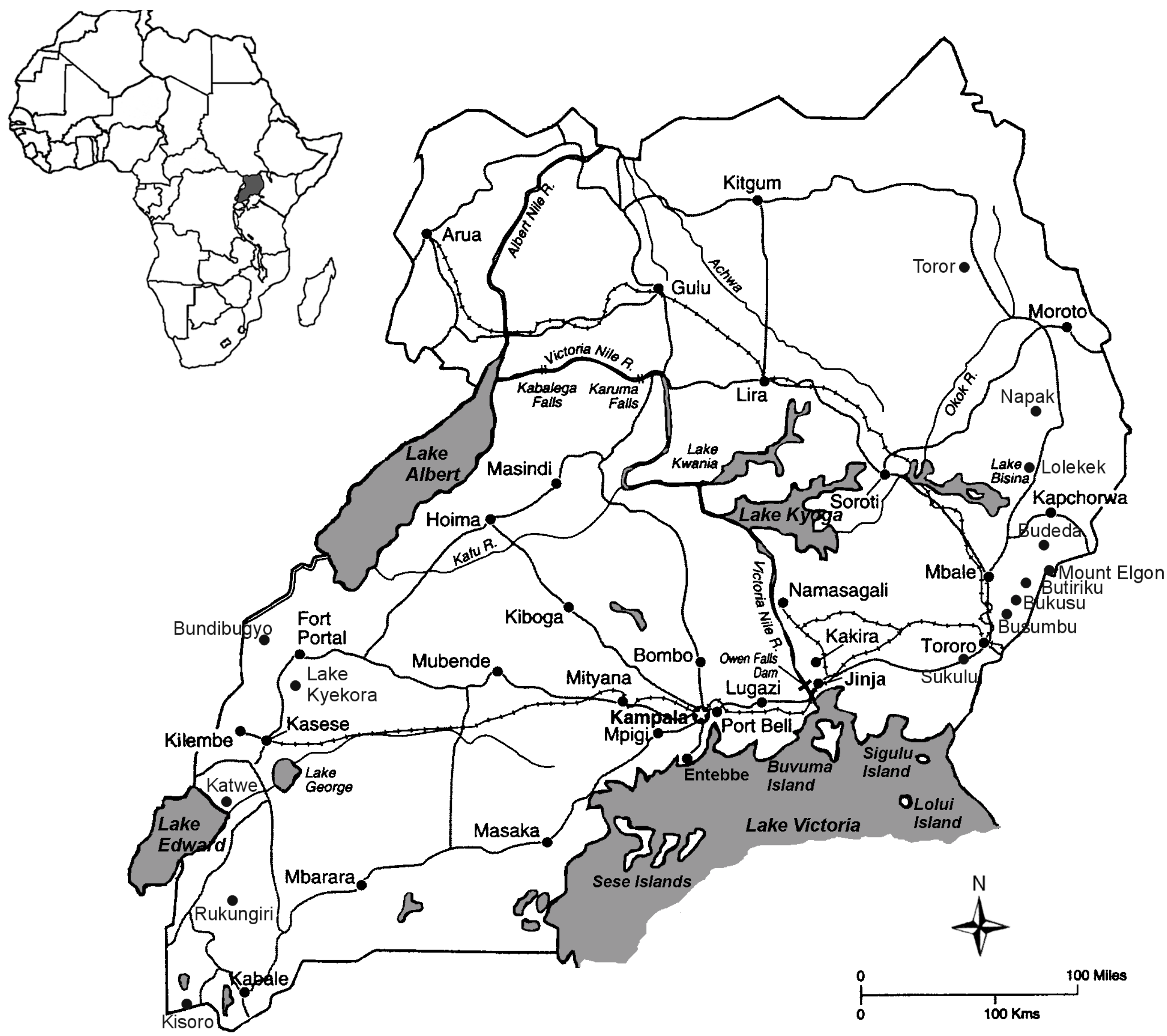
Uganda

Total population (July 2000 estimate): 23,318,000
Area: 236,040 km^2
Annual population growth rate (2000): 2.72 %
Life expectancy at birth (1998): 40.7 years
People not expected to survive to age 40 (1998): 45.9 % of total population
GDP per capita (1998): US $1,074



Uganda is a landlocked country in central East Africa, north and west of Lake Victoria. The landscape of central Uganda is characterized by gently undulating hills and broad valleys at elevations between 1,000 and 1,500 m above sea level. The western part of the country consists of rolling mountainous land, and the Ruwenzori Mountains, an uplifted block at the flanks of the Western Rift Valley. The south-eastern section of the country, at the border with Kenya, is dominated by the Mount Elgon strato-volcano.

Agriculture dominates the economy, contributing 44% of the GDP, and employing an estimated 80% of the working population. The main food crops of Uganda are plantains, cassava, sweet potatoes, maize and millet. The main export crops are coffee and tea. Other crops include sugarcane, potatoes, beans, tobacco, cotton and groundnuts. Non-traditional agricultural exports include cut flowers.

At present, mining plays only a minor role in the economy of the country. The Kilembe copper mine at Kasese and the copper smelter at Jinja closed in 1978. Approximately 1.1 million tonnes of cobalt-rich tailings from the Kilembe mining operation are currently being treated using bioleaching, solvent extraction and electrowinning techniques. Other small mineral related-activities include gold exploration in the south-eastern part of the country and industrial mineral development.

Geological outline

Precambrian rocks underlie two-thirds of Uganda. Archean rocks are exposed in the south-east of Uganda. They are part of the extensive granite-greenstone terrane of the Tanzania Craton. Three major Proterozoic belts underlie central and west Uganda: the Paleoproterozoic Buganda-Toro metasediments, the Mesoproterozoic Karagwe-Ankolean (Kibaran) Belt in the southwest of the country and Neoproterozoic Pan-African rocks (Gabert 1984). The Neoproterozoic includes the Bunyoro Series with tillites and argillites (Bjorlykke 1973), and the undeformed shallow water sediments of the Bukoban Supergroup. Tertiary to Recent sediments have filled parts of the down-faulted Western Rift. Tertiary carbonatites and Cenozoic volcanics are related to rift activities and occur along the eastern and western borders of the country. The distribution of carbonatites and alkaline intrusions in southeast Uganda is shown in Figure 2.20.

AGROMINERALS

Phosphates

1. Sukulu

Extensive phosphate resources in eastern Uganda have been discovered in the Sukulu carbonatite complex, located 6 km southwest of Tororo. The Sukulu carbonatite complex is the southernmost member of the Tertiary alkaline province in eastern Uganda (Fig. 2.20). Davies (1947), Williams (1959), Bloomfield *et al.* (1971) and Reedman (1984) have carried out geological and geochemical work at the Sukulu carbonatite ring complex. This carbonatite, approximately 4 km in diameter, is mainly made up of calcium-carbonatite (soevite/alvikite) with minor amounts of dolomite and Fe-carbonates. Accessory minerals in the carbonatite are magnetite, mica (in places weathered to vermiculite), apatite, and small amounts of pyrochlore and zircon. A thick blanket of phosphate-rich ‘residual soils’ covers the carbonatite complex. In one of the three principal valleys the residual soil reaches a depth of 67 m (Reedman 1984).

The main constituents of the residual soils covering the carbonatite are magnetite (at places up to 50%), hematite, goethite, apatite with minor amounts of quartz, ilmenite, micas, zircon, pyrochlore and baddeleyite. Detailed studies of the residual soils have also recorded the presence of Al-phosphates, for instance crandallite. Apatites make up over 20% of the soil and in some places more than 50%. Detailed mineralogical and chemical studies of the apatite by scientists from the International Fertilizer Development Centre (IFDC) show that the neutral ammonium citrate (NAC) solubility of a concentrate of the Sukulu phosphate rock (Sukulu PR) is low, 1.6% P_2O_5. This is lower than the NAC solubility of the neighbouring Busumbu phosphates (NAC = 2.3% P_2O_5). The total reserves of the residual phosphates at Sukulu have been calculated as 230 million tonnes averaging 12.8% P_2O_5 (Van Kauwenbergh 1991).

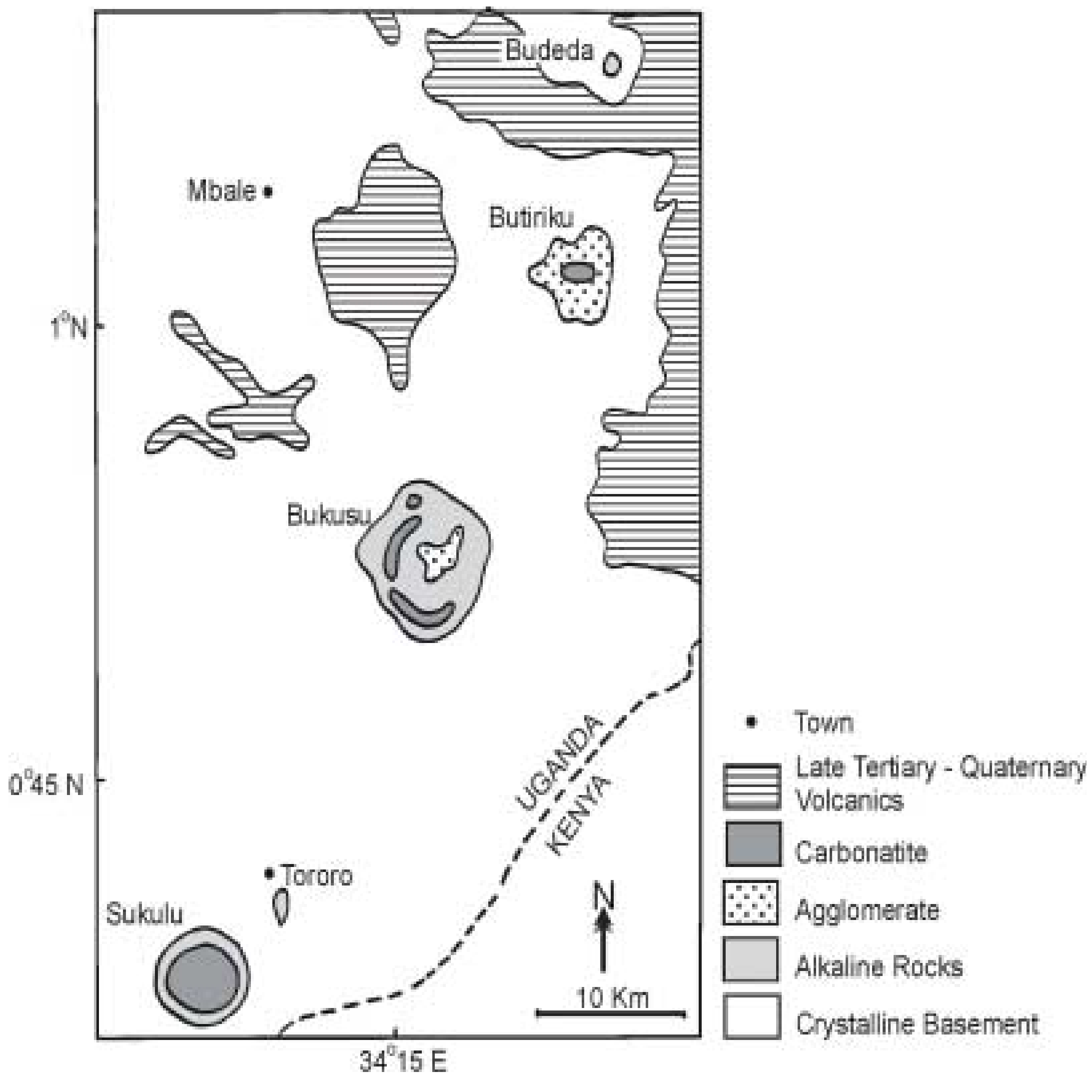


Figure 2.20: Distribution of carbonatites and alkaline complexes in southeast Uganda (after Davies 1956).

The 'ore' mined at Sukulu between 1962 and 1978 consists of residual soil, the weathering products of the Sukulu carbonatite with an average grade of 12.8% P_2O_5. Tororo Industrial Chemicals and Fertilizer Ltd. (TICAF) started out by mining the residual soils of the North Valley, which contain approximately 32% apatite, 57% magnetite and goethite, as well as 0.25% pyrochlore. The apatite from the Sukulu soils was won through grinding and magnetic separation, followed by flotation. The apatite concentrate (40-42% P_2O_5) was acidulated with sulphuric acid and converted into single superphosphate. TICAF produced approximately 160,000 tonnes of apatite concentrate (40-42% P_2O_5) from 2.16 million tonnes of ore. In 1969, TICAF produced 13,800 tonnes of apatite concentrate and 22,390 tonnes of single superphosphate.

During the 1980s, the fertilizer plant was destroyed and partly dismantled and more recently, the plant has been leveled and the remaining equipment dismantled.

The phosphate resources of Sukulu have been investigated intensively. A comprehensive economic and engineering study was carried out by Bearden-Potter Corporation of Florida (financed by the World Bank) in the early 1980s (Bearden-Potter Co. 1982). However, the 230-million tonne Sukulu phosphate deposit has yet to be developed for a number of reasons, one being the high capital investment required for the production of soluble P-fertilizers (US $121 million) (Annual Mining Review 1988). In addition, the processing techniques proposed by Bearden-Potter Co. are technically sophisticated and capital intensive.

Agronomic Testing of Sukulu Phosphate Rock

Various researchers have tested Sukulu PR on its agronomic performance, including Zake and co-workers (Zake *et al*. 1988; Nkwiine *et al.*) and Butegwa *et al.* (1996a, b). Both research groups showed that Sukulu PR used as direct application P-fertilizer was ineffective on acid soils. Better performance could be achieved by combined application with organic matter and 25-75 kg sulphur per hectare (Zake 1988). The use of partially acidulated phosphate rock (PAPR) manufactured from Sukulu PR had a lower agronomic effectiveness than Sukulu PR compacted with TSP at a total P ratio of 50:50 (Butegwa *et al.* 1996a). The effectiveness of partially acidulated phosphate rock (PAPR) was low on soils with high fixing capacities (Butegwa *et al.* 1996b).

2. Busumbu:

The Busumbu phosphate rock deposit is located at Busumbu Hill, some 10 km west of the Kenyan border at 0^o 50'12" N and 34^o 15'55" E, approximately 30 km north of Tororo. It is a residual phosphate deposit that overlies the Busumbu carbonatite, which in turn is part of the circular, 24-26-million year old alkaline Bukusu complex, one of the largest alkaline complexes in Africa. The main carbonatite forms a partial ring, cutting ultramafic and alkaline rocks (Fig. 2.20).

The Busumbu ridge, approximately 2,000 m long and 400 m wide, is made up of a deeply weathered phosphate-enriched residual soil. The primary carbonatite underlying the residual phosphate deposit consists of a calcite-magnetite-apatite-phlogopite assemblage.

Davies discovered carbonate rocks at Busumbu in the early 1930s. A pitting and drilling program, conducted between 1942 and 1945, revealed about 5 million tonnes of phosphate rock with grades between 8 and 35% P_2O_5. The average P_2O_5 content from samples of 430 m of pitting was 11.9% (Davies 1947, 1956). After Davies, the deposit has been studied by a succession of geologists, including Taylor (1955, 1960), Baldock (1969), Bloomfield (1973), Celenk and Katto (1993) and Mathers (1994). A joint team from the Department of Geological Survey and Mines (DGSM) and the United Nations Department for Development Support and Management carried out detailed geological investigations at Busumbu. Findings indicate that proven reserves of higher grade 'hard' phosphates (average grade 28.5 % P_2O_5) are 332,000 tonnes, and lower grade 'soft' phosphates with an average grade of 13.5 % P_2O_5 account for more than 2,468,000 tonnes (Celenk and Katto 1993). These initial and preliminary reserve estimates were based on limited pit excavations to a depth of 6 m from the surface.

Subsequent work by Katto (1995, 2000) proved ore reserves of 8.5 million tonnes. This included 3 million tonnes with an average grade of 11% P_2O_5 in the soil with an average thickness of 2 m. An additional 5.5 million tonnes of phosphate ore has been delineated in the underlying 4 m of weathered material (saprolite) with an average grade of 15% P_2O_5. The calculations are based on a total thickness of soil plus weathered material of only 6 m. However, since the deposit is thicker than 6 m, the reserves are most likely higher than the 8.5 million tonnes reported by Katto (1995). Proven reserves on one of the ridge-forming hills, Hill 2, are calculated to be 8.4 million tonnes grading 12.6% P_2O_5 (Wolukawu, pers. comm. 1998).

Two types of phosphate have been identified at Busumbu: the ‘hard rock’ and the ‘soft rock.’ The ‘soft rock’ below the 1-2 m thick red soils consists of soft brown friable material with unaltered primary apatite in an iron-rich earthy matrix. This material is very friable and can easily be excavated by pick and shovel operation or by simple mechanical means. Apart from fluor-apatite, the ore contains mainly magnetite and other iron oxides. The ‘hard rock,’ which makes up approximately 13% of the deposit (Davies 1956), is a mixture of primary apatite cemented together by secondary phosphate. Davies (1947) identified the secondary phosphate mineral as carbonate-substituted francolite. A mineralogical study of Busumbu PR indicates that the francolite is a low-substituted variety (Van Kauwenbergh 1991). The neutral ammonium citrate (NAC) solubility of the total rock is reported by Van Kauwenbergh (1991) as 2.3% P_2O_5, somewhat higher than most typical igneous apatites. For example the NAC solubility of apatites from Rangwa in Kenya is 0.4% P_2O_5 and that of the Sukulu concentrate is 1.6% P_2O_5. The unit-cell a-value of the Busumbu PR is 9.362 Å.

Mineralogical studies of the soft phosphate ore including X-ray diffractometry by Katto (1995) and Scanning Electron Microscopy (SEM) studies by van Straaten (unpublished) indicate the presence of fluor-apatite, and small amounts of Al-phosphates including crandallite, as well as magnetite, goethite, and hematite.

Scanning electron microscopy of hard phosphate samples shows a clear difference between primary apatites and the secondary apatites, which surround them. The primary apatites contain 41-42% P_2O_5, have CaO/P_2O_5 ratios of 1.31-1.34, and low F-values (1.5-2.0%). The corresponding data for the secondary apatites are: 37-38% P_2O_5, CaO/P_2O_5 ratios of 1.43-1.46, and 3.7-4.4% F (van Straaten 1997).

Phosphate rocks from Busumbu were mined between 1944 and 1963 from small open pits along Busumbu ridge. Until 1956 the ‘hard’ phosphate rock was excavated, crushed and screened before being exported to neighbouring Kenya for the manufacture of citric-soluble soda phosphate fertilizer (using soda-ash from Lake Magadi). The undersized, fine phosphatic material was used as direct application fertilizer. From 1956 onward the customer requirement changed and ‘hard’ phosphate rock was replaced by a blend of soft phosphate rock with a P_2O_5 content of 15% P_2O_5 and hard phosphate with a P_2O_5 content of 30%. This phosphate blend was upgraded using magnetic separation techniques. The annual production reached 6,000 tonnes and a total of 62,000 tonnes of phosphate concentrate were produced during the lifetime of the mine. The production of this small-scale operation ceased when the large phosphate fertilizer plant at Sukulu came into operation.

Agronomic Testing of Busumbu ‘Soft’ Phosphate Rock

Researchers from the Kenya Agricultural Research Institute (KARI), and the International Centre for Agroforestry (ICRAF) tested the concentrates from the Busumbu soft ore (Busumbu soft PR) on acid P-deficient soils of western Kenya between 1998 and 2001. In most fields the relative agronomic effectiveness (RAE) of unmodified Busumbu soft PR is low (28-45 %). However, Busumbu soft PR blended with triple superphosphate at a rate of 30% TSP and 70% Busumbu soft PR show high yield increases, the RAE reaching 70-80% (Buresh, pers. comm. 1998). Greenhouse testing with Busumbu phosphate rock blended with TSP and mono-ammonium phosphate (MAP) at a ratio of 50:50 show RAEs of 80% and more than 90% respectively (Ngoze *et al.* 2000).

Initial results of Busumbu soft PR composted with various locally available organic wastes show low agronomic effectiveness in near neutral, sandy soils in eastern Uganda (Oshier, 2002).

Other phosphates

Small bodies of secondary phosphates were discovered at the western edge of the Butiriku carbonatite complex during exploration studies by Reedman (1974). The volume and grade of the Bukiribo and Bududa phosphate rocks, both within the Butiriku carbonatite complex, have not yet been established but seem to be on the order of several hundred thousand tonnes.

Scanning electron microscope studies by van Straaten (unpubl.) show that these phosphates are mainly made up of secondary phosphates, specifically francolite. Ground and directly applied Bukiribo phosphate rock were agronomically tested in western Kenya and showed very good initial and residual effects (ICRAF, unpubl. data).

The carbonatitic lavas from Western Uganda contain small amounts of apatite. The P_2O_5 content of two samples of vesicular and zeolitic carbonatitic lava from Kalyango near Fort Portal is 3.32 and 3.57 respectively (Von Knorring and du Bois 1961).

Limestone/dolomite/travertine

There are several well-investigated limestone resources in Uganda. Sedimentary limestone and travertine resources are found spatially related to the Western Rift. Metamorphosed dolomitic limestones and marbles are associated with Precambrian metasediments. The Proterozoic rock sequences of the Buganda-Toro and Karagwe Ankolean (Kibaran) belts are largely devoid of carbonates. The Ugandan carbonatites are voluminous point sources of Ca- and Ca-Mg-carbonates.

Sedimentary limestones and travertines, commonly low in magnesium content, occur in Quaternary sediments of the Western Rift valley close to Lake George in western Uganda. These deposits are mainly lacustrine, chemically precipitated tufaceous limestones and travertines deposited close to mineral springs. They are generally fine-grained with a vuggy texture (Mathers 1994). At least three limestone deposits occur in the Kasese area in western Uganda: the Hima deposit, the Dura deposit and the Muhokya deposit. The Hima limestone deposit, approximately 15 km northeast of Kasese, with measured reserves of 18 million tonnes is currently exploited for the manufacture of cement. The Hima cement factory has an installed capacity of 300,000 tonnes per annum.

The Dura limestone deposit located at the eastern side of the Western Rift, 18 km east of Kasese contains powdery marls, grey compact travertines and satin spar (Mathers 1994). The reserves of these high-grade limestones are estimated at 1.5 million tonnes (Department of Geological Survey and Mines -DGSM, written comm. Feb. 2000).

The Muhokya limestone, 13 km south of Kasese, is a sedimentary lacustrine deposit with reserves estimated at 0.25 million tonnes. The deposit has been worked intermittently since 1945 for the exclusive manufacture of lime as soil stabilizer in road construction, for sugar refining, as lime mortar and whitewash. It is not known whether some of the lime has also been used for agricultural purposes. Local companies involved in lime production include Equator Lime Ltd. This company operates continuous vertical shaft kilns and produces up to 5 tonnes of hydrated lime per day.

Other limestone/travertine resources in western Uganda include Kainanira in the Kaku Valley, 16 km from Kisoro in Kigezi District (1 million tonnes), which is currently exploited for the manufacture of lime using batch kilns. Other small limestone resources are located near Ndorwa, Kitumba, Bubale, Kigata and Kigararma (all in the vicinity of Kabale), and Kisiizi, Rubabo, and Rwonye in Rukungiri District (DGSM, written comm. Feb. 2000).

Enormous reserves of dolomitic limestone, dolomite and marble occur in eastern Uganda, along the border with Kenya and south and east of Moroto. The Neoproterozoic Karasuk metasedimentary sequence of metamorphosed limestones contains approximately 13 billion tonnes of dolomitic marble (DGSM, written comm. Feb. 2000). Unfortunately these limestone and dolomite resources occur in a semi-arid area, distant from the main markets for cement, lime consumption and from agricultural areas with acid soils.

Carbonate resources related to carbonatites in eastern Uganda are associated with the Sukulu, Tororo, Bukusu, Butiriku, and other carbonatites along the Kenya-Uganda border. The Sukulu Hills carbonatite, about 6 km southwest of Tororo, is mainly composed of soevitic limestone with possible carbonate reserves of 16.3 million tonnes. Small-scale miners are currently excavating a small portion of the Sukulu carbonatite complex and calcine the limestone in batch kilns. The Tororo Cement Industries excavate some other parts of the deposit.

The Limekiln Hill and Cave Hill phosphatic carbonates of the Tororo carbonatite complex, just outside Tororo, have been used for many years as raw material by the company Tororo Cement Industry. The P_2O_5 level in the raw material reaches up to 1.7%. Reserves are estimated at 82 million tonnes.

Carbonates are also reported from the Bukusu alkaline/carbonatite complex in Mbale District. A small portion of this large ring complex is made up of carbonates. No reserve figures are available and no mining is currently being carried out. Other carbonates, located at the Butiriku carbonatite complex in the Bukiribo area, 3 km north of Bududa in Mbale District, have probable carbonate reserves of 16.3 million tonnes. The proven reserves are 3 million tonnes. Information on the carbonate resources of other carbonatites in eastern and northeastern Uganda, such as the Budeda, Lolekek, Napak and Toror, is sparse.

Other carbonate-rich rocks include calcite-bearing tuffs from the foot of Mount Elgon in the Mbale district and in volcanic rocks from the Fort Portal and Kisoro area in western Uganda.

Carbonatitic lavas are known from the Katwe area, from Kalyango volcano near Fort Portal and from Lake Kyekora, south of Fort Portal. The groundmass of the vesicular carbonatitic lava from Kalyango is composed of minute grains of pyroxene, olivine, biotite, magnetite, apatite and calcite (Gittins 1966).

Gypsum

The best known source of natural gypsum, $CaSO_4{\cdot}2H_2O$, is at Kibuku, at the southwestern end of Lake Albert in Bundibugyo District (Kabagambe-Kaliisa 1977). The gypsum occurs as coarse selenite in 1-4 m thick clay layers with a tonnage of approximately 12 million tonnes. Currently small-scale miners of the Bundibugyo Miners Association extract the gypsum through simple manual washing and sorting techniques and sell 2,500 tonnes of final product per year to the Hima cement plant, near Kasese.

The ‘waste gypsum’ produced from the bioleaching process of cobalt-bearing pyrite tailings near Kasese in western Uganda reaches 300 tonnes per day. This chemical gypsum has been considered as cement retarder. This ‘waste gypsum’ could also be considered for agricultural applications provided the elevated trace element concentrations of nickel and copper can be reduced.

K-rich igneous rocks

Potassium in silicate rocks is found in Uganda mainly in K-rich lavas and intrusive rocks like mica-pyroxenites. The potassium occurs in the crystal structure of phlogopite and biotite mica, and in feldspar.

Samples from carbonized volcanic vent agglomerates in the Bukusu alkaline complex in eastern Uganda, contain up to 8.6% K_2O and 15% CaO (Baldock 1967). Samples from fresh pyroxenite of the same complex contain up to 6.4% K_2O. Apatite-magnetite-phlogopite bands in the pyroxenite of the Bukusu complex contain up to 3.4% K_2O and 12.4% P_2O_5 (van Straaten, unpubl.). Feldspathic agglomerates that form the large areas of the central part of the Butiriku carbonatite complex contain up to 9.8% K_2O (Reedman 1973). Bukusu and Butiriku are both areas of intensive banana cultivation, a crop known for high K requirements.

Trachytes from the Toror carbonatite complex near Moroto in eastern Uganda contain up to 13.9% K_2O (Sutherland 1965; King and Sutherland 1966). On the western side of Uganda, the volcanic fields north-northeast of Lake George, especially the Katwe-Kikorongo and Bunyanguru (Kichamba) fields, contain up to 7% K_2O (Lloyd *et al.* 1991). The very extensive (more than 2500 km^2) Virunga fields in southwest Uganda and northern Rwanda contain large lava flows with considerable amounts of potassium-silicates, mainly in the form of silica-undersaturated leucite tephrites (Lloyd *et al.* 1991). The potassium occurs in leucite, which is relatively unstable in weathering systems. Electron microprobe analyses of leucite and interstitial groundmass, reported by Lloyd *et al.* (1991), showed K_2O concentrations between 19.55 % and 27.26 %. Other rocks, like olivine leucitites (also called ugandites) may, upon weathering, provide potential valuable nutrients to the soils, especially to soils with low base saturations.

Vermiculites

A vermiculite deposit was discovered in the early 1950s near Namekara, 1 km west of the Busumbu phosphate mine in the Bukusu alkaline complex. Detailed pitting and trenching in the 1950s showed reserves of about 0.5 million tonnes of vermiculite-bearing residual soil to a depth of 15 m beneath a surface layer of magnetite rubble (Taylor 1956). In the mid 1950s, the amount of recoverable vermiculite was estimated at 350,000 tonnes. Recent exploration work to greater depth and in adjacent areas resulted in the delineation of sizeable additional vermiculite resources in the Namekara area. The average depth to the unweathered bedrock is 40-45 m. Vermiculites in the Namekara area are spatially related to mica-pyroxenites and 'glimmerites' of the pyroxenite zone of the Bukusu alkaline complex.

The quality of the Namekara vermiculite is good, the cation exchange capacity exceeds 110 $cmol^+/kg$ and the exchangeable Mg^{2+} content reaches 4,390 mg/kg. The Namekara vermiculite is well suited for export but will also have a small local market in the emerging horticultural and floricultural industry of Uganda.

Natural zeolites

So far only small amounts of natural zeolites have been found in volcanic rocks, for instance in vesicles of carbonatitic lava in western Uganda (Von Knorring and du Bois 1961). There are extensive pyroclastic deposits in the volcanic areas of western Uganda, some of which could be zeolitic.

Agromineral potential

The potential for using indigenous agrogeological resources in Uganda depends largely on the agronomic effectiveness of the various agrominerals on Ugandan soils. The phosphate resources are extensive and some of these resources, specifically from Busumbu and Butiriku, have shown that they can be applied effectively on P-deficient acid soils in neighbouring Kenya. More data and agronomic tests will have to be conducted on acid P-deficient soils in Uganda to validate their usefulness as part of Uganda's agricultural modernization plans. Liming materials are present in several areas, some of them, however, in remote locations. Calcareous tuffs and K-rich volcanics occur very close to banana growing areas (Bukusu, Butiriku) of eastern Uganda, and in volcanic areas of western Uganda. These 'ultra-potassic' volcanics should be investigated regarding their potential as local K-sources. Agronomic tests should be conducted with these materials, especially on crops that require large amounts of potassium, such as starchy food crops, bananas and potatoes.

The potential for discovering substantial amounts of natural zeolites within pyroclastic and volcaniclastic sediments associated with young volcanics and Quaternary sediments in western Uganda is regarded as high (Mathers 1994).

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