PanAfGeo2 training WPA-M3 in Malawi, 2023

"Field Geoscientific Mapping"

Excursion Guide to the Blantyre-Zomba-Liwonde area, South Malawi

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Blantyre, 2023

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Foreword

The second phase of the international programme PanAfGeo2 (2021–2024) funded by EU and twelve European geological surveys is targetted at the practical improvement and capacity building for the staff of geological surveys of African states. "Work Package A" is focused on the practical skills in the field geoscientific mapping and represents the most variegated work package of seven work packages included in the programme. Similar trainings were held in Ethiopia, Namibia, Morocco, and Senegal during the first phase of the programme, and some more are planned.

The third training M3 of the "Field Geoscientific Mapping" trainings in Malawi was focused on the person to person intense teaching of the logistic, geoscientific, RS, GIS, and interpretation methods leading to the construction of geological maps on different scales, of which the 1 : 25 000 was applied to the training. An important role in the mapping process was played by remote sensing and GIS approaches including mobile applications that formed an important part of the training.

The mapping training in English was prepared and launched in this country for the first time, taking the advantage of status of GSD of Malawi as the Deputy Co-leader of the Work Package A.

Two areas North of Zomba, where the Geological Survey Department of Malawi resides, hosted the training parts. The introductory and interpretation parts of the training were held in Blantyre, and the field part was hosted by Liwonde and localities and training polygons in its northern vicinity.

This Field Guide documents the activities of this specific training in 2023 and may provide a useful practical information on this part of Malawi for future students, teachers of geology or even tourists focused on geosciences.

1. INTRODUCTION TO THE REGIONAL GEOLOGY

The African continent contains several cratons that are separated by a network of younger orogenic belts of broadly Paleo-, Meso- and Neoproterozoic ages (Karmakar and Schenk, 2016). Malawi lies at the junction of three mobile belts (Figure 1), namely Ubendian (2300–1800 Ma), Irumide 1350–950 Ma, and Pan African or Mozambican 900–450 Ma (Lenoir et al., 1995; Ring et al. 1997; Ring et al., 2002; De Waele and Mapani, 2002; Sommer et al., 2003). The Mozambique

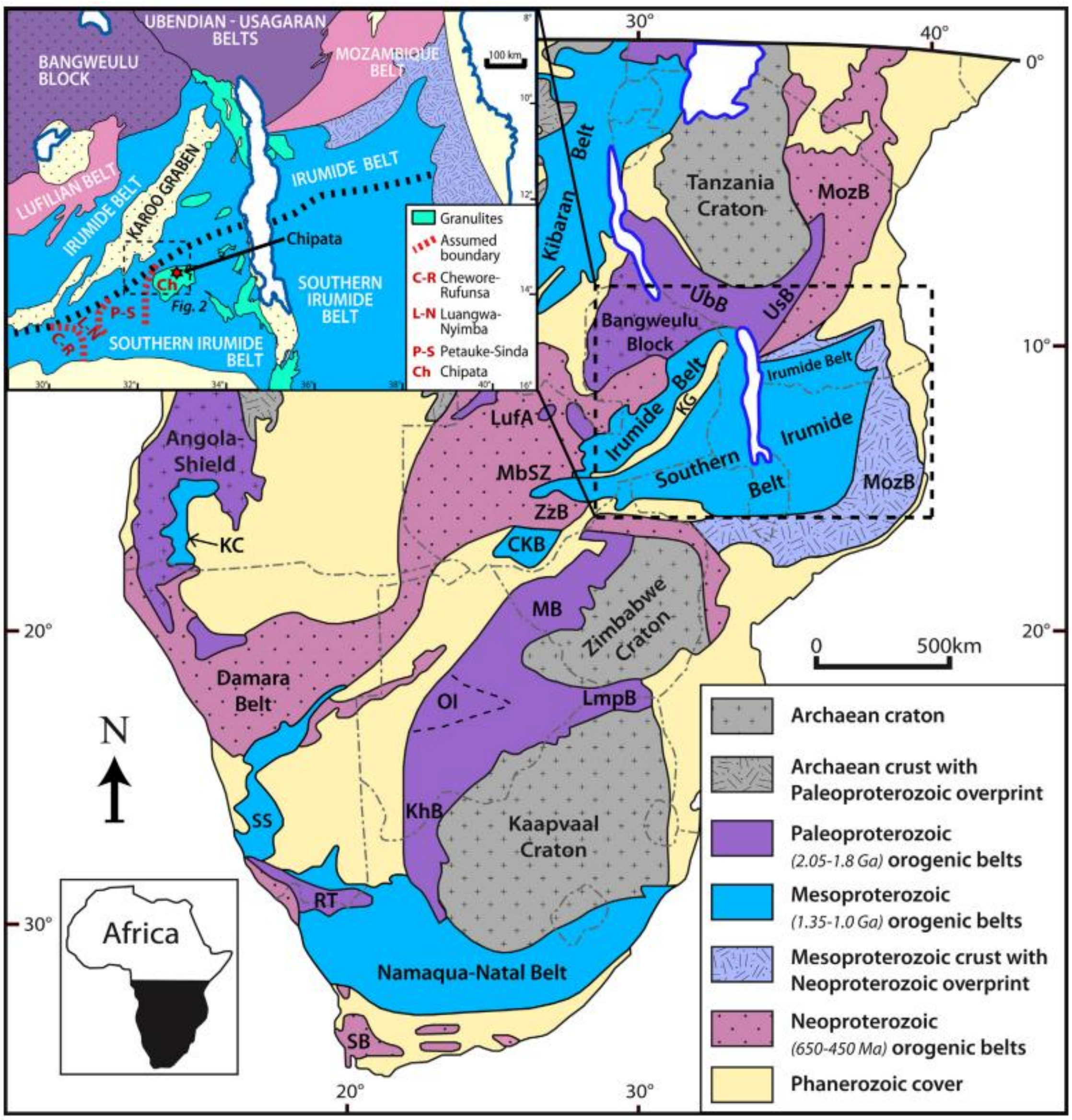


Figure 1: Regional tectonic map of southern Africa, showing distribution of Precambrian rock units (Karmakar and Schenk, 2016). CKB: Choma-Kalomo Block; KC: Kunene Complex and associated granites; KG: Karoo Graaben; KhB: Kheis Belt; LmpB: Limpopo Belt; LufA: Lufilian Arc; MB: Magondi Belt; MbSZ: Mwembeshi Shear Zone; MozB: Mozambique Belt; OI: Okwa Inlier; RT: Richtersveld Terrane; SB: Saldania Belt; SS: Sinclair Sequence; UbB: Ubendian Belt; UsB: Usagaran Belt.

Belt (Southern portion of the East African Orogeny) represents a major north-south continental collision zone between the various cratonic elements that formed East and West Gondwana (Johnson and Oliver, 2003).

1.1. Geological framework of Malawi

The geological history of Malawi is that of Precambrian "mobile belt" (Basement Complex) overlain by Permo-Triassic sediments (Karoo system), cut by Mesozoic igneous intrusion (Chilwa alkaline Province), and disrupted by Cenozoic rift faulting. Most of the Malawian territory is formed of the Precambrian to early Palaeozoic sequences of metamorphic rocks of both sedimentary and igneous origin. This is termed "Malawi Basement Complex" (Cater & Bennet, 1973). These rocks have undergone high-grade metamorphism and polyphase deformation (Achille & Andreoli, 2001; Cater & Bennet, 1973, Dill, 2007; Dulanya, 2017; Dulanya, Morales-Simfors, & Sivertun, 2010; Hori & Tomita, 1997) and a prolonged structural and metamorphic history.

The bulk of the most significant economic mineral occurrences occur within the igneous metasomatic and high-grade metamorphic rocks of this Complex. Marble is the most important economic rock type found in this unit. Other minerals commodities associated with the Malawi Basement Complex include vermiculite, corundum, graphite, iron sulphides, kyanite and apatite.

The Karoo System occurs in the north and south of the country. This consists of sedimentary and subordinate volcanic rocks, which unconformably overlie the Basement Complex. These are restricted to six small fault-blocked outliers. Coal is the main mineral commodity in this category. Other potential minerals commodities include uranium and limestone.

The Jurassic to Cretaceous Chilwa Alkaline Province comprises at least two large syenitic massifs as well as numerous small, but economically significant nepheline syenite, pyroxenite bodies, carbonatite centres, alkaline dykes and swarms and agglomerates veins. In the north, equivalent Mesozoic intrusive activity includes kimberlitic breccias cutting Karoo sedimentary rocks in the Livingstonia coalfield and numerous dolerite dykes, diorite and pyroxenite intrusions. The main mineral commodities associated with this group include REEs and niobium.

Superficial tertiary and quaternary lacustrine and alluvial deposits occur in the north along the western shore of Lake Malawi and in the Vwaza Basin along the Zambian border. Extensive deposits also occur along the southern shoreline of Lake Malawi and in the general vicinities of Lake Malombe, Lake Chilwa, and the Shire Valley. Important residual and alluvial/eluvial concentrations in this category include ceramic and brick clays, phosphates, gypsum, and silica sand. Figure 2 shows the geological map of Malawi.

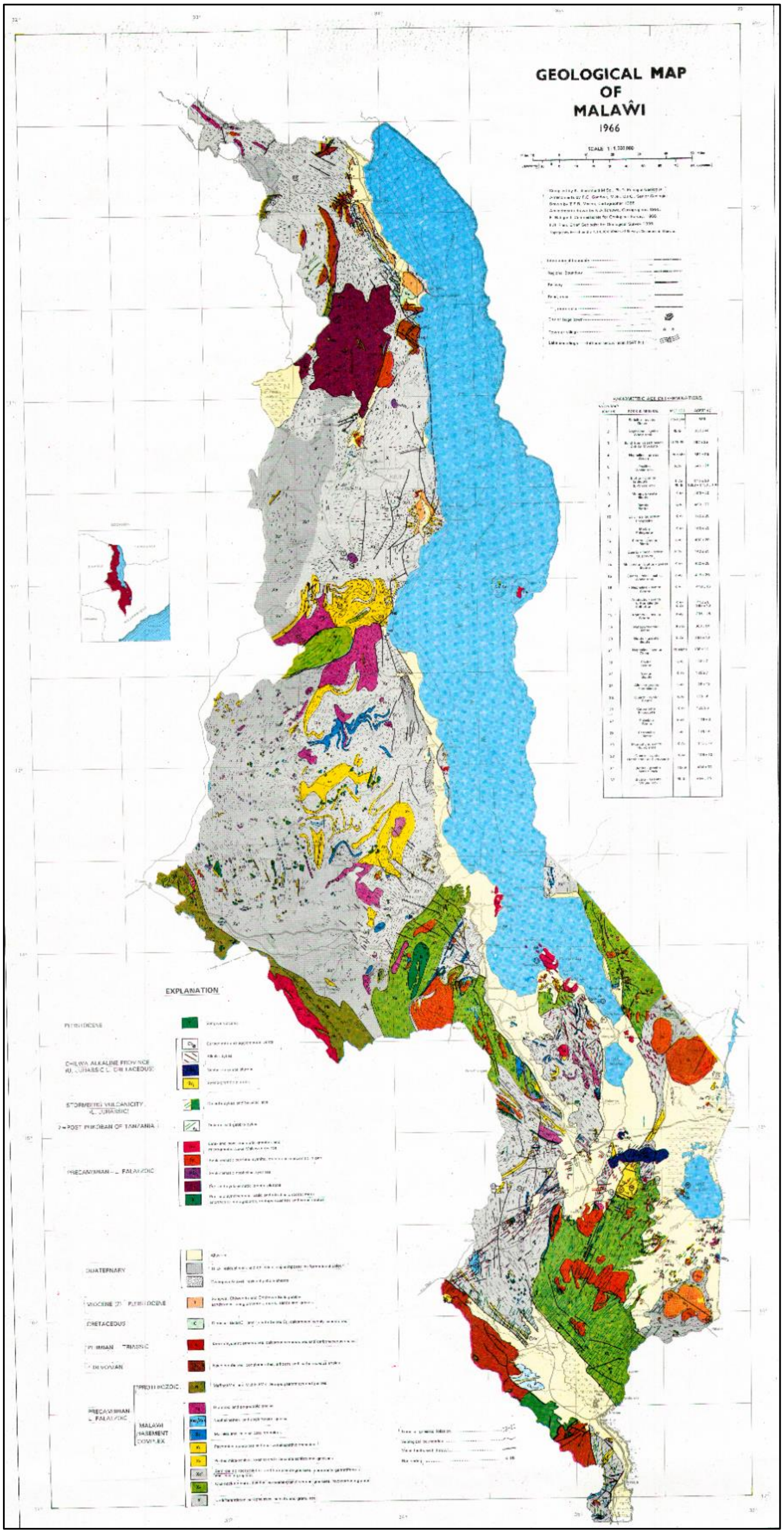


Figure 2: Geological map of Malawi (1 : 1 000 000, GSD)

1.2. Regional tectonometamorphic framework

The Ubendian belt is characterized by NW-SE trending structures and was first described by McConnell (1950). It was formed during the Palaeoproterozoic Ubendian Orogeny between 2200–1800 Ma (De Waele et al., 2003). The rocks of the Ubendian belt are characterized by sequences of medium- to high grade metamorphic supracrustal gneisses and schist that were intruded by various plutonic igneous rocks (Lenoir et al., 1994). The rocks experienced peak metamorphic conditions of 750–850ºC at 18 kbar and record high pressure granulite facies conditions (Ring et al., 1997). The Ubendian belt rocks were structurally overprinted during the Mesoproterozoic (Irumide) and Neoproterozoic (East African/Pan-African) orogenies. These later events extensively altered the internal architecture of the belt and partly obscured the Palaeoproterozoic history.

Mesoproterozoic Irumide orogeny is a north-east trending orogenic belt. It is marked by rapid increase in metamorphic grade from greenschist facies conditions to granulite facies conditions. The Irumide Belt was first described by Ackermann (1950) and Ackermann and Forster (1960). The main structural trend of the Irumide belt is northeast and is related to extensive crustal shortening during the main stage of the Irumide orogeny. This orogenic belt is subdivided by crustal-scale shear zones into the Irumide s.s, the Southern Irumide, the Unango Subprovince, and the Nampula Subprovince with a general trend of NE-SW (De Waele et al., 2006; Boyd et al. 2009; Macey et al. 2010).

The regional metamorphic grade in the Irumide Belt is of medium pressure/medium temperature Barrovian type, which is more consistent with an accretionary setting then a continent–continent collision. P-T-t models suggest a clockwise metamorphic P-T-t path (Mapani, 1999) that is linked to the major shortening event recorded by northwest-verging thrusts. The timing of peak metamorphism in the Irumide belt constrained by SHRIMP U–Pb zircon dates between 1021 ± 16 and 1018 ± 5 Ma (De Waele et al., 2003).

The Pan African Orogeny occurred roughly at 800-500 Ma (De Waele et al., 2003), forming the Mozambique Belt. (Ring et al., 1997; Lenoir et al., 1994). The Pan African Orogeny (De Waele et al., 2003) was the last major orogenic event that shaped the overall geology of Malawi and resulted in significant overprinting of older orogenic features from the Ubendian- and Irumide orogenies (Ring et al., 1997). The Pan African Orogeny created N-S trending structures and reactivated older pre-existing structures. Peak conditions for the orogenic event were suggested to be 750–800ºC at roughly 12–13 kbar and subsequent amphibolite facies retrogression occurred at 550–700ºC at 5–8 kbar (Sommer et al., 2003).

1.3. Field Excursion from Blantyre along the Chikwawa Road

Drive along the Chikwawa Road, up to 1h:30 from Blantyre to the North-West (Sat. May 27, 2023)

Leaders: Joseph Chirwa, Annock Chiwona, Brave Manda and the team of WPA-M3 trainers

There are several locations that exhibit variable geological features, rocks and structures of the Malawi Basement Complex. These geological phenomena are found in natural outcrops, roadcuts, riverbanks, and other areas where underlying rock bodies are exposed. Keep a keen eye for rock outcrops, their patterns, or changes in the landscape while travelling along the Chikwawa Road. An alternative suitable excursion area is along the Zalewa road to the South, with

Figure 3: Abandoned quarry Mgodi nearby M1 road. The rock quarried was gabbro to metagabbro.

Figure 4: Google image of Mgodi Quarry 300 meters North of M1 road.

structurally varied outcrops along the road cuts (Figure 3). It is about one hour drive from Blantyre.

The coordinates given for the stops in this excursion are in the system used by GSD of Malawi.

Stop 1. Mgodi Quarry (X 704929 – Y 8291814)

Description: Quarry site in pyroxene metagabbro, Mota Engil, inactive since 2014. In the central part, coarse-grained magmatic fabric is preserved, while weak metamorphic foliation and younger metamorphic mineral assemblage is developed towards the margins of the mafic body (Figs 3, 4).

Stop 2. Epidote-hornblende bearing gneiss (X 703084.35 – Y 8310013.75)

Figure 5: Ep-Qtz-Fs gneiss forming a steeply dipping blocky ridge, Zalewa Road.

Description: road, ca 10–15m thick horizon of coarse-grained intermediate calc-silicates with green epidote, dark grey to green diopside, minor amount of amphibole, plagioclase and quartz evenly disseminated in the matrix); to the south in contact with migmatitic medium-grained Qtz-rich gneiss (Figs 5 and 6).

Figure 6: Migmatitic gneiss interbedded with Ep-Qtz-Fs gneiss. Zalewa Road.

Stop 3. Boudinage of varied lithologies in gneiss (X 702651.40 – Y 8313862.98)

Figure 7: Biotite gneiss showing mega-scale sc-fabrics enveloping boudins of amphibolite.

Description: road outcrop ca 100 m, layered sequence made of Bt-Qtz-Fs gneiss and intercalated Grt amphibolite forming layers of 1–2 m thickness (Fig. 7). The amphibolite is commonly boudinaged and then outlines mega SC-fabrics suggesting W-directed transports.

Structural Observations

Feature	Azimuth	Dip	2nd Attrib	Comment
Foliation_Penetrative_Inclined	116	55		could be also shear zone (c-fabrics)
Foliation_Penetrative_Inclined	122	40		could be also shear zone (c-fabrics)
Lineation_Plunging	48	25		Elongation-Lin
Fault_plane_Dip	0	85		or prominent joint system

Other optional geosites along the Chikwawa Road

4. Iron ore (X 722798, Y 8274072): Excavation on magnetite boulders (sub in place) showing a general banding underlined by spots of white minerals (Feldspar?)

5. Pegmatite dyke in the road cut (X 699107.5381, Y 8295556.6172): pegmatite swarm intruding into migmatitic orthogneiss. Pegmatite comprises m-cg quartz and feldpars, fsp with minor biotite.

6. Roadcut with biotite orthogneiss (X 697799.4161, Y 8293663.9393): migmatitic mesocratic medium-grained biotite-rich orthogneiss and older gneissic to migmatitic domain is refolded at small-scale, foliation planes shallow dipping W/NW without apparent transposition of mica.

7. Layered biotite paragneiss (X 704276.5396, Y 8306772.4863): marked by very disharmonic fold style at 1 to 10 m scale. Both SE and N verging folds occur; N verging folds could be reverse folds. Some boudins of m-scale are made of amphibolite, asymmetric shape suggests SW-directed transports.

8: Roadcut with marble (X 703820.9687, Y 8308229.6647): ca 20 m thick horizon of pure marble intercalated into highly weathered Bt-Qtz-Fsp gneiss.

Figure 8: Highly weathered dolerite dyke along the sharp contact with sheared granulitic gneiss.

9: The road from Chikwawa to Balaka

Garnet rich granulite with the weathered dolerite dyke

(GPS S14°58.176´ E034°52.921´):

Monocline of steeply dipping granulite-facies rocks hosting up to 1 m thick dolerite vein, with highly weathered matrix preserving relics of feldspars and biotite porphyrocrysts (Fig. 8).

1.3. Mapping areas

1. The first proposed option was having all the mapping blocks in one area. The proposed six mapping blocks are located in Ulongwe area in Balaka district. Each mapping block marked 1 to 3 has an area of about 9.15 km^2 (Figure 9).

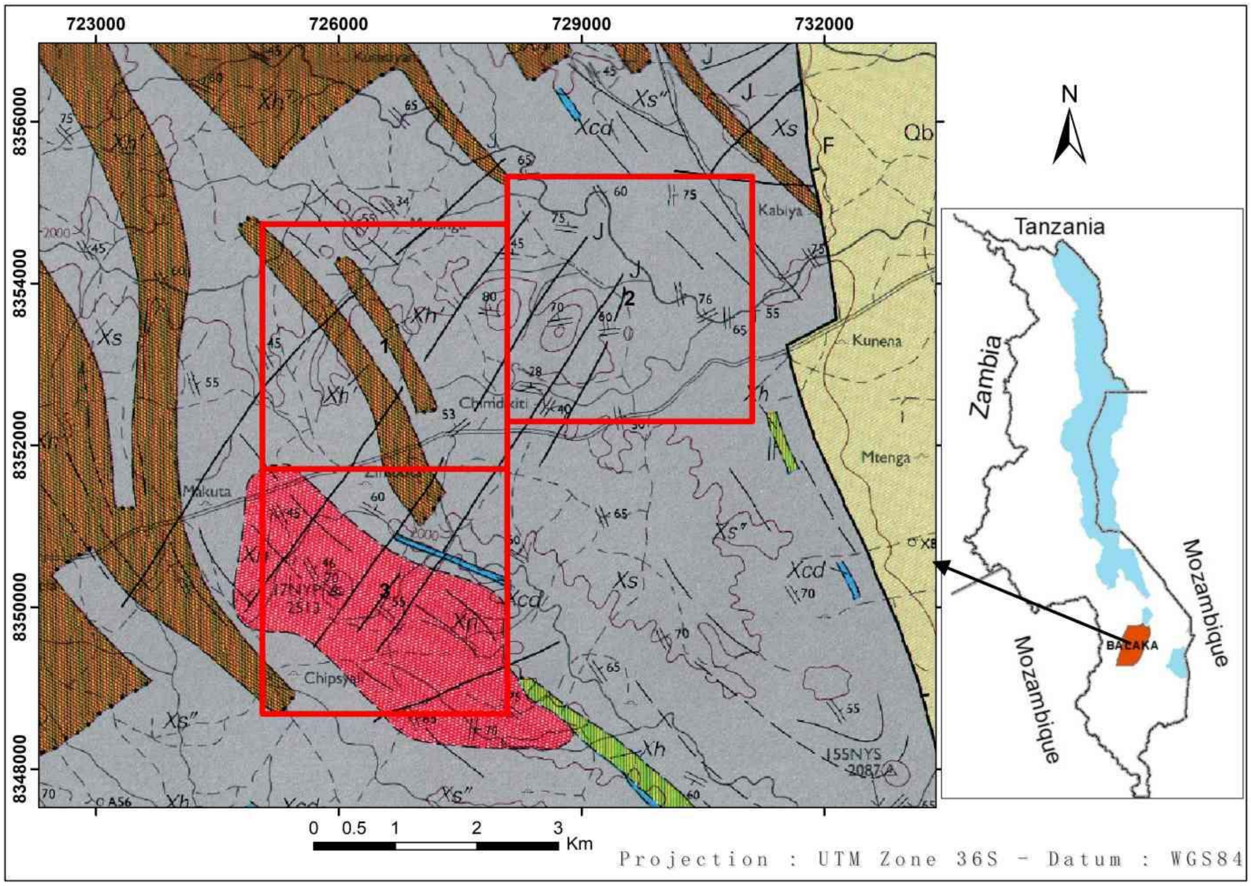


Figure 9: Mapping blocks 1, 2 and 3 in red squares proposed for the western Ulongwe-Balaka area, overlaid on the existing 1 : 100 000 geological map, were used for the mapping training in 2023.

It can be observed for instance from the figure 3 in the mapping block A that the whole area was mapped as having one rock unit (Xs" hornblende biotite gneiss). However, during the reconnaissance field work by GSD team in this block, it has been established that the geology varies from migmatitic garnet hornblende biotite gneiss (Figure 10), to quartzofeldspathic gneiss, amphibolite, felsic and mafic granulite, with alkaline dykes, Karoo dolerite dykes (Figures 8, 9) and pegmatite with iron minerals. Hence the need for the western area to be remapped.

1.4. Examples of selected localities from the mapping polygons

Figure 10: Locality P01 (X 729613, Y 8352670) in Kandabwako stream, comprising mainly of migmatite hornblende biotite gneiss with some evidence of brittle and ductile deformation in places: General outcrop view – amphibolite body disrupting the gneissic fabric.

Feature	Azimuth	Dip	2nd Attrib	3rd Attrib	Grouping	Comment
Foliation_Penetrative_Inclined	140	55				

Figure 11: General view of the two adjacent hills (Mawere Anyangu Hills) which are a prominent feature in the area (Locality 05, coordinates: X 728727, Y 8353943.51)

Figure 12: Outcrop on the side of the road located in Polygon 2 (X 727138, Y 8352111) moderately weathered.

Figure 13: Granulites with migmatitic partitioning between mafic and felsic portions, top of the eastern Mawere Anyangu Hill.

2. Two areas for mapping as depicted in Figures 9 and 14 and were selected for mapping at the end, each with three and two mapping blocks: A, B, and C in the Ulongwe-Balaka area (geology as described in the above sections, West) and the other two mapping blocks in Liwonde-East, Machinga district. The area was visited by Veronika Štědrá, Jan Franěk, Kondwani Dombola, Annock Chiwona and Joseph Chirwa in February 2023. In the eastern Liwonde area, the expected geology includes felsic and intermediate granulites, meta-arcose, coarse-grained biotite augen gneiss, leucogneiss (Figures 12 and 13), mafic bodies, Karoo dykes and pegmatites.

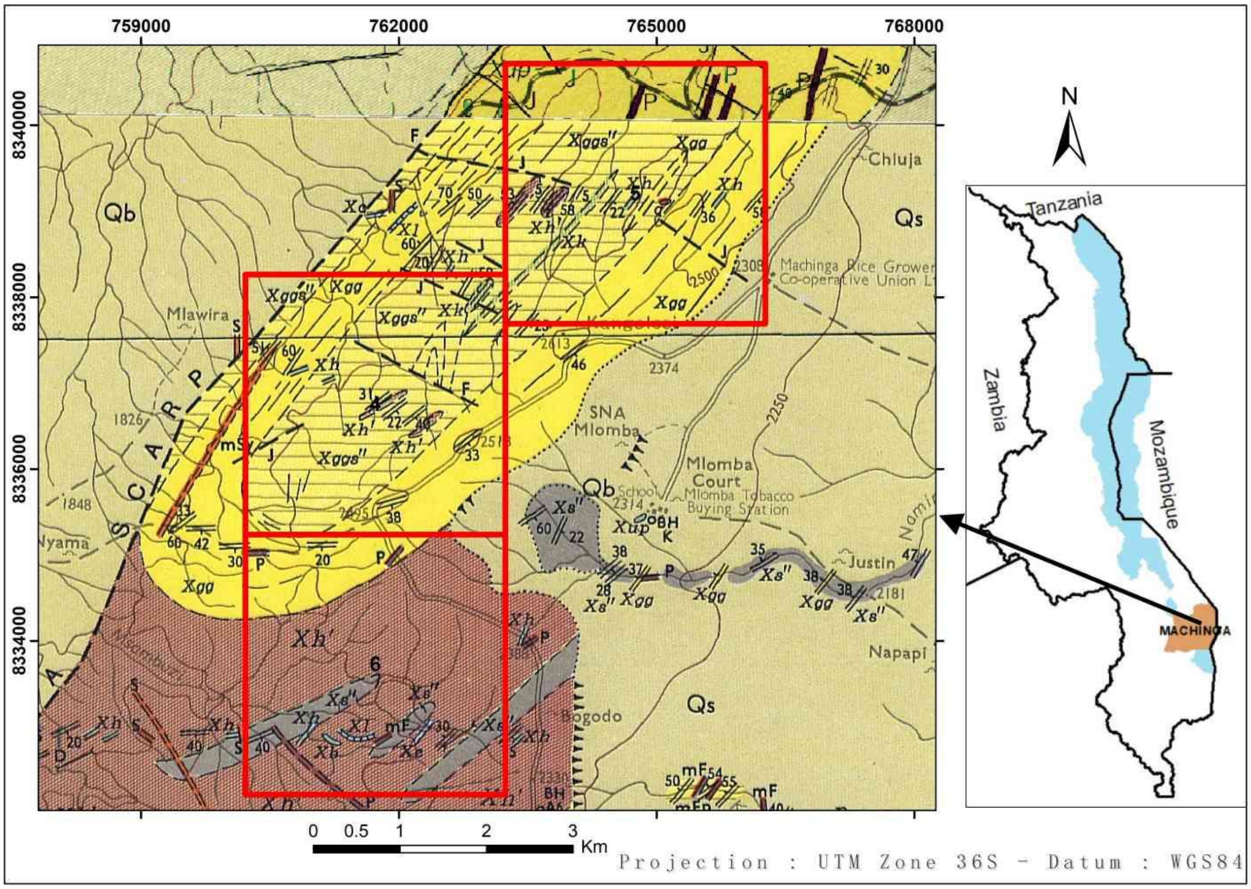


Figure 14: The mapping blocks in eastern Machinga district in the Liwonde area overlaid on the existing geological map (sheets Zomba and Lake Malombe, 1 : 100 000).

Location Description: Liwonde East (weathered road cuts)

Summary label: Quartzofeldspathic gneiss, well foliated layered biotite-bearing quartzofeldspathic gneiss in places highly sheared, migmatite with biotite amphibolite boudins, lenses and discontinuous layers, and dark resistant fine-grained rock. Intruded by pale quartz-feldspar leucogranite veins up to 1 m thick and younger massive phonolite dykes (Figure 15).

Structural Observations

Feature	Azimuth	Dip	2nd Attrib	3rd Attrib	Grouping	Comment
Foliation_Penetrative_Inclined	332	40				

Figure 15: General road cut overview (X 759396.5 Y 8335217.9) on the S131 Liwonde-Nsanama road.

Location Description: Liwonde East (a weathered roadcut 2)

Road excavation exposing leucocratic Qtz-Fs-Bt gneiss with abundant biotite-hornblende rich mafic layers and pods up to 1 m thick. The general dip is shallow to the NW, but foliation is folded on a 2m scale into open, SW-plunging folds, with a periclinal antiform as the most obvious feature (Figure 16).

Feature	Azimuth	Dip	2nd Attrib	Grouping	Comment
Foliation_Penetrative_Inclined	298	30			
Foliation_Penetrative_Inclined	198	65			Ductile sinistral SZ
Fold_Axis_Inclined	255	15			Minor antiform

Figure 16: SW-plunging part of open periclinal antiform in quartz-feldspathic leucogneiss with mesocratic-mafic lenses.

2. METHODICAL EXCURSIONS

Methodical excursion No. 1 Geology and lithology (2.1)

Leaders: Pavel Pitra, Vladimír Žáček

Localities: Marble and calc-silicate rocks. Active quarry at Zalco, Chiendausiku, Liwonde District (1)
Granulite-facies rocks, abandoned quarry at Chiwaula village near Domasi (2)
River bed in Ulongwe North-West (3)
Alkali-amphibole syenite, roadcut at Machinga pass, Liwonde District (4)

Methodical excursion No. 2 Structural geology (2.2)

Leaders: Kryštof Verner, Josef Chirwa

Localities: Gneiss quarry at Chiendausiku, Balaka

Methodical excursion No. 3 Geophysics (2.3)

Leaders: Brave Manda, Joshua Chisambi

Locality: Geophysical polygon in the Machinga region,
Mapping polygon 6 in Liwonde East area

Methodical excursion No. 4 Geochemistry (2.4)

Leaders: Veronika Štědrá, Annock Chiwona - Geochemistry,

Localities: Eastern outskirts of Liwonde, Chimwalira River bed and its left tributory

Remote Sensing Lucie Koucká - Remote Sensing and mobile applications – indoor at the Sun Hotel **(2.5)**

Important rock types encountered during the mapping training and excursions are shown in detail in the section 4 (Plates 1-7).

2.1. Excursion No. 1 GEOLOGY AND LITHOLOGY

2.1.1. Marble and calc-silicate rocks at Chiendausiku, Balaka District

GPS: S15°02.614´, E 035°03.725´

The active marble quarry of Zalewa Limestone Company (Zalco), is situated about 3 km from the M8 road and is close to the Chenkumbi Hills (Figure 23). The size of the quarry is approximately 100 × 50 m, the depth reaches up to ca 7 m. The size of the body is apparently much larger as indicated by numerous diggings of small-scale miners scattered in the wider vicinity of the quarry. The locality represents example of the big marble body metamorphosed together with the surrounding crystalline complex under high amphibolite- to granulite-facies metamorphic conditions. The quarried rock is coarse to very coarse calcitic marble with the granularity of ca 5–15 mm with abundant hexagonal black flakes of graphite (up to 7 mm) along with brown phlogopite of the similar size. Structural pattern, as metamorphic foliation, is not apparent, locally folding of small calc-sillicate intercalations is apparent. Locally also diopside, prismatic pale green clinozoisite-epidote and green mica, probably chromian muscovite, rare dark brown prismatic mineral, probably tourmaline and rare blue spinel appear as aggregates of 5 mm to 4 cm size occur. The marble includes locally up to several metres large lenses of calc-silicate rocks with zoned assemblage of the minerals developed at the contact. Dark-green diopside, prismatic clinozoisite-epidote, accumulations of graphite and phlogopite are most abundant minerals along with feldspars and quartz, as well. The marble is locally cut by 1 m sized dykes of coarse-grained barren pegmatite rimmed also by an aureole of calc-silicate rocks with large diopside crystals and also of cm-sized accumulations of massive pyrrhotite and minor pyrite and chalcopyrite.

Figure 17: The marble quarry by Zalewa Limestone Company (Zalco), at Chiendausiku, Balaka.

This very coarse-grained pegmatite-like quartzo-feldspathic rocks were found as blocks at the quarry margin. They probably represent “pegmatoid” of metasomatic origin developed at the marble margin and carry prismatic crystal of green diopside up to 10 cm long and euhedral brown titanite reaching 2 cm. Marble and calc-silicate rocks can carry other minerals, there is necessary additional study as microscopy, X-Ray powder diffraction and electron microprobe analyses.

2.1.2. Abandoned high-grade gneiss quarry site near Domasi

GPS: S15° 15.276´, E35° 22.549´

The quarry is situated c. 2.7 km NNW of Chiwaula village of Domasi, Zomba district, about 500 m W of the M3 road. The quarry front is about 30 m wide and 6 m high (Figures 18). A small lake occupies the middle of the quarry in wet season.

The main rock type is a medium-grained (1–3 mm in average) felsic gneiss that contains amphibole (hornblende?), biotite, orthopyroxene and locally garnet. Pyroxene is commonly rimmed by a dark corona (probably amphibole). Amphibole and biotite aggregates define the gneissic foliation / banding that dips c. 60° WNW (≈300/60°). In places that banding is marked by the presence of coarser-grained felsic leucosomes, locally rimmed by mafic melanosomes, suggesting partial melting. These observations suggest that the gneiss reached granulite-facies P–T conditions that affected a granitoid protolith.

Figure 18: The methodical excursion to the abandoned quarry at Domasi.

The gneiss contains subordinate enclaves or lenses or bands of 1) mafic slightly finer-grained rock dominated by amphibole and biotite and 2) coarser-grained (3–5 mm) weakly deformed felsic rock. The former could represent mafic enclaves in the original granitoid, whereas the latter could result from the collection of melt produced during metamorphism. The slight deformation of the felsic lenses suggests that partial melting was coeval with the main deformation. In the eastern part of the quarry, the main foliation is cut by flat-lying shear zones suggesting superposed deformations. A dyke of undeformed garnet- and magnetite-bearing aplite (up to 20 cm thick) that contains xenoliths of the country rocks cuts across the gneiss at the NE entrance of the quarry. A slight, apparently dextral displacement is observed along the dyke. Well developed charnockites and coarse-grained mafic granulites were quarried in the Four Mile Quarry south of Zomba (Fig 19).

Figure 19: An abandoned quarry at Four Miles South of Zomba Town. Banded sequence of garnet and orthopyroxene-bearing granulites and granulitic gneisses can be encountered here.

2.1.3. River bed in Ulongwe North-West

GPS: 14°48.772´ E 035°07.405 (X 728510.9, Y 8361332.1)

The well exposed river outcrop is about 6.5 km from the Ulongwe trading centre which is along the M3 road (Figure 26). The river outcrop is heterogenous in nature and comprises of the migmatitic gneiss as the main rock unit, with amphibole and biotite rich domains, pegmatite veins and partially molten felsic injections. Homogeneous fine-grained mafic dyke up to 60 cm in thickness displays higher resistance to weathering.

Figure 20: Wide river stream with well exposed smoothed surfaces of heterogeneous basement rocks.

2.1.4. Alkali-amphibole syenite. Roadcut at Machinga pass, Liwonde township.

GPS: S15°10.616´, E 35°19.482´

Syenite belonging to the Chilwa alkaline province is well exposed in the roadcut at Machinga boma near the Chingale turn-off (Figure 21). The syenite is randomly oriented coarse-grained rock composed of prismatic to ruler-shaped crystals of potassium feldspar and minor black alkali amphibole. The size of feldspar crystals varies between 5–10 mm, the Carlsbad-type twinning is common and mostly well visible. Quartz is not observed. Black amphibole is probably arfvedsonite, which was described from the similar rocks in the close vicinity in the Zomba area. Locally, the syenite is cut by dm-sized pegmatitic dykes or domains of the same composition with sometimes with open vughs in central parts. However, the boundary between syenite and pegmatite is mostly unsharp. The pegmatite domains display granularity of 1–4 cm and locally large accumulation of black alkali amphibole occur.

Figure 21: The road-cut at the Machinga Village exposing coarse-grained syenite and related pegmatitic bodies with arfvedsonite-feldspar aggregates.

2.2. Excursion No. 2 STRUCTURAL GEOLOGY

Gneiss quarry at Chiendausiku, Balaka district

GPS: S15°01.543´ E035°07.159´ (X 727968 Y 8337856)

The abandoned quarry site is about 120 m from the M8 road to Balaka (Figures 20-21). Currently there are a few small-scale miners around the area. The quarry has an excellent flesh surface, in the central part with water pool.

It comprises of highly deformed high-grade migmatitic gneiss with older mafic portions of melt cut by network of coarse to very coarse pegmatitic and leucogranitic veins up to 50 cm thick, forming various spatial relationships. Occasionally, quarry walls expose also minor irregular metadiorite and amphibolite bodies.

The locality presents the entire succession of deformational and intrusive structures, making it an excellent site to comprehend regional tectonic evolution and to provide practical training for common structural and mapping techniques. The structural study is focused on the onset of geological structures, techniques of their measurements, and interpretation of the local geological succession.

Migmatitic gneisses exhibit a wide range of deformational structures, reflecting a successive tectonic evolution on a regional scale. The regional foliation demonstrates deformational and compositional banding, mainly defining the boundaries of individual lithologies. The foliation planes dip steeply to the SW (WSW) or NE (ENE) with well-developed lineations plunging steeply

Figure 22: General outcrop view of the disused rock aggregate Chiendausiku quarry site with a ponded central part.

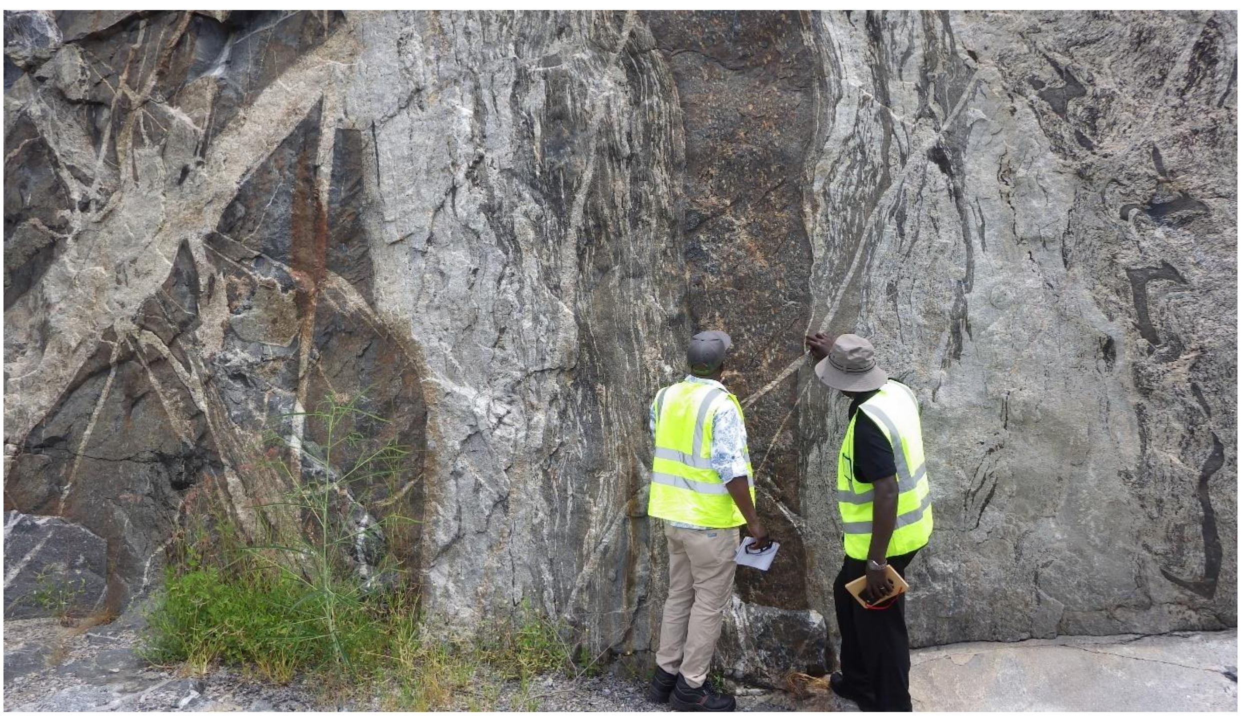


Figure 23: Highly deformed section of the migmatitic gneiss with randomly oriented crosscutting leucogranite veins and disrupted mafic veins in the Chiendausiku Quarry.

to the south. In some areas, older metamorphic fabrics in the form of tight to isoclinal folds are enclosed within these foliations.

Additionally, several superimposed shear zones have been identified. The first generation of NW-SE trending shear zones indicates thrusting and top-to-the-southwest shearing kinematics. The second generation of localized E-W trending shear zones shows predominantly right-lateral displacement. The relatively oldest leucogranites intruded the metamorphosed complex mostly parallel to the regional metamorphic foliation, bearing evidence of weak solid-state deformation. In contrast, the younger leucogranite and pegmatite veins reveal mostly irregular and discordant contacts.

2.3. Excursion No. 3 GEOPHYSICAL SURVEY METHODS

2.3.1. Aim of the survey

The aim of the survey is to impart ground geophysical data acquisition, basic processing and interpretation skills to the participants.

2.3.2. Survey area

The survey area is in Chiendausiku in the Balaka district, in a close vicinity to the marble body.. The geology of the area is mainly obscured by superficial deposits. However, the aeromagnetic geophysical survey has shown that the area might have a buried dyke. The ground magnetic geophysical survey was thus necessary to confirm the presence and orientation of this dyke.

(Note: Due to dense post-seasonal vegetation, the survey was shifted to the mapping polygon 6 to the NW of Liwonde, see Fig. 14.)

2.3.3. Magnetometry – methodology

The survey lines followed traverses that were planned based on google earth and the geological structures, this was done to ensure to delineate possible geological structures (i.e dyke). The base station was maintained at the same spot for all the three transects. The traverse lines were transferred into the Garmin GPS and mobile phone using Locus GIS software which was being used to ensure that the traverse lines/truct/footpath are followed. The magnetometer rover and base station had both GPS which stream the location of each data point in real-time. The data collection interval for the base station was set at 10 seconds. This ensured that enough data point was collected for data reduction.

2.3.4. Data acquisition

Magnetometer data was acquired using a G857-Proton Precession Magnetometer and G859-Cesium magnetometer. The stations at each sampling point were continuously located using Garmin GPS and Locus GIS mobile phone application. A base map was extracted online through open street map using plugin functionality in QGIS. GIS and general topographical maps were used to locate and mark all the stations along with the designed profiles/footpath. The survey profiles were designed to cut perpendicular to the strike.

Figure 24: Data acquisition using G-859 Caesium magnetometer by Chrispin Ngwata, with Brave Manda using the GPS for navigation.

2.3.5. Field operations

Several checks would always be conducted before the field survey is launched such as the instrument battery being fully charged; traverse lines designed; cleaning data from the previous work from the instrument as well as setting the new date and time (as explained in standard operation procedure, SOP's). It was ensured that there were no metal objects close to traverse lines. Geological and geophysical rock properties observations were made on the traverse lines using KT20 magnetic susceptibility meter. The data was acquired close to the ground level by a person carrying a magnetometer sensor placed at an average 3-meter height (Figures 27 and 28). To initiate the survey, a constant point called a base station was identified for continuous data capture. Thereafter, measurement stations were planned along the traverse lines. The data from the base station served as a control point for temporal changes in the magnetic field, which was subtracted from the measured survey data. The magnetometer height was maintained. At each survey point, data were acquired in an automatic mode set at 10 seconds and in survey mode.

The data was downloaded to the laptop using Magmap200 Software (latest software can be downloaded at Geometric website) and stored in XYZ format.

Figure 25: Some of the participants taking magnetic susceptibility mesurements of the possibly Karoo dolerite dyke.

2.3.6. Magnetic data processing

The data collected was processed using Geosoft, the first step involved loading the data into the database, and then checking all the data points if there are any false anomalies by checking the profile and using QC for quality control. The data was then gridded using minimum curvature with default cell size. No algorithm was calculated in the Geosoft package to enhance geological structures since there were only threelines/profiles.

2.3.7. Survey design

The traverse and line spacing were designed using Geosoft and all the planned traverse was finalized using QGIS and base camp software. The following survey parameters were used in this study; traverse direction at 450, line spacing at 250 m, tie line at 1350 (Fig. 26).

Figure 26: Ground magnetics survey plan.

(NOTE Due to dense seasonal vegetation, the survey was shifted to the sixth polygon to the NW of Liwonde)

2.3.8. Results of the magnetometry survey

The data acqured shows magnetic variations, a line close to the main road has varies from high to moderate magnetic anomalies. The higher areas could be due to the movement of motor vehicles since this profile were acquired close to the main road. The lithology of this area is comprised of quartozofeldpathic gneiss and a phonolite dyke, the KT20 magnetic susceptability has a a very low values (K values between 3 to 6 for Qtz-feldspar gneiss and 0.3 to 1 for the dyke); this correlate well with the gridded data as shown in figure 27.

The profile in the middle varies from moderate to very high magnetic anomalies; the area with high anomalies correspond to mafic rocks defined as Karoo dollerite dyke in the field. This results agrees well with the KT20 measurements and the geological map of the area, the values of the KT20 for the dyke ranges from 30 to 45. The third profile, far south-west (Figure 27) has shows low to moderate magnetic anomalies, this part the lithology is composed of felsic rocks, felsic rock with no magnetic minerals have low in magnetic signature.

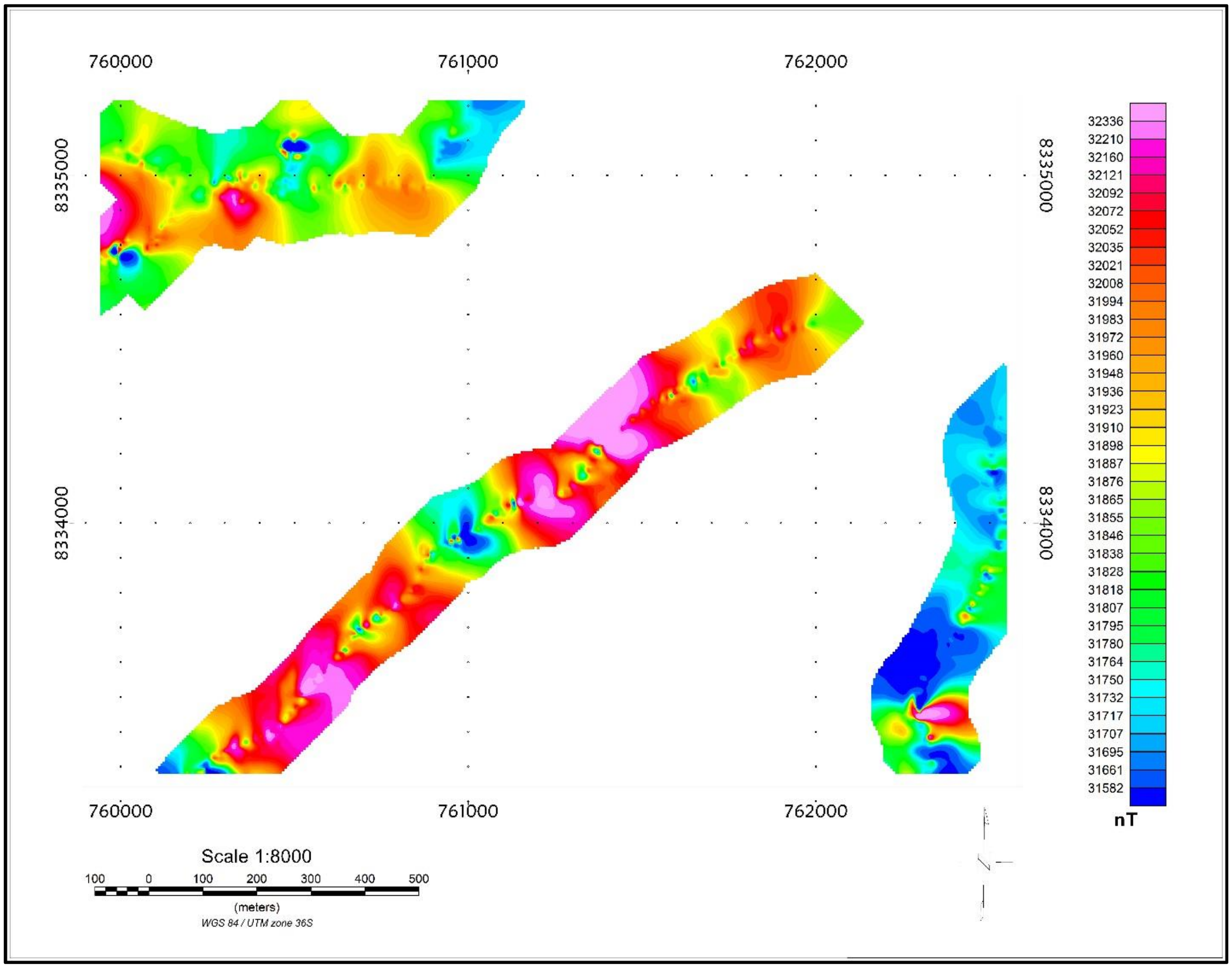


Figure 27: Total magnetic intensity for the part of the Nsanama area, Machinga district.

2.3.9 Radiometric survey

The radiometry survey was carried out using RS 125 Spectrometer during the methodical week. The techniques were introduced to trainees who were equipped with this device. Furthermore, the equipment was also used to survey following the same profile lines as that of magnetic survey (Figure 27). The equipment was set to Assay mode, and 30 seconds was set for each survey point. Also, during the field excursion to Kangankunde, the equipment was used to collect data by the trainees to assess the carbonatite body (Figures 29, 30).

The Kangankunde carbonatite complex displays a general weak airborne spectrometry anomaly in Th, with a much higher and sharper, N-S elongated, airborne spectrometry anomaly in Th on its eastern half. All ground spectrometer values were very low in uranium, and most of them were moderately anomalous in Th (mostly in the range of 50 to 160 ppm). High thorium values are noted both in the mineralized carbonatite and in the fenitized host-rock (Figure 31). The obtained ground values are also in agreement with the results of the High-Resolution Airborne Geophysical

Survey that was carried out by the Sanders Geophysicists Limited (CGL) of Canada in 2013 to 2014 covering the whole Malawi.

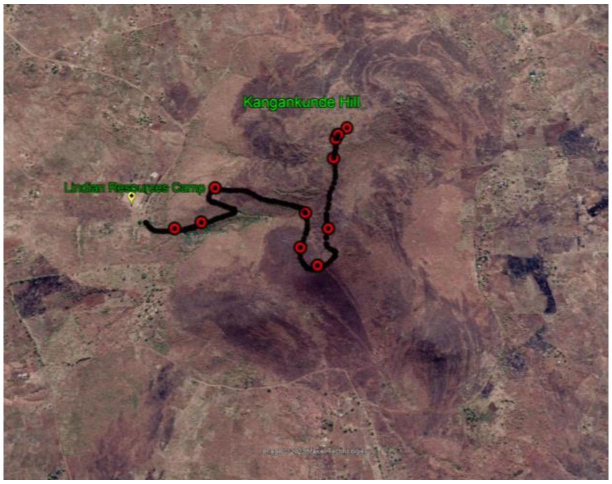


Figure 28: Google Satellite image showing the Kangankunde hill, the black dotted line is the traverse line, the red spheres are the data collection points using RS 125 device.

Figure 29: Gamma-ray spectrometry measurement in Kangankunde, showing slightly elevated signature of thorium and potassium.

Figure 30: Gamma-ray spectrometry measurement in Kangankunde.

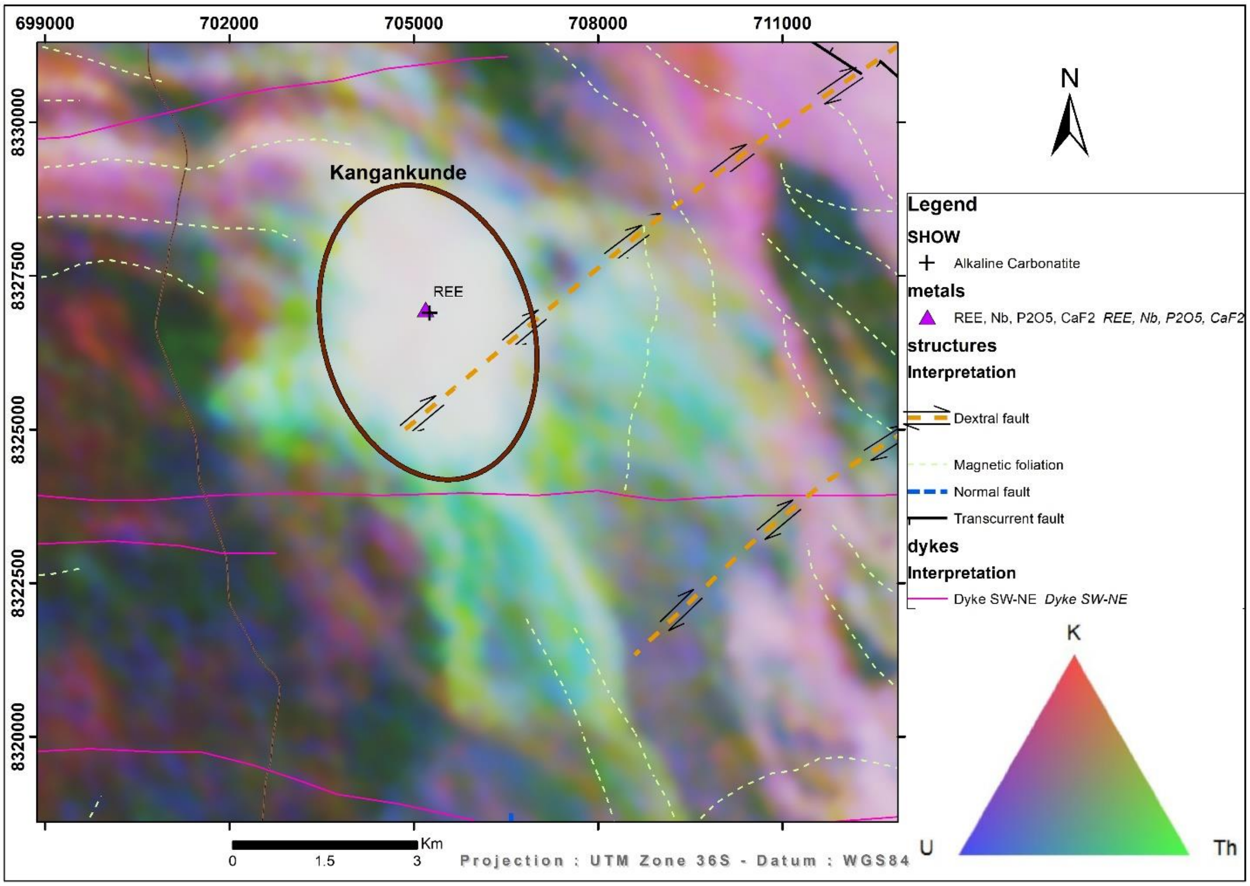


Figure 31: Ternary image interpretation map for the Kangankunde Hill.

2.4. Excursion No. 4 GEOCHEMICAL SAMPLING PRACTICE

The area in the vicinity of Liwonde is used for demonstration of several important geochemical methods often used during geological mapping. For description of these methods in detail and the sampling patterns, we refer to the handbok published by the Czech Geological Survey (Seifert et al., 2004) and provided to participants in a soft copy format.

2.4.1. Soil sampling

The practice took part near the Liwonde railway station. For the type of shallow soil horizon sampling, the soil sounding bar for heavy soils and the plastic sledge hammer were used (Figure 32). In case of intense compaction of soils, the different types of augers is also used allowing deeper hand sounding. Wider augers with extension bars are also used in wetlands, where light soils allow deeper drilling and a good recovery of organic-rich material.

The sounding bar can sample soils down to 1 m depth. The sample up to 0.5 kg of soil can be taken from the selected target horizons along profiles or given grid for different types of laboratory or in-situ tests depending on the purpose of the soil sampling.

Figure 32: Soil sampling with the core soil bar for heavy soils, Liwonde-East.

2.4.2 Heavy mineral sampling

The practical training of panning for heavy mineral concentrates from local sources are demonstrated and practised in the rocky Chimwalira River Valley West of Liwonde (S15 °01.807´ E35° 07.706´, Figure 33). Samples should be of equal volume (10 l) or weight (15 kg), preferably taken from the vicinity of bedrock in a given distance. Depending on target heavy minerals, various shapes of concentrators and sieves can be used during the exploration stages, made of different materials (wood, plastic, steel, aluminium). For the training, the Estwing plastic pans of various diameters, and the iron pan of 'Chinese hat' shape were used for concentrating (Fig. 33). Magnetic fraction (magnetite, pyrrhotite) was separated by magnet on spot, reducing ferromagnetic fraction in the concentrate, while non-magnetic (mostly rutile, ilmenite and non-magnetic spinelides, pyrope/spessartite/grossular garnet, apatite, zircon, monazite, baryte, etc.) and paramagnetic fraction (with almandine garnet, Fe-oxides, hematitized grains, amphiboles,

Figure 33: Heavy minerals and stream sediment exploration methods in practice, Chimwalira River bed.

pyroxenes) were kept for the microscopical mineralogical inspection in the GSD. Gold-bearing river placers with numerous coarse-grained heavy minerals, several types of garnet and fine-grained gold along the Ntobwa River NNW of the Mawere Anyangu Hills were also inspected.

2.4.3. Stream sediment sampling

Metals and other elements are prone to adsorption to certain clay minerals. This property is used for the stream sediment sampling that consists of the selection of the very fine-grained, clayey or muddy portions of complex profiles of alluvial accummulations. Normally, samples up to 300 grams of material from the low-energy sedimentary profile with grain size below 0.18 mm are taken.

2.4.4. Biogeochemical sampling

Samples of several types can be taken from the areas where rocks in situ are covered by any type of sediment (e.g., the desert crust-like calcrete, large colluvial fans, shallow water continental sediments, marshes, or thick alluvial sediments in large river valleys. It benefits from the ability of plant roots to extract local elements from the deep rocks covered by any other material and use them in tissues of leaves, bark, twigs, or fruits, or concentrate them in these parts of the plant, or even select some metal elements preferentially. Another method used in dry areas is to sample the termite nests, where the material from the deep parts of the Quaternary sediment is availabe at the surface, the higher above the ground, the deeper is the source. Materials are sampled and analysed by common analytical portable or laboratory methods.

2.5. Excursion No. 5 REMOTE SENSING AND MOBILE METHODS

2.5.1 Field data collection using mobile app

To ensure geological mapping and data acquisition are recorded in a uniform way by all participants, the mobile application is used to collect field information. It was decided to use the free version of the Locus GIS Android application which is available in the google store. The mobile application provides offline display of the 1 : 25 000 topographic map and orthophoto images of selected mapping areas (Figure 34). The important part is presented by the point vector layer that is structured to the form with attributes necessary to acquire in the field (Figure 35). The preparation of the input data and the appropriate setup of the mobile application have been practised and the data collection sufficiently tested by all participants during the second week of the training.

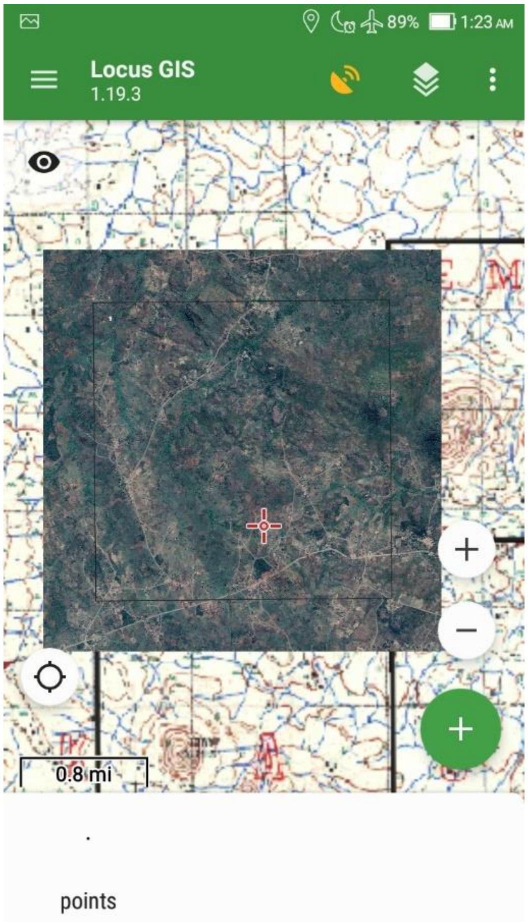


Figure 34: Mobile app with background maps

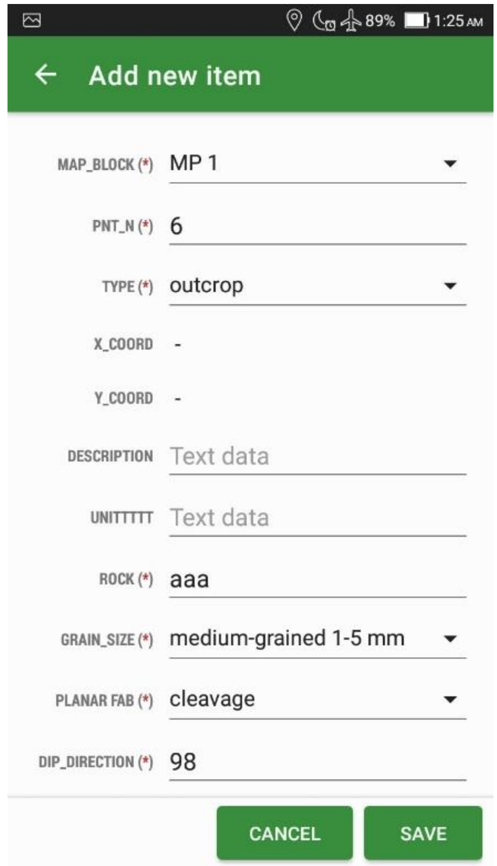


Figure 35: Point layer attribute structure

2.5.2 Introduction to remote sensing methods

Remote sensing data have been a useful source of information to explore geology during the last decades. Participants were taught the basic principles of remote sensing methods, different types of remote sensing data, and free sources of satellite data available worldwide. Optical multispectral data of Sentinel-2 and ASTER images were downloaded in advance for further analysis and provided to trainees. Basic band combinations, indices, and PCA transformation of Sentinel-2 and ASTER multispectral images are practiced, tested, and used for better recognition of lithological trends in the landscape (Figure 36). Basic principles of "unmanned aerial vehicles" (UAV) data acquisition were presented as well.

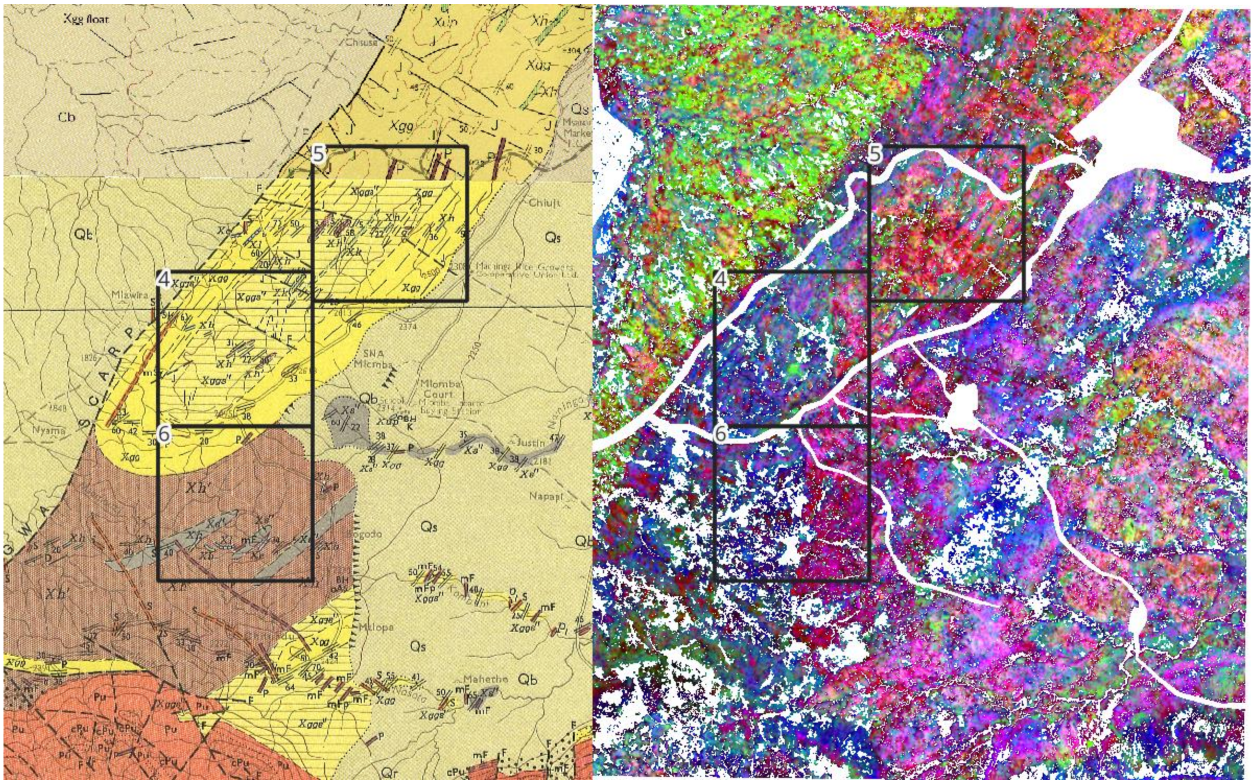


Figure 36: Comparison of 1:100 000 geological map and PCA transformation of Sentinel-2 data in the area of mapping polygons 4–6.

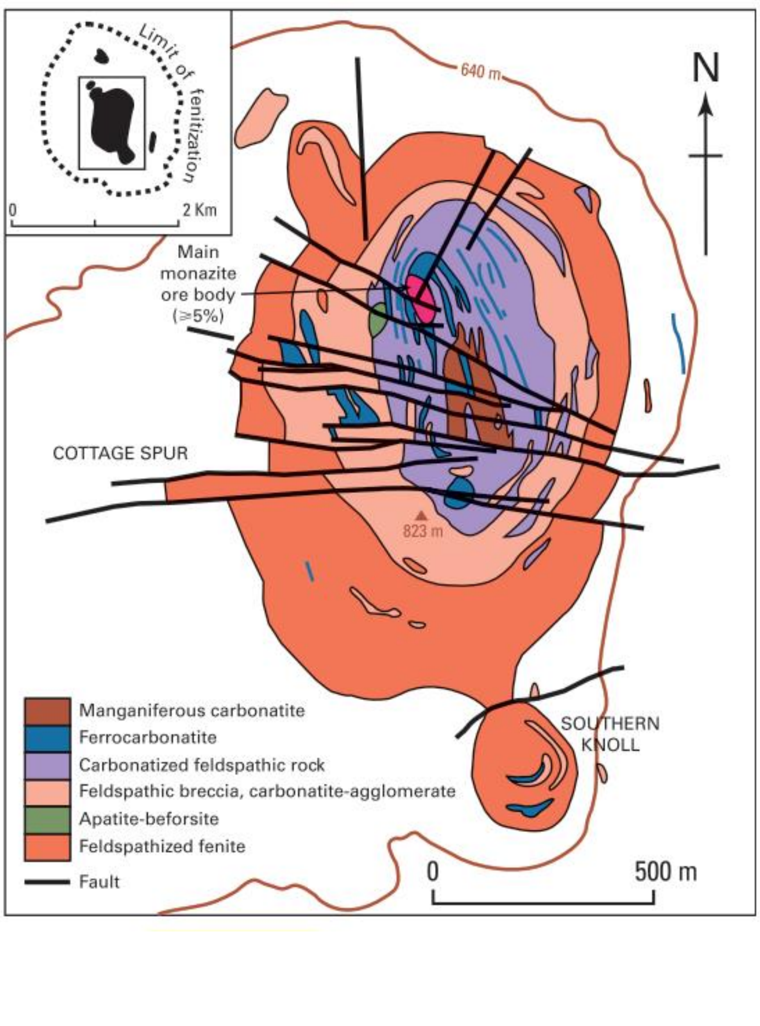
2.6. MINE EXCURSION: The carbonatite intrusion at Kangankunde, Balaka

GPS: S15°07.642´, E34° 54.652´ (top of the hill)

The Kangankunde Hill is located in Balaka, about 3 km from the M1 Road (Figures 28, 37–39). The hill is about 3 to 4 km in diameter, with a core of carbonatite body, hosted in fenitized basement gneiss. This is one of the intrusions within the Chilwa Alkaline Province of the upper Jurassic to lower Cretaceous in age. The carbonatite core is surrounded by a collar of potassic feldspathic breccias, agglomerate and metasomatic fenite along the contacts to host gneiss.

From the drill cores and the carbonatite outcropping along the slopes, several types of lithologies can be observed (Figure 38). Coarse- to medium-grained white carbonatite hosts the altered dark brown zones enriched in iron and manganese carbonates alteration, mostly oxidized to dark brown (Fe) to black (Mn) crusts of hydro-oxides. Within these darker domains, the rich green coarse-grained monazite forms well zones veins with patchy or rarely linear arrangement depending on the presence of lamellar carbonate (strontianite?), quartz, siderite or other primary minerals. On the top and along eastern slopes of the hill, massive monazite veins with minor vughs were encountered. Fine crystals of colourless and whitish carbonates, quartz and euhedral crystals of grass green monazite up to 2 mm cover irregular walls of these cavities. Soluble carbonate minerals were probably partialy leached away. Another type of economic mineralization was

Figure 37: A distant view of the Kangankunde Hill from the Blantyre-Lilongwe M1 Road.



detected by the drill exploration in deeper central parts of the carbonatite body, with colourless monazite disseminated in white carbonate. Both massive veins and disseminated carbonate mineralization show economic contents of REE´s, mostly Y, Nb, and Th (up to 4% TREO). Besides monazite-bearing mineralizations, apatite-quartz veins with elevated REE contents were described from outer parts of the carbonatite body by Broom-Fendley et al. (2016).

Figure 38: Geological map of the Kangankunde carbonatite (after BGS, 2009).

The Kangankunde occurrence is one of the most economically viable carbonatite complexes in the Chilwa Alkaline Province.

Our acknowledgement goes to the staff of Lindian Resources Ltd. who enabled us to visit the site and provided a full safety, technical end expert support (Fig. 39).

Figure 39: The PanAfGeo Group at the Kangankunde carbonatite deposit field base, accompanied by staff members of Lindian Resources Ltd.

3. PLATES 1-7: LITHOLOGY OF THE TRAINING AREA

Plate 1 – Charnockites and mafic granulites

Plate 2 – Granulite and granulite gneisses

Plate 3 – Gneiss unit, orthogneiss, migmatites

Plate 4 – Marble, pegmatite, carbonatite

Plate 5 – Chilwa alkaline series granitoids

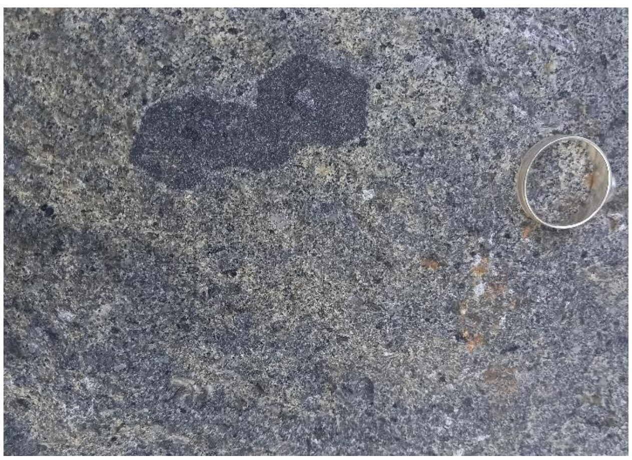
Plate 6 – Alkaline dykes, Karoo dolerites

Plate 7 – Quaternary Deposits

Plate 1 – Charnockites and mafic granulites

Charnockite gneiss with Opx poikiloblasts in the partially molten domain.

Orthopyroxene and garnet rich coarse domain in charnockites, Four Mile Quarry, West of Liwonde Rd.



Mafic granulite, part of the charnockitic series. Road cut North of Zomba.

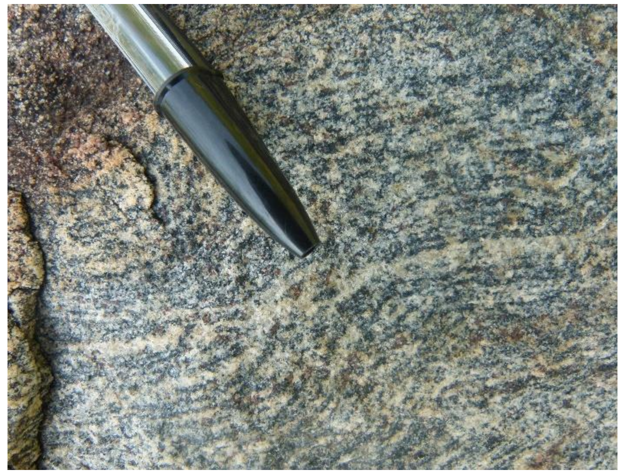
Mafic boudin with linear fabric of partial melts, enclosed in gneiss. A quarry in the Chiendausiku (Balaka) area.

Opx-rich granulite, west of the Liwonde road.

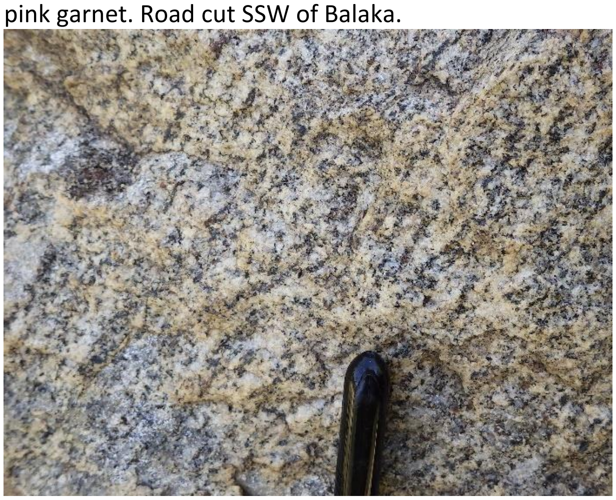
Coarse-grained metagabbro preserving magmatic Cpx-Pl texture. East of Chimdikiti Village.

Plate 2 – Granulite and granulite gneisses

Weathered m-grained granulite, in places rich in pale pink garnet. Road cut SSW of Balaka.



Fine-grained garnet-pyroxene granulite, Liwonde East polygon.



Fine-grained granulite with Grt and Opx.

Banded fine-grained granulite, Four Mile Quarry.

Granulite with garnet aggregate, Liwonde West.

Opx granulite with large garnet porphyroblasts from the Four Mile Quarry South of Zomba.

Plate 3 – Gneiss unit, orthogneiss, migmatites


Felsic gneiss, polygon D point 50.


Augen orthogneiss, quarry WNW of Nsanama.


Migmatitic gneiss with randomly oriented crosscutting leucocratic veins. Chiendausiku-Balaka Quarry.


A micro fault in mafic gneiss. Kandabwako River crossing, Chiendausiku area.

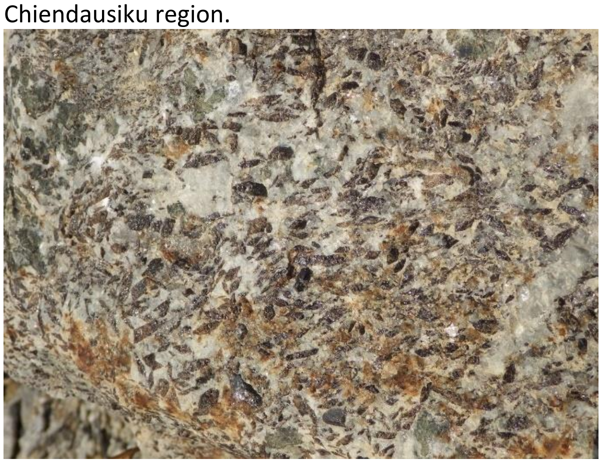

Highly sheared quarzofeldspathic gneiss with mafic lenses and Qtz-Fs (Bt) melt patches. Nsanama road.


A mafic pod in deformed schistose leucocratic Qtz-Fs gneiss (surface affected by excavation). Nsanama road.

Plate 4 – Marble, pegmatite, carbonatite

Coarse-grained graphite marble from the Zalco Quarry, Chiendausiku region.

Folded and banded fine-grained calc-silicate layer in the pure marble. Zalco Quarry, Chiendausiku.



Euhedral titanite and diopside in coarse-grained molten pocket. Zalco Quarry, Chiendausiku.

A pegmatite block with a large dark magnetite aggregate. Chiendausiku area.

Unaltered white carbonatite drill cores exposed in the core shed, Kangankunde.

Monazite-rich vein and its brown altered exocontact in carbonatite, the top of the Kangankunde Hill.

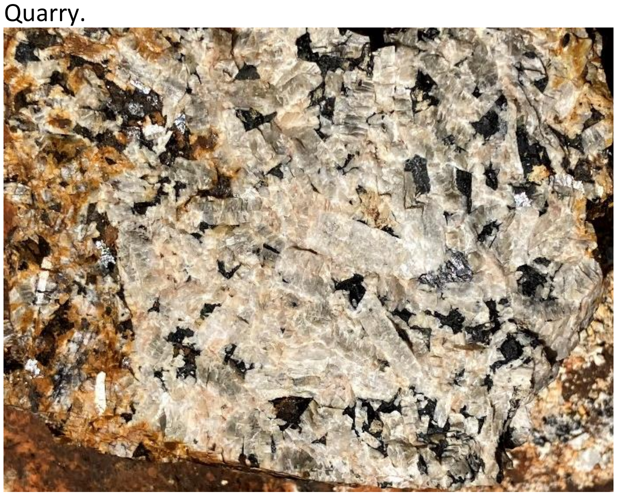
Plate 5 – Alkaline Series granitoids


Fine-grained alkaline granite intruding foliated gneiss, Balaca region.


Medium-grained syenite (Pl-Hbl), Zomba Plateau.


Orthogneiss cut by a thin microsyenite vein. Domasi Quarry.


Nepheline syenite with brownish glassy nepheline in the Hbl-Pl matrix. Chikala Hills, Machinga region.


Coarse-grained syenite pegmatite with twinned feldspars up to 4 cm. Machinga Pass.

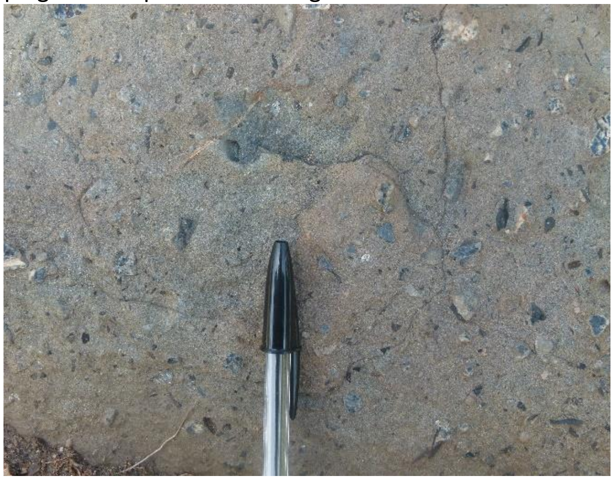

Afvedsonite hornblende-rich syenite pegmatite, Machinga Pass.

Plate 6 – Alkaline dykes, Karoo dolerites

Massive phonolite fragment showing contrasting and zoned weathering crust. Liwonde, Nsanama road.

Very coarse-grained trachyte dyke with megacrysts of plagioclase up to 8 cm. Ulongwe West area.

Fine-grained trachyte. Liwonde West area.



Alkaline dyke with phenocrysts of plagioclase feldspar and biotite. Ulongwe West, polygon 2, river bed.

Dolerite dyke hosted by gneisses, a river bed near Chiendausiku.

Irregular contact between dolerite dyke (lower margin) and the host Qtz-rich gneiss. A river bed block.

Plate 7 – Quaternary deposits

Layered alluvial brown soils disturbed by SSM gold prospectors. East of Chimdikiti Village.

Mixed fluvial sediment with gravel and sandy layers, Ulongwe West area.

Lateritic red soils used for brick production.

Colluvial conglomeratic sediment cemented by clay in a southern slope of eastern Mawere Anyangu Hill.

A “zero Quaternary” valley, with completely exposed bedrock. Nsanama road.

4. PANAFGEO TRAINING WPA-M3 PARTICIPANTS (2023)

Trainees	Last name	First name	Country
1	Akpo	Livinus Olia	Cameroon
2	Ruot	Gatluak Paul	Ethiopia
3	Yimer	Getnet Gezahegn	Ethiopia
4	Oblitey	Abdul Rashid	Ghana
5	Koech	Milly Jepkogei	Kénya
6	Kiruthu	Robert	Kénya
7	Lesupi	Mopule	Lesotho
8	Lawson Jr.	Joseph	Libéria
9	Njala	Chifundo	Malawi
10	Muacanhia	Okhala	Mozambique
11	Nhamutole	Nelson Ernesto	Mozambique
12	Ononiwu	Darling Chima	Nigéria
13	Toye	Olusegun	Nigéria
14	Nsengiyumva	Cedrick	Rwanda
15	Abdulai	Josephus	Sierra Leone
16	Shongwe	Samkeliso	Eswatini
17	Malambo	Innocent	Malawi
18	Atugonza	Stella	Uganda
19	Ayikobua	Joseph	Uganda
20	Daka	Ntombizodwa	Zambia
21	Kachila	Lungu	Zambia
22	Gebremariam	Merhawi Eyob	Eritrea
23	Ghebretatios	Novel Yonas	Eritrea
24	Ngwata	Chrispin	Malawi
25	Mwambananji	James	Malawi
Experts	**Trainers and officials (CGS, GeoZS, and GSD of Malawi)**		
26	Veronika Štědrá	Coordination/GCh, mapping	Czechia
27	Vladimír Žáček	Mapping, legend, geology	Czechia
28	Lucie Koutská	RS, GIS	Czechia
29	Zuzana Tasáryová	RS/mapping/volcanology	Czechia
30	Kryštof Verner	Struct. geo/mapping/granitoids	Czechia
31	Matevž Novak	Struct.geo, RS, mapping, karst	Slovenia (GeoZS)
32	Pavel Pitra	Metamorphic petrology,	Czechia, France
33	Kondwani Dombola	Acting Director of GSD	Malawi
34	Annock Chiwona	Coordination, GCH, ind. mins.	Malawi
35	Joseph Chirwa	Mapping, RS, geophysics	Malawi
36	Joshua Chisambi	Reg. geology (UM)	Malawi (UM)
37	Brave Manda	Geophysics, mapping	Malawi
38	Elias Kachigamba	IT expert	Malawi

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