The industrial sand and gravel industry continued to be concerned with safety and health regulations and environmental restrictions in 2017, especially those concerning crystalline silica exposure. The U.S. Occupational Safety and Health Administration finalized new regulations to further restrict exposure to crystalline silica at mine sites and other industries that use it. Phased implementation of the new regulations are scheduled to take effect from 2017 through 2021.

IODINE

by Emily K. Schnebele, National Minerals Information Center, U.S. Geological Survey

In 2017, iodine was produced from brines in the United States by three companies operating in Oklahoma. Domestic production data for iodine were withheld to avoid disclosing company proprietary data. However, the United States was one of the three top producers in the world along with Chile and Japan. World production of iodine in 2017, excluding the United States, was estimated to be about 31 kt (34,000 st) compared with 32.5 kt (35,800 st) in 2016. Excluding the United States, Chile accounted for about 65 percent of world production in 2017.

Consumption

Globally, iodine and its compounds were primarily used in X-ray contrast media, pharmaceuticals, liquid crystal displays (LCDs) and iodophors, in descending order of quantity consumed. Other applications of iodine include animal feed, biocides, food supplements and nylon. U.S. consumption of iodine in 2017 was estimated to be 4.5 kt (5,000 st), essentially unchanged from the 4,530 t (5,000 st) consumed in 2016.

Prices

The spot price of crude crystal iodine, 99.5 percent minimum purity, in 50 kg drums, as reported by Industrial Minerals ranged from $18.50 to $21/kg at the beginning of 2017, increasing throughout the year to range from $22 to $24/kg in December. However, iodine prices were still considerably lower than the historically high levels of $65 to $85/kg in late 2012 and early 2013.

Foreign trade

In 2017, U.S. imports of crude iodine were 4,180 t (4,607 st), a 3 percent decrease from the 4,320 t (4,761 st) imported in 2016. The average cost, insurance, and freight value of crude iodine imports in 2017 was $19.55/kg. Chile was the leading source of crude iodine imports into the United States, accounting for 87 percent of the total quantity imported. Exports of crude iodine increased 18 percent to 1,230 t (1,355 st) compared with 1,050 t (1,157 st) in 2016. The primary recipients of U.S. exported crude iodine in 2017 were Germany (49 percent) and Canada (23 percent).

Outlook

Iodine consumption will likely follow market demand for medical applications and LCDs as these are the primary consuming markets of iodine and iodine derivatives. Iodine prices in the near future will likely be influenced by the amount of production from Chile. As the world’s largest supplier, production from Chile greatly affects global iodine supply.

KYANITE, ANDALUSITE AND SILLIMANITE

by William L. Lassetter Jr., Virginia Department of Mines, Minerals and Energy

The naturally occurring polymorphic minerals kyanite, andalusite and sillimanite have the same chemical formula, Al₂SiO₅, containing up to 63 percent Al₂O₃, and are valued in the manufacture of high-alumina refractories and ceramics. Although identical in chemical composition, the minerals vary slightly in their crystal structures and physical properties. Mullite is a closely related mineral with the chemical formula Al₆Si₂O₁₃ that occurs rarely in nature, but can be produced synthetically by sintering or fusing kyanite or any of the other related polymorphs. Together, these minerals are used in the manufacture of refractories that require chemical and thermal shock resistance, and volume stability. Due to the qualities of hardness, durability and chemical resistance, exceptional specimens of kyanite, andalusite and sillimanite are often marketed in the gemstone and jewelry industry.

Geology and economic deposits

Kyanite, andalusite and sillimanite are common constituents in metamorphic rocks, typically making up a percent or two of the mineral composition of peraluminous gneisses and schists. Often, the predominance of one of these minerals over the other polymorphs in a particular metamorphic rock setting reflects the different pressure and temperature conditions under which each mineral forms. In medium- to high-grade metamorphic rocks formed under relatively low-pressure conditions, andalusite typically predominates. These rocks may include hornfels and other thermally altered pelitic rocks within contact metamorphic aureoles. In regional metamorphic terrains formed under high pressure...
and temperature conditions, sillimanite is often the predominant polymorphic mineral. Kyanite, characterized by the densest crystal structure of the polymorphs, is most often associated with metamorphic rocks formed under high pressure and mid to lower temperatures.

Economic deposits are found in a variety of settings that include massive segregations in metamorphosed aluminous sediments, stratiform replacements within quartzose rocks associated with meta-volcanic strata, mineralized quartz veins and pegmatites, and in residual soils, sediments and concentrated placer deposits. In the United States, economic and subeconomic concentrations of kyanite, andalusite and sillimanite occur in the Appalachian regions of Georgia, North Carolina, South Carolina and Virginia. Other known geologic occurrences are in Alaska, California, Idaho, Nevada, and New Mexico. Significant occurrences of kyanite and sillimanite are found in heavy mineral sand deposits in Florida. Outside of the United States, these minerals are mined in Australia, Brazil, Canada, China, France, India, Kenya, Nigeria, Norway, Peru, Russia, South Africa, Ukraine and Zimbabwe.

**Mineral production**

Global production figures for kyanite and related minerals are rough estimates at best. Annual production figures are often held as proprietary information by mining companies and reliable estimates of output in many producing countries are often not available. Nevertheless, the U.S. Geological Survey (USGS) estimated global production in 2017 to be more than 385 kt (424,000 st) including about 180 kt (198,000 st) of andalusite produced in South Africa, 90 kt (99,000 st) of kyanite and calcined kyanite from the United States, 75 kt (83,000 st) of combined sillimanite and kyanite from India, and 40 kt (44,000 st) of andalusite from Peru (Tanner, 2018). For comparison, the British Geological Survey (BGS) estimated global production in 2016 to be about 509 kt (561,000 st), including combined minerals mined in Brazil, France, India, Madagascar, Nepal, South Africa and the United States (Brown et al., 2018).

Kyanite Mining Corp. (KMC), a privately owned company based in Dillwyn, VA, remains the world’s largest producer of high-grade kyanite (>57 percent Al₂O₃, <0.75 percent Fe₂O₃) and calcined kyanite (mullite). The company mines kyanite-bearing quartzites that occur in the volcanic rocks of the Chopawamsic Formation in the central Virginia Piedmont region. In the vast resources located at Willis Mountain, the host quartzite rock contains 10 to 40 percent kyanite. Current surface mining operations and processing facilities are located in eastern Buckingham County near the town of Dillwyn. In the annual production report to the Virginia Department of Mines, Minerals and Energy (VDMME), KMC reported about 91 kt (100,000 st) of combined kyanite and calcined kyanite in 2017. This is about a 15-percent increase over the production reported in 2016. KMC stated the annual production capacity at the Virginia operations is about 150 kt (165,000 st) for commercial-grade kyanite concentrates and calcined kyanite. Current production can be readily increased to meet demand. The company markets a range of milled kyanite and mullite products that are shipped by truck, rail and air to domestic customers and to port facilities for delivery to international customers. Exports currently account for about 50 percent of KMC’s sales.

Resco Products Inc.’s Piedmont Minerals Division, located in Hillsborough, NC, mines deposits of massive pyrophyllite (AlSi₂O₅(OH)) containing natural mixtures of andalusite, topaz and quartz. The mineralized zones were formed in structurally controlled, hydrothermally altered metavolcanic rocks of the Carolina slate belt geologic terrane. The deposits of high-purity silica and alumina provide the materials for a range of monolithic refractories, high-alumina brick, and specialty mineral products serving the foundry and ceramic industries.

Imerys Refractory Minerals is the world’s leading producer of industrial andalusite and calcined products for refractories, with major markets located in Western Europe, North America and emerging market countries. In 2017, the company produced andalusite in France and South Africa. The Kerphalite Mine, located in the Glomel region of France, has been in operation since the 1960s. It recovers andalusite from deeply weathered Ordovician-age schists proximal to granitic rocks of the Armorican Massif. Imerys markets andalusite products from this mine under the trademarked name Kerphalite. In South Africa, surface mining operations in Limpopo Province include the Annesley Mine near Burgersfort, and the Rhino Mine near Thabazimbi. The Krugerspost Mine at Lydenburg remained closed in 2017. These deposits were formed in pelitic rocks of the Pretoria Group within the contact metamorphic aureole of the Bushveld Igneous Complex. Imerys markets a variety of fine-, medium- and coarse-grade products under the trademarked names Durandal, Randalusite and Purusite. Annual production tonnages and capacities for the individual Imerys mine sites are not readily available. In the annual financial report for 2017, Imerys reported total mineral reserves estimates for “minerals for refractories” (proven and probable at worldwide operations) of about 11 Mt (12 million st). Estimated total mineral resources (measured, indicated, inferred) for the same product were reported to be about 25 Mt (27.5 million st).

Since 2003, Andalusite Resources (Pty) Ltd. has produced milled and run-of-mine andalusite products from surface mine operations at the Maroeloesfontein

www.miningengineeringmagazine.com
Mine located near Thabazimbi in Limpopo province, South Africa. The deposit is situated on strike and to the southwest of Imerys’s Rhino Mine. Andalusite Resources reported annual production capacity in excess of 70 kt (77,000 st), with reserves amounting to about 100 years of mining at that annual rate. The company globally markets a range of fine- and medium-grade products under the trade name Marlusite with average alumina content stated to be >57 percent Al₂O₃.

In northern Peru, Andalucita S.A. extracts andalusite from alluvial sediments in surface mining operations near the port of Paita. The company markets products ranging from fine (0-1 mm) premium grade andalusite (58.5 percent Al₂O₃, <0.75 percent Fe₂O₃) to coarse (3-6 mm) premium grade (58 percent Al₂O₃, <1 percent Fe₂O₃) in 25-kg (55-lb) bags up to bulk quantities. The company reported more than 120 Mt (132 million st) of proven mineral reserves.

India continues to increase capacity in the production of sillimanite, kyanite and andalusite minerals. The Indian Bureau of Mines reported estimated total sillimanite resources of about 70 Mt (77 million st), of which about 73 percent is classified as granular high-grade material contained in coastal sediments. During 2016-2017, 68 kt (75,000 st) of sillimanite were produced at four operations located in the states of Andhra Pradesh, Odisha, Kerala and Maharashtra. About 21 percent was exported, mainly to China, Nepal, Japan and Western Europe. The bureau reported about 105 Mt (116 million st) of kyanite resources in the country, of which less than 2 percent is classified as medium- to high-grade. During 2016-2017, five mines located in the states of Maharashtra and Karnataka reported total production of about 3 kt (3,300 st) of kyanite (>40 percent Al₂O₃), these Less than 5 percent of the total kyanite product was exported, mainly to Greece. Estimated andalusite resources, classified as reconnaissance category, stand at about 28 Mt (31 million st), but there has been no reported production of the mineral since 1988.

Consumption
About 90 percent of kyanite, andalusite, sillimanite and mullite sold worldwide is used in the manufacture of refractories and ceramic products. Refractories used in the steel-manufacturing industries may account for as much as 70 percent of the consumption of these minerals. These industries require high-temperature refractory linings for metallurgical furnaces and other high-performance heat and corrosion resistant materials. Refractory products include monolithics, firebrick, mortars, kiln furniture and investment casting shell molds.

In the steel and foundry industries, as well as other metallurgical and glass applications requiring extreme durability, temperature and corrosion resistance, mullite and calcined kyanite products are often used exclusively. Other important end products include glazes and chamotte for porcelain and sanitary ware, electrical insulators, heating elements, ceramic tiles, brake shoes and spark plugs.

Prices
Sale prices for imported and exported minerals vary depending on many factors including quantity, grade and purity, particle (mesh) size, packaging, monetary exchange rate, source and destination. Compared to relatively weak demand for refractories during much of 2016, reported sales during 2017 increased slightly in most regions of production. Export sales unit prices reported by the U.S. Census Bureau indicate relatively stable price ranges throughout the year, averaging about $350/t ($317/st) for kyanite, sillimanite, andalusite, including calcined minerals. The U.S. Geological Survey reported average prices of $270/t ($245/st) for kyanite concentrate produced in the United States, $420/t ($381/st) for calcined kyanite from the United States and $340/t ($308/st) for andalusite from South Africa. The estimated export price of sillimanite (56-60 percent Al₂O₃) f.o.b. from India in 2016-2017 averaged about $121/t ($110/st).

Trends and outlook
The performance of the global steel industry as measured by steel output has been a reliable indicator of the demand for refractories and the raw minerals used in their manufacture. The World Steel
Association reported global crude steel production in 2017 reached 1,691.2 Mt (1,864.2 million st), up by about 5.3 percent over the previous year and a new annual record high. For the United States, this is good news for refractory minerals producers. Exports of combined kyanite, sillimanite, andalusite and calcined minerals also reached a record annual high in 2017, about 42.4 kt (46,700 st) (Fig. 1). Indeed, the growth trend of U.S. exports of these minerals since 2000 is highly correlated ($r = 0.86$) with global steel production over the same period.

The outlook for the global steel industry in 2018-2019 is cautiously positive with annual growth in demand predicted in the 1-2 percent range. Positive demand for refractories will likely continue in Asia, North America and Western Europe. There are also numerous market growth opportunities in the emerging and developing economies in Brazil, India and Russia. The recent implementation of new environmental protection measures in China has resulted in disruptions to supplies of alumina and bauxite among other raw materials used for the manufacture of refractories. This has forced industries in Asia to look for alternatives. If the developed economies continue along the present pathway toward full recovery following the Great Recession, opportunities are likely to abound for expanding refractory markets, especially in the steel production, construction and infrastructure development sectors. (References are available from the author.)

**LITHIUM**


In 2017, estimated world lithium production (excluding production in the United States) was about 43 kt (47,000 st) of lithium recovered from minerals and brines, a 13 percent increase from 2016. Estimated world lithium consumption was about 42 kt (46,000 st) of lithium contained in minerals and compounds, a 13 percent increase from 2016. Estimated U.S. consumption was about 3 kt (3,300 st) of contained lithium, rounded to one significant digit to avoid disclosing company proprietary data. The United States was thought to rank fourth in consumption of lithium globally but was the leading producer of value-added lithium materials. One company, Albemarle Corp., produced lithium compounds from domestic brine resources near Silver Peak, NV.

Worldwide lithium production capacity was estimated to be 64 kt (70,500 st) in 2017, with capacity utilization estimated to be 67 percent. Despite available capacity, spot lithium carbonate prices in China in 2017 ranged from $15,000 to $24,000/t ($13,000 to $22,000/st) owing to a tight supply of spodumene imported from Australia. The rest of the world experienced more modest spot price increases owing to availability from more diversified sources of lithium. *Industrial Minerals* reported an annual average U.S. lithium carbonate price of $13,900/t ($12,600 st).

U.S. imports of lithium compounds in 2017 were 18 kt (20,000 st) (gross weight), an increase of 7 percent compared with 2016. Import sources of lithium chemicals were Argentina, 55 percent; Chile, 38 percent and others, 7 percent. Exports of lithium compounds from the United States were 11.7 kt (12,900 st), an increase of 30 percent from 2016. About 88 percent of all U.S. exports of lithium compounds went to Japan, Germany and Canada, which received 7.3 kt (8,000 st); 2.3 kt (2,500 st) and 774 t (853 st), respectively.

The two dominant sources of lithium are brines and hard rock mineral concentrates. Essentially the same lithium compounds can be produced from either type of deposit. However, owing to typically lower production costs, brines became the principal source for lithium compound production at the end of the 1990s. During the past several years, however, owing to growing lithium mineral concentrate demand from China’s chemical companies (where the concentrate is converted to battery-grade lithium carbonate and lithium hydroxide), mineral-sourced lithium has regained market share and was estimated to account for one-half of the world’s lithium supply in 2017. Globally, ceramic and glass applications also use mineral concentrate feed. The lithium content of the minerals added to the ceramics and glass melt reduces the melting temperature and viscosity and increases the resistance to thermal shock; other constituents of the concentrates provide other important glass components. Potential additional sources of lithium include geothermal brines, hectorite clay, jadadite and oilfield brines.

Chile has been a global leader in the production of lithium carbonate since 1997, the year that it surpassed the United States. Albemarle and Sociedad Química y Minera de Chile S.A. (SQM) operated lithium brine facilities on the Salar de Atacama in the Andes Mountains. Albemarle produced lithium carbonate and lithium chloride, and SQM produced lithium carbonate and lithium hydroxide at plants in Antofagasta. In Argentina, FMC Corp. produced lithium carbonate and lithium chloride from brines from the Salar de Olaroz in Jujuy Province.

Australia led the world in lithium production in 2017. Talison Minerals [jointly owned by China’s