Phosphate in South Africa*

by E.H. ROUX†, D.H. DE JAGER†, J.H. DU PLOOY†, A. NICOTRA†, G.J. VAN DER LINDE†, and P. DE WAAL†

SYNOPSIS
This paper reviews the geology, history, current beneficiation practices, uses, marketing, and future outlook of phosphate in South Africa. The vastness of the reserves, and the industry's efficiency and competitiveness in world terms, are highlighted.

OCURRENCE AND GEOLOGY

The commercially important phosphate deposits in South Africa are confined to igneous and marine sedimentary geological environments (Fig. 1). The former environment is by far the most important in South Africa in that roughly 95 per cent of the country's production comes from the Phalaborwa Complex in the northeastern Transvaal. For this reason, the other deposits are dealt with only briefly in this paper.

Marine Sedimentary Deposits

The marine sedimentary deposits are mainly confined to the western and southern coastal regions and comprise both on-shore and off-shore deposits.

Onshore Deposits

The onshore deposits occur intermittently from Saldanha Bay in the south to Lamberts Bay in the north. Samancor has been exploiting the New Varswater deposit in the vicinity of Langebaan since 1943. Individual deposits in this area are reported to have contained from 1 Mt to nearly 50 Mt of ore grading from 8.0 to 12.8 per cent $P_2O_5$. The ore consists of phosphatic sand horizons and is overlain by limestone and/or younger sand. The phosphate occurs in the form of the mineral francolite (carbonate apatite), which is soluble in citric acid and thus suitable as a direct-application fertilizer.

The New Varswater orebody was deposited on a raised beach, which was cut into a phosphatic sandstone horizon. Rounded beach pebbles and phosphatic sandstone accumulated, and today a 1 m-thick discontinuous layer of brown phosphatic sandstone forms the base of the orebody. Although the average grade of this basal layer is 15 per cent $P_2O_5$, most of the phosphate is present as a cement binding the quartz grains. This layer is not mined because the phosphate slimes when the sandstone is comminuted, and becomes too fine for beneficiation.

Offshore Deposits

The offshore deposits occur on the continental shelf at Agulhas Bank, stretching from Cape Town eastwards as far as Port Elizabeth. Deposits on the shelf off the west coast extend from Cape Town northwards as far as Lamberts Bay. The deposits consist of scattered nodules and sands lying at depths ranging from 100 to over 1000 m. The nodules are comparatively low-grade, averaging approximately 16 per cent $P_2O_5$, and are not readily amenable to upgrading. Although the technology of offshore mining has progressed considerably during the past two decades, it is doubtful whether these deposits can be exploited economically since it would be difficult to find a market for such low-grade material.

Igneous Deposits

Carbonatite–peralkaline complexes, of which the Phalaborwa Complex is by far the most important, represent the major type of host rock for phosphate in South Africa, and also for valuable minerals of copper, zirconium, and uranium. Besides Phalaborwa, there are a number of other carbonatitic complexes in South Africa and its neighbouring territories that have been mined for phosphate, or are potential phosphate sources.

The Glenover complex in the northwestern Transvaal was mined on a small scale until 1984, when the high-
grade reserves were exhausted. Apatite also occurs in appreciable concentrations in the upper zone of the Bushveld Complex, but so far no economic deposits have been located.

The geology of the Phalaborwa Complex has been the subject of numerous publications and reports. It comprises a pipe-like intrusion that is 2030 million years old, emplaced in Archaean granite-gneiss. The main body is roughly kidney-shaped (Fig. 2), measuring 1.5 to 3.5 km in width and 6.5 km in length. It is made up of three coalescing and concentrically zoned lobes designated Northern Pyroxenite, Loolekop, and Southern Pyroxenite.

Deep diamond-drill holes have shown that the contacts and mineral banding are essentially vertical, and that the general geological features, as well as the extent of the mineralization, are essentially continuous to a depth of at least 1000 m.

The greater part of the Complex (about 95 per cent) consists of pyroxenite zones containing varying proportions of pyroxene (diopside), phlogopite, and apatite. The pyroxenitic rocks exhibit large variations in grain size; they are usually medium- to coarse-grained but, where they are exceptionally coarse-grained, they are referred to as pegmatoid. Apatite occurs in all the pyroxenitic zones except the central part of the Northern Pyroxenite. The phosphate content of the pyroxenite is between 6 and 7.5 per cent P₂O₅ on the average (15 to 19 per cent apatite).

The foskorite (serpentine–magnetite–calcite–dolomite–apatite) zone contains the highest concentrations of apatite, and is at present the major source of the phosphate produced at Phalaborwa. The average in situ grade of the foskorite is in the region of 10 per cent P₂O₅ (25 per cent apatite). The carbonatite contains an average of only 3.5 per cent P₂O₅, and does not qualify as a phosphate ore.

The apatite has a hardness of 5 on the Moh scale and a relative density of 3.2. It occurs in the following forms:

(a) prismatic crystals, often poikilitically enclosed by diopside, phlogopite, calcite, and magnetite, and therefore early in the crystallization sequence; the crystals are euhedral to subhedral—they vary in size from 0.001 to 0.150 mm in the pyroxenites, and are much larger in the foskorite (up to 1 cm) and pegmatoid (up to 15 cm);
(b) sugary aggregates between other minerals; and
(c) granular, monomineralic veins, dykes, bands and segregations that may represent a late stage of enrichment.

The colour of the apatite can be light green, greyish green, white, or pink. It is mainly fluorapatite, but subordinate amounts of hydroxyapatite and chlorapatite also occur, the latter most prominently in the foskorite–pyroxenite contact zone.
HISTORY
The history of the 3 main deposits is dealt with separately.

Phalaborwa
During the seventeenth century, the tribes of the Mono-motapa empire were driven south by Rozwi invaders from the north. A tribal group under a chief named Malatji wandered as far south as Bushbuck Ridge, where they settled temporarily. They were metalworkers and searched widely for iron and copper, eventually finding a huge deposit that they named Phalaborwa, meaning 'Better than the South'. They produced hoes, axes, spearheads, and arrowheads from iron. They also processed oxide copper into bangles, necklaces, and copper rods called 'lirale', which were used as a form of money. There are indications that the metal economy of Phalaborwa was felt deep into Mozambique and as far south as the Witwatersrand, but it was ruined in the nineteenth century by the advent of cheap metal from Europe.

Malatji's people replaced the Shokane tribe at Phalaborwa, a people so primitive that they are reputed not to have known the use of fire. In 1965, blasting operations in the foskorite zone revealed a shaft 6 m deep and less than 1 m wide, at the bottom of which charcoal was found. Radio-carbon dating indicated the charcoal to be 1200 years old. The origin of these ancient miners is unknown and may well remain one of the Bushveld's unsolved mysteries.

The Phalaborwa Complex was rediscovered in 1904 by E.T. Mellor, and was subsequently studied by such distinguished geologists as Cohen, Wilson-Moore, Du Toit, and Merensky.

LEGEND

- Dolerite
- Carbonatite
- Foskorite
- Syenite and injection breccia
- Fenite
- Phlogopite-pyroxene-apatite-pegmatoid
- Apatite-rich phlogopite-pyroxenite
- Feldspathic pyroxenite
- Phlogopite-pyroxene pegmatoid
- Apatite-poor pyroxenite
- Serpentine-phlogopite pegmatoid
- Granite and gneiss

Fig. 2—The geology of the Phalaborwa Complex
From 1930 to 1934 a small company named South African Phosphates Ltd mined high-grade apatite pockets in the pyroxenite, ground the mineral, bagged it, and sold it as fertilizer. Apart from being insoluble to plants, the apatite was more expensive than imported Moroccan phosphate rock, and the operation soon went bankrupt.

Dr Hans Merensky established the Transvaal Ore Company in 1937, which started mining vermiculite in 1940, and he launched a prospecting operation in 1945 to delineate the extent of the apatite mineralization. The deposit was found to be vast, but of too low a grade by the standards of the time to be of economic importance.

During the Second World War, the importation of phosphate came to a standstill for three years, which is also the average half-life of phosphatic fertilizer in the soil, and by 1946 there was a very real possibility of food rationing. After the war, the possibility of a phosphate mine was investigated as a matter of strategic importance. Eventually, in 1951 the State acquired the necessary claims from Dr Merensky, and the Industrial Development Corporation (IDC) established the Unie-Fosfatt-Ontginingsmaatskappy (Eiendoms) Beperk to develop the deposit. A few years later, the name was changed to the Phosphate Development Corporation Limited, and in 1987 to Foskor Limited.

Production started in 1954 under difficult conditions. The nearest railhead was 60 km away, and all transportation was by truck over dirt roads. The country's fertilizer factories were not used to igneous phosphate rock, and the scale of the mining operation was too small to be economic. The State was criticized for starting the venture, and considered closing it down rather than risking more money on its future.

Gradually the fertilizer producers adapted to the new rock, production was increased to economic levels, and in 1961 the first profits were reported. By 1969 the production was sufficient, together with that of Amcor's smaller mine at Langebaan, to satisfy the country's entire needs.

In 1976 expansions were commissioned that gave Foskor a substantial export capability. Today one-third of the production is consumed domestically, one-third is converted to phosphoric acid and fertilizer for export, and the rest is exported as phosphate rock.

As a State-owned corporation, Foskor has been very successful. Apart from the original investment of £2,710,000 in the 1950s, no further State financing was used. The home market for phosphate rock is not protected artificially either by import restrictions or by import duties. Foskor's competitors in Europe, namely the USA, the USSR, North and West Africa, and the Middle East, all have head grades in excess of 18 per cent P₂O₅, are within 100 km of harbours, and enjoy relatively short shipping distances to their customers. Phalaborwa is more than 800 km from Richards Bay, the long-term average head grade is only 7 per cent P₂O₅, and it is a very long haul to markets in Europe and the Far East. Between 1955 and 1985, the f.o.r Phalaborwa domestic price of phosphate rock decreased in real terms by 70 per cent.

Today Foskor's rock costs 20 to 27 per cent less delivered at Richards Bay, and 35 to 40 per cent less delivered at Potchefstroom, than imported rock.

Langebaan

African Metals Corporation (Amcor) started mining on the farm Langberg near Langebaan in 1943 to counter the shortage of imported phosphate, which was needed for the production of phosphoric pig iron at Newcastle and for the production of fertilizer. Initially, high-grade lumpy ore (15 to 16 per cent P₂O₅) was mined at a rate of 35 kt per annum. By October 1965, Amcor was producing 136 kt per annum of a product containing 29 per cent P₂O₅ by the flotation of phosphatic sands with a head grade of 9 per cent P₂O₅. By 1975 the capacity had been raised to 250 kt per annum, but towards the end of 1977 spiralling costs and marketing problems caused the mine to shut down. Production was resumed at 50 kt per annum in 1981, and has been gradually increased to the current annual level of 135 kt. Reserves at the mine are sufficient to sustain this level of production for about 30 years, but a further 120 years of reserves have been established on the farms Zandheuwel and the recently acquired Elandsfontein.

Glenover

The Glenover complex is situated about 90 km north of Thabazimbi and 70 km west-southwest of Ellisras. It consists of a central carbonatite plug 600 m in diameter and containing an average of 2.3 per cent P₂O₅, surrounded by a 200 m wide iron- and phosphate-rich breccia analysing 25 to 37 per cent P₂O₅. The breccia, in turn, is surrounded by a massive oval-shaped pyroxenite deposit 3 to 4 km in diameter with an average P₂O₅ grade of 3.3 per cent.

Gold Fields of South Africa mined the high-grade breccia from 1958 until 1984, when the reserves were exhausted. The annual output was 70 to 90 kt of lumpy ore grading about 30 per cent P₂O₅ and 7 to 10 per cent iron. The ore was used by Samancor to produce elemental phosphorus and ferrophosphorus in an arc furnace at Meyerton. Today, the Meyerton plant operates on briquetted Phalaborwa phosphate rock.

MINING

Mining methods are described for Phalaborwa and Langebaan.

Phalaborwa

The mining activities at Phalaborwa involve conventional open-pit methods for hard rock, namely drilling, blasting, and haulage of the broken rock to the crushers in 92 to 150 t rear-dumper trucks.

Apart from the original claims acquired from Dr Hans Merensky and subsequent mining leases granted by the State, Foskor was granted the rights to the phosphate minerals in the entire Phalaborwa Complex.

Foskor began mining foskorite ore at the western side of Loolekop in 1953 and ceased in 1966, when more than 20 Mt of ore had been mined.

In 1957 Rio Tinto, together with Newmont Mining, formed the Palabora Mining Company Ltd (PMC), which started mining the Loolekop carbonatite-foskorite complex primarily for copper in 1966. Of necessity, Foskor had to move its mining activities to the northern pyroxenite orebody, where it operated a 10 Mt per annum.
open-pit mine until 1980. The conventional bench method of open-pit mining was used, with a bench height of 12 m and a slope of 45 degrees. The pit at present is 120 m deep (bench 10), but has been planned to a depth of 360 m. It has yielded 55 Mt of ore and 36 Mt of waste, and contains a further 275 Mt of ore reserves. The ratio of ore to waste is 1.0;66.

The primary drilling was done by means of two electrically driven Bucyrus Erie 45R drills, which drilled blast-holes of 250 mm diameter to a depth of 14 m. An average primary blast consisted of about 100 holes using 50 t of slurry explosives to produce 150 kt of ore.

Secondary drilling for the fragmentation of rocks that were too large for the primary crusher was done by means of much shorter drills. These holes were charged with conventional explosives.

The loading of the ore was done by 10 yd³ P&H 1900 electric shovels at a rate of about 1 kt per hour. Michigan 475 front-end loaders were used as standby units.

The ore was hauled by Unit Rig Lectrahaul trucks with a payload of 92 t. The ore was dumped into an Allis-Chalmers gyratory crusher (54 in by 74 in) with a throughput of 2.7 kt per hour, transferred via conveyor belts to the secondary and tertiary crushers, crushed to minus 19 mm, and conveyed to the mills for further processing.

Other general equipment included bulldozers, graders, and water tankers for the building and maintenance of roads and working surfaces.

In 1979 Foskor and PMC concluded an agreement by which PMC would extend their open cast mine and Foskor would participate in the cost and receive certain categories of ore. This made the mining of the northern pyroxenite unnecessary for Foskor.

The ore mined by PMC is mostly dumped on stockpiles from which Foskor reclaim it with 10 yd³ P&H 1900 shovels and 92 t Lectrahaul trucks. Whenever practical, PMC delivers the ore direct to Foskor’s primary crusher. Today, Foskor does no primary mining or blasting, oversized rocks being fragmented by a hydraulic hammer.

A mobile primary crusher, designed by PHB Weserhütte, was commissioned in 1981 (Fig. 3). It comprises an Allis-Chalmers gyratory crusher, 54 in by 74 in, mounted on a hydraulically operated walking mechanism. A P&H 1900 shovel loads the crusher direct from the stockpiles, and the crushed ore is transported to the secondary crushers by a movable conveyor-belt system. This system eliminates the need for a fleet of haulage trucks and is simple to maintain. Since the shovel, crusher, and conveyor system are all powered by electricity, the need for diesel fuel is also eliminated. This system has resulted in considerable cost savings over those of the conventional truck-haulage system.

The complex genesis of the Phalaborwa Complex from a series of concentric volcanic intrusions over a time span of about 1300 million years has left a legacy of extreme variability in the mineralogy, especially in the transition zones of contact between the successive volcanic pipes. Foskor produces copper concentrate and various grades of phosphate and baddeleyite for different market sectors. The rigorous quality-control requirements, especially of the phosphate and baddeleyite products, and the variations in metallurgical-process requirements depending on the mineralogical variations, have made it necessary for Foskor to classify the ore delivered by PMC into different categories, and the reserves in Foskor’s own mine into five categories. Sophisticated computerized systems have been developed to keep track of the ores delivered by PMC and those mined by Foskor, and to assist in production planning.

The phosphate reserves at Phalaborwa are vast. Theoretically, the Complex contains 2159 Mt of ore, which could yield 298 Mt of merchant-grade phosphate rock per 100 m of depth; that is, every 100 m could sustain the current production, which is approximately three times the current domestic demand, for a century. Economic and practical mining considerations would reduce the theoretical reserves considerably.

**Langebaan**

At Langebaan, the ratio of overburden to ore is 2:1, and the overburden is removed by bottom-loading bowl scrapers, which are push-loaded with bulldozers. The latter are also used to pre-loosen the overburden by ripping. The waste is hauled to the slimes dam about 2 km away, and is used for the building of retaining walls 20 m high with a base width of 130 m and a top width of 20 m.

Because of the water table, the orebody is mined in two cuts with faces of 7 m, the top cut being mined with face shovels and the bottom cut with a dragline. The ore is transported 1.2 km to the primary crushers in rear-end dump trucks.

The ore shows extreme variability both laterally and vertically, and the mining faces, as well as the boreholes drilled ahead of the mining faces, are sampled regularly so that the P₂O₅ content, the slime content, and the characteristics of the minus 150 mesh fraction can be monitored. The mine is operated for two shifts per day, six days per week.

The deposit is a treasure chest of the fossil remains of creatures that lived in the Pliocene era, about 4 million years ago, and is well known to palaeontologists throughout the world. The mining operations are conducted with due regard to palaeontological needs.

**BENEFICIATION**

The beneficiation methods used at Phalaborwa, being more complex than those at Langebaan or Glendover, are described in some detail.
Phalaborwa

Foskor can produce phosphate rock from three main sources, namely pyroxenite ore, foskorite ore, and PMC tailings. Fig. 2 gives the geological details and Fig. 4 the plant flowsheet.

Pyroxenite

When the pyroxenite mine was in operation, the ore was crushed to minus 220 mm in an Allis-Chalmers gyratory crusher, 54 by 74 in, and then conveyed to a 30 kt coarse-ore stockpile, reclaimed onto a conveyor belt by a plough feeder, crushed to minus 19 mm in Symons cone crushers, conveyed to a 60 kt fine-ore stockpile, reclaimed by three plough feeders, and conveyed to the milling plant, where it was milled to 15 per cent plus 300 μm and 20 per cent minus 74 μm in rod mills in closed circuit with 750 mm cyclones and sievebends.

A straight-chain petroleum sulphonate (e.g. Mobil Alconate 80, molecular weight 550) was added in the mill at a rate of 200 to 250 g per ton of ore, and distilled tall-oil fatty acid (e.g. Uniotol DSR90) was added at a rate of 250 to 350 g/t just prior to flotation in Denver 50 ft \( (1.4 \text{ m}) \) flotation cells. From ore with a head grade of 7 per cent P\(_2\)O\(_5\), a concentrate analysing 36.5 per cent P\(_2\)O\(_5\) was produced with a P\(_2\)O\(_5\) recovery of 80 per cent, i.e. the concentration ratio was 6.5:1.

The concentrate was thickened, filtered on Eimco disc filters, dried in coal-fired Flu-o-solids dryers, and railed to the domestic fertilizer factories. Pyroxenite ore was processed between 1966 and 1980. Currently, a dry high-intensity magnetic-separation process for the beneficiation of pyroxenite ore is under development\(^{29}\).

Foskorite

When Foskor's operations began in 1953, the foskorite was crushed in a jaw crusuer, followed by three stages of cone crushing and a single stage of rod milling. After the gyratory crusher mentioned earlier (for pyroxenite) had been installed (1966), the two crushing trains alternately processed pyroxenite and foskorite ores. After the Weserhütte mobile crusher train already mentioned had been commissioned (1981), the jaw crusuer was used only to crush ore for experimental purposes. Today, foskorite ore is processed at a rate of 9 Mt per annum.

The milling plant consists of twelve 2.4 by 3.6 m Vecor rod mills and twelve 2.7 by 4.05 m Allis-Chalmers rod mills equipped with 750 mm cyclones. A form of open-circuit rod milling has been developed. The product of two rod mills is fed to a cyclone, and the cyclone undersize is fed to a third rod mill in open circuit. The cyclone overflow joins the product of the third mill.

After milling, the copper sulphide minerals are recovered by flotation in Wemco–Fagergren 8.5 m\(^2\) flotation cells in a rougher circuit and 2.8 m\(^2\) cells in a cleaner circuit. Potassium amyl xanthate is used as the collector, sodium ethyl xanthate as the co-collector, and tri-ethoxy butane as the frother. The average copper head grade is...
0.2 per cent, the concentrate grade is 35 per cent copper, and the recovery is 70 per cent, i.e. the concentration ratio is 250:1.

After the copper flotation, the magnetite is removed by Sala low-intensity drum magnets and the phosphate flotation reagents are added: 400 g/t sodium silicate as a dispersant, 20 g/t sodium hydroxide as a pH regulator, 45 g/t nonyl phenyl tetraglycol ether as a modifier and depressant, and 230 g/t distilled tall oil fatty acid as a collector.

The average head grade of the foskorite ore is 8.5 per cent P₂O₅, the concentrate analyses 36.5 per cent P₂O₅, and the recovery is 70 per cent, i.e. the concentration ratio is 6.1:1.

The tailings from the phosphate flotation plant go to a heavy-minerals plant, where the tailings stream is classified by hydrocyclones and the cyclone underflow is passed over Reichert cones and shaking tables for the recovery of the ZrO₂ mineral baddeleyite. The baddeleyite content in the original ore is about 0.21 per cent, the overall recovery is about 55 per cent, and the concentration ratio is about 850:1.

**PMC Tailings**

Palabora Mining Company mines and processes the central carbonatite plug and the surrounding foskorite ore (Fig. 2) separately. The carbonatite contains an average of 3.5 per cent P₂O₅, and its magnetite contains up to 1 per cent TiO₂. It is referred to as Lo-Ti or Lo-Phos ore. The foskorite averages 10 per cent P₂O₅, and its magnetite contains 4 to 6 per cent TiO₂; hence, it is also known as Hi-Ti or Hi-Phos ore. These two types of ore are mined, crushed, milled, and beneficiated separately.

After PMC has extracted the copper and magnetite from the Hi-Phos ore, the slurry is classified by means of hydro-separators and cyclones, and the coarse fraction (95 per cent plus 43 μm) is treated in a gravity-separation plant for the recovery of the zirconium and uranium minerals. Thereafter, the ore is reground and, after a final copper flotation circuit, the slurry is pumped to Foskor for the recovery of the phosphate.

Apart from the flotation reagents used for the foskorite circuit at Foskor as mentioned above, a polysaccharide is used mainly as a dispersant. Polysaccharides that have been used successfully include gum arabic, guar gum, and caustic starch.

**Characteristics of Phalaborwa Ore**

The contact zones between the successive volcanic intrusions are not sharply delineated. They are broad, diffuse, ill-defined bands in which there is a gradual transition from one ore type to another, and in practice the 'foskorite' ore passing through PMC's Hi-Phos circuit is contaminated with carbonatite from the inner zone, and on occasion with a bit of pyroxenite from the foskorite-pyroxenite contact zone. The 'foskorite' ore delivered by PMC to Foskor's stockpiles is likewise contaminated, and the 'pyroxenite' mined by PMC for Foskor is contaminated by foskorite.

These cross-contaminations result in rapid and extreme variations in the mineralogical composition of the ore entering Foskor's plant. To cope with these fluctuations in ore characteristics, the mineralogical composition of the PMC tailings and of the foskorite ore fed to the plant is determined hourly by quantitative X-ray diffraction on a Siemens D500 diffractometer. These results, together with hourly analyses of the pulp densities, flowrates, and particle-size distributions, are correlated with historical data on flotation-reagent dosage rates and plant performance by means of a series of regression analyses. The system runs on a Hewlett Packard 9817H computer. The plant operators are supplied with hourly printouts giving the mineral composition, recommended reagent-dosage rates, and the plant performance (concentrate and recovery) to be expected for both the copper and the phosphate beneficiation circuits.

On-line P₂O₅ analysis by means of X-ray diffraction is currently being implemented. It is envisaged that the time lapse for the analysis of the feed, concentrate, and tailings streams will be reduced from 2 hours to less than 10 minutes.

**Pretreatment of Phalaborwa Ore**

During 1985 and 1986, a number of cyclones of 100 and 200 mm diameter were installed to deslime the foskorite and PMC tailings streams just prior to the phosphate flotation. The two-stage cycloning operation removes about 85 to 90 per cent of the minus 12 μm slime fraction, which is low in P₂O₅ but provides a large surface area onto which the flotation reagents can absorb. The savings in the consumption of flotation reagents, depending on the type of ore and the specific reagent, have been between 15 and 40 per cent.

**Foskor's Capacity and Products**

The fixed crusher train can handle 9 Mt of ore per annum, and the mobile crusher train 5 Mt per annum. The latter could be uprated, but then the crushing capacity would exceed the annual grinding capacity of 14 Mt. The flotation plant can handle 24 Mt annually, the remaining 10 Mt being available for PMC tailings.

Typical analyses of Foskor's phosphate and baddeleyite products are given in Tables I and II. The phosphate beneficiated plant can produce 3.4 Mt per annum of a concentrate analysing 36.5 per cent P₂O₅, representing about 87 per cent pure apatite. This product results from a four-stage flotation circuit comprising rougher, scavenger, cleaner, and reclaimer stages, with the recirculation of middlings, and is designated Palfos 80M.

Internationally, the phosphate content of phosphate rock is expressed in BPL (bone phosphate of lime), an archaic term that dates back to the time when phosphate fertilizer was manufactured by the digestion of crushed animal bones in sulphuric acid. The conversion factor is as follows:

$$\text{BPL} = \% \text{P}_2\text{O}_5 \times 2.185.$$  

The Palfos 80M product contains mainly calcite, dolomite, diopside, and phlogopite as diluent minerals. The magnesium-bearing minerals give it an MgO content of about 1.5 per cent on the average. Although this relatively high MgO content causes difficulties in the production of highly concentrated phosphoric acid, and in the production of certain ammoniated phosphate fertilizers such as di-ammonium phosphate (DAP), the South African manufacturers have developed means to cope with it.
TABLE I
FOSKOR'S PHOSPHATE PRODUCTS

<table>
<thead>
<tr>
<th>Typical analysis</th>
<th>Palfos 80M</th>
<th>Palfos 86S</th>
<th>Palfos 88</th>
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<tr>
<td>BPL %</td>
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<td>88</td>
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<td>P₂O₅ %</td>
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<td>168</td>
</tr>
<tr>
<td>As₂O₃, p.p.m.</td>
<td>13</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Cu, p.p.m.</td>
<td>200</td>
<td>150</td>
<td>90</td>
</tr>
<tr>
<td>Ni, p.p.m.</td>
<td>20</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Zn, p.p.m.</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Cd, p.p.m.</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Bi, p.p.m.</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>ThO₂, p.p.m.</td>
<td>150</td>
<td>100</td>
<td>110</td>
</tr>
<tr>
<td>UO₂, p.p.m.</td>
<td>12</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>VO₂, p.p.m.</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>PbO, p.p.m.</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Hg, p.p.m.</td>
<td>&lt;0,2</td>
<td>&lt;0,2</td>
<td>&lt;0,2</td>
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</tbody>
</table>

Physical characteristics

<table>
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<tr>
<th>Moisture, % H₂O</th>
<th>1,0 – 1,5</th>
<th>0,5 – 1,0</th>
<th>0,5 – 1,0</th>
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<tr>
<td>Relative density</td>
<td>3,17</td>
<td>3,18</td>
<td>3,18</td>
</tr>
<tr>
<td>Bulk density, kg/m³</td>
<td>1,885</td>
<td>1,885</td>
<td>1,70 – 1,75</td>
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<tr>
<td>Hardness, Moh scale</td>
<td>5,0</td>
<td>5,0</td>
<td>5,0</td>
</tr>
<tr>
<td>Angle of repose, °</td>
<td>33 – 38</td>
<td>33 – 38</td>
<td>33 – 38</td>
</tr>
</tbody>
</table>

Particle-size distribution, μm

| + 425 | 1,4 | 0,0 | 0,1 |
| + 300 | 7,1 | 0,4 | 2,5 |
| + 212 | 19,9 | 6,2 | 13,1 |
| + 150 | 34,8 | 25,1 | 30,0 |
| + 106 | 53,9 | 52,4 | 53,4 |
| + 75  | 64,7 | 75,7 | 69,6 |
| + 53  | 72,7 | 85,4 | 79,3 |
| + 38  | 77,5 | 92,3 | 84,3 |

However, all the other phosphate rocks available on the world market have MgO contents of less than 0,4 per cent and, in order to render the Phalabora rock acceptable to overseas customers, the content of gangue minerals has to be reduced. This is done by reflation and cyclone classification of the Palfos 80M rock to produce Palfos 86S with 39,3 per cent P₂O₅ and 0,65 per cent MgO, and Palfos 88 with 40,3 per cent P₂O₅ and less than 0,5 per cent MgO.

This extra flotation step reduces the primary flotation capacity of the plant in proportion to the quantity of high-grade product produced. In practical terms, Foskor can produce about 1,2 Mt of the high-grade products and 1,5 Mt of Palfos 80M per annum.

Langebaan

The beneficiation flowsheet at Langebaan is shown in Fig. 5. The ore is fed to two grizzlies with 200 mm and 114 mm spacings. The oversize material is crushed in a 750 by 1070 mm Hadfields single-toggle jaw crusher and a 375 by 750 mm Kue-Ken double-toggle jaw crusher. The crushed material joins the minus 114 mm grizzly under size on a conveyor belt to two stockpiles with a combined capacity of 4,5 kt, which is equivalent to 30 hours of milling capacity. The ore is fed by front-end loaders onto a 4,25 by 2,45 m rotary scrubber, where water is added until a pulp density of 50 per cent solids is attained. Sodium silicate is added at a rate of 200 g per ton of ore in order to disperse the slimes and depress the quartz. The scrubber discharges onto a double-deck vibrating screen with 15 mm and 6 mm openings. The plus 15 mm rock is utilized at the Koekfontein works of Chemfos as partial furnace burden in the production of elemental phosphorus.

The 6 to 15 mm fraction is fed to an Allis–Chalmers ball mill, 2130 mm in diameter by 2440 mm in length, and the minus 6 mm fraction to a stock surge bin. Primary desliming at 105 μm involves pumping of the underflow from the stock surge bin to a 750 mm hydrocyclone. The overflow is discarded to the slimes dam, and the underflow passes over six cascade sieve-bend screens with 1 mm openings. The screen oversize joins the pebble feed to the ball mill. The ball-mill discharge is recirculated to the stock surge bin.

The sieve-bend undersize is sent to a 600 mm cyclone for secondary desliming. The overflow is used as dilution water for the ball mill, and the underflow is deslimed in a second 600 mm cyclone. The overflow from this tertiary desliming step goes to the scrubber as pulping water, and the underflow goes to a flotation conditioner, where caustic soda is added to a pH of between 8,9 and 9,2, semi-refined tall oil is added at a rate of 1,85 kg per ton of flotation feed, and diesel fuel is added at a rate of 0,11 kg per ton as a froth regulator.

Flotation takes place in 1,14 m³ Agitair flotation cells. The circuit comprises rougher, scavenger, and cleaner stages. The concentrate, typically analysing 29 per cent P₂O₅, is filtered on a Dorr–Oliver horizontal filter of 3,5 m diameter and dried in two forced-draught fluidized-bed (Dorco Fluosolids) dryers. The dried concentrate is milled in a 2,13 by 6,10 m Compeb mill, bagged, and sold under the name Langfos Premium.

Glenover

As mentioned earlier, mining at Glenover ceased in 1984. The beneficiation process consisted merely in screening at 6 mm and removal of the hematite by high-intensity magnetic separation.

PRODUCTION STATISTICS

South Africa's annual production rate of phosphate rock is given in Fig. 6. With the combined production capacity of Langebaan and Glenover at a maximum of 350 kt annually but seldom exceeding 270 kt in any given year, Foskor's contribution to these figures was about 90 per cent until 1984, and is now about 95 per cent.

MARKETING, USES, AND FUTURE OUTLOOK

Phosphorus is an essential element for all forms of life,
TABLE II

<table>
<thead>
<tr>
<th>BC Grade</th>
<th>96</th>
<th>99E3</th>
<th>99E6</th>
<th>99E8</th>
<th>99P</th>
<th>99S</th>
<th>99SEF</th>
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<tr>
<td>Application</td>
<td>Abrasives</td>
<td>Refractory</td>
<td>Refractory</td>
<td>Pigments</td>
<td>Pigments</td>
<td>Pigments</td>
<td>Plasma Spray PDR</td>
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<tr>
<td>ZrO₂ + HfO₂</td>
<td>&gt;96</td>
<td>&gt;98</td>
<td>&gt;98</td>
<td>&gt;98</td>
<td>&gt;98</td>
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<td>TiO₂</td>
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<td>&lt;0,3</td>
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<tr>
<td>Fe₂O₃</td>
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<td>&lt;0,3</td>
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<td>&lt;0,3</td>
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<td>SiO₂</td>
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<td>&lt;0,6</td>
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<td>&lt;0,5</td>
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<tr>
<td>P₂O₅</td>
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<td>&lt;0,02</td>
<td>&lt;0,02</td>
<td>&lt;0,02</td>
<td>&lt;0,02</td>
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<tr>
<td>CuO</td>
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<td>&lt;0,05</td>
<td>&lt;0,05</td>
<td>&lt;0,05</td>
<td>&lt;0,05</td>
<td>&lt;0,01</td>
<td>&lt;0,01</td>
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<tr>
<td>ThO₂</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
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<tr>
<td>U₂O₈</td>
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<td>&lt;0,07</td>
<td>&lt;0,07</td>
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Screen analysis

<table>
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<tr>
<th>Colour</th>
<th>Bulk density, g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>3,05 - 3,15</td>
</tr>
<tr>
<td>Black</td>
<td>3,05 - 3,15</td>
</tr>
<tr>
<td>Black</td>
<td>3,05 - 3,15</td>
</tr>
<tr>
<td>Black</td>
<td>3,05 - 3,15</td>
</tr>
</tbody>
</table>

Fig. 5—The flow diagram at Langebaan
and also for modern technology. Fertilizers account for about 89 per cent of the total phosphate consumption. From the soil, phosphate is assimilated by plants, animals, and human beings, and is returned to the soil to restart its cycle.

Some 5 per cent of the total phosphate is utilized directly in feeds for livestock and poultry. The biological function of phosphate (as Adenosine-di/tri-phosphate) is to provide energy storage and release in living cells.

The industrial uses of phosphate account for the remaining 6 per cent. The most important application in this sector is in the detergent industry. Other significant applications include antifreeze, foods and beverages, dentifrices and pharmaceuticals, fire fighting and flame proofing, leather and paper treatment, photography, metal-surface treatment, and textile manufacture.

The World Industry

The world-wide phosphate market amounts to about 150 Mt of phosphate rock (equivalent to some 50 Mt of P\textsubscript{2}O\textsubscript{5}) per annum. The growth in demand has been phenomenal during this century, and the industry has contributed substantially towards improvements in living standards world-wide.

From the beginning of this past decade, the phosphate market has been facing a critical period. In the industrialized countries, the standstill in the population growth, the already high standards of living, and the worsening environmental conditions have caused domestic phosphate markets to contract. On the other side, the financial and social crisis in the third world countries is preventing them from boosting their industries and markets despite their high population growth and need for improved living conditions.

The South African Industry

Because Langfos Premium is soluble in citric acid, it is used as a direct-application fertilizer for specific crops in areas where the pH value of the soil is low. Hence, marketing is done mainly via the agricultural cooperatives.

As mentioned earlier, Foskor delivers phosphate rock domestically at a price far below the cost of the imported material. Price control by the State ceased in 1985, and the home market is not protected by import restrictions or duties. Because nitrogen is much cheaper in countries with resources of low-cost oil or natural gas than in South Africa, the possibility of importing finished fertilizers is a greater potential threat to the domestic producers of phosphate rock than the importation of phosphate rock.

Foskor's position in the domestic market is protected not only by its low production cost and the transportation cost barrier faced by an external producer, but also by the high quality of the rock. It has a high P\textsubscript{2}O\textsubscript{5} content, a low CaO content (which reduces the acidulation cost during fertilizer production), and a low content of deleterious impurities such as iron, carbon dioxide, arsenic, lead, mercury, cadmium, and organic carbon. It is, in fact, these characteristics that have enabled the local fertilizer industry to export phosphoric acid, and Foskor to export phosphate rock, despite Phalaborwa's unfavourable geographic location. The high-grade rock is particularly well-suited to the manufacture of industrial phosphates such as sodium tripoly phosphate, and of phosphates for animal and human consumption. It is also much more suitable than most sedimentary phosphates for manufacturers who use processes involving nitric acid attack. Producers who employ the more usual route of attack by sulphuric acid find that the gypsum product is purer, whiter, and generally has a lower radioactivity than gypsum made from sedimentary rock, thereby rendering it more attractive for industrial purposes, such as the manufacture of building materials.

Given the vast reserves at Phalaborwa and the substantial reserves at Langebaan, coupled with enviable track records for efficiency and innovative process improvements, both producers should be able to at least maintain their current positions in their established markets.
In the short term, the possibility of Foskor’s increasing its exports is considered to be favourable owing to a growing shortage of high-quality igneous apatite on the world market and a tightening of fertilizer supplies generally. In the longer term, the decline in population growth in the developed countries, coupled with increasing agricultural efficiencies and concern for environmental pollution, will place an upper limit on the consumption of phosphate in those countries. A positive factor on the demand side will be an increased need for phosphate for agriculture, as well as for industrial, use as the lesser developed nations progress.

As the higher-grade ores are gradually mined out by other producers, their head grades will continue the declining trend of the past ten years. The head grades at Phalaborwa and Langebaan are essentially constant over the long term, and the South African producers may well find themselves becoming gradually more competitive.

Domestically, the next wet cycle of about ten years is supposed to begin soon, and it is probable that the consumption of fertilizers will recover from the decline of some 40 per cent that was experienced between 1981 and 1987.

In common with most other firms in South Africa, the phosphate producers are emerging leaner and fitter from the period of drought and recession. All factors considered, their short-term outlook appears bright, and over the longer term there are indications that a healthy industry can be maintained.

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