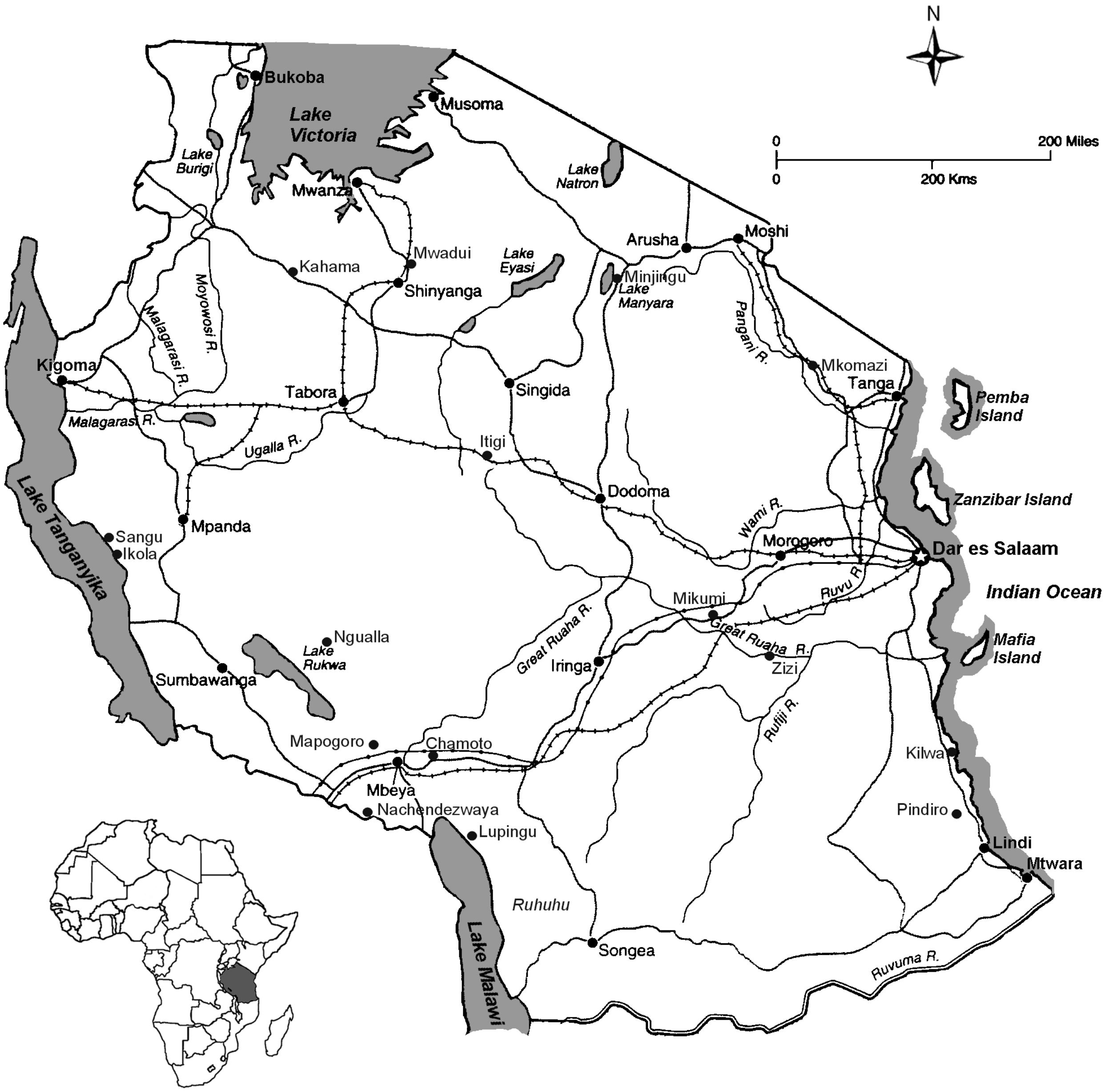
Tanzania

Total population (July 2000 estimate): 35,306,000
Area: 945,087 km^2
Annual population growth rate (2000): 2.57%
Life expectancy at birth (1998): 47.9 years
People not expected to survive to age 40 (1998): 35.4% of total population
GDP per capita (1998): US $480



The United Republic of Tanzania (referred to here as Tanzania) is made up of the islands of Zanzibar and Pemba, and the mainland of Tanzania.

Tanzania's landscapes and climates can be grouped into several zones:

- the hot and humid coastal zone near the Indian Ocean,
- the hot dry central plateau zone, with altitudes around 1,000-1,200 m,
- the semi-temperate mountainous areas around Mt. Kilimanjaro, and the Southern Highlands in the south-central and south-western part of the country.

Agriculture is the mainstay of Tanzania's economy. In 1999, the agricultural sector accounted for 45% of the GDP. More than 80% of the employed population work in agriculture, mainly at a subsistence level. Ninety-three percent of farmers work small-holdings with an average cultivated area of less than 2 hectares. Over 50% of persons living in rural areas of Tanzania are poor, many of them under the 'one dollar a day' level commonly used to define poverty.

The main food crops are cassava, maize, bananas, rice, sorghum and sweet potatoes. Export crops are coffee and tea, cloves (from Zanzibar), cotton, sisal, pyrethrum, cashew nuts, flowers and seeds. Other crops include sugar cane, coconut, mangoes and pineapple.

The mineral sector of Tanzania is becoming a more significant part of the economy with the opening of several new gold mines. Large-scale diamond and gold mining as well as small-scale mining operations play a major role in Tanzania's mineral development. Gold production from the small-scale mining sector alone provided some 76% of Tanzania's total mineral export in 1992, when small-scale miners sold 4.5 tonnes of gold worth US $40.4 million to the Bank of Tanzania. The International Labour Organization (1999) estimated the number of people employed in small-scale and artisanal mining in Tanzania at 450,000-600,000.

Tanzania is in the planning stage of developing the 880 billion cubic feet natural gas resources of the Songo Songo Island deposit, southeast of Dar es Salaam.

Geological outline

Precambrian rocks underlie most of central and western Tanzania. Archean granite and greenstone rock assemblages form the central nucleus of the country, the Tanzania Craton. The craton is surrounded by Proterozoic belts: the Paleoproterozoic Usagaran-Ubendian belt, and the Mesoproterozoic Kibaran (Karagwe-Akolean). The Neoproterozoic Mozambique Belt occurs in the eastern part of the country. Parts of the Usagaran-Ubendian belt were rejuvenated during the Neoproterozoic to early Cambrian Pan-African thermo-tectonic event (Gabert 1984). Shallow water sediments of the Neoproterozoic (900-800 million years) Malaragazi Supergroup underlie parts of western Tanzania (Halligan 1962). The Karoo basin crosses southern Tanzania in a northeasterly direction. Mesozoic and younger marine sediments occur along the coast of Tanzania.

The Tertiary to Recent Eastern Rift Valley reaches into Tanzania from Kenya in the north. Lake Tanganyika and Lake Nyassa (Lake Malawi) form part of the Western Rift of Tanzania. Volcanics and carbonatites are associated with both the Eastern and the Western Rift. Lacustrine sediments fill large parts of the rift valleys.

There are several distinct kimberlite fields in the Archean craton of Tanzania, including the Mwadui kimberlite pipe in central Tanzania.

AGROMINERALS

Phosphates

Tanzania hosts different types of phosphate deposits and occurrences (Harris 1981; Mtuy 1986; Chesworth e*t al.*1989; Mchihiyo 1991; Mwambete 1991; Van Kauwenbergh 1991; van Straaten 1995).

The four main types of phosphates in Tanzania are:

- igneous phosphates, associated with carbonatites,
- lacustrine phosphates in rift valley sediments,
- metamorphic phosphates,
- guano deposits.

Igneous phosphates

All known igneous phosphates in Tanzania are associated with Precambrian and Mesozoic carbonatites (Figure 2.17). These carbonatites are related to the two rift systems that cross Tanzania, the Eastern Rift and the Western Rift.

The phosphorus content in carbonatites of the Eastern Rift is generally low. The carbonatites in the southern extension of the Eastern Rift, near Morogoro, contain generally high concentrations of Light Rare Earth Elements (LREE) but only low concentrations of phosphorus.

The carbonatites with the highest phosphorus concentrations occur along the tectonically active Western Rift. They include the carbonatites of:

- Sangu-Ikola at Lake Tanganyika,
- Ngualla,
- the carbonatites in the vicinity of Mbeya and Mbozi, specifically the carbonatites of Mbalizi, Songwe Scarp, Nachendezwaya, Sengeri Hill, and Panda Hill.

In west and southwest Tanzania, several carbonatites are known to have intruded along re-activated north-northwest striking shear and fault zone (van Straaten 1989). Their ages vary from Proterozoic (Sangu-Ikola, Ngualla, and Nachendezwaya) to Mesozoic (Panda Hill, Sengeri Hill, Mbalizi, Songwe Scarp).

The Sangu-Ikola carbonatite

The Sangu-Ikola carbonatite at Lake Tanganyika is the most extensive carbonatite in Tanzania. The carbonatite is composed of three elongated bodies, the largest of which is 14 km long and 1.5 km wide. The total length of this elongated carbonatite complex is more than 30 km. Coetzee (1959) reported 'the presence of ubiquitous and fairly abundant apatite in the carbonate rocks, locally as much as 50% by volume.' Initial phosphate exploration work delineated residual phosphate-rich soils on parts of the Sangu-Ikola Carbonatite Complex. At places the P_2O_5 concentration reached up to 10% and 15% P_2O_5 (van Straaten 1983). The primary soevitic (Ca-carbonate) carbonatite contained up to 7% P_2O_5. So far, no detailed phosphate surveys in the primary and residual environments have been undertaken.

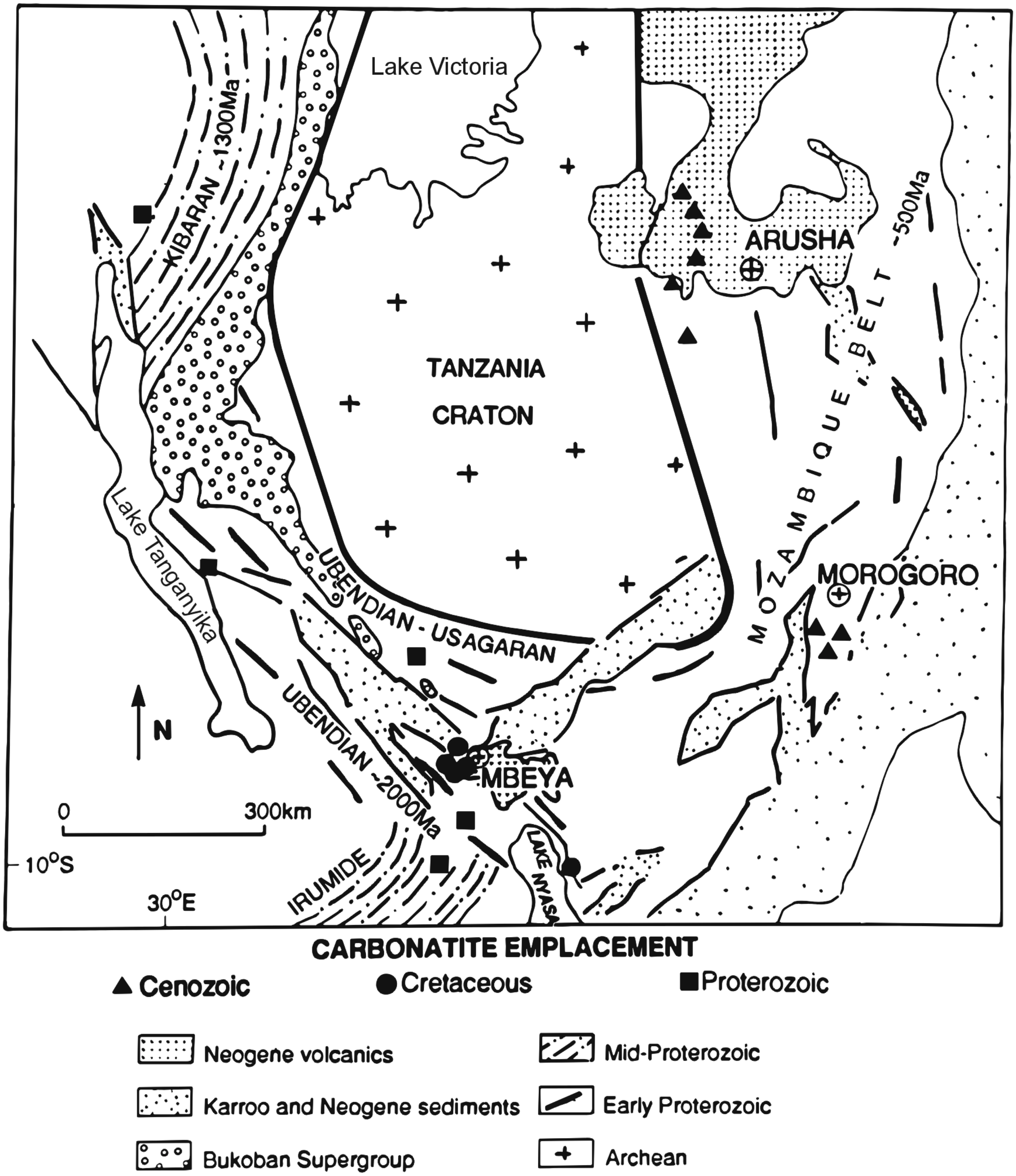


Figure 2.17: Distribution of carbonatites in Tanzania (after van Straaten 1989)

The Ngualla carbonatite

The Proterozoic Ngualla carbonatite (±1,000 million years old), is located in a remote area, approximately 200 km north of Mbeya in southwest Tanzania (7° 42'S; 32° 50'E). This plug-like intrusive carbonatite with a diameter of about 3 km is made up of various successive carbonatite phases. Phosphorus concentrations of the primary carbonatite decrease from 3 to 6% P_2O_5 in the Ca-rich phase of the carbonatite, to 3% P_2O_5 in the Mg-carbonatite phase, to 0.4% P_2O_5 in the Fe-rich carbonatite phase (van Straaten 1995). A late-phase magnetite-apatite vein, 15-20 m wide and several hundred metres long, was discovered during the work of the Tanzania-Canada agrogeology project (Chesworth *et al.* 1988). Several exploration pits in residual red soils revealed phosphate concentrations of 12-20% P_2O_5 to a depth of 5 m and more. No formal phosphate resource evaluation has been undertaken as yet at this remote site.

The more accessible Cretaceous carbonatites of Mbalizi (8° 55' S; 33° 21'30" E), Songwe Scarp 8° 45-54'S; 33° 12-30'E), and Sengeri Hill (8° 57'30"S; 33° 11'30"E) contain only small igneous phosphate resources.

Panda Hill

Presently, the only phosphate resource in the Mbeya area of economic and agronomic interest is located at Panda Hill (8° 59'30"S; 33° 14'E), some 25 km west-southwest of Mbeya along the Tanzania-Zambia railway. The Yugoslav Mining Association RUDIS (1980) calculated the primary carbonatite resources suitable for Nb and P recovery to be 480 million tonnes with an average grade of 0.33% Nb_2O_5 and 3.5% P_2O_5. The Tanzania-Canada agrogeology team delineated approximately 1 million tonnes of residual phosphates with an average grade of 10.31% P_2O_5 in the Kunja-Mtoni zone of Panda Hill (van Straaten *et al.* 1992; van Straaten 1995). Niobium concentrations in the 1 million tonnes residual soils have a mean concentration of 0.77% Nb_2O_5.

Detailed investigations of the chemistry and mineralogy of apatites from Panda Hill show a unit-cell a-value of 9.387 to 9.397 Å (Mchihiyo 1990) indicating a fluor-apatite with very low rate of substitution and hence low solubility.

Modification Techniques of Panda Phosphate Rock

Several agronomic studies using Panda phosphate rock (PR) concentrates from the Panda residual phosphate occurrence have been conducted. Most of the studies confirmed the low solubility of this igneous phosphate rock and hence low yield response (van Straaten *et al.* 1992; Mnkeni *et al.* 1994; Weil 2000).

In order to increase the reactivity of Panda PR several modification techniques were tested, including partial acidulation (Lombe, unpubl. report) and reaction with a natural zeolite as a cation exchanger (Mkeni *et al.* 1994). Initial tests using blending techniques with the soluble P fertilizer triple superphosphate (TSP) blended and pelletized with Panda PR at a 50/50 ratio showed significantly increased yield and P uptake responses for maize (van Straaten *et al.* 1992). More pronounced results have been achieved using canola (rapeseed) as the test crop (Mnkeni *et al.* 2000). These results show that the roots of rapeseed can extract P from blended unreactive PRs. Weil (2000) tested Panda PR and Minjingu PR on their suitability as direct application rock P fertilizers and showed that a cabbage variety was able to effectively extract P from the unreactive Panda PR.

Metamorphic apatite-limestones

Stockley (1946) described apatite-bearing limestones from the remote Zizi area in the Morogoro District, and van Straaten *et al*. (1992) observed apatite-bearing folded limestones near Lupingu along Lake Nyassa (Lake Malawi). The Zizi apatite-limestone in the northern Selous Game Reserve, in a remote location south of Morogoro, was discovered by Stockley in 1931 (Stockley 1946). He described them as apatite-limestones. The reserves of this 20 m wide, 1,150 m long lens in high grade metamorphic rocks were reported as 2 million short tons to a depth of 100 feet (average grade of 6.9% P_2O_5). RUDIS (1980) reinterpreted the Zizi apatite-carbonate ‘dyke’ as a carbonatite with estimated reserves of 1 million tonnes to a depth of 20 m. The average grade of the primary apatite-carbonate rock was calculated as 4.4% P_2O_5. The phosphate content of grab samples taken by the Tanzania-Canada agrogeology team vary widely, ranging from 0.5-7% P_2O_5 (Chesworth *et al.* 1988). The REE and Nb values are low, and seem to confirm that this body is probably not of igneous origin, but rather a metamorphosed phosphatic limestone, as suggested by Stockley (1946).

Lacustrine phosphates

Minjingu

The lacustrine-biogenic Minjingu phosphate deposit in Northern Tanzania is unique. Situated about 110 km southwest of Arusha, the phosphate deposit was discovered in 1956 during a search for uranium. The deposit has been mined since 1983. The layered phosphates of Minjingu are located in the Eastern Rift Valley, in a paleo-rift valley lake environment. The phosphate beds are intercalated with greenish claystones, chert beds and cm-thin analcime bearing volcanic tuff beds. Extensive drilling proved that the phosphate beds are confined to the close vicinity of the small Minjingu Hill, which in Upper Pliocene or Pleistocene times (Schlueter 1997) was a small island on which large colonies of cormorants roosted. Detailed geological, geophysical (radiometric) and palaeontological studies by Schlueter and van Straaten in 1985 (unpublished manuscript) and Schlueter and Kohring (1992) revealed that the coarse-clastic laminated phosphate beds consist mainly of detrital cormorant *Phalacrocorax khueneanus* bones (Schlueter 1991) and vertebrae, fins, spines, etc. of cichlid fishes. The beds also contain clastic silicate fragments, derived from the metamorphic rocks that form the centre (paleo-island) of Minjingu Hill.

Two types of phosphate ores have been identified at Minjingu, the ‘soft’ ore and the ‘hard’ ore. The soft ore is composed of several up to 2-3 m thick, whitish-grey, coarse-clastic phosphate bone beds. The grade of most of these beds is 22-25% P_2O_5. The hard phosphate ore surrounds Minjingu Hill, overlying and rapidly grading into the soft phosphates below. The hard phosphate ore is several metres thick and consists of indurated, massive, siliceous phosphorites. The grade of the hard ore averages about 24% P_2O_5.

Early reserve calculations of the deposit were 10 million tonnes. More recent reserve figures, cited by the mine geologist (Mwambete, pers. comm. July 1997), are 3.3 million tonnes soft ore and 4.8 million tonnes hard ore.

Detailed chemical and mineralogical investigations of the soft ore, carried out by the International Fertilizer Development Centre, USA (Van Kauwenbergh 1985, 1991) and by the author, show high fluorine (F) contents in the bones (up to 4% F), as well as lower P_2O_5 content than expected of a typical fluor-apatite. Van Kauwenbergh (1985) noted that bones originally composed of slightly soluble carbonate-hydroxy-apatite may have been altered into francolites or fluor-apatites. The high F content in the bones could indicate a francolitic composition.

Agronomically, the Minjingu soft phosphates are well suited for direct application because of the relatively high solubility of the phosphates. The neutral ammonium citrate solubility ranges from 5.6% P_2O_5 in the raw phosphate product to 12.9% P_2O_5 in bird bone concentrate (Van Kauwenbergh 1985). These values are very high and compare well with the most soluble phosphate rocks in the world (Van Kauwenbergh 1991). Of particular interest is the relatively high concentration of barium (1,100 to 2,100 mg/kg), strontium (2,500 to 9,900 mg/kg), and uranium (410 to 1,100 mg/kg) in the Minjingu PR. For comparison, uranium concentrations from marine PR in northern Florida are in the range of 60-100 mg/kg, in Morocco 80 mg/kg, and in North Carolina 50 mg/kg.

Makweba and Holm (1993) and Banzi *et al.* (2000) published data on the radioactivity of Minjingu phosphate rocks. They conclude that workers at the mine could possibly become affected by direct external radiation from the phosphates and through inhalation of dust from the mine. This confirms the unpublished data of Mustonen and Annanmaeki (1988) from the Finnish Centre for Radiation and Nuclear Safety who carried out studies on radiation exposure of workers at the Minjingu phosphate mine, at the processing plant, at the store, the loading station (in Arusha) and at the fertilizer factory in Tanga. The results of their findings showed that the major part of the total radiation exposure is through inhalation of long-life natural radionuclides associated with the phosphate dust. They concluded that these risks could largely be reduced by wearing masks at both the mine and the processing site.

The external radiation for farmers who use Minjingu PR and Minjingu PR-based fertilizers is considered insignificant compared to that of normal background terrestrial sources (Makweba and Holm 1993). But results of Banzi *et al.* (2000) show that the radiation dose of ambient air over five years time at the mine site is 12 times the allowed average dose limit for public exposure. The findings suggest a potential health risk when the phosphates are ingested. Samples taken from the phosphate ores, phosphate wastes, water at the site and wild and edible leaf vegetables at Minjingu, as well as chicken feed using Minjingu PR as a component, show elevated concentrations of ^{226}Ra and ^{228}Ra (Banzi *et al.* 2000). A full risk assessment of radiation exposure for people living in Minjingu and those who handle and use Minjingu PR was recommended (Banzi *et al.* 2000).

Agronomic Testing of Minjingu Phosphate Rock

Results of agronomic experiments using Minjingu PR as direct application P-fertilizer on Tanzanian soils are reported by Anderson (1970), Mnkeni *et al.* (1991), Ikerra *et al.* (1994), and on Kenyan soils by Okalebo and Woomer (1994), Sanchez *et al.* (1997), Buresh *et al.* (1999), ICRAF (1999), Mutuo *et al.* (1999), and Ngoze (2001). Extensive studies by scientists from the Kenya Agricultural Research Institute (KARI) and the International Centre for Research in Agroforestry (ICRAF) in western Kenya showed a generally high yield increase upon directly applied ground Minjingu PR. The relative agronomic effectiveness (RAE) of Minjingu PR on maize in the first season averaged 74% at application rates of 50 kg P ha^{-1} and 80% at 250 kg P ha^{-1}. In general, the RAE of Minjingu PR in comparison to imported soluble P-fertilizers ranged from 65-85% (Sanchez *et al.* 1997). On the same soils, Mutuo *et al.* (1999) calculated the RAE of Minjingu PR in the range of 84-98% in the short rainy season. The results of pot and field trials by Ngoze (2001) confirm these results. The RAE of Minjingu PR was 75% and 91% for the long and short rains period respectively.

Other experiments with Minjingu PR on P-deficient ultisols of Ethiopia with the forage crop *stylosanthes guianensis* showed excellent responses. Minjingu PR applied directly to these soils was as effective as triple superphosphate (TSP). The partially acidulated form was found to be similarly effective (Haque *et al.* 1999). It seems evident that acidulation or partial acidulation of Minjingu is not necessary to make this highly reactive PR an agronomically effective P fertilizer in acid P-deficient soils.

Farmers using the product for direct application complained about the product's dustiness. Tests at IFDC showed that fine soft Minjingu ore mixed with urea and granulated or compacted gave a product that handles well and that contains not only P but also N.

The Minjingu Phosphate Company (a subsidiary of the State Mining Corporation) started production of Minjingu phosphate concentrate in 1983 and shipped the concentrate to the fertilizer plant in Tanga for processing into single superphosphate (SSP). However the Tanga fertilizer plant closed in 1991 and subsequently no further phosphate concentrates were shipped there. In 1996, the Minjingu Phosphate Company sold only small quantities (1,000 tonnes) of Minjingu PR for direct application, of which some 300 tonnes were sold to Kenya. Small amounts of Minjingu PR were sold to tea and sisal estates, for bean production and for pasture experiments (Mwambete, pers. comm. 1997).

Other lacustrine phosphates:

Additional lacustrine phosphatic sediments of similar origin are reported from 'The Pyramides,' a group of hills 12 km south of Minjingu. The amount and grade of the phosphates have not been established as yet.

Another much smaller phosphate occurrence, of possibly similar origin, is reported from the Chali Hills in the central Dodoma Region. A thin phosphatic layer covers bare quartzite rocks and fills joints in the isolated Chali Hill that stands out at the southern end of the Bahi depression, a paleo-lake in a rift structure.

Another small lacustrine phosphate occurrence in Pleistocene in rift valley sediments is known from Chamoto in the Usangu Flats in southwest Tanzania. Slightly radioactive nodules of 'cherts' were found by Williams in the early 1960s (Williams, unpubl.). Field work by Guest (1956), McKie (1958) and geologists of the Tanzania-Canada agrogeology project (Chesworth *et al.* 1988) delineated a 10-60 cm irregular bed of cherty phosphorite in lacustrine sediments and volcaniclastic beds.

The occurrences of Chali Hills and Chamoto are of importance as they confirm the presence of other lacustrine phosphate deposits in the rift valley and demonstrate the potential for finding other phosphate rock occurrences in rift valley sediments.

Other sedimentary phosphates

Kreuser *et al.* (1990) describe phosphate pebbles and 'phosphate-enriched horizons in the bone-bearing nodular K6 Formation' of the Karoo sediments in the Mikumi area of eastern Tanzania. However, the economic value of these occurrences is regarded as insignificant.

Kent *et al.* (1971) described phosphatized ammonites in the lower Cretaceous (Albian) in the Mandawa area of southern Tanzania. The extent of this mineralization is unknown.

Other agrominerals

Limestone/dolomite

A comprehensive account of limestone, dolomite, calcrete and travertine resources in Tanzania is presented by Bosse (1996). The calcitic and dolomitic rocks in Tanzania include young calcrete, travertine, lacustrine limestones, coral reef limestones, massive limestones and dolomites of Jurassic to Tertiary age, as well as Precambrian crystalline limestones, dolomites, and carbonatites.

Precambrian marbles and dolomitic marbles are mainly found in the Neoproterozoic Mozambique Belt, to the east of the central Tanzania Craton, in the Paleoproterozoic Usagaran and, to a lesser extent, in the Paleoproterozoic Ubendian System in western Tanzania. The limestone and dolomite resources in southwest Tanzania have been compiled by the Tanzania-Canada agrogeology team (van Straaten *et al.* 1992). No limestone deposits are exposed in the Mesoproterozoic Kibaran (Karagwe-Ankolean) in northwest Tanzania.

Compact, fine-grained limestones and dolomitic stromatolitic limestones, in places silicified, occur in the Neoproterozoic platform sediments of the Malaragazi Supergroup. They are found mainly in the sparsely populated area northeast and east of Kigoma and used at several places used for the production of lime.

Several smaller limestone occurrences are reported from the Karoo basins of the Lake Rukwa and Ruhuhu areas (Bosse 1996). Mesozoic to Tertiary limestones occur in abundance in the coastal area of Tanzania. Jurassic limestones near Tanga are utilized for the local cement industry. Tertiary to Recent coral limestones occur in numerous locations along the Indian Ocean and are mined for several purposes. At Wazo Hill, a few km north of Dar es Salaam, a 15 m thick coral limestone bed is quarried for use in the cement industry.

Bosse (1996) describes 64 calcretes of varying quantity and quality from many parts of Tanzania. Calcrete deposits are usually thin indurated carbonate rocks mixed with sand and clay. These calcareous duricrusts, surface crusts or secondary limestones are developed largely under semi-arid conditions on crystalline rocks rich in calcium and magnesium silicates. They are often found in seasonal wetlands in morphological depressions (locally called ‘mbugas’). Calcretes are the only carbonate rocks found in the area of the central Tanzania Craton. In some areas in the northeastern part of the country and in the Shinyanga region, the resources are very extensive and lend themselves to extraction. Commonly the calcretes are calcium-rich but poor in magnesium. Many of these resources are developed for local lime production, mainly for use as whitewash.

Travertine deposits are located in several rift-related areas of Tanzania. The most voluminous travertine (about 50 million tonnes) is located along the Songwe River area, near Mbeya in southwest Tanzania. The travertine is used for the Mbeya cement industry and local lime producers.

There are several carbonatites exposed in Tanzania. Most of them have extensive volumes of either soevitic (Ca-carbonatite) and/or dolomitic carbonatites. Some of the carbonatites (for instance Ngualla and Sangu-Ikola) occur in remote areas and their usefulness is inevitably much reduced. But carbonatites located in farming areas with acid soils should be further investigated and agronomically tested, for instance, the Nachendezwaya carbonatite in southwestern Tanzania along the border with Zambia.

Guano

Bat guano deposits are known from Sukumavera in southwest Tanzania near Mbeya, from the Amboni caves, 10 km from Tanga, and from the Haitajwa and Manapwani caves on Zanzibar Island. The bat guano deposits of Sukumavera in the Mbeya area are located in caverns in horizontal travertine formations. From 1934 to 1957 some 3,223 tonnes were excavated from these caves (Spurr 1954). A re-investigation of the guano deposit at Sukumavera revealed only small easily accessible resources (a few hundred tonnes) with grades between 26 and 37% P_2O_5. Small amounts of bat guano have also been extracted from the Amboni caves near Tanga (Harris 1981) and the caves on Zanzibar (Hutchinson 1950).

A small bird guano deposit is located on the Lantham Island, a coral island some 65 km east-southeast of Dar es Salaam (Hutchinson 1950; Harris 1981). The coral limestone of this island, 1,000 x 500 feet in extent, is covered with a thin veneer of bird guano. The limestone has been phosphatized by solutions from the overlying guano. The grade of the phosphatized limestone is low at 8.5% P_2O_5 and reserves are estimated at 190,000 tonnes (Harris 1981). No guano or phosphatized limestones have been excavated at this location, partially because of environmental concerns.

Sulphur/sulphides/sulphates

Only a small amount (approximately 2,500 tonnes) of elemental sulphur has been reported from Tanzania, and this is located in a remote location, the inner crater of Kilimanjaro, at an altitude of almost 6,000 m(!).

No major, easily extractable pyrite deposits have been identified and although sulphides are ‘waste products’ of the gold mining industry their grades are low and their heavy metal content is high.

A major rock gypsum and anhydrite resource is located in a remote area, at Pindiro and Mandawa in southeastern Tanzania, about 100 km north of Lindi (Harris 1981). The deposit is part of a salt dome structure. Proven reserves of a section of this deposit, as determined by the State Mining Corporation (STAMICO), are 5 million tonnes containing 85% gypsum. The gypsum rock has not been extracted as yet.

Low-grade and low-volume gypsum resources are found in seasonal swamp environments (mbugas) at Msagali and Itigi in central Tanzania and at Mkomazi in the Lushoto District of eastern Tanzania (Harris 1981). As so-called ‘gypsite’ the gypsum occurs in crystal form in nodules and as finely distributed crystals in a sandy, silty and clay-rich groundmass. Small-scale mining of gypsum from the low-grade gypsite deposit of Mkomazi in northeast Tanzania started in 1952. The ore is hand-sorted to produce a concentrate of 60-80% gypsum. Since 1953, annual production has been in the range of 4,000-9,000 tonnes with a maximum annual production in the late 1970s of 22,000 tonnes (Richardson 1982).

Natural zeolites

The Tanzania-Canada agrogeology team discovered several small zeolite occurrences in southwest Tanzania (Chesworth *et al.* 1988), including the phillipsite occurrence at Mapogoro in the Rukwa Rift Valley (more than 84,000 tonnes) and chabazite tuff beds of Shingo (more than 80,000 to 100,000 tonnes). Other natural zeolites (erionite) are reported from the Lake Natron area in the Eastern Rift.

Natural Zeolites to Induce Apatite Breakdown

Phillipsite from Mapogoro in combination with phosphates from Tanzania (Panda Hill PR and Minjingu PR) was tested by Mnkeni *et al.* (1994) as a means of inducing apatite breakdown. The results clearly showed that the addition of large amounts of Mapogoro phillipsite had no effect on the dissolution of the unreactive Panda PR, but that the breakdown of Minjingu PR could be enhanced. However, Mnkeni *et al.* (1994) noted that the amount of zeolite necessary to enhance the breakdown of Minjingu PR (ratio = 100 phillipsite: 1 Minjingu PR) is large. Other methods should be devised which require lower quantities of zeolites, for example the method of using NH_4^+-exchanged zeolites (Lai and Eberl 1986).

Rock wastes

Large-scale diamond mining from primary kimberlite pipes started in 1940 at Mwadui near Shinyanga in central Tanzania. Tailings and waste rock from the kimberlite pipe and overlying tuffs and crater sediments have been stockpiled for more than 50 years. Chemical analyses of the Mwadui tailings indicate calcium contents of more than 10% CaO, more than 11% MgO and 2% K_2O. The tailings are located within the perimeter of the Mwadui mine site and are currently not accessible. Several million tonnes of waste rock and tailings from the abandoned Nyamwele kimberlite diamond field, some 40 km north of Kahama, are stored adjacent to farmers fields near Lake Nyamwele.

Agromineral potential

The potential for developing agromineral resources in Tanzania is good. There are several phosphate rock resources in Tanzania. The mineralogical and chemical characteristics of phosphates from Minjingu in northern Tanzania are excellent. Agronomic tests with directly applied Minjingu PR have shown good agronomic response on acid P-deficient soils. Blending and granulation techniques should be tested to make this phosphate product less dusty and more attractive to the farmers and a good marketing effort needs to be launched to bring this valuable resource to market.

A potential drawback is the relatively high content of radio-nuclides in the phosphate rock. Geochemical dispersion and plant uptake studies must be undertaken to study element transport in soils and to determine to what extent the radio-nuclides are taken up by crops.

The easily accessible and easily extractable residual and igneous phosphate resources at Panda Hill contain approximately 1 million tonnes of PR grading 10% P_2O_5. To utilize these resources, small-scale mining techniques could be applied for extraction. Phosphate solubility problems have to be overcome as the apatites are unreactive. Locally adapted modification techniques, or the application of Panda phosphates as blended P-fertilizer (Panda PR + TSP for example) should be tested on crops like cabbage, a phosphorus-responsive crop (Weil 2000).

Other phosphate resources for future considerations are the residual and primary phosphate resources at Ngualla and Sangu-Ikola. However, both occurrences are located in remote areas.

Upper Cretaceous and Tertiary sediments along the coast should be investigated for their phosphorite potential. Paleogeographic and facies analyses should focus on Cretaceous and Tertiary sediments, similar to those in other parts of Africa that have yielded major phosphate accumulations. As a first step, samples from oil and gas exploration campaigns should be checked for elevated radioactivity in drill cores using a gamma-ray spectrometer.

In areas where soil acidity and associated aluminum and manganese toxicities are the limiting factors for crop production. For example, in southern Tanzania, the use of locally available liming materials should be initiated. There are extensive dolomitic limestone occurrences in southern and eastern Tanzania and their agricultural effectiveness should be tested. In order to serve a greater number of small farmers over large areas, a study of the suitability of locally manufactured crushing and grinding units is suggested. Small crushing plants could be utilized for several purposes, for gravel and concrete aggregate production as well as for agricultural limestone and/or dolomite production.

The natural zeolites found in Tanzania should be studied for their potential usefulness in agricultural, horticultural and environmental applications.

Calcareous ‘waste materials’ from the existing cement industries should be investigated for their potential use in agriculture in the immediate surroundings. The diamond tailings at Nyamwele, north of Kahama should be analyzed for their calcium and magnesium contents and agronomically tested on the nearby infertile sandy soils on granitic parent material.

References:

Anderson GD 1970. Fertility studies on sandy loam in semi-arid Tanzania. II. Effects of phosphorus, potassium and lime on yields of groundnuts. Exp. Agric. 6:213-222.

Banzi FP, Kifanga LD and FM Bundala 2000. Natural radioactivity and radiation exposure at the Minjingu phosphate mine in Tanzania. J. Radiol. Prot. 20:41-51.

Bosse H-R 1996. Tanzania. In: Bosse H-R, Gwosdz W, Lorenz W, Markwich, Roth W and F Wolff (eds.) Limestone and dolomite resources of Africa. Geol. Jb., D, 102:424-459.

Buresh RJ, van Straaten P, Place FM and BA Jama 1999. Agronomic and economic evaluation of phosphate rocks as phosphorus source in Kenya. Abstract, Ann. Meeting Am. Soc. Agron., Salt Lake City, Utah, USA, p.43.

Chesworth W, Semoka JMR, van Straaten P, Mnkeni PNS, Kamasho JAM and EP Mchihiyo 1988. Tanzania-Canada Agrogeology Project. Report on completion of the first phase. Univ. of Guelph, Ont., Canada, 93pp.

Chesworth W, van Straaten P and JMR Semoka 1989. Agrogeology in East Africa: The Tanzania-Canada project. J. Afr. Earth Sci. 9:935-939.

Coetzee GL 1959. Unpublished report, Western Rift Exploration Company, Chunya, Tanganyika.

Gabert G 1984. Structural-lithological units of Proterozoic rocks in East Africa, their base, cover and mineralisation. In: Klerkx J and J Michot (eds.) Geologie Africaine - African Geology, Musee Royale de l'Afrique Centrale, Tervuren, Belgium:11-22.

Guest NJ 1956. Radioactivity north of Igurusi, Mbeya District. Geol. Surv. Tanganyika, Rec.IV, 1954:43-44.

Halligan R 1962. The Proterozoic rocks of Western Tanzania. Bull. Geol. Surv. of Tanganyika, 34, 34pp.

Haque I, Lupwayi NZ and H Ssali 1999. Agronomic effectiveness of unacidulated and partially acidulated Minjingu rock phosphates on *Stylosanthes guianensis*. Trop. Grasslands 33:159-164.

Harris JF 1981. Summary of the geology of Tanganyika, Part IV: Economic geology. Geol. Surv. Mem. 1, 143pp.

Hutchinson GE 1950. Survey of existing knowledge of biogeochemistry - The geochemistry of vertebrae excretion. Bull. Am. Mus. Nat. History, 96, 554pp.

ICRAF 1999. International Centre for Research in Agroforestry. Report to the Rockefeller Foundation on preparation of Ugandan phosphates (September 1998 to August 1999). Nairobi, Kenya, 25pp.

Ikerra TWD, Mnkeni PNS and BR Singh 1994. Effects of added compost and farmyard manure on P release from Minjingu phosphate rock and its uptake by maize. Norw. J. Agr. Sci. 8:13-23.

International Labour Organization 1999. Social and labour issues in small-scale mines. TMSSM/1999, 99pp.

Kent PE, Hunt JA and DW Johnstone 1971. The geology and geophysics of coastal Tanzania. Inst. Geol. Sci., Geophys. Paper 6, 101pp.

Kreuser T, Wopfner H, Kaaya CZ, Markwort S, Semkiwa PM and P Aslandidis 1990. Depositional evolution of Permo-Triassic Karoo basins in Tanzania with reference to their economic potential. J. Afr. Earth Sci. 10:151-167.

Lai TM and DD Eberl 1986. Controlled and renewable release of phosphorus in soils from mixtures of phosphate rock and NH_4-exchanged clinoptilolite. Zeolites 6:129-132.

Makweba MM and E Holm 1993. The natural radioactivity of the rock phosphates, phosphatic products and their environmental implications. Sci. Tot. Environm. 133:99-110.

Mchihiyo EP 1990. Geochemical and mineralogical aspects associated with weathering of apatite from Panda Hill carbonatite SW Tanzania. M.Sc. Thesis Univ. of Guelph, Canada, 147pp.

Mchihiyo EP 1991. Phosphate potential in Tanzania. Fert. Res. 30:177-180.

McKie D 1958. A radioactive phosphorite at Chamoto, north of Igurusi, Mbeya District. Geol. Surv. Tanganyika Rec., Vol. VI 1956:85-86.

Mnkeni PNS, Semoka JMR and JBBS Buganga 1991. Agronomic effectiveness of Minjingu phosphate rock as a source of phosphorus for maize in four soils of Morogoro District, Tanzania. Zimbabwe J. Agric. Res. 30:27-37.

Mnkeni PNS, Semoka JMR and EG Kaitaba 1994. Effects of Mapogoro phillipsite on availability of phosphorus in phosphate rocks. Trop. Agric. (Trinidad) 71:249-253.

Mnkeni PNS, Chien SH and G Carmona 2000. Effectiveness of Panda Hill phosphate rock compacted with triple superphosphate as source of phosphorus for rape, wheat, maize, and soybean. Commun. Soil Sci. Plant Anal. 31:3163-3175.

Mtuy FT 1986. The agrogeological resources of Tanzania. In: Wachira JK and AJG Notholt (eds.) Agrogeology in Africa. Commonwealth Sci. Council, Technical Publ. Series 226:84-89.

Mustonene R and M Annanmaeki 1988. Studies on the radiation exposure of workers in connection with processing of the Minjingu phosphate in Tanzania. Suppl. Report to the Finnish Center for Radiation and Nuclear Safety, 666/622/87, 18pp.

Mutuo PK, Smithson PC, Buresh RJ and RJ Okalebo 1999. Comparison of phosphate rock and triple superphosphate of a phosphorus deficient Kenyan soil. Comm. Soil Sci. Plant Anal. 30:1091-1103.

Mwambete I 1991. Tanzania fertilizer mineral deposits. Fert. Res. 30:181-185.

Ngoze SO 2001. Agronomic evaluation of Tanzanian and Ugandan phosphate rocks in western Kenya. Unpubl. Master's thesis, Moi University, Eldoret, Kenya, 114pp.

Ngunangwa FE 1982. Potential of small scale mining in Tanzania. In: JM Neilson (editor) Strategies for small-scale mining and mineral industries, AGID report 8:55-61.

Okalebo JR and PL Woomer 1994. Use of rock and fertilizer phosphate in Eastern and Southern Africa: A data summary. Presentation 14th conference Soil Sci. Soc. East Africa, Mbarara, Uganda.

Richardson DS 1982. Small scale mining of gypsum at Mkomazi, Tanzania. In: JM Neilson (editor) Strategies for small-scale mining and mineral industries, AGID report 8:112-120.

RUDIS (1980). Prefeasibility study. Fertilizer raw materials. Report, Lubljana, Yugoslavia.

Sanchez PA, Shepherd KD, Soule MJ, Place FM, Buresh RJ, Izac AMN, Mokwunye AU, Kwesiga FR, Ndiritu CG and PL Woomer 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. In: Buresh RJ, Sanchez PA and F Calhoun (eds.) Replenishing soil fertility in Africa. Soil Sci. Soc. Amer. Special Publ. 51:1-46.

Schlueter T 1991. Systematik, Palaeo-oekologie and Biostratonomie von *Phalacrocorax kuehneanus* nov. spec., einem fossilen Kormoran (Aves: Phalacrocoracidae) aus mutmasslich oberpliozaenen Phosphoriten N-Tansanias. Berl. Geowiss. Abh. A 134:279-309.

Schlueter T 1997. Geology of East Africa. Gebrueder Borntraeger, Berlin-Stuttgart, 484pp.

Schlueter T and R Kohring 1992. Trace fossils from a saline-alkaline lake paleoenvironment in northern Tanzania. Berl. Geowiss. Abh. E3:295-303.

Spurr AMM 1954. The Songwe guano caves, Mbeya District. Geol. Surv. Tanganyika Records 1,1951:35-37.

Stockley GM 1946. Phosphate deposits in Tanganyika Territory, south of Kisaki. Min. Res. Pamphl. Geol. Surv. Tanganyika 45, 12pp.

van Straaten P 1983. Interim report on results from the Sangu-Ikola carbonatite. Eastern and Southern African Mineral Resource Centre, Rep. ESAMRDC/83/TECH/26, 26pp.

van Straaten P 1989. Nature and structural relationships of carbonatites from southwest and west Tanzania. In: K Bell (ed.) Carbonatites - Genesis and Evolution, Unwin Hyman, London, UK:177-199.

van Straaten P 1995. Mineral exploration for carbonatite related phosphates in SW Tanzania. In: Blenkinsop TG and PL Tromp (eds.) Sub-Saharan Economic Geology, Geol. Soc. Zimbabwe Spec. Publ., Balkema, Rotterdam, Netherlands:87-102.

van Straaten P, Semoka JMR, Kamasho JAM, Mnkeni PNS and W Chesworth 1992. Report on the Tanzania-Canada agrogeology project, Phase II (1988-1991). Univ. of Guelph, Ont., Canada, 127pp.

Van Kauwenbergh SJ 1985. Cursory characterization of a phosphate ore and concentrate sample from Minjingu, Tanzania. Unpubl. Rep. International Fertilizer Development Center (IFDC), 10pp.

Van Kauwenbergh SJ 1991. Overview of phosphate deposits in East and Southeast Africa. Fert. Res. 30:127-150.

Weil RR 2000. Soil and plant influences on crop responses to two African phosphate rocks. Agr. J. 92:1167-1175.