Strategic Graphite A Survey

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An appraisal of domestic resources

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STRATEGIC GRAPHITE—A SURVEY

By Eugene N. Cameron and Paul L. Weis

ABSTRACT

Strategic graphite consists of certain grades of lump and flake graphite for which the United States is largely or entirely dependent on sources abroad. Lump graphite of high purity, necessary in the manufacture of carbon brushes, is imported from Ceylon, where it occurs in vein deposits. Flake graphite, obtained from deposits consisting of graphite disseminated in schists and other metamorphic rocks, is an essential ingredient of crucibles used in the nonferrous metal industries and in the manufacture of lubricants and packings. High-quality flake graphite for these uses has been obtained mostly from Madagascar since World War I. Some flake graphite of strategic grade has been produced, however, from deposits in Texas, Alabama, and Pennsylvania. The development of the carbon-bonded crucible, which does not require coarse flake, should lessen the competitive advantage of the Madagascar producers of crucible flake.

Graphite of various grades has been produced intermittently in the United States since 1644. The principal domestic deposits of flake graphite are in Texas, Alabama, Pennsylvania, and New York. Reserves of flake graphite in these four States are very large, but production has been sporadic and on the whole unprofitable since World War I, owing principally to competition from producers in Madagascar. Deposits in Madagascar are large and relatively high in content of flake graphite. Production costs are low and the flake produced is of high quality. Coarseness of flake and uniformity of the graphite products marketed are cited as major advantages of Madagascar flake. In addition, the usability of Madagascar flake for various purposes has been thoroughly demonstrated, whereas the usability of domestic flake for strategic purposes is still in question.

Domestic graphite deposits are of five kinds: deposits consisting of graphite disseminated in metamorphosed siliceous sediments, deposits consisting of graphite disseminated in marble, deposits formed by thermal or dynamothermal metamorphism of coal beds or other highly carbonaceous sediments, vein deposits; and contact metasomatic deposits in marble. Only the first kind comprises deposits sufficiently large and rich in flake graphite to be significant potential sources of strategic grades of graphite. Vein deposits in several localities are known, but none is known to contain substantial reserves of graphite of strategic quality.

Large resources of flake graphite exist in central Texas, in northeastern Alabama, in eastern Pennsylvania, and in the eastern Adirondack Mountains of New York. Tonnages available, compared with the tonnages of flake graphite consumed annually in the United States, are very large. There have been

indications that flake graphite from Texas, Alabama, and Pennsylvania can be used in clay-graphite crucibles as a substitute for Madagascar flake, and one producer has made progress in establishing markets for his flake products as ingredients of lubricants. The tonnages of various commercial grades of graphite recoverable from various domestic deposits, however, have not been established; hence, the adequacy of domestic resources of graphite in a time of emergency is not known.

The only vein deposits from which significant quantities of lump graphite have been produced are those of the Crystal Graphite mine, Beaverhead County, Mont. The deposits are fracture fillings in Precambrian gneiss and pegmatite. Known reserves in the deposits are small.

In Texas, numerous flake-graphite deposits occur in the Precambrian Packsaddle schist in Llano and Burnet Counties. Graphite disseminated in certain parts of this formation ranges from extremely fine to medium grained. The principal producer has been the mine of the Southwestern Graphite Co., west of the town of Burnet. Substantial reserves of medium-grained graphite are present in the deposit mined by the company.

In northeastern Alabama, flake-graphite deposits occur in the Ashland mica schist in two belts that trend northeastward across Clay, Coosa, and Chilton Counties. The northeastern belt has been the most productive. About 40 mines have been operated at one time or another, but only a few have been active during or since World War I. The deposits consist of flake graphite disseminated in certain zones or "leads" consisting of quartz-mica-feldspar schists and mica quartzite. Most of past production has come from the weathered upper parts of the deposits, but unweathered rock has been mined at several localities. Reserves of weathered rock containing 3 to 5 percent graphite are very large, and reserves of unweathered rock are even greater.

Flake graphite deposits in Chester County, Pa., have been worked intermittently since about 1890. The deposits consist of medium- to coarse-grained graphite disseminated in certain belts of the Pickering gneiss. The most promising deposit is one worked in the Benjamin Franklin and the Eynon Just mines. Reserves of weathered rock containing 1.5 percent graphite are of moderate size; reserves of unweathered rock are large.

In the eastern Adirondack Mountains in New York there are two principal kinds of flake-graphite deposits: contact-metasomatic deposits and those consisting of flake graphite disseminated in quartz schist. The contact-metasomatic deposits are small, irregular, and very erratic in graphite content. The deposits in quartz schist are very large, persistent, and uniform in grade. There are large reserves of schist containing 3 to 5 percent graphite, but the graphite is relatively fine grained.

INTRODUCTION

Several more or less similar terms that convey a particular meaning to people in the graphite industry are used in this report. Their meanings, as intended here, are defined below.

Type.—Natural graphite is divided into three types, depending on the physical form of the graphite particles: (a) amorphous, (b) flake, and (c) lump and chip. Lump and chip graphite is sometimes referred to as amorphous lump and chip, sometimes as crystalline lump and chip, and, because it occurs exclusively in veins, it is also sometimes called vein-type graphite.

Grade.—Graphite in marketable form (of any "type") is classified into various categories depending on one or more characteristics such as percent graphitic carbon, particle size, amount of impurity, nature of impurity, and use. Such categories are called grades. There are, for example, several grades of lubricating flake graphite, distinguished from each other solely on the basis of flake size. The term "grade" is also used, somewhat loosely, to denote strategic and nonstrategic grades—that is, grades (again, of any type) that are considered of critical importance during a period of national emergency, as distinguished from those that are not of critical importance, as measured by the probable effect of their loss to critical industries and their availability.

"Grade" is also a miners' term and is applied to ore, either in the ground or after mining, but generally before concentration. In that sense, it refers to the content of valuable minerals in the material mined, and is synonymous with the term "tenor." Context of the sentence should make it clear in what sense the word "grade" is used.

Quality.—Quality is a term used somewhat loosely by the graphite industry when referring to such properties of graphite as packing index, durability, density, and toughness. It may sometimes be said that graphite from one mine is of a different quality from graphite from another mine, when the speaker isn't quite sure just what that difference is but can only point to apparently identical products that perform differently in use.

THE GRAPHITE PROBLEM

Certain grades of graphite are of critical importance in American industry. Some of the graphite used in the United States has been supplied by intermittent production from domestic deposits, but since World War I certain grades of graphite have been supplied largely by imports from Madagascar and Ceylon. These are the strategic grades; they consist of flake graphite suitable for crucible manufacture or for lubricating and packing materials, and high-purity amorphous lump graphite.

The reasons for our dependence on foreign sources for strategic graphite have been debated for many years, and there is a broad range of opinions on the subject. The debate hinges on whether strategic graphite can be obtained from domestic deposits in time of emergency. Some believe that domestic resources are adequate for all contingencies; others are convinced that domestic resources cannot yield substantial amounts of strategic grades. This is the basic problem of domestic graphite. An adequate solution to this problem requires detailed information on the size, tenor, and distribution of domestic deposits, their potential rates of yield, costs, and the nature of the final products. Some of this information is at hand, but there is not enough for a complete solution of the graphite problem. One of the objectives of this report is to point out the strengths and weaknesses of present information and thereby contribute to an ultimate solution.

SCOPE OF REPORT

This report discusses the nature, commercial grades, and uses of graphite, the history of the domestic graphite industry and the factors influencing domestic production, and the characteristics of geologic types of graphite deposits. An appraisal of domestic graphite resources is given, followed by brief descriptions of those domestic deposits that are of actual or potential importance as sources of strategic graphite. An annotated selected bibliography is also included.

PREVIOUS INVESTIGATIONS

The literature of graphite is voluminous, and only a brief summary of some of the more important works will be given. The principal sources of statistical information are the volumes of Mineral Resources of the United States for 1913 to 1932, and the volumes of Minerals Yearbook for the period 1934 to 1954. The accounts given in these volumes are brief, but they are invaluable to anyone who attempts to trace the evolution of the domestic graphite industry.

The most comprehensive accounts in English of the occurrence, uses, and technology of graphite are those by Cirkel (1907) and Spence (1920). No comparable work of subsequent date is available, but excellent discussions of various aspects of the graphite industry have been given by Tyler (1929a, b, c, d; 1941), and briefer general discussions have been given by Miller (1933, 1937) and by Gwinn (1943, 1949).

Numerous papers deal with specific domestic deposits or groups of deposits. The graphite deposits of Montana were discussed by Winchell (1911a, b), Bastin (1912), Heinrich (1949a and b), and Ford (1954). Those of Texas were described by Paige (1911, 1912), Barnes (1940), and Chelf (1943). There is much literature on the graphite deposits and industry of Alabama. Among the more important papers are those by Prouty (1917a, b, c; 1923), Brown (1925), Jones (1929), Clemmer and others (1941), Pallister and Smith (1945), and Pallister and Thoenen (1948). The first comprehensive account of the graphite deposits of eastern Pennsylvania was given by Miller (1912) in a report that also contains a discussion of the difficulties that beset the domestic graphite industry. The reports by Sanford and Lamb (1949) and Lamb and

Irving (1955) contain an account of later operations in this area.

Alling (1917) gave the fullest report on the deposits in New York State. He described the deposits, discussed the industry based on them, and presented an analysis of the economic factors that influenced the continuance of the industry.

In addition to those cited above, there are a great many articles, most of them brief, dealing with special aspects of the occurrence, uses, and technology of graphite. These are listed in the bibliography.

There is also considerable literature on the occurrence and technology of graphite in foreign countries. An exhaustive survey of this literature is beyond the scope of the present investigation, but a few of the works to which reference has been made may be cited. Much information on developments in the graphite industry abroad is contained in the U.S. Bureau of Mines Mineral Trade Notes. Accounts of the graphite deposits of Ceylon were given by Ferguson (1885), Diersche (1898), Bastin (1912), and Wadia (1943). The deposits of Madagascar were described by Shelley (1916), by Savanorin (1935), and by Bésairie and others (1951). General accounts of European occurrences were given by Dammer and Tietze (1913) and by Stutzer and others (1933). The amorphous graphite in Mexico was described by Hess (1909) and Hornaday (1912). Canadian occurrences were discussed by Spence (1920). McLaren (1945) and Andersen (1954) reported on the occurrence and mining of graphite at the most productive Canadian deposit, the Black Donald.

SOURCES OF INFORMATION

Information for the present report was drawn from many sources. Geologists of the U.S. Geological Survey provided information on certain graphite districts, and additional data were obtained from reports of the U.S. Bureau of Mines. The extensive literature on graphite has likewise been consulted freely. Acknowledgment of sources is made at appropriate places in the text. The information thus obtained was supplemented by a series of conferences with representatives of firms engaged in the production, processing, and consumption of graphite, and by examination, during the summer of 1950, of deposits in the major graphite districts of the United States—Dillon, Mont., central Texas, eastern Alabama, eastern Pennsylvania, and the Adirondack area of New York.

LIMITATIONS

This report represents an attempt to bring together and analyze existing information on domestic graphite resources of actual or possible strategic importance. No comprehensive investigation of domestic graphite resources was made. Much excellent work on graphite deposits has been done by geologists and mining engineers, but no graphite district of the United States has been fully mapped, fully studied, or otherwise investigated to a degree commensurate with the needs of a modern mineral resource appraisal. Much of the material available, furthermore, was written with reference to economic and technologic conditions different from those of the present day.

Deficiencies in data are in part related to distribution, size, and tenor of individual deposits. More serious, however, are deficiencies in data on the commercial grades of graphite that can be produced from various deposits and on their usability for industrial purposes. The lack of such information is the heart of the problem of domestic graphite resources.

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MINERALOGY

Graphite is pure crystalline carbon. It crystallizes in the hexagonal system, but well-formed crystals are rare. It has a hardness of 1 to 2, specific gravity of 2.1 to 2.3, earthy to metallic luster, and black color and streak. It is opaque even on thinnest edges. It has a characteristic slippery feel that is due to its softness and excellent basal cleavage. It is sectile and flexible though not elastic and is a good conductor of heat and electricity. Graphite is inert to the common chemical reagents, but if heated with a mixture of HNO_3 and $KClO_3$ for several days it will form a golden-yellow compound called graphitic acid, which has the same form and shape as the graphite itself (Spence, 1920, p. 4). The test can be used to distinguish graphite from charcoal and diamond, the other two allotropic forms of carbon. Charcoal (true amorphous carbon) forms a brown water-soluble compound when treated with the mixture; diamond, the other crystalline form of carbon, remains unaffected. The resistance of graphite to chemical alteration can be readily observed in residual soils formed from graphite-bearing rocks. The graphite thus liberated remains as bright, unaltered flakes.

Graphite melts at a temperature of about 3,500°C and vaporizes at a temperature of 4,500°C. In the presence of oxygen it decomposes slowly at a temperature of 600–700°C to form CO_2.

COMMERCIAL TYPES AND GEOLOGIC OCCURRENCE OF NATURAL GRAPHITE

Three principal commercial types of natural graphite are recognized on the basis of their physical properties. They are lump and chip, flake, and amorphous. Each has one or more characteristic modes of occurrence.

Lump and chip graphite occur in veins cutting igneous or metamorphic rocks, as illustrated by the deposits of Ceylon. (Ceylon lump is sometimes referred to as "crystalline lump," sometimes as "amorphous lump.") Ceylon graphite forms masses consisting of coarse, platy intergrowths of fibrous or needlelike aggregates. It breaks into spear-shaped or irregular, sharp-cornered pieces composed of interlocking crystals or crystal fragments that are denser and tougher than other types of graphite (Thiessen, 1919, p. 508–542). Commercial grades of Ceylon graphite are classified according to size and purity (Tyler, 1929a, p. 26). Lump graphite is described as consisting of pieces ranging from the size of a walnut to that of a pea. It ordinarily contains 90 percent or more carbon. Chip graphite ranges from the size of a pea to a little less than the size of a wheat grain; it is ordinarily 90 to 92 percent carbon. "Dust" consists of fines, about 40- to 60-mesh size, and contains from 55 to 90 percent carbon.

Flake graphite occurs in metamorphic rocks, particularly in schists. This type of graphite, as the name implies, consists of isolated flat flakelike particles with irregular, rounded, or angular edges. The flakes range from a fraction of a millimeter to more than 2.5 cm in diameter; the average is probably 5 mm or less. Thickness, toughness, density, size, and shape vary from one deposit to another. In the most important deposits, flakes normally are disseminated through certain layers of metamorphic rock sequences. Flake graphite also occurs in contact-metamorphic and contact-metasomatic deposits in marble. Most commercial grades contain a minimum of 85 percent carbon. There are many subdivisions based on flake size and nature of impurities.

Amorphous graphite is extremely fine grained, and individual flakes can be distinguished only with the aid of a microscope. The term "amorphous" is a misnomer, for all true graphite is crystalline. Amorphous graphite is found in a variety of geologic environments, including those that yield flake and lump, for the finest sizes of graphite from these sources are sometimes sold as amorphous graphite. Much of the production, however, is from coal seams that have undergone thermal metamorphism by nearby intrusive bodies. The graphite from these altered coals is extremely fine grained, soft, dull, black, earthy looking, and commonly somewhat porous; its purity depends largely on the purity of the original coal seam. Material averaging 80 to 85 percent graphite has been mined in Mexico. Commercial grades are generally about 85 percent carbon.

Amorphous graphite is also manufactured by an electric furnace process and marketed as "artificial" graphite. It is true graphite in every sense and can be used for any purpose for which natural amorphous graphite is used. The process is similar to that used in making carborundum, but the furnace temperature is raised to 2,800°C, at which point the carbides are broken down and the metallic elements are volatilized. Manufactured amorphous graphite of extremely high purity can be produced.

MINERALS ASSOCIATED WITH VARIOUS TYPES OF GRAPHITE

The diversity of origin and occurrence that is responsible for the differences among the three commercial types of natural graphite is also responsible for differences in the associated minerals. The identity, amounts, and modes of occurrence of these associates are important because they may have as much effect on the commercial value of a particular graphite as the properties of the graphite itself.

Minerals commonly associated with graphite include quartz, feldspar, mica, calcite, clay minerals, iron sulfides, garnet, pyroxene, zircon, rutile, and apatite. Many others occur locally in small amounts. As might be expected, each type of graphite has its characteristic associates. Vein-type graphite commony occurs with quartz, feldspar, mica, pyroxene, zircon, apatite, rutile, iron sulfides, and sometimes with calcite. Most of these minerals form isolated grains or pockets, rather than intimate intergrowths. Flake graphite is found with quartz, feldspar, mica, and iron sulfides in unweathered schists and quartzites, and with clay minerals and calcite in the weathered products from such rocks. It is not unusual to find mica, quartz, or even pyrite or feldspar intergrown with or included in the flakes. In contact-metamorphic and contact-metasomatic deposits flake graphite occurs with any of a variety of minerals—calcite, diopside, garnet, quartz, tremolite, actinolite, and sphene are common associates. Amorphous graphite contains clay and iron sulfides as its most common impurities, but quartz and other detrital minerals may also be found with it in places.

USES

Owing to its unique physical and chemical properties, graphite has become an essential constituent of a wide variety of manufactured articles. It is also used in several processes without entering into final products. Its softness, opacity, thermal and electrical conductivity, resistance to chemicals and heat, and ability to form a clinging film on metallic surfaces make it ideal for many entirely unrelated uses. The different commercial types of graphite differ in properties and find favor in different uses. However, they are interchangeable to some extent.

The principal uses of flake graphite are for crucibles and related refractory articles, for lubricants and packings, for batteries, and for foundry facings; the principal uses of lump and chip graphite are for crucibles and for carbon brushes and other articles that require graphite of high purity; the principal uses of amorphous graphite are for foundry facings, batteries, pencils, paints, and polishes. Flake, lump, and chip graphite, for crucibles, lubricants and packings, and carbon brushes is supplied largely from sources outside North America. These types of graphite, containing 85 to 98 percent carbon, constitute the strategic grades.

The importance of graphite in industry is not measured in tons. Ordinarily, less than 5,000 tons of graphite of strategic grade is required annually by the industries of the United States; yet the elimination of this small tonnage would have far-reaching effects in several industries. Lump, chip, and flake graphite is therefore of great strategic importance.

CRUCIBLES AND REFRACTORY WARES

The largest use of strategic graphite is in refractory wares, comprising crucibles, stoppers, covers, sleeves, nozzles, phosphorizers, retorts, and many special-purpose items. The nonferrous metal industry uses almost all these articles in smelting and metallurgical processes. The most economically important article manufactured is the crucible. Charges are put into the crucible, melted, and poured. The crucible must therefore have good heat conductivity and an extremely high resistance to heat, oxidation, and the corrosive effect of the melt. It must also be durable and inexpensive. For these purposes, graphite compounds are more nearly ideal than any other material discovered. Lump and chip graphite was preferred at one time, but after Madagascar began producing quantities of coarse, high-purity flake, the manufacturers gradually changed over, and Madagascar flake graphite is now standard for the industry.

Two principal types of crucibles are in use, the clay-graphite and the carbon-bonded. The clay-graphite type has been in use for more than a hundred years. The carbon-bonded type was developed in the 1930's, and its use has increased greatly. Clay-graphite crucibles are composed of three essential constituents: clay, sand, and graphite. Small amounts of other materials may be added to give special properties. Graphite commonly makes up 40 to 50 percent of the total volume. For this purpose manufacturers desire flake that is fairly coarse (20–90 mesh), is tough enough to stand up under several hours of mixing, and has the maximum possible thickness and density. Thick dense flake requires less binder; hence, when it is used graphite can form a higher proportion of the article. Size distribution is important; uniform coarse flake is not as satisfactory as the proper mixture of coarser and finer sizes. The graphite gives the crucible its heat conductivity and its resistance to decomposition at temperatures necessary to melt the charge. Proper internal structure allows a certain amount of deformation during heating and handling (Spence, 1920, p. 119–144). The ideal structure has been found to be an overlapping scalelike orientation of the graphite flakes parallel to the crucible walls.

Exact specifications for flake for the manufacture of clay-graphite crucibles are trade secrets, and only general specifications can be given. The following are general specifications for Madagascar crucible flake:

Carbon content 85 to 87 percent on a wet basis.
Mesh specifications:

Percent graphite (by weight) retained	*On screen mesh (U.S. standard)*
1–3	+14
8–12	+20
30	+30
40–45	+40
15 (maximum)	+50
2 (maximum)	—50

Mesh specifications vary from manufacturer to manufacturer. The following are general specifications of one manufacturer:

Percent graphite (by weight) retained	*On screen mesh (U.S. standard)*
10	+20
35	+30
45	+40
8	+50
Remainder	−50

During World War II, the War Production Board classified flake graphite according to the following schedule:

Grade	Percent (by weight) retained on screen mesh (U.S. Standard)—							Tolerance	Carbon (percent)
	+20	−20 +30	−30 +40	−40 +50	−50 +70	−70 +100	−100		
1A	8	20	40	27				5	85
1		15	20	60				5	85
1B		5	30	55				10	85
2					90			10	85
3						90		10	80
4							100	10	65

Grades 1A, 1, and 1B would include the range of sizes of material normally regarded as crucible flake.

Graphite for clay-graphite crucibles must meet additional requirements for toughness, cleanness, thickness, and uniformity of flake, and for fusibility of ash. Packing index, a measure of volume per unit weight, must also be satisfactory. The index is determined by comparing volume against weight after the flake has been shaken down in a Ro-Tap machine or similar device. Toughness is measured in terms of the resistance of the flake to comminution and is determined by means of a ball mill or similar device.

At the time of writing (1955), most recent purchase of crucible flake for stockpile had been made under National Stockpile Specification P–22a–R (14 January 1953). The specification was:

P–22a–R
14 January 1953
(Supersedes issue of 1 December 1947)

National stockpile material purchase specifications

Graphite—crystalline flake (crucible grade)

1. Description:
   These specifications cover crystalline flake graphite suitable for use, after usual industry processing, in the manufacture of crucibles.
2. Chemical and physical requirements:
   Each lot of graphite purchased under these specifications shall conform to the following requirements:
   a. Chemical requirements:
      All graphite shall have a minimum graphitic carbon content of 85 percent, on a moisture-free basis. The graphitic carbon content shall be the difference between 100 percent and the sum of the percentages of ash and volatile matter.
   b. Physical requirements:
      All graphite delivered under any contract shall be uniform in quality and free from foreign material.
      Graphite, after processing in accordance with industry practices, shall conform to the requirements of crucible manufacturers for processed crystalline flake graphite, with regard to toughness of flakes, freedom from oil, and freedom from thin or ragged edges.
      A representative 50-gram sample, agitated 15 minutes on a Tyler

Ro-Tap sieve shaker or equivalent machine, shall conform to the following sieve analysis:

Pass U.S. standard sieve	*Percent (by weight)*
No. 8	Minimum—99
No. 20	Maximum—92
No. 30	Maximum—66
No. 40	Maximum—25
No. 50	Maximum— 5
No. 60	Maximum— 3

3. Packaging and marking:
   a. Packaging:
      (1) Iron oxide contamination from the container shall be avoided. Any of the following containers are acceptable, but wooden barrels are preferred:
         (a) Wooden barrels shall be equal to Grade No. 1, Federal Specification NN–B–109: Barrels, wood, slack, and shall have an overlapping inner liner on top, bottom, and sides which shall comply with requirements for Class B–3, Federal Specification UU–P–271b: Paper, wrapping, waterproofed kraft.
         (b) Steel drums equal to Type 6D, Federal Specification RR–D–746: Drums, steel, may be used provided the drums are coated both inside and outside and lined as required by Section 3–a–(1)–(a).
         (c) In an emergency, paper sacks equal to, or other type sacks equal in quality to, Nos. 2X, 9X, or 14X, Federal Specification UU–S–48b: Sacks, paper, shipping, may be used.
      (2) Material in substandard packages in the stockpile shall be repacked in wooden barrels, at first sign of container failure.
      (3) All containers comprising any lot shall be of the same nominal size and shape.
   b. Marking:
      Each container shall be permanently and legibly marked and shall include the name of the product, gross and net weights, Government contract number, and, where applicable, the number of containers. The containers shall not carry a security classification or any marking, other than the contract number, indicating National Stockpile ownership. Appropriate identifying documents shall accompany each shipment.
4. Inspection and analysis:
   Each lot of graphite shall be subject to inspection and analysis by the purchaser or his designee.

So far as the writers are aware, no graphite of any type was being purchased for national stockpiles as of 1959. At that time, the Office of Civil and Defense Mobilization was the source of information on stockpile specifications.

Specification P–22a–R conforms, in a general way, to the specifications for clay-graphite crucible flake laid down by industry, but it is not fully satisfactory. There are no fixed standards for toughness or for smoothness of outline, and nothing is said about character of ash, packing index, thickness of flakes, or rate of oxidation. Graphite brought under this specification is not necessarily equivalent to standard Madagascar flake on which industry practices are based.

The difficulty is that at present (1959) no precise basis for framing specifications exists. A particular graphite may pass rigid inspection and standard laboratory tests but must still be tested in actual use. There is no quantitative basis for appraising the characteristics of flake graphite that determine its behavior under actual commercial conditions. Progress toward this end was made through investigations by Mackles and others (1953) and by Heindl and Mohler (1955), but the proof of usability of any given graphite still rests on successful use in industry.

About 1947 a new type of crucible, the carbon-bonded crucible, was developed by Mr. Kenneth E. Buck of the National Crucible Co. Carbon-bonded crucibles are similar to clay-bonded crucibles except that petroleum coke or coal tar and a highly refractory oxide or silicate, such as corundum, manganese oxide, alumina, chromite, or zircon, are added in small quantities. When this crucible is annealed at high temperature, a thin fused film of highly refractory material forms over the surface. The refractory material protects the graphite from oxidation and the result is a much more durable crucible.

According to Mr. Buck (oral communication, 1950), the carbon-bonded crucible was first manufactured from "Bama flake," at one time one of the standard products of the Bama Graphite mine, which is near Verbena, Ala., and was owned (in 1951) by the Alabama Machinery and Supply Co. Mr. W. W. Doe, Sr., treasurer of the company, furnished the following information on the characteristics of Bama flake:

Volatile matter	1.64 percent
Graphitic carbon	93.14 percent
Ash	5.22 percent
Size	+60-mesh

According to Mr. Buck, Bama flake was consistent and uniform in characteristics and conformed approximately to the following size specifications:

Percent graphite (by weight) retained	*On screen mesh (U.S. standard)*
2	+30
7	−30+40
49	−40+50
16	−50+60
17	−60+80
9	−80

A consignment of 600 tons of Bama flake from the Bama Graphite mine in the midthirties proved wholly satisfactory in the manufacture of carbon-bonded crucibles. When this supply was exhausted the manufacturing process was finally adjusted, after some difficulties, to use of Madagascar flake graphite as a substitute.

The carbon-bonded crucible requires less graphite and finer flake than the clay-graphite crucible. Actually, the lower limit of fineness permissible has not been determined, and there is no reason to suppose that finer flake than that defined above cannot be used. This is an important matter, for the carbon-bonded crucible appears to be displacing the clay-bonded crucible, and if this trend continues, the need for coarse flake will correspondingly diminish.

Several attempts have been made to determine whether commercial graphite from domestic sources is as satisfactory as that from foreign sources for the manufacture of crucibles. Thiessen (1919, p. 508) investigated the relation between the structural and textural characteristics of various foreign and domestic flake graphites and the structures and textures of clay-graphite crucibles made from them to find out why crucibles made from American flake were less durable than those made from Ceylon and Madagascar flake. Stull (1919, p. 208) tested graphite used in clay-graphite crucibles, but domestic flake was compared only with Ceylon flake. Stull and Bole (1923, p. 4) compared graphite from Madagascar and Ceylon with American graphite used in clay-graphite crucibles in the steel industry. As crucibles are now very little used in the steel industry and as the manufacture of clay-graphite crucibles was greatly improved during 1925–55, their findings are no longer of much significance.

R. S. Hodges studied the ash content of flake graphite from three Alabama mines (Jones, 1929, p. 19–21), but it is generally recognized that so long as crucible flake contains at least 85 percent carbon, the kind of ash is more important than the amount. A study of the burning rate of natural graphite by Coe (1943, p. 3) is likewise of limited significance, because burning rate is only one of the elements of the behavior of graphite that determine usability for the manufacture of crucibles.

Sanford and Lamb (1949, p. 15) cite a report of August 25, 1944, by the Mica-Graphite Division of the War Production Board, on tests of domestic flake used by five manufacturers of clay-graphite crucibles. The graphite came from the Benjamin Franklin mine, Pennsylvania, and the Crucible Flake and Ceylon Graphite mines, Alabama. The results were decidedly adverse to the use of domestic flake in clay-graphite crucibles.

Heindl (1952) made tests with flake graphite from Madagascar, from Alabama graphite from the government stockpile, and from the Benjamin Franklin mine in Pennsylvania. Flake from each lot of graphite was prepared by separating it by screening into various size fractions and then combining the size fractions in proportions specified by two crucible manufacturers. Two manufacturers then made carbon-bonded and clay-graphite crucibles by standard commercial procedures, and sent them to six brass foundries for testing in normal use. The crucibles of both types made from domestic flake are stated to have given service equal or even superior to that given by crucibles made from Madagascar flake.

Heindl's work is an important step toward establishing the usability of certain domestic flake graphites for crucibles. Some questions still unanswered, however, have an important bearing on appraisal of graphite from the two domestic mines represented: First, what proportion of the total flake recoverable from the Alabama deposit is represented by the stockpile lot from which the test flake was prepared? Second, what proportion of the stockpile lot is represented by the test materials prepared? Similar questions arise for the graphite from the Benjamin Franklin mine, although a partial answer is given by the report (Lamb and Irving, 1955, p. 5) that 25 percent of the product of experimental mining and milling at the mine during 1953 and 1954 was +50-mesh flake, suitable for crucible flake.

Results of tests described above cannot be applied to domestic deposits as a group because only a few domestic flake-graphite deposits have been worked during the years 1925–55. Graphite available for testing during this period thus could come from only a small fraction of the total number of domestic deposits. General conclusions as to the usability of domestic graphite are therefore not possible at the present time.

It should be emphasized that crucible manufacture, either clay— or carbon–bonded, is not a standardized procedure. Differences in the size, toughness, density, or other physical properties of any one of the ingredients may have a marked effect on the durability of the final product, and a change in one constituent may require changes in the others. For example, certain types of graphite work best only with a few types of clay; to change one requires changing the other as well. Differences in handling, drying, curing, and annealing may also affect the life of a crucible. The properties that control the behavior of each ingredient, individually and in combination with the other ingredients, are not completely understood. Manufacturers try various combinations and proportions until they find a formula that yields an acceptable product. This formula often becomes a closely guarded secret, and how satisfactory it would be if substitutions were made may not be known. In a business as small and as highly competitive as the graphite industry, cost makes extensive experimentation almost impossible. Owing to this and to the secrecy that quite understandably surrounds successful formulas, the public record of the physical properties controlling the quality of the crucibles produced is incomplete, and the evaluation of graphite from any one source is correspondingly difficult. Some facts, however, are well known. Crucible graphite must be at least 85 percent carbon, and certain mineral impurities are recognized as being more detrimental than others. As quartz sand and clay are usually added in fabrication, their presence in moderate amounts is not objectionable, nor are small amounts of feldspar and zircon. Mica is considered the most undesirable impurity; it fluxes readily and causes pinholing in the crucible walls. Calcite, pyrite, and pyrrhotite are also detrimental. The calcite decomposes, and escaping CO_2 causes blowholes in the crucible walls that, weakened, tend to crack when heated. The iron sulfides also decompose when heated, add sulfur to the charge, and cause holes, spots, and cracks in the crucible.

Similar problems and practices exist in the fabrication of other refractory products that contain graphite. In general, however, it may be said that while the problems are the same, they are less serious than those in crucible manufacture, mainly because the articles are subjected to less stress in use.

An additional refractory product that requires graphite is brick for furnace linings. This type of brick is heat-resistant and has the advantage of providing a furnace lining that does not react with slags or stick to them. Specifications for the graphite used in the bricks are not known to the authors.

LUBRICATING COMPOUNDS

Lubricating compounds absorb another large segment of the strategic grade of graphite. For this use a different group of properties is important. Spence (1920, p. 155), in summarizing these properties, says:

> Graphite possesses a very low coefficient of friction, a property that it retains under practically all working conditions. In addition, it is soft and readily adheres to metallic surfaces under light pressure, filling up the pores in the metal and smoothing the microscopic roughness of the surfaces in rubbing contact. The surfaces thus coated are covered with a veneer of graphite which reduces their coefficient of friction to practically that of graphite itself and

also serves to protect them from the action of corrosive solution or vapours. This applies especially to cylinder lubrication, where high pressure steam, oil or gas is used. Under such conditions oil and grease tend to lose body or to char or vapourize under the action of the heat and vapour to which they are exposed, and graphite has now largely supplanted lubricants of the above nature for cylinder lubrication.

Graphite is used in lubricants wherever very high temperatures, corrosive materials, or extreme pressures are expected. It is also used wherever the presence of a liquid lubricant is undesirable, as in certain musical instruments, or where wooden surfaces are involved.

Requirements of composition and purity of graphite used for lubricants are quite different from those for crucible manufacture. Purity requirements are generally much higher, chiefly because the common impurities are abrasive. Such impurities as quartz, feldspar, zircon, garnet, and pyroxene would obviously be detrimental in a lubricant. Iron sulfides are also objectionable. They are abrasive and also break down to form sulfuric acid, which corrodes metal surfaces. Free sulfur is undesirable for the same reason, as is an unduly low pH of the compound. Calcite and clay are less abrasive but still undesirable. Mica is almost the only impurity that can be tolerated in significant amounts.

Lubricants made wholly or partly of graphite include a wide variety of products, the graphite in each of which conforms to specifications laid down by the manufacturer or worked out jointly by the manufacturer and supplier. These specifications, like those for crucible flake, are trade secrets, and there are no standard specifications to which one can refer. The lack of such data has inevitably hampered attempts to define, for purposes of stockpiling, what is meant by lubricant- and packing-grade graphite. Two principal points of view have been expressed. One view is that if flake comparable to the high grades of Madagascar flake (about 87 to 90 percent graphitic carbon) is stockpiled, all necessary types of lubricant- and packing-grade graphite can be made therefrom by appropriate processing. A stockpile composed of this flake will have maximum flexibility, because the processing of the flake can be modified to produce types according to demand. The advocates of this procedure have stated that a single specification for graphite for stockpile would suffice and that there is no need for setting up a series of specifications for different grades.

This view is based to some extent on experience and practice in the preparation of lubricant- and packing-grade graphite from Madagascar flake, the principal source. In part, however, it is also based on the belief that for most commercial lubricants coarse flake is necessary. From this standpoint, Madagascar flake is ideal, owing to the large amount of coarse flake it contains.

Others, however, question this view, believing that coarse flake is unnecessary for the majority of lubricants and packings materials. They maintain that, because in use the coarse flake rapidly breaks down into fine particles, there is no advantage in using the coarser, more expensive grades, and that, therefore, finer sizes of flake can be accepted for stockpiling. This has been a serious matter for the domestic graphite industry, because domestic deposits have yielded only a small proportion of +50-mesh flake. If a single specification based on Madagascar flake had been set up, domestic graphite would automatically have been excluded from the stockpile, and an important potential outlet for domestic graphite would have been closed.

The controversy was settled by a canvass of consumers, which showed that large amounts of pulverized flake are used. The following specifications were therefore established for grades of graphite acceptable for the stockpile:

P-22b-R
16 December 1952
(Supersedes issue of
22 May 1951)

National stockpile material purchase specifications

Graphite—Crystalline Flake (Lubricant and Packing Grade)

1. Description:
   These specifications cover five grades of crystalline flake graphite suitable for use in lubricants and graphite packings.
2. Chemical and physical requirements:
   Each lot of graphite purchased under these specifications shall conform to the following applicable requirements:
   a. Chemical requirements:
      The graphitic carbon content shall be the difference between 100 percent and the sum of the percentages of ash and volatile matter. The graphitic carbon content, on a moisture-free basis, for each grade shall be as follows:

Grade	*Graphitic carbon (minimum percent)*	*Ash-plus-volatile (maximum percent)*
A—Large flake	95	5
B—Medium flake	95	5
C—Small flake	95	5
D—Fine flake	95	5
E—Extra fine flake	[1] 96	4

[1] The graphitic carbon content for Grade E may be a minimum of 95 percent with a maximum ash-plus-volatile content of 5 percent for graphite which has an abrasive loss of less than 4 milligrams; otherwise, the minimum graphitic carbon content shall be 96 percent.

   b. Physical requirements:
      Oil shall not show on the surface when a heaping teaspoon of a representative sample is placed in a one-liter beaker of distilled water.
      All graphite in any lot shall be uniform in quality and free from foreign material.
      All graphite shall have an unctuous feel.

Abrasion loss shall not exceed 5 milligrams of the weight of the brass disk when determined as specified in Section 4.

A representative 100-gram sample, agitated for the time specified on a Tyler-Ro-Tap sieve shaker or equivalent machine, shall conform to the following sieve analysis:

Grade	*Pass U.S. standard sieve*	*Percent (by weight)*
A—Large flake (agitate 15 min.)	No. 20	Minimum—95
	No. 50	Maximum—40
	No. 100	Maximum—2
B—Medium flake (agitate 15 min.)	No. 50	Minimum—95
	No. 100	Maximum—15
C—Small flake (agitate 15 min.)	No. 100	Minimum—70
	No. 200	Maximum—30
D—Fine flake (agitate 30 min.)	No. 100	Minimum—98
	No. 200	Minimum—95
E—Extra fine flake (agitate 45 min.)	No. 100	Minimum—99½
	No. 200	Minimum—98
	No. 325	Minimum—95

3. Packaging and marking:
   a. Packaging:
      (1) Iron oxide contamination from the container shall be avoided. Any of the following containers are acceptable, but wooden barrels are preferred:
         (a) Wooden barrels shall be equal to Grade No. 1, Federal Specification NN–B–109: Barrels, wood, slack, and shall have an overlapping inner liner on top, bottom, and sides which shall comply with requirements for Class B–3, Federal Specification UU–P–271b: Paper, wrapping, waterproofed kraft.
         (b) Steel drums equal to Type 6D, Federal Specification RR–D–746: Drums, steel, may be used provided the drums are coated both inside and outside and lined as required by Section 3–a–(1)(a).
         (c) In an emergency, paper sacks equal to, or other type sacks equal in quality to, Nos. 2X, 9X, or 14X, Federal Specifications UU–S–48b: Sacks, paper, shipping, may be used.
      (2) Material in substandard packages in the stockpile shall be repacked in wooden barrels at first sign of container failure.
      (3) All containers comprising any lot shall be of the same nominal size and shape.
   b. Marking:
      Each container shall be permanently and legibly marked and shall include the name of the product, grade, gross and net weights, Government contract number, and where applicable, the number of containers. The containers shall not carry a security classification or any marking, other than the contract number, indicating National Stockpile ownership. Appropriate identifying documents shall accompany each shipment.

4. Inspection and analysis:

Each lot of graphite shall be subject to inspection and analysis by the purchaser or his designee.

The abrasion loss test shall be as follows: Apparatus for the abrasion loss test shall consist of a smooth-bottom brass container 2½ inches in diameter and ¾-inch in depth. A brass disk 2 inches in diameter, polished on one face, and weighing approximately 60 grams, shall be connected to a shaft and rotated under a weight of 4 pounds. Any other suitable apparatus for determining abrasion loss may be used.

Thirty grams of a 15 percent suspension of graphite in oil complying with Grade 8, Federal Specification VV-O-581, shall be placed in the container and the polished, weighted disk shall be placed upon the graphite and connected to the shaft. The disk shall be rotated 2,000 revolutions at 100 rpm, removed, washed with chloroform, wiped clean, allowed to come to room temperature, and weighed to a fraction of a milligram. This procedure shall be repeated twice and the total loss in milligrams for the 6,000 revolutions shall be the abrasion loss.

For comparison, Air Force-Navy Aeronautical Specification AN-G-24a, September 14, 1948, for one grade of lubricant graphite is summarized as follows:

Type of graphite: Natural or manufactured.

Must be free of abrasives or other undesirable impurities as defined below.

Ash content not greater than 2 percent by weight.

Graphite-carbon content not less than 96 percent by weight. Carbon content is defined as 100−(ash+volatile matter).

Acidity: pH not less than 5.0 nor more than 9.0.

Abrasion: To be determined by the apparatus described below. Loss of weight of brass disc shall not exceed 5 milligrams.

Size: (a) No residue on 100-mesh screen.

(b) Not more than 2 percent retained on 200-mesh screen. Residue on 200-mesh screen must be free from hard particles.

The apparatus for determining abrasion consists of a brass disc that is rotated under a load of 4 pounds at a speed of 100 rpm in a metal cup containing a weighed sample of graphite in an oil suspension. The disc is carefully cleaned and weighed before the test, then rotated for 1,000 revolutions, weighed again, and rotated once more. This procedure is continued for a total of 6,000 revolutions.

Flake of at least 92 percent purity is used for most lubricants that contain graphite. Some consumers, however, prefer either natural or artificial amorphous graphite to crystalline flake graphite, particularly for compounds having heavy oil or grease as a suspension medium. The finer sizes of graphite are essential in preparing very thin penetrating suspensions.

Graphite is also used in packings and bearings. Graphite packings have the same advantages as graphite lubricants. Bearings that contain graphite and are therefore partly or wholly self-lubricating have also been made. These uses absorb small amounts as compared with lubricating compounds.

BRUSHES

The use of graphite in the manufacture of carbon brushes for electric motors is minor from the standpoint of tonnage but extremely important strategically. The softness and high electrical conductivity of pure graphite make it ideal for this purpose. Graphite for this use must be very pure and must contain no abrasive material that would quickly wear grooves in the soft copper of the commutators. High-performance electric motors, such as those used in aircraft accessories, consume a large part of the output of the carbon-brush industry. Graphite brushes are especially desirable in aircraft because they reduce sparking, particularly in the rarified atmosphere of high altitudes. They are also self-lubricating—an important advantage, as any liquid lubricant tends to collect dust and grit, which may cause excessive wear.

In manufacturing, graphite for brushes is formed into slabs under high pressure, after which it is baked, cooled, and sawed into the desired shapes. Varying amounts of clay, petroleum coke, or coal tar may be added to act as a binder and to control the hardness.

NONSTRATEGIC USES

This report is concerned primarily with the strategic uses of graphite, but brief descriptions of other uses are pertinent, because nonstrategic graphite is almost inevitably produced by operations for strategic graphite. The two uses of graphite are therefore elements of a single economic problem.

BATTERIES

A sizable quantity of graphite is used annually in dry cells for portable radios and flashlights. Graphite is added to manganese oxide to give the oxide better conductivity and to act as an absorbent material that furthers the chemical reactions of the cell.

Graphite for batteries must contain 85 percent or more carbon, must have a low Fe_2O_3 content, and must contain no metals, heavy-metal oxides, or sulfides. Metals or sulfides, especially copper in any form, will cause reaction with the zinc in the batteries, with resulting loss of shelf life and poorer general performance. Comparatively inert minerals, such as quartz and mica, are not considered particularly detrimental. Fine material is normally preferred; both natural amorphous graphite and finer grades of flake and chip graphite have been used. Manufactured amorphous graphite is also satisfactory but is generally more expensive than natural graphite.

As specifications are not rigid and any fine graphite free of metals and sulfides can be used, battery-grade graphite is not considered strategic. Furthermore, most battery makers are now using compounds such as acetylene black in their better grades of batteries. Acetylene black gives better performance and longer shelf life, partly because of its finer size and greater absorbent capacity.

FOUNDRY FACINGS

The largest single use of graphite is for foundry facings. Graphite is applied to molds to provide smooth surfaces that will not adhere to the metal casting. The graphite is mixed with a small amount of clay and then suspended in an adhesive material such as glue or molasses water. The mixture is applied as a thin coating.

Flake graphite is preferred for foundry facings, but natural amorphous graphite is also used in large quantities, partly because of its lower cost. Purity requirements are low. Sulfides are objectionable in the material, but any of the other common mineral impurities are tolerated in considerable quantities. As impurities are not harmful, low-grade, low-cost, fine-grained flake or amorphous graphite can be used. These lower grades are readily available and are not considered strategic.

STEELMAKING

The tonnage of natural amorphous graphite used in recarburizing steel actually makes this an important use. High-purity graphite, however, is unnecessary for this purpose, and carbon in other forms (coal or coke) can be substituted.

PENCILS

This most familiar use of graphite is still of some quantitative importance. Pencil "leads" are formed by mixing graphite and clay. Stibnite, lampblack, or even metallic lead, are sometimes added to give special qualities. Mixtures are extruded from dies under pressure, then dried, fired, and placed in grooved pieces of wood to form the pencils. Hardness is controlled by varying the amount of clay and the firing temperatures.

Either amorphous or flake graphite can be used for pencils, and in the United States both Ceylon graphite and Mexican amorphous graphite are employed. Impurities are not important unless hard and gritty. Ordinarily, graphite containing at least 85 percent carbon is preferred, and it is ground as fine as possible to assure uniform texture and writing qualities in the final product. Manufactured amorphous graphite is also sometimes used.

PAINTS

Graphite has been used as a pigment in special purpose paints intended to protect surfaces from steam or corrosive smoke or fumes. Its chemical inertness makes it ideal for protecting smokestacks, tanks, pipes, railroad cars, roofs, and other metal surfaces exposed to unusually rigorous conditions.

Pure graphite mixed with a standard base, such as linseed oil, makes a very poor paint (Spence, 1920, p. 158-159). Graphite fine enough to be useful as a paint pigment will flow and spread very readily and form a film too thin to be of value as a protective coating. The use of impure graphitic rocks or the addition of other materials to the paint is necessary to eliminate the spreading characteristic. Impure graphitic slates are used extensively as paint pigments. The rock is ground to the desired fineness without concentration. Rocks containing as little as 25 to 30 percent graphite are thus used without treatment other than grinding. The only impurity that may cause rejection is iron sulfide; this will break down and form sulfuric acid which attacks the metal surface the paint is supposed to protect.

Natural amorphous graphite is the type most used in paints, but other types are equally satisfactory, provided some other inert material is added to prevent excessive spreading. Because of the low purity requirements, graphite for paints is available in large amounts from many sources and is not considered of strategic importance.

OTHER USES

Graphite is also used for a variety of other purposes, including electrodes, brake linings, coatings for tea leaves, coffee beans, and smokeless powder grains (to protect the grains from moisture and to make them flow easily), stove polish, fertilizer and hard rubber fillers, and many other minor uses, such as electrotyping and elimination of boiler scale. None of these uses requires large quantities of graphite or graphite of extreme purity, and they are therefore not considered strategic. The development of atomic piles resulted in rather extensive use of graphite for the insulating rods that absorb the radiation and control the rate of reaction. Manufactured amorphous graphite is used exclusively for this purpose, because of the very high degree of purity necessary.

PRODUCTION

DOMESTIC PRODUCTION

HISTORY

The localities of the principal graphite deposits of the United States are shown in figure 12. Graphite production in the United States began between 1644 and 1648 at Sturbridge, Mass. (Haynes, 1901), but between this time and about 1850 production, which came from scattered operations in New England, New York, and New Jersey, apparently was low and sporadic. During the period 1850–1900 deposits in New York, New Jersey, Alabama, Pennsylvania, Michigan, Texas, California, Nevada, and Rhode Island were explored and developed, and a domestic graphite industry came into being. From the 1850's to 1900, the mines of the Joseph Dixon Co. near Ticonderoga and Lake George, N.Y., were the principal domestic source of flake graphite, but about 1900 mines in Alabama and eastern Pennsylvania began intermittent production of substantial amounts of flake graphite. In 1911 Alabama took first place as a producer of flake graphite, a position that she maintained until after World War II. From about 1946 to 1954, Texas and Alabama produced nearly equal amounts of flake graphite. By the end of 1954, however, only a deposit of amorphous graphite in Rhode Island was being mined; all flake-graphite production had stopped, although production in Texas was scheduled to be resumed in 1955.

Amorphous graphite was apparently first mined in quantity from deposits in Rhode Island, North Carolina, California, and Nevada, then later in Michigan, Wisconsin, and other States.

Records of domestic graphite production prior to 1882 are lacking. In 1882, 212.5 short tons, mostly from New York, was reported, and between 1882 and 1900 production increased irregularly to about 2,750 short tons per year. The first record of amorphous graphite production shows a total output of 2,793 short tons during 1895. No satisfactory breakdown of figures for the year before 1909 is possible, because until then the flake-graphite production of Alabama and Alaska was erroneously classified as "amorphous," and the low-grade graphitic slates of Georgia were also included under amorphous graphite. Figures 14 and 17 show total domestic production of amorphous graphite and strategic grades of graphite (flake) for the period 1910 to 1949, as far as figures are available. Data for the years 1929 to 1939 are approximate; the figures used are estimates based on averages given in the U.S. Bureau of Mines Minerals Yearbooks for these years. No graphite production is recorded for 1940 and 1941. The figures for strategic grades include 2,200 tons of lump (Ceylon-type) graphite produced in Montana between 1914 and 1937, mostly during the years 1914 to 1918.

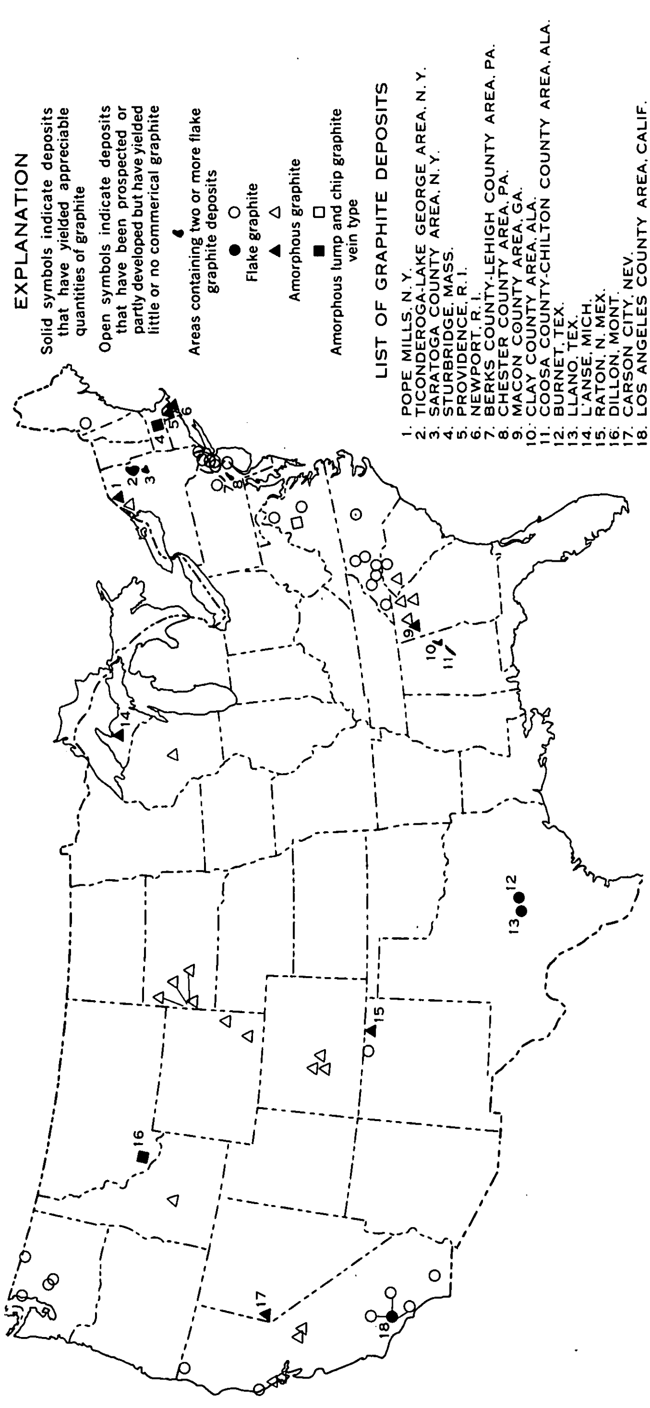

FIGURE 12.—Map of localities of principal graphite deposits, areas of substantial yield, and types of graphite found in the United States.

For the years 1942 to 1949, separate figures for production of amorphous graphite and flake graphite are not available.

The graphs emphasize the vicissitudes of the domestic mining industry. The irregular increase in production after 1900 culminated in the all-time record production of nearly 13,600 tons in 1917. After 1917, both total production and production of strategic grades declined irregularly until 1932. In that year and until 1942 total production was only a few hundred tons annually. In 1942 World War II brought about a revival of the industry, and a peak production of 9,016 tons was reached in 1943. Production declined from 1944 to 1947. A sharp increase to 9,026 tons took place in 1948, but from 1949 production declined. In 1953 production was about 5,000 tons.

FACTORS INFLUENCING DOMESTIC PRODUCTION

The principal factors which have contributed to the irregularity of domestic production have been competition from low-cost sources abroad, inability of single mines to produce a wide variety of acceptable grades of graphite, limitations of the market for graphite, inability of individual producers to assure the industry of a continuing supply of uniform graphite products, technological changes in the consuming industries, fluctuations in the general world level of economic activity, and strategic factors. All these factors are interrelated in some degree, but for convenience of discussion they are treated separately below.

Competition from sources abroad.—The better domestic flake-graphite deposits are neither exceptionally high nor exceptionally low in tenor. In general they average from 2 to 8 percent flake graphite. Flake-graphite deposits in Madasgascar have been reported to yield ore containing as much as 60 percent flake graphite (Redfield, 1920, p. 258–262)), but 10-percent ore was considered workable as long ago as 1917 and ore carrying as little as 4 percent has been worked. Laplaine (1950) in a report on certain deposits of the east coast of Madasgascar stated that ore containing 5 to 8 percent graphite was being worked at one mine, and ore containing 4 to 5 percent at another. In New York and Texas the deposits worked are in unweathered rock, but in Alabama and Pennsylvania weathered ore is available in quantity, as it is in Madagascar. It is commonly stated in the industry that a part of the problem is relaive cost of production. The low cost of labor in Madagascar is often cited as an important factor in the favorable competitive position held by that country in the flake-graphite market; however, it is not clear to what extent this has been a factor. Cost data for American mines currently active are not matters of publication, and data for the operations of the past are not on record. In 1956 standard Madagascar flake (85 to 87.5 percent carbon) sold at $235 per metric ton, or approximately $0.11 per pound, f.o.b. New York. The price for Madagascar flake delivered in New York probably is not far different from the production costs per pound for average domestic flake, but average domestic flake does not command so high a price. Part of the differential in labor costs may be offset by the greater mechanization of American mines.

Much of the fluctuation in domestic production of flake graphite has been attributed to poorer quality of domestic flake compared with foreign graphite. Prior to World War I, the principal foreign source of graphite was Ceylon, which was considered to produce the best graphite available, especially for crucible use. Since World War I, the principal competition has been with Madagascar flake, although Ceylon graphite continues to be in limited demand for crucible manufacture and for special products, such as carbon brushes, which require lump graphite of high quality. Graphite from Ceylon and Madagascar is considered superior to domestic graphite in uniformity and is said to be more carefully graded. Furthermore, domestic operators have not been generally successful in producing high-carbon graphites, and Ceylon and Madagascar graphite has supplied the market with these grades.

Because of its superior thickness, toughness, and coarseness Madagascar flake has been preferred to domestic flake by industry for clay-graphite crucibles and as a base material for the manufacture of lubricant and packing grade graphites. Since World War I, domestic consumers have in general turned to domestic flake only when the supply of graphite from abroad has been curtailed. This has happened twice since World War I, during part of World War II and during the inception of a more active defense program in 1948. Both periods were marked by increase in domestic production.

Range of types of domestic flake.—In normal times Madagascar flake graphite comes from ten or more mines. Some of these have produced graphite for many years, and the characteristics of their products are well known to the purchasers. Importers of graphite process the flake as received and also blend flake from different deposits; thus they produce a variety of grades and qualities of flake. Domestic production, on the other hand, is normally derived from only a few mines, and at the time of this report no domestic operator had produced from more than one mine. In competing with the imported graphite, the domestic operator's market is limited according to the characteristics of the flake in his deposit. Blending to obtain a wide variety of products is therefore impossible.

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Limitations of the market for graphite.—The market for graphite in this country is small. During the period 1910 to 1948, total domestic consumption of graphite ranged from about 8,000 tons to nearly 63,000 tons annually; average consumption of all grades was about 30,000 tons. Since 1940, consumption has ranged from 30,000 tons to peaks of 63,000 tons in 1948 and 1951. Totals for both the latter years, however, include about 35,000 tons of amorphous graphite from Mexico, which in 1956 sold for $9 to $18 per metric ton, f.o.b. Mexico. This price provides an extremely favorable competitive position. Even if a domestic operator were able to furnish graphite of every grade required by industry and just the right proportions of the various grades, his potential market would not be great. If he could capture the entire market for natural graphite, his total sales would be a few million dollars per year. Actually, no operator is able to produce all these grades; hence, even if costs were of no significance, he could compete only in a limited part of the market. It seems probable that even maximum success could not result in sales of more than $2 million per year. The incentive toward large investment and toward the extended research and sales effort necessary to develop acceptable products and find markets for them is therefore not great. (See Tyler, 1929d, p. 1–2.)

An important factor determining the potential value of a graphite deposit is the range in prices of the possible marketable products. There are two ways to determine the value of graphite from a given deposit. One is based on the price that the graphite may bring after extraction, milling, and concentration, but with no further treatment: what may be termed crude graphite. The other way to determine its value is to estimate its sales price after the crude concentration has been separated into various marketable finished products, such as lubricating flake, crucible flake, and so on. Prices of flake graphite during the period 1910 to 1956 are given in figure 13. Estimates of the market value of crude graphite can be made from the following more or less standard prices:

Flake graphite:
- Standard Madagascar flake, 85 to 57 percent carbon, $235 per ton, c.i.f. New York, 1956.

Amorphous lump and chip (prices for 1949; later prices unavailable):
- Ceylon lump, 10 to 14 cents per pound, f.o.b. New York.
- Ceylon carbon lump, 10 to 11 cents per pound, f.o.b. New York.
- Ceylon chip, 8 to 9 cents per pound, f.o.b. New York.
- Ceylon dust, 4 to 6 cents per pound, f.o.b. New York.

Amorphous graphite:
- Mexico amorphous, $9–$18 per metric ton, f.o.b. mine (1956).

These prices are significant to the domestic producer, however, only if he sells his product crude or semifinished to the importers of foreign graphite, in which case the prices he receives will depend

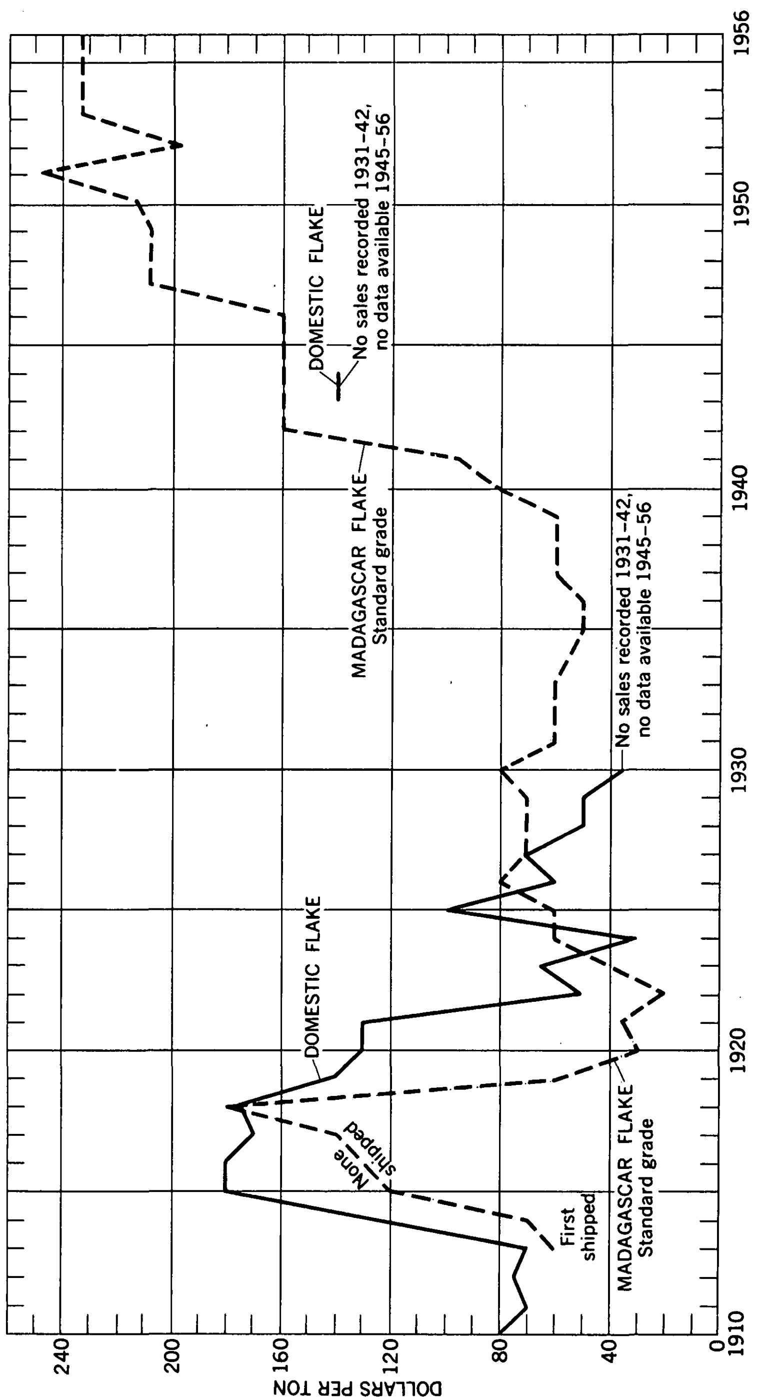


FIGURE 13.—Flake graphite prices, 1910–56. Data from U.S. Geological Survey Mineral Resources volumes and U.S. Bureau of Mines Minerals Yearbooks.

on the quality of his product relative to that of the imported graphites. Because domestic flake graphite is, in general, in disfavor among consumers, he must sell at lower prices than those quoted for imported flake. Furthermore, much of his product will consist of the finer grades of flake and will command a price that may be as low as 4 cents per pound. Under these circumstances, the changes of profit are small.

The alternative is to enter into production of finished grades of graphite. This is difficult. He must first develop his processing methods to the point at which he can give assurance of uniform products; then he must establish their usability with individual consumers. The returns from such a venture can be learned only after a long period. Furthermore, prices for finished grades of graphite vary over a wide range, probably from 4 cents per pound to more than 40 cents per pound. There are no standards; most sale prices are the result of specific negotiations with various users. The producer must interest customers for all his products, and the sizes of contracts must be adjusted to the proportion of the various grades that he is able to produce. The producer's most likely opportunity for profit lies in the wide spread between the sales prices of crude graphites and those of finished graphites.

Inability to assure consumers of a steady supply of uniform grades of graphite.—The history of the domestic graphite industry is now one of its principal liabilities. It is marked by a long succession of ventures, most of which have been short-lived failures. Domestic production consequently has fluctuated widely both in tonnage and grades of graphites produced. In contrast to this, the supply of the principal grades of graphite from abroad has been steady, and several organizations have specialized in converting the imported materials into the particular grades required by industry. Under these circumstances, the consumer is reluctant to place reliance on domestic sources, particularly because time-consuming and costly changes in his manufacturing processes must often be made if he changes his sources of material. A domestic operator newly entering into graphite production therefore faces a long and difficult struggle to convince potential consumers, first, of the quality of his products, and second, of his ability to furnish steady supplies of uniform materials. This necessity has unquestionably been a deterrent to domestic production.

Technological changes in the consuming industry.—Technological changes in the industries that consume graphite have had a heavy influence on domestic production (figs. 14 and 15). The peak use of graphite was from 1912 to 1920. During this period the greatest use of flake was in the manufacture of crucibles for the steel and other metal industries (table 1). According to Gwinn (1949, p.

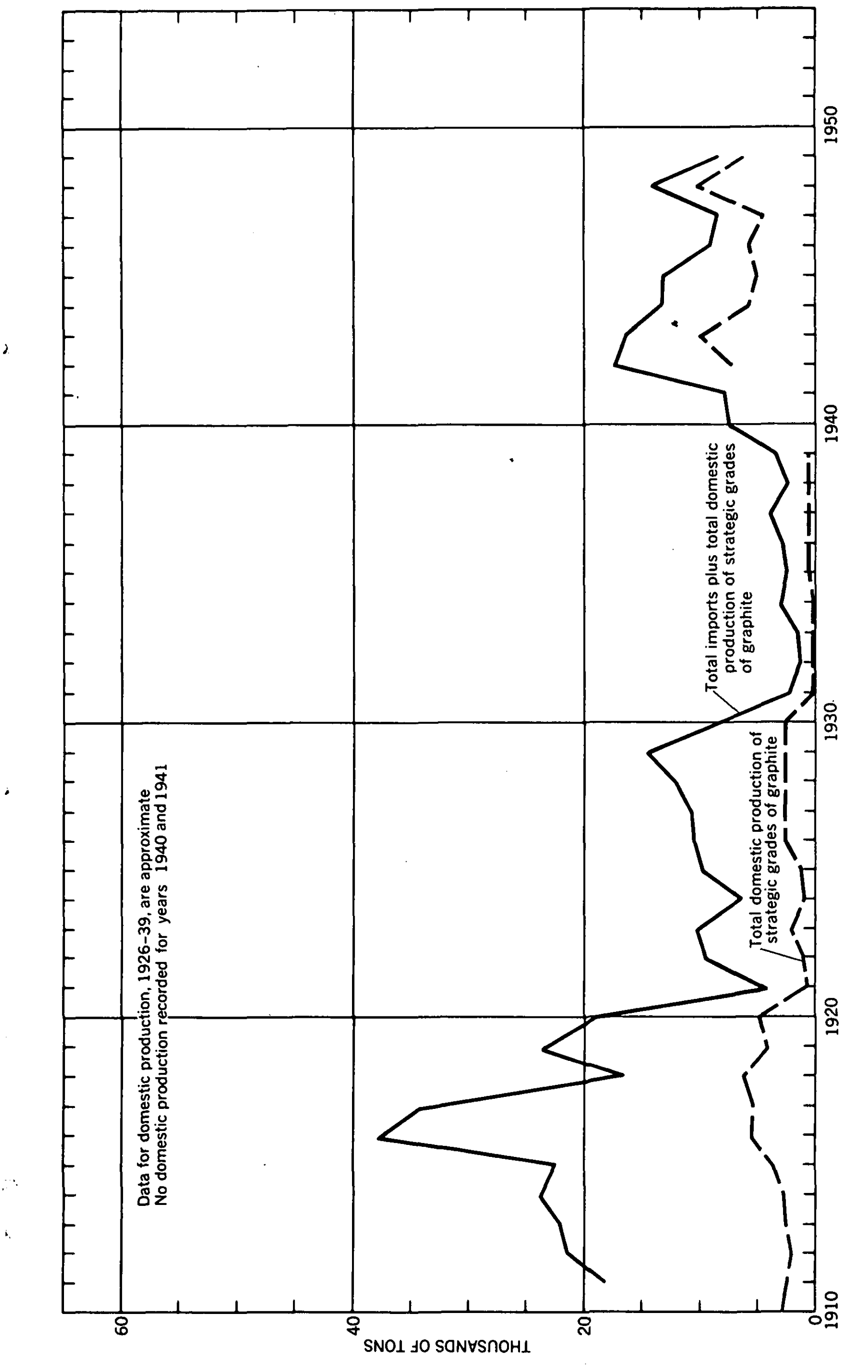


FIGURE 14.—Supply of strategic graphite for United States, 1910–48. Data from U.S. Geological Survey Mineral Resources volumes and U.S. Bureau of Mines Minerals Yearbooks.

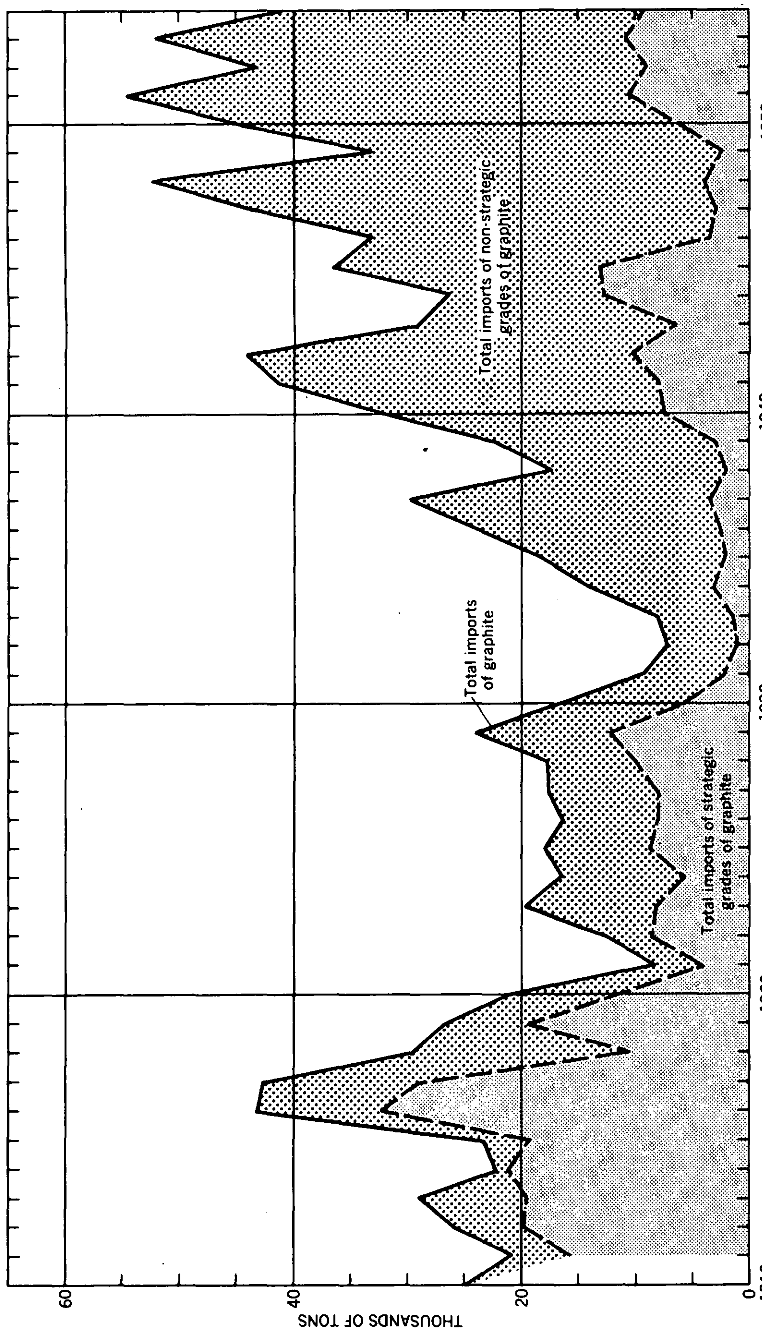


FIGURE 15.—Graphite imports, 1910–54, by types. Data from U.S. Geological Survey Mineral Resources and U.S. Bureau of Mines Minerals Yearbooks.

427), the peak of crucible flake consumption was reached in 1912 at 20,000 tons. Beginning about 1920, use of crucibles in the steel industry was abandoned, and their use is now largely restricted to the nonferrous metal industries. In addition, crucibles have been improved so that they will withstand more heat than formerly. Still a third factor is the development of the carbon-bonded crucible, which requires less flake than the clay-graphite crucible. The effect of these three technological changes has been a marked decrease in the use of crucible flake. In 1954 only about 2,715 tons was used for this purpose. As crucible manufacture was once one of the principal outlets for the better grades of domestic flake, the effect of this decrease, together with the increasing preference for Madagascar flake, has been detrimental to the domestic industry.

TABLE 1.—*Consumption, by uses and percentage, of natural graphite in the United States during certain years from 1918 to 1953*

[Compiled from statistics of the U.S. Bureau of Mines, as listed in Mineral Resources of the United States (1918-31) and in the Minerals Yearbooks (1934-53)]

Use	Year					
	1918	1923	1924	1933	1949	1953
Crucibles	45	12.5	10.7	17.6	12.5	9.7
Retorts, stoppers	(1)	1.3	1.0	(1)	6.2	(1)
Sleeves, nozzles	(1)	(2)	(2)	(1)	(3)	(1)
Stove polish	5-10	1.9	1.3	3.7	(4)	(4)
Paints, pigments	2.5	13.3	15.1	8.6	1.1	1.9
Foundry facings	25	37.0	43.1	37.8	33.9	34.4
Batteries	(3)	.2	.3	(3)	16.1	5.7
Lubricants, packings, bearings	10	2.7	2.3	11.2	15.3	15.5
Pencils and crayons	2.5	7.5	4.4	12.1	5.2	4.6
Brushes	(3)	7.2	4.0	3.4	(3)	1.4
Semifinished products	(3)	15.3	16.5	(3)	(3)	(3)
All other	5-10	1.1	1.3	5.6	9.7	26.8
Total (rounded)	100.0	100.0	100.0	100.0	100.0	100.0

1 Included in crucibles.
2 Included in all other.
3 Included in retorts, stoppers.
4 Included in paints, pigments.

The development of the carbon-bonded crucible may be beneficial to the domestic industry. This type of crucible does not require the coarse flake needed for clay-graphite crucibles; hence the inability of domestic operators to produce a high proportion of coarse flake should be less of a handicap than formerly. Whatever benefit they may derive from extension of the use of carbon-bonded crucibles, however, may be partly offset by a decline in the total amount of graphite used in crucibles.

The increase in consumption of graphite is largely due to increased use of amorphous graphite, chiefly that from Mexico. The strong competitive position of Mexican graphite, however, suggests that the domestic producer cannot hope to capture any sizeable part of this market so long as the Mexican supply continues to be available at low prices.

There have been other changes in the industry, but none of such importance to the domestic industry as those listed.

Economic and strategic factors.—A final factor influencing domestic production has been the overall level of domestic and worldwide industrial activity. Plate 8 and figures 16 and 17 show the effects of the great depression of the 1930's, when domestic production of all grades of graphite nearly ceased. In general, graphite production has risen as business has improved. Superimposed upon the effects of industrial activity, however, are the even greater effects of war. During both World Wars shipments of graphite from Madagascar and Ceylon were curtailed at the very times when industrial demand was highest. During these periods domestic production reached its peaks.

For a time after World War II, an additional factor contributing to the maintenance of a small domestic graphite industry was the emphasis on stockpiling strategic minerals. Part of the stockpile was supplied from domestic sources, and prices set under purchase contracts enabled the producer to make a profit. All contracts for stockpile objectives, however, were either filled or let by 1953 (Lamb and Irving, 1955, p. 334). Barring actual conflict, the domestic operator's ability to survive will depend on his success in competing in the industrial market.

DOMESTIC CONSUMPTION

The history of domestic graphite consumption is parallel in some respects to the record of production but markedly different in others (fig. 17). From 1860 to 1953, domestic consumption exceeded and during most of the period it ranged from 4 to 8 times above production. The same was true, in general, for strategic graphite, except that most of the domestic strategic graphite produced from 1942 to 1949 was absorbed in stockpiles. The principal changes in domestic consumption are the relative decline in the use of crucible flake, the development of the carbon-bonded crucible, and the increase in consumption of amorphous graphite (table 1).

WORLD PRODUCTION

World production of all types of graphite, by countries, is given in plate 8 for 1910 to 1955. The principal producing localities are shown in figure 18. Two peaks of production were reached during the First and Second World Wars, and the highest production of all time was reached in 1943. After both wars there was a precipitous drop in production; the drop after the Second World War was particularly severe. A third peak, in 1955, was due largely to greatly increased production from Korea.

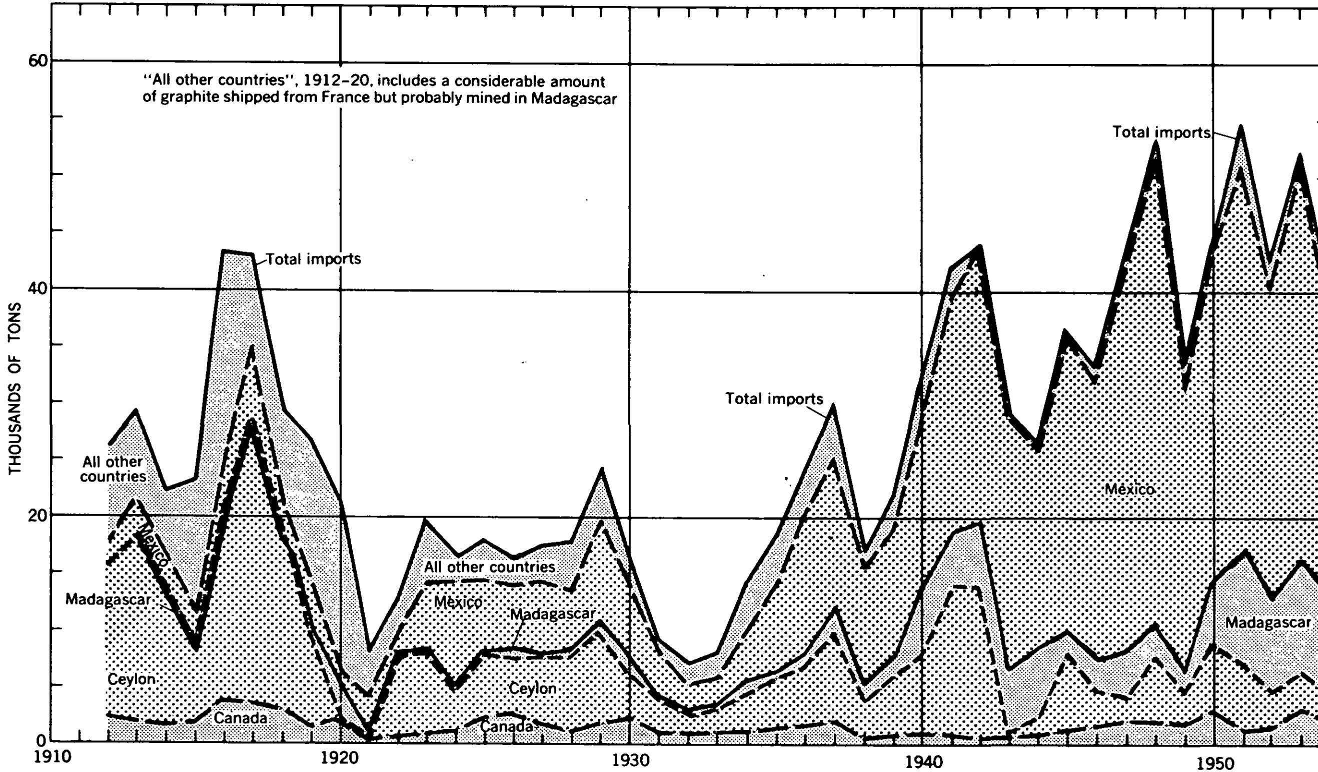


FIGURE 16.—Graphite imports to the United States, 1912–54, by countries of origin. Data from statistics of the U.S. Bureau of Foreign and Domestic Commerce, from U.S. Geological Survey Mineral Resources volumes, and from U.S. Bureau of Mines Minerals Yearbooks.

NOTE: Data for 1948 and 1949 were taken from Dept. of Commerce statistics and do not correspond with figures given by Bureau of Mines.

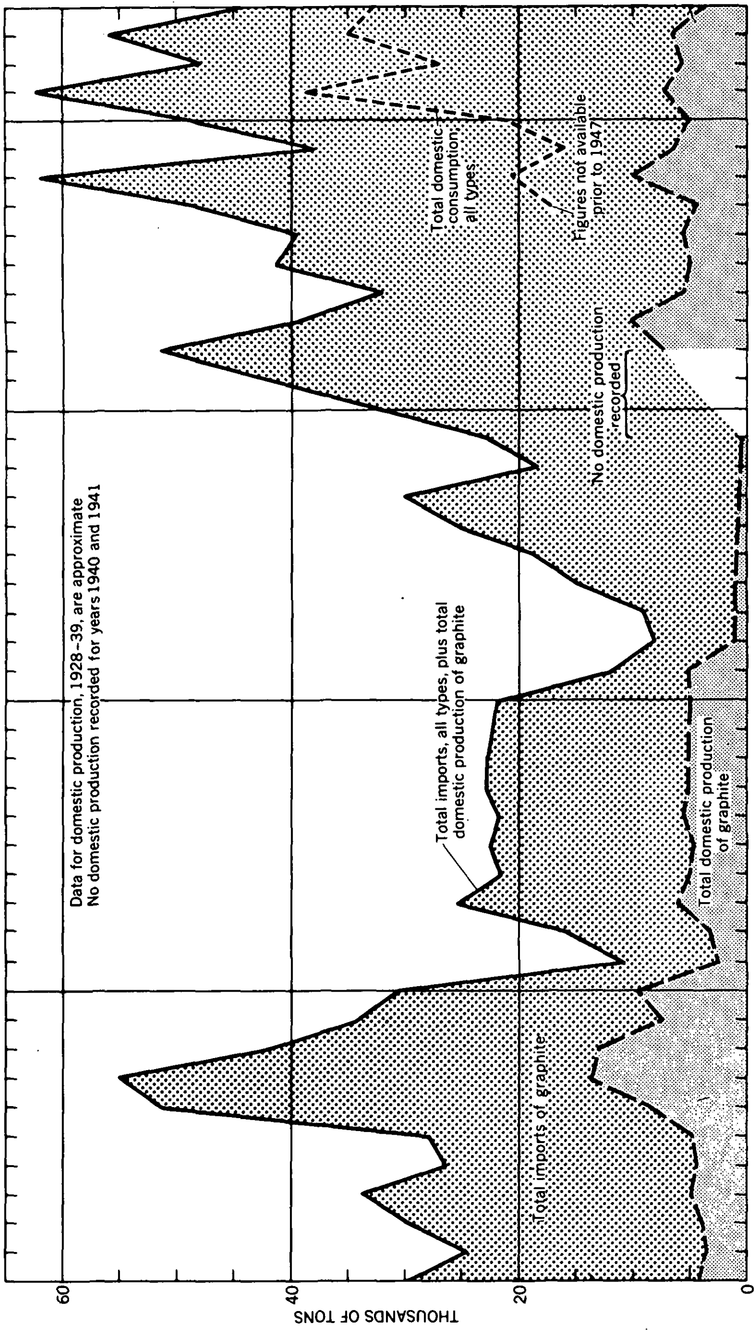
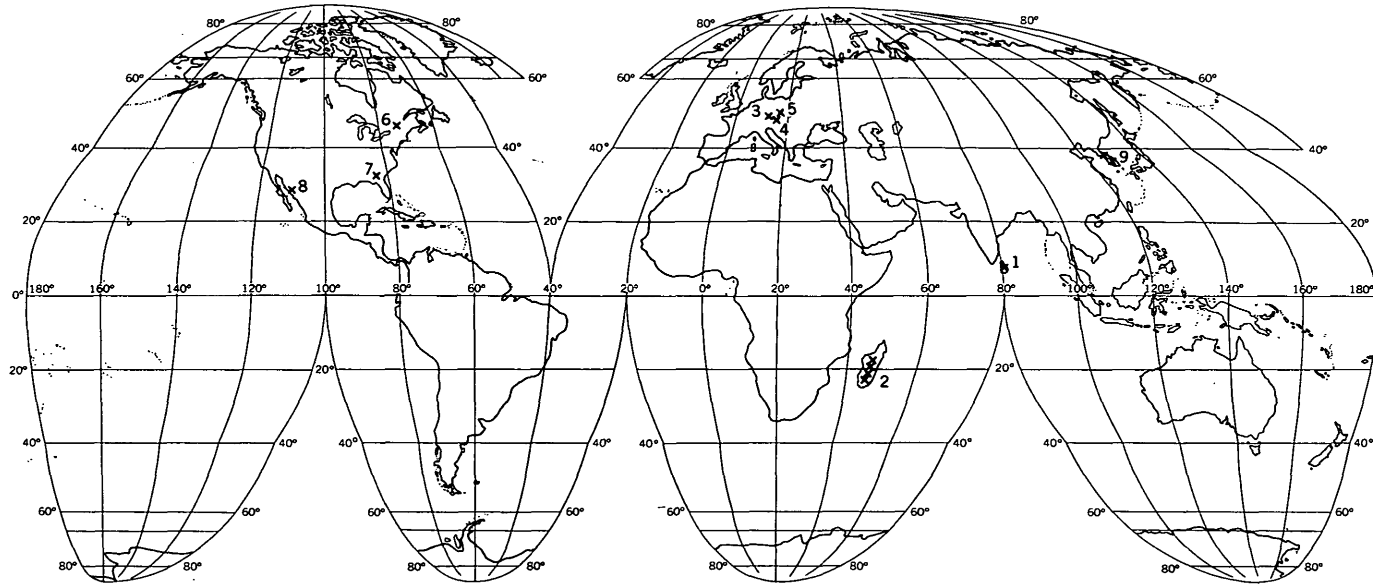


FIGURE 17.—Graphite supply for United States, 1910–54, including total imports and total domestic production. Data from U.S. Geological Survey Mineral Resources volumes and U.S. Bureau of Mines Mineral Yearbooks.



AMORPHOUS LUMP AND CHIP GRAPHITE

1. CEYLON

FLAKE GRAPHITE

2. MADAGASCAR
3. GERMANY (BAVARIA)
4. AUSTRIA (KREMS AREA)
5. CZECHOSLOVAKIA (MORAVIA)
6. CANADA (CALABOGIE, ONTARIO)
7. ALABAMA

AMORPHOUS GRAPHITE

8. MEXICO (SONORA)
9. KOREA

FIGURE 18.—Map of localities of principal graphite deposits of the world.

Over the long run there have been marked changes in the proportions of graphite produced by various countries. Annual production from the deposits of Ceylon (fig. 19), if we discount the ups and downs of the chart that characterize the curve for total world production, was about the same from World War II to 1944 but declined in 1945 and has not regained its previous level. Production from the deposits of Madagascar (fig. 20), which began about 1910, reached its peak during the First World War and a lesser peak in the 1920's but has since remained at a moderate level, only rarely exceeding 15,000 tons. The graphite industry of Czechoslovakia, important until 1930, virtually ceased production during the depression of the 1930's. It was revived by Germany during the Second World War but apparently has been dormant since 1948. Bavarian production has diminished in importance, but Austria has regained her pre-World War II position as a leading producer of graphite. Coincidental with these declines in output from the earlier established sources, there has been a marked increase in production from Korea and some increase in production from Mexico. Production from Korea after the Second World War was for a time at a low level, but in 1955 it reached a record tonnage.

Production from Austria, Bohemia, Mexico, Italy, and Korea is mostly amorphous graphite, from Bavaria and Madagascar mostly flake; production from Ceylon includes significant amount of flake in addition to lump and chip types. As Germany normally consumes most of the Bavarian product, only Ceylon and Madagascar graphite have been important in world flake markets.

FACTORS INFLUENCING WORLD PRODUCTION

World production has been influenced both by local factors and by some of the same factors that have influenced the domestic industry. Ordinary competition among sources, as between Madagascar and Ceylon, and Korea and Mexico, has partly determined the proportions of the world market held by each country. Political developments, however, have had a heavy hand. The unsettled conditions and dismemberment of political units in Europe after each of the two World Wars have, in general, adversely affected production from Bavaria, Bohemia, Italy, and Austria for varying periods. The graphite industry of Europe received a considerable stimulus under the Hitler regime. Korean production under the Japanese occupation in the late 1930's and early 1940's has been exceeded since only in 1955.

In all countries production has been strongly influenced by general economic conditions (fig. 17). Exhaustion of reserves does not appear to have been a heavy factor, though undoubtedly the best deposits in those countries that have been producing for long

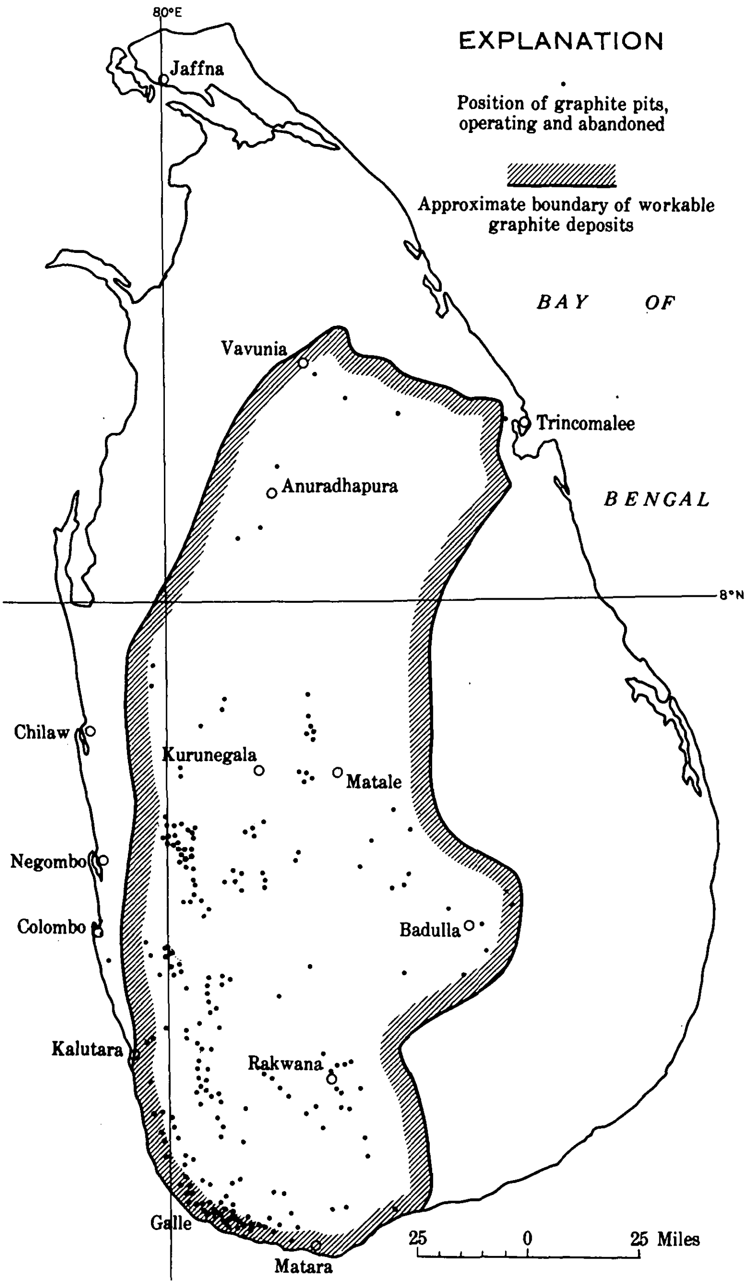


FIGURE 19.—Map of localities of graphite deposits of Ceylon. After Wadia (1943).

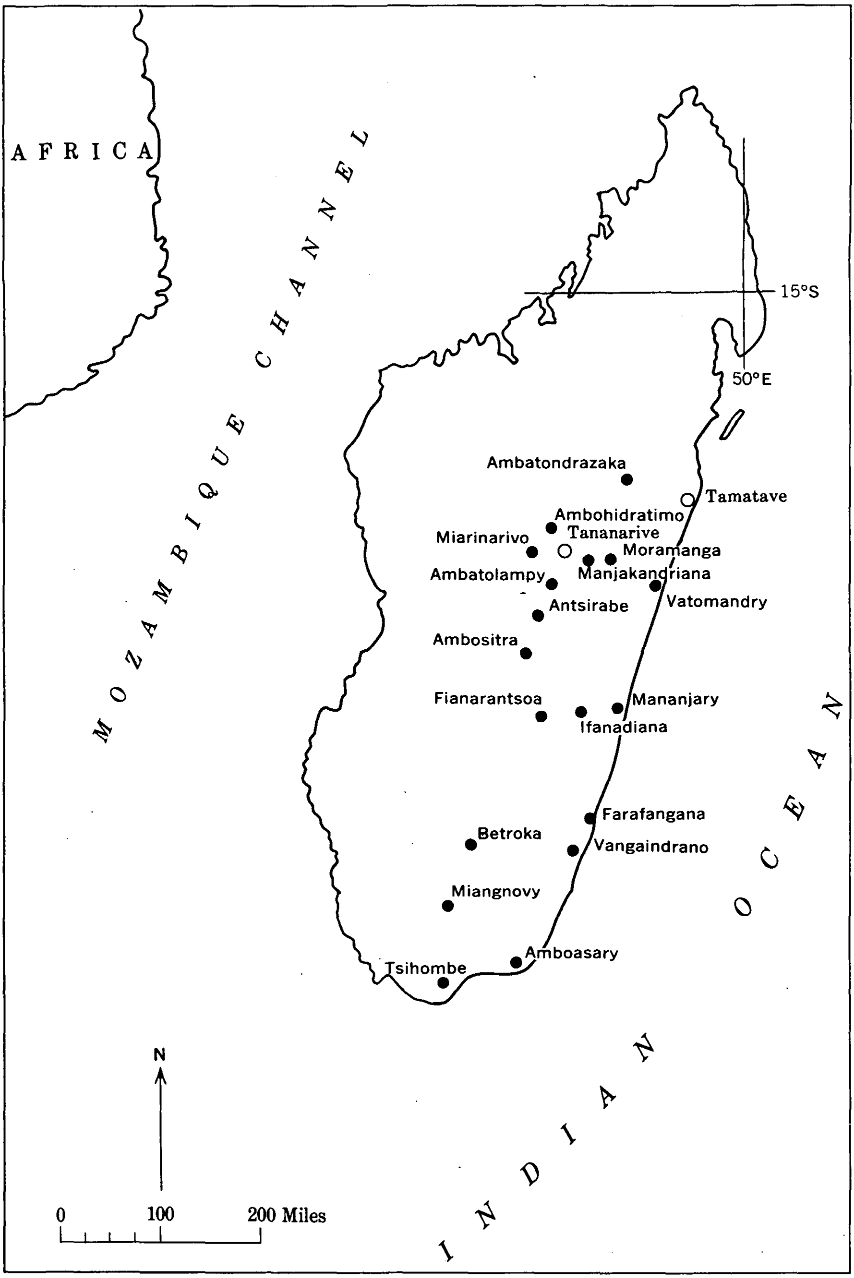


FIGURE 20.—Map showing graphite production of Madagascar. Solid circle indicates principal graphite-production district. From Bevillard (1934).

periods have been wholly or partly depleted. Conditions in Ceylon and Madagascar, the sources of greatest strategic importance to the United States, are of special interest. Production in Ceylon is said to be restricted only because of the limited demand. Reserves are thought to be large (Wadia, 1943, p. 23–24), and there is an ample labor supply. The situation in Madagascar is somewhat different. Reserves in that country are believed to be almost limitless, although apparently no real effort has been made to estimate them. But it does not necessarily follow that production there can readily be expanded to meet unusual demands. This became apparent during 1945–49, when, although the demand for Madagascar graphite was at a record level, production increased only after 1948 and did not attain the prewar-peak level until 1951. There were several reasons: An abortive rebellion in 1947 resulted in destruction of machinery and equipment at some of the principal mines, and a typhoon in 1948 damaged the railroad over which graphite is shipped to the east coast port of Tamatave. A further difficulty, and one that has not been solved, is a shortage of labor. A final factor probably is the reluctance of the producers to see a rapid exapnsion that might prove to be overexpansion if there were a drop in world demand. Such a drop is not unlikely once stockpiling requirements are met and demand from that source declines.

Changes in the domestic graphite-consuming industry (p. 30–33) have influenced foreign production. The use of Madagascar flake for crucibles adversely affected production from Ceylon. The rise in world consumption of amorphous graphite greatly stimulated production from Korea and Mexico and, for a time, production from European sources as well.

GEOLOGY OF GRAPHITE DEPOSITS IN THE UNITED STATES

Graphite is widely distributed in many types of igneous and metamorphic rocks and, locally, in sedimentary rocks. The more important concentrations of graphite, however, are those in hydrothermal deposits and those in regionally or thermally metamorphosed sedimentary rocks. Graphite deposits in general are restricted to metamorphic terranes; there are five reasonably distinct groups that have been mined or prospected. These are, (1) deposits consisting of graphite disseminated in metamorphosed siliceous sedimentary rocks, (2) deposits consisting of graphite disseminated in marble, (3) deposits formed by thermal or dynamothermal metamorphism of coal beds or other highly carbonaceous sedimentary rocks, (4) vein deposits, and (5) contact-metasomatic deposits in marble.

The range of geologic conditions under which graphite is formed are reflected in corresponding variations in size, form, tenor, and character of graphite, and in character of associated minerals. All these factors markedly affect exploration and development, estimation of tonnages, processes of extraction, and commercial products obtainable.

DISSEMINATED DEPOSITS IN METAMORPHOSED SILICEOUS SEDIMENTARY ROCKS

A large share of the world's strategic and nonstrategic graphite is obtained from disseminated deposits in metamorphosed siliceous sedimentary rocks. In this country these deposits are exemplified by occurrences in Texas, Alabama, Pennsylvania, and New York (fig. 12). The deposits have points of difference, but even brief comparison indicates that they have many geologic and economic characteristics in common.

The principal deposits consist of flakes of graphite disseminated in quartz-mica schists, micaceous quartzites, or micaceous feldspathic quartzites. These rocks occur in folded metamorphosed sequences of detrital sedimentary rocks. The deposits themselves are individual beds or lenses that are richer in graphite than associated beds. The size, form, and persistence of the deposits are functions, in part, of the thickness and extent of the original sedimentary beds, and in part, of deformation. Their attitudes are functions of local and regional deformation.

Individual deposits range from less than a foot to tens of feet in thickness. Certain deposits in Alabama and Texas are more than 100 feet thick; they range in length from a few feet to as much as half a mile. A few deposits in Alabama and the eastern Adirondacks in New York may have lengths (in outcrop) measurable in miles, but they are commonly not uniform either in tenor or thickness throughout such distances. In general, however, deposits in this group are larger and more uniform and are more readily explored, sampled, developed, and mined than those of any other type. They therefore offer the best possibilities for low-cost quantity production of graphite, and it is largely for this reason that they have yielded the bulk of the domestic production in the past.

Few deposits of this group have been adequately explored; hence their over-all form and structural relations are not well known. The commonest form is a tabular or lenticular body of uniform or nearly uniform dip within a part of a graphitic bed on the limb of a major fold. Dips of most deposits worked range from vertical to 20 degrees. Most of the deposits that have been worked are structurally simple, but some are complicated by minor folds. The deposit of the Southwestern Graphite Co. in central Texas is a noteworthy example. Here the graphitic beds are involved in minor folds ranging in amplitude from a few feet to tens of feet. The result is a deposit that is complex in cross section.

The graphitic rocks in deposits of this group range from fine grained (phyllitic) to coarse grained (schistose). Most of the deposits worked are in schists, which have a wide range of composition. Quartz is an abundant constituent of all graphitic beds; biotite, muscovite, or both, are widespread throughout. Plagioclase and potash feldspars are present in many deposits. Some deposits contain garnet, magnetite, pyrrhotite, or pyrite. Pyrite is abundant in unweathered graphitic rock in Alabama.

An undesirable textural feature common in many graphitic schists is a parallel intergrowth of graphite with other minerals. Particularly objectionable are intergrowths of graphite and mica; their separation requires such fine grinding that the resulting graphite flakes are too thin and small to be acceptable for many uses. Intergrowths of graphite and other minerals, while also objectionable, generally do not require such fine grinding; the resulting graphite product is likely to be coarser than flake recovered from graphite-mica intergrowths.

The belts of graphitic rock in Texas, Alabama, Pennsylvania, and New York contain many bodies of pegmatite, aplite, granite, or combinations of these rocks, which range from small dikes, sills, or lenses exposed in the workings in individual deposits, to features large enough to be shown on regional maps. Some bodies, particularly of granite, are sharp-walled crosscutting intrusions. Many of the bodies of aplite and pegmatite, however, are vaguely defined lenses that are more or less concordant to the foliation of the enclosing rocks. Gradations between such bodies and injection gneiss are particularly well shown in some of the deposits of Alabama and Pennsylvania. In some of these deposits the graphitic rocks appear to have been impregnated with pegmatitic and aplitic materials consisting mostly of quartz and feldspar. To the operator such bodies may appear completely objectionable, for they dilute the ore and below the zone of weathering may be tough and costly to mine. There is evidence, however, that the flake size of graphite is directly related to the degree to which these granitic bodies, particularly the pegmatites, are developed. Coarse flake apparently occurs only where there is abundant impregnation of the graphitic rocks with aplitic or pegmatitic material. The relation between coarseness of flake and degree of impregnation in the deposits of Alabama has been noted by W. S. White (written communication, 1941). The relationship is even more strikingly displayed in the graphite district of central Texas. The graphite deposits of this district occur in the Packsaddle schist. Where the schist is cut by abundant dikes

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of granite and pegmatite, as at the mine of the Southwestern Graphite Co., deposits of relatively coarse flake are found. In other parts of the district, as at the Texas Graphite Co. mine south of Llano, the schist contains neither granites nor pegmatites, and the graphite is so fine grained as to approach "amorphous" graphite.

In any given deposit in which there is pegmatitic material the coarsest flake is found either at the margins of small pegmatite lenses or in lenses of coarse quartz-rich material that apparently is related to the pegmatites. At the Benjamin Franklin mine, Chester County, Pa., quartz-rich lenses contain flakes as much as 25 mm in diameter.

There has been some discussion as to whether the graphite was introduced into schists and quartzites at the time when pegmatitic material was developed. Many pegmatites in graphitic schists or quartzites contain disseminated flakes of graphite. W. S. White (written communication, 1941), however, has pointed out that in Alabama similar pegmatite bodies outside the graphitic schists contain no graphite. The writers' observations support this conclusion. The role of pegmatites is apparently that of stimulating recrystallization and coarsening the texture of graphite flakes present before pegmatite development. Movement of carbon during pegmatite development undoubtedly took place, but the distances involved appear to be only inches or feet.

L. W. Currier and R. H. Jahns (written communication, 1944), believe that the deposit near Pope Mills, St. Lawrence County, N.Y., has an origin quite different from that proposed for the deposits of eastern New York, Pennsylvania, Alabama, and Texas. They regard the deposit as due to partial hydrothermal replacement of quartzite beds by graphite, apatite, feldspar, and calcite.

The discussion of disseminated deposits thus far given applies to the graphite deposits of central Texas, the bedded deposits of the eastern Adirondacks, N.Y., and the unweathered parts of the deposits in Alabama and Pennsylvania. In Alabama and eastern Pennsylvania, however, much of the graphitic schist is intensely weathered to depths of 50 to 100 feet. Most of the graphite mined in the past has come from this weathered material. In these deposits iron sulfides have been oxidized to limonite; feldspars (especially plagioclase) have been changed to kaolin; garnet, biotite, and other ferromagnesian minerals have been converted to mixtures of clay and iron or manganese oxide. Where weathering is well advanced the original rock is converted to a soft, friable material consisting chiefly of clay minerals, iron oxides, and residual quartz and graphite. This material is easily mined by simple excavating equipment, and the graphite is recovered with a minimum of crushing.

Graphite-bearing rocks in Alabama and eastern Pennsylvania exhibit all degrees of weathering, over a vertical range from a few feet to more than 100 feet. The average depth of weathering in most of the deposits is probably about 50 feet. Factors that influence depth and degree of weathering are rainfall, topography, drainage, rock structures, and geomorphic history. W. S. White (written communication, 1941) has pointed out the importance of these factors in estimating resources of weathered graphitic rock in Alabama. The writers' observations suggest that any appraisal of weathered ore will require close attention to all of the above factors, and particularly to the geomorphic history of the area.

RELATIVE VALUE OF HARDROCK AND WEATHERED DEPOSITS

By virtue of the condition of the material composing them, the weathered deposits are less expensive to mine, the material excavated is more readily and cheaply crushed, and the graphite more easily freed. Moreover, there may be a certain amount of enrichment of the rock due to chemical decay of the minerals associated with the graphite and to removal of soluble constituents in solution. A further advantage claimed for these deposits is that the graphite is less damaged in milling, as less crushing and grinding are required to free it. The clay fraction of the ore can be separated by simple washing. These advantages are given such weight that in Alabama unweathered rock in general is not considered workable, and most of the production of graphite in this area has been from weathered rock. However, the weathered deposits also have certain disadvantages. For one thing, tonnages of thoroughly weathered material in some of the deposits are limited. Furthermore, weathering is not a uniform process either vertically or horizontally; most deposits show considerable variation in this respect, and these variations are superimposed on whatever differences in rock composition were present before weathering. It follows that the feed to a mill treating weathered ore is far from uniform in its characteristics. This may explain some of the difficulties experienced in milling weathered ores.

In the hardrock deposits, variations in feed are only those due to differences in the texture and mineralogy of the original graphitic rock. Unweathered material therefore lends itself to more uniform treatment, and it is a fair question whether this may not result in products that are themselves more uniform than products won from weathered ore. Another advantage of the hardrock deposits is that operations in unweathered deposits of moderate or gentle dip can be carried to greater depths than those in weathered deposits. No quantitative data is available concerning the extra damage to the flake produced by milling hard ore. Opinions among operators vary. At least one mine in Alabama appears to have operated for several years in hard ore, and the mine of Southwestern Graphite Co. in Texas is entirely in unweathered ore.

Provided that milling processes can produce satisfactorily uniform products from soft ore, the relative merits of hard ore as against soft ore are of no immediate strategic importance; reserves of weathered ore in Alabama are still large, and moderate reserves of such ore exist in eastern Pennsylvania. In the future, however, the question may be important, for resources of hardrock graphite are undoubtedly many times greater than those of soft ore.

DISSEMINATED DEPOSITS IN MARBLE

The Precambrian marble belts of the Appalachian Mountains, and the areas in northern New York, southeastern Ontario, and southwestern Quebec that are underlain by rocks of the Grenville series include layers of marble that contain disseminated graphite. Most such layers contain less than 1 percent graphite, but 5 percent or more flake graphite occurs locally. Many such occurrences have been prospected, particularly in Canada, but very few have been developed that contain sizable reserves of rock with 5 percent or more flake graphite. Operations in such deposits have everywhere been short lived. The marble in which the graphite deposits occur has generally been folded. The deposits as a group are structurally complex and show marked variations in thickness and in content of graphite along dip or strike. Kinds and proportions of associated minerals also vary within ore bodies, and this apparently has complicated milling of the ore and recovery of graphite. Occurrences of this type appear to be of little economic importance.

DEPOSITS FORMED BY METAMORPHISM OF COAL OR OTHER HIGHLY CARBONACEOUS SEDIMENTARY ROCKS

Deposits formed by metamorphism of coal or related highly carbonaceous sediments are further subdivided according to whether they are due to thermal metamorphism by igneous rocks or to regional deformation and metamorphism.

The best-known occurrences in the United States of the first type are in the Raton coal field of New Mexico, where coal beds have been intruded by sills of diabase and have locally been metamorphosed to amorphous graphite. E. S. Bastin (written communication, 1917) also described graphite in Chaffee County, Colo., interbedded with marble, schist, and quartzite; he regards them as beds of coal and highly carbonaceous shale that were metamorphosed by the heat of large masses of intruded granite. This type of deposit yields only amorphous graphite and has never been of much economic significance in the United States.

Deposits formed by regional metamorphism of coal or highly carbonaceous shale are represented by the graphitic anthracite deposits of the Narragansett basin of Rhode Island. These are beds of coal that locally have been converted into graphitic material by intense deformation. This material has been marketed as a low-grade variety of amorphous graphite for foundry facings and paint pigment.

The most important deposits of amorphous graphite on the North American continent are those in the State of Sonora in northern Mexico. There beds of coal interlayered with sandstones have been folded and intruded by granite. According to Hess (1909), the metamorphism to graphite was caused by the heat of intrusion. The beds are considerably deformed, however, and have been thickened in some places and thinned in others. Folding may have contributed to metamorphism.

Graphite deposits formed by metamorphism of coal and highly carbonaceous rocks have yielded only amorphous graphite. The graphite particles are so fine grained that beneficiation other than hand separation of obvious larger impurities is scarcely feasible. The material must therefore be sold in the form in which it is mined; the graphite content will depend on the original carbon content of the beds involved and the degree of metamorphism. Mexico is preeminent in the production of amorphous graphite because in the productive district substantial parts of beds of high original purity have been uniformly altered to graphite.

As coal tends to deform plastically during folding, the structure of deposits such as those of Rhode Island and Mexico is complex. This gives rise to numerous problems in prospecting, exploration, and mining.

VEIN DEPOSITS

Vein deposits of graphite apparently are formed by simple filling of open fractures in the country rocks. The veins are commonly sharp walled, and the graphite fillings are partly or wholly crustified, except where later movement has deformed them. The simplest veins consist of two layers, one on either wall of the fracture, made up of parallel close-packed elongate plates of coarse graphite. The lengths of the plates vary with the thickness of vein and in places are as much as 10 cm. The central parts of some veins, particularly the thicker ones, consist of platy layers parallel to the walls of the fractures. Flaky graphite and masses of radiating elongate flakes are also found. Where movement has taken place, masses, lenses, or small pods of foliated, crushed, and slickensided graphite occur and fragments of the country rocks are incorporated in the veins. In some localities, such as Dillon, Mont., graphite is apparently the only vein mineral. In others, such as Ceylon, graphite is accompanied by quartz, pyrite, calcite, and minor amounts of biotite, orthoclase, pyroxene, apatite, allanite, molybdenite, and rutile (Bastin, 1912; Wadia, 1943, p. 16).

A noteworthy feature of these deposits is the virtual lack of alteration in the walls of the veins. Graphite may occur in the wall rocks for short distances from the veins but apparently only along grain boundaries or where subsidiary fractures extended from the main fissures into the walls.

The overall form of such deposits is dependent upon the pattern of pregraphite fractures. The veins range from single simple fissure veins to stockworks occupying complex fissure zones. Individual veins range from less than an inch to several feet in thickness.

The principal vein-type deposit in this country, near Dillon, Mont., has been explored to a depth of about 300 feet. The graphite veins of Ceylon, however, have been mined (Wadia, 1943, p. 23) to depths as great as 1,600 feet.

The domestic graphite deposits have many economically disadvantageous features. Single veins with minable widths over long distances have not been found. Pinching and swelling and complete pinchouts within short distances along dip or strike are common. The only hope of developing sizable tonnages of graphite in such deposits lies in discovering persistent groups of veins that collectively contain substantial reserves. Development work, which must consist largely of drifts, shafts, and crosscuts, is costly, and none of the vein-type graphite occurrences of North America thus far sustained the expense for any length of time.

There is a striking contrast between the textural and structural characteristics of the vein deposits, which suggest deposition in open fissures formed at no great depth, and the types of country rocks with which they are associated. The rocks are gneisses, schists, marbles, pegmatites, and grantiic rocks of the kinds that are commonly regarded as having formed under deep-seated conditions. This contrast is unexplained. The veins have been attributed variously to crystallization of veins of asphalt or other hydrocarbons or to deposition from solutions, or have been linked to the development of the pegmatites that form part of the country rock. The first hypothesis is untenable, as Bastin (1912, p. 439) pointed out, because in Montana, New York, and Ceylon the veins are younger than any intrusion or regional metamorphism that could be responsible for such a change. In addition, the textures of the veins are those of simple fracture fillings. The textural evidence given for a genetic relationship between graphite and associated pegmatites (Wadia, 1943, p. 17; Heinrich, 1949a and b) is unconvincing (Ford, 1954, p. 41). As Ford points out, the graphite in Dillon veins occupies fissures that plainly were formed later than any of the associated rocks, and the occurrence of graphite in small amounts in pegmatites at Dillon is no more significant than its occurrence in gneiss and other rocks at these localities. Small fractures control the occurrence of graphite in both groups of rocks. It seems probable that the interval between formation of host rocks and formation of graphite at Dillon was very long.

Vein deposits in Argenteuil, Labelle, and Hull Counties in Quebec, and in the Ticonderoga district of New York occur in silicated marbles that have been ascribed in general to the contact-metasomatic type of deposit described below and will be discussed with those deposits.

CONTACT-METASOMATIC DEPOSITS IN CARBONATE ROCKS

Concentrations of graphite are found at many places in the silicated marbles of the Grenville series of southeastern Ontario, southwestern Quebec, and the Ticonderoga district of eastern New York. Many of the occurrences have been prospected, and a few have been mined for short periods. One apparent variant of the type was for a time an important Canadian source of flake graphite. These occurrences are grouped under the heading of contact-metasomatic deposits in the present report, but as a group they are varied, inadequately known, and vaguely defined. They show gradations to hydrothermal replacement deposits, to the disseminated deposits in marble (p. 46), and to the fissure vein deposits.

The deposits that occur west and northwest of Ticonderoga, N.Y., near the eastern edge of the Adirondack Mountains, are found in irregular aureoles of silicated marble bordering small pegmatites. The marbles have been erratically altered to calcite, diopside, scapolite, sphene, wollastonite, and other minerals. Graphite occurs as flakes disseminated irregularly through the silicated rock, as sporadic nests and patches, or in veins associated with calcite and quartz; the veins show the characteristics described above for other vein deposits. This graphite is apparently a late-formed mineral. It occurs in flakes from a fraction of a millimeter to as much as 50 mm in diameter.

These deposits were prospected and mined on a small scale in the latter half of the nineteenth century and in the early part of the present century, but they have serious disadvantages that frustrated most attempts to exploit them. Small bodies of rock with 20 percent or more flake graphite are not uncommon in the deposits, but the distribution of graphite is highly erratic and the average tenor of large tonnages of rock is low; moreover, the ores are extremely variable in mineral content. It seems unlikely that they will be exploited again unless a need should arise for small amounts of extremely coarse flake graphite.

Some of the contact-metasomatic deposits of flake graphite in the rocks of the Grenville series of southeastern Ontario and southern Quebec resemble those of the Ticonderoga district; others appear to be beds of silicated marble in which graphite has developed after silication. The mineral assemblages of such deposits resemble those of the other contact-metasomatic deposits, but structurally they have a closer resemblance to bedded deposits. Very few have yielded appreciable amounts of flake graphite. The most important Canadian deposit, that of the Black Donald mine at Calabogie, Ontario, is worked out. It was described by McLaren (1945) as a thickened lens of drag-folded ore, more than 1,000 feet long, 15 to 70 feet thick, and about 50 to 80 feet in height. It was a steeply dipping lens that plunged northeastward apparently parallel to the plunge of folds in the enclosing rocks. The ore in this lens is reported to have averaged 55 to 65 percent graphite (Spence, 1920). Most of the flake was fine grained; the coarsest product marketed during the main period of operation was +74-mesh size.

GRAPHITE RESOURCES AND RESERVES

The terms "resources" and "reserves" as used in this report have essentially the same meaning as those suggested by Blondel and Lasky (1956). Resources comprise all deposits of graphite-bearing rock regardless of their size or tenor or the quality of the material that can be produced from them. Resources thus include deposits that can be worked at a profit under present economic and technologic conditions, as well as those that cannot. Reserves include only those deposits that can be worked at a profit under present conditions.

In discussing graphite deposits in the United States we are concerned mostly with resources, not reserves. During the years 1920 to 1955, operations based on domestic graphite deposits were generally submarginal or uneconomic. Subsidy prices during and after World War II supported a few operations for a time, and one domestic operator had some success in competitive markets, but on the whole, domestic deposits have not been able to compete with sources abroad. The reasons are many, and much of the present report is devoted to analyzing them.

DOMESTIC RESOURCES OF GRAPHITE

There are two principal obstacles to an accurate estimate of graphite reserves and resources in the United States. One is that data for estimating reserves of graphitic rock in individual deposits are too meager; the second is that even if the tonnages and grades were known for all deposits, these figures would still fall far short of giving the information that is needed to appraise the country's graphite resources in terms of requirements. The data needed are not those for overall tonnage and grade, but for tonnages of the commercial grades of graphite that can be produced from individual deposits or districts. These are the only estimates that are significant. At the present time no such estimate can be made for any mine in the country. The few figures for reserves that appear in the literature are therefore of little value as an indication of the ability of the United States to produce strategic grades of graphite.

An illustration of this point is the estimate by the U.S. Bureau of Mines of flake graphite in Alabama (Pallister and Thoenen, 1948, p. 76–78):

	Thousands of tons
Weathered ore:	
Measured (containing +50-mesh flake assaying > 85 percent carbon):	
Containing > 15 lb of graphite per ton	2,399
Containing 10–15 lb of graphite per ton	1,575
Containing 5–10 lb of graphite per ton	7,085
Total	11,059
Inferred	3,351
Total	14,410
Unweathered ore:	
Measured	700
Indicated	6,798
Inferred	4,002
Total	11,500

Using 3 percent (or 60 pounds per ton) as the average recovery potential from all measured weathered graphite, Pallister and Thoenen concluded that, based on a need of 10,000 tons per year of processed graphite, about 35 years' supply of flake graphite had been blocked out in Alabama by the exploratory program of the U.S. Bureau of Mines at the time of their writing.

The present writers have seen most of the deposits represented in the above estimates and agree that in the Alabama districts the reserves of weathered graphitic rock averaging 3 percent recoverable graphite are very large. The existence of a 35-year supply of graphite, however, would depend upon the acceptance of Alabama graphite by industry, but at present industry is geared almost entirely to graphite from other sources. Furthermore, the percentage of graphite of strategic grade recoverable from the Alabama deposits has not been determined.

Resources of flake and lump and chip graphite (all grades) potentially recoverable in the principal districts of the country are summarized in the following table:

District	*Type of graphite*	*Estimate of recoverable graphite (in tons)*
Dillon, Mont	Lump and chip	<5,000.
Southwest Texas	Flake	In excess of 10 years' supply at present district rate of production.
Alabama	Flake	>300,000.
Chester County, Pa	Flake	>10,000.
New York:		
Deposits in schist	Flake	>250,000.
Vein deposits	Lump and chip	Negligible.

The table indicates only the order of magnitude of domestic resources. It shows clearly, however, that the resources of flake graphite are large, whereas resources of lump graphite are small. No figures for amorphous graphite are given in the table because the United States possesses only negligible reserves of high-grade amorphous graphite.

GRAPHITE DISTRICTS

MONTANA

The Crystal Graphite mine in Beaverhead County, owned by the Crystal Graphite Co., is the only mine in Montana that has produced significant quantities of commercial graphite (pl. 9). It is in the south end of the Ruby Range, about 10 miles east of Dillon, in secs. 29, 30, 31, and 32, T. 8 S., R. 7 W. The principal workings are in sec. 31 at altitudes near 7,500 feet. They can be reached by a gravel and dirt road that is usually in good condition during the summer but may be blocked by snow in winter or by mud in the spring.

The deposit was discovered in 1899 by a Mr. Robbins, who later sold his interest to Pearl I. Smith of Dillon. Mr. Smith retained ownership until his death in 1937, when it passed to his heirs, Mrs. Pearl I. Smith and Ralph I. Smith of Dillon, and Rachael Smith of Istanbul, Turkey. The owners reorganized in 1949 or early 1950 under the name Montana Graphite Co., with Ralph G. Smith as president.

The production records of the mine are not available, but the following figures are believed to be correct. The first shipment of about 50 tons came from the Birds Nest claim (fig. 13) in 1902, and from then until 1941 the total production is said to have been about 2,150 tons, most of which was mined in 1918 and 1919. All later production came from the Groundhog claim. Only the highest grade material was mined, and after a rough hand-cobbing it was shipped without further treatment. The mine was worked intermittently between 1920 and 1941, and produced about 50 tons. In November 1941 the mine was reopened by the Crystal Graphite Co., and a mill was built. Between November 1941 and June 1945 about 150 tons of graphite was produced. Operations were stopped in 1946, but in 1948 the mill was remodeled and the mine was reopened by the Montana Graphite Co. From January to August 1948, about 22 tons of concentrates, none of which had been sold as of July 1950, was produced.

The main workings are on four levels, as shown by the map and cross section in plate 9. Since the map was made, the Dubie and Antelope adits have been extended slightly and a 250-foot adit has been driven about 200 feet below the Badger discovery pit. These and the older workings total more than 3,500 feet of drifts, crosscuts, shafts, and raises, together with several stopes, prospect pits, and two adits each about 75 feet long. Parts of some of the older workings are caved and inaccessible, but for the most part they are in reasonably good condition and can be entered and examined.

The geology of the Crystal Graphite mine was described by Winchell (1910, p. 528–532 and 1911a, p. 218–230), Bastin (1912, p. 419–443), Heinrich (1949b, p. 307–334), and Ford (1954, p. 31–43). The area near the mine was mapped in detail by F. C. Armstrong and R. P. Full (1946); the writers have drawn heavily on their data (pl. 9). The rocks on the property are a metamorphosed sedimentary series that has been correlated with the Cherry Creek group of Precambrian age. The structure and lithology are complex. Garnetiferous granite gneiss, schists, marbles, and quartzites strike approximately N. 60°–75° E. and dip 70°–80° NW. but show local variation. They contain small pegmatitic bodies that range from nearly massive to markedly metamorphosed. Perry (1948, p. 14) and Heinrich (1949b) assigned the pegmatites to two different ages, the metamorphosed bodies to Precambrian, and the unmetamorphosed bodies to Laramide. Ford (1954), however, concluded that they are all of the same age because he found that all gradations between metamorphosed and unmetamorphosed rock occur in a single pegmatite.

The richest graphite ore in the deposit occurs as fracture fillings in pegmatite and gneiss. The fillings range from thin films to veins more than 2 feet thick, most ranging ¼ to 4 inches in thickness. They are short, and very few reach lengths of 50 feet. In places the veins form closely spaced intersecting networks that resemble stockworks. The veins contain graphite as the only primary mineral, but movement along the fractures has dragged fragments of the wall rock into the veins in places, apparently both during and after graphite deposition. The graphite occurs mostly as coarse interlocking plates as much as 1 inch long, but in places it shows well-developed comb or needle structure. Contacts between graphite veins and wall rock are sharp, and no alteration of the wall rock is evident.

Graphite also occurs as flakes, films, and rosettes disseminated in the pegmatites and the gneisses and is noticeably more abundant near the graphite veins. In the wall rocks the graphite occupies minute fractures between or within mineral grains and occurs as flakes formed by replacement of quartz or feldspar. Where the country rock is foliated, the graphite flakes are oriented parallel to the foliation. Although disseminated graphite is fairly common, it does not appear to be present in sufficient quantity throughout a large enough body of rock to be of economic interest. Only the vein ore is worth considering as a possible source of further production.

There is evidence that structural features have helped to localize graphite deposition. An isoclinal fold that strikes about N. 50° E. and dips about 45° NW. is described by Armstrong and Full (written communication, 1946). The nose of this fold plunges N. 20° W. at about 45 degrees. There is extensive fracturing around the nose of the fold both on the surface and in underground exposures. These fractures contain graphite that constitutes the richest ore body exposed in the deposit. Evidence for structural control is limited, however, and proof is lacking that such evidence can be used as a basis for estimation of reserves. Further investigation, either by drilling or drifting, should be aimed at checking the continuity and importance of the fracture zone, for such work would be a logical step in blocking out more ore. No large tonnage of rock containing abundant vein graphite is exposed.

The graphite produced from the deposit is vein-type graphite, ranging from coarse flake to lump to "needle" lump. Needle lump is abundant; it seems to occur where the veins were deformed by the evidently widespread movement that took place after deposition of the graphite. Most veins are less than 4 inches thick, although a single vein 6 feet thick reportedly yielded 50 tons of high-grade graphite during the early period of operation.

According to Armstrong and Full (written communication, 1946), during 1941 to 1945 the graphite was picked out of the veins with long iron hooks, collected in powder boxes, and taken to the mill for crushing and flotation. Mine-run ore, muck from old stopes, and dump material were also treated at the mill during this period. Mill concentrates averaged 87 percent carbon. Graphite of this carbon content could meet crucible specifications for purity, but it would also have to meet requirements for shape and toughness. If material of 95 to 97 percent average carbon content could be produced, it might be acceptable for use in carbon brushes as a substitute for Ceylon graphite.

How much high-purity graphite could be produced by careful mining, hand sorting, and special treatment is unknown. The graphite does not break cleanly from the wall rock of the veins, for films of graphite $\frac{1}{4}$ to $\frac{1}{2}$ inch thick remain on many vein walls in the stopes. This material evidently could not be hooked out. Wall-rock fragments that have been dragged into the veins are an additional obstacle to the production of a very high grade concentrate. Separating these fragments would be difficult, and hand-sorting would be tedious and costly. Perhaps 10 to 20 percent of the hooked-down graphite might be hand sorted and concentrated to high-purity chip and lump. The cost would be high.

TEXAS

Parts of Llano and Burnet Counties (fig. 21), Tex., are underlain by the Packsaddle schist of Precambrian age, which has been intruded by bodies of granite. Certain zones in the schist are graphitic and have been mined or prospected in a number of places. The graphite ranges from extremely fine grained to medium grained; only the latter is capable of furnishing commercial flake.

The only deposit that has been mined for more than a few years is that of the Southwestern Graphite Co., in Burnet County. None of the other deposits of the area appears to contain sizable tonnages of rock with as much as 2 to 3 percent graphite coarse enough to be marketed as flake.

SOUTHWESTERN GRAPHITE CO. MINE

The mine and mill of the Southwestern Graphite Co., are in the Burnet quadrangle 7.9 miles N. 77° W. of Burnet, Tex., on the west side of Clear Creek (pl. 10). To reach the mine, take State Route 29 west from Burnet for 3.4 miles, then turn right on the gravel road and drive 3.6 miles to a fork. Take the left-hand road for 1.9 miles. The mine road, an all-weather dirt and gravel road, turns to the left at this point. Follow the road for 1.1 miles to the mine office.

The mine and mill lie within the Vernon Dorbant ranch but are on property owned by the Southwestern Graphite Co., (pl. 10). The property is said to have been worked first in 1913 by P. B. McCabe of Denver, Colo. The Southwestern Consolidated Graphite Co. assumed control of the property in 1917 and continued operations until 1930. A mill built on the property in 1922 burned in 1927 but was replaced immediately by the present mill. The mine and mill were idle in 1930, but operations were resumed Sept. 1, 1942, and continued with brief interruptions to 1955. The property was sold to the Southwestern Graphite Co. in 1935.

From 1917 to 1930 the products of the operation were sold to the battery and foundry-facing industries. Most of the graphite pro-

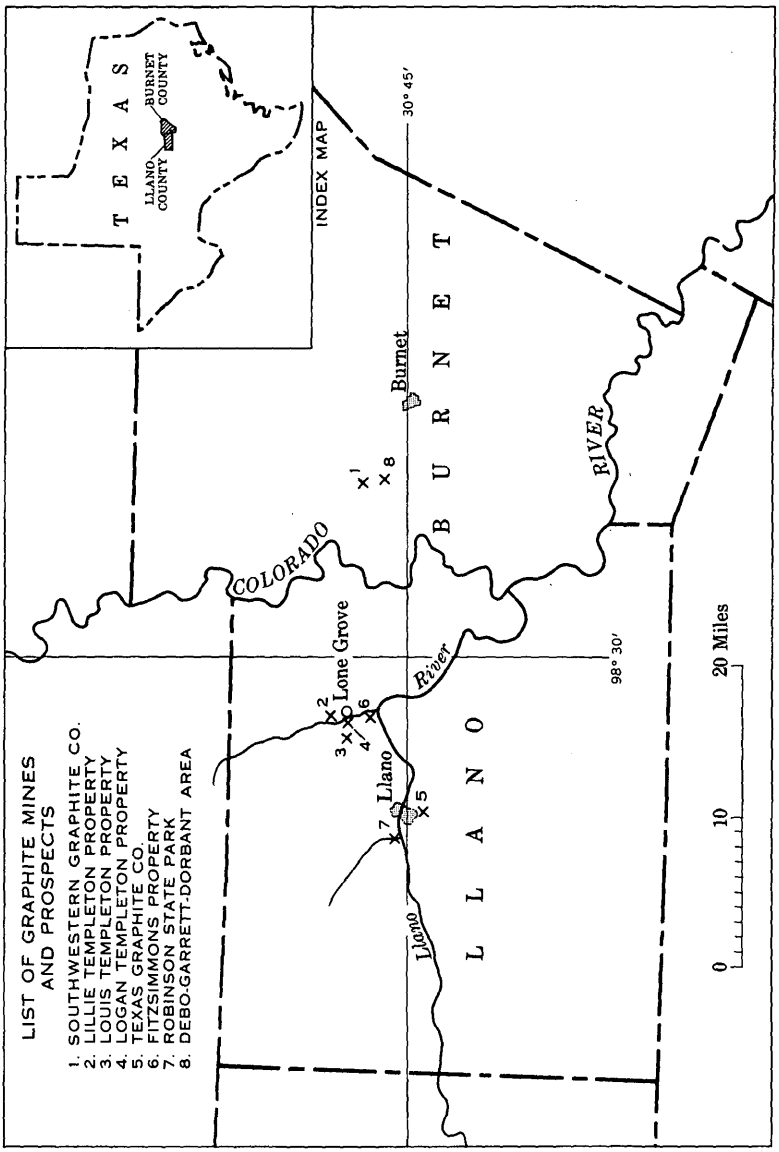


FIGURE 21.—Map of localities of graphite deposits of Llano and Burnet Counties, Tex.

duced from 1942 to April 1949 was sold to the foundry-facing industry, but after April 1949 the company marketed a diverse group of flake-graphite products. In October 1948 two Government contracts for a total of 1,900 tons of C flake (small), Munitions Board Spec. P–22–b, were awarded to the company, the graphite to be stockpiled. This contract was filled by the company.

The main working is an open pit about 1,000 feet long, 60 to 200 feet wide, and 30 to 70 feet deep (pl. 10). This pit lies in the middle of the property in what is referred to as the main ore body. A second open pit, about 350 feet long, 150 feet in average width, and 5 to 50 feet deep, was excavated in a second or south ore body. In addition, an open pit about 50 feet long, 50 feet wide, and 15 feet in maximum depth was opened in the third or north ore body during the summer of 1950. The total tonnage of rock moved from 1917 to 1958 was probably 800,000 to 900,000 tons.

Mining by the company has been done largely in the main working. Two 16-foot benches are run simultaneously. Blast holes are cut by wagon drill. Much secondary shooting of boulders is required. Loading is by ¾-cubic yard power shovel into 2-ton trucks that haul the rock directly from the quarry faces to the mill. Processing of the ore was described by Needham (1946).

The deposit is in a sequence of rocks consisting of micaceous quartzite, quartz-mica schist, and injection gneiss. The entire sequence is 130 to 160 feet thick, and graphite is present in all the layers. The graphitic rocks are overlain by a rock that ranges from hornblende and hornblende-biotite schist to hornblende and hornblende-biotite-feldspar gneiss. Contacts of the graphitic rocks with the hornblendic rocks are sharp; the hornblendic rocks apparently contain no graphite. The graphitic rocks form a belt through the middle of the property and beyond, which changes in trend from N. 75° E. at the southwest end to N. 11° E. at the northeast end. In the main opencut the southeast contact of the graphitic rocks with the hornblendic rocks is apparently simple in structure, although its dip ranges from 65° SE. to 65° NW. The northwest contact of the graphitic rocks with hornblende gneiss, however, is highly irregular and is involved in a series of isoclinal folds of different amplitudes. These folds have caused difficulty in mining, for in vertical cross section the contact weaves back and forth laterally. During mining it was necessary to leave considerable amounts of graphitic rock in the west wall in order to keep operations within the graphitic rocks. Fortunately, the part of the belt of the graphitic rocks nearest the northwest contact includes much of the leaner rock of the deposit.

Isoclinal folding on a small scale is evident at many places within the ore bodies. Axial planes vary in strike and dip; most folds have axial planes that dip 20° to 35° SE. and axes that plunge southward at gentle to moderate angles. Limited observations suggest that the deposit lies on the northwest limb of a major anticline.

The south ore body, in the southwestern part of the graphitic belt, has walls that dip steeply northwest to steeply southeast. The structure of the walls is for the most part fairly simple, although the southeast contact is locally isoclinally folded. The graphitic rocks of the north ore body are poorly exposed, and attitudes of the contacts with hornblende gneiss are unknown. The trend of this part of the belt suggests that it has a steep westerly dip.

The graphitic rocks are cut at the northeast end of the south ore body by a granite dike ranging from 65 to 240 feet in width. The dike probably has a steep dip. Part of a narrow northeasterly offshoot of this dike has been mined in the main workings. There are many other smaller granite dikes that cut the graphitic belt; they range from 1 inch to about 6 feet in thickness and occupy fractures having a wide range of attitudes. One horizontal body at least 5 feet in maximum thickness capped the bench on the 955-foot level over part of the central section of the main working. Numerous granitic pegmatite dikes, most of them a foot or less in thickness, cut the graphitic rocks. Both granite and pegmatite are barren of graphite. In places they have been responsible for serious dilution of the ore, as they ordinarily cannot be mined separately and eliminated from the mill feed. Available exposures of the north ore body suggest that dilution by granite and pegmatite may seriously affect potential production of graphite from this body.

The graphitic rocks consist dominantly of quartz, muscovite, biotite, plagioclase feldspar, microcline, garnet, and graphite in various proportions. The most abundant rock type appears to be a graphitic micaceous quartzite, but small, thin lenses, layers, and knots of granitic and pegmatitic material are abundant in parts of the belt. Some of the rock is of the type commonly referred to as injection gneiss. Pyrite is a fairly conspicuous accessory mineral in parts of the graphitic series. The graphite content varies markedly from place to place; assays of churn-drill cuttings show from 0.15 to 13.0 percent graphite. No systematic variation in graphite content from part to part of the graphitic belt has been detected. The graphite content cannot be estimated visually with any accuracy; however, in the main working the average graphite content of parts of the belt nearest the northwest contact appears to be abnormally low.

The graphite varies in texture. Flakes disseminated in micaceous quartzite and quartz-mica schist probably average 1 mm in diameter, but adjacent to the granitic and pegmatitic material the graphite is coarser. A few specimens with flakes 3 to 6 mm in diameter were seen. The graphite was apparently recrystallized during formation of the pegmatitic material.

In 1928 a serious effort was made to determine the amount and grade of graphitic rock then remaining in the deposit. At least 50 churn-drill holes averaging 75 feet in depth were put down, and test pits, trenches, and shafts were also made. The cuttings from the churn-drill holes were assayed at 5-foot intervals. Comparison of the assay data with actual yields from the rock mined suggests that the assays are reliable and that they can be used as a basis for estimating grade of ore now remaining. The rock drilled has been partly mined out, but as sizeable tonnage still remains above the bottoms of the drill holes. As of 1958, reserves available in the deposit are adequate for an extended period of operation.

OTHER DEPOSITS

Graphitic rocks occur in other places in Burnet and Llano Counties (Chelf, 1943; Barnes, 1940; Paige, 1912), and small amounts of graphite have been mined at a few of the localities. In Burnet County two belts of graphitic schist crop out in an area about 2 miles south of the Southwestern Graphite Co. mine (fig. 21). One of the belts has graphitic rock exposed intermittently over a distance of nearly 3 miles; the other has discontinuous exposures for about 1½ miles. The longer belt is 10 to 120 feet wide at the surface, has a strike of N. 65°–80° E., and dips 30°–65° S. The second belt strikes about N. 40°–85° E., with various dips. The longer belt has been prospected on the Dorbant, Debo, Watson, and Garrett properties and was mined on the Garrett property. The rocks are coarsely banded feldspathic quartz schists and quartzites containing fine-grained flake graphite.

At least six graphite deposits near Lone Grove in eastern Llano County have been reported. These are the Lillie Templeton, Louis Templeton, Logan Templeton, Letson Mill, Fitzsimmons, and Heath properties. The graphitic rocks at these places resemble those in Burnet County in that they are a series of feldspathic mica schists and quartzites. All the graphite seen by the writers was fairly fine grained; probably little or none is coarser than 50-mesh. Graphite content of the rocks is locally as high as 10 percent, but no estimate of average grade could be made without detailed exploration and sampling.

The extent, grade, and structure of the graphite-bearing rocks in Burnet and eastern Llano Counties are not known.

One and one-half miles south of the town of Llano is the mine and mill of the Texas Graphite Co. The mine workings consist of three open pits north of the mill, each about 20 feet long, 10 feet wide, and 5 feet deep.

The graphite-bearing rocks strike N. 45° W., dip steeply, and are exposed over an area 800 feet long and 100 to 250 feet wide. The graphite-bearing layer is a graphitic quartz-mica schist that locally

535373 O—60——5

contains minor quantities of andalusite. The graphitic rocks are bordered on the southwest by marble. The rocks to the northwest are covered.

Graphite exposed at this mine is extremely fine grained; probably none could be marketed as flake. Graphite content of individual layers ranges from about 2 to 25 percent and averages about 18 percent. According to local report, operation of the mine was discontinued because of the fineness of the graphite.

Other graphite deposits are known in the Llano-Burnet Counties area, notably at Robinson State Park near Packsaddle Mountain; these were not visited by the writers.

ALABAMA

The flake-graphite deposits of Alabama occur in two belts that are on strike with one another and trend northeastward. The area of the deposits is shown in figure 22. The southwestern belt, which is about 35 miles long, extends from near Verbena in Chilton County

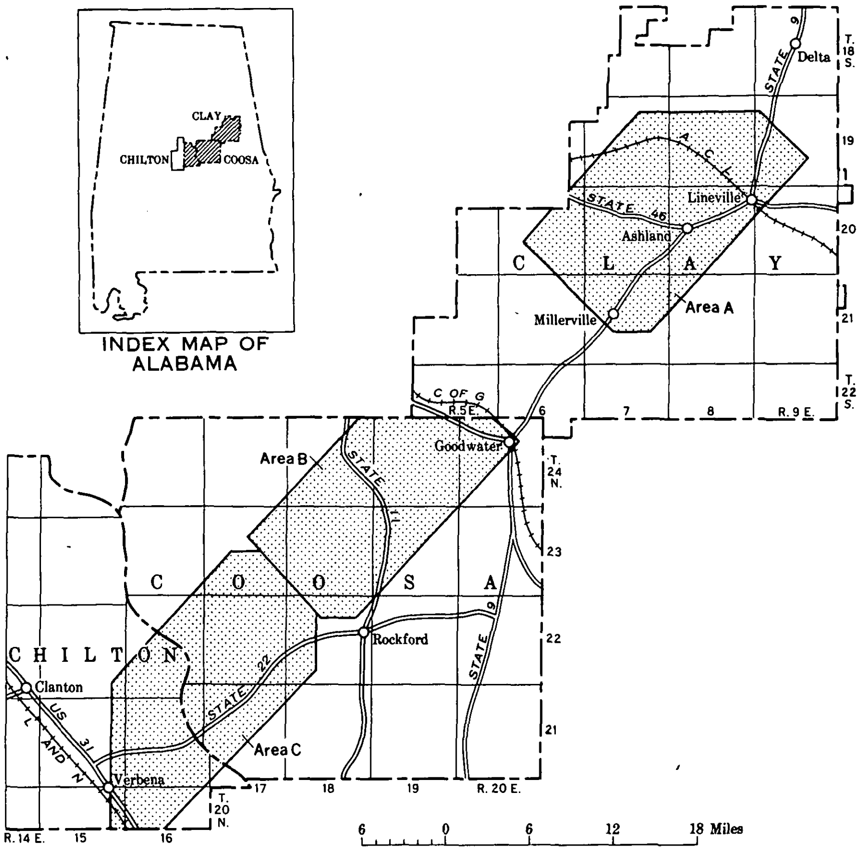
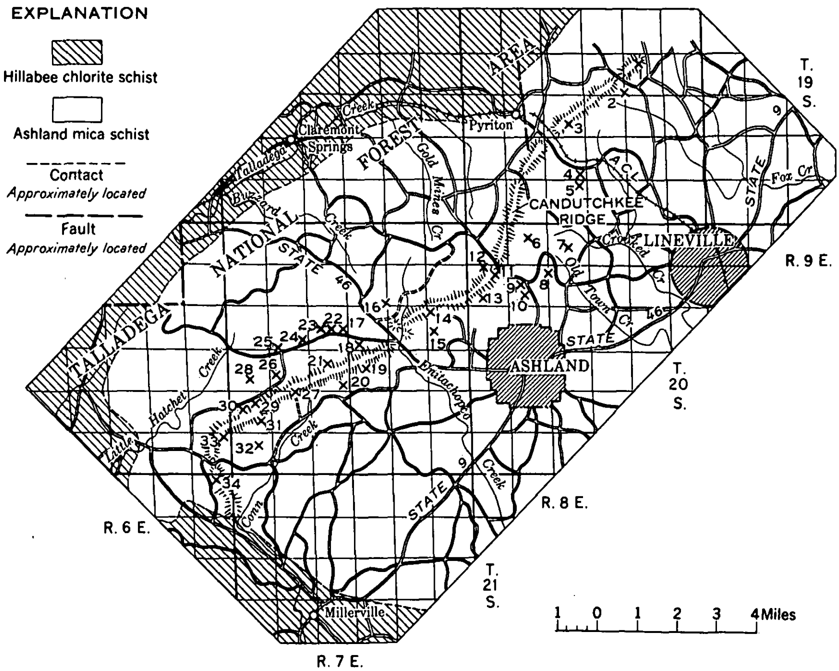


FIGURE 22.—Map of the areas of graphite deposits of Clay, Coosa, and Chilton Counties, Ala. (Area *A* of fig. 22.) After Pallister and Thoenen (1948).

almost to Goodwater in Coosa County and lies within areas *B* and *C* of figure 22. The northeastern belt extends from Millerville (figs. 22, 23) across Clay County to a point beyond Delta (Jones, 1929, p. 10), but, so far as the authors know, graphite mines and prospects exist only in the part of the belt included in area *A* of figure 22. The southwestern belt (fig. 24) extends about 40 miles from Goodwater to near Verbena.

NORTHEASTERN BELT

The northeastern belt (area *A*, fig. 22) is the better known and more productive of the two and includes the majority of the deposits that have been mined. The graphitic rocks of the belt are part of the Ashland mica schist of Precambrian age. Prouty (1923) showed the general geology of the belt on his geologic map of Clay County (fig. 23); the geology of the part of the belt north and west of Ashland was mapped and studied in more detail by Brown (1925).



MINES AND PROSPECTS

1. LIBERTY
2. W. L. SMITH PROPERTY
3. LINEVILLE
4. CARBON MOUNTAIN
5. PEERLESS
6. MONITOR
7. CRYSTALLINE FLAKE
8. JENNINGS
9. REPUBLIC
10. CLAY COUNTY
11. KING
12. BARRETT
13. AMERICAN
14. NATIONAL
15. SOUTHERN
16. ACME
17. REDDING
18. ASHLAND
19. GREISSIMER
20. POCAHONTAS
21. ALABAMA 1
22. SOUTHERN STAR
23. MAY BROTHERS
24. AXTON-NOE
25. ALABAMA 2
26. C. B. ALLEN
27. JEFFERSON
28. QUENELDA
29. EAGLE
30. SUPERIOR FLAKE
31. CRUCIBLE FLAKE
32. EMPIRE
33. ATLAS
34. HOOD-GRAVES

FIGURE 23.—Map of localities of graphite mines and prospects in part of Clay County, Ala. (Area of *A* of fig. 22.) After Pallister and Thoenen (1948).

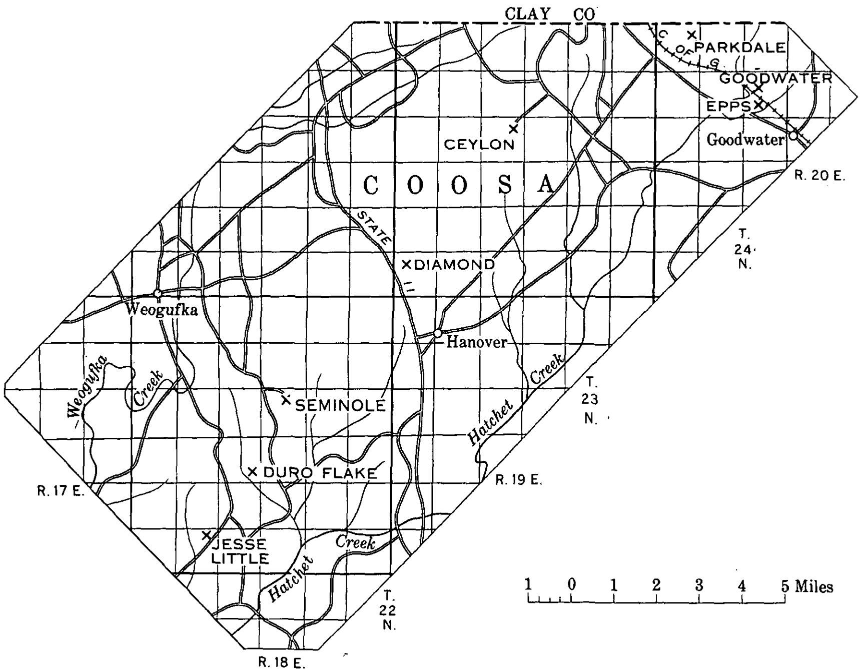


FIGURE 24.—Map of localities of graphite deposits in part of Coosa County, Ala. (Area *B* of fig. 22.) After Pallister and Thoenen (1948).

Later, Griffin (1951) mapped the western part of the area of Ashland mica schist, including parts of the graphite belt, and studied the Hillabee chlorite schist (post-Carboniferous?) and Talladega slate (Precambrian? to Carboniferous?), which border the Ashland mica schist on the west and south.

Over most of the area underlain by the Ashland mica schist the foliation and bedding trend northeastward. West and southwest of the town of Ashland, dips in general are steep to the southeast, whereas northwest of Ashland the dips have a wide range. In the southern part of the schist area the strike swings sharply to southeast, and dips are generally to the northeast.

The Ashland mica schist consists of several layers of quartz-muscovite schist, quartz-muscovite garnet schist, graphitic quart-vanadium mica schist, and graphitic quartz schist alternating with layers and lenses of hornblende schist and gneiss reported (Brown, 1925) to enclose bodies of diorite and cortlandite. This assemblage has been invaded by quartz diorite, aplite, and pegmatite and has been impregnated with quartz and feldspar apparently related to the pegmatite bodies.

The outcrop area of the Ashland mica schist is 10 to 12 miles wide, but the graphite-bearing rocks within the schist occur in a belt 1 to 2 miles wide. The graphite deposits occur on the crest and sides of

Candutchkee Ridge, which extends northeastward across the area. The graphitic rocks are lenses or layers of coarse siliceous mica schist containing 1 to 5 percent disseminated graphite flake. The lenses or layers are known to the mining industry as leads. Contacts of the leads with enclosing schists are apparently gradational. In most of the mines the limits of ore were assay boundaries, and sharp contacts between graphitic and nongraphitic rock are visible in only a few places.

In a structure section across Candutchkee Ridge and neighboring ridges, Brown (1925) distinguished 13 leads in the Ashland mica schist; five of these had been worked at the time of his study and a sixth, the Pocahontas lead, was being mined in 1950. The number of leads distinguished, however, is necessarily based on more or less arbitrary definition of their boundaries. Each of the main leads includes layers of barren rock; moreover, some of the rock separating the leads distinguished by Brown includes graphitic layers. Exposures outside the mine workings are poor, and none of the individual leads is fully exposed. The Pocahontas lead was traced by trenching for a distance along strike of about 4,000 feet, and Brown reported that he was able to trace a lead mined on the Griesemer property for a like distance. Certain other leads have been mined along strike for distances of more than 500 feet without exposing the ends. The total length of some of the larger leads may be measurable in miles, but the full length of a lead is not necessarily ore, for there is much variation in graphite content both along and across the strike. A typical section shows alternating layers of rocks of low graphite content, of high graphite content, and of intermediate graphite content. The individual layers range from fractions of an inch to 10 feet in thickness, but most of the leads mined consist of several layers, with aggregate thickness in some cases greater than 100 feet. Trenching is essential in determining the variations in thickness and grade of a lead along strike.

The structural significance of the presence of so many leads is unknown; some of the leads within the graphite belt may be repeated by folding. Furthermore, although both thrusts and normal faults are exposed in some of the mines, the effect of faulting on the distribution of leads within the graphite belt has not been determined.

SOUTHWESTERN BELT

The geology of the southwestern belt and the occurrence of graphite in it are not well known. The deposits, which are in the Ashland mica schist, resemble those of the northeastern belt in general characteristics and mode of occurrence. Most of the leads dip steeply or moderately steeply to the southeast. The only mines that have yielded large amounts of graphite are the Fixico, Ceylon, and Bama mines. The Ceylon and Bama mines were visited by the writers and are described in a succeeding section. The Fixico mine was visited briefly but the workings were so deteriorated that little could be seen of the deposits exploited there.

STRUCTURAL CHARACTERISTICS OF THE GRAPHITE DEPOSITS

The structure of the graphite deposits is largely determined by the structures of the leads. The simplest deposits are tabular and are parts of graphite leads that are of uniform width and are constant or nearly constant in attitude. Such deposits are represented by the Pocahontas, Redding, Allen, and Southern Star mines (fig. 23). At other mines the deposits are complicated by folding. Thus, in the open pit at the Crucible Flake mine the southeast lead shows intricate isoclinal folding of the lead and the enclosing rocks. The rocks there are further disturbed by faulting. Owing to these structural complications, the deposit narrows in width from about 140 feet at the southwest end of the cut to about 40 feet at the northeast end, in a distance of about 450 feet.

Faulting is responsible for numerous complexities of form. In the westernmost open pit near the old millsite of the Alabama No. 1 mine, the northwest-trending tabular graphite lead is offset progressively by a series of oblique-slip faults that strike N. 55°–65° E. and dip 65°–85° NW. Along each fault the hanging wall has moved upward. The form of the double lead at the Superior Flake mine is complicated by steep faults and low-angle thrusts.

GRADES OF GRAPHITE ORE AND YIELDS OF FLAKE

The ores mined in Alabama apparently have contained about 1 to 5 percent graphite. The graphitic rocks exposed in the mine workings probably average about 3 percent graphite. Flake size in remaining rock varies from less than 1 to more than 5 mm, but most of the flake is 1 mm or less in diameter. Assays of samples from 32 graphite properties in the northeastern belt gave recoveries of flake as follows (Pallister and Thoenen, 1948, fig. 4):

Pounds of flake per ton of ore	*Retained on mesh size*
6 to 40	+50
7 to 38	−50+100
8 to 70	−100
35 to 130 (total recovery)	

The percentage of coarse flake (+50-mesh size) was greatest, on the average, in the samples from deposits in the southwestern part of the belt.

Flake content and size vary from place to place in each individual lead. Variations in content are presumably due to variations in the carbon content of the original sediments. Size variations appear to be largely a function of the amount of injection and soaking by pegmatitic fluids. The writers agree with W. S. White (written communication, 1941) that the graphite was not introduced with the pegmatites, but that the pegmatitic fluids facilitated recrystallization of graphite and growth of larger flakes.

GEOLOGIC FACTORS INFLUENCING MINING IN ALABAMA

The geologic factors that determine whether a given deposit in Alabama can be mined are the physical condition, size, shape, attitude, and grade of the deposit. As exposures are poor, these factors must be determined by surface trenching across the leads, commonly at intervals of 50 to 100 feet. Supplementary information must be obtained by drilling.

The physical condition of the graphite ore is determined primarily by the degree of weathering. In typical pits in weathered rock the rock mined ranges from partly to thoroughly decomposed. Most ore mined is weathered to such an extent that it disintegrates readily and can be mined without blasting; weathered ore is therefore cheap to mine. Furthermore, weathering largely destroys the bonds between graphite and associated minerals, and hence reduces the amount of crushing needed in the milling process. It is said locally that weathered rock yields larger proportions of coarse flake than unweathered rock because the crushing necessary to unlock graphite from associated minerals in hard rock damages more of the flake. This view has not gone unchallenged, however, for a few operators have mined unweathered rock, and one operator interviewed by the authors said that there is little difference between the size of flake obtained from unweathered rock and that obtained from weathered rock of the same deposit. One advantage of the unweathered ore is that it furnishes a more uniform feed.

The depth of weathering of a deposit is governed principally by the position of the water table, which in turn is influenced by topography and by the attitude of the beds involved. W. S. White (written communication, 1941) has given an excellent discussion of the factors involved:

1. Where slopes are 5 degrees or less, weathering in the ridges is as deep and probably deeper than the level of the streams between ridges. Where slopes are steeper, the weathering may be deep or shallow, depending on other conditions. Ridges with broad tops will be more deeply weathered than those with narrow tops.

2. At most places, weathering seems to extend at least to the level at which ground water would drain from a given zone if all drainage were parallel to the schistosity. Leads which strike into slopes can drain at the level of the base of the slope and seem to have a weathering profile which rises gradually into the hill from the base. The only exception to this rule was noted at the

western pit of the American mine, where slivers of almost unweathered rock extend nearly to the surface on a hillside. Leads which strike parallel to a ridge may have deep or shallow weathering, depending on their dip. Where gullies cross leads which strike parallel to a ridge, weathering is locally the same as in situations where leads cross ridges.

3. Where the schistosity strikes parallel to a ridge, the depth of weathering seems to depend primarily on the direction of dip of the rocks. Drainage must be primarily through joints. In general, weathering is shallower on the slope of a ridge which dips in the opposite direction from the dip of the schistosity. At the Ceylon and Superior Flake mines, where the schistosity dips southeast, cross sections reveal that weathering is deeper below and southeast of the crest of the ridge than northwest of it. Where the schistosity dips from 50 to 70 degrees southeast, weathering near the top of the southeast slope is from 40 to 70 feet deep, and near the top of the northwest slope is from 20 to 40 feet deep. On very steep slopes 50 to 100 feet vertically below the broad top of a high ridge, weathering may be only 10 to 20 feet deep regardless of direction and amount of dip. Where the dip of the rocks is 70 to 90 degrees, weathering averages 40 to 70 feet deep near the tops of ridges, and somewhat less farther down the slope.

4. Where the schistosity is flat or very gently dipping, as at the southeastern pit of the American mine and at the northern pit of the Clay County mine, the weathering is probably nearly parallel to the slope of the hill.

MINING AND MILLING METHODS

Open-pit methods exclusively have been employed in the Alabama graphite mines. The soil or overburden is stripped before mining. The ore is blasted down, or where sufficiently weathered, it is dug out with a power shovel and then loaded into cars or trucks and taken to a mill nearby. Mining is continued until the bottom of weathered ore is reached, until slumping from the sides becomes excessive as the pit is deepened, or until the ratio of overburden to ore, if the deposit is inclined, becomes excessive. The average depth of weathered ore mined is probably between 40 and 50 feet, but mining in weathered ore has been carried to depths as great as 80 feet.

Milling methods employed in Alabama during the Second World War were described in detail by Pallister and Thoenen (1948). The basic steps were crushing, sizing, flotation, and screening.

SELECTED DEPOSITS

Peerless mine.—The Peerless mine (fig. 23) consists of several workings in the valley of a small creek south of the road that connects Pyriton with Lineville. The principal workings are on the south side of the creek, up the valley from the old millsite. The middle working is a bench, about 370 feet long and 15 to 60 feet high, cut into the south side of the valley. The bench trends approximately N. 60° E., roughly parallel to the strike of the beds, which dip 10°–30° SE. into the hill. A thickness of at least 50 feet of graphitic rock is exposed, of which the lower 30 feet is estimated to contain 3 to 4 percent flake graphite. The upper 20 feet is poorly exposed but appears to contain less graphite. The upper 10 feet of the quarry face consists of weathered rock, which passes downward into nearly unweathered rock at the base of the cut. Most flake is 2 mm or less in diameter, but scattered flakes up to 4 mm in diameter are present. A sample from the lower 13 feet of beds yielded 48.00 pounds of flake per ton, from which 13.00 pounds of +50-mesh flake was recovered (Pallister and Thoenen, 1948, p. 20).

The northwest pit is 285 feet long and 10 to 30 feet deep. Like the middle working, it is cut into the side of the valley, which here trends nearly north, and is roughly parallel to the valley. The beds strike N. 35°–40° E. and dip 40°–55° SE., but there are marked local variations in attitude. The thickness of graphitic rock mined is estimated to be about 50 feet. The upper 10 to 15 feet of rock in the face is weathered, but the rock in the lower part of the face is relatively fresh. The grade appears to be lower on the average than that of the rock at the middle working.

The deposits at the Peerless mine are of interest chiefly for the large potential tonnage available at the middle working, but much of the rock there is unweathered, and underground mining would be necessary for extraction of large amounts of ore.

Jennings mine.—The Jennings mine is about 1.5 miles north of Ashland (fig. 23) in an area straddling the forks of a small southeastward-flowing stream. The mine workings consist of at least six open pits in several of the graphitic zones in the Ashland mica schist. The graphitic zones strike N. 48°–65° E. and dip 30°–48° SE. The southwesternmost workings are two small open pits, on separate leads on the southwest side of the southwest fork of the stream. The southeastern and larger cut is 120 feet long, 30 to 35 feet wide, and has a maximum depth of 25 feet. The total thickness of beds exposed is about 25 feet. The rocks in the base of the cut are unweathered. The material mined is a medium-grained quartz-muscovite schist with graphite in flakes 1 mm or less in diameter. The grade is estimated to be less than 3 percent graphite. Exposures in the smaller pit, which is estimated to be less than 3 percent graphite. Exposures in the smaller pit, which is 20 feet long by 15 feet wide, are poor; the pit is partly filled by debris.

Between the forks of the stream graphitic beds about 50 feet thick have been worked in an open pit. The rock exposed appears to be low in graphite content. Most of the graphite flakes are less than 1 mm in diameter, although scattered flakes as large as 3 mm are present.

Northeast of the northeast fork of the stream are two parallel open pits separated by a narrow rock partition. The northwestern open pit is approximately on strike with the pit that lies between the forks of the stream. It is about 215 feet long, 75 feet in maximum width, and 40 feet in maximum depth. Graphitic rock, about 35 feet thick, comprising muscovite quartzite, quartz-feldspar-muscovite gneiss, and quartz-muscovite schist, is exposed in the headwall. The beds strike about N. 65° E. and dip 48° SE. A sample taken across 25 feet of the graphitic rocks yielded 84.88 pounds of flake per ton of ore, of which 13.04 pounds was +50-mesh size (Pallister and Thoenen, 1948, p. 24, 28). The depth of weathering in the headwall is only about 15 feet.

The southeast pit is about 170 feet long, 60 feet in maximum width, and 38 feet in maximum depth. The headwall exposes about 24 feet of graphitic schist overlain by hornblende-biotite schist. The schist contains disseminated graphite flakes, many of which are between 1 and 3 mm in diameter. A 25-foot sample across graphitic rocks yielded 68.68 pounds of flake per ton of ore, of which 8.20 pounds was +50-mesh flake (Pallister and Thoenen, 1948, pp. 24, 28).

In addition to the workings described, there is a small cut in unexposed rocks north of the two main cuts.

Data from trenching by the Bureau of Mines suggests that the graphite leads explored by the two open pits northeast of the forks of the stream continue to the northeast for at least 400 feet across a low ridge, and data from drill holes suggest that along the axis of the ridge the depth of weathering is at least 50 feet. As much as 50,000 tons of weathered ore may be present. Southwest of the creek forks, however, the graphite leads appear to be low grade, and their attitude is complicated in places by folds.

The deposit is less promising, both in size and in coarseness of graphite, than the deposits southwest of the gap in Candutchkee Ridge about 2½ miles west-northwest of Ashland (fig. 23).

National mine.—The National mine (fig. 23) consists of an opencut about 225 feet long that extends northwestward into the southeast side of a prominent broad-topped ridge at a place nearly opposite the highest part of the ridge. The cut is about 80 feet in maximum width and about 45 feet in maximum depth. The open pit exposes graphitic schist that strikes northwestward, dips 23°–65° S., and is overlain by quartz-vanadium mica schist. The beds are locally folded, and at the rim of the headwall the structure is complex. The beds are offset along a series of normal faults that strike northeastward and dip 52°–85° SE.

The mine was explored by the U.S. Bureau of Mines during World War II (Pallister and Thoenen 1948, p. 26-27). Five trenches were dug at intervals along the ridge, transverse to its trend, and six diamond-drill holes were put down. Pallister and Thoenen concluded that the top of the ridge is underlain at shallow depth by a large almost horizontal ore body. However, after inspecting the drill-hole logs and examining the trenches, the writers concluded that graphitic rock is cut only in limited parts of the trenches. The dip of the foliation varies within wide limits, and in places the structure is evidently complex. Where local folding is absent, the foliation in general strikes N. 5°–25° E. and dips 43°–90° E. Further exploration and detailed mapping would be necessary to establish the structure and the tonnage of ore available. No assays of the drill cores were given by Pallister and Thoenen, but the trench samples show 0.5 to 3.0 percent graphite. On the basis of the data available this deposit appears to be one of the less promising deposits of the northeastern belt.

Southern mine.—The Southern mine (fig. 23) consists of two open pits, presumably on the same graphite lead, on opposite sides of a small creek. The northeast cut is approximately 100 feet long, 55 feet in maximum width, and 35 feet deep at the headwall. A series of layers of graphitic rocks with a combined thickness of 25 to 30 feet were mined. The layering of the rocks strikes N. 70° E. and dips 30°–35° SE. A sample (sample A–36, which, contrary to the description given by Pallister and Thoenen, 1948, p. 44–45, is evidently from the northeast pit) across 12 feet of beds yielded 85.96 pounds of flake per ton, of which 23.20 pounds was +50-mesh size. Pallister and Thoenen noted that the sample probably is not representative. The writers estimate that the rocks contain an average of about 3 percent flake graphite. The depth of weathering in the headwall of the pit is apparently not greater than 12 feet.

Northeast from the headwall the ground rises for a distance of about 500 feet to the crest of the ridge, which is roughly 100 feet higher than the open pit. Additional graphitic schist is indicated in trenches and poor outcrops for a distance of at least 600 feet on strike to the northeast, but further trenching is needed to determine the continuity and grade of graphitic rock over this distance.

The southwest open pit is approximately 325 feet long, 65 feet in average width, and 12 to 35 feet deep. The graphitic beds mined are poorly exposed but are probably at least 30 feet thick. The layers strike N. 56°–69° E. and dip 32°–35° SE. over most of the length of the open pit, which is mostly in weathered rock but in places is in slightly weathered or unweathered rock. The graphite content appears to average about 3 percent, and flakes are mostly between 2 and 4 mm in diameter. There is considerable range in grade and size of flake, however, from layer to layer.

Fifty feet from the southwest end of the open pit the ground drops off steeply to the bed of a small creek. Beyond the creek, farther to the southwest, the ground rises in the nose of a long, low ridge. Trenches along this ridge exposed graphitic rock along strike for about 400 feet southwest of the open pit and to within 300 feet of the highest point on the ridge. Exposures suggest at least a moderate tonnage of weathered ore southwest of the open pit, but mining would require the removal of considerable overburden.

Northern group of deposits.—A group of deposits, here termed "the northern group," consists of several graphite leads north of the old Talladega-Ashland road, on the west side of Enitachopco Creek (fig. 23). The leads strike N. 50°–75° E. and dip 25°–75° SE. The two most important leads are separated by about 50 feet of rock that is low or lacking in flake-graphite. Beginning at the northeast end, the following mines are located successively along the strike: Redding, Southern Star, May Brothers, Axton-Noe, and Alabama No. 2. The southeastern lead has been worked at all the mines and appears to have been the principal source of production except possibly at the Axton-Noe mine. The northwestern lead was mined or prospected at the Southern Star mine and probably at the Axton-Noe mine. At the Axton-Noe mine a third lead, northwest of the other two, has been worked.

The leads trend across a series of small valleys that drain east-southeast into Enitachopco Creek. In the ridges separating these valleys, the graphite leads are weathered to depths ranging from 20 to 55 feet. Each mine, except where noted, consists of two open pits, one driven northeast, the other southwest into a ridge from a valley bottom.

The leads mined consist of flake disseminated in quartz-mica schist, which is more or less impregnated with thin layers and stringers of pegmatitic material. The southeast lead apparently ranges from 25 to 50 feet thick, but its walls as exposed in the open pits appear to be assay walls.

A sample from the southeast lead at the Southern Star mine yielded 102.60 pounds of flake per ton of ore, of which 1.48 pounds was +50-mesh size (Pallister and Thoenen, 1948, p. 47-48). A sample from the same lead at the Alabama No. 2 mine yielded 116.84 pounds of flake per ton of ore, of which 22.08 pounds was +50-mesh. A sample from the northwestern lead at the Southern Star mine yielded 72.64 pounds per ton or ore, of which 25.04 pounds was +50-mesh size.

The southeastern lead was by no means mined out, and mapping and exploration probably would establish the existence of a tonnage of ore roughly comparable to that mined in the past. The northwestern lead is still largely unmined; its continuity and grade are not known, but southwest of the Redding mine a thickness of about 55 feet of graphitic schist, apparently a continuation of the northwestern lead, is exposed for nearly 400 feet. There are several other areas along both leads that appear promising for prospecting. Samples taken from this group of leads by the Bureau of Mines, however, show a lower average percentage of coarse flake than samples from a similar group of leads to the southeast (Pallister and Thoenen, 1948, fig. 4). The leads are likewise narrower than some of those to the southeast.

The fact that three leads were mined at the Axton-Noe workings suggests that prospecting across strike from the other mines might discover additional leads.

Quenelda and C. B. Allen mines.—The Quenelda and C. B. Allen mines are south and west of the Alabama No. 2 mine, in a group of leads southeast of the northern group of deposits (fig. 23). The old Quenelda mine consists of 7 pits spaced along the strike of the leads for about 2,000 feet. The area was mapped, trenched, and sampled by the U.S. Bureau of Mines during World War II (Pallister and Thoenen, 1948, p. 55–57). The mine workings are located where two graphite leads, 20 to 45 feet apart, intersect a series of spurs that separate small northwestward-draining valleys. The workings are almost entirely in weathered ore. Owing to the condition of the workings, the thickness of graphitic rock mined was difficult to determine. The southeast lead is estimated to range from 40 to 65 feet thick and the northwest lead from 50 to 80 feet thick. The leads strike N. 55°–75° E. and at most places dip 55°–85° SE. Locally, however, the leads are vertical or dip steeply west.

Most of the weathered ore in the 2,000-foot interval along which the workings are located has been mined out. The principal reserves indicated by the exploratory work of the Bureau of Mines are in a group of leads southwest along strike for about 2,000 feet. There is probably a large amount of graphitic rock here, but the analyses indicated that the grade of rock in general ranges from 1 to 3 percent graphite. The proportion of coarse flake is also low, but Pallister and Thoenen suggested that sampling of the deeper material would show a higher proportion of coarse flake.

The C. B. Allen mine is on a lead northeast of the Quenelda leads. The mine is an open pit about 200 feet long, 50 to 55 feet wide, and 25 feet deep at the southwest end (headwall). The layers of graphitic rock mined have a total thickness of about 35 feet, but the lead is probably at least 50 feet thick. The weathered ore probably extends at least 15 feet below the floor of the open pit. Trenching, drilling, and sampling by the Bureau of Mines indicate that the lead extends both northeastward and southwestward from the open pit and has an overall length of at least 2,000 feet. About one-third of this length is in valley bottom and would probably be difficult to mine, but substantial reserves probably are present in the remainder. Samples yielded 2.5 to 6 percent of graphite, of which about a third was +50-mesh size.

In terms of richness and coarseness of flake, the C. B. Allen mine appeared to be one of the more promising properties of the area.

Alabama No. 1 and North Griessemer mines.—The Alabama No. 1 and North Griessemer mines are roughly on strike with one another and are either on the same lead or the same group of leads, northeast of the lead worked in the C. B. Allen mine (fig. 23). The pit of the Alabama No. 1 is 325 feet long, 12 to 65 feet deep, and 95 feet in maximum width. It was driven about N. 68° E. roughly along the strike of the graphite lead into a ridge that rises abruptly beyond the headwall and then drops off sharply to a small valley 250 feet northeast of the open pit. The graphitic beds mined strike about N. 60°–68° E. and dip 52°–60° SE. The limits of the rock mined were evidently assay limits, for the rock structurally above and beneath them carries graphite. The depth of weathering at the head of the open pit is between 40 and 45 feet; the lower portion of the headwall is partly concealed by fill but is evidently little weathered.

A sample of graphite rock from the south side of the pit yielded 83.6 pounds of flake per ton of ore, of which 39.92 pounds was +50-mesh size (Pallister and Thoenen, 1948, p. 51).

The ridge in which the mine is developed probably contains only a small tonnage of weathered ore, but a sizeable extension of the lead beyond the valley northeast of the mine is possible.

The North Griessemer mine consists of an open crosscut leading to an opencut about 380 feet long and 16 to 45 feet deep. The open pit is along a graphitic bed 35 feet thick which strikes N. 72° E. and dips 65°–73° SE. A sample taken across the northeast face of the cut yielded 86.12 pounds of flake per ton of ore, of which 15.20 pounds was +50-mesh size (Pallister and Thoenen, 1948, p. 50). The face at the southwest end is about 45 feet high and is entirely in weathered rock. The ground rises steadily to the southwest at an angle of about 4 degrees, and scattered exposures indicate that graphitic schist extends on strike for at least 360 feet. To the northeast there may be an even greater extension.

Middle Griessemer mine.—The middle Griessemer mine is at the summit of Candutchkee Ridge. The mine consists of a crosscut leading to an opencut 290 feet long, 45 to 60 feet wide, and 32 feet in maximum depth. The cut trends N. 65° E., roughly parallel to the strike of the foliation of the schists exposed in it. Opposite the crosscut, which is at the southwest end of the open pit, a tunnel was driven 100 feet to the southeast slope of the ridge.

A layer of graphitic schist about 55 feet thick is exposed in the northeast face of the pit, where the foliation strikes N. 66° E. and dips 82° SE. The face is 25 feet high and is entirely in weathered rock. Southwestward the opencut narrows, and the layer mined near the southwest end is about 25 feet thick. At the southwest end the deposit is complexly faulted; mining evidently was stopped here for this reason.

Large reserves of unweathered ore may remain to the northeast of the open pit. Graphitic schist is exposed at intervals along the strike for 180 feet to the northeast. Beyond this, however, heavy brush conceals the bedrock, and the full extent of the graphite lead is therefore unknown.

A sample taken from the open pit yielded 69.28 pounds of flake per ton of ore, of which 17.40 pounds was +50-mesh (Pallister and Thoenen, 1948, p. 50).

Pocahontas mine.—The Pocahontas mine of the Alabama Flake Graphite Co. is about 2,000 feet south of the crest of Candutchkee Ridge (fig. 23). In 1950 it was the only graphite mine in operation in Alabama. The mill is in the valley of a small creek that cuts across the graphite leads. The workings consist of two parallel opencuts extending northeast from the valley. These were abandoned after thick kaolinized dikes cutting the graphite leads were intersected. A third opencut was being excavated southwestward across the valley along what appeared to be the northwestern of the two leads originally mined. In July 1950 this opencut was 135 feet long and 45 to 50 feet wide at the base; the working face was 40 feet high and was entirely in weathered rock. The lead in the headwall was at least 50 feet thick; the northwest limit of ore had not been disclosed by mining. The foliation of the schist in the cut varies in attitude from place to place but generally dips steeply southeast. The operators stated that the ore averaged 4 to 5 percent flake graphite.

About 100 feet southeast along the slope from the third open pit, a second graphite lead is indicated by exposures. Presumably this is the extension of the lead worked in the southeastern pit across the valley.

This property was extensively explored by the U.S. Bureau of Mines (Pallister and Thoenen, 1948, p. 51–52); the work included trenching, sampling, and drilling. Graphite schist was shown to extend for about 2,400 feet southwest from the third opencut, and the depth of weathering in places may exceed 80 feet. The ground rises rapidly from the rim of the third opencut and remains at a high level, relative to the creek bottom, for about 1,500 feet.

Samples taken by the Bureau of Mines from trenches southwest of the valley yielded 1.7 to 3.7 percent flake. The yield of +50-mesh flake per ton of ore ranged from 1.16 to 17.96 pounds (Pallister and Thoenen, 1948, p. 29, 30).

From the standpoint of reserves and ease of mining, this property is one of the best in the Albama graphite district.

Crucible Flake mine.—The Crucible Flake mine is on the south side of Candutchkee Ridge (fig. 23). It was worked during 1942 and 1943 by Haile Gold Mines, Inc., after extensive trenching and drilling had indicated a sizable tonnage of ore. According to Pallister and Thoenen (1948, p. 62), 5,700,000 pounds of refined graphite was produced, of which 15.5 percent was grade 1B, 17.5 percent grade 2, 17 percent grade 3, and 50 percent grade 4 (War Production Board specifications). Two large opencuts were made in parallel northeastward-trending leads. The southeast opencut is 580 feet long, 8 to 56 feet deep, and 87 feet in maximum width. The northwest opencut is irregular in outline. It is 250 feet long, 100 to 200 feet wide, and 20 to 55 feet deep.

The structure of the deposits at this mine is complicated by folding and modified to some extent by faulting. A substantial tonnage of ore remains, but no estimate can be made until detailed geologic mapping and further exploration have been done. In the event of a shortage of graphite, however, this deposit would appear to merit careful consideration from the standpoint of reserves.

Ceylon Graphite Co. mine.—The mine and mill of the Ceylon Graphite Co. are in the NW¼ sec. 16, T. 24 N., R. 19 E., about 8 miles west of Goodwater, Coosa County (fig. 24). It is one of the largest graphite mines in Alabama. Production began in 1916 and continued until 1929. No mining was carried on between 1929 and 1939. The property was purchased in 1936 by C. J. Johnson, who built a new mill and treatment plant; production was resumed in 1939. The mine was in continuous operation from 1939 until it was closed in 1947.

Exact production figures are not available. For the period 1926–27, the average production was 100 tons of finished graphite per month (C. J. Johnson, oral communication, 1950). The graphite was marketed in a variety of grades and was used for crucibles, foundry facings, and lubricants. An appreciable amount of this production came from unweathered ore.

The workings consist of a large open pit 925 feet long, with a maximum width of 300 feet and maximum depth of 70 feet. The pit is on two levels 10 feet apart.

The graphite deposit consists of one or more layers of graphitic rock which have an average strike of N. 50° E. and dip 40°–60° SE; the graphite layers appear to pinch and swell along strike. The changes in the beds along strike are not known, but the continuity of graphitic layers is obvious enough to permit an estimate of reserves.

The structure is apparently simple. Minor variations in strike and dip do not seriously affect the size or location of the ore body. The only fault seen is in the lower level near the northwest end of the center cut. It strikes N. 70° W., dips 79° S., and has an apparent displacement of about 30 feet. The south block is downthrown.

The rock mined is a quartz-muscovite schist, which contains minor amounts of biotite and 2 to 6 percent graphite. It averages about 3 percent graphite. The flakes average about 2 mm in diameter, but a fairly high proportion is 3 mm or more in diameter. Pyrite is present in places. The rock in the west half of the center entryway crosscut is fresh and hard, as is the rock exposed in knobs left in the center of the northeast segment of the pit and near the center of the southwest segment. Elsewhere the rock is partially to almost completely weathered. The footwall rocks are intensely weathered hornblende-biotite schists and hornblende-biotite-feldspar gneisses. The hanging wall is quartz-muscovite schist. Reserves of ore are believed to be large.

Bama mine.—The Bama mine is in Chilton County (fig. 25) near the southwest end of the southwestern graphite belt. In 1951 the mine was owned by the Alabama Machinery and Supply Co., Montgomery, Ala. According to Mr. W. W. Doe, Sr., treasurer of the company, the mine was operated from 1925 to 1930; in 1930 the mill, which had a capacity of 3 tons of graphite per day, burned. Five grades of graphite were produced: Special Bama, 96 percent carbon; special Bameco, 95 percent carbon; Bama, 93 percent carbon; Bameco, 93 percent carbon; and M–2, 70 percent carbon. The Bama grade was +60-mesh flake, the Bameco grade was −60+80 mesh, and the M–2 grade was −80 mesh. The Bama flake is of particular interest because carbon-bonded crucibles were first manufactured with it, and Madagascar flake was used for these crucibles only when Bama flake became unavailable.

The main working at this mine is an open pit 625 feet long, 150 feet in average width, and 30 to 74 feet in depth to main floor level. The cut trends about N. 30° W. Three crosscuts through the east wall of the openpit were used as entrances. The open pit is separated into two segments by a discontinuous partition of slightly weathered schist. An area 275 feet long and 30 to 90 feet wide in the bottom of the southwestern part of the cut is flooded.

The rocks mined are medium-grained muscovite-biotite-quartz schists containing disseminated flake graphite. The foliation in general strikes N. 16°–25° W. and dips 50°–60° SW., but in places there is much minor folding. The north end of the open pit is a fault surface that strikes N. 16° W. and dips 58° SW. The rock beyond the fault is graphitic. The rock ranges from partially weathered and firm to soft and thoroughly decomposed; some layers are weathered to much greater depths than others, but most of the rock at the base of the highest parts of the walls of the openpit is partly weathered.

A substantial tonnage of weathered to partly weathered rock probably remains in the deposit worked in the main open pit, but

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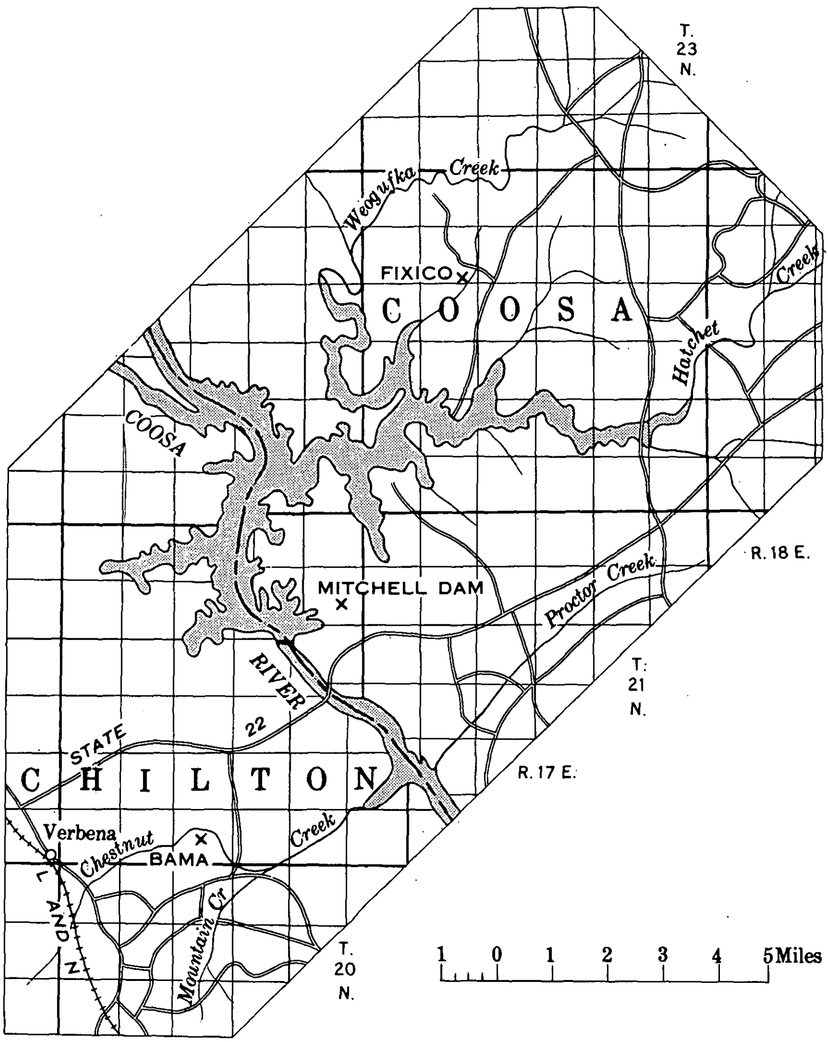

FIGURE 25.—Map of localities of graphite deposits in parts of Chilton and Coosa Counties, Ala. (Area C of fig. 22.) After Pallister and Thoenen (1948).

actual estimates cannot be made until the deposit and the surrounding area have been mapped in detail and the leads explored. Some ore remains northwest of the working, but its extent is uncertain owing to faulting and minor folding in this part of the deposit. To the southeast a large tonnage of weathered ore may be present on strike with the southwestern section of the deposit. The ground elevation rises in this direction but falls along the northeastern section of the working.

The tenor of the ore remaining in the deposits is not known. Three samples were taken by the U.S. Bureau of Mines (Pallister and Thoenen, 1948, p. 75). One of these, taken across 20 feet of the east side of the north face of the cut, yielded 73.96 pounds of flake graphite per ton of ore, of which 15.56 pounds was +50-mesh. A second sample, taken across 20 feet of the west side of the north face, yielded 85.84 pounds of flake per ton of ore, of which 17.04 pounds was +50-mesh size. These two samples represent the two layers last mined. The third sample, taken across 20 feet of the south face, yielded 157.16 pounds of flake of low-carbon content per ton of ore; this sample seems of dubious significance despite the authors' statement that the poor assay of the sample may explain why mining was stopped at this end (p. 75). Further sampling is needed.

Some smaller, parallel openpits, northeast of the main working, apparently in narrow graphite leads, do not appear promising.

PENNSYLVANIA

The graphite deposits of Pennsylvania occur in the metamorphic rocks of the Piedmont Plateau area, in the southeastern part of the State. Miller (1912) described the deposits and the mine operations and workings as they appeared at that time. Graphite has been mined in Berks, Bucks, Lehigh, and Chester Counties, but the principal deposits are west of Phoenixville, in Chester County (fig. 26). The most important localities are in the valleys of French and Pickering Creeks, where two nearly parallel northeastward-trending areas of gneisses and schists contain graphitic layers.

The deposits near Pughtown in the valley of French Creek have not been worked since about 1920. Only one mine, the Eynon-Just, produced a significant amount of graphite.

The belt of graphite deposits in the valley of Pickering Creek is the largest and best known in Pennsylvania. The mines in this area were operated intermittently between 1890 and 1914 and then, like those in other areas of domestic-graphite production, experienced a boom during World War I. No production was recorded between 1920 and 1940 (Sanford and Lamb, 1949). Between 1943 and 1947 the Benjamin Franklin and Just mines were operated intermittently; later they were explored and sampled by the Bureau of Mines.

The deposits are in the Pickering gneiss of Precambrian age, a metamorphosed sedimentary sequence, consisting of orthoclase, plagioclase, quartz, and biotite, with hornblende and other minerals as accessories. Variations in proportions of mineral constituents are common. Most of the rock at or near the surface is intensely

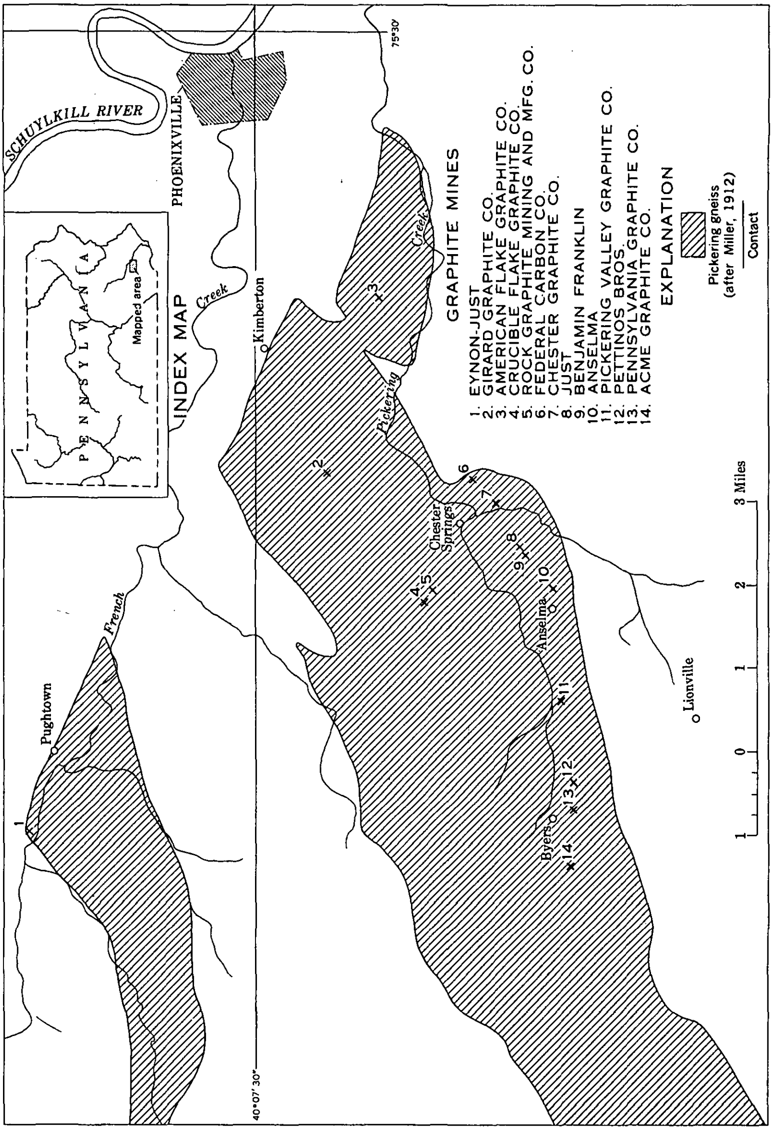

FIGURE 26.—Map of localities of graphite mines in Phoenixville, Pa., area.

weathered, and kaolin, carbonates, and iron oxides constitute much of the rock. Certain layers or zones contain graphite, which in places makes up as much as 10 percent of the rock. These graphitic layers occur for about 8 miles along the south side of the gneiss area from about 1 mile southeast of Kimberton almost to the village of Byers. The graphitic layers have not been fully traced out, but the distribution of mines suggests there are several belts of graphitic gneiss.

The belts of gneiss trend approximately N. 65° E. and in general dip 30°–60° SE. Much local variation in attitude, the result of small-scale folding, is visible in some of the mines. Some large-scale faulting has been recognized. Rocks exposed in certain of the old workings show extensive injection of pegmatitic material, and the phenomenon is present to some degree in all mines. Some of the pegmatitic material contained sufficient graphite to justify mining. The flake graphite in the pegmatites is normally coarser than that in the enclosing gneiss; in some pegmatites the flakes are as much as 25 mm in diameter. Most of the larger pegmatites contain graphite only in the outer parts. The pegmatites and gneiss are markedly weathered where exposed in mine workings.

BENJAMIN FRANKLIN AND JUST MINES

The Benjamin Franklin and Just mines (pl. 11) are on the crest of a low ridge south of Pickering Creek, 1 mile N. 50° E. of Anselma, in West Pikeland Township, Chester County.

The Benjamin Franklin property, including 70 acres of mineral land and a treatment plant, was purchased by the U.S. Government in 1942, and in 1943 the construction of a mill was authorized by the War Production Board. The Just property, which includes an area of 15 acres, adjoins the Benjamin Franklin mine on the northeast. The properties are separated by a gravel road that provides access to both.

After construction of the treatment plant in 1943, the Benjamin Franklin mine was leased to the Benjamin Franklin Graphite Co., which owned the Just mine. This company produced 398 tons of graphite from the Just mine in about 5 months in 1943. All operations were halted in November 1943.

In April 1946 the Benjamin Franklin mine and mill and Just mine were leased by the newly formed North American Graphite Co., and operated the mine and mill for 4 months in 1947 and produced 58 tons of graphite. Messrs. Hess and Schmehl subleased the properties in October 1947 and produced 120 tons of graphite (Sanford and Lamb, 1949, p. 4) before shutting down operations in January 1948.

In 1948 the Benjamin Franklin and Just properties were explored by the U.S. Bureau of Mines (Sanford and Lamb, 1949). Nine trenches and three diamond-drill holes were made, samples were collected and assayed for graphite content, and flake size and depth of weathering were determined. The graphitic zone was found to contain an average of about 1.5 percent graphite and the depth of weathering was found to be as much as 120 feet. In 1950 geology and topography of a small area around the two mines was mapped by the writers (pl. 11).

There are two principal open pits on the properties. One, just northeast of the mill on the Benjamin Franklin property, is 240 feet long, 30 to 100 feet wide, and 40 feet deep at its deepest point; the other, on the Just property, is 600 feet long, 25 to 200 feet wide, and 40 feet in maximum depth. Other workings consist of the trenches dug by the U.S. Bureau of Mines in 1948.

The general geology of the deposit is fairly simple. The graphitic rocks form a zone that has been traced along strike for about 3,200 feet, but, as neither end of the zone has been located, its total length may be considerably greater. The zone is exposed in trenches and workings over widths ranging from 200 to 400 feet, but the total width is not known. The zone trends about N. 64° E. Dips of foliation range from 20° SE. to as much as 60° SE. The overall attitude is obscure, owing to lack of key horizons and to locally intense minor folding. The zone is exposed only in the trenches and mine workings.

The graphitic rocks within the zone consist of micaceous quartz schist, nearly pure quartzite, and feldspathic quartz-muscovite gneiss. The three rock types grade into one another. The graphite content varies markedly across strike. Thin lenses of coarse granitic to pegmatitic material are abundant in parts of the graphitic zone and are commonly arranged parallel to the foliation. A few pegmatites as much as 5 feet in thickness occur in the gneiss.

Weathered graphitic quartz and mica schist interlayered with quartzite, barren feldspar gneiss, clayey material, and pegmatite are exposed in the southwest wall of the Just open pit. Graphitic layers range from a few inches to more than 10 feet in thickness. Individual graphite flakes are 1 to 6 mm in diameter. A layer of nearly pure graphite ½ to 2 inches thick is along the footwall of one small pegmatite. Southwest of the quarry face, where an area roughly 120 feet wide by 230 feet long has been stripped of overburden, the rocks show numerous small folds, but the general continuity does not appear to be affected.

The rocks exposed in trenches between the open pit on the Just property and the open pit near the mill are similar in composition to those in the Just open pit. There is much small-scale variation in rock type and graphite content across the strike. Locally, thin lenses of pegmatitic material are abundant. The graphite occurs as disseminated flakes 1 to 6 mm in diameter, parallel or subparallel to the foliation. The flakes are noticeably coarser near the coarse granitic or pegmatitic material but probably do not average more than 3 or 4 mm in diameter. Graphite content of individual bands and layers ranges from ½ to more than 10 percent. Assays of samples taken by the Bureau of Mines show an average tenor of about 1.5 percent graphite.

The graphitic rocks in the open pit north of the treatment plant are somewhat more uniform in structure and graphite content than those on the Just property. Much of the rock here is graphitic quartz-mica schist, although other rock types also occur.

Southwest of the mill, trenches and stripped areas show rocks similar to those exposed in the open pits. As far as the authors could determine from available exposures, the geologic structure there is relatively simple; less small-scale folding is visible than in the pits. The rocks toward the southwest end of the property appear to contain a higher proportion of quartz, and the flake size of the graphite in the rocks appears to increase. No quantitative estimate of flake size or graphite content was made, but the average graphite content apparently diminishes in this direction.

The rocks enclosing the graphitic zone do not form outcrops on either property. Test pits and trenches gave only limited information on the composition and structure of the rocks. In general they are hornblende gneiss or hornblende-biotite schist that appear to have the same general attitude as the graphitic rocks. Some small-scale folding was noted.

The rocks on the Benjamin Franklin and Just properties are deeply weathered at most places, and mining has largely been confined to the weathered ore. Feldspar has decomposed to form clay, the mica has been bleached and altered, and hornblendic rocks have been changed to a soft reddish-brown clay. Only the thicker layers of quartz and the graphite flakes seem unaffected by weathering

The value of the deposits on the properties depends to a large extent on the suitability of the flake sizes of strategic uses. Assays by the U.S. Bureau of Mines (Sanford and Lamb, 1949, p. 12) show that although the average graphite content of the ore is only about 1.5 percent, nearly one-third of the concentrates produced during World War II consisted of flake coarser than +50-mesh size. On this basis the properties would therefore appear to offer more promise for the production of standard clay-graphite crucible flake than is indicated by the figures for grade alone. The results of tests of the flake for crucible use have been discussed in a previous section (p. 14–15). The value of the flake for lubricant and packing-grade materials has not been determined; the true value of the property is therefore still in doubt. The presence of a modern mill and equipment, together with a sizeable tonnage of graphitic rock, is a definite asset. Future operation of the plant, however, will create a problem of tailings disposal, as the area used for this purpose in the past is now almost entirely filled.

ANSELMA MINE

The Anselma graphite mine (fig. 26), which has not been operated since World War I, is one-fourth mile east of the village of Anselma and about one-half mile southwest along strike from the Benjamin Franklin mine. Five inclines of unknown depth and one small open pit 20 by 60 feet make up the workings. Graphite-bearing quartz-schist containing 3 to 5 percent graphite, in flakes ranging from 0.5 to 18 mm in diameter, is exposed in the inclines. Material of this grade, however, is shown only in one very limited exposure. The inclines were caved or filled with water to within short distances of the surface and could not be explored. The hanging wall, which is exposed in only one place in the open pit, consists of fine-grained pegmatitic gneiss, which contains feldspar and quartz but no graphite. As the footwall is not exposed, the thickness of the graphite zone could not be determined.

The rocks exposed at the mine are similar to those of the Benjamin Franklin mine and are schists that have been modified by the addition of coarse massive quartz in lenses and stringers parallel to the schistosity. In exposures, schistosity and bedding strike N. 58°–75° E. and dip 45° SE.

No estimates of reserves are possible without more information. This property appears to justify further investigation, however, because of the unusually rich coarse-flake graphite it contains. The mine is only a short distance along strike from the Benjamin Franklin mine and is presumably on the extension of the same broad zone of graphitic rock.

OTHER DEPOSITS

Two other deposits in the Pickering Creek graphite belt were examined by the writers. They presumably are a continuation of the graphitic rocks at the Benjamin Franklin, Just, and Anselma mines, as they occur approximately along the projected strike of the belt.

The workings of the Chester Graphite Co. mine (fig. 26), last operated in 1918, are one-half mile south-southeast of the village of Chester Springs. They consist of an irregular open pit, about 400 by 300 feet in maximum dimensions, and two caved inclines of unknown depth. Several small prospect pits are east and northeast of the large pit.

The workings are badly slumped and overgrown and the nature or occurrence of the mined material could not be determined. E. S. Bastin (written communication) described the rock mined as weathered quartz-feldspar-graphite schists of medium coarseness, in part containing muscovite. Locally the rock is granitic injection gneiss.

The open pits one-fourth mile south of the village of Byers (fig. 26) probably represent the mine of the Pennsylvania Graphite Co. They are badly slumped. Three very large irregular open pits, 300 to 500 feet long and 150 to 300 feet wide, were filled with water. Underground workings at the property were inaccessible. The graphitic layer is reported to be about 10 feet thick (Bascom, 1938, p. 128). Very little graphitic material could be seen, and it was impossible to draw any conclusions as to the nature and amount of graphite remaining.

SUMMARY

Graphite is found in four counties in Pennsylvania, but an area in Chester County about ½ mile wide and 8 miles long, on the south side of the valley of Pickring Creek, is the only one that appears to be worthy of attention as a potential source of commercial and strategic graphite. The graphitic rocks of Pennsylvania do not crop out except in the vicinity of the Benjamin Franklin and Just mines. There the graphitic schists appear of sufficient richness to warrant further attention and more detailed investigation. The proportion of coarse flake in the graphite of this area may well be greater than at any other locality in the United States.

NEW YORK

The principal graphite deposits of New York are in the eastern Adirondack Mountains, in Essex, Warren, Saratoga, and Washington Counties (fig. 27). Graphite is also found near Suffern in Rockland County, and near Pope Mills in St. Lawrence County (fig. 12). The last two deposits are of minor importance, although the deposit at Pope Mills was in operation during both World Wars. The greatest number of mines and deposits and by far the largest reserves of graphite are in the eastern Adirondacks.

The area has a relief of 2,700 feet. Hills reach an elevation of 3,000 feet within a short distance of Lake George and Lake Champlain, which are only about 300 feet above sea level. Most of the land is heavily forested. Several excellent highways cross the district, but many of the mines are some distance from good roads.

The graphite deposits of New York were investigated in much the same manner as the other areas covered in this report. In general, only the larger deposits were visited, although certain of the others were seen for purposes of comparison. No detailed mapping

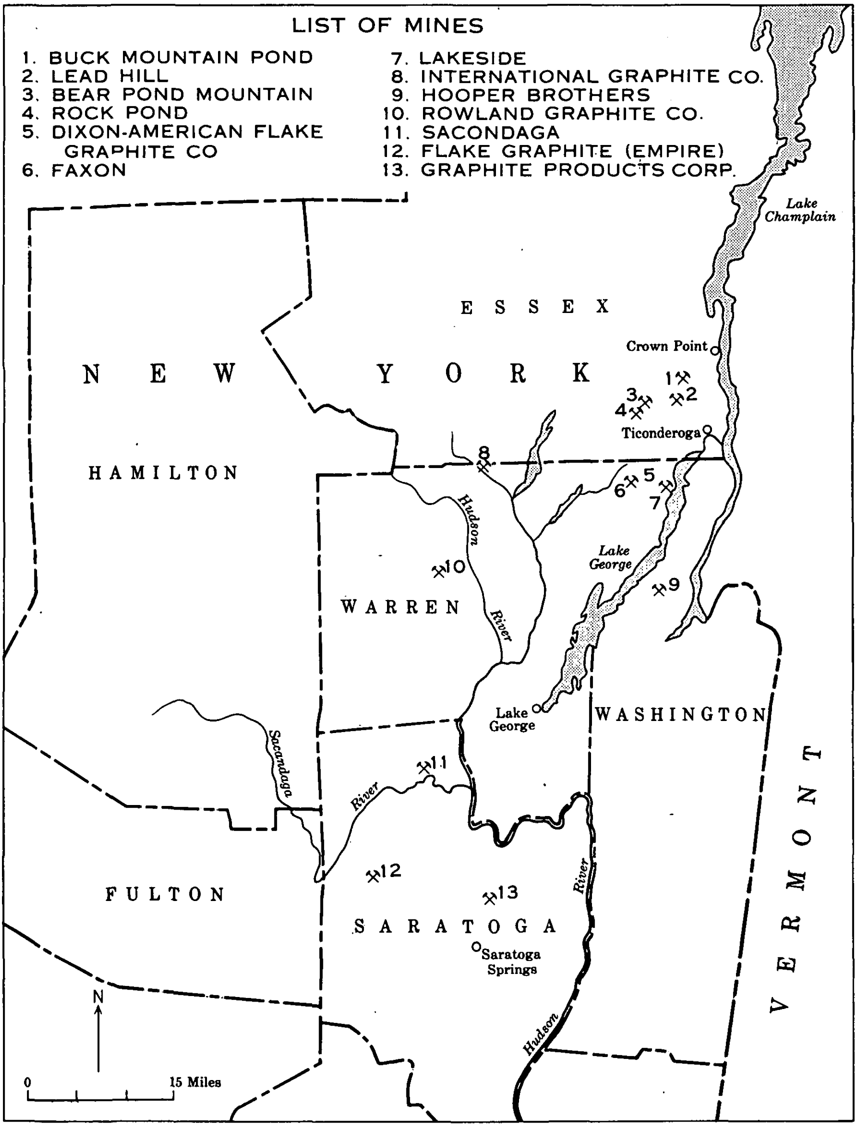

FIGURE 27.—Map of localities of principal graphite mines of the eastern Adirondack Mountains area.

was attempted. Alling (1917) is the best source of information on the deposits, and much of the material given below is taken from his work.

HISTORY OF GRAPHITE MINING

Graphite was first mined in the Adirondacks in the 1850's (Alling 1917, p. 8–9). From then until the early 1920's the mines of the area produced over 5,000 tons of flake. Large tonnages of graphitic rock remained, but a number of unfavorable economic factors discouraged mining activity after World War I. In 1950 no mining equipment or mill buildings remained anywhere in the area. Mines ranged from mere prospect pits to extensive underground workings. The largest mine was that of the Dixon-American Graphite Co. at Graphite.

The mines were worked for the most part by subsurface methods. A vertical, inclined, or horizontal opening was made in the graphitic layer, and the ore commonly was removed by modified room-and-pillar methods. Treatment plants were crude. Modern flotation reagents and techniques were not known at the time the mines were operated, but several of the operations were nevertheless successful for a time.

GENERAL GEOLOGY

The Adirondack Mountains are underlain chiefly by Precambrian igneous and metamorphic rocks. Their structure and stratigraphy is complex and not completely understood. The graphite deposits are confined to a series of metamorphosed rocks—paraschists, paragneisses, quartzites, amphibolites, and marbles—assigned by Alling (1917, p. 42) to the Grenville series. These are sedimentary rocks that have been folded, metamorphosed, and invaded by igneous rocks.

TYPES OF GRAPHITE DEPOSITS

There are three distinct kinds of graphitic deposits in New York. Graphite-bearing veins have been found along the shores of Lake Champlain, between Ticonderoga and Split Rock Point. Contact-metamorphic deposits have been found chiefly in southern Essex County. Deposits consisting of graphite disseminated in schist make up the third and most important type.

Vein deposits in general contain only small reserves. They consist of fine to coarse platy graphite, commonly with accessory quartz, feldspar, calcite, and biotite (Alling, 1917, p. 31). The veins are fracture-fillings in several kinds of country rocks.

The contact-metamorphic deposits are in marble adjacent to intruded pegmatites. The marble has been irregularly recrystallized and silicated, and graphite is found in both the marble and the silicate rocks. Facies of extremely coarse material are present in places, and these may contain graphite flakes as much as 5 cm in diameter and calcite crystals 15 cm or more in length. Diopside, scapolite, phlogopite, and minor amounts of sphene and tourmaline are commonly associated with the calcite and graphite. The graphite occurs as coarse flakes disseminated in the marble and silicate rock or as nests, bunches, and radiating aggregates in the silicate rock. It also appears a veinlike concentrations in association with coarse calcite and rounded quartz crystals in silicate rock or marble.

It is also present as large flakes along crystal boundaries in the pegmatites or in small, local concentrations near the contacts between pegmatite and country rock. The rocks locally include patches that are rich in graphite, but the average graphite content of most deposits is probably less than 1 percent. The boundaries between pegmatite and country rock are very irregular, and the occurrence of graphite is extremely erratic; hence it is difficult to block out ore in these deposits.

The graphitic schist deposits consist of quartz and graphite, commonly with feldspar and mica. Other minerals are present locally, but only a few are recognizable in hand specimens. The schists are layered and show variations in the proportions of quartz, feldspar, and graphite from one layer to another. In some deposits the graphite content is 5 to 7 percent of the rock and grade and flake size are both remarkably uniform in the graphitic layers (table 2). Flakes more than 3 mm in diameter are rare. The flakes are elongate or rounded and are well oriented parallel to bedding or banding. Graphitic layers range in thickness from less than a foot to more than 12 feet. Because of their origin as metasediments, graphitic layers exhibit considerable continuity along strike, and large tonnages can be blocked out where exposures are adequate to show the structure. Upper and lower contacts of the graphitic layers with the country rock are commonly gradational through short distances. In many deposits both hanging-wall and footwall contacts are shear surfaces or narrow shear zones, parallel or nearly paral-

TABLE 2.—*Flake size and graphite content of Adirondack graphite deposits*

[After Alling, 1917]

Deposit	Source of material	Percent graphite (by weight)	Maximum flake size (mm)	Minimum flake size (mm)	Average flake size (mm)
Lead Hill	Ore	6.0			
	Concentrate		0.80	0.32	0.38
	Thin section		2.80	1.50	1.84
Dixon-American Graphite Co.	Thin section	5.2	3.50	.34	1.10
	Thin section	7.8	2.50	.40	1.03
	Concentrate [1]		1.11	.23	.37
Faxon	Ore [2]	6.7	1.10	.25	.66
	Ore [2]	8.7	2.70	.60	1.20
Lakeside	Ore [2]	9.1	1.20	.30	.71
Hooper Bros	Ore [2]	7.7	.85	.20	.44
	Ore [2]	5.7	1.20	.30	.68
	Concentrates	89.00	1.05	.21	.33 x .65
International Graphite Co.	Ore	7.1			
	Thin section		1.70	.40	1.03
Flake Graphite Co	Fine ore [3]	4.5	.92	.30	.50 x .68
	Coarse ore [3]	7.0	2.40	.50	.76 x 1.10
	Concentrates [4]	90.80	.91	.20	.42 x .58
Graphite Products Corp.	Ore [2]	7.7	1.30	.30	.75
	Mill concentrate		.600	.133	.205 x .437
	Final concentrate		.831	.233	.268 x .451

[1] Coarse.
[2] Thin section.
[3] Hand specimen.
[4] No. 2 flake.

lel to the bedding. In most places these do not affect the thickness of the potential ore, but in some deposits the graphitic layers show pinching and swelling related to the shears. Structure of the graphitic layers in general is simple. Changes in attitude are mostly gradual, and vertical or cross-cutting faults of large displacement are rare. Lack of exposures commonly prevents tracing of the graphitic layers away from existing mine workings, but in some places layers overlying or underlying the graphitic layers can be traced for long distances. For example, in the area west of Lake George a distinctive garnet-feldspar gneiss associated with the graphite schist forms a nearly continuous exposure on slopes of more than a few degrees. In other places, however, hanging-wall rocks are less resistant, and little was learned of the structure or probable extent of graphitic rock.

SELECTED DEPOSITS

Lead Hill.—The Lead Hill deposit lies 3 miles northwest of Ticonderoga, in the southeast corner of Essex County (fig. 27); it is on the south slope of a hill about 500 feet north of State Route 73, a paved road between Ticonderoga and Severance. The access road is now (1950) impassable to a car.

The mine is in the first graphite deposit known to have been worked in the State. It was operated as early as the 1850's by the Joseph Dixon Crucible Co. (Alling, 1917, p. 24).

The workings of the mine are scattered over an area more than 1,200 feet long and nearly 800 feet wide. They include many small prospect pits and two larger openings known as the Woodchuck and Young Lyon workings. The rocks exposed near the mine include coarse calcite marble, medium-grained quartz-feldspar pegmatite, massive quartz, and diopside-scapolite and phlogopite rocks. Several pegmatite bodies are believed to be present, but their position and size are not known. The bedding in the marble trends west, parallel to the hill slope.

The deposits are of interest only because they exhibit the characteristic features of contact-metamorphic graphite deposits. Graphite is irregularly developed along contacts of pegmatite with marble and silicated marble consisting of diopside, phlogopite, sphene, calcite, and scapolite in various proportions. It occurs disseminated or patchily distributed in marble, silicated marble, and pegmatite, and in quartz or quartz-calcite fissure veins that cut the other types of rock. The graphite content varies markedly from place to place, without recognizable pattern.

The reserves of the Lead Hill mines are probably small. There are local pockets and zones that are very rich, but the overall average graphite content of any large volume of rock is very low. The distribution of the richer parts is extremely erratic. Large-scale mining would not be possible.

Buck Mountain Pond.—The Buck Mountain Pond property is in Essex County, and extends for 1,000 feet west from Buck Mountain Pond. To reach it, drive 4 miles north on State Route 8–9N–22 from Ticonderoga to Street Road, then west on a county road 1.5 miles to a small stream and an abandoned mine road. The mine is 1½ miles northeast along the abandoned road. The mine was operated for a short time around 1900 but yielded little graphite. There are two principal workings and many prospect pits scattered over a distance of about 1,200 feet along the north and west sides of a small hill. The eastern working is an opencut 40 feet long and 20 feet in maximum height driven into the north slope of the hill about 25 feet above the old millsite. The western working is about 1,000 feet from the old millsite, at the west end of the hill. It consists of two broad inclined openings 60 feet apart that open downward into opposite ends of a single partly flooded slope that is at least 50 feet deep at the north end.

Graphitic marble and silicated marble cut by pegmatite are exposed in the workings. The graphite content of these rocks varies erratically from 0 to as much as 20 percent, but the average grade is very low. Most of the graphite is in marble but no sizeable tonnage of material containing more than 1 percent graphite is indicated. Flake size varies from 0.1 to 5 mm.

Quartz veins containing scattered flakes of coarse graphite are found in several pits between the two workings.

Like the deposits of Lead Hill, those at Buck Mountain Pond appear too irregular in form and erratic in graphite content to be of any economic interest.

Dixon-American Graphite Co. mine.—The Dixon-American Graphite Co. mine is in Warren County, 4½ miles west of Lake George and a quarter of a mile west of the village of Graphite (fig. 27). It can be reached by car on State Route 8. The mine was operated continuously for over thirty years by the Joseph Dixon Crucible Co. Its total production is unknown, but it probably was the largest and most productive graphite mine in the State. There are two sets of workings (fig. 28). The main workings are about 900 feet northwest of the highway. According to Alling (1917, p. 45), a main haulageway was driven for nearly one-half mile southwestward along the strike of a southeastward-dipping bed of graphitic schist; stoping was done both up and down the dip from the haulageway. Stoping was carried downward to the southeast for as much as a quarter of a mile, where the graphitic bed was cut off by a fault. The southern workings, known as the Summer Pit, lie about 30 feet south of the highway and are an open pit that trends

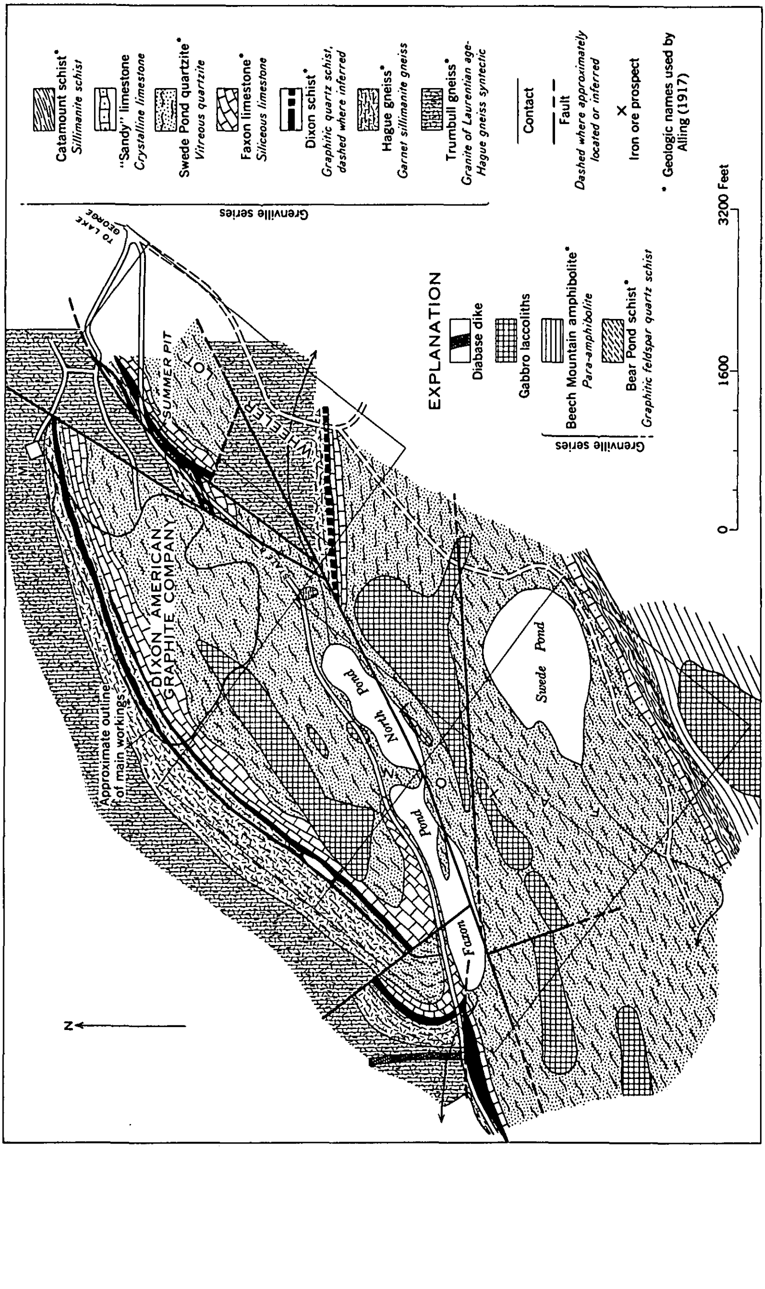

FIGURE 28.—Geologic map of Dixon-American Graphite Co. and Faxon mine properties, near Graphite, Warren County, N.Y.

N. 45° E. and is about 660 feet long. Inclines from the Summer Pit lead south, down the dip of the bed of graphitic schist worked, into an extensive series of stopes. The partly flooded stopes extend at least 100 feet down the dip from the opencut.

According to Alling (1917, p. 40), the general geology and stratigraphic sequence of this locality are about the same as for all localities in the eastern Adirondacks where disseminated graphite deposits in schist occur. Alling gives the following names and sequence of lithologic units of the Grenville series:

Rock type	*Name*
Para-amphibolite	Beech Mountain amphibolite
Graphite schist	Bear Pond schist
Sillimanite schist	Catamount schist
Limestone (marble)	
Quartzite	Swede Pond quartzite
Limestone (marble)	Faxon limestone
Graphite schist	Dixon schist
Garnet-sillimanite para-gneiss	Hague gneiss
Syntectic rock	Trumbull gneiss

The Dixon schist of Alling (1917) is the graphitic bed worked at the Dixon-American Graphite Co. mine. According to Alling (1917, p. 46), his Dixon schist consists of two layers of graphite quartz schist separated by garnet-sillimanite gneiss similar to the underlying Hague gneiss. The lower graphite layer, from 2½ to 15 feet thick, is the more important of the two on the property of the Dixon-American Graphite Co., and the Summer Pit is probably in the up-faulted segment of this layer. The layer consists of quartz, oligoclase-andesine, biotite, and graphite, with accessory pyrite, apatite, zircon, sphene, and tourmaline. According to Alling (1917, p. 48), the graphite in the Dixon schist is almost always associated with biotite and commonly interleaved with biotite and, in places, with pyrite. The three minerals occur in bands parallel to the schistosity, but at the Dixon-American Graphite Co. mine the mica content is very low. The graphite content was reported by Alling (1917, p. 49) as 5.2 to 7.8 percent, and the average flake diameter as 0.67 to 1.79 mm. Apart from scattered patches or lenses of pegmatitic material, the ore is remarkably uniform in grade.

As shown in figure 28, a fault runs between the main workings and the Summer Pit and is responsible for duplication of the outcrop of the bed. The main workings are partly terminated against this fault, and the segment of the graphitic bed worked in the Summer Pit must likewise terminate westward against the fault. The bed in the Summer Pit was shown by Alling (1917) to be cut by still another fault near the west end of the pit.

In the Summer Pit the graphite layer is characterized by pinching and swelling due to movement along or subparallel to its upper and lower contacts. These contacts are almost everywhere slickensided surfaces, and the original gradational contacts with overlying and underlying gneiss are shown only in a few places. The graphitic layer ranges from 2½ to 9 feet in thickness, and much of this variation appears a consequence of movement. Similar relationships in the main workings have been reported, but Alling gave the average thickness of the graphite bed there as 15 feet.

Reserves remaining in this mine have not been clearly indicated in published information. Alling estimated that reserves in the main mine in 1917 were small. The graphite bed may extend down dip from the workings of the Summer Pit, however, and reserves here may be very large.

Faxon property.—The Faxon property joins that of the Dixon-American Graphite Co. on the southwest, as shown in figure 28. There has been little mining, but the property was prospected and diamond drilled. Alling showed an extension of the graphitic zone of the Dixon-American mine on his geologic map, and data from the diamond-drill holes indicate that the Dixon schist continues across the Faxon property (see Alling, 1917, p. 43, 52). The upper graphite layer, with a thickness of 18 to 20 feet, apparently is the more important here. The lower layer is much thinner.

The Wheeler lot, which joins the Summer Pit on the south, was part of the Faxon property in 1918. The continuation in depth of the ore zone mined in the Summer Pit was explored by drilling, and a thickness of 15½ feet of graphitic rock was intersected in one drill hole.

The Faxon property probably contains reserves much larger than those of the Dixon-American Graphite Co. property, and if the graphitic rock is of comparable richness, thickness, and continuity, future production from this area could probably be most easily won from the Faxon holdings. North Pond and Faxon Pond could furnish ample water for milling.

Rowland Graphite Co. mine.—The Rowland Graphite Co. mine is about one-half mile east and 1 mile south of the village of Johnsburg, Warren County (fig. 27). The mine workings are about 300 yards northwest of a farmhouse. The workings consist of an open pit 120 feet long and 15 to 20 feet wide that trends S. 86° W. An incline and other subsurface workings of unknown extent are below the west end of the pit (Alling, 1917, p. 84). The underground workings are flooded.

The graphitic zone is a layer of quartz schist 7 feet thick that contains accessory feldspar, mica, and graphite. Alling (1917, p. 87) reported that the layer lies in the trough of a syncline. He calculated reserves at about 105,000 tons of rock containing an average of 5 percent graphite.

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Hooper Bros.' mine.—The Hooper Bros.' mine is 4 miles west of Whitehall in the Township of Dresden, Washington County. It can be reached by following a town road 1½ miles south along the west side of South Bay, Lake Champlain, then turning west and continuing 1 mile to the top of the hill. The mine property is one-fourth mile to the south on the ridge crest; it is about 2,000 feet long and 1,000 feet wide (figs. 27, 29).

The main workings consist of an open pit, a nearly horizontal adit 150 feet long, and a small stoped area. There are also several small prospect pits. The adit is driven into the graphitic layer in a southwesterly direction but curves to the west within a distance of about 30 feet and becomes nearly parallel to the strike. It continues for 100 feet, then leads back to the surface along a small stope or incline 75 feet long.

The graphitic rock is quartz schist, with accessory feldspar and mica. The graphite forms an estimated 5 to 6 percent of the rock and occurs as disseminated flake with a maximum diameter of 2.5 mm. In the main workings biotite is moderately abundant both as isolated flakes and as intergrowths with graphite.

Feldspar bands and lenses are found locally in the schist. Pyrite is present in minor amounts as scattered grains or as veinlets. The graphitic rock appears fairly uniform in grade, but there are local bands as much as 2 inches in thickness that are of lower grade. The footwall contact is not exposed, and in most places the hanging wall is inaccessible. The graphitic rock in the main workings is probably at least 15 feet thick.

The strike changes gradually from N. 43° W. at the south end of the property to N. 81° W. in the main workings, and the dip ranges from 22° to 27° south. No bedding-plane shearing was seen.

The mine is in the north or lower limb of an overturned isoclinal syncline (Alling, 1917, p. 72). The axis of the fold is probably about one-quarter of a mile south-southeast of the mine. Erosion has removed most of the upper limb, and the graphitic layer pinches out along the strike to the west. That part of the lower limb that contains the thicker part of the graphitic layer is nearly flat-lying and appears to have no appreciable small-scale folding or faulting that might complicate further mining operations.

The property appears to contain large reserves, but the value of the ore may be affected by the abundant mica, which might be difficult to separate.

International Graphite Co.—The International Graphite Co. mine is in Chester Township, Warren County, 3½ miles west-northwest of Pottersville, 200 feet east of the junction of Trout and Alter Brooks (fig. 27). It can be reached by road. The property was

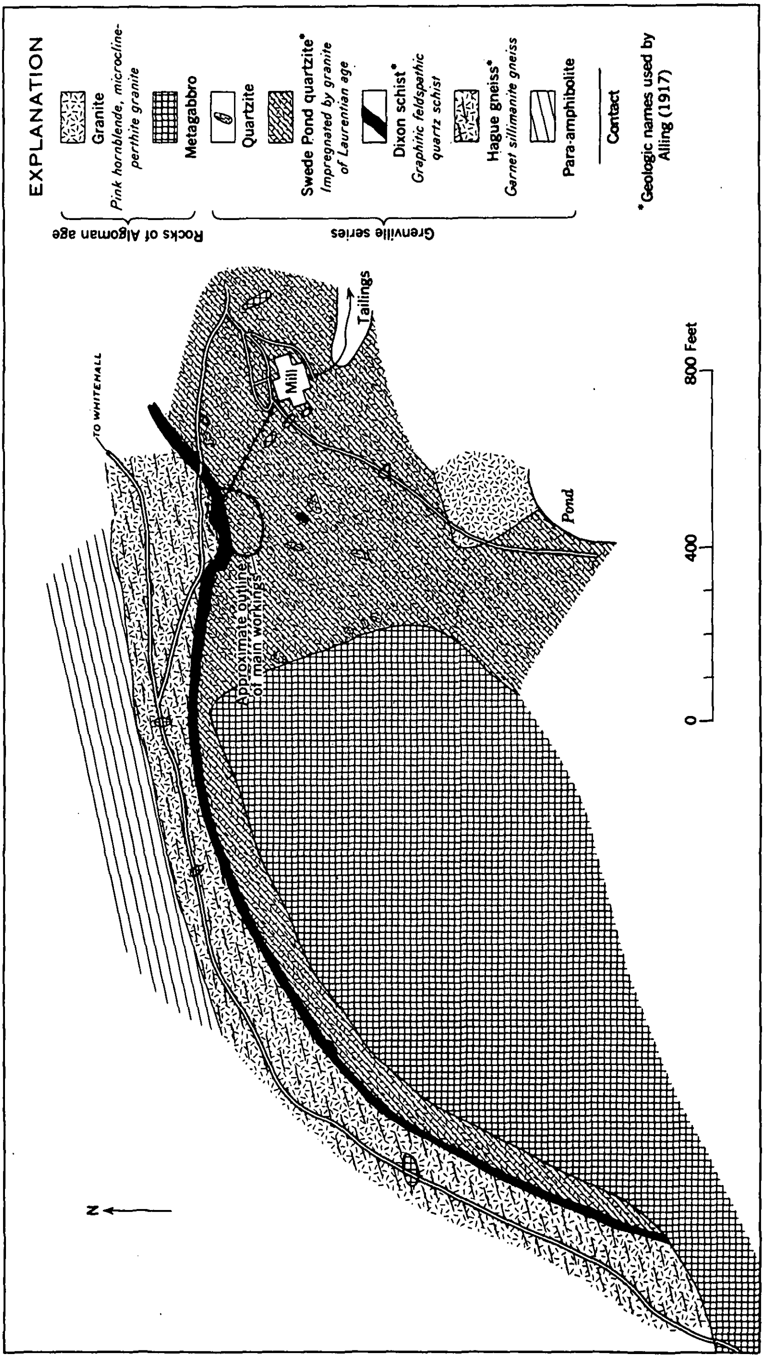

FIGURE 29.—Geologic map of Hooper Bros. graphite mine, near Whitehall, Washington County, N.Y. After Alling (1917).

worked for a few years beginning about 1898, but production was small.

Workings include an inclined shaft, a vertical shaft, a small open pit, and underground workings (Alling, 1917, p. 80). At the time of the present writing the underground workings are not accessible, and the open pit is filled with debris. Exposures in the vicinity of the mine are poor, and the only indications of the rock mined are in the remains of a dump or ore pile near the old millsite and in scattered specimens near the open pit. The ore was apparently a quartz-feldspar-mica schist containing from 1 to 15 percent fairly coarse flake graphite. Pyrite is unusually abundant in the specimens examined. Coarse calcite marble and pegmatitic material were also seen. Both contain coarse-flake graphite. Alling (1917, p. 81) reported that the graphitic zone was 18 to 30 feet thick but that its graphite content was very erratic because of redistribution related to the intrusion of pegmatite. He also stated that an abnormally high percentage of mica in the rock made milling and separation difficult and in part was responsible for abandonment of the property. The close proximity of a sizable stream, Trout Brook, made a great deal of pumping necessary to prevent flooding of the underground workings. The problem of handling so much water, the irregular distribution of the graphite, and the presence of abundant mica in the graphitic rock all suggest that this property offers little promise for future production.

Lakeside mine.—The Lakeside mine is 600 feet west of Lake George, behind the old Trout House at Hague, in Warren County (figs. 27, 30). It can be reached easily by a short walk up the hill from the end of a street that follows the old mine road.

The mine was opened some time before 1900 and was worked intermittently by the Joseph Dixon Co. for several years. The workings are much less extensive than those at Graphite, but a substantial tonnage was probably mined.

The workings consist of three nearly parallel adits, which extend north into the hillside along a graphitic bed (fig. 30). They are very nearly parallel to the surface of the ground, and the accessible parts of the lower two probably are within 25 feet of the surface. All three adits trend slightly down dip and consequently contain water too deep to allow access for more than about 150 feet from the entrances. The adits are connected by an irregular open pit cut into the graphitic layer.

The lower adit, which trends N. 33° W., can be entered for 200 feet; only the upper 9 feet of the graphitic layer is exposed in it. The strike of the layers is N. 16° E., and the dip averages 20° W., with minor variations.

The graphitic layer is a fine-grained weathered quartz schist containing 3 to 6 percent graphite and small amounts of altered feldspar. It is thin bedded and soft. The graphite is in disseminated flakes less than 1.5 mm in diameter. The upper 4 feet of graphite schist contains many thin siliceous bands that are remarkably continuous. The writers noted one ¾-inch thick band that had no change in attitude or thickness for 75 feet. Similar siliceous bands constitute about 10 percent of the lower part of the graphite schist.

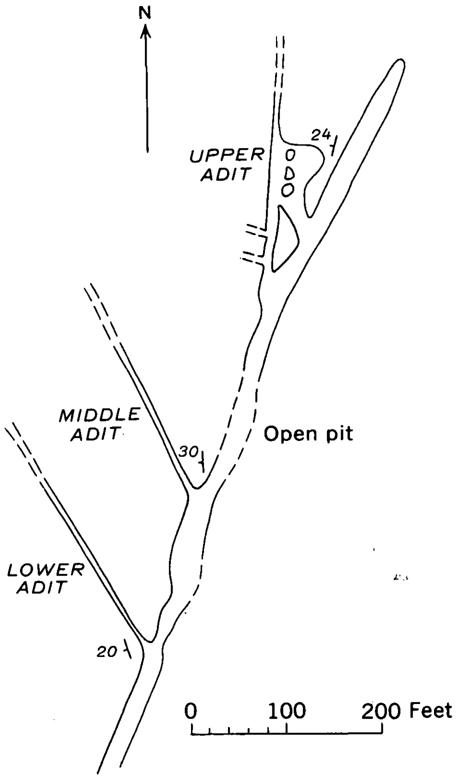

FIGURE 30.—Sketch map of underground workings of Lakeside mine, Warren County, N.Y.

Shearing along the bedding planes is indicated by slickensided surfaces and gouge layers near the top of the schist. The shearing very closely parallels bedding wherever exposed. The thickness of the schist is apparently not affected.

The middle adit trends N. 28° W., is accessible for 175 feet, and continues for at least another 75 feet. The rock layers in general strike N. 24° E. and dip 30° W. The bedding is regular; a 2-inch thick quartzite band was traced without change or break from the portal to the limit of the accessible workings. The jointed and thin-bedded hanging wall caves rather easily. It has covered the lower part of the drift with debris; only the upper 3 feet of the graphitic zone is exposed. This part of the graphite schist contains fewer quartzite bands than the corresponding part of the lower adit, and the schist appears to contain a higher percentage of graphite. The graphite content here was estimated to be 6 percent. Near the upper contact a weathered 6-inch layer that contains pyrite forms a pronounced zone of weakness.

The upper adit trends N. 6° W. and is accessible for 200 feet. Two inclines of unknown depth filled with fallen rock extend about 20 and 60 feet, respectively, down to the west from the portal. Seventy-five feet from the portal an area about 100 by 50 feet has been stoped out up-dip along the adit. The southern part of this stope connects with the open pit at the surface, as indicated on the sketch map (fig. 30). This set of workings may be more extensive than the other two.

A total thickness of 12 feet of graphitic rock is exposed in the upper adit. The lower contact is not visible but is probably very close to the floor of the workings. This graphitic layer strikes N. 39° E. and dips 24° NW; it is more uniform in appearance and grade than the graphitic layer in the lower workings. It is a quartz schist containing an estimated 6 percent fine-flake graphite. Disseminated sulfides are present in small quantities, but the rocks here are in general less altered than those of the other workings.

Some shearing along bedding planes has taken place. A crushed zone 1 to 2 feet thick can be traced for 30 feet along the upper wall of the stope. The bedding is also crumpled badly, but there is no pinching and swelling of the graphitic zone as a result of shearing.

The property appears to contain very large reserves, and no structural complications that might hamper mining are known. The average graphite content is apparently about 5 to 6 percent, and the graphitic zone is probably as much as 9 feet thick. The graphite flakes are small but not much smaller than those at the Dixon-American mine at Graphite, and the schist is unusually low in mica. Crushing of the soft weathered schist in the lower and middle workings should be easy.

The Lakeside property would appear to be one of the more promising deposits in the Adirondacks.

Flake Graphite mine.—The Flake Graphite (Empire) mine is 2¼ miles west of Porter Corners in the Township of Greenfield, Saratoga County (fig. 27). It is 1¼ miles west of the end of a private road but can be reached along an abandoned mine road that continues west from the private road. The mine road and mine location are shown on the topographic map of the Saratoga quadrangle.

The mine was worked between 1900 and 1918. Total production is unknown but was probably fairly large.

The workings consist of an open pit 200 feet long, 10 to 25 feet deep, and 20 to 40 feet wide. Two inclines extend down the dip of a layer of graphitic rock. One is caved, the other filled with water. Alling (1917, p. 97) reported that they extend to a depth of 207 feet. He also recorded a third incline, which has probably been covered by slumped material, along the wall of the open pit.

The rocks of the area are much the same as those associated with other schist deposits of the southern Adirondacks. The graphitic rock is a quartz-biotite-feldspar schist containing 4 to 8 percent fine flake graphite. Alling (1917, p. 102) reported the biotite content as ranging from a trace to as much as 7 percent. The hanging wall is a quartz-feldspar schist that contains 10 to 20 percent bleached biotite. The footwall rocks are not exposed.

The graphitic schist is 14 feet thick where best exposed and is unusually uniform in appearance and grade. Alling (1917, p. 98) stated that there is an upper graphitic zone 10 to 14 feet thick and below it another graphitic layer 4 to 5 feet thick separated from the upper layer by a 4-foot thickness of quartzite and thin-bedded limestone. The graphitic rock crops out along a belt extending for 1,500 feet west from the workings. The graphitic schist in the opencut strikes N. 86° W. to N. 66° W. and dips 30°–50° S. Slip-surfaces and gouge material were seen in a few places near the upper contact of the graphite layer. The displacement does not appear large, and the thickness of graphitic rock is unchanged.

Reserves available in this deposit may be large, but folding and invasion by metagabbro and granite have so complicated the structure that a substantial amount of exploration would be needed to determine the distribution and extent of the graphitic beds.

Sacandaga mine.—The Sacandaga mine is 1¼ miles west of Conklingville, Saratoga County, and 1 mile west of the dam of Sacandaga Reservoir (fig. 27). The mine workings are one-fourth mile up the hill on the east side of a small valley that enters the valley of the Sacandaga River from the north.

The mine was opened in 1906 and operated intermittently until about 1916. Production was small.

The accessible workings consist of three open pits or trenches cut into the nose and upper (northeast) limb of a syncline. In the southern pit the graphitic rock has been removed for about 40 feet along the trough of the syncline. The strike of the beds on the southwest limb is west, and the dip is 36° N. The beds on the northeast limb strike N. 56° W. and dip 55° N. The trough of the fold plunges 20° N. 26° W. The rock enclosing the graphitic layer is a quartz-mica-feldspar rock containing several thin bands of highly siliceous material. The graphitic rock has been entirely removed from the pit, and exposures at the ends of the pit are poor.

The middle pit, on the upper limb of the syncline, is about 40 feet long. A water-filled adit or incline extends south from the south end of the pit for an unknown distance. The graphitic rock strikes N. 4° W., dips 48° NE., and ranges in thickness from 5 to 8 feet; variations are due to shearing and folding along the hanging wall. The rock is a very thin bedded feldspathic schist, which contains quartz, mica, traces of pyrite, and not more than 4 or 5 percent graphite. The flakes are from 1 to 3 mm in diameter, and some layers are much lower in graphite content than others. Small local "patches" show intense folding and crumpling.

The north pit extends for about 60 feet along the upper limb of the syncline. The graphitic layer strikes N. 66° W. at the northwest end, but near the midpoint of the pit it bends rather sharply and at the south end strikes N. 1° W. It dips 75°–85° NE. Both of the contacts are slip surfaces, and movement along them causes pinching and swelling of the graphitic rock, with the result that the layer ranges from 6 to 9 feet in thickness.

The graphitic rocks are part of a syncline with nearly parallel limbs. This fold is overturned to the southwest and pitches to the northwest. Parts of the graphitic layer now exposed show a highly feldspathic schist, with quartz, mica, and an estimated 3 to 10 percent graphite. Alling (1917, p. 95), however, reported a "very rich zone" of graphite.

This property probably contains moderate reserves of graphitic rock, but there are several features that detract from its value. The structure is likely to hinder mining, and shearing along one or both contacts has produced irregularities in the thickness of the zone. The graphite content varies from place to place. The average graphite content is apparently 4 percent or less. The flakes average 1 mm in diameter, about the same as those in other schist deposits in the region.

Bear Pond Mountain.—Graphite deposits have been mined or prospected on the north, south, and west sides of Bear Pond Mountain (figs. 27, 31). They are more inaccessible than most of the other graphite mines in the region. To reach them follow a dirt road 1½ miles southwest from the town of Chilson, then walk 1½ miles along the old mine road to Bear Pond. The Bly, Joan, and Eutoka prospects are south and southwest of Bear Pond. The Rock Pond mine is on the north shore of Rock Pond, and can be reached by a foot trail that parallels the east side of Bear Pond Mountain.

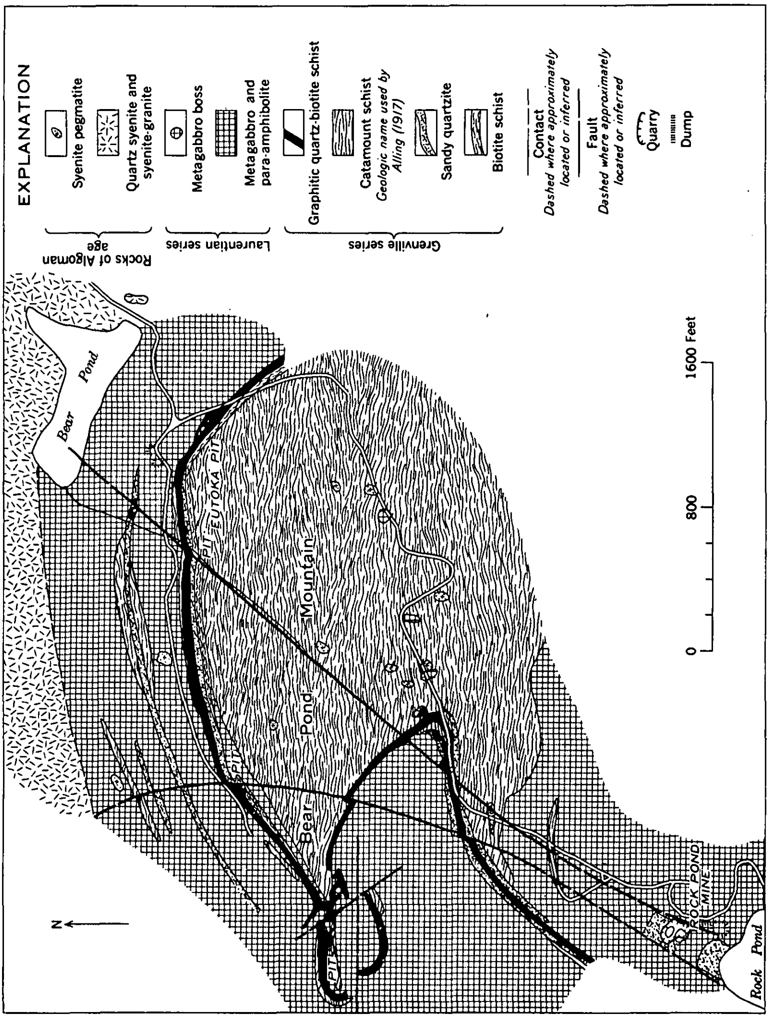

FIGURE 31.—Geologic map of area of Bear Pond Mountain and Rock Pond graphite deposits near Chilson, Essex County, N.Y. After Alling (1917).

Alling (1917) showed that there are two separate deposits in the area. The Bly, Joan, and Eutoka prospects are on a graphitic schist bed, the Bear Pond schist, about 30 feet thick. Alling described this as a quartz-feldspar-mica schist with accessory pyrite and 5.5 to 6.5 percent graphite averaging 0.73 to 1.23 mm in diameter. The bed is folded into an isoclinal syncline and anticline, both plunging westward and both cut by cross-faults. Alling estimated the tonnage as being large but pointed out that the steep attitude of the bed is unfavorable. In addition, the graphite is intergrown with biotite.

The Rock Pond mine was in a pyritic metamorphosed micaceous arkose containing 0.4 to 2.7 percent graphite in flakes averaging less than 0.66 mm in maximum diameter. The structure of the deposit was obscure even at the time of Alling's work, but he suggested that the mine is in a block of ore bounded by faults on all sides.

Graphite Products Corp. mine.—The Graphite Products Corp. mine is 3¼ miles north of Saratoga Springs, in Saratoga County. It is one-half mile west of U.S. Highway 9, in a small, narrow valley (fig. 27). An old mine road leads to the workings, but it is passable only to trucks or jeeps.

Alling reported (1917, p. 105) that the mine was first worked in 1910 by the Saratoga Graphite Co. It was later sold to the Graphite Products Corp., which did most of the mining. The mine was still in operation in 1917. From the extent of the exposed workings, this mine appears to have been one of the largest in the Adirondack area; it probably ranked second only to the Dixon-American Graphite Co. mine at Graphite.

The property has two sets of workings (fig. 32), on two roughly parallel belts of graphite schist that Alling regarded as fault-segments of a single bed. The northern working is an open pit 250 feet long, 20 to 80 feet wide, and at least 30 feet deep (Alling, 1917). The southern workings consist of an open pit 500 feet long with 14 inclines extending down the dip of the graphite schist to an unknown depth. Alling reported that the inclines connect downward with drifts driven along the strike. The subsurface workings are now flooded.

The rock mined is a graphitic quartz schist with subordinate mica and feldspar. Alling (1917, p. 107) determined the graphite content as nearly 8 percent. The flakes average less than 1 mm in diameter. The thickness of the bed is apparently between 15 and 20 feet. The footwall is quartz schist interlayered with quartzite and biotite schist. The hanging wall is limestone. The graphite bed is injected in places by lenses and knots of pegmatitic material.

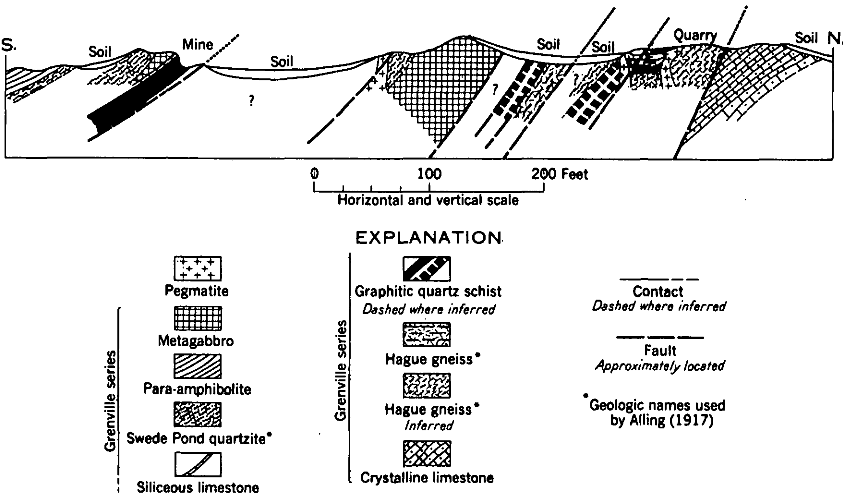

FIGURE 32.—Cross section of Graphite Products Corp. mine area and quarry, near Saratoga Springs, N.Y. After Alling (1917).

Alling's interpretation of the structure is shown in figure 32. In the northern workings the graphitic schist in general strikes N. 81°–89° W. and dips 35°–40° S. In the southern workings the graphitic schist strikes N. 83°–85° E. and dips 35°–43° S. The bed is cut by a few vertical faults of small displacement that strike N. 43° E. West of the south working, diabase dikes cut across the outcrop of the graphitic schist (Alling, 1917, p. 109).

Reserves of graphite in extensions of the graphitic bed along strike may be large, but exploration is needed to determine this.

Long Valley Ore Co.—The Long Valley Ore Co. mine is in the Hammond quadrangle, Township of MacComb, in western St. Lawrence County, 1½ miles south of Pope Mills (fig. 12). The property is in the Grenville lowland area. The workings are on the north side of a valley, about 500 feet west of the highway.

This mine was first operated by the MacComb Graphite Co. in 1906, but production at that time was only about 100 tons a year. It was also operated on a small scale in 1915, 1916, 1938, and 1939; in 1940 it was operated under lease by the Long Valley Ore Co. and in 1941 was under control of Charles Pettinos of New York (L. W. Currier and R. H. Jahns, written communication, 1942). At about this time the deposit was mapped and studied for the Geological Survey by Currier and Jahns.

The deposit consisted of a northward-trending body of graphitic schist and quartzite that was originally exposed along the southeast flank of a low ridge. The wall rocks include quartzites and feldspathic and calcareous quartz-rich rocks. An open pit has been exacavated along the trend of the graphitic rock for about 630 feet. The width of the pit ranges from 15 feet at the northeast end to 60 feet near the center. In 1950 the pit was nearly filled with water, but Currier and Jahns (written communication, 1942) reported it to have a maximum depth of 40 feet below water level. Owing to flooding and to removal of most of the graphitic rock, the form and structure of the deposit are no longer clearly indicated. The northwest side of the cut shows vitreous, fairly coarse quartzite for about 200 feet from the southwest end. From this point to the northeast end of the cut, the wall consists of layers of quartzite containing from a trace to as much as 20 percent graphite. These rocks in general strike about N. 84° E., but they vary markedly from place to place in dip, from about 50° SE. at the southwest end to 80° NW. at the northeast end.

The beds exposed in the pit are involved in a series of isoclinal folds and associated small-scale crumples. According to Currier and Jahns (written communication, 1942), the pattern of minor folds indicates that the deposit consisted of graphitic rocks lying on the southeast limb of an anticline. Exposures at the northeast end of the cut suggest, however, that the graphitic rocks mined in this part of the deposit lay along the trough of an open, nearly upright syncline, the limbs of which are complicated by minor folding.

Little of the high-grade graphitic rock remains above water level. A few thin bands exposed along the footwall contain an estimated 15 to 20 percent extremely fine flake graphite. The rock mined was reported to have run 20 to 30 percent graphite, all very fine grained. It was concentrated to about 85 percent graphite and sold chiefly as foundry-facing material. Production figures are not available. Currier and Jahns estimated that about 25,000 tons of graphitic rock remained at the time of their study, but much of this has since been mined. All buildings have been taken down. The property does not appear to offer much promise of further production.

APPRAISAL OF GRAPHITE DEPOSITS OF THE ADIRONDACK AREA

Graphite deposits of possible commercial interest in the Adirondack area are all of the so-called schist type. These have several features in common that probably account for the lack of exploitation at present. Among these are small flake size, relatively high mica content, and the necessity of subsurface mining. In addition, most of the graphitic rock is fresh and hard and would be expensive to crush. The graphite properties of Pennsylvania and Alabama have a more favorable competitive position because they contain much graphitic rock that is soft and can be mined by inexpensive open-pit methods. Activity in the Adirondack area might conceivably be stimulated, however, if it could be shown that graphite satisfactory for lubricating flake and for carbon-bonded crucibles can be produced.

The reserves of graphitic rock in the Adirondack area are probably large. Alling (1917, p. 140) estimated that reserves in the Hooper Bros., Faxon, Flake Graphite, and Graphite Products Corp. properties alone are between 10 and 13 million tons of ore.

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