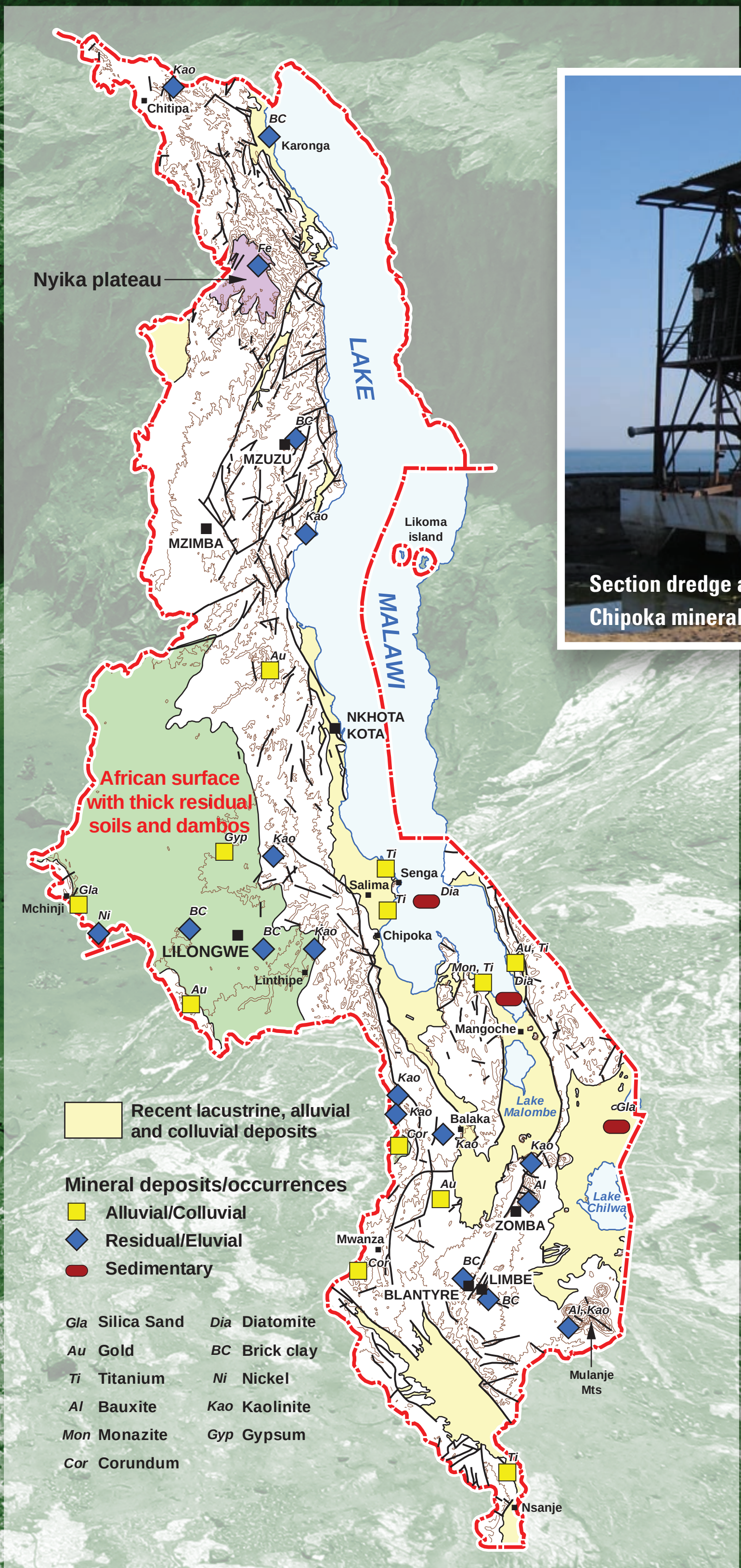
Ministry of Energy and Mines
REPUBLIC OF MALAWI

Mineral potential of Malawi

4 Deposits resulting from residual weathering, placer and rift-related sedimentation. (bauxite, saprolitic nickel, Ti±REE±Zr, gold and gemstone placers, etc.)

Produced for the Ministry of Energy and Mines of Malawi by the British Geological Survey under the auspices of the UK Department for International Development.



Section dredge and floating concentrator: Chipoka mineral sands pilot project, Lake Malawi

Cenozoic deposits

Superficial deposits (residual to eluvial, colluvial, and alluvial to lacustrine) contain important mineral resources in Malawi. They cover large tracts of the Lake Malawi littoral, the Shire Valley and the Lilongwe-Kasungu and Mzimba plains. Residual and placer deposits developed during the Cenozoic as a consequence of complex evolving geomorphic cycles of weathering, erosion and deposition under varying climatic conditions. Residual deposits include bauxites, clays, saprolitic nickel and gemstones. Dambos are a potential source of gypsum, brick clays and silica sand. Heavy mineral alluvial placers with ilmenite, rutile, monazite, zircon, gold and/or gemstones have largely developed along the major rivers and around the lakes of the East African Rift Valley. They are also a potential source of columbite-tantalite, cassiterite, PGM's, etc. Lacustrine deposits in the Malawi Rift include diatomite, phosphate, and unconsolidated marls. The thick sediment fill of the rift is a target for hydrocarbon exploration.

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Landforms

The Malawi uplands (750–1350 m) on the western side of the country represent the African Surface which dominated the scenery at c.30 Ma. This is a composite erosion surface resulting from at least 100 Ma of continental denudation, characterised by low relief and deep regolith profiles that developed by protracted and aggressive weathering and differential leaching. Low lying areas are occupied by dambos or clay-filled bottomlands with sluggish drainage. At the culmination of this prolonged peneplanation episode most elevations on the African Surface probably rose no more than c.200 m above the pediment. Stripping of this surface began in the Miocene with the initiation of the western arm of the East African Rift system. Residual deposits are poorly preserved in the eastern and southern parts of the country due to the greater rift-related uplift and denudation. Alluvial placer deposits, which are an important source for gemstones, precious metals, titanium and rare metal minerals, largely formed during this recent period of rift tectonics.

The **Malawi Rift** comprises a segment of the western branch of the East African Rift System that extends for about 800 km from southern Tanzania to the Shire Valley in southern Malawi. The rift structures extend further south by the Shire trough in Malawi and Urema graben in Mozambique. The Malawi Rift is largely occupied by Lake Malawi at an average elevation of 474 m which overflows southwards into the Shire River and joins the Zambezi. The lake is 570 km long, 50–90 km wide and some 700 m deep i.e. >200 m below sea level. The rift shoulders reach c.1300 metres higher than the rift floor after erosion.

The Malawi Rift is largely non-volcanic but hot springs are located at various places along the western and southern parts of the lake area. The Malawi Rift is at an early stage of development. It began to subside in during the late Miocene and major rifting took place in northern Lake Malawi at 6–5 Ma. The Lake Malawi basin consists of seven linked half-graben units (typically 120 km x 40 km) alternating asymmetrically along a single axis. The seismic reflection profiles show that the thickness of the sedimentary fill in the northern part of the lake is > 2 km and thickens to >4 km near the major border faults. The sedimentary sequences generally thin towards the south and in the Lower Shire valley are of the order of 1.6 km.

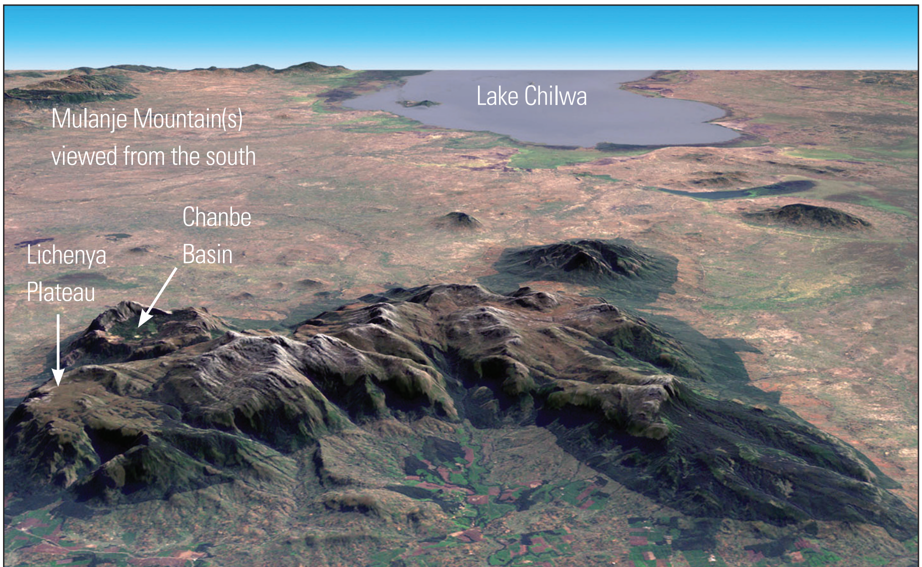
The sediments of Lake Malawi consist of homogeneous diatomites, pelagic diatomaceous oozes, varved diatomite muds, turbidites, littoral sand sheets and extensive deposits of ferro-manganese nodules. Turbidite channels and coarse clastic deposits are found off many of the major rivers and border faults even in water depths of several hundred metres. These are most common in the northern lake basin where large deltas have developed off the Ruhuhu and North and South Rukuru Rivers.

Bauxite

Bauxite comprises variously hydrated aluminium oxides (gibbsite, diaspore, etc) and constitutes the principal ore of aluminium. It forms as a result of intensive surficial weathering on well drained plateaux in regions with wet tropical climates. The process of bauxitisation involves intense leaching of the protolith and/or regolith and dissolution/desilicification of kaolinite. Lateritic (silicate) bauxites comprise >75% of the World's bauxite resources. They can form from various silicate rocks (granite, gneiss, syenite, basalt, shale) but are preferentially derived from lithologies with low silica content, high aluminium content, vitreous textures and high porosities.

Bauxite has developed from the prolonged weathering of syenogranitic rocks that form Mulanje Mountain which rises 600–700 m above the surrounding Phalombe plain. The Mulanje bauxite resource has been known since 1924 and has been explored by the Anglo American Corporation (1934), the British Aluminium Company (1951–58) and Lonrho (1969–72) amongst others. Six extensive bauxite areas have been identified but the best deposits occur on the Lichenya and Linje plateux at an elevation between 1800 and 2000 metres. The bauxite is a trihydrate gibbsite which overlies kaolinite and has goethite and quartz as the main contaminants. An average analysis yields 43.3% Al_2O_3, 13.3% free quartz, 2.2% combined silica, 14.2% Fe_2O_3, 1.8% TiO_2, <5.0% kaolinite and 28.8% LOI. Total reserves on the mountain are estimated to be >50 Mt. Lonrho showed that the two main deposits amount to 28.8 Mt using a cut-off grade of 30% Al_2O_3 with an average depth of 4.5 metres. A feasibility study executed by MET-CHEM Canada Inc.on behalf of MIDCOR in 1993 estimated 25.6 Mt bauxite at a grade of 43.3% and proposed a mining output of 580,000 tpa of bauxite to produce 200,000 tpa alumina for an annual production of 100,000 tonnes of aluminium.

The bauxitic outliers on Mulanje Mountain are associated with remnants of the African Surface



Perspective image using natural colour Landsat 7 band composite 1,2,3 from data acquired on 26/05/02 coupled with elevation data from the Shuttle Radar Topography Mission – SRTM. Released on the NASA Website (Earthobservatory.nasa.gov).

View of Chimimbe hill, from the north-east.

inherited from the Paleogene (70–40 Ma) bauxite-forming event which involved top-down bauxitisation of mature kaolinitic mantles. Bauxite deposits are rare in East Africa which has been influenced by rift-related uplifts. Within the Malawi rift these appear to be preserved at elevations of 1800–2000 m.

Bauxitisation was the dominant process on the planated summit of Zomba mountain (2134 m) which is at a similar altitude to the Mulanje deposits. Bauxite development up to three metres thick occurs beneath a layer of soil one metre thick. The greatest thickness occurs at the border of the plateau. The bauxite is being supplanted by kaolinitisation under current weathering conditions.

Kaolinitic clays

Substantial resources of kaolinitic clays suitable for the production of ceramic wares occur at Linthipe in the Dedza district and at Senzani and Nkhande in Netcheu district. At Linthipe, the clays formed as a result of in situ weathering of a meta-anorthosite body within the Basement Complex. The Linthipe meta-anorthosite, composed of 95% labradorite, forms a negative topographic feature covering 230 km^2.The weathering profile passes upward from bedrock through slightly altered meta-anorthosite to kaolinitic saprock and into a saprolite of plastic kaolin on top and overlain by distinctive thin pale grey savannah soils. Four groups of deposits each containing between 1.0 and 3.5 km^2 of clay 0.7 to 1.7 m thick have been outlined. The total area amounts to 7.6 km^2 with indicated reserves of 15 Mt. The clays, which consist principally of highly-disordered kaolinite with halloysite, have plasticity indices between 20 and 40. The clay could form the basis for production of earthenware, stoneware, aluminosilicate refractories and sand moulds.

Reserves amounting to 0.5 Mt and 0.6 Mt have been delineated also at Senzani and Nkhande respectively.

Lateritic/saprolitic nickel

Lateritic nickel deposits form by prolonged and pervasive weathering of ultramafic rocks in tropical to subtropical climates. They typically develop from serpentinitic rocks that have a significant background level of nickel (c. 0.3%). Being restricted to the weathering mantle they tend to be tabular, flat and areally large and therefore amenable to low cost open pit or strip mining. Lateritic nickel deposits are estimated to comprise 73% of the worldwide continental nickel resources.

Lisungwe Mineral Resources Ltd have identified deposits of nickeliferous saprolite on the Chimwadzulu and Chimimbe ultramafic bodies close to the western border of Malawi with Mozambique and Zambia respectively. Surface pitting indicated that both deposits have estimated non-compliant resources in excess of 3.0 Mt of ore grading better than 0.5% nickel.

Both deposits are still open along strike, down plunge and at depth. Potentially recoverable quantities of ferro-chrome and magnetite are also present.

Chimwadzulu hill is the type locality for Nyala rubies and nickel exploration was suspended upon re-issue of the primary licence to Nyala. Initial exploration work shows Ni grades from 0.3%–1.0% at half metre intervals over a sample depth of two metres. The resource estimate based upon a depth of three metres is equivalent to 12,000 t of metallic nickel recovered at 80%.

Chimimbe Hill rises from an extensive peneplain (African surface) about 80 km east of Lilongwe and is just 12 km from paved highway and railroad access and 6 km from a power line. The Chimimbe Hill surface mineralisation overlies an east-dipping lenticular ultramafic sheet emplaced into

Lisungwe exploration camp and colluvial fan (red soils) on the east side of Chimimbe hill.

Rotary air blast (RAB) drilling to a nominal depth of 20 m using a small mobile tracked rig (hole diameter 12 cm) at the Chimimbe Hill prospect.

Mchinji sandstones of the Muva Supergroup. The ultramafic body dips at about the same angle as the hillslope and mostly comprises peridotite but there is extensive development of talc schist in the SE part of the hill which may be part of the exposed hangingwall. The sheet is cut by NNE-trending faults.

The initial programme of pitting covered an area of 1 x 0.5 km with some pits reaching a depth of 7 metres. Hand-held XRF analyses indicate grades of 0.3% to 1.3% nickel and 0.3% to 2% chrome. The peridotitic bedrock yields 0.2–0.8% Ni. The explored area remains open at both ends and down-dip to the east. The present phase of rotary air blast (RAB) drilling on an 80-metre square grid to a target depth of 20 m to determine the true thickness of saprolite ore grades (typically 10–20 m) has yielded encouraging results including the identification of near-surface enrichment zones. Infill holes initially on a 40 m grid and possibly deeper holes will be drilled where required.

There is an extensive talus apron and colluvial spread on the pediment to the east of the hill which carries not only high Ni-Co but also exploitable ferrochrome. This extends up to 400 metres from the break of slope as two outwash fans.

Early metallurgical test work indicates that 85% of the nickel contained in the non-magnetic fraction of the potential ore can be rapidly extracted using hot sulphuric acid at atmospheric pressure. Potentially economic quantities of ferro-chrome and magnetite may also be recovered with simple magnetic/gravity methods of separation.

The conservative estimate of 3 Mt constitutes in excess of 15,000 tonnes contained nickel. Sulphuric acid will be a significant cost factor and its ready availability may be critical to the viability of this venture.

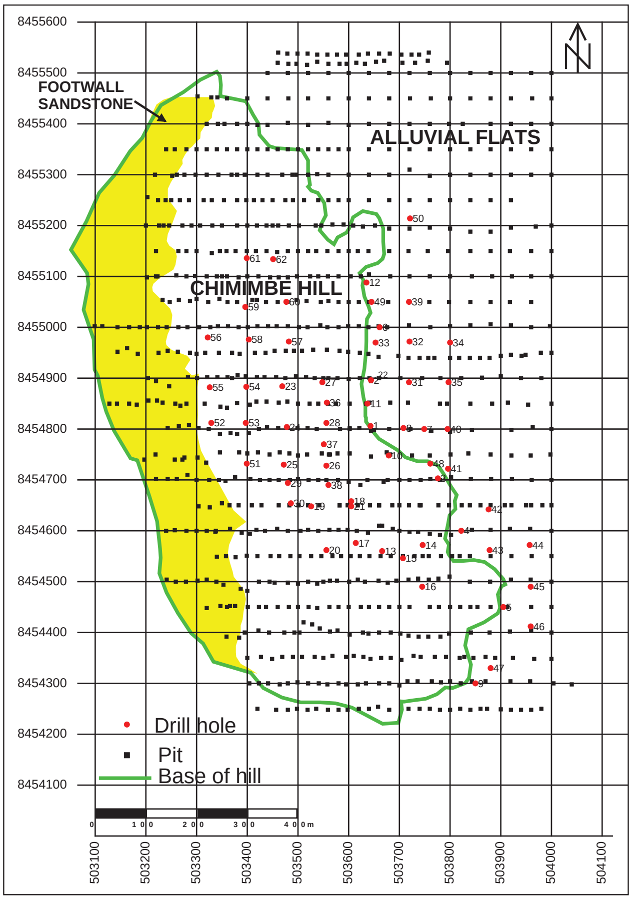
Numerous ultramafic bodies with elevated Ni values occur within the basement complex (see Brochure 2). Exploration for lateritic/saprolitic nickel mineralisation, which depends upon the preservation of deep weathering mantle, should focus on the African planation surface in the west-central part of the country.

Phosphate

Carbonatites and other alkaline igneous rocks commonly contain elevated phosphate concentrations in the form of fluorapatite. Weathering of these igneous rocks leads to natural enrichment in apatite and other resistant minerals (e.g. magnetite, pyrochlore, monazite) mostly by removal of soluble carbonate minerals and gravitational sorting. Deep weathering profiles overlying and derived from apatite-rich carbonatites can produce economic eluvial deposits.
Apatite is an essential raw material that is widely used as a phosphatic fertiliser (either by manufacture of compound phosphate or by direct application) and for the production of phosphoric acid and various other chemicals. According to present practice for apatite to be directly applied to the soil the average P_2O_5 content of the ore should be ⩾16% and the Fe content <5% and it should be free of potential contaminants.

The Kangankunde and Chilwa Island carbonatites, contain only small amounts of primary apatite but the P_2O_5 concentration in residual and eluvial phosphate accumulations range from 1.32 to 8.9% P_2O_5 with an average of 2.5% P_2O_5. Eluvial soils overlying the pyroxenite near Ligowe carry an average of 7.8% chlorapatite, and weathered pyroxenite 1.6 km further south contains 12% apatite. Other eluvial phosphate accumulations are reported from the Chingale metapyroxenite (estimated reserves 8.76 Mt at 3.76% P_2O_5), the Bilira metapyroxenite (mean 1.42% P_2O_5) and the Mlindi ultrapotassic pyroxenite to syenite complex.

At Mlindi, two areas with apatite-rich residual soils were delineated overlying the



Sampling plan of Chimimbe Hill and eastern pediment, showing pitting and drill holes to November 2008 courtesy of Lisungwe Mineral Resources Ltd.

metapyroxenite with estimated probable reserves of 2.4 Mt with grades of 7% to 14% P_2O_5.

Gypsum

Gypsum is a hydrated form of calcium sulphate that can be used in the manufacture of drywall plaster board linings, a plaster ingredient, Plaster-of-Paris for casting moulds, etc., a fertiliser and soil conditioner, in Portland cement, medicines and pharmaceuticals. Calcined gypsum can be used for drinking water defluoridisation in areas of Malawi where dental fluorosis is prevalent. Malawi currently imports most of its gypsum requirements (c. 6000 tpa).

The dambos of Dowa and Lilongwe district contain deposits of crystalline gypsum. The Mdika and Mponela dambos in the Dowa district are estimated to have a combined resource of >500,000 tonnes at a grade of 6–10% gypsum.

Dambos are seasonally flooded channelless shallow valleys that have developed on the African planation surface in the northern and central parts of Malawi. The gypsum accumulates along with magnesium sulphate, calcrete nodules etc. at the margin of the dambo floors during dry season through upward discharge of deep water at the spring line. At the Kasangadzi Dambo, 5 km NW of Mponela the gypsum horizon has an average thickness of 0.9 m and is overlain by 0.5–1.0 m thick sticky black cotton soils (vertisols). At the Livuno Dambo in Dowa West the gypsum clay is 0.5–0.7 m thick with an average grade of 7% amounting to a total estimated reserve of >300,000 tonnes of the +2 mm fraction. Mining of these gypsum resources is generally regarded as difficult due to flooding and the hardness and stickiness of these gypsum bearing soils. The Geological Survey Department undertook detailed assessments of the gypsum deposits in Livuno and Katete dambos and concluded that they could be worked as a small-scale labour-intensive operations.

Silica (industrial) sands

Silica sands contain a high proportion of silica (up to 99% SiO_2) in the form of quartz and, more importantly, low levels of deleterious impurities, particularly clay, iron oxides and refractory minerals, such as chromite. Silica sands are essential raw materials for glass manufacture and a wide range of other industrial and horticultural applications.

Processing plant at Chimwadzulu Mine — soon to be replaced (photo courtesy of Nyala Mines Ltd.).

Glass sand for colourless glass containers generally has an iron content of <0.035% Fe_2O_3, for flat glass in the range 0.060 to 0.1% Fe_2O_3, and for coloured containers 0.2–0.3% Fe_2O_3. Closely-sized grades (generally 0.5-1.0mm) of silica sand are the principal filtration medium used by the water industry.

Substantial deposits of good quality silica sands occur in dambos in the Mchinji area of central Malawi. Recoverable reserves in six dambos amount to 1.6 Mt with 96–99% (average 97%) SiO_2 and 0.12–0.2% iron oxide. The Lake Chilwa — Chiuta sand bar is estimated to contain 25 Mt of glass sands averaging 92.7% SiO_2 and 0.62% iron and are suitable for the manufacture of brown (amber) quality glass containers.

Further beneficiation would improve the quality of the sand to make it suitable for manufacture of plate and window glass and reasonably clear glass containers.

Placer deposits

At Chimwadzulu Hill in the Kirk Range (gem-quality corundum), Thambani, Mwanza (opaque corundum and zircon), Makoko, Nsanje (industrial corundum) and at Kapiridimba (kyanite and rutile) heavy minerals have accumulated in the weathering mantle and include residual, colluvial and eluvial deposits.

The Chimwadzulu Hill deposit is essentially an eluvial gemstone deposit yielding both rubies and sapphires that has developed over a meta-(ultra)basic complex from which they are ultimately derived (see brochure 2). The Ministry of Mines, Natural Resources and Environment (2004) recorded a grade of 75.6g/m^3 for the Chimwadzulu Hill gemstone deposit. The ruby resource was estimated to be 247 kg (Yager, 2001). The regolith which is commonly 2–4 metres thick (max. 20 m) includes a basal clayey saprolite. The distribution of the gemstones is highly localised. Current throughput is 20–25m^3 per day with a production of about 300 gm of gem quality rough stones per month. The rubies account for approximately one third of the gems and range from pink to red to orange to the rare pinkish orange known as padparadscha sapphire. Single crystals up to 40 carats have been recorded. Unlike most other ruby deposits of its type the colour is completely natural and they are marketed under the name of 'Nyala rubies™' through the Columbia Gem House. The sapphires need heat treatment. The deposit is currently worked by Nyala Mines Ltd. who are installing a new plant with a 300–400 m^3 per day capacity and are planning exploit the deposit by systematic contour terracing of the hill to bedrock. This should increase production to $\geqslant$ 3.5 kg/month including 2 kg of pink to red ruby.

The **Thambani** eluvial corundum and zircon deposit, 60 km WNW of Blantyre, is derived from pegmatites that intrude nepheline syenite gneisses over an area of c.260 km^2 of the Precambrian basement. The deposit was worked intermittently between 1923 and 1952 and produced over 1745 tonnes of abrasive quality corundum. The opaque corundum from Thambani graded A1 on alumina content. Known reserves amount to over 100,000 tonnes with good prospects for extending the available resource to over 500,000 mt. There is obvious potential for discovering gem quality material.

Alluvial Gold ± PGM

Alluvial gold has been reported in the Lisungwe river system in the Kirk Range area, the Dwangwa river and its tributaries straddling the districts of Nkhotakota and Nkhata Bay in central Malawi and in the areas of Nathenje and Mwanza.

The Lisungwe River and some of its affluents draining the Manondo gold district contained some of the richest alluvial gold concentrations and have been worked intermittently. The Likudzi River, a tributary of the Lisungwe draining an area of faulted ultramafic sheets additionally carries PGM minerals (e.g. ferroplatinum). The Lisungwe and Likudzi yielded coarse angular gold indicating a proximal source.

The alluvial gold potential is limited but its occurrence is a useful indicator of bedrock sources.

In the Nathenje area alluvial gold is spatially related to outcrops of calcsilicate granulites or skarns. The main sources of the gold, however, appear to be shear zone-hosted concordant quartz stringers in the paragneisses and pyritised veins in carbonatised schists. Gold occurrences have been documented for the Malindi-Makanjira area in the Mangochi district also but attempts to trace the gold so far have been inconclusive.

Heavy Mineral Sands

Malawi hosts at least two billion tonnes of mineable heavy mineral sands around the shore of Lake Malawi and along the Shire River. Heavy mineral sand deposits comprise high density minerals (SG $\geqslant 4.2$) that occur as disseminated, lenticular or layered concentrations within the sands and most commonly include Ti minerals, gold, cassiterite, zircon, monazite and garnet. By far the most important resource in Malawi is the Ti mineral sand deposits. The high strength-to-weight ratio, corrosion resistance, bio-compatibility and non-toxic characteristics make titanium ideal for strategic and critical applications in the aerospace, military and medical fields. Ti oxide is the main component of white pigments in paints, paper and plastics.

Three heavy mineral sands deposits have been investigated. They include the colluvial deposits at Tengani in Nsanje district, the beach sands in the lakeshore districts of Salima, Nkhotakota and Mangochi and the sand bar at Lake Chilwa in the Zomba district.

In the Tengani area at the foot of the east-dipping Mulaka Hills the reserves of colluvial heavy mineral sands and gravels are estimated at 108 Mt with a heavy mineral content ranging from 3.5 to 35% averaging 0.34% rutile and 1–14% ilmenite. Other estimates put the rutile: ilmenite ratio in the heavy mineral fractions in the range 1:12 to 1:4. An assessment by the Geological Survey Dept. in 1997 indicated 2.5 Mt of heavy mineral sands grading at 3% ilmenite and 0.3 Mt containing 0.3% rutile. Elevated contents of Ti minerals mainly occur on the interfluves between the Nkande and Namyala rivers.

The Mpyupyu Hill colluvial heavy mineral sands contain over 11.9 Mt grading at 3.8% ilmenite and 0.01% rutile (MMNRE, 2004). These heavy mineral sands spread across the Lake Chilwa flooplain on which the eastern foothills of the Zomba plateau level off. Between Mpyupyu Hill and the present-day shoreline of Lake Chilwa, two separate sand bodies have been delineated that total of about 15 Mt with an average grade of 6.93% ilmenite, 0.38% zircon, 0.02wt% rutile, 0.04% leucoxene and 0.06% garnet (Dill, 2007).

The reserves of beach sands around Chipoka/ Salima along the western shore of Lake Malawi are estimated to be 700 Mt with an average grade of 5.6% total heavy minerals. The sands contain ilmenite, rutile, monazite, garnet and minor zircon. Other minerals present include amphibole, ortho- and clinopyroxenes, magnetite, titanite, apatite, orthite, epidote and chromite. The exploitable bed is up to five metres thick. Allied Procurement Agency and Mineral Sands Ltd. of South Africa conducted a pilot suction dredging and processing operation along the shoreline to the north of Chipoka in 2006 with the intention of starting large scale exploitation of zircon and rutile. Contained resources of zircon and rutile at Chipoka Bay amount to 6.7 Mt and 3.6 Mt respectively.

In the Mangochi district large resources of heavy mineral sands occur at Makanjila on the southeastern lake shore of Lake Malawi. Sand dunes extend 6 km inland along a 20 km shoreline and up to 100 metres above the current water level of the lake. Reserves are estimated at 800 Mt grading at an average of 13.0% total heavy minerals with ilmenite (5.2%) being the dominant economic commodity.

Millenium Mining Ltd. of Australia have considered the development of the Makanjila and Salima Bay mineral sands deposits with a view to producing 500,000 tpa of ilmenite which would have been smelted at Chipoka. A co-product would be high quality pig iron.

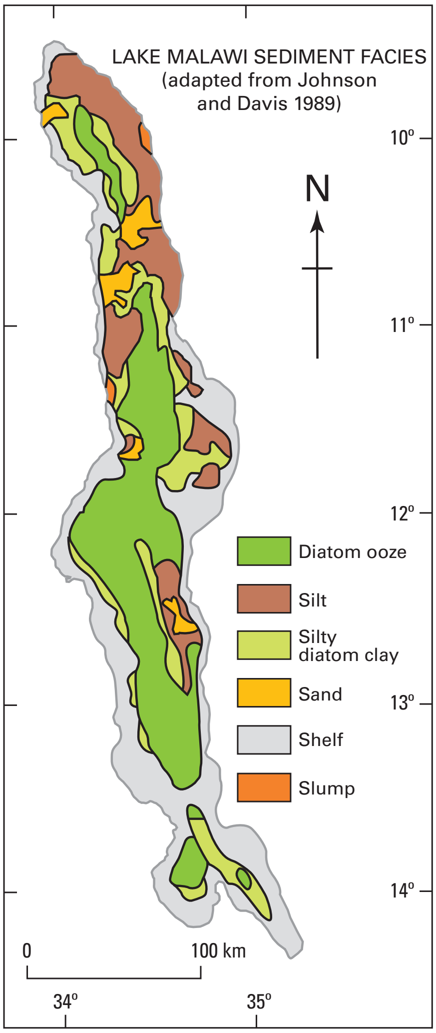
Exposed heavy mineral sand layers at the shoreline north of Chipoka.

Development of the smelter with a planned capacity of 250,000 t/yr titanium slag would be dependent upon obtaining power supplies from Mozambique.

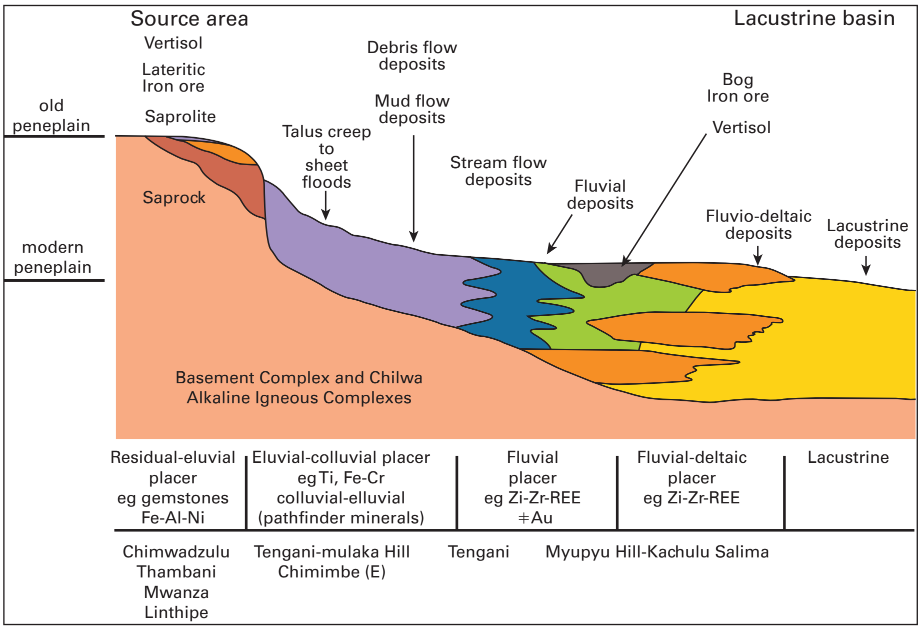
Lacustrine sediments

Diatomite is an amorphous biogenic silica comprising porous siliceous skeletal remains of diatoms. It is very light weight, chemically inert, abrasive and highly absorbent. Diatomite is used as a filtration aid (drinks, medicine, petrol, chemicals, dyes, swimming pools, etc.), heat insulation material, a functional filler (rubber, paper, cosmetics, toothpaste, chinaware products, etc), a chemical carrier (catalysts, activators, pesticides and fertilisers) and a bonding agent. It has many environmental applications as a dessicant, for oil absorption and waste water treatment.

Diatomites and diatomaceous clays occupy the shallowest, highly productive settings



Distribution of diatomite and diatomaceous clays in the Lake Malawi sediments.



Schematic cross-section (modified after Dill & Ludwig (2008)).

of southern Lake Malawi. The uppermost Songwe unit (max thickness 115 m) comprises a white laminated varved sequence with sporadic beds of homogeneous diatomaceous mud. The couplets of light (100% diatoms) –dark (50% diatoms) laminae are seasonal phytoplankton blooms with an overall sedimentation rate of 1mm /yr. No resource estimates are available.

Iron±manganese deposits

Extensive fields of ferromanganese nodules up to 50 cm thick and comprising up to 95 wt% of the sediment occur off the Nkhotakota shoreline and on the slopes of tilt-block structures at Mbenje and Likoma Islands. The nodules are typically 1–8 mm diameter and range from relatively pure ferric nodules (<2% Mn) to spheroids containing >60% Mn. These fields occur at the present sediment/water interface and are largely confined to water depths of 80–160 m i.e. above the anoxic-oxic boundary at 200–250 metres depth. Known regions with high concentrations of ferromanganese nodules always occur at the boundary between littoral sands and detrital muds. Sporadically high Ag and Au values reported for nodules from Likoma and Mbenje are significant in terms of economic potential.

Nodular iron-rich deposits overlie diatomite or coarse grained clastic sediments in the southernmost part of the lake but these are predominantly of the nontronite and limonite-opal facies. Nontronite nodules are most common near diatomite deposits and in proximity to geothermal sources. There are several distinct nodules horizons with limonite-opal types toward the base and ferro-manganese types near the top. Vivianite (iron phosphate) nodules and crusts are also present. The various iron-rich sediment layers range in thickness from 13 cm to >80 cm and are separated by siliciclastic muds and silts.

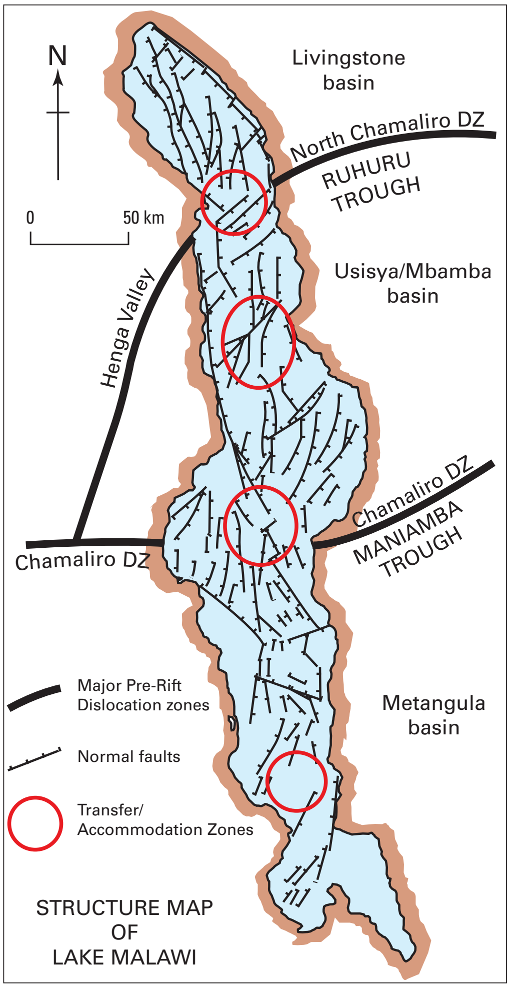
The Lake Malawi type of iron enrichment is an example of a precursory to mature phase of precipitation of metalliferous muds of Red Sea-type deposits.

Calcareous/marly sediments

Very large quantities of unconsolidated marls with 20–45% CaO and <2% MgO occur in parts of the bed of Lake Malombe in the Mangochi district that could be used for the production of natural cement and hydraulic lime. These calcareous sediments are highly variable in terms of carbonate content which tends to increase with distance from the shoreline and decrease with increasing depth below surface giving way to sands at depths of 3 to 4.5 m.

Hydrocarbon potential

75% of Africa's petroleum has been generated during the past 30 Ma and 50% of it lies in reservoirs of Eocene to Holocene age. Rift basins are well known as prolific hydrocarbon-bearing provinces worldwide.



Adapted from Schalz and Scott (1989), Project PROBE.

Tectonically-derived topography is the prime control on both sedimentary processes and facies distribution of hydrocarbon source rocks, reservoirs and seals in syn-rift successions. Reservoirs are abundant throughout continental syn-rift successions but good seals tend to be uncommon. Potential reservoirs and seals can be identified by integrating sequence stratigraphic concepts with the predicted spatial facies distribution although this can be difficult to interpret in non-marine systems because of rapid lake level changes.

Previous exploration projects in the Lake Malawi basin have demonstrated the existence of thick sedimentary rock sequences and structures that could trap hydrocarbons beneath the northern part of Lake Malawi and in the Lower Shire valley. In the northern part of Lake Malawi, where the sedimentary sequences reach their greatest thickness (>2.5 km), shallow cores from the lake bottom indicate organic-rich sediments are being deposited under highly anoxic conditions. Potential reservoir rock in the form of deltaic sandstones is being deposited locally along the lake margins and extend into the lake. Project PROBE (1985–87) revealed four sedimentary sequences in the lake stratigraphy and further indicated potential for hydrocarbons in the shallow waters in the central parts of the lake, especially around the lakeshore districts of Nkhotakota and Salima.

A key factor in evaluating prospectivity is determining the presence or absence of mature source rocks. Thick sequences of the Lake Nyasa Group extend as far south as 13°15'S but at present geological evidence is lacking that thermal maturity has been reached. Sequences of Karoo sediments intersect the lake axis at two locations. Therefore the possibility also exists for source/reservoir rocks of Karoo age succeeded by post-Karoo Mesozoic reservoir rocks capped by the Miocene to Recent lake sediments.

Despite the overall stratigraphic similarity between half-grabens in the rift system each sub-basin is filled independently so that details of lithostratigraphy vary. Therefore, the source rock potential of the rift system can only be identified after each half-graben is drilled.

Helium

Natural gas resources in Lake Kivu, one of the great lakes on the western arm of the East African Rift lying on the border between the Democratic Republic of the Congo and Rwanda, contain 5–10% helium. Gas-rich waters with an estimated reserve of 50 billion m^3 occur at a depth of $\geqslant$300 metres. By analogy, Lake Malawi, one of the deepest lakes on the rift system could be a source of helium-rich natural gas also. The northern end of the lake is considered particularly favourable for helium accumulation and retention. See also brochure 3.

Brochures in the series on the Mineral Potential of Malawi

1. Mineral deposits associated with alkaline magmatism.
2. Mineral deposits associated with the Basement metamorphic and igneous rocks.
3. Mineral deposits associated with sedimentary and volcanic cover rocks: Karoo and post-Karoo.
4. Deposits resulting from residual weathering, placer and rift-related sedimentation.

Sources

Geological Surveys Department bulletins, memoirs and reports.
Mining Journal Annual Reviews.
US Geol. Survey Minerals Yearbook.
Minex Company annual reports and release updates on the Worldwide Web.
Dill, H.G., 2007. Journal of African Earth Sciences 47, 153-173.
Dill, H.G. & Ludwig, R.-R., 2008. Ore Geology Reviews 33, 411-434.
Report by Mintek and its contractors 2002.
Lisungwe PLC (pers comm).
Nyala Mines Ltd. (pers comm).

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