PanAfGeo

Geoscientific Knowledge & Skills in African Geological Surveys

WP - E Geohazards and Environmental Management of Mines

Blantyre, Malawi, 7th - 12th November 2022

Field Trip Guide

LIETUVOS GEOLOGIJOS TARNYBA
LITHUANIAN GEOLOGICAL SURVEY

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1 Geological framework of Malawi

The geological history of Malawi is that of Precambrian “mobile belt” (Basement Complex) overlain by Permo-Triassic sediments (Karroo system), Cut by Mesozoic igneous intrusion (Chilwa alkaline Province), and disrupted by Cenozoic rift faulting.

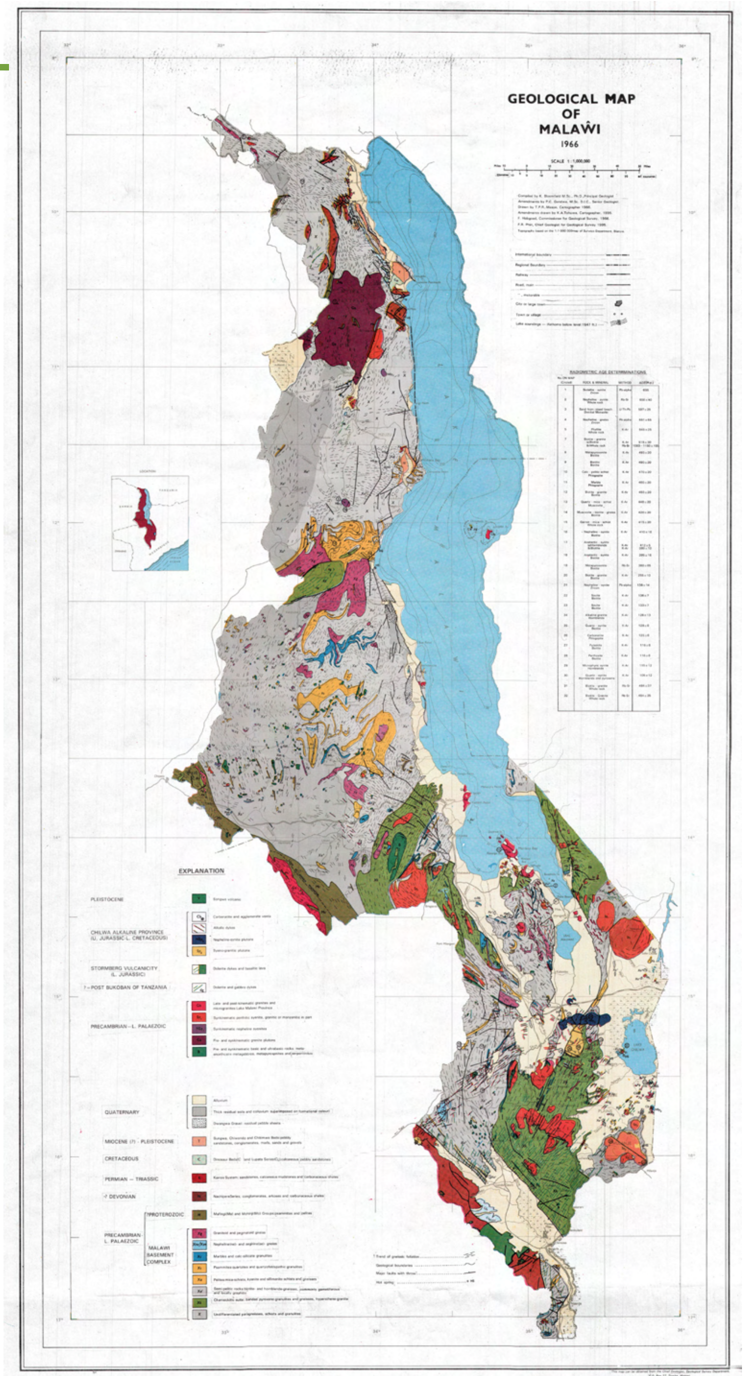
Most of Malawi is overlain by Precambrian to early Palaeozoic sequences of metamorphic rocks of both sedimentary and igneous origin. This is termed “Malawi Basement Complex”. The bulk of the most significant economic mineral occurrences occurs within the igneous metasomatic and high-grade metamorphic 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 Karroo 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 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 Karroo 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 Viwaza 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 1 - Geological Map of Malawi scale 1:1.000.000



2 Field trip description

The field trip will take two days. The first day, from Blantyre, after about an hour of travelling, we will reach the Shire River Valley (Stop from 1 to 6). Here (Stop 4) geophysical survey on seismic noise measurement will be carried out. The second day we will travel north and after half an hour we will reach the Njuli Quarry (Stop 7). Here, field exercises on geomechanics classification methods will be carried out. Later we will continue north up to the last Stop in Changalume old limestone mine (Stop 8). Figure 2 shows the Stops locations placed on the Geohazard Map of Malawi, scale 1:250.000.

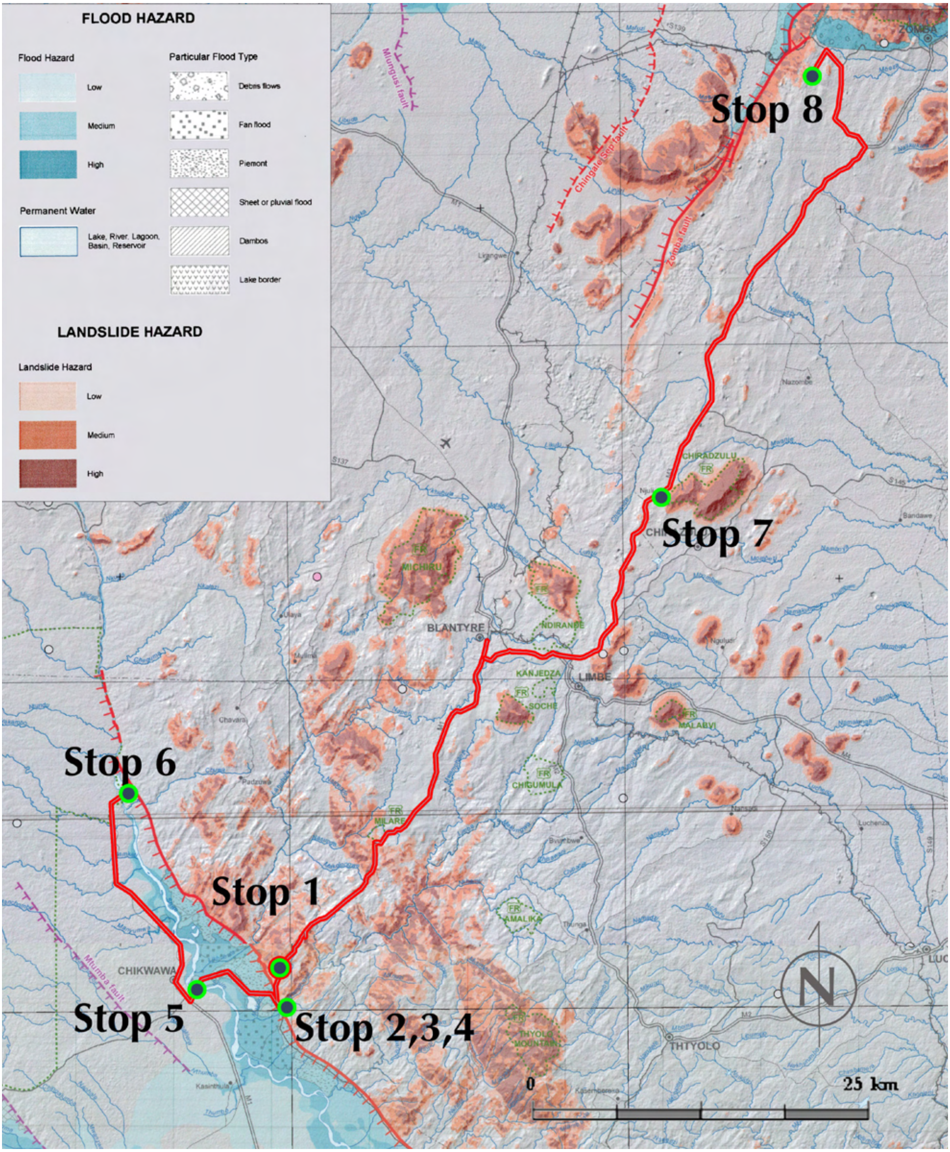
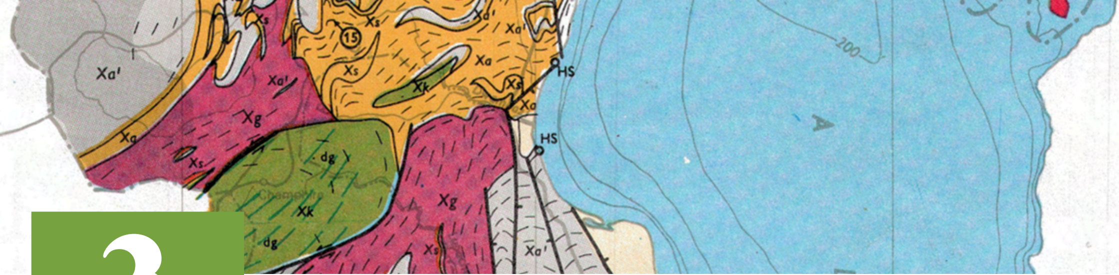


Figure 2 - Field trip stops on Geohazard Map of Malawi scale 1:250.000.



3

Day 1: Blantyre - Shire River Valley

The road from Blantyre to Shire River Valley is characterised by biotite-hornblende gneisses and charnockitic granulites. Other rocks within the area include quartzo-feldspathic and calc-silicate granulites, intrumafic rocks and perthitic gneisses. The Basement Complex within the area is crosscut by a swarm of NE trending dolerite dykes. Superficial deposits of various types mask the metamorphic and igneous rocks within the area. Figure 3 shows the Stops from 1 to 6 on the Geological Map of Malawi scale 1:1.000.000.

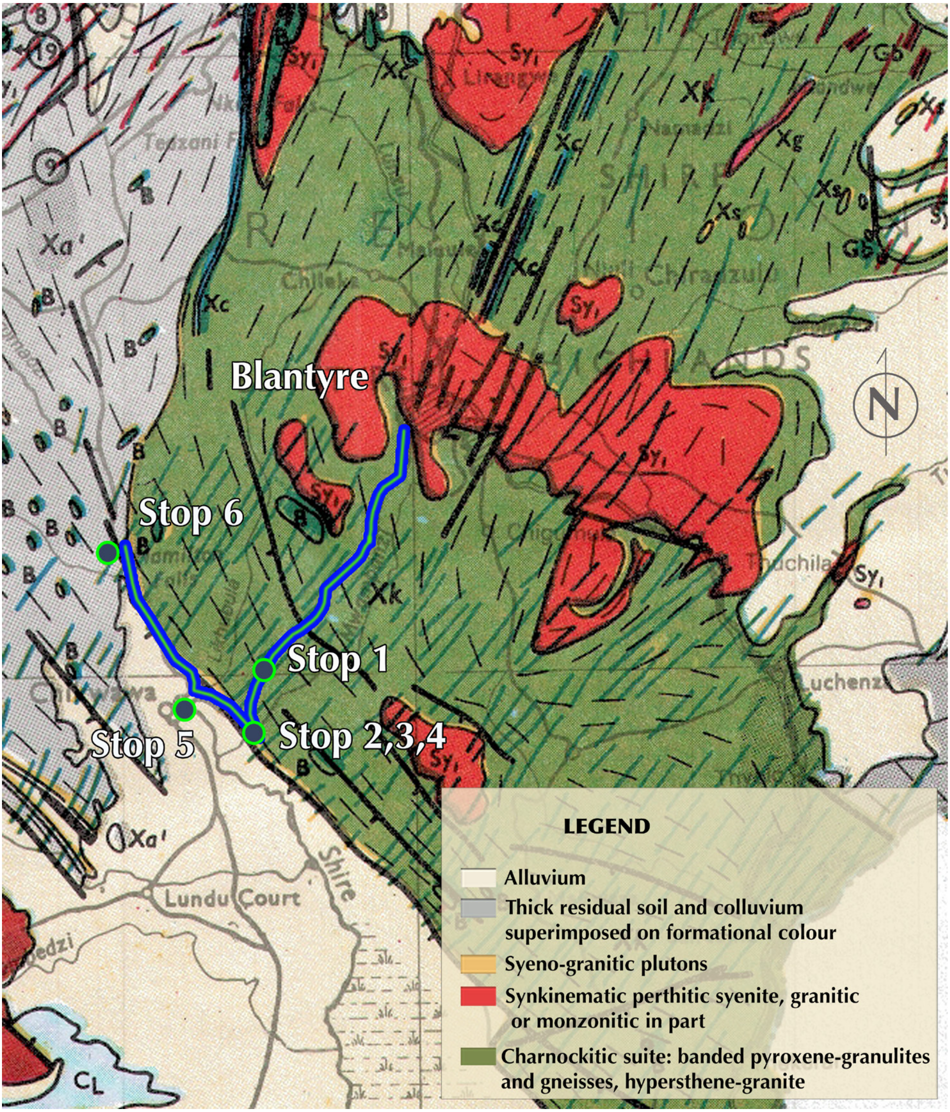


Figure 3 - Day 1 - Field trip stops on Geological Map of Malawi scale 1:1.000.000

Stop 1 - Shire River valley view

The actual Shire River Valley (Figure 4) is a low relief area forming a plain that is defined by the Thyolo fault (Figure 5) escarpment to the north and north-east. It is commonly affected by floods almost each and every rainy season.
The Shire River is the most important river in Malawi. The Shire River is 250 miles (402 km) long and issues from the southern shore of Lake Malawi, of which it is the only outlet. It enters Lake Malombe (q.v.) 5 miles (8 km) south of Mangochi and exits to flow through swampy banks flanked by the Mangochi Hills and the Zomba Mountain scarp to the east and the Chiripa Plateau to the west. The Shire then enters its narrow middle valley. Between Matope and Chikwawa, it drops 1,260 feet (384 m) through 50 miles (80 km) of gorges and cataracts, falling successively over Kholombidzo (formerly Murchison) Falls, Nkula Falls, and Tedzani Falls, through the Mpatamanga Gorge, and over Hamilton Falls and Kapichira (formerly Livingstone) Falls. Dams at Nkula Falls and Tedzani Falls, northwest of Blantyre, harness the river's waters for hydroelectric power. Below Chikwawa, the river enters a wide marshy extension of the Mozambique coastal plain, the only area of Malawi below an elevation of 500 feet (150 m). The Lower Shire River valley's borders are distinct only to the northeast (the Cholo Escarpment) and the southwest (the Nsanje Hills). The chief tributary, the Ruo River, joins the mainstream in the lower valley, forming a narrow levee on which the village of Chiromo is located. The replenished waters then pass-through Elephant Marsh (160 square miles [414 square km]) and Ndindi Marsh on a tortuous lower course to the confluence with the Zambezi River 30 miles (48 km) below Sena, Mozambique.
The Shire River's flow was formerly totally dependent upon the level of Lake Nyasa and the varying volume of the Ruo River; but a dam to regulate the flow from Lake Nyasa through the hydroelectric stations and to provide flood control in the lower reaches has been built at Liwonde. Of the Shire's minor tributaries only the Lisungwe, Wankurumadzi, Masenjere, and Tangadzi East are perennial. Water is lost through evaporation and transpiration in Lake Malombe and the miles of swamp and marshy banks, which are cultivable only during the dry season.
(https://www.britannica.com/place/Shire-River)

Figure 4 - The Shire River Valley, viewed from the Thyolo Fault escarpment

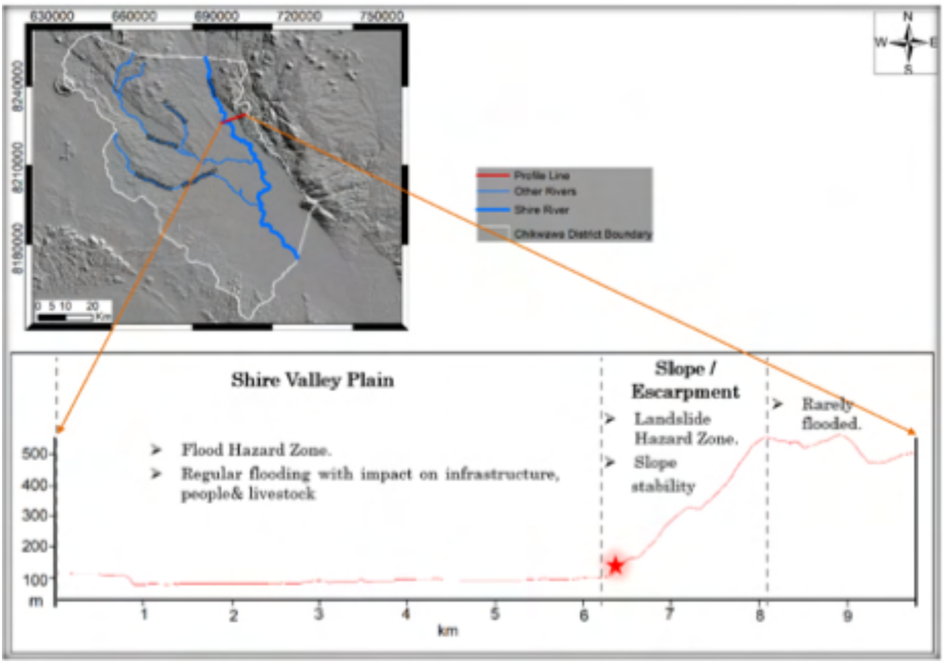


Figure 5 - Thyolo Fault Scarp

Stop 2 - Thabwa condrul quarry

The Quarry is located just at the edge of the Thyolo fault scarp at Thabwa area, a few meters east of the Thabwa Roadblock at on the Blantyre-Chikwawa Road. In the quarry, the excavated rock material is used as aggregates for concrete or road foundations. The rock is mainly composed of gneiss which is extracted with the use of explosive and further crushed in the plant located inside the quarry. The type of rocks being mined at this site are Biotite gneisses. The geology around Stop 3 and 4 is similar to Stop 2 i.e., mostly characterised by weathered biotite gneisses. Both stops (3 & 4) lies on the edge of the Thyolo Fault scarp, the Basement Complex at Stop 3 is exposed to the surface due to excavation work that took place at this site. However, in most of the areas around this site, the Basement is rarely exposed as it has been obscured by superficial deposits.

Figure 6 - Thabwa Quarry

Figure 7 - Rock boulder at Thabwa Quarry

Stop 3 - Outcrop

Figure 8 - Erosial surface near Thabwa Quarry

Stop 4 - River erosion at Mwamphazi River

The Mwamphazi bridge is a strategical infrastructure from logistic, hydrological, and environmental perspectives. The bridge is one of the few connecting structures of the riverbanks in that area and represents a vital infrastructure for the mobility and economy of the local population. Nevertheless, part of the bridge foundations and abutments are heavily damaged due to river erosion probably connected to human exploitation of river sand in that area.

From an engineering point of view, the bridge is a reinforced concrete structure characterised by 5 pylons (Figure 9). The right bank abutment was reinforced with stone gabions to protect the abutment and the upper road from the river erosion. The gabions were likely placed over a concrete superficial platform, clearly visible in the aerial images from 2019 (circle in Figure 10). Presently, the gabions are damaged and no longer work as a protection for the bridge/road system.

A simple multi-temporal analysis by using Google Earth® images from 2001 to 2022 (Figure 11) helps understand the fluvial dynamics and local geomorphology, uphill and downhill the bridge location.

The analysis of the images provides some good indications on local fluvial dynamics. The river presents a general straight trend after an abrupt bend uphill the bridge. In that area, the erosion of the left bank is clearly visible as well as a general trend to soil deposition in the right bank. The flood plain, mostly covered by vegetation, is well visible in the 2001 image. The vegetation progressively disappears in the last decade. The area is being interested by excavation and exploitation of sand, used mainly for construction purposes. The effects of human exploitation of the area are well detectable in 2022 image. Some conclusions of this brief analysis are the following:

- The effect of damage on the Mwamphazi bridge are quite evident and temporally attributable to events occurred mostly in the last decade,
- The local river geomorphology has changed mostly due to human interventions on local flood plain since the natural flow dynamics, also during seasonal flood events, cannot likely justify the magnitude of the structural damage of the bridge,
- Such human effects can be resumed in progressive deforestation of the right riverbank and excavation of the river bottom, especially around the bridge area,
- Anthropogenic actions have produced an acceleration of the river erosion due to increase of the local river bottom slope (and increase of flow velocity) and lack of vegetation which generally acts in reducing erosion and water flow velocity during flood events,
- Erosion effects have mostly affected

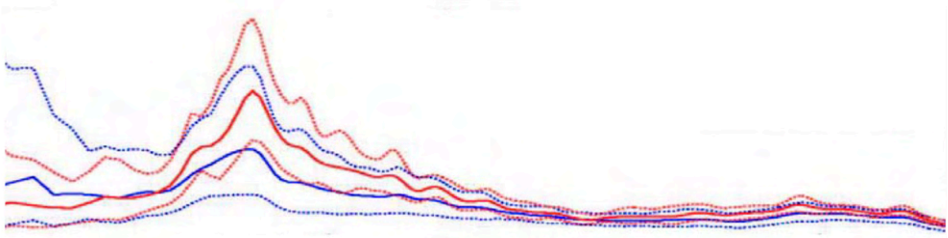
the river right bank where the road embankment is creating a dam effect during flood events.

The above points will be discussed with the trainees along with other subjects such as the present highly vulnerable conditions of the structure, the flood hazard in this sector, the possible reinforcement interventions to improve the structural conditions of the bridge and other river flood hazard structural and non-structural mitigation measures. Passive seismic measurements will be also implemented for the local characterization of the subsoil.

Figure 9 - The Mwamphazi bridge

Figure 10- River erosion at the Mwamphazi bridge

Figure 11 - Multi-temporal analysis images from 2001 to 2022 (Google Earth®)



Single station ambient vibrations recordings

Investigation of the amplification effects of ground motion in sedimentary basins is considered one of the key issues in the field of seismology and earthquake engineering. The so-called "site effects" often result in a large amplification of the seismic ground motion, which may enhance the incoming seismic motion therefore possibly inducing large damages to structures. Amplification of the seismic ground motion in sedimentary basins has been observed worldwide during earthquakes, regardless to the magnitude of the events. It is mainly affected by the heterogeneity and geometry of sediments filling the basin, in terms of geotechnical properties and stratigraphic setting. In case of soft sedimentary covers, the determination of the fundamental resonance frequency at the site is essential in earthquake engineering perspective. In areas of low to moderate seismicity, due to the lack of significant earthquake recordings (if compared to high seismicity areas) a possible solution is to provide information about stratigraphic resonance phenomena by means of using ambient vibrations as a seismic source.

The main goal of our survey is to perform seismic noise measurement at a site, by means of using a portable instrument able to simultaneously records vibrations along two horizontal (orthogonal) directions and along the vertical one. The field procedure adopted here is fully described inside the SESAME 2004 Guidelines attached and briefly summarized here below as a quick field reference:

- Choose the recording site avoiding the proximity of anthropogenic noise sources (buildings and other structures, trees, roads with heavy traffic of car/pedestrians); also measuring above underground structure (sewer, pipes) should be avoided,
- At the chosen site, on soft soil remove stones, cobbles, grass (if any) and any other superficial dirt to prepare an approximately levelled 30x30 cm spot. In case of firm soil/rock, remove the superficial altered layer ensuring that the instrument can be placed on the unaltered soil/rock unit,
- Configure recording parameters on the instruments,
- Place the instrument on the spot previously prepared, ensuring to tightly coupling it to the ground and to reach a good horizontal levelling. Some light and portable instruments use spikes for coupling on soft terrains; it has to be considered that a tight coupling is far more important than an accurate levelling,

- Measure the direction of the main axes of the instrument (at least one) with respect to North and/or to other local references.,
- Start recording and keep distance (some tens of meters) from the instrument to avoid low-frequencies (anthropic) noise influencing the wavefield,
- The measurement conditions at each site along with the recording parameters should be reported in a field-sheet (see the field-sheet proposed in the attached "SESAME 2004 Guidelines"), filling it with the main information concerning the geographical coordinates (e.g. by using a portable GPS device), ground type encountered, weather conditions, known nearby disturbances, quantity and typology of transient noise sources (i. e., cars, trucks)
- At the end of the recording, check the horizontal levelling of the instrument before removing it from the ground, as if this does not match the initial (good) levelling it is recommended to repeat the recording after restoring a good horizontal levelled position,
- Extract the recorded file saving it on PC,
- Each measurement is composed by 3 recordings having the same length, two signals pertaining the horizontal (NS and EW) components and one signal for the vertical (Z) component of the seismic noise. During the following days of the training signals will be extracted and processed following the procedure known as Horizontal-to-Vertical Spectral Ratios or HVSR approach [see SESAME (2004) and references therein],
- The results will be interpreted to possibly infer some constraint to the geotechnical properties of soils and the possible occurrence of stratigraphic amplification phenomena (with related frequencies). If supported by additional geological and geotechnical data, the same HVSR data will also provide information about the depth of the basin as well as about the relative seismic impedance contrasts between seismic strata. For practical purposes, it could also represent a basic tool for differentiate geological unit for earthquake hazard assessment along urbanized areas, with the aim of adopting risk mitigation strategies like, e.g., Seismic Microzonation,
- SESAME (2004). SESAME Project-Site Effects assessment using Ambient Excitations, 2004. European Commission -Research General Directorate Project No. EVG1-CT-2000-00026. Deliverable 23.12 "Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: measurements, processing, and interpretation",
- Many relevant scientific papers can be downloaded at http://sesame.geopsy.org/SES_Reports.htm,
- Reports, Deliverables and Guidelines are available at http://sesame.geopsy.org/SES_TechnicalDoc.htm.

Stop 5 - River erosion

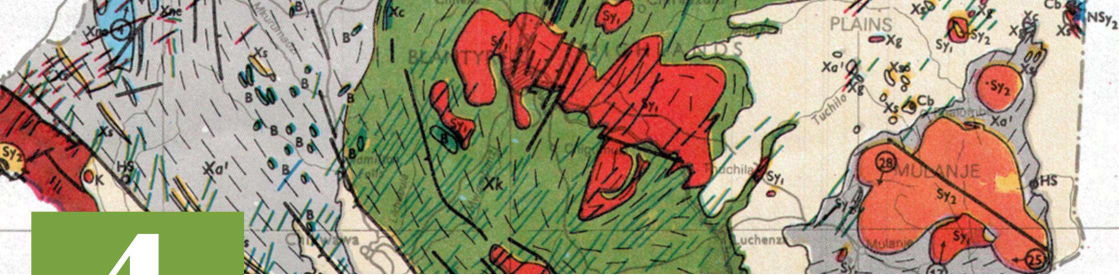
Stop 5 is an exposed profile within Shire River where bank erosion has steeply eroded the banks of this river (Figure 12). The eroded profile on the banks of this river exposes a thick superficial layer (sediments).

Figure 12 - Erosional surface (up) as viewed from Kamuzu Bridge (down) on Shire River

Stop 6 - Kapichira hidropower dam site

The dominant rock type developed in the Shire Highlands and the eastern side of the Shire Valley is a banded hypersthene granulites. The geology around Kapichira falls (Figure 13) is characterized by migmatitic hornblende-biotite gneisses. The area is underlain by rocks of the Mesoproterozoic age which comprises juvenile ~1 Ga (arc-related) rocks deformed and metamorphosed to high grade during the Irumide orogeny. The migmatitic hornblende-biotite gneisses within this locality have been highly folded and strongly foliated. Granitic and pegmatitic veins run parallel to foliation with some veins crosscutting these gneisses.

Figure 13 - Highly folded migmatitic hornblende-biotite gneisses around Kapichira Falls. In the background is the Kapichira Dam before being damaged by Hurricane Ana



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Day 2: Blantyre – Njuli Quarry and Changalume old limestone mine

The road from Blantyre to Njuli Quarry (Figure 14) is characterized by hornblende biotite gneisses and Charnockitic granulites that are either intermediate or basic in character. In some areas, the Charnockitic granulites have been interbanded with a series of paragneisses which include calcareous and quartzo-feldspathic types. Orthogneises are also common in the area and these include metagabbros, metapyroxenites, foliated microgranites and a series of perthite rich rocks. The type of rock being mined at Njuli Quarry site is mobilised and magmatitic mafic Charnockitic granulites.

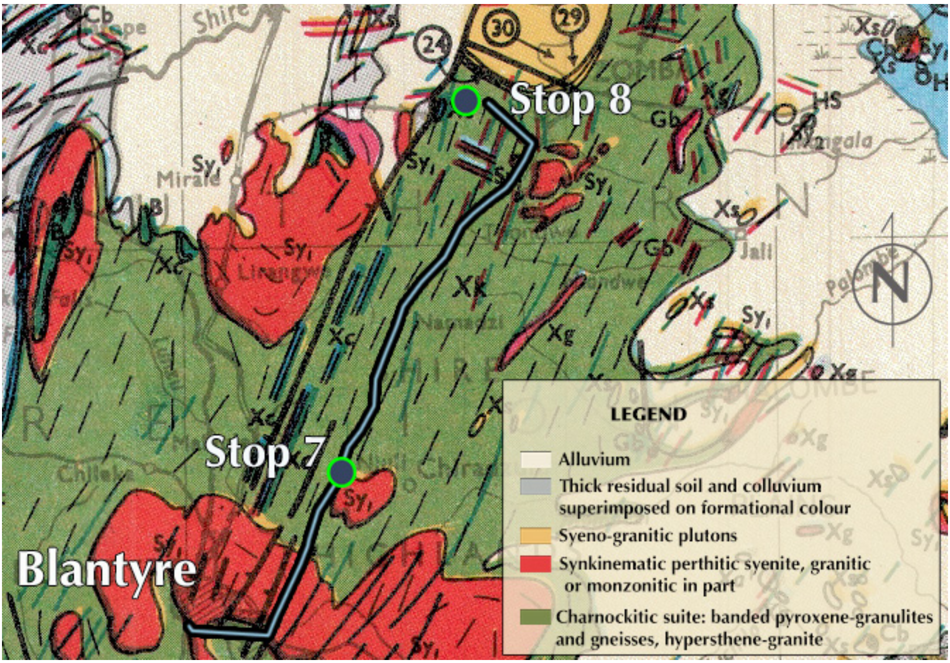


Figure 14 - Day two - Field trip stops on Geological Map of Malawi scale 1:1.000.000.

Stop 7 - Njuli quarry: geomechanical rock mass classification

The Njuli Quarry (Figure 15) is located approximately 30 km NE of Blantyre. The outcropping rock at this site is made prevalently of Charnockitic Granulites that are being exploited as construction materials. Inside the quarry, a steep slope formed by jointed rock material outcrops and represents a very good example to implementing a rock mass characterization.As discussed in the class lecture on engineering geological methods applied to rock mass analysis and stability, discontinuities control the mechanical behaviour of rock masses along with other elements such as circulating waters, type and geotechnical characteristics of the rock, slope geometry, etc.

The scope of the field exercise is make the trainees familiar with methods and practical site analysis to collect engineering geological data needed to perform simplified classification systems (e.g. Rock Mass classifications) which are based on empirical correlations between rock mass parameters and a set of engineering projects including open and underground mining, and slope stability.

The reconstruction of the overall behaviour of a rock mass, both the engineering properties of the rock material and the discontinuities should be taken into consideration. The most significant parameters that are used in classification systems are the following:

- Strength and deformability of intact rock,
- Rock Quality Designation (RQD) which considers the intensity of

Figure 15 - Aerial view of Njuli Quarry Mine for rock aggregates (Google Earth®)

discontinuities observed in a drill core and/or in an rock mass,

- Discontinuities parameters (i.e spacing, orientation, width, roughness, weathering),
- Groundwater pressure and flow;
- In-situ stress,
- Geological structures such as faults and folds.

For the field analysis, some engineering geological tools are needed such as: (i) a geological and/or structural compass to measure orientation of discontinuities and slope, (ii) a Schmidt-hammer for in-situ assessment of rock compressive strength, (iii) a profilometer (Burton comb) to reconstruct the roughness of discontinuity surfaces and determine the rock JRC (Joint Roughness Coefficient).

Procedure

Description of the main characteristics of the site (e.g. location, date, geology) using a survey data sheet (Figure 16).

INPUT DATA FORM: GEOMECHANICS CLASSIFICATION (ROCK MASS RATING SYSTEM)

Name of the project Site of survey: Conducetd by: Date:	STRUCTURAL REGION	DEPTH m	ROCK TYPE

STRENGH INTACT ROCK MATERIAL

Designation	Uniaxial compressive strenght, Mpa	Point -load strenght index, Mpa
Very High	Over 250.......	> 10............
High	100 - 250.......	4 - 10 ....
Medium Heigh	50 -100.........	0 - 4 ....
Moderate	25 - 50..........	1 - 2 ....
Low	5 - 25............	< 1 ....
Very Low	1 - 5..............	

DRILL CORE QUALITY RQD

Excellent quality :	90 - 100%	....
Good quality :	75 - 90%	....
Fair quality :	50 - 75%	....
Poor quality :	25 - 50%	....
very poor quality :	0 - 25%	....

R.Q.D. = Rock Quality Designation

STRIKE, DIP AND DIP DIRECTIONS

	(average)	(angle)	(angle)
Set 1	Strike	DIP	DIP DIRECTION....................
Set 2	Strike	DIP	DIP DIRECTION....................
Set 3	Strike	DIP	DIP DIRECTION....................
Set 4	Strike	DIP	DIP DIRECTION....................

NOTE: Refer all directions to magnetic north

SPACING OF DISCONTINUITIES

		Set 1	Set 2	Set 3	Set 4
Very wide:	Over 2 m	....	....	....	....
Wide	0.6 - 2 m	....	....	....	....
Moderate	200 - 600 mm	....	....	....	....
Close	60 - 200 mm	....	....	....	....
Very close	< 60 mm	....	....	....	....

GROUND WATER

INFLOW per 10 m of tunnel lenght	liters/minute	....	GENERAL CONDITIONS (completely dry, damp,wet, dripping or flowing under low/medium or high presuure
WATER PRESSURE	kPa		

CONDITION OF DISCONTINUITIES

		Set 1	Set 2	Set 3	Set 4
PERSISTENCY (CONTINUITY)					
Very Low	< 1 m	....	....	....	....
Low	1 - 3 m	....	....	....	....
Medium	3 - 10 m	....	....	....	....
High	10 - 20 m	....	....	....	....
Very High	> 20 m	....	....	....	....
SEPARATION (APERTURE)					
Very tight joints	< 0.1 mm	....	....	....	....
Tights joints	0.1-0.5 mm	....	....	....	....
Moderately open joints	0.5-2.5 mm	....	....	....	....
Open joints	2.5-10 mm	....	....	....	....
Very wide aperture	> 10 mm	....	....	....	....
ROUGHNESS (state also if surfaces are stepped, undulating or planar)					
Very rough surfaces		....	....	....	....
rough surfaces		....	....	....	....
Slighty rough surfaces		....	....	....	....
Smooth surfaces		....	....	....	....
Slickensided surfaces		....	....	....	....
FILLING (GOUGE)					
Type:		....	....	....	....
Thikness:		....	....	....	....
Uniaxial compressive strenght Mpa		....	....	....	....
Seepage		....	....	....	....
WALL ROCK OF DISCONTINUITES					
Unweathered		....	....	....	....
Slightly weathered		....	....	....	....
Moderately weathered		....	....	....	....
Highly weathered		....	....	....	....
Completely weathered		....	....	....	....
Residual soil		....	....	....	....

GENERAL REMARKS AND ADDITIONAL DATA

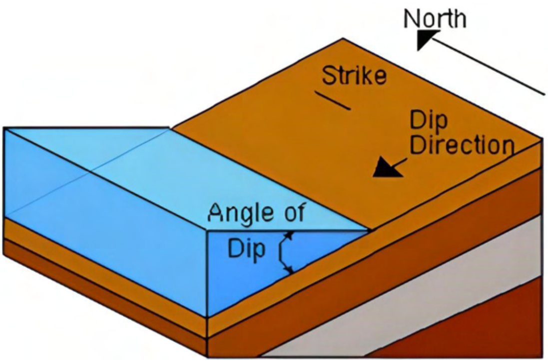
MAJOR FAULTS specify locally, nature and orientation

Note: consult ISRM document: *Quantitative description of discontinuities in rock..*

Figure 16 - Example of survey data sheet

Implementation of a scanline (Figure 17) which intersects the main sets of discontinuities (i.e. faults, joints, main fractures, bedding planes) and Measurement of a discontinuity plane with a structural compass (Figure 18).

Figure 17 - Scanline in the rock slope outcropping in the Njuli Quarry



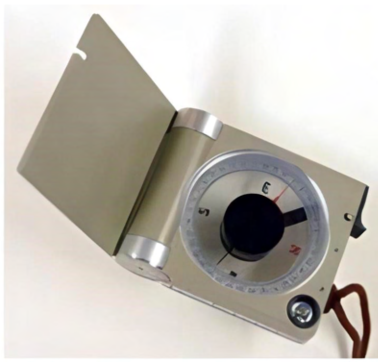


Figure 18 - Measurement of a discontinuity plane with a structural compass

Assessment of UCS (Uniaxial Compressive Strength) with Schmidt-hammer (Figure 19).

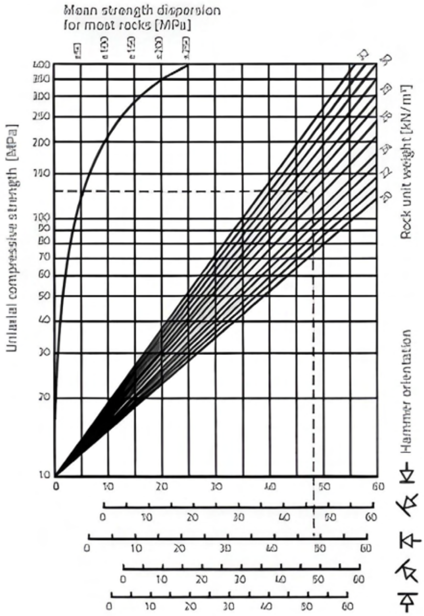


Figure 19 - Assessment of UCS (Uniaxial Compressive Strength) with Schmidt-hammer.

Assessment (Figure 20) of Joint Roughness Coefficient (JRC) with profilometer (Burton comb).

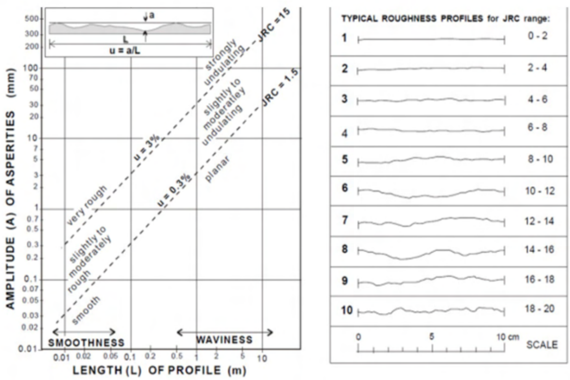


Figure 20 - Assessment of JRC with profilometer

Assessment of other relevant parameters which characterize discontinuities such as spacing, persistence, opening, presence and type of filling, weathering and presence of water/humidity. Each of the above operations have to be made for any single set of discontinuities.

It is important to analyse the general condition of the rock slope as a whole as well as observing specific portions where the density of discontinuities can determine a higher fragmentation of the rock due to i.e., presence of a fault or major joints. Those areas can likely be the most prone to slope instability processes and, therefore, have to be more carefully examined and assessed.

Usually, unstable slopes are characterised by three or more sets of discontinuities. The number, persistence and spacing of discontinuities determine the volume of blocks as well as the rock mass aspect. The orientation of the discontinuities and position of blocks vs. the slope face govern the type of potential slope failure.

The field data collection is followed by a desk analysis that is mainly addressed to determining the geotechnical rock mass condition by applying the most common Rock Mass classifications like RMR, GSI, RMi, Q.

Another fundamental analysis regards the actual and potential slope stability conditions of the slope. The analysis starts from the stereographic projection (figure of the discontinuities,planes and poles) which is generally performed with specific software, (Figure 21).

The detection of different typologies of potential failure in rock masses (e.g. planar, toppling, sliding) is a fundamental condition to i.e. (i) plan and install distinct monitoring systems, (ii) design and implement specific typologies of landslide mitigation works, (iii) determine the opportunity and ways of exploitation and excavation of open mines and quarries.

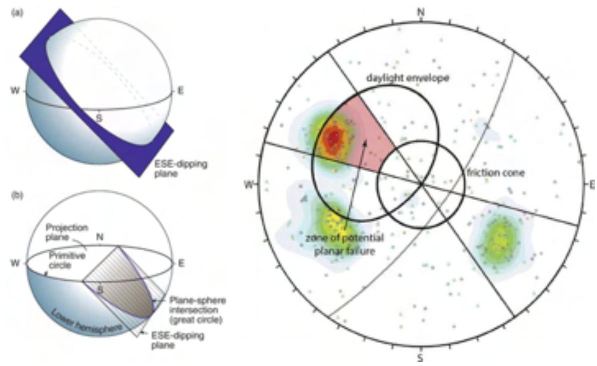


Figure 21 - Stereographic projection and example of kinematic analysis

More complete information: https://civilenglineering.files.wordpress.com/2014/10/rock_slope_engineering_civil_and_mining.pdf

Stop 8 - Changalume old limestone mine

The Basement Complex paragneisses and charnokitic granulites outcrop over about a third of Zomba area, the remaining one third is covered by colluvium. Within the Changalume area the outcropping rocks are dominated by a marble that forms the Changalume Hill (Figure 22), the marble at this site ranges in colour from white to grey or pink with a granular to saccharoidal texture.

For the past years this marble was being mined for cement production by Portland Cement Company before it was turned into a military base.

Figure 22 - Aerial view of Old Changalume Marble Mine (Google Earth®)

Bibliography

ASTM (2001).
Standard test method for determination of rock hardness by rebound hammer method. ASTM Stand. 04.09 (D 5873-00).

Barton N, (1976). *The shear strength of rock and rock joints. Int.* L. Rock Mech. Min. & Geom. Abstracts 13, 255-279.

Barton N. (1999). *General report concerning some 20th Century lessons and 21st Century challenges in applied rock mechanics, safety, and control of the environment.* Proc. of 9th ISRM Congress, Paris, Balkema, Netherlands, 3, 1659-1679.

Barton N.R. and Choubey (1977). *The shear strength of rock joints in theory and practice.* Rock Mech. 10 (1-2), 1-54.

Barton N., Lien R. and Lunde J. (1974). *Engineering classification of rock masses for the design of rock support.* Rock Mechanics 6, 1974, pp. 189-236.

Bieniawski Z.T. (1976). *Rock mass Classification in Rock Engineering. Proc. of the Symp.* "Exploration of rock Engineering", 1, 97-106.

Bieniawski, Z.T. (1989). *Engineering rock mass classifications.* Wiley, New York.

Bridges M.C. (1975). *Presentation of fracture data for rock mechanics.* 2nd Australia-New Zealand Conf. on Geomechanics, Brisbane, 144-148.

Hoek E. and Brown E.T. (1988). *The Hoek-Brown failure criterion - a 1988 update*. Proc. 15th Canadian Rock Mech. Symp. (Curran J.H., ed.), Toronto: Civil Engineering Dept., University of Toronto, 31-38.

Hudson J.A. and Priest S.D. (1979). *Discontinuities and rock mass geometry.* Int. Journ. Rock Mech. Min. Sci. & Geomech. Abstracts, 16, 339-362.

Hudson J.A. and Priest S.D. (1983). *Discontinuity frequency in rock masses.* Int. Journ. Rock Mech. Min. Sci. & Geomech. Abstracts, 20, 2, 73-89.

ISRM, Commission on Standardization of Laboratory and Field Tests (1978a). *Suggested methods for the quantitative description of discontinuities in rock masses.* Int. Journ. Rock Mech. Min. Sci. & Geomech. Abstracts, 15 , n.6, 319-368.

ISRM, Commission on Standardization of Laboratory and Field Tests (1978b). *Suggested methods for determining hardness and abrasiveness of rocks.* Int. J. Rock Mech. Min. Sci., Geomech. Abstr. 15, 89 – 97.

ISRM, Commission on Standardization of Laboratory and Field Tests (1981). *Basic Geotechnical Description of Rock Masses.* Int. Journ. Rock Mech. Min. Sci. & Geomech. Abstracts, 18, 85-110.

ISRM - Commission on Standardization of Laboratory and Field Tests (1985). *Suggested methods for determining point load strength.* Int. J. Rock Mech. Min. Sci. & Geomech. Abstracts, 22, 51-62.

MIDIMAR (2015). *The National Risk Atlas of Rwanda, Ministry of Disaster Management and Refugee Affairs,* 173 p.

Palmström A. (2000). *Recent developments in rock support estimates by the RMi. Journal of Rock Mechanics and Tunnelling Technology.* Vol. 6, No. 1 May 2000, pp. 1–19.

Phillips F.C. (1971). *The use of stereographic projection in structural geology.* Edward Arnold, London, 3rd ed.

Priest S.D. (1985). *Hemispherical projection methods in rock mechanics.* George Allen and Unwin, 124 p.

Priest S.D. (1993). *Discontinuity analysis for rock engineering.* Chapman & Hall Ltd, London, UK, pp. 473.

Priest S.D. and Hudson J.A. (1976). D*iscontinuity spacings in rocks.* Int. Journ. Rock Mech. Min. Sci. & Geomech. Abstracts, 13, 135-148.

Priest S.D. and Hudson J.A. (1981). *Estimation of discontinuity spacing and trace length using scanline surveys.* Int. J. Rock Mech. Min. Sci and Geomech., 18, 183-197.

Sen Z. and Eissa E.A. (1992). *Rock Quality Charts for log-normally distributed block sizes. Int. Journ. Rock Mech.* Min. Sci. & Geomech. Abstracts, 29, 1-12.

Sen Z. and Kazi A. (1984). *Discontinuity spacing and RQD estimates from finite length scanlines.* Int. Journ. Rock Mech. Min. Sci. & Geomech. Abstracts, 21(4), 203-212.

SESAME (2004). - *Site Effects assessment using Ambient Excitations. SESAME Project European Commission -Research General Directorate Project No. EVG1-CT2000-00026. Deliverable 23.12 "Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: measurements, processing, and interpretation"*

Shorey P.R., Barat D., Das M.N., Mukherjee K.P., Singh B. (1984). S*chmidt hammer rebound data for estimation of large scale in situ coal strength.* Int. J. Rock Mech. Min. Sci., Geomech. Abstract., 21, 39-42.

Stille H. and Palmström A. (2003). *Classification as a tool in rock engineering.* Tunnelling and Underground Space Technology, Vol. 18, pp. 331-345.

Trunk U. and Honish K. (1989). *Reported in "Engineering Rock Mass Classification".* Bieniawski Z.T.

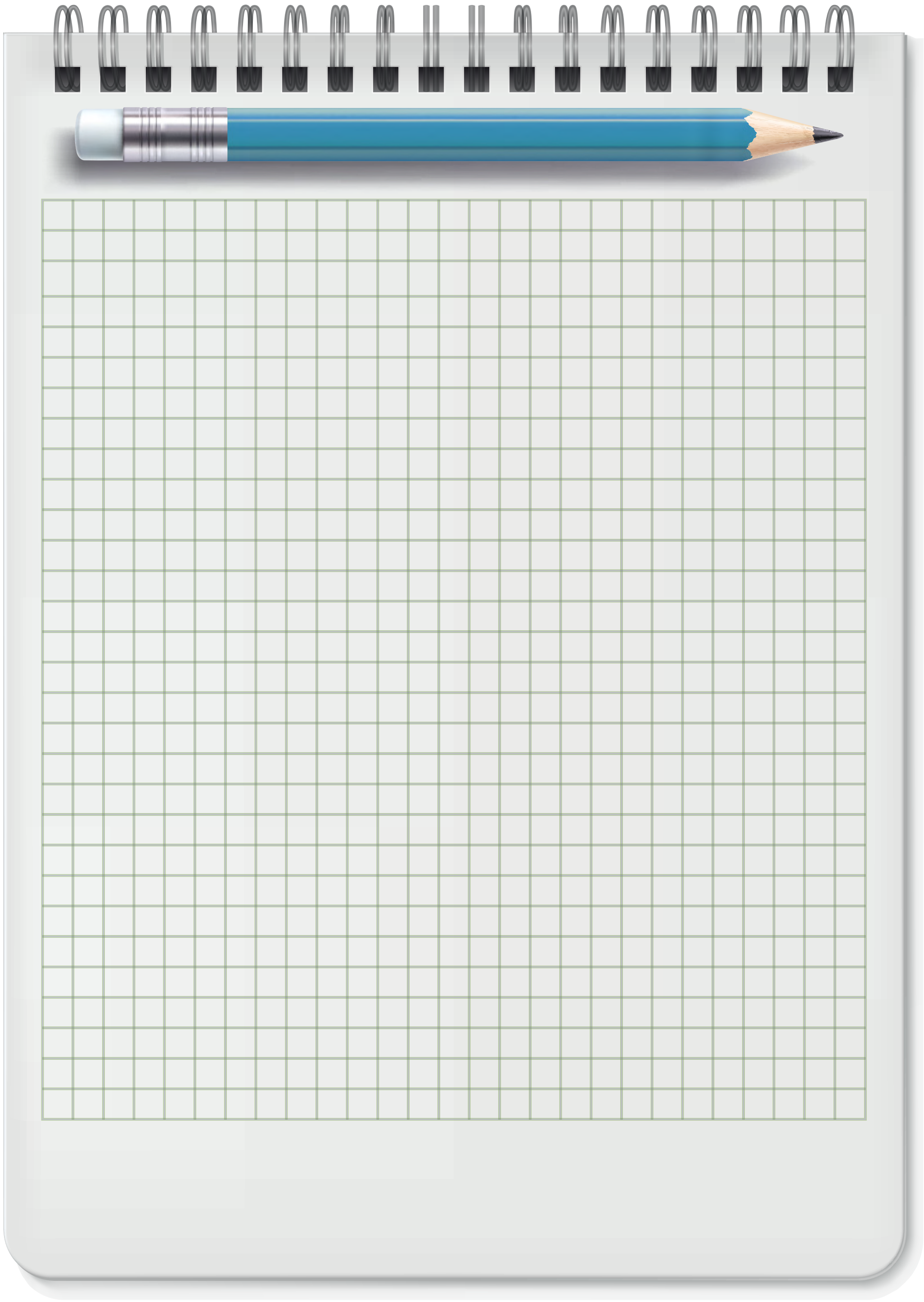
VV.AA. (1966). *Geological Map of Malawi Scale 1: 1.000.000*

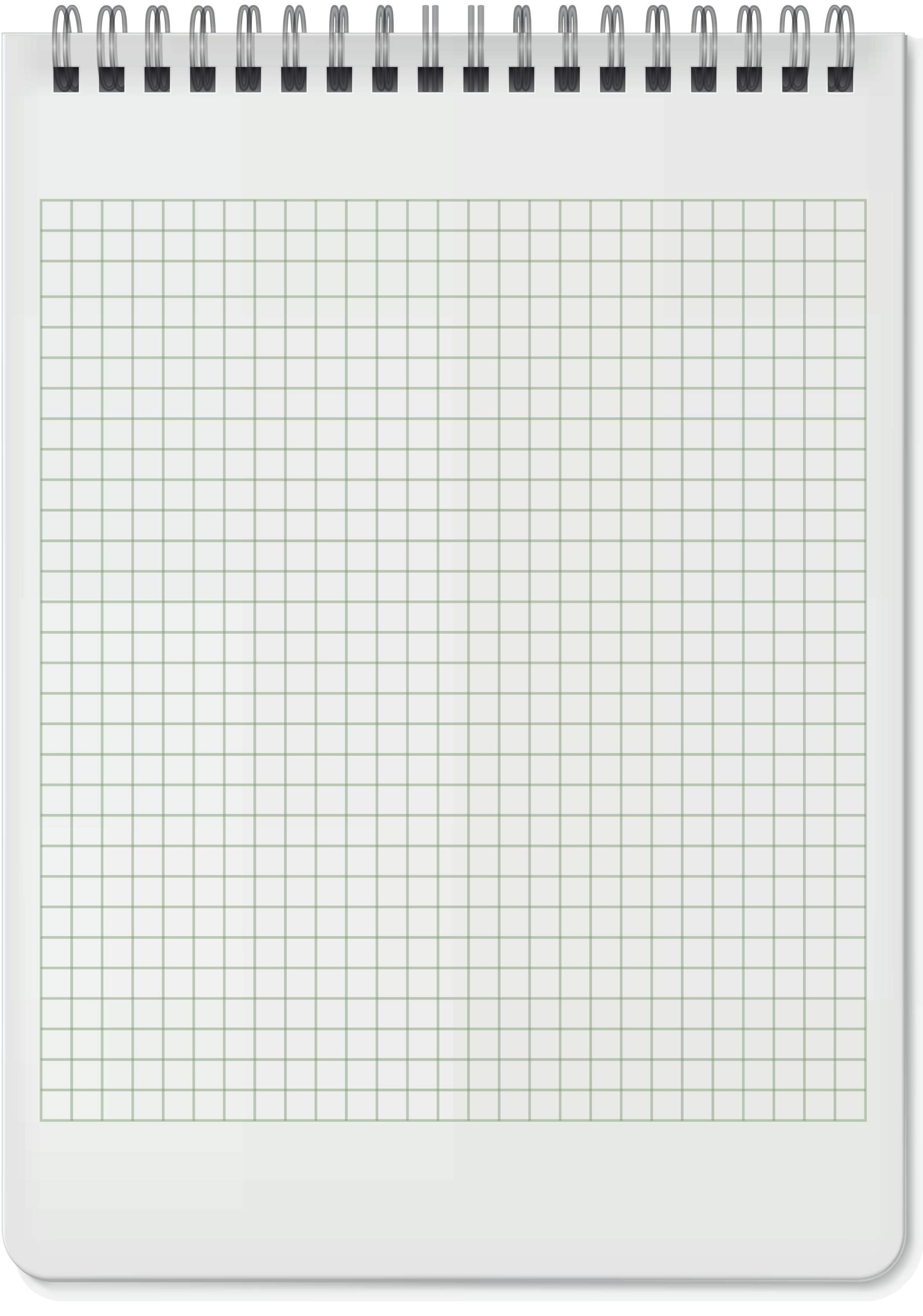
VV.AA (2021). *Geohazard Map of Malawi at 1:250.000 – II Zomba. Geological Mapping & mineral assessment – The Ministry of Mining - Project (GEMMAP) of MALAWI*

Web sites

https://www.britannica.com/place/Shire-River

https://civilenglineering.files.wordpress.com/2014/10/rock_slope_engineering_civil_and_mining.pdf





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LITHUANIAN GEOLOGICAL SURVEY

GeoZS Geološki zavod Slovenije

MINMIDT Ministères des Mines, de l'Industrie et du Développement Technologique

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

Council for Geoscience