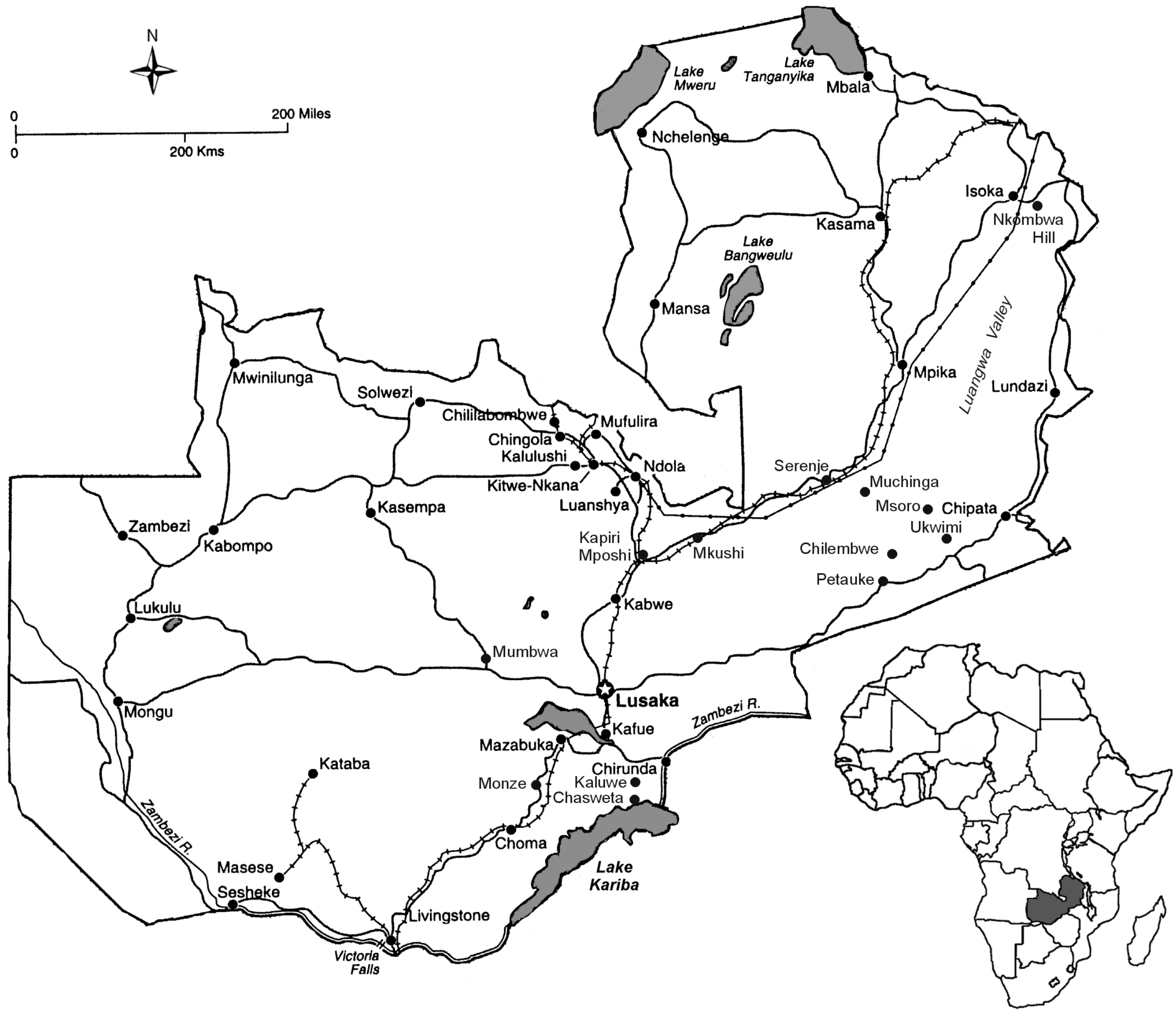
Zambia

Total population (July 2000 estimate): 9,582,000
Area: 752,614 km^2
Annual population growth rate (2000): 1.95 %
Life expectancy at birth (1998): 40.5 years
People not expected to survive to age 40 (1998): 46.2 % of total population
GDP per capita (1998): US $719



Zambia is a landlocked country in central southern Africa. The dominating landscape of Zambia is a plateau at elevations around 1,000 m, which is incised by large open rift valley-related river systems, such as the northeast-southwest Luangwa River and the Zambezi and Kafue Rivers. The alluvial plains in the south of the country, with altitudes around 300 m, form the lowest and hottest parts of the country.

Zambia is one of the most urbanized countries in sub-Saharan Africa. Urban development is restricted to the six major Copperbelt towns and along the railway via Lusaka to Livingstone at the border with Zimbabwe. Zambia's economy is historically based on the mining industry of copper and cobalt. The mineral sector contributes between 8 and 20% of the GDP, and employs approximately 15% of the wage-earning work force and accounts for about 75% of Zambia's export earnings. With declining copper prices and revenue the government diversified the economic base with a focus, among other things, on agricultural development.

Agriculture generates about 25% of the country's GDP. The livelihood of most of the rural population depends on subsistence farming. Efforts to increase agricultural production depend largely on increasing soil productivity. Hence, the government's strategy stressed the increase of soil nutrient inputs like fertilizers and manures. Currently, all fertilizers are imported, costing substantial amounts of foreign exchange.

The main food crops in Zambia are cassava, maize, millet, groundnuts and sugar cane. Cash crops for export are sugarcane, cotton, tobacco and green coffee.

Geological outline

The Precambrian geology of Zambia can be divided into several domains:

- the Paleoproterozoic (Eburnian) in the Bangweulu Block,
- the Mesoproterozoic (Kibaran) Irumide Belt,
- the Neoproterozoic Katanga Supergroup.

Phanerozoic rocks include the Karoo Supergroup, the Late Tertiary to Pleistocene Kalahari sands and Recent sediments.

In northern Zambia, the Proterozoic basement is largely made up of rocks of the Bangweulu Block, which was deformed during the Paleoproterozoic (Eburnian). Also, the northeast striking Mesoproterozoic Irumide Belt and the Neoproterozoic rocks of the Katangan Supergroup, which form the Lufilian Arc, are exposed in the northern and north-western parts of the country (Drysdall *et al.* 1972; Andersen and Unrug 1984). The Katangan Supergroup has been subdivided into the Roan Group (in which the copper-cobalt mineralization occurs), the Mwashia Group and the Kundelungu Group. While the Roan Group is represented by marine sediments including carbonates, the Mwashia and Kundelungu Groups consist of various types of sediments. Two fluvio-glacial (possibly tillite) deposits, the 'Grand Conglomerat' in the Roan Group and the 'Petit Conglomerat' in the Kundelungu Group, occur in the Katanga Supergroup.

Neoproterozoic to early Cambrian Pan-African granitoids and Pan-African fault zones are reported in the southeast part of the country. The Neoproterozoic Zambezi Belt links with the Mozambique Belt, the Lufilian Arc and the inland branch of the Neoproterozoic Damara Belt in the southeast of the country (Hanson *et al.* 1994).

The Karoo sedimentary succession, Carboniferous to lower Cretaceous in age, is made up of clastic sediments, coal and tillites. Karoo beds are found in the Luangwa Rift Valley and the Zambezi Rift Valley. Late Tertiary to Pleistocene Kalahari sands cover large parts of western Zambia.

Several carbonatites occur in Zambia that are spatially related to rift valley structures. The Proterozoic Nkombwa carbonatite is spatially associated with the Luangwa Rift Valley. The cluster of carbonatites in the Rufunsa Rift Valley (Kaluwe, Nachomba, Mwambuto and Chasweta) are Jurassic to Cretaceous in age, located at the triple junction of rift valley structures (Bailey 1966).

AGROMINERALS

Phosphates

The phosphate occurrences and deposits in Zambia have been described and summarized by many authors, among them Deans and McConnell (1955), Bailey (1966), Bwerinofa and Somney (1977), Davidson (1986), Turner *et al.* (1986), Tether (1987), Borsch (1988a, 1988b, 1991), Tether and Money (1991), Mulela (1991), Sliwa (1991), Simukanga *et al.* (1994) and Chileshe *et al.* (2000).

The phosphate mineralizations in Zambia are associated with two types of igneous rocks, carbonatites and syenites. While the phosphate mineralization related to carbonatites is well described from many parts of the world, the association of phosphate mineralization with syenites is not well documented as yet.

No sedimentary phosphates have been found in Zambia so far, and the chances of finding sedimentary marine phosphates in Zambia are very small. The types of sediments, ages and geological settings of sediments deposited in Zambia are unfavourable for phosphate deposition (Davidson 1986; Mulela 1991).

Phosphate accumulations associated with carbonatites have been studied in detail at Nkombwa Hill in northern Zambia and at the Kaluwe carbonatite in the south of the country. The well-studied syenite-related phosphate mineralizations are Chilembwe and Mumbwa North (Sugar Loaf). The location of the phosphate mineralizations is shown in Figure 2.21.

1. Phosphates associated with the Nkombwa Hill carbonatite

The Nkombwa Hill carbonatite occurs in northeastern Zambia, some 25 km east of Isoka (10^{o}09'S; 32^{o}51'E). The carbonatite forms a prominent hill rising approximately 300 m above the surrounding area. The size of the carbonatite is 1.5 x 2.5 km. The age of Nkombwa Hill is 689 ± 26 million years. This carbonatite is part of the chain of Proterozoic carbonatite and alkaline complexes that intruded along an extensive structural zone from northern Zambia via western Tanzania into Burundi and the Democratic Republic of Congo (Tack *et al.* 1984).

At least four major lithologies have been identified at the Nkombwa Hill carbonatite complex (Mambwe 1993):

- fenitic phlogopite carbonatite,
- dolomitic carbonatite,
- ankeritic carbonatite,
- silicified carbonatite .

The main phosphate mineral at Nkombwa Hill is isokite ($CaMgPO_4F$), a mineral discovered in the early 1950s by Deans and McConnell (1955). The other main phosphate mineral found at Nkombwa Hill is a strontium-rich fluor-apatite. The primary reserves of the Nkombwa phosphate-bearing rocks have been estimated at more than 200 million tonnes with a grade of 4.6% P_2O_5. A selected part of the dolomitic and ankeritic carbonatite of Nkombwa Hill yields 130 million tonnes with 7.3% P_2O_5 (Sliwa 1991). Accessory minerals include Rare Earth Element (REE) bearing minerals, and to a smaller extent the niobium (Nb)-bearing mineral pyrochlore.

The foot of Nkombwa Hill is covered with weathered residual and transported iron-rich brown soils. These soils are enriched in phosphorus relative to the original carbonatite rock. The resources of these brown soils are estimated at 1 million tonnes. Analyses of the residual and transported soils at Nkombwa Hill have shown up to 10-18% P_2O_5 in the soil, 15-30% Fe, 1-2% REE and 0.5% Nb. In order to concentrate the phosphates from the residual and transported soils several methods have been tried. Coventional flotation methods have been unsuccessful mainly because of limonite coating of the phosphates. Alternative methods to concentrate and release phosphorus from the P-rich soils, such as heap leaching and biological solubilization have been tested. Some preliminary laboratory test work using acid heap leaching techniques have indicated positive results (Borsch 1988b).

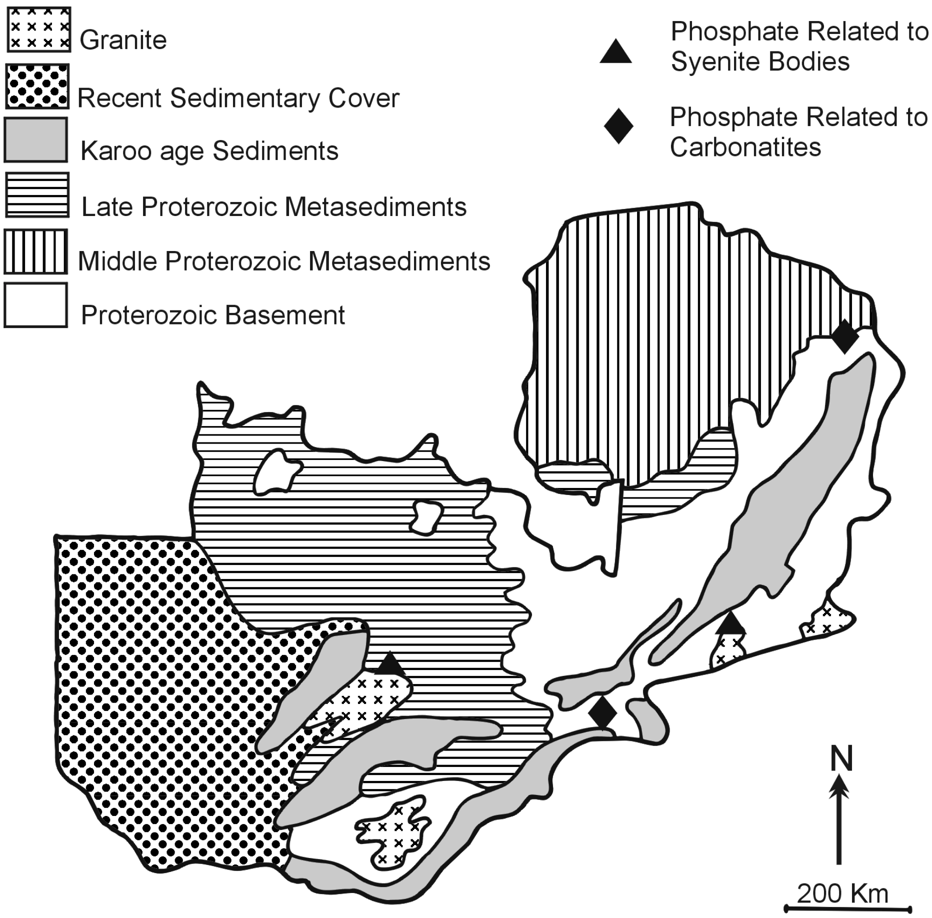


Figure 2.21: Simplified geology of Zambia with location of known phosphate deposits.

2. Phosphates associated with the Kaluwe carbonatite.

Kaluwe is the most extensive and voluminous carbonatite in Zambia. It is located at the triple junction between the middle Zambezi, lower Zambezi and Luangwa Rift Valleys in southern Zambia ($15^o10'S$; $30^o01'E$). The sheet-like carbonatite, at least 250 m thick and on average of 1.5 km wide, is slightly folded into a northwest plunging syncline. The main outcrop extends for more than 10 km from east to west. The carbonatite has been studied in detail by Bailey (1960, 1966), Turner (1988), as well as geologists from the Zambian Geological Survey Department and the Mineral Development Corporation (MINDECO) and the Mineral Exploration (MINEX) department of the Zambia Industrial and Mining Corporation Ltd.

The volume of the Kaluwe carbonatite resource is 207 million tonnes at 2.5% P_2O_5 **(**Bwerinofa and Somney 1977). Beneficiation tests of the primary carbonatite rock have shown that the recovery of apatite from this resource is difficult because the apatite grains are intergrown with carbonates. The low grade of the primary deposit and the difficulties of beneficiation render this resource uneconomic.

Of greater practical and economic interests are the residual brown soils overlying the Kaluwe carbonatite in southwest Zambia. They have been extensively sampled, trenched, drilled and analyzed. The resource base of the Kaluwe brown soils was estimated by two different methods, indicating 6.6 million tonnes at 11% P_2O_5 or 10.8 million tonnes grading 4.14% P_2O_5 respectively (Sliwa 1991). Beneficiation tests have been conducted to evaluate the recovery of apatite and the niobium-bearing mineral pyrochlore. The results of these tests were encouraging. They indicate that a phosphate concentrate of 30.4% P_2O_5 could be produced at a recovery rate of 73.8% (Mulela 1991). Niobium is concentrated in these residual soils as pyrochlore and could form a valuable co-product to phosphate. Currently, this resource is not considered for phosphate extraction for various technical and economic reasons.

3. The syenite-related phosphate mineralization at Chilembwe.

The syenite-related Chilembwe phosphate deposit is the most promising of all the phosphate mineralizations in Zambia. It is located approximately 40 km northeast of Petauke in the Eastern Province of Zambia (13°59'S; 31°41'E). The phosphate deposit at Chilembwe, discovered in 1978 during a regional prospecting campaign by MINEX, consists of five small massive leucocratic apatite-bearing bodies composed of mainly apatite and quartz and apatite-biotite-amphibole rocks. These bodies occur within the syenite that borders the 510 million year old Sinda Batholith (Sliwa 1991). The origin of this phosphate mineralization is unclear. Tether (1987) suggested that the phosphate accumulation as a result of late-stage injections of segregated fluids derived from the syenite intrusion.

Mulele (1991) calculated the reserves of the Chilembwe deposit and reported the tonnage of two of the four phosphate ore bodies as:

- Body No. 2 = 1.64 million tonnes at 11.8% P_2O_5 (cut-off grade = 6% P_2O_5),
- Body No. 4 = 0.22 million tonnes at 9.9% P_2O_5.

Although the Chilembwe phosphate deposit is relatively small, the ease of extraction and processing makes it currently the most attractive phosphate resource in Zambia.

The solubility of the Chilembwe phosphate concentrate is low, having a neutral ammonium citrate solubility (NAC-AOAC method) of only 1.0% P_2O_5 (Frederick 1991, referencing an IFDC characterization study of an ore sample from Chilembwe). This low solubility renders the Chilembwe phosphates unsuitable as direct application P fertilizer. Modification is required to make this phosphate more agronomically effective. Several modification techniques were tested by Zambian researchers, including partial acidulation (Nkonde *et al.* 1991; Zambezi and Chipola 1991; Borsch 1993; Simukanga *et al.* 1994; Chileshe *et al.* 2000) and fusion with magnesium sources (Mulela 1991). Innovative low-cost technologies for the partial acidulation process were developed at the University of Zambia and at MINEX (Nkonde *et al.* 1991; Zambezi and Chipola 1991; Borsch 1993; Nkonde and Simukanga 1993; Chileshe 2000). One of the innovative pieces of equipment tested for this process is a low-tech, modified concrete mixer (Borsch 1993).

In addition to technical studies, a financial evaluation (Simukanga *et al.* 1993), an economic assessment of partially acidulated Chilembwe PR (Frederick 1991) and an environmental impact assessment for the proposed Chilembwe mining project were conducted (Phiri 1993). In addition, Mukuka (1993) carried out a preliminary study on the social impact of producing PAPR fertilizers in rural Zambia, near Chilembwe.

Agronomic Testing of Chilembwe Phosphate Rock

The Chilembwe phosphate concentrate was agronomically tested on various soils as a directly applied P-source, as partially acidulated phosphate rock (PAPR) and as phosphate fused with magnesium sources (Fused Magnesium Phosphate, FMP). The direct application of Chilembwe PR was generally unsuccessful in producing short-term response and yield increases. However, testing of PAPR from Chilembwe using millet and maize as test crops on various soils showed agronomic effectiveness comparable to that of the soluble P-fertilizer TSP (Damaseke *et al.* 1993; Phiri *et al.* 1993; Simukanga *et al.* 1994; Chileshe *et al.* 2000). Also the use of a fused magnesium phosphate (FMP) with Chilembwe PR showed encouraging agronomic effects (Goma *et al.* 1991). The processing of FMP but was constrained by technical and economic problems.

4. The syenite-related phosphate mineralization at Mumbwa North.

The Mumbwa North phosphate mineralization was discovered by MINEX in 1984 in the course of a systematic survey of syenite bodies peripheral to large granite batholiths. The syenite-hosted phosphate mineralization is located at latitude 14°45'S, longitude 26°50'E, approximately 50 km northwest of Mumbwa in the Central Province.

Mulela (1991) differentiates between three types of phosphate mineralization at Mumbwa North:

Type 1. apatite associated with primary copper and iron mineralization (at Sugar Loaf),
Type 2. copper-phosphate mineralization in the supergene environment, such as turquoise-chalcosiderite,
Type 3. ‘apatite pegmatite’ bodies.

The apatite in the Type 1 mineralization occurs as fractured prismatic crystals in a ferruginous breccia of altered syenite fragments (Sliwa 1991). Mulela (1991) interpreted this body as fractionated cumulate that was subsequently brecciated and subjected to hydrothermal alteration. Resource estimates of this mineralization indicate 0.5 million tonnes of ore with grades between 8 and 12% P_2O_5 (Sliwa 1991).

The phosphate mineralization of some interest for agricultural purposes is the apatite in pegmatites (Type 3). The apatite pegmatite bodies occur as irregular veins with sharp contacts to the surrounding country rock. The rocks are almost monomineralic apatite with occasional K-feldspar and crack-filling iron oxides. The apatite near the contact is fine to medium-grained and in the central part of the pegmatite the apatite is coarse grained with crystals up to 10 cm in diameter (Sliwa 1991). According to Mulela (1991), the mineralogical composition is that of a hydroxy-apatite with elevated levels of rare earth elements (REE) and radionuclides. The largest of the pegmatite bodies is estimated to contain 0.22 million tonnes of ore with an average grade of 16% P_2O_5 (Mulela 1991).

Other phosphate occurrences

Tether and Money (1991) describe two other small phosphate occurrences, one at Chikombwe within a veined stockwork in gabbros, the other in an amphibolite near Chakanga, north and northeast of Petauke. Both have irregular phosphate mineralization with generally low grades. These occurrences seem to be of small volume and low grades, and thus are of no economic interest.

Other agrominerals

Liming material

Large parts of Zambia are covered by acid and strongly depleted soils especially the strongly leached soils developed from felsic rocks under high rainfall regimes in the north of the country. The nature of these strongly acid soils, with pH levels ($CaCl_2$) below 4.5, and corresponding high aluminum (Al^{3+}) saturation, are major constraints to crop production (Singh 1989; Goma 1994). Experiments carried out on these soils by the Ministry of Agriculture and various organizations have shown the effectiveness of finely ground 'liming materials' including dolomitic limestones.

In Zambia, carbonate rocks have been classified into three groups:

- crystalline limestones and dolomitic limestones of the Precambrian,
- chemically formed limestone-travertine deposits, deposited from spring water,
- plug and sheet-like carbonatite bodies.

Most of the limestone and dolomite resources of Zambia are found in central Zambia, occurring in an area from Lusaka via Kapiri Mposhi and Kitwe to the Solwezi area in the Northwestern Province. The volume of these deposits is very large. Some of these resources are used for the Zambian cement industry, for example the carbonate resources at Chilanga (20 km south of Lusaka) and Ndola. Others are used for aggregate production. Small, relatively undeveloped resources are described from north of Mkushi (Rao 1986; Bosse 1996).

In the west of Zambia only few sizeable carbonate resources have been delineated. Dolomitic limestone resources are located 16 km northwest of Kabompo (1.4 million tonnes). Other liming resources occur 43 km north of Zambezi town (dolomitic limestone: 3 million tonnes; marble: 1 million tonnes). The neutralizing value of the dolomitic limestones and marbles is high, ranging from 97-112% (Rao 1986).

In eastern Zambia, carbonate rocks are known in the Lundazi, Chipata and Petauke areas. A quarry south of Lundazi supplies eastern Zambia with hard rock aggregates. Several more dolomitic limestones are reported in this area, south and southwest of Lundazi. Near Msoro Mission, lenses with dolomitic marble were used in the past for lime production. Near Ukwimi, coarse-grained, white calcitic marbles with accessory phlogopite, apatite and graphite were extracted and processed into lime until 1960 (Bosse 1996). North and west of Petauke, there are several extensive dolomitic marbles. Some of these carbonate deposits were previously processed into agricultural lime, for example the marble from Muchinga, east of Serenje. In the 1980s, annual production from this source was 3,000 tonnes.

Only a few, small occurrences of carbonate rocks are known from Northern, Luapula and Eastern Central Provinces where liming material is most needed. The limestones in Luapula Province occur in the Kundelungu Group near Matanda and Bukanda (approximately 70 km west of Mansa). The reserves of the Matanda deposit alone are in the range of 5 million tonnes. The neutralizing values of these limestones are high, ranging from 89-104 % (Rao 1986).

The main carbonate resource in the Northern Province is Nkombwa Hill, a large carbonatite complex, some 25 km east of Isoka. The volume of easily extractable dolomitic carbonatite is in excess of 700,000 tonnes (Nalluri 1984). Tests by Singh (1989) and Tveitnes and Svads (1989) on local soils indicate low initial response to liming, but good response to liming in combination with P application.
In addition to the sedimentary limestone and dolomite resources, the carbonatites in the Rufunsa area, specifically Kaluwe and Chasweta, contain significant volumes of carbonate rock.

The need for liming materials, especially for the acid soils of the northern part of Zambia prompted some investigations on appropriate crushing and grinding equipment. Rao (1986) collected equipment quotes for a 10,000 tonne per year capacity crushing and grinding plant. The equipment including drilling equipment, primary crusher, a hammer mill and tertiary crushers is quoted at US $121,932 (Rao 1986).

The British Geological Survey in co-operation with the Geological Survey of Zambia, the University of Zambia, and the Ministry of Agriculture is currently developing a demonstration lime production facility. They plan to test various limestones (and phosphates) in cooperation with small-scale farmers.

Guano

Several guano deposits are reported by Tether and Money (1991) in the northwest of the country and near Lusaka. However, no details on location, chemical composition and tonnage have been provided.

Potassium-rich minerals

There are no known evaporite-type potash deposits in Zambia. In the search for alternative K-bearing materials, Borsch (1990) and Tether and Money (1991) describe some initial tests on potassium-containing silicates. Extraction tests on clays and K-feldspar-bearing rocks from Zambia showed low available potassium, although treatment with various acids improved potassium release. The experiments carried out by Borsch (1990) showed that shales and argillites from the Copperbelt mining area contained 1.5-7.4% total K_2O, but that only 0.01-1% K_2O was available. After acid treatment the available K_2O content reached 3.9% using nitric acid and 5.7% using sulphuric acid. Micas from pegmatites with a total K_2O content of 7-14% released only 0.8% K_2O in water. Nitric acid treatment increased the available K_2O content to 2-4%, and sulphuric acid treated biotites released 9.6% K_2O (Borsch 1990).

Tether and Money (1991) report on tests on metasomatized mudstone and feldspathic breccia surrounding the Mwambuto and Nachomba carbonatites (between Kaluwe and Chasweta). The total K_2O levels reached 16%. However, very little K is readily soluble in HCl. They concluded that the recovery of K from K-feldspars is unlikely to be economic.

Sulphides/sulphates

Zambia's sulphur resources occur in the form of sulphides. Primary pyrite is extracted from the 20 m thick lode of the Nampundwe pyrite mine (48 km west of Lusaka). Reserves are approximately 10 million tonnes averaging 16.8% S (Tether and Money 1991). Other sulphide mineralizations are associated with base metal ores. However, in recent years, Zambia's copper industry has imported large volumes of sulphuric acid from neighbouring Zimbabwe.

Other sulphur-resources in Zambia include gypsiferous clays (gypsite). They occur in surficial environments of the Kafue Flats and the Siloana Plain, close to hot springs (Tether and Money 1991). The gypsiferous clays of Lochinvar, some 38 km from Monze, occur in layers up to 2 m thick under a thin layer of clay on the edges of the alluvial plain of the Kafue River (Sikombe 1982). The gypsum content in these clays reaches 40% with crystals up to 4 cm in size. Detailed exploration revealed 320,000 tonnes of recoverable gypsum from an area of 200 ha (Sikombe 1982). The extraction of gypsum, required by the cement industry as retarder, ran into problems at Lochinvar, and economic and technical problems (removal of gypsum from clay) forced the Chilanga cement factory to withdraw from the project. Consequently, the Lochinvar gypsum resource was not developed and the Chilanga cement factory found its own gypsum supplies from 'waste gypsum,' a material produced from neutralization of acid effluents from electrolytic copper refineries.

Agromineral potential

Zambia is well endowed with igneous phosphate resources. The phosphate resources in carbonatites are large but generally of low grade and low reactivity. The very low-grade residual soils at Kaluwe are relatively easy to extract and concentrate. However, the best potential for development of an indigenous phosphorus source is the syenite-related phosphate resources at Chilembwe, and to a smaller extent, at Mumbwa North. The resource base is relatively small and classical, large-scale industrial acidulation techniques of P-fertilizer production seem to be uneconomic. Because direct application of phosphate rock (PR) of unreactive composition is largely ineffective in the short term, teams at the University of Zambia and MINEX have tested alternative innovative processing techniques (for example partial acidulation). These efforts have been successful and require continued support. Additional low input techniques, such as biological modification, blending and compaction/pelletizing techniques should also be included in the processing and testing program.

The potential of slow release of potassium from micas, specifically biotites and phlogopites, should be investigated. The studies should focus on potential K-resources in close proximity to K-deficient soils, and on areas where high K-demanding crops such as potatoes, sunflowers and bananas are grown.

The limestone and dolomite resources of Zambia are extensive. However, the distribution of these resources is concentrated in the southern, northwestern and central areas. The highest demand for liming materials is in the northern areas of Zambia where only few limestone and dolomite resources are located. Efforts should be made to use the carbonate resources of the Nkombwa Hill carbonatite complex in the Northern Province, the resources in the Luapula Province, for instance, Matanda, and the occurrences in the Mkushi area.

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