



Madagascar is the largest island-nation and fourth largest island in the world. Madagascar is comprised of at least three contrasting north-south striking landscapes. The central plateau forms the central 'spine' of the country with elevations between 750 and 1,500 m. Several massifs reach as high as 2,800 m. To the east of the highlands lies the narrow coastal strip with tropical rainforests. To the west are low plateaux and wide plains of savannah and forest. The southern part of Madagascar is arid.

The economy of Madagascar is largely based on agricultural production, which accounts for about 30% of the GDP and provides the livelihood for more than 80% of the population. The principal food crops are rice, cassava, sweet potatoes, potatoes, bananas, maize and beans. Cotton, sugarcane and livestock are other agricultural commodities. The main agricultural export crops are coffee, vanilla, cloves, and sugar.

Intensive farming practices, combined with heavy population pressure and uncontrolled deforestation, have caused serious problems of soil erosion and soil nutrient depletion. The central highlands, where agricultural production is intensive, have the highest rate of soil degradation. Forest clearing in the eastern coastal strip has caused severe land degradation and erosion. Approximately 150,000 hectares of forest are cut down every year due to population increase and rice cultivation.

The geological natural resource bases of Madagascar are graphite, chromite, coal, bauxite and salt. The International Labour Organization (1999) estimated that 5,000-20,000 people are involved in small-scale mining in Madagascar.

### **Geological outline**

Geologically, Madagascar can be divided into two main zones, the Precambrian basement complex in the eastern part of the country, and the sedimentary cover formations in the west. The Precambrian is subdivided into Archean, medium to high-grade metamorphic rocks such as gneisses, migmatites, mica schists and amphibolites, and Proterozoic metasediments (Windley *et al.* 1994; Tucker *et al.* 1999). Karoo sediments and Jurassic to Tertiary sediments, mainly marine in origin, cover the basement rocks in the west of the country.

## **AGROMINERALS**

### **Phosphates**

Sedimentary phosphates of largely unknown extent and quality occur in Cretaceous and Tertiary sediments of the Mahajanga (Majunga) Basin of northwest Madagascar. Phosphatic nodules occurring in lower Cretaceous marls are described from Ambato-Boeni (Lacroix 1922; Besairie 1966), and in the area of Anjajia, 3 km west of Ankilahila, as well as near Maevarano, all in the Mahajanga Basin (Lacroix 1922; Besairie 1966). Some of the phosphate nodules contain 16-23% P<sub>2</sub>O<sub>5</sub>, and are in the form of 'collophanite' (Lacroix 1922; Besairie 1966). Phosphates also occur in upper Cretaceous sediments near Marovoay, and south of Soalara, as well as near Sitampiky. Reported concentrations are 'less than 20% P<sub>2</sub>O<sub>5</sub>' (Besairie and Collingnon 1972, quoted in Notholt *et al.* 1989) and 9.6% P<sub>2</sub>O<sub>5</sub> (Lacroix 1922; Besairie 1966). Phosphatic concentrations are also reported from the Antonibe Peninsula where they occur at the base of Palaeocene sediments. Low-grade phosphatic sediments occur in lacustrine environments at Lake Alaotra, and in Pliocene marls near Antanifotsy (Besairie and Collingnon 1972, quoted in Notholt *et al.* 1989).

Igneous apatites are reported from phlogopite-bearing pyroxenites in the south of the country, near Betroka and Bekily. Here, phlogopite mica has been mined since 1913, with an annual production of approximately 300-400 tonnes. The total pyroxenite rock mined (also containing diopside, and apatite as accessory minerals) is approximately 6,000 tonnes per year (Murdock 1963). Only a few of the phlogopite

mines report apatite in the 'wastes,' but in some of the pegmatoid veins apatite 'is actually predominant' (Murdock 1963, p. 127).

## Guano

Considerable amounts of bird guano have accumulated on coral limestone in the Mozambique Channel. Murdock (1963) describes the guano deposit of the French island of Juan de Nova (17° 03'S; 42° 45'E), 175 km northwest of Maintirano and 420 km from Mahajanga/ Majunga (Hutchinson 1950). The size of the deposit is 5.4 km by 1.5 km. Analyses of the bird guano showed 29.1% P<sub>2</sub>O<sub>5</sub>, 44 % CaO, 8.5% H<sub>2</sub>O. Mining on this island was conducted by hand on a contractual basis, with typical production of 1 tonne per person per day. The guano 'ore' was mechanically crushed. The guano production started in 1922 and lasted until 1940 with a total output of 122,316 tonnes and a maximum annual production of 13,400 tonnes in 1929. Guano production was taken up again in 1956 and until 1960, the average annual production was 6,071 tonnes. The guano fertilizer product was mainly shipped to Mauritius and South Africa (Murdock 1963).

The Malagasy guano deposits of the Barren Islands, 10-20 km from the western coast of Madagascar (Lacroix 1922; Hutchinson 1950; Troung *et al.* 1981) are currently considered for extraction. The government of Madagascar has given permission to GEMEX (50% Malagasy, 50% French and South African) to develop the Barren Island guano deposits with estimated reserves of 613,000 tonnes. Over half of these deposits (312,000 tonnes) are located on the island of Andrano (Support and Supervision Team 1997).

Lacroix (1922) described the guano-related phosphates as 'collophanite,' a fine-grained concretionary fibrous apatite with the composition: 35.66% P<sub>2</sub>O<sub>5</sub>, 49.64% CaO, 2.45% CO<sub>2</sub>, 6.44% H<sub>2</sub>O<sup>+</sup> and 3.49% H<sub>2</sub>O. Chemical and mineralogical analyses by Troung *et al.* (1981) showed that the phosphates of the bird guano islands in the Mozambique Channel also contain various amounts of aragonite. The crystallographic unit-cell a-value for the phosphates from the island of Andrano was determined as a = 9.451 Å (Troung *et al.* 1981). These phosphates have a very high solubility (15.84% citrate AOAC solubility) and contain generally less than 0.15% F (Troung *et al.* 1981).

Mining of bird guano from the Barren Islands is expected to have severe environmental impacts on the coral reefs and marine life surrounding the islands. In a report prepared for the World Bank, the Support and Supervision Team (1997) recommended that a strict and sound environmental management system be put in place to reduce the ecological damage caused by guano mining from the islands, or alternatively consider a buy-out option.

The application of guano from Barren Islands to maize (which accounts for only 13% of the area under cereals) on Malagasy soils showed considerably higher agronomic responses and economic benefits than on paddy rice (Support and Supervision Team 1997).

In addition to bird guano deposits there are several small bat guano deposits in caves of the calcareous zone of Madagascar, near Amboarana (Hutchinson 1950), Andoraharo (Jourdan 1962), and Toliara in southwestern Madagascar. The bat guanos also have high phosphate solubilities (20-28% citrate AOAC solubilities) and F concentrations of less than 0.1% (Truong *et al.* 1981). Like the bird guano deposits, these phosphates are considered suitable for direct application in agriculture (Truong *et al.* 1981).

## **Other agrominerals**

### **Limestone/dolomite/marble**

There are large carbonate reserves in Madagascar. Precambrian marbles and dolomitic marbles occur at several localities in central and eastern Madagascar. Gwosdz (1996) describes numerous Precambrian marble deposits in the following areas:

- near Ambatondrazaka, northeast of Antananarivo,
- to the southeast of Antananarivo,
- south of Antsirabe,
- near Ambatofinandrahana,
- northwest and south of Fianarantsoa,
- southwest of Ihosy,
- northwest of Betroka,
- near Miandrivazo,
- southwest of Maevatanana.

Numerous marble resources, including the marbles of the Ambatondrazaka area and the dolomitic marbles of Diavonaomby (south of Fianarantsoa), have been exploited for quicklime manufacture (Gwosdz 1996).

Mesozoic and Tertiary sediments underlie large areas in the western part of the country. Reserves of limestones are considerable in the Antsiranana area, in the Antsohiyi area, at Narinda Bay. Abundant Cretaceous limestones and marls are reported at Amboania close to Mahajanga (Majunga) and near Soalara, 25 km south of Toliara. Relatively small Jurassic limestone deposits have been mined for quicklime production on the Bemaraha plateau along the road from Miandrivazo to the west coast.

How much of the limestone/dolomite resources of Madagascar are currently used for soil improvement is not known.

### **Gypsum**

Small gypsum lenses, up to 3 m thick and 10-85 m long, approximately 100,000 tonnes in size, occur on the banks of the Ankey River, 20 km north of Mahazoma. The gypsum could replace a small fraction of the imported gypsum for the local cement industry (Murdock 1963).

### **Glauconite**

Glauconite occurs 'in abundance' in lower Cretaceous (Neocomian) sands and sandstones within the Analavelona massif, northeast of Toliara (Murdock 1963). In the Menarandroy Valley, west of Betioky, rich glauconite beds occur in Hauterive (lower Cretaceous) sediments, where certain weathered zones consist of 'quasi-pure' glauconite (Besairie 1966).

### **Agromineral potential**

The potential for development of the agromineral resources in Madagascar is good. However, additional soil data are needed to identify nutrient deficiencies and the distribution of low pH soils. The size and chemical/mineralogical characteristics of the local sedimentary phosphate rock deposits in the Mahajanga Basin are largely unknown. A geological survey to identify, characterize and quantify the local sedimentary phosphate resources is urgently needed. The data obtained to date are only indications and need verification and assessment. Exploration work for additional sedimentary phosphates, especially in

association with minerals commonly associated with sedimentary phosphate deposits, (attapulgitite) and glauconite, should be initiated.

One of the clay minerals that is commonly underlying sedimentary phosphates in sub-Saharan Africa (for instance in Niger, Nigeria, Senegal, Togo) is the fibrous clay mineral palygorskite (attapulgitite). And in Madagascar a large Eocene 'bentonitic' clay deposit, made up of 60% illite and 40% palygorskite (attapulgitite), occurs on the Eocene limestone plateau to the west of Ejeda (Murdock 1963). The Eocene is a time period in which many phosphate deposits have been discovered in other parts of sub-Saharan Africa.

The general, preliminary assessment of known phosphates and phosphate indicator minerals shows that there is a good potential of finding sizeable sedimentary phosphate resources in Madagascar.

The mining of guano deposits on the offshore islands of Madagascar should be carefully monitored to reduce environmental damage. The possibility of erecting artificial roosting platforms like in Namibia (see chapter Namibia) to 'harvest' guano in a sustainable and environmentally controlled manner should be evaluated.

There are substantial reserves of limestone and dolomite, as well as glauconite, in Madagascar. Their suitability for use on the local soils and crops needs further agronomic testing.

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