



2011 Minerals Yearbook

KYANITE AND RELATED MATERIALS

KYANITE AND RELATED MINERALS

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The United States continued to be the world's leading producer of kyanite and mullite (calcined kyanite), with an estimated production of 98,000 metric tons (t) in 2011 (tables 1, 6). Domestic production of synthetic mullite was estimated to be 40,000 t. Andalusite was mined and marketed as part of a mineral mixture at one U.S. operation, but data were withheld to avoid disclosing company proprietary data. No U.S. production of sillimanite was reported. Refractory products continued to be the dominant end use for kyanite and related materials. Of the refractory usage, an estimated 60% to 65% was used in ironmaking and steelmaking and the remainder in the manufacture of chemicals, glass, nonferrous metals, and other materials. World production of kyanite and related materials was estimated to be a minimum of 434,000 t (tables 1, 6).

This report includes information on andalusite, kyanite, and sillimanite (all of which have the formula Al_2SiO_5), and mullite and synthetic mullite ($3Al_2O_3 \cdot 2SiO_2$). Andalusite, kyanite, and sillimanite are the primary minerals of what is referred to as the kyanite group, especially in the United States where kyanite is prevalent, but are also known collectively (including natural mullite) as the sillimanite minerals. Mullite, typically the most desired of these minerals because of its superior refractory (heat resistant) properties and high strength, is rarely found in nature in quantities that are economical to develop. Mullite can be made by calcining kyanite at a high temperature of or above 1,450 °C, and synthetic mullite typically refers to mullite made by calcining certain mixtures of alumina- and silica-containing minerals and materials, including bauxite and kaolin, at similarly high temperatures.

Production

In 2011, an estimated 98,000 t of kyanite was produced in the United States, a 5.4% increase compared with the reported production of 93,000 t in 2010 (Lassetter, 2011, 2012) (tables 1, 6). The estimated value of kyanite produced in the United States in 2011 was slightly more than \$29 million, up from \$28 million in 2010 (table 1). This was based upon an estimated average unit value for raw and worked kyanite that remained at about the \$300-per-metric-ton level of 2009–10.

Kyanite Mining Corp. (KMC) has mined the kyanite deposits in central Virginia since 1945 and was the sole U.S. producer of kyanite and kyanite-derived mullite. KMC operated two open pit mines, the East Ridge Mine and the Willis Mountain Mine, in Buckingham County and beneficiated the ore into a marketable kyanite concentrate. The company also had two kilns at its Dillwyn, VA, facility, the Gieseke Plant, at which typically an estimated 30% to 35% of the kyanite is converted by calcination into mullite. Actual U.S. production data reported to the U.S. Geological Survey (USGS) were withheld to avoid disclosing company proprietary data. KMC produced a

92% to 96% kyanite concentrate containing between 55% and 60% alumina (Al_2O_3). KMC's mullite product contained about 80% mullite and was produced by calcining kyanite. KMC estimated that reserves at its two Virginia mines would last for 50 to 75 years. If operated on a 24-hour basis, KMC's annual integrated mining and processing capacity was more than 135,000 t of commercial-grade kyanite concentrate, a portion of which would be calcined to more than 45,000 t of mullite (Kyanite Mining Corp., 2006).

C-E Minerals (part of Imerys SA Group) produced various synthetic mullite products from calcined bauxitic kaolin near Americus, GA, including products that contained 65%, 77%, and 87% mullite (C-E Minerals, 2012). Based on nongovernment estimates from previous years, U.S. production of synthetic mullite in 2011 was about 40,000 t at an estimated value of about \$12 million (table 1).

Piedmont Minerals Co., Inc. (Hillsborough, NC) mined a deposit of andalusite combined with pyrophyllite and sericite. The company sold products containing blends of the three minerals to producers of ceramics and refractories.

Consumption

Kyanite increases in volume, depending upon particle size, typically by 3% for very fine particles (325 mesh) to as much as 25% for coarser particle fractions (35 mesh) when calcined to mullite but can be used as a raw concentrate in a refractory mixture to offset the shrinkage on firing of other components, especially clays. Andalusite expands irreversibly by about 4% to 6% when calcined and can be used directly in refractories in its raw state (Lassetter, 2011). In other refractory applications, kyanite concentrate is calcined to mullite and added to refractory mixes if the volume increase of kyanite is not required. Mullite is resistant to abrasion and penetration of deleterious dusts, gases, and slags and has beneficial creep resistance, which limits physical deformation under load at high temperatures (Roskill Information Services Ltd., 1990, p. 56, 63).

Examples of refractories that contain andalusite, kyanite, or mullite include insulating brick, firebrick, kiln furniture, refractory shapes, and monolithic refractories (made of a single piece or as a continuous structure) including castables (refractory concrete), gunning mixes, mortars, plastics, and ramming mixes. Monolithic refractories are supplied in unfired and unshaped form, in contrast to prefired and preshaped brick products, and may be gunned, hand packed, molded, poured, pumped, rammed, or vibrated into place (Moore, 2004).

Iron and steel production continued to be the leading user of refractories. World and U.S. crude steel output increased by about 6% and 7%, respectively, in 2011 from that of 2010, following increases of about 17% and 38%, respectively, in 2010 from that of 2009. The leading steel-producing countries and their shares

of 2011 world steel output of nearly 1.5 billion metric tons were China, 45.9%; Japan, 7.2%; the United States, 5.8%; India, 4.8%; Russia, 4.6%; the Republic of Korea, 4.6%; and Germany, 3%. These countries, accounting for nearly 83.0% of world production, produced 1.13 billion metric tons of crude steel in 2011, a 6% increase from that of 2010 (World Steel Association, 2011a, b; 2012). Other prominent refractories users were the nonferrous metal and glass industries.

Other end uses of kyanite and related materials included abrasive products such as grinding and cutting wheels and brake shoes and pads; ceramic products such as electrical insulating porcelains, sanitaryware, and whiteware; foundry products and precision casting molds; and other products. KMC offered a dimension stone product containing kyanite for use in countertops and tiles (Kyanite Mining Corp, 2006).

Foreign Trade

An estimated 45% of U.S. kyanite and mullite output was exported in 2011. Exports of kyanite to more than 30 countries increased slightly to a total of 38,100 t valued at \$11.6 million (table 3). Exports of mullite (calcined or synthetic, unspecified) to 30 countries decreased by 6% to 21,200 t valued at \$7.1 million (table 4). Germany, Belgium, Japan, China, and Netherlands, combined, received 54% of kyanite exports, and more than 80% of the mullite exports went to Canada, Mexico, and the United Kingdom, in descending order of quantity (tables 1, 3, and 4).

U.S. imports of andalusite, kyanite, and sillimanite more than doubled to 5,390 t valued at \$2.23 million in 2011 from 2,180 t valued at \$938,000 in 2010. Virtually all of this material was thought to be andalusite. Of the imported materials in 2011, 80% was from South Africa, 13% from France, and 6% from Peru (tables 1, 5). Imports of mullite increased by more than 75% to 7,340 t valued at nearly \$7.2 million. No U.S. imports of kyanite or sillimanite were reported in 2011.

World Review

South Africa continued to be the leading producing country of andalusite, with an estimated 240,000 t produced in 2011. France produced an estimated 65,000 t of andalusite. India, the leading producer of sillimanite, produced an estimated 17,000 t of sillimanite and 7,800 t of kyanite in 2011 (table 6). Countries thought to be producers of synthetic mullite [sintered mullite and (or) fused mullite] included Brazil, China, Germany, Hungary, and Japan (Taylor, 2005).

In addition to the steady resurgence in the world's steel industry, a steady decline of readily available, inexpensive refractory bauxite from China continued, serving to increase the demand for alternate raw refractory materials such as andalusite. The main andalusite producers in China, Peru, and South Africa expanded their operations, and in Spain, development of a new andalusite mine began (Feytis, 2011a). A refractory bauxite mine was being developed in Russia, which was expected to begin production in 2012, could create new competition for the sillimanite minerals (Watts and others, 2011).

China.—Although China was thought to produce andalusite, kyanite, and sillimanite, detailed production data have been

unavailable since 2003 (O'Driscoll, 2010b). Imerys Yilong Andalusite Mineral Co. reported increased production capacity at its facilities to 40,000 t/yr, up from 15,000 t/yr in September 2010 (Feytis, 2011a).

Peru.—In northern Peru, Andalucita S.A. (a subsidiary of Refractorios Peruanos S.A.) continued development and production from its andalusite resources within unconsolidated sand and gravels of the Tablazo Mancora flood plain and evaluation of other unproven mineral resources in northwestern Peru. Andalucita reached full production capacity of 30,000 t/yr in 2009, its first year of production, but by mid-2011, decreased production to a rate of 15,000 t/yr with revised plans to increase capacity to 50,000 t/yr by mid-2012. With world demand for top quality andalusite rising, Andalucita increased marketing activities to demonstrate the quality and advantages of Paita andalusite. The primary andalusite grade containing 59% Al_2O_3 and a maximum of 0.8% Fe_2O_3 was produced for refractory consumers, mainly in Asia, Europe, and North America. Imerys S.A. owned nearly 50% of the same andalusite deposit but had not yet put it into production (O'Driscoll, 2010a; Feytis, 2011a).

South Africa.—Andalusite Resources (Pty.) Ltd. mined andalusite near capacity at its Maroeloesfontein Mine in Thabazimbi, Limpopo Province, about 220 kilometers (km) northwest of Johannesburg. In early 2011, the company reduced impurities in its final product and increased production by 40% to 70,000 t/yr from 50,000 t/yr. Andalusite Resources revised expected mine life to 60 years at 70,000 t/yr, and anticipated a rise to 80 years following the conversion of its exploration license to a mining right for its additional reserves. Depending upon market growth, the mine could expand to 80,000 to 100,000 t/yr by yearend 2012. The company's main markets were in China, Europe, India, and South Africa (O'Driscoll, 2010b; Feytis, 2011a).

Damrec SA (a subsidiary of Imerys, Paris, France) produced more than 70% of the andalusite in South Africa and planned to increase output nearly 30% within 3 years. Rhino Minerals (Pty.) Ltd. operated three of Damrec's four South African mines. Rhino obtained approval from the Government of South Africa to begin work on its Segorong andalusite project. Samrec (Pty.) Ltd. operated the fourth mine in the Mpumalanga region, near Lydenburgh (Feytis, 2011a).

Spain.—Picobello Andalucita SL, hampered in the past several years by the slow permitting process and lack of funding, made progress on both areas in 2011 and expected its Picobello andalusite deposit, 15 km from El Ferrol port northwest of Galicia, to begin production in mid-2012. The expected plant and mine life was 15 years, extracting ore to a depth of 20 to 40 meters (m) at a rate of 65,000 t/yr, of which 50,000 t/yr would be refractory grade and 15,000 t/yr for metallurgical applications. The company's products were mainly intended for European markets, but talks had begun with Chinese companies interested in purchases and possible investment (Feytis, 2011a).

Outlook

U.S. apparent consumption of steel, the refractories market's leading industry customer, was projected to increase by 5% in 2012 after an 11.5% rise in 2011, showing a slowing, yet

ongoing recovery in the U.S. economy. Because of efforts by the Chinese Government to moderate growth, especially in its real estate sector, growth in China's steel consumption was expected to slow to 7.5% in 2011 after an 8.5% rise in 2010 and was projected to slow to about 6% in 2012. India's steel consumption was expected to increase by 8% in 2012, a significant increase from 4.3% growth in 2011. World steel consumption growth, at 6.5% in 2011, was forecast to increase by 5.5% in 2012 (World Steel Association, 2011b).

Natural raw materials, such as andalusite and kyanite, which have continued to be important in refractory manufacturing, have become increasingly sought after as alternative materials to bauxite in certain refractory applications. The availability of refractory bauxite for export from China has declined in recent years because of a depletion of higher-grade deposits in the country; the Government of China placed restrictions on exports of bauxite owing to increasing domestic raw material use, substantial price increases for bauxite driven by the same domestic demand, and closures at several of China's bauxite mining and processing locations as a result of environmental and safety controls (Feytis, 2011b). Subsequently, the dependence upon Chinese bauxite developed during the past two decades may lessen for many countries depending upon the ability of refractories producers to use or substitute andalusite, kyanite, and similar raw materials in refractory applications; the quantities of andalusite and similar materials produced at new and expanded mines at affordable prices; and the quantities of affordable refractory bauxite available for export from a new mine in Russia. This alternate source of bauxite, while lessening dependence upon China, may be another source of competition for andalusite and kyanite in some applications, such as steel and industrial boilers.

With other refractory materials available as substitutes for bauxite in various applications, andalusite, sillimanite, and synthetic mullite often have better thermo-mechanical properties than many others, although they contain slightly less alumina than bauxite. When compared with higher alumina raw materials, andalusite is expected to be an increasingly attractive alternative because it requires firing at a lower temperature than most other alternative materials when used in producing a dense and shrinkage resistant refractory aggregate, reducing energy consumption and greenhouse gas emissions (Feytis, 2011b, p. 50–51). Available andalusite supplies are expected to increase owing to mine expansions or new mines in France, Peru, South Africa, and Spain. For durable refractories, technological advances are likely to include increased use of synthetic mullite (Feytis, 2011a).

According to the Freedonia Group, the Asia Pacific region is the largest market for refractories, and China will remain the leading national market comprising the majority of global demand. Above-average growth is expected to take place in India. For the next several years, significant increases in refractory demand are likely to take place in Eastern Europe, North America, and Western Europe, with Eastern Europe having the highest growth of these regions. North America may have solid growth, resulting from recovery in manufacturing

and steel producing, but in the longer term, North American growth is expected to lag from the global average, as a result of a shift in steel production to developing countries. Finding and procuring a consistent supply of refractory raw materials, especially at affordable prices, is likely to remain difficult for refractory producers, particularly those in Europe and the Western Hemisphere (Deneen, 2011).

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GENERAL SOURCES OF INFORMATION

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- Historical Statistics for Mineral and Material Commodities in the United States, Data Series 140.
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Other

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TABLE 1
SALIENT U.S. KYANITE AND RELATED MINERALS STATISTICS¹

		2007	2008	2009	2010	2011
Production						
Kyanite:						
Quantity	metric tons	118,000 ²	97,200 ³	71,000 ⁴	93,000 ⁵	98,000 ^{6, c}
Value	thousands	\$30,000	\$26,000	\$21,000	\$28,000	\$29,000 ^c
Synthetic mullite:^c						
Quantity	metric tons	40,000	40,000	40,000	40,000	40,000
Value	thousands	\$10,000	\$10,000	\$10,000	\$12,000	\$12,000
Exports:⁷						
Quantity	metric tons	35,700	36,100	25,800	37,900	38,100
Value ⁸	thousands	\$8,650	\$10,400	\$7,510	\$11,300	\$11,600
Imports for consumption:^{7, 9}						
Quantity	metric tons	1,760	5,580	4,880	2,180	5,390
Value ⁹	thousands	\$646	\$1,930	\$2,060	\$938	\$2,230
Consumption, apparent ¹⁰	metric tons	124,000	107,000	90,100	97,200	102,000 ^c
World, production ^{c, 11}	do.	475,000	408,000	331,000	389,000	434,000

^cEstimate. do. Ditto.

¹Data are rounded to no more than three significant digits.

²Source: Lassetter, W.L., Jr., 2008, Kyanite, andalusite, sillimanite and mullite: Mining Engineering, v. 60, no. 6 June, p. 44–45.

³Source: Lassetter, W.L., Jr., 2009, Sillimanite minerals: Mining Engineering, v. 61, no. 6, June, p. 68–69.

⁴Source: Lassetter, W.L., Jr., 2010, Sillimanite minerals: Mining Engineering, v. 62, no. 6, June, p. 74–76.

⁵Source: Lassetter, W.L., Jr., 2011, Sillimanite minerals: Mining Engineering, v. 63, no. 6, June, p. 96–98.

⁶Source: Lassetter, W.L., Jr., 2012, Sillimanite minerals: Mining Engineering, v. 64, no. 6, June, p. 88–90.

⁷Source: U.S. Census Bureau data for kyanite concentrate using the Harmonized Tariff Schedule of the United States code 2508.50.0000.

⁸Free alongside ship (f.a.s.) value.

⁹Customs value.

¹⁰Includes kyanite and synthetic mullite production+imports–exports.

¹¹In addition to the countries in table 6, a number of other countries produce kyanite and related materials, but output is not reported quantitatively, so these total world output levels are a minimum.

TABLE 2
PRICES OF KYANITE AND RELATED MINERALS IN 2011

(Dollars per metric ton)

	Price
Andalusite, South Africa, 57% to 58% alumina, 2,000-metric-ton bulk lots	311–358
Andalusite, free on board, South Africa, 55% to 59% alumina, 2,000-metric-ton bulk lots, European port	466–540
Kyanite, United States, ex-works, raw, 54% to 60% alumina	247–353
Kyanite, United States, ex-works, calcined (mullite), 54% to 60% alumina, 22-ton lots	411–484

Source: Industrial Minerals, December 2011, p. 61–62.

TABLE 3
U.S. EXPORTS OF KYANITE, BY COUNTRY^{1,2}

Country	2010		2011	
	Quantity (metric tons)	Value ³ (thousands)	Quantity (metric tons)	Value ³ (thousands)
Australia	731	\$215	124	\$204
Belgium	3,710	1,090	4,450	1,340
Canada	2,400	742	2,580	842
China	3,780	1,050	3,400	884
Egypt	726	161	340	80
Germany	4,310	1,500	5,640	1,670
India	609	186	282	81
Italy	2,250	582	2,130	585
Japan	4,300	1,440	3,850	1,360
Korea, Republic of	2,790	697	2,710	765
Malaysia	262	60	648	158
Mexico	930	261	518	173
Netherlands	3,890	1,160	3,230	950
Sweden	1,210	316	1,120	303
Taiwan	198	50	707	186
Turkey	526	123	547	127
United Kingdom	2,230	729	1,850	649
Other	3,100	901	3,970	1,230
Total	37,900	11,300	38,100	11,600

¹Harmonized Tariff Schedule of the United States code 2508.50.0000.

²Data are rounded to no more than three significant digits; may not add to totals shown.

³Free alongside ship (f.a.s.) value.

Source: U.S. Census Bureau.

TABLE 4
U.S. EXPORTS OF MULLITE, BY COUNTRY^{1,2}

Country	2010		2011	
	Quantity (metric tons)	Value ³ (thousands)	Quantity (metric tons)	Value ³ (thousands)
Belgium	2,210	\$1,140	633	\$292
Brazil	31	18	200	82
Canada	13,100	3,320	12,900	3,520
China	71	34	1,200	332
Germany	200	123	975	474
Hungary	--	--	132	55
Italy	--	--	325	131
Kazakhstan	366	401	--	--
Mexico	2,400	1,090	2,870	1,300
Netherlands	105	32	153	58
United Kingdom	4,060	2,030	1,500	733
Other	64	21	267	107
Total	22,600	8,210	21,200	7,080

-- Zero.

¹Harmonized Tariff Schedule of the United States code 2508.60.0000.

²Data are rounded to no more than three significant digits; may not add to totals shown.

³Free alongside ship (f.a.s.) value.

Source: U.S. Census Bureau.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF ANDALUSITE,
KYANITE, AND SILLIMANITE^{1,2,3}

Country	2010		2011	
	Quantity (metric tons)	Value ⁴ (thousands)	Quantity (metric tons)	Value ⁴ (thousands)
France	228	\$174	703	\$360
Peru	412	138	342	130
South Africa	1,500	598	4,320	1,740
Other	37	28	20	7
Total	2,180	938	5,390	2,230

¹Most material is thought to be andalusite.

²Harmonized Tariff Schedule of the United States code 2508.50.0000.

³Data are rounded to no more than three significant digits; may not add to totals shown.

⁴Customs value.

Source: U.S. Census Bureau.

TABLE 6
KYANITE AND RELATED MINERALS: ESTIMATED WORLD PRODUCTION, BY COUNTRY^{1,2}

(Metric tons)

Country and commodity ³	2007	2008	2009	2010	2011
Australia:					
Kyanite	1,000	1,000	1,000	1,000	1,000
Sillimanite ⁴	300	300	300	300	300
Total	1,300	1,300	1,300	1,300	1,300
Brazil, kyanite, marketable	600	600	600	600	600
China, unspecified	3,500	4,000	4,000	4,000	4,000
France, andalusite	65,000	65,000	65,000	65,000	65,000
India:					
Kyanite	7,300	7,500	7,700	7,800	7,800
Sillimanite	15,200	16,000	16,500	16,800	17,000
Total	22,500	23,500	24,200	24,600	24,800
South Africa, andalusite	264,645 ⁵	216,667 ⁵	165,217 ^{r,5}	200,000 ^r	240,000
United States, kyanite ^{5,6}	118,000 ⁷	97,200 ⁸	71,000 ⁹	93,000 ¹⁰	98,000 ¹¹
Grand total ³	475,000	408,000	331,000	389,000	434,000

^rRevised.

¹U.S. and estimated data are rounded to no more than three significant digits.

²Table includes data available through April 29, 2012.

³In addition to the countries listed, a number of other nations produce kyanite and related materials, but output is not reported quantitatively, and no reliable basis is available for estimation of output levels, consequently, grand total output levels are at a minimum.

⁴In addition, about 7,000 metric tons of sillimanite clay (also called kaolinized sillimanite) that contains 40% to 48% Al₂O₃ is produced.

⁵Reported figure.

⁶Excludes synthetic mullite.

⁷Source: Lassetter, W.L., Jr., 2008, Kyanite, andalusite, sillimanite and mullite: Mining Engineering, v. 60, no. 6, June, p. 44–45.

⁸Source: Lassetter, W.L., Jr., 2009, Sillimanite minerals: Mining Engineering, v. 61, no. 6, June, p. 68–69.

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¹¹Source: Lassetter, W.L., Jr., 2012, Sillimanite minerals: Mining Engineering, v. 64, no. 6, June, p. 88–90.