Sillimanite supply surge

February 2010

Andalusite and kyanite players emerge and expand capacity as sillimanite minerals target bauxite substitution in refractory market recovery

Some good news in the mineral sector at last. It would appear that prospects are promising for the sillimanite group minerals and alusite, kyanite, sillimanite, and mullite whose key market is refractories, followed by casting, abrasives, and ceramics (see panel for definitions p.35).

At the expense of bauxite, and with the refractories market showing some signs of initial recovery, those active in the supply of sillimanite minerals might be forgiven for some cautious optimism not long after the dark days of 2009.

Indeed, if truth be told, sillimanite mineral suppliers were already “on the case” as it were in 2008 with Imerys unveiling its €30m. investment in new and expanded aluminosilicate refractory raw materials supply, and the much awaited Peruvian andalusite source beginning (at last) to show serious signs of coming to fruition.

However, the rapidly unfolding financial debacle of late 2008-2009 squandered any hope of anticipated market demand for 2009, and unsurprisingly, some plans were placed on hold.

But it was hoped to be only a temporary setback. Come the latter months of 2009, as the steel market, and China especially, started to recover, optimism returned with the same signs of anticipated buoyancy in the market. This trend has reassured and strengthened continued plans for increasing production capacity for sillimanite minerals supply.

Andalusite dawn: South African andalusite output is set to rise significantly by 2014. Courtesy Andalusite Resources (Pty) Ltd

Supply overview

The global sillimanite minerals supply market is a relatively limited one, owing to avery few deposits being commercially developed (see map p.29).

The natural sillimanite mineral supply sector is restricted in the main to just two primary geographic sources of andalusite (France and South Africa) and one primary source of kyanite (the USA).

On a smaller scale, kyanite is produced in India (five mines), Ukraine (one miner, one processor), captively in Brazil by a refractories producer, and produced intermittently as a by-product of mineral sands mining in Australia.

Sillimanite is rarely produced in any large volumes and production appears restricted to India (four mines) and China.

Data on Chinese sillimanite group production is sparse. Aside from the established Yilong, Xinjiang andalusite mine, kyanite and sillimanite supply is certainly small scale: in 2003 China operated three mines producing 28,000 tonnes kyanite and 19 mines producing 36,000 tonnes sillimanite.
From a corporate viewpoint, of significance is the ownership by Imerys, France, through subsidiaries, of the dominant andalusite producing mines in France, South Africa, and China.

However, in recent years, Andalusite Resources (Pty) Ltd, South Africa, has emerged as the one independent andalusite supplier to Imerys. Towards the end of 2009, a second independent emerged in the form of Andalucita SA, of Peru.

In Ukraine, Ukraine Minerals Ltd intends to increase kyanite processing and develop a new kyanite deposit and plant.

With regard to synthetic mullite production, this is concentrated in the USA, Brazil, Europe, China, India, and Japan. With the exception of C-E Minerals, USA, and a few Chinese producers, most sintered production units are <20,000 tpa, while fused mullite units are <10,000 tpa.

Again, it is worth noting that significant mullite production capacity comes under Imerys in the USA, Germany, and Brazil (see producer tables for summary of main sillimanite mineral producers p.42-43).

Supply highlights

Andalucita

For many years, the andalusite within unconsolidated sands and gravels of the Tablazo Mancora flood plain of northern Peru, and the as yet unproven resource of in situ andalusite in nearby shales and schists, has been under evaluation.

In 2006, Andalucita SA, owned by Refractarios Peruanos SA, was formed to develop the 10m. tonne 58-60% Al₂O₃ alluvial andalusite deposit 20km south of the port of Paita, north-west Peru.

After a series of studies, September 2009 saw production start for an initial operating phase of 30,000 tpa, with, at that time, eventual production for export planned for 60,000 tpa.

In January 2010, plans were revised slightly. Carlos De Ferrari, managing director at Andalucita told IM: “This new state-of-the art andalusite operation in Peru is presently scheduled to reach its initial first phase full capacity production level of 40,000 tpa by mid-year 2010.”

The primary andalusite grade being produced and intended for shipment contains a minimum of 58 % Al₂O₃ and a maximum of 0.8 % Fe₂O₃.

“Works trial production samples are now being distributed to key world refractory markets. Markets presently placing initial orders for Paita andalusite involve refractory consumers in Europe, Asia, and North America.” said de Ferrari.
Keen to boost production capacity at its kyanite operations at Dillwyn, Virginia, Kyanite Mining Corp. used the 2009 slowdown to completely upgrade the iron reduction stage of its kyanite beneficiation process; shown here are spirals and the new magnetic separation house under construction at the East Ridge facility. Courtesy KMC.

Andalusite Resources

In September 2009, Andalusite Resources (Pty) Ltd, announced plans to increase its andalusite production from 50,000 tpa up to 100,000 tpa by 2012.

Andalusite Resources’ Maroeloesfontein mine, Thabazimbi, Limpopo province, is about 220km north-west of Johannesburg. “We are mining the same strike line as Rhino Minerals [Samrec’s Thabazimbi mine]. We are mining the southern tail end of this ore body.” said Andreas Pabst, sales and marketing director Andalusite Resources.

Andalusite Resources’ main markets are in Europe, South Africa, China, and India. “We also sell into Russia, Japan, Korea, Taiwan and other countries in Asia and the Middle East, but our production capacity so far has been the main limiting factor when selling into these territories.” Pabst told IM.

The company is producing at almost its full capacity of 50,000 tpa, and at this rate the mine life is about 20 years.

Andalusite Resources’ has licenses to mine all the farms north of its site up to the Rhino mine (except for one farm). The immediate extension which borders onto Maroeloesfontein has already been found to add at least another 25 years of life to the mine (at 50,000 tpa).

At the end of 2009, the company completed its latest drilling programme, which encompassed the remaining six farms between Maroeloesfontein’s northern extension and Samrec’s concessions to the north. “We have found bigger reserves there than expected; which will add an additional 25 years of life. So in total, Maroeloesfontein has reserves to last at least 70 years at 50,000 tpa.” said Pabst.

Given the proven large reserves, Andalusite Resources has decided to aim for a production expansion in the region of 80,000-100,000 tpa by the end of 2012.

Imerys

Imerys, the Paris based world leader in industrial minerals, over the years has steadily built up its portfolio of impressive aluminosilicate producing subsidiaries, and has made no secret of its expansion plans.

In October 2008, in response to customer demand and as a strategic move for the future, Imerys launched a €30m. investment programme to secure near and medium term supply of aluminosilicate minerals primarily for the refractories market.

The programme included: adding a new 70,000 tpa sintered mullite rotary kiln to C-E Minerals’ plant at Andersonville, Georgia in February 2009; debottlenecking at Samrec’s Krugerspost and Thabazimbi andalusite mines in South Africa, adding 30,000 tpa; ongoing work to start a new andalusite mine at Segorong; adding 25,000
tpa capacity to the existing 15,000 tpa capacity at Imerys Yilong Andalusite Mineral Co., Xinjiang province (Imerys acquired a 65% stake in 2007); and a new 20,000 tpa white fused alumina furnace at Treibacher Schleifmittel Zschornewitz GmbH.

At that time, the management of Minerals for Refractories, Imerys, told IM: “We are very bullish about mid-term prospects [for aluminosilicates].”

Some 15 months on, despite the recession slowing things somewhat, Imerys is still on course to bring these developments to fruition.

Talking to IM in January 2010, Damien Chauveinc, general manager Imerys Andalusite Business Unit, said: “Our debottlenecking investments at Thabazimbi and Krugerpost are now nearly completed and will be fully commissioned during Q1 2010. Our Capex in China at Yilong in Xinjiang was commissioned late 2009 and is ready to start up after the winter break. As for the so called Segorong project, involving village relocation and opening up of a new mine, we are still in line with the plan announced at that time, and start building up the new village beginning of 2010.”

The Segorong project has clearly taken more time than Imerys initially expected, with inhabitants of Segorong village proposed to be relocated at a new village at Praktiseer, a few kilometres distant. Imerys secured final approval from the South African government for this development in July 2009.

The new Segorong mine, expected to produce 85,000 tpa by 2014, is to be located between Samrec’s existing Havercroft and Annesley mines, and will apparently extend reserves currently exploited by these mines by 15 years.

Andalucita SA’s new operation near Paita, Peru is scheduled to reach its initial first phase full capacity production level of 40,000 tpa by mid-year 2010. Courtesy Andalucita SA.

**Kyanite Mining Corp.**

The world’s unsurpassed leader in kyanite production and development is Kyanite Mining Corp. (KMC) which has been exploiting the kyanite deposits in central Virginia, USA, since 1945. The company produces both kyanite and mullite.

KMC’s operations are concentrated around Dillwyn, Virginia and produce one kyanite grade, Virginia Kyanite ranging between 55-60% Al₂O₃, and a second product, Virginia Mullite, which KMC describes as “a true mullite, and not a synthetic blend”.

Variations of the two products are limited to their particle sizes offered, which are mesh sizes 35, 48, 100, 200, 325, and micronised kyanite and mullite with a d₅₀ value of around 4.7 microns.

Hank Jamerson, vice president, director of sales and marketing, KMC, told IM: “The key markets for KMC are refractories for steel production, investment casting flours and grains, kiln furniture, ceramic parts, and metal foundries. We also participate in the brake shoe/abrasive market, electrical insulating porcelains and the sanitaryware/whiteware markets.”
Although KMC is confident of its kyanite reserve base, the company continues to actively invest in the exploration of suitable deposits around the world.

“Given the current consumption levels for kyanite, we conservatively feel that the reserves from Willis Mt. and East Ridge will last for 50-75 years, which does not include our reserves in Canada.” Jamerson commented.

That said, KMC is still keen to boost production capacity at Dillwyn. KMC used the slowdown in the market during 2009 to completely re-engineer and replace the critical iron reduction stage of its beneficiation process.

“This significant plant renovation will allow us to produce a higher quality kyanite through significant removal of the current existing iron in our product while also increasing our recovery of kyanite.” said Jamerson.

KMC is hopeful that these upgrades and re-designs will permit an increase in production capacities at this stage of the process.

KMC has also completed its automated processing and bagging facility, which included construction of additional warehouses that allows KMC to have >5,000 s.tons of “certified and pre-qualified” material bagged in inventory which is available to be shipped at a moment’s notice.

**Togni SA**

Brazilian refractories producer Togni S/A Materiais Refratarios, which celebrates its centenary in 2010, mines kyanite for captive use and produces sintered mullite based on Brazilian gibbsitic clays containing 72% $\text{Al}_2\text{O}_3$ at its plant in Sacramento, Minas Gerais.

Togni also produces 15,000 tpa chamotte (45-60% $\text{Al}_2\text{O}_3$) at its Plant 1 at Pocos de Caldas, Minas Gerais, where a wide range of refractories are produced. By mid-2011 Togni expects to expand this plant to 120,000 tpa. The expansion will include a new milling facility, a mixing facility for unshaped products, a line of eight automatic hydraulic presses and a tunnel kiln for high temperature operation.

The company is augmenting its aluminosilicate portfolio by expanding its Plant 2 in Pocos de Caldas, Minas Gerais. The plant currently comprises two kilns for dead burned magnesia production, and Togni has bought a new rotary kiln for the production of 45-60% $\text{Al}_2\text{O}_3$ chamotte to be in operation by mid-2011.

“That the total production capacity of raw materials [at Plant 2] will be in the range of 40,000 tpa. This facility is also equipped with a milling plant and a concentration plant for kyanite.” said Livio Togni, operation vice president, at Togni.

Regarding markets, Togni told IM: “As with other refractories producers, iron and steel is the most important market to our company (45%), but we also supply to non-ferrous metals (15%), cement, lime and non-metallic minerals (15%), glass (10%), petrochemical, ceramics, and others (15%).

**Ukraine Minerals**

Ukraine Minerals Ltd (Umin) was formed in 2008, and owns several mineral processing plants in Ukraine, and exports worldwide. Umin’s key minerals processed include kyanite, and also kaolin, ilmenite, rutile, zircon, staurolite, foundry and glass sands, and aggregates.

Based in Dnepropetrovsk, Umin operates a processing plant in Volnogorsk (Ukraine trans. = Vilnohirsk), which it acquired from mineral sands producer Vilnohirsk Mining & Metallurgical Plant (VMMP), itself once state owned, but owned by Ukrainian titanium dioxide producer (80,000 tpa) CJSC Crimea Titan since November 2004.

Umin was effectively born out of DVS Co. Ltd, a trading company founded in May 1994, specialising in Ukrainian minerals and chemicals, and distributing VMMP products.

VMMP operates a huge open pit mine complex producing ilmenite, rutile, zircon, staurolite, and kyanite (in the past, latter was <20,000 tpa). Umin has a license to process certain VMMP tailings resources as well as some new deposits yet to be developed by Umin as mining operations. The Volnogorsk deposit is claimed to host 2m. tonnes of aluminosilicates.
Umin processes 25,000 tpa aluminosilicate minerals, including kyanite, and 25,000 tpa titanium-zircon minerals. The natural grain size of the products is about 140-200 microns, and it is milled up to 45-60 microns.

Umin’s kyanite-sillimanite has found application in the production of high-alumina refractories and in non-stick coatings in the foundry industry. Key markets are in Ukraine, Russia, Belorussia, Turkey, Italy, Germany, India, and Iran.

Umin is also looking to expand its kyanite production. “In the near future, in Prosyana [site of Umin’s kaolin mine and plant], we plan to quarry another deposit that contains kyanite.” Denis Prohorov, export manager, Umin Ltd told IM.

Umin also plans to increase mineral production by 300% through expanding its processing plant in Volnogorsk.

Prospects elsewhere

In China, there were unconfirmed reports that Hainan Chansheng Mineral Industry Co. Ltd was investing $146m. into developing a possible 200,000 tpa andalusite and sericite resource near Danzhou city, Hainan island, south China.

The company plans to construct an initial 20,000 tpa processing facility near the 6.38m. tonne deposit, before implementing further expansion to the reach 200,000 tpa at a later date.

In Russia, Moscow-based miner, Kianit LLC, a subsidiary of JSC Granit, has announced plans to mine 100,000 tpa kyanite ore from the Khysovaarskoe deposit in the Republic of Karelia, north-west Russia.

The company intends to construct a mill, in addition to an open pit kyanite mine, with processing capacity to produce 20,000 tpa kyanite concentrate. Mining is expected to start in 2011, with metallurgical tests of bulk samples currently in process.

Market outlook

Refractory markets, especially steel refractories, consume the vast majority of sillimanite minerals, although they are also used in casting, abrasive, and ceramic applications.

Consumption of sillimanite minerals generally reflects the geographic distribution of mineral sources. For example, consumption of andalusite is relatively low in the USA, around 15,000 tpa, compared to Europe’s approximate 150,000 tpa. This is mainly owing to the distance the North American markets are from established andalusite sources, creating high freight costs, and thus encouraging US refractory formulations to use alternative aluminosilicates such as bauxites, mullite, and kyanite.

Towards the end of 2009, refractory mineral markets were showing some signs of recovery, with traders and consumers reporting healthy signs of some returning demand.

The World Steel Association reported that global steel production grew to 107.5m. tonnes in November 2009, representing the third consecutive year-on-year growth since September 2009, and a 24.2% rise on November 2008 levels.

Perhaps not surprisingly, China led the way with a steel output of 47.3m. tonnes in November a 37.4% growth on November 2008 figures, and almost half of total world production.

Across the board production rises were seen throughout Asia, Europe and North America, with the most promising increases coming from Russia (up 42.6% year on year), Ukraine (up 67.1%), and the USA (up 26.9%).

Meanwhile, total crude steel production for the first 11 months of 2009 was 1,090m. tonnes; almost 11% lower than steel production during the same period last year.

In India, CUMI, which is mostly a captive producer of fused mullite, reported that its Q2 2009 (to 30 September 2009) fused minerals business continued with strong performance, with a 11% growth in sales over Q2 of 2008 (to Rs.400m.($8.7m.)). CUMI has expanded markets for its mullite in glass and carbon black refractory applications.

Most sillimanite producers would have experienced a tough 2009, and many will hope that 2010 will provide some
welcome relief.

Denis Prohorov, export manager, Umin Ltd, told IM: “The market situation of the refractory industry in 2009 was not good. The downturn started in the first quarter of 2009, and only in September-October 2009 did we see some positive trends in that industry. Production capacities of refractory plants in Ukraine and Russia were functioning only at 40% of their capacity.”

Andreas Pabst, director, Andalusite Resources, echoed the trials of 2009: “Last year was obviously a tough trial for Andalusite Resources. Many of our traditional markets contracted sharply, whilst India and China performed much better overall and thus really proved their value to us. Very recently, we have seen a solid resurgence of demand across the board, from our long-standing customers as well as new ones whom we have not supplied recently (or only with limited volumes).”

Certainly, owing the range of activity in production expansions and upgrades reported earlier in the article, it seems that recovery is anticipated, although caution is still the watchword.

Damien Chauveinc, general manager Imerys Andalusite Business Unit, commented: “As far as 2010 market trends are concerned, we have been experiencing a pick-up in demand for a few months, since November, but it’s far too early to be able to give any forecasts.”

Philippe Bourg, sales & marketing manager - Minerals for Refractories Division at Imerys, added: “The situation both on the end users demand side, mainly steel producers, and Chinese supplies, mainly bauxite, needs to be clarified first.”

Regarding kyanite, there are some new market directions, as Hank Jamerson, vice president, director of sales and marketing, KMC, explained: “We are currently experiencing success in new markets such as ceramic foam filters for metal production, and refractories for aluminium production. In general, the performance of our key markets is weaker than it was 18 months ago, but much more lively than it was 8-12 months ago. We look to the near term future with cautious optimism.”

The bauxite question

Perhaps the greatest talking point surrounding the outlook for sillimanite minerals is whether they can make any inroads into markets supplied by bauxite. This topic, while a traditional talking point, has been increasingly in discussion over the last two years, and is now generating even more interest.

The key driver for this has been the steady decline of cheap and readily available refractory bauxite from China. Indeed, many refractory manufacturers had actually used sillimanite minerals before being wooed to cheap Chinese bauxite exports from the 1980s. They were further lured to China by intermittent supply of RASC bauxite from Guyana and limited, specific grade bauxite production from Par‡, Brazil, which eventually halted in December 2003.

Since then the tables have turned, with Chinese government policies reducing bauxite (and other mineral) exports, increased demand for bauxite within China, and Bosai Minerals Group, of Chongqing, China acquiring the RASC Guyana operations.

Matters have been compounded with government restrictions and closures in bauxite mining in Shanxi, and closures of shaft and round kilns, owing to environmental and safety controls.

Pre-recession, this created tight availability of refractory bauxite worldwide with a consequent rise in its price. Then the recession provided somewhat of a breathing spot, as global consumers cleared their inventories and battened down the hatches to ride out the crisis.

With market recovery underway, and, critically, no change in China’s position on bauxite exports nor domestic bauxite mining (the former likely to remain unchanged, the latter might possibly change in H2 2010), a return to tight supply and high prices is anticipated.

Jack Gao, general manager of mineral processor and exporter Refmin China Co. Ltd told IM: “The alternative material for bauxite we are now selling is low grade bauxite with 75-84% Al₂O₃, plus mullite, Alpha Star bauxite [a calcined high alumina aggregate produced in Xiuwen, Guizhou, by Guizhou Star Minerals, a C-E Minerals j-v],
and brick grog. Shanxi material is quite short and a new source is Guizhou, where some refractory grade is now coming out. Supply [of refractory grade] is very short due to strong demand at the end of 2009, and it is very difficult to get 85-89% Al$_2$O$_3$ bauxite, and also the price keeps increasing."

Owing to this situation, consumers are researching the economic and technical suitability of using andalusite. This has very much helped to oil the wheels of the expansion plans of Imerys and Andalusite Resources, but has also prompted Andalucita to emerge as a new player in Peru.

Traditionally, andalusite has not competed directly with bauxite in refractories. Indeed, it is not always a straightforward substitution of sillimanite minerals for bauxite. For certain applications it is possible, but not for others.

In his paper “Andalusite in Peru, South America”, presented at UNITECR’09 last October, Bill McCracken discussed that certain performance factors of andalusite (eg. high degree of mullitisation at 1,400°C, high thermal conductivity, small expansion coefficient, low porosity, and increased spalling resistance) could be favourably compared to 85-90% Al$_2$O$_3$ refractories, and not directly compared favourably nor equivalent to other 60% Al$_2$O$_3$ mullitised refractory materials.

However, McCracken noted that: “The iron content in refractory grade andalusite is a major negative factor, with global usage specifications calling for less than 1%.”

The bottomline appears to be that alumina content is not everything, with sillimanite minerals offering key properties, and the outcome against bauxite coming down to price versus performance (see panel left) as outlined by Bernd Durstberger, former Head of Minerals for Refractories Division, Imerys, in his presentation “Alternative solutions to non-metallurgical metallurgical bauxite and alumina in a tight supply scenario”, at the 15th International Bauxite & Alumina Seminar, 11-13 February 2009.

Durstberger was of the opinion that the price/performance ratio in many refractory applications is favorable for mullite/chamotte versus Chinese bauxite. Significantly, influencing risk factors for continued bauxite reliance by consumers include currency fluctuations, freight market developments, and most crucially, the unpredictability of Chinese bauxite supply (exports and actual mining).

Durstberger considered that there is taking place a revision of previous “overshooting” by refractory manufacturers, ie. where they “overshot” their initial replacement of aluminosilicates with Chinese bauxite, especially in lower temperature uses.

The upshot is that low-temperature applications are leaning to chamotte/flint clay usage and high temperature applications to mullite/andalusite usage. There is also a trend in blending in of lower alumina raw materials.

Talking to IM in January 2010, Damien Chauveine, general manager Imerys Andalusite Business Unit confirmed: “We still believe our capacity expansions make sense in light of our assessment of the demand trends for our minerals in refractories and of the development of Chinese bauxite pricing and availability.”

Some sillimanite mineral producers are already reaping the benefits of consumers looking to alternative aluminosilicate sources.

KMC has enjoyed raw material substitutions of its Virginia Kyanite in place of bauxite fines, andalusite fines, calcined alumina, and fumed silica. “The utilisation of Virginia Kyanite as a substitute for the [previously mentioned] raw materials has been driven by a number of factors such stable/reasonable pricing, consistent/repeatable quality, as well as the fact that Virginia Kyanite has always been readily available while other materials were in limited supply.” said Jamerson.

Clearly, there is potential for sillimanite minerals like andalusite and kyanite to benefit from refractory bauxite’s predicament. But it still requires a bit of a leap on the part of the consumers, many of which remain to be “converted”.

Andreas Pabst, Andalusite Resources, observed: “With regard to bauxite, I truly believe that andalusite’s potential to act as substitute or added product, is not fully grasped yet by the industry.”
Pabst makes the point that the larger refractory groups, such as RHI and Vesuvius, which enjoy well funded research and development programmes, are very much clued up about what andalusite can and cannot do in refractory applications. However, many of the mid-sized and smaller refractory companies are not yet fully in this position.

“We often encounter real reluctance of technological departments to change their approach. They stick to what they know and that is it. However, if one looks at the price development of andalusite versus bauxite for instance, it needs to be noted that bauxite has more than quadrupled in price over the last 5-6 years, while andalusite’s price levels have only increased by about 20-30% over the same time period.” said Pabst

It appears that although there is much interest in andalusite’s potential as a refractory raw material, particularly with regard to the bauxite supply situation, only a few consumers seem willing to test the water.

For its part, Andalusite Resources, in co-operation with its chief marketing agent Cofermin Rohstoffe GmbH is looking into commissioning more research into the technical aspects of andalusite replacing bauxite, and thus expanding its market share.

Pabst concluded: “This expansion [at Maroeloesfontein] will depend very much on the market situation of steel, ceramics, refractories, and bauxite; but from our point of view we believe strongly in the long term growth and viability of the andalusite market.”

Indeed, another keen observer of the market is emerging new producer Andalucita SA of Peru. Carlos De Ferrari, Andalucita SA, recognises the interest in andalusite from the refractories market and is hopeful. “On a steel production comparative basis, the western hemisphere consumes roughly 20% of the andalusite refractories used in Europe. Based on the above, the western hemisphere industrial world could be consuming at minimum €100,000 tpa of Peruvian quality andalusite.”

For Brazilian refractories producer Togni SA, the bauxite issue has played an important role in its development. “It forced us to find viable alternatives; we can now produce synthetic bauxite in our Plant 3 with a Brazilian source of raw materials without depending on imports anymore, especially with the monopoly that is being created by the Chinese suppliers. For synthetic bauxite, we use some synthetic additions, decreasing the amount of iron oxide to 0.8% and the alkalis to very low amounts, with improved physical properties, giving us a much better product compared to natural calcined bauxite.” said Livio Togni, operation vice president, Togni.

Togni also underlined that Brazil is a very rich country regarding aluminosilicate minerals “which gives us some good possibilities to supply refractories production.”

Certain high grade sillimanites remain largely unaffected by the bauxite debate. Sintered and fused mullites made from higher purity raw materials mean predominately higher application temperatures and longer life cycles of refractories ie. very specific niche market applications.

Jan Kupfer, director Business Division Technical Ceramics, Nabaltec AG, told IM: “That’s basically the reason why Nabaltec expects a further increase in demand and consumption for its synthetic sintered mullites in the future.”

Nabaltec’s Symulox® products find application mainly in high alumina refractory products, typically in steel and glass manufacture, incinerator linings, and kiln furniture production. “Due to their high purity, M72 and Z72 products are used rather in high performance refractories, than as a substitute for refractory bauxite. Nabaltec does not expect any significant impact from the shortage of these minerals on its own business.” said Kupfer.

In conclusion, with the future of Chinese bauxite supply very much in doubt, and already emerging trends of increasing sillimanite mineral use in certain refractory applications, it would appear that there are good prospects for market penetration for these minerals.

The next bridge to cross, given market recovery continues, will be to reassure consumers of a quality consistent, stable supply of high quality sillimanite minerals at attractive prices. (see p42-43 for producer tables).

World production of andalusite, kyanite, sillimanite & mullite (tonnes)
Sillimanite minerals in brief

Andalusite, kyanite, sillimanite, and mullite are all aluminium silicate, or aluminosilicate minerals, typically occurring in metamorphic rocks such as gneiss or schist, and their weathered derivatives, including some mineral sand deposits.

They are also referred to as the sillimanite group of minerals, since supply was originally dominated by Indian sillimanite output. In the USA, owing to kyanite’s predominance, the group is referred to as kyanite and related minerals.

Their commercial development is limited to just a few producers worldwide (see map and producer table).

In the case of mullite, natural occurrences are uneconomic to mine and thus all commercially produced mullite is synthetic, ie. produced from natural minerals by calcination and fusion (see 'Mullite matters’ panel).

With the exception of mullite, these minerals are mined using open pit methods. Drilling and blasting for hard rock deposits, followed by primary and secondary crushing, high intensity dry or wet magnetic separation, sometimes heavy media separation, possibly flotation and gravity separation, and acid leaching for concentrate upgrades.

Kyanite and sillimanite are also produced as by-products from mining of certain mineral sands.

When these minerals are subject to high temperatures they undergo mullitisation, a chemical reaction of their constituents to form a mullite phase. The mullite imparts superior refractory properties and high strength. Thus, the main market applications for these mineral are in refractories, ceramics, abrasives, and foundries.

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### Mullite matters

Mullite is rare in nature, and is named from one locality on the Isle of Mull, Scotland, where argillaceous sediments have been fused by igneous intrusion.

Mullite, $3\text{Al}_2\text{O}_3\text{-2SiO}_2$, is a mineral phase much sought after as a major constituent of refractory and ceramic products owing to its extremely high refactoriness and strength (the latter owing to the interlocking of its needle-like crystals). Mullite is very refractory, breaking up into corundum and liquid silica at 1,810ºC.

Since mullite does not naturally occur in deposits of commercial value, the mineral is produced synthetically by either sintering or fusing carefully selected aluminosilicate raw materials.

Sintered mullite maybe produced by calcining kyanite (as produced by KMC), calcining a bauxitic kaolin (as produced by C-E Minerals), or by calcining carefully selected blends of alumina, kaolin, and bauxite (as in China).

Commercial sintered mullite grades have alumina contents in the 45-50%, 60%, and 70+% $\text{Al}_2\text{O}_3$ categories. Other important properties are low iron (<1% $\text{Fe}_2\text{O}_3$) and low cristobalite, and of course, the all important mullite phase, which can range from 65-90%.

Fused mullite grades, which include so-called white fused mullite grades, can be produced from fusing Bayer process alumina and high purity silica (eg. Washington Mills), or by fusing certain blends of bauxite, aluminas, and refractory kaolins (eg. in China).

There are a range of commercial grades of sintered and fused mullite on offer. A typical analysis would be: 71.7-76.2% $\text{Al}_2\text{O}_3$, 23.0-23.6% $\text{SiO}_2$, 0.11-3.0% $\text{TiO}_2$, 0.13-1.17% $\text{Fe}_2\text{O}_3$, 0.04-0.06% CaO, 0.05-0.06% MgO, 0.05-0.44% alkalies.

Mullite has a melting point of 1,810ºC, softens at 1,650ºC, and has a specific gravity of 3.156.

Fused zirconia mullite, with a melting point of 1,750ºC and specific gravity of 3.5-3.6 is produced by fusing calcined alumina and zircon sand. During melting, the zircon and alumina react to yield a mixture of mullite and zirconia.

Fused zirconia mullite is composed of large, needle-like mullite crystals, containing co-precipitated monoclinic zirconia. Average crystal width is 100 microns, with an average length of 10,000 microns. Traces of dendritic, monoclinic zirconia and about 5% glass is present in the interstices between the mullite crystals.
Fused zirconia mullite provides high resistance to environmental corrosion and a low coefficient of thermal expansion, and is used in steel and glass refractories, also ceramic pressure casting tubes and ceramic rollers. Courtesy Washington Mills Electro Minerals Corp.

**Sillimanite minerals in refractories**

**Key Properties**

- Refractoriness
- Thermal stability
- Flow resistance
- Shock resistance
- Abrasion resistance
- Hot load and hot strength
- Porosity
- Alkali content

**Market penetration**

**Mullite**
- Mullite 47 (M47) in blast furnace tap-hole clays
- Chamotte/M47 and Mullite 60 (M60) in tundish backup linings
- M60 and Mullite 70 (M70) used in steel lances
- M60 and M70 in electric arc furnace delta sections
- M60 and M70 in slide gate formulations
- M60 in construction grade plastics
- M47-70 used to replace fine grain calcined bauxite in mortars, plaster, and plastics
- M60 in iron runners
- M60 grain of choice in torpedo ladle applications
- M70 and M60 in various pressed brick shapes.

**Andalusite**
- in steel ladles
- in hot stove bricks
- in bricks for cement rotary kilns
- Andalusite-SiC in iron ladles

**Aluminosilicate raw materials in refractories**

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Alumina content (%)</th>
<th>Max. service temperature (°C)</th>
<th>Typical applications</th>
</tr>
</thead>
</table>

indmin.com/Print.aspx?ArticleId=2378811
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tabular alumina</td>
<td>99.7</td>
</tr>
<tr>
<td>White fused alumina</td>
<td>99.7</td>
</tr>
<tr>
<td>Brown fused alumina</td>
<td>95</td>
</tr>
<tr>
<td>Bauxite</td>
<td>85-88</td>
</tr>
<tr>
<td>Sintered mullite</td>
<td>45-70</td>
</tr>
<tr>
<td>Andalusite</td>
<td>58-60</td>
</tr>
<tr>
<td>Chamotte/Flintclay</td>
<td>35-45</td>
</tr>
</tbody>
</table>


**Price comparisons**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andalusite</td>
<td></td>
</tr>
<tr>
<td>55-59% Al2O3, FOB European port,</td>
<td>€335-385/tonne</td>
</tr>
<tr>
<td>57-58% Al2O3, 2,000 tonne bulk,</td>
<td>€225-255/tonne</td>
</tr>
<tr>
<td>mine South Africa</td>
<td></td>
</tr>
<tr>
<td>Bauxite</td>
<td></td>
</tr>
<tr>
<td>Shanxi rotary kiln</td>
<td></td>
</tr>
<tr>
<td>87% Al2O3/1.8% Fe2O3/BD 3.20+,</td>
<td>$470-535/tonne</td>
</tr>
<tr>
<td>FOB Xingang</td>
<td></td>
</tr>
<tr>
<td>Guizhou round kiln</td>
<td></td>
</tr>
<tr>
<td>87% Al2O3/2.0% Fe2O3/BD 3.20,</td>
<td>$450-525/tonne</td>
</tr>
<tr>
<td>FOB Zhanjiang/Fangcheng</td>
<td></td>
</tr>
<tr>
<td>Kyanite</td>
<td></td>
</tr>
<tr>
<td>Kyanite, crude, ex-works USA, 55-60% Al2O3</td>
<td>$211-301/s.ton</td>
</tr>
<tr>
<td>Calcined kyanite, ex-works USA, 55-60% Al2O3, 22 ton lots</td>
<td>$351-414/s.ton</td>
</tr>
<tr>
<td>Mullite</td>
<td></td>
</tr>
<tr>
<td>Sintered mullite, 47% -70% Al2O3 (sized in bulk bags), FOB USA</td>
<td>$130-500/s.ton</td>
</tr>
</tbody>
</table>
Major natural sillimanite mineral producers*

<table>
<thead>
<tr>
<th>Country/company</th>
<th>Mineral(s)</th>
<th>Mine/plant location</th>
<th>Capacity (unless otherwise stated)/remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>several kyanite mines in Minas Gerais, 1.5m. tonnes reserves; captive feedstock for refractories production, capacity 60,000 tpa both shaped and unshaped.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Togni S/A</td>
<td>kyanite</td>
<td>Pocos de Caldas, Minas Gerais; concentration plant</td>
<td></td>
</tr>
<tr>
<td>Materiais Refratários**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>exports &gt;100,000 tpa of range of minerals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Henan Mines and Kyanite, Zhengzhou, Henan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refractory Corp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imerys Yilong Andalusite Mineral Co.</td>
<td>15,000 tpa; +25,000 tpa commissioned late 2009, start-up after winter.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>80,000 tpa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damrec</td>
<td>andalusite Glomel, France</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imerys</td>
<td>80,000 tpa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>andalusite Bangalore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bajaj Associates**</td>
<td>kyanite Bangalore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indian Rare Earths Ltd</td>
<td>sillimanite Chavara, Kerala</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chatrapur (Oscom), Orissa</td>
<td>By-product of titanium, zircon, and rare earth mineral sands production; total combined mineral prod. cap.: 200,000 tpa Chavara; 500,000 tpa Oscom.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peru</td>
<td>40,000 tpa 0.6-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Industrial Minerals
Refractarios Peruanos SA
andalusite Peita

4mm planned as initial production mid-2010; 2007 reserve estimates indicate primary grade exceeds 10m. tonnes 58-60% Al2O3 low iron finished product.

South Africa

Andalusite Resources (Pty) Ltd
andalusite Maroeloesfontein, Thabazimbi, Limpopo

50,000 tpa; min. 57% Al2O3, max. 1% Fe2O3, 1-3mm, 0.5-1.5mm, 0-1mm, 100#, 200# other sizes upon request; licence to mine north of site, proven reserves = 70 year mine life at current rate; plans to increase to 80-100,000 tpa by 2012.

Samrec Pty Ltd
Imerys 4 mine/plant sites:
Annesley, Penge, Limpopo
Havercroft, Burgersfort, Limpopo
Rhino, Thabazimbi, Limpopo

195,000 tpa combined; debottlenecking at Thabazimbi (adding 20,000 tpa) and Krugerpost (10,000 tpa) will be fully commissioned during Q1 2010; ongoing project to develop mine at Segorong (85,000 tpa) by 2014; Annesley and Havercroft (60,000 tpa combined) expected to in line with Segorong start-up total prod. cap. est. 250,000 tpa by 2014.

Ukraine

25,000 tpa concentrate 57-58% Al2O3 processed from tailings from Vilnohirsk Mining & Metallurgical Plant

Ukraine

Vilnohirsk,
<table>
<thead>
<tr>
<th>Minerals Ltd</th>
<th>kyanite processing plant operation; owns 2m. tonnes reserves; planning to expand plant and develop kyanite mine and plant at Prosyana.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vilnohirsk Mining &amp; Metallurgical Plant</td>
<td>Large open pit mining and processing operation exploiting ilmenite, rutile, zircon with kyanite, staurolite, quartz by-products.</td>
</tr>
<tr>
<td>Crimea Titan</td>
<td>kyanite Vilnohirsk, mine and plant</td>
</tr>
<tr>
<td>USA</td>
<td>Vilnohirsk, mine and plant</td>
</tr>
<tr>
<td>USA Kyanite Mining Corp.**</td>
<td>Dillwyn, Virginia; mine sites, Willis Mt. and East Ridge; 3 plants, 1 calcines Virginia Kyanite into Virginia Mullite, 2 grind, bag, and inventory Virginia Kyanite and Virginia Mullite. 130,000 s.tpa kyanite (55-60% Al2O3); can expand by 20% by increasing to 7-day shift from 5-day;</td>
</tr>
<tr>
<td>Piedmont Minerals</td>
<td>Captive feedstock for refractories production; the only andalusite deposit mined in the USA, the ore is a mixture of pyrophyllite and andalusite.</td>
</tr>
</tbody>
</table>

ie. andalusite, kyanite, and sillimanite not synthetic mullite

** see also mullite producer table

Major mullite producers (fused & sintered)

<table>
<thead>
<tr>
<th>Country/company (parent company)</th>
<th>Sintered or</th>
</tr>
</thead>
</table>

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<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Supply Type</th>
<th>Plant Location</th>
<th>Capacity (tpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elfusa Geral de Eletrofusão</td>
<td>fused</td>
<td>São João da Boa Vista, São Paulo</td>
<td>120,000 combined total prod. cap. of range of fused minerals incl. white fused mullite, fused ZrO2 mullite</td>
</tr>
<tr>
<td>Grupo Curimbaba</td>
<td>fused</td>
<td></td>
<td>15,000 tpa; based on 72% Al2O3 gibbsitic clays; plant has high temperature rotary kiln, grinding, and concentration facility with two 120x120x110 filter press.</td>
</tr>
<tr>
<td>Togni S/A Materiais Refratários</td>
<td>sintered</td>
<td>Sacramento, Minas Gerais</td>
<td>3,000 tpa</td>
</tr>
<tr>
<td>Treibacher Schleifmittel Brazil Ltda</td>
<td>fused</td>
<td>Salto, Sao Paulo</td>
<td>80,000 tpa total combined cap. incl. calcined bauxite, kaolin; 60%, 70% Al2O3 grades</td>
</tr>
<tr>
<td>Imerys</td>
<td>fused</td>
<td>Datong, Shanxi</td>
<td>60%, 70% Al2O3 grades</td>
</tr>
<tr>
<td>Datong Alumina-Silicate Refractory Co. Ltd (Aluref)</td>
<td>sintered</td>
<td>Xing Pingwang, Datong, Shanxi</td>
<td>20,000 tpa 45%, 60%, 70% Al2O3 grades plus ZrO2 blends</td>
</tr>
<tr>
<td>Henan Mianchi Great Wall Corundum Co. Ltd</td>
<td>fused</td>
<td>Mianchi, Henan</td>
<td>exports &gt;100,000 tpa of range of minerals</td>
</tr>
<tr>
<td>Henan Mines and Refractory Corp.</td>
<td>fused, sintered</td>
<td>Zhengzhou, Henan</td>
<td></td>
</tr>
<tr>
<td>Huang He Minerals Co. Ltd</td>
<td>fused, sintered</td>
<td>Yima, Henan</td>
<td></td>
</tr>
<tr>
<td>Hunan Chenxi Huazhong Mullite Co. Ltd</td>
<td>fused, sintered</td>
<td>Chenxi, Hunan</td>
<td></td>
</tr>
<tr>
<td>Inner Mongolia Sanhe Calcined Kaolin Ltd Co.</td>
<td>sintered</td>
<td>E’erduosi, Inner Mongolia</td>
<td></td>
</tr>
<tr>
<td>Jie Xiu Bauxite Plant</td>
<td>sintered</td>
<td>Jie Xiu, Shanxi</td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>
Jungar
Mengsheng New Materials Co. Ltd
sintered Jungar, Inner Mongolia

75,000 tpa rotary kiln capacity; 47.5%, 60%, and 70% Al2O3 grades.

Shanxi Diversified Industrial Corp.
CMP-Shaowu Haisheng
Minerals Co.- sintered Taiyuan, Shanxi
Zhongtian Weitu Trading Co. j-v

100,000 tpa, 45%, 47%, and 60% Al2O3 grades

Nabaltec GmbH sintered Schwandorf

10,000 tpa, 72% Al2O3, also incl. ZrO2 mullite

Treibacher Schleifmittel Zschornewitz GmbH

8,000 tpa fused ZrO2 mullite, 23,000 tpa white fused mullite; incl. new white fused alumina kiln cap.

Hungary
Motim Electrocorundum fused Mosonmagyaróvár Ltd

5,000 tpa white fused mullite; 2,000 tpa fused ZrO2 mullite

India
Bajaj Associates sintered Bangalore

12,000 tpa, 60% Al2O3, from calcined kyanite

Carborundum Universal Ltd (CUMI)
Murgappa Group fused Kalamassery, Kochi, Kerala

1,000 tpa 78% Al2O3 white fused mullite 73-77% Al2O3, also fused ZrO2 mullite; total fused minerals cap. 21,000 tpa, total calcined minerals cap. 74,250 tpa

Orient Abrasives Ltd fused Porbandar, Gujarat

Japan
Itochu Ceratech Corp.
Itochu Corp. sintered Seto City, Aichi

10,000 tpa, 70-76% Al2O3 grades
10,000 tpa total prod. cap combined fused minerals incl. fused mullite (76% Al2O3) and fused ZrO2 mullite

Showa Denko KK fused Shiojiri, Nagano
<table>
<thead>
<tr>
<th>Country</th>
<th>Company Name</th>
<th>Type</th>
<th>Location</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>Cermatco Ltd</td>
<td>fused, sintered</td>
<td>Aylesham, Kent</td>
<td>10,000 tpa total mineral cap., incl. white fused mullite. produced by firing andalusite and alumina; June 2009 $1.17m. expansion of mullite capacity by 50%; total mineral processing capacity 50,000 tpa.</td>
</tr>
<tr>
<td></td>
<td>DSF Refractories &amp; Minerals Ltd</td>
<td>sintered</td>
<td>Friden, Derbyshire</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>C-E Minerals</td>
<td>sintered</td>
<td>Andersonville, Georgia</td>
<td>700,000 s.tpa incl. 70,000 tpa kiln added Feb. 2009; also distributes fused mullite produced by Triebacher in Brazil and Germany.</td>
</tr>
<tr>
<td></td>
<td>Kyanite Mining Corp.</td>
<td>sintered</td>
<td>Dillwyn, Virginia</td>
<td>two kilns; ability to convert 40,000 s.tpa of Virginia Kyanite into Virginia Mullite – 57% Al2O3, 0.5% Fe2O3; current capacity utilisation is about 70%.</td>
</tr>
<tr>
<td></td>
<td>Washington Mills Electro Minerals Corp.</td>
<td>fused</td>
<td>Niagara Falls, New York</td>
<td>10,000 tpa fused mullite; 10,000 tpa fused ZrO2 mullite.</td>
</tr>
</tbody>
</table>