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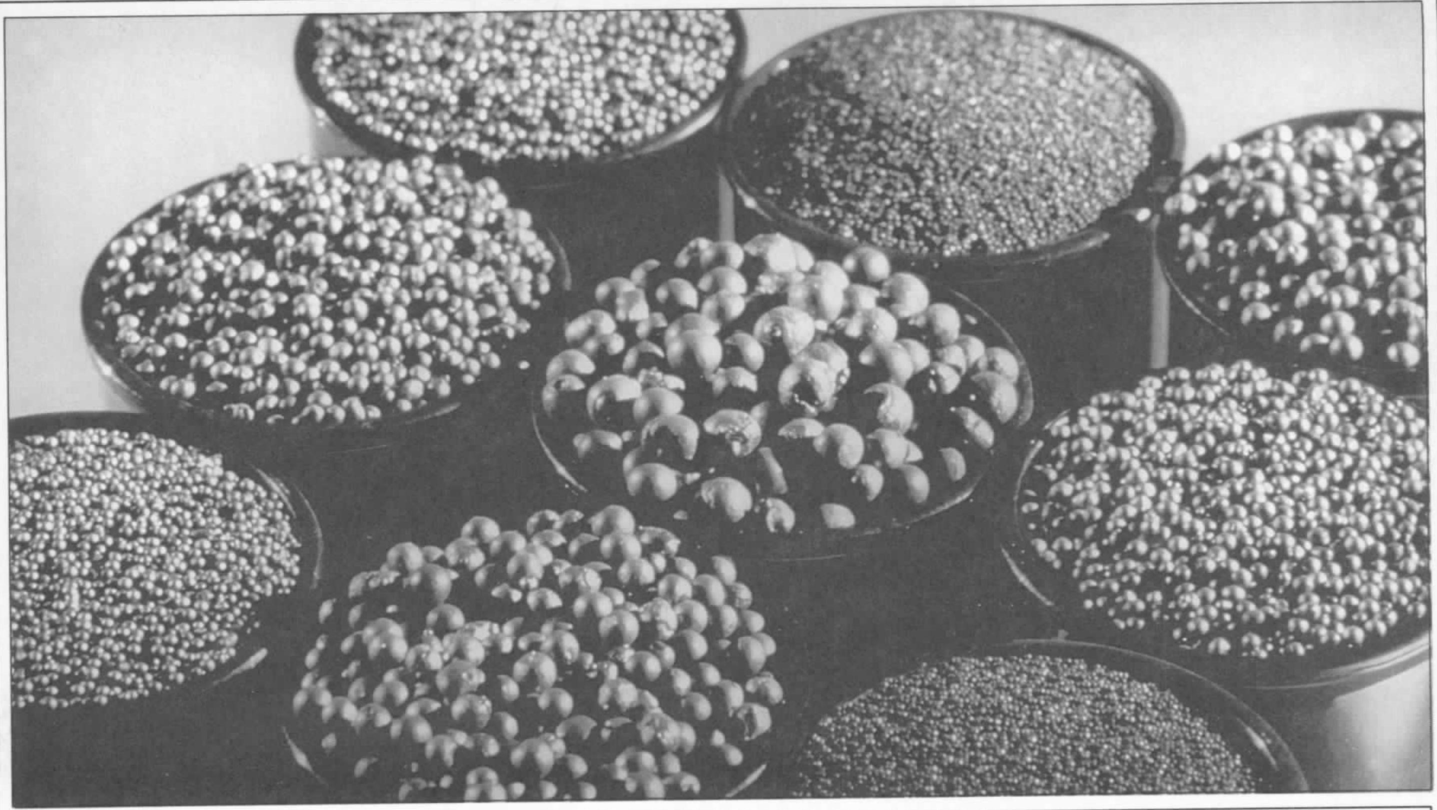

ABRASIVE MATERIALS

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Bruce Babbitt
Secretary

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COVER PHOTO:
Metallic abrasives. (Photo courtesy of Metallic Steel Abrasives Co.)

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ABRASIVE MATERIALS

By Gordon T. Austin

Mr. Austin, a physical scientist with more than 30 years of industry and Government experience, has been the commodity specialist for abrasive materials since 1986. Mr. William Field, statistical assistant, prepared the domestic data tables.

The combined value of production of natural abrasives, which include tripoli, special silica stone, garnet, staurolite, and emery, increased in 1993. The increase in the value of tripoli production was the result of an increase in total production. Special silica stone experienced an increase in unit value but decrease in the quantity produced. Garnet showed a 19% decrease in quantity and an 8% decrease in value. Staurolite increased about 51% in the quantity produced and 136% in value compared with those of 1992. Staurolite's significant increase in value of production resulted from a 56% increase in the unit value.

The fused aluminum oxide industry showed an 8% decrease in the quantity produced and a 13% decrease in the value of production. The silicon carbide industry saw an 11% decrease in the quantity produced and an 8% decrease in the value of production. Combined, the industries decreased 9% in quantity and 11% in value compared with those of 1992.

The quantity of metallic abrasives sold and shipped increased slightly in quantity and decreased 7% in value compared with those of 1992. The industry includes the primary producers of steel, chilled and annealed iron, cut wire shot and grit, and shot and grit reclaimed by primary producers. Shipments in 1993 were about 9% below the industry's high of 239,619 metric tons[1] in 1979. *(See table 1.)*

The United States continued as the world's largest manufacturer, exporter, importer, and consumer of synthetic industrial diamond. The estimated apparent U.S. consumption of industrial diamond stones was 2.0 million carats, a decrease of 60% compared with that of 1992, but was still greater than the 48-year low in 1987.

DOMESTIC DATA COVERAGE

Domestic production data for abrasive materials were from seven separate voluntary U.S. Bureau of Mines (USBM) surveys. Of the 61 operations producing natural and manufactured abrasives canvassed, all responded, representing 100% of the total production shown in tables 1, 5, 6, 8, 12, and 14.

FOREIGN TRADE

The total value of abrasive materials, exports plus reexports, was $421.3 million, about a 10% increase compared with the 1992 value.

The total value of abrasive materials imported was $529 million, an increase of 9% compared with the 1992 value.

The United States has shown a trade deficit in abrasive materials for every year of the past 10 years. In 1993, the deficit was $107.7 million, an increase of 9% compared with that of 1992. *(See tables 2, 3, and 4.)*

TRIPOLI

The category of tripoli, as broadly defined, is composed of extremely fine-grained crystalline silica in various stages of aggregation. The particle sizes usually range from 1 to 10 micrometers, but particles as small as 0.1 to 0.2 micrometer are common. Commercial tripoli contains 98% to 99% silica and minor amounts of alumina (as clay) and iron oxide. Tripoli may be white or some shade of yellow, brown, or red depending on the percentage of iron oxide. The USBM includes not only tripoli, but other fine-grained, porous silica materials that have similar properties and end uses such as rottenstone and novaculite. It does not include fine-grained or porous silica materials included in other Mineral Annual Report chapters, such as pumice.

Annual Review

Production.—In 1993, the quantity of crude tripoli produced increased 11% and the value of production increased 7% compared with those of 1992. In the United States four firms produced tripoli. Malvern Minerals Co., Garland County, AR, produced crude and finished material. Malvern also produces a black material from novaculite. American Tripoli Co. produced crude material in Ottawa County, OK, and finished material in Newton County, MO. Unimin Specialty Minerals Inc.'s Alco and Tamms plants, in Alexander County, IL, produced crude and finished material. Keystone Filler and Manufacturing Co. in Northumberland County, PA, processed rottenstone, a decomposed fine-grained siliceous shale, produced by B. J. Ulrich & Sons, also in Northumberland County, PA. *(See table 5.)*

Consumption and Uses.—Processed tripoli, sold or used, increased 3% in quantity and 10% in value compared to those of 1992.

Tripoli is processed in mills that are

jasper lined using flint or jasper pebbled in closed circuit with banks of mechanical classifiers. Materials from the mechanical classifiers are fed to micronizing mills, in which it is ground and sized at the same time. Material that is 100% minus 10 micrometers and 96% minus 5 micrometers is the smallest particle-size material sold. Even this very fine particle material is not the result of fragmentation of individual crystals; instead, clusters of quartz crystals, many less than 1 micrometer in size, that are joined at their points are broken apart. The ultrafine-grained tripoli is a collection of clusters and individual quartz crystals.

Tripoli has had unique uses as an abrasive because of its hardness and its grains lack distinct edges and corners. It is a mild abrasive, making it suitable for use in toothpaste and tooth polishing compounds, industrial soaps, and metal and jewelry polishing compounds. The automobile industry uses it in buffing and polishing compounds in lacquer finishing.

The end-use pattern for tripoli has changed significantly in the past 20 years. In 1970, nearly 70% of the processed tripoli was used as an abrasive. Today, 76% is used as a filler and extender in paint, plastic, rubber, caulking compounds, and enamel.

The largest use of tripoli is as a filler and extender in paints. These uses are estimated to account for as much as 85% of the tripoli used as filler and extender. Its use in exterior latex paints is as a low-micrometer-grade micronized product. In these paints, tripoli aids in tint retention, durability, leveling, and flowability. In enamels, it permits higher loading with no appreciable increase in vehicle demand and improves sheen. Because of its controlled grain or particle size, paints containing tripoli disperse easier and result in a uniform film. Additionally, because of its abrasive qualities, the paints are more resistive to wear and to chemicals than those in which water-ground whitings and other reactive fillers are used.

Plastics, rubbers, and resins each use about 5% of total annual tripoli filler and extender production. It is used extensively in plastics for electrical uses because of its dielectric properties and its effects on flexural and compressive strengths. Its chemical resistance, weatherability, and resistance to salt spray also are important to its use in plastics. Its physical properties allow high loading in most compounds, but its abrasiveness results in high wear in extruding nozzles and molds. The same properties that makes tripoli useful as a filler and extender in plastics make it valuable to the rubber and resin industries.

Tripoli contains essentially 100% crystalline silica, so its use can cause silicosis and falls under the jurisdiction of the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard. The International Agency for Research on Cancer (IARC) and other independent studies have determined that crystalline silica is a probable carcinogen for humans. As a result, OSHA is required to regulate materials containing more than 0.1% crystalline silica. To date, it does not appear that these regulations have adversely affected the use of tripoli, but all tripoli must be labeled in compliance with OSHA regulations.

In the filler and extender uses listed, ground calcium carbonate, ground silica sand, pyrogenic and precipitated silica, calcined kaolin, and talc can be substituted.

The use of tripoli as an abrasive increased about 4% in 1993, ending 8 consecutive years of decline. During the 8-year period, consumption declined about 50%.

After 4 consecutive years of decline, from 1988 through 1991, the amount of tripoli used as filler increased. The 2% increase in 1993 followed a 10% increase in 1992, a 7% decrease in 1991, a 10% decrease in 1990, an 8% decrease in 1989, and an additional 4% decrease in 1988. USBM data show that tripoli use in the United States as a filler is about 74% of the total; abrasive, 21%; and other uses, about 1%.

Prices.—The average reported value of abrasive tripoli, sold or used, in the United States was $152 per ton. The value of abrasive tripoli has increased over the past 11 years and the increase has been continuous.

The average reported value of filler tripoli, sold or used, in the United States was $212 per ton. The average reported value has increased for the past 11 years.

SPECIAL SILICA STONE PRODUCTS

Special silica stone products include hones, whetstones, oilstones, stone files, grindstones, grinding pebbles, tube-mill liners, deburring media, and certain specialty products. These do not include products made from artificially bonded abrasive grains. Manufacture of these products was from novaculite, quartzite, or other quarried microcrystalline quartz rock.

Annual Review

Production.—Plants manufactured oilstones, hones, whetstones, and files in Arkansas. Additional production includes grindstones in Ohio, deburring media in Arkansas and Wisconsin, and grinding pebbles and mill liners in Minnesota. Production of the crude materials was in the same State as the products manufactured.

The production of oilstones, hones, whetstones, files, and grindstones decreased about 21% in quantity to 267 tons and 17% in value to $3.8 million. *(See tables 6 and 7.)*

The industry manufactured four main grades of Arkansas whetstone. They ranged in grade from the high-quality Black Hard Arkansas Stone down to the Washita Stone. The Black Hard has a porosity of 0.07% and a waxy luster, while Washita Stone has a porosity of 16% and resembles unglazed porcelain.

Arkansas accounted for essentially 100% of the value and total quantity of special silica stone products reported as sold or used by U.S. producers.

Consumption and Uses.—The domestic consumption of special silica stone products is a combination of residential, industrial, leisure, and craft uses. The major residential uses were the sharpening of knives and other cutlery such as scissors, shears, and lawn and garden tools. Major industrial uses were the sharpening and honing of cutting surfaces, polishing of metal surfaces, and the deburring of metal and plastic castings. The manufacture, repair, and modification of guns also make use of stone files. The recreational uses were the sharpening of sports knives, arrowheads, spear points, fish hooks, and other recreational items. Craft applications included uses in sharpening tools for wood carving, gun engraving, jewelrymaking, and other engraving work.

Prices.—The value of crude novaculite suitable for cutting into finished products varied from $13 per ton to $895 per ton. The low value was for Washita grade and the high for Black Hard Arkansas grade. The manufacture of deburring media or special-purpose crushed stone is from material not suited for making oilstones, hones, or whetstones. The value of these materials ranged from $469 per ton to $1,176 per ton. The average value in 1992 of oilstones, hones, whetstones, and grindstones, sold or used by U.S. producers, was $14,107 per ton. New products can be duplicated by competitors quickly because the special silica stone products industry is not high technology. This very quickly results in short-term price pressures.

Foreign Trade.—The value of exported special silica stone products was $7.2 million, a decrease of 5% compared with that of 1992.

The value of imported products was $2.4 million, down 4% from the record high of 1992. The United States continues to be a net exporter of special silica stone products. A portion of the finished products imported was from crude novaculite produced within the United States and exported for processing. In 1993, the trade surplus in special silica stone products was $4.8 million, a decrease of about 8%.

GARNET

Technical-grade industrial garnet from the United States is a solid solution of almandite and pyrope that, when under pressure, breaks into sharp chisel-edged plates. Industry uses this garnet as an abrasive powder and to manufacture coated abrasives. Low-quality industrial garnet found uses primarily as airblasting or hydroblasting media and as filtration media.

Background

Definitions, Grades, and Specifications.—Garnet is a general name for a family of complex silicate minerals having similar physical properties and crystal form. The general formula for garnet is $A_3B_2(SiO_4)_3$, where A can be calcium, magnesium, ferrous iron, or manganese and B can be aluminum, ferric iron, or chromium, or rarely titanium. The most common garnet species are $Mg_3Al_2Si_3O_{12}$ (pyrope) and $Fe_3Al_2Si_3O_{12}$ (almandite). Almandite and almandite-pyrope solid solution garnets are the best abrasive garnets, but andradite, grossularite, and pyrope also are used. Garnet displays the greatest variety of color of any industrial mineral, having been found in all colors except blue. For example, grossularite can be colorless, white, gray, yellow, yellowish green, various shades of green, brown, pink, reddish, or black. Andradite garnet can be yellow-green, green, greenish brown, orange-yellow, brown, grayish black, or black. Pyrope is commonly purplish red, pinkish red, orange-red, crimson, or dark red; almandite is deep red, brownish red, brownish black, or violet-red. Spessartite garnet can be red, reddish orange, orange, yellow-brown, reddish brown, or blackish brown.

The Mohs hardness of garnet varies from 6.5 to 9.0. Grossularite and uvarovite have a hardness of 6.5 to 7.5; andradite is 6.5 to 7.0; and pyrope, almandite, and spessartite are 7.0 to 7.5 in hardness. There are reports of almandite having a hardness of between 8.0 and 9.0.

As with hardness, the specific gravity of garnet varies considerably. The specific gravity may be as low as 3.2 grams/cubic meter or as high as 4.3 grams/cubic meter depending on chemical composition.

Consumers purchase garnet that has been crushed, ground, and graded to different particle sizes for different end uses. Descriptions of testing methods for materials to be used in the manufacturing of coated abrasives are contained in American National Standards Institute (ANSI) Specifications B74.18-1977, "Specifications for Grading of Certain Abrasive Grains on Coated Abrasive Products."[2] Other specifications are contained in ANSI Specification B74.12-1976, "Specification for Size of Abrasive Grains-Grinding Wheel, Polishing, and General Industrial Uses."[3]

If the garnet is to be used as a sandblasting medium at a U.S. Navy shipyard or a private shipyard working on U.S. Navy vessels, then it must meet MIL-A-22262(SH) specifications that qualify it for product list QPL-22262. These specifications set forth limits on the content of total metals, soluble metals, and radiation; specify the acceptable level of chemical conductivity; and require that the material be certified by the California Air Resources Board.

The California Air Resources Board (ARB) requires all loose-grain abrasives used in the State to be certified at the ARB testing facility. The testing is conducted according to "Methods of Test of Abrasive Media Evaluation," Test Method No. Ca 371-A, and as required under ARB's Title 17, Subchapter 6 entitled "Abrasive Blasting." Copies of these documents are available from the Compliance Division of the California Air Resources Board, Sacramento, CA. In addition, air pollution control agencies in Utah, Minnesota, and Louisiana have adopted the ARB tests and require that only ARB-certified abrasives be used on State projects requiring sandblasting. The ARB's testing procedures and standards are focused on the environmental impact of sandblasting abrasives, not on their qualities or cutting performance and/or efficiency.

The Steel Structures Painting Council, a technical organization in Pittsburgh that has a committee on abrasives, is currently drafting abrasive specification SSPC-XAB1X, "Mineral and Slag Abrasives," which will address garnet specifically. The specification defines the requirements for selecting and evaluating mineral and slag abrasives used in blast cleaning steel and other surfaces for painting and other purposes.

The American Water Works Association (AWWA) has established specification B100-89, "Standards for Filtering Materials," but this specification does not cover high-density media such as garnet and ilmenite. The AWWA plans to include garnet and ilmenite in the updated specification B100-94. In general, specifications for filtration involve garnet's particle shape, specific gravity, effective grain size, coefficient of grain-size uniformity, content of acid-soluble impurities, and content of radioactive and heavy metals.

The sale of garnet for sandblasting, water filtration, and abrasive cutting is by screen size. In U.S. sandblasting, the most widely used domestically produced garnet is -1.0 + 0.3 millimeters, followed by -0.59 + 0.21 millimeters. The most popular grade of imported garnet in the U.S. market is the -0.59 + 0.25-millimeter grade from Australia. In U.S. multimedia water filtration systems, two grades of garnet are used, a coarse grade that is -4.75 + 1.41 millimeters, and a fine grade that is either -0.84 + 0.3 or -0.71 + 0.25 millimeters. Abrasive cutting applications most popular grade of garnet is -0.25 + 0.177 millimeters, which may account for as much as 90% of the garnet used.

There is no definitive method for testing the quality of garnet or any other loose-grain abrasive except by actual application. There are tests and examinations that can indicate a garnet product's probable abrasive performance in use. The fracture, sharpness, shape, and structure of the garnet and the presence of inclusions all can be studied with a microscope. The hardness and friability of the garnet can be evaluated by placing a sample between two glass microscope slides and rubbing them together. The relative scratch hardness of the grains and their degree of breakdown (attrition) can be measured in this manner. Additionally, ANSI Standard B74.8-1965, "American Standard Test for Ball Mill Test for Friability of Abrasive Grain," can be used to determine the friability of garnet grains.

The U.S. National Institute for Standards and Technology developed an apparatus for evaluating the abrasive quality of corundum. This tester can be adapted for use with any loose-grain abrasive. Testing of loose-grain abrasives also can be performed with various production-scale and laboratory machines where the removal of glass from flat plates is evaluated. Data from such tests can be correlated with the anticipated performance of any abrasive grain relative to the other material to be abraded. In these tests abrasive performance is determined by the amount of stock removed, as found either by weighing or by dimensional measurements.

In judging the abrasive quality of garnet, stock removal is not the only important factor. Surface finish is just as important. If an abrasive is too hard or contains too-coarse grains for use on a certain material it can cause deep scratches in the surface, which cannot be removed in subsequent finishing operations. Additionally, if an abrasive does not have the proper grain shape or does not break down in such a manner as to resharpen itself, it will tend to burn or gouge the material being abraded, thus defeating the purpose of its use.

The California ARB's testing facility tests loose-grain abrasives for certification for use in the State. The test is focused on the environmental impact of sandblasting abrasives, not on their abrasive quality.

Other firms or laboratories that test the quality of loose abrasive grains include three firms involved in the abrasive cutting industry, Flow International Corp., Ingersoll Rand Corp., and Jet-Edge, Inc., that have laboratories for testing and evaluating garnet for use in their systems. Most of the evaluations in these laboratories involve the comparative testing of various abrasive grits, including measurements of particle size distribution and mechanical properties.

KTA-Tator, Inc. of Los Angeles, CA, is a major consulting/engineering/testing firm whose laboratory tests and evaluates the quality of garnet and other abrasives. Much of its work is oriented to the Steel Structures Painting Council (SSPC) specifications. The SSPC also can carry out comparative testing of garnet and other loose-grain abrasives to determine whether they meet military specifications, how clean the material is, how well the material cleans, the amount of degradation during use, and other quality factors. SSPC is part of the Carnegie-Mellon Research Institute and must be careful not to conduct research that favors one abrasives supplier over another supplier who may be a member of the Council.

Industry Structure.—Currently four firms produce garnet from four plants in two States. Each domestic producer has distinctive products. The Barton Mines Corp., Warren County, NY, garnet is a mixture of almandite and pyrope and is at the top of the garnet hardness range. It occurs as large crystals and exhibits incipient lamellar parting planes that break under pressure into sharp chisel-edged plates. It retains this chisel-edged shape even when crushed to a very fine size. Its garnet is used in coated abrasives, glass grinding and polishing, and metal lapping. The NYCO Div. of Processed Minerals Inc., Essex County, NY, and International Garnet Abrasive Inc., Clinton County, NY, garnet is a mixture of andradite and grossularite, and the crude garnet concentrate may contain diopside-hedenbergite ($Ca[MgFe]Si_2O_6$). NYCO recovered garnet as a byproduct from its wollastonite operation. It sold both crude garnet concentrate for additional refining and refined garnet for use as blasting and filtration media. International Garnet Abrasives produced refined garnet from NYCO's crude garnet concentrate for use as blasting and filtration media. Emerald Creek Garnet Milling Co. was purchased by Hawkeye Development Co., an Idaho corporation, in November 1991. Under the new name of Emerald Creek Garnet Co., it continued mining and milling operations in Benewah County, ID. Blasting and filtration media were the primary uses of the garnet.

Abrasive garnet production in the United States began in 1878 at the Gore

Mountain site of Barton Mines, near North Creek, Warren County, NY. During the first year, production was less than 100 tons. It was used in coated abrasives, both paper and cloth.[4] Barton Mines Corp. mined and processed the abrasive-grade garnet on Gore Mountain until the company moved the mining operation and processing plant in 1982 to the adjoining Ruby Mountain. Barton Mines has been a family owned operation since its formation. Reported past domestic garnet production was from California, Connecticut, Florida, Maine, New Hampshire, North Carolina, and Pennsylvania.[5]

Nine manufacturers at ten plants produced garnet-coated abrasive papers and cloths. The plants are in New York and Virginia, two in each, and Massachusetts, Michigan, Minnesota, Mississippi, Ohio, and Pennsylvania, one in each.

Geology-Resources.—Garnet is found as an accessory mineral in a wide variety of rocks. Most commonly it is found in gneisses and schists, but it also is found in contact metamorphic rocks, crystalline limestones, pegmatites, volcanic rocks, eclogites, and serpentinites. Additionally, garnet is found in the gangue of veins formed at high temperatures. Because garnet is resistant to chemical and mechanical weathering, it is common in the sands of current or ancestral beaches, streams, and other types of alluvial deposits. Commercially attractive industrial garnet occurrences are not common. Many garnets that occur in deposits of economic size degrade during processing because of internal stresses. These stresses developed in the garnet crystal during formation and cooling. Stress relieving is not economical; therefore, these deposits have no commercial value as a high-grade abrasive material source.

Garnets are usually small in size. Grossularite crystals range up to about 15 centimeters in diameter. Almandite approximates the same range in size except at Gore Mountain and North Mountain, NY, where crystals range up to 60 centimeters in diameter. Spessartite crystals from Brazil can weigh as much as several kilograms. Most garnet crystals are less than 2.54 centimeters in size.

The majority of world garnet production is from alluvial deposits in the United States, Australia, China, and India. Possibly the world's highest quality garnet is mined, however, from almandite-bearing rock of uncertain origin in the Adirondack Mountains of New York.

New York and Maine have the only known high-quality garnet reserves in the United States. The Wing Hill garnet deposit, near Rangeley in western Maine, is one of the largest and highest grade garnet deposits in the world. The host rock is a homogeneous garnet granofels that consists of 50% to 70% almandite garnet. It is medium grained and consists essentially of garnet and andesine plagioclase along with biotite and minor quartz. The garnet is present as discrete, well-formed crystals from less than 1 millimeter to about 10 millimeters in diameter but averaging 1.5 to 2 millimeters. The granofels is an east-west trending, tabular body more than 1,000 meters in length and as much as 700 meters thick. The garnet ranges in Mohs hardness from 7 to 8 and in density from 3.6 to 4.3 grams/cubic meter. When crushed, the garnet breaks into blocky grains, a shape that persists down to the finest fragment. The garnet is amenable to gravity and magnetic concentration when the ore is crushed to -3.36 millimeters. The estimate of reserves in the igneous rock deposit near Rangeley, ME, is more than 1.8 million tons of garnet.

Deposits of industrial garnet are found at two locations in New York. In the Gore Mountain area, technical-grade garnet is mined as the primary product, and near the town of Willsboro, commercial-grade garnet is recovered as a byproduct of wollastonite mining.

The deposit near Gore Mountain is an almandite-bearing diorite of uncertain, igneous or metamorphic origin. The ore body is approximately 2 kilometers long and 15 to 90 meters wide. The ore grade varies from less than 5% to about 20% garnet and averages slightly less than 10%. Hornblende and plagioclase feldspar make up 40% to 80% of the host rock, while hypersthene, magnetite, biotite, apatite, and pyrite are present in minor amounts. A rough estimate suggests that more than 600,000 tons of high-quality garnet can be recovered from the Barton Mines Corp. deposit on Ruby Mountain in New York. The garnet is present as imperfectly developed crystals surrounded by a rim of coarsely crystalline hornblende. The crystals range from about 1 millimeter to almost 1 meter in diameter but average about 100 millimeters in diameter. The garnet has a pronounced laminated structure, which enables it to naturally break into thin plates from about 2 to 6 millimeters in thickness. Garnet fragments maintain this platy particle shape even as they are crushed smaller and smaller.

Garnet is recovered as a byproduct from a wollastonite deposit on the western side of Lake Champlain near Willsboro. The deposit is in a belt of wollastonite-bearing rocks that is about 10 kilometers long and 0.4 kilometer wide. The largest zone of wollastonite rock within the belt is from about 9 meters to more than 20 meters thick but averages about 13 meters thick. The wollastonite is interbanded with andradite garnet and iron-rich diopside. The garnet and diopside together comprise 10% to 20% of the ore. Both the garnet and diopside are feebly magnetic and are easily separated from the wollastonite by magnetic separators.

Alluvial deposits of almandite garnet were discovered in the early 1880's near Fernwood in Benewah County, but commercial mining did not start until the early 1940's. The deposits are on Emerald, Carpenter, and Meadow Creeks about 6.4 kilometers from a mica-garnet schist formation. The source schist is estimated to be about 1,200 meters thick. The garnet-bearing gravels are from nearly 1 meter to about 1.2 meters thick and contain 8% to 15% garnet. Garnets from these gravels range up to 40 millimeters in diameter, although about 95% of the garnet is smaller than 7 millimeters in diameter. The quantity of garnet-bearing gravels reported at Emerald Creek and Carpenter Creek in Idaho is large. A minimum of 450,000 tons of garnet is available in the Emerald Creek Garnet Co. deposits.

There can be little doubt that tremendous reserves of garnet similar to the lower priced materials can be located as needed.[6] Also, the production of byproduct garnet from many current mining operations is possible if demand improved.

Reserves are significant in Australia, China, India, and the Newly Independent States, (formerly U.S.S.R.), but accurate data are not available. Huge inferred and undiscovered resources are likely to exist throughout the world.[7]

Technology.—**Exploration.**—Successful exploration for garnet deposits begins with selection of target areas based on the presence of known favorable host rocks. Geologic studies and maps, topographic maps, and aerial photographs are used to identify favorable metamorphic, igneous, alluvial, or eolian geological formations.

The second step is field examination of the selected targets. This may include geologic mapping and limited sampling but in many cases reconnaissance studies are sufficient. The next step, if warranted, is to sample the deposit in detail, the purpose being to measure the physical parameters of the deposit, specifically its grade and size.

The method of sampling used depends upon the type of deposit. Hard-rock deposits, igneous or metamorphic, are sampled differently than alluvial or eolian deposits.

Hard-rock deposits can be either diamond core drilled or trenched. Trenches should be oriented perpendicular to the strike of the formation and can be dug by hand, with a dozer, or with a backhoe.

Placer deposits can be sampled by drilling, trenching, or by excavating pits or shafts. The physical nature of the deposit, its thickness, hardness, grain size, and whether it is above or below the water table influence the method of sampling chosen. For shallow deposits, hand augers or power augers can be used to drill sample holes. In deposits that are too hard to hand auger because of the presence of clay, iron oxide cement, or mild calcium carbonate cement, two-person motor-driven augers or vehicle-mounted augers (such as post hole diggers or telephone pole hole diggers) work well. However, augering does not always provide uncontaminated samples and is not effective below the water table.

Truck-mounted water-jet drills and rotary hammer drills are used to test thick deposits and deposits that are too hard to drill with other methods. A water-jet drill uses flush-jointed drill pipe with perforations near the bit to direct jets of water forward and downward from the bit. A hammer advances the drill bit and casing at the same time. Water from the jets flushes out the hole and returns cuttings to the surface in the annulus between the drill pipe and casing. Also, truck-mounted rotary drills equipped with double-pipe drill string and downhole hydraulic hammers can be used. Compressed air is forced down the inner pipe and returns samples to the surface in the annulus between the inner pipe and outer casing. Bits are selected depending on the type of material to be drilled.

Trenching can be carried out using either a dozer or a backhoe, depending on the size and depth of the deposit. In unconsolidated sediments it is difficult to maintain the stability of the walls of trenches, and samples can be contaminated by material sloughing from above. Bulk samples can be collected from 1-cubic-meter pits or shafts. However, here again, wall stability can be a problem unless some form of shoring is used.

Evaluation of Deposits.—The evaluation of garnet deposits to determine their suitability for commercial production can be divided into five major factors: (1) size and grade of the reserves; (2) mining conditions; (3) quality of the garnet; (4) location of the deposit relative to markets and infrastructure; and (5) milling costs. The relative importance of each of these factors will vary from one deposit to another, but the final determination of economic viability will depend upon all of them.

1. Size and grade of reserves: An economic garnet deposit has reserves that are large enough and high enough in grade to provide full project capital recovery, meet all operating costs, and furnish a reasonable profit over the depreciable life of the project, which is normally at least 10 to 20 years. Generally, a deposit should contain a minimum of 2 million tons of ore. The cutoff grade used in calculating reserves will depend on the economics of the specific deposit, but cutoff grades for most deposits average about 20% garnet.

2. Mining conditions: Mining conditions greatly affect the economics of a deposit and can even control whether the deposit can be developed. Early field examinations should identify any conditions, such as nearby houses, historical sites, national monuments, archaeological or paleontological sites, wildlife refuges, municipal watersheds, etc., that could preclude mining the deposit. Local, county, and State zoning regulations, environmental regulations, and other constraints should be checked to establish their effects on mining the deposit.

Hard-rock garnet deposits are mined in benched open pits using conventional drill-and-blast methods. Some placer deposits are mined with dredges. The configuration and structure of the deposit should be such that there are no blocks of waste rock within the ore body and that the garnet is, ideally, uniformly distributed throughout the ore. All physical and chemical features of the ore and overburden will influence whether the deposit is amenable to open pit mining and will impact the total mining cost per ton.

3. Quality of the garnet: The garnet in a deposit must be tested to evaluate its performance and marketability as an abrasive. It should be recognized in this regard that most garnet used in abrasive applications is either the almandite or almandite-pyrope type. The garnet should be present in the deposit as discrete crystals that are at least 6 to 13 millimeters in size and that are liberated when the ore is crushed to -2 millimeters. The crystals should be free of any inclusions, such as quartz, mica, hornblende, and feldspar, and also should be free of alteration. The garnet should

be relatively uniform in hardness and density throughout the deposit. It should not be badly weathered or highly friable. If an incipient parting is present in the garnet crystals, the effect this parting has on the quality of the final product and the distribution of such crystals within the deposit should be determined.

4. Location relative to markets and infrastructure: The location of a garnet deposit must be evaluated relative to its proximity to the markets for garnet abrasives and filter media. If the deposit itself is not near major market areas, then it must be near adequate and inexpensive means of transportation, especially by rail or water. Deposits should be reasonably accessible from existing roads.

5. Milling costs: The type of milling required and the cost of processing the ore must be analyzed carefully. Ideal ore is that from which the garnet can be liberated with minimum crushing and can be recovered using gravity/density-based methods of mechanical concentration and where size classification of the concentrate yields a complete range of product sizes. In some cases portions of the concentrate will be ground to achieve proper particle size distribution.

Mining.—At the Barton Mine in New York, the Ruby Mountain ore body covers approximately 41,000 square meters, which is nearly the entire mountain. The ore is mined by open pit methods with benches 9 meters high. The ore is drilled and blasted, a drop ball provides secondary breakage, and power shovels load ore into trucks for haulage to mill, about 0.4 kilometer away.

At Emerald Creek and Carpenter Creek, Benewah County, ID, backhoes are used to strip 1 to 2 meters of overburden, exposing the garnetiferous gravel. Mining is then carried out with draglines, and ore is trucked to a mill for processing.

Wollastonite mining at Willsboro, NY, yields a byproduct concentrate containing garnet, diopside-hedenbergite, and minor amounts of wollastonite. After drilling, blasting, and loading, the ore is transported 22 kilometers to the plant for separation of the wollastonite from the garnet-diopside.

Beneficiation.—The primary factors controlling the behavior of garnet ore during processing are the identity and characteristics of the minerals present, the percentage of each mineral present, and the size of the garnet grains. The major minerals associated with garnet in most deposits are feldspar, mica, hornblende, pyroxene, and quartz. Magnetite, pyrite, ilmenite, limonite, pyrrhotite, and occasionally chalcopyrite, rutile, zoisite, chlorite, and corundum may be present in much smaller amounts. Sodium feldspar is the most common feldspar, biotite is the most common mica, and hypersthene and diopside are the most common varieties of pyroxene present. The most important physical property controlling the behavior of the major and minor minerals during concentration of the garnet is their specific gravity.

At Barton Mines Corp.'s plant in New York, garnet is liberated, concentrated, and further processed by combinations of crushing and grinding, screening, tabling, flotation, magnetic separation, water sedimentation, drying, heat treating, and air separation. Occasionally, a single process will accomplish both sizing and the removal of gangue minerals, but this usually requires several processes. Particle size control can be difficult but is important for the concentration processes to work effectively.

The process used by Barton Mines to recover garnet has evolved over time. It began in 1924 with construction of the first "modern" plant where separation was accomplished using jigs. In 1941, heavy-media separation was added to the system, and in 1945 flotation was added. The current state-of-the-art mill is a combination of heavy-media and flotation circuits. Ore crushed to -7 millimeters is screened to 3.36 to 2.38 millimeters with the coarse fraction going to a heavy-media circuit using a density of 3.02 grams/cubic meter for primary separation and a density of 3.20 to 3.40 grams/cubic meters for secondary separation. The fine fraction from the screen goes to a flotation circuit where it is first ground to -0.3 millimeter in ball mills and then fed to float cells. The concentrate from the heavy-media circuit is roll crushed, combined with the float concentrate, and then dried and heat-treated in a rotary kiln.

At Emerald Creek Garnet Co.'s operation in Idaho, the ore is first processed through trommels to remove the gravel and is then concentrated in jigs and on shaking tables. The garnet concentrate is dried, crushed, and screened. The maximum grain size of finished products is 46 millimeters.

At NYCO Minerals' mill in New York, beneficiation of the wollastonite-garnet ore requires two stages. The first stage involves drying, crushing, screening, and recrushing the feed to -1.19-millimeters. In the second stage, the -1.19-millimeter ore passes over a series of screens to attain -1.19 + 0.84-, -0.84 + 0.42-, -0.42 + 0.25-, and -0.25-millimeter splits. A battery of magnetic separators then removes the garnet from each of these fractions. Four sizes of final product are bagged for shipment.

Today, practically all grade-grain abrasive garnet is heat treated as a processing function, not to improve its inherent abrasiveness. Impurities picked up during processing stick to the garnet particle surfaces. These impurities destroy the cleanliness and capillarity needed in later processing to give adhesion for bonding. In the early 1960's, scientific investigations determined that heat treating only cleaned the particle surfaces and that too high a temperature could destroy the abrasive quality of garnet. In the mid-1960's, the coated abrasive industry accepted uniform color standards. These standards ensured the cleanliness of the grain surface and a color most closely approaching the natural red color of abrasive garnet. The heat treatment needed to do this is the RT treatment.[8]

Annual Review

Production.—In 1993, the four U.S. firms produced 43,995 tons of crude garnet concentrate worth $4.4 million, an 18% decrease in quantity and a 4% increase in value compared to those of 1992.

Consumption and Uses.—In 1993, the quantity of garnet sold or used by producers was 55,760 tons, an increase of 21%, and the value increased 18% to $15.4 million. *(See table 8.)*

The major industrial use for high-quality, high-value garnet since before 1880 has been as loose-grain abrasive for applications such as optical lens grinding and plate-glass grinding. In recent years, its applications included the high-quality, scratch-free lapping of semiconductor materials and other metals. The finishing of wood, leather, hard rubber, felt, and plastics often requires the use of garnet-coated abrasive papers and cloths.

The aluminum aircraft and shipbuilding industries in California and the Pacific Northwest use lower quality, lower cost alluvial garnet, primarily from Idaho, for sandblasting. Similar uses in the Eastern United States are for the cleaning and conditioning of aluminum and other soft metals and for the cleaning of metal by structural steel fabrication shops. Mixed-media water filtration, using a mixture of sand, anthracite, and garnet, has displaced older filtration methods because it is more reliable and gives a better quality of water. Garnet also is used in hydrojet cutting—it is entrained in a high-pressure stream of water to cut many different materials. Demand for these uses has greatly increased. The manufacturers of nonskid floor paint also use alluvial and other low-cost garnets.

Garnet has obtained an intermediate place in the coated-abrasive field between low-cost quartz sand and more costly synthetic abrasives (silicon carbide and fused alumina). Garnet is reportedly more efficient based on unit production costs than quartz sand. It also produces a more desirable finish on items made of wood, leather, hard rubber, felt, and plastic.

Garnet, especially the lower grades, cannot compete with synthetic abrasives for most metalworking applications requiring substantial metal removal because of its friable nature and lower hardness.

Prices.—The average value per ton of crude garnet concentrates was $100, a 12% increase compared with the 1992 average. In 1993, the average value per ton of garnet sold or used was $299, a 12% increase from that of 1992.

Foreign Trade.—Garnet exports, as reported to the USBM, by producers were about 11,400 tons, a 50% increase from that of 1992. Export data on garnet were not available from the Bureau of the Census (Department of Commerce). Producers have reported exports to the USBM for the past 7 years. According to reports by producers, exports, with the exception of those for 1992, have increased significantly.

Mineral brokers and other garnet importers reported to the USBM about 12,200 tons of imported garnet, essentially unchanged from that of 1992. Import data for garnet also were not available from the Bureau of the Census. The United States was a net importer of garnet in 1992 for the first time in history and continued this new trend in 1993.

World Review.—The United States was the dominant world producer and consumer of garnet, accounting for approximately 45% of the estimated world output and nearly 40% of estimated world consumption. Studies are under way on two new garnet operations; Bitteroot Resources Ltd. is evaluating an almandite deposit in Arizona, and Royalstar Resources is evaluating an andradite deposit in New Mexico.

European Garnet Ltd. announced plans to install garnet recovery plants at gravel pits in the Po Valley of northern Italy. The company plans to recover up to 20,000 tons of garnet per year from its first 10 plants.[9]

Target Mines Ltd. (a subsidiary of Barton Mines) continued to produce at near capacity from its Australian garnet sand operation.

The Chinese mines continued to increase production of garnet for the domestic and world market. Two mineral sand mining operations in India continued to produce garnet as a byproduct of mineral sands production. Turkey and the Newly Independent States (formerly the U.S.S.R.), primarily produce for local markets.

Outlook

The U.S. production and consumption of industrial garnet during the next 5 years will be a function of the installed capacity and imports. Currently, the industry is operating at or near capacity. If capacity can be added, production and consumption will increase to approximately 80,000 tons per year by 1998. If garnet were not available, other abrasives could be used in its place, but in many cases with some sacrifices in work volume, quality of work, or cost.

Substitution of other natural and synthetic material is present to some extent for all major end uses of garnet. Fused alumina and staurolite compete with garnet as a sandblasting material in the transportation equipment industries. Ilmenite and plastics compete as filtration media. Diamond, corundum, and fused alumina compete for lens grinding and for many lapping operations. Finally, sand, silicon carbide, and fused alumina compete for grinding and finishing of plastics, wood furniture, and other products.

EMERY

Emery is a gray to black rock containing various minerals, including corundum, magnetite, hematite, or hercynite, and trace minerals such as mullite, titania, silica, and magnesia. Its hardness ranges between 7 and 9 on the Mohs scale and its specific gravity ranges from 3.2 to 4.5, depending upon its composition. It is used as an abrasive aggregate for nonskid, wear-resistant floors, pavements, and stair treads; as tumbling or deburring media; and in the manufacture of coated abrasives.

Annual Review

Production.—A single firm, Oregon Emery, Albany, OR, produced emery in 1993 using open pit mining methods. U.S. production of emery decreased about 34% in quantity and value compared with those of 1992.

Consumption.—The USBM estimated that the United States consumed approximately 10,000 tons of emery in 1993. Imports from Greece and Turkey accounted for most of the material consumed. Four firms processed and distributed emery for domestic consumption: Washington Mills Abrasives Co., Emeri-Crete Inc., Oregon Emery, and General Abrasives Co.

Foreign Trade.—The United States did not export emery in 1993, nor has it done so in the past 10 years. The Bureau of the Census reports emery imports, exports, and reexports in mineral group categories; thus, exact data on emery are not available.

World Review.—Turkey was the world's largest producer of emery. Its production is handled by Etibank in Ankara, by Ranar Minerals Industries Corp. in Istanbul, and by Lutfullah E. Kitapci Minerals Co., Ltd. in Izmir. Total production in 1993 was estimated to be in excess of 20,000 tons. Prices of Ranar emery ranged from $34 to $48 per ton for crude and from $220 to $460 per ton for micronized grades.

The second largest producer was Greece. In Greece, Government-owned deposits on the Island of Naxos are worked by villagers. It is estimated that 1993 production was about 10,000 tons.

STAUROLITE

Staurolite is a naturally occurring, complex, hydrated aluminosilicate of iron having a variable composition. The mineral most commonly occurs as opaque, reddish-brown to black crystals. It has a specific gravity ranging from 3.74 to 3.83 and Mohs hardness of between 7 and 8.

Annual Review

Production.—Georgia, North Carolina, and Virginia produced mineral specimen staurolite crystals. The crystals were in the cruciform twinned form commonly called "fairy crosses." E.I. du Pont de Nemours & Co. Inc. produced industrial-grade staurolite in Florida. Publishing production data would disclose company proprietary data, but production of industrial staurolite increased 51% in quantity and 136% in value compared with those of 1992.

Industrial staurolite was a byproduct of heavy-mineral concentrates recovered from a beach sand deposit in Clay County, north-central Florida. Electrical and magnetic separators remove staurolite from the concentrates after scrubbing, washing with caustic, rinsing, and drying. The resulting material was about 77% clean, rounded, and uniformly sized grains of staurolite, with minor amounts of tourmaline, ilmenite and other titanium minerals, kyanite, zircon, and quartz. A nominal composition of this staurolite sand is 45% aluminum oxide (minimum), 18% ferric oxide (maximum), 5% silica (maximum), and 3% zirconium dioxide (maximum).

Consumption.—During 1993, shipments of staurolite decreased 4% in tonnage but increased 49% in value compared with those of 1992. Staurolite, marketed under the trade name Biasill, was used as molding material in nonferrous foundries because of its low thermal expansion, high thermal conductivity, and high melting point. Its low softening temperature often restricts its use to nonferrous casting. The major use of staurolite was as an abrasive for impact finishing of metals and sandblasting of buildings. The blasting media trade names were Starblast (80 mesh) and Siasill (90 mesh). A coarse grade (55 mesh) also was used as an abrasive. Some portland cement formulations consumed a minor amount. As regulations limiting the amounts of free silica in airblasting media became more stringent, the demand for staurolite increased.

Foreign Trade.—Neither the Bureau of the Census nor the staurolite industry reported any exports or imports of staurolite. Given the limited market and the low price per ton, no international market for staurolite should develop in the near term.

World Review.—India continued to produce small amounts of staurolite for local consumption. Other countries sometimes produce small amounts of staurolite as a byproduct of mineral sands or gemstone production.

INDUSTRIAL DIAMOND

Industrial diamond is natural diamond that does not meet the standards of gem diamond because of its color, size, or other imperfection. Also, it may be a synthetic diamond that is tailor-made for industrial applications.

Background

Definitions, Grades, and Specifications.—Natural industrial diamond is diamond that, because of color, structure, size, or shape, is unsuitable for use as gemstones. Major categories are industrial stones (die stones, tool stones, and drilling stones), crushing bort, and grit and powder. The distinction between stone and grit is not well defined; generally, the dividing line is a range of sizes. Stones usually are particles larger than 16 to 20 mesh, grit from 16 to 20 mesh to 325 to 400 mesh, and powder as particles smaller than 325 to 400 mesh. These categories are subdivided further into more than 100 groups.[10]

Bort is natural diamond that occurs in finely crystalline aggregates and usually is crushed into finer material. Originally, the term was the name for all crystalline diamonds not usable as gems. Later it designated those diamonds not usable as gems, tool stones, die stones, or drill stones. Currently, the term refers to low-grade industrial diamond suitable only for use in a fragmented form.

Most synthesized diamond marketed to date is 20 to 30 mesh and smaller. Recently, producers began to manufacture synthetic stones of 2 carats or larger. Marketing of these stones to date is of engineered pieces of the stones, not the entire stone. Polycrystalline synthetic diamond compacts and shapes can replace some larger stones. There are several types of synthetic diamond. They range from very friable material with a highly irregular shape to blocky, regular shapes with excellent crystal structure. The manufacture of industrial diamond stones is not commercially viable.

The metric carat, 0.2 gram, is the unit of measure for industrial diamond. One pound contains 2,268 carats, and 1 kilogram contains 5,000 carats. The carat is equal to 100 points. Diamond grit and powder sizes are identified by U.S. standard screen classifications, by ANSI Specification B74.16-1971,[11] ANSI Specification B74.20-1981,[12] and by a proposed standard developed by the Industrial Diamond Association[13] for subsieve micron-sized diamond or cubic boron nitride powders. The terms "sand," "grit," and "powder" also describe decreasing orders of fine diamond.

Machine-shop waste containing diamond is sludge if obtained from wet grinding and is called swarf if obtained from dry grinding.

Industry Structure.—The original discoveries of diamond in India, Borneo, and Brazil, and later in the Republic of South Africa, were due to chance finds by local inhabitants. Certain desirable characteristics in diamond were noted first in India and led to active search by open pit workings and to concentration by hand methods.

Probably the first industrial use of diamond was as diamond powder for polishing gem diamonds and other precious stones. The art of diamond cutting and polishing was known in India, probably well before A.D. 1400.

Glasscutting was an early application of diamond in industry. It was the most important use of industrial diamond until the 1860's.

England issued a patent in 1819 for drawing wire through a diamond die. Diamond wiredrawing dies gave close dimensional accuracy to wire, even after long periods of use.

The use of diamond for metalcutting began in the 1860's, but the high price of diamond tools was a drawback to their acceptance. As the economic advantages of using diamond tools became known, demand increased rapidly.

The use of the first diamond drill was in 1864. The discovery of diamond in South Africa in 1867 provided ample supply for the new and growing demand for diamond drill bits.

With the introduction of cemented tungsten carbide cutting tools during World War I, industrial diamond use increased. The cause of the increase was that diamond was the most effective agent in grinding tungsten carbide. Requirements for industrial diamond expanded tremendously because of World War II, when demand increased for grinding wheels, die stones, tool stones, drill bits, dresser stones, and polishing dust. The apparent supply of industrial diamond decreased rapidly following World War II.

In 1955, General Electric Co. announced the development of a process for the manufacturer of diamond at its Schenectady, NY, laboratories. Commercial production started in 1957 at its plant in Detroit, MI. In 1969, production moved to Worthington, OH. In 1959, De Beers Consolidated Mines Ltd. announced the manufacture of industrial diamond at its laboratory in Johannesburg, Republic of South Africa. Since these two announcements, the production of synthetic diamond by General Electric, De Beers, and others continued to increase. Today it exceeds the production of natural diamond worldwide about five times.

Geology.—The major source of inplace diamond is kimberlite, an altered, dark-green basic rock of igneous origin. Throughout the world there are approximately 1,000 occurrences of kimberlite, but most do not contain diamonds or do not contain diamonds in economic quantities. The term "diamond pipe" refers to an occurrence of kimberlite large enough and sufficiently diamondiferous to be mined. The size and shape of these pipes depend on the manner in which molten kimberlite passed through the country rock. They may be columnar, tabular, or irregular in shape. Where mining is deep enough, the diamond pipe always decreases in area and assumes a dikelike habit. The diamond may contain inclusions of many minerals, and many of these minerals have inclusions of diamond. These accessory minerals include olivine, garnet, diopside, ilmenite, magnetite, rutile, and phlogopite. Every mine has some diamond that is typical of it, but most diamond is indistinguishable from that of other mines.

Currently, approximately 40% of diamond is from alluvial deposits. These may be alluvial placers, recent or elevated marine beach placers, or glacial deposits. Often the distance of transport has been great. In many areas, the diamond-bearing, alluvial placers were deposited in former drainage systems unrelated to any present system.[14]

Technology.—**Mining.**—Currently, the United States has no commercial deposits of diamond. In other countries, mining methods range from very crude hand mining and panning to block caving of kimberlite pipes. Large-scale surface mining operations in Australia, Zaire, Angola, Namibia, and Sierra Leone[15] use modern equipment, such as continuous bucket wheel excavators, power shovels, draglines, scraper-loaders, and motor trucks, to remove overburden and to mine and transport the diamond ore.

Processing.—The type of ore, size of operation, and other factors decide the types of processing equipment used. Crushing, where necessary, is done mostly with gyratory and roll crushers to avoid impact to diamond stones. Additional grinding is done with attrition and ball mills to further separate the gangue from diamond stones. Clayey ore may require the use of log washers. Diamond washing pans, jigs, heavy-medium separators, or hydrocyclones collect the primary or intermediate concentrates. Depending on the types, shapes, and sizes of diamond present, various final treatments are used. They include the use of grease tables and grease belts, electromagnetic separators, electrostatic separators, optical sorters, X-ray sorters, and other devices. In all processing plants, hand sorting is the final recovery process.[16]

Reclaiming industrial diamond stones from drill bits and grit from the wastes generated in grinding, sawing, and other operations is common. This is because of the high unit value of diamonds. Reclamation processes include physical methods such as distillation to remove coolants and lubricants, followed by electrostatic, magnetic, or flotation separation. Reclamation also uses chemical methods, including combustion, acid treatment, and fusion with alkalies.[17] The treatment used depends primarily on the contaminants present.

Commercial production of synthetic diamond grit is by two basic methods. Currently, the primary method used involves the application of ultrahigh pressure and high temperature to carbon-metal catalyst mixtures by powerful hydraulic presses. This method uses pyrophyllite and other materials for the reaction vessel. Pyrophyllite for this purpose is from the Republic of South Africa, where the local name for it is wonderstone. The major user of the method now uses synthetic reaction-vessel materials, alleviating the dependency on foreign sources for pyrophyllite. The material used for these replacement reaction vessels is proprietary. The other method employs explosive shock to the carbon-metal catalyst mixtures.

Industrial diamond particles of good quality up to 20 mesh and perhaps larger are produced. The shape and other characteristics can be controlled by proper manipulation of the variables, pressure, temperature, time, and catalyst type. Only micrometer-size particles are presently available from the explosive process. Other methods of diamond synthesis exist, but none are in commercial use in the United States. Other countries produce diamond grit; all of these apparently use the ultrahigh-pressure, high-temperature method involving hydraulic presses.

Polycrystalline synthetic diamond compacts are a laminated structure of synthetic diamond powder bonded to a cemented carbide substrate. Their production is by a proprietary high-pressure, high-temperature process that gives the product excellent uniform physical properties.[18]

The polycrystalline synthetic diamond shape is a dense, nonporous, fully intergrown product that is thermally stable to 1,200° C. Production uses a proprietary high-pressure, high-temperature process using a special binder phase that is retained as an integral part of the product and results in high resistance to shock loading.[19]

Annual Review

Government Programs.—The National Defense Stockpile (NDS) for industrial diamonds, as of December 31, 1993, had a goal of zero and an inventory of 4.0 million carats for crushing bort. The goal for industrial stones was 3.0 million carats and the inventory was 6.46 million carats. There is currently legislative authority for disposal of 4.0 million carats of bort and 3.0 million carats of industrial stones. The inventory of small diamond dies was 25,473 pieces compared with a goal of zero pieces, but no disposal authorization was issued.

Production.—The United States was the largest producer of synthetic industrial diamond. This has made the United States independent of foreign sources for crushing bort or similar diamond except for grit sizes larger than about 20 mesh. Having no production of natural diamond, it was dependent on other countries for its natural diamond supply.

Three domestic firms produced synthetic industrial diamond in the United States: Du Pont Industrial Diamond Div., Gibbstown, NJ; General Electric Co., GE Superabrasives, Worthington, OH; and Suprahards, Inc. Cedar Knolls, NJ. Two firms, Megadiamond Industries Inc., a subsidiary of Smith International Inc., Provo, UT, and U.S. Synthetics Corp., Orem, UT, manufactured polycrystalline diamond from purchased synthetic diamond grit. Both firms had the capability to manufacture synthetic industrial diamond grit, but chose not to for economic reasons. Publishing production data would disclose company proprietary data. Domestic production did increase significantly. The United States continued to be the largest single producer of synthetic industrial diamond, a role it has enjoyed since 1957.

U.S. secondary production of industrial diamond was from six firms. They were Amples Corp., Bloomfield, CT; Diamondsharp Corp., Keene, NH; Industrial Diamond Laboratory Inc., Bronx, NY; Industrial Diamond Powders Co., Pittsburgh, PA; International Diamond Services Inc., Houston, TX; and National Research Co., Fraser, MI. The firms reclaimed a total of about 16.1 million carats from used drill bits, diamond tools, and wet and dry diamond-containing waste.

Consumption and Uses.—The United States continued to be the largest single consumer of industrial diamond. The USBM estimate of apparent consumption of industrial diamond was approximately 149 million carats, an increase of about 51% compared with 1992 consumption.

Diamond is far harder than any other natural or artificial abrasive material, so it was essential for some uses and much more efficient than other abrasives for many others. The principal uses of industrial diamond stones are in drilling bits and reaming shells, single- or multiple-point diamond tools, diamond saws, diamond wheels, abrasive, and diamond wiredrawing dies. Miscellaneous uses include: engraving points, glasscutters, bearings, surgical instruments, and special tools. Changes in technology and conventional wisdom have resulted in an increased use of synthetic industrial diamonds and polycrystalline diamond shapes (PDS) and compacts (PDC) for many of the uses listed. There has been an increased use of PDS, PDC, and matrix set synthetic diamond grit in drilling bits and reaming shells in the past 3 years. Diamond saws, diamond wheels, and diamond abrasive grit and powder are almost exclusively made from synthetic diamond. PDS and PDC are used in the manufacture of single- and multiple-point tools, and PDC is used in a majority of the diamond wiredrawing dies.

Mineral, oil, and gas exploration were the primary uses of drilling bits and shells. Foundation testing for dams, buildings, and other construction also used diamond bits and shells, as did masonry drilling in buildings for conduits and access and testing of concrete in various structures and other similar applications. The primary uses of diamond tools were for dressing and trueing grinding wheels and for cutting, machining, boring, and finishing. Beveling glass automobile windows also were a use. Cutting dimension stone, ceramics, and concrete in highway reconditioning were the major uses of diamond saws. The forming of refractory shapes for furnace linings also uses diamond saws. Diamond wire dies were essential for high-speed drawing of fine wire, especially from hard, high-strength metals and alloys.

Diamond grit, powders, and fragmented bort go into diamond grinding wheels, saws, impregnated bits and tools, and loose abrasives compounds for lapping and polishing.

Three major types of grinding wheels were made—resinoid, metal, and vitrified bonds—in many shapes and sizes designed for specific applications. The sizes range up to 1 meter in diameter for very large industrial wheels. Sharpening and shaping of carbide machine tool tips, grinding of dies, edging of plate glass, and optical grinding were among the primary applications of diamond grinding wheels. The cutting of concrete, stone, ceramics, and composite materials were uses of saws made with diamond grit. Very fine saws sliced wafers from brittle metals and crystals for use in electronic and electric devices.

Finishing optical surfaces, jewel bearings, gemstones, wiredrawing dies, cutting tools, and metallographic specimens were the primary uses of polishing and lapping powder and compounds. Hundreds of other important items made from metals, ceramics, plastics, and glass also were finished with diamond compounds.

Prices.—The USBM does not collect price data on industrial diamonds. It did track the average import value of various classifications of industrial diamonds. The average value of U.S. imports of natural grit and powder, synthetic grit and powder, and industrial stones was $1.14 per carat, $0.64 per carat, and $4.56, respectively.

Foreign Trade.—The United States was the largest exporter of industrial diamond grit and powder in the world. The United States exported and reexported a record 106.6 million carats of natural and synthetic grit and powder, an increase of 23% over the record set in 1992. The material was worth a record $139.3 million. Additionally, the U.S. exported and reexported approximately 3.4 million carats of industrial stones, valued at $49.1 million.

Imports of dust, grit, and powder in 1993 were about 37% more than those in 1992, a record high 132.8 million carats.

The 1993 imports of diamond stones were about 47% less than 1992 imports. *(See table 9.)*

World Review.—Botswana and the Republic of South Africa were the largest producers of good-quality industrial diamond stones. Australia and Zaire were the world's largest producers of natural industrial diamond and were the primary sources of natural crushing bort as well as substantial producers of industrial stones. Estimates suggest that the former U.S.S.R. was the third largest producer of natural industrial diamond, but reliable data were lacking.[20] The next largest, in order of volume, were Botswana and the Republic of South Africa. Other smaller but significant producers were Angola, Brazil, China, Ghana, and Venezuela.[21] Total world output of natural industrial diamond in 1993 was approximately 50.4 million carats, a 3% increase over that of 1992.

Synthetic industrial diamond production is significantly larger than the production of natural industrial diamonds. The countries that have synthetic diamond production, in declining order, are the United States, Ireland, Russia, South Africa, China, Germany, Japan, Sweden, Republic of Korea, Czechoslovakia, Romania, France, and Greece.

Outlook

Diamond grit and powder should experience substantial increases in domestic demand for every end use during the next 5 years. The increases for synthetic grit and powder are expected to be greater than for natural. The constant-dollar prices of these materials, especially the synthetic diamond products, should continue to decrease or at least remain constant. This is because planned production increases will make them more cost-effective. The contract construction industry is an area in which the greatest increases will occur. This is because large quantities of saw-grade diamond will be required for highway and bridge repair and replacement. Large increases also are expected in the dimension stone industry as a cutting and polishing media. The stone, clay, and glass industries will increase their uses in cutting, shaping, and polishing media. Additionally, polycrystalline synthetic diamond compacts and shapes will continue to displace natural diamond stone and tungsten carbide drill bits in the mineral services sector. The probable average annual growth rate in U.S. production is about 10%, based on estimates by the U.S. producers. U.S. production of synthetic material is sufficient to supply U.S. diamond grit and powder demand. The United States will continue to be a major exporter.

The major domestic end use for industrial stones in the next 5 years will continue to be in the oil, gas, and mineral industries. These stones are natural and cannot yet be manufactured commercially. Polycrystalline synthetic diamond compacts and shapes have had a major negative impact on the natural industrial diamond stone markets. This will limit the growth of U.S. demand for stone during the next 5 years. U.S. consumption should average between 6 and 7 million carats per year for the next 5 years. Approximately 50% of the potential natural stone applications will be replaced by the synthetic compacts and shapes by the year 2000. *(See table 10.)*

MANUFACTURED ABRASIVES

Manufactured abrasives include fused aluminum oxide, silicon carbide, alumina-zirconia oxide, and metallic shot and grit. Production data for fused aluminum oxide, silicon carbide, and alumina-zirconia oxide were for the United States and Canada. Data for metallic shot and grit were for the United States only.

The fused aluminum oxide, silicon carbide, and metallic abrasives industries continued to undergo consolidation and reorganization during the year. *(See table 11.)*

Fused Aluminum Oxide

Government Programs.—The NDS, as of December 31, 1993, contained 223,959 tons of crude fused aluminum oxide and 43,614 tons of abrasive-grain fused aluminum oxide. There is no NDS goal for abrasive-grain fused aluminum oxide or crude fused aluminum oxide; all of the material is targeted for disposal. During 1993 the NDS disposed of 3,193 tons of crude fused aluminum oxide and 2,555 tons of abrasive-grade fused aluminum oxide.

Production.—At yearend, four firms were producing fused aluminum oxide at seven plants in the United States and Canada. Production of regular-grade fused aluminum oxide in 1993 was 132,403 tons, a decrease of about 7% from that of 1992.

Production of high-purity fused aluminum oxide decreased 12% to 21,276 tons. Total 1993 production of 153,680 tons was 8% less than that of 1992.

Consumption and Uses.—Fused aluminum oxide has a number of different end uses in the form of graded grain. The total value of sales of fused aluminum oxide-graded grain for all uses decreased 7% compared to that of 1992, which was a 10-year high. The value of sales for use in bonded abrasives declined 4%, coated abrasives increased 4%, refractories decreased 24%, tumbling media increased 14%, blasting abrasives increased 5%, polishing cake and buffing compounds decreased 21%, antislip abrasives decreased 21%, polishing abrasives decreased 10%, and all other uses increased 13%. *(See table 12.)*

Prices.—The USBM did not collect data on the prices of various grades of fused aluminum oxide. It did collect data on the value of fused aluminum oxide production. The average value of regular-grade fused aluminum oxide, as reported by producers, was approximately $366 per ton. In 1993, the average value of high-purity fused aluminum was $621. The average value of all grades of fused aluminum oxide in 1993 was $401 per ton. Mineral price quotations in various December issues of trade magazines listed prices for regular-grade fused aluminum oxide of $555 to $660 per ton, while high-purity was quoted at $810 to $938 per ton.

Foreign Trade.—The quantity of exports plus reexports of fused aluminum oxide decreased 8% to 11,019 tons; the value of exports plus reexports increased slightly to $28.5 million. The average value per ton of fused aluminum oxide, exported or reexported, increased 9% to $2,588.

Imports increased about 16% in 1993 to 158,000 tons, and the value of imports increased about 4% to $76.9 million.

Silicon Carbide

Government Programs.—The NDS, as of December 31, 1993, contained 31,508 tons of silicon carbide; the goal was zero. During 1993, the Defense National Stockpile Center of the Defense Logistics Agency disposed of 5,797 tons of silicon carbide. Existing legislation authorizes disposal of all of the silicon carbide.

Production.—During 1993, three firms produced silicon carbide at four plants in the United States and Canada. Production of abrasive-grade material decreased 14% to 38,296 tons. Production of metallurgical-grade silicon carbide decreased about 7% to 36,650 tons. Total production of silicon carbide decreased 11% in 1993 to 74,945 tons.

Consumption and Uses.—Silicon carbide has a number of different end uses in the form of graded grain. The total value of sales of silicon carbide graded grain for all uses decreased 8% in 1993. The total value of sales by individual end use was a mixture of increases and decreases. Sales for use in bonded abrasives were down slightly, coated abrasives were up 3%, refractories increased 8%, tumbling media decreased slightly, blasting abrasive increased 12%, wiresawing abrasive was down 22%, polishing cake and buffing compounds were down 33%, antislip abrasives were up 14%, polishing abrasives were down 24%, metallurgical was up 11%, and all other uses were up 8%. *(See table 12.)*

Prices.—The USBM did not collect price data on the various grades of silicon carbide. Data were available on the value of production of the various grades. The average value per ton of abrasive-grade silicon carbide, as reported by producers, was $539; metallurgical-grade averaged $526; and the average value of all grades was $533. Mineral price quotations in various December issues of trade magazines listed prices for abrasive grade as $900 to $1,425 per ton.

Foreign Trade.—Exports plus reexports of silicon carbide in 1993 were 16,754 tons, a 24% increase compared to that of 1992. While the total value of silicon carbide exported plus reexported increased 31% to $15.8 million, the value per ton increased 6% to $942.

Imports of silicon carbide in 1993 increased 29% in quantity to 115,000 tons, the total value increased 14% to $57.9 million. The average value per ton decreased 23% to $441.

Alumina-Zirconia Oxide

One firm produced fused alumina-zirconia oxide in two plants, one each in the United States and Canada. Abrasive applications accounted for all the production. Publishing production data would disclose company proprietary data. Export and import data were not available.

Metallic Abrasives

Production.—Nine firms produced metallic abrasives in 10 plants in 1993. The quantity and value of steel shot and grit produced decreased about 2% and 6%, respectively. The average value per ton was $389, a 3% decrease compared with that of 1992. Michigan, Pennsylvania, Virginia, and Ohio, in decreasing order of quantity, supplied the production of steel shot and grit.

During 1993, two firms, one in

Michigan and one in New York, reported production of cut wire shot. Production of shot and grit other than steel inclined significantly in 1993, 34% in quantity to 15,389 tons, and decreased 6% in value to $7.7 million. The average value per ton decreased about 30% to $503. *(See tables 13 and 14.)*

Consumption.—The quantity of steel shot and grit sold or used decreased slightly to 202,925 tons, the total value decreased 8% to $79.2 million, and the average value per ton decreased 6% to $390.

The quantity of other shot and grit sold or used increased 31% to 15,855 tons. The value was essentially unchanged at $8.7 million. The average value per ton decreased 24% to $547.

The estimated apparent domestic consumption of all types of metallic shot and grit increased 4% in quantity to 203,555 tons, decreased slightly in total value to $79 million, and decreased 4% in average value per ton to $388. The formula to calculate U.S. estimated apparent consumption is U.S. sold or used plus imports minus exports.

Foreign Trade.—U.S. exports of metallic shot and grit increased 9% to 29,305 tons. The total value of exports decreased 40% to $14.7 million, and the average value per ton decreased 44% to $502.

U.S. imports of metallic abrasives increased 105% in quantity to 26,140 tons, increased about 59% in total value to $14.2 million, and decreased 22% in value per ton to $542.

The United States was a net exporter of metallic abrasives in 1993, a position it has enjoyed for the past 10 years with the exception of 1984.

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[1]All units of measure in this chapter are metric.

[2]American National Standards Institute. Specifications for Grading of Certain Abrasive Grains on Coated Abrasive Products. ANSI B74.18-1977, 37 pp.

[3]———. Specification for Size of Abrasive Grains-Grinding Wheel, Polishing, and General Industrial Uses. ANSI B74.12-1976, 11 pp.

[4]Coes, Jr., L. Abrasive. Springer-Verlag, NY, 1971, 177 pp.

[5]Vogel, H. H., and Barton Mines Corp., Staff. Abrasives. Ch. in Industrial Minerals and Rocks (Nonmetallic Other Than Fuels). AIME, New York, 5th ed., 1983, pp. 21-25.

[6]Thaden, R. E. Abrasives. Ch. in United States Mineral Resources. U.S. Geol Surv. Prof. Paper 820, 1973, pp. 27-33.

[7]Work cited in footnote 4.

[8]Work cited in footnote 5.

[9]Industrial Minerals. No. 318, Mar. 1994, p. 13.

[10]Candler, H. P. Industrial Diamond. A Materials Survey. BuMines IC 8200, 1964, 150 pp.

[11]American National Standards Institute. Specifications for Checking the Size of Diamond. ANSI B74.16-1971 12 pp.

[12]———. Specification for Grading of Diamond Powder in Subsieve Size. ANSI B74.20-1981, 12 pp.

[13]Industrial Diamond Association Inc. 1983 Listing of Members.

[14]Wilson, A. N. Diamonds From Birth to Eternity. Gemological Inst. of Am., 1982, 450 pp.

[15]Works cited in footnotes 9 and 13.

[16]De Beers Consolidated Mines Ltd. Occurrences, Mining and Recovery of Diamonds. Kercim Pres. Ltd., Slough, Bucks, England, 1973, 44 pp.

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[17]Born, W. What Diamond Recovery Should Mean to You. Abrasive Eng. Soc., July-Aug. 1980.

[18]General Electric Co., Specialty Materials Department. Stratapax Drill Blanks. Sales Brochure No. SMD31-451, 8 pp.

[19]Indiaqua. New Polycrystalline Diamond Product Development at DRL. V. 38, 1984/1, p. 125.

[20]Work cited in footnote 14.

[21]Hawkins, B. Diamonds in China. Dep. Mines and Energy Affairs, Republic of South Africa, No. 1/82. July 1982, 10 pp.

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Industrial Diamond. Ch. in Mineral Commodity Summaries, 1993.

Manufactured Abrasives Mineral Industry Surveys, quarterly.

Mineral Facts and Problems, 1985.

TABLE 1
SALIENT U.S. ABRASIVES STATISTICS

Abrasive materials		1989	1990	1991	1992	1993
Production of:						
Natural abrasives:						
Tripoli (crude)	metric tons	105,230	94,390	88,642	84,924	93,943
Value	thousands	$2,537	$3,194	$3,271	$3,256	$3,493
Special silica stone (crude)[1]	metric tons	898	3,709	2,205	1,732	528
Value	thousands	$147	$230	$161	$239	$240
Garnet[2]	metric tons	42,605	47,009	50,860	54,139	43,995
Value	thousands	$4,408	$6,939	$7,534	$4,842	$4,441
Emery	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Staurolite	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Manufactured abrasives[3 4]	metric tons	535,213	514,869	454,572	468,772	447,532
Value	thousands	$227,761	$218,207	$195,635	$208,560	$189,337
Foreign trade (natural and artificial abrasives):						
Exports (value)[5 6]	do.	$260,363	$270,928	$295,743	$351,187	$369,090
Reexports (value)[5 6]	do.	$33,771	$24,545	$24,209	$32,088	$52,200
Imports for consumption (value)[5 7]	do.	$419,084	$512,766	$450,880	$482,134	$529,003

W Withheld to avoid disclosing company proprietary data.
[1]Includes crude material used for producing grindstones, oilstones, whetstones, and deburring media; excludes data on material used for grinding pebbles and tube-mill liners.
[2]"Primary" garnet; denotes the first marketable product and includes crude concentrate.
[3]Includes Canadian production of crude silicon carbide and fused aluminum oxide plus shipments of metallic abrasives by producers.
[4]Excludes U.S. and Canadian production and value of aluminum-zirconium oxide.
[5]Source: Bureau of the Census, U.S. Department of Commerce.
[6]F.a.s.
[7]Customs value.

TABLE 2

U.S. EXPORTS OF ABRASIVE MATERIALS, BY KIND

Kind		1992 Quantity	1992 Value (thousands)	1993 Quantity	1993 Value (thousands)
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	thousand carats	81,474	$119,146	105,233	$136,570
Industrial diamond, natural or synthetic, other	do.	2,920	14,997	1,036	4,982
Natural abrasives, crude	thousand kilograms	2,193	1,741	1,463	1,161
Natural abrasives, other	do.	14,778	13,426	11,613	12,852
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	11,531	27,407	10,719	27,934
Silicon carbide, crude or in grains	do.	13,512	11,844	16,742	15,775
Grinding and polishing wheels and stones:					
Diamond	thousands of items	812	22,973	792	23,811
Polishing stones, whetstones, oilstones, hones, and similar stone	do.	1,969	7,365	1,985	6,758
Wheels and stones, n.e.c.	do.	1,608	7,044	2,280	11,340
Abrasive paper and cloth, coated with natural or artificial abrasive materials	thousand kilograms	14,924	101,096	14,507	113,260
Metallic abrasive: Grit and shot, including wire pellets	do.	26,587	24,147	29,183	14,646
Total[1]		XX	351,187	XX	369,090

XX Not applicable.
[1]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 3

U.S. REEXPORTS OF ABRASIVE MATERIALS, BY KIND

Kind		1992 Quantity	1992 Value[1] (thousands)	1993 Quantity	1993 Value[1] (thousands)
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	thousand carats	2,091	$6,233	1,389	$2,683
Industrial diamond, natural or synthetic, other	do.	2,676	21,730	2,328	44,105
Emery, natural corundum, pumice in blocks	thousand kilograms	163	269	16	196
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	437	935	300	585
Silicon carbide, crude or in grains	do.	35	161	12	8
Grinding and polishing wheels and stones:					
Diamond	thousand items	28	579	39	865
Polishing stones, whetstones, oilstones, hones, and similar stone	do.	31	227	73	431
Abrasive paper and cloth, coated with natural or artificial abrasive materials	thousand kilograms	309	1,784	438	3,260
Metallic abrasives: Short grit, pellets, etc.	do.	349	170	122	68
Total		XX	32,088	XX	[2]52,200

XX Not applicable.
[1]F.a.s.
[2]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF (NATURAL AND ARTIFICIAL) ABRASIVE MATERIALS, BY KIND

Kind		1992		1993	
		Quantity	Value[1] (thousands)	Quantity	Value[1] (thousands)
Silicon carbide, crude	thousand metric tons	83	$36,019	109	$44,574
Aluminum oxide, crude	do.	115	46,310	133	49,342
Abrasives, ground grains, pulverized or refined:					
Silicon carbide	do.	6	14,776	6	13,350
Aluminum oxide	do.	21	27,897	25	27,546
Emery, corundum, flint, garnet, other, including artificial abrasives	do.	21	6,172	31	2,910
Papers, cloths, other materials wholly or partly coated with natural or artificial abrasives	do.	20	132,007	26	155,592
Hones, whetstones, oilstones, polishing stones	thousand items	4	2,505	3	2,394
Abrasive wheels and millstones:					
Burrstones manufactured or bound up into millstones	do.	935	3,890	338	2,870
Solid natural stone wheels	do.	153	796	176	629
Diamond	do.	664	18,918	877	20,624
Abrasive wheels bonded with resins	do.	5,734	29,308	5,050	27,634
Other	do.	(2)	42,204	(2)	50,688
Grit and shot including wire pellets	metric tons	12,779	8,931	26,140	14,156
Diamond, natural and synthetic:					
Natural industrial diamond stones	thousand carats	3,570	21,221	3,281	18,275
Miners' diamond	do.	6,215	23,415	1,924	17,389
Powder and dust, synthetic	do.	86,720	55,739	124,880	69,765
Powder and dust, natural	do.	10,565	12,027	7,952	11,265
Total		XX	[3]482,134	XX	529,003

XX Not applicable.
[1]Customs value.
[2]Quantity not reported.
[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 5

PROCESSED TRIPOLI[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use		1989	1990	1991	1992	1993
Abrasives	metric tons	26,192	24,090	21,239	18,603	19,385
Value	thousands	$3,172	$3,083	$3,382	$2,779	$2,955
Filler	metric tons	63,080	56,468	52,334	57,603	58,877
Value	thousands	$9,185	$11,041	$10,009	$11,326	$12,571
Total quantity[2]	metric tons	89,272	80,558	73,575	76,205	78,262
Total value	thousands	$12,357	$14,124	$13,391	$14,105	$15,526

[1]Includes amorphous silica and Pennsylvania rottenstone.
[2]Data may not add to totals shown because of independent rounding.

TABLE 6

SPECIAL SILICA STONE FINISHED PRODUCTS SOLD OR USED, AS REPORTED BY U.S. PRODUCERS[1]

Year	Quantity (metric tons)	Value (thousands)
1989	377	$5,459
1990	450	6,328
1991	272	3,600
1992	340	4,554
1993	267	3,767

[1]Includes grindstones, oilstones, and whetstones. Excludes grinding pebbles, tube-mill liners, and deburring media.

TABLE 7

U.S. PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1993

Company and location	Type of operation	Product
Arkansas Abrasives, Inc.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Buffalo Stone Corp.:		
Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media and deburring media.
Cleveland Quarries Co.:		
Amherst, OH	Stone cutting and finishing	Grindstones.
Do.	Quarry	Crude silica stone.
Dans Whetstone Cutting Co., Inc.:		
Royal, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
B&J Construction:		
Paron, AR	do.	Do.
Hall's Arkansas Oilstones, Inc.:		
Pearcy, AR	Stone cutting and finishing	Whetstones and oilstones.
Hardrock Mining, Inc.:		
Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media and deburring media.
Hiram A. Smith Whetstone Co., Inc.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Ed Kramer & Sons:		
Baraboo, WI	Crushing and sizing	Deburring media.
Do.	Quarry	Crude silica stone.
Norton Co. Oilstones, Norton Pike Div.:		
Hot Springs, AR	do.	Do.
Littleton, NH	Stone cutting and finishing	Whetstones and oilstones.
Pioneer Whetstone Co. (Blue Mountain):		
Hot Springs, AR	do.	Do.
Taylor Made Crafts:		
Lake Hamilton, AR	do.	Do.
Wallis Whetstone:		
Malvern, AR	Quarry	Crude novaculite.

TABLE 8
GARNET SOLD OR USED, AS REPORTED BY U.S. PRODUCERS

Year	Quantity (metric tons)	Value (thousands)
1989	41,320	$9,768
1990	45,935	11,759
1991	48,051	13,044
1992	46,098	13,049
1993	55,760	15,433

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL DIAMOND, BY COUNTRY

(Thousand carats and thousand dollars)

Country	Natural industrial diamond stones (including glazers' and engravers' diamond, unset) (7102.21.3000 and .4000)				Miners' diamond, natural and synthetic (7102.21.1010 and .1020)				Diamond powder and dust, synthetic (7105.10.0020; .0030 and .0050)				Diamond powder and dust, natural (7105.1011 and .0015)			
	1992		1993		1992		1993		1992		1993		1992		1993	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	118	$240	9	$216	3	$24	270	$165	—	—	26	$19	1	$48	1	$6
Belgium	66	504	96	420	339	5,414	528	6,713	536	$208	383	652	2,280	5,653	1,250	2,734
Canada	(2)	2	—	—	14	100	—	—	198	114	176	139	223	44	10	13
China	46	26	39	34	—	—	—	—	1,738	698	5,142	1,709	138	143	43	35
Germany	(2)	7	(2)	104	6	208	(2)	23	4,758	6,068	11,932	9,691	403	798	101	157
Ghana	617	4,397	236	3,303	11	88	6	300	42	55	32	36	180	475	65	111
Hong Kong	11	9	—	—	1	60	—	—	262	71	48	22	7	80	302	53
India	173	207	76	58	—	—	22	5	11	12	—	—	25	19	34	31
Ireland	79	363	169	536	5,293	6,681	94	269	54,928	35,833	76,394	45,827	3,227	2,090	4,085	5,885
Israel	3	390	32	25	—	—	(2)	15	52	58	15	10	(2)	7	154	49
Japan	7	539	9	82	9	108	2	118	2,275	1,952	3,734	2,664	336	438	132	189
Netherlands	8	2,605	47	2,186	128	1,767	203	2,293	—	—	—	—	—	—	—	—
South Africa, Republic of	25	137	23	81	—	—	(2)	38	340	411	389	111	—	—	3	2
United Kingdom	1,224	8,379	1,564	7,116	318	5,178	422	3,855	2,273	2,052	2,650	2,265	800	672	836	1,447
Zaire	1,130	3,198	960	3,776	77	3,379	115	2,384	31	28	—	—	1,131	517	359	234
Other	63	216	21	338	16	409	262	1,211	19,276	8,180	23,959	6,620	1,812	1,043	577	319
Total[3]	3,570	21,221	3,281	18,275	6,215	23,415	1,924	17,389	86,720	55,739	124,880	69,765	10,565	12,027	7,952	11,265

[1]Customs value.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1989				1990				1991			
	Natural			Synthetic[4]	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[5]	1,165	80	1,245	—	1,060	73	1,133	—	899	62	961	—
Australia	17,540	17,540	35,080	—	17,331	17,331	34,662	—	17,978	17,978	35,956	—
Belarus	—	—	—	—	—	—	—	—	—	—	—	—
Botswana	10,680	4,570	15,252	—	12,150	5,200	17,352	—	11,550	4,950	16,506	—
Brazil	350	150	500	—	600	900	1,500	—	600	900	[e]1,500	—
Central African Republic	334	81	415	—	303	78	381	—	296	82	379	—
China[e]	200	800	1,000	15,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[e 6]	9	3	[7]12	—	9	3	12	—	11	4	15	—
Czech Republic[8]	—	—	—	—	—	—	—	—	—	—	—	—
Czechoslovakia[e 9]	—	—	—	[r]10,000	—	—	—	[r]10,000	—	—	—	[r]10,000
France[e]	—	—	—	4,000	—	—	—	[r]5,000	—	—	—	4,000
Gabon[e]	400	100	500	—	400	100	500	—	400	100	500	—
Ghana[10]	[r]395	[r]99	494	—	[r]520	[r]130	650	—	[r]560	[r]140	700	—
Greece[e]	—	—	—	1,000	—	—	—	1,000	—	—	—	1,000
Guinea[e 6]	137	10	147	—	119	8	127	—	91	6	97	—
Guyana	3	5	8	—	5	13	18	—	6	16	[r]22	—
India	[r]12	[r]3	15	—	[r]15	[r]3	18	—	[r]15	[r]3	18	—
Indonesia[e]	7	25	32	—	7	23	30	—	8	24	32	—
Ireland[e]	—	—	—	60,000	—	—	—	60,000	—	—	—	60,000
Japan[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	30,000
Liberia[e 11]	[7]62	[7]93	[7]155	—	40	60	100	—	40	60	100	—
Namibia	910	20	927	—	750	15	763	—	1,170	20	1,187	—
Romania[e]	—	—	—	[r]5,000	—	—	—	[r]3,000	—	—	—	[r]3,000
Russia[e]	—	—	—	—	—	—	—	—	—	—	—	—
Serbia and Montenegro[12]	—	—	—	—	—	—	—	—	—	—	—	—
Sierra Leone[6]	90	39	129	—	66	12	78	—	160	83	243	—
Slovakia[9]	—	—	—	—	—	—	—	—	—	—	—	—
South Africa, Republic of:												
Finsch Mine	1,600	3,000	4,610	—	1,480	2,700	4,178	—	1,200	2,280	3,483	—
Premier Mine	700	1,520	2,215	—	720	1,600	2,328	—	700	1,550	2,250	—
Venetia Mine	—	—	—	—	20	40	62	—	100	200	303	—
Other De Beers' properties[13]	1,350	530	1,880	—	1,200	460	1,652	—	1,500	400	1,897	—
Other	350	50	411	—	380	100	488	—	400	100	498	—
Total	4,000	5,100	9,116	[e]60,000	[r]3,800	4,900	8,708	[e]60,000	3,900	4,530	8,431	[e]60,000
Swaziland	33	22	55	—	25	17	42	—	34	23	57	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Tanzania	105	45	[e]150	—	60	25	85	—	70	30	100	—
U.S.S.R.[e 14]	11,500	11,500	23,000	[r]120,000	12,000	12,000	24,000	[r]120,000	10,000	10,000	20,000	[r]120,000
Ukraine	—	—	—	—	—	—	—	—	—	—	—	—
United States	—	—	—	W	—	—	—	W	—	—	—	90,000
Venezuela	70	185	255	—	[r]85	[r]248	333	—	102	112	214	—
Yugoslavia[e 15]	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
Zaire	[7]2,663	[7]15,092	17,755	—	[7]2,914	[7]16,513	19,427	—	3,000	14,814	17,814	—
Total	[r]50,665	[r]55,562	106,242	[r]325,000	[r]52,459	[r]58,452	110,919	[r]269,000	[r]51,090	[r]54,737	[r]105,832	[r]423,000

See footnotes at end of table.

TABLE 10—Continued

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1992				1993[e]			
	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[5]	[r]1,100	[r]80	[r]1,180	—	470	30	500	—
Australia	[r]17,750	[r]22,250	[r, e]40,000	—	19,000	23,200	42,200	—
Belarus	—	—	—	[e]30,000	—	—	—	30,000
Botswana	[r]11,160	[r]4,790	[r]15,946	—	12,000	5,000	17,000	—
Brazil[e]	[r]653	[r]665	[r]1,318	—	600	900	1,500	—
Central African Republic	[r]307	[r]107	[r]414	—	307	106	413	—
China[e]	200	800	1,000	15,000	230	850	1,080	15,500
Côte d'Ivoire[e, 6]	11	4	15	—	11	4	15	—
Czech Republic[8]	—	—	—	—	—	—	—	5,000
Czechoslovakia[e, 9]	—	—	—	[r]10,000	—	—	—	—
France[e]	—	—	—	[r]3,500	—	—	—	3,500
Gabon[e]	400	100	500	—	400	100	500	—
Ghana[10]	[r]570	[r]140	[r]710	—	600	150	750	—
Greece[e]	—	—	—	750	—	—	—	1,000
Guinea[6]	90	5	95	—	90	5	95	—
Guyana	[r]13	[r]32	[r, e]45	—	14	36	50	—
India	[r]15	[r]3	18	—	16	3	19	—
Indonesia[e]	6	21	27	—	7	20	27	—
Ireland[e]	—	—	—	60,000	—	—	—	66,000
Japan[e]	—	—	—	30,000	—	—	—	32,000
Liberia[e, 11]	[r, 7]62	[r, 7]93	[r, 7]155	—	60	90	150	—
Namibia	[r]1,500	50	[r]1,548	—	1,100	40	[7]1,139	—
Romania[e]	—	—	—	[r, 7]—	—	—	—	—
Russia[e]	9,000	9,000	18,000	80,000	8,000	8,000	16,000	80,000
Serbia and Montenegro[12]	—	—	—	5,000	—	—	—	5,000
Sierra Leone[6]	[r]200	[r]96	[r]296	—	90	68	[7]158	—
Slovakia[9]	—	—	—	—	—	—	—	5,000
South Africa, Republic of:								
Finsch Mine	1,200	2,250	3,446	—	700	1,300	[7]2,012	—
Premier Mine	740	1,700	2,444	—	500	1,100	[7]1,596	—
Venetia Mine	660	1,200	1,868	—	1,750	3,200	[7]4,969	—
Other De Beers' properties[13]	1,350	500	1,849	—	900	350	[7]1,249	—
Other	450	100	549	—	450	100	550	—
Total	[r]4,400	[r]5,750	[r]10,166	[e]60,000	4,300	6,050	10,324	75,000
Swaziland	36	24	[r]51	—	27	18	45	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000
Tanzania	[r]48	[r]20	[r]68	—	48	20	68	—
U.S.S.R.[e, 14]	—	—	—	—	—	—	—	—
Ukraine	—	—	—	[e]10,000	—	—	—	10,000
United States	—	—	—	90,000	—	—	—	103,000
Venezuela	[r]302	[r]176	[r]478	—	335	200	535	—
Yugoslavia[e, 15]	—	—	—	—	—	—	—	—

See footnotes at end of table.

TABLE 10—Continued

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1992				1993[e]			
	Natural			Syn-thetic[4]	Natural			Syn-thetic[4]
	Gem[2]	Indus-trial	Total[3]		Gem[2]	Indus-trial	Total[3]	
Zaire	r 7 8,934	r 7 4,567	r 13,501	—	9,500	5,500	15,000	—
Total	r 56,757	r 48,773	r 105,521	r 419,250	57,205	50,390	107,620	456,000

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Table includes data available through June 8, 1994. Total natural diamond output (gem plus industrial) for each country actually is reported, except where indicated by a footnote to be estimated. In contrast, the detailed separate production data for gem diamond and industrial diamond are U.S. Bureau of Mines estimates except Brazil (1989-90), and Central African Republic (1989-90), for which source publications give details on grade as well as totals. The estimated distribution of total output between gem and industrial diamond is conjectural, and for most countries, is based on the best available data at time of publication.

[2]Includes near-gem and cheap-gem qualities.

[3]Natural gem and industrial data may not add to totals shown because of independent rounding.

[4]Includes all synthetic diamond production.

[5]Figures do not include smuggled artisanal production.

[6]Figures are estimates based on reported exports and do not include smuggled diamonds.

[7]Reported figure.

[8]Formerly part of Czechoslovakia.

[9]Dissolved on Dec. 31, 1992.

[10]"Gem" vs. "Industrial" diamond breakdown has been revised to reflect the value of near-gem material, classified as industrial prior to 1991, but which was ultimately being sold for well above industrial prices.

[11]Data for 1989 do not include smuggled production. Data for 1990-92 are estimates of artisanal production, likely smuggled out of Liberia, but which are comparable to that hitherto reported to the Government.

[12]Formerly part of Yugoslavia.

[13]Other De Beers' Group output from the Republic of South Africa includes Kimberley Mines, Koffiefontein Mine, and Namaqualand Mines.

[14]Dissolved in Dec. 1991.

[15]Dissolved in Apr. 1992.

TABLE 11

CRUDE ARTIFICIAL ABRASIVES MANUFACTURERS IN 1993

Company	Location	Product
The Exolon-Esk Co.	Hennepin, IL	Silicon carbide.
Do.	Thorold, Ontario, Canada	Fused aluminum oxide (regular).
General Abrasives Triebacher, Inc.	Niagara Falls, NY	Fused aluminum oxide (regular and high-purity).
Do.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular) and silicon carbide.
Praxair Surface Technologies, Inc.	Indianapolis, IN	Fused aluminum oxide (high-purity).
Saint-Gobain/Norton Industrial Ceramics Corp.	Huntsville, AL	Fused aluminum oxide (high-purity) and aluminum-zirconium oxide.
Do.	Worcester, MA	General abrasive processing.
Do.	Chippawa, Ontario, Canada	Fused aluminum oxide (regular and high-purity) and aluminum-zirconium oxide.
Do.	Shawinigan, Quebec, Canada	Silicon carbide.
Superior Graphite Co.	Hopkinsville, KY	Do.
Washington Mills Electro Minerals (Canada) Corp.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).
Washington Mills Electro Minerals (US) Corp.	Niagara Falls, NY	Fused aluminum oxide (high-purity).
Washington Mills Ltd.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).

TABLE 12

END USES OF CRUDE SILICON CARBIDE AND ALUMINUM OXIDE (ABRASIVE GRADE) IN THE UNITED STATES AND CANADA, AS REPORTED BY PRODUCERS

Use	1992			1993		
	Quantity (metric tons)	Value (thousands)	Yearend stocks	Quantity (metric tons)	Value (thousands)	Yearend stocks
SILICON CARBIDE						
Abrasives	44,673	$23,954	2,956	38,296	$20,647	1,448
Metallurgical	39,611	19,510	5,258	36,650	19,284	3,092
Refractories and other	W	W	—	W	W	—
Total[1]	84,283	43,464	8,214	74,945	39,931	4,540
ALUMINUM OXIDE						
Regular: Abrasives and refractories	142,545	56,284	6,388	132,403	48,482	14,392
High purity	24,231	14,388	1,134	21,276	13,220	1,256
Total[1]	166,777	70,672	7,522	153,680	61,700	15,648

W Withheld to avoid disclosing company proprietary data; included with "Metallurgical."

[1]Data may not add to totals shown because of independent rounding.

TABLE 13

U.S. PRODUCERS OF METALLIC ABRASIVES IN 1993[1]

Company	Location	Product (shot and/or grit)
Alco Tech Wire Co.	Traverse City, MI	Cut wire.
Abrasive Materials, Inc.	Hillsdale, MI	Cut wire, steel.
Barnsteel Abrasives	Butler, PA	Annealed iron and steel.
Chesapeake Specialty Products	Baltimore, MD	Steel.
Durasteel Abrasive Co.	Pittsburgh, PA	Do.
Ervin Industries, Inc.	Adrian, MI	Do.
Do.	Butler, PA	Do.
Metaltec Steel Abrasives Co.	Canton, MI	Do.
National Metal Abrasive Co.	Wadsworth, OH	Do.
Pellets, Inc.	Tonawanda, NY	Cut wire.
The Platt Brothers, Inc.	Waterbury, CT	Other types.
Premier Shot Co.	Cleveland, OH	Cut wire shot.
The Wheelabrator Co.	Bedford, VA	Steel.

[1]Excludes reclaimed materials.

TABLE 14
ANNUAL PRODUCTION, SHIPMENTS, AND PLANT CAPACITIES FOR METALLIC ABRASIVES IN THE UNITED STATES, BY PRODUCT[1]

Product	Production		Shipments		Capacity[2]
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	(metric tons)
1992:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	202,325	$81,330	205,623	$85,700	235,705
Other[3]	11,477	8,270	12,089	8,725	XX
Total[4]	213,802	89,601	217,712	94,424	XX
1993:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	197,547	76,832	202,925	79,216	247,440
Other[3]	15,389	7,746	15,855	8,672	XX
Total	212,936	84,578	218,780	87,888	XX

W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.

[1]Excludes secondary (recycle) producers.

[2]Total quantity of the various types of metallic abrasives that a plant could have produced during the year, working three 8-hour shifts per day, 7 days per week, allowing for usual interruptions, and assuming adequate fuel, labor, and transportation.

[3]Includes cut wire, aluminum, stainless steel shot, and items indicated by symbol W.

[4]Data may not add to totals shown because of independent rounding.