Mica and vermiculite in South Africa*

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SYNOPSIS

In South Africa and in the rest of the world, the two mica minerals that have the most important commercial value are muscovite and vermiculite.

Muscovite has been making a comparatively small but steady contribution to South Africa's mineral exports since about 1960.

Vermiculite mining and concentration were started by the late Dr Hans Merensky at Phalaborwa during 1946. Vermiculite has enjoyed good overseas sales since then, and during the past four years has become an important earner of foreign currency for South Africa.

The various aspects of the micas that could be of general interest are briefly reviewed, such as the history of their exploitation, their mineralogy and chemistry, and their mining, concentration, production, sales, and future.

SAMEVATTING

In Suid-Afrika, asook in die wêreld as 'n geheel, is die twee mika (glimmer) minerale met die belangrikste handelswaarde, muskowiet en vermikuliet.

Muskowiethet 'n betreklike klein, maar bestendige bydrae gelewer tot Suid-Afrika se minerale uitvoere vanaf ongeveer 1960. Vermikuliet mynbou en konsentrering was begin te Phalaborwa deur wyle Dr. Hans Merensky gedurende 1946. Vermikuliet het goeie oorsese verkope geniet vanaf 1946 en gedurende die afgelope vier jaar 'n belangrike buitelandse valuta verdien vir Suid-Afrika geword.

Die verskeie aspecte van die mikas wat van algemene belangstelling kan wees word kortlik bespreek sos die geskiedenis van hul ontginning, mineralogie en chemie, mynbou, konsentrering, produksie, verkoop en toekoms.

INTRODUCTION

The only two species of mica that occur very commonly are muscovite and biotite. These two micas are important constituents of many igneous, sedimentary, and metamorphic rocks, and of all kinds of loose surface deposits derived from them such as river and beach sands, and soils. Muscovite is, in fact, one of the most indestructible of minerals in nature and can withstand any degree of weathering. Biotite is rather less-resistant in this regard.

A third species of mica, phlogopite, is much more sparsely distributed. It is found in certain ultrabasic rocks such as kimberlites and the ultrabasic members of alkaline and carbonatite complexes; for example, the Palabora Igneous Complex. It is also found in certain metamorphosed dolomites and serpentinites.

The only two micas of established commercial value in South Africa are muscovite and phlogopite—muscovite for its own properties, and phlogopite essentially because of its alteration product, hydrophlogopite alias vermiculite.

MICA-GROUP MINERALS

Physical Properties

The various micas have certain very characteristic common physical properties. The most notable is their flaky form due to highly perfect crystallographic basal cleavage. Mica normally takes the form of numerous single flakes adhering naturally together to form books. The individual flakes, which are pliable, resilient, and tough, can be separated like the pages of a book and can be rendered as thin as some 20 μm by delamination.

A further notable feature of all micas is that the flakes have glass-smooth surfaces and have high reflectivity. In this regard, the Germanic name glimmer is undoubtedly most descriptive and apt.

The colour varies according to the particular species. Muscovite is colourless or of a pale colour, biotite is brown to black, phlogopite has a purple or bronze colour, and lepidolite (lithia mica) is rose- or lilac-coloured.

The micas have very low electrical and heat conductivity, and can withstand high temperatures. In this respect, the two pertinent micas are muscovite with an upper limit of 550°C and phlogopite with a much higher limit of 1000°C.

The size of the flakes varies, generally in relation to the texture of the rocks in which they occur. The coarsest micas, as is to be expected, are found in igneous rocks of pegmatitic structure. The granitic pegmatites are the source of coarse muscovite, including the exceptionally large crystals of sheet mica. Coarse phlogopite is a constituent of pegmatoid ultrabasic rocks such as those of the Palabora Complex. The occurrences of pyroxene pegmatoid and the serpentine pegmatoid shown on the geological map of Fig. 2 contain a substantial proportion of coarse phlogopite and of its derivative, hydrophlogopite.

Chemical Composition

The chemical composition of various micas is as follows:
Muscovite (potassium mica) \( \text{H}_2\text{KAl}_6(\text{SiO}_4)_3 \)
Biotite (magnesium–iron mica) \( \text{H}_2\text{K}(\text{MgFe})_5(\text{Al}, \text{Fe})(\text{SiO}_4)_3 \)
Phlogopite (magnesium mica) \( \text{H}_2\text{KMg}_3(\text{SiO}_4)_3 \)

Of the several other species in the mica group, only lepidolite (lithia mica) is of more than academic interest.

Chemically considered, the micas are silicates, and in most cases orthosilicates, of aluminium with potassium and hydrogen, and also often magnesium and ferrous iron. Ferric iron, lithium, and other elements also occur in certain species.

The mica species all yield water on ignition, mostly from 4 to 6 per cent. This can be regarded as water of constitution, and hence the micas are not proper hydrous silicates. As will become evident later in this review, this is in contrast to the vermiculites, which are hydrous silicates.

It can be seen from Table I, that the conversion of phlogopite to hydrophlogopite is a matter of loss of alkalies and a gain in water. The same holds for the conversion of biotite to hydrobiotite. Muscovite apparently is resistant to such conversion because of its resistance to weathering. Therefore there are, for practical purposes, only two minerals in the vermiculite group, if one can use the term, namely hydrophlogopite and hydrobiotite.

A theoretical chemical formula for hydrophlogopite is given later in this review under the heading ‘Vermiculitization’. Hydrobiotite would have a similar formula but with less or no magnesium content.

### TABLE I

<table>
<thead>
<tr>
<th>Constituent</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
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<td>100,89</td>
<td>100,10</td>
<td>99,46</td>
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</table>

1 Coarse unaltered phlogopite, VOD orebody (Gevers, p. 154, analysis I)
2 Golden-yellow vermiculite, VOD orebody (Gevers, p. 154, analysis II
3 Brownish-yellow, VOD orebody (Gevers, p. 154, analysis III)
4 Surface-weathered, leathery, golden-yellow vermiculite, VOD orebody (Gevers, p. 154, analysis IV)
5 Fine-grained vermiculite (hydrobiotite), southwest of Loolekop (Gevers, p. 154, analysis VI)
6 Muscovite, Marble Bath Mine, Mica (McLachlan & Lazar (Pty) Ltd, 1984)

### History

Muscovite owes its name to the Latin *vitrum muscovitum* or muscovy glass, formerly a popular name for the mineral. In the following text *mica* is synonymous with *muscovite*.

In South Africa, the areas around Mica in the eastern Transvaal and the Kenhardt andNamaqualand districts of the northwestern Cape Province have been the only localities in which the production of muscovite of any importance has taken place (Fig. 1).

In the Mica area, muscovite production on a mentionable scale first started in 1909, but was hampered by the fact that the nearest railway station was at Pietersburg, a distance of 190 km over a primitive earth road. After 1912, when the Selati railway line came into operation, the conditions for transportation and marketing improved considerably. The railway line happened to pass over this mica field, hence the name Mica Siding—later, Mica Station.

The pegmatite belt in the northern Cape Province has had a longer and more interesting and colourful history than the Mica field, but not because of its muscovite production, which has never been important. Since well into the past century, its attraction has always been the great variety of rare and valuable minerals that have been found and recovered from this vast pegmatite belt. Substantial quantities of beryl have been produced over a long period, and also quantities of tourmaline, gadolinite, cassiterite, spodumene, columbite-tantalite, garnet, lepidolite, scheelite, wolframite, etc., from thousands of small to comparatively large workings by individual diggers, syndicates, and mining companies.

### Uses

Initially, the demand was for muscovite in comparatively large laminae, known as sheet mica, with dimensions of 5 to over 20 cm, but production declined and sheet mica has not been marketed in South Africa since 1970, except of the order of 50 to 200 kg per year in certain years.

Sheet mica has always been a scarce commodity because it makes up only a small portion of the total mica in pegmatites, and the perfect quality, ruby mica, is not available from South African pegmatites. Effective substitutes for sheet mica have been evolved, which, coupled with its scarcity, has virtually phased it out of world markets.

However, the much more abundant mica of the pegmatites, the smaller size flake mica, is put to many uses. It is concentrated out of the host pegmatite and is almost entirely finely ground, mainly in wet form, water-ground mica, but it is also ground dry, dry-ground mica.

Water-ground and dry-ground micas have a variety of applications as filler and brightener for paints, filler in plaster boards, roofed roofing, asphalt shingles, special cements, moulded electrical insulation, fire-resistant boards, rigidized plastics, a component in wallpaper coating, concrete and tile surfacing, welding-rod coatings, absorbents, special greases, lubricant in the manufacture of moulded rubber products such as tyre moulds, heat insulation of boilers and steam pipes, and drilling muds. A small quantity is even used in cosmetics. A smaller
amount of flake mica is not processed to ground mica, but goes mainly into the production of mica paper, as a substitute for sheet mica.

An extremely fine mica product, less than 40 μm in size, has become a competitor to the conventionally ground mica. It is micronized mica, and is produced by the acceleration of fine particles of flake mica to very high speeds in a confined space so that they collide and disintegrate. Micronized mica was first introduced in Europe to retain the paint market previously held by water-ground mica.

**Occurrences**

The two muscovite-producing regions of South Africa are shown in Fig. 1. In order of current economic importance they are the Mica region of the north-east Transvaal and the northwestern Cape region.

The occurrences of muscovite in the eastern Transvaal are along a belt 4 to 8 km wide, extending from west of Mica, eastwards towards the Lebombo Mountains in the Kruger National Park, a distance of about 100 km.

The deposits of commercial muscovite from this area are restricted to coarse-grained pegmatites intrusive into Archaean granites and gneisses. The pegmatites are as much as several hundred metres in length and 20 m or more in width; they are more or less parallel to one another, and their strike direction is approximately east-northeast. They are composed essentially of quartz and felspar, with scattered muscovite as flakes and sometimes as books, the latter forming irregular nests and pockets up to 3 m in size.

The easily recoverable near-surface muscovite from a large number of quarries in pegmatite outcrops has been mined out, and very little is now obtained from open workings. The once-numerous mines have now been reduced to only a few with a significant output.

In the northwestern Cape Province, the pegmatites are associated with late- to post-tectonic granites and gneisses of Mokolian age, in a belt 15 to 20 km wide and some 450 km long, between Kenhardt in the east and Steinkopf in the west.

**Production**

Pegmatites are notoriously difficult to mine because of the sporadic and unpredictable distribution of all the economic minerals, including muscovite, recovered from them. In South Africa, the mining of mica can be payable only if felspar and other minerals are recovered at the same time. Muscovite has been mined for its own sake only at Noumas No. 1 Mine in the Steinkopf Coloured Reserve, halfway between Steinkopf and Vioolsdrif.

In 1986, ground mica was produced mainly by two companies. The Mica area (Geltich Mining Industries) contributed 92.3 per cent of the total mass, with the balance from the Steinkopf Reserve (Garieb Minerals). Of the total mass of mica produced in South Africa during 1986, water-ground mica contributed 60 per cent, the rest being dry-ground mica and usable flake mica.
The production and sales of muscovite from 1957 to the end of 1986 are given in Table II, which is a combination of two tables derived from publications by De Villiers and Hugo and by Gössling. The annual sales revenues after 1979, at the request of the producers, are not available for publication.

### TABLE II
Production and Sales of South African Muscovite

<table>
<thead>
<tr>
<th>Year</th>
<th>Sheet mica</th>
<th>Flake mica</th>
<th>Ground mica</th>
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<th>Value R</th>
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<td>4 065</td>
<td>48 414</td>
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<td>4 083</td>
<td>32 408</td>
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* Production figures are based on total sales
† Including usable flake mica

In respect of the world production of mica in 1985, Table III shows that South Africa’s contribution is small.

### Future Markets
Alternative materials such as polyamides, polyesters, polystyrene, alumina, steatite ceramics, fused quartz, and silicon rubber have lately made inroads as substitutes for mica, notably sheet mica.

The total annual world tonnages of mica are small compared with those for other base minerals, and these relatively small tonnages of mica are made into a large number of technical products requiring a variety of different raw materials and supplied in relatively small quantities to widely dispersed markets around the world.

Therefore, despite the threat of substitutes, the traditional outlets of mica products are considered relatively stable with limited growth within the construction, automotive, and oil industries. The production and marketing of mica should progress slowly yet with stability and, despite pronouncements to the contrary, there appear to be no major disturbing influences on the horizon.

### Mining
The pegmatite mines of the eastern Transvaal and northwestern Cape Province are essentially felspar-muscovite mines with accessory pure quartz. The pegmatites of the Mica area are of the barren type, with little or no valuable minerals such as common and ruby corundum, common and emerald beryl, cassiterite, and gem tourmaline. The pegmatites of the northwestern Cape Province are more often of the complex unhomogeneous type, and valuable accessory minerals have been recovered from them.

The main constituent of most pegmatites in South Africa is rock composed of intergrowths of felspar and quartz in variable proportions. The quartz has no value but has to be mined together with the accompanying felspar and mica. In earlier times, the miners tried to mine out the felspar and muscovite selectively, and for this reason the older quarries are often unbelievably irregular excavations resembling dolomite sinkholes and caverns. The later quarries, where such selectivity was not applied, are more conventional excavations.

In the Mica area, opencasting was followed by underground mining. One of the first mines was the now-abandoned Lady Godiva Mine. Some years ago, the Marble Bath Mine operated by Gelletich Mining Industries also progressed from open to underground mining. At the latter operation, access to the underground working is by a 30-degree inclined haulage shaft fitted with a 450-mm gauge track. Ore and waste are hand-loaded into cocopans in the stopes, and are hauled via the inclined shaft to the surface by mechanical rope hoisting.

The mine has reached a depth of about 120 m below surface and has natural ventilation. The rock is drilled with compressed-air jackhammers in a stowing operation. It is blasted with Dynagel cartridges used in conjunction with igniter and safety fuse.

The article used for reference does not give the ton-
nage output for this mine, but it is not a large-scale operation.

Concentration Processes

Concentration involves the excavation of the muscovite, and also the felspar and quartz, out of the broken aggregate of pegmatite and wall-rock, and includes various arrangements of crushing, hand-sorting, trommelling, screening, washing, and blowing according to the preference and ingenuity of the individual operator. In the fields of both Mica and the northwestern Cape Province, this can vary from primitive procedures to a fairly high degree of sophistication. The Marble Bath Mine at Mica can serve as an example of the latter.

After blasting at the Marble Bath Mine, the felspar and quartz are sorted out underground from the mica and waste rock. On the surface, the former two minerals are separated on a sorting belt and stored. The waste rock, made up of felspar-quartz intergrowths (Quagga Klip) and wall-rock schists and granites, is mainly sorted out underground and, on reaching the surface, is put onto waste dumps. The remaining constituent, the muscovite, is kept separate underground as much as possible, and is conveyed to the beneficiation plant admixed with some felspar, quartz, and waste rock.

This muscovite-rich material is passed over a 25 mm vibrating screen. The oversize is hand-sorted on a conveyor belt, where the felspar and quartz are picked out. The remaining rock goes to waste. The muscovite is sent either to a dry-grinding plant or to a mica stockpile. The minus 25 mm undersize is passed through an air separator, and the concentrate is deposited on the mica stockpile. The middlings fraction is sun-dried and then reconcentrated twice through an air separator, and the residual tailings go to waste.

The mica stockpile, which contains material that is to be water-ground, is ground in series through three Chilean mills. Each of these consists of two steel milling wheels of 1,83 m diameter, rolling round the floor of a cylindrical pan. The discharge from the third Chilean mill is passed over a 4 mm screen. The oversize, consisting of mica flakes and rock grit, is sent to the mill middlings plant, where it is trommelled to remove the grit. The trommel oversize is returned to the Chilean mills together with the stockpiled mixture of mica flake and grit.

The finely ground screen undersize pulp is size graded over three screens in series to produce three size grades, namely 60, 180, and 325 mesh. These products are allowed to settle out in tanks of various sizes over a 48-hour period. After the water has been decanted, the dewatered pulps from the tanks are pumped onto large drying surfaces known as Roman tables. On these drying tables, the pulp is heated from below by means of hot air supplied by burning coal. The dry pulp is broken up in a small hammer mill and is then bagged according to the above-mentioned size grades and sold as water-ground mica.

In respect of dry-ground mica, Geltech Mining Industries started to produce this material in 1982. South Africa's needs for dry-ground mica were formerly met by imports, but the plant at the Marble Bath Mine can now supply the demands of the domestic market. Unlike water-ground mica, it is not a payable export because of low prices in the consuming countries.

This material is produced by putting mica from the abovementioned mica stockpile through a series of hammer mills and then over screens to produce two commercial grades, minus 20 and minus 60 mesh. By the use of other screens, other size grades can also be produced.

Biotite

Biotite is used on a limited scale in other countries in place of muscovite, but in South Africa it has no applications. The Palabora Complex holds considerable quantities of biotite in two places—on the western side of Loolekop, the zone of predominantly mica rock shown in Fig. 2, and also in a large patch (not denoted in Fig. 2) about 1.5 km southwest of Loolekop.

Phlogopite

The word phlogopite comes from the Greek word meaning 'fire-like' in allusion to its colour.

Geological Setting

As mentioned previously, phlogopite is a characteristic component of ultrabasic rocks in alkaline and carbonatite complexes, of which there are three well-known examples in the Transvaal. The Klein Letaba Complex to the east of Bandellerkop and the Glenover Complex in the far northwestern Transvaal contain considerable reserves of phlogopite, but the most important reserves are in the Palabora Complex.

Fig. 2 gives a picture of the lithological assemblage constituting the Palabora Igneous Complex. The ultrabasic rocks form its central core. This is a deeply eroded volcanic pipe—probably the deep root zone of a very ancient volcano that erupted some 2000 million years ago. In Fig. 2, it is the area of irregular outline measuring some 6 km north–south and some 2.5 km east–west.

The early intrusion of the ultrabasic rocks was followed by a final alkaline phase of intrusion that resulted in many bodies of syenitic rock scattered over a wide region around the central ultrabasic pipe of Fig. 2. The syenite rocks are resistant to erosion, and have formed the many picturesque bare rock tors and rocky hills of the Phalaborwa lowveld region.

The areas of pyroxene pegmatoid and serpentine pegmatoid of Fig. 2 are underlain by phlogopite rock in which much of this mineral is of coarse flake structure.

The mining at Phalaborwa has shown that the phlogopite in the abovementioned areas is almost completely altered to vermiculite to a maximum of some 50 m below surface. This top zone is followed downwards by a transition zone of vermiculite intermingled laterally with more or less vermiculitized phlogopite. This zone is probably fairly thick everywhere. It is, in turn, underlain by unaltered phlogopite to great depth.

Uses

In the past, phlogopite was evidently a more costly commodity than muscovite. To quote from a 1955 publication: 'The higher cost of phlogopite prevents it from competing successfully against muscovite, except for electrical insulation, for which it is preferable'. Therefore, in the past, this consideration may have prevented its use in industry.

Vermiculite mining at Phalaborwa has exposed great
Fig. 2—The Palabora Igneous Complex

PMC = Palabora Mining Company
PP&V = Palabora Phosphate & Vermiculite Company—now part of Palabora Mining Company
VOD = Vermiculite Operations Department of Palabora Mining Company
reserves of phlogopite that can be recovered relatively cheaply. The properties of muscovite and phlogopite are much the same, and it seems feasible that phlogopite could be a less costly substitute for muscovite. The primary criterion, of course, is that the phlogopite must be fresh and unaltered.

Extraction of Potassium

South Africa is well endowed with many minerals but it has poor reserves of potash and alumina, and to date no economic deposits of these two commodities have been found. For this reason, Palabora Mining Company has carried out full-scale investigations over recent years to extract the 10 per cent K₂O contained in phlogopite, with the recovery of alumina as a byproduct. Two processes were evolved: the Gypsum Process and the Acid Process. The latter gave the more promising results, but, to quote from Basson: 'it is safe to say that a vast reserve of potassium exists and that a process or processes have been developed for the selective recovery of this. It may not be an economic viability under current conditions, but it can be exploited whenever the need arises'.

In respect of the extraction of potash from phlogopite, the prime criterion of a fresh unaltered state also applies. With the process of weathering and consequent vermiculitization, the K₂O content of fresh phlogopite is reduced to a trace in vermiculite, as demonstrated by the chemical analyses of Table I.

To obtain sufficient fresh phlogopite for uses such as those that apply to muscovite need not be a problem because the tonnages required are not likely to be large. For use as a source of potash, however, large tonnages of phlogopite would have to be processed, and the availability of sufficient fresh material could pose a cost problem.

VERMICULITE-GROUP MINERALS

Hydrophlogopite

History

The history of vermiculite mining in South Africa is essentially the history of vermiculite (hydrophlogopite) mining at Phalaborwa. Comparatively small quantities were produced for limited periods in the past from other deposits such as the occurrence near Bandelierkop in the northern Transvaal, but production from them has long since ceased.

The discovery of the remarkable degree to which phlogopite expands on heating was probably made a long time ago. A small book of vermiculite, when heated, can expand to thirty times its original volume, stretching out slowly into a long worm-like form. This characteristic has given the name to this mineral—from the Latin vermiculari, which means to breed worms.

The excellent fire-resistant and heat- and sound-insulation properties of expanded vermiculite eventually resulted, some fifty years ago, in its being used for these purposes.

In a review of the Phalaborwa vermiculite, Gevers' wrote: 'Although reddish brown mica (phlogopite) has been mentioned by Dr Mellor as early as 1906 and in spite of the fact that considerable quantities of "rotten mica" had been found to be associated, particularly with the coarse and lumpy apatite in the pyroxenite to the South East of Looekop, no notice seems to have been taken until 1936.'

In that year, samples of Russian vermiculite were sent to South Africa from London. One sample eventually reached Phalaborwa through Government agencies, and was shown to Carter Cleveland, a wandering American pioneer prospector from the State of Alabama who had made his home in these lowveld regions. He confirmed that he had seen large beds of rotten mica that had experienced exfoliation during a grass fire.

This started prospecting for vermiculite in the Palabora Complex. The hydrophlogopite area to the north of Looekop (now the VOD area shown in Fig. 2) soon came under the ownership of Dr Hans Merensky, the legendary discoverer of platinum and diamonds, millionaire, and visionary. By 1946, the open-pit mine and concentrating plant were in operation. All Merensky's vermiculite interests were purchased by Palabora Mining Company in 1963, which simply continued the operation as the Vermiculite Operations Department (VOD). Thus vermiculite has been mined and concentrated continuously at Phalaborwa since 1946.

Another concern, the Palabora Phosphate & Vermiculite Company, started a similar operation in 1942, a few years before Merensky had initiated the abovementioned venture. A plant was erected to concentrate apatite (calcium phosphate) and vermiculite (hydrophlogopite) out of the orebody, denoted as the PFV Area on Fig. 2. The operation, however, was shortlived and survived for only six years. The vermiculite rights to this orebody were acquired by Dr Merensky, and thus in 1963 also became the property of Palabora Mining Company.

Around 1936, the deposits of hydrobiotite (black vermiculite) in the Palabora Complex were also prospected but abandoned in favour of the hydrophlogopite deposits.

Vermiculitization

In the Palabora Complex, vermiculite has resulted from the hydration of phlogopite (and biotite) by the loss of alkali and the addition of water. Vermiculite is therefore essentially a complex hydrous silicate of magnesium and aluminium with varying amounts of iron, possibly of isomorphous replacement. The ideal formula for hydrophlogopite is given as

\[ 22 \text{MgO} \cdot 5 \text{Al}_2\text{O}_3 \cdot \text{FeO} \cdot 22 \text{SiO}_2 \cdot 40 \text{H}_2\text{O}. \]

At Phalaborwa all evidence indicates that surface weathering, under the influence of percolating meteoric water, was the main cause of the conversion of phlogopite to vermiculite. According to Gevers,

The main effect in the process of vermiculitisation is the progressive leaching of the alcalies, mainly K₂O, from 9.9 percent in the phlogopite through 4.73 percent in the transitional material to practically nothing (0.05 percent) in the golden yellow vermiculite. At the same time the total water content increases from 6.76 percent in the phlogopite through 14.58 percent in the intermediate material to 22.10 percent in the high grade vermiculite.

These changes are clearly evident from a comparison of the chemical analyses given in Table I.

As would be expected, there is a definite relationship between the expansion coefficient, or as more commonly termed the exfoliation ratio, and the water content. This ranges from nil for fresh phlogopite, through intermediate stages of hydration and expandability, to the last-
named high-grade vermiculite containing about 22 percent water and having an average exfoliation ratio of around 26 times the original volume. The vermiculite is expanded by commercial users in gas or dieseline burners at temperatures of 850 to 1000°C.

Hanekom et al. describe the process of vermiculitisation as follows:

Generally the process of vermiculitisation begins from the edges of books and flakes of phlogopite and works progressively inwards. In such a way books of vermiculite resulted, showing yellow vermiculite in the marginal portion and reddish brown phlogopite in the core. The alteration is accompanied by a change in colour and a concomitant loss in elasticity and transparency on the part of the phlogopite.

The gradations are seen clearly in the open-pit mine. The near-surface vermiculite is generally a pale yellow, and the colour grades downwards through golden-yellow to amber and brownish varieties.

Mining

Because the vermiculite has resulted from surface weathering, the vermiculite ore forms a surface layer that grades downwards into rock containing too much phlogopite, which is an undesirable contaminant of the vermiculite concentrate. Thus, the vermiculite orebody, that is the VOD orebody, does not extend to more than some 50 m below the surface, but it has a lateral spread of more than 2 km².

The vermiculite ore has been mined from the start by open-cast methods, the bench height being maintained at 5 m. The vertical blastholes are spaced at 3 m, with a 2,5 m burden. The holes are a standard 65 mm in diameter, drilled with a track-mounted pneumatic drill.

The explosive is a blend of granular ammonium nitrate and fuel oil. In the dry holes, the detonation is by electrical detonators connected in series. In the wet holes, blasting is effected with high-explosive primer cartridges set off by detonating fuse. The powder factor is satisfactory at 6,5 t per kilogram of explosive.

The method of mining has a severe restraint placed on it by the fact that it must be extraordinarily selective. This is necessary because of the many size gradings of vermiculite required to satisfy market requirements. The concentrating plants are also designed and geared to meet these same demands. This means that mining is strictly controlled on an hour-to-hour basis so that a balanced ore feed in respect of flake sizing is continuously supplied to the concentrator.

The ore grade and quality are controlled by a combination of visual evaluation of all the blasthole chippings and laboratory assays. In the laboratory, flake sizing of the samples of blasthole chippings is determined by screening and exfoliation ratio through heating of the samples in high-temperature ovens to 1000°C.

Based on the visual and laboratory assays, the piles of broken ore after blasting are subdivided into loading 'blocks'. These are regarded as individual entities, and are loaded separately one from another. Loading from these blocks is so arranged that a consistently blended feed results.

The bulk exfoliation ratios pertaining to the six grades of final concentrate must be controlled as well as possible, and is done by the blending of ores from shallower and deeper levels in the open pit. This adds a further constraint on the style of mining.

The VOD open pit puts out about 8500 t per day of ore and waste. So it is a fairly large-scale operation but, for the reasons given above, the mining style is rather small-scale. There is no question of going to a more bulky style of mining through, say, an increased bench height or the use of large loaders and trucks.

The loading and hauling equipment consists of three rubber-tyred front-end loaders of 3,6 m capacity and six trucks of about 30 t payload. The open pit operates on a six-day week, with two 8-hour shifts per day.

The additional earth-moving operation, that is the reclamation of the concentrator tailings dump, requires the loading and transportation of about 1300 t per day. This is done with one 3,6 m rubber-tyred front-end loader and one 25-ton tractor-loader.

Concentration

Although chemically a well-altered product, vermiculite is still a distinct mineral and retains the flaky structure of phlogopite, its parent mineral. This flaky structure makes it possible, by winnowing, to separate the vermiculite from the gangue minerals that, by contrast, assume a granular form after comminution. This winnowing does not basically differ from the age-old proverbial process of 'separating the grain from the chaff', but here the 'chaff' is the desired commodity.

Like phlogopite, the vermiculite also occurs mainly in book form, but these books have to be delaminated; that is, the books have to be rendered into thin flakes in the concentrating process, or at least into thinner books for efficient winnowing. As the coarser grades of vermiculite are higher-priced than the finer grades, a further requisite in milling is that the vermiculite should not be subjected to unnecessary comminution.

The concentrating processes are therefore essentially exercises in size gradings by screenings, with concomitant winnowings.

Markets and Supply

The market for vermiculite has shown an interesting progression over the years. Initially, only the coarser grades were in demand, but this has changed in that consumers have found increasing applications for fine to very-fine flake material. This has had a beneficial financial effect by increasing the total tonnage demand, and the finer material that was formerly valueless now has value.

This has made the retreatment of the old tailings dump and the recent erection of an additional concentrating plant to treat these tailings an economic viability. Some 7,7 Mt of tailings have been brought back onto treatable reserves, with an average grade of about 27 per cent for vermiculite larger than 35 mesh, amounting to a total vermiculite content of 2,1 Mt. If the smaller vermiculite is also taken into account, a further 2,7 Mt of tailings at an average grade of 46 per cent vermiculite can be added to the tailings-dump reserves.

As shown in Table IV, there are no fewer than six commercial grades of vermiculite for which there is a market.

Ore-concentration Plant

The various sections making up the vermiculite-ore
TABLE IV  
MARKETABLE GRADES OF VERMICULITE

<table>
<thead>
<tr>
<th>Product grade</th>
<th>ISO screen sizes, mm</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Middle size</td>
<td>From</td>
</tr>
<tr>
<td>Premium</td>
<td>5,66</td>
<td>16.00</td>
</tr>
<tr>
<td>Large</td>
<td>2.80</td>
<td>8.00</td>
</tr>
<tr>
<td>Medium</td>
<td>1.40</td>
<td>4.00</td>
</tr>
<tr>
<td>Fine</td>
<td>0.71</td>
<td>2.00</td>
</tr>
<tr>
<td>Superfine</td>
<td>0.355</td>
<td>1.00</td>
</tr>
<tr>
<td>Micronized</td>
<td>0.180</td>
<td>0.50</td>
</tr>
</tbody>
</table>

concentrator at Palabora Mining Company are shown in Fig. 3.

The raw ore from the open pit is tipped by the mine haulage trucks into a stationary sloping-bar grizzly to separate the boulders of diopside and serpentine larger than 300 mm, which are the two gangue constituents. The undersize material is passed over a second stationary grizzly at a gap of 150 mm. The oversize rocks are also discarded as a coarse low-grade waste product.

The undersize material, now upgraded in respect of vermiculite, is passed over a screen fitted with a screen cloth containing apertures of 20 mm square mesh. The oversize is fed through a primary impact crusher with a 38 mm setting between low bars on rotor and stationary beater plates. The undersize joins the crushed oversize and is put on a stockpile before the dryers.

It is an essential condition for efficient winnowing that the vermiculite should be dried to a moisture content of 4 percent and be free-flowing, even down to sizes smaller than 180 μm. Two coal-fired dryers are used for the pit ore, and a similar dryer for the reclaimed tailings.

After being dried, the ore is crushed in a closed crushing-screening circuit to minus 16 mm. In the process, the screen oversize is passed through two winnowers to discard a further low-grade waste-rock product.

As can be seen from Fig. 3, the remainder of the ore-concentrating plant consists essentially of winnowing and screening circuits. The complicated arrangements are necessary to produce the six different grades of concentrate.

A similar but separate plant, the tailings concentrator, has recently been commissioned to treat the old tailings dump for the extraction of vermiculite, but without a crushing plant, which, of course, is not necessary.

Fig. 4 gives a cross-sectional view of the standard type of winnower employed at Phalaborwa. It has been evolved for the specific purpose of winnowing the local vermiculite.

The two concentrators give approximately the following performances:
Ore Concentrator
Open-pit ore, t/d
Vermiculite grade, %
Dryer feed, t/d
Vermiculite grade, %
Recovery from pit ore, %
Recovery from dryer feed, %
Vermiculite concentrate, t/d
Vermiculite concentrate, t/a
Tailings Concentrator
Tailings from dump, t/d
Vermiculite grade,
Recovery, %
Vermiculite concentrate, t/d
Vermiculite concentrate, t/a

Tailings from dump, t/d
Vermiculite grade,
Recovery, %
Vermiculite concentrate, t/d
Vermiculite concentrate, t/a

Uses
Vermiculite has a considerable range of uses in the countries to which Palabora exports. It is invariably used in the expanded form but, because of its high volume in this condition, it is expanded as near as possible to the place where it is applied. Mandoval Vermiculite (Pty) Ltd, Alberton, concerned with the exportation, give the following approximate proportions of usage: fire protection 30 per cent, high-temperature insulation 20 per cent, ambient-temperature refrigeration and sound insulation 10 per cent, agricultural uses 30 per cent, animal feed 5 per cent, and minor uses 5 per cent.

Vermiculite can withstand temperatures of up to 1100°C. For fire protection, it is sprayed or moulded onto any surface to the desired thickness. It can prevent, to an important degree, the warping, bending, or collapse of the reinforced-concrete or steel-beam frameworks of high-rise buildings, bridges, etc.

Because of its inertness in respect to heat and fire, it has a great advantage over light-weight plastic foams that are all flammable under certain conditions and give off deadly fumes on burning. This seems to have been the cause of the Kinross Mine tragedy that claimed so many lives. In respect of structures with a high fire risk like oil rigs and petrochemical plants, it is an invaluable safeguard.

In addition to its fire-proofing use, vermiculite is an important high-temperature insulator. For ambient-temperature refrigeration and sound insulation, it is equally useful. For these two classes of insulation, the vermiculite is applied in much the same way as for fire-
proofing.

Another major application is in agricultural fields since it retains water and air better than natural soil does. It has become a much-favoured ingredient in composts, together with peat moss, pine bark, etc. It is also an absorbent of fluid plant nutrients and also a filler for granular or powdered fertilizer.

Vermiculite is also finding increasing application in animal feeds, chiefly as an absorbent and filler for nutrients. Other uses are as a filler or extender of pigments, paints, rubber, enamel, plastic, and ink.

In South Africa, it has some minor and unusual uses, for instance as a substitute for river sand to nest crocodile eggs. At a crocodile farm on the South Coast of Natal, there was great consternation recently. The female crocodiles became very upset because there was no vermiculite in which to lay their eggs owing to the late arrival of an expected consignment of vermiculite!

Production and Sales

The main producer of vermiculite on the world scene is the USA, followed by South Africa. Lesser producers are the Soviet Union, Argentina, Brazil, and India.

The US vermiculite is almost all produced at Libby, Montana, from a huge dyke-like basic igneous intrusion. The vermiculite is hydrobiotite, and not hydrophlogopite as at Phalaborwa. This hydrobiotite is mainly consumed within North America.

Fig. 5 depicts the sales of South African vermiculite, being exclusively hydrophlogopite. Since Phalabora has been the sole producer, the graph refers only to that supplier.

The tonnages of vermiculite produced have always corresponded closely to the tonnages sold, and there has never been an accumulation of unsold stocks.

The 1960 to 1974 figures are those provided by Schoeman and Brabers. The later yearly figures were kindly supplied by the marketing division of Rio Tinto Management Services Ltd, Sandton, Johannesburg.

A relatively minor part of the Palabora vermiculite is expanded and consumed in South Africa, but most of the production is exported to a number of countries. It is exported in raw unexpanded form. Transportation is mainly in the loose bulk state by rail to ports on the eastern seaboard.

It can be seen from Fig. 5 that there has been a steady increase in sales over the years, even if on a somewhat fluctuating basis. The sales respond principally to the state of the building and construction industries in the consumer countries, and therefore fluctuate accordingly year by year.

Reserves

The reserves of hydrophlogopite rock in the Phalaborwa deposits that are regarded as economic ore amount to roughly 22 Mt at an average grade of about 22 per cent vermiculite. In addition, there is a further 34 Mt of rock, at an average grade of 21 per cent hydrophlogopite that, for certain reasons such as accessibility to the concentrator plant in the VOD area (Fig. 2), are now classified as sub-economic ore. This material, however, is more than likely to be exploited in the next century.

Thus, there is no reason for concern regarding the future of vermiculite mining at Phalaborwa.

Mention was made earlier of rock containing a mixture of vermiculite and phlogopite. A great amount has already been stockpiled, carrying more than 20 per cent vermiculite and, furthermore, large reserves have become readily accessible at the bottom of the VOD open pit. If it does prove possible to utilize this material—even only a portion of it—then there is no end in sight to the vermiculite operations at Phalaborwa.
A practical and economical means for the separation of phlogopite from vermiculite would be of incalculable benefit. Unfortunately, this has not been achieved to date but, if it were possible, it can be stated with full confidence that vermiculite mining at Phalaborwa could last indefinitely.

In contrast to the Palabora alkali complex, other alkali complexes such as Klein Letaba and Glenover are unlikely to ever be exploited for their hydrophlogopite content because of adverse factors such as remoteness and lack of infrastructure.

Hydrobiotite

The biotite in the two occurrences in the Palabora Complex—to the west and southwest of Loolekop—has been altered to vermiculite in the weathered zone. This hydrobiotite (black vermiculite), compared with the hydrophlogopite, is of inferior quality in that it is fine-grained and has a much lower expandability on being heated.

It is improbable that these deposits will be worked, although the reserves of hydrobiotite are fairly considerable.

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Special thanks go to Mr P. Retief of the Vermiculite Operations Department and to Mr N.S.L. Steenkamp of the Technical Department, and to their respective staff members for the assistance given; also to Mr C. Lessing and staff of the Engineering Drawing Office for the four figures and to Mr B. de Wet for the drawing of the winnower assembly.

The manager of the Marble Bath Mine at Mica, Mr L.R. Alexander, made possible a most informative and pleasant visit to that mica–felspar operation.

REFERENCES


BIOGRAPHY


Obituary: J.J. Schoeman

Jan Jacobus Schoeman was born on 28th May, 1919, at Lydenburg and passed away at Warmbaths on 23rd July, 1988.

He was educated at King Edward VII High School in Johannesburg and the University of the Witwatersrand, where he obtained the following degrees:

B.Sc. Mining and Engineering 1940
B.Sc. Mining Geology 1942
D.Sc. Geology 1953.

In addition, he obtained the Certificate of Competency for Mine Managers.

During the earlier part of his career, Dr Schoeman worked for the Geological Survey of Kenya, and then as Senior Geologist with Messina (Transvaal) Development Company Limited for the period 1950 to 1957. During those early years of his career, he was primarily engaged in exploration activities, but he also worked for mines in Zimbabwe and South Africa, and for short spells in the Sudan, Tanzania, and Zambia. From 1957 to 1962, he was Head of the Economic Geology Division of the Geological Survey of South Africa.

In 1962, Dr Schoeman joined Palabora Mining Company Limited as Chief Geologist, to be promoted in 1963 to Chief Mine Engineer and Geologist, the post he held until his retirement in February 1976. From the date of his retirement until his death, he rendered consulting services to Palabora.

He was the author or co-author of a variety of technical papers.

Despite his full mining career, Dr Schoeman still found time to venture into tobacco farming in Zimbabwe, and lucerne farming and cattle ranching in the Transvaal. He was a keen tennis player, and also painted a few canvasses, particularly of the bushveld that he loved so much.