Production and consumption

Based on statistics released by the U.S. Geological Survey (2023 Mineral Commodity Summary), domestic clay production in 2022 was estimated at 26 Mt for a total market value of $1.7 billion, with approximately 120 companies operating mines in 38 states. Kaolin minerals accounted for about 4.6 kt, or about 17.7 percent of all clay materials recovered in the United States. One-half of the total kaolin produced (about 52 percent) went into development of coatings, fillers, extenders and binders, while about 25 percent was used in ceramic products. Large revenue generated by paper production has been attributed to continued economic and cultural impacts of the COVID-19 pandemic: for example, increasing consumer demand for packaging, such as for food deliveries.

Exports and imports

In 2022, the United States exported about 2.1 Mt of kaolin minerals to Mexico, China and Japan (listed in descending order of tonnage; USGS statistics). Compared to 2021, the total clay and shale exports decreased by 4 percent. This decline has been explained by a decrease in product exported to Belgium, India and Germany. By comparison, in 2022 only 0.17 Mt of kaolin was imported into the United States. In total, kaolin exports accounted for $53.5 million, and imports $903,000, resulting in a positive U.S. trade balance of $52.6 million.

Trends and outlook

Academic research showed that the annual global kaolin market was approximately $4.41 billion before the end of 2022 and is projected to reach $5.87 billion by 2030. According to the same study, growth is primarily driven by the rising demand for kaolin used in the paint, plastic, paper and ceramic industries. Its high silica and aluminum contents can be utilized in the production of paint, a cheaper alternative to titanium dioxide. More cost-effective and chemically inert kaolin pigment may also reduce environmental burdens. *References are available from the author.*

KYANITE, ANDALUSITE AND SILLIMANITE

by David W. Hawkins, Virginia Department of Energy, Geology and Mineral Resources Program

The sillimanite minerals group includes the naturally occurring polymorphic minerals kyanite, andalusite and sillimanite. These minerals share the same chemical composition (Al_2SiO_5) but have differences in their respective physical, thermodynamic and crystalline structure properties. The high alumina content (more than 60 percent Al_2O_3), thermal and volumetric stability of these minerals make them useful for refractory applications, metallurgy, investment casting molds, glass manufacturing and ceramics. Additionally, high-quality samples of these sillimanite minerals have a market for use as gemstones.

Geology and economic deposits

Kyanite, andalusite and sillimanite are accessory minerals in some high-grade metamorphic rocks. Kyanite forms under relatively high pressure and low to high temperature conditions, andalusite forms under relatively low pressure and low to moderate temperature conditions, and sillimanite forms under low to moderate pressure and high temperature conditions. Deposits may occur within thermally altered rocks associated with contact metamorphism, such as hornfels. Alumina enrichment of silica-rich metasedimentary and metavolcanic rocks via hydrothermal alteration is also a source of stratiform replacement deposits. Sillimanite may occur within mineralized quartz veins and pegmatites. Additionally, these minerals may occur as paleo and modern heavy mineral beach and stream placers.

Economic and subeconomic concentrations of kyanite, andalusite and sillimanite occur in the Appalachian regions of the Southeastern United States. Other known localities for occurrences include Alaska, California, Florida, Idaho, Nevada and New Mexico. Other economic occurrences outside of the United States include Australia, Brazil, Cameroon, Canada, China, Finland, France, India, Ireland, Kenya, Madagascar, Nigeria, Norway, Peru, Russia, South Africa, Spain, Ukraine and Zimbabwe.

Industrial properties and uses

The unique thermodynamic properties of these refractive minerals provide resistance to thermal shock and corrosion, and volumetric stability during high-heat intensive manufacturing processes. The sillimanite group minerals convert to mullite ($3Al_2O_3{\cdot}2SiO_2$) and silica at temperatures ranging from 1,250 to 1,650 °C at predictable stable volumes. Pure mullite may have up to 72 percent Al_2O_3 content. Synthetic mullite has a melting point of about 1,840 °C, which contributes to highly resistant ceramic products. Up to 70 percent of mined sillimanite minerals are used in steel and iron manufacturing annually, so the production of iron and steel is a good proxy of mineral production trends at the global scale. Approximately 30 percent of these minerals are used to produce ceramics, glass, nonferrous metals and cement. Other refractory uses include insulating brick, firebrick, refractory concrete, kiln furniture, mortar and gunning mixes. Additional end products include brake shoes and pads, abrasive

products, electrical insulators, additives and fillers. Kyanite has recently been used to filter aluminum slag and impurities during the production of aluminum cans.

Mineral production

Globally, the supply of sillimanite group minerals is primarily sourced from the United States, France, India, Peru and South Africa. Although refractory minerals are mined in other countries such as China, Australia, Madagascar and Nepal, production data are not readily available. Annual world production estimates reported by the U.S. Geological Survey (USGS) from 2017 to 2021 averaged approximately 357 kt. Global production in 2022 was estimated at 368 kt and included 160 kt of andalusite from South Africa, 86 kt of kyanite and calcined kyanite from the United States, 65 kt of andalusite from France, 42 kt of andalusite from Peru, and 15 kt of combined sillimanite and kyanite from India (not including reclassified beach deposits). The 2022 global production total is based on preliminary estimates by the USGS and production data from the Virginia Department of Energy's Mineral Mining Program. It represents an increase of approximately 3 percent over the previous five-year average (2017-2021), but production remained lower than 2021 levels.

Kyanite Mining Corp. (KMC), located in central Virginia, is the world's largest producer of industrial-grade kyanite and mullite under the trademark names Virginia Kyanite and Virginia Mullite, respectively. Ore deposits are extracted at KMC's Willis Mountain and East Ridge mine sites, located near Dillwyn, VA. The geology consists of kyanite quartzite associated with a sequence of interlayered felsic and mafic metavolcanic strata of Ordovician age. Each mine site is located on a resistant topographic ridge along opposing limbs of the Whispering Creek Anticline. KMC has operated surface mines and processing facilities since 1945 and produces and markets a range of milled kyanite and calcined kyanite (more than 55 percent Al_2O_3, less than 0.85 percent Fe_2O_3) products that are shipped mainly by truck to domestic customers and port facilities for delivery to international customers. Ore-grade material contains 10 to 40 percent kyanite, averaging about 25 percent.

In 2022, KMC reported production of approximately 86 kt of combined kyanite and mullite product. Annual production capacity at the Virginia operations is about 130 kt for commercial-grade kyanite concentrates and up to 39 kt for calcined kyanite per permit specifications and demand. In 2022, KMC received a statewide reclamation award given jointly by the Virginia Department of Energy's Mineral Mining Program and the Virginia Transportation Construction Alliance. The award acknowledges KMC's commitment to environmental stewardship and accomplishments in reclamation of the multiphased East Ridge Reclamation site, where refuse had been placed since 1993.

Resco Products Inc. (Piedmont Minerals Division) has mined andalusite from an andalusite-pyrophyllite ($AlSi_2O_5(OH)$)-sericite deposit to produce high-alumina firebrick and other specialty foundry and ceramic products in Hillsborough, NC. The mineral deposit formed in hydrothermally altered and structurally controlled andesitic to dacitic metavolcanic rocks that are part of the Proterozoic-age Carolina terrane.

Globally, France, South Africa and Peru produce the largest amount of industrial-grade andalusite. Imerys Group mines andalusite from the Brittany region of France at its Kerphalite Mine in Glomel. It is the leading producer of andalusite, with operations in France and South Africa. The source of the andalusite near Glomel, France is highly weathered Ordovician-age schists adjacent to granitic rocks of the Armorican Massif. Imerys Group mines andalusite from the Rhino Mine in the Limpopo Province in South Africa. Mineral deposits are hosted in highly weathered pelitic rocks of the Pretoria Group associated with contact metamorphic rocks of the Bushveld Igneous Complex. Production statistics for 2022 are not readily available for these mine sites. Andalusite Resources (Pty) Ltd. began mining operations in 2001 at the Maroelasfontein Mine, located near Thabazimbi, in the Limpopo Province, South Africa. Additional details have not been made available for the status of andalusite production for the company since 2019. Andalucita S.A. has been recovering andalusite since 2009 in northern Peru, with an estimated production capacity of 50 kt as of 2018.

India is the primary source for the global supply of sillimanite. The Indian Bureau of Mines has estimated total resources of more than 70.2 Mt of sillimanite, which includes about 6.5 to 7.2 Mt in the reserves category. Upward of 73 percent of the sillimanite resources occur in heavy mineral sand placers along India's modern beaches. Production statistics for sillimanite, kyanite and andalusite are not available for 2021 or 2022. The production estimate for 2019-2020 was 13.2 kt from three mines within the state of Maharashtra. Trimex Sands Pvt Limited carries out mining and mineral separation activities in the Srikurman deposit in Srikakulam, in the state of Andhra Pradesh, with capacity to produce 50 kt/a of sillimanite. Sillimanite is also mined in the states of Odisha and Kerala, in association with other heavy minerals. The Indian Bureau of Mines has estimated there is approximately 105 Mt of kyanite resources in the country, with medium- to high-grade deposits occurring at less than two percent of these resources. Between 2019 and 2020, kyanite production was reported at 3.5 kt from three operations within the states of Karnataka and Maharashtra. Andalusite production has not been reported since 1988.

Foreign trade and prices

Prices of imported and exported mineral commodities are dependent upon multiple factors that vary annually such as grade and purity, quantity, particle (mesh) size, packaging, monetary exchange ranges, source and destination. In 2022, the U.S. Census Bureau reported global exports of approximately 52 kt of kyanite and 26 kt of mullite. Kyanite was valued at $383/t, up from $369/t in 2021, and mullite was valued at $509/t, also an increase from $430/t in 2021. According to the U.S. Census Bureau, imports of sillimanite minerals to the United States were estimated at 7.6 kt in 2022, up from the previous year.

Trends and outlook

The market demand for sillimanite minerals is typically associated with the global steel manufacturing industry, as this industry predominantly utilizes refractory mineral products. The World Steel Association estimated that global steel production decreased approximately 4 percent from 2021 levels to 1,885 Mt for 2022. China produced the most steel in 2022 (1,018 Mt), equivalent to 54 percent of the global output. The United States was the fourth largest producer of steel in 2022 at 80.5 Mt, down 6 percent from the 2021 production level. Countries of the European Union produced 136.2 Mt of steel in 2022, down 11 percent from the 2021 level.

The decrease in steel production was likely influenced by multiple factors, including but not limited to, the ongoing Russia-Ukraine war, COVID-19 related restrictions, supply-chain disruptions, and increased inflation costs. In the United States, the push for vehicle electrification and increased manufacturing, increased urban development, and funds from the Infrastructure Investment and Jobs Act will likely bolster construction and improvement projects and result in a low to medium increase in demand for steel. Due to the Russia-Ukraine war, increased costs for raw materials and transportation, there remains uncertainty for significant growth in the refractory minerals market in Europe, while demand for these materials is likely to continue in North America, Asia and Africa. *Source citations available from the author on request.*

LIME

by L.E. Apodaca, National Minerals Information Center, U.S. Geological Survey

In 2022, all commercially produced lime in the United States was manufactured from limestone or dolomite, but lime also can be produced from a variety of similar carbonate materials, such as aragonite, chalk, coral, marble and seashells, if they are of high chemical purity. The term lime in this report refers to high-calcium and dolomitic quicklime, their hydroxide (hydrated) forms and dead-burned dolomite.

In the United States, most lime (about 80 percent) is produced as quicklime. Hydrated lime (also called slaked lime) is a dry calcium hydroxide powder made from reacting quicklime with a controlled amount of water in a hydrator. Slaked lime is widely used in aqueous systems as a low-cost alkali to neutralize or balance acidity. Dead-burned dolomite is the primary form of lime used in refractories.

Production and consumption

In 2022, an estimated 17 Mt of quicklime and hydrate were produced (excluding independent commercial hydrators), essentially unchanged from that in 2021. At year end, 28 companies were producing lime, which included 18 companies with commercial sales and 10 companies that produced lime strictly for internal use (for example, sugar companies). These companies had 73 primary lime plants (plants operating quicklime kilns) in 28 states and Puerto Rico. Five of these 28 companies operated only hydrating plants in nine states. In 2022, the five leading U.S. lime companies produced quicklime or hydrate in 22 states and accounted for about 79 percent of total U.S. lime production. Principal producing states were, in alphabetical order, Kentucky, Missouri, Ohio and Texas. The United States was the world's second-ranked lime producer in the world after China.

Apparent consumption at 17 Mt was estimated to be essentially unchanged from that in 2021. Major markets for lime were, in descending order of consumption, steelmaking, chemical and industrial applications (such as the manufacture of fertilizer, glass, paper and pulp, and precipitated calcium carbonate and in sugar refining), flue-gas treatment, construction, water treatment, and nonferrous-metal mining.

Foreign trade

Imports of lime increased by 10 percent to 354 kt in 2022 from 323 kt in 2021. Canada (79 percent) and Mexico (17 percent) were the leading sources of U.S. lime imports. U.S. lime exports decreased by 9 percent to 303 kt in 2022 from 335 kt in 2021. Lime exports were primarily shipped to Canada (96 percent).

Prices

The U.S. Geological Survey calculates unit values of lime products from the quantity and value data reported for lime sold or used by the lime producers