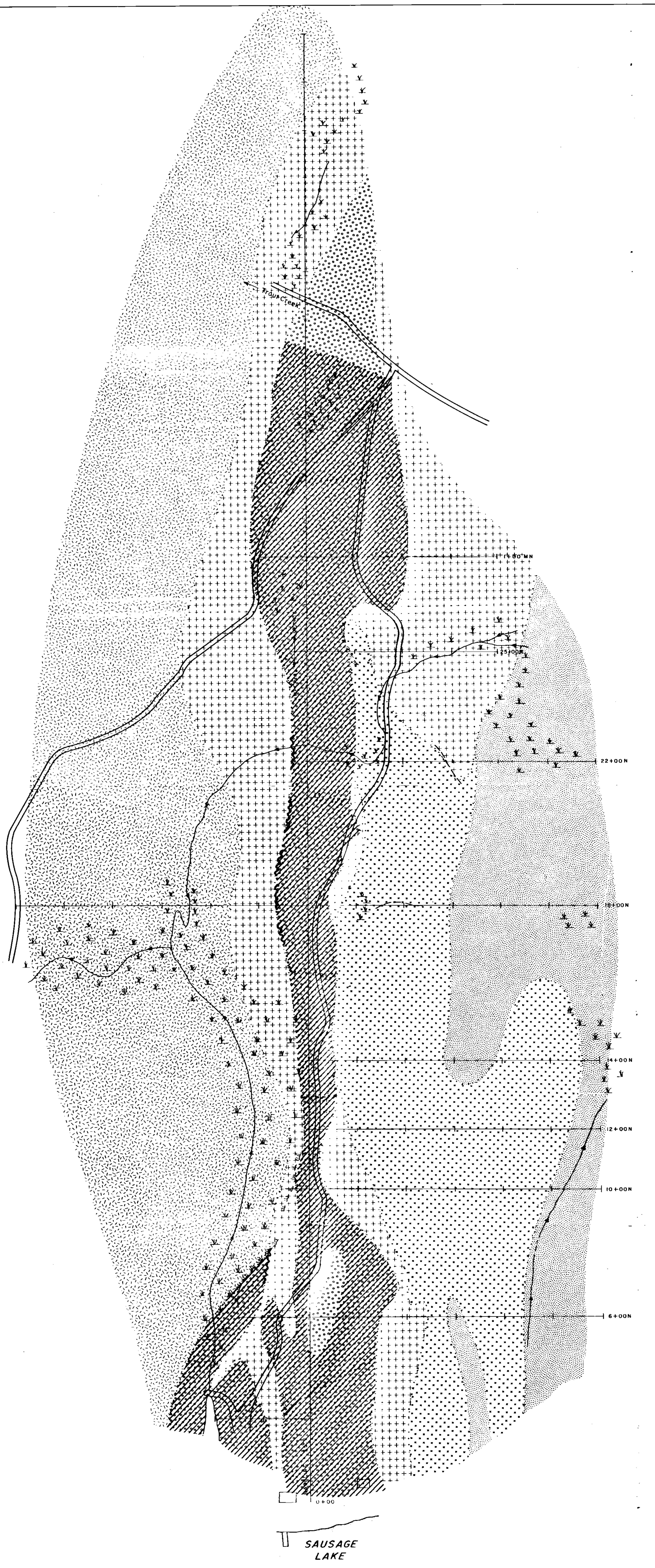
LAURIER TOWNSHIP
GEOLOGY
OPEN FILE REPORT
MAP 3

SCALE 1: 2500 DATE:

N.T.S. 31 E/14

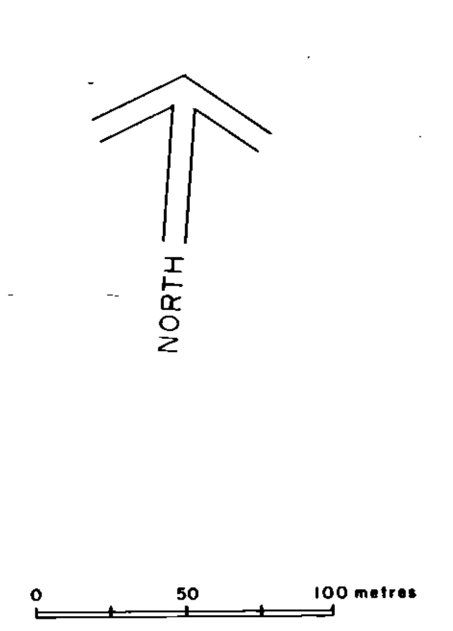


LEGEND

- ▨ 1a FELDSPAR-QUARTZ-BIOTITE SCHIST
- ▨ 1b QUARTZ-FELDSPAR-MUSCOVITE SCHIST
- ▨ 2 GRANITIC INTRUSIVE/WITH FELDSPAR AUGENS
- ▨ 2a GRANITIC INTRUSIVE/GNEISSIC, FELDSPAR AUGENS STRETCHED AND RECRYSTALLIZED
- ▨ 3b QUARTZ-FELDSPAR-BIOTITE-GARNET GNEISS
- ▨ INTERPRETED GRAPHITIC HORIZON FROM OUTCROP MAPPING
- 〰 SILICIFIED GRAPHITIC SHEAR ZONE

SYMBOLS

- ═ ‒ ‒ ROADS/TRAILS
- ☐ BUILDING
- ⊻ SWAMP
- CLIFF
- ⋯ GEOLOGICAL CONTACT-INTERPRETED



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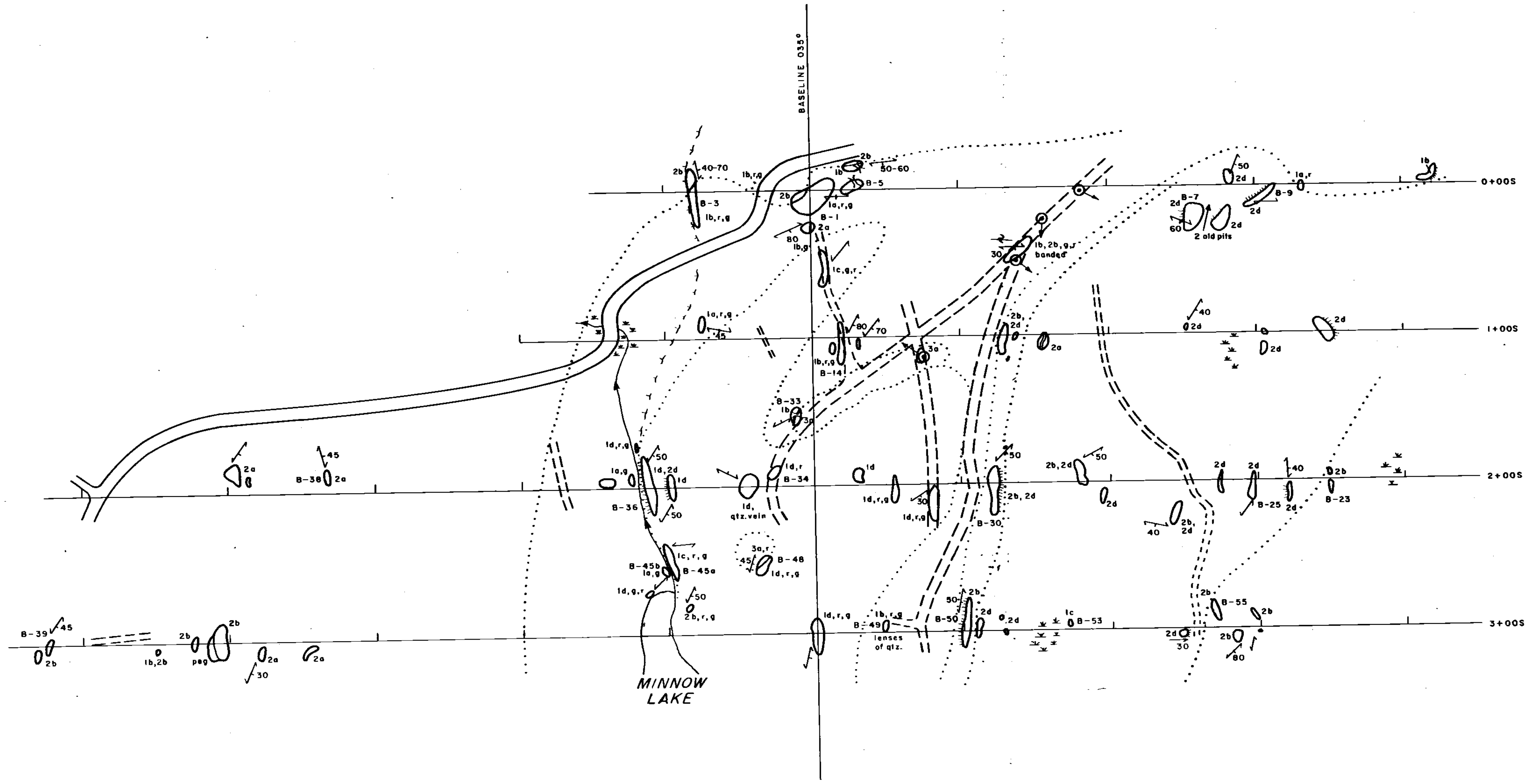
LAURIER TOWNSHIP
GRAPHITIC ZONES

OPEN FILE REPORT
MAP 4

SCALE 1:2500 DATE:

N.T.S. 31E/14



LEGEND

1a, 1b	META-QUARTZITE / WITH BIOTITE
1c	QUARTZ-FELDSPAR-BIOTITE SCHIST
1d	QUARTZ-FELDSPAR-HORNEBLENDE-BIOTITE-GARNET SCHIST (GARNETS LIGHT-RED TO RED)
2a	QUARTZ-FELDSPAR-BIOTITE GNEISS
2b	QUARTZ-FELDSPAR-HORNBLENDE-CLINOPYROXENE-GARNET GNEISS
2d	QUARTZ-FELDSPAR-BIOTITE-GARNET GNEISS / WITH WELL DEVELOPED QUARTZ RODS AND STRINGERS
3a	DIORITE OR PLAGIOCLASE-AMPHIBOLITE
r	INTENSE RUSTING
g	GRAPHITE

SYMBOLS

ROADS: GRAVEL / BUSH

SWAMP

OUTCROP

GEOLOGICAL CONTACT - OBSERVED

GEOLOGICAL CONTACT - INTERPRETED

70 STRIKE AND DIP OF FOLIATION

20 TREND AND PLUNGE OF LINEATION

FOLD, TREND OF AXIAL PLANE

DIAMOND DRILL HOLE

TRENCH

B-30 SAMPLE LOCATION

NORTH

0 50 100 metres

Ontario
Ministry of Northern Development and Mines

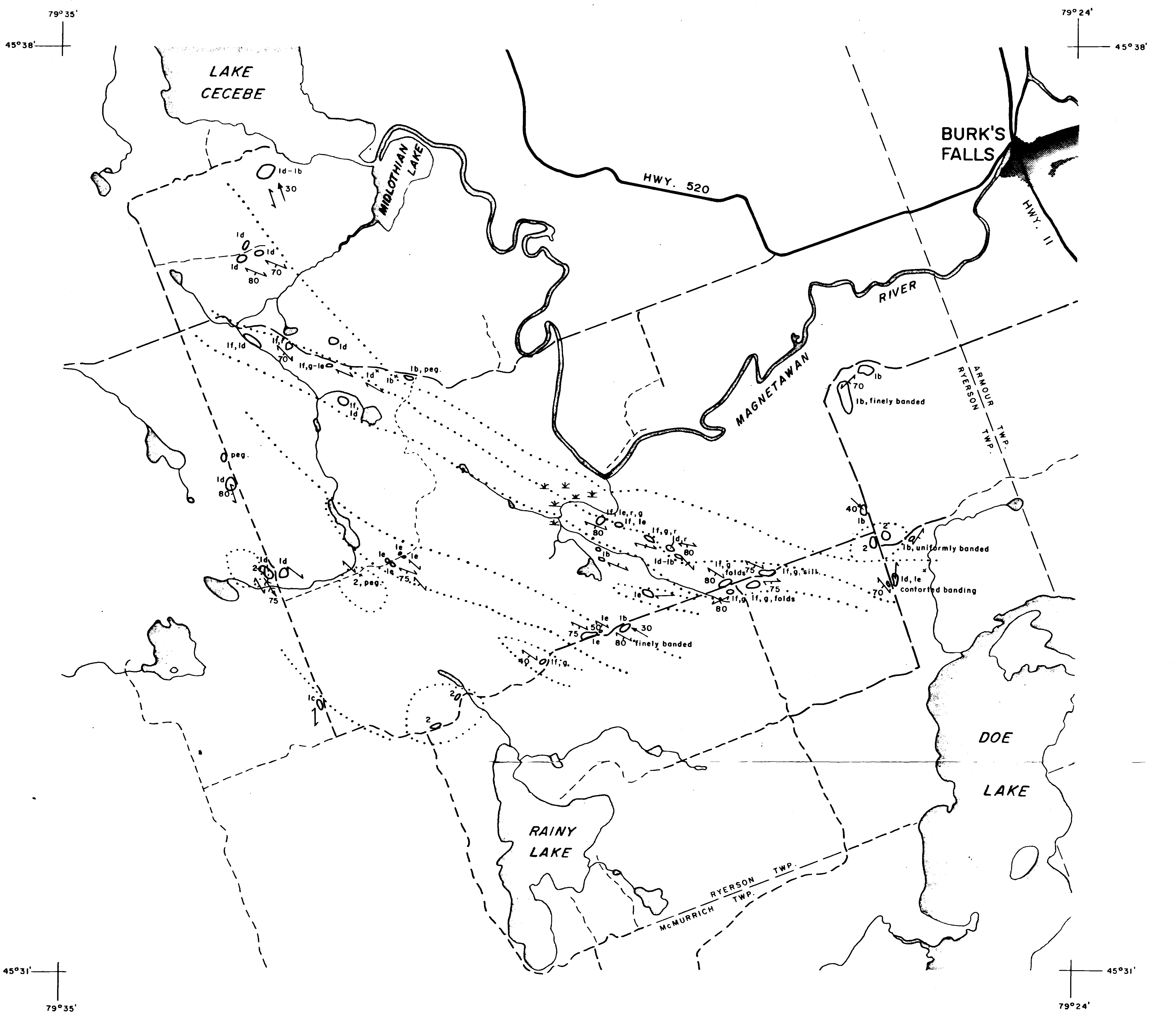
BUTT TOWNSHIP
GEOLOGY

OPEN FILE REPORT
MAP 5

SCALE 1:2500 DATE:

N.T.S. 31E/11

5



LEGEND

Ib	QUARTZ-FELDSPAR-HORNBLENDE-GARNET GNEISS
Ic	HORNBLENDE-FELDSPAR-QUARTZ GNEISS
Id	QUARTZ-FELDSPAR-BIOTITE-GARNET GNEISS
Ie	QUARTZ-FELDSPAR-BIOTITE GNEISS
If	QUARTZ-FELDSPAR-BIOTITE SCHIST
g	GRAPHITIC
r	RUSTY
2	MAFIC INTRUSIVE

SYMBOLS

ROADS: ASPHALT, SECONDARY, TERTIARY

SWAMP

OUTCROP

GEOLOGICAL CONTACT–INTERPRETED

STRIKE AND DIP OF FOLIATION

TREND AND PLUNGE OF LINEATION

FOLDS — TREND AND PLUNGE OF AXIS

0 1 2 kilometres

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RYERSON TOWNSHIP
GEOLOGY

OPEN FILE REPORT
MAP 6

SCALE 1:50000 DATE:

N.T.S. 31E/11, 12