

Rocks are made of minerals

What is a mineral? The definition may sound difficult – a mineral is a chemical element or compound (combination of elements) occurring naturally as the result of inorganic processes. The world contains more than 1 100 kinds of minerals, which can be grouped into three general classes.

Group 1: Metallic minerals. If named a mineral, chances are that they would be part of this group. It includes copper, silver, mercury, iron, nickel and cobalt. Most metallic minerals are found in combination with other minerals, such as ores. We get lead from galena, or lead sulfide. Tin comes from the ore cassiterite; zinc from sphalerite and zinblend or blackjack. Chromium comes from chromite. Many minerals contain aluminium. Uranium occurs in about fifty minerals, most of which are rare. Twenty-four carat gold is a metallic mineral. A 14-carat gold ring is 14/24 (or 58%) gold.

One thing to remember is that some minerals like to be together – lead and zinc, tungsten and tin, molybdenum and copper, and so on. There are also ores called 'massive sulfides' that contain copper, lead, zinc, gold and silver and often there are other minerals identified. Such a find usually shows that the ore can be mined economically and can yield a profit. Of course, all depends on where it is found and its accessibility for transportation. An average sample of earth contains 9% aluminum, 5,5% iron, 0,01% zinc, 0,008% copper, 0,004% tin, 0,002% lead, 0,0005% uranium, and 0,0000006% gold or platinum. It would be hopelessly expensive to recover such metals from an average tonne of earth. That is why metallic minerals are taken from concentrated deposits in mines.

Many valuable minerals are found in veins running through rock. Veins can be formed in three ways:

- 1) Mineral-laden groundwater seeps into cracks, evaporates, and leaves mineral grains behind that build up into a vein.
- 2) Hot water from deep within the Earth fills cracks, then cools and deposits much of the material in solution as a mineral in a vein. This sometimes includes metals such as gold and silver.
- 3) Molten gaseous material squeezes into cracks near the Earth's surface, then slowly hardens into a vein.

Group 2: Nonmetallic minerals. These are of great importance to certain industries. You will find them in insulation and filters and are used extensively in the ceramic and chemical industries. They include sulfur, graphite (the 'lead' in pencils), gypsum, halite (rock salt), borax, talc, asbestos and quartz.

Group 3: Rock-forming minerals. These are the building materials of the earth. They make mountains and valleys. They furnish the ingredients of soil and the salt of the sea. They are largely silicates – they contain silicon and oxygen. (Silicon is a non-metallic element, always found in combination with something else. It is second only to oxygen as the chief elementary constituent of the Earth's crust.) Other rock-forming minerals are the large family of micas, with names like muscovite, biotite and phlogopite. There are the feldspars, including albite and orthoclase. Others are amphiboles, pyroxenes, zeolites, garnets and many others you may never find or hear about unless you become a true mineralogist.

A rock may be made almost entirely of one mineral or of more than one mineral. Rocks containing different combinations of the same minerals are different. Even two things made of the same single mineral can be quite different. Carbon may be found as a lump of coal or as a diamond.

How Minerals Were Named

Names of most minerals end in 'ite' – apatite, calcite, dolomite, fluorite and molybdenite, for example. However, many do not: amphibole, copper (the most common pure metal in rocks), feldspar, galena, gypsum, hornblende, mica and quartz.



Many minerals take their names from a Greek word referring to an outstanding property. For example, haematite, an oxide of iron, was named about 325BC from the Greek haima, or blood, because of the color of its powder. Sphalerite got its name from the Greek word meaning to deceive – being mistaken for other ores. Some minerals are named for the locality in which they were first discovered. Coloradoite was found in Colorado. Bentonite, a clay, was found at Fort Benton in Montana. The same applies to labradorite and brazilite.

Other minerals got their names from famous people. Willemite was named in honor of Willem I, King of the Netherlands. The great German poet-philosopher, Goethe, could turn up in your collection as goethite. And there's smithsonite, named for James Smithson, founder of the Smithsonian Institute.

Out of this World

Minerals from outer space fall to Earth as meteorites, which are rock fragments. Every day, millions of them enter the Earth's atmosphere. Most are burned up by the heat from air friction and never reach the ground, but those large enough to reach the Earth are called meteorites. Most minerals found in meteorites are the same as those we have on Earth, but there are some rare minerals found only in meteorites. Two of them are cohenite and schreibersite.

Types of Rock

Rocks are the building blocks of the Earth's crust. They may be massive, as in granite ledges, or tiny. Soil, gravel, sand and clay are rocks.

There are three main types of rocks:

- 1) **Igneous rocks** are those formed at very high temperatures or from molten materials. They come from magmas, which are molten mixtures of minerals, often contain gases and come from deep below the surface of the Earth. If they cool off while below the surface, they form intrusive rocks, which may later be revealed by erosion. When magmas reach the surface red hot, they form extrusive rocks, such as volcanic rocks. Thus, granite is an igneous, intrusive rock and lava an igneous, extrusive rock.
- 2) **Sedimentary rocks** are formed by the action of wind, water, snow or organisms. They cover about three quarters of the Earth's surface. Most are laid down as sediments on the bottom of rivers, lakes, and seas. Water, wind, waves, currents, ice or gravity has moved many. The most common sedimentary rocks are sandstone, limestone, conglomerate and shale. Oil and natural gas are found in sedimentary formations.
- 3) **Metamorphic rocks** are those that have been changed from what they were initially, into something else by heat, pressure or chemical action. All kinds of rocks can be changed. The result is a new crystalline structure or a change in the rock's texture. Slate was once shale. Marble came from limestone. Granite is changed into gneiss.

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Apatite

Apatite is a group of phosphate minerals and usually refers to hydroxylapatite, fluorapatite and chlorapatite. They are named for high concentrations of OH^- , F^- , or Cl^- ions, respectively, in the crystal. The formula of the mixture of the three most common endmembers is written as $\text{Ca}_5(\text{PO}_4)_3(\text{OH}, \text{F}, \text{Cl})$. The formulae of the individual minerals are written as $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$, $\text{Ca}_5(\text{PO}_4)_3\text{F}$ and $\text{Ca}_5(\text{PO}_4)_3\text{Cl}$, respectively.

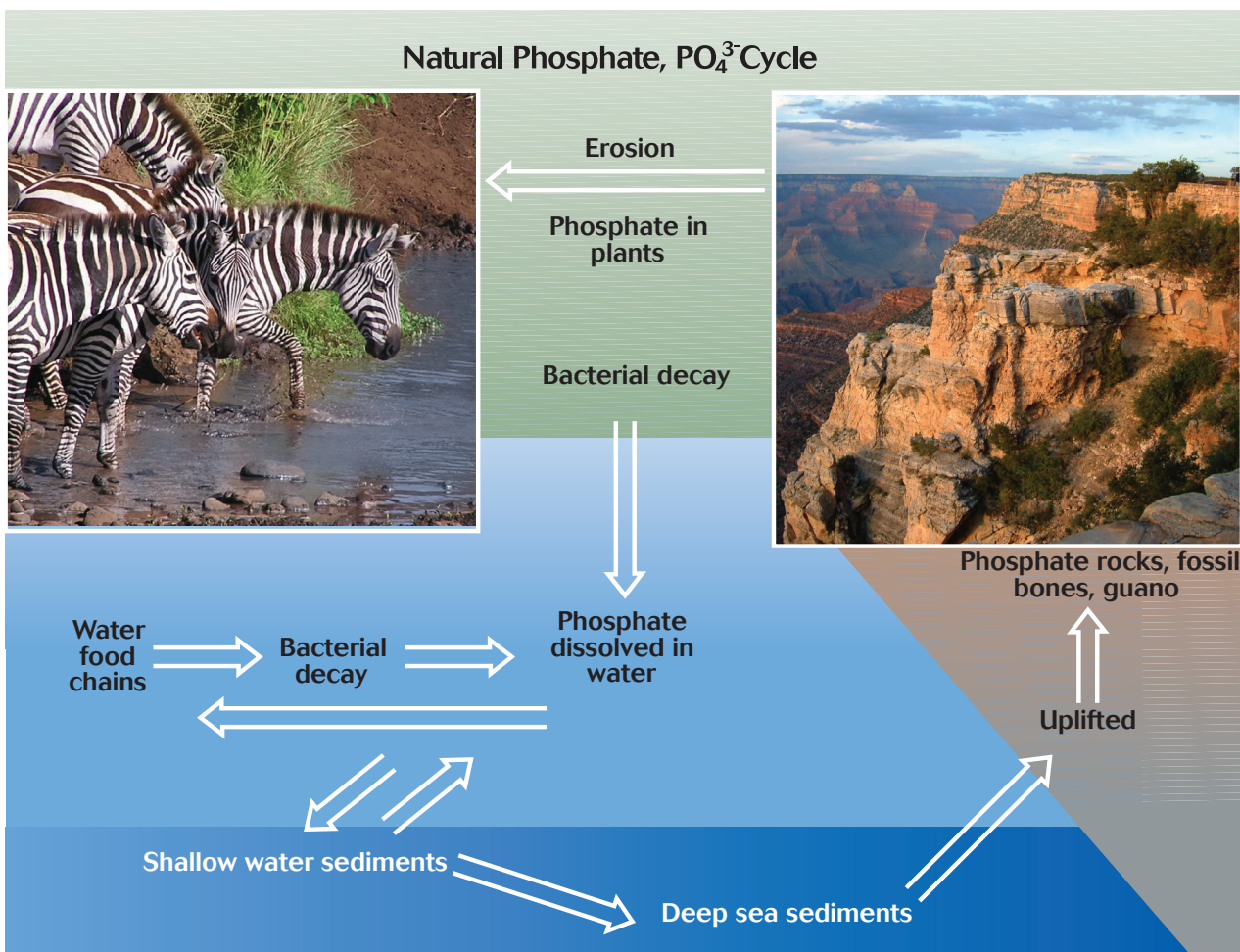
Apatite is one of few minerals that are produced and used by biological micro-environmental systems. Hydroxylapatite is the major component of tooth enamel. A relatively rare form of apatite is a large component of bone material. In this, most of the OH -groups are absent and contain many carbonate and acid phosphate substitutions. Fluorapatite (or fluoroapatite) is more resistant to acid attack than is hydroxyapatite. For this reason, toothpaste typically contain a source of fluoride anions (e.g. sodium fluoride, sodium monofluorophosphate). Similarly,



fluoridated water allows exchange in the teeth of fluoride ions for hydroxyl groups in apatite. Too much fluoride results in dental fluorosis and/or skeletal fluorosis.

Phosphorite is a phosphate-rich sedimentary rock, that contains between 18% and 40% P_2O_5 . The apatite in phosphorite is present as cryptocrystalline masses referred to as collophane.

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Phosphorus Cycle

Phosphorus enters the environment from rocks or deposits laid down on the Earth many years ago. The phosphate rock in the commercially available form is called apatite. Other deposits may be from fossilized bone or bird droppings (called guano). Weathering and erosion of rocks gradually releases phosphorus as phosphate ions, which are soluble in water. Land plants need phosphate as a fertilizer or nutrient.

incorporated into many molecules essential for life such as ATP (adenosine triphosphate), which is important in the storage and use of energy. It is also in the backbone of DNA and RNA, which is utilised in genetic coding.

When plant materials and waste products decay through bacterial action, the phosphate is released and returned to the environment for re-use.

Much of the phosphate is eventually washed into the water by erosion and leaching. Water plants and algae utilize the phosphate as a nutrient. Studies have shown that phosphate is the controlling agent in the growth of plants and algae. If not enough is present, the plants grow slowly or are stunted. If too much phosphate is present, excess growth may occur, particularly in algae.

A large percentage of the phosphate in water is precipitated from the water as insoluble iron phosphate. If the phosphate is in shallow sediments, it may be readily recycled back into the water for re-use. In sediments located deeper in water, it is available for use only as part of a general uplifting of rock formations for the cycle to repeat itself.

Human Inputs to the Phosphorus Cycle

Human influences come mainly from the introduction and use of commercial synthetic fertilizers. The phosphate for fertilizer is obtained through the mining of certain deposits of calcium phosphate called apatite. Huge quantities of sulfuric acid are used in the conversion of the phosphate rock into a fertilizer product called 'super phosphate'.

Human Influences on Phosphate Cycle



Mining phosphate rock

Phosphates in fertilizers



Animal wastes

Run-off and erosion

Phosphates in municipal sewage



Excess phosphate dissolved in water

Plants may not be able to utilize all of the phosphate fertilizer applied and, as a consequence, much of it is lost from the land through the water run-off. The phosphate in the water is eventually precipitated as sediments at the bottom of the body of water.

In certain lakes animal wastes or manure may also be applied to the land as fertilizer. If misapplied on frozen ground during the winter, much of it may be lost as run-off during the spring thaw. In cases where large groups of animals are present it may also result in excessive run-off of phosphates and nitrates into streams.

Other human sources of phosphate are in the out-flows from municipal sewage treatment plants. Without an expensive tertiary treatment, the phosphate in sewage is not removed during various treatment operations. Again an extra amount of phosphate enters the water.

This material was written by Prof Charles E Ophardt. Learners – if you use any part of it, you need to write it in your own words and include the following in your reference list: Ophardt, C. E. 2003. Phosphorus Cycle. [Online]. Available: <http://www.elmhurst.edu/~chm/vchembook/308phosphorus.html> [15 December 2008]

Phosphate as an Essential Mineral

'Although the story of phosphorus is a long and fascinating one, here we are primarily interested in knowing about its role in agriculture,' wrote Vincent Sauchelli in a 'Manual on Phosphates in Agriculture' published in 1942.

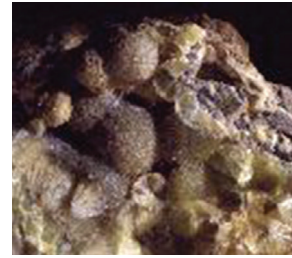
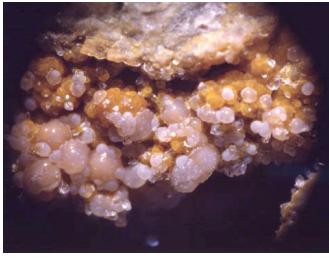
'In order to start at the beginning of our story, we shall have to go back to the year 1840 – the year when Justus von Liebig, a German scientist, made a historical address before the British Association of Science in which he for the first time gave a clear, intelligent exposition of the role of minerals in plant growth and laid the groundwork for modern agricultural science. He was the first to show that insoluble phosphates such as bone could be made to release their phosphorus in a form more quickly accessible to growing plants if they were caused to react with sulfuric acid. That suggestion stimulated John Bennett Lawes, an Englishman, to treat coprolites, a phosphorus-bearing ore fairly abundant in Great Britain, with sulfuric acid and to test the resultant phosphate as a plant nutrient. In 1842 Lawes was given a patent on this idea, which permitted him to establish the first 'superphosphate' works. From then on is fertilizer history.

Within twenty years after Lawes got his patent, the British were producing 150 000 tonnes a year of superphosphate. Then occurred the discovery of sources of mineral phosphates – rich deposits of rock phosphate in South Carolina in 1867 and in Florida in 1887. These discoveries gave the American industry the opportunity to take the lead in the mining of rock phosphates and the production of superphosphate – a lead which has been maintained ever since.'



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In a message to the United States Congress in 1938, President Franklin D Roosevelt underscored the importance of phosphate to agriculture and people.

'The phosphorus content of our land, following generations of cultivation, has greatly diminished,' President Roosevelt said. 'It needs replenishing. I cannot over-emphasize the importance of phosphorus not only to agriculture and soil conservation but also the physical health and economic security of the people of the nation. Many of our soil deposits are deficient in phosphorus, thus causing low yield and poor quality of crops and pastures...'

The Importance of Phosphorus

Phosphorus (P) is required by every living plant and animal cell. Deficiencies in available phosphorus in soils are a major cause of limited crop production. Phosphorus deficiency is also probably the most critical mineral deficiency in grazing livestock, according to 'The Effect of Soils and Fertilizers on Human and Animal Nutrition,' US Department of Agriculture (USDA) Information Bulletin No. 378, issued in 1975. When phosphorus fertilizers are added to soils deficient in the available form of this element, increased crop and pasture yields ordinarily follow.

Phosphorus is one of the primary nutrients essential for plant growth and crop production. It is a non-renewable resource that must be mined from nature. It cannot be artificially produced. We do not, however, mine phosphorus. We mine phosphate minerals.

Phosphorus is highly reactive and is not found in its elemental form in nature. It occurs in nature as phosphate, which is a charged group of atoms, or an ion. It is made up of a phosphorus atom and four oxygen atoms (PO_4) and carries three negative charges. The phosphate ion combines with various atoms and molecules within living organisms to form many different compounds essential to life.

Some examples of phosphate's role in living matter include:

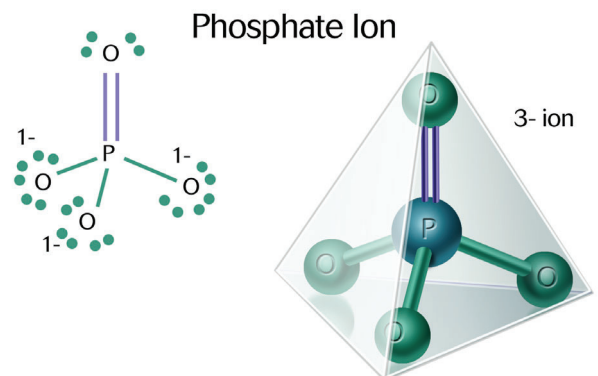
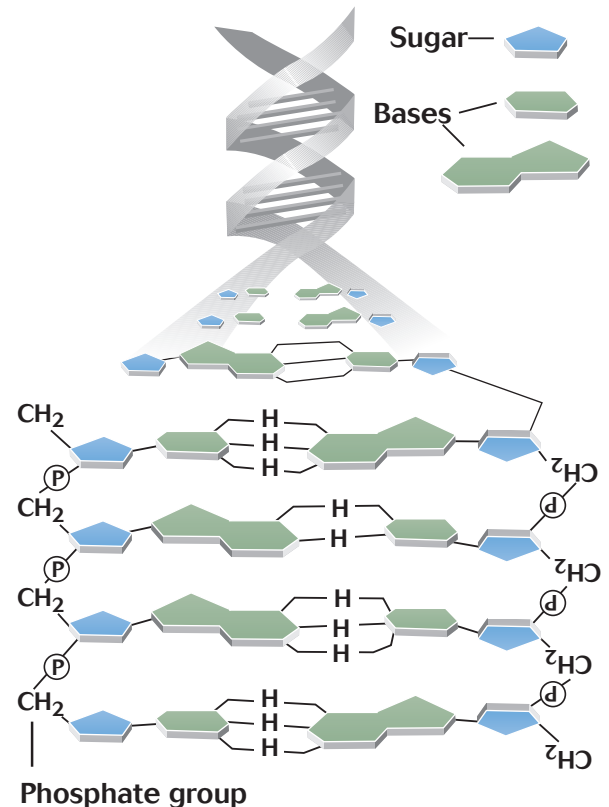
- Giving shape to DNA (deoxyribonucleic acid), which is a blueprint of genetic information contained in every living cell. A sugar-phosphate backbone forms the helical structure of every DNA molecule.
- Playing a vital role in the way living matter provides energy for biochemical reactions in cells. The compound adenosine triphosphate (ATP) stores the energy that living matter gets from food (and sunlight in plants) and releases it when it is required for cellular activity. After the energy is released in the form of a high-energy phosphate bond, the ATP becomes a lower-energy adenosine diphosphate (ADP) or a still-lower-energy adenosine monophosphate (AMP) molecule. These will be replenished to the higher-energy ATP (or ADP) state with the addition of phosphate by various mechanisms in living cells.
- The forming and strengthening of bones and teeth.

Plants get phosphate from the soil along with nitrogen, potassium and a number of other nutrients they need to thrive. Fertilizer is added to nutrient-deficient soil to replenish these vital chemicals. Animals get phosphate from their food.

The bulk of the phosphate we mine – about 90% – is used to produce phosphate fertilizers. Another 5% is used to make animal feed supplements. The remaining 5% goes into making a variety of products, from soft drinks to toothpaste to metal coatings.

Phosphate is a limited resource that cannot be replaced. As such, an international group of earth science and mineral resource agencies have designated it a strategic mineral resource. This group includes Australia, Canada, Germany, South Africa and the USA.

DNA Molecule



C. Ophardt, c. 2003

Source: <http://www.elmhurst.edu/~chm/vchembook/204tetrahedral.html>

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'The International Strategic Minerals Inventory Summary Report – Phosphate' (USGS Circular 930-C) is a cooperative effort of this international group and published in 1984 by the US Geological Survey. It describes Phosphorus as 'an important component of the cell tissues of plants and animals; it is necessary for the structure, growth, and propagation of living organisms. Phosphorus enters the organic food chain from the soil through the roots

of plants. The human body contains about 1% by weight phosphorus, most of it in the bones and teeth. The human body requires a daily intake of 0,6–0,7 g of phosphorus.'

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Humans get phosphate from the foods they eat. These examples show the amount of phosphorus* (mg phosphorus per 100 grams of food) in various foods.

Type of food	Amount of phosphorus (mg/100 g)
Milk	93
Lean beef	204
Potatoes	56
Broccoli	72
Wheat flour	101
Cheddar cheese	524

* Note: Although phosphorus is not found in elemental form in food, by convention the phosphate content of foods is expressed in terms of its phosphorus content.

History of Phosphate Mining in South Africa

Phalaborwa

During the seventeenth century, the tribes of the Monomotapa 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.

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 1 200 years old. The origin of these ancient mines 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.

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 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 phosphate 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-Fosfaat-Ontginningsmaatskappy (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 the 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 entire country's 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 initial investment of £2 710 000 in the 1950s, no further State financing was used. The home market for phosphate rock is not protected artificially by import restrictions or duties, Foskor's competitors in Europe, namely the USA, the USSR, North and West Africa, and the Middle East, all have head grade in excess of 18% P_2O_5 , 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% P_2O_5 , and it is a very long haul to markets in Europe and the Far East. Between 1955 and 1985, the Phalaborwa domestic price of phosphate rock decreased in real terms by 70%. Today Foskor's rock costs 20–70% less delivered at Richards Bay, and 35–40% less delivered at Potchefstroom, than imported rock.

This material was obtained from an article that was published by the Southern African Institute of Mining and Metallurgy. Learners - if you use any part of it you need to write it in your own words and include the following in your reference list: Roux, et al. 1989. Phosphates in South Africa, J.S. Afr. Inst. Min. Metall., 89(5): 129-139.

Phosphate: The South African Market

Foskor delivers phosphate rock domestically at a price 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 own low production cost and the transportation cost barrier faced by an external producer, but also by the high quality of rock. It has a high P_2O_5 content, a low CaO content (which reduces the cost for acidification 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 phosphate 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 tri-poly-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 apply the more usual route of attack by sulfuric 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.

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FOSKOR – A Company Overview

Having started out as a single phosphate mining operation some 55 years ago, Foskor has rapidly grown into a reputable and highly-profitable producer and processor of phosphate and phosphoric acid.

As a result of Foskor's strategic expansion over the years, their primary business activity extended from basic mining to the current focus on the beneficiation of phosphate rock and the production of phosphoric acid and phosphate-based fertilizers. These end products are sold locally and globally.

Today the Foskor Group comprises three main mining and production facilities:

Foskor Richards Bay is located in the Kwa-Zulu Natal Province of South Africa, an area known for its huge industrial development and harbour export facilities. Foskor Richards Bay is primarily a producer of phosphoric acid and phosphate based fertilizers, while also distributing lower volumes of sulfuric acid to customers within the South African market.

Foskor Phalaborwa is situated in the Limpopo Province of South Africa. The Phalaborwa region is known for its extensive phosphate and copper reserves. The Foskor facilities in this area are focused on the mining and beneficiation of phosphate rock as well as recovering low concentrates of copper minerals.

Foskor Zirconia is located in Phalaborwa and produces fused zirconia products (both monoclinic and stabilized), for local and international distribution.

Foskor is also involved in the production of electro-fused zirconia from zircon sand. Whilst this is a



non-core activity for the group, it contributes significantly to Foskor's bottom line, as does the secondary activity of recovering copper sulfide from Foskorite ore. The mining of Foskorite also generates magnetite, which Foskor stockpiles as a potential future source of iron and titanium.

Ultimately, Foskor is a dynamic and highly-regarded South African group of companies that strives for excellence in all their mining and production undertakings and approaches everything they undertake with determination and a desire to be the best at what it does.

As one of the world's largest producers of phosphate and phosphoric acid, Foskor is proudly South African, but internationally focused. At Foskor, they are determined to unlock value for all their stakeholders through the profitable, responsible and sustainable beneficiation of phosphates for local and international markets.

While Foskor started in 1951 as a single phosphate mine, it has transformed over the years into one of the world's leading miners of phosphate rock and producers of phosphate, phosphoric acid and a number of secondary acid and mineral products that are in high demand around the world.

Today the Foskor Group employs close on 2 000 people comprising mining and production facilities:

- Foskor Phalaborwa is focused on the mining and beneficiation of phosphate rock as well as recovering low concentrates of copper minerals.
- Foskor Richards Bay is primarily a producer of phosphoric acid and phosphate based fertilizers, while also distributing lower volumes of sulfuric acid.

Mining Activities

All of Foskor's mining activities take place at their facilities in Phalaborwa. The region has extensive phosphate and copper reserves and Foskor focuses



on the mining and beneficiation of this phosphate rock as well as recovering low concentrates of copper minerals.

Foskor Rock & Copper operates an opencast mine that extracts phosphate rock and ore at a rate of 11 million tonnes per annum. The process involves crushing, grinding and de-sliming the ore, much of which is then transferred by rail to the Foskor Richards Bay plant for processing.

Low concentrates of copper minerals are also extracted through this extraction process and this generates a further, secondary income for the organisation.

This material was obtained from the Foskor website www.foskor.co.za.

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Phosphate Mining – Introduction

The impetus for modern mining activity in Phalaborwa was triggered by the discovery in 1906 of appreciable quantities of the phosphate mineral apatite in the rocks of the Phalaborwa complex. Although phosphate mining took place during the early 1930s, it proved unsuccessful. It was not until some twenty years later that phosphate once again attracted attention.

In 1951 the state acquired the necessary claims from Dr Hans Merensky, and the Industrial Development Corporation (IDC) established Foskor. Production started in 1954 under difficult conditions but continued for strategic reasons, and in 1961 the first profits were reported.

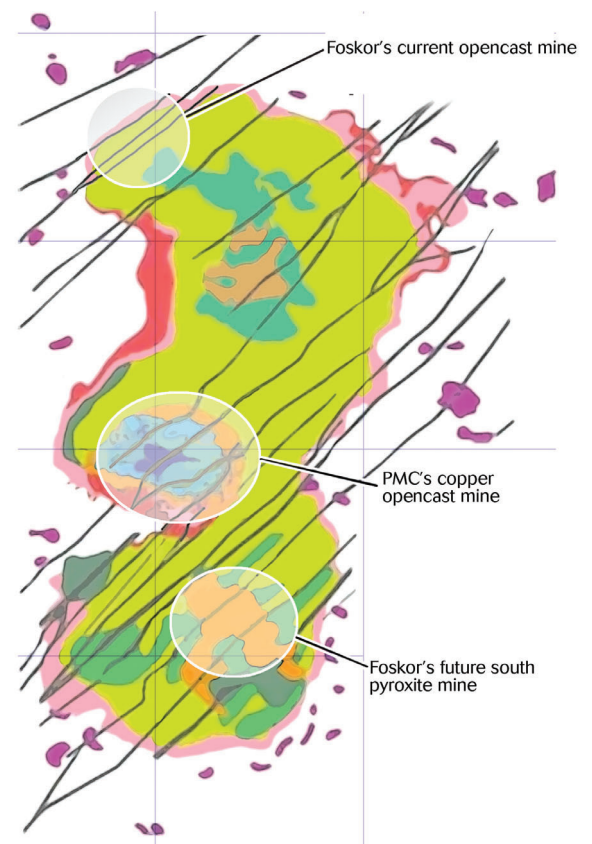
General Geology

The Phalaborwa Igneous Complex (PIC), situated south of the town of Phalaborwa (Limpopo Province), comprises a group of 14 distinct rock types, each with its own characteristic mineral assemblage. Figure 1 illustrates the geology of the PIC. It is a vertical volcanic pipe, roughly kidney-shaped and 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 the North Pyroxenite, Loolekop and South Pyroxenite.

Apatite is the only phosphate-bearing mineral in the PIC, and although sometimes present in very small quantities in the pyroxenite, it is never completely absent and often figures as an abundant mineral constituent. Carbonatite and foskorite are the two copper-bearing host rocks, which also contain magnetite and apatite.

As a result of exploration drilling, higher concentrations of apatite mineralisation were highlighted in three areas, namely the north-western portion of the PIC (North Pyroxenite), in the centre (Loolekop), and in

Figure 1: The geology of the Phalaborwa igneous complex



the southern portion (South Pyroxenite). The presence of apatite is expressed in % P_2O_5 .

There are three mines currently operating in the PIC. Palabora Mining Company (PMC) operates a copper mine in the central portion of the complex, as well as a vermiculite mine in the southern portion of the complex. Foskor's current opencast mine is situated in the North Pyroxenite and Foskor's future mining venture is in the South Pyroxenite (refer to Figure 1).

Geological Exploration

There have been numerous phases of drill testing of the in situ phosphate deposits in the PIC. The first substantial drilling programmes were in the late 1950s, and the most recent substantial drilling programme was completed in 2006. A total of 100 544 metres have been drilled to delineate the North and South Pyroxenite Mineral Resources. Drilling programmes of the PMC active tailings dam were also embarked upon to determine the mineral resources and reserves.

Samples acquired from the delineation drill holes were assayed at Foskor's chemical laboratory. The

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laboratory is not internationally accredited but participates in the Association of Fertilizer and Phosphate Chemists (AFPC) monthly round-robin assay programme. Foskor is not currently exploring for new phosphate resources.

Resource Estimation

The information obtained from the drilling was analysed geostatistically and used to compile geological block models. Ordinary kriging was used to estimate the phosphate mineral distribution in the three-dimensional block model. The block models were validated and the estimated values correlated with the original drillhole assays. This was done for North and South Pyroxenite as well as the PMC active tailings dam.

The classification of the mineral resource into measured, indicated and inferred categories is based on the drill hole density, kriging parameters (in particular, kriging efficiency) and the combined 50 years' knowledge and experience of Foskor's geologists on the PIC.

Mineral Resources and Reserves

The South African Minerals Resource Committee (SAMREC) Code (the code for reporting of exploration results, mineral resources and mineral reserves – 2007) was used as a guideline to classify the mineral resources and reserves.

According to the SAMREC Code: a 'mineral resource' is a concentration or occurrence of material of economic interest in or on the Earth's crust in such form, quality and quantity that there are reasonable and realistic prospects for eventual economic extraction. The location, quantity, grade, continuity and other geological characteristics of a mineral resource are known, or estimated from specific geological evidence, sampling and knowledge interpreted from an appropriately constrained and portrayed geological model. Mineral resources are subdivided, and must be so reported, in order of increasing confidence in respect of geo-scientific evidence, into 'Inferred, Indicated or Measured categories' (refer to Table 1).

According to the SAMREC Code a 'mineral reserve' is the economically mineable material derived from a measured and/or Indicated mineral resource. It includes diluting and contaminating material and allows for losses that are expected to occur when

the material is mined. Appropriate assessments to a minimum of a pre-feasibility study for a project, or a life of mine plan for an operation, must have been carried out, including consideration of, and modification by, realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors (the modifying factors)" (refer to Table 2).

The cut-off grade for % P_2O_5 was calculated using the methods from Kenneth F Lane's book 'The Economic Definition of Ore'. The cut-off grade for the North and South Mineral Reserves is 5,5 % P_2O_5 and for marginal ore between 4,4 and 5,5 % P_2O_5 .

Table 1: Mineral Resources as at 31 March 2008

Resource Category	Mineral Resources ¹			
	Dolerite ⁵ (Mt)	Pyroxenite ⁶ (Mt)	% P_2O_5	
North Pyroxenite ²	Measured	78,3	1 792,8	6,58
	Indicated	1,6	201,7	5,94
	Inferred	8,5	508,9	5,42
	Sub-total	88,4	2 503,4	6,29
South Pyroxenite ³	Measured	207,8	2 501,5	6,15
	Indicated	191,8	769,1	5,72
	Inferred	475,2	3 211,3	6,00
	Sub-total	874,8	6 481,9	6,03
PMC Tailings Dam ¹⁴	Measured		238,3	6,70
	Indicated		48,8	6,80
	Inferred		9,9	6,40
	Sub-total		297,0	6,67
Grand Total	963,2	9 282,3	6,12	

1. Mineral Resources are reported inclusive of mineral reserves
2. Internally estimated, current opencast mine
3. Externally audited by SRK in 2007, PEP project
4. Externally audited by Snowden in 2002
5. Excluded from P_2O_5 estimation, selectively mined in mineral reserve
6. Includes internal waste
- 14 Feasibility done in 2002/3 showed resource not economical to exploit therefore not included at this stage as a reserve

Table 2: Mineral Reserves as at 31 March 2008

Reserve category	Mineral Reserves ⁷					
	Ore ¹¹ (Mt)	% P_2O_5	Marginal ¹² (Mt)	% P_2O_5	% Cu	Waste ¹³ (Mt)
North Pyroxenite ⁸	Proved	442,5	7,34	18,3	5,04	
	Probable	-	-	0,1	4,53	
	Sub-total	442,5	7,34	18,4	5,04	44,5
South Pyroxenite ⁹	Proved	854,9	7,04	76,0	5,10	
	Probable	126,9	6,51	8,6	5,24	
	Sub-total	981,8	6,97	84,6	5,11	196,9
Stockpiles ¹⁰	Proved:					
	Area 9	24,7	6,96	-	-	0,07
	Area 6	-	-	11,1	4,35	0,19
	Area 2	0,5	6,90	-	-	
Sub-total	25,2	6,96	11,1	4,35		
Grand Total	1 449,5	7,08	114,1	5,03	241,4	

7. Calculated at a selling price of \$75/tonne at exchange rate of R7,20
9. Internally estimated, current opencast mine
9. Internally estimated, future opencast mine
10. Annual end of year stockpile audit by Premier Mapping
11. Ore > 5,5% P_2O_5 (includes internal waste)
12. Marginal 4,4–5,5% P_2O_5
13. Waste (selectively mined)

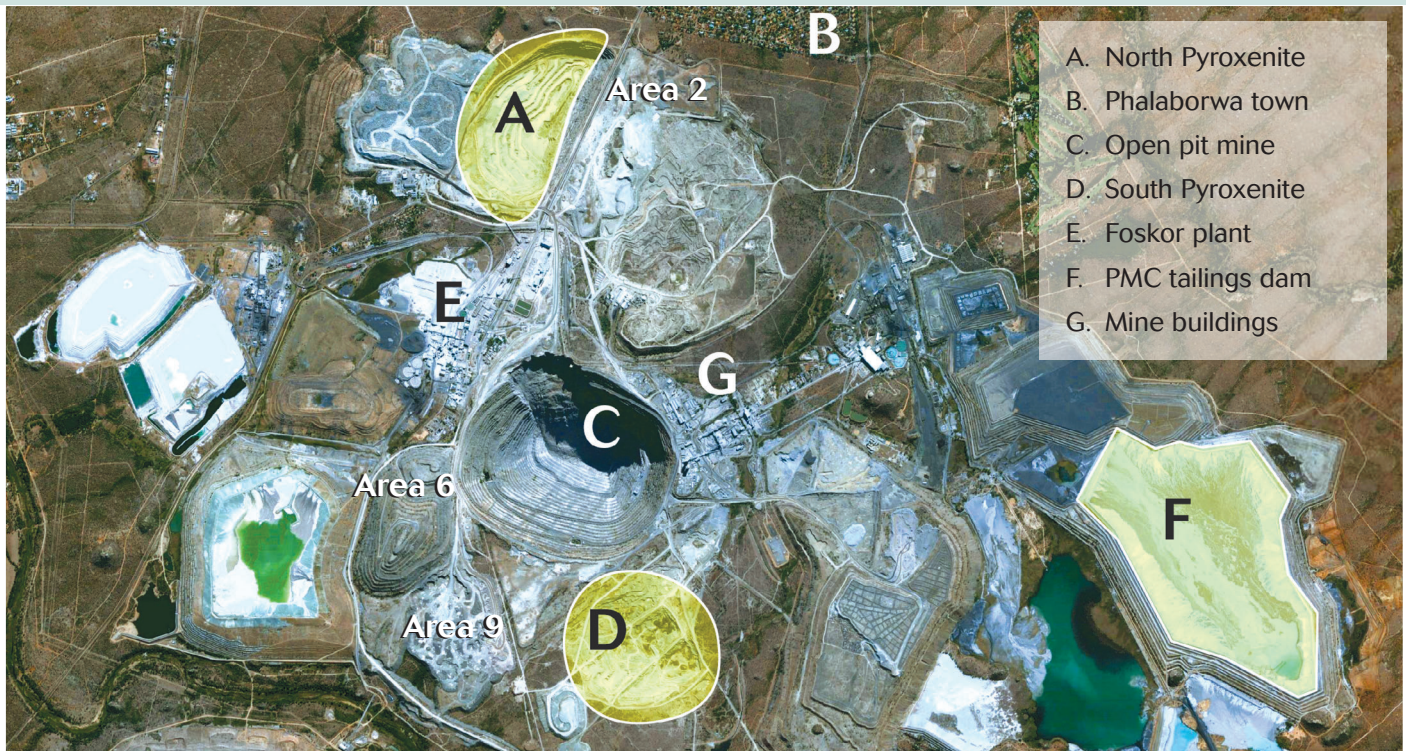


Figure 2: Location of deposits in PIC.

North Pyroxenite Deposit

The North Pyroxenite Deposit (refer to Figure 1 and Figure 2) is located in the north-western part of the PIC. Foskor commenced mining phosphate-bearing ore from this deposit in 1966. During the period 1961–1977 a drill programme consisting of 149 drill holes totaling 24 377 metres was carried out. A second phase of drilling in and around the existing pit was started in 1980 and completed in 1984, totaling 23 200 metres (55 drill holes).

The litho logical information from these holes was geologically interpreted, and a resource model of mineralisation was created. The mineral resources were internally estimated and categorised as measured, indicated and inferred resources according to the SAMREC Code. A Whittle pit optimisation was undertaken, from which the optimised pit was designed. By applying modifying factors, the mineral reserves were estimated. The North Pyroxenite Reserves totalled 442,5 million tonnes at 31 March 2008. The North Pyroxenite mineral reserve was also internally estimated.

South Pyroxenite Deposit

The first substantial drilling programmes in the South Pyroxenite area (refer to Figures 1 and 2) were carried out during the late 1950s and late 1960s. The infill-drilling programme, which commenced during the

1990s, was terminated prematurely due to financial considerations, but was completed during 2005/6 and incorporated additional definition drill holes. The total number of metres drilled was 49 584 from a total of 143 drill holes. Bulk and trench sampling has also been done in the South Pyroxenite area.

The geological and resource models for the South Pyroxenite area were based on the information obtained from all the drilling campaigns.

The geological contacts were interpreted from the diamond drilling data. Ordinary kriging was used to estimate the P_2O_5 block model values and it was validated by comparing it to the original drill hole data.

The South Pyroxenite Mineral Resource was audited by Steffen, Robertson and Kirsten Consulting (SRK) in 2007. The South Pyroxenite Mineral Reserve of 9818 million tonnes was internally estimated.

PMC Active Tailings Dam

Phosphate-rich tailings have been deposited on the PMC active tailings dam (refer to Figure 2) since the late 1970s. Foskor has rights to the apatite in this tailings dam and it is located on the premises of PMC. A resource of approximately 297 million tonnes with an in-situ grade of 6,75% P_2O_5 was delineated through drilling and sampling during the 1990s.



The data collected from the exploration was valued for geo-statistical application. An oriented block model was created and ordinary kriging was applied to estimate the grade distribution through the dam. The drill spacing was used to categorise the resource in terms of measured, indicated and inferred resources.

The feasibility study of reclaiming the tailings, which was completed in 2003, revealed that capital and operating costs would be more than forecast. For that reason, Foskor decided to exploit other sources of phosphate ore prior to exploiting PMC's active tailings dam.

Snowden Mining Industry Consultants and Rio Tinto Technical Services provided input to the feasibility study, although the report itself was compiled by Foskor staff. PMC continued to add tailings to the dam after Foskor had completed estimating the Mineral Resources.

Stockpiles

The carbonatite intrusion in the centre of the PIC (refer to Figure 1) is surrounded by foskorite and phlogopite-pyroxene-apatite pegmatoid. PMC used to mine and stockpile the foskorite and pegmatoid as a by-product of mining the copper-bearing carbonatite by opencast methods. PMC selectively mined and stockpiled the foskorite and pegmatoid according to the Extension 100F Agreement between Foskor and PMC, which gave PMC the right to process rocks with less than an agreed P_2O_5 grade, and retain all the valuable constituents within those rocks, except

phosphate. The rights to the rocks mined by PMC were determined by conventional grade control practices that were implemented by PMC and monitored by Foskor. PMC commenced mining in 1965, and in 2002 the opencast mine reached its maximum planned depth of 750 metres, after which PMC mined from the underground mine developed in the same ore body below the opencast mine. The foskorite and apatite-rich pegmatoid mined by PMC that contained more than 6% P_2O_5 was stockpiled and referred to as foskorite stockpiles.

Foskor reclaimed material from these stockpiles; most of these stockpiles have been completely reclaimed. In the mineral reserve statement (see Table 2) the remainder of the stockpiles have been listed as Area 2, Area 6 and Area 9. Foskor is currently reclaiming the Area 9 stockpile (refer to Figure 2).

PP&V Tailings

Currently, PMC operates a vermiculite opencast mine in the South Pyroxenite Area, which produces a vermiculite concentrate from the plant using dry winnowing methods. PMC trucks the high P_2O_5 tails from this plant to a stockpile located close to Foskor's East Crusher. Foskor has been reclaiming the high phosphate tails from this stockpile for the past two years.

This material was obtained from the Foskor Annual Report 2008 (pages 17–20). Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Foskor (Pty) Ltd. 2008. Review of mineral resources and ore reserves. [Online]. Available: www.foskor.co.za/library/Foskor%20Report%202008.pdf [22 January 2008]



Phosphate Mining in South Africa

South Africa has a highly-developed domestic and export oriented phosphate industry.

There are several types of phosphate rocks in South Africa, the main source being of igneous origin (currently mined at Phalaborwa), as well as sedimentary and biogenic resources. The latter two types are not mined at present. Large resources of phosphate-rich sediments are located offshore.

Igneous Phosphates

Phalaborwa

The largest igneous phosphate deposit in Africa is that of Phalaborwa (old name Palabora) in the lowveld of Limpopo, adjacent to the Kruger National Park. The Phalaborwa Complex, about 2050 million years old, is an igneous intrusion composed of three vertical pipes that continue, according to gravity data, to depths of more than 5 km. The central feeder pipe is composed of copper-bearing carbonatite and serpentinized olivine-apatite-magnetite rock, (named foskorite after the company Foskor) set in a large body of pyroxenites and syenites. The total complex occupies an area of about 20 km². Pyroxenites occupy about 95% of the surface area (excluding the syenites), 3% are coarse-grained foskorites, and 2% are carbonatite rocks. Apatite is not distributed equally. It is almost absent in the central part of the northern pyroxenite, but is enriched in foskorite and apatite-rich pyroxenite and glimmerite, a rock type with apatite and more than 75% phlogopite. Typical grades are: carbonatite 1-8,5% P₂O₅, massive pyroxenite 6% P₂O₅, glimmerite 9% P₂O₅ and foskorite 10% P₂O₅.

Palabora Mining Company (PMC) Ltd., a subsidiary of Rio Tinto, shares the mining area of the Phalaborwa Complex with Foskor Ltd., a wholly-owned subsidiary of the state-owned Industrial Development Corporation (IDC). While PMC focuses on the production of copper from the central carbonatite of the Phalaborwa Complex, Foskor Ltd. is primarily a phosphate mining company. However, until recently





Foskor also produced the zirconium mineral baddeleyite.

Foskor Ltd. receives phosphate ore from three different sources of Phalaborwa mining operations:

- Foskor's own pyroxenite ore from the open pit (20%)
- Foskorite ore mined by PMC on Foskor claims (40%)
- High-grade phosphate tailings from PMC's copper operation (40%)

The feed streams are concentrated by various methods into high grade phosphate concentrates (36–40% P_2O_5). These three sources of phosphate rock supply Foskor Ltd. with about 2,9 million tonnes of phosphate concentrate per year. The apatite concentrate is traded under the name Palfos (Palfos 80 = 36,5% P_2O_5 , and Palfos 86 = 39,5% P_2O_5). Some 900 000 tonnes are exported directly, one million tonnes are sold for domestic fertilizer consumption, and the remaining one million tonnes are converted by local phosphoric acid producers and exported. As a result of the changes at PMC, which produced 80 000 tonnes per day of copper ore and will change in 2002 into a 30 000 tonnes per day underground mining operation, Foskor plans to expand its direct mining operation and generate a total of 3 650 000 tonnes of phosphate concentrate per year. A large amount of phosphate rock from Foskor is converted to phosphoric acid and fertilizer products by Indian Ocean Fertilizers (IOF), a wholly owned subsidiary of Foskor Ltd., at its Richards Bay facility and exported, largely to Asian markets.

Drill-proven and stockpiled phosphate ore reserves exceed 300 million tonnes at an average grade of 7,45% P_2O_5 . The total in-situ resources of phosphate rock at Phalaborwa, to a depth of 600 m, are estimated at 13 000 million tonnes with an average grade of 6,8% P_2O_5 .

Agronomically, the phosphate rock from Phalaborwa is not suitable for direct application because the main phosphate mineral is a fluor-apatite with very low reactivity.



Glenover

Phosphate mineralization at the Glenover Carbonatite Complex, located in the Limpopo Province, is associated with a breccia zone along the carbonatite-pyroxenite contact. The whole ovoid-shaped complex is 4,7 km long and 3,5 km wide. The iron- and apatite-rich ore body occurs near the centre of the Glenover complex. Between 1962 and 1983 the high grade ($> 30\% \text{P}_2\text{O}_5$) central portion of the ten million tonne ore body was mined by Goldfields of South Africa (GFSA) producing some 1 445 000 tonnes of 36% P_2O_5 concentrate. The ore consisted of 75–95% apatite, the rest being haematite, martite, limonite and clay. Considerable ore resources grading 20–25% P_2O_5 remain in situ below the open cast floor in the northwestern section of the mine.

Approximately

2,5 million tonnes of residues finer than 12 mm (from crushing and screening) were left on dumps. Plans are underway by the company Fer-Min-Ore Ltd. to leach these fines (20–37% P_2O_5) to produce phosphoric acid for animal feed products.

Other Phosphate Occurrences

Phosphate ore can also be found in the Schiel and Spitskop Complex in the Limpopo Province. Phosphate

rock of varied grade can be found at these sites.

Small apatite enrichments are found at Kruidfontein, 40 km east of Pilansberg in the Rustenburg area and the Bandolier Kop in the Limpopo Province. These occurrences are of little economic value. Other phosphate deposits include Uloa, Weenen and Stanger in Kwazulu-Natal and Matjiesfontein in the Karoo.

Sedimentary Phosphates

Several types of sedimentary phosphates are described from offshore and onshore South Africa. The largest sedimentary phosphate resources are the replacement deposits offshore west and south of South Africa. On the western margin of South Africa, phosphorite pellets are found not only offshore, but are also abundant on the adjacent coastal terraces on land.

The Agulhas Bank deposits consist of boulders and cobbles of phosphatized limestone. Samples from the Agulhas Bank range from 10–25% P_2O_5 . With an area of 35 000 million m^2 , an average thickness of 0,5 m, and an average grade of 16% P_2O_5 the Agulhas Bank offshore phosphate deposits would contain about 5 000 million tonnes P_2O_5 . However, on technical and economic grounds they are not

considered for mining at present.

Part of the major sedimentary phosphate province that stretches along the western coast of South Africa into Namibia is the onshore phosphorite deposits of the Saldanha embayment in the Langebaan area in the Sandveld region of the Western Cape Province. Here, several types of phosphates occur, from guano-derived Al-rich phosphates to unconsolidated pelletal and consolidated crust type (phoscrete) deposits.

Some of the phosphorites have been mined in the past, others are, for various reasons, not developed. The Varswater deposit on the farm Langeberg 188 near Langebaanweg on the western coast of South Africa produced about 24 million tonnes before it closed in 1992. Some 25 million tonnes of ore at a grade of 8,5% P_2O_5 remain as proven reserves. The ore was concentrated to 29–30% P_2O_5 and sold as 'Langfos' fertilizer.

Agronomic evaluation by Thibaud et al. (1992) showed that Langebaan phosphate rock (Langfos) was not an effective substitute for superphosphate. In a further study they showed that the relative agronomic effectiveness of a superphosphate-Langfos blend increased in close association with an increase in the proportion of the superphosphate (Thibaud et al. 1993).

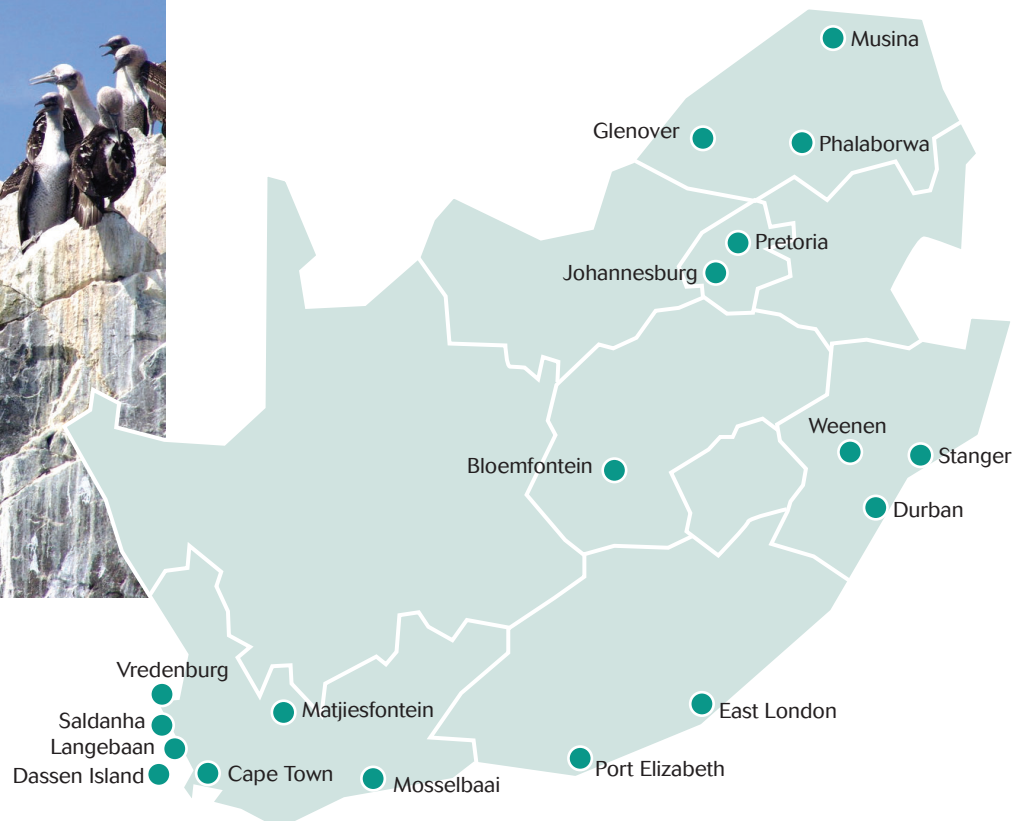


Guano Deposits

Several small island guano deposits were mined at the beginning of the 20th century off the coast of South Africa, north of Cape Town. For example, some 771 tonnes were produced in 1919 from Dassen Island. The islands are part of a chain that is inhabited by seabirds feeding on the fish in the nutrient-rich upwelling zone of the Benguela Current.

A small aluminium phosphate deposit with a grade of 15% P_2O_5 was mined in the early 1900s on the farm Klipfontein in the Hoedjes Bay area on the Atlantic coast, near Saldanha Bay. The Hoedjes Bay deposit (also referred to as Kreeftebaai and Klipvlei) was formed from the reaction of sea-bird excretions and granite. The small operation ceased shortly after World War I. Another guano-derived Al-phosphate mineralization that has been mined is that of Constable Hill, with an average grade of 22,48% P_2O_5 . The ore was processed to yield aluminium sulphate and feed-grade calcium-phosphate.

This material was obtained from the publication 'Rocks for Crops: Agrominerals of sub-Saharan Africa' by Prof P. van Straaten. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Van Straaten, P 2002. Rocks for Crops: Agrominerals of sub-Saharan Africa. ICRAF, Nairobi, Kenya, 338pp.



How Phosphate is Mined

After a mine site is permitted and reclamation plans are in place, the land is prepared for mining.

Endangered species are relocated and measures are taken to protect wetlands and other preservation areas. In addition, systems are put in place to offset any impact to water levels and flow in the surrounding areas. After these measures are taken, the land is cleared.

Phosphate rock is mined using conventional open-pit methods for hard rock mining. The overburden (top layer of soil) is removed, after which holes are drilled in a specific pattern and loaded with explosives. After blasting, the broken rock is moved with dragline buckets onto 72-tonne haulage trucks. Secondary blasting by means of conventional explosives can be used when rocks are too big for transportation or rocks can be fragmented using hydraulic hammers. The rock is taken to the primary crusher. After crushing, it is conveyed to the coarse-ore stockpile.

This material was obtained from an article that was published by the Florida Institute of Phosphate Research. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: FIPR. 2004. Phosphate Mining. [Online]. Available: <http://fipr1.state.fl.us/PhosphatePrimer> [28 October 2008]

Phosphate Beneficiation

From the stockpile the rock is conveyed to a secondary crusher and crushed to < 19 mm. It is then conveyed to the fine-ore stockpile and then to the milling plant. In the milling plant water is added to produce slurry and it is milled to 15% plus 330 microns (μm) and 20% minus 74 μm in rod mills in a closed circuit.

After the milling step the slurry is pumped to the flotation cells. Chemicals are added to change the surface properties of the components of the ore and air is bubbled through the mixture to separate the phosphate from the gangue. A concentrate of 36,5% P_2O_5 is produced. The concentrate is thickened, filtered and dried and then railed to fertilizer factories or used in the manufacturing of phosphoric acid.

Some phosphate ore contains copper and iron and undergoes two additional processes before the phosphate flotation process. Copper is removed using a copper flotation process and magnetite (Fe_3O_4) is removed using magnetic separators.



Chemical Processing of Phosphate

Phosphorus occurs in nature as phosphate rocks called apatites ($\text{Ca}_3(\text{PO}_4)_2$). Phosphate rock as it exists in the ground is not soluble and is hard for the plant to access. To provide the plant with the phosphate it needs, in a form it can take up through its roots, the phosphate rock is converted to phosphoric acid. Phosphoric acid is used to make fertilizer.

Most of the phosphoric acid produced, about 90%, is used to make agricultural products. Another 5% is used to make animal feed supplements. The remaining 5% is used in a wide variety of products including soap, toothpaste, and soft drinks. There is phosphate in camera film and inside light bulbs. It helps make steel harder and water softer. It plays a part in dyeing cloth and in washing clothes. Phosphate is used in the cement a dentist uses on teeth and in the fluids used to drill for oil and gas. It is part of making cloth and helps to polish aluminium. Other uses include the manufacture of plastics, shaving cream and bone china dishes.

Phosphoric acid is produced at a fertilizer manufacturing facility (sometimes called a chemical processing plant) that is not necessarily connected to the mining operations. After the phosphate rock has gone through the beneficiation plant it goes to the processing plant to make superphosphates.

At the processing plant it is reacted with sulfuric acid to make superphosphates as shown below. The mixture of H_3PO_4 and CaSO_4 (called superphosphate) is soluble in water and used by farmers to supplement the phosphorus content of soil.



Rock phosphate can also be used to make triple-superphosphate by reacting it with phosphoric acid. This product is also used as a fertilizer and has higher phosphorus content than superphosphates.





Phosphate Mining and Processing in South Africa

Simple flow diagram for the phosphate mining process

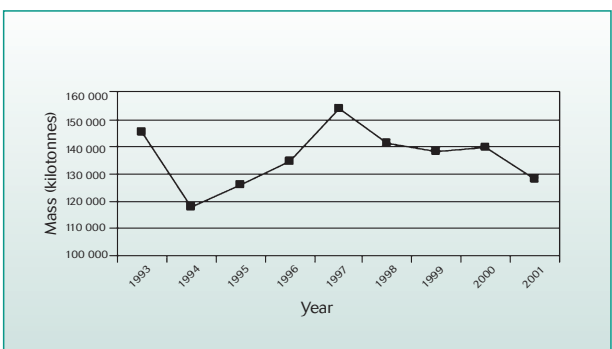
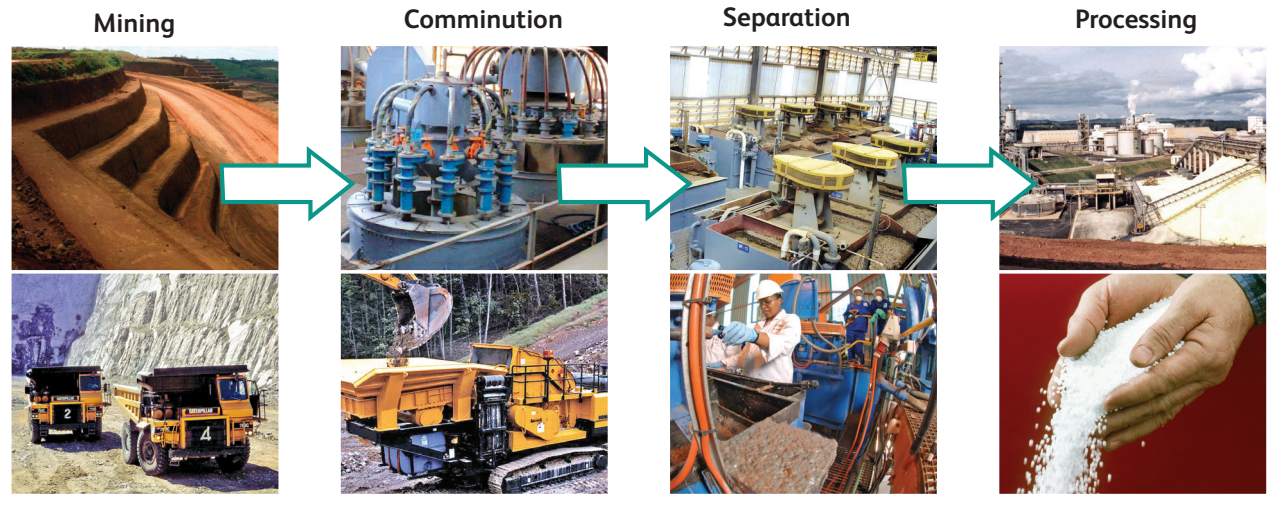


Figure 1: World production of phosphate rock 1993 - 2001

Source: Department of Minerals and Energy 2003

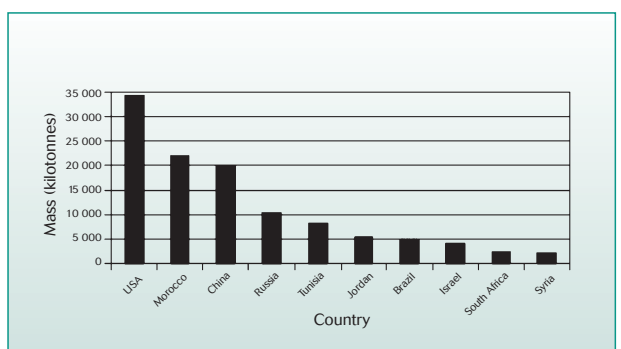


Figure 2: World production of phosphate rock by country, 2001

Source: Department of Minerals and Energy 2003

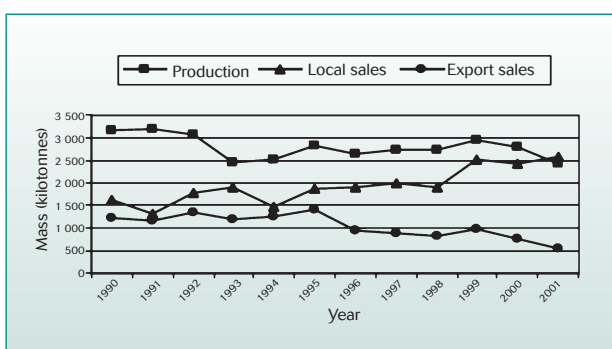


Figure 3: South Africa's production, local sales and export sales of phosphate rock

Source: Department of Minerals and Energy 2003

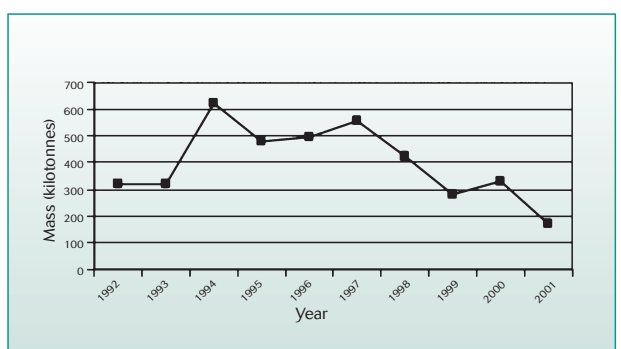
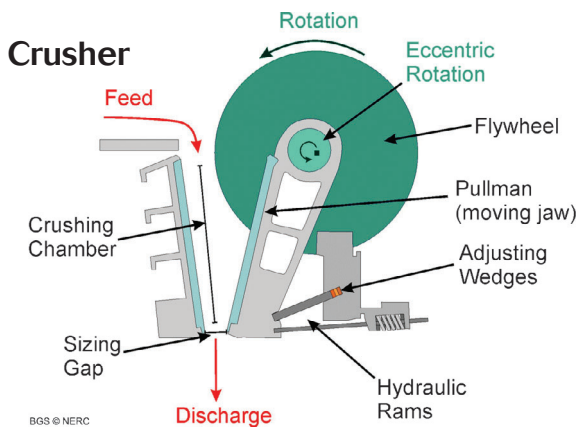


Figure 4: South Africa's imports of phosphate rock concentrate

Source: Department of Minerals and Energy 2003

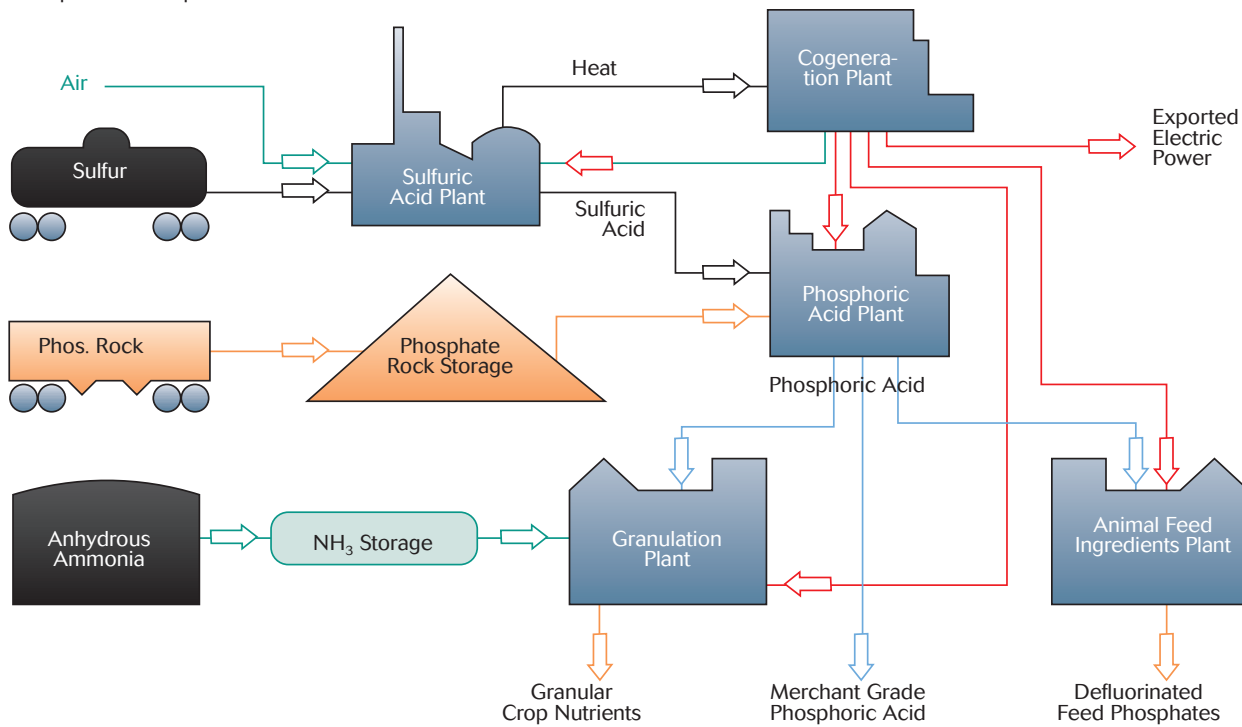
This material was obtained from an article that was published by the Southern African Institute of Mining and Metallurgy. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Roux, et al. 1989. Phosphates in South Africa, J.S. Afr. Inst. Min. Metall., 89(5): 129–139.

How Phosphate is Mined



- N** Nitrogen 21%
Key nutrient in plant growth
- P** Phosphorus 3%
Important for establishment
- K** Potassium 20%
Will increase stress tolerance

Example of a Phosphate Chemical Plant Process Flow Sheet



This diagram was published by the Florida Institute of Phosphate Research. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: FIPR. 2004. Chemical Processing of Phosphate. [Online]. Available: <http://fipr1.state.fl.us/PhosphatePrimer> [28 October 2008]

Introduction to Phosphate as a Fertilizer

Phosphate fertilization of soils has always been important. Vast areas of agricultural land can be poor if the soil has a phosphate deficiency.

The term 'available phosphate' is used because phosphate is the most immobile of major plant nutrients and if it is not in a soluble form it is difficult, if not impossible, for plants to get it.

Phosphorus deficiency is generally not as easy to recognize in plants, as are deficiencies in many other nutrients. A phosphorus-deficient plant is usually stunted, thin-stemmed, and spindly, but its foliage is often dark, almost bluish-green. Thus, unless many larger, healthy plants are present to make a comparison, phosphorus-deficient plants often seem quite normal in appearance. In severe cases, phosphorus deficiency can cause yellowing and senescence (aging) of leaves. Some plants develop purple colors in their leaves and stems as a result of phosphorus deficiency, though other related stresses, such as cold temperatures, can also cause purple pigmentation. Phosphorus is needed in especially large amounts in meristematic tissues, where cells are rapidly dividing and enlarging.

Phosphorus is very mobile within the plant, so when the supply is short, phosphorus in the older leaves is mobilized and transferred to the newer, rapidly growing leaves. Both the purpling and premature senescence associated with phosphorus deficiency is therefore most prominent on the older leaves. Delayed maturity, sparse flowering and poor seed quality also characterise phosphorus-deficient plants.

Phosphorus in Soil

The phosphorus problem in soil fertility is threefold.

- 1) The total phosphorus level of soils is low, usually no more than one-tenth to one-quarter that of nitrogen, and one-twentieth that of potassium. The phosphorus content of soils ranges from 200 to 2 000 kg phosphorus in the upper 15 cm of one hectare of soil, with an average of about 1000 kg.
- 2) The phosphorus compounds commonly found in soils are mostly unavailable for plant uptake, often because they are highly insoluble.
- 3) When soluble sources of phosphorus, such as those in fertilizers and manure, are added to soils, they are fixed (changed to unavailable forms) and, in time, form highly insoluble compounds. We will examine these fixation reactions in some detail because they play an important role in determining how much and in what manner phosphorus should be added to soils.

Fixation reactions in soils may allow only a small fraction (10 – 15%) of the phosphorus in fertilizers and manure to be taken up by plants in the year of application. Consequently, farmers who can afford to do so apply two to four times as much phosphorus as they expect to remove in the crop harvest.

Repeated over many years, such practices have

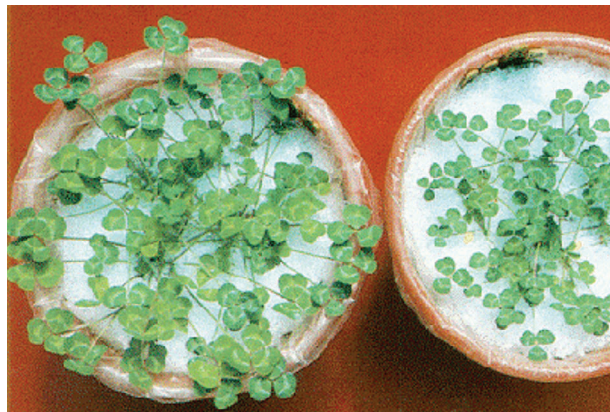




saturated the phosphorus-fixation capacity and built up the level of available phosphorus in many agricultural soils. Soils having such high levels of soil phosphorus no longer need to be fertilized with more than the amount of phosphorus removed in harvest. In fact, many agricultural soils in industrialized countries with long histories of phosphorus build-up from manure or fertilizer application have accumulated so much available phosphorus that little if any additional phosphorus is needed until phosphorus is drawn down to more moderate levels over a period of years. The statistics on fertilizer use in the United States reflect the fact that farmers have recently begun to recognise that fertilizer applications can be reduced where soil phosphorus levels have been built up. The long-term build-up of phosphorus has improved soil fertility, but has also resulted in certain undesirable environmental consequences.



In many developing countries, especially in Africa, such overuse of fertilizer phosphorus is not the rule. In most of sub-Saharan Africa, where per capita food production has been declining in recent years, fertilizer additions of this element for food crops are a fraction of the rate of removal of phosphorus in the harvested crops. The soils have been mined of phosphorus for years, with the result that in many areas lack of this element is the first limiting factor in food-crop production. Such phosphorus constraints also indirectly affect the supply of nitrogen, since the growth of most nitrogen-fixing legumes is constrained under low phosphorus conditions. The decline in per capita food production in sub-Saharan Africa will not likely be reversed until the critical phosphorus deficiency problems are solved.



Phosphorus in the Environment

Unlike certain nitrogen-containing compounds that are produced during the cycling of nitrogen, phosphorus added to aquatic systems from soil is not toxic to fish, livestock, or humans. However, too much or too little phosphorus can have severe and widespread negative impacts on environmental quality. The principal environmental problems related to soil phosphorus are land degradation caused by too little available phosphorus and accelerated eutrophication caused by too much. Both problems are related to the role of phosphorus as a plant nutrient.

Many highly-weathered soils in the warm, humid and sub-humid regions of the world have very little capacity to supply phosphorus for plant growth. The low phosphorus availability is partly a result of extensive losses of phosphorus during long periods of relatively intense weathering and partly due to the low availability of phosphorus in the aluminium and iron combinations that are the dominant forms of phosphorus in these soils.

Undisturbed natural ecosystems in these regions usually contain enough phosphorus in the biomass and soil organic matter to maintain a substantial standing crop of trees or grasses. Most of the phosphorus taken up by the plants is that released from the decomposing residues of other plants. Very little is lost as long as the system remains undisturbed.

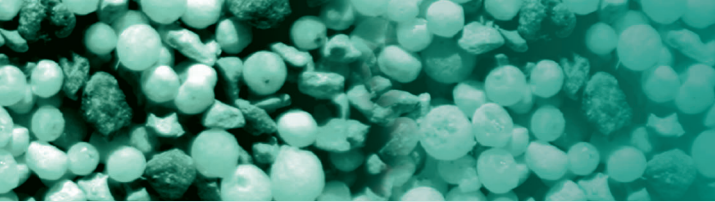
Once the land is cleared for agricultural use (by timber harvest or by forest fires), the losses of phosphorus in eroded soil particles, in run-off water and in biomass removals (harvests) can be substantial. Within just a few years the system may lose most of the phosphorus that had cycled between the plants and the soils. The remaining inorganic phosphorus in the soil is largely unavailable for plant uptake. In this manner, the phosphorus-supplying capacity of the disturbed soil rapidly becomes so low that re-growth of natural vegetation is sparse and, on land cleared for agricultural use, crops soon fail to produce useful yields.

Leguminous plants that might be expected to replenish soil nitrogen supplies are particularly hard hit by phosphorus deficiency, because low phosphorus supply inhibits effective nodulation and



retards the biological nitrogen-fixation process. The spindly plants, deficient in both phosphorus and nitrogen, can provide little vegetative cover to prevent heavy rains from washing away the surface soil. The resulting erosion will further reduce soil fertility and water-holding capacity. The increasingly impoverished soils can support less and less vegetative cover, and so the degradation accelerates.

This article was written by Professor Stefano Grego and published by the Florida Institute for Phosphate Research. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Grego, S. 2001. Introduction to phosphate as a fertilizer. [Online]. Available: <http://fipr1.state.fl.us/PhosphatePrimer/> [28 October 2008]



Caution – Not all Rock Phosphates are the Same!

The Fertilizer Society of South Africa (FSSA) has noted that some agricultural consultants recommend rock phosphate, irrespective of origin, as direct soil application.

It is probably assumed that all rock phosphates will lead to enhanced soil fertility and plant growth. The FSSA has received numerous inquiries in this regard.

The matter needs clarification and the following points are brought to the reader's attention:

Commercial mineral phosphates, collectively known as rock phosphate, belong to the broad category of apatite minerals and are mostly found in two forms in nature, namely igneous intrusions and sedimentary deposits.

There are important differences between the two forms.

- Igneous rock phosphate originated from volcanic eruptions, which occurred many millennia ago and are primarily made up of fluoro apatite, $\text{Ca}_5\text{F}_2(\text{PO}_4)_6$, (very similar to the enamel on human teeth!) and contributes to approximately 15% of the world phosphate rock production. It is mined mainly in Kola (Russia), Phalaborwa (South Africa), Araxa and Jacupiranga (Brasilia) and Siilinjärvi (Finland). Fluoro apatites are for all practical purposes insoluble in weak organic acids. These acids – for example 2% citric acid – are used to assess the various phosphate rock products for their fertilizer value. In actual fact, concentrated sulfuric acid is needed to dissolve the rock in order to extract the phosphorus (P) and to produce phosphoric acid, which is then used in the production of fertilizers.

- Sedimentary rock phosphate, on the other hand, originated some 50 to 70 million years ago in shallow lakes and seas from decomposing animal life. This type of phosphates is the main source of commercial mineral phosphates and constitutes about 85% of the world production. Sedimentary rock phosphates differ from igneous phosphates in that significant amounts of calcium (Ca) were replaced by magnesium (Mg) and sodium (Na), whilst as much as 25% of the phosphorus was replaced by carbonates (CO_3^{2-}). These 'soft' rock phosphates are much more soluble in weak organic acids and are therefore suitable for direct application under certain circumstances. As much as 50% of the total available phosphorus can be soluble in 2% citric acid. In contrast to this, often less than 2% of the available phosphorus in igneous rock is soluble in the same acid. Important deposits of this type of phosphate occur in North Africa (Senegal, Togo, Morocco, Algeria and Tunisia), the Middle East (Jordan, Israel and Egypt), Australia (Queensland) and the USA (Florida, North Carolina and Idaho). In general, these types of phosphates, in contrast to igneous phosphates, contain much higher concentrations of heavy metals, such as cadmium (Cd) and other toxic elements such as arsenic (As).

At present, only igneous rock phosphate is produced in South Africa. Most of it comes from the Phalaborwa Igneous Complex, although a small amount is also produced at Glenover. Some sedimentary rock phosphate deposits do occur along the western seaboard (e.g. Langebaan, Langfos), but are not being exploited currently.

This article was published by the Fertilizer Society of South Africa. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Van der Linde, G. 2008. All rock phosphates are not the same: a caution. IOnline. Available: <http://www.fssa.org.za/pebble.asp?reid=303> [28 October 2008]

The Impact of Mining on Agriculture

The landscape of South Africa is characterized by an extensive central inland plateau, mountainous areas in the east and north-east of the country and gentle 'Table Mountain' landscapes in the Cape Province.

The climatic conditions differ in the various parts of the country. While in the eastern parts of the country, specifically along the coast, humid subtropical conditions prevail, the west of the country is dry with semi-arid to arid conditions.

The wealth of South Africa is largely based on its natural resources sector, specifically mining and farming, and its developed industrial sector. South Africa is a relatively developed country in terms of modern mining and farming practices. Over many decades, however, the country has been divided by unequal distribution and access to land, mineral and other resources. In both the mining and farming sector there are gradual changes taking place that have the goal of a non-discriminatory, equitable and profitable sharing of resources.

The mining industry of South Africa, one of the best developed in the world, forms a crucial part of South Africa's economy. Sales of minerals and mineral products contribute to about 16% of the GDP. The mining sector directly employs approximately 550 000 people. Indirectly, the mining sector involves many more people. It is estimated that approximately ten million people, a third of South Africa's population, rely on the mining sector. Mineral production is dominated by gold, diamonds, platinum-group metals, chromium, manganese, vanadium and other metals, as well as coal and industrial minerals.

Mineral exports made up about 37% of all exports from South Africa. Large national and trans-national companies develop most of these resources. Only in recent years has the government encouraged small-scale mining.

The agricultural sector, including the government, farmers, agri-business and national and international organizations expressed the common commitment to a more equitable partnership for a united, globally competitive, profitable and sustainable agricultural sector. Although the primary agricultural sector accounts for only 4,5% of the GDP, the larger agri-food sector accounts for another 9%. The farming sector consists of about 50 000 large commercial farms with a labour force of about one million workers. The small-scale farming sector provides livelihoods to more than one million persons and occasional employment for another half-million persons. Another three million farmers live in 'communal areas,' primarily producing food for their own families. Unused productive soils are rare in South Africa and expansion is limited. Therefore the agricultural sector has to increase output per unit of land. Soil degradation is a major concern to the farming community.

The agriculture of South Africa is largely based on the production of maize, but is also diversified in many producing and value-added agro-based industries. Other crops include wheat, oats, sugar cane and sunflower. South Africa is well known for its deciduous fruits and grapes.

Only about 13% of the surface area of South Africa can be used for crop production, but large areas of the country are used for grazing. The soils of much of South Africa are nutrient deficient.

This material was obtained from the publication 'Rocks for Crops: Agrominerals of sub-Saharan Africa' by Prof P. van Straaten. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Van Straaten, P 2002. Rocks for Crops: Agrominerals of sub-Saharan Africa. ICRAF, Nairobi, Kenya, 338pp.



Agro-Mineral Potential in South Africa

The potential for development of agro mineral resources in South Africa is good. The indigenous fertilizer industry is well developed to provide processed P-fertilizers for modern farming practices. However, the potential to develop alternative, low-cost fertilizers for smallholder farmers and subsistence farmers in high-population density, low-income areas has not been investigated. As a first step, areas have to be identified where low-cost mineral amendments are available, where nutrient and crop needs are defined, and where poverty is widespread. Soils in these areas have to be investigated for their deficiencies, and nutrient replenishing strategies have to be tailored for the different soils and crops.

In addition, a systematic survey of nutrient containing 'waste' materials, both inorganic-mineral and organic, for use on nutrient deficient soils in high-density population areas needs to be undertaken.

The major phosphate mine in the country, Phalaborwa, produces inexpensive phosphate rock concentrates. The closed Glenover phosphate mine has substantial 'fines' as potential phosphorus resources. These concentrates should be tested on their potential for development of low-cost, agronomically effective phosphate blends for communal and small-scale farmers. Experiences from Kenya and Zimbabwe indicate that phosphate rock concentrate and



phosphate fines currently discarded as 'wastes,' can be pelletized or compacted with acidifying superphosphates or with other nutrients and nutrient-containing 'waste products' to form low-cost alternative fertilizers and soil amendments.

Alternative uses of mineral wastes should also focus on crops with high K and Mg requirements and trees. For example, the K-Mg silicate phlogopite in combination with various locally available N- and P-supplying materials should be agronomically tested on local soils in rural areas close to Phalaborwa. Biological processing techniques using organic 'wastes' should be tested on locally available silicate and phosphate rocks. Strong collaboration with scientists of the Agricultural Research Council or universities is recommended.



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History of Phosphate Fertilizer Production in the USA

Until the 1950s, fertilizer-manufacturing facilities were relatively small and produced fertilizers tailored to the soil needs of area farmers, commonly within a 100-mile radius. Prior to 1950, only 4 million tonnes of primary nutrients – nitrogen (N), phosphate (P) and potassium (K) – were produced yearly. But in the late 1940s this began to change. Domestic agriculture and industry, as well as European and Western Pacific markets devastated in World War II, increasingly requested these nutrients.

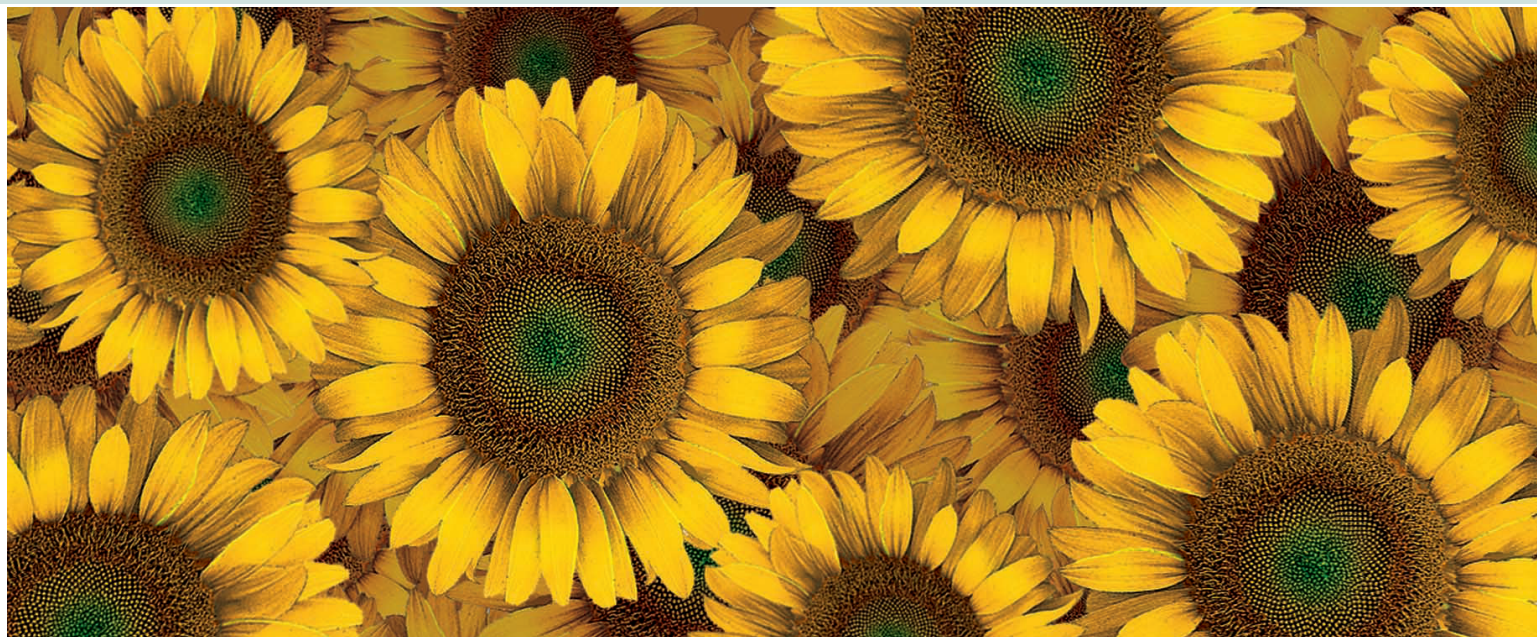
In the 1960s, the Tennessee Valley Authority (TVA) and the Land Grant Colleges began to promote higher analysis fertilizers so that more phosphate could be delivered to the farmers at lower costs and changed the way fertilizers were produced. In the 1960s, more concentrated phosphates began replacing normal superphosphate as the primary fertilizer commodity, turning what had been strictly a mining business into chemical production. This was especially true in Florida, which produces approximately 75% of the phosphate rock mined in the US. Phosphate rock is no longer sold for fertilizer manufacture. It is exclusively used to make phosphoric acid, almost all of which is used in the production of phosphate fertilizers.

Today (2005) the ammoniated phosphate fertilizer products produced in Florida allow the farmer to apply more fertilizer in one pass, which cut back significantly on labour costs. The higher analysis fertilizers also save on freight costs.

Florida phosphate products today include:

DAP (diammonium phosphate)

The fertilizer that quickly became the item of commerce because it had the highest concentration of phosphate and nitrogen at 18N – 46P₂O₅ – 0K₂O.



MAP (monoammonium phosphate)

This fertilizer is essentially the same as DAP, but it has a lower concentration of nitrogen at 11N – $52\text{P}_2\text{O}_5 - 0\text{K}_2\text{O}$.

GTSP (granulated triple superphosphate)

This fertilizer is very similar to the superphosphate fertilizer that was the fertilizer that traditionally provided the most nutrients to the plant at 46% P_2O_5 . Since GTSP is made by reacting phosphate rock with phosphoric acid, it also provides some calcium and sulfur to the plant.

Superphosphoric Acid

A product that is used to make a higher analysis, or a more concentrated, fluid fertilizer. Liquid fertilization was said to be the future for fertilizers in the 1970s. It did not, however, prove to be much better than traditional DAP or MAP, which both can be slurried if needed. Today the demand for the product is not high and only a few companies produce superphosphoric acid.

Phosphoric Acid

In the past, phosphoric acid was shipped to granulation plants that flourished in farming areas. There it was mixed with ammonia to make phosphate fertilizer. Today only a few independent granulation plants exist because the phosphate companies add the ammonia themselves to produce the ammoniated phosphate fertilizer products they sell. Purified technical- and food-grade phosphoric acid are also sold for use in items such as soft drinks. This product,

however, mostly comes from North Carolina and Louisiana phosphate operations.

Animal Feed Supplements

De-fluorinated phosphate rock or phosphoric acid is used to make animal feed supplements. PCS, in north Florida, and Mosaic are two Florida phosphate companies that produce animal feed supplements. One way to produce the feed is to combine phosphate rock with a small amount of phosphoric acid, sodium carbonate and then calcine. The most common method, however, is to de-fluorinate phosphoric acid and react it with lime to get dicalcium phosphate.

Sulfuric Acid

This acid is produced at phosphate manufacturing plants to be used to react with phosphate rock to produce phosphoric acid. The heat generated off the sulfuric acid production is used to power phosphate manufacturing plants and extra energy is often sold back to the area electricity grid. Some sulfuric acid may be sold as a product.

This article was published by the Florida Institute of Phosphate Research. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: FIPR. 2004. History of phosphate fertilizer production. [Online]. Available: <http://fipr1.state.fl.us/PhosphatePrimer> [28 October 2008]

Eutrophication

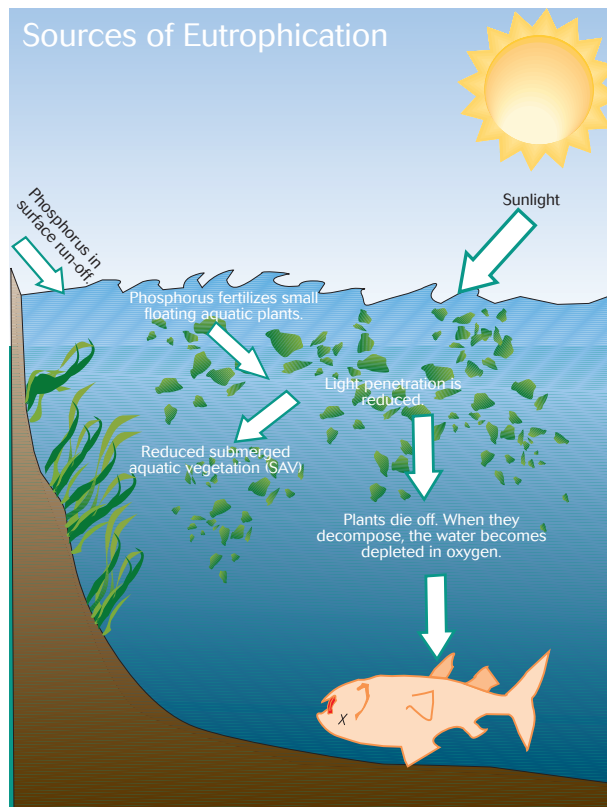
Eutrophication (pronounced you-tro-fi-KAY-shun) is a natural process that occurs in an ageing lake or pond as that body of water gradually builds up its concentration of plant nutrients.

Cultural or artificial eutrophication occurs when human activity introduces increased amounts of these nutrients, which speed up plant growth and eventually choke the lake of all of its animal life.

In nature, eutrophication is a common phenomenon in freshwater ecosystems and is really a part of the normal ageing process of many lakes and ponds. Some never experience it because of a lack of warmth and light, but many do. Over time, these bodies of freshwater change in terms of how productive or fertile they are. While this is different for each lake or pond, those that are naturally fed rich nutrients from a stream or river or some other natural source are described as 'eutrophic,' meaning they are nutrient-rich and therefore abundant in plant and animal life. Eutrophication is not necessarily harmful or bad, and the word itself is often translated from the Greek as meaning 'well-nourished' or 'good food.' However, eutrophication can be speeded up artificially, and then the lake and its inhabitants eventually suffer as the input of nutrients increases far beyond the natural capacity of the lake.

Too Much of a Good Thing

Natural eutrophication is usually a fairly slow and gradual process, occurring over a period of many centuries. It occurs naturally when, for some reason, production and consumption within the lake do not cancel each other out and the lake slowly becomes overfertilized. While not rare in nature, it does not



Source:
<http://www.thirteen.org/edonline/studentstake/water/schoolwater/Phosphorous/phosphorous.html>

happen frequently or quickly. However, artificial or human-caused eutrophication has become so common that the word eutrophication by itself has come to mean a very harmful increase and acceleration of nutrients. It is as if something receives too much fertilizer or has too much of a good thing.

Humans Increase the Rate of Eutrophication

Human activities almost always result in the creation of waste, and many of these waste products often contain nitrates and phosphates. Most nitrates are produced by bacteria and are a compound of nitrogen. Phosphates are phosphorus compounds. Both nitrates and phosphates are absorbed by plants and are needed for growth. However, the human use of detergents and chemical fertilizers has greatly increased the amount of nitrates and phosphates that are washed into our lakes and ponds. When this occurs in a sufficient quantity, they act like fertilizer for plants and algae and speed up their rate of growth.

Algae are a group of plant-like organisms that live in water and can make their own food through photosynthesis (using sunlight to make food from

Eutrophication

simple chemicals). When additional phosphates are added to a body of water, the plants begin to grow explosively and algae takes off or 'blooms.' In the process, the plants and algae consume greater amounts of oxygen in the water, robbing fish and other species of necessary oxygen.

All algae eventually die, and when they do, oxygen is required by bacteria in order for them to decompose or break down the dead algae. A cycle then begins in which more bacteria decompose more dead algae, consuming even more oxygen in the process. The bacteria then release more phosphates back into the water, which feed more algae. As levels of oxygen in the body of water become lower, species such as fish and molluscs literally suffocate.

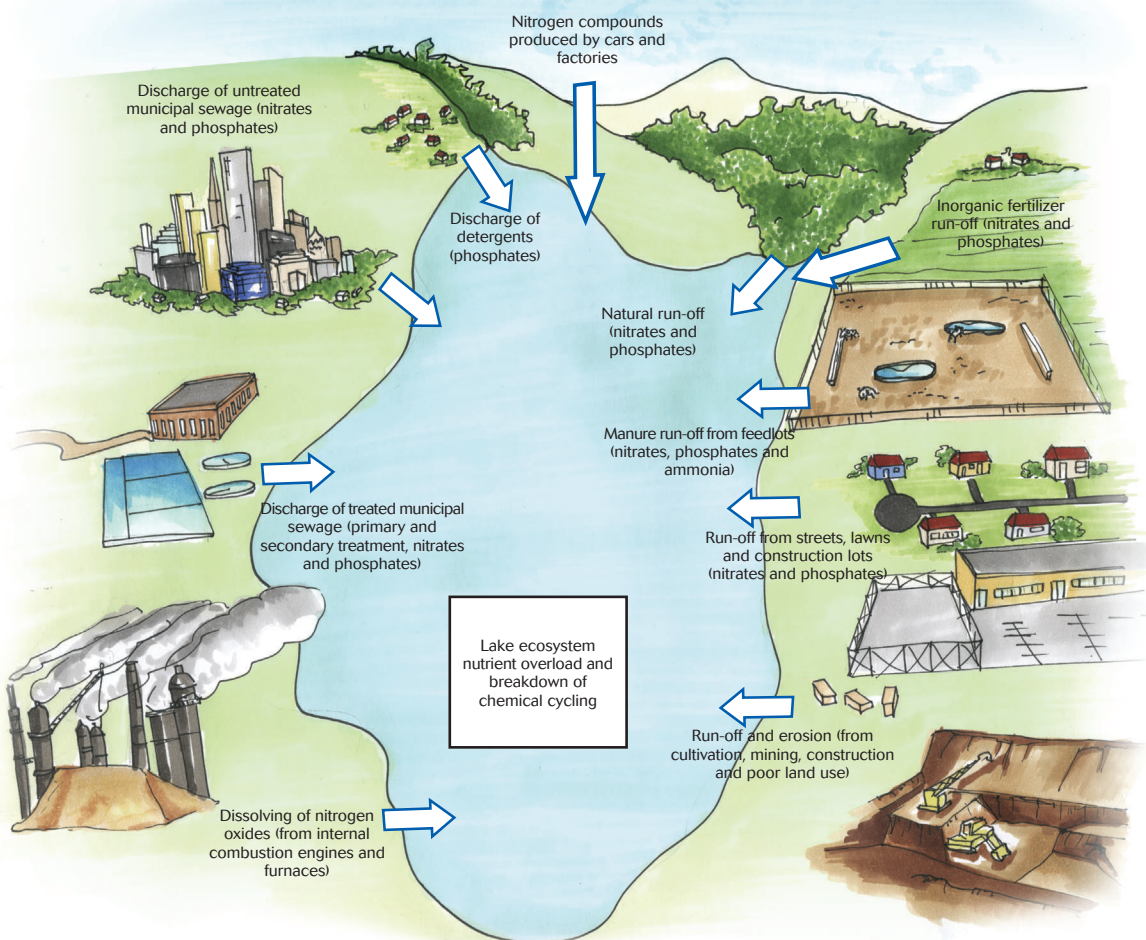
Eventually, the lake or pond begins to fill in and starts to be choked with plant growth. As the plants die and turn to sediment that sinks, the lake bottom starts to rise. The waters grow shallower and finally the body of water is filled completely and disappears.

This can also happen to wetlands, which are already shallow. Eventually, there are shrubs growing where a body of water used to be.

In the 1960s and 1970s, Lake Erie was the most publicized example of eutrophication. Called a 'dead lake,' the smallest and shallowest of the five Great Lakes was swamped for decades with nutrients from heavily developed agricultural and urban lands. As a result, plant and algae growth choked out most other species living in the lake, and left the beaches unusable due to the smell of decaying algae that washed up on the shores. New pollution controls for sewage treatment plants and agricultural methods by the United States and Canada led to drastic reductions in the amount of nutrients entering the lake. Forty years later, while still not totally free of pollutants and nutrients, Lake Erie is again a biologically thriving lake.

This article was published on the website: www.scienceclarified.com. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: www.scienceclarified.com. 2008. Eutrophication. [Online]. Available <http://www.scienceclarified.com/EI-Ex/Eutrophication.html> [15 December 2008]

Sources of Cultural Eutrophication



This diagram was obtained from the website www.thinkquest.org. Learners – if you use it you need to include the following where you use the diagram: "Diagram obtained from Thinkquest Team "Fish" March 2005, (www.thinkquest.org) and include the following in your reference list: Thinkquest 2005. Eutrophication [Online]. Available: <http://library.thinkquest.org/04oct/01590/pollution/eutrophication.html> [28 October 2008]

South Africa's Soil Resources and Sustainable Development

The Nature of South Africa's Soil Resources

Approximately 35% of South Africa receives enough rain for dry-land crop production. However, South Africa has only 13% (about 14 million hectares) arable land, i.e. land suitable for crop production. Most of this is marginal for crop production, i.e. it has low production potential. Only 3% is considered to be high-potential land. Using the international norm that 0,4 hectares arable land is required to feed a person, would mean that South Africa could produce food for only 35 million people on its 14 million ha arable land. Normally over-exploitation and very accelerated degradation follows when the human carrying capacity of the land is exceeded. In comparison the USA has 350 million people, but has arable land to feed 800 million.

South Africa has very limited irrigation potential. It is estimated that a maximum of 1,5 million hectares can be irrigated. Limited water availability is the main reason for this, but on some of the south-eastern rivers limited irrigable soil is the main factor. Only 10% of the irrigated soils in South Africa have high potential. In comparison, Iran, a country the same



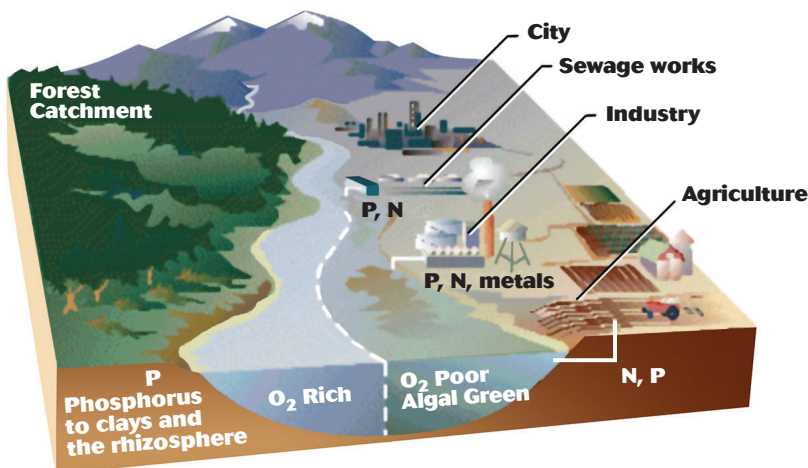
size as South Africa, has the potential to irrigate 7,5 million hectares.

A characteristic of most South African soils is that they are extremely vulnerable to various forms of degradation and have low resilience (recovery potential). Thus even small mistakes in land use planning and land management can be devastating, with little chance of recovery once the degradation has been caused. In some cases, for example in the Drakensberg-Maluti area, environments are described as being robust against degradation, but having very low resilience once they give in.

Soil Fertility Degradation

The annual loss of the three main plant nutrients due to soil erosion in South Africa is estimated at 30 000 tonnes N, 26 400 tonnes P and 363 000 tonnes K. The estimated cost to replace these is R365 million per annum at 1985 prices, and probably up to five times as much at present prices. This does not include all the other nutrients that are lost due to erosion. Due to various reasons, very little fertilizer is applied in small-farmer agricultural systems, leading to exhaustive cropping and soil fertility decline. Because yields are low, the annual amounts of nutrients removed, are small, but the long-term effects are large. In commercial agriculture there has been a tendency of 'nutrient capital building' for some nutrients, especially phosphorus and zinc. In some cases phosphorus has even built up to excessive levels, where it decreases yields. Statistics for the last twenty years indicate that trends in phosphorus levels follow two opposite directions: in a significant proportion of fields phosphorus levels are declining from adequate to deficient, whereas in other cases it is still increasing from adequate to excessive levels due to over-fertilization.

Catchment altered by human activity



Source: http://www.virtualsciencefair.org/2005/chow5a0/public_html/overall%20eutrophication%20causes.gif

Eutrophication

Effects of Urbanization, Industrialisation and Mining

Apart from their pollution effects, urbanization, industrialization and mining have several other negative impacts on soil – to such an extent that internationally there is presently often more concern about the impacts of urbanization than erosion or pollution on soils. In South Africa, indiscriminate invasion of the scarce prime and unique high-potential, arable land by urban expansion, industrial development and mining is a major problem. It represents a complete and irreversible form of land degradation. It has always been a problem, but has during the last ten years escalated due to the fast expansion of informal settlements – often onto prime agricultural land. During the last few years there have also been a number of cases of development of shopping centers and other urban complexes in wetlands – areas in which no type of development should ever be permitted because of their key ecological roles.

This material was taken from an article published by the Department of Environmental Affairs and Tourism. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Laker, M. C. 2005. South Africa's Soil Resources and Sustainable Development [Online]. Available: http://www.environment.gov.za/nssd_2005/Web/NSSD%20Process%20Documents%20and%20Reports/REVIEW_Soil_and_Sustainability_Oct05.pdf [28 October 2008]



Soil Degradation

Global population in the year 2020 will be a third higher than in 1995, but demand for food and fibre will rise by an even higher proportion, as incomes grow, diets diversify and urbanization accelerates.

However this demand is met, population and farming pressure on land resources will intensify greatly. There is growing concern in some quarters that a decline in long-term soil productivity is already seriously limiting food production in the developing world, and that the problem is getting worse.

Despite this increased public attention and the commitment of land management specialists, many policymakers remain unconvinced that agricultural soil degradation warrants priority attention. Policymakers typically consider soil quality not as a policy objective in itself, but as an input into achieving other objectives. Before taking concrete action, policymakers need a clear understanding of policy and research priorities, that is, which geographical regions and which farming systems are experiencing what types of degradation problems, and how important these problems are in relation to other challenges facing the farm sector.

Magnitude and Effects of Soil Degradation

Humans use about 8,7 billion hectares of land worldwide. About 3,2 billion hectares are potentially arable, of which a little less than half is used to grow crops. The remaining 1,7 billion hectares of potentially arable land, along with most non-arable land, function as pasture, forest and woodland. Recent global studies estimate that soil quality on three-quarters of the world's agricultural land has been relatively stable since the middle of the twentieth century. On the rest, however, degradation is widespread and the overall pace of degradation has accelerated in the past fifty years. Productivity has declined substantially on



Soil Degradation

approximately 16% of agricultural land in developing countries, especially on cropland in Africa and Central America, pasture in Africa, and forests in Central America. Almost 75% of Central America's agricultural land has been seriously degraded as has 20% of Africa's and 11% of Asia's.

Although the economic importance of this observed



degradation has long been a matter of debate, extensive literature has developed only recently. A review of this literature, even with its limitations, suggests that economic effects may be of much greater importance than previously thought.

The cumulative productivity loss for cropland from soil degradation over the past fifty years is estimated to be about 13%, and for pasturelands 4%. Crop yield losses in Africa from 1970 to 1990 due to water erosion alone are estimated to be 8%. Sub-regional studies have documented large aggregate declines in crop yields due to degradation in many parts of Africa, China, South Asia, and Central America. A global agricultural model suggests a slight increase in degradation relative to baseline trends could result in 17–30% higher world prices for key food commodities in 2020 and increased child malnutrition.

Besides affecting aggregate food supply, soil degradation also diminishes agricultural income and economic growth. In South and South East Asia estimates for total annual economic loss from degradation range from under 1–7% of agricultural gross domestic product (AGDP). Given that more than half of all land in this region is not affected by degradation, the economic effects in the degrading areas would appear to be quite serious. Estimates for eight African countries show annual economic losses ranging from under 1% of AGDP in Madagascar to 9% in Zimbabwe. Country models simulating the effects of soil degradation in Ghana and Nicaragua find annual economic growth to be reduced by nearly a percentage point. The effects of soil degradation on the environment and longer-term national wealth in soil resources have not been studied adequately, but are likely to add considerably to the economic impact.

Because the poor are particularly dependent on agriculture, on annual crops (which generally degrade soils more than perennial crops) and on common property lands (which generally suffer greater degradation than privately managed land), and because they often lack the capacity to make land-improving investments, the poor tend to suffer more than the non-poor from soil degradation. In West Africa, for example, the proportion of children who died before the age of five was highest (more than 30%) in areas with high soil degradation. The link between poverty and soil quality, however, has not been studied widely.

Soil Degradation in the Future

On the whole, degradation appears likely to pose only a modest threat to aggregate global food supply or trade by 2020, because of the global capacity for supply substitution and the dominance of less-degraded temperate regions in world food trade. However, world commodity prices and malnutrition may rise as land expansion and technological development fail to compensate for decreasing soil productivity.

Future soil degradation is likely to have its greatest impact on agricultural incomes, as yields decrease and input costs grow in irrigated, high-quality rain-fed and densely-populated, lower-quality lands. Countries or sub-regions that depend upon agriculture as the engine of economic growth will probably suffer the most. Degradation will threaten the consumption of poor farmers most of all. The greatest problems will probably occur in the densely-populated marginal lands of sub-Saharan Africa and Asia, especially where markets are less developed and industrial inputs expensive.

Estimates of land loss due to degradation vary widely, from 5 to 12 million hectares every year. Assuming that land loss continues at current rates, an additional 150 to 360 million hectares would go out of production by 2020. But because much of this is lower-quality land, the greater concern would be a serious decline in the quality of soils that remain in production. Countries with large areas of high-quality agricultural land – Brazil, China, India, Indonesia, and Nigeria – may need to worry less about long-term loss in soil wealth than the more immediate economic effects of degradation. But the 57 developing countries with high population pressure on the land and only 1–10 million hectares of arable land and the 38 countries with less than 1 million hectares may need to consider not only putting more emphasis on soil protection, but also developing long-term programs to protect and enhance the quality of some of their vulnerable lands.

Policy and Research Priorities

A necessary though not sufficient step in combatting soil degradation is to implement policies that support broad-based agricultural development and enhance farmers' incentives and capacity for land-improving investment. Many soil degradation problems could then 'self-correct' to a considerable extent by 2020. In some areas, a policy environment that promotes

information dissemination about already existing good land husbandry practices and supports research on technologies to reduce conservation costs may be sufficient for addressing degradation concerns. But policies and investments targeted to specific development pathways, farming systems, soil types and degrees of degradation are also necessary.

Policy actions in densely-populated but lower-quality lands include improving soil quality as a key element in increasing yields and reducing risk and yield variability; addressing nutrient depletion by increasing nutrient inputs, including organic matter, and improving nutrient use efficiency; urgently finding low-cost sources of plant nutrients to replace or supplement fertilizer use in areas far from markets and for farmers who practice subsistence production; and helping farmers organize and finance investment in land improvements. Research priorities include developing nutrient management systems for specific soils, low-cost soil rehabilitation techniques, economical methods for incorporating more perennial plants on farmlands, profitable systems to manage local forest and grazing lands, and documenting and sharing the more effective soil management practices from intensive farming systems with farmers that are making the transition to such systems.

The two priority policy actions to combat irrigated land degradation are fairly well known: (1) improve system- and farm-level water management regimes and (2) invest in proper drainage systems where this has not been done. Plans must be made to retire lands that are irreversibly degrading with minimal disruption to farm communities. Research priorities include exploring problems of micronutrient depletion and other soil-related factors that may lead to yield stagnation, identifying effective water management regimes, developing low-cost methods to control or reverse salinization, and finding alternative uses for saline lands.

Policies for high-quality rain-fed lands include better integrating technology development and extension for productivity growth on the one hand with good soil husbandry, agricultural machinery use, and agrochemical management on the other; developing market-based mechanisms to improve distribution systems for fertilizers that reduce cost and improve nutrient balance; and encouraging complementary use of organic nutrients. Research priorities include developing recommendations and technologies for fertilizer and organic nutrient management for specific soils, climates and crops; identifying or developing

low-cost organic nutrient sources for smallholder producers; and designing biotechnologies and other technical advances for integration into sustainable resource management systems.

Much of the policy action needed to promote better soil quality in urban and peri-urban agriculture centers around zoning rules, land access, controls on agricultural land conversion and regulation of agrochemicals and livestock waste disposal. Research priorities include designing technologies to improve the use of urban waste products in soil nutrient management and livestock feed, minimizing toxic agrochemical use, controlling livestock disease in urban environments, and developing physical and institutional barriers to protect farmland from urban soil pollutants.

In systems with extensive agriculture on marginal lands, policies should aim to limit the environmental damage of farming practices at a minimal cost to farmers; help farmers make the transition to more sustainable short-fallow or permanent-cultivation systems; raise the value of forest and tree products to reduce land clearing, increase local incomes, and initiate a long-term transition to an economy based on permanent crops; and improve employment opportunities for the landless outside agriculture. Research priorities include developing technologies for low-input farming, higher-value products that encourage spatial concentration of production; and instituting crop, forest, or range management systems that will meet both local economic and broader environmental objectives.

Many degrading regions have no apparent alternative livelihood options, sources of food supply, or non-agricultural development potential. And while soil degradation poses particular problems for the poor – and is sometimes a result of poverty – its effects appear likely to have far-reaching consequences for overall economic development in some countries. Active policy intervention will be needed to avert the graver consequences of soil degradation and harness land improvement to broader development efforts. National policy priorities will vary widely and must be determined by each country's resource endowment, the structure of agricultural supply, the geographic distribution of poverty, and the principal agricultural sources of economic growth.



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Environmental Concerns for Phosphate Mining

This section outlines environmental and safety issues connected to the phosphate industry.

When considering environmental quality and safety there are three major categories: air, water and land.

Air quality

- **Fluoride emissions.** Fluoride is in the phosphate mineral 'fluorapatite'. Fluoride in small doses, like in the fluoride in our toothpaste, is beneficial to our health and can strengthen our bones and teeth. In large doses, however, it can cause tooth mottling and even deterioration of bones (fluorosis). Phosphate companies use scrubbers in the stacks of their chemical processing plants to control fluoride emissions.
- **Dusts from rock and product storage.** As you might think, an industry that deals with crushed rock and dry granulated products puts some dust in the air. The mining sites use water to transport ore, so dust isn't an issue during transportation of matrix. In the processing plants more dry materials are handled, but the dust is only an on-site concern. Dust can be an irritant so workers in dusty areas wear dust masks. The dust

connected to the processing and storage of phosphate rock was never a big health concern and changes in the way the rock is processed and handled has made it even less likely to cause a problem.

- **SO₂ emissions.** The SO₂ (sulfur dioxide) emitted from sulfuric acid operations at phosphate chemical processing plants is very low compared to that emitted from power plants. It is, however, highly regulated because in high enough concentrations it could cause severe damage to the respiratory system. The emissions have dropped significantly since the 1980s because phosphate companies started operating double absorption plants and began recovering more of the valuable sulfur in the SO₂ to make sulfuric acid.
- **Noise.** Hearing protection is an important issue for mining, beneficiation and chemical processing sites. Environmental health and safety staffs are diligent about posting areas where hearing protection is required, instructing workers on how to properly select and wear hearing protection, and monitoring to ensure workers are using the protective gear appropriately.



Air quality fluoride emissions



Dust from rock and product storage



SO₂ emissions

Water Quality

- **Acid water that makes its way into the environment.** Requirements and regulations are in place to define how companies store the acidic water they produce in connection with the processing of phosphate rock into phosphoric acid and what they must do to neutralize and clean it before they are allowed to release it into the environment in an emergency situation.

In South Africa, special measures have been taken to ensure the recycling of process water. Settling dams are designed to ensure that no water is leaked to the environment and soil and water samples are regularly taken and tested to monitor the situation.

Land

- **Spill from a truck, train or pipeline.** Materials of concern are transported through the phosphate mining region. They include chemicals used in processing, phosphoric acid, ammonia, etc. At the mining areas slurry is also moved several kilometres by pipeline to the beneficiation plants and settling areas. If a pipe breaks and the slurry makes its way into a stream or a river, the spill

can cause environmental problems. Pipes are patrolled regularly to watch for breaks. For the most part leaks are found quickly because the flow at the end is diminished. When a leak is detected, the pipeline is shut down.

The trucks, trains and pipes that are used to transport these materials are all specially designed with safety systems. There is, however, always the possibility of an accident as with trucks carrying hazardous material.

- **Settling dam breaks.** When a settling area dam breaks, millions of litres of water with suspended solid particles can be loosed into the environment and cause damage to the land and any waterway it makes its way over and into. South Africa has strict measures in place when settling dams are built and operated.

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Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: FIPR. 2004. Environmental quality, safety and public health.
[Online]. Available: <http://fipr1.state.fl.us/PhosphatePrimer> [14 November 2008]



Noise



Water quality



Land (spill from a truck, train or pipeline)



Settling dam breaks

Environmental aspects and concerns

Most agrominerals are chemically benign and pose no additional risk to the health of miners or farmers. However, with phosphate rocks there are several environmental concerns that have to be addressed, not only for the large-scale and high-tech production of agrominerals but also for the small-scale sector. The inherent chemistry of several 'natural' sedimentary phosphates is characterized by elevated concentrations of cadmium, uranium and arsenic, which can pose potential health and environmental hazards. The cadmium problem especially has to be addressed, as its accumulation in soils and crops can have potentially harmful effects on humans. More phosphate rocks from sub-Saharan Africa, especially sedimentary phosphate rocks, should be analysed for this potentially harmful element.

There are other environmental concerns with the extraction and use of naturally occurring agrominerals and the disposal of 'wastes' from these operations. Examples include the mining of bird guano from islands close to Madagascar or the Seychelles, which can have serious environmental impacts on marine wildlife. Unprotected extraction of bat guano from caves can have significant health effects through the inhalation of Histoplasmosis spores. The disposal of wastes from agromineral operations has to be carefully planned and managed. The disposal of wastes from agromineral operations should be done using best management techniques. The dumping of 'wastes' into the ocean can have serious negative effects on the environment. Most of these potential damages can be prevented when following 'best environmental management practices' and educating both management and the persons mining and processing the ore.

Definition:

Best management practices are methods that have been determined to be the most effective and practical means of preventing or reducing pollution. These practices are often employed in agriculture, forestry, mining and construction. The EPA, working with partners in industry and the academic community have established and published best management practices for soil erosion, wastewater treatment, fuel storage, pesticide and fertilizer handling and the management of livestock yards. The ultimate goal of these practices is to increase efficiency while reducing pollution.

Source: <http://www.epa.gov/ebtpages/envibestmanagementpractices.html>

General environmental concerns are also related to transport and energy uses. More efficient use of fuel wood for agricultural lime 'burning' for example can substantially reduce the environmental damage caused by this practice. It has been demonstrated that it is possible to reduce fuel wood consumption through better kiln designs and management practices. In many cases, the limestone or dolomite resources do not even need to be 'burned' to be agronomically effective. Transport costs will generally be high if the deposits are not located close to the soils where they are most effective and alternative transportation methods may be required, particularly for small agromineral resources.

This material was obtained from the publication 'Rocks for Crops: Agrominerals of sub-Saharan Africa' by Prof P. van Straaten. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Van Straaten, P. 2002. Rocks for Crops: Agrominerals of sub-Saharan Africa. ICRAF, Nairobi, Kenya, 338pp.

The impact of guano mining in South Africa

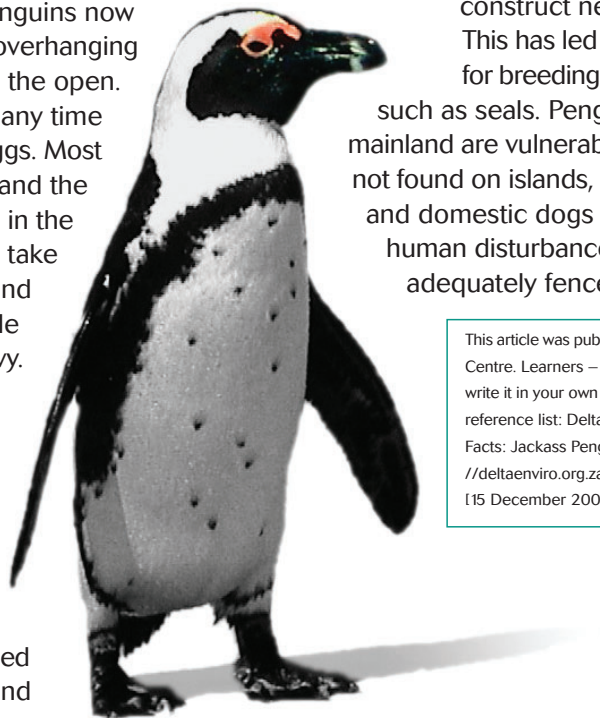
Jackass Penguins

The jackass penguin, a flightless seabird, is found nowhere in the world except off the coast of southern Africa, i.e. it is endemic to this area. It breeds on 24 offshore islands between Namibia and Port Elizabeth. Additional colonies were established in the 1980s on the mainland at Betty's Bay and Simonstown. There is also a colony on the mainland of Namibia, although it is not known when this colony was established. Nesting on the mainland is unusual for jackass penguins because they are ground-nesting birds and are vulnerable to the many predators on the mainland.

Jackass penguins used to nest by burrowing into guano (bird droppings which have accumulated into a hardish substance, sometimes several metres deep). Most of the nutrient-rich guano was removed for fertilizer in the 19th century. Penguins now nest in burrows in sand, under overhanging rocks, under bushes, or even in the open. Jackass penguins can breed at any time of the year, usually laying two eggs. Most adult birds feed during the day and the chicks are fed regurgitated food in the late afternoon. The parent birds take turns in guarding the nest site and catching food. Fish eaten include sardine, maasbanker and anchovy. Squid are also eaten.

Collapse

The total present population of jackass penguins is about 120 000 birds. In 1930, the total population numbered at least 1,2 million birds. Penguin numbers have therefore decreased by at least 90% in sixty years, and



this fall is continuing. Dassen Island, off Yzerfontein, may have once sheltered over one million penguins – it now has about 30 000. Dyer Island, near Gansbaai, now has about 20 000 penguins. The largest colony at present is St. Croix Island near Port Elizabeth, with about 50 000 penguins.

Threats to Penguins

The collapse of the jackass penguin population this century has been a result of the following:

- Harvesting of eggs for human consumption.
- Reduction of the penguin's food supply by commercial fishing.
- Oil pollution from oil tankers. This could devastate the major colonies. Oil tankers may illegally clean out their tanks as they pass round the Cape to fill up with oil in the Middle East.
- Large-scale removal of guano in the 19th century has decreased the ability of penguins to construct nests through burrowing. This has led to increased competition for breeding space with larger animals such as seals. Penguins breeding on the mainland are vulnerable to mainland predators not found on islands, such as leopards, genets and domestic dogs and cats, and also to human disturbance unless the colonies are adequately fenced and patrolled.

This article was published online by the Delta Environmental Centre. Learners – if you use any part of it you need to write it in your own words and include the following in your reference list: Delta Environmental Centre. 2008. Enviro Facts: Jackass Penguin [Online]. Available: [//deltaenviro.org.za/resources/envirofacts/penguin.html](http://deltaenviro.org.za/resources/envirofacts/penguin.html). [15 December 2008]

News

Foskor recycles water to preserve environment

South Africa

'One of the biggest projects in South Africa to address a single environmental issue was undertaken at Foskors site at Phalaborwa in the Limpopo Province.

The Foskor Water Management Project entails the collection of seepage water emanating from the filter drains around the tailings dams which will be pumped back into the plant for re-use. Both the phosphate rock and copper division, and Foskor Zirconia are located in the region. In terms of the National Water Act, process water from Foskor operations may not be released into the Selati River. Foskor has allocated R200 million (US\$31 million) to the water recycling project despite the difficult trading conditions under which it is operating.

Apart from the direct benefit of reducing the continuous surface process water run-off to the Selati River to zero, the project has also enabled Foskor to reduce its industrial water intake,' Anton Nienaber, project director at Foskor says. Foskors intake of 'raw' water from the Olifants River will be reduced from the current 40 to 45 megalitres per day to less than 20 megalitres per day, making this water available to other users in the region including the Kruger National Park.

In terms of the legislation, the project was required to simply prevent process effluent water from reaching the Selati River, but Foskor adopted a holistic view of the environmental management surrounding its tailings dam water.

Special attention was paid to the needs of local wildlife during the design of the collection reservoirs. It was immediately recognised that they might attract animals during the winter and periods of drought. 'We included ramps in our designs to allow animals to walk out in the event of them accidentally falling into the reservoirs,' Nienaber says. The lights at the



Water from filter drains around Foskors tailings dams is reused

pump stations of the reservoirs, required by the Mine, Health and Safety Act, have been fitted with a screen and are directed downward to reduce light pollution of the surrounding area.

Foskors tailings dams are situated on both sides of the Selati River. The larger of the two is 1 000 hectare and some 60 megalitres of liquid is pumped into this dam each day, making it arguably the largest tailings dam in southern Africa. The southern tailings dam is 640 hectare in extent with an intake of 12 megalitres per day. Foskor is responsible for the deposit of 6% of all tailings generated in South Africa. These two active tailings dams are 400 metres above sea level.

The dams are designed with filter drains around the perimeter at the toe of the tailings dam walls. These drains collect all the seepage water and channel it to weirs. When the tailings dams were designed and built in the 1970s and 80s, there was no legislation preventing the weirs from discharging seepage water into the nearby river, but times have now changed. The seepage, or weir water as it has become known, does not contain the same phosphate reagents as the return water which is siphoned off the top of the tailings dams. This has allowed it to be re-used in

the copper flotation processes.

In total, 17 point sources of process water run-off into the Selati River have been identified. The Foskor Water Management Project involves collecting the water from each one of these point sources before it reaches the river, and then pumping it to a central collection point before being pumped back to the Foskor plant for re-use.

There are two different weir sizes in the plant: 150 m³ and 300 m³. One of the design challenges was to determine the flow rate of the water that would need to be pumped from the weirs to ensure that they would not overflow into the river. Data was collected over two years and after statistical analysis, the team used design criteria of two standard deviations above the average. This is a dynamic process which will be continually evaluated. Provision

has also been made to upgrade the electrical facilities should additional power be required in the future.

The water level in the weirs is controlled through simple level monitoring. A telemetry system at each weir allows the central control room to monitor the situation. Should a fault condition be reported, personnel are on hand to rectify it. The system is sufficiently sophisticated to report the actual quantity of water that has overflowed into the river in the event of this occurring. Two of the concrete weirs are fed by their own intake systems as well as by two additional intakes from other reservoirs. This means that these reservoirs are equipped with more than one pump: Weir 6 has three Warman vertical spindle pumps, while Weir 13 has two Warman vertical spindle pumps. Due to system requirements it was decided to standardise as much as possible, thereby reducing the parts stockholding. Warman 65 QV and 100 RV vertical spindle pumps were selected by the design engineers, with each being adjusted by means of different pulleys and belts to accommodate the individual system requirements of each installation. The pumps are capable of delivering flows of 40 litres/second at a maximum head of 40 metres.

During the design phase of this project, the hilly environment surrounding the actual installation points was taken into account, and careful attention was given to the selection of the pumps in terms of the pipework with regard to siphoning. In instances where siphoning was identified, the problem was overcome by means of a combined air release/vacuum break valve at the high points in the circuit.

The only site suitable for the collection and temporary storage of the weir water was the existing Van Ryssen dam. However, this dam did not have sufficient storage capacity and has now been upgraded from approximately 30 000 kilolitres to 1 127 000 kilolitres. The dam size was also increased to allow for a one in fifty year flood. From the upgraded Van Ryssen dam, the water is pumped back to the Foskor plant



Three Warman 100RV vertical spindle pumps pumping in parallel to the Van Ryssen dam

into buffer dams. From there the water is distributed to the Foskor plant as well as to the Palabora Mining Company (PMC) marginal ore milling section at PMC.

In implementing this project, four pump systems were installed. The first involves pumping water from the weirs to the Van Ryssen dam via a pipe network. There are 18 weirs located around the tailings dams. Each of the weirs is fitted with one, two or three Warman vertical spindle pumps, depending on the flow. The system is designed to operate automatically using level control instrumentation and a telemetry system that transfers operations and management information back to the 300 thickener control room.

The second system involves the pump station at the Van Ryssen dam, where four centrifugal pumps have been installed. They are operated on a two running, two on standby basis and pump the collected process water to the buffer dams which have been constructed in the main plant area near Cyfos cyclone station.

The third system consists of the two buffer dams and four centrifugal pumps which convey the water either to PMC for re-use in the marginal ore circuit or to the milling circuit at Foskor.

The last system consists of a single buffer dam and four centrifugal pumps situated on the PMC site at the Foskor Export Station. The buffer dam collects and stores water pumped from Foskor for reuse in the marginal ore circuit. A total of 25 km of piping

is used in the collection and transportation of weir water and 4,500 kW of power is required to drive all the pumps. Twenty kilometres of electric cabling has been installed on the site.

Another solution to the seepage water problem would have been to put it into an evaporation pond, but this would have required additional land. This option would have been cost effective, but because the area already experiences water shortages this option was abandoned. Another option investigated was to purify and release the water. This proved to be uneconomical.

Boreholes have been drilled at strategic places around the entire Foskor site and will be used to monitor the ground water quality. They will also be used to monitor the ground water flows.

Foskor Ltd is a wholly-owned subsidiary of the Industrial Development Corporation (IDC). The company produces phosphoric acid.

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The Foskor tailings dam

