GRAPHITE

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One of three known forms of carbon (the other two being coal and diamond), graphite occurs naturally in the Earth's crust in metamorphic rocks such as crystalline limestone, schist, and gneiss. The word "graphite" is derived from the Greek word graphein, to write. Other common names for graphite include black lead, plumbago, and mineral carbon.

Graphite exhibits a perfect basal cleavage. Depending upon the purity, the specific gravity is 2.20 to 2.30. The "ash free" theoretical crystallographic density is grams per cubic centimeters. It is gray to black in color, opaque, and has a metallic luster. It is flexible but not elastic. Graphite is a soft mineral with a Mohs hardness of 1 to 2. It has high thermal and electrical conductivity, is highly refractory, and chemically inert.

There are two general types of graphite, natural and synthetic. In the graphite industry, natural graphite is classified into three types: flake, high-crystalline, and amorphous. These, in turn, are subdivided into numerous grades for commercial purposes on the basis of such factors as graphite content, particle size, and impurity types.

Natural graphite is formed in either igneous or metamorphic rock formations. Most commercial deposits of natural graphite are of metamorphic origin.

Flake graphite, as the name implies, exhibits a flaky morphology. Typical geologic environments include regionally metamorphosed "organic" limestones or argillaceous deposits with organic inclusions. Most flake graphite probably results from the metamorphism of organic carbon deposited in ancient deep oceans and continental shelf environments. Flakes can be homogeneously distributed throughout the ore body or in concentrated lens-shaped pockets. Carbon concentrations in ore can vary between 5% and 40% graphite.

Flake graphite, which is removed from its ore by froth flotation, is available as 80% to 98% carbon. Flake graphite of purity higher than 98% is typically manufactured by chemical refining. It is found in many localities throughout the world. Current U.S. supplies are being imported from Brazil, Canada, China, Madagascar, Mozambique, and Zimbabwe.

Crystalline vein graphite is believed to be a naturally occurring pyrolytic graphite, condensed from a gas or liquid phase. Deposits consist of veins of variable thickness, ranging from centimeters to meters. Veins consist of solid, graphitic carbon with a massive structure composed of needle-like, intergrown crystals with the long axis perpendicular to the enclosing wall rock. In some instances, it is found adjacent to flake graphite.

Owing to the nature of the deposition process, gas/fluid-to-solid, vein graphite deposits are typically above 90% purity with some vein graphite as pure as 99.5% graphitic carbon. Within a typical vein formation, the ash (inorganic) content of the graphitic rock is somewhat related to its proximity to the enclosing wall rock. Generally, the farther from the wall rock, the lower the ash content.

Amorphous graphite is the least graphitic of the natural graphites. The term "amorphous," however, is a misnomer because this material is very crystalline. It is a massive form of graphite with a microcrystalline structure. Its crystal structure can only be observed by using x-ray diffraction methods.

Amorphous graphite is formed by the thermal metamorphism of coal seams. Though crystalline in nature, its low degree of crystalline order and very fine particle size make it appear amorphous. It is usually of lower purity than the crystalline flake graphite and, therefore, commands a lower price than its crystalline counterpart.

Naturally occurring pyrolytic graphite is found in a number of localities, including the northern Midwestern United States. Sri Lanka is the only area known to produce commercially viable quantities, the supply is limited. Vein graphite is mined by using conventional shaft or surface methods. The lump graphite is hand sorted into various grades. Some veins in the Sri Lankan formations contain powdered or flakelike deposits that are sometimes called amorphous graphite.

Amorphous graphite typically contains a higher ash content than other forms of natural graphite. The purity of commercially available material ranges from 60% to 85% carbon. Some amorphous graphite deposits produce material as high as 90% carbon. The ash in this form of graphite is generally very similar to the ash in the corresponding anthracite coal from which it was formed. Amorphous graphite is extracted using conventional coal-mining techniques. The present supply of amorphous graphite available in the United States is imported from Mexico and China.

Legislation and Government Programs

Total National Defense Stockpile graphite inventories, excluding nonstockpile grade, were 14,600 metric tons (t) with a dollar value of about $4.6 million. The uncommitted inventory, which was authorized for disposal, was reported to be 4,930 t valued at $2.5 million. Madagascar natural graphite inventories in the United States were 9,710 t with a value of $1.53 million (table 2). There is no longer a Government stockpile goal for graphite.

Production

Graphite is mined from open pit and underground mine operations. Open pit operations are more economical and, thus, are preferred where the overburden is thin enough to remove. Mines in Madagascar are mostly this type. In the Republic of Korea, Mexico, and Sri Lanka, where the deposits are deep, underground mining techniques are usually required.

Because natural graphite was not mined in the United States in 1998, the need for natural graphite was met by importation from foreign sources. These imports totaled 61,600 t at a value of $34.8 million (tables 2 and 6).

Consumption

Graphite is used in a wide variety of industrial applications. It is a unique material in that it has properties of a metal and a nonmetal. The metallic properties include thermal and electrical conductivity. The nonmetallic properties include inertness, extremely high thermal resistance, and anisotropy. The combination of conductivity and high thermal stability is perhaps its most valuable trait, allowing graphite to be used in many applications.

Perfect basal cleavage of graphite makes it an excellent lubricant. The combination of lubricity and thermal conductivity is highly desirable in high-temperature applications because it results in a material that provides thin film lubrication at a friction interface while furnishing a thermally conductive matrix to remove heat from the same interface.

Graphite also provides a unique combination of lubricating property and electrical conductivity, thus allowing its use as the primary material in the manufacture of brushes for electric motors. A graphite brush effectively transfers electric current to a rotating armature while the natural lubricity of the brush minimizes frictional wear.

U.S. consumption of natural graphite declined by 16%, to 26,000 t, in 1998 from 31,100 t in 1997 (table 3). The amorphous grade, however, declined by 22%, to 11,900 t, in 1998 from 15,400 t in 1997. This decline followed a 30% increase in 1997.

The refractories industry was again the major consumer of crystalline graphite followed by the manufacture of brake linings and metal powders. Refractory applications of graphite included castable ramming, gunning mixtures, and shaped carbon-bonded brick.

Carbon-magnesite-brick-containing crystalline flake graphite has applications in high-temperature corrosive environments such as steel furnaces, ladles, and blast furnaces. Carbon-alumina linings are principally used in continuous steel-casting operations. Magnesite- and alumina-carbon refractory bricks require a fine particle size of 100 mesh and a purity of 95% to 99% graphite.

Its lubricating character and high thermal conductivity make graphite an excellent substitute for asbestos in brake lining manufacture to reduce friction, thus enhancing brake life. Other significant uses of graphite include the manufacture of low-current, long-life batteries, steelmaking, manufacture of rubber, and powder metallurgy. The use of graphite in low-current batteries is gradually giving way to carbon black, which is more economical and more efficient. The four major industries– refractories, brake linings, lubricants, and foundries–again led the way in graphite usage, accounting for approximately one-half the graphite consumed by U.S. industry in l998 (table 3).

Additional applications for graphite include: electrically conductive composites, pencils, foundry facings, additives for iron and steel manufacture, solid carbon shapes, static and dynamic seals, valve and stem packing, fire retardants, plastics, chemically resistant coatings, paints, greases and oils, catalyst supports, flexible gaskets, and porosity enhancing inert fillers.

Prices

Graphite prices have remained constant during the past 5 years. Prices for crystalline flake graphite concentrates ranged from $480 to $550 per ton, command higher prices than the amorphous (microcrystalline) type, priced at $220 to $235 per ton. Carbon content, flake and crystal size, size distribution, and ash content affect the price of graphite. Natural graphite prices are often subject to negotiations between the buyer and the seller, leading to a wide price range throughout the year (table 4).

Foreign Trade

Total imports of natural graphite (flake, crystalline, and amorphous) increased for the second consecutive year to 61,600 t in 1998 compared with 58,100 t in 1997. This is an increase of 6.0%. Principal import sources of natural graphite were China, Mexico, Canada, and Brazil, which accounted for two-thirds of the dollar value of total imports. Mexico continued to be the major supplier of amorphous graphite, and Sri Lanka provided the chip and lump varieties. In addition to the major suppliers, a number of other producers supplied various types and grades of graphite to the United States, among the more notable being Germany, India, Japan and Madagascar (table 6). Total exports also showed a noticeable increase in total revenue to $76.8 million in 1998 compared with $74.3 million in 1997, even though quantity exported was 110,000 t in 1998 compared with 119,000 t in 1997 (tables 5-7).

World Review

World production of graphite was estimated to be 578,000 t in 1998, compared with 581,000 t in 1997. China maintained its position as the world's leading graphite producer, at 200,000 t, with India in second place with 125,000 t, followed by Brazil, Mexico, and North Korea. These five countries continued to account for three-quarters of the world production (table 8).

For the past several years, Sri Lanka has accounted for nearly all the high-crystalline graphite produced. Sri Lankan deposits were estimated to average 95% graphite in situ.

The combination of a decrease in world demand in the early

1990's and competition from cheap Chinese material forced many non-Chinese producers to reduce production or even to leave the market altogether. China accounted for one-third of world production. Economic recovery, however, encouraged the opening of new operations that produce high crystalline flake in Canada, Mozambique, and Tanzania (Roskill Information Services Ltd., 1998).

Current Research and Technology

Most new uses for graphite products are being developed through advances in graphite thermal technology. The ability to refine and modify graphite and carbon products will be the key to future growth in the graphite industry. Innovative refining techniques have enabled the use of improved graphite in friction materials, electronics, foil, and lubrication applications (Hand, l997). Some of the new application areas include electrically conductive asphalt for heated runways at airports and roadway bridges.

Outlook

The main areas of natural graphite consumption in the near future will be in high temperature applications for the iron and steel industry as the industry modernizes its production facilities. Brake linings and other friction materials will steadily consume more natural graphite as new automobile production continues to increase and more replacement parts are required for the growing number of existing vehicles. Flexible graphite product lines, such as grafoil (a thin graphite cloth) will probably be the fastest growing market but will consume small amounts of natural graphite compared with major end-use markets.

In the event of any price increases, China may increase its production to take advantage of potential high profits, leading to a sharp price decline in certain grades and possibly to a production stoppage in other countries. If, however, the Chinese iron and steel industry expands its consumption of natural graphite, then Chinese exports may eventually decline, encouraging new producers to enter the market (Roskill Information Services Ltd., 1998).

Industry trends that appear to be common to advances in graphite technology and markets include higher purity and consistency in specifications for high-tech applications. Production of higher purity graphite, using thermal processing and acid leaching techniques, for such applications as advanced carbon-graphite composites continues to be the trend.

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS 1/

		1994	1995	1996	1997	1998
United States:						
Apparent consumption 2/	metric tons	32,900	23,500	27,400	18,400	33,600
Exports	do.	20,300	37,300	26,000	39,700	27,900
Value	thousands	$13,100	$17,900	$14,600	$20,500	$14,100
Imports for consumption	metric tons	53,100	60,700	53,400	58,100	61,600
Value	thousands	$26,900	$30,100	$28,600	$32,400	$34,800
World: Production	metric tons	517,000	584,000 r/	555,000 r/	581,000 r/	578,000

r/ Revised.

1/ Data are rounded to three significant digits.

2/ Domestic production plus imports minus exports.

TABLE 2
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND
STOCKS OF NATURAL GRAPHITE IN 1998, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	(1/)	9,710
Sri Lanka amorphous lump	(1/)	4,930
Crystalline, other than Madagascar and Sri Lanka	(1/)	--
Nonstockpile-grade, all types	(1/)	51

1/ This commodity no longer has a goal.

Source: Defense National Stockpile Center, Inventory of Stockpile Materials as of December 31, 1998.

TABLE 3
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE 1/

(Thousand metric tons and thousand dollars)

End use	Crystalline		Amorphous 2/		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1997:						
Batteries	W	W	--	--	W	W
Brake linings	782	877	4,720	3,620	5,500	4,500
Carbon products 3/	448	1,560	363	278	811	1,840
Crucibles, retorts, stoppers, sleeves, nozzles	872	758	5	10	877	768
Foundries 4/	423	337	674	225	1,100	562
Lubricants	141	300	1,540	1,230	1,680	1,530
Pencils	680	757	152	30	832	787
Powdered metals	420	1,000	33	73	453	1,080
Refractories	5,810	4,260	5,560	4,030	11,400	8,290
Rubber	66	102	645	389	711	491
Steelmaking	22	18	907	300	929	318
Other r/ 5/	6,090	7,280	684	612	6,770	7,890
Total	15,800	17,200	15,300	10,800	31,100	28,100
1998:						
Batteries	W	W	--	--	W	W
Brake linings	725	942	2,610	2,360	3,330	3,300
Carbon products 3/	388	1,210	303	225	691	1,440
Crucibles, retorts, stoppers, sleeves, nozzles	993	845	5	7	998	853
Foundries 4/	378	307	788	232	1,170	539
Lubricants	326	529	1,250	946	1,580	1,480
Pencils	597	692	122	86	719	778
Powdered metals	445	1,020	26	55	471	1,080
Refractories	5,320	3,460	4,860	3,350	10,200	6,810
Rubber	56	89	657	394	713	484
Steelmaking	20	15	816	270	836	285
Other 5/	4,780	6,420	501	312	5,280	6,730
Total	14,000	15,500	11,900	8,230	26,000	23,800

r/ Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."
1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Includes mixtures of natural and manufactured graphite.
3/ Includes bearings and carbon brushes.
4/ Includes foundries (other) and foundry facings.
5/ Includes ammunition, antiknock and other compounds, drilling mud, electrical-electronic devices, industrial diamonds, magnetic tape, mechanical products, packings, paints and polishes, seed coating, small packages, soldering-welding, and other end-use categories.

TABLE 4
REPRESENTATIVE YEAREND GRAPHITE PRICES 1/

(Per metric ton)

Type	1997	1998
Crystalline large flake, 85% to 90% carbon	$480-$550	$480-$550
Crystalline medium flake, 85% to 90% carbon	330-450	370-410
Crystalline small flake, 80% to 95% carbon	270-500	270-500
Amorphous powder, 80% to 85% carbon	220-300	220-235

1/ Prices are normally "cost, insurance, and freight" (c.i.f.) main European port.

Source: Industrial Minerals, no. 363, December 1997, p. 78; no. 375, December 1998, p. 78.

TABLE 5
U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY 1/ 2/

	Natural 3/		Artificial 4/		Total	
Country	Quantity (metric tons)	Value 5/	Quantity (metric tons)	Value 5/	Quantity (metric tons)	Value 5/
1997:						
Canada	3,770	$2,890,000	7,980	$10,800,000	11,700	$13,700,000
France	357	219,000	9,540	5,960,000	9,900	6,180,000
Japan	1,170	1,090,000	19,000	9,930,000	20,200	11,000,000
Korea, Republic of	3,130	1,250,000	9,180	5,550,000	12,300	6,800,000
Mexico	19,400	8,570,000	4,000	2,650,000	23,400	11,200,000
Netherlands	281	116,000	8,160	3,370,000	8,440	3,490,000
Taiwan	3,080	1,420,000	1,670	1,380,000	4,750	2,790,000
Other	8,470	4,900,000	20,200	14,200,000	28,700	19,100,000
Total	39,700	20,500,000	79,700	53,800,000	119,000	74,300,000
1998:						
Canada	5,320	3,330,000	9,410	15,900,000	14,700	19,200,000
France	10	49,400	8,820	5,040,000	8,830	5,080,000
Japan	450	562,000	19,200	9,540,000	19,600	10,100,000
Korea, Republic of	417	192,000	10,200	4,990,000	10,600	5,180,000
Mexico	14,400	5,320,000	4,550	2,730,000	19,000	8,060,000
Netherlands	257	131,000	8,670	3,600,000	8,930	3,730,000
Taiwan	1,280	697,000	1,370	2,120,000	2,650	2,810,000
Other	5,810	3,780,000	19,700	18,800,000	25,500	22,600,000
Total	27,900	14,100,000	81,900	62,700,000	110,000	76,800,000

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Numerous countries for which data were reported have been combined within the "Other" category under the "Country" list.
3/ Amorphous, crystalline flake, lump and chip, and natural, not elsewhere classified. The applicable Harmonized Tariff Schedule (HTS) nomenclature title and code(s) are "Natural graphite in powder or in flakes"/"Other;" HTS numbers 2504.10/90.0000.
4/ Includes data from the applicable HTS nomenclatures: "Artificial graphite" and "Colloidal or semicolloidal graphite;" their respective HTS code numbers are 3801.10/20.0000.
5/ Values are free alongside ship (f.a.s.)

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY 1/ 2/

Country or territory	Crystalline flake and flake dust		Lump and chippy dust		Other natural crude; high-purity; expandable		Amorphous		Total	
	Quantity (metric tons)	Value 3/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)
1997:										
Brazil	--	--	--	--	3,100	$4,950	--	--	3,100	$4,950
Canada	15,900	$10,000	--	--	46	20	--	--	15,900	10,000
China	3,470	1,870	--	--	9,970	3,900	3,330	$1,030	16,800	6,800
Germany	--	--	--	--	154	581	--	--	154	581
India	62	116	--	--	--	--	--	--	62	116
Japan	--	--	--	--	944	2,390	--	--	944	2,390
Madagascar	3,700	2,080	--	--	--	--	--	--	3,700	2,080
Mexico	--	--	--	--	--	--	14,600	2,230	14,600	2,230
Mozambique	378	316	--	--	--	--	--	--	378	316
South Africa	54	93	--	--	380	967	--	--	434	1,060
Sri Lanka	--	--	809	$820	--	--	--	--	809	820
Zimbabwe	198	136	--	--	--	--	--	--	198	136
Other 4/	342	390	--	--	281	454	400	67	1,020	911
Total	24,100	15,000	809	820	14,900	13,300	18,300	3,320	58,100	32,400
1998:										
Brazil	--	--	--	--	3,450	6,110	--	--	3,450	6,110
Canada	13,400	7,870	--	--	19	15	--	--	13,400	7,880
China	7,410	1,470	--	--	10,200	6,870	2,500	735	20,200	9,080
Germany	--	--	--	--	149	850	--	--	149	850
India	123	156	--	--	13	58	--	--	136	214
Japan	--	--	--	--	924	1,750	--	--	924	1,750
Madagascar	4,310	2,390	--	--	--	--	--	--	4,310	2,390
Mexico	--	--	--	--	--	--	15,400	2,560	15,400	2,560
Mozambique	1,900	1,620	--	--	--	--	--	--	1,900	1,620
Sri Lanka	--	--	838	1,000	--	--	--	--	838	1,000
Zimbabwe	440	200	--	--	--	--	--	--	440	200
Other 4/	384	721	--	--	49	320	84	138	517	1,180
Total	28,000	14,400	838	1000	14,900	16,000	17,900	3,430	61,600	34,800

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ The information framework from which data for this material were derived originated from Harmonized Tariff Schedule base data.

3/ Customs values.

4/ Includes Australia, Austria (1998), Belgium, France, Greece (1998), Hong Kong , Italy, the Republic of Korea (1997), Namibia (1997), the Netherlands, Poland, Sweden, Switzerland, Taiwan (1997), Tanzania (1997), Ukraine (1998), and the United Kingdom.

Source: Bureau of the Census, adjusted by the U.S. Geological Survey.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION
OF GRAPHITE ELECTRODES, BY COUNTRY 1/ 2/

Country	Quantity (metric tons)	Value 3/ (thousands)
1997:		
Canada	12,900	$38,400
Germany	5,550	16,100
Italy	11,600	25,600
Japan	7,160	24,300
Mexico	12,800	27,100
Other 4/	20,200	42,400
Total	70,200	174,000
1998:		
Canada	11,300	32,700
Germany	4,590	14,600
Italy	8,420	17,100
Japan	9,170	31,700
Mexico	12,600	21,300
Other 4/	16,900	37,800
Total	63,000	155,000

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ The applicable Harmonized Tariff Schedule (HTS) code and nomenclature title are (HTS 8545.11.0000); "Electric Furnace Electrodes."
3/ Customs values.
4/ Includes data for countries reflecting less than 1,000 metric tons for yearly imports.

Source: Bureau of the Census.

TABLE 8
GRAPHITE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

Country	1994	1995	1996	1997	1998 e/
Austria	12,324	12,019	12,000 e/	12,000 e/	12,000
Brazil (marketable) 3/	35,965	28,028	36,332 r/	44,400 r/	44,400
China e/	183,000	204,000	185,000	190,000	200,000
Czech Republic e/	25,000	27,000	30,000	25,000 r/	25,000
Germany (marketable)	4,369	5,214	2,603	2,500 r/	2,500
India (run-of-mine) 4/	93,597	129,368	115,233	120,000 e/	125,000
Korea, North e/	38,000	40,000	40,000	40,000	35,000
Korea, Republic of	4,300	1,938	1,113	1,083 r/	1,000
Madagascar 5/	12,715	16,119	12,134 r/	12,820 r/	13,000
Mexico:					
Amorphous	29,903	32,938	38,967	46,707 r/	42,200
Crystalline flake	960 e/	1,450	1,445	1,275 r/	1,300
Mozambique	430	3,019 r/	3,283 r/	5,125 r/	9,000
Norway	5,566	2,588	2,500 e/	2,600 e/	2,500
Romania	2,335	2,179	2,931	2,500	2,500
Russia e/	8,000	8,000	6,000	6,000	6,000
Sri Lanka	2,946	8,000	5,618	5,127 r/	5,000
Tanzania	--	359	6,776	11,000 r/ e/	-- 6/
Turkey (run-of-mine) e/ 7/	20,000	20,000	20,000 r/	15,000 r/	15,000
Ukraine e/	30,000	30,000	25,000	25,000	25,000
Zimbabwe	7,890	11,381	7,691	12,779 r/	12,000
Total	517,000	584,000 r/	555,000 r/	581,000 r/	578,000

e/ Estimated. r/ Revised.
1/ World totals and estimated data have been rounded to three significant digits; may not add to totals shown.
2/ Table includes data available through May 13, 1999.
3/ Does not include the following quantities sold directly without beneficiation, in metric tons: 1994--2,735; 1995--3,368; 1996--4,134; 1997--4,500 (estimated); and 1998--4,500 (estimated).
4/ Indian marketable production is 10% to 20% of run-of-mine production.
5/ Exports. Source: United Nations, Department of International Economic and Social Affairs, Statistical Office.
6/ Graphtan Limited Mine closed. Only remaining stocks shipped in January-February 1998.
7/ Turkish marketable production averages approximately 5% of run-of-mine production. Almost all is for domestic consumption.