AN OVERVIEW OF ANDALUSITE IN SOUTH AFRICA: GEOLOGY AND MINERALOGY

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Abstract

Andalusite is part of the sillimanite-group minerals, as well as sillimanite and kyanite, which are all structural polymorphs of Al$_2$SiO$_5$. The importance of these minerals is due to fact that at 1350°C they convert to mullite (Al$_6$Si$_2$O$_{13}$), a highly refractory compound.

South Africa has the largest known reserves of Andalusite in the world and the largest portion of the andalusite is concentrated in various localities around the Bushveld Complex. The emplacement of the Bushveld Complex led to large scale metamorphism of the Pretoria Group rocks (floor rocks of the Bushveld Complex). The contact metamorphism resulted in a zonal development of cordierite-sillimanite, andalusite, and biotite-chloritoid hornfelses and slates.

Extensive andalusite deposits are found in areas with optimum metamorphic grade and chemistry of the host rock. Andalusite is exploited where the concentration is of economic grade, host rock sufficiently weathered for optimal extraction, and the quality of the material has not deteriorated due to retro-grade metamorphism or secondary alteration.

1. Introduction

The aim of this paper is to briefly discuss the mineralogy and geological of andalusite occurrences in South Africa.

South Africa is the world’s largest producer of andalusite and has the largest andalusite resources. Other note worthy andalusite deposits is in France, China and Peru. The deposits in France, China and Peru occur in dynamic metamorphic areas, whereas the most of the South African deposits are related to thermal metamorphism.

The South African andalusite production is concentrated on the south-western, eastern and northern edge of the Bushveld complex.
Figure 1: Simplified geology and andalusite deposits in South Africa

Most of the work presented here is based on work done by Imerys and Anglovaal as well as M. Blain from the geological survey.

2. **Mineralogy and chemistry**

Andalusite was first described and named after Andalusia in Spain where it occurs as a metamorphic mineral in the Pyrenees mountain range.
The general chemical composition of andalusite is $\text{Al}_2\text{O}_3\text{SiO}_2$ of which 62.9% is $\text{Al}_2\text{O}_3$ and 37.1% is $\text{SiO}_2$. Substitution of the $\text{Al}^{6+}$ by $\text{Fe}^{3+}$ gives the andalusite a pinkish colour and the substitution with $\text{Mn}^{3+}$ gives a green colour. Substitution $\text{Al}^{6+}$ is less than 2%.

Andalusite is a neosilicate were the $(\text{SiO}_4)^4-$ is linked with $\text{Al}^{5+}$ and $\text{Al}^{6+}$. This leads to a high symmetry of the crystal lattice and is the contributing factor to the hardness of andalusite.

Andalusite is the low temperature and pressure end member of the alumina silicate group with kyanite (high pressure) and sillimanite (high temperature) as the other end members.

Andalusite forms at temperatures in excess of 550°C through dynamic metamorphism or thermal metamorphism. The andalusite occurrences in South Africa, which are currently being mined, all resulted due to thermal metamorphism.

Andalusite commonly exhibits a cross of carbonaceous material called chiastolite. The chiastolite forms thought the entrapment of carbonaceous material during crystal growth as indicated in Figure 2.
Figure 3: Formation of chiastolite and andalusite

The chiastolite cross normally contain mineral inclusions that cannot be removed during beneficiation such as biotite (Fe2+), which affects the final product grade. An example of biotite inclusion in the chiastolite cross can be seen in Figure 4.

Figure 4: Biotite inclusion in chiastolite

As soon as the pressure or temperature that lead to the development of the andalusite crystals, the crystals starts back on a retro-grade metamorphic path back to its original state. This leads to the formation sericite and muscovite alteration rims on the crystals. In severe cases most of the crystal is substituted by sericite and muscovite which leads to “light” andalusite crystals that cannot be recovered during beneficiation. The amount of retro-grade metamorphism also determines the friability of the andalusite crystals and therefore the size of the crystal recovered.
3. **South African Andalusite Occurrences**

As mentioned andalusite form at a temperature of 550°C at low pressures under two possible mechanisms. The first being dynamic metamorphism associated with collision zones such as continent – continent plate of oceanic plate and continental plate collision zones. In the Northern Cape in the Namakwa metamorphic belt andalusite occurs as as small lenses and narrow zones, which is not of economical importance.

The second mechanism is thermal metamorphism, also referred to as contact metamorphism. This is where a heat source is required, normally a magmatic intrusion, that elevates the temperature of the surrounding rocks to the necessary temperatures required for andalusite formation. The best example of this is the Bushveld complex which covers an area of 66,000 km² and the most economically viable andalusite occurs here, not only in South Africa, but the world.

The Bushveld complex intrusion into the Pretoria Group sequence took place approximately 1.6Ba ago. The Pretoria Group consisted of a sequence of coarse grained and silt material. The shales of the Preoria Group, especially the politic units of the Timeball Hill and Silverton Formations, were rich in alumina. The intrusion metamorphosed the floor rocks in a zonal fashion with the development from a cordirite-sillimanite, to andalusite, to biotite-hornfelses and slates.

The Pretoria Group sequence was also deformed during the emplacement of the Bushveld complex. The Pretoria Group dips toward the center of the Bushveld complex. This new geometry assisted in the exposure of the andalusite bearing schist to the elements. This led to the characteristic valley-and-hill landscape of the areas surrounding the Bushveld complex. This is important as andalusite recovery from its host rock is dependant on the hardness of the host rock.

It is important to note that the optimal conditions were only present in certain areas in the Bushveld metamorphic aureole that lead to economical viable andalusite deposits.

Currently andalusite is being mined in the northern-western Bushveld, Thabazimbi, and the eastern Bushveld, Lydenburg and Penge. Economical deposits also occurs south-western limb of the Bushveld complex, Groot Mariko, but is not currently being exploited.
A short summary of each deposit follows.

3.1 Thabazimbi (Rhino Andalusite Mine)

- Mineralisation occurs in the lower pelitic unit of the Timeball Hill formation of the Pretoria group.
- The succession is steeply dipping at 45 degrees to the south.
- Up to 15% andalusite in the host rock.
- Al₂O₃ > 59%, FeO₂ < 1%.
- The host rock is highly weathered hornfels.
- Crystals show Fe²⁺ staining, which is most probably due to leach of iron from the nearby banded iron formations.
- Crystals in top part of the deposit is also more altered due to weathering.

3.2 Penge (Havercroft and Annesly Andalusite Mine)

- Mineralization occurs in the upper politic unit of the Timeball Hill formation of the Pretoria group.
- The mineralized strata dips at 13 degrees to the west.
- Increase in crystal quality and size towards the bottom of the succession.
- Mineable zone qualities: Al₂O₃ > 58.5% and FeO₂ < 1%.
- Large crystal sizes especially in last 10m of succession.
- Little to no crystal alteration.
- Occurrence of various diabase sills in the upper part of the succession that leads to an increase in the FeO of the andalusite (discarded as waste) through the secondary growth of biotite in the chiastolite.

3.3 Lydenburg (Krugerspost Andalusite Mine)

- Mineralization occurs in the Lydenburg member of the Sylverton formation of the Pretoria group (this is a younger sequence than the Timeball Hill formation and is due to the variance in the metamorphic effects of the Bushveld complex).
- Mining areas divided by lateral faults.
- Dip of mineralized strata variable due to faulting, but predominantly 5 degrees east.
- Homogenous mineralized zone with small to medium sized crystals.
- High levels of FeO coatings on the crystal surface, which is related to the original host rock chemistry.
- Al₂O₃ > 55% and FeO < 0.1.
- Well developed chiastolite.
4. **The Andalusite Value Chain**

Although this article focuses on the overview of mineralogy and geology, it will not be complete if it is not discussed in relation with beneficiation and subsequent temperature treatments.

Mining of andalusite is generally done opencast utilizing trucks and shovels. Blasting of the material is required only to crack the material in useable sizes for loading and transportation.

The beneficiation process of andalusite is quite simple. The ore from the mine is crushed to -100mm. The +60mm is discarded as coarse waste. The -0.5mm is discarded as slimes. Normally the crystals liberate easily from the host rock as it is normally highly weathered.

In some instances the ore goes through a scrubber to ensure that crystal coatings and host rock attachments are removed.

Thereafter the crushed and screened material is separated into ore and waste through a heavy medium separation circuit with cyclones and ferro-silicone as medium. The andalusite reports to the underflow, which then passes through a dryer.

The last stage of beneficiation is passing the ore through a magnetic separation circuit to remove the iron rich crystals, garnets and other waste from the final product stream.

The final product is sent to the refractory industry for castables, gunning, mortars, plasters and refractory bricks.

Challenges for the andalusite producing industry is establishing methods to beneficiate the large amounts of iron rich (1% to 1.5%) andalusite ore that is currently not mined and/or discarded as waste.

5. **Conclusion**

South Africa has very large resources of andalusite of which a large percentage is economically viable and is being exploited along the rim of the Bushveld complex.

The development of andalusite resulted mainly from the metamorphism due to the emplacement of the Bushveld Complex and the chemistry of the politic rocks of the Pretoria Group. Although variances in the host rock chemistry was a factor in andalusite formation the degree of metamorphism was the decisive controlling factor.

In South Africa the following factors are all in place to ensure the optimal exploitation of its andalusite resources:
• Well developed infrastructure on the Bushveld Complex rim;
• Optimal metamorphic grade (influences crystal size) and chemistry of host rock (influences crystal quality and abundance);
• Weathering of the bed-rock;
• Lack of retro-grade metamorphism and secondary alteration;
• Very low occurrences of detrimental minerals such as staurolite and intergrowths of biotite, sericite and iron oxides.

Due to all the above factors South Africa is ideally placed to stay the world leader in andalusite production.

6. References