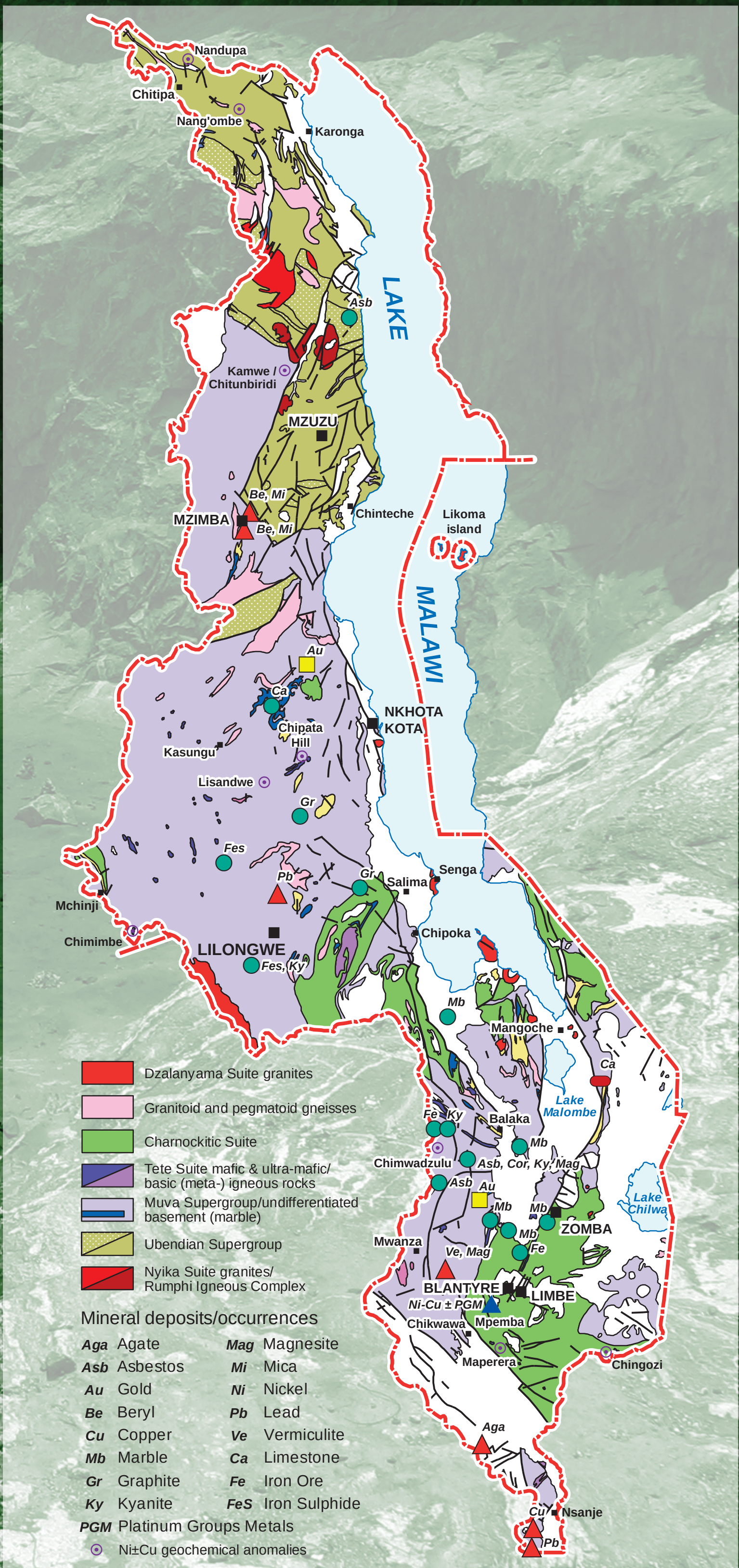
Ministry of Energy and Mines
REPUBLIC OF MALAWI

Mineral potential of Malawi

2 Mineral deposits associated with the Basement metamorphic and igneous rocks (precious and base metals, gemstones and industrial minerals)



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.

Manondo gold prospect

The geology of Malawi comprises an early Precambrian to early Paleozoic Basement Complex, an overlying sequence of Permo-Carboniferous to Lower Jurassic sedimentary rocks of the Karoo Supergroup and superficial Tertiary to Recent post-Karoo sediments.

The Malawi Basement Complex, which occupies 85% of the land area, is mainly composed of paragneisses, granulites and felsic to ultramafic (meta-) igneous intrusive rocks.

Known deposits include gold, nickel, copper, graphite, limestone/marble, iron sulphide, kyanite, gem corundum/ruby and pegmatite-hosted precious and semiprecious gemstones.

January 2009

Geological context

Malawi lies at the junction of the Ubendian (c.2300–1800 Ma), the Irumide (c.1350–950 Ma) and the Pan African or Mozambiquan (c.900–450 Ma) mobile belts. The Ubendian and Irumide orogenies were restricted to the northern and central parts of the country. The Ubendian Supergroup is distinguished to the north of the Chimaliro Dislocation Zone on the southern edge of Champhira dome and comprises the Misuku gneisses and Jembia River granulites. The Misuku gneisses are divided along the Mugeshe shear zone into the Songwe micaceous and amphibole gneisses with amphibolites in the north and the Chambo micaceous pelitic/semipelitic biotite paragneisses and quartzites to the south. The Jembia River granulites are sillimanite-cordierite gneisses. Ubendian amphibolitic to granulite facies metamorphism and magmatism took place between 2000 and 1800 Ma with the emplacement of the Rumphi Igneous Complex and Nyika Suite granites.

The Muva Supergroup, which dates from c.1850 Ma, is a supracrustal association that overlies the Ubendian Supergroup and Nyika granites and forms much of the basement in south-central Malawi. It is characterised by pelitic to semipelitic rocks dominated by hornblende-biotite paragneisses with units of marbles, calcsilicate gneisses, quartzites and mica schists. The Mafingi Group in the north and Mchinji Group in the south are c.1400 Ma second-cycle siliciclastic metasediments. Both supergroups were deformed and metamorphosed during the Irumide orogeny at c.1100 Ma followed by the emplacement of calc-alkaline granitoids (1.05–0.95 Ma).

The entire basement was affected by the polycyclic Neoproterozoic Mozambiquan orogeny which is evident as a regional overprint on the basement. In the southern half of the country Pan African magmatism and high grade metamorphism resulted in large areas of banded pyroxene granulites, charnockitic orthogneisses, perthitic complexes and minor basic and ultrabasic intrusions. The upper crustal Mafingi and Mchinji group rocks, however, underwent only low grade (greenschist) metamorphism.

Nickel — Copper — Platinum Group Metals (PGM)

The principal sources of nickel are magmatic sulphide deposits associated with mafic-ultramafic rocks which can occur in a variety of tectonic settings (e.g. ophiolite complexes, synorogenic Alaskan-type complexes, alkaline complexes with carbonatites). Ni–Cu–PGM mineralisation can also occur in hydrothermal veins and in unconformity-related settings with gold and uranium. The most important deposits, however, are orthomagmatic in origin occurring in layered mafic-ultramafic intrusions primarily as stratiform bodies.

There are 85 known mafic/ultramafic (or ultrabasic) bodies of significant size with possible nickel-copper mineralisation in the Basement Complex in Malawi. These bodies include serpentinised peridotites, pyroxenites and metapyroxenites, biotitites, olivine gabbros, gabbros, norites, anorthosites and amphibolites. Some could be parts of layered intrusions.

Several bodies have been investigated by Minex companies and the Geological Survey but economic Ni–Cu deposits have yet to be identified.

The **Ubendian Belt grouping** in the Chitipa-Karonga area of northern Malawi comprise 17 mafic-ultramafic bodies emplaced synkinematically into the host c.2Ga gneisses. The **Mzuzu grouping** includes four pyroxenitic bodies and four noritic bodies. The pyroxenite bodies are undeformed and unmetamorphosed and are considered to be later than the Mozambiquan orogeny. The **Central Region grouping** comprises variably differentiated bodies of metagabbro, amphibolite and serpentinite. The **Kirk Range grouping** consists essentially of serpentinised peridotite and metapyroxenite bodies most of which have an outer envelope of amphibolite. The **Shire Highlands grouping** mostly comprise metapyroxenite bodies emplaced as sills in granulite and amphibolite facies gneisses, e.g. Mpemba, Chingozi and Maperera.

From geochemical surveys the following bodies show some potential:

(a) Nandupa, Nang'ombe, Usale Hill, Kaulasisi, Kamwe and Chitumbiridi in the northern region. At Nandupa values of ≤2000 ppm Ni and ≤1000 ppm Cu were recorded over serpentinite and at Nang'ombe values of ≤1000 ppm each for Ni and Cu whilst at Kaulasisi a zone about 220 x 100 m was identified with values of 500–700 ppm Ni and 1300–2500 ppm Cu over pyroxenite.

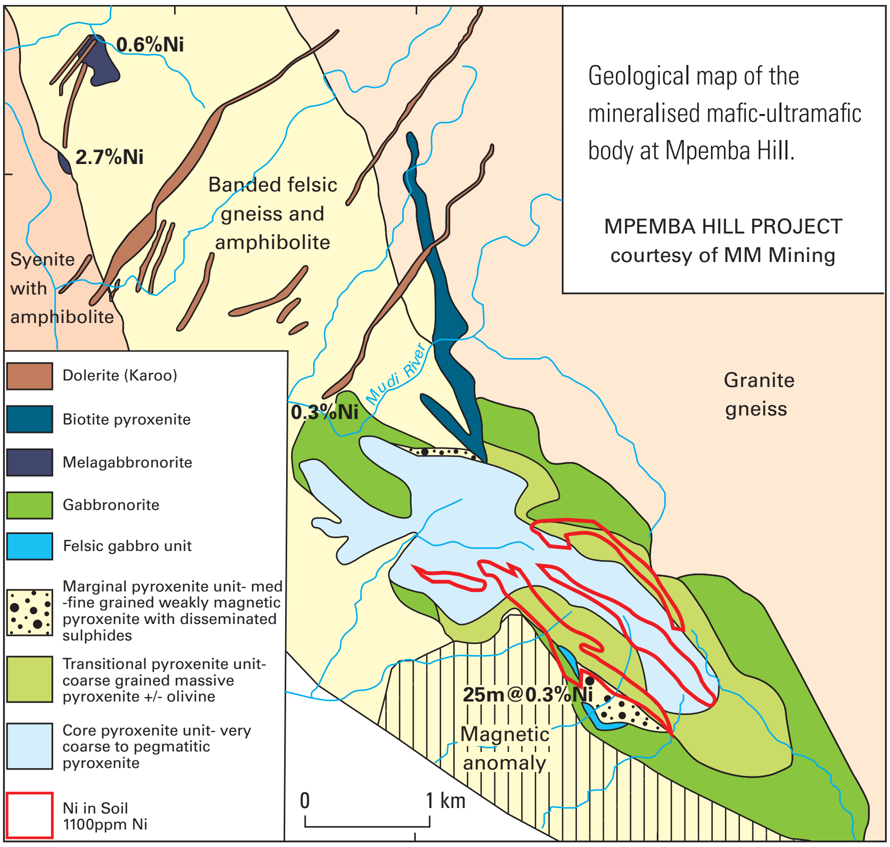
(b) Chimimbe Hill, Lisandwa and Chipata Hill in the central region. Values of 2000–4000 ppm (max 9000 ppm) Ni have been recorded whilst Cu values are ≤215 ppm. Drilling undertaken on an EM anomaly at Lisandwa showed no correspondence with the geochemical anomaly. Smaller Ni anomalies occur at Chipata Hill, Chamsani and Kaombe Stream. Chipata Hill registered soil Ni values of ≤1750 ppm against a background of 200 ppm over a gabbro.

(c) Mpemba, Maperera, Chimwadzulu and Likudzi in the southern region. The Mpemba Hill ultrabasic body registered values up to 6000 ppm Ni in the residual soil. At Likudzi an area of serpentinite measuring c.900 x 200 m yielded values of 2000 ppm (max. 7000 ppm) Ni and 300–500 ppm Cu . Anomalous PGM values of up to 420 ppb Pd and 104 ppb Pt also have been reported by Lisungwe PLC over a strike length of >1 km. At Maperera and Chingozi there are strong coincident Cu-Ni anomalies over pyroxenite. At Chingozi the Cu-Ni and geophysical anomalies are coincident.

At Chimwadzulu and Chimimbe Hill where there are no sulphides and no correlation with the mapped rock types with high nickel values the anomalies are largely attributed to supergene enrichment (see brochure 4). Chromite and Cr magnetite occur in the overburden on Chimwadzulu and Chimimbe hill ultramafic bodies. Chimwadzulu is also characterised by a linear PGM anomaly that closely parallels the base of the intrusion. This suggests that the primary nickeliferous mineralisation is associated with cumulate PGM-enriched chromitite layers.

The **Mpemba Hill Prospect** is located 20 km to the SW of Blantyre in southern Malawi is currently being investigated by MM Mining Pty Ltd. (75%) in partnership with Albidon Ltd.

It comprises a series of pyroxenitic to gabbroic intrusive rocks that contain disseminations and clots of nickel sulphides at many localities plus a Ni and Cu soil geochemical anomaly that extends over an area greater than 3km². There are historical reports of rock samples yielding assay results of up to 2.9% Ni and 2.7g/t PGM, along strike to the northwest of the main intrusion.



Geological map of the mineralised mafic-ultramafic body at Mpemba Hill.

MPEMBA HILL PROJECT
courtesy of MM Mining

Recent geological mapping of Mpemba Hill has defined a more or less concentric structure concordant with the host rocks (strike 130° and dip at 40° to the SW) that comprises a central core of coarse to very coarse pyroxenites, surrounded by an inner margin of sulphide-mineralised medium to coarse feldspathic pyroxenites and an outer margin of medium-grained pyroxenite to locally melanocratic gabbros and gabbronorites. The mafic-ultramafic body occurs within mafic to felsic pyroxene granulites and banded hornblendic gneisses with amphibolites. The granulitic basement also contains mafic rocks of probable volcanic origin.

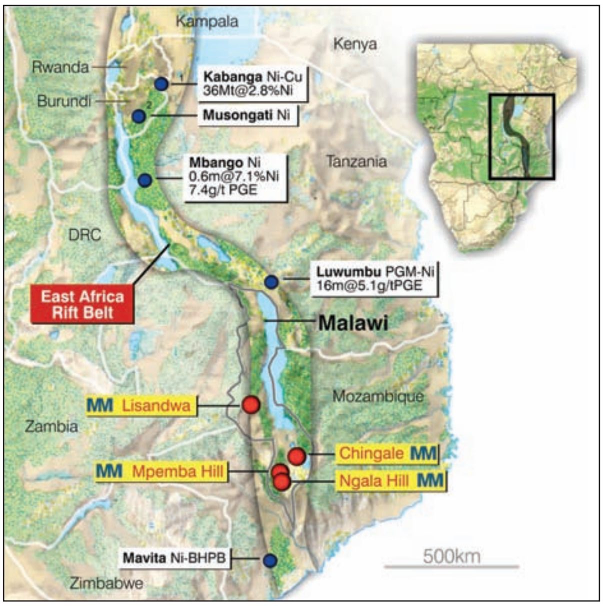
The ultramafic body is dominantly websteritic with slightly more diopside (47%) than hypersthene (41%) together with minor interstitial plagioclase, hornblende and biotite. Olivine is locally present and is coincident with rock values of >1500 ppm Cr. The sulphides are scattered in apparently haphazard patches throughout the whole intrusion as pyrite, nickeliferous pyrrhotite and subordinate chalcopyrite where they typically form 0.5–1% of the rock. The greatest visible concentration of Ni–Cu sulphides (c.5%) occurs in the Nseche sector in the northwest suggesting that this might be the locus of a feeder at depth. This is comparable with the Mudi River feeder zone where a 100 m wide zone with c.10% pyrrhotite-pentlandite had been previously reported. The sulphides have ratios of po:pn:cp of about 79:9:12, typical of moderate tenor magmatic sulphide mineralisation derived from gabbroic rather than picritic or ultramafic magma.The sulphides appear to be orthomagmatic rather than hydrothermal in origin.

Ni values from trenches typically averaged 0.2% Ni (maximum of 0.32% Ni) and Cu contents in the region of 0.1%. Pt and Pd levels in soils and mineralised rocks were low and dispel earlier ideas of Platreef-style marginal PGE mineralisation at Mpemba. There has been some surficial upgrading of Ni and Cu values although none of the rocks currently exposed at surface exhibit strong lateritic weathering as at Chimwadzulu and Chimimbe.

Sulphide-mineralised gabbronorite from the Mudi River (courtesy of MM Mining).

Assay results of 18 reconnaissance drill holes completed to test an extensive soil geochemical anomaly at Mpemba Hill confirm the presence of widespread mineralisation but this is limited to very low grades (values seldom higher than 0.3% Ni and 0.2% Cu: max. 0.64% Ni). The focus of exploration has now shifted towards the north-western sector which differs from Mpemba Hill, in that small high-grade massive Ni-Cu±PGM sulphide bodies associated with small tubular to dyke-like magma conduits within the country rocks are more likely to occur.

The **Ngala Hill Copper prospect** was first investigated by Phelps Dodge and Placer and the licence was granted to MM Mining in December 2007. Ngala Hill ultramafic body consists of metapyroxenite, pyroxene amphibolite and hornblendite with a small zone of malachite mineralisation. The



Courtesy of MM Mining.

East African Rift Nickel Belt after MM Mining.

ultramafic body (2.5 x 0.35 km) is emplaced into NW–SE striking pyroxene- and hornblende-bearing foliated gneisses of the basement complex. A Cu-mineralised zone is c.15 m wide and 60 m long and contains about 2% malachite as coatings on cleavage planes and interstitial sites. Geochemical soil sampling showed separate discrete areas of high Cu (>300 ppm), Ni (>400 ppm), Cr (>800 ppm) and Co (>150 ppm). In some parts there is considerable overlap of the Cu and Ni anomalies but, whereas the Ni, Cr and Co values are close to local background, the Cu values are anomalously high. Values of $\geqslant$2000ppm Cu occupy an area of 100 m x 50 m, the long axis being NW–SE.

The area includes the zone of malachite staining. Values of >500 ppm Cu offer a much larger target. Trenches have registered 64 m @ 0.14% Cu and 1.4 g/t PGM and 12 m @ 3 g/t with a maximum of 0.75% Cu and 3.8 g/t PGM. The results of a drill programme conducted in October 2008 are pending.

The importance of relatively small intrusions as parts of larger magmatic systems should not be underestimated e.g. Voisey Bay and Noril'sk-Talnakh. Their role as conduits for large volumes of magma provides sites for sulphide accumulation. In virtually all these magmatic bodies the sulphide ores are most likely to be found at the base. In large layered mafic-ultramafic intrusions, however, exploration for PGM deposits should be focussed in the vicinity of the main mafic – ultramafic contact. Identification of structural traps and determination of the geometry/morphology of individual intrusions is critical for evaluating the mineralisation potential of magmatic systems.

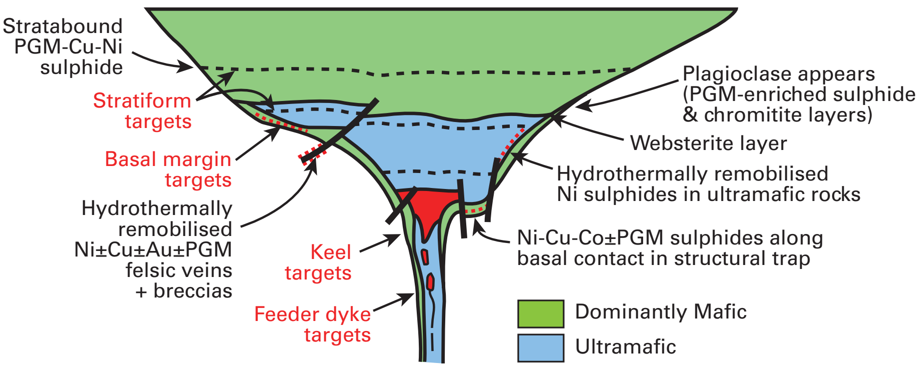
MM Mining note that a number of significant Ni±Cu±PGM prospects, including the Kabanga deposit within the 1.8-1.4Ga Kibaran belt, lie along a broad zone that approximately coincides with the western branch of the East African Rift Belt. This has been a zone of crustal weakness associated with known or inferred suture(s) since the late Mesoproterozoic and has been the locus for recurrent alkaline magmatism during the Pan-African and Early Cretaceous (see brochure 1). It implies that most of the potentially economic mafic-ultramafic intrusions were emplaced during the Neoproterozoic assembly of the East African Orogen.

Gold

Gold has been previously worked in the Kirk Range-Lisungwe valley area in southern Malawi and has been reported in the Dwangwa and Malindi-Makanjira areas. The Kirk Range-Lisungwe valley has been subject to various investigations by the Geological Survey Department (1934–35; 1958–62; 1992–93) and, after re-examination of the UNDP airborne magnetic and radiometric data acquired in 1984–85, is currently drilling some target areas in the Manondo area following a detailed geological and geochemical survey. The gold is mainly hosted in decimetre-scale quartz±pyrite lodes and stringer zones up to 1–2 metres thick and enhanced residual concentrations occur in the overlying regolith. The main workings date from the 1930s and include Breeze's, Palula Mine and Peterkin's vein. An inclined shaft sunk to 27 metres depth on a gold mineralised structure at Palula Mine yielded channel sample values of 0.6-11.8g/t (av. 2.7g/t) over a 1.2 metre width. The geochemical survey indicated that the mineralised zone extends NE–SW and appears to be part of the same system as mined at Breeze's, 1.5 km to the southwest. The gold is structurally controlled and is now recognised as being associated with the Manondo-Choma thrust. Residual gold contents of 12–42 g/t have been reported in the regolith above the bedrock mineralisation and averages at 2.6 gt/t over a workable area.

The northeast-trending gold-bearing Manondo-Choma thrust is 13 km long and dips SE. Pelitic gneisses with calcsilicate-rock and marble units and with historical gold workings occur in the hangingwall rocks and pelitic gneisses with metabasic gneisses and amphibolites in the footwall. Old gold workings, Manondo or Breeze's are located at the southwest end of this zone.

A report by ERA-Maptec Ltd. (2000). who carried out a satellite image interpretation and integrated this with other remote sensing (gravity, aeromagnetic, airborne radiometric and em) and map data indicates gold anomalies and old workings occur in an arcuate belt 40 km long and 5 km wide surrounding the Lisungwe Anatectic Complex. The anomalies correlate with the Chongwe



Conceptual model of the localisation of Ni±Cu± PGE sulphides within a mafic-ultramafic intrusion (modified after Hoatson, 2005).

Schist and its radiometrically interpreted equivalents on the southeast side of the complex. ERA suggested four genetic models for gold deposits in the area:

1. Disseminated deposits associated with graphitic schists
2. Hydrothermal vein, breccia, skarn or replacement deposits with copper associated with intermediate composition granitoids
3. Granodiorite-granite related deposits perhaps related to Mesozoic intrusives
4. Epithermal veins associated with rift faulting and hydrothermal activity

Adit entrance at the Breezes gold mine, Manondo district.

The dominant target for gold exploration in the Basement Complex are considered to be intrusion-related gold systems (IRGS) which encompass a wide range of geological features and are characterised by a range of deposits as typified by hydrothermal vein, breccia, skarn and replacement mineralisation styles.

Key geological features of IRGS deposits include:

- Spatial and/or temporal relationships with I-type intermediate to felsic intrusions
- Metal or deposit zoning centred on a mineralising intrusion
- Low sulphide mineral assemblage typified by arsenopyrite, pyrrhotite and pyrite
- Metal association with Bi, Te, W, Mo, As, Sb, etc.
- Restricted zones of hydrothermal alteration

Corundum (ruby and sapphire)

The Chimwadzulu Hill and Likudzi ultramafic bodies in the Kirk Range district to the south of Ntcheu in southern Malawi have both yielded gem quality ruby corundum. At Likudzi, small pieces of dark red corundum occur in amphibolitic zones within the serpentinite body.

Chimwadzulu Hill is a rootless alpine-type meta(ultra)basic complex emplaced in basement hornblende and biotite paragneisses that strike NW-SE. It comprises variably serpentinised harzburgites, metapyroxenites amphibolites and amphibole schists. A band of locally talcose tremolite-nephrite±actinolite rock borders the southern margin of the hill. To the east this breaks up into many small masses and lenses. This rock type has formed by metasomatism of the hornblende amphibolites. Chlorite-talc rocks have developed as a result of hydrothermal alteration of the serpentinised peridotite via amphibolite. Smectite clays and aggregates of vermiculite occur near surface and were probably derived in part by supergene alteration. Primary corundum mineralisation is associated with zoisite-rich amphibolite.

Historically the Chimwadzulu Hill production consists of approximately 30% ruby, 30% orange and padparadscha, 25% pink and 15% purple and lavender sapphire colour, largely due to an extraordinary variation in Cr and Fe contents. Colourless corundum or leuco-sapphire is also present. The most highly prized are the slightly purplish or pigeon's blood red rubies. Rubies of >3 carats are discovered monthly with individual stones up to 7 carats occasionally being recovered. The mine has produced rubies from the regolith for nearly 20 years (see brochure 4). It is currently operated by Nyala Mines Ltd. which is planning to expand production tenfold within the next year.

Typically rubies, sapphires and industrial grade corundum associated with mafic/ultramafic rocks and their metamorphic equivalents either occur within or adjacent to albitite and alkali feldspar or mica pegmatite dykes or plugs or along contacts with peraluminous and other felsic country rocks. They are essentially contact metamorphic to metasomatic deposits. Industrial grade corundum is commonly contemporaneous with the metamorphism whereas gem quality corundum usually post dates the peak tectonism and metamorphism. Pockets of corundum may also be present along tectonic contacts between gneiss and serpentinite. Metasomatic zones cross-cutting ultramafic rocks at Chimwadzulu Hill are characterised by vermiculite and chlorite development.

Desilication of felsic dykes is the dominant process in fracture-controlled mineralisation whereas in contact metamorphic metasomatic settings rocks with high alumina saturation will favour corundum formation. Where felsic rocks are thrust against ultramafic rocks reaction zones may form during regional metamorphism. Any silica undersaturated rocks characterised by high alumina/total alkali ratios within or adjacent to a mafic/ultramafic body should be considered prospective for corundum. Some vermiculite occurrences also may be worth examination for gemstones. Thus the ultramafic/glimmerite bodies in the Feremu area may have potential.

Some primary gemstone and industrial grade corundum deposits that are uneconomic may form viable residual or placer deposits with prolonged weathering (see brochure 4).

Pegmatite minerals

A wide range of precious and semiprecious stones are found in the districts of Nsanje, Chikwawa, Mwanza, Ntcheu in the south and Kasungu, Mzimba, Rumphi and Chitipa in the north of the country respectively. The commonest semi-precious stones are aquamarine (blue beryl), emerald, amethyst, gem tourmaline (pink, green and yellow), smoky and rose quartz, sunstone, heliodor, rhodolite (pyrope-almandine) and almandine garnet. Canary yellow tourmalines were first discovered in Malawi in the autumn of 2000 and are highly prized.

Quartz-feldspar or granitic LCT (Li-Cs-Ta) pegmatites are the most important host rocks for these stones as well as for books of muscovite mica. These pegmatites tend to be peraluminous and are commonly enriched in beryllium, rubidium, tin, gallium and boron.

A swarm of gem-bearing pegmatites occur in the Mzimba district and extend from northern Kasungu through Chikangawa to the Kafukula area on the Zambian border. The host pegmatites range in length up to several hundred metres. They both obliquely crosscut and are concordant with the Basement Complex gneisses which strike predominantly NE–SW. The gems include aquamarine, amethyst, some rose quartz and coloured varieties of tourmaline.

Gem-quality aquamarines (blue beryl) occur in zoned mica pegmatites at several localities in the Mzimba district. The Mphungu pegmatite strikes NE conformable to the schistosity of the host sillimanite-biotite gneisses. It has a simple zonation with outer zone of fine-grained feldspar intergrown with quartz and muscovite while its core is made up of microperthite.

The Mperekezi granite pegmatite is also conformably emplaced within mica schist and is representative of pegmatites showing a more complex zonation. The core zone comprises granular white to rose quartz and plates of muscovite whereas the outer zone is enriched in microperthitic feldspar. The aquamarines generally occur in the feldspar-quartz wall zone and project into the quartz core. Accessory minerals include rare uranium and tungsten-bearing pseudo-ixiolites (Nb-Ta-Fe oxides).

Garnets and rose quartz occur in the Ntcheu District. Occurrences of aquamarine also have been reported. **Amethyst** occurrences been reported in the Chitipa area. **Sunstone** is an oligoclase feldspar attractively spangled with minute aligned plates of haematite. It occurs as veinlets in pegmatite sheets and stringers at a locality about 1.5 km west of Senzani village in Ntcheu district.

Gemstone potential

Zambia is a major world supplier of emerald and amethyst and additionally produces gem-quality aquamarine, tourmaline and garnet (pyrope-almandine). Aquamarine is derived mostly from certain granitic pegmatites in the Lundazi district in eastern Zambia. The Lundazi pegmatite swarm is emplaced in metamorphic rocks of the eastern part of the Irumide orogenic belt which extends into the Mzimba area of Malawi.

A wide variety of gemstone deposits are densely scattered along the Mozambique Belt through the neighbouring countries of Mozambique and Tanzania. Gemstone production in Mozambique includes tourmaline, garnet, dumortierite, aquamarine, emerald and morganite. The northern continuation of the Mozambique Belt in Tanzania has yielded spectacular gem occurrences including sapphires, padparadschas, rubies, variously coloured spinels, garnets, chrysoberyls and various quartz and beryl varieties as well as tourmaline, zircon and diamond. The Tunduru area in southern Tanzania has produced large quantities of sapphires, spinels and chrysoberyls including some stunning alexandrites and vanadium-coloured varieties.

Rubies sapphires and emeralds have been recovered from high-grade granulite-facies gneisses that occur throughout the Ubendian and Usagaran of Tanzania. These same rocks pass into northern Malawi.

The Mzimba area warrants more systematic exploration. Generation of GIS-based prospectivity maps (data-driven or knowledge-driven) potentially could justify new targets and stimulate further exploration for aquamarine and other gemstones.

Recognition criteria for gem-bearing pegmatite would include:

- Presence of or proximity to mapped granitoids
- Presence of or proximity to favourable structures for granite emplacement
- Radioelement signature reflective of granitic-pegmatite clusters
- Juxtaposition of Be-bearing pegmatites with mafic or ultramafic rocks that can provide Fe, Cr and V chromophores are particularly prospective for coloured gemstones.

Vermiculite

Vermiculite is a sheet silicate that has the remarkable ability to expand to many times its original volume when heated. Exfoliated vermiculite has extremely low density and thermal conductivity which make it attractive for a variety of applications including horticultural, hydroponics, soil conditioning and as fertiliser carriers in agriculture (40%), lightweight concrete and plaster aggregates or premixes (32%), refractory insulation, loose fill insulation and fireproofing (23%), packing materials etc. In recent years it has become

Kapirikamodzi vermiculite prospect, Feremu area, Mwanza district.

Vermiculite concentrate on dressing floor at Kapirikamodzi.

more widely used as a safe alternative to asbestos for insulation, brake and clutch linings.

Some 2.5 Mt at 4.9% of proven reserves have been identified around the Feremu-Garafa area in the Mwanza district with an expansion ratio of 12 (range 8-20) and Dry Bulk Density (DBD) averaging 125kg/m^3. The basement complex in this area is dominated by amphibolite facies hornblende ± biotite gneisses with subordinate calcsilicate rocks and metapsammites with scattered ultramafic (mostly glimmerite) and syenite bodies. The NW-trending Wankurumadzi shear zone is the dominant structure in the area. There are 23 known vermiculite deposits in the area (c.130 km^2) of which nine average >0.06 km^2. They are always associated with ultramafic rocks consisting almost entirely of dark mica, either biotite or Fe phlogopite, in contact with syenites and quartz-feldspar pegmatites. The vermiculite develops by hydration of the dark micas during periods of intense weathering or near surface alteration. Vermiculite grades therefore rarely extend to more than a few tens of metres below surface. The largest deposit, Kapirikamodzi, which has an area of 0.25 km^2, and the Ngolongonda and Chitimbe deposits extend to at least 10 metres depth.

Ore controls and guides

(i) the existence of a suitable protore, commonly a potash metasomatised mica-rich ultramafic rocks;

(ii) preservation of the paleo-regolith or peneplanation surface which has undergone intense supergene alteration ;

(iii) a well developed joint-fracture system which enhances the permeability and permits the circulation of meteoric waters;

(iv) the occurrence of golden mica flakes in the soil and the presence of ramifying porcellaneous magnesite veins.

The Feremu-Garafa cluster generally belongs to the smaller class of vermiculite deposits. The largest commercial deposits typically form in roof zones of the cores of ultramafic or alkaline complexes and are commonly associated with some sort of alkali activity, be it only alkali granite or syenite dykes. They may have a negative topographic relief. Vermiculite has been reported in the eastern part of the Mlindi Ring Complex in the same area (see Brochure 1).

Limestone, dolomitic limestone and marble

Limestone is essential in many chemical and industrial processes for construction industry, agriculture, food products, glass, alumina, paper and steel manufacture, and for environmental remediation. Its primary utilisation in Malawi is for the manufacture of Portland cement, agricultural lime and in sugar refining. Malawi is well endowed with limestone in the Basement Complex with most of the resources occurring in the southern region between Blantyre and Lilongwe. The most important low magnesia limestones or calcitic marble (<3% MgO) suitable for cement, alumina and paper manufacture and agricultural applications occur at Changalumi near Zomba, Malowa Hill, east of Dedza and at Golomoti in the Bwanje Valley, Chikowa and Livwezi in the Kasungu district and at Chenkumbi Hills in the Balaka district.

The largest known deposit occurs at Changalumi, 13 km west of Zomba, with an estimated resource of 100 Mt. This was exploited by the Portland Cement Co. Ltd. in a 200,000 tpa operation up to 2002. The overall poor quality of the marble (85% $CaCO_3$) and large volumes of waste adversely affected the economics of the operation.

Deposits of calcitic and dolomitic limestone amounting to >10 Mt occur in the Chenkumbi Hills, c.10 km east of Balaka. The marble is variable in texture and composition in which calcite makes up 60–99% and dolomite up to 40%. Parts of the deposit comprise pure dolomitic marble that has been exploited on a small scale for lime burning. Following the ITDG-USAID funded operation in the 1980s the Chenkumbi limeworks, using the more efficient vertical shaft kilns, was established in 1991. Lefarge Portland is now commencing a new USD 75 Million limestone project at Chenkumbi Hills which is expected to be operational in 2009.

The Bwanje Valley limestone deposit at the southern end of Lake Malawi was evaluated by Met Chem Inc. of Canada in 1997 for the manufacture of chemical grade lime. 4 Mt of calcitic ore grading 52% CaO, 0.99% MgO and 5.2% SiO_2 was delineated. Another block of 14.85 Mt with 46.8% CaO and 1.2% MgO was also outlined. 22.4 Mt of dolomitic marble reserves occur in the same area.

The Chikowa-Livwezi limestones/marbles have 17 Mt of proven reserves with <1.5% MgO but contain abundant silicate impurities. The marbles are interbanded on all scales with garnet-biotite paragneisses, quartzofeldspathic rocks and calc-silicate gneisses. There are, however, substantial bodies of marble with <10% silicates.

Marbles with ⩾93% total carbonate grade at 52–54% CaO and 0.2-0.5% MgO. Those with 75–93% total carbonate contain 45.6–46.0% CaO and 0.7–1.5% MgO. The Shayona Cement Corporation currently produces 150 t of cement per day using vertical shaft kiln technology using limestone from Livwezi. There are plans to expand production to 400 t/d (>140,000 tpa) by the end of 2009. High magnesia dolomitic limestone contains

>15% MgO and is mainly used as building lime and in the sulphite paper-making process. Pure dolostone/marble (c.21.7% MgO) is an important material for the manufacture of refractories. The Lirangwe marble in the Kirk Range is highly dolomitic (>18% MgO). There are two types: <10% calcite and 25–40% calcite. A local lime burning industry has been in operation for many years and reserves appear adequate for this to continue on a small-scale for some time to come. The Matope marble from the same area has reserves of c.650,000 t of highly magnesian marble composed almost entirely of dolomite (54.8–56.7% CaO; 41.8–42.6% $MgCO_3$). It has been also the focus of traditional small-scale lime burning.

Graphite

Deposits of crucible-grade flake graphite occur at Katengeza village in Salima district about 60 km northeast of Lilongwe. A feasibility study carried out in the early 1990s delineated 2.7 Mt of graphite ore averaging 5.8% carbon (i.e. total of 157,000 t of carbon).It is well located in terms of transport infrastructure.

Large resources of flake graphite has also been discovered at Chimutu to the east of Lilongwe. Detailed evaluation of this resource is required but the provisional average grade of the ore is about 10% carbon.

Iron Sulphide

Pyrite is mainly used for the production of sulphur dioxide for the paper industry and sulphuric acid for the chemical industry. Although such applications are declining worldwide, feedstock pyrite could be used in Malawi for a stand-alone sulphuric acid plant to produce ammonium sulphate and phosphate fertilizers and for hydrometallurgical processing of nickel laterite.

10 Mt of proven reserves at 10% sulphur occur at Malingunde Hill in the Lilongwe district and a further 34 Mt grading at 8% Sulphur occur at Nkhanyu Hill in the Chisepo area of the Dowa district. Additional resources of 5.5 Mt of pyrite-pyrrhotite grading at 8.9% sulphur have been delineated on Kadamsana Hill in the Chisepo area. On Malingunde Hill the disseminated sulphide mineralisation is hosted by interlayered kyanite-graphite-muscovite schists, gneisses and metaquartzites that dip at a moderate angle to the ENE. It is probable that there are large unexplored resources in the poorly exposed Lilongwe-Dowa area. Localisation of the Malingundi and Chisepo iron sulphide deposits close to a major north-south structural discontinuity may be significant and is worthy of further investigation. They have been reported to be associated with low angle shear zones. Graphitic iron sulphide belts in Central Malawi have extensive gossan mantles and yield gravity and magnetic anomalies. Elevated values of gold, silver and zinc have been noted at Malingunde Hill.

Bodies of disseminated sulphides (mainly pyrrhotite with some pyrite) also occur near Nanzeka Hill in the Nkhotakota district. The sulphide content locally exceeds 25%.

Pyrite deposits exploited worldwide are normally massive (>90% pyrite) or semi-massive (40–90% pyrite); the cut-off for industrial use being c.30% pyrite. Low grade pyrite deposits such as Malingunde and Chisepo would not normally be considered for industrial use but have the potential for restoring the fertility of alkali wastelands by direct soil application. Sulphuric acid is the major cost component (>50%) in the processing of nickel laterite ores and exploitation of low grade pyrite for this purpose could alter the entire economics of any mining operation.

Copper

There are a number of copper showings recorded in the Basement Complex but the most significant is at Namikunda Hill in the Nsanje district of southern Malawi. The stratabound primary copper mineralisation comprises disseminated pyrrhotite with minor amounts of chalcopyrite and covellite within thin bands of calcsilicate gneiss. Ferruginous gossans with secondary copper carbonates (malachite and azurite) are developed at surface. The shallow-dipping principal lode, which is 0.6–1.3m thick has been described as a gently undulating shear zone. This has a drill indicated reserve of 1675 t at 3.5%Cu over a strike length of 33 m. Very low grade Cu and Zn mineralisation has been reported over a 600m thickness and is locally associated with graphitic gneisses.

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.

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