REPORT R83/2009

STRUCTURE OF THE ANDALUSITE INDUSTRY

DIRECTORATE: MINERAL ECONOMICS

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1. INTRODUCTION

The silliminate minerals are a group of naturally-occurring anhydrous aluminium silicates, the principal members of which are andalusite, kyanite and silliminate, all with the formula $Al_2O_3.SiO_2$, and mullite which has the formula $3Al_2O_3.2SiO_2$. Their importance stems from the fact that at 1 350^oC (known as calcination) they convert to highly refractory mullite and silica, hence the group is used as a raw material for the production of high-alumina refractories and ceramics. Of the three minerals, andalusite is the most exploited for refractory use followed by kyanite. True silliminate is not extracted in any significant quantities.

Due to the dominance of kyanite in the United States (US), the group is generally referred to as kyanite and related minerals in the US. Related, but currently non-commercial minerals, such as topaz ($9Al_2SiO_4(OH,F)_2$), dumortierite ($Al_7(BO_3)(SiO_4)_3O_3$) which also yield mullite and silica on calcining, are therefore often included in this group.

Because the products of calcination are highly refractory (able to withstand high temperatures) the silliminate minerals are industrially important and are in demand wherever high temperature processes such as smelting of metals and making of glass are carried on. They are also used in certain types of porcelain and various other products.

The aim of this report is to unpack the andalusite industry in the Republic of South Africa, but will also focus on international developments. The report will attempt to address questions such as: Occurrences, Markets, Production Process, Supply & Demand, Key drivers and Health and Safety compliance of andalusite.

2. WORLD

2.1 GEOLOGICAL SETTING, OCCURENCES AND RESERVES

Silliminate minerals typically occur in Aluminium-rich metamorphic rocks like schist and gneisis or their weathered derivatives. High temperature and pressure may convert aluminium-rich clay sediments into massive kyanite nodules, knots and huge boulderized segregations.

The main classes of deposits of the silliminate group of minerals are:

- Disseminations and massive concentrations in regionally metamorphosed quartzose and argillaceous rocks, these are particularly in East Africa, India and the US.
- Occurrences in contact-metamorphosed argillaceous rocks, a notable example of this thermal metamorphism of shales by the Bushveld igneous complex in South Africa
- Occurrences in sedimentary rocks, the Florida and Kerala (India) beach sands
- Deposits of miscellaneous origin including hydrothermal alteration in quartz veins and pegmatites, and deposits which have originated by a combination of geological processes.

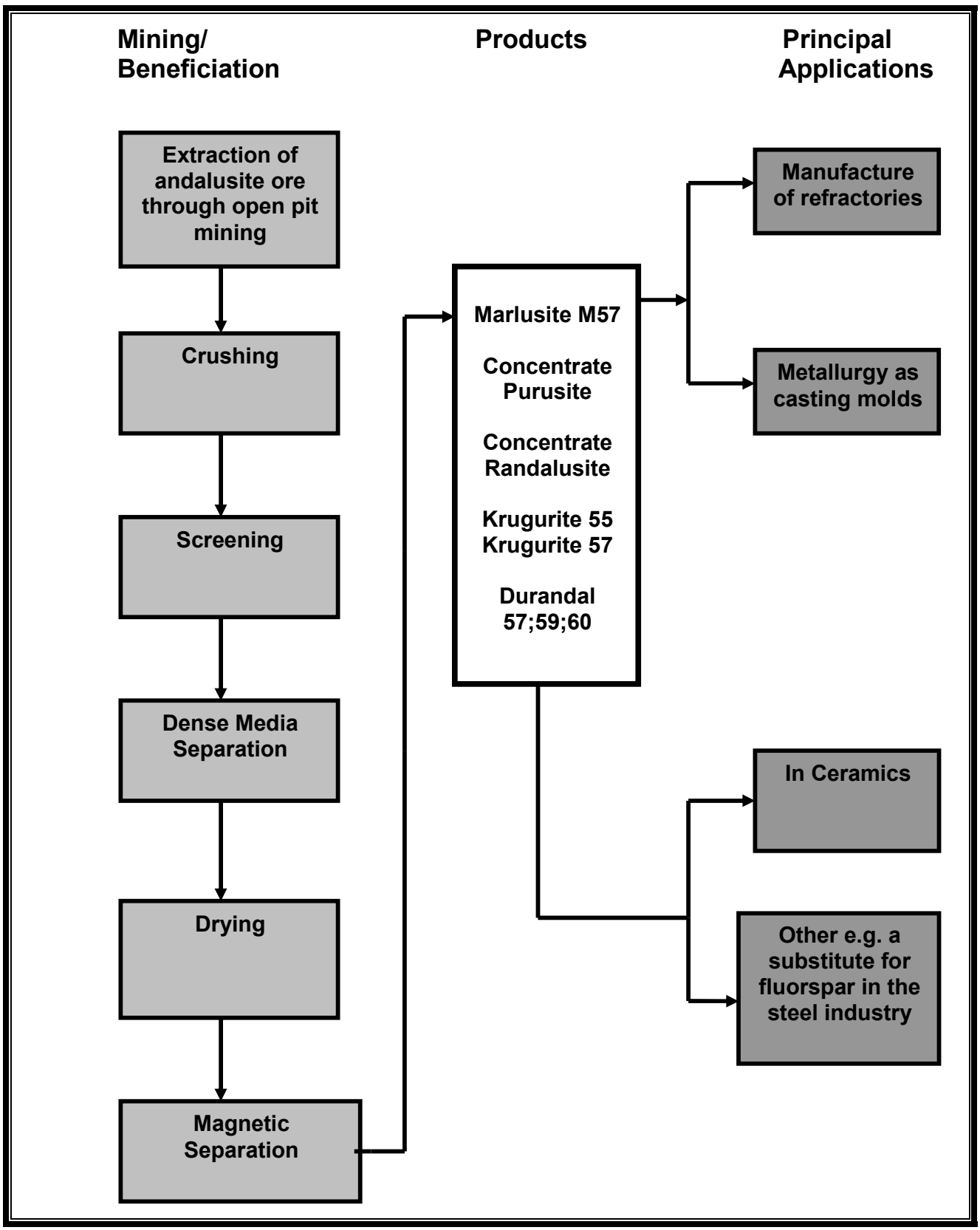
Large resources of kyanite and related minerals are known to exist in the US. These resources are not economical to mine at present, however, should economic conditions change, these deposits may be worth mining. South Africa has 51 million tons reserves of alumino-silicates ore (andalusite and silliminate). South Africa possess what are by far the largest known deposits of andalusite in the world and is the leading supplier of this mineral to the refractory industry.

2.2 MINING AND PROCESSING OF ANDALUSITE

By far the greater part of the world production of the silliminate minerals comes from opencast workings. Mining in the United States (US) is through open pit mining by drilling, blasting and secondary breaking, whereas in South Africa it is by bench mining using a mechanical digger or front-end loaders. Primary crushing and secondary grinding by cone or roll crushers to liberation size before high intensity, dry or wet magnetic separation, possibly flotation and gravity separation methods such as tabling or jigging. Acid leaching is used to upgrade the concentrate.

Andalusite ore is crushed and screened followed by dense media separation, drying and magnetic separation (Figure 1). Further processing may reduce the iron content from 1% to 0.5%. Kyanite undergoes grinding and flotation, followed by drying and high intensity magnetic separation, and grinding to commercial grain sizes which are sold as raw or calcined material. Silliminate is produced by hand picking or separated from mineral sands via gravity, electrostatic and magnetic methods.

FIGURE 1: OVERALL PROCESS FLOW DIAGRAM FOR ANDALUSITE PROCESSING

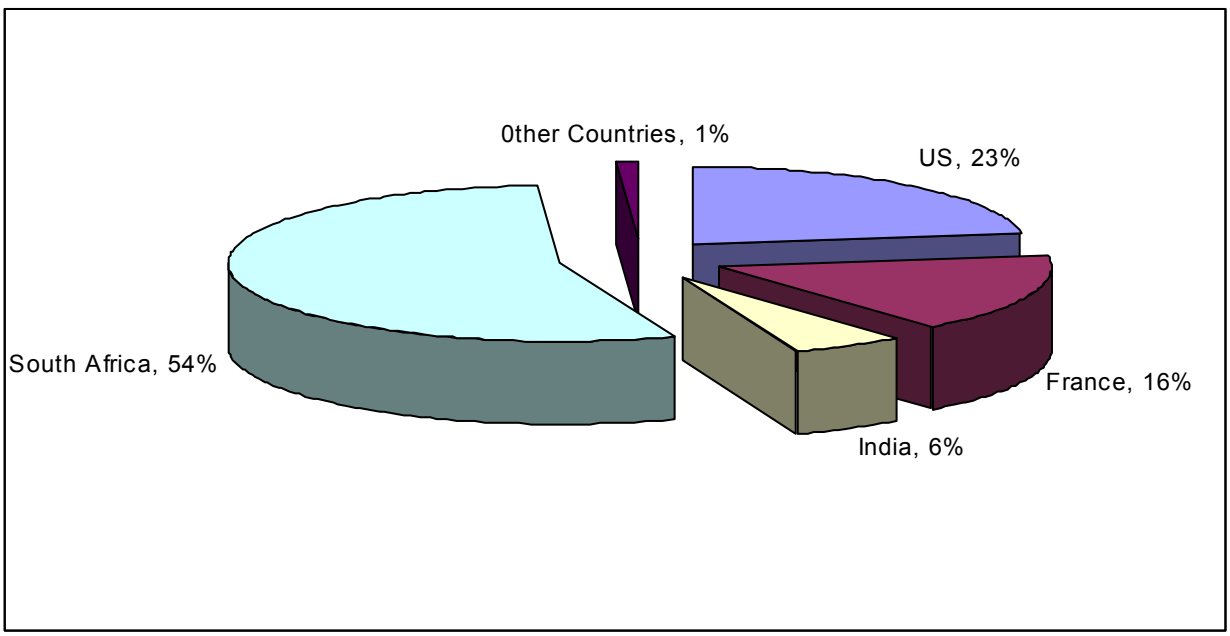


Source: DMR, Directorate Mineral Economics

2.3 WORLD PRODUCTION/ SUPPLY

World output for all three alumino-silicate minerals, namely: andalusite, kyanite and sillimanite amounted to 400 kt in 2008 (excluding production from China, which is believed to be from numerous small mines). The 10.9 percent decline compared with 449 kt produced in 2007, resulted from a 18.1 percent decrease in South Africa's annual production. South Africa, where only andalusite is produced, remained the largest producer, accounting for 54 percent of world output followed by the US at 23 percent and France at 16 percent (Fig. 1).

FIGURE 2 – WORLD PRODUCTION OF ALUMINO-SILICATES BY COUNTRY, 2008



Sources: USGS, 2008
DMR, Directorate Mineral Economics

2.4 WORLD DEMAND

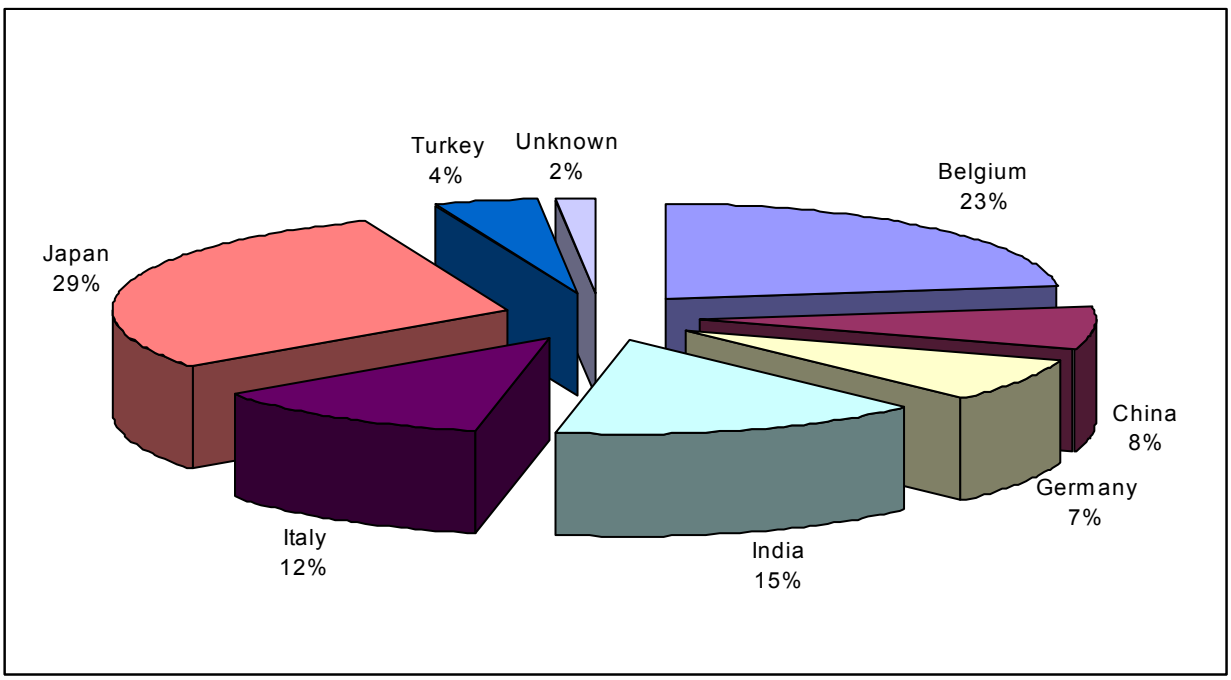
Refractory products continued to be the major end use of alumino-silicates. The steel industry is the leading consumer of refractories worldwide, consuming about 70 percent of global output of alumino-silicates, with the balance used for glass, aluminium, cement and foundry applications.

According to the World Steel Association, world crude steel production amounted to 1,3 billion tons in 2008, a decrease of 1,2 percent compared with 2007, resulting in lower demand for alumino silicates.

2.5 WORLD TRADE

The leading andalusite exporters are South Africa, France and the United states. Major importers of silliminate minerals and mullite are: Germany, the United Kingdom, Japan, Spain and Canada. South Africa exported 148 kt of andalusite in 2008, a decrease of 15.5 percent compared with 2007 due to lower demand.The major consumers of South African andalusite were Japan at 29 percent, Belgium at 23 percent and India at 15 percent (Fig. 3).

FIGURE 3 – SOUTH AFRICA'S EXPORTS OF ANDALUSITE BY DESTINATION, 2008



Sources: DMR, Directorate Mineral Economics

2.6 WORLD PRICES

According to UK publication, Industrial Minerals, South African market prices (2 000 tonne bulk, FOB) for 57-58 percent aluminium trioxide (Al_2O_3) andalusite concentrate ranged from €160-190/ t. The US prices for raw and calcined (54-60 percent) Al_2O_3 kyanite ranged from $ 167-309/ t and $ 295-423/ t respectively, in 2008.

South African average local and export prices increased by 12 percent to R1 548/t and 21.2 percent to R1 954/t respectively, as a result of annual price increases, in 2008 compared with 2007.

2.7 SUBSTITUTES

Substitute materials for sillimanite refractories include super-duty fireclay, high-alumina, fused-alumina, fused aluminium silicate, magnesia-alumina, silica and other refractories. Where it is the practice to use mullite refractories, however, the use of these substitutes would generally entail substantial loss in efficiency. In addition, some of the substitutes are themselves either difficult to obtain, to make or to install or they may be expensive.

Consequently in those countries where there is a domestic shortage of naturally-occurring raw materials for making mullite, attention has turned to the manufacture of synthetic mullite rather than to use of substitutes. Indeed, the shortage of supplies of the natural minerals and the strategic importance of mullite refractories have encouraged the production of synthetic product. The US alone, produces 40kt of synthetic mullite and has a significant reserve capacity.

Synthetic mullite can be made from a wide range of raw materials, since it appears to be formed whenever silica and alumina react at sufficiently high temperature. The principal raw materials of interest are bauxite, kaolin and low-grade silliminate minerals.

3. SOUTH AFRICA

3.1 LOCATION AND TYPE OF ANDALUSITE MINES IN SOUTH AFRICA

The South African andalusite production sites are shown on Figure 4. Most andalusite has developed in the metamorphic aureole of the Bushveld Complex. In the Thabazimbi, Groot Marico-Zeerust and Chuniesport-Penge-Lydenburg areas, optimum metamorphic conditions affected the argillaceous members of the Pretoria group resulting in the development of viable deposits of andalusite or chiastolite slates.

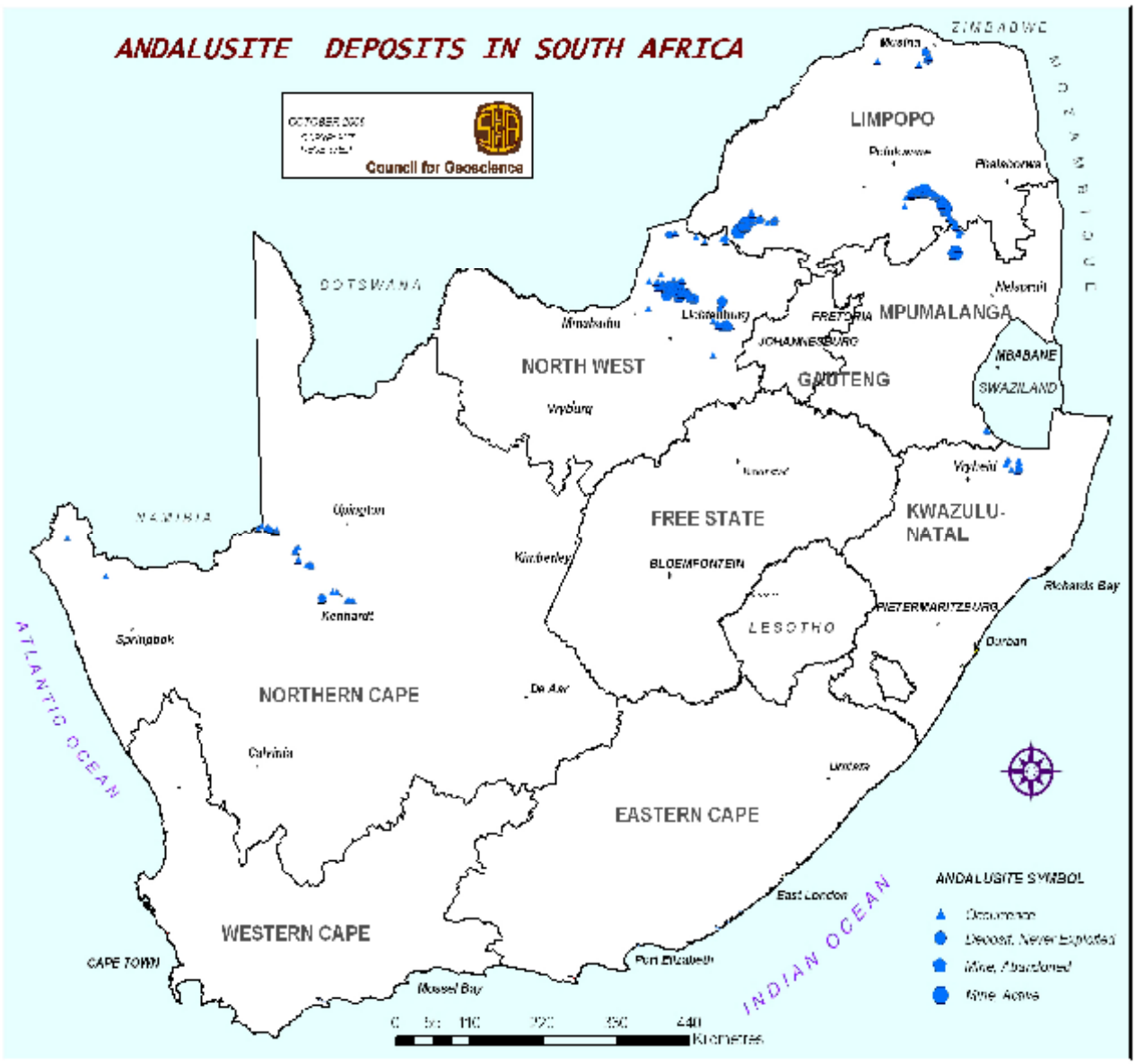
South Africa's andalusite production is dominated by Samrec, a company belonging to France's Imerys Group. Samrec has four mines and a processing plant in South Africa.

- Rhino Andalusite Mine near Thabazimbi, Limpopo Province
- Krugerspost Mine Lydenburg, Mpumalanga Province
- Havercroft Mines near Sekhukhuneland, Limpopo Province

- Annesley mine, on the outskirts of Burgersfort
- Apiesdoring Plant near Burgersfort, Limpopo Province

Andalusite Resources, the only other producer of andalusite, is locally owned and has a mine near Thabazimbi.

FIGURE 4: OCCURRENCE OF ANDALUSITE IN SOUTH AFRICA



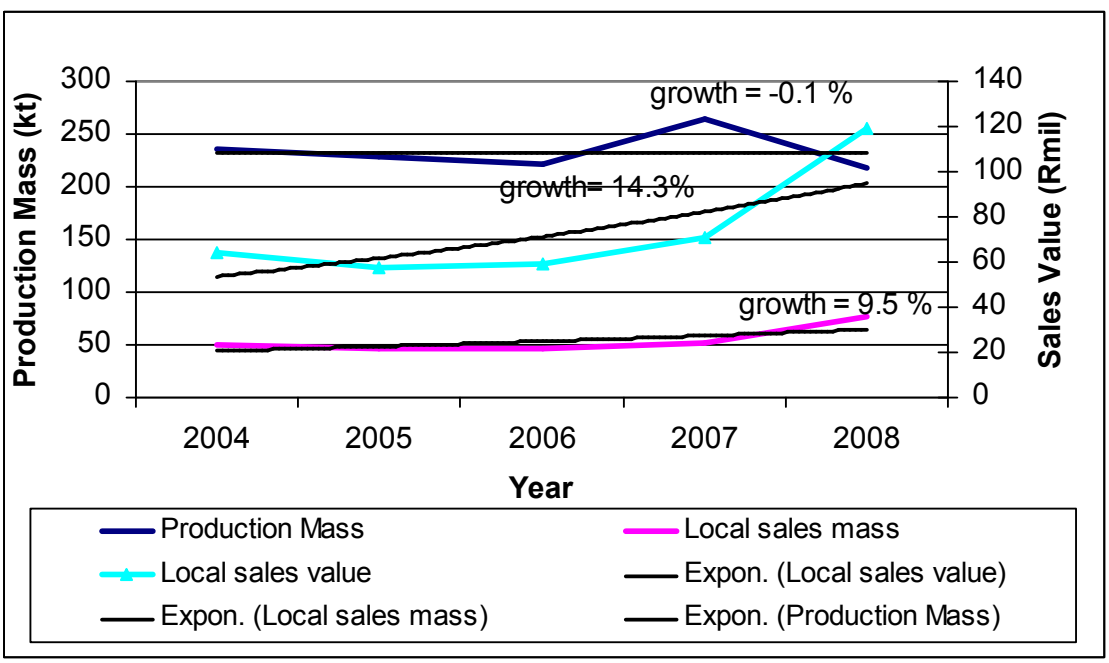
Source: Council for Geoscience, 2009.

3.2 PRODUCTION AND SALES

South Africa's andalusite production declined by 0.1 percent per annum between 2004 and 2008, with a crucial decline of 18.1 percent between 2007 and 2008, due to the effect of the global economic crisis (Fig. 5). Local sales mass increased at an annual growth rate of 9.5 percent boosted by increase in government infrastructure development projects, which enhance the consumption of steel. The value of local sales increased by 14.3 percent per annum, on the back of higher local sales volume and higher prices.

There is a need to promote local beneficiation of andalusite in line with the government's desire to ensure maximal value extraction from the country's mineral resources. Also the job creating potential of such value addition activity should not be under-estimated and will also contribute to greater economic growth in our country.

FIGURE 5: SOUTH AFRICA'S ANDALUSITE PRODUCTION AND SALES, 2004 – 2008

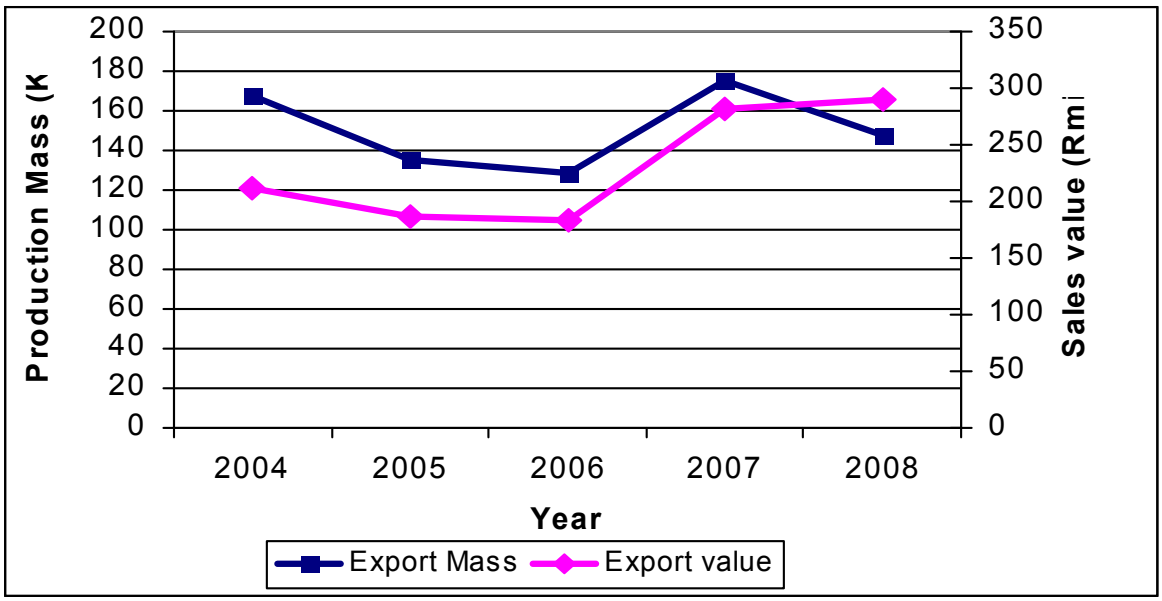


Source: DMR, Directorate Mineral Economics, 2008.

3.3 EXPORTS

Exports increased by 4 percent per annum from 168 kt to 175 kt due to an increase in demand from international markets, while export value also increased at an annual growth rate of 10 percent on the back of higher prices, during the period under study

FIGURE 6: SOUTH AFRICA'S EXPORTS OF ANDALUSITE, 2004 – 2008

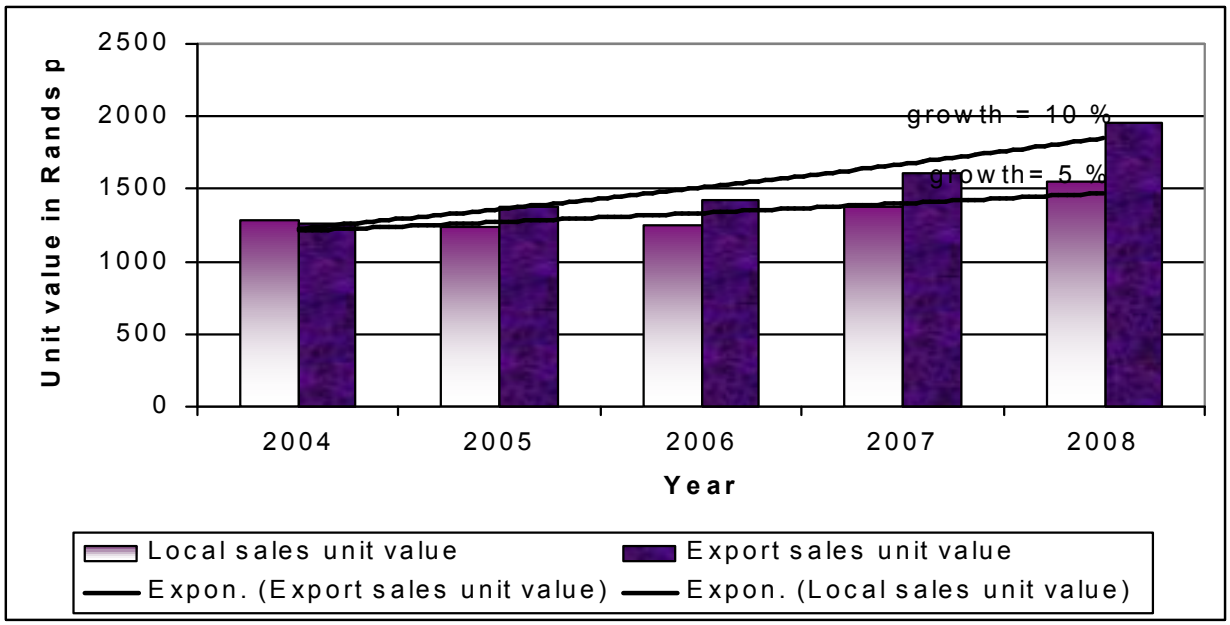


Source: DMR, Directorate Mineral Economics, 2008.

3.4 PRICES

Between 2004 and 2008, average local and export prices increased at an average of rate of 5 percent and 10 percent per annum respectively, owing to an increase in production costs and transport costs.

FIGURE 7: AVERAGE UNIT PRICES FOR ANDALUSITE, 2004 – 2008



Source: DMR, Directorate Mineral Economics, 2008.

4. SILLIMINATE MINERALS APPLICATIONS

Silliminate minerals have the following applications:

- **Refractories:** By far the most important use of mullite and silliminate minerals is as a refractory material. Andalusite is relatively inert refractory raw material that does not require calcining prior to use, and involves an internal conversion to mullite on heating to 1 350-1 600 ^{o}C.

  The chemical reaction for mullite production is as follows:

  $3(Al_2O_3.SiO_2)$ + heat ⟶ $3Al_2O_3.2SiO_2$ + SiO_2
  Silliminate mineral — Mullite — Free Silica

  At higher temperatures of approximately 1 800^{o}C, the mullite converts to corundum and liquid silica. The favourable characteristics of andulusite based refractories include: low thermal conductivity, high heat strength and low porosity. These special characteristics allow andalusite-based refractories to be effectively used in many refractory applications such as:

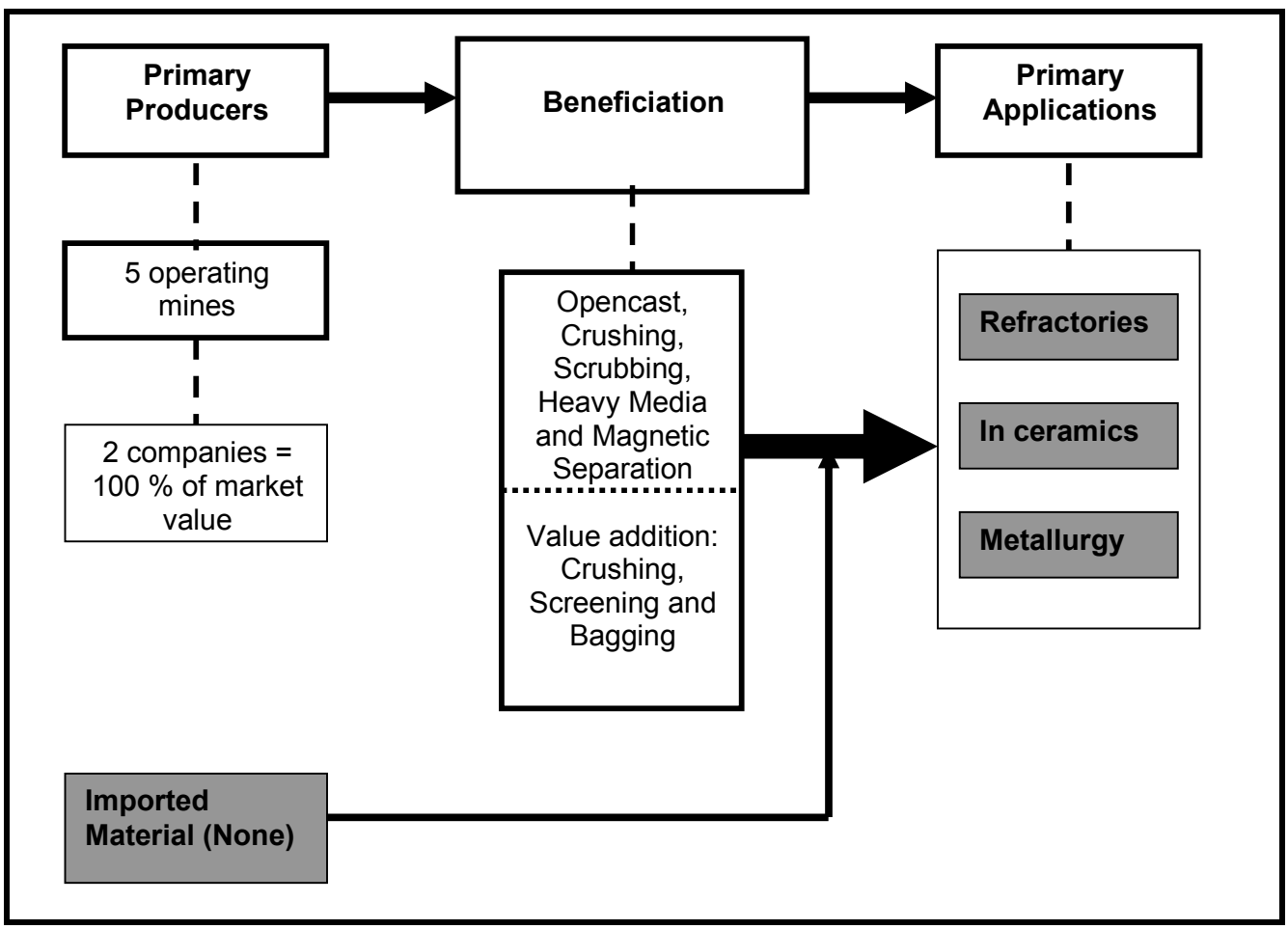
  - 50-60% alumina bricks used in ladles, tundishes and electric arc furnace rods
  - Graphite-alumina bricks for ladle floors
  - Delta sections in electric arc furnace roofs
  - Manufacture of mortars, blast furnace taphole clays and castables in blast furnaces and hot blast stoves
  - 60 % Al_2O_3 dry rammed, coreless induction furnace lining

- **Ceramics:** Andalusite and kyanite may be used as a source of alumina and silica in ceramics i.e. sanitaryware, cookware, dinnerware, ceramic tiles and electrical porcelain
- **Metallurgy:** Silliminate minerals are used as high temperature sands in forming casting molds, and finer mesh (200 and 325 mesh) grades are included in the mold sprays used to facilitate the removal of the metal casting from the mold i.e. ferrous and non-ferrous foundaries

- **Abrasives:** The silliminate minerals have a moderately high specific gravity and hardness with an uneven and tough fracture and act as a bond for abrasive particles e.g. grinding and cutting wheels

The major market for andalusite in South Africa is as a refractory material, as well as minor use in metallurgy and in ceramics (Figure 8).

FIGURE 8: SOUTH AFRICA'S ANDALUSITE INDUSTRY STRUCTURE

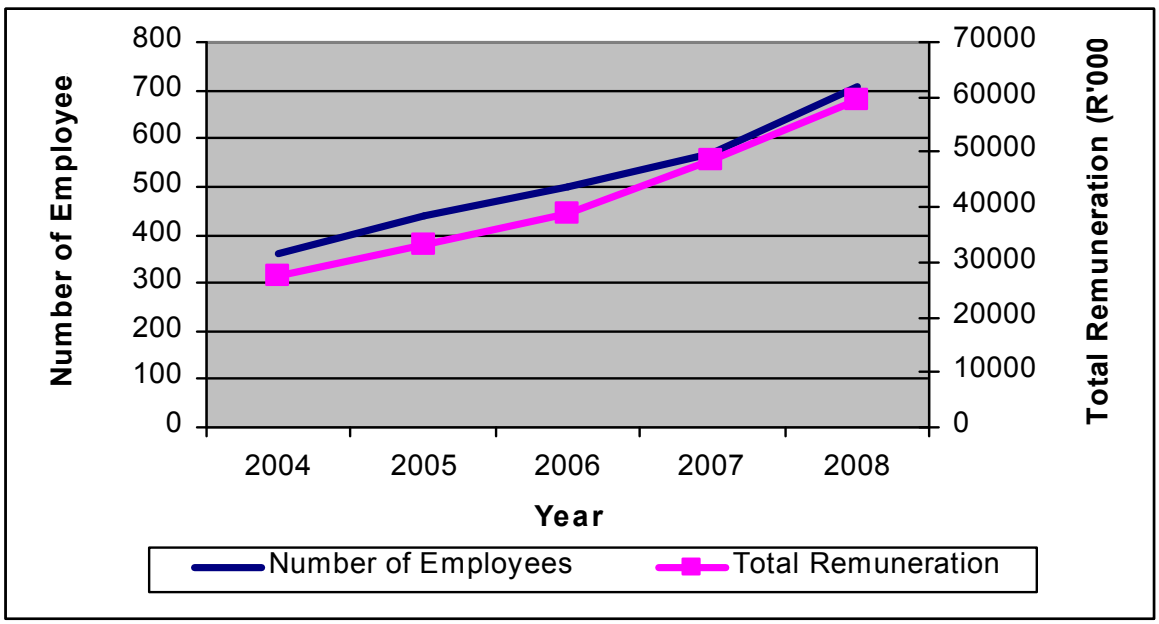


Source: DMR, Directorate Mineral Economics, 2008

5. EMPLOYMENT AND REMUNERATION

During the past five years, employment in the alumino-silicate industry increased by 16 percent per annum and remuneration by 19 percent per annum. The increase was attributed to the boom in the local and international steel markets.

FIGURE 9: SOUTH AFRICA'S ANDALUSITE EMPLOYMENT AND REMUNERATION, 2004-2008



Source: DMR, Mineral Economics

6. HEALTH AND SAFETY COMPLIANCE

Andalusite is a naturally occurring mineral that has been used beneficially in numerous industrial applications. It has been demonstrated as being safe to use, and no serious health risks have been found resulting from exposure to andalusite. Although andalusite is not a hazard, but dust can be present during handling causing coughing or sneezing, thus wearing of dust masks is recommended. Spillage of andalusite has no impact on the environment. The product should be transported in either bags or in bulk, the railway or road wagon to be tarpaulined in order to avoid excessive dust.

However, associated minerals such as silica, is unique to a particular deposit and, in some cases, could pose health risk if present in significant quantities. In South Africa many naturally occurring raw materials like minerals, ores and concentrates are subject to the authorizations provisions of the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), due to the fact that most ores concentrates contain naturally occurring hazardous substances.

The extensive global trade in chemicals attributed the formation of a globally harmonized approach to the classification, labelling and Material Safety Data Sheets (MSDS) for chemicals which resulted in the Globally Harmonized System of classification and labelling of chemicals (GHS). Chemical substances must be registered under the REACH, then classified under the GHS Regulation, before being evaluated, authorised and restricted.

The duty to produce MSDS, which are GHS compliant, will remain part of the REACH Regulation. In most countries manufacturers are required to publish and make available Material Safety Data Sheets (MSDS), which have to align with the requirements set out in the GHS. These sheets will typically identify any hazards associated with the material and also provide information on safe handling and proper disposal.

7. THREATS, RISKS AND OPPORTUNITIES IN THE INDUSTRY

Barriers for new entrants to the andalusite industry are:

- High start-up and production costs,
- Technical know-how regarding processing,
- Continued capital expenditure from day one,
- A need for continuous Research and Development (R&D) programs and funding,
- Strong competition from possible substitutes.

New entrants would need to undercut established producers on price or offer a more consistent product. Generally, it is easier to purchase an existing operation, or acquire an interest in one, than to start a new operation as compliance costs for first-time producers have escalated. Using an established company's brand name to promote a new product or material is an alternative approach. As relatively low-cost refractory product, andalusite has a firm position in the local and international market place and is not threatened in the short and medium-term.

8. CONCLUSION

The demand for silliminate minerals hence andalusite is dependent on the refractory manufacture for the steel industry, which is in turn linked to the construction industry. Prior to the global economic crisis, the demand for andalusite was strong. However, in 2008, there was a decline in the global crude steel production by 1, 2 percent due to the global market volatily, resulting in lower demand for silliminate minerals. The steel market has started to show some signs of recovery during the second half of 2009.

Although the local andalusite market was slightly depressed by the end of 2008, it is picking up slowly as customer's inventories are becoming depleted and are beginning to bear fruits. Despite the economic downturn, South Africa continues to be the major supplier of this vital commodity, since much effort has been made into improving, not only effiency of the plants, but also the quality of the products, through application of new technology so that the country's dominant position in this particular area can be maintained.

South Africa's andalusite producers, Imerys and Andalusite Resources are expected to increase South African production by 40 percent by 2012 attributed by the shortage of andalusite in the refractory market during the last two years. Prices are expected to continue to increase, especially with the increased usage of improved high quality refractories in the steel industry.

Natural raw materials such as andalusite and kyanite will continue to be important in the refractory manufacture. As the technology for refractories manufacture continues to improve, the use of andalusite in the production of refractories could continue to grow. The global refractories market will also be driven by the rapid industrialization of regions such as Asia, Eastern Europe and Africa.

Andalusite competes with a wide range of calcined kaolinitic and bauxitic alumina, with the determining usage factor being delivered raw material costs and comparative industrial service life of the finished refractory product. Nonetheless, andalusite has a firm position in local and international steel market and is not threatened in the short and medium term.

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