GTK Consortium Geological Surveys in Mozambique 2002–2007,
edited by *Yrjö Pekkala, Tapio Lehto & Hannu Mäkitie*
Geological Survey of Finland, Special Paper 48, 307–321, 2008

MINERAL RESOURCES POTENTIAL IN MOZAMBIQUE

by
Tapio Lehto & Reinaldo Gonçalves

Lehto, T. & Gonçalves, R. 2008. Mineral resources potential in Mozambique. *Geological Survey of Finland, Special Paper 48*, 307–321, 9 figures.

The metallic mineral, industrial mineral and construction material resources in Mozambique have been mapped as part of the Mineral Resources Management Capacity Building Project, financed by a grant provided by the Nordic Development Fund. A database covering the location and characteristics of more than 600 mineral indications, showings and deposits within the geographical contract area assigned to the GTK Consortium was created. A total of 140 mineral occurrences were selected for field surveys and assessments that were mainly carried out during May-November 2003, 2004 and 2005. All available data in the report archives of the client, the National Directorate of Geology (DNG), was collected and transferred to the mineral occurrence database, which was then updated with information from field surveys and with new data published by exploration and mining companies on the Internet.

New mineral resources maps at the scales 1:50 000 (part of contract area), 1:250 000 and 1:1 million were prepared with the corresponding symbols for various commodities plotted. Favourability maps showing zones with high potential for selected commodities were compiled at the 1:250 000 scale. The mineral resources in Mozambique were described in the four map explanation volumes and summarized in the final reports for the projects Geological Mapping LOT 2 and Geological Mapping LOT 3.

As a consequence of increased geological knowledge, facilitated by the activities of the GTK Consortium, investments in Mozambique's mineral potential by leading international and regional mining companies is already increasing. Currently, global mining houses are investing in exploration for energy minerals (hydrocarbons, coal and uranium), for titanium and zirconium in heavy mineral sands, for gold and gemstones, for the agricultural minerals lime and phosphate and for tantalum, fluorite and other industrial minerals.

Key words (GeoRef Thesaurus AGI): review, economic geology, mineral resources, mineral exploration, possibilities, potential deposits, Mozambique.

Tapio Lehto, Geological Survey of Finland, P.O. Box 96, FIN-02151 Espoo, Finland.
Reinaldo Gonçalves, Gondwana Ltd, Rua John Issa 57, Maputo, Mozambique

E-mail: tapio.lehto@gtk.fi

GENERAL

Mozambique has a large and diverse unexploited mineral resources potential, which has been manifested by a large number of exploration reports and studies, summarized recently by Lächelt (2004). Despite this, commercial mining has played a relatively minor role in the development of the coun-

try's economy. The situation is gradually changing, mainly due to the production of aluminium and natural gas and the development of world-class coal and heavy mineral sand deposits. There are plans for the production of gold, rare earth minerals and tantalite from pegmatites and industrial minerals. The main reasons for the low utilisation of the country's mineral resources have been, amongst others, an incomplete geological database and the weak infrastructure – the lack of transport and energy supply – which hampers the exploitation of resources.

Despite the above, artisanal small scale miners and prospectors have played an important role in the local economy, especially at the village level. Their activities have resulted in the identification and exploitation of deposits of gold, gemstones and building materials.

To utilize the nation's mineral resources, the National Directorate of Geology (DNG), with the support of private mining companies and technical aid, has carried out significant exploration work during recent decades. As a consequence of increased geological knowledge, facilitated by the activities of the Mineral Resources Management Capacity Building Project, investments in Mozambique's mineral potential by leading international and regional mining companies is already increasing. Global mining houses are investing in exploration for energy minerals (hydrocarbons, coal and uranium), for titanium and zirconium in heavy mineral sands, for gold and gemstones, for the agricultural minerals lime and phosphate and for tantalum, fluorite and other industrial minerals.

METHODOLOGY

In the inventory of known mineral deposits and occurrences, ArcGIS and MS Access software were used for the storage, retrieval, manipulation and display of geo-information. The data compiled by the Geological Survey of Finland (GTK) was incorporated in the Mineral Information System (MIS) that was developed in conjunction with the Documentation Centre as a separate project. The first format for the mineral deposit databank, provided by DNG and dealing with approximately 90 mineral deposits, was incorporated into an ArcGIS project format for the drafting of mineral deposit maps.

Forms were designed for the collection of mineral resources data, which was transferred directly to the database during field mapping. Complementary data was extracted from both digital and analogue DNG reports, published sources and from the Internet (such as company press releases and annual reports).

The GTK Consortium has compiled a new database of 640 mineral deposits and occurrences, also including stone, aggregate, gravel and sand quarries and covering the entire GTK Consortium Contract areas. A total of about 140 mineral deposits (including construction materials) were checked in the field. The collected data comprise an inventory of the mineral commodities, geology and the mode of occurrence, sampling and digital photographs taken.

All the geological maps prepared by the GTK Consortium carry the symbols for mineral indications and occurrences with the name and commodity. In addition, separate maps at the 1:250 000 scale have been produced showing areas of resource potential for 12 commodities or groups of commodities. The potential areas have labels with the name, commodity and reference to the Explanatory Note Volume (1 to 4), where details are explained (GTK Consortium 2006a, b, c and d). Target areas identified by geochemical surveys are discussed by Korkiakoski 2008 (this volume).

MINERAL RESOURCES

The geological field mapping, including inventory of mineral resources, gave the GTK Consortium an opportunity to visit many active and previous mining sites. A brief review of mineral deposits and the extractive industries as a whole is given in this article as a synthesis together with the results of this work. The location of the mineral deposits and occurrences is shown on the geological maps at the scales 1:250 000 (Fig. 1 and Fig. 2) and 1:50 000. Areas of resource potential are indicated on separate map sheets on the geological background at the scale 1:250 000. Overviews at the scale 1:1 million with generalized geology were also prepared (Fig. 3).

According to the International Monetary Fund statistics for 2006, mining-related activities have contributed about 2% of Mozambique's Gross Domestic Product (GDP). However, it is believed that the potential of various mineral commodities is con-

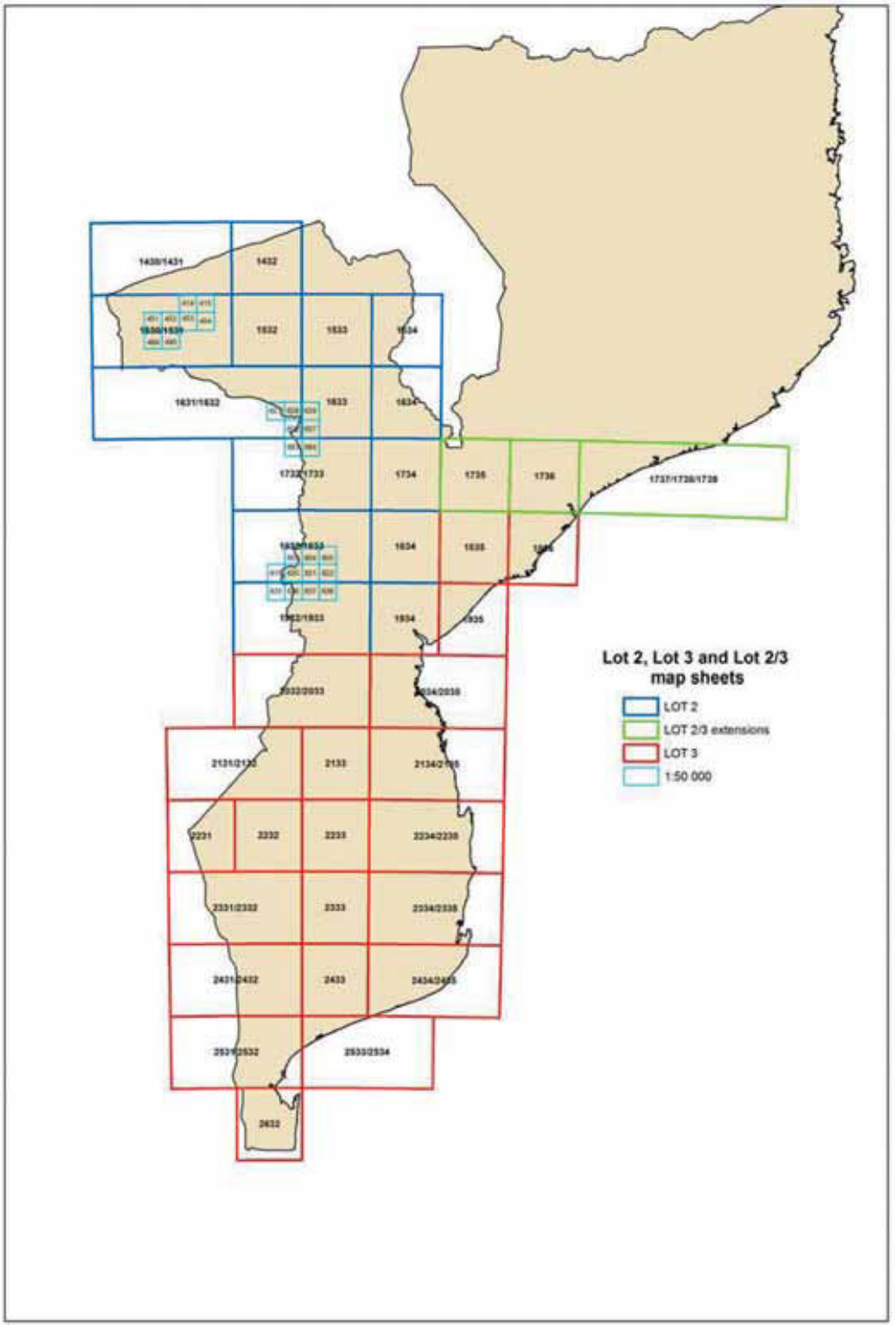

Fig. 1. Map grid of Mozambique, showing the geological and mineral resources maps prepared by GTK Consortium. The detail shown in Fig. 2 is obtained from map sheet 820 in scale 1:50 000.

siderably higher than the present utilization level indicates. Large deposits of ilmenite, rutile, zircon and coal are known to occur, as well as deposits of gold, copper and iron, in addition to asbestos, base metals, bentonite, cassiterite, diatomite, feldspar, fluorite, gemstones, gypsum, kaolin, limestone, mica, nepheline syenite, perlite, phosphate rock, rare earths, silica sand and uranium. Most gold, base metal, gemstone and carbonatite-hosted deposits are located in the older Precambrian terranes. The younger sedimentary formations contain various energy and industrial minerals: coal, gas, heavy minerals (Ti-Zr), limestone, bentonite and diatomite. At present, ongoing major projects are focused on heavy mineral sands, coal and natural gas.

Overview of recent production in mozambique

Mozambique produces natural gas on a large scale and also aluminium, but from imported raw materials. Construction materials, such as rock aggregates, gravel, sand, clay, limestone, marble and dimension stone, and ilmenite are produced on a medium scale. Gold, tantalite, coal, bauxite, diatomite, bentonite and other clays, as well as gemstones and sea salt, are all produced on a small scale. There are also at least 50 000 artisanal small scale miners who mainly work on alluvial and weathered gold and gemstone deposits. This production is not seen in the official statistics (Table 1).

Fig. 2. A detail of a 1:50 000 scale geological map showing the numerous minor gold indications in the Archaean greenstone belt in Manica (yellow rings). Based on the work of the GTK Consortium.

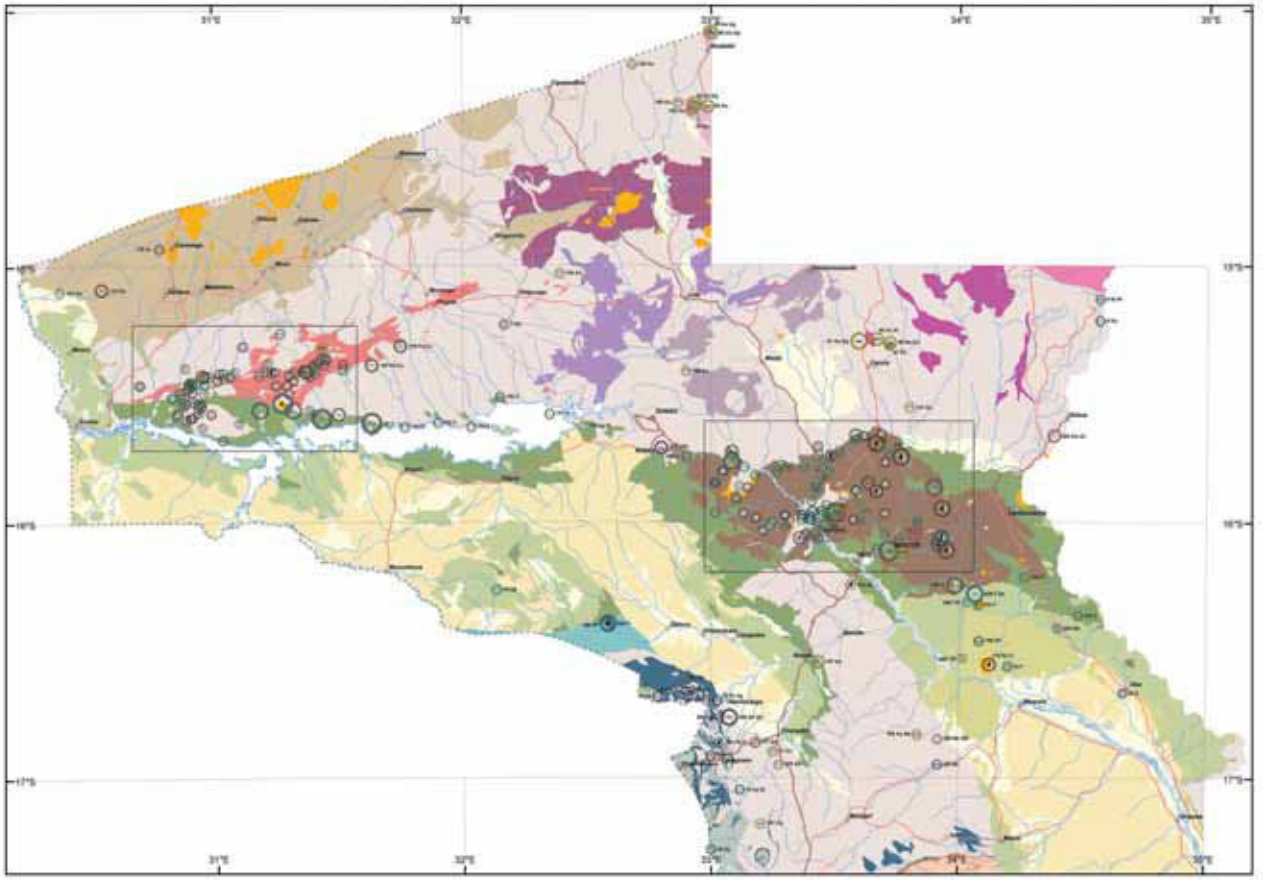

Fig. 3. An example of a generalized geological map at the scale 1:1 million, based on the work of the GTK Consortium and showing the locations of mineral indications in the Tete Province. Two areas (boxed): Fíngoè north of Cahora Bassa lake and Tete, further to the east, show a higher concentration of copper and iron mineralizations (ring symbols).

Table 1. Production figures for some commodities in 2004-2006 in Mozambique (source: Ministry of Mineral Resources, May 2007).

Mineral resource	Unit	2004	2005	2006
Coal	ton	16 525	3 417	10 000 est
Bauxite	ton	8 977	9 518	11 069
Bentonite (raw)	ton	3 366	0,0	n/a
Bentonite (processed)	ton	578	547	610
Bentonite ground	ton	16 627	17 318	4 207
Tantalite	ton	712	281	51
Industrial beryl	ton	27.3	146.3	16.4
Dumortierite	ton	113	10	664
Quartz	ton	173.0	295.0	195.1
Gold	kg	56	63	68
Aquamarine (gem quality)	kg	18.1	15.6	14.0
Aquamarine (reject quality)	kg	2 391	5 475	n/a
Tourmaline (gem quality)	kg	1 570	245	n/a
Tourmaline (reject quality)	kg	4 915	69 292	n/a
Garnet (gem quality)	kg	2 686	2 172	4 400
Garnet (reject quality)	kg	4 270	3 630	n/a
Limestone	ton	1 593 450	654 179	155 870
Clay	ton	108 231	32 031	222 052
Building sand	ton	1 429 743	833 113	1 404 184
Stone aggregate	m3	779 581	850 919	1 178 997
Granite	m3	521	2 198	5 500
Marble (processed slabs)	m2	13 666	12 158	12 825
Marble blocks	m3	617	509	472
Natural gas	GJ	49 739 070.0	88 907 651.0	90 000 000 est

Mineral resources in the GTK project area

The economically most important commodities in northwest and central Mozambique (LOT 2) are coal, gold and various construction materials (such as rock aggregate, dimension stone, limestone and clay). Occurrences of iron ore, copper and other base metals, cassiterite and fluorite are well known. The southern half of Mozambique, south of the 20th parallel, is to a large extent covered by Phanerozoic rocks. The economically most interesting mineral resources in the LOT 3 area are the gas occurrences in Pande and Temane fields in Inhambane as well as the heavy mineral sands in paleo-dunes in Gaza and Zambézia Provinces. The increasing demand for construction materials has reactivated many rhyolite quarries and gravel, sand and clay pits, especially in the Maputo Province, where construction of all kinds is very active.

Industrial rocks and minerals represent an important resource for domestic use. In the Maputo Province these include rhyolite for aggregates in the Boane – Massingir area, limestone in Salamanga for cement, which together with sand, gravel and various types of clay are the backbone of the growing construction industry. Possibilities for creating a stronger market for good quality diatomite resources in Maputo and Gaza Province, replacing imported material, should be considered more seriously. Most of the bentonite from Boane is exported without further treatment. More marketing and product development are required in order to add value and increase revenues from bentonite. Resources of thermal water are abundant along the rift faults of the mountain ridges in the western border area with South Africa and Zimbabwe, providing the potential for local power generation. Demand for good quality mineral water is also steadily growing, both for local consumption and for export. The southernmost indications of coal in lower Karoo strata are found in Espungabera (SDS[1] 2032), close to the Zimbabwe border in Manica Province. Alluvial, micro-sized diamonds have been found in the Limpopo and Singédzi rivers in Gaza Province, probably transported by the rivers from the South African Kaapvaal Craton. Sedimentary deposits of glauconite-bearing phosphorite are located near Magude, NNW from Maputo, in calcarenites of the

[1] Square Degree Sheets, at the scale 1:250 000, about 100 km by 100 km

Jofane Formation. For local production of phosphate fertilizer there are small reserves of bat guano in the Buzi area. The Eocene Cheringoma and the Miocene Jofane Formations contain large resources of limestone, halite and gypsum.

Energy Minerals

Hydrocarbons. Although investigation of hydrocarbons does not belong to the scope of this project, some general observations have been made, mainly due to the economic interests involved. The delineation of sedimentary rocks in terms of reservoirs for oil and gas is of major importance to Mozambique, since hydrocarbons potentially generate large revenues. The improvements in infrastructure and in deep-water technology together with high oil prices create favourable conditions for exploration.

Economic quantities of *natural gas* have been discovered at Pande (in 1961) and Temane (in 1967). Sub-commercial gas has been encountered at Búzi (in 1962) and Inhassoro (in 2003). Commercial gas has been reported from several horizons in the Lower Grudja in the central portion of the basin.

Production of natural gas rose twenty-fold in 2004, mainly due to the start up of the Temane Gas Project in Inhambane in late 2003. The natural gas production was close to 90 million GJ in 2006 and 2005, compared to 50 million GJ in 2004 and to 2.5 million GJ in 2003. Natural gas is also produced from the Pande field, some 40 km NNW from Temane. The gas fields have enough potential for additional production if required (Yager 2006).

To date, Mozambique is not a *crude oil* producer. Det Norske Oljeselskap (DNO) and Petronas of Malaysia have carried out (2002–2003) off-shore exploration in Sofala Province for petroleum (Yager 2004). Exploration for oil is also ongoing in the Rovuma basin, further north, close to the Tanzanian border. Preliminary results are encouraging (Pilskog *et al.* 2006).

Hydrocarbon exploration in central and northern Mozambique is focused on the Rovuma sedimentary basin, together with the offshore Zambezi deltaic complex and the entire off-shore, including the deep off-shore of the Mozambique Basin. These exploration targets have come within reach due to the strongly increased oil (and gas) price, together with novel deep-water technologies, which have rapidly improved during the past few years.

Coal. In November 2004 CVRD[2] won the international bidding process to explore coal deposits in the Moatize region. The feasibility study started in January 2005 with a comprehensive core drilling campaign. The forecasted production will be 14 million tonnes of coal in a year and the planned start is in 2009 (CVRD press release 13.07.2007). The demand for locally available construction materials is expected to increase considerably, especially considering the plans to construct a dam in the Zambezi River at M'Panda Uncua. There is a railway network linking the Moatize region to the coast at Beira port, but the coal terminal needs upgrading. The railway network needs significant rehabilitation and reconstruction to fulfil the requirements of the planned coal production. Local resources of construction materials were evaluated by the GTK Consortium as part of the Industrial Mineral Surveys.

In 2004 and onwards the coal production in Mozambique has only been around 10 000 t/a, having been 500 000 t/a in the 1980s. Mozambique has substantial coal deposits situated in the Moatize and Mucanha-Vúzi coal basins in the Tete Province. The Moatize coal basin, which is considered by CVRD as the largest unexplored coal province in the world, contains six coal seams and has total resources of 4 000 Mt in categories measured, indicated and inferred. The Mucanha-Vúzi basin is estimated to contain as much as 3 600 Mt in coal resources (Lächelt 2004), although the basin is severely block faulted.

The world's leading steel group, the multinational ArcelorMittal, will in a joint venture with Black Gold Mining of Mozambique investigate the Rio Minjova sub-basin, 20 to 50 km SE from Moatize Mine (AncelorMittal press release 21.11.2007). In 2006 the Central African Mining and Exploration Company (CAMEC press release 01.02.2006) claimed large parts of remaining prospective ground in the Moatize and Mucanha-Vúzi basins. Detailed geological investigations are ongoing to evaluate

Fig. 4. Coal bearing siltstone layers outcropping along the dry river channel of M'Pote Pote in Espungabera. The hammer is 60 cm long.

[2] Companhia Vale do Rio Doce from Brazil

the reserves of good quality coal in other prospective areas of Sanangoè-Mefideze, Baixo Chire and Maniamba basins between Moatize and the Malawi border.

The southernmost indications of coal seams in Mozambique are located in the Espungabera sub-basin, near the Zimbabwean border, along the M'Pote Pote River (Fig. 4).

The Karoo sedimentary sequence in the Espungabera sub-basin is superposed on the northern marginal zone of the Limpopo mobile belt. The productive series occurs near the surface, but block faulting is common, making the resource evaluation without geophysics and drilling quite unreliable. In addition, the location of the Espungabera coalfields is very remote, far from potential industrial users in Mozambique. The riverbank outcrops, however, could be quarried for local consumption as fuel.

Uranium exploration is actively carried out over the country, due to positive commodity price development and the availability of recent airborne radiometric surveys, the processing of which has identified a number of highly anomalous uranium targets. A number of prospects that were actively explored by uranium industry majors from the mid 1970s to the uranium price collapse of the early 1980s, are again explored. Elevated contents of radiometric minerals, mainly davidite, are quite common in quartz-calcite veins in the Tete Suite (Omega Corporation 2005, 2006). The Mavudzi Mine, that was closed 1967, is located in an approximately ten kilometres long fault zone in gabbro and anorthosite about 40 km NW of the town of Tete. The upper Karoo sandstones and the sandstones, conglomerates and felsic volcanis of the Lupata Group have good potential for uranium deposits (TEAL Exploration & Mining, press release 18.04.2008).

Industrial Minerals

Ilmenite, Rutile and Zircon. Based on extensive heavy mineral sand (HMS) deposits located along most of the 2700 km long coastline, Mozambique has the potential to become the world's foremost producer of Ti and Zr minerals. A few major companies have recently been active in completing feasibility studies on potential mining projects. The deposits occurring in the GTK contract area are briefly described below.

The "*Corridor Sands*", near the Limpopo River, about 190 km north of Maputo and 50 km inland from the present coastline, close to the town of Chibuto in the Province of Gaza, was a major discovery in 1997. The Chibuto deposit (SDS 2533, 554556/7272167) is one of the largest heavy mineral deposits in the world with an estimated lifespan of well over a hundred years. It has a resource of at least 14 000 Mt of ilmenite-rich sands at an average heavy mineral grade of 4.9% (MBendi statistics, 22.05.2006). Australian WMC[3] reported in 2003 a measured resource of 1 765 Mt @ 4.14% ilmenite and an indicated resource, containing 73 Mt of ilmenite (Mining Review Africa 2003). The heavy mineral concentrations are characterised by the absence of Cr, V and radioactive minerals and the thickness of heavy mineral bearing (>2% HM) layers may be locally up to 70 m (Lächelt 2004). The project was taken over by BHP Billiton in 2005. Although the date for starting production is pending, the capacity of the planned processing plant is designed for a production of about 400 000 tpa of sulphate and chloride titanium dioxide slag, with a by-product output of nearly 200 000 tpa of iron, together with rutile and zircon.

Italian Aquater SPA started HMS exploration in the early 1980s along the coast at Xai-Xai near Chongoene. Aquater (1985) reported a resource of 480 Mt grading 6% total heavy minerals (THM). The company carried out further follow-up exploration in 1997. Recent exploration by Rio Tinto has concentrated on map sheet 2533 at Xai-Xai, where a significant HMS resource has been identified. Rio Tinto acknowledged total reserves of 186 Mt @ 4.4% THM, of which 59.6 Mt is in the proved, 112.7 Mt in the probable and 13.8 Mt in the possible category (Rio Tinto RTZ 2004). The Xai-Xai deposit is reported to contain 49 Mt of THM concentrate with 66% of ilmenite, 0.4% of zircon and 0.5–0.7% rutile. Further exploration is ongoing (Albanese 2005).

Bentonite occurs as a weathering product of rhyolites and rhyolitic tuffs of the Karoo volcanics distributed in the Pequenos Libombos range. In Boane, a zone about 2 km long and 500 m wide with an average thickness of 6 m has been calculated to contain 15 Mt of bentonite (Lächelt 2004). The thickness of bentonite varies from a few metres to up to 20 m, depending on the intensity of weathering. The total reserves of the Boane-Pequenos Libombos bentonite deposits have been estimated at 2.5 Mt in the proven category and 4.2 Mt in the probable category (Noticia Explicativa 1995). The production of low-grade bentonite for export is ongoing in Boane.

[3] Western Mining Company

Fig. 5. Diane quarry, exploiting a one–metre-thick diatomite layer (in the middle of the picture), Manhiça (SDS 2532, 463968/ 7193482).

Bentonite has been found at various other locations over a distance of 40–60 km in rhyolite ridges of the Pequenos Libombos and it is occasionally mined in places suh as Luzinada (SDS 2632, 424394/ 7119062).

Diatomite has accumulated in many fluvial and lagoonal depressions between Pleistocene dunes from Inhambane in the north to Matituine south of Maputo. The diatomite was deposited in rivers, small lakes and ponds under brackish to freshwater conditions. The deposits are usually small with a maximum thickness of 1.5 – 2.5 m. The Boane and Manhiça occurrences are best known.

The diatomite occurrences are located about 10 km SW of the town of Manhiça. The main pit (Diane deposit) has been in production since 2005, and there the horizontal diatomite layer measures 60 x 50 m and is about 0.8 to 1.0 m thick at an average depth of 8 m below the surface (Fig. 5).

Estimated reserves are 1.5 Mt with an average bulk density of 0.32 g/cm^3 and grading 50% pure diatomite (Afonso & Marques 1993). Diatomite is screened and split into various qualities and at present all is exported to South Africa. Diatomite is locally used as an additive to cattle food against parasites and other sicknesses. For now, the real added value to these products is still made abroad. Instead of utilizing this thoroughly studied and tested domestic resource, commercial diatomite products are imported into Mozambique.

Between Magode and Chokwe, in Gaza Province, there are diatomite deposits in the southern margin of the East African Rift. Another large diatomite domain, measuring 70 x 10 km, occurs some 100 km to the ENE, around Mafuiane and Buana. Further investigations are warranted to establish whether there is a sufficient volume for commercial exploitation of diatomite.

Bauxite. In 2006 a total of 11 069 tons of bauxite was produced, which comes from the small Moriangane mine in the Penhalonga zone in Manica Province. The mine is operated by E.C. Meikles (Pty) Ltd of Zimbabwe and most of the bauxite is exported to be used as a raw material for alun (aluminium sulphate) in Zimbabwe. There are deposits of kaolinite and other clays hosted by weathered pegmatites and syenites in the provinces of Zambézia and Manica.

Construction Materials

Aggregates. Karoo rhyolites provide a good raw material for aggregate. The majority of active mining licences for stone quarries are located around Maputo, in the districts of Namaacha, Boane, Matutuine and Moamba where the economic activity is highest. In other parts of the country the peaks of consumption go together with the construction of roads, bridges and major buildings. In most parts of country, aggregate rocks, gravel and sand are commonly available: aggregate from hard bedrock, such as felsic volcanics; and gravel and sand from riverbeds and beach deposits.

The quarried aggregate rocks are mostly rhyolites of the Lebombos Range. Rhyolite does not weather as easily as andesite and basalt in the same range and can be regarded as good material for most road and other construction purposes. In the Moamba district a suitable, fine-grained nepheline syenite is being quarried by CMC for aggregate (Fig. 6). Table 2 lists the rhyolite quarries in operation in Maputo Province in 2005.

Fig. 6. Solbrita quarry in porphyritic nepheline syenite (SDS 2632, 431316/ 7150467).

Table 2. Aggregate rock quarries in operation in Maputo Province in 2005.

Quarry Name	Map Sheet	Coordinates
CMC	2632	428176E/7121877N
Tamega	2532	424318E/7145310N
Extramac	2632	424951E/7108576N
Riolitos	2632	422028E/7119151N
Probrita	2632	428363E/7123749N
ARA Sul	2632	423486E/7114906N
MAM	2632	413124E/7105831N
Agroareias	2632	435016E/7115962N
Solbrita	2632	431316E/7150467N

The aggregate from these sites is transported and used along the coast as far as Gaza and Inhambane (along highway EN1), where no suitable aggregate rock has been found. Occasionally, aggregate for road rehabilitation is transported by trucks up to the Save River. Properly constructed road pavement with aggregate layers, like sub-base, road base and wearing layers, requires considerable amounts of stone material. Road transport of bulk aggregate over hundreds of kilometres is expensive.

Inland in Gaza Province, rhyolite is quarried at Massingir (SDS 2332, 393081/ 7352065). Large rhyolite blocks are transported over 28 km along a new gravel road to the Massingir construction site, where the blocks are used for earth wall protection of the irrigation dam in Rio dos Elefantes.

In the coastal zones of Inhambane Province no hard silicate rocks are exposed. As an alternative, several pits have been developed in limestone close to or along highway EN1. These include artisanal quarries close to Massinga town, in the villages of Mambadine and Chacane. Limestone aggregate is used for the construction of homes and for local road maintenance.

Along Beira Corridor the rounded, granodioritic hills are quarried for aggregate material in many places between Chimoio and Manica. The Xiluvo Complex, with its felsic volcanics and carbonatite, is the closest rock aggregate occurrence to the coast and the town of Beira. Ballast and aggregates for the rehabilitation of railway lines and roads are at present produced from the Xiluvo carbonatite body. The ballast is loaded directly onto railway wagons in the village of Xiluvo.

The demand for aggregate rock is expected to increase to a great extent due to the Moatize coal project and reconstruction of the Moatize – Beira railway. In 2006, crushed rock and aggregate production amounted to 1 178 997 m^3, steadily increasing from previous years. Production of construction sand was about 1.4 Mt in 2006, which is a normal level in Mozambique (Ministry of Mineral Resources May 2007).

Dimension Stone. Some of the Karoo rhyolites, exposed in the Maputo Province, have been quarried for dimension stone, for example near Boane and Estevel and also near Ressano Garçia. The banding and folding in the light brown rhyolites may be highly ornamental (Fig. 7). However, block size in the fractured, dense rock is generally problematic.

Massive ‘grey granite’ (actually gabbro) is periodically quarried for export at Chainça in Manica (0481281/7908276), as well as anorthosite from the Tete Suite. Some other sites have also occasionally been exploited for dimension stone, but only on a small scale. The demand for Tete anorthosite/gabbro in particular seems to fluctuate greatly, which obviously depends on the trends in the world market at which these blocks are mainly aimed. Transportation by trucks to Beira port is currently very costly.

Sand and Gravel. The availability of high quality sand and gravel close to Maputo and surroundings is only satisfactory and not as good as for stone aggregate. Most of the visited extraction sites ex-

Fig. 7. Flow structure in rhyolite at an old dimension stone quarry known by the name of Estevel.

ploit fine-grained flood-plain sand along the Umbeluzi (Boane area) and Incomati Rivers (Moamba area, Uetimane deposits). Sand from these locations is best suited for mortar purposes and filling. Fine dune sand is excavated for the same use. Gravel of satisfactory quality is only found along the Umbeluzi River, near Goba town.

In the southern part of Gaza Province, sand and gravel deposits occur along the Rio dos Elefantes and the main Limpopo River. There are a large number of sand pits in in Chilembene-Chókwè and Massingir areas. Rehabilitation of the Massingir dam (414026E/ 7355195N) has consumed a large quantity of sand and gravel, which has been extensively extracted from the river valley at several locations.

Limestones of the Tertiary Salamanga Formation, south of Maputo, of the Cheringoma Formation west of Beira along the Buzi River and in the type-locality north of Beira on the Cheringoma plateau, have high calcium carbonate contents. The Miocene Jofane Formation is a second important accumulation of limestone. A large area with limestone outcrops extends from the Save River southwards to Inhambane. Limestone occurrences are also known at Urrongas.

Currently, limestone for cement production is quarried only at Salamanga, some 60 km SSE from Maputo, where it is transported by rail and trucks to the 'Cimentos de Moçambique' plant in Matola over a distance of 100 km. The Salamanga limestone is of Tertiary age and exposed over a zone more than 10 km long and 1.5–2.0 km wide. The thickness of the limestone layer varies from 11 m to 55 m with an average of 32 m. A measured reserve of 1200 Mt and an inferred reserve of 1200 Mt limestone of Portland cement quality has been reported (Diallo 1979).

Tertiary, somewhat sandy limestone is known at Mangulane, about 40 km NE from Moamba in Maputo Province. The rather large quarry was active in 1960s with good road and railway connections. The overburden above the limestone is 2 – 10 m thick and consists of gravel and sand. Removal of large volumes of overburden prior to limestone quarrying was required, considerably increasing the cost of operation.

Cimentos de Moçambique (CIMOC) has a plant at Dondo, outside Beira. At present, imported clinker is used as raw material for cement production instead of local limestone. An extensive potential for limestone exists in Cheringoma Plateau in Sofala Province, generally within Tertiary and Cretaceous sediments. Proterozoic carbonate-bearing metasediments may also host pure calcite marble in Tete, Manica, Niassa, Capo Delgado, Zambezia and Sofala Provinces. In 2006, only about 750 000 tonnes of limestone was produced, about half of the production level in 200 –2004 (Ministry of Mineral Resources).

Brick Clay. Common clay is taken for local brick production around most major towns where clay beds occur in and along river valleys. Bricks are burned on demand for building of local houses. However, the quality of the clay used is highly variable, often too sandy and bricks are easily broken. No systematic quality data on various clay materials exist.

Brick clay is excavated close to Boane, on the eastern bank of the Umbeluzi River. This deposit supplies clay for brick production to most of the brick works in the Maputo area. A dormant clay pit is located in Bela Vista and a large number of small clay occurrences are known at Namaacha and Maguiguane along the valley of the Incomati River.

Phosphate. Large carbonatite bodies located in Tete province, such as Mt Muande and Mt Fema, on opposite sides of the Zambezi River, have potential for phosphate (apatite). Carbonatite pipes, such as Cone Negose, on the northern shore of Cahora Bassa (Fig. 8) and Mt Muambe, SE of Tete, could also be considered as resources for agricultural fertilizers.

Thermal water

Thermal and mineral water springs are common in the Karoo rhyolite zone close to the South African border (Lebombos) in Maputo Province. There, springs such as Namaacha and Goba are well known for good quality bottled water. Further to the north, in the Espungabera-Dombe-Chibabava region, between Buzi and Save Rivers, several thermal springs are known along the Karoo faults.

Gemstones

Gemstones can be found in pegmatites where beryl, tourmaline and various feldspars occur, mainly in Zambézia, Nampula and Tete Provinces. Skarn rocks and biotite schists intruded by pegmatites and garnetiferous gneisses provide prospective ground for emeralds and garnets. Karoo basalts may be agate bearing. Most gemstones have been produced by artisanal small scale miners and are not properly registered.

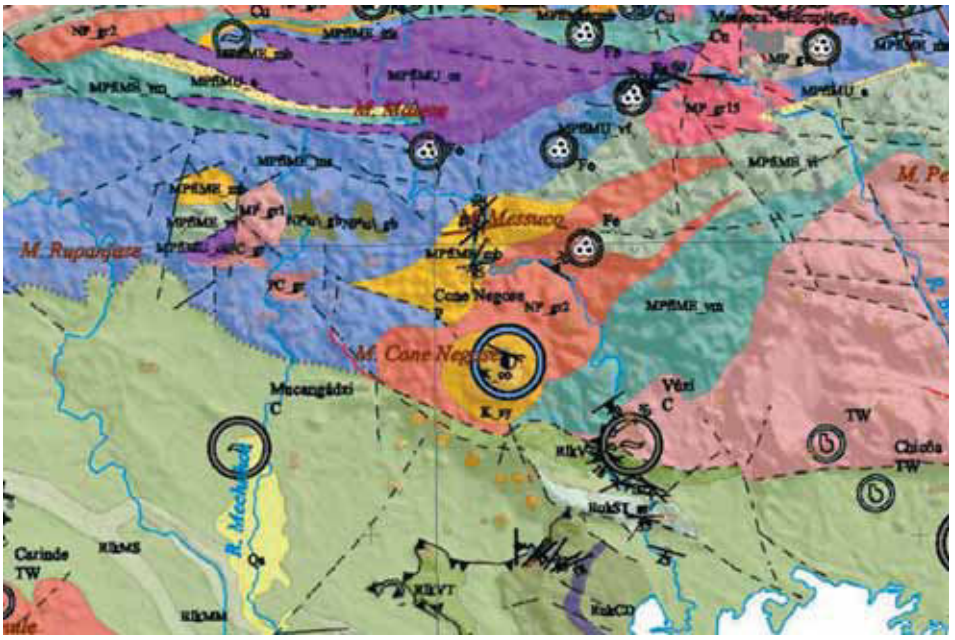

Fig. 8. Location of the Cone Negose carbonatite body on map sheet 1531 (blue ring), north of Cabora Bassa lake, which is visible on the southernmost part of the map. Based on the work of the GTK Consortium.

Gold

Gold has been mined in the Mutare-Manica border area between Zimbabwe and Mozambique since prehistoric times. However, the official production figures have been very low, less than 100 kg annually during the current decade. The official production figure for whole of Mozambique is 68 kg of gold in 2006 (Ministry of Mineral Resources May 2007).

In Manica, gold mining in hard rock started 1893 at Bragança and Guy Fawkes and has irregularly continued since then. Monarch mine, just on the border with Zimbabwe (Fig. 2), was operated periodically by Mincor de Mozambique until its closure in 1997. The gold is connected to shear zones in Archaean mafic and ultramafic volcanics, banded iron formation and chert or in the fractured contact between the supracrustals and the surrounding granites. Principal alluvial deposits that are important for the local economy have been located within the Revuè, Inhamucarra, Muza and Chimezi Rivers.

A resource of 1 550 million ounces of gold at 2.96 g/t Au was in 2007 reported by Pan Africa Resources (press release 13.08.2007) within their Manica claims (covering mainly the Fair Bride zone). A prefeasibility study was completed in 2007, while drilling at depth is ongoing with very encouraging gold grades (press release 21.02.2008). The results of the recent exploration utilizing modern multidisciplinary techniques indicate that the Archaean Manica greenstone belt has the potential for profitable gold mining on an industrial scale.

In 2006 African Eagle Resources reported (press release 05.09.2006) interesting gold grades in drilling intersections from their claims in the Fíngoè belt, to the north of the Lake Cahora Bassa in Tete Province. The exploration target in iron oxide-copper-gold mineralised zones was compared with the Eagle Eye field in Ndomba, Zambia, where economic gold potential zones have been located.

The Central African Mining and Exploration Company (CAMEC) has commenced ground exploration after radiometric and satellite image surveys on their 540 sq km exploration licence area at Rio Muda in Nhamatanda, in the Beira Corridor in Sofala Province. Recently, around 2 000 artisans have been producing over 20 kg of coarse gold per month along Rio Muda. A simple plant has been built to allow local miners a facility to process their ore (CAMEC press release 01.02.2006).

Uncontrolled artisanal gold workings cause local environmental problems in the Manica mountain region. In addition to soil erosion (Fig. 9) and water siltation, the use of mercury in recovering fine gold causes air and water pollution. The Ministry of Mineral Resources, DNM[4] and DNG[5] have taken preliminary measures to improve the situation by emphasizing and introducing environmentally better and safer methods for gold recovery.

[4] National Directorate for Mines

[5] National Directorate for Geology

Fig. 9. Artisanal gold panning site at Bandire, map 1933, Manica Province.

Base Metals, Copper Etc.

Rather few comprehensive investigations on base metals have been carried out in Mozambique. Base metal concentrations of copper, nickel, gold and silver are found in altered ultrabasic volcanics of the Archaean Manica greenstone belt. Mundonguara is the best-studied deposit, the exploration history of which is summarized by Korkiakoski (1990). Currently exploration is carried out by Baobab Resources, an exploration company focused on base and precious metals in Mozambique.

The Mundonguara copper-gold-silver occurrence is located on the southern hillside of the Isitaca Mountains, about 12 km west of the town of Manica (SDS 1832, 477977/ 907124). Altogether, ten E-W trending mineralised bodies have been identified. Reserves, calculated for an average mining thickness of 2.9 m, amount to 123 000 t with 2.36% Cu (Lächelt 2004). Other calculations by LIMEX (1980) indicate a reserve of 325 000 t grading 3.1% Cu and 0.58 g/t Au. In 2007, Baobab Resources reported (press release 13.07.2007) significant gold and copper grades and elevated Ni and Co grades in surface rock chip samples from the Seymour Prospect, which is a part of the Mundonguara mineralized stockworks system.

The Chíduè copper deposit close to the town of Tete was a target for minor geological investigations in the 1950s, which resulted in defining 8.6 Mt of copper ore grading 1.65% Cu (Lächelt 2004). This suggests that more detailed exploration in the area is justified.

RECOMMENDATIONS FOR EXPLORATION

Based on the overview of mineral occurrences in the area and on the ideas gained during the project, the following recommendations for future exploration are presented:

- Economically natural gas is the most important mineral product at present in Mozambique. Additional resources can be expected in the Temane and Panda fields in Inhambane. In Sofala Province, further to the north along the coast, gas indications have also been recorded. Oil has not yet been found, although some exploration has been carried out in the Inhaminga onshore block north of Beira and in an offshore block near the Zambezi Delta (Yager 2005). In June 2005, Sasol was awarded exploration licences (gas and petroleum) for offshore blocks just east of the Pande-Temane gas fields. Exploration in the deeper offshore, including the Mozambique Channel, will supposedly come within reach in the next decade.
- Exploration drilling for gas has indicated large volumes of gypsym in the Temane field. Gypsum is currently imported to Mozambique for use in cement plants. Exploration to investigate the extent and availability of gypsum is justified.
- The Corridor Sands heavy mineral project near Chibuto is closest to the start up decision, in addition to Moma deposit in Nampula Province, which went into operation in 2007. Uncertainty over the price development of titanium and electricity has delayed decision-making. After the construction of the plant in Chibuto, the potential area for heavy mineral resources will increase in Gaza and stretch along the Limpopo River valley from the coast to Chókwè. The outlook for utilisation of these titanium resources will depend heavily on global market trends and a reliable domestic power supply. The use of natural gas from Pande and Temane gas fields as a power resource has been discussed. The full potentiality of the heavy mineral sands close to Maputo, in the Marracuene-Limpopo estuary to the north and Ponta de Ouro-Lagoa Piti zone to the south, should be investigated. The coastal zone from Limpopo River to Inhambane has a high HMS potential, as well as the Inhassoro zone, further to the north.

- Coal in the Moatize and Matinde Formations of the Lower Karoo Group is without doubt one of the greatest mineral resources in Mozambique. Intensive exploration by international companies (e.g. CVRD, ArcelorMittal and Tata Steel) is ongoing in Mucanha-Vúzi, to the north of Lake Cahora Bassa and in Minjova area, SE of the town of Tete, which still have an untested coal potential.
- In the Mesoproterozoic Fíngoè Supergroup rocks (min age 1327±16 Ma), such as felsic and mafic volcanics, volcanic breccias, banded ironstones and metacherts, the shearing in a NE-SW direction has in many places created traps in which mobile sulphides and gold may have been concentrated. On SDS 1531 there are several indications and gold occurrences connected to oxide phase iron formations that would require further exploration. African Eagle Resources has reported (press release 5.9.2006) encouraging results from their claims in the Fíngoè belt where they are carrying out geological mapping and stream sediment geochemical surveys in iron oxide-copper-gold mineralised zones. The Pan African Mining Corporation is also active in the Fíngoè area, planning to execute reconnaissance geochemical sampling programmes (press release 11.9.2006). Their claims cover known gold and Cu-Fe occurrences, skarn alteration and hematitic breccias within zones belonging to the Mesoproterozoic Fíngoè Supergroup. Banded ironstones, mafic metavolcanics and pyroclastic rocks form the principal target zones.
- Mesoproterozoic mafic volcanics and volcanoclastics of the Mualadze Group that are surrounded by Desaranhama Granites (age 1041±4 Ma) have been sheared mainly in a northerly direction. These shears are gold bearing on map sheet SDS 1432, containing gold mineralizations in Fundão, Missale, Chifumbazi and Muande. These structures have further untested gold potential. The Cazula field, in a similar geological environment in Desaranhama Granites on SDS 1533, also has gold potential, which is currently being tested by Pan African Mining Corporation (press release 13.8.2007). The target for gold exploration at the old mining site of Machinga is associated with quartz veining and hydrothermally altered and brecciated host rocks within regional shear zones.
- The Tete Suite represents a mafic-ultramafic part of a Mesoproterozoic bi-modal suite. The Suite has been explored in the past for ilmenite, nickel, copper, gold and uranium. Further exploration seems warranted, especially along the northern mylonitic border zone of the Tete Suite within the 'Conua-Chiduè Resource Potential Zone' on SDS 1533. The Mussata porphyritic, biotite-bearing and locally mylonitic granite (age 1046±20 Ma) has provided channels for Cu-Au bearing fluids.
- At present, uranium is also seen as an economically feasible target for exploration, especially within the anorthosites of the Tete Suite in the Mavudzi area (SDS 1533) and in the upper Karoo sandstones (SDS 1530. The Australian Omega Corp. Ltd reported in May 2006 (press release 3.5.2006) that based on extensive fieldwork involving ground geophysics and RC drilling, they have succeeded in identifying 'a suit of significant uranium radiometric anomalies' in their Mavudzi project. The NNE trending radiometric U-anomalies connect the historic Mavudzi, Inhatóbuè and Castro mines. The airborne radiometric surveys will, when processed and interpreted, provide useful tools for uranium exploration, for example in the sedimentary and volcanic rocks of the Lupata Group in central Mozambique.
- Igneous rocks associated with Karoo and younger rifting, such as alkaline and carbonatite complexes, have potential for phosphate, pyrochlore, REE's and fluorite deposits. The local need for fertilizers could be covered by mining carbonatite in Mt Muande and Mt Fema, with the production of agrolime and fertilizers with interesting by-products (Fe, REE). Further exploration is recommended in the Mt Fema – Mt Muande Resource Potential zone as well as in Salambidua and at Monte Xiluvo.
- A good source for lime could be developed in the Boroma calcitic marble deposit if local demand increases.
- The availability and quality of various construction materials close to the Tete-Moatize development centre and along the roads to Zimbabwe, Malawi and Zambia should be studied. Large construction projects related to mining (Moatize coal), infrastructure (roads, bridges, railroads) and hydropower (M'Panda-Uncua dam) will commence in the near future.

The road network from Tete to the north and west on the northern side of the Cahora Bassa dam will require upgrading using locally available aggregates. Aggregate in the Maputo area is especially important and the quality and volumes should be evaluated. Rock types other than rhyolite and nepheline syenite might also prove valuable.

- The availability of various types of clay, e.g. brick clay for building of houses along the development corridors, should also be investigated. Bentonite weathering in Pequenos Libombos range around Boane should be further evaluated. The rhyolites and rhyolitic tuff of the Karoo Supergroup form quite a large potential for bentonite along the South African border.
- The market potential of diatomite should be studied, including domestic consumption. If the prognosis is positive, the volume and quality of the diatomite fields in Manhiça, (SDS 2532), Lagoa Ramo (SDS 2433) and Mafuiane, in Gaza (SDS 2434) require confirmation. The establishment of local enterprises should be encouraged through training and investments.
- Exploration targets in the Manica greenstone belt include primitive-type (or Kid Creek-type) volcanogenic massive sulphide deposits, komatiite-hosted Ni-sulphide deposits, and structurally controlled and ironstone-hosted gold deposits. The Manica and Mavita Resource Potential zones provide targets for further exploration of gold.
- Metasediments and migmatites of the Báruè Complex are possibly derived from a monotonous sequence of turbidites. The potential for structurally hosted gold deposits is evident. Assuming that the metasediments of the Báruè Complex have been thrusted on top of the Zimbabwe Craton, possible remobilisation of metals from below augments the potential. Special attention should be paid to Karoo boundary faults and to faults filled with brecciated gouge material.
- TTG granitoids emplaced in the Báruè Complex have potential for pegmatites, veins and stockwork, carrying tin, tungsten, niobium-tantalum, gemstones etc.
- The cement plant at Dondo (SDS 1934) could use domestic limestone as a raw material, since good quality limestone occurs extensively in the Cheringoma Formation, close to the roads and railway of the Beira development corridor.
- The cement plant at Matola (Cimentos de Moçambique) utilises limestone from Salamanga (Maputo, SDS 2632). The possible extension of this type of limestone should be studied closer to the Matola plant. Exploration for a marketable quality and volume of limestone in the Miocene Jofane Formation, between the Save River and Inhambane, is recommended close to the main roads (e.g. Urrongas, SDS 2134).
- A few micro-diamonds have been found in alluvial sources in the river valley of Limpopo and Rio dos Elefantes near Pafúri, in western Gaza (SDS 2231). It is assumed that the diamonds have come from the diamond fields in South Africa and in Zimbabwe, since the nearest known occurrences are located only 25 km from the border with South Africa. Further exploration is, however, justified, particularly in the area underlain by the Umkondo Group.

PROSPECTS FOR THE MINERAL INDUSTRY IN GENERAL

In general, the outlook for developing an active mineral industry in Mozambique seems promising. However, the future greatly depends on several internal and external factors. *Firstly*, there should be a fully transparent policy in awarding and controlling various permits for prospecting, exploration and finally for mining. The recently adopted cadastre system is the first step in the right direction. *Secondly*, the government should consider measures that promote investments in the mineral sector, including general improvement of infrastructure such as ports, roads, railways and power lines. As a *third* measure, a reduction in taxation and the price of electricity and fuel could be considered.

One major problem is also the scarcity of entrepreneurs to set up and manage small to medium scale enterprises, first to exploit and then to process and sell various mineral-based materials and goods. At the moment, by far the majority of these everyday goods (bricks, tiles, pottery, ceramic products, refractory materials, fertilizers, lime, etc.) are imported.

The success of the extractive industry in Mozambique heavily depends on the world market for various minerals. In order to enter the market and compete successfully the price, quality of commodities and the certainty of production must be guaranteed. The same also concerns the domestic market; if local mineral commodities or products do not meet adequate requirements, the imported products will put them out of the market. Mozambique certainly has great potential to promote investments in exploration and mine projects, but much depends on the strategy and active measures taken by the Mozambican authorities.

REFERENCES

Afonso, R. S. & Marques, J. M. 1993. Recursos Minerais da República de Moçambique. Contribuição para o seu conhecimento. Instituto de Investigação Científica Tropical de Portugal and Direcção Nacional de Geologia de Moçambique. 1a. Edição, Lisboa, Portugal, 149 p.

Aquater 1985. Prospecçao das areias costeiras mineralizadas entre Micaúne e o rio Licungo-Zambézia. Rel. final ING, DNG Library No 1333, scan 1277.

Diallo, O. R. 1979. Relatório sobre a prospecção pormenorizada das argilas de Bela. Instituto Nacional da Geologia, Maputo.

GTK Consortium 2006a. Map Explanation; Volume 1: Sheets 2032 – 2632. Geology of Degree Sheets, Espungabera/Chibabava, Nova/Mambone, Massangena, Chidoco, Save/Bazaruto, Chicualacuala, Machaila, Chigubo, Mabote/Vilanculos, Rio Singuédzi/Massingir, Rio Changana, Funhalouro/Inhambane, Chilembene, Chókwè, Zavala/Inharrime, Maputo, Xai-Xai/Zavala and Bela-Vista, Mozambique. *Direcção Nacional de Geologia (DNG), Maputo*, 341 pages and 5 appendices.

GTK Consortium 2006b. Map Explanation; Volume 2: Sheets 1630 – 1634, 1732 – 1734, 1832 – 1834 and 1932 - 1934. Geology of Degree Sheets Mecumbura, Chioco, Tete, Tambara, Guro, Chemba, Manica, Catandica, Gorongosa, Rotanda, Chimoio and Beira, Mozambique. *Direcção Nacional de Geologia (DNG), Maputo*, 411 pages and 4 appendices.

GTK Consortium 2006c. Map Explanation; Volume 3: Sheets 1735–1739, 1835–1836 and 1935. Geology of Degree Sheets Mutarara, Quelimane, Namacurra/Maganja, Pebane, Marromeu/Inhaminga, Chinde and Savane, Mozambique. *Direcção Nacional de Geologia (DNG), Maputo*, 240 pages and 2 appendices

GTK Consortium 2006d. Map Explanation; Volume 4: Sheets 1430–1432 and 1530–1534. Geology of Degree Sheets Inhamambo, Maluwera, Chifunde, Zumbo, Fíngoè-Mágoè, Songo, Cazula and Zóbuè, Mozambique. *Direcção Nacional de Geologia (DNG), Maputo*, 382 pages and 4 appendices.

Korkiakoski, E. 1990. Mundonguara Cu-(Au) Mine in the Manica Province, Mozambique. Unpublished Report UNDP Project MOZ/86/023, Maputo 19.01.1990, 8 p.

Korkiakoski, E. 2008. Geochemical surveys in Mozambique: a data compilation project, Geological Survey of Finland, Special Paper 48, 263–287.

Limex GmbH 1980. Revição dos aluviões auriferos de Vila de Manica. Relatorio final (2 volumes) Unpubl. Rept., DNG Library No. 1068, Maputo.

Lächelt, S. 2004. Geology and Mineral Resources of Mozambique. DNG, Maputo, Moçambique, 515 p.

Noticia Explicativa 1995. Noticia Explicativa da Carta de Jazigos e ocorrências minerais de Moçambique 1 : 1 000 000, Maputo.

Pilskog, B., Soderstrom, B., Averty, J. & Gomes, P. 2006. The Petroleum potential of areas 2&5, Rovuma Basin, Mozambique, Abstract Volume, 21st Colloquium of African Geology, Maputo July 2006.

Internet references

African Eagle Resources, press release 05.09.2006, retrieved from www.mbendi.co.za/company news.

Albanese, T. 2005. Exploration Seminar, Rio Tinto Exploration (RTE), September 30, 2005, Final Print of Presentation, retrieved from www.riotinto.com.

ArcelorMittal, press releases 13.07.2007 and 21.11.2007, retrieved from www.mbendi.co.za/company news.

Baobab Resources, press release 13.07.2007, retrieved from www.mbendi.co.za/company news.

CAMEC, press releases 01.02.2006 and 01.02.2007, retrieved from www.mbendi.co.za/MozBusiness.

CVRD, press release 13.07.2007, retrieved from www.mbendi.co.za/MozBusiness.

Mbendi 2005. Mining industry statistics, retrieved from www.mbendi.co.za.

Mining Review Africa 2003, issue 5, retrieved from www.miningreview.com/archive/035/08

Omega Corporation Limited. 2005. Annual Report 2005, retrieved from www.omegacorplimited.com.au.

Omega Corporation Limited. 2006, press release 03.05.2006, retrieved from www.omegacorplimited.com.au.

Pan African Resources Company, press releases 11.09.2006, 13.08.2007, 30.01.2008 and 21.02.2008, retrieved from www.mbendi.co.za/company news.

Rio Tinto RTZ. 2004. Annual Exploration Report 2004, retrieved from www.riotinto.com.

Tata Steel, press release 06.08.2007, retrieved from www.mbendi.co.za/MozBusiness.

TEAL Exploration&Mining, press release 18.04.2008, retrieved from www.mbendi.co.za/company news.

Yager, T. R. 2004. The Mineral Industry of Mozambique, USGS Minerals Yearbook 2004, retrieved from www.usgs.gov/minerals/pubs/country.

Yager, T. R. 2005. The Mineral Industry of Mozambique, USGS Minerals Yearbook 2005, retrieved from www.usgs.gov/minerals/pubs/country.

Yager, T. R. 2006. The Mineral Industry of Mozambique, USGS Minerals Yearbook 2006, retrieved from www.usgs.gov/minerals/pubs/country.