FIELD TRIP GUIDE

PanAfGeo

Pan-African Support to Geological Sciences and Technology Africa-EU Partnership

WP-E GEOHAZARD AND ENVIRONMENTAL MANAGEMENT OF MINES

KIGALI, RWANDA, 19TH – 25TH NOVEMBER 2023

RMB Rwanda Mines, Petroleum and Gas Board

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

Lietuvos Geologijos Tarnyba LITHUANIAN

GeoZS Geološki zavod Slovenije

Council for Geoscience

MINMIDT Ministry of Mines, Industry and Technological Development

Editors
G. Delmonaco, F. Traversa (ISPRA)
Graphic project
P. Moretti (ISPRA)
Field Trip Committee
J. Satkūnas (LTG)
T. Niyitegeka (RMB)
G. Delmonaco, F. Traversa (ISPRA)

Authors:
ISPRA, Geological Survey of Italy:
G. Delmonaco, F. Traversa, P. Moretti,
S. Nisio, L.M. Puzzilli
Rwanda Mines, Petroleum and Gas Board (RMB):
J. C. Ngaruye, T. Niyitegeka
Geological Survey of Lithuania (LTG):
J. Satkūnas
Council for Geoscience of Republic of S. Africa (CGS):
S. Diop
Polish Geological Institute (PGI):
S. Wołkowicz
Geological Survey of Slovenia (GeoZS):
D. Rokavec, P. Gostinčar
Geological Survey of Cameroun:
F. Tchoffo
University Omar Bongo, Gabon, University of Warsaw, Poland
D. Mouketou Tarazewicz

Summary

ORGANISATION OF AFRICAN GEOLOGICAL SURVEYS OAGS
EuroGeoSurveys European Geoscience for Society
The Geological Surveys of Europe
European Commission

GEOHAZARDS OF AFRICA

The aim of the Work Package "Geohazards and Environmental Management of Mines (WP-E)" of the PanAfGeo project is to organize theoretical and practical sessions on assessment, monitoring of geohazards (natural and anthropogenic) and prevention or mitigation of hazardous consequences.

Participants of the courses are specialists of African Geological Surveys and trainers are geoscientists from Geological Surveys of Italy, Lithuania, Poland, Slovenia and South Africa.

The Geohazards courses were organized in South Africa (2017), Tanzania and Zambia (2018), and Ethiopia (2019). The four courses were attended by 121 participant from 34 African countries. The courses on Geohazards and environmental management of mines were carried out in Cameroon (2022), Malawi (2022) and Gabon (2023). Now we are in Rwanda.

The courses not only provide presentation and transfer of knowledge and technologies available but also give an opportunity to learn about geohazards in Africa.

Investigation of geohazards however is not a priority task of many Geological Surveys Organizations (GSOs) of African countries so far.

The Review of African Geological Survey Organisation Capacities and Gaps carried out by the Economic Commission for Africa in 2018 shows that GSOs in Africa, in general, lack information on geological hazards.

A vast range of geohazards in Africa is related with mining contamination of environment by heavy metals, acid mine drainage, subsidence of surface, change of landscape etc.

We assume that relevance of research and prevention of geohazards will increase due to increasing urbanization, exploitation of mineral resourse and number of population, climate change and related phenomena, extreme events and global water level rise.

Background photo: Virunga Mountains

GEOLOGICAL FRAMEWORK OF RWANDA

The Geology of Rwanda (Figure 1) generally is made up of sandstones alternating with shales, which are all assigned to the Mesoproterozoic Burundian Supergroup, sometimes intercalated by granitic intrusions. In the east of the country predominate older granites and gneisses. Neogene volcanics are found in the northwestern and southwestern parts of Rwanda. Young alluvial and lake sediments occur along the rivers and lakes.

In various localities of Rwanda, for instance to the south and southwest of Butare and in the Congo-Nile watershed to the southwest of Rwengeri, pre-Burundian migmatites and gneisses accompanied by crystalline whitish quartzites occur. Some of these rocks in the Butare area have been retrometamorphosed (initial stages of sericitization) and slightly cataclased by a later deformation. Generally, the stratigraphic sequences established in Rwanda can be nearly identified with those, which appear in neighbouring Burundi. However, in Rwanda it was not yet possible to observe the contact with the underlying Archean basement. The sedimentary succession of the Burundian Supergroup can be subdivided into the following units: The Lower Series ("La Série Inférieure"), the Byumba Series, and the Miyove Series; each of these can be subdivided into formations of quartzites and various undifferentiated rocks.

The base of the Lower Series is the most developed formation, characterized by black sericitic shales.

The metamorphic rocks in the east of the country probably represent metamorphosed Burundian formations.

All these sedimentary sequences indicate a former shallow marine, high-energetic environment, as often shown by the oblique stratification, the conglomerates and the symmetric ripplemarks within the layers.

At least four types of granitic rocks are known within the Kibaran Belt.

Of these, the two first are synorogenic and the two last postorogenic.

The culmination of the Kibaran orogeny occurred from about 1,370 to 1,310 Ma.

The first of these ages' dates early granites in Rwanda. Post-orogenic granites are also known from Rwanda and have been dated at about 1,136 Ma.

Cenozoic to Recent volcanic rocks occur in the northwest and west of the country.

Some of these volcanoes are highly alkaline and extensions from the Virunga volcanic area of southwestern Uganda and eastern Democratic Republic of Congo.

Tertiary and Quaternary clastic sediments fill parts of the Western Rift in the western part of the country.

Gneiss quarry in Nyacyonga

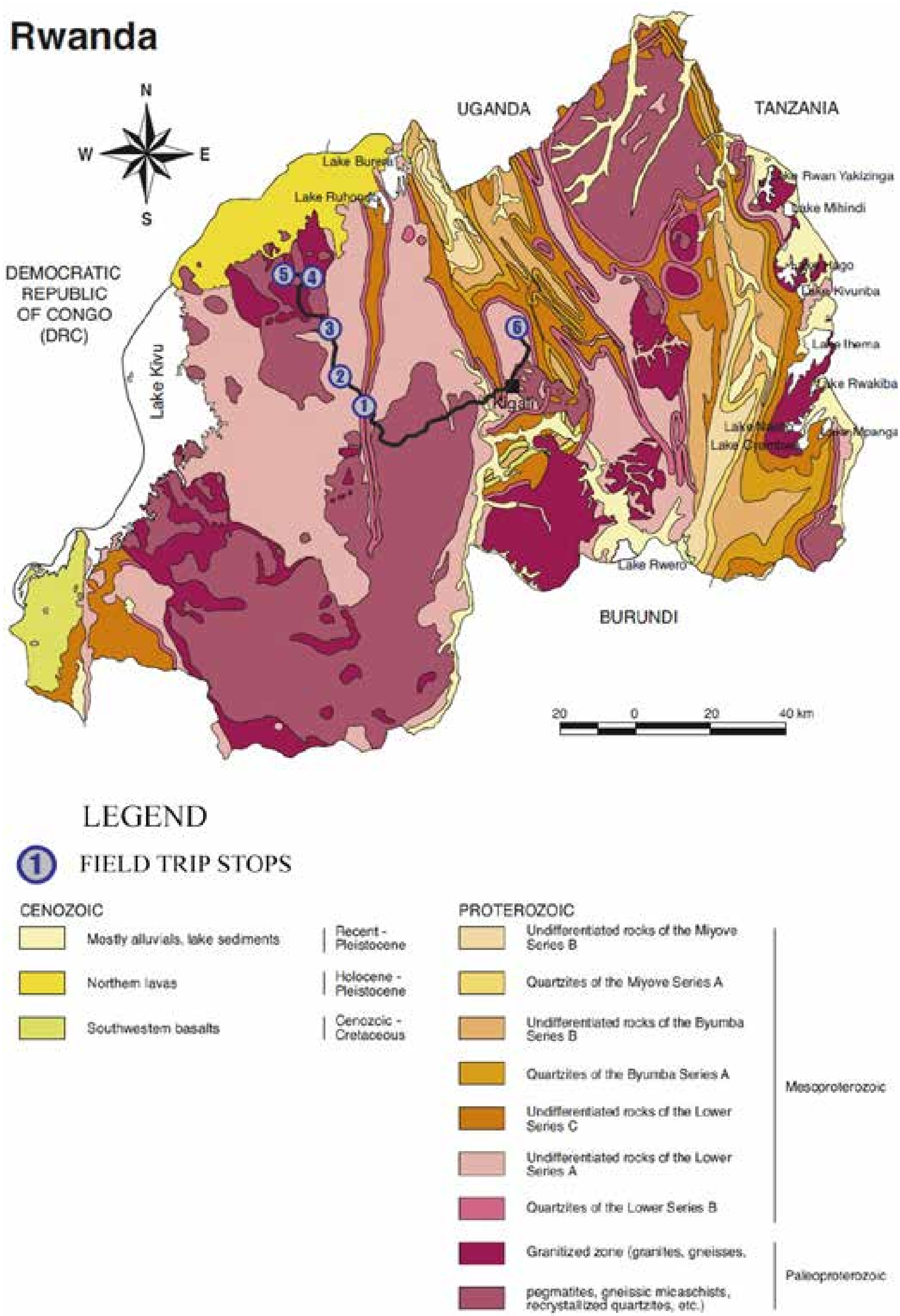


Figure 1 - Geological overview of Rwanda (Schlüter T. 2006, mod.)

LANDSLIDE HAZARD IN RWANDA

The National Risk Atlas of Rwanda (MIDIMAR, 2015) reports data on geology and landslide hazard which are briefly described as follows. The Rwandan relief is hilly and mountainous with an average altitude of 1,700 meters. The highest point, on Mt Karisimbi, is 4,507 meters above sea level. Rwanda has volcanic mountains at the northern fringe and the western province extends over an unstable mountainous area while the central plateau is dominated by undulating hills. This topography is characterized by steep slope often affected by landslides. However, the eastern part of the country is relatively flat with altitudes well below 1,500 meters. The lowest point is in the Bugarama area at 900 m, corresponding to the rift valley where Kivu Lake is situated.

Landslides affected different areas of Rwanda in the past. Landslides have led to loss of lives, injuries, and left many homeless and without livelihood. However, little research or literature exists about landslide hazards in Rwanda till date. In addition, there are significant data gaps on historical landslide events. A systematic recording of disasters started in 2010 by MIDIMAR. Prior to this period, international centres of data collection such as CRED (EM-DAT) and the Royal Museum for Central Africa (RMCA) were the only sources of disaster data. Most often the recorded events are not well georeferenced, and the inventory is challenging.

From RMCA data, around 8,000 people were affected since 1963 up to 2010, among them 45 died and a few houses were destroyed. Since the establishment of MIDIMAR, a systematic recording system was installed and from 2011 to 2013, 74 deaths, 22 injuries, 573 houses destroyed or damaged, and 656 ha of affected land were recorded due to landslide. The most impacted is the western province with more than half of the total deaths' records (51%), followed by the northern province (38%) of the total cases. Districts Nyabihu, Rulindo, Burera and Karongi experienced more deaths than others.

Given time limitations and scarce data, the landslide hazard mapping in Rwanda was implementing using a semi-quantitative slope susceptibility index approach by adopting a Spatial Multi-Criteria Evaluation (SMCE) method on the Integrated Land and Water Information System (ILWIS-GIS). Semi-quantitative approaches consider explicitly several factors influencing the slope stability. The methodology considered the following factors: lithology, soil type, soil depth, rainfall, slope, land cover, and distance to roads. A range of scores and settings for each factor were used to assess the extent to which that factor is favorable or unfavorable to the occurrence of instability (slope). Figure 2 shows the Rwanda slope susceptibility map produced using SMCE in ILWIS where colors from green to red indicate the susceptibility classes from very low to very high.

The western high lands are more prone to landslide while the eastern lowlands are of low susceptibility. Due to its hilly topography, Rwanda shows high susceptibility to landslide, 42% of the country's area is classified with moderate to very high susceptibility. The map was further validated by the results of the field surveys and historical records.

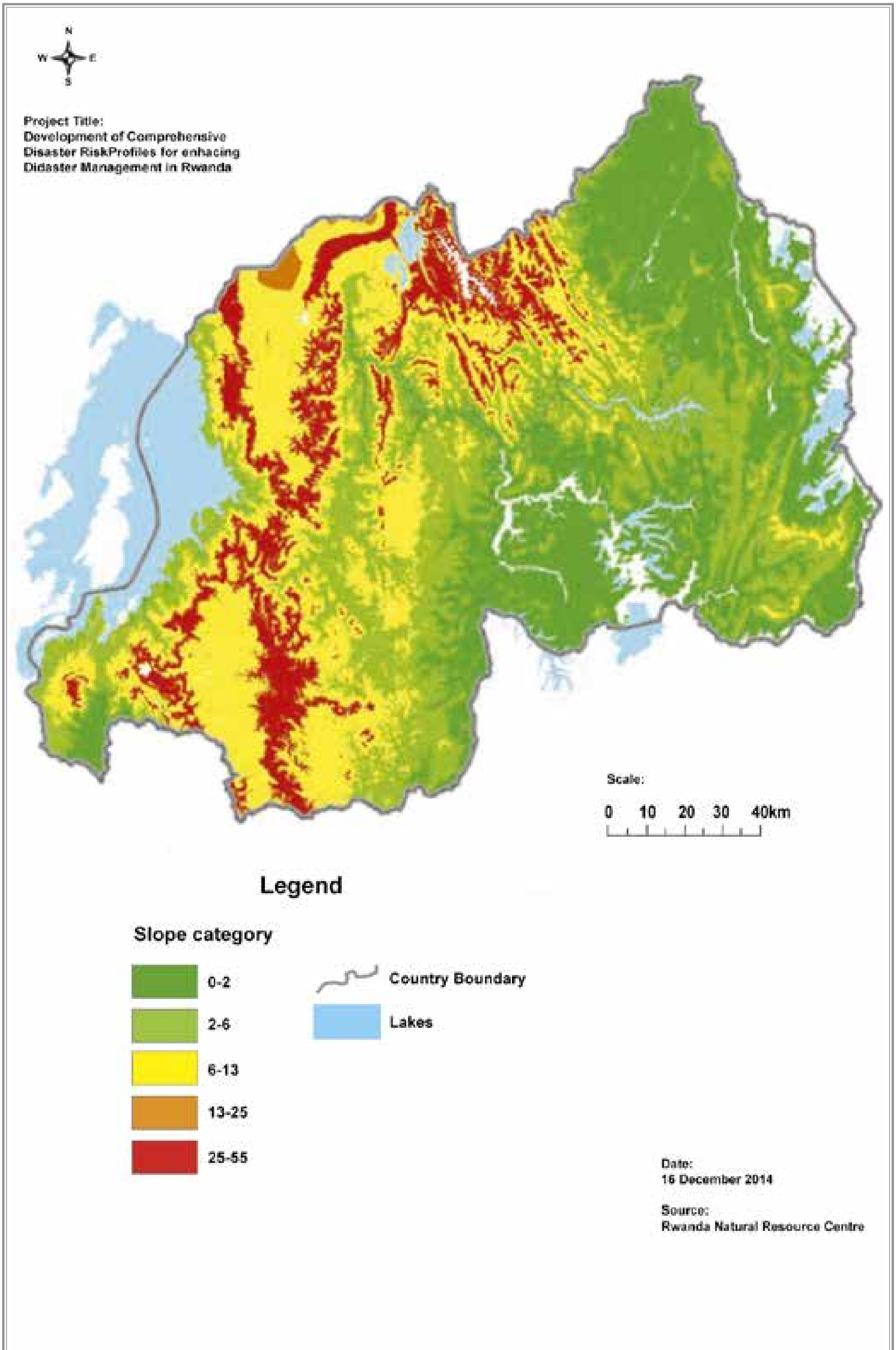


Figure 2 - Slope susceptibility map of Rwanda (MIDIMAR 2015, mod.)

GEOPHYSICAL METHODS APPLIED TO LANDSLIDES

Geophysical methods applied to landslide are usually adopted in supporting engineering geological studies.
They can be implemented to efficiently investigate the internal structure of a soil or rock mass, aiming at estimating mechanical properties of terrains and reconstructing buried geometries, with a reasonable degree of certainty.
Near-surface geophysical surveys have been widely used for decades to investigate landslide areas, often characterized by a complex geological setting that can be efficiently "imaged" by using 2D, 3D and time-lapse (4D) techniques.
Different geophysical methods can be applied in slope stability analysis and jointly used for the investigation of different typologies of landslides, regarding the following engineering aspects: 1) detection of the shear surfaces and failure planes; 2) 2D/3D reconstruction of boundaries within the landslide body; 3) reconstruction of the hydrogeological regime within the slip mass.
Measurement of changes of geophysical parameters with time (4D) are also used nowadays, as significant in assessing changes in the states of landslide materials.
Among indirect (geophysical) methods, the seismic methods are often the most suitable since measurements depend on the mechanical properties that, in turn, are fundamental in modelling the geotechnical behaviour of the terrains in slope stability analyses.
Other geophysical methods, such as electric resistivity tomography, self-potential, electromagnetic and gravity methods, can be useful to determine the internal structure and geometries of a landslide body; the modelled parameters will require a (site-specific) correlation with mechanical properties.
The application of two or more integrated geophysical methods is highly recommended to reduce the intrinsic uncertainties of each single methods, allowing the strengths and weaknesses of the various methods to mutually complement.
Suitable methods are chosen based on preliminary information, derived from field observations and geotechnical reconnaissance.
A detailed description of the landslide-affected materials and in-situ undisturbed geological formations are needed to preliminarily evaluate the feasibility of geophysical measurements and properly design geophysical campaigns.
A possible stepwise procedure is here briefly described.

Identification of the investigation area

The study area may correspond to the entire landslide body or to a part of it, on which it is important to gather information.
Geophysical prospection should be extended over undisturbed areas, i.e., not affected by the instability, therefore it is important to extend and report field observations on adjacent areas that can be reached safely.

Soil/rock mass assessment (physical properties)

Field observations on the different units should be made mostly focusing on lithology, being the geophysical parameters mostly depending on e.g., density, water content, grain size, stiffness, degree of cementation, mineral composition of grain/rock type, jointing, degree of jointing etc.
Observation should be done at a number of points along the landslide and within the area to be investigated, in order to possibly use such observations to calibrate the geophysical imaging.

Preliminary subsoil modelling

A first assignment of physical properties/geophysical parameters to each terrain or rock mass is done, usually based on value ranges proposed in scientific literature, possibly referred to the same geographic area or comparable geological formations/landslide materials.

As an example, the ranges of some parameters are reported in the following tables modified from R. Hack (2000) "Geophysics for slope stability". Surv. Geophys. 21 (available online at https://hack.home.xs4all.nl/WORKHack/Publications/).

Note that the material descriptions do not account for local variations in, e.g., water content, jointing, inhomogeneities, clay content due to weathering, mineral salinity of water.

Geoelectrical survey in Muleti (Ethiopia)

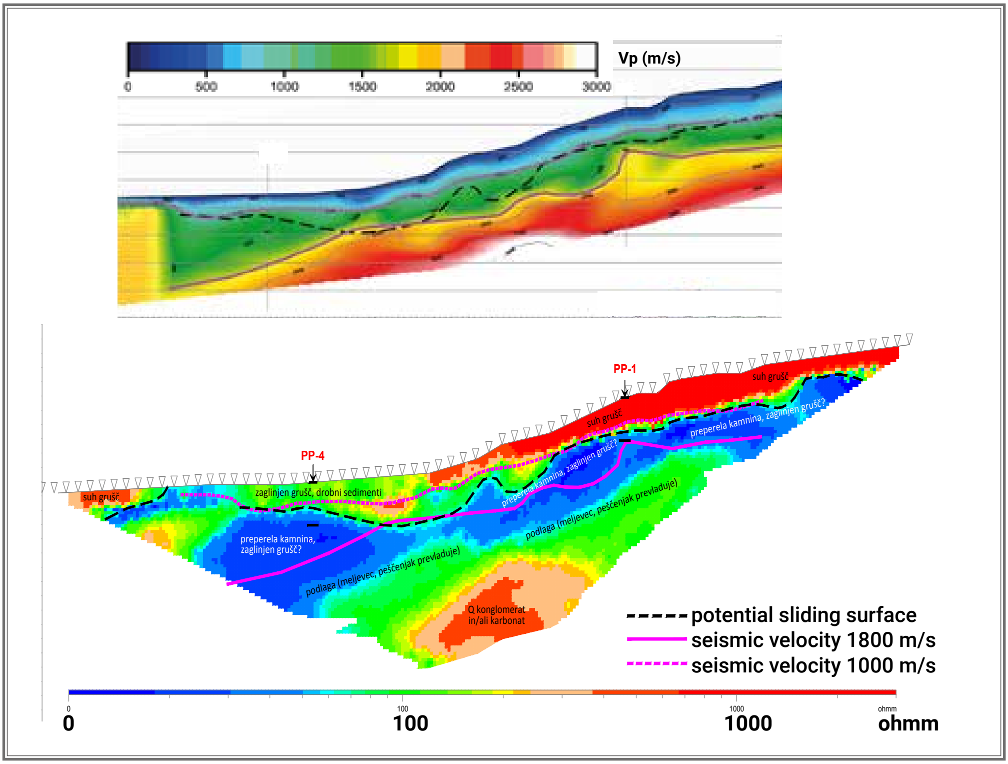


Figure 3 - Potential sliding surfaces (Koroška Bela landslide) based on seismic (up) and geoelectrical (down) surveys (Geological Survey of Slovenia, mod.)

Material	P-wave velocity (m/s)	Material	P-wave velocity (m/s)
Air	360	Weathered sedimentary rock	300-3000
Dry sand	400/1000	Metamorphic rock	1000-6000
Clay	300/1800	Unweathered basalt	1000-1300
Weathered igneous and metamorfic rock	450-3700	Limestone	500-6700

Table 1. P-wave velocities (Hack R. 2000, mod.)

Material	Resistivity range (Ohmm=Ωm)
Dry sand (2)	800-5000
Clay (2)	3-150
Slate (1)	6 x 102- 4 x 10^7
Limestone (2)	500-3500
Sandstone (2)	300-3000
Granite (1)	300-1 x 10^6
Debris and dumped soil (2)	200-350
Domestic garbage (2)	12-30
Natural water in sediment (1)	1-100
Sea water (1)	0.2
Scrap metal (2)	1-12

Table 2. Resistivity ranges of soil and rock masses (Hack R. 2000, mod.)

Material	Dielectric constant	Electric velocity (for frequency 1000 MHz (m/ns)	Attenuation (for frequency 100 MHz) (dB/m)
Air	1	0.3	0
Metal			Infinite
Fresh water	80	0.33	2 x 10-1
Seawater	80	0.01	0.1
Dry sand	3-5	0.15	0.01
Wet sand	20-30	0.06	0.03-3
Limestone	4-8	0.12	0.4-1
Clay	5-40	0.06	1.0-300
Granite	4-6	0.13	1.01-1
Rock salt	5-6	0.13	0.01-1
Shale	5-15	0.09	1.0-100

Table 3. Electromagnetic properties of rock and soil masses (Hack R. 2000, mod.)

Expected contrast in properties:

Density	☐ low	☐ medium	☐ medium to high	☐ high to very high
Resistivity	☐ low	☐ medium	☐ medium to high	☐ high to very high
Stiffness	☐ low	☐ medium	☐ medium to high	☐ high to very high
Water content	☐ low	☐ medium	☐ medium to high	☐ high to very high
Dielectric constant	☐ low	☐ medium	☐ medium to high	☐ high to very high

Preliminary Geophysical Survey Design

For each target to be investigated, a preliminary survey design can be implemented (supported by geophysicist)

Target to be resolved ....

Depth to target ....

Depth to bedrock ....

Expected resolution ☐ very high (1m) - ☐ high (2-3m) - ☐ medium ☐ low (>5m)

Additional parameters to consider: ....

....

Method to be implemented	2D ☐ ERT	2D ☐ SR-P	2D ☐ GPR	1D ☐ MASW	1D ☐ NOISE	1D/2D ---
Number of 2D lines/profiles						
Number of sensor and spacing						
Measurements/profiles density						

FIELD TRIP DESCRIPTION

The field trip will take two days.
In the first day, from Kigali, after about two hours of travelling, we will reach the Stop 1 where a quarry closes the RN11 not far from Nyabarongo River. Here, field exercises on geomechanical classification methods will be carried out. Later we will continue north along the RN11, about 60 km. The RN11 is a hillside road, built on slopes made of a thick cover of laterite sediments.
Slope cuts, made without adequate superficial water control, promoted the trigger of numerous landslides along the road.
We will see: Stop 2 – landslide consolidation works (retaining wall, gabions); Stop 3 – Large landslide; Stop 4 and Stop 5 – Road collapse due to a landslide triggered by river erosion of the riverbanks.
The second day, after about one hour of travelling we will visit Rutongo Mines (Stop 6). Figure 4 shows the stop locations, placed on Google Maps®.

Kigaly city

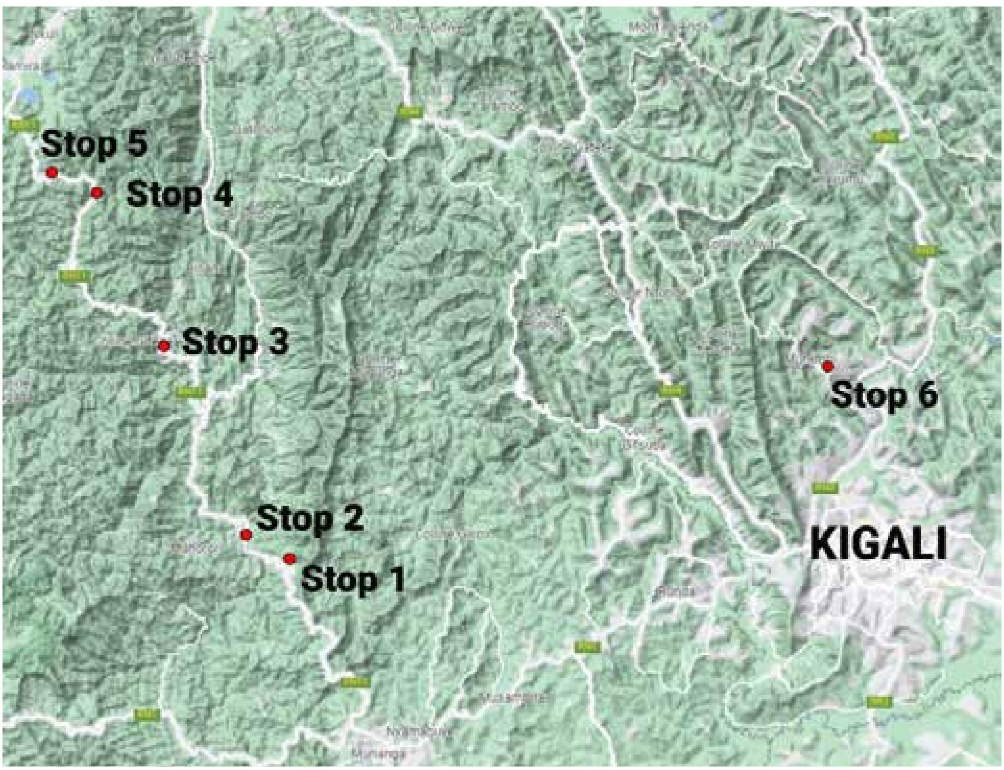


Figure 4 – Field trip stops on Google Maps®

TUESDAY 21 NOVEMBER

DAY ONE

Kigali – Rambura

Leaving from Kigali, we will travel east for approx. 50 km along RN1 until Muhanga. From there, we will travel north along RN11 where 5 sites of day 1 will be visited (Stops 1-5)

Gatumba quarry: field exercises on geo-mechanical classification methods.

STOP 1

The Gatumba quarry is located approximately 60 km from Kigali.

The outcropping rock at this site is made prevalently of quartzite. 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 making 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 discontinuities observed in a drill core and/or in a 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).
References on scientific literature are reported in bibliography.

Gatumba quarry

Aerial view of Gatumba Quarry area (Google Earth®)

Procedure

Description of the main characteristics of the site (e.g., location, date, geology) using a survey data sheet (Figure 5).

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

	Strike (average)	DIP (angle)	DIP DIRECTION (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

PERSISTENCY (CONTINUITY)		Set 1	Set 2	Set 3	Set 4
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 5 - Example of survey data sheet

Implementation of a scanline (Figure 6) 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 7). Assessment of UCS (Uniaxial Compressive Strength) with Schmidt-hammer (Figure 8).

Figure 6 - Scanline in the rock slope outcropping in Gatumba Quarry

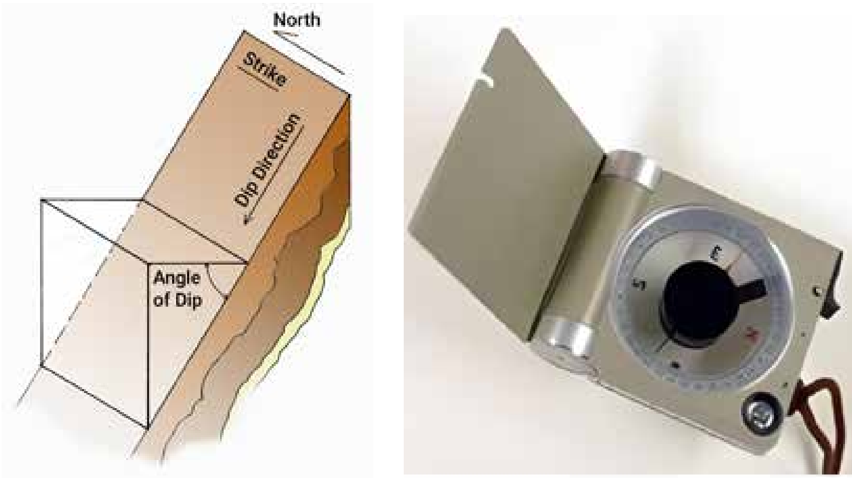


Figure 7 - Measurement of a discontinuity plane with a structural compass

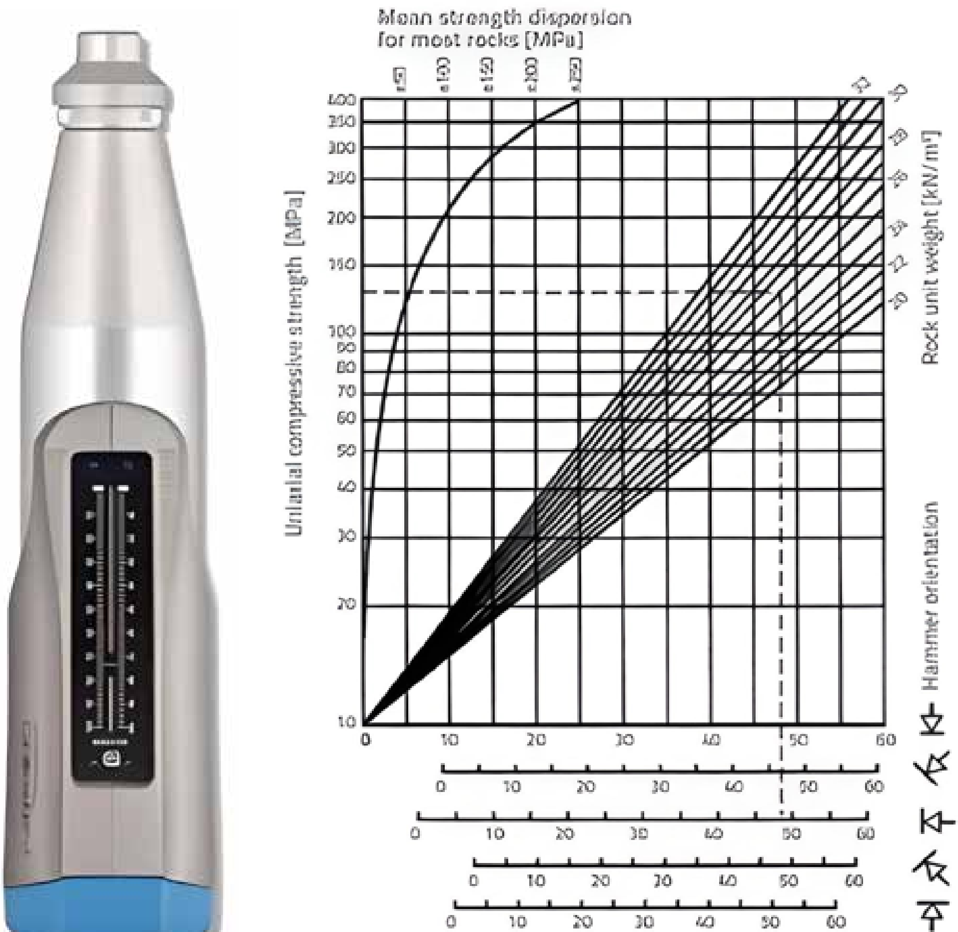


Figure 8 - Assessment of UCS (Uniaxial Compressive Strength) with Schmidt-hammer.

Assessment (Figure 9) of Joint Roughness Coefficient (JRC) with profilometer (Burton comb).

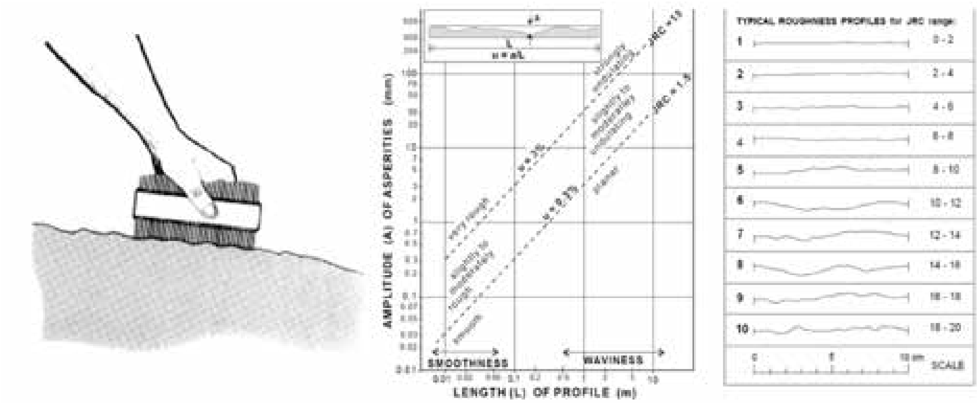


Figure 9 - Assessment of JRC with profilometer

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 10). 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.

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

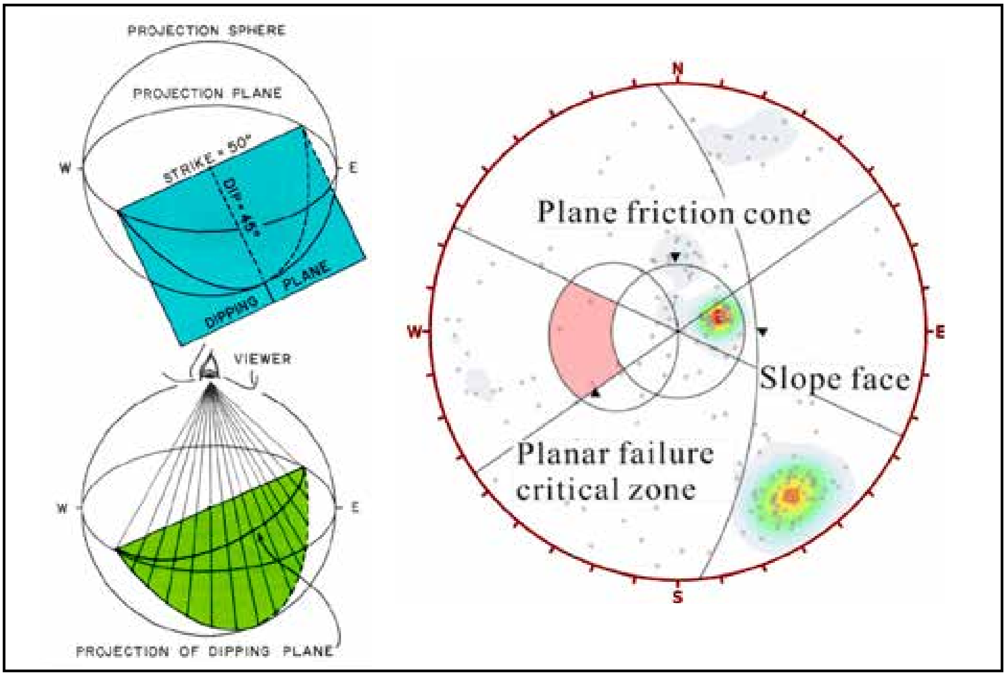


Figure 10 - Stereographic projection and example of kinematic analysis

STOP 2

Retaining structures and slopes-Muhororo

Retaining walls (Figure 11) are common structures used as landslides mitigation works.

Designing retaining structures often needs to ensure only that total collapse or failure does not occur.

Thus, the approach to the design of retaining structures is to analyze the conditions that would exist at a collapse condition, and to apply suitable safety factors to prevent collapse. This approach is known as limit design and requires limiting equilibrium mechanics (Lambe & Whitman, 1979).

A general description of the geomorphology of the area, landslide type and possible triggering mechanisms will be discussed.

A special attention will be addressed to landslide mitigation measures and structural interventions commonly used to counteract the instability movement.

Retaining wall

Mass movements and gabions

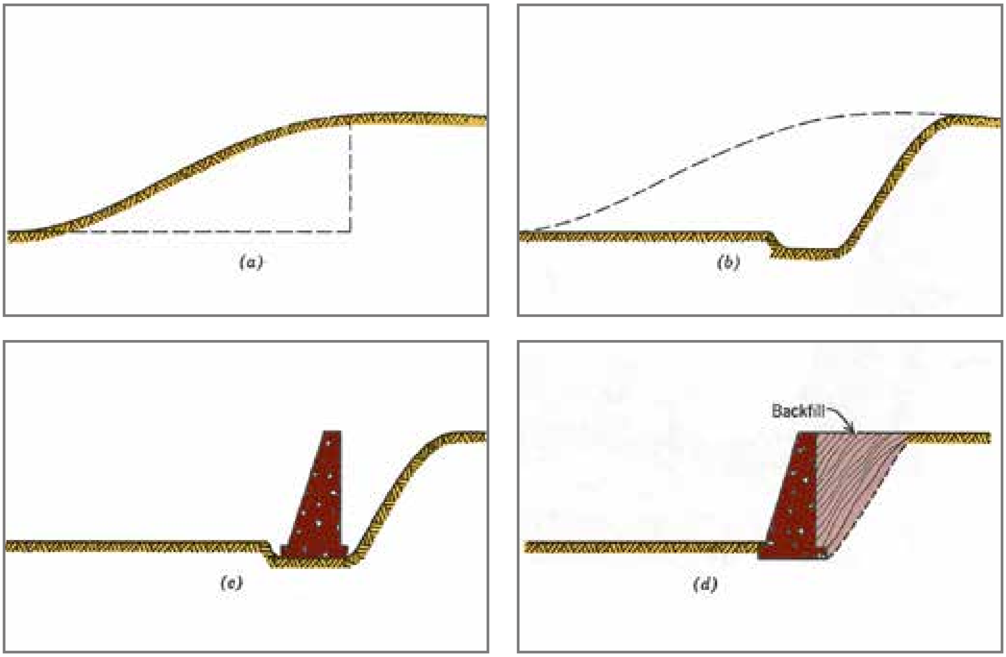


Figure 11 – Stages in construction of typical gravity retaining wall. (a) Proposed excavation. (b) Excavation completed. (c) Wall formed and poured. (d) Backfill placed. (Lambe & Whitman, 1979, mod.)


Landslide crown area
consolidation – upper side


Landslide crown area
consolidation – lower side


Landslide body/geomorphological instability near Muhororo village

STOP 3

Large landslide in Hindiro

A large landslide is located near the village of Hindiro.
The mass movement can be classified as a rotational landslide evolving in earthflow.
The landslide involves an area of ca. 300 m of length with variable width from 60 to 150 m; the estimated volume is at least 150.000 m^3. A multi-temporal analysis (2006/2020) performed with Google Earth® images, evidences the presence of the landslide forms since 2006. From 2006 to 2020, a retrogressive movement of the landslide crown towards the road and the increasing of the earthflow area can be observed.
The site discussion will focus on the complexity of large volume landslides. Such phenomena need a multi-discipline and multi-methods approaches to fully understand the origin, trigger, and evolution of the event.
In addition, possible landslide mitigation strategies must consider structural and non-structural interventions and policies where geological and engineering solutions should comply with environmental, social and economic aspects.


View of the large landslide in Hindiro

Evolution of Hindiro landslide (Google Earth®)


Front view of Hindiro landslide


Crown area of Hindiro landslide

View of the road crossing the Hindiro landslide

View of the road crossing the Hindiro landslide

STOP 4

Landslide in Jomba

The landslide of stop 4 involves a ca. 60 m length of a road section placed ca. 500 m north of the village of Jomba.

A multi-temporal analysis performed with Google Earth® images helps detecting the occurrence of the mass movement in the period 2017-2020, likely triggered by the river through toe erosion of the riverbanks.

The typology and effectiveness of the structural interventions undertaken in the past to protect the road and counteract the landslide movement will be discussed, with a special regard to strategies for the safeguard and protection of linear infrastructures.

Road collapse in Jomba

Evolution of Jomba landslide (Google Earth®)

View of the landslide caused by river erosion

STOP 5

Road Collapse in Rambura

The mass movement of stop 5 involves a ca. 50 m road sector located approx. 1,500 m east before the village of Rambura. A multi-temporal analysis was performed with Google Earth® images taken from 2017 to 2020. Similarly to the landslide of stop 4, the failure (rotational) was caused by river erosion at the slope toe. In this stop, a geomorphological assessment of the area will be discussed along with an analysis of typology, design and long-term effectiveness of the structural interventions recently built on the road side and slope toe.

Rupture of the retaining wall in Rambura

Evolution of Rambura landslide (Google Earth®)


Displacement of the retaining wall in Rambura


View of Rambura landslide

Displacement of the retaining wall in Rambura

WEDNESDAY 22 NOVEMBER

DAY TWO

Kigali – Rutongo Mines

STOP 6

Rutongo mines

The Rutongo area is located on the Rutongo anticline, bordered by the Yanza syncline to the west and the Nzoko-Rwamahili syncline to the east by the Rutongo area is dominated by mesoproterozoic rocks belonging to the lower and middle part of the Rwanda Supergroup.

The mesoproterozoic rocks consist of a succession of low grade metamorphosed quartzite units, separated by large packages of metapelites with intercalations of quartzite.

The Rutongo tin mines are estimated to contain approximately 54,000 tonnes (t) of recoverable tin.

The primary mineralisation in the Rutongo is associated with cassiterite hosted within the mineralised quartz veins occurring in sub-parallel swarms and restricted to the quartzite units.

With an average vein width varying between 0.5 m and 1 m, the quartz veins are oriented in a north-south direction, dipping 60° towards the west.

Underground mining at the Rutongo tin mines is carried out in eight mine shafts use conventional drilling and blasting techniques.

The ore extraction is done manually and is assisted by the use of underground trains, bobcat loaders, and onsite excavators.

The mechanised crushers are used to break the tin bearing rocks and further refined onsite with the use of short sluices and panning.

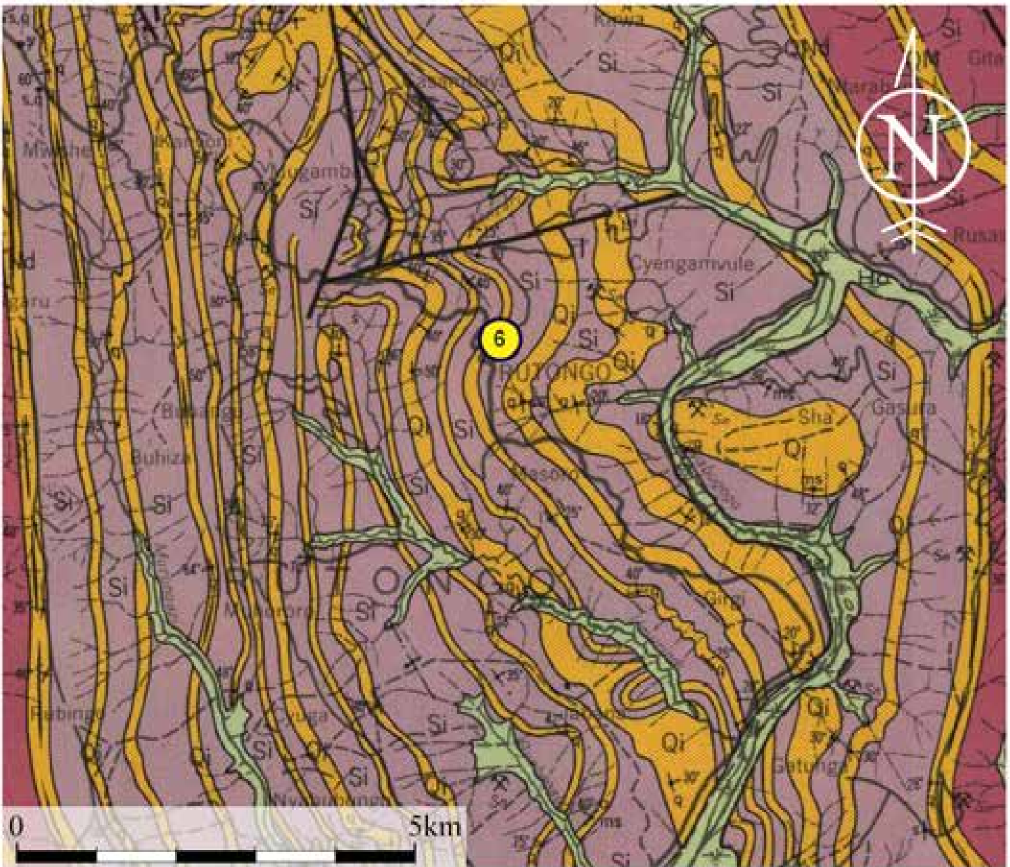
The ore is then bagged at the sub-site and dried on open fires before being weighed and evaluated for quality.

The ore is then trucked to the mechanised processing plants consisting of shaking tables, jigs, and classifiers for initial processing.

The processed ore is transported in 500 kg sacks by road to Dar-es-Salaam in Tanzania for shipping to Asia.

The Rutongo underground mines currently produce up to 100 t of ore a month grading 71% tin concentrates. The monthly production capacity is expected to be increased to 250 t with subsequent development programmes.

(https://www.nsenergybusiness.com/projects/rutongo-tin-mines/)



UPPER SERIE

Upper pelitic beds of Quartzite de Nduba: black or blue grey phyllades and sericitoschists, sometimes graphitic, whitish when altered; zoned grey or black quartz-phyllades, locally with pyrite and greysh seritoschists; on top of the upper levels, intercalation of dark grey fine clayey micaceous and coarse quartzite; micaschists.

Sandstone beds: light grey to white quartzite, generally fine-grained, locally coarse, enriching in mica at contact with granites.

Pelagic and arenaceous beds: sequence of phyllades and sericitoschists, often dark grey, frequently banded, and grey to whitish and red quartzites; micaschists, micaceous quartzites and quartzites with tourmaline in the vicinity of granites.

Lower pelitic beds of Quartzite de Nduba: sequences of phyllades and sericitoschistes, often dark grey, frequently banded; micaschists in the vicinity of granites.

LOWER SERIE

Pelitic beds (Si)

Quartzite of Mulindi (QM)

Quartzite of Nduba (QNd)

Indistinguishable pelitic and arenaceous beds (SQ). In the Rutongo anticline, the distinction can be done between arenaceous beds (Qi) and pelitic beds (Si)

Figure 12 - Extract from the geological map of Rwanda - Sheet Kigali (VV.AA., 1967, mod.)


Mine entrance


Trailers

View of Rutongo mines

Samples of ore with cassiterite

Rutongo mines main gallery

REMEDIATION OF MINING AREAS

Abandoned and closed mines (on surface and underground), exploration and production boreholes, including mine and metallurgic waste deposits, are all associated with potential environmental and social issues. Remediation is a complex process that targets devastated areas. In terms to diminish the impacts to the environment the proper remediation measures should be planned in time. The final result is that degraded land is/should be returned to a beneficial end use (the same as before or a new land use). To establish an agreed sustainable positive land use different methods of reclamation should be performed as post-mining activities. Remediation is important for several reasons: to minimize erosion, to protect surface and groundwater from drainage contamination, to maintain the landscape appearance and, the most importantly, to prevent environmental disasters. Mine remediation consists of three successive phases:

- geotechnical remediation for bank slope stabilisation, including drainage system,
- biological remediation (recultivation),
- medium- or long-term monitoring.

The implementation of surface remediation requires different techniques depending on the environment (humid or arid, flat or mountainous areas). The materials used for remediation are topsoil /overburden, inert waste materials (eg. demolition waste) or combination of different materials. Remediation could be carried out after mining operation or at the same time as mining operations.

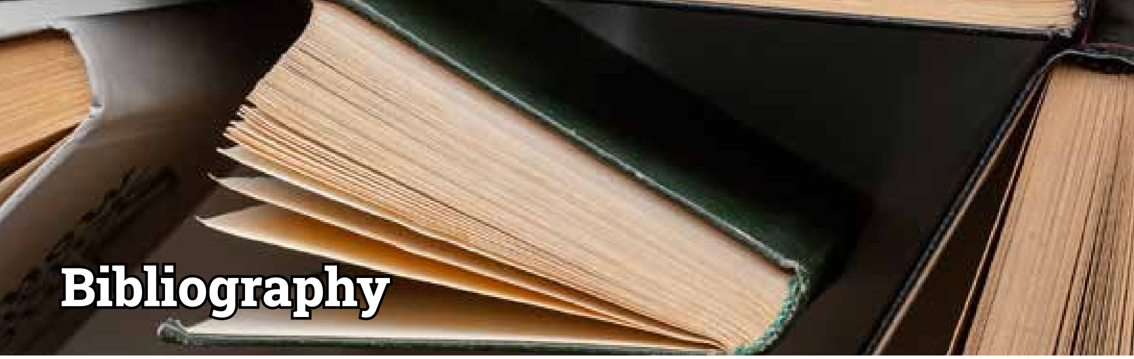
The remediation of the underground mines can be done by filling the mining halls by water or/and different materials in terms of ensure stability of the terrain. At a minimum, removal of surface facilities must be completed.

Final land use must be beneficial to the local community (open space, wildlife habitat, agriculture, residential or commercial areas, recreational areas etc.).

Regular monitoring, especially for waste sites, is essential.


Remediation and recultivation of dolomite quarry (Mozelj, Slovenia)

Remediated gravel pit in Pannonian basin (Lakoš, Slovenia)



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Editors:
G. Delmonaco, F. Traversa (ISPRA)
Graphic project
P. Moretti (ISPRA)
Field Trip Committee
J. Satkūnas (LTG)
T. Niyitegeka (RMB)
G. Delmonaco, F. Traversa (ISPRA)

Authors:
ISPRA, Geological Survey of Italy:
G. Delmonaco, F. Traversa, P. Moretti,
S. Nisio, L.M. Puzzilli
Rwanda Mines, Petroleum and Gas Board (RMB):
J. C. Ngaruye, T. Niyitegeka
Geological Survey of Lithuania (LTG):
J. Satkūnas
Council for Geoscience of Republic of S. Africa (CGS):
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