Republic of Malawi
Ministry of Natural Resources, Energy and Mining

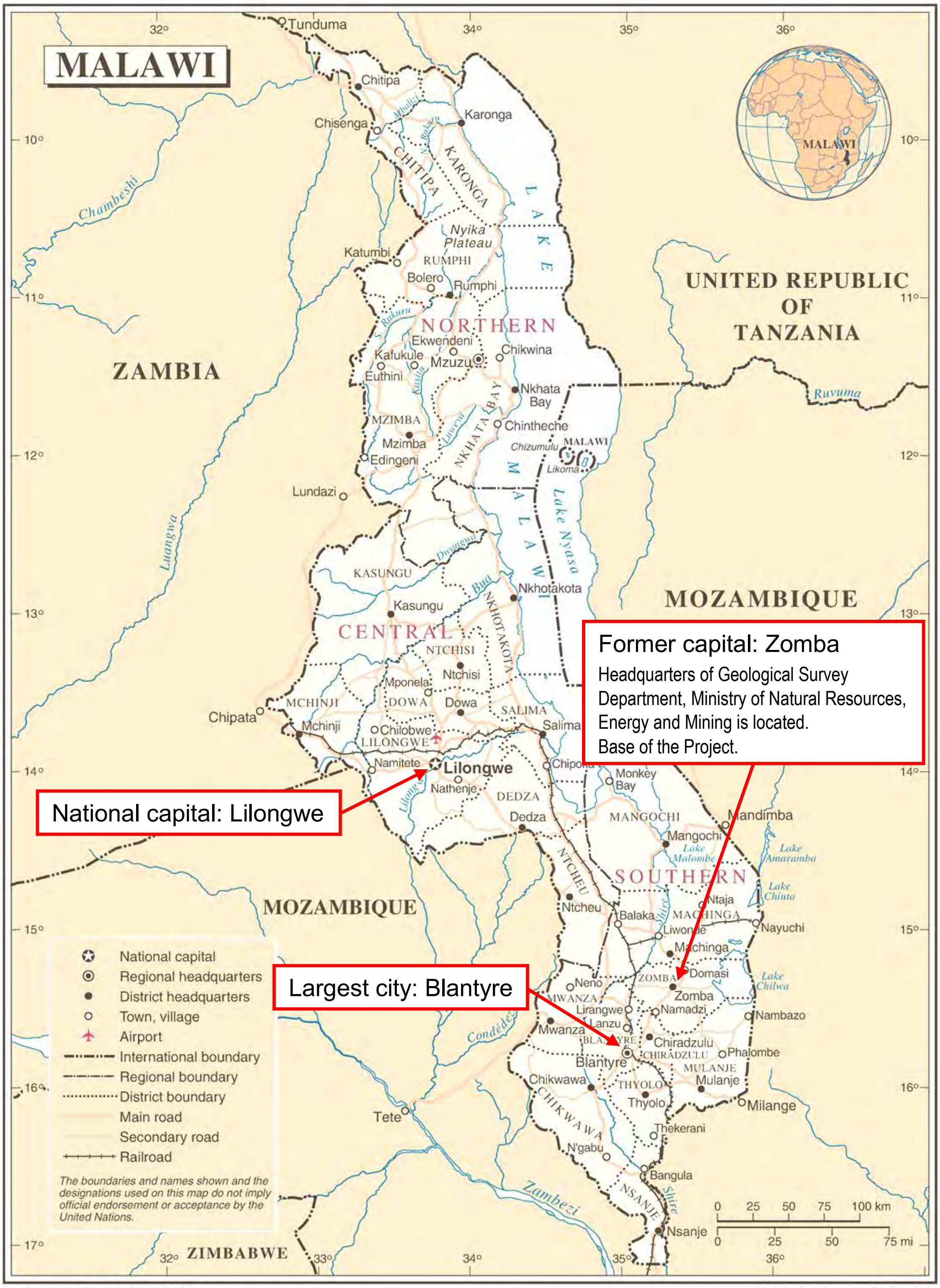
Final Report
of
Project on Capacity Building in Mining Sector in the Republic of Malawi

March 2016

Japan International Cooperation Agency

Joint Venture
Sumiko Resources Exploration and Development Co., Ltd.
Mitsubishi Materials Techno Co.

Frontispiece



Map No. 3858 Rev. 3 UNITED NATIONS
January 2004

Department of Peacekeeping Operations
Cartographic Section

Abbreviation

AIST	National Institute of Advanced Industrial Science and Technology, JAPAN
ArcGIS	ArcGIS for Desktop Basic (software name) / Previous name is ArcView.
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
C/P	Counterpart
DB	Data Base
DoM	Department of Mines, MALAWI
EITI	Extractive Industries Transparency Initiative
F/S	Feasibility Study
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
GSD	Geological Survey Department, MALAWI
HIPC	Heavily Indebted Poor Countries
ICP	Inductively coupled plasma mass spectrometry
JICA	Japan International Cooperation Agency
JOGMEC	Japan Oil, Gas and Metals National Corporation
Ma	Mega-annum
MEGS	Malawi Economic Growth Strategy
MGDS	Malawi Growth and Development Strategy
MGGSP	Mining Governance and Growth Support Project
MMTEC	Mitsubishi Materials Techno Corporation
M/M	Minutes of Meeting
MNREE	Ministry of Natural Resources, Energy and Environment, MALAWI
MNREM	Ministry of Natural Resources, Energy and Mining, MALAWI
MWK	Malawi Kwacha
NMSP	Malawi National Mining Sector Policy
OCM	Office of the Commissioner for Mines, MALAWI
OJT	On-the-Job Training
PALSAR	Phased Array type L-band Synthetic Aperture Radar
R/D	Record of Discussions
REE	Rare Earth Elements
SRED	Sumiko Resources Exploration & Development Co., Ltd.
SMM	Sumitomo Metal Mining Co., Ltd.
WB	World Bank
XRF	X-ray fluorescence

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Figures and Tables

1 Outline of the Project

1.1 Background of the Project

Malawi has traditionally been considered as an agro-based economy, as a result, there was insufficient mining culture and little technical capacity, and the contribution of mining to GDP was only 3% before 2009. However, Kayelekera Uranium mine started the production in early 2009, and its contribution rose to 10% in 2009 and is expected to be about 16% in 2016. Furthermore, local and foreign companies have interests in potentials of Rare Earth Elements (REE) and rare metals caused by the geological features in Malawi and explorations of rare earth resources have proceeded in several areas in the south of Malawi.

In order to develop mining sector in the future, it is necessary to promote the further foreign and local investments. However, the basic information of mineral resources is insufficient in the Ministry of Natural Resources, Energy and Mining (MNREM) in Malawi and arrangement of geochemical information is an urgent issue to explore REEs. The Geological Survey Department (GSD) of MNREM has prepared the digital geological maps and Geographic Information System (GIS) database, but has limited capacity and personnel who has the knowledge of geochemical information.

Artisanal and Small-scale Mining (ASM) operations support the construction industry in Malawi, and contribute to foreign exchange earnings and savings through import substitutions as well. The contribution of ASM to the economy is generally under-estimated, because the Government does not grasp enough the situation of ASM. Therefore, establishment of enabling environment and capacity building are urgent issue to formalize ASM for management of its production.

1.2 Circumstances of the Project

The Japan International Cooperation Agency (JICA) had implemented the project from February 2012 to July 2013, whose objectives were to strengthen systems for upgrading of mineral resources information on mining sector and to develop human resources for remote sensing data analysis of satellite data and construction of mineral resources GIS database. The World Bank (WB) and the European Union (EU) have conducted the airborne geophysical survey on whole Malawi from 2013 to 2016. Therefore, nationwide information of geology, mineral resources, satellite images and geophysical survey has been maintained.

Based on the above background and circumstances, the Malawi Government requested the Japanese Government the following cooperation on August 2013.

(i) Capacity development in study of geochemical information

(ii) Integration of geochemical survey results into GIS database

(iii) Cooperation on ASM measures

(iv) Human resource development

In response to this request, JICA implemented "study on formulating a detailed plan" on March 2014 and then signed "Record of Discussions" to start the cooperative project on April 2014.

1.3 Purpose of the Project

The Ministry of Natural Resources, Energy and Mining obtains nationwide geochemical survey plan, geochemical data of model areas and upgraded geological database, and its human capacity is enhanced on sustainable development of mining through field survey and long-term training.

Overall goal of the Project is that sustainability, health and safety in mineral resources development is improved in Malawi.

1.4 Objectives of the Project

To contribute the sustainable development of mining sector in Malawi through the capacity building of Malawi mining sector and the upgrade of GIS database of geology and mineral resources.

1.5 Scope of the Project

(1) Target area of the Project

Whole area of Malawi

(2) Relevant government organizations

Ministry of Natural Resources, Energy and Mining

1.6 Outputs of the Project

(a) Capacity in geochemical survey is strengthened.

(b) Capacity in integrating geochemical survey results into GIS database is developed.

(c) Environment for ASM activities is enhanced.

(d) Government officers are well trained for establishing information infrastructure and ore geology and mining engineering etc.

1.7 Implementation items of the Project

(1) Geochemical survey

(2) GIS database integration

(3) ASM measures

(4) Long-term training

(5) Project monitoring

1.8 Project implementation system

The joint venture of Sumiko Resources Exploration and Development Co., Ltd. (SRED) and Mitsubishi Materials Techno Co. (MMTEC) implements the Project.

The JICA study team is composed of the following five persons.

・Leader/ Mine development	: Takumi ONUMA	(SRED)
・Sub-leader/ Mine development	: Ioki SUZUKI	(SRED)
・Geochemistry	: Toshiharu TASHIRO	(SRED)
・GIS database development	: Atsushi MOMOSE	(MMTEC)
・ASM and mine environment measures	: Kazuyasu TSUDA	(MMTEC)

1.9 Schedule of the on-site Works in Malawi

Table 1-1 Schedule of the on-site Works in Malawi

On-site Works	Period	Period in charge				
		Onuma	Suzuki	Tashiro	Momose	Tsuda
First	17 August ~ 30 August 2014	17 August ~ 30 August	17 August ~ 30 August	—	—	—
Second	14 September ~ 15 November 2014	26 October ~ 15 November	14 September ~ 10 October	14 September ~ 25 October	5 October ~ 13 November	26 October ~ 15 November
Third	14 February ~ 27 February 2015	14 February ~ 27 February	—	14 February ~ 27 February	—	—
Fourth	17 May ~ 12 September 2015	17 May ~ 11 June	18 July ~ 12 September	17 May ~ 2 August	21 June ~ 12 September	17 May ~ 11 June
Fifth	18 January ~ 5 February 2016	18 January ~ 5 February	—	18 January ~ 5 February	22 January ~ 5 February	22 January ~ 5 February

2 Contents of activities

2.1 Outline of activities

Contents of the project are divided into the following five items. Implementation methods and activities of each item are described in Chapters 3 to 7 respectively.

(1) Geochemical survey

- Create a nationwide geochemical survey plan and settle model areas of geochemical survey based on the geological data and other relevant information
- Create a procedure document of geochemical survey
- Consider and procure necessary equipment for the project
- Implement the geochemical survey in model areas through On-the-Job-Training (OJT)
- Conduct chemical analysis
- Implement statistical analysis of assay results and create geochemical maps
- Create a maintenance manual of assay equipment
- Revise the nationwide geochemical survey plan
- Create a roadmap to improve geochemical laboratory of GSD

(2) GIS database integration

- Create a plan to integrate geochemical survey results into GIS database and create a procedure document of its integration
- Integrate geochemical survey results into GIS database through OJT
- Revise the integration plan based on the nationwide geochemical survey plan

Note: This GIS database was constructed in "The Project for Establishment of Integrated Geographic Information System (GIS) Database for Mineral Resources", which JICA implemented from February 2012 to July 2013.

(3) ASM measures

- Review the ASM policy in Malawi
- Implement field inspections for coal mines in the north of Malawi and kaolinite clay deposits at Linthipe in the middle of Malawi
- Advise and support the environmental and safety measures of ASM

(4) Long-term training

- Support the long-term training (master's and doctor's courses) in Japan for officials of the Ministry of Natural Resources, Energy and Mining
- Support the intern training at relevant organizations and enterprises in Japan

(5) Project monitoring

- Monitor the project progress by settling Joint Coordination Committee (JCC) whose chairman is the Principal Secretary of MNREM, and Technical Coordination Committee (TCC) composed of GSD staffs.

2.2 Schedule of activities

Outline schedule of activities are as follows. Flow of activities is shown in Section 2.3 and Figure 2.1.

(I) The first year program

(i) The 1st Works in Japan: August 2014

Information gathering, creation of project plan and work plan, examination of procurement equipment

(ii) The 1st On-site Works in Malawi: August 2014

Holding of the 1st TCC, discussion and confirmation of project plan and contents, decision of model areas of geochemical survey, preparation for the 2nd On-site Works in Malawi

(iii) The 2nd Works in Japan: September 2014

Creation of geochemical survey plan in model areas, creation of procedure manual of geochemical survey, examination procedure manual of GIS data integration, procurement of equipment

(iv) The 2nd On-site Works in Malawi: September to November 2014

Implementation of geochemical survey, shipment of geochemical samples, implementation of ASM survey, creation of GIS data, holding of the 2nd TCC and 1st JCC, completion of Work Plan, procurement of equipment

(v) The 3rd Works in Japan: January to February 2015

Statistical analysis of assay results, creation of geochemical maps, creation of GIS data, advice for ASM measures, creation of nationwide geochemical survey plan, creation of progress report

(vi) The 3rd On-site Works in Malawi: February 2015

Holding of the 3rd TCC, report of results of the 1st year program, holding of technology transfer seminar, discussion and creation of procedure manual of database integration, examination of the 2nd year program, advice for long-term trainee

(vii) The 4th Works in Japan: March to April 2015

Summarization of the 1st year program, preparation of procedure manuals, preparation for the 2nd year program

(II) The second year program

(i) The 4th On-site Works in Malawi: May to September 2015

Implementation of geochemical survey, shipment of geochemical samples, implementation of ASM survey, creation of GIS data, holding of the 4th TCC and the 2nd JCC, creation of progress report

(ii) The 5th Works in Japan: September to December 2015

Statistical analysis of assay results, creation of geochemical maps, creation of GIS data, advice for ASM measures, revises of nationwide geochemical survey plan and GIS database integration plan, creation of progress report

(iii) The 5th On-site Works in Malawi: January 2016

Holding of the 5th TCC and the 3rd JCC and report of project results, holding of technology transfer seminar and report conference of project results, creation of roadmap for laboratory upgrading, examination and advice for long-term trainee

(iv) The 6th Works in Japan: February 2016

Integration of geochemical survey results into GIS database, creation and submission of final report

2.3 Flow of activities

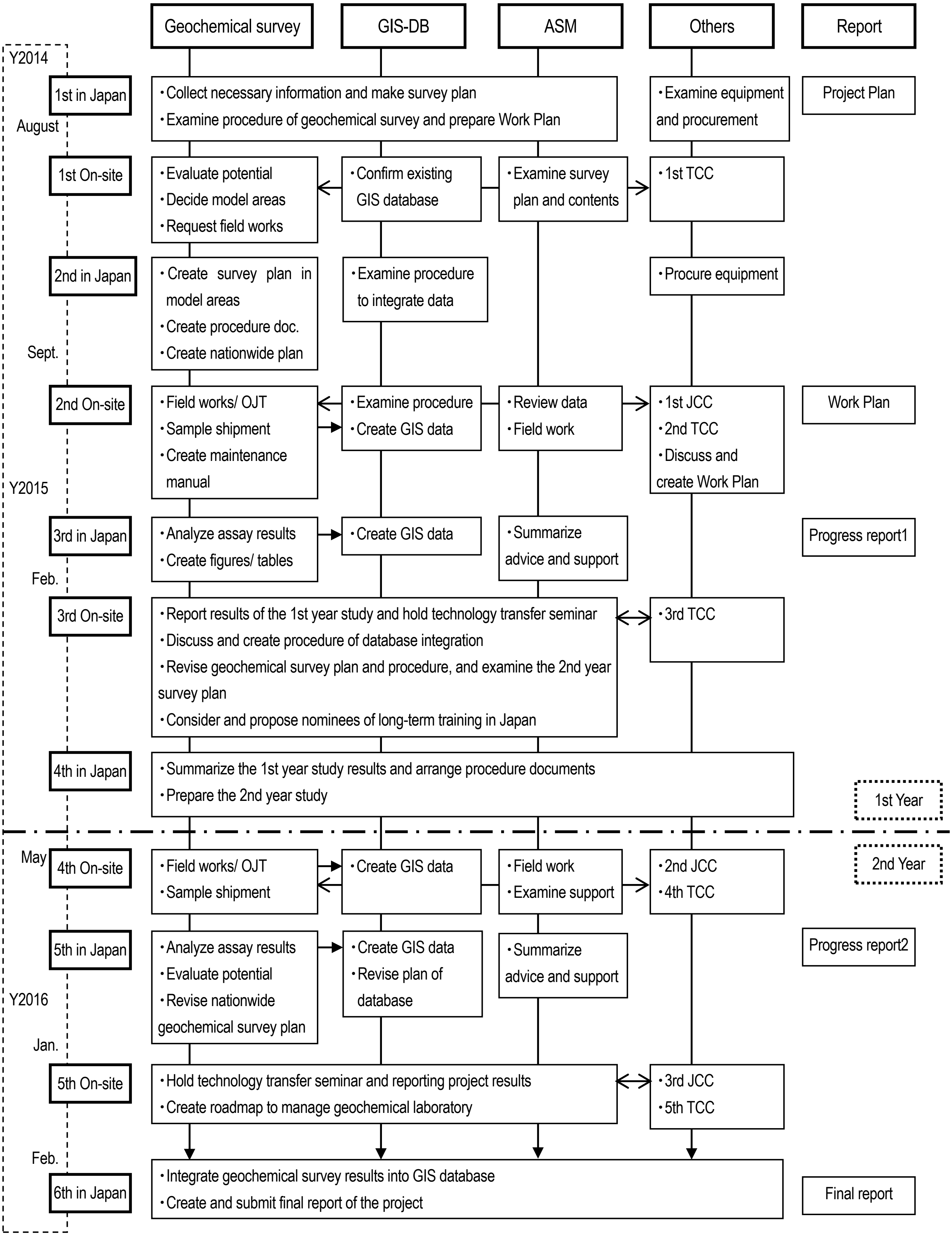


Figure 2-1 Flow chart of the Project Implementation

2.4 Work Plan

The JICA study team created the Project Plan in the 1st Works in Japan, in which basic policies, activities, implementation methods and schedule of the project were described. Then the study team discussed it with JICA Headquarters and created the Work Plan in English.

The study team held the first TCC in the 1st On-site Works in Malawi, and explained the contents of the Work Plan and shared overall framework of the Project. After the discussion of contents, implementation methods, schedule of the Project in TCC, the study team revised the Work Plan. In the 2nd On-site Works in Malawi, the study team discussed it again in the 2nd TCC, and got the agreement on the project contents in the 1st JCC, and then created the final version of the Work Plan.

The Work Plan is composed of the following items.

(a) Outline of the project

(b) Basic policies of the project implementation

(c) Concrete methods of the project implementation

(d) Implementation system of the project

(e) PDM (Project Design Matrix)

(f) Plans of the nationwide geochemical survey and GIS database integration

(g) Flow chart of the project

(h) Flow chart of the geochemical survey

(i) Personnel plan

(j) Undertakings from counterpart organization

(k) Other necessary items

3 Geochemical survey

3.1 Implementation flow of geochemical survey

Implementation flow of the geochemical survey is shown in Figure 3.1.

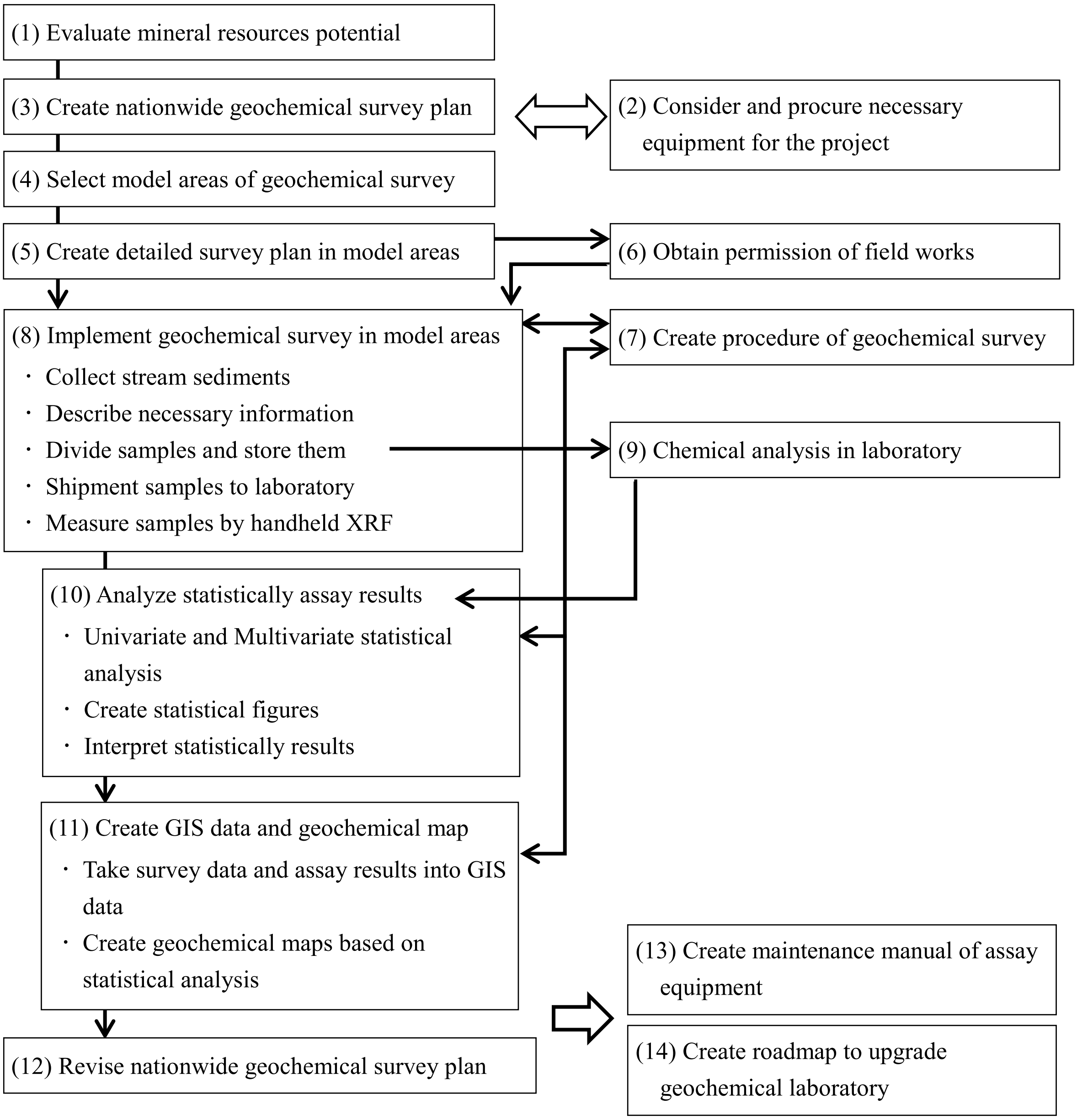


Figure 3-1 Flow of the geochemical survey

3.2 Preparation prior to field geochemical survey

3.2.1 Creation of nationwide geochemical survey plan

The study team collected and reviewed results of the previous JICA project and the existing data of geology and mineral resources, and evaluated the potential of mineral resources. Based on the evaluation, areas where the existence of mineral resources was expected were extracted and implementation priorities on geochemical survey were considered. Based on this consideration and geological maps, nationwide geochemical survey plan in Malawi was created.

Geochemical survey in this JICA Project targets a part of nationwide plan and is carried out as a model area. One of objectives on geochemical survey is that C/P organization will be able to implement the geochemical survey in whole of Malawi by itself through OJT on the survey of the model area and technology transfer by the procedure manual.

3.2.2 Selection of model areas of geochemical survey

The study team selected 17 candidate areas (900 km^2 in each) to implement the geochemical survey on stream sediments in the Project based on the existing GIS data of geology and mineral resources and the evaluation of mineral resources. Candidate areas are selected mainly based on high priority of mineral resources potential, and also based on accessibility, relation of the existing tenement, permission of the survey. The geochemical survey in this Project has a plan to collect 1,000 stream sediments samples with sample density of 1 piece/ 5 km^2.

The study team held the 1st TCC in the 1st On-site Works in Malawi and considered model areas of the geochemical survey. Seventeen candidate areas selected beforehand were discussed respectively about geology, mineral resources potential, accessibility, weather and others while surrounding a large print of geological map. As the GSD requested other areas, those also were discussed in addition. Ten model areas were finally selected.

The survey period in 2014, from the latter half of September to the first half of November, is the hottest season as the end of dry season, and the period in 2015, from the latter half of May to the first half of September, is the cool season as the beginning to middle of dry season. Therefore, it is decided that the north region of Malawi being highlands and cool should be surveyed in 2014 and the south region of Malawi which includes lowlands along Sire River and is severely hot should be surveyed in 2015.

When preparing the detailed survey plan of model areas in the 2nd and 4th Works in Japan, the study team considered geology and accessibility again and then decided 8 model areas (Table 3-1, Figure 3-2). Five areas (GC01 to GC05) were surveyed in 2014 and 6 areas (GC06 to GC11) in 2015.

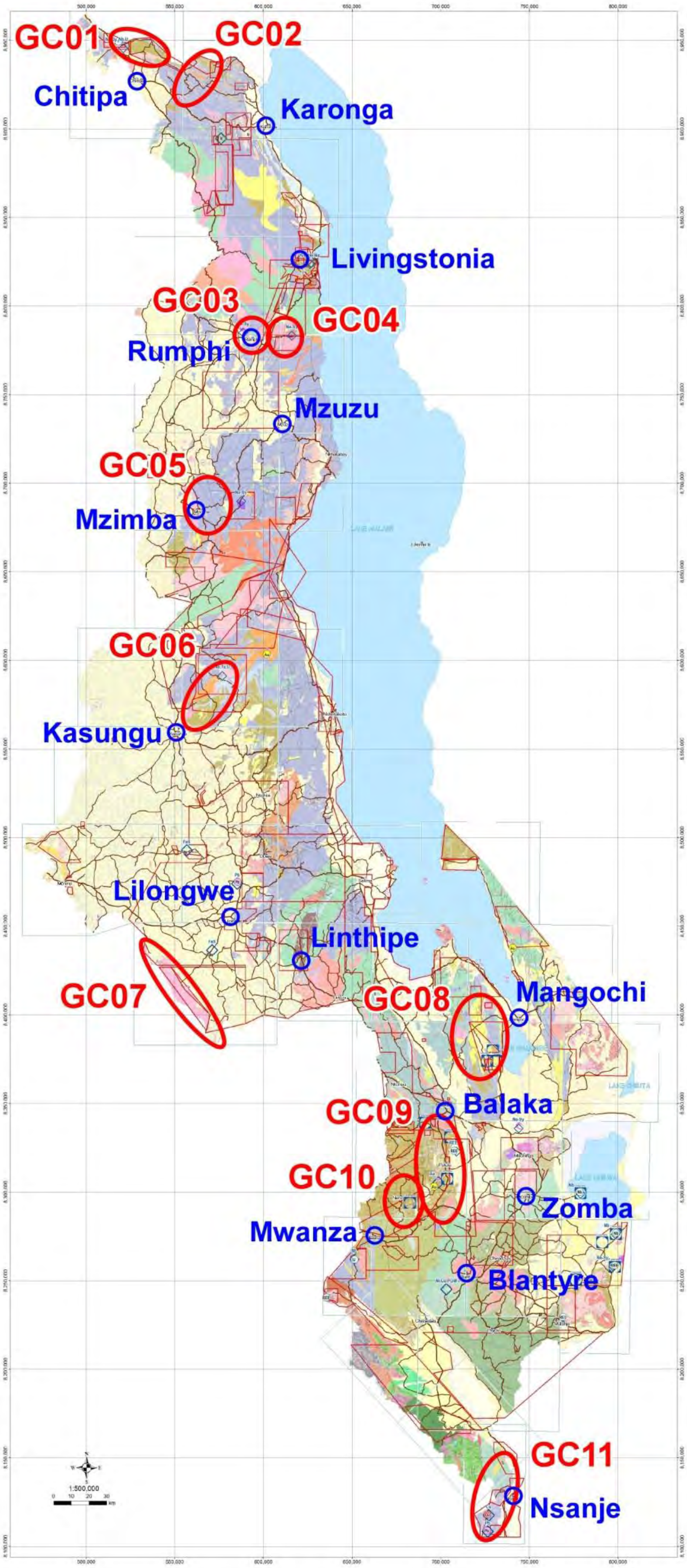


Figure 3-2 Location of model areas of geochemical survey

Table 3-1 Summary of model areas of geochemical survey

Model area	Area name	Geology	Mineral resources expected	Access
Chitipa	GC01	Meta gabbro, amphibolite, gneiss	Nb, U, Cu	Normal
	GC02	Granite, meta gabbro, gneiss	U	Worse
Rumphi	GC03	Granite, gneiss	Au	Normal
	GC04	Granite, gneiss	Au	Good
Mzimba	GC05	Gneiss, granite, pegmatite	Nb, Ta	Normal
Kasungu	GC06	Pelitic schist	Au	Normal
Lilongwe	GC07	Granite, basic rocks	Ni, Au	Normal
Mangochi	GC08	Carbonatite, granitic rocks, pelitic schist	REE, Nb	Worse
Balaka	GC09	Carbonatite, granitic rocks, pelitic schist	REE, Nb, Au	Worse
	GC10	Granitic rocks, pelitic schist	REE, Nb, Au	Normal
Nsanje	GC11	Pelitic schist	Cu, Pb	Normal

3.3 Planning of field geochemical survey

3.3.1 Creation of survey plan on model areas

As a general rule, the area of one model survey area was set to be approximately 500 km^2. It was planned that 100 samples would be collected in each model area with the sampling density of 1 piece/ 5 km^2.

Sampling location was planned considering topography, river system and accessibility in each model area. Sampling sites were generally planned at two sites of upstream of river junction, but they were arranged by river scale, sampling density and geology.

3.3.2 Acquisition of permission on field survey

It is necessary to submit the official documents to the District and police offices prior to the filed geochemical survey in order to obtain the permission for the field works. Therefore, the study team informed GSD the location and schedule of geochemical survey before the 2nd and the 4th On-site Works in Malawi and requested GSD to prepare the necessary documents and send them to the relevant organizations.

The survey teams visited the District and police offices before the field survey in each model area, and explain the schedule and contents of the survey and then obtained the permission for survey implementation. As Malawi has the traditional tribal governance districts, the survey teams also visited Paramount Chiefs, Traditional Authority and/or Group Village Headman, and got the permission for survey implementation. Because of these procedures, the effective and safety field works could be realized. As the Lilongwe survey area includes the Dzalanyama forest reserve and the illegal logging has become a problem, the survey team visited the Department of Forestry and the Malawi Army, and obtained the permission for survey implementation.

3.3.3 Preparation of procedure document of geochemical survey

The study team creates the procedure document of geochemical survey in order that counterparts should implement sustainably the geochemical survey by themselves after the completion of this JICA project. A plan of the procedure was created based on results of geochemical survey in the 2nd On-site Works in Malawi. Its contents were discussed with counterparts and then the first version of the document was created. It was revised repeatedly as necessary according to the progress of the project and the final version was created in the end of the project.

3.4 Implementation of field geochemical survey

Based on the survey plan described above, the study team carried out the geochemical survey on stream sediments in model areas in cooperation with counterparts, and aimed technology transfer through OJT. Eleven areas in total; 5 areas from GC01 to GC05 in 2014 and 6 areas from GC06 to GC11 in 2015, were surveyed (Figure 3-2 and Table 3-2). The total number of samples collected was 1,019; as 319 in 2014 and 710 in 2015. Location maps of stream sediments in each model areas are shown in Figure 3-3 to 3-10.

The procedure of field geochemical survey is as follows.

(1) Preparatory works

- Create a detailed plan as sampling location and process
- Create a document to obtain the permission for filed survey and send it to the relevant organization (works by C/P side)
- Visit the relevant organizations and Paramount Chief and obtain the permission for survey implementation

(2) Field works

- Make a daily plan of sampling location every day and prepare for field work

- ✓ Move to the sampling site by vehicle and foot
- ✓ Take stream sediments, and collect over 600 grams of fine sand sieved by 30-mesh sieve, and put it in plastic bag, and bring it back to the accommodation (photos 2 to 4 in Figure 3-11)
- ✓ Get the location information by GPS, and take photos in/around sampling site
- ✓ Fill up the necessary information in the description card (Figure 3-13)

- ➢ Dry samples naturally by air
- ➢ Divide each sample into 2 portions according to sample division procedure. One portion is 120 grams for chemical analysis (photos 3 to 5 in Figure 3-12). Another portion is stored in GSD.

(3) Works after field works

- ➢ Pack samples for chemical analysis and measure total weight for shipment
- ➢ Create a certification of export permit to send samples to laboratory in Johannesburg, South Africa and get the approval of the Director of the Department of Mines (works by C/P side)
- ➢ Send samples to laboratory by international delivery service
- ➢ Bring samples for storage to GSD in Zomba (works by C/P side)

Table 3-2 Implementation contents of geochemical survey

Model area	Area name	Location	# of samples	Survey period
Chitipa	GC01	North of Chitipa	60	19 September to 4 October 2014
	GC02	East of Chitipa	46	
Rumphi	GC03	North of Rumphi	51	23 October to 8 November 2014
	GC04	East of Rumphi	49	
Mzimba	GC05	Northeast of Mzimba	113	5 October to 22 October 2014
Kasungu	GC06	Northeast of Kasungu	100	22 May to 6 June 2015
Lilongwe	GC07	Southeast of Lilongwe	103	7 June to 28 June 2015
Mangochi	GC08	West of Mangochi	132	16 July to 30 July 2015
Balaka	GC09	South of Balaka	190	31 July to 5 September 2015
	GC10	Northeast of Mwanza	82	
Nsanje	GC11	West of Nsanje	103	29 June to 15 July 2015
Total			1,029	

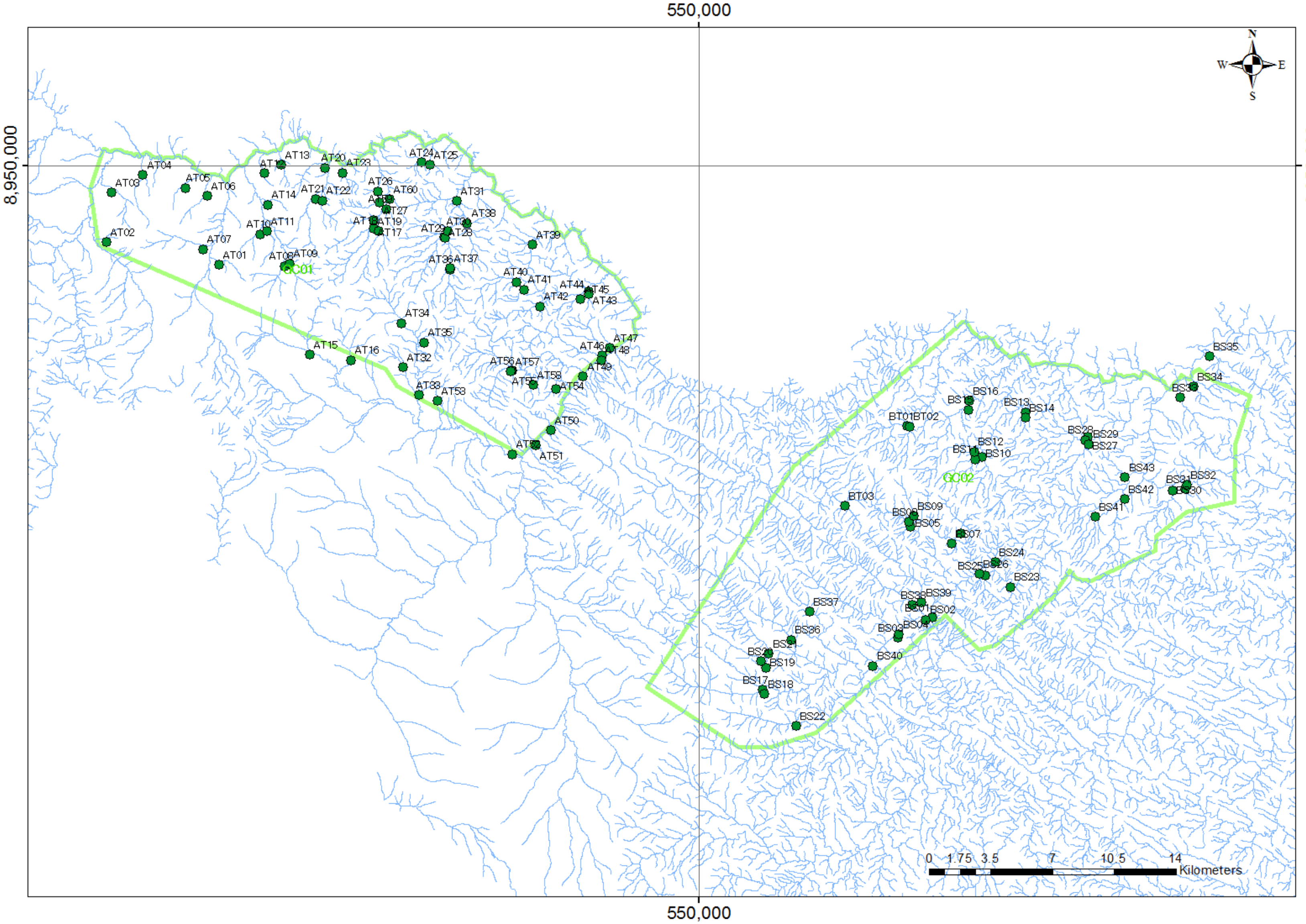


Figure 3-3 Geochemical sample location map (1: Chitipa are)

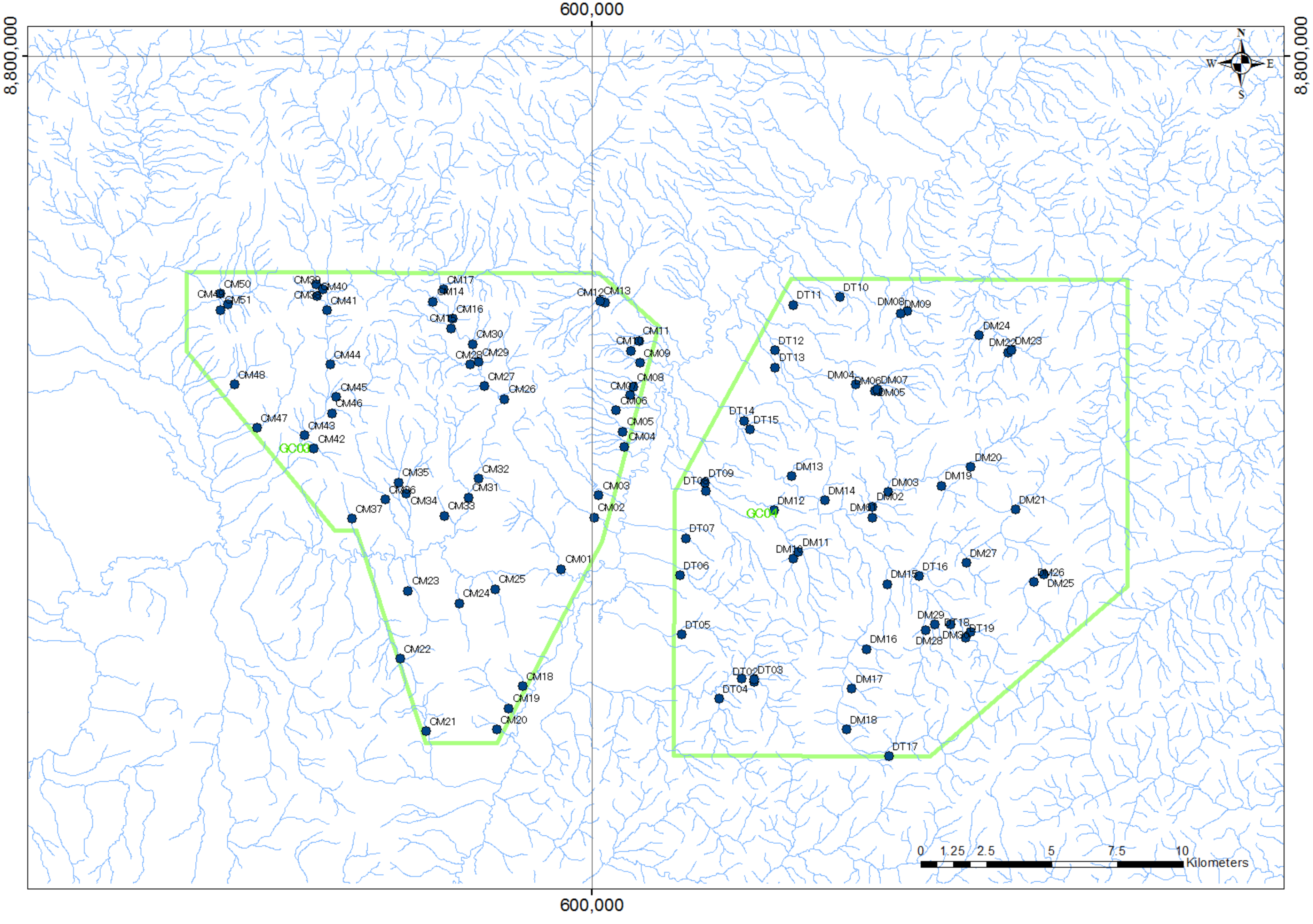


Figure 3-4 Geochemical sample location map (2: Rumphi are)

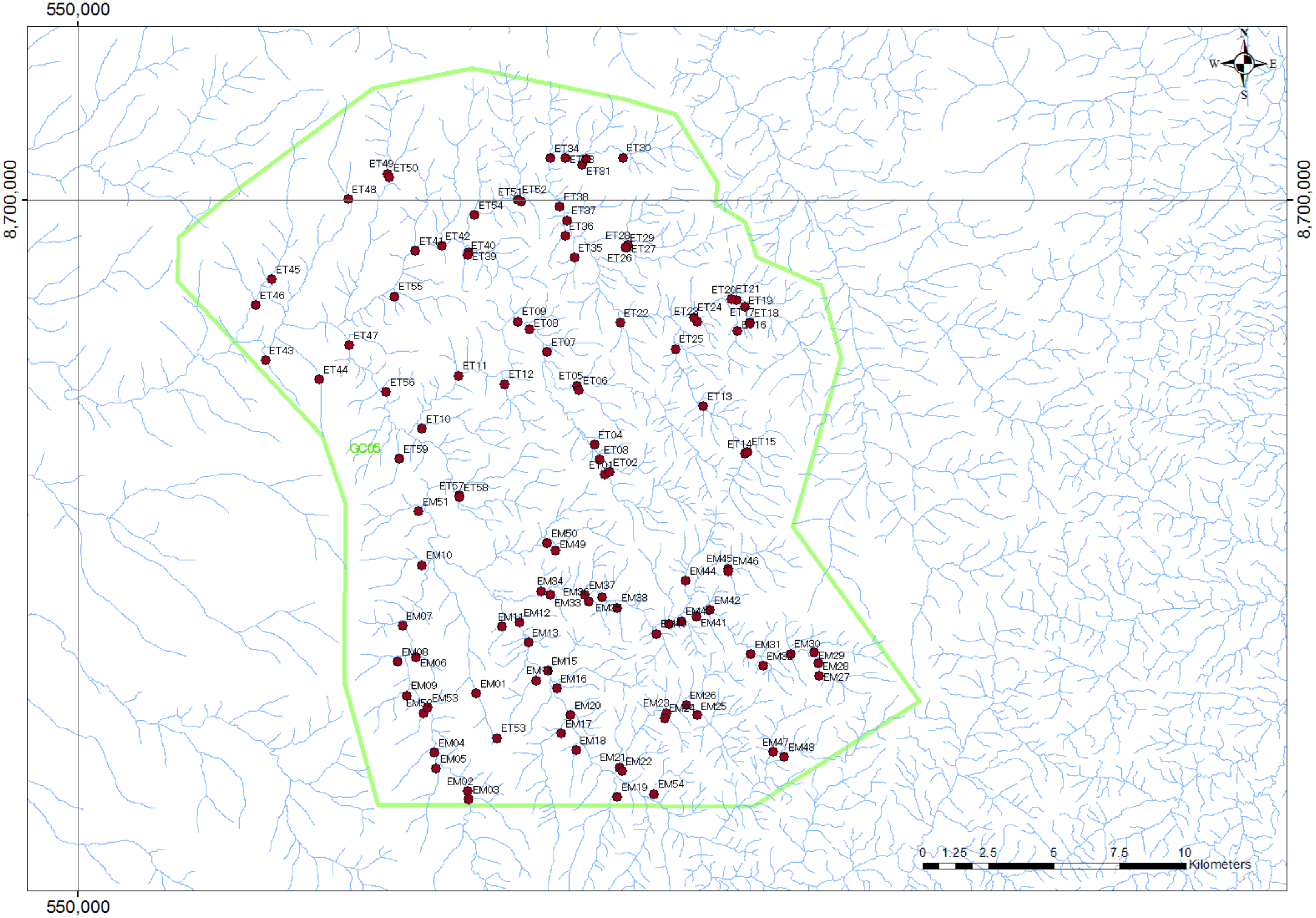


Figure 3-5 Geochemical sample location map (3: Mzimba are)

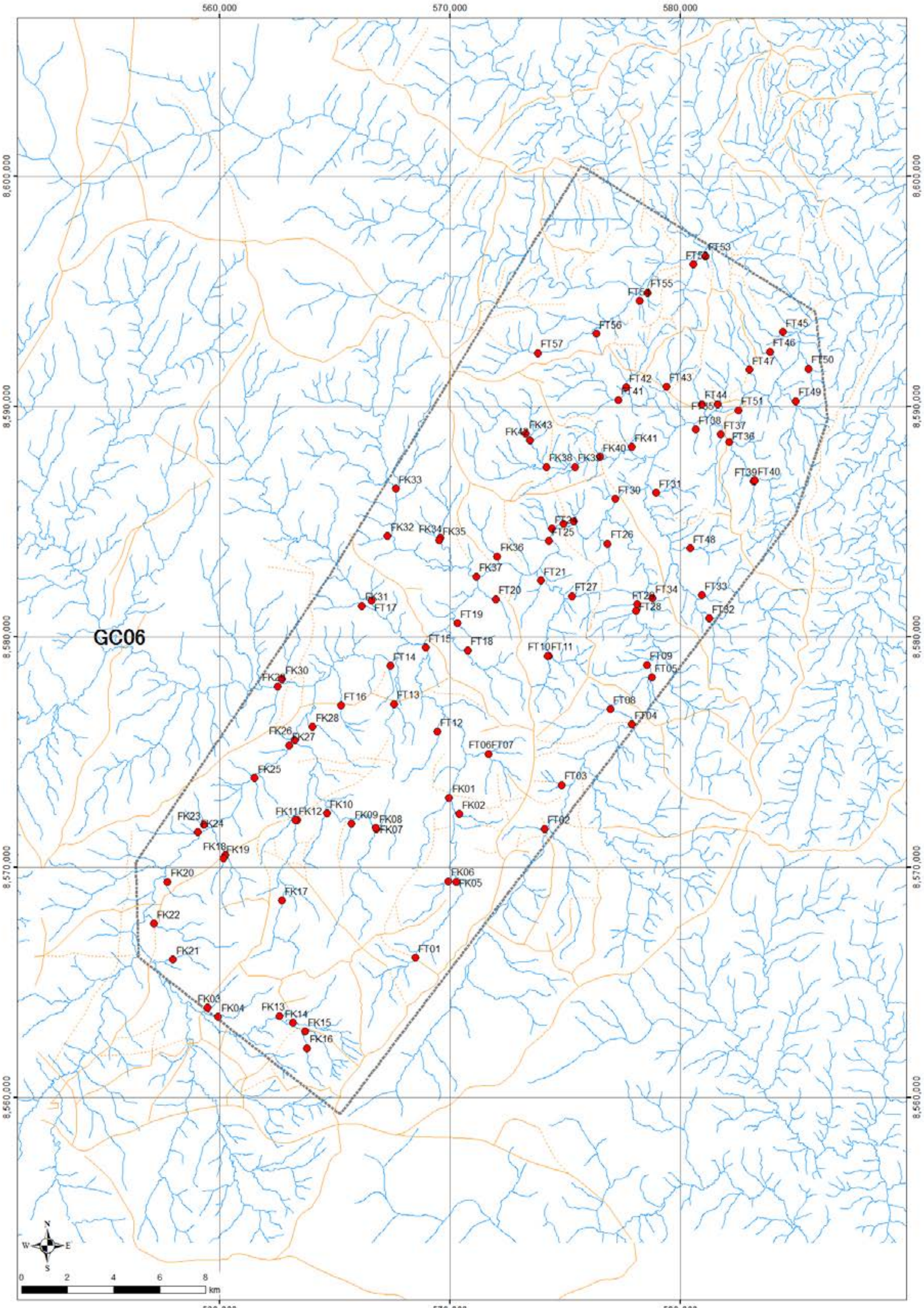


Figure 3-6 Geochemical sample location map (4: Kasungu are)

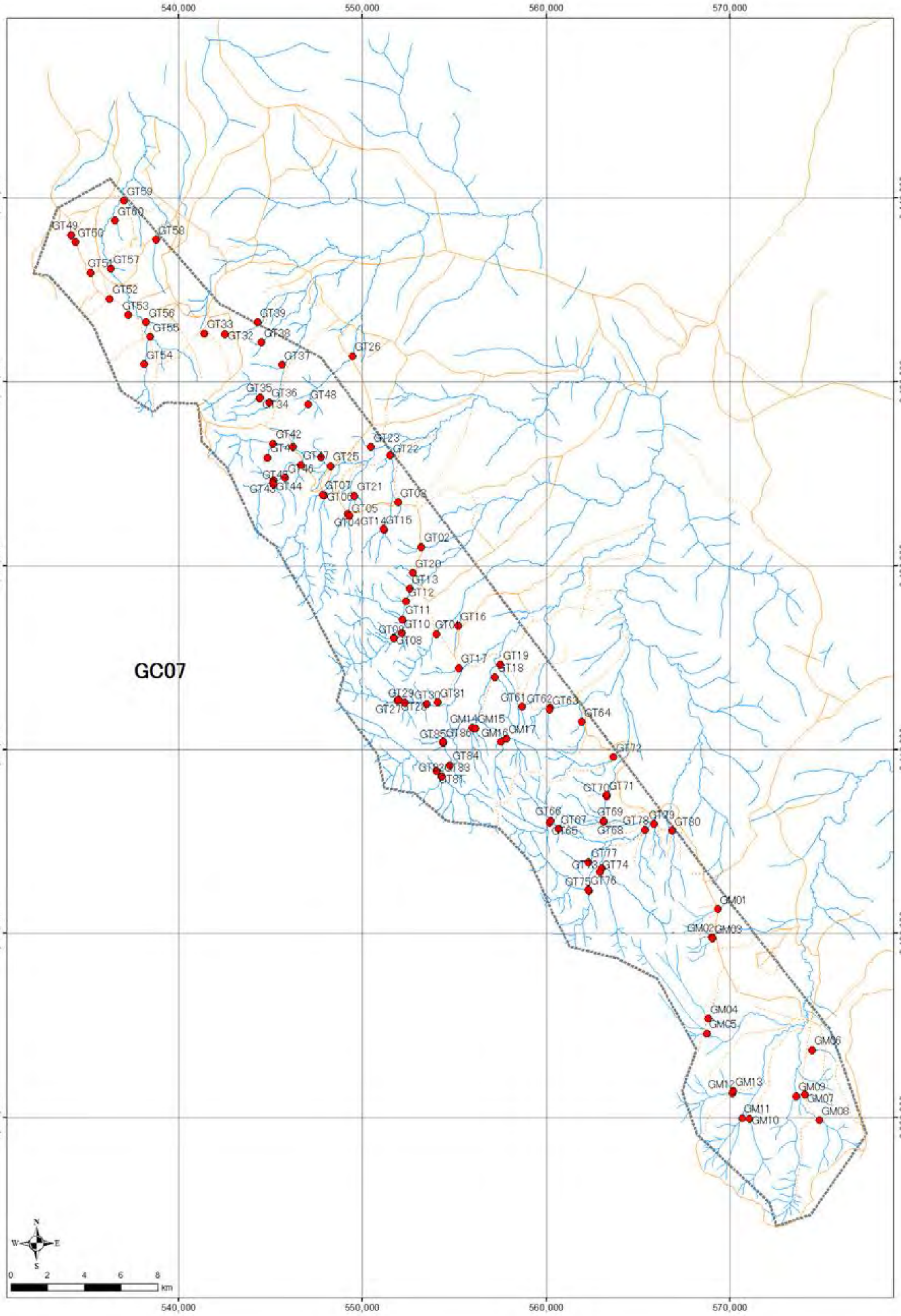


Figure 3-7 Geochemical sample location map (5: Lilongwe are)

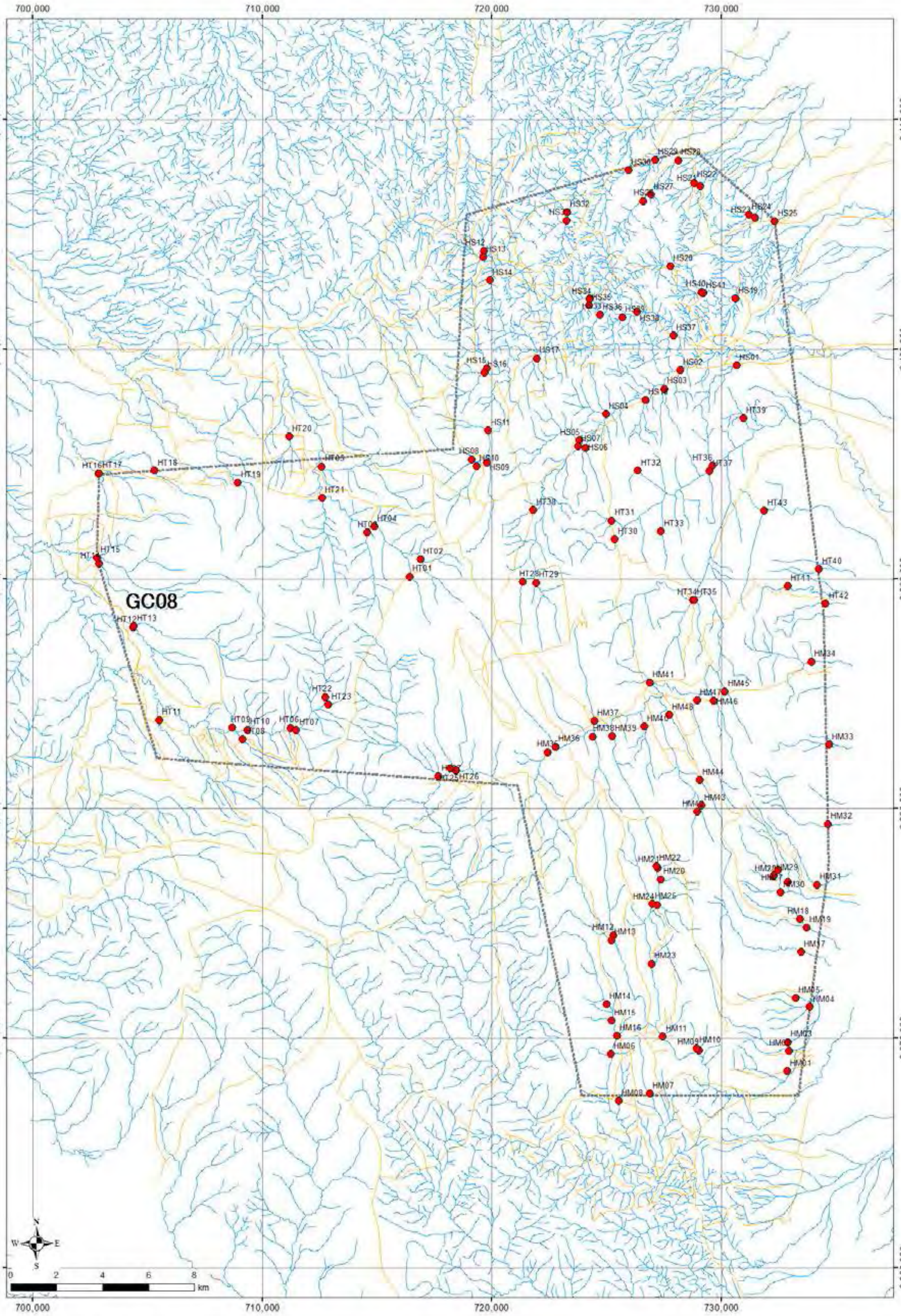


Figure 3-8 Geochemical sample location map (6: Mangochi are)

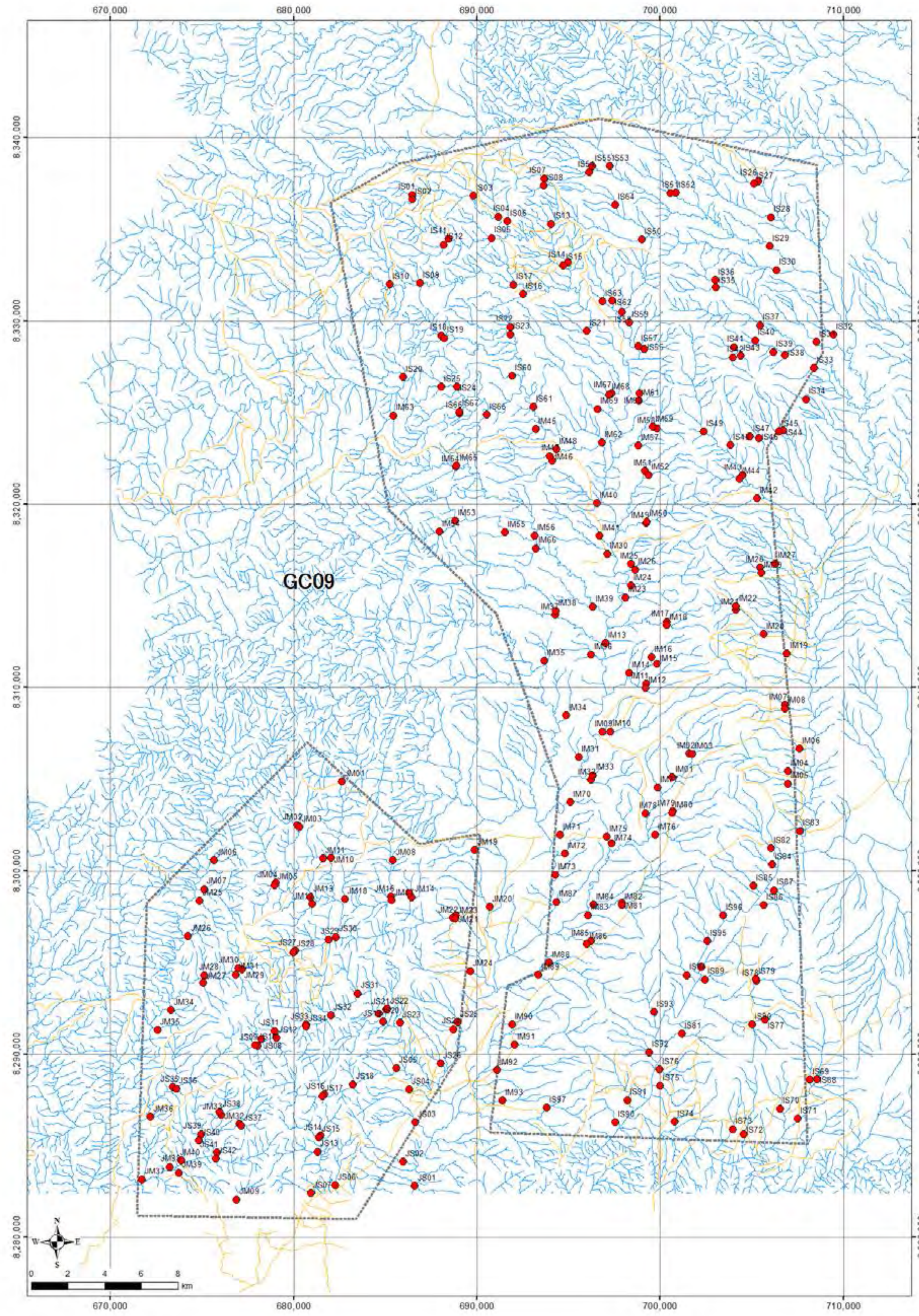


Figure 3-9 Geochemical sample location map (7: Balaka are)

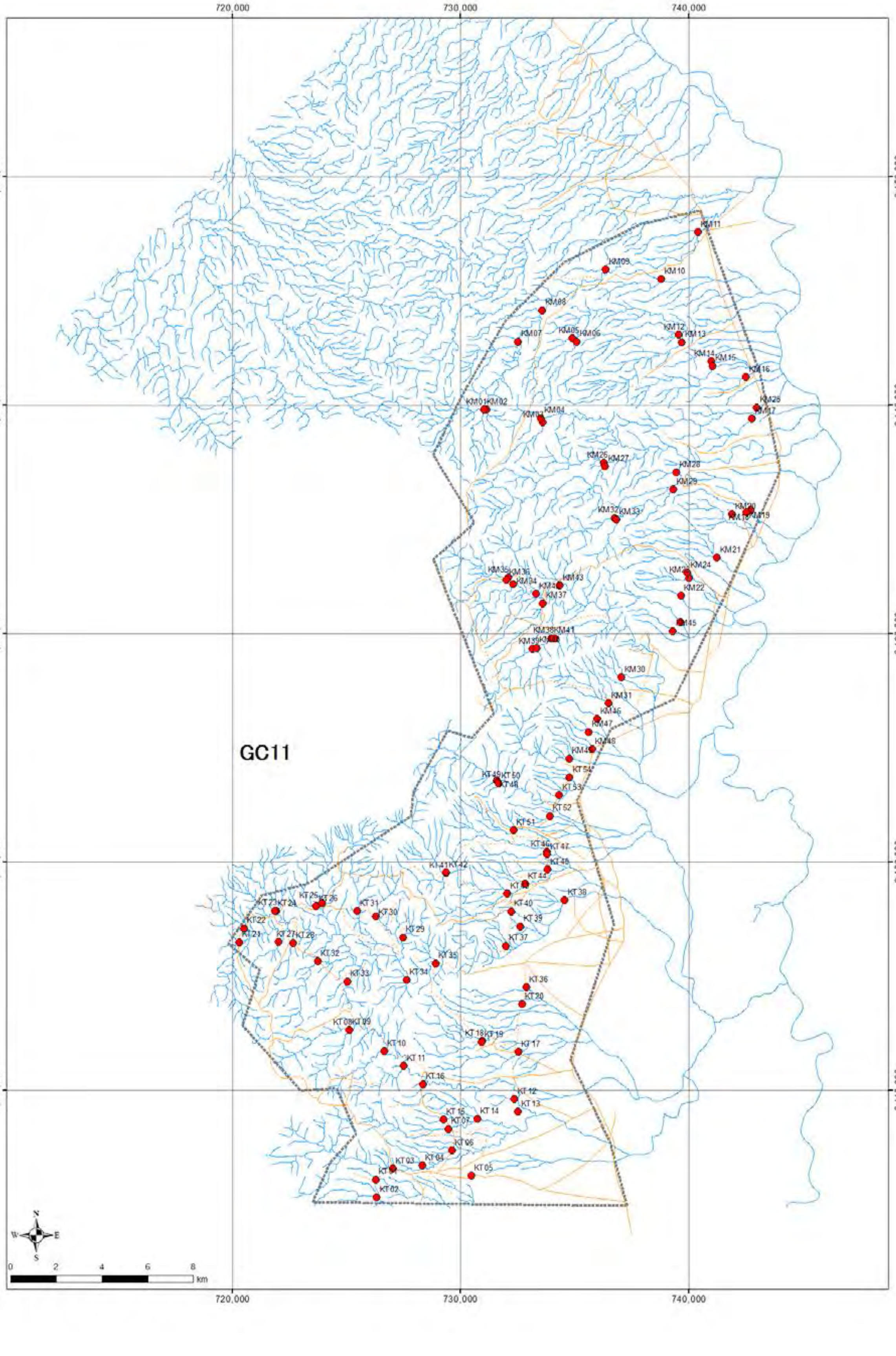
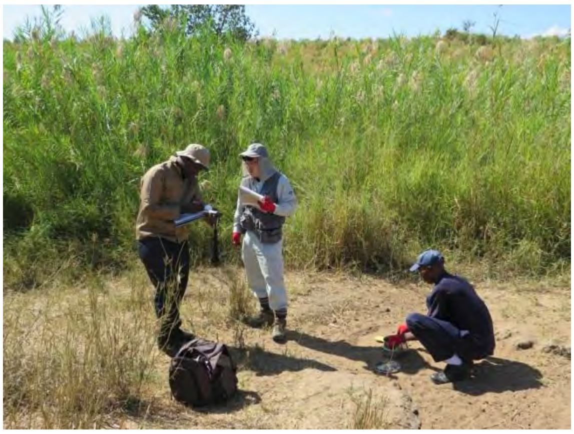


Figure 3-10 Geochemical sample location map (8: Nsanje are)



1: OJT on description (Kasungu area)

2: Sampling at stream without water (Kasungu area)

3: Sampling at stream with running water (Rumphi area)

4: Sampling while being watched by residents (Kasungu area)

5: Road crossing river after unseasonal rain (Mzimba area)

6: Stacked place of vehicle in Mzimba area (Mzimba area)

Figure 3-11 Photos of geochemical survey (field work)

1: Drying samples at hotel in Kasungu

2: Drying samples at hotel in Nsanje

3: OJT on sample reduction method

4: Sample preparation at hotel in Mzimba

5: Sample preparation at hotel in Rumphi

6: Sample preparation at hotel in Mangochi

Figure 3-12 Photos of geochemical survey (sample preparation)

Description Card of Drainage Geochemical Survey (2014) ver.1.3(2)

A	**Survey Area:** *14GC01, 14GC02, 14GC03, 14GC04, 14GC05*	**Collector:**
	Site No.:	**Date & Time:**
	Weather Condition: *Clear, Cloudy, Rainy, (Stormy)*	

B	**UTM-easting:** (GPS reading, ARC1950)	**Planned UTM-E:**
	UTM-northing: (GPS reading, ARC1950)	**Planned UTM-N:**
	Elevation: m (GPS reading)	

C	**Drift types:** *1)Alluvium, 2)Coarse Gravel, 3)Soil, 4)Marsh, 5)Clay, 6)Scree(Talus), 7)Made Ground*
	Drainage types: *1)Dry, 2)Wet, 3)Seepage, 4)Ditch(Waterway), 5)Drains, 6)Small stream[<3m], 7)Stream[3-10m], 8)Small river[10-33m], 9)River[33m<]*
	Drainage-Sediment conditions: *1)Dry-sand/gravel bar, 2)Ponded with dry sections, 3)Low flow, 4)Moderate flow, 5)Strong flow, 6)Channel filled bank to bank, 7)Overflow-bank burst, 8)Spate(Flood)*
	River name[ ], **Drainage Order:** [*1, 2, 3, 4*]
	Additional Comments on Locality:

D	**Land use:** *1)Coniferous Forest, 2)Deciduous Forest, 3) Sparse forest in burned-off field, 4)Small Pit-Pan Minning, 5)Quarrying, 6)Gravel Pit, 7)Rough Grazing, 8)Arable[Maize, Tabacco, Cassava, Cotton, Millet, Sorghum, Groundnuts, Coffee, Tea], 9)Pasture, 10)Heather, 11)Forest or Wildlife Reserve, 12)Industrial[type:]*

E	**Clast Precipitates Colour:** *1)Orange, 2)Brown, 3)Black*, **Clast Precipitates Abundance:** *1)Light, 2)Moderate, 3)Heavy*
	Sediment Colour: *1)White, 2)Grey, 3)Light Brown-Orange, 4)Dark Brown-Black*
	Sediment Composition: Clay [*1)Low clay, 2)Modelate clay, 3)High clay*], **Organics** [*1)Low organics, 2)Moderate organics, 3)High organics*]

F	**Catchment Geology Description(from published geological map):**
	Site Geology(within 100m of site) Description:
	Outcrops(within 100m of site): *1)No, 2)Minor, 3)Modelate, 4)Abundant*
	Clast Lithologic Composition(descending abundance):
	Mineralization style in bedrock: 1) None, *2)Vein, 3)Fault, 3)Pod, 4)Lens, 5)Stratiform, 6)Joint or Fracture, 7)Disseminated, 8)Staining or Coating*
	Mineral Occurrences: *1)None, 2)Oxides[ ], 3)Sulphides[ ], 4)Others[ ]*
	Mineral Abundances: *1)None, 2)Rare, 3)Common, 4)Frequent,* **Associated Alteration:** *[ ]*

G	**Possible Site Contamination:** *1)Manufactured Metal, 2)Iron-Steel wire, 3)Galvanized iron, 4)Copper, 5)Lead, 6)Zinc, 7)Brass, 8)Aluminium, 9)Ceramic, 10)Pottery, 11)Tiles, 12)Bricks(Adobes), 13)Glazed China, 14)Glass, 15)Plastic, 16)Fertilizer sack, 17)Rubber, 18)Chemical, 19)Paint, 20)Liquid effuluent, 21)Farm effluent, 22)Cattle manure, 23)Domestic effluent, 24)Bulk industrial waste, 25)Metal mine tailing, 26)Coal tailing, 27)China clay tailing, 28)Slag(furnace waste), 29)Agro-chemicals, 30)Fertilizer, 31)Lime*

REF.1: Rock Classification Scheme

Igneous rock, Dolerite, Lamprophyre, Pegmatite(granite), Aplite, Quartz porphyry, Felsite, Granite, Granodiorite, Diorite, Rhyolite, Andesite, Dacite, Basalt, Gabbro, Mafic rock, Ultrabasic rock, Amphibolite, Pyroxinite, Dunite, Peridotite, Serpentinite, Syenite, Carbonatite, Kimberlite, Agglomerate, Tuff, Ash(tephra)

Sedimentary rock, Conglomerate, Sandstone, Arcosic sandstone, Felspathic arenite, Siltstone, Mudstone, Shale, Oil shale, Clay, Marl, Chalk, Limestone, Dolomite, Ironstone, Agate, Chert, Flint, Gypsum, Anhydrite, Coal, Carbonaceous mudstone, Carcareous mudstone, Laterite(Duricrust, Pisolitic, Limonite)

Metamorphic rock, Quartzite, Psammite, Pelite, Phyllitic Pelite, Phyllite(Micaceous), Slate, Marble, Schist(Muscovite, Tectonic, Quartz, Hornblend-Epidote-Chlorite), Gneiss(Amphibole/Biotite/Muscovite/Granitic/Cordierite/ Charnokitic/Sillimanite/Garnetiferous/Calc-silicate), Augengneiss, Granulite(Charnokitic, Pyroxine), Cataclasite, Mylonite, Migmatite

REF.2: Mineral Abbreviations

Apy-Arsenopyrite, Ba-Baryte, Beryl-Brl, Biotite-Bt,Bor-Bornite, Cal-Calcite, Cass-Cassiterite, Cp-Chalcopyrite, Cr-Chromite, HgS-Cinnabar, Epi-Epidote, Feldspar-Fd, Flu-Fluorite, Ga-Galena, Gt-Garnet, Hem-Hematite, Ilm-Ilumenite, K-Feldspar-Kfd, Mag-Magnetite, MoS-Molybdenite, Mon-Monazite, Py-Pyrite, Pyrr-Pyrrohtite, Qtz-Quartz, Muscovite-Mus, AsS-Realgar, TiOx-Rutile, Schee-Scheerite, Specularite-Sp, ZnS-Sphalerite, SbS-Stibnite, Tour-Tourmarine, Wolf-Wolframite, Zr-Zircon, Coal-Coal

H	**Photo: Whole site view** **Sampling site view**

Figure 3-13 Description card of geochemical survey

3.5 Chemical analysis

The study team requested chemical analysis of geochemical samples to the laboratory both in 2014 and 2015, ALS Geochemistry – Johannesburg, because there is no laboratory in Malawi, which is reliable in quality and precision. The ALS Chemex Labs, Ltd. provides assaying and analytical testing services with high quality and reliability for mining and mineral exploration companies in Canada and internationally. (http://www.alsglobal.com/)

The study team sent geochemical samples on 12 November 2014, the last day in the 2nd On-site Works in Malawi. The team leader received the confirmation document on 18 November 2014 and received assay results on 9 January 2015 by emails. In 2015 the study team sent geochemical samples on 7 September.

The analytical components are the following 61 elements including Au, REEs and basic important elements for mineral resources exploration. The total number of analytical samples is 1,000. Assay results are shown in Appendix 3-1.

The specification of the chemical analysis is as follows.

(1) Sample preparation

・Dry at under 60 °C

・Sieve under 80 mesh (180µ) : fine sand sieved are analyzed

(2) Analytical method

・Inductively coupled plasma mass spectrometry (ICP-MS) by four acid (HCl: hydrochloric acid, HNO_3: nitric acid, HF: hydrofluoric acid and $HClO_4$: perchloric acid) digestion

(3) Analytical elements

(a) Multi-element geochemistry package by ICP：48 elements

Ag, Al, As, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, Zr

(b) REE：12 elements

Dy, Er, Eu, Gd, Ho, Lu, Nd, Pr, Sm, Tb, Tm, Yb

(c) Precious metal：1 element

Au

3.6 Statistical analysis of assay results

The statistical analysis of assay results was carried out on the basis of geochemistry. Examples of analytical results in Mzimba area are shown in Figure 3-14 to 3-16. Analytical results (basic statistics) in each model areas are shown in Table 3-3 and Appendix 3-2.

Basic procedure of statistical analysis is as follows.

- Consider target elements to be analyzed statistically based on assay results, correlation between elements and relation on mineral resources expected in Malawi
- As a result, thirty three elements shown in Table 3-3 were selected.
- Calculate basic statistics such as mean, standard deviation, etc. (Table 3-3)
- Draw histograms (Figure 3-14) and cumulative frequency diagrams (Figure 3-15) of elements related to mineral resources and being noticeable
- Conduct multivariate analysis (Factor analysis)
- Draw histograms and cumulative frequency diagrams of factors related to mineral resources
- Extract statistical "geochemical anomaly population" in consideration of statistic values and graphs
- Draw "geochemical map" (Figure 3-16) based on the statistic values

In order to make statistical analysis and draw graphs described above, special software for each process is necessary. The following software was donated (see Appendix 1-3).

(a) Statistical analysis: XLSTAT-Pro (Addinsoft Co.)

This can make multivariate analysis and be add-in to Microsoft Excel.

(b) Graphics: Grapher (Golden Software Co.)

This can draw cumulative frequency plot on normal probability graph

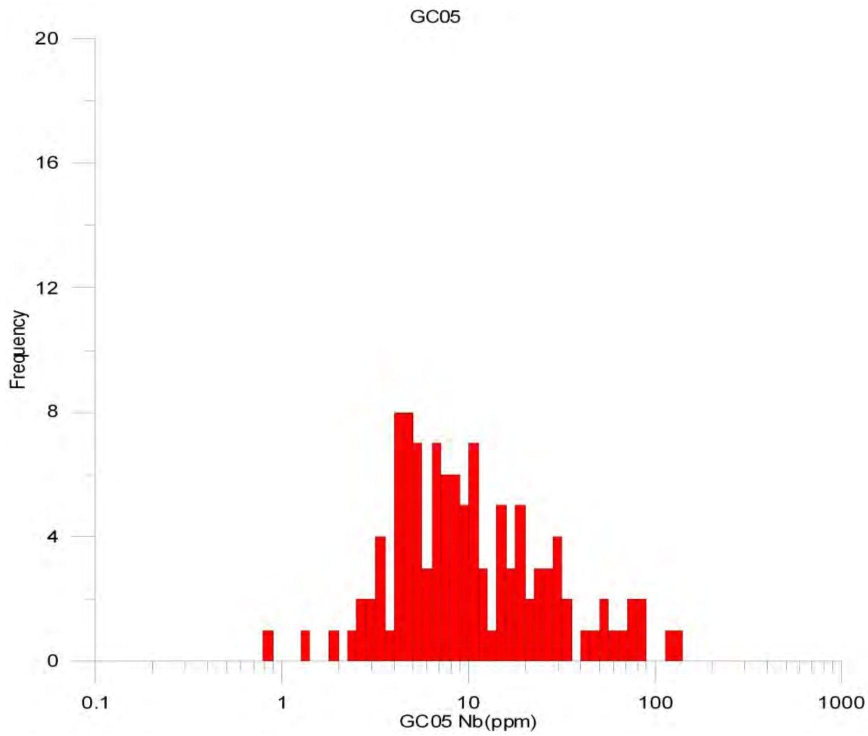


Figure 3-14 Histogram (Mzimba area, Nb)

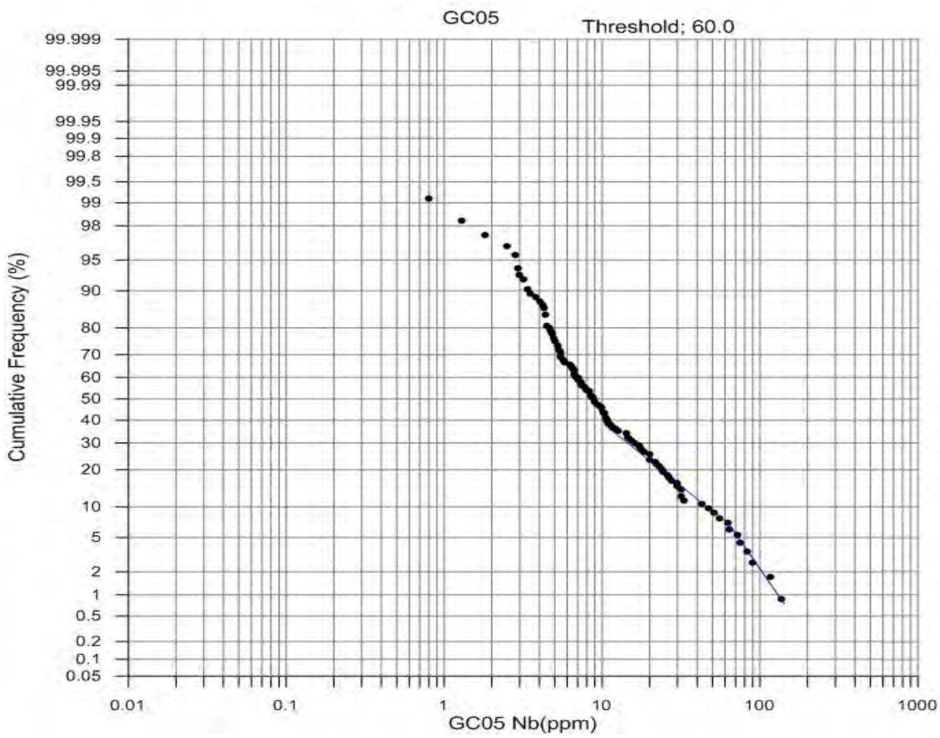


Figure 3-15 Cumulative frequency diagram (Mzimba area, Nb)

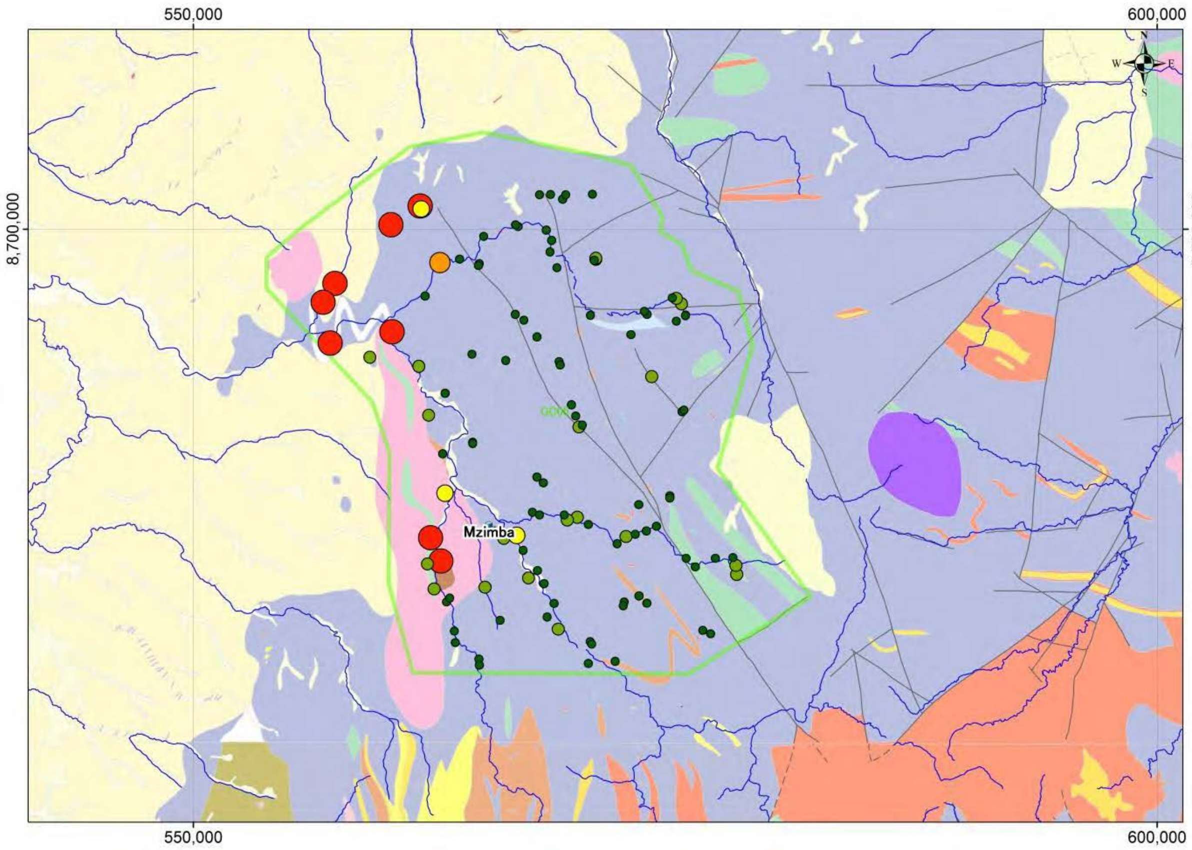


Figure 3-16 Geochemical map (Mzimba area, Nb)

Table 3-3 Basic statistics of all 11 areas

Elements			Au_ppm	Cu_ppm	Ni_ppm	Co_ppm	Cr_ppm	LREE_ppm	HREE_ppm	U+Th_ppm	Nb+Ta_ppm	P_ppm	Ti_%	Fe_%	Mo_ppm	Zn_ppm	Zr_ppm
Chitipa	GC01	mean	0.0013	28.317	41.087	31.125	146.467	255.973	20.397	15.665	116.529	535.667	2.264	8.258	1.312	72.767	110.002
		min.	0.0005	8.100	5.300	4.900	22.000	105.730	7.380	2.600	14.080	70.000	0.339	1.610	0.430	17.000	27.400
		max.	0.0040	54.700	158.500	79.000	822.000	1273.420	78.250	219.200	556.200	1480.000	10.000	21.700	2.710	163.000	375.000
	GC02	mean	0.0018	22.124	29.480	22.274	128.630	396.904	25.016	32.676	42.190	440.217	1.114	8.215	1.143	55.522	94.911
		min.	0.0010	7.200	8.900	5.500	35.000	104.430	8.240	2.900	5.460	100.000	0.258	2.630	0.330	19.000	34.700
		max.	0.0120	46.300	67.000	49.400	605.000	1594.200	106.260	176.800	348.150	2230.000	3.610	25.200	2.200	137.000	428.000
Rumphi	GC03	mean	0.0018	16.818	19.255	13.133	84.039	404.089	24.998	57.369	109.902	394.902	0.950	4.969	1.513	52.706	105.141
		min.	0.0010	5.300	3.400	2.800	6.000	89.850	6.540	6.000	12.150	120.000	0.196	1.180	0.430	20.000	25.500
		max.	0.0030	59.700	83.900	44.900	465.000	2651.200	209.060	479.000	478.600	2630.000	4.580	12.900	4.150	108.000	500.000
	GC04	mean	0.0011	10.414	8.861	8.212	24.816	357.788	25.396	22.729	186.885	506.939	1.557	5.610	2.152	87.612	152.159
		min.	0.0005	0.100	1.100	1.400	2.000	79.460	8.140	5.200	7.570	70.000	0.087	0.930	0.450	27.000	14.500
		max.	0.0020	67.900	28.400	31.600	120.000	1139.610	90.670	108.200	576.600	1970.000	9.940	27.100	10.800	286.000	500.000
Mzimba	GC05	mean	0.0017	5.830	9.267	6.515	31.478	1582.760	96.341	333.528	18.755	988.142	0.691	2.507	0.322	28.204	252.898
		min.	0.0010	0.100	1.200	0.800	5.000	12.130	0.640	0.800	0.850	100.000	0.037	0.390	0.025	5.000	6.000
		max.	0.0110	32.000	37.100	29.100	122.000	9320.800	662.100	2244.000	145.630	3790.000	4.450	10.950	1.740	100.000	500.000
Kasungu	GC06	mean	0.0038	19.955	34.120	18.977	104.550	268.895	25.377	35.673	42.987	629.300	1.620	6.168	0.796	55.110	120.579
		min.	0.0005	3.700	5.000	5.100	14.000	29.360	4.850	3.600	4.490	170.000	0.325	1.650	0.260	23.000	30.000
		max.	0.1330	58.500	90.500	39.200	316.000	3310.550	295.080	451.300	540.500	4540.000	10.000	30.800	6.550	129.000	500.000
Lilongwe	GC07	mean	0.0005	3.332	3.371	3.552	10.534	135.232	35.423	35.577	11.794	378.835	0.251	1.487	0.481	39.864	235.454
		min.	0.0005	0.400	0.400	0.400	2.000	18.060	4.960	2.200	2.360	50.000	0.058	0.190	0.100	2.000	21.900
		max.	0.0010	16.600	29.800	26.200	181.000	448.690	101.070	811.200	36.460	2040.000	2.930	4.750	1.400	145.000	500.000
Mangochi	GC08	mean	0.0006	11.011	20.957	18.506	90.220	948.202	61.141	179.255	116.942	1140.152	3.107	9.908	2.587	115.295	264.317
		min.	0.0005	1.900	3.900	3.900	10.000	95.680	11.810	4.900	9.100	240.000	0.229	1.590	0.430	19.000	15.700
		max.	0.0020	33.600	54.600	43.700	284.000	4377.350	402.860	1160.000	450.000	3980.000	10.000	29.300	13.900	332.000	500.000
Balaka	GC09	mean	0.0010	20.447	38.829	24.270	106.763	433.962	35.177	12.489	41.369	2228.158	2.285	9.055	1.856	105.558	41.496
		min.	0.0005	4.200	7.700	5.900	7.000	26.220	6.120	0.300	4.680	190.000	0.257	1.660	0.120	25.000	4.700
		max.	0.0350	74.200	265.000	63.600	1220.000	13142.400	230.560	141.300	333.650	10000.000	10.000	27.300	75.700	1370.000	335.000
	GC10	mean	0.0008	18.280	32.490	20.826	104.220	317.102	38.131	21.165	37.488	3350.732	1.639	8.478	2.073	78.195	104.122
		min.	0.0005	4.400	4.000	3.900	10.000	36.250	7.130	2.800	2.380	230.000	0.318	1.140	0.420	15.000	7.600
		max.	0.0060	55.000	194.000	47.400	1340.000	1476.450	106.940	77.500	157.250	10000.000	6.740	34.100	6.650	170.000	394.000
Nsanje	GC11	mean	0.0085	21.018	40.444	21.720	126.194	928.117	58.928	157.655	133.048	2056.505	1.638	7.518	2.173	102.602	161.466
		min.	0.0005	3.200	13.300	8.900	28.000	23.080	3.470	0.400	3.120	280.000	0.254	2.210	0.130	25.000	10.300
		max.	0.5010	61.500	158.500	52.100	626.000	5767.000	414.560	1581.500	593.600	5260.000	8.930	28.500	6.840	203.000	500.000
Total		mean	0.0021	15.631	26.256	17.457	86.533	603.149	44.623	92.723	69.390	1332.760	1.676	6.757	1.523	76.735	152.200
		min.	0.0005	0.100	0.400	0.400	2.000	12.130	0.640	0.300	0.850	50.000	0.037	0.190	0.025	2.000	4.700
		max.	0.5010	74.200	265.000	79.000	1340.000	13142.400	662.100	2244.000	593.600	10000.000	10.000	34.100	75.700	1370.000	500.000

3.7 Creation of GIS data and geochemical maps

The study team created GIS data of location information (UTM36S, WGS1984) in field works and assay results of geochemical samples using EXCEL. Geochemical maps of each element were drawn by ArcGIS software as bubble plots applying symbology-color-size combination (5 categories by boundary values of Mean, Mean+σ, Mean+1.5σ, Threshold, as shown in Table 3-4) based on the results of statistical analysis, which mentioned at former section.

For example, Cu value of Table 3-4 shows the categories of bubble plots with boundary values of the mean value (15.631ppm), mean+σvalue (26.974ppm), mean+1.5σ value (32.646ppm) and threshold value(50ppm). Over threshold value (here 50ppm<) shows with red maximum bubble size to show visually the anomaly distribution. Figure 3-17 to figure 3-24 show whole anomaly distribution detected in 11 model survey areas.

Table 3-4 Basic statistics and boundary values of bubble plots categorization

Statistic	No. of samples	Min.	Max.	Freq. of min.	Freq. of max.	Range	Mean	Standard deviation (σ)	Mean	Mean+σ	Mean+1.5 σ	Threshold
Au_ppm	1029	0.001	0.501	481	1	0.501	0.002	0.018	0.002	0.020	0.029	0.07
Ag_ppm	1029	0.005	4.870	176	1	4.865	0.057	0.196	0.057	0.253	0.351	0.5
Ba_ppm	1029	60.000	4540.000	1	1	4480.000	799.913	540.652	799.913	1340.565	1610.891	2000
Be_ppm	1029	0.100	14.050	1	1	13.950	1.829	1.389	1.829	3.218	3.912	5
Bi_ppm	1029	0.005	5.910	2	1	5.905	0.125	0.269	0.125	0.394	0.528	0.7
Ce_ppm	1029	5.950	500.000	1	180	494.050	201.504	174.213	201.504	375.717	462.823	200
Co_ppm	1029	0.400	79.000	2	1	78.600	17.457	11.615	17.457	29.072	34.879	20
Cr_ppm	1029	2.000	1340.000	18	1	1338.000	86.533	107.625	86.533	194.158	247.971	300
Cu_ppm	1029	0.100	74.200	12	1	74.100	15.631	11.343	15.631	26.974	32.646	50
Fe_%	1029	0.190	34.100	1	1	33.910	6.757	5.464	6.757	12.221	14.952	28
La_ppm	1029	2.700	10000.000	1	1	9997.300	180.385	475.612	180.385	655.997	893.803	700
Li_ppm	1029	1.100	81.700	1	1	80.600	10.388	8.996	10.388	19.384	23.882	21
Mn_ppm	1029	27.000	16400.000	1	1	16373.000	1487.359	1345.752	1487.359	2833.111	3505.987	5000
Mo_ppm	1029	0.025	75.700	1	1	75.675	1.523	2.820	1.523	4.343	5.753	6
Nb_ppm	1029	0.800	500.000	1	11	499.200	65.217	92.505	65.217	157.723	203.976	185
Ni_ppm	1029	0.400	265.000	1	1	264.600	26.256	26.501	26.256	52.757	66.007	100
P_ppm	1029	50.000	10000.000	2	10	9950.000	1332.760	1649.380	1332.760	2982.140	3806.830	7000
Pb_ppm	1029	1.700	2990.000	1	1	2988.300	24.897	93.800	24.897	118.697	165.597	72
Sn_ppm	1029	0.100	500.000	1	1	499.900	3.631	15.825	3.631	19.456	27.369	23
Sr_ppm	1029	7.500	2950.000	1	1	2942.500	333.706	331.782	333.706	665.487	831.378	900
Ta_ppm	1029	0.050	93.600	1	1	93.550	4.172	7.353	4.172	11.525	15.201	40
Th_ppm	1029	0.200	2030.000	2	1	2029.800	84.300	196.219	84.300	280.518	378.628	1000
Ti_%	1029	0.037	10.000	1	8	9.963	1.676	1.861	1.676	3.537	4.467	5
U_ppm	1029	0.100	217.000	11	1	216.900	8.423	17.904	8.423	26.327	35.279	56
V_ppm	1029	1.000	1100.000	1	1	1099.000	157.830	149.752	157.830	307.582	382.458	820
W_ppm	1029	0.100	63.400	29	1	63.300	1.883	4.542	1.883	6.425	8.696	22
Y_ppm	1029	0.900	403.000	1	1	402.100	48.736	43.065	48.736	91.802	113.335	100
Zn_ppm	1029	2.000	1370.000	1	1	1368.000	76.735	64.838	76.735	141.573	173.992	300
Zr_ppm	1029	4.700	500.000	1	83	495.300	152.200	147.449	152.200	299.649	373.374	264
Dy_ppm	1029	0.160	156.500	1	1	156.340	11.250	13.426	11.250	24.676	31.390	36
Er_ppm	1029	0.080	33.500	1	1	33.420	4.879	3.761	4.879	8.640	10.521	20
Eu_ppm	1029	0.070	93.400	1	1	93.330	2.946	4.191	2.946	7.137	9.233	11
Gd_ppm	1029	0.240	396.000	1	1	395.760	18.789	31.973	18.789	50.763	66.749	90
Ho_ppm	1029	0.030	19.500	1	1	19.470	1.901	1.789	1.901	3.690	4.584	4
Lu_ppm	1029	0.010	5.690	1	1	5.680	0.652	0.481	0.652	1.132	1.373	2.4
Nd_ppm	1029	2.200	3780.000	1	1	3777.800	146.972	272.765	146.972	419.737	556.120	1000
Pr_ppm	1029	0.620	1000.000	1	2	999.380	43.972	94.876	43.972	138.848	186.285	300
Sm_ppm	1029	0.390	634.000	1	1	633.610	27.369	53.103	27.369	80.473	107.024	200
Tb_ppm	1029	0.030	40.500	1	1	40.470	2.307	3.368	2.307	5.676	7.360	7.5
Tm_ppm	1029	0.010	4.640	1	1	4.630	0.669	0.483	0.669	1.153	1.394	2
Yb_ppm	1029	0.080	32.800	1	1	32.720	4.175	3.023	4.175	7.199	8.711	10
Nuclear_ppm	1029	0.300	2244.000	1	1	2243.700	92.723	212.364	92.723	305.086	411.268	950
LREE_ppm	1029	12.130	13142.400	1	1	13130.270	603.149	960.141	603.149	1563.290	2043.360	2000
HREE_ppm	1029	0.640	662.100	1	1	661.460	44.623	55.129	44.623	99.751	127.316	150
Coltan_ppm	1029	0.850	593.600	1	1	592.750	69.390	99.081	69.390	168.471	218.012	950

ArcGIS software was donated to GSD in the previous JICA project and upgraded to the latest version in the present Project. All GIS data created in geochemical survey will be integrated into existing GIS database.

Among geochemical maps of model survey area (Figure 3-17 to Figure3-24) below indicated seven anomalous commodities are detected, which cover dominantly several 10s sq. km. order within the 500sq.km order survey area. The relationship between anomalies and associated geological units such as intrusive rocks and structure will be discussed in next section.

1) Anomaly of Cu-Co-Ni-Cr etc. of base metals
   North: GC01-02 (Chitipa)
   Central: GC06 (Kasungu)
   South: GC09-10(Balaka-Mwanza) and GC11 (Nsanje)
2) Anomaly of REE etc.
   North: GC05 (Mzimba)
   South: GC08 (Mangochi), GC09-10(Balaka-Mwanza) and GC11 (Nsanje)
3) Anomaly of Nb-Ta (Coltan metal)
   North: GC01-02 (Chitipa), GC03-04(Rumphi),
   South: GC08 (Mangochi), GC09-10 (Balaka- Mwanza) and GC11 (Nsanje)
4) Anomaly of Zr
   North: GC03-04 (Rumphi) and GC05 (Mzimba)
   Central: GC06 (Kasungu) and GC07 (Dzalanyama)
   South: GC08 (Mangochi) and GC11 (Nsanje)
5) Anomaly of Ti
   North: GC01-02(Chitipa)
   Central: GC06 (Kasungu)
   South: GC08 (Mangochi) and GC09-10 (Balaka- Mwanza)
6) Anomaly of P
   South: GC09-10 (Balaka- Mwanza)
7) Anomaly of Sr-Ba
   North: GC03-04 (Rumphi)
   South: GC09-10 (Balaka- Mwanza) and GC11 (Nsanje)

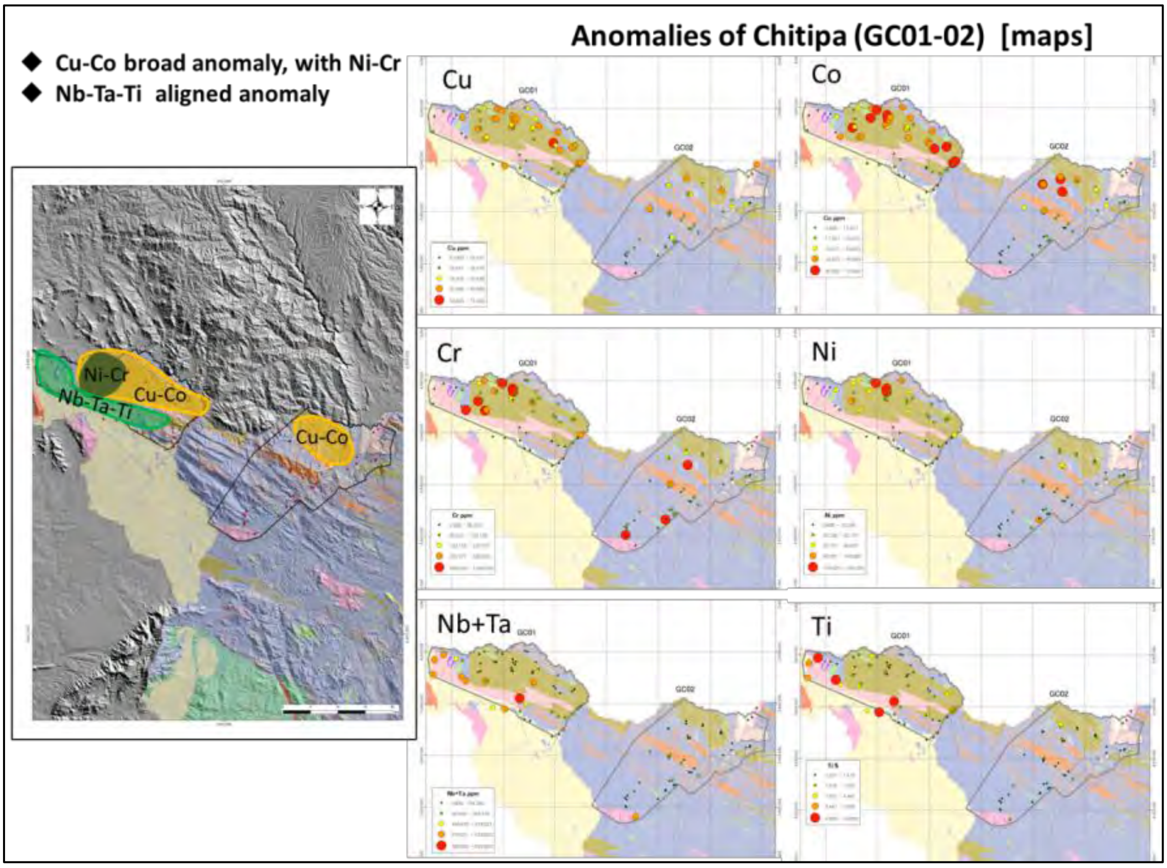


Figure 3-17 Geochemical maps in Chitipa area

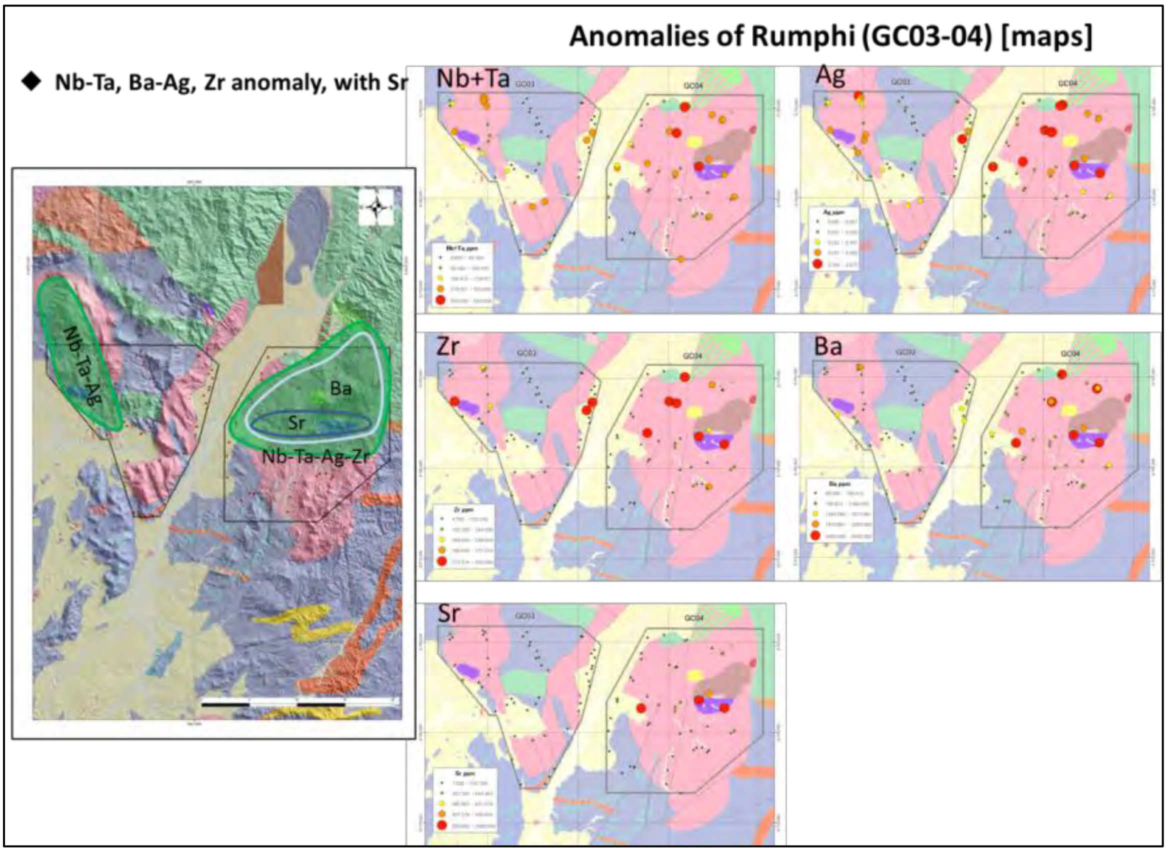


Figure 3-18 Geochemical maps in Rumphi area

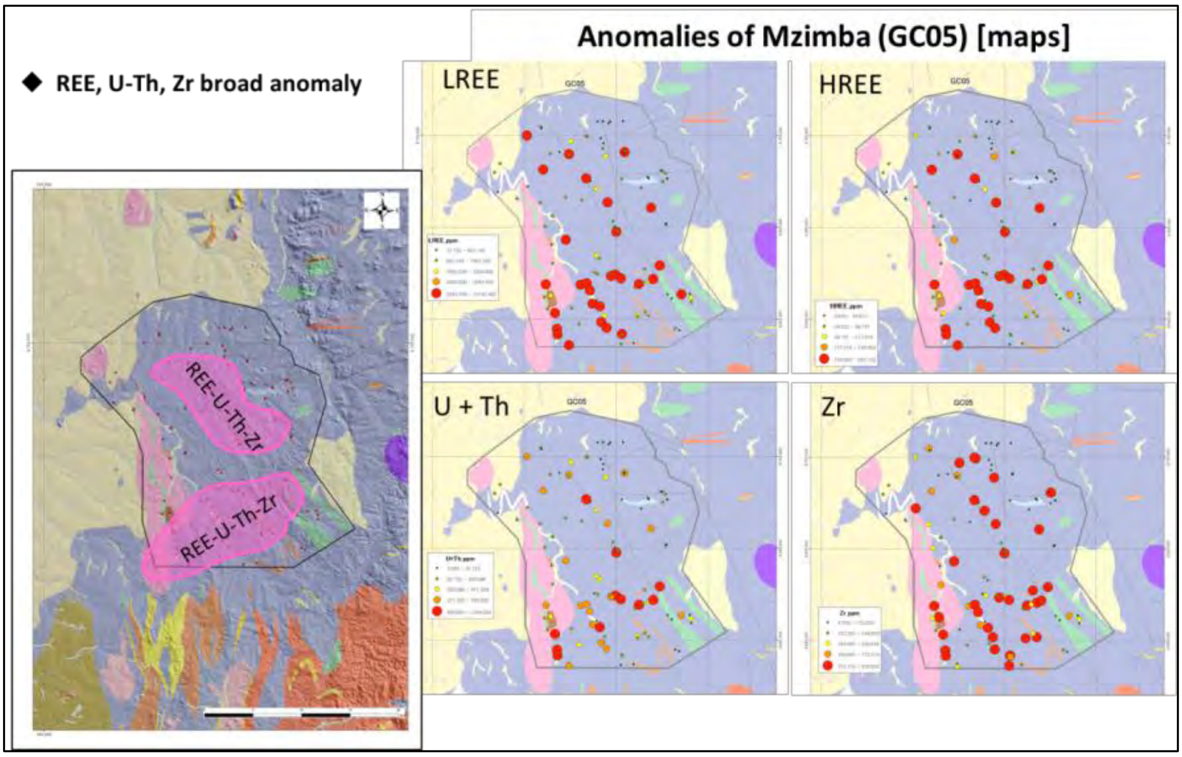


Figure 3-19 Geochemical maps in Mzimba area

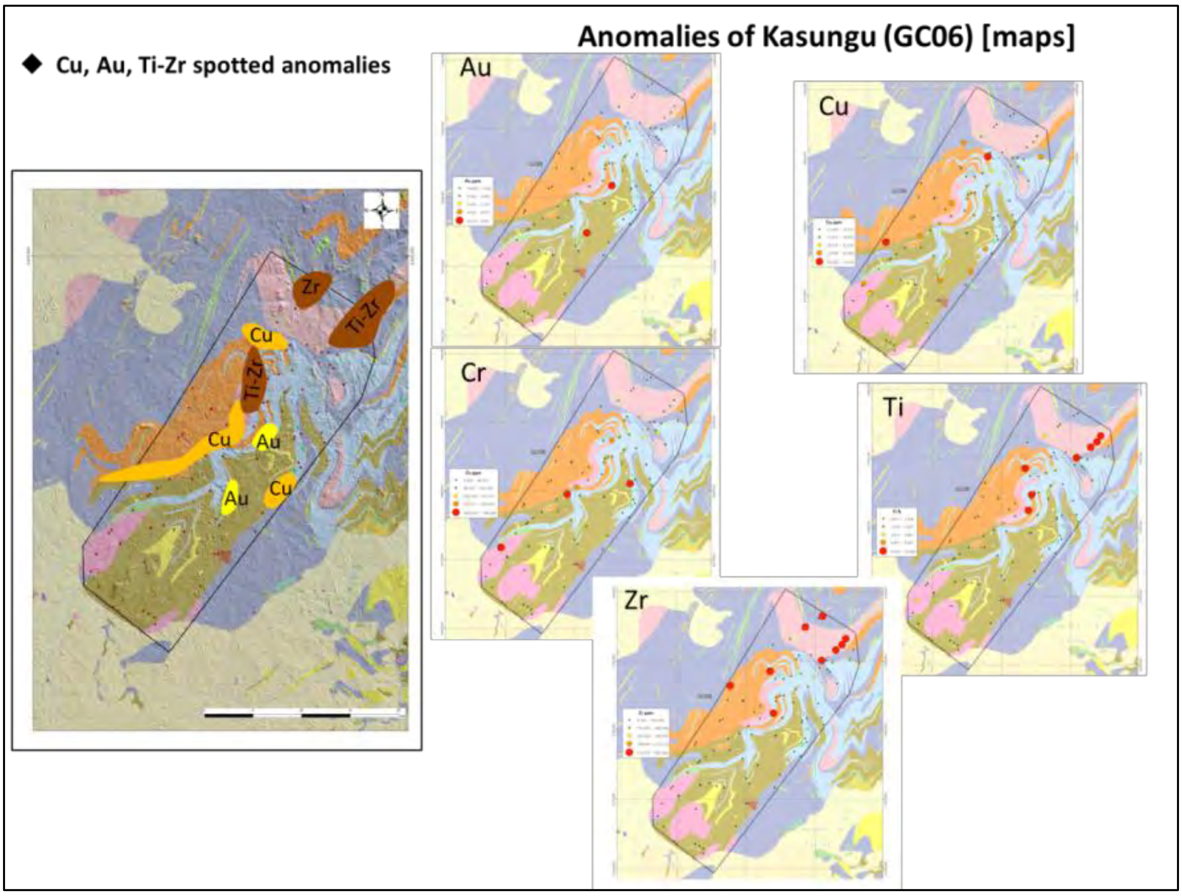


Figure 3-20 Geochemical maps in Kasungu area

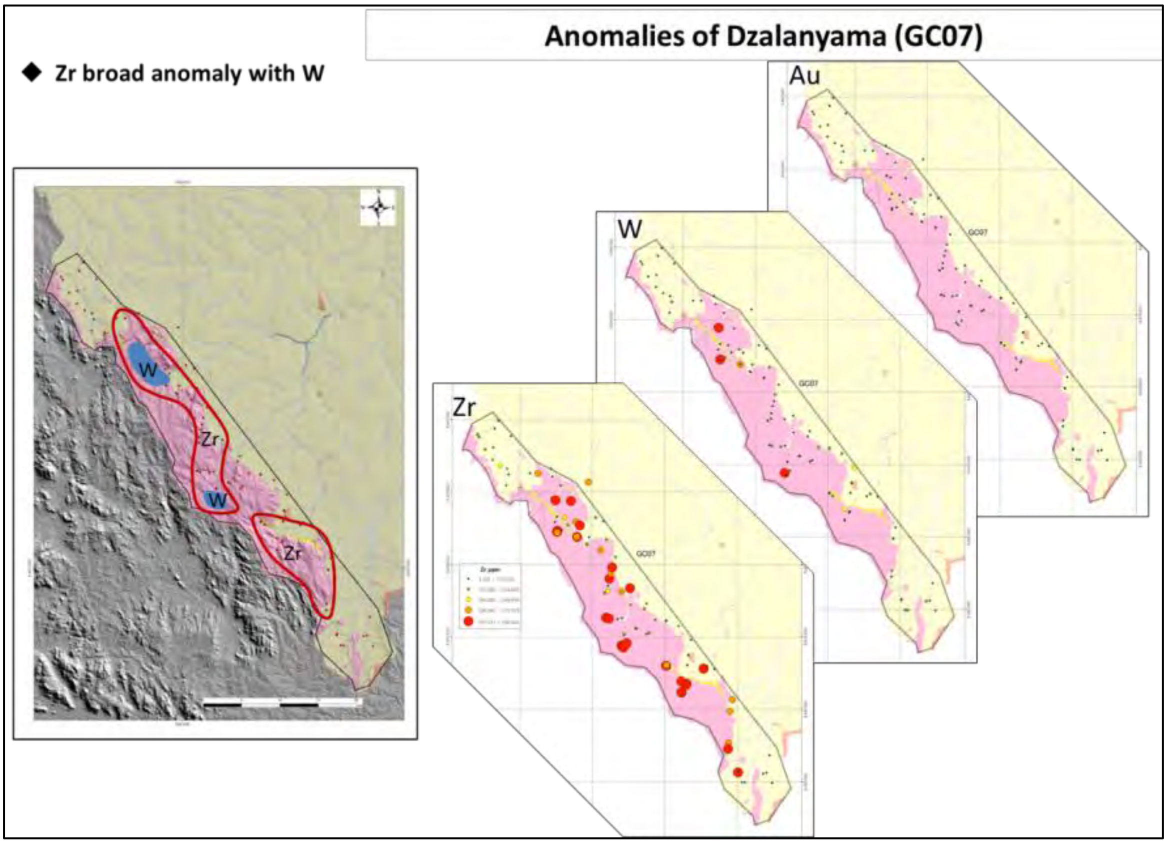


Figure 3-21 Geochemical maps in Lilongwe area

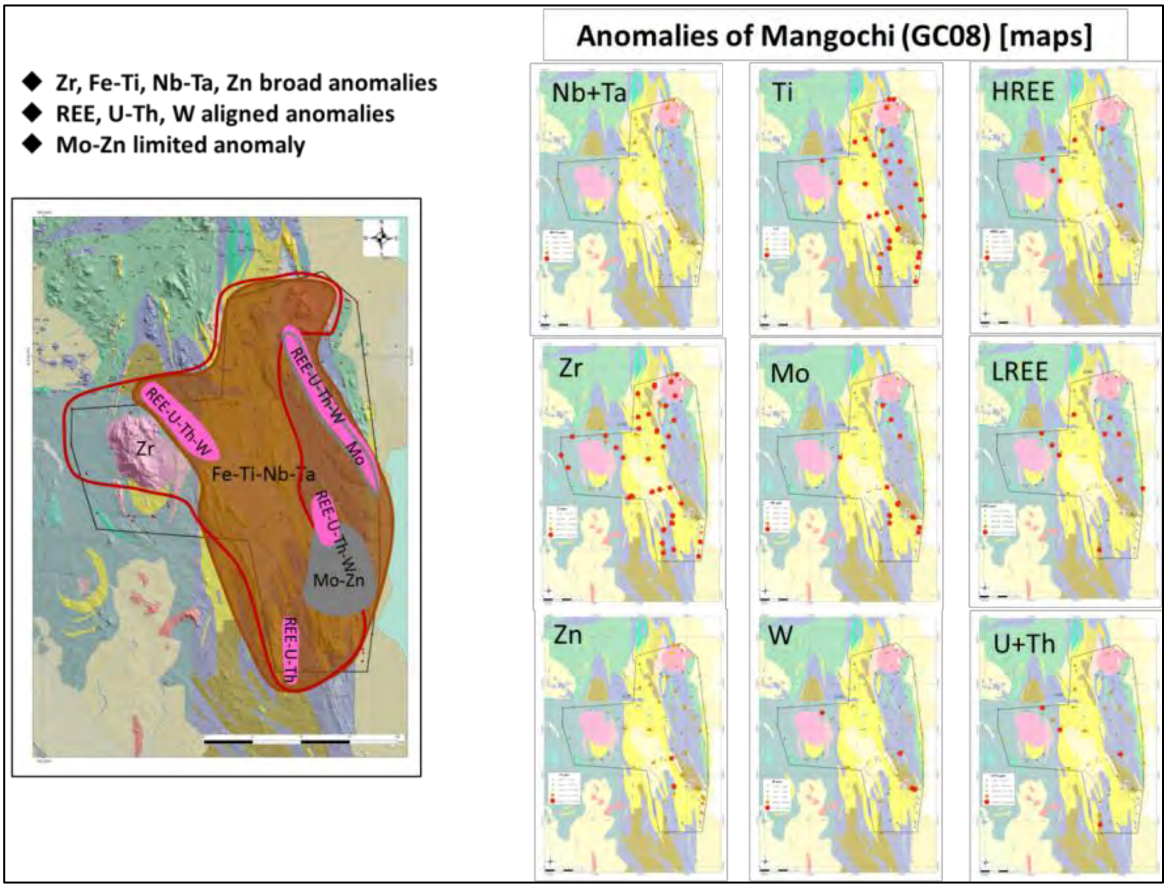


Figure 3-22 Geochemical maps in Mangochi area

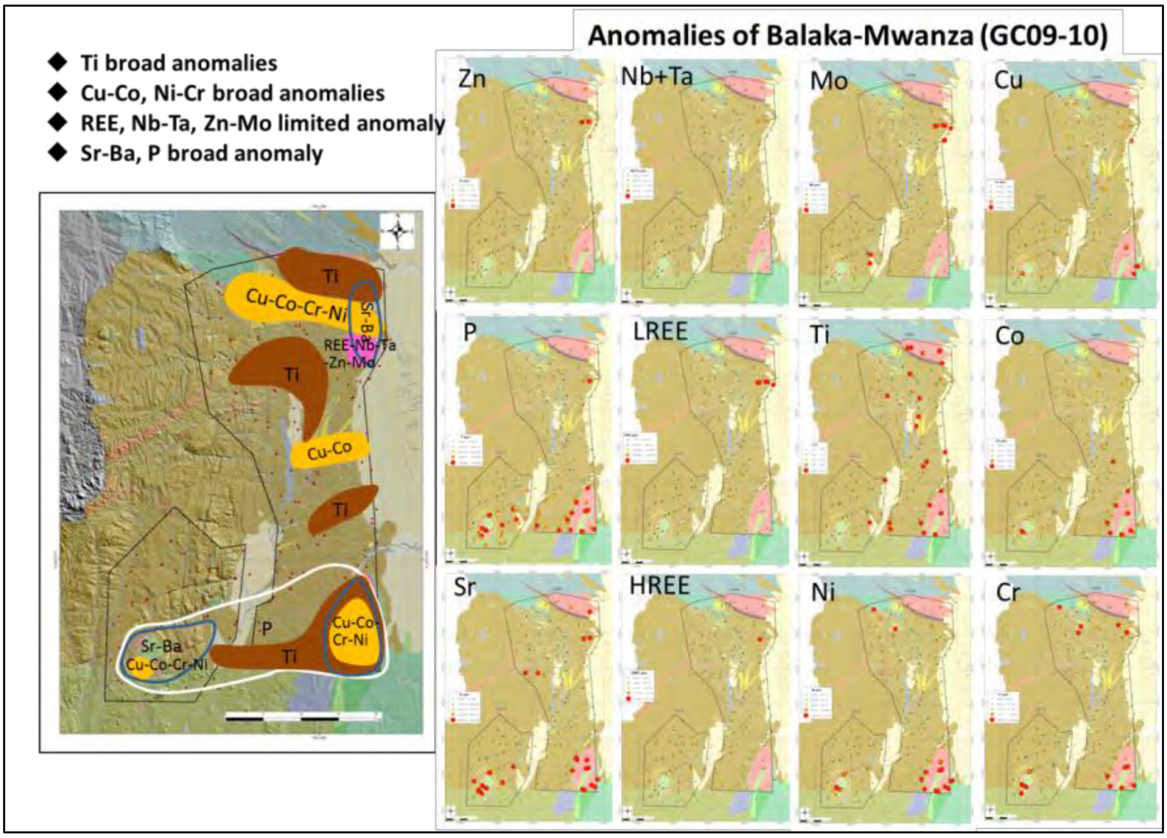


Figure 3-23 Geochemical maps in Balaka area

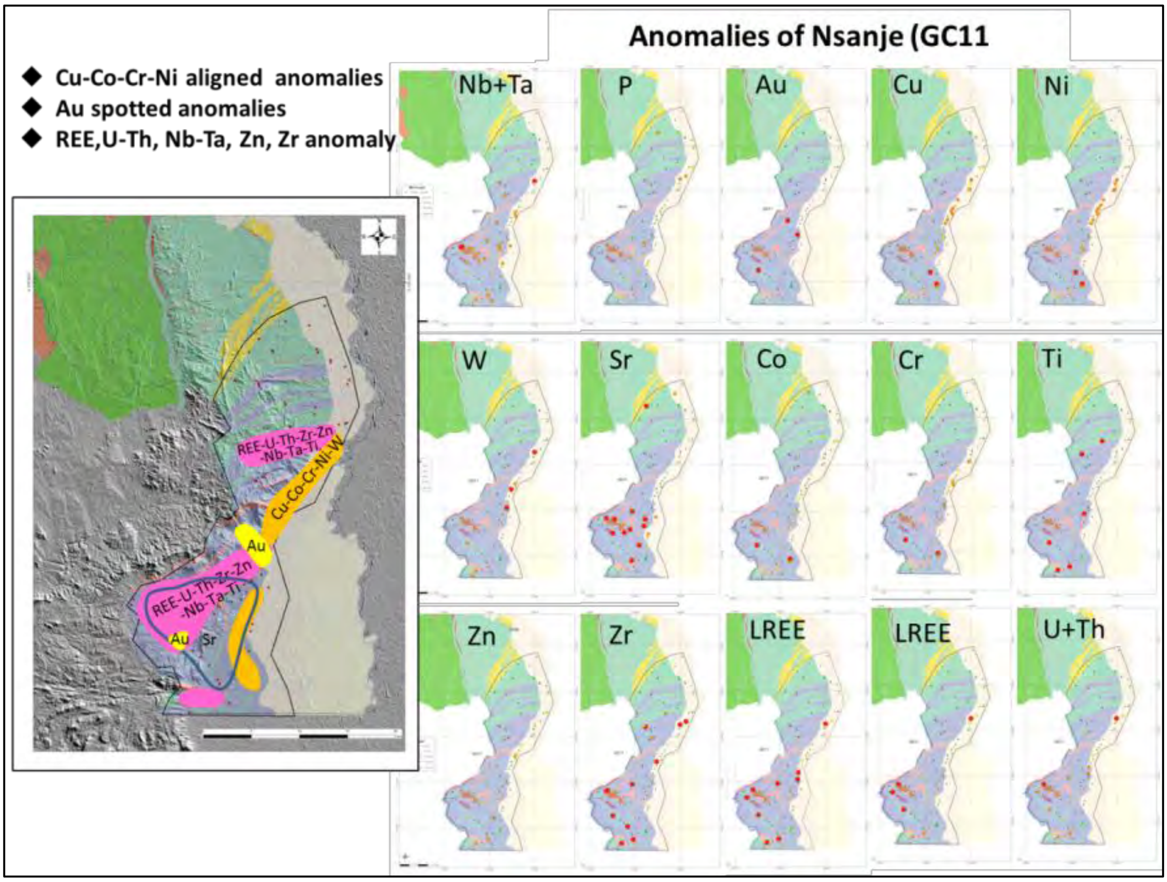


Figure 3-24 Geochemical maps in Nsanje area

3.8 Consideration of geochemical analytical results

The summary of geological and geochemical consideration for the assay results of 8 model areas (Chitipa, Rumphi, Mzimba, Kasungu, Lilongwe, Mangochi, Balaka and Nsanje) is as follows.

3.8.1 General geology and associated commodity in Malawi

(1) Geology of Malawi

Malawi comprises of 5 geologic units, mainly, as follows. Basal complex of metamorphic-intrusive rocks of Pre-Cambrian to Paleozoic age (including North Nyasa alkaline intrusive) as a basement is occupied major part of the nation, which is covered partly by sedimentary rocks, always by unconformity, of the Karoo super group (sandstone-mudstone) in Carboniferous-Jurassic age, Dinosaurs bed-red sandstone formation (mainly sandstone) in late Jurassic-Neogene age, and the Quaternary lacustrine-fluvial sediments, and is intruded by Chilwa alkaline rocks associated with carbonatite in late Jurassic-early Cretaceous age in southern region (BGS, 2009-1,2).

Figure 3-25 shows the generalized geological map (modified from Dill, 2007), and Figure 3-26 expresses the schematic geological column of Malawi (edited from Dill, 2007 etc.).

Geochemical survey areas of the Project (11 areas) are classified through above mentioned geologic context to following 3 types as;

- Basal complex dominant areas (3 areas: GC02-05-07)
- North Nyasa alkaline intrusive associated basal complex areas (4 areas: GC01-03-04-06)
- Chilwa alkaline intrusive associated basal complex areas (4 areas: GC08-09-10-11)

Malawi comprises a segment of East African Rift System (The Great Rift Valley) that extends for about 800 km from southern Tanzania (Rungwe), via Lake Malawi, to the middle Shire Valley in southern region. The rift structures extend further south by Shire trough and Urema graben in Mozambique. Malawi rift consists of 7 linked half-graben units alternating asymmetrically along single axis, with fault systems of N-S trend graben boundary faults, stepwise faults in rift oriented tilted blocks (EL: 1,200m-2,500m), and elevated monoclinic structure. Every half graben linkage is bounded by non-faulted accommodation zone. In Shire valley of southern region general trend of the Malawi rift twists to NW-SE, at latitude 16S to southward, from N-S trend and connects to Urema graben. The Malawi rift is largely non-volcanic but hot springs are located at various places along the lake area. The thickness of the sedimentary fill of lake Malawi and lower Shire valley is estimated by seismic reflection profile more than 3km (BGS, 2009-4, Figures 3-25 and 3-26).

As below, associated commodity with every geological unit is summarized by British Geological Survey (BGS, 2009-1,2,3,4) and is described expectable commodity and occurrences [1 to 9] in-around geochemical survey areas.

(a) Associated commodity with basal complex

Metamorphic and plutonic rocks of basal complex comprise of various orogenic belts of Ubendian (2,300-1,800Ma), Irumidian (1,350-950Ma) and Pan-African or Mozambiquian (900- 450 Ma), and are bounded by large-scale shear zone (Mugesse/Mwenbeshi shear zone, Figure 3-25). In Mozambiquian belt is well known by multi-cycled intrusion-metamorphism and a wide variety of the associated commodities.

These are [1] Ni-Cu mineralization with mafic-ultramafic intrusive rocks (GC01 etc.), [2] Li-Cs-Ta, Be-Rb-Sn-Ga-B and U-Th-REE concentration with pegmatite veins (GC05 etc.), [3] Cu(-Zn) mineralization with vein-shaped fault related calc-silicate gneiss (GC11), principally. And additionally as a placer, [4] Ti concentration with heavy mineral sand (rutile and ilmenite etc.) derived from decomposed basal complexes in Shire river jointed tributary (GC08, GC11 etc.), [5] Au concentration is expected from skarn occurrences by felsic intrusion along Dwangwa river (GC06) and Shire river tributaries (GC09-10).

(b) Associated commodity with North Nyasa alkaline intrusive (587-542Ma)

Commodities associated with North Nyasa alkaline intrusive are known as, [6] U-Nb-Ta concentration of Uranium-bearing pyrochlore and Nb-bearing titanite and eudialyte in Ilomba Hill syenite (GC01) and [7] Nb-Ta-U and Zr concentration of pyrochlore-rich pegmatite in nepheline syenite of Kanyka polymetallic deposit (GC06 northeastward).

(c) Associated commodity with Chilwa alkaline intrusive (137-98Ma)

In southern region within the Chilwa alkaline rock province, [8] REE, U-Th concentration of bastnäsite-monazite-pyrochlore, Sr concentration of strontianite and P concentration of apatite are known in carbonatite complexes for example Kangankunde (GC09).

(d) Associated commodity with Karoo dolerite dyke swarm (181Ma)

In southward from the Chilwa alkaline rock province (Blantyre to south) are distributed densely intruded dolerite dykes of Karoo age (Figure-1, Woolley 1996). [9] These mafic intrusions are expected some occurrences of base metals (Ni-Cu(-Cr) etc.) as well as the basal complex case (GC11).

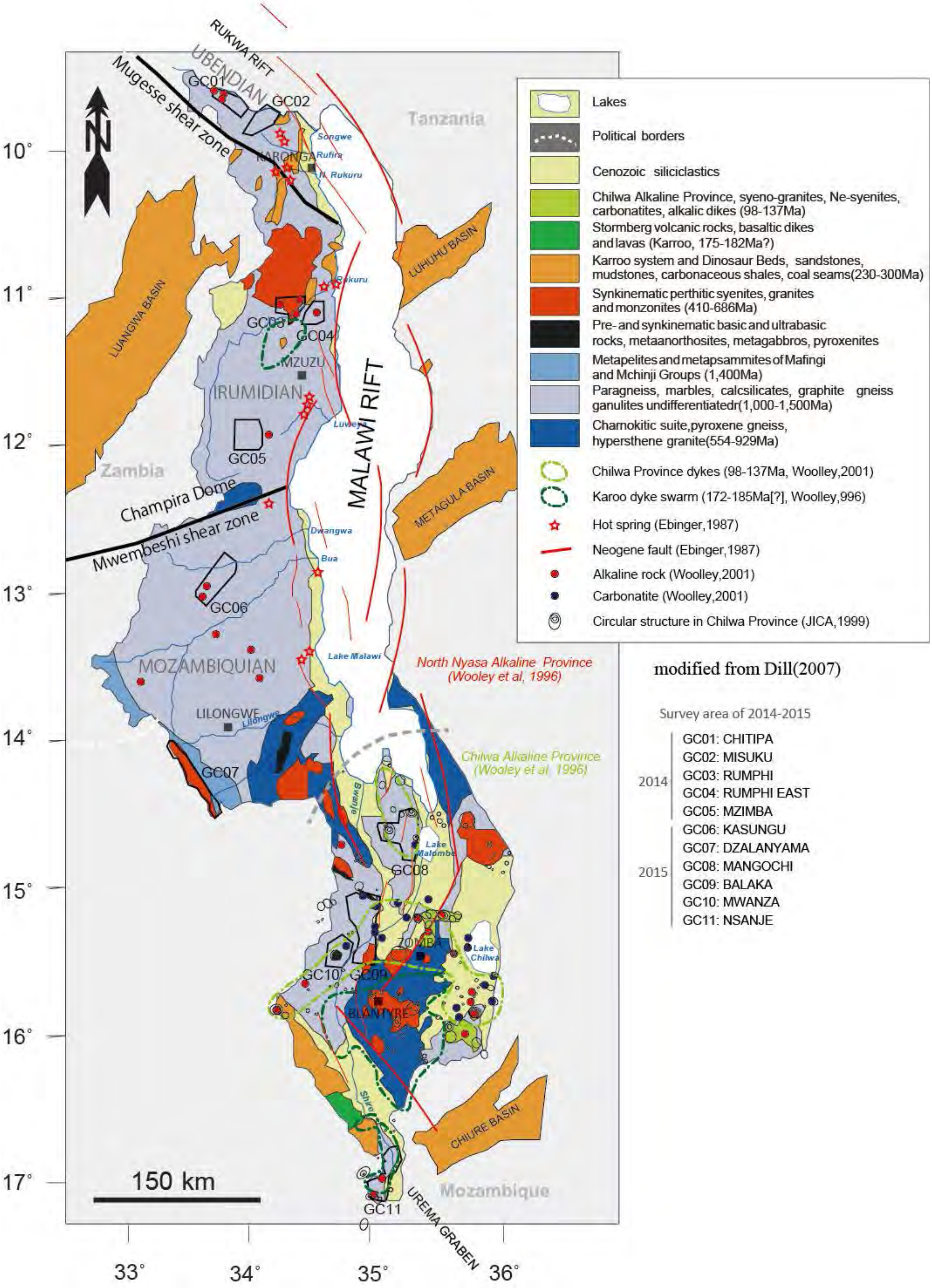


Figure 3-25 Generalized geologic map of Malawi (modified from Dill, 2007)

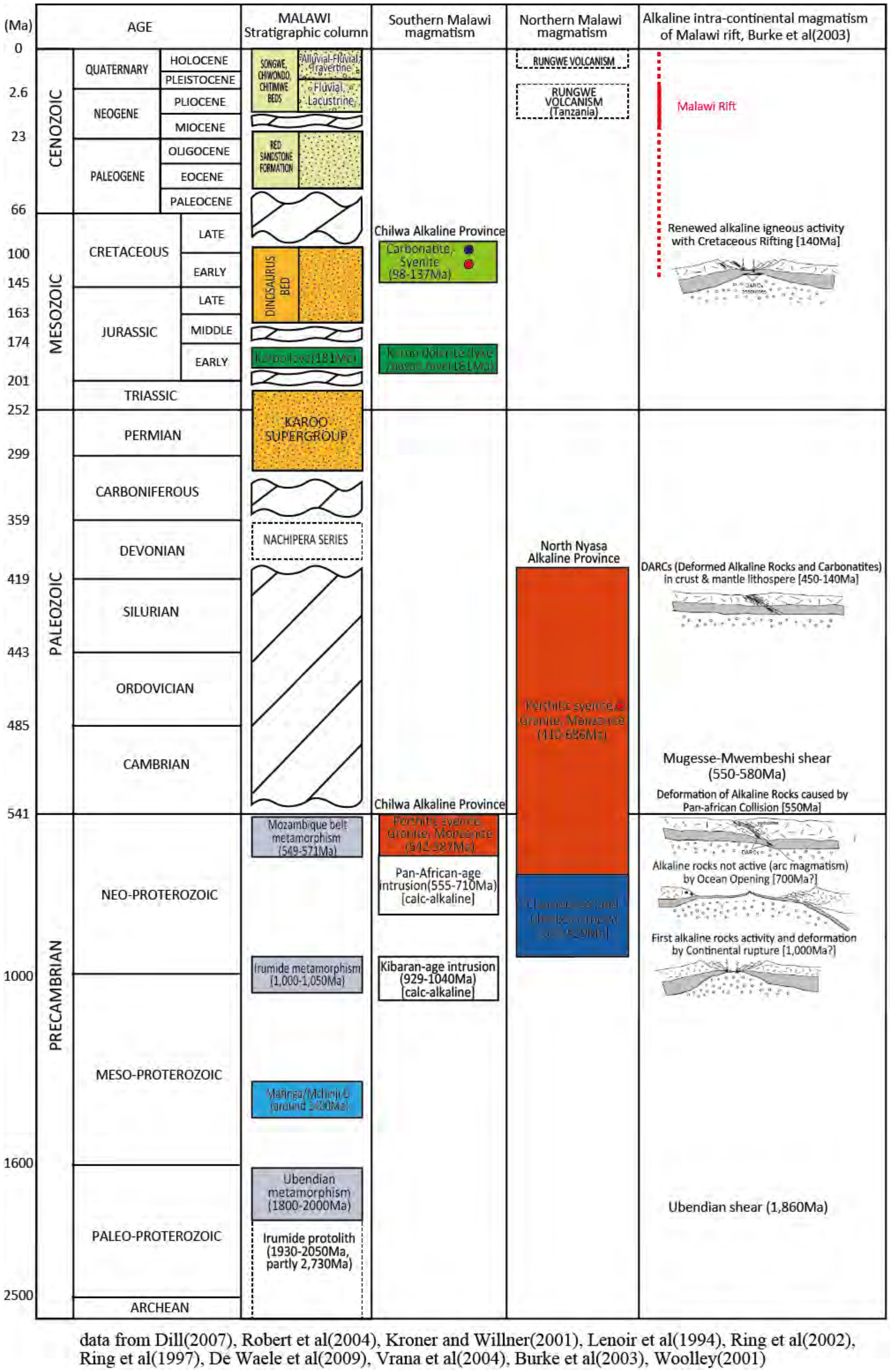


Figure 3-26 Generalized geologic column of Malawi (edited from Dill, 2007 etc.)

(2) Geology of 8 model survey areas

Summary of geology of 8 model survey areas are described below by established geological map by GSD and other published documents. Figure 3-32 to Figure 3-39 show the GIS generated geological map with sampling sites and simplified geological sections.

(a) Chitipa area (GC01-02)

Basal complexes of biotite-amphibole gneiss (partly augen-gneiss) are dominant lithological unit, which contain several intrusive rocks of amphibolite / syenite and scarce granitic pegmatite veins. Songwe syenite elongated intrusions are distributed along 1st order tectonic line of Mugesse shear zone (cataclasite- mylonite) trending WNW in southern part of GC01, and Ilomba hill and Ulindi syenite stocks are independently recognized in westrn part of GC0 (Wooley, 2001, Figure 3-27). Karoo sediments are covered in eastern extreme of GC02 in lowland area of Songwe river.

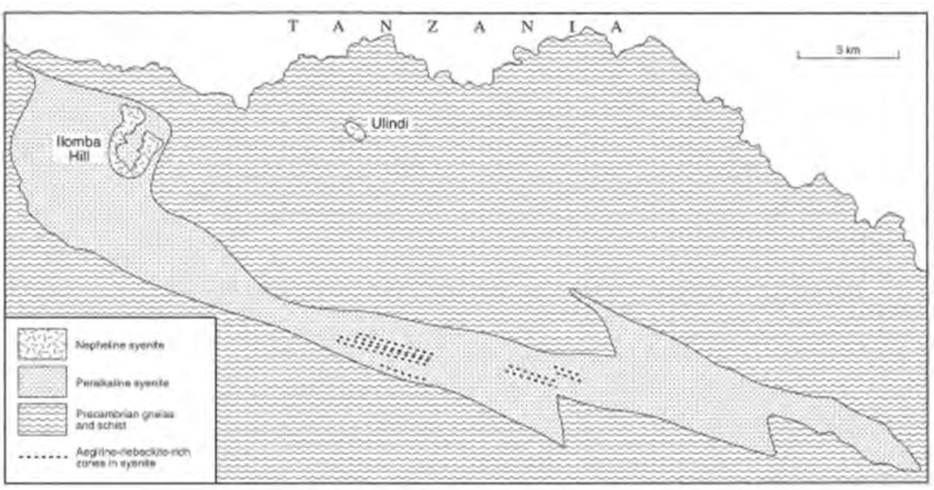


Fig. 144. Songwe syenite. (after Ray 1975, 1:100 000 map Chitipa).

Figure 3-27 Syenite bodies of Songwe, Ilomba hill and Ulindi in Chitipa area

(b) Rumphi area (GC03-GC04)

Biotite granite complexes, named Nkonjera and Rumphi body, are dominant lithological unit, which contain roof component of basal complexes of biotite-cordierite gneiss between them. Granite complexes envelope several map scale syenite bodies, which named Telelele / Njakwa body in GC03 and Mphompha body in GC04 (Figure 3-28, wooley, 2001), and transit gradually to diorite in north end of GC04. Additionally NNE trending Karoo dolerite dyke swarm occur in southern end of GC04.

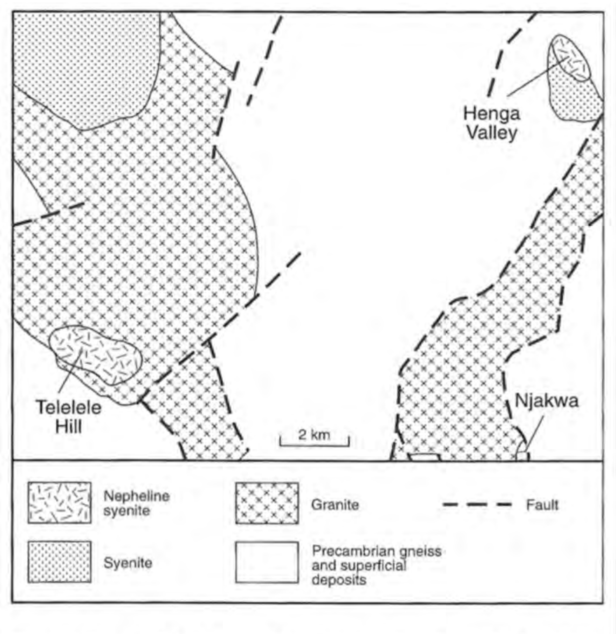


Fig. 146. Henga, Telelele and Njakwa (after Thatcher 1974, 1:100 000 map Nyika S).

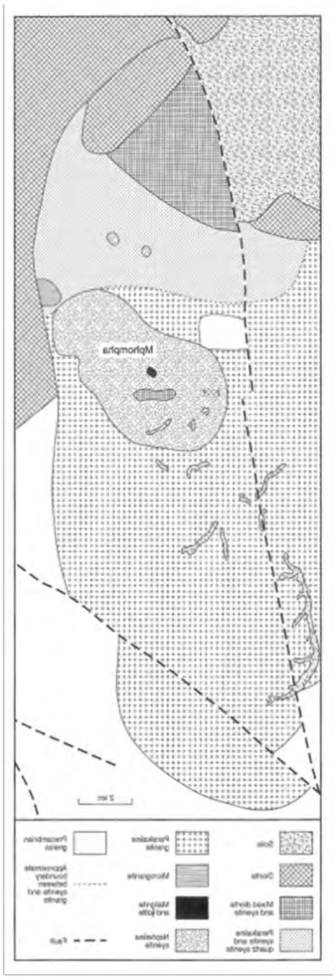


Figure 3-28 Syenite bodies (Telelele, Njakwa and Mphompha) in Rumphi area

(c) Mzimba area (GC05)

Basal complexes of biotite-garnetiferous biotite gneiss are dominant lithological unit, which contains NW to NNW trending lenses of charnockitic - pyroxene granulite and muscovite schist appear in eastern margin and NS trending elongated granitic gneiss-granite suite in western margin. Karoo sediments are covered on this granitic suite on southwestern end. Particularly granitic pegmatite and quartz veins appear in basal complexes widely.

(d) Kasungu area (GC06)

Basal complexes of biotite-sillimanite gneiss and hornblende biotite gneiss with amphibolite thin dykes are dominant, which consisted of lower part with calcareous-quartzose gneiss, felsic granulite and granitic stocks along incised Dwangwa river valley. In center part of survey area pass the NE trending anticlinal structure axis (perpendicular to 1st order Mwembeshi shear zone), so show slight complicate lithological distribution on map.

(e) Lilongwe area (GC07)

NW trending foliation and fault well developed Dzalanyama granite body are almost covered the area, and comprise partly of quartzose schist-quartzite lenses in parallel position. Isolated Dzalanyama range foot is completely covered by alluvial sediments with highland moors and grass lands, while no outcrop the basement in the area.

(f) Mangochi area (GC08)

Basal complexes of felsic granulite-gneiss, biotite gneiss, hornblende-biotite gneiss and charnockitic gneiss are principal lithological units, and contact parallel in NNW trending rift faults. In northeastern and western dome structure are centered by granitic stocks. In southeastern part well known Lake Malombe vents of carbonatite associated ricks are distributed (Wooley, 2001, Figure 3-29).

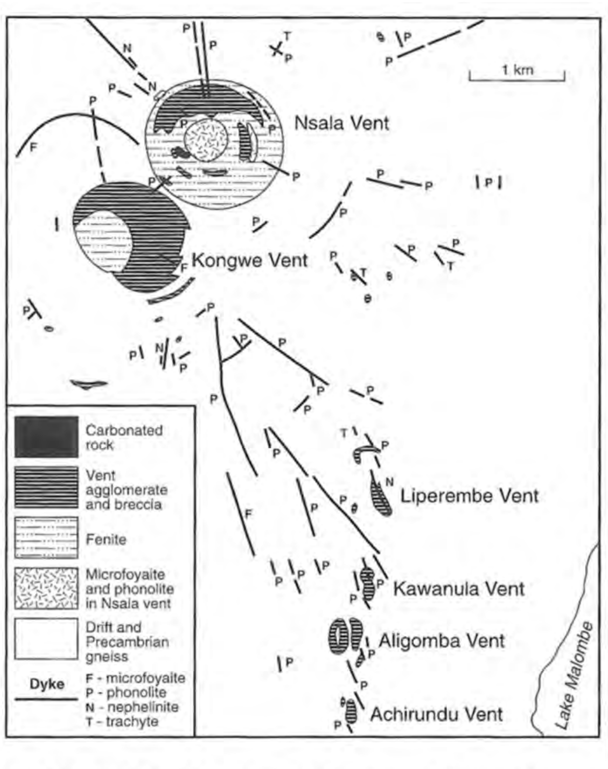


Fig. 149. The Lake Malombe vents (after Garson 1965*a*, fig. 18).

Figure 3-29 The Lake Malombe vents in Mangochi area (Wooley,2001)

(g) Balaka area (GC09-10)

Basal complexes of folded hornblende-biotite gneiss is dominant, and several variation of gneiss are distributed such as lenticular bodies (graphite-muscovite gneiss and garnet-biotite gneiss), circular dykes (felsic granulite-gneiss) and as banded structure (granitic gneiss-augen-gneiss in northernmost of GC09). Large ring ultramafic complexes appear in southern GC09 along NS trend rift fault (Lisungwe fault) and in southern GC10western neighbored Mlindi ring complex, which composed mainly of meta-pyroxinite and perthosite with apparent ring structure. Between two ring structure appear ENEtrend parallel sorvergite dyke swarm of Chilwa alkaline rock province. And in northeastern GC09 Kangankunde carbonatite complex is located (Figure 3-30, Wooley,2001)

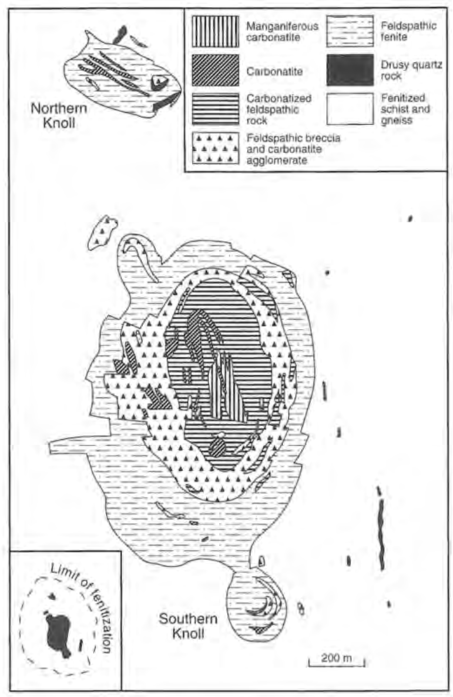


Fig. 151. Kangankunde (after Garson 1965*a*, fig. 10).

Figure 3-30 Kangankunde carbonatite in Balaka area (Wooley,2001)

(h) Nsanje area (GC11)

Basal complexes of folded biotite gneiss and graphite gneiss are dominant, which contain lenticular bodies of quartzose schist and nepheline-biotite gneiss (Figure 3-31, Wooley, 2001). Intrusive rocks of felsic stock and Karoo NS trending dolerite dyke swarm and its effusive (basalt and pyroclastics) are concentrated in southern half of survey area. Karoo sediments are also in southern small part.

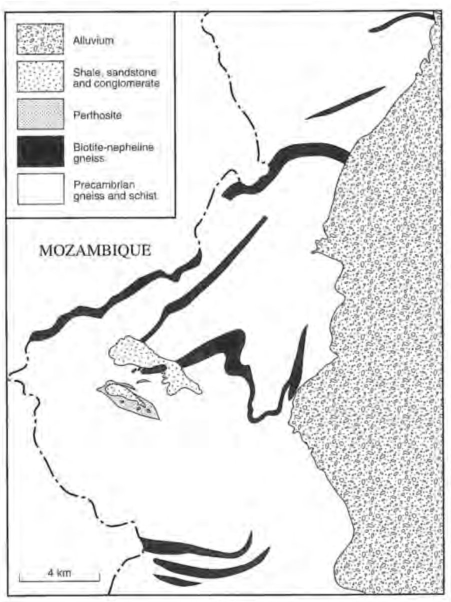


Fig. 161. Distribution of nepheline-bearing gneisses in the Nsanje area (after Bloomfield 1958, 1:100 000 geological map).

Figure 3-31 Nepheline bearing gneiss in Nsanje area (Wooley,2001)

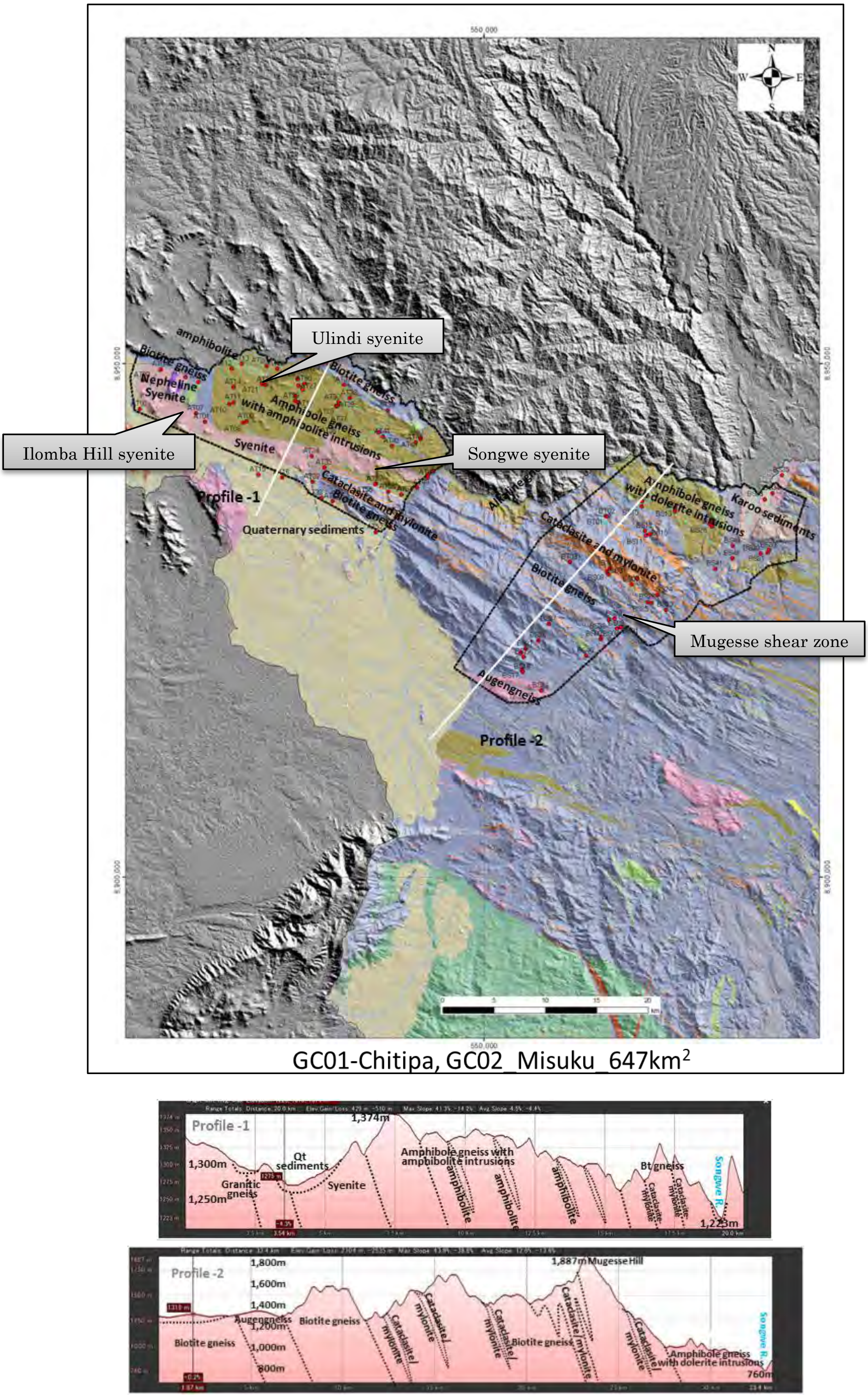


Figure 3-32 Geological map and sections of Chitipa area

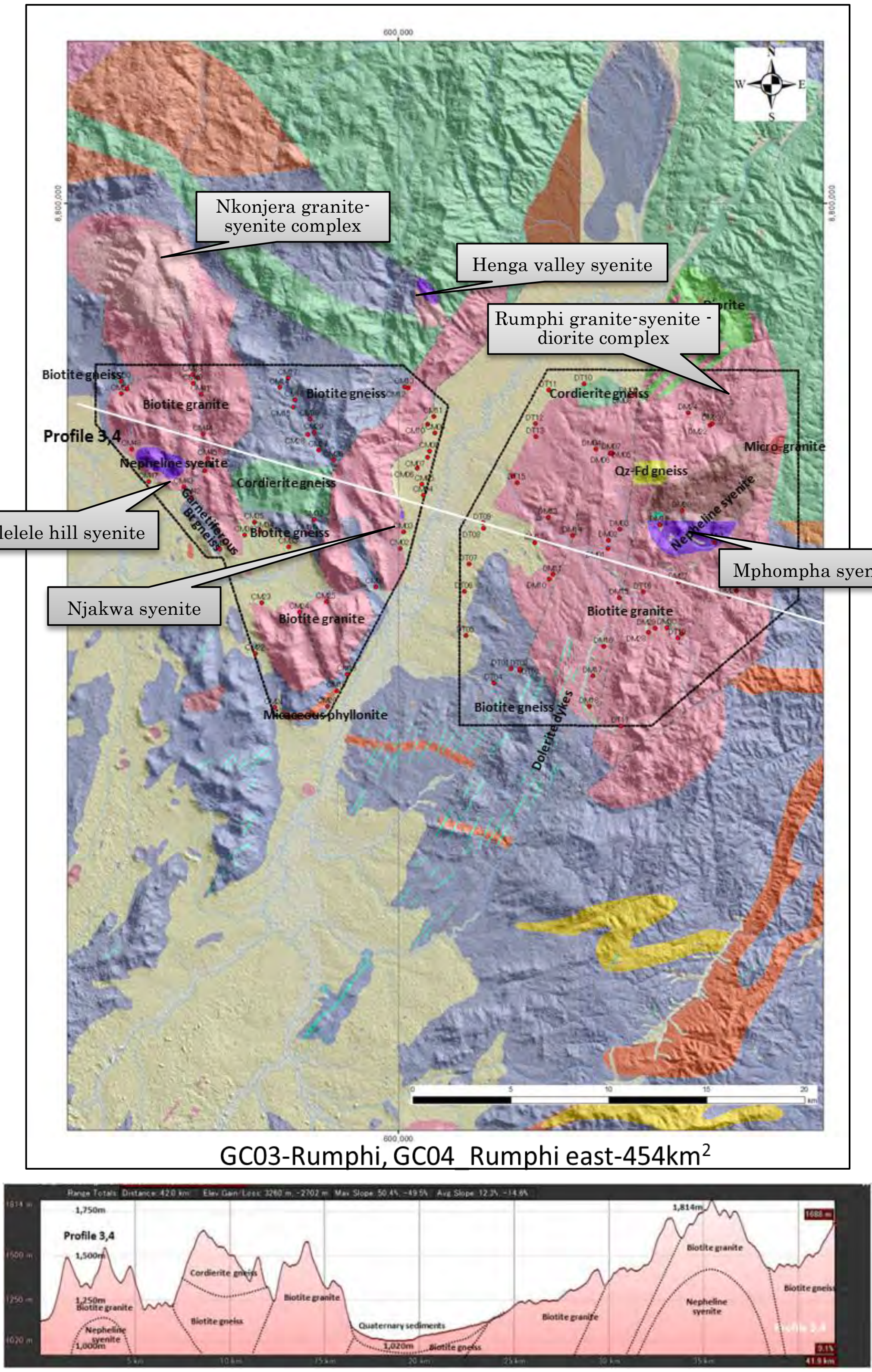


Figure 3-33 Geological map and sections of Rumphi area

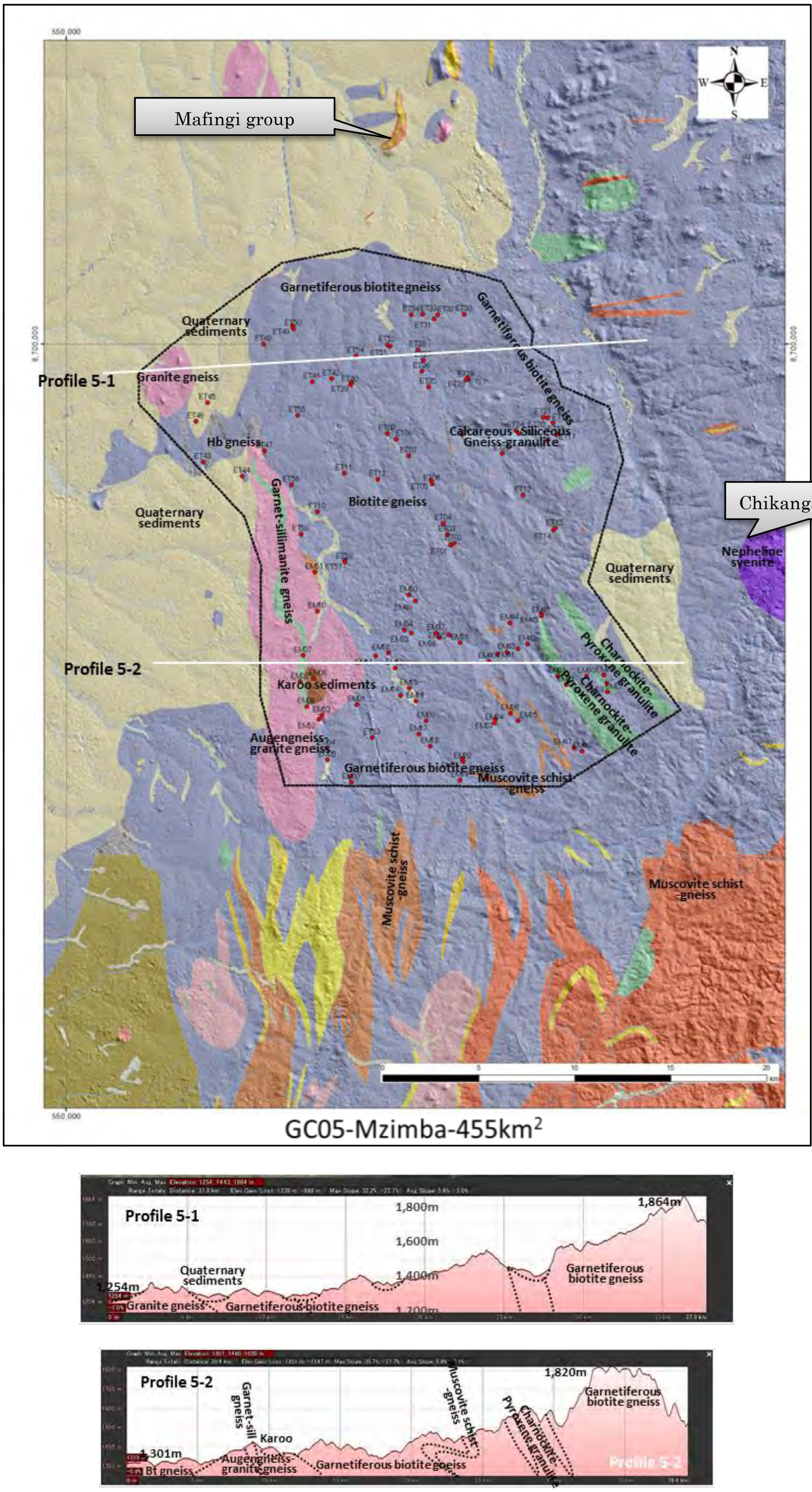


Figure 3-34 Geological map and sections of Mzimba area

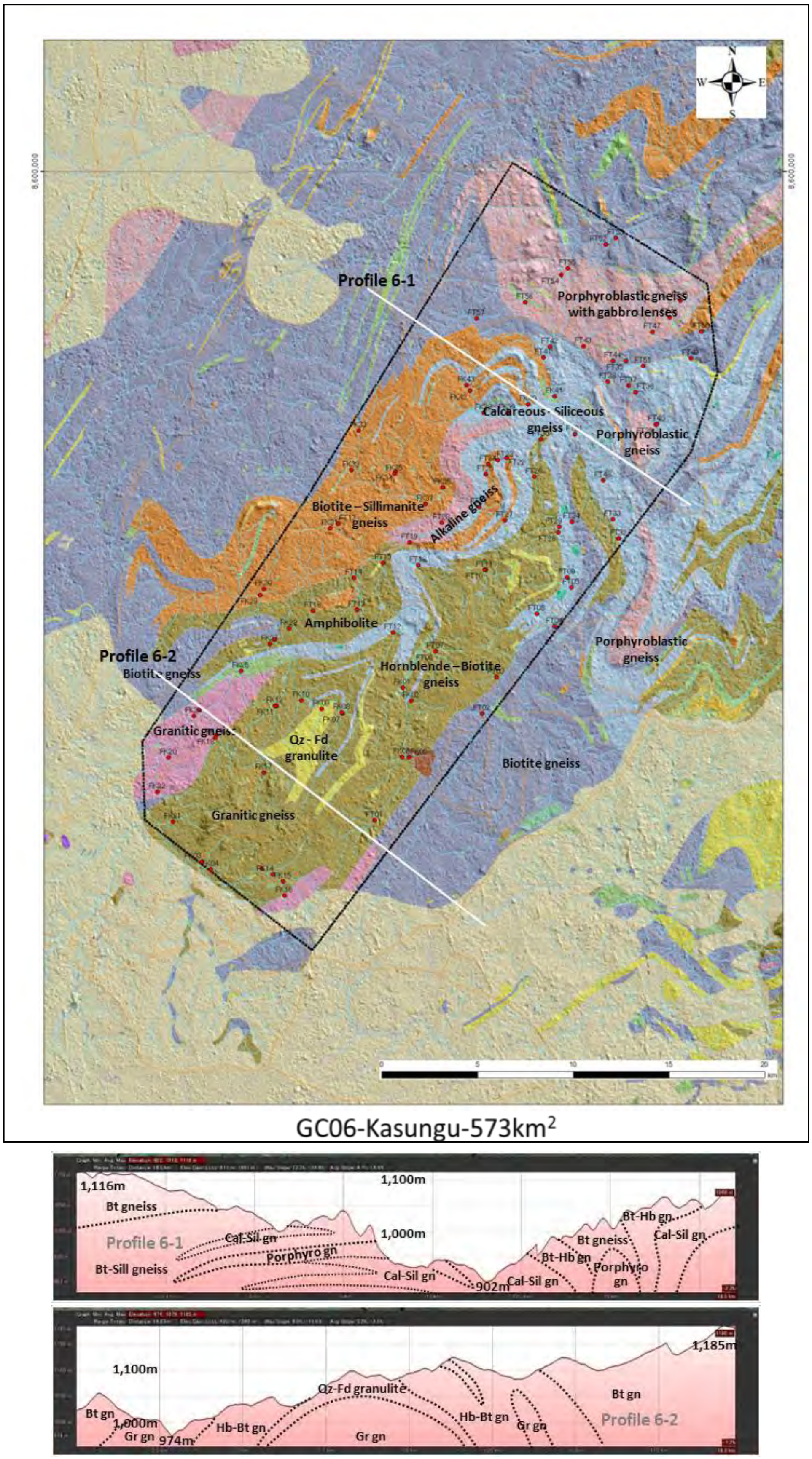
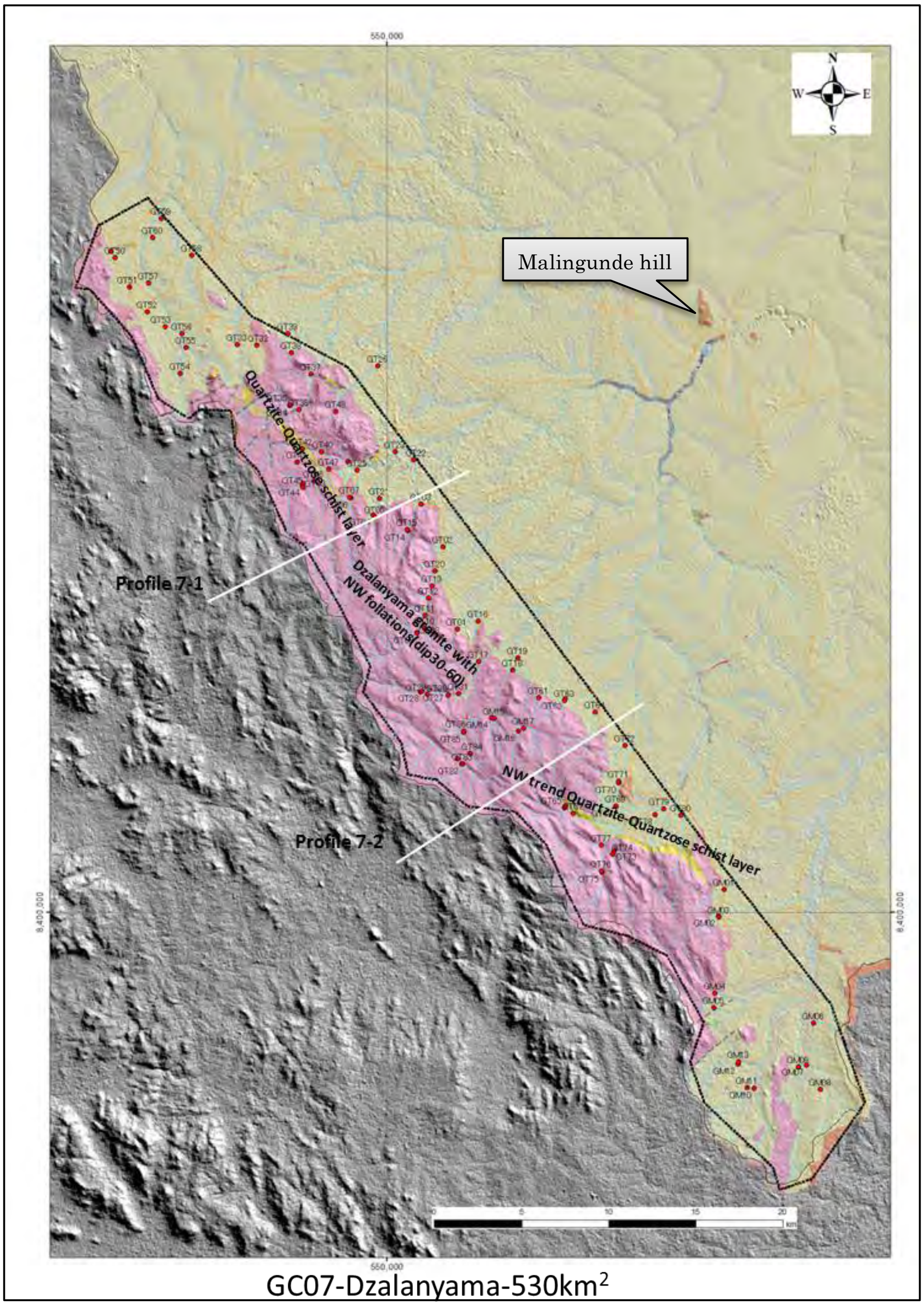


Figure 3-35 Geological map and sections of Kasungu area



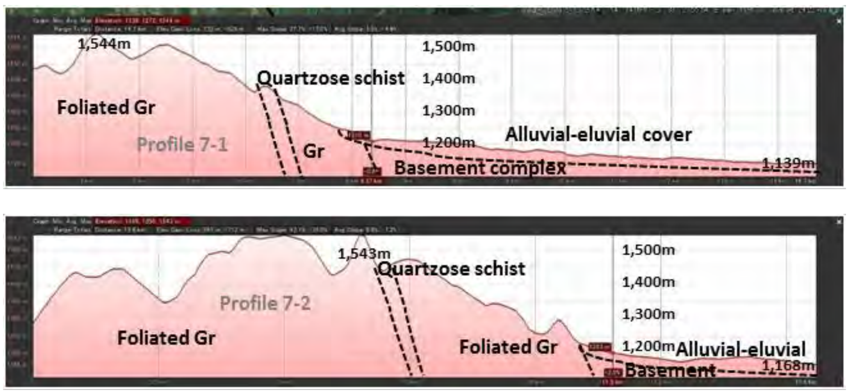


Figure 3-36 Geological map and sections of Lilongwe area

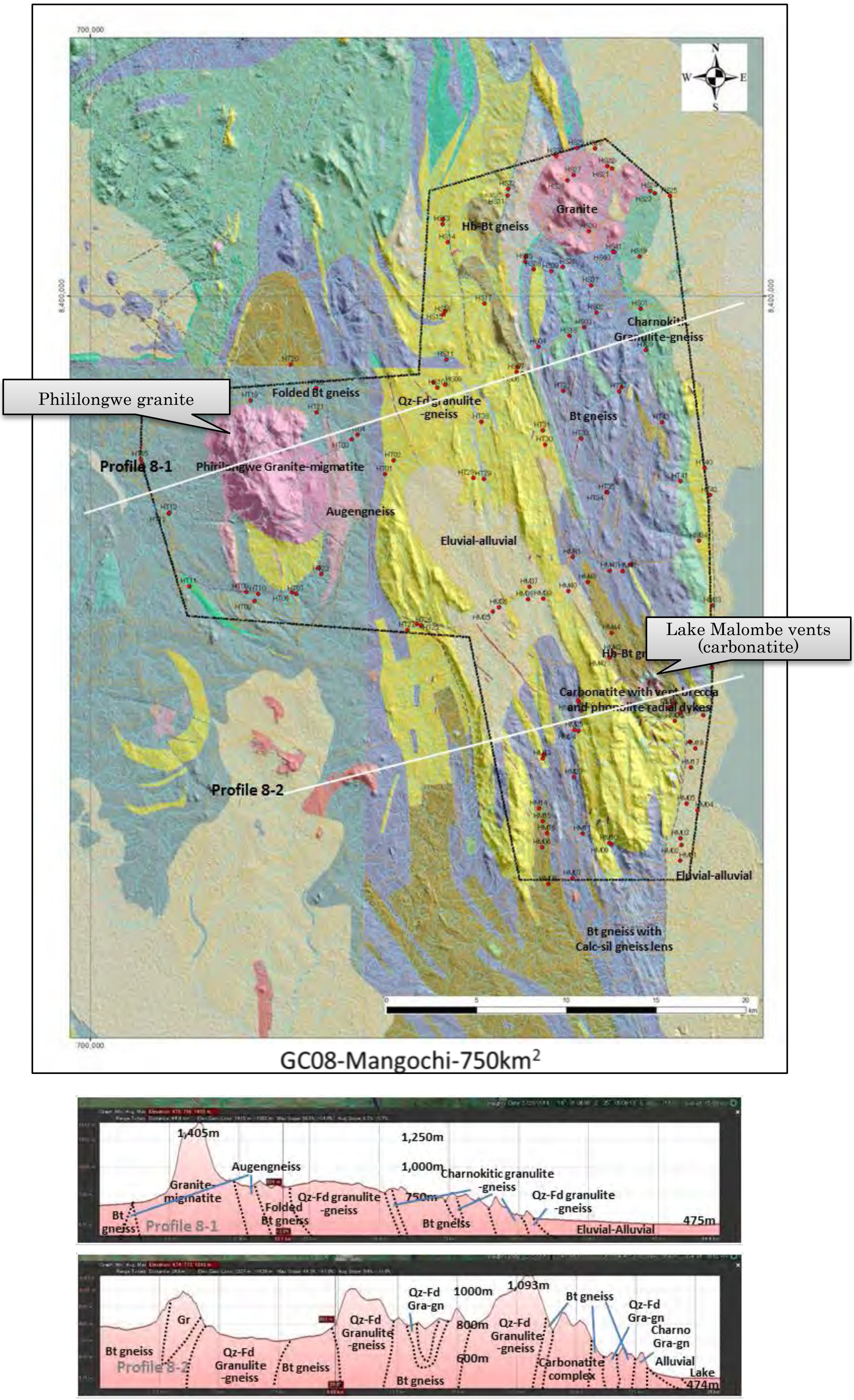


Figure 3-37 Geological map and sections of Mangochi area

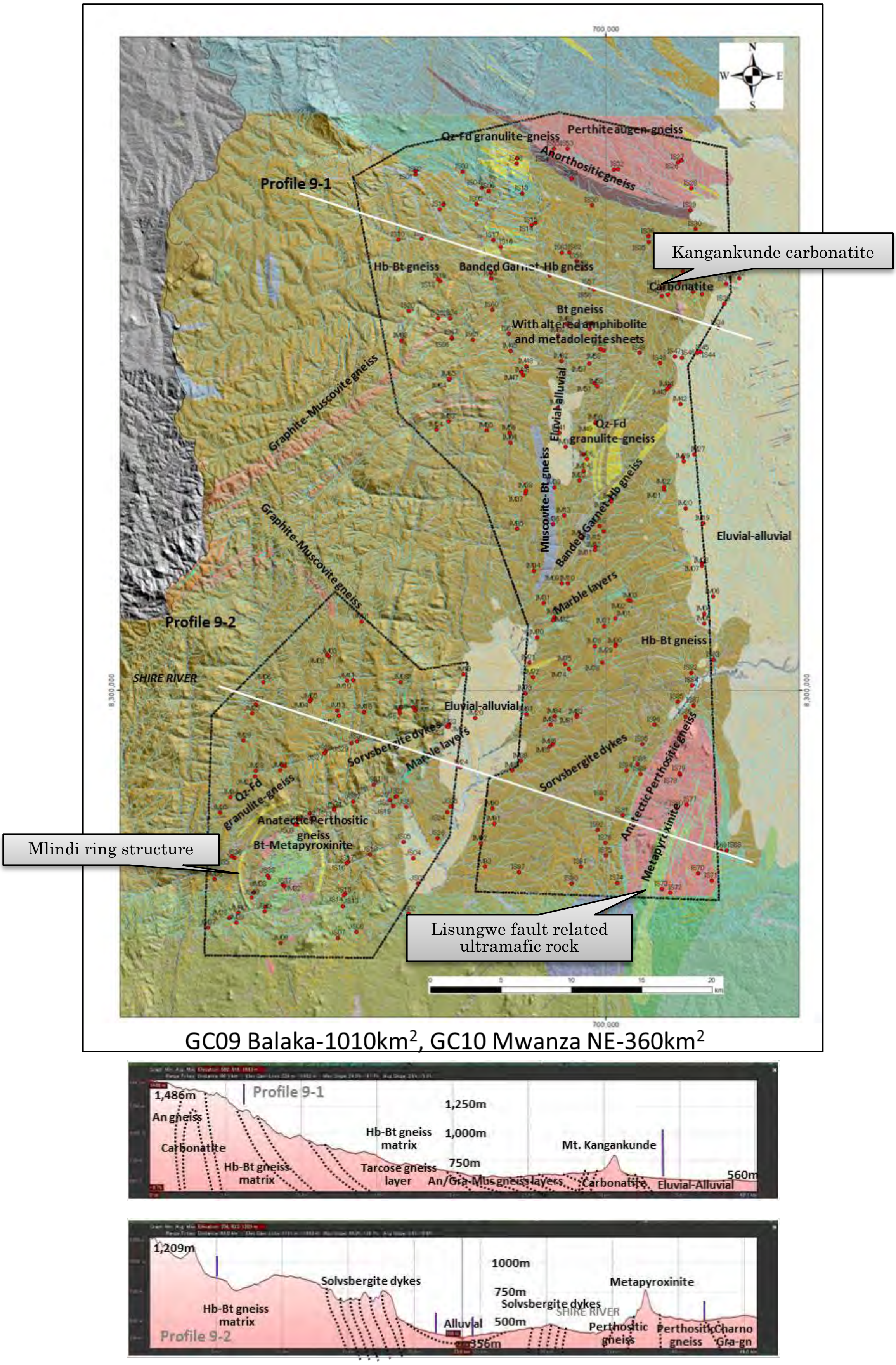
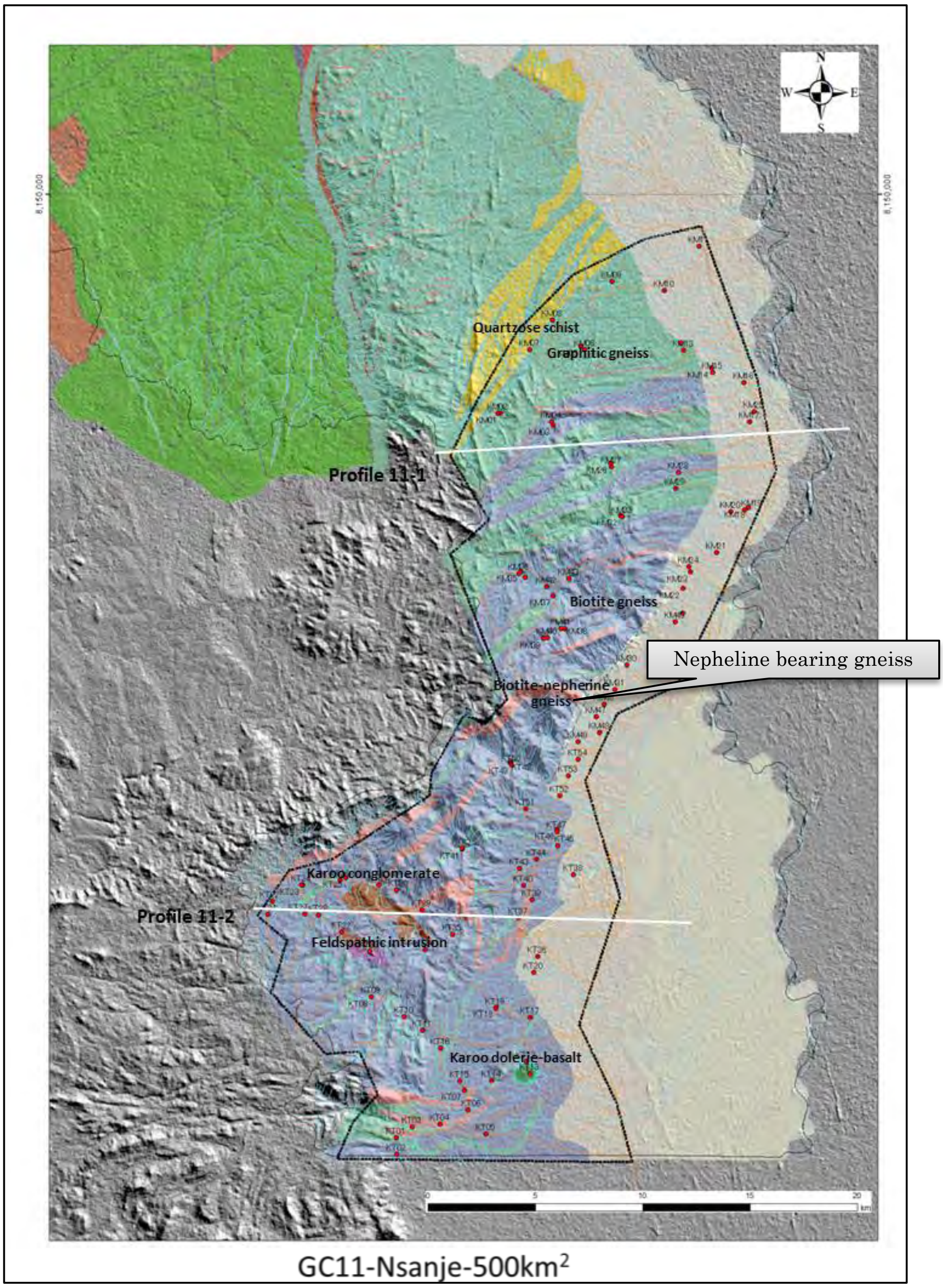


Figure 3-38 Geological map and sections of Balaka area



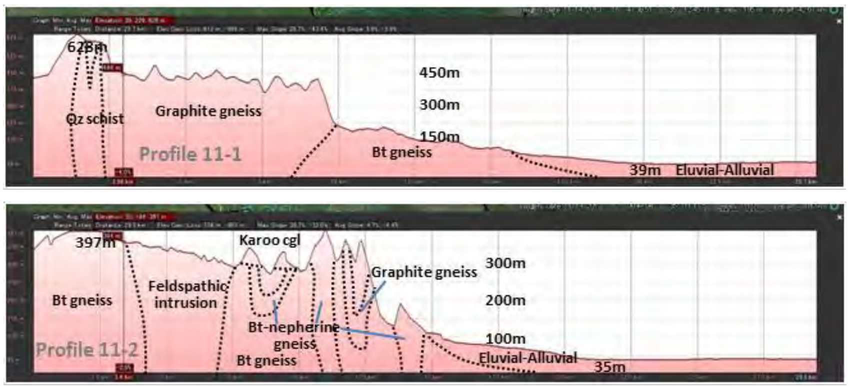


Figure 3-39 Geological map and sections of Nsanje area

(2) Former geochemical survey results

Malunga G.W.P.(2001) summarized a essence of drainage geochemical survey result organized by GSD before 1973, and introduced several geochemical anomalies of five element groups of Cu, Au, Sn-Mo, Ni, Nb-U as follows.

- Cu
  - North: Rumphi eastward (Chimaliro dome): ave.62ppm, max.150ppm, 204km^2
  - Central: Lilongwe, Ndodo Dambo : ave.14ppm, max.200ppm, over 2km^2
  - Central: Madziainsa Dambo, Kampini: soil, max.1500ppm, over 3km^2
  - South: Nsanje south part, Lulwe: ave.60ppm, max.150ppm
- Au: derived from crystalline schist and pyritized zone, schist of greenstone belt
  - Central: Kasungu, Dwangwa river southern tributary: strong anomaly, central and southwestern part also (incl. As)
  - Central: Lilongwe, Malingunde and Khongoni pyrite zone: 0.15ppm, incl. Ag-Zn)
  - Central: Lilongwe, southward. Ndodo Dambo
  - Central: Lilongwe, Nathanje: soil with As anomaly
  - Central: Kirk Range, Lisungwe
- Sn and Mo
  - North: Nyika, Sn-Mo ave.3ppm, max.6-15ppm, 15km^2
  - North: Livingstonia, westward, Kalabwe: Sn max.40ppm, Mo max.25ppm
  - South: Nsanje, south part, Mbale: ave.10ppm, 3km^2
- Ni: derived from mafic-ultramafic rocks
  - Central: Chimimbe Hill: rock max.6000ppm
  - Central: Chipata Hill: soil max.1750ppm, background 200ppm, Cu215ppm
  - Central: Kasungu, Chimwale: sediment max.250ppm, background 23ppm
  - South: Mpemba Hill: soil max. 6000ppm, Cu2000ppm
- Nb and U
  - North: Rumphi eastward, Chimaliro Hill: max.3000ppm, U also
  - North: Rumphi, Nkhonjera nepheline syenite gneiss: heavy minerals max. 3000ppm

As shown in above, reported several geochemical anomalies in northern region several anomalies of Cu, Sn-Mo, Nb-U, in central region Au, Cu, Ni and in southern region Cu, Sn-Mo, Ni. Such distribution of anomalies are available as a reference data to interpret current geochemical analysis results.

3.8.2 General topography and associated commodity in Malawi

Figure 3-40 shows elevation plots of whole 1029 sampling sites in this survey, which express model survey area in northern and central region plot around EL 1000-1500min mountain and plateau area, while southern region relatively lower plots along Shire valley lowland.

As generalized physiographical map shown in Figure 3-41 (modified from Chilton and Smith-Carlington, 1984), topographically Malawi comprises 4 units of 1) rift valley plains, 2) surrounded rift valley escarpments, 3) isolated mountains of alkaline rocks such as of Mt. Nyika-Zomba-Mulanje etc.(Highland areas / Escarpment towers), and 4) inter-mountainous plateau area.

Elevated plateau area of Lilongwe-Kasungu-Mzimba region is known as African surface (BGS, 2009-4), which is characterized by thick residual soils formed after Cretaceous (100Ma-) by long lived deep-weathering and dilution processes and clay filled alluvial plain ('Dambo'). North and southward regions from this plateau, it is not well-defined the surface by exhausted valley incision after Miocene (23Ma-).

It means that regolith-type geochemical anomalies (source anomalies) are expected in/around African surface preserved region, otherwise placer-type geochemical anomalies (hydraulic anomalies) with heavy mineral selective sorting tend to develop in erosion dominant region up to rift valley plain (Figure 3-42, Fretcher, 1997).

Dill (2007) shows the clear tendency, in a review paper of mineral resources in Malawi, of simultaneous Al_2O_3 reduction and TiO_2 augmentation to downstream-ward (from source rock to placer). Thus geochemical survey areas including rift valley plain (GC08-09-10-11) are expected to detect the Ti concentration as a hydraulic anomalies, while plateau dominant areas (GC01-02-03-04-05-06-07) are more probable to appear the source anomalies, particularly in GC05-06-07 areas located within African surface.

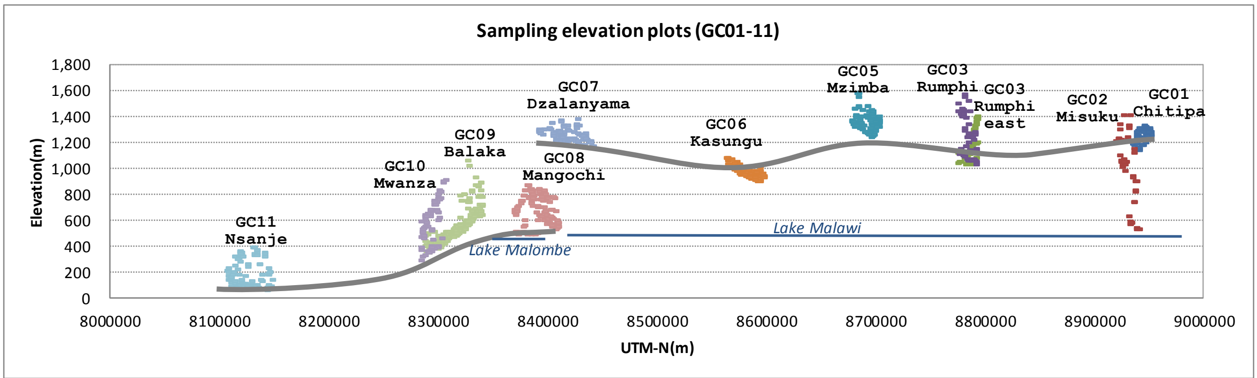


Figure 3-40 Elevation plots of whole 1029 sampling sites

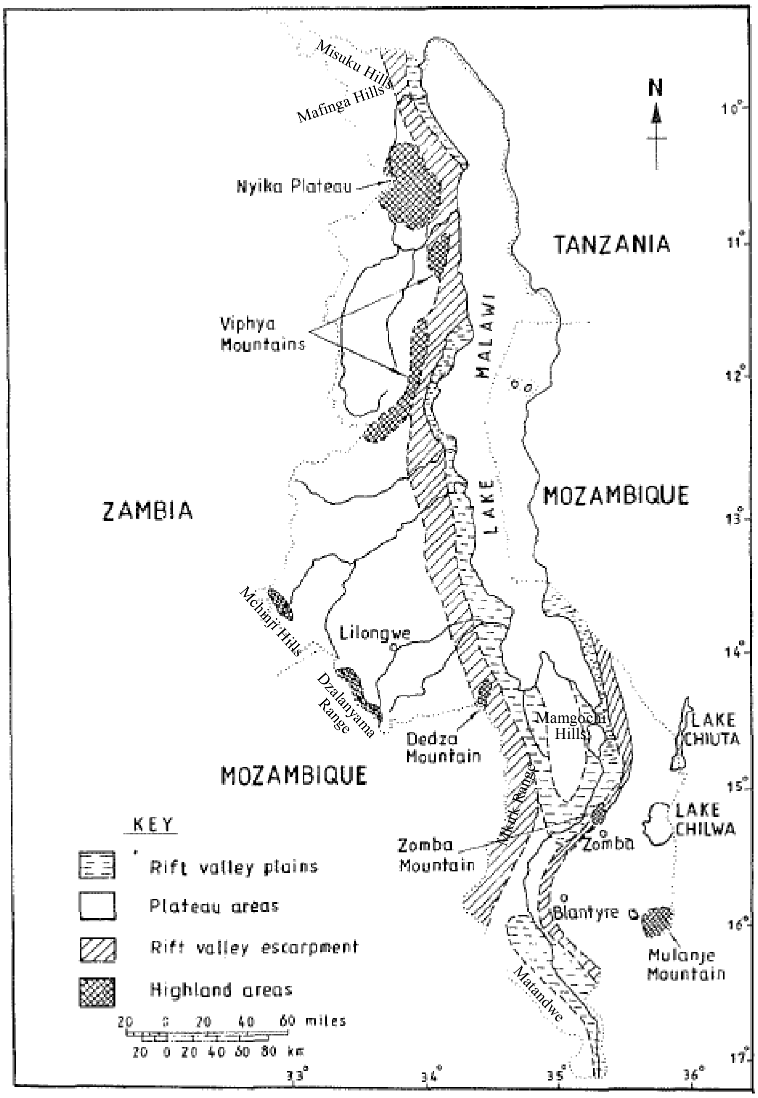


Figure 3-41 Generalized physiographical map of Malawi (modified from Chilton et al., 1984)

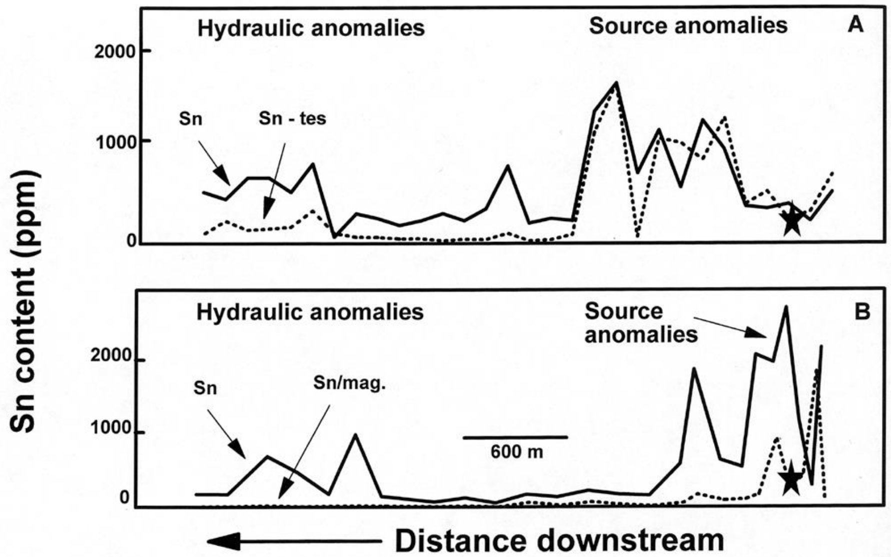


Figure 3-42 Generalized geologic map of Malawi (modified from Dill, 2007)

3.8.3 Summary of geochemical survey results

Geochemical survey results are explained by respective model survey area of GC01-11 (total, 1,029samples, Figure 3-43) which carried out in 2014-2015, after show the general distribution of selected 33 elements.

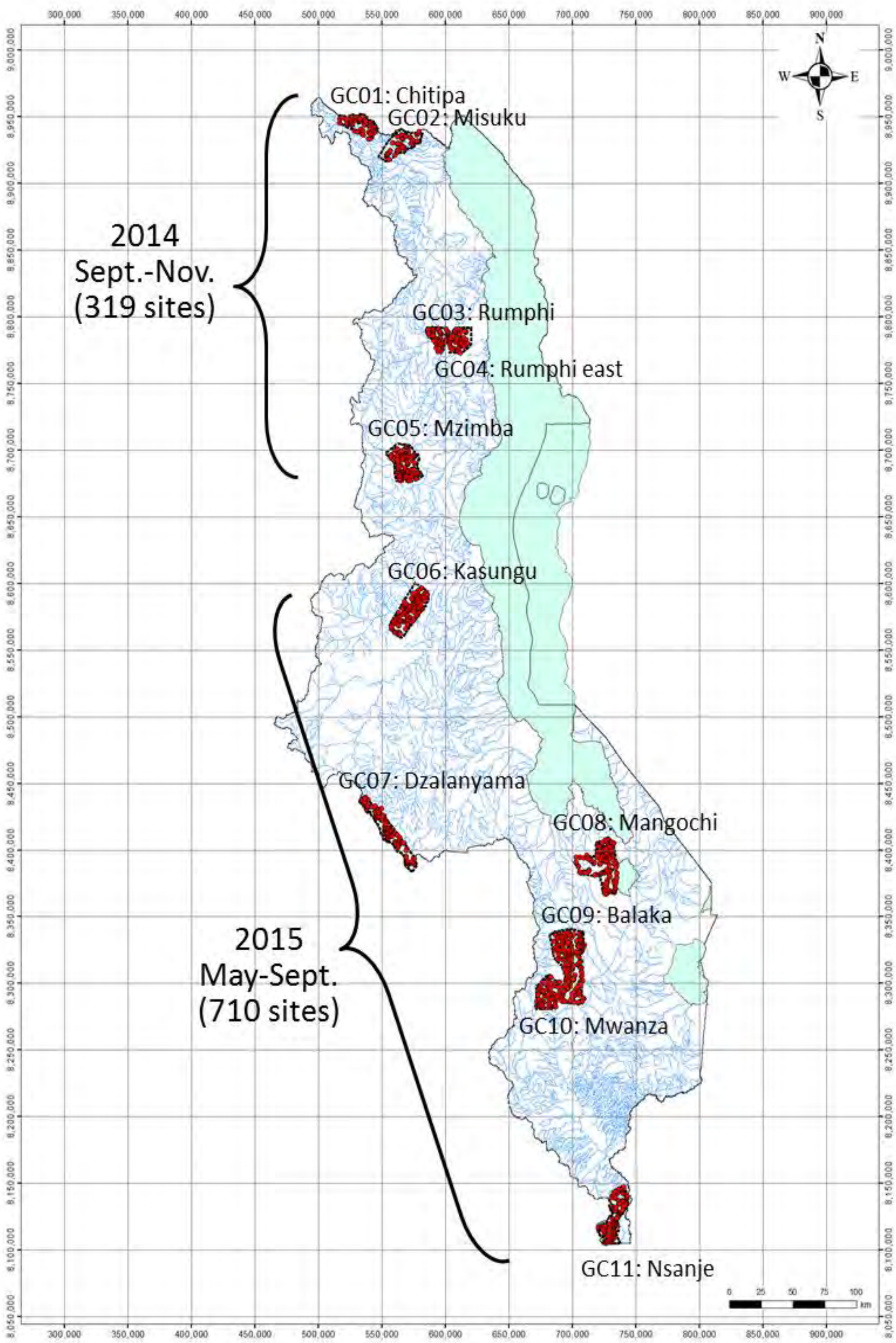


Figure 3-43 Drainage geochemical sampling sites

(1) General elemental distribution (Historgam - Cumulative frequency - Box plots)

Geochemical survey results on GC01-11 (1,029 samples) of 2014-2015 fiscal year are explained, firstly distributions through survey areas of selected 33 elements, secondly anomalous element distributions in respective survey area.

Referring to Ohta et al. (2008), box plots of 33 elements were drawn by using XLSTAT-2014 in order to compare statistically the distributions through survey areas (Figure 3-44). As a result, 4 groups of elements (A-D, Figure 3-45 to Figure 3-48) are recognized by their characteristic distribution pattern among survey areas, as follows.

A) Base metals (Cu-Fe-Cr-Co-Ni-Ti-V-Mn, 9 elements): Element group descending from GC01 to GC05, and extremely low value recorded in GC05 and GC07

B) Rare Earth Elements (LREE: Ce-La-Y-Eu-Nd-Pr-Sm, HREE: Dy-Er-Gd-Ho-Lu-Tb -Tm-Yb, 15 elements), Nuclear metals etc. (U-Th-Zr-P-Sr-W-Pb-Sn, 8elements): Element group rather ascending from GC01 to GC05, particularly recorded bigger value in GC05-08-11 (total, 23elements)

C) Coltan metal etc (Nb-Ta and Ag, 3 elements): Element group particularly concentrated in GC03-04-08-11

D) Others (Au-Bi-Ba-Be-Li, 5 elements): Element group of non-characteristic distribution pattern or least value

Box plots shown in Figure 3-29 are expressed data distribution, simply, by the descriptive statistics values, and are not included the geochemical interpretation. Top and bottom of box mean the third and first quantile values (median value within upper median group, median value within lower median group), respectively, and centered level means the median value. The length of whisker lines is defined 1.5 times of box height, thus both exclusive values are might be outliers statistically (XLSTAT-2014). Red markers are the mean values and blue markers minimum-maximum values.

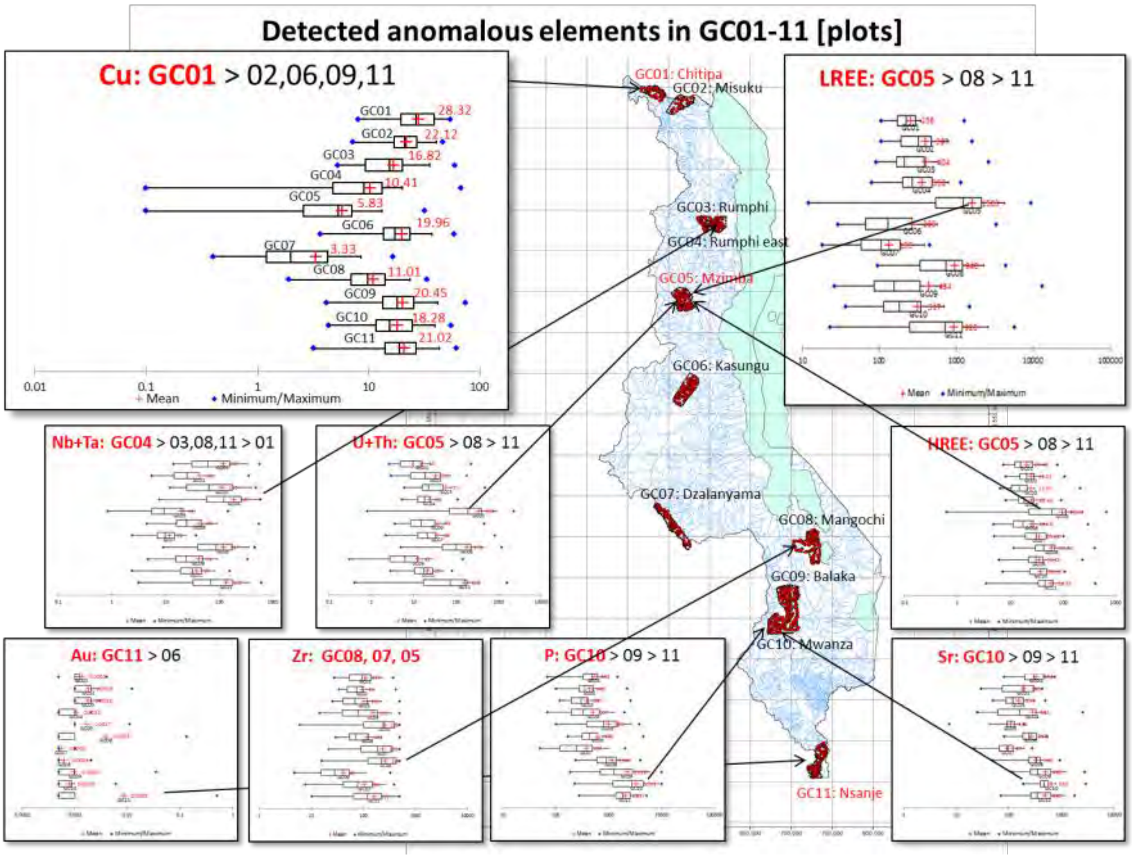


Figure 3-44 Box plots of major elements

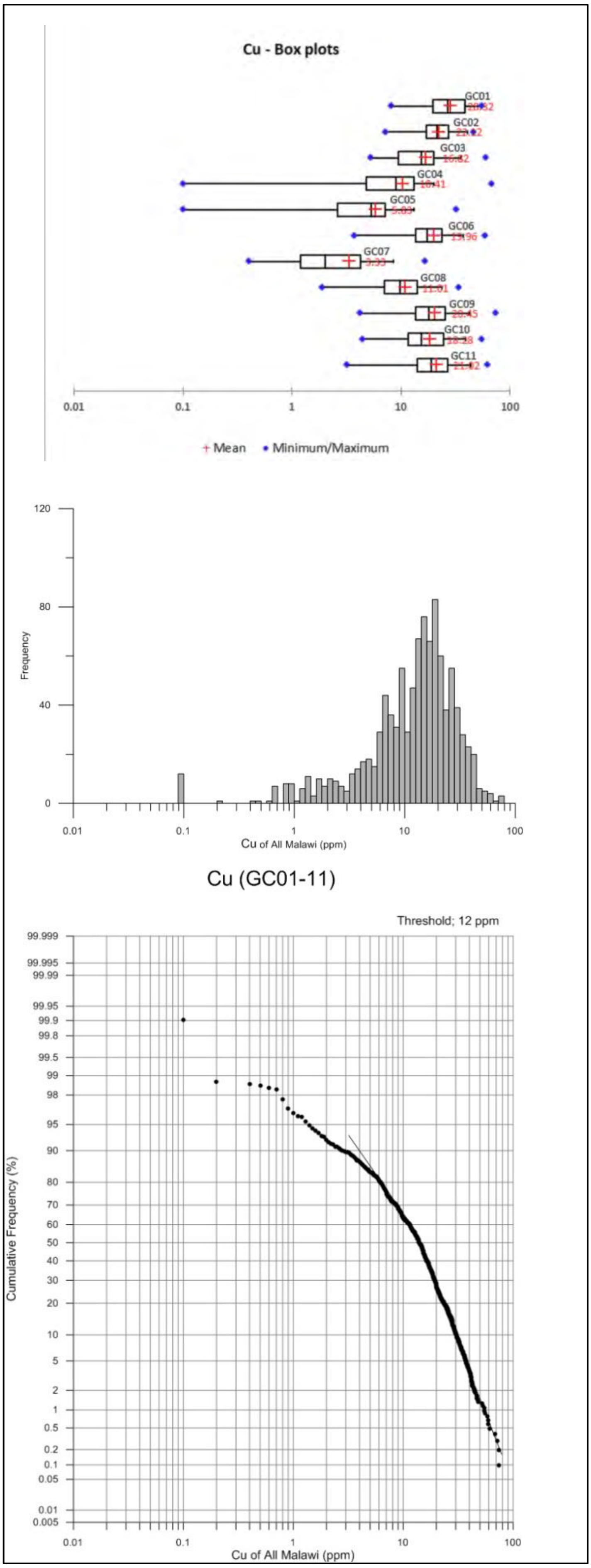


Figure 3-45 Figures of statistical analysis on base metals (Cu)

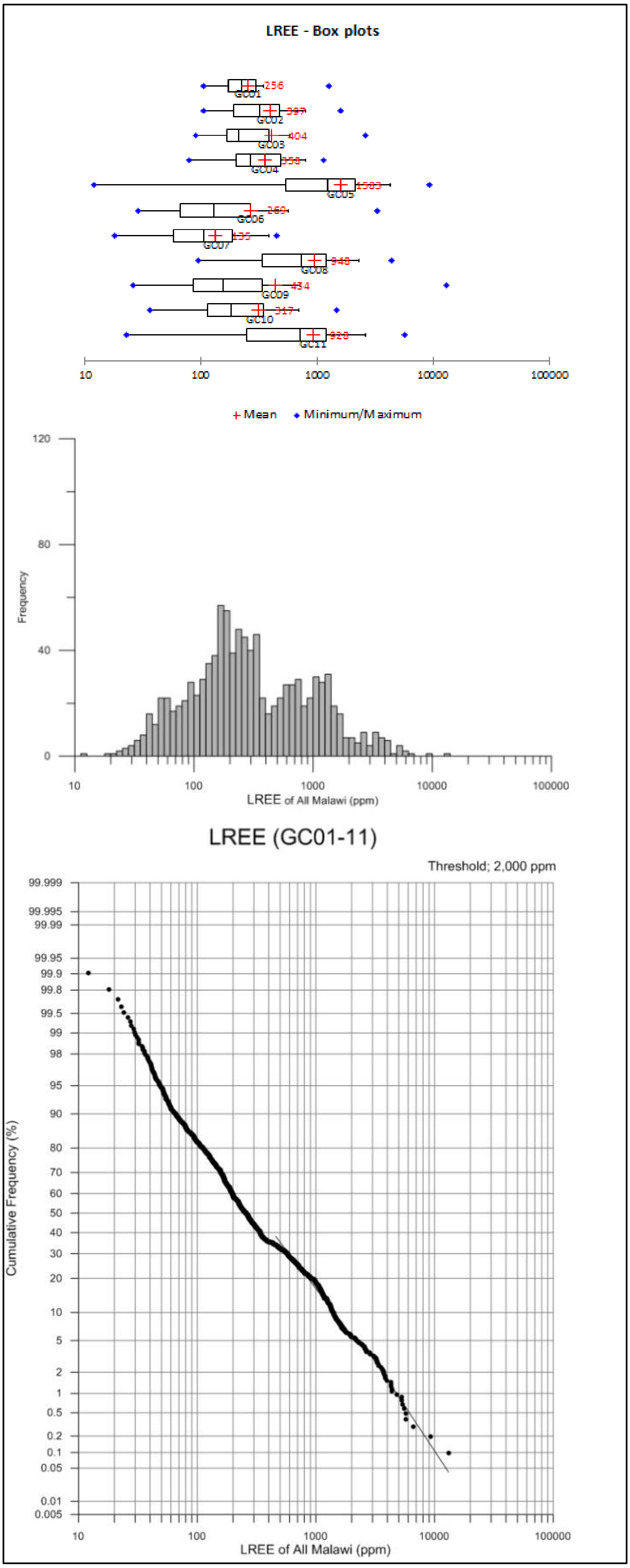


Figure 3-46 Figures of statistical analysis on REEs (LREE)

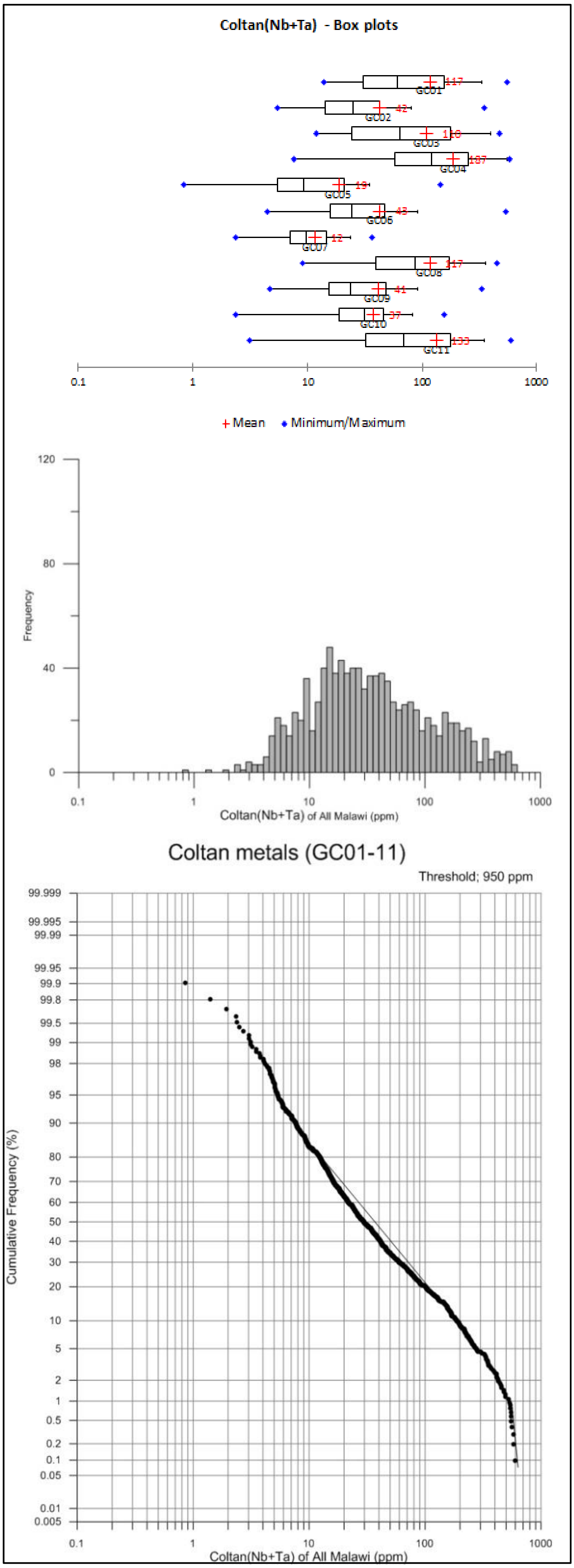


Figure 3-47 Figures of statistical analysis on coltan metals (Nb+Ta)

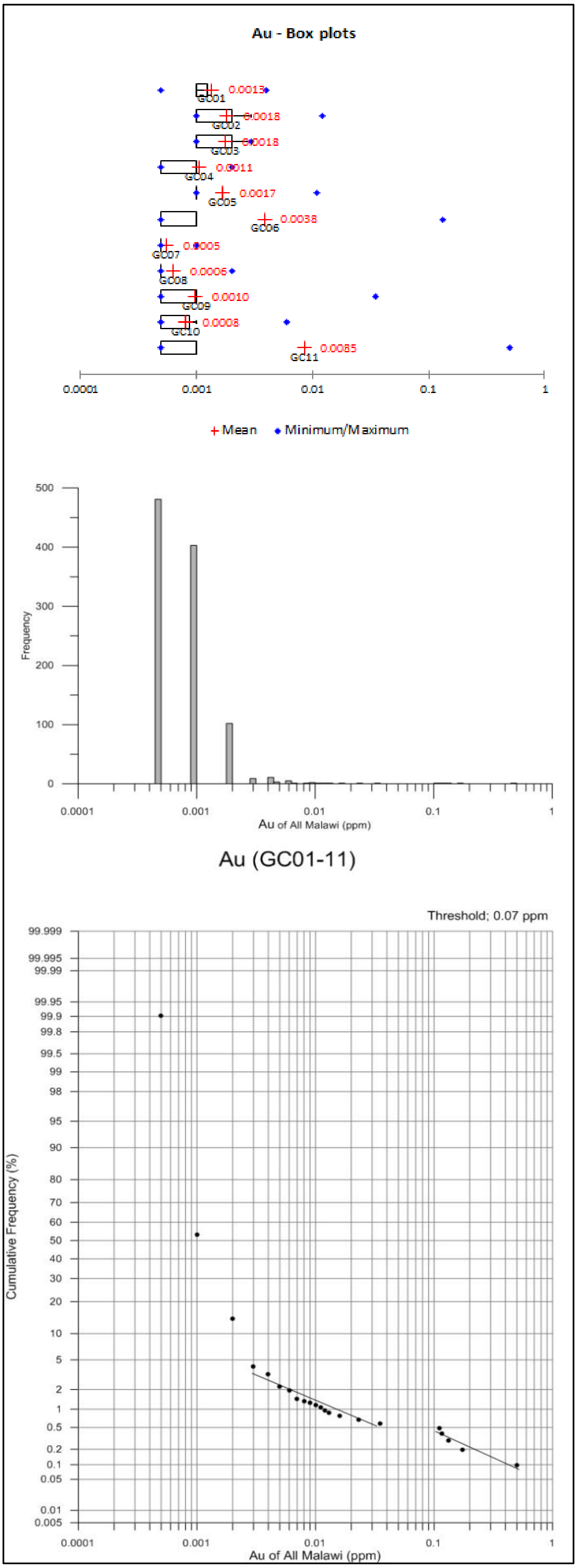


Figure 3-48 Figures of statistical analysis on Au

(2) Correlative analysis of every element pairs (factor analysis)

Factor analysis leads to correlative matrix of element distribution (Figure 3-49) and the distribution conductive factors (F1-F6), thus these parameters are enabling to consider the correlations among lithology/mineralization/geological structure and element concentration (Figure 3-50).

Figure 3-49 shows the strong positive correlations (over 0.8) between REE internal, REE-U-Th (Monazite, pyrochlore etc.), U-Zr (Zircon), Nb-Ta (columbite-tantalite), Co-Cr-Fe-Ni-V (mafic-ultramafic rocks), Mn-Ti-Zn, Fe-Ti-Mn-V-Zn (Magnetite etc.), which is supposed to derive from particular mineral or rock suite. And fair positive correlation (0.6-0.8) is shown between Cu-Co-Ni-Cr (mafic-ultramafic rocks), Be-Li (pegmatite), Pb-Th-U-Zr (zircon and inclusion), P-REE (apatite), which also are supposed to particular mineral or lithology.

Comparing with geochemical mapping and factor analysis results in Figure 3-50, it is highly probable that the first factor (F1: REE, U-Th, Nb-Ta, Mn-Fe-Mo-P, Ti-Zr-W, Zn-Sn: positive) is subject to pegmatite (GC05), syenite (GC01-02-03-04), carbonatite intrusion (GC08-09-10-11). Following F2 (Cu-Zn-Co-Ni-Cr: positive) assume to be Cu bearing mineralization with mafic-ultramafic rocks. F3 (LREE: positive, HREE: negative) shows an ambivalent results seems to denudation state of carbonatite complex suite. F4 (Nb-Ta-W, positive) is correlate to skarnization or hydrothermal alteration in GC06-07. F5 (Li-Be-Bi, positive) seems to be correlate with shear zone (GC01-02, Mugesse shear zone). Finally F6 (P-Sr-Ba) is identified ring ultramafic complex and Chilwa alkaline rock dykes and its residual soil (GC09-10).

F1: Y, LREE, HREE, Nb-Ta, Th-U, Mn-Fe-Mo-P, Ti-Zr-W, Zn-Sn (positive, 29 elements)

- **Associated with pegmatite (GC05), syenite (GC01-02-03-04) and alkaline rock-carbonatite intrusions (GC08-09-10-11)**

F2: Cu-Zn, Fe-Co-Ni-Mn, V-Cr-Sr-Ti (positive), Pb-U (negative)

- **Associated with mafic-ultramafic intrusions (GC01-02-06-08-09-10-11)**

F3: La-Ce [LREE](positive), Tm-Yb-Lu [HREE])(negative),

- **Associated with carbonatite denudation state (GC08-09)**

F4: Nb-Ta-W

- **Associated with skarnization (GC06-07)**

F5: Li-Be-Bi

- **Associated with shear zone (GC01-02)**

F6: P-Sr-Ba

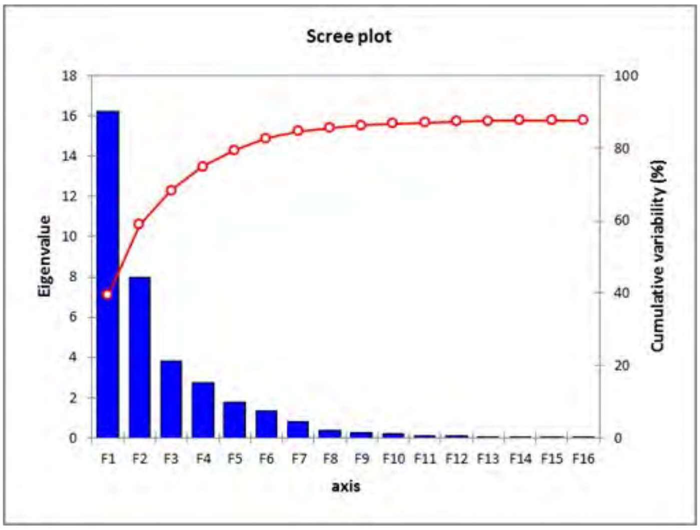
- **Associated with Chilwa alkaline rocks and residual soil (GC09-10-11)**

Variables	Au_ppm	Ag_ppm	Ba_ppm	Be_ppm	Bi_ppm	Ce_ppm	Co_ppm	Cr_ppm	Cu_ppm	Fe_%	La_ppm	Li_ppm	Mn_ppm	Mo_ppm	Nb_ppm	Ni_ppm	P_ppm	Pb_ppm	Sn_ppm	Sr_ppm	Ta_ppm	Th_ppm	Ti_%	U_ppm	V_ppm	W_ppm	Y_ppm	Zn_ppm	Zr_ppm	Dy_ppm	Er_ppm	Eu_ppm	Gd_ppm	Ho_ppm	Lu_ppm	Nd_ppm	Pr_ppm	Sm_ppm	Tb_ppm	Tm_ppm	Yb_ppm
Au_ppm	1																																								
Ag_ppm	0.228	1																																							
Ba_ppm	0.005	0.062	1																																						
Be_ppm	-0.141	0.035	0.357	1																																					
Bi_ppm	0.002	-0.044	-0.059	0.408	1																																				
Ce_ppm	0.145	0.045	0.321	0.207	0.018	1																																			
Co_ppm	0.113	0.122	-0.113	-0.175	0.068	0.225	1																																		
Cr_ppm	0.189	0.030	-0.077	-0.256	0.029	0.301	0.842	1																																	
Cu_ppm	0.179	0.265	-0.081	-0.154	0.031	0.074	0.760	0.642	1																																
Fe_%	0.069	0.148	-0.124	-0.183	0.024	0.325	0.876	0.742	0.586	1																															
La_ppm	0.156	0.007	0.287	0.178	0.057	0.948	0.146	0.244	-0.019	0.255	1																														
Li_ppm	-0.026	0.075	0.183	0.716	0.508	0.202	-0.183	-0.193	-0.155	-0.272	0.235	1																													
Mn_ppm	0.081	0.185	-0.050	-0.141	-0.033	0.373	0.777	0.569	0.519	0.869	0.317	-0.221	1																												
Mo_ppm	-0.038	0.174	0.174	0.113	-0.033	0.342	0.531	0.392	0.435	0.659	0.264	-0.125	0.649	1																											
Nb_ppm	0.021	0.191	0.201	0.164	-0.057	0.480	0.416	0.292	0.251	0.611	0.405	-0.080	0.700	0.764	1																										
Ni_ppm	0.174	0.097	-0.072	-0.178	0.064	0.223	0.899	0.924	0.775	0.706	0.150	-0.121	0.575	0.389	0.243	1																									
P_ppm	-0.116	-0.061	0.150	0.157	0.155	0.446	0.559	0.433	0.327	0.574	0.436	0.030	0.539	0.421	0.312	0.498	1																								
Pb_ppm	0.095	0.001	0.558	0.495	0.233	0.547	-0.331	-0.166	-0.310	-0.309	0.605	0.508	-0.254	-0.078	0.068	-0.238	0.017	1																							
Sn_ppm	-0.126	0.009	0.066	0.420	0.215	0.396	0.253	0.156	0.041	0.458	0.347	0.199	0.374	0.556	0.636	0.073	0.319	0.252	1																						
Sr_ppm	-0.131	-0.061	0.368	0.033	-0.029	0.030	0.540	0.404	0.451	0.425	-0.014	-0.179	0.401	0.367	0.233	0.527	0.585	-0.194	0.037	1																					
Ta_ppm	0.015	0.179	0.170	0.222	0.011	0.448	0.329	0.205	0.170	0.539	0.383	-0.021	0.632	0.681	0.970	0.144	0.257	0.118	0.667	0.152	1																				
Th_ppm	0.121	-0.051	0.276	0.325	0.148	0.810	-0.112	0.059	-0.230	0.042	0.865	0.342	0.085	0.133	0.337	-0.089	0.196	0.745	0.411	-0.239	0.379	1																			
Ti_%	-0.025	0.015	-0.044	-0.214	-0.004	0.324	0.728	0.575	0.386	0.880	0.280	-0.336	0.838	0.613	0.702	0.505	0.534	-0.229	0.478	0.404	0.662	0.125	1																		
U_ppm	0.061	-0.079	0.238	0.447	0.402	0.627	-0.185	-0.071	-0.300	-0.032	0.697	0.423	-0.014	0.054	0.247	-0.196	0.234	0.713	0.432	-0.222	0.348	0.868	0.083	1																	
V_ppm	0.058	0.018	-0.151	-0.261	0.051	0.217	0.913	0.824	0.622	0.926	0.161	-0.310	0.748	0.542	0.442	0.789	0.573	-0.348	0.345	0.508	0.366	-0.042	0.838	-0.094	1																
W_ppm	0.042	0.077	0.175	0.406	0.440	0.360	0.168	0.161	0.018	0.319	0.367	0.314	0.311	0.426	0.550	0.052	0.181	0.359	0.597	-0.033	0.607	0.507	0.416	0.578	0.233	1															
Y_ppm	-0.118	-0.083	-0.100	0.333	0.370	0.538	0.165	0.093	-0.081	0.325	0.602	0.281	0.316	0.249	0.279	0.054	0.605	0.272	0.500	0.020	0.316	0.550	0.341	0.640	0.230	0.415	1														
Zn_ppm	-0.046	0.185	-0.022	0.085	0.052	0.313	0.732	0.530	0.525	0.838	0.245	-0.016	0.818	0.741	0.660	0.563	0.587	-0.215	0.535	0.421	0.571	0.027	0.720	-0.054	0.706	0.332	0.381	1													
Zr_ppm	0.039	-0.017	0.321	0.388	0.220	0.531	-0.216	-0.091	-0.360	0.007	0.557	0.287	0.020	0.130	0.352	-0.264	0.080	0.621	0.478	-0.224	0.438	0.747	0.137	0.802	-0.098	0.590	0.464	-0.016	1												
Dy_ppm	-0.048	-0.074	-0.035	0.288	0.319	0.672	0.174	0.140	-0.073	0.331	0.741	0.267	0.333	0.235	0.312	0.084	0.598	0.370	0.483	-0.005	0.340	0.665	0.355	0.703	0.236	0.412	0.972	0.354	0.507	1											
Er_ppm	-0.170	-0.063	-0.122	0.362	0.375	0.444	0.177	0.067	-0.064	0.353	0.495	0.258	0.344	0.312	0.329	0.035	0.574	0.189	0.543	0.045	0.364	0.459	0.369	0.563	0.244	0.435	0.979	0.440	0.438	0.924	1										
Eu_ppm	0.072	0.011	0.235	0.024	0.086	0.708	0.526	0.451	0.277	0.573	0.724	-0.012	0.592	0.429	0.427	0.463	0.752	0.178	0.292	0.453	0.363	0.428	0.556	0.367	0.524	0.208	0.615	0.495	0.196	0.704	0.550	1									
Gd_ppm	0.053	-0.050	0.084	0.204	0.193	0.828	0.185	0.207	-0.042	0.319	0.898	0.228	0.339	0.228	0.331	0.136	0.577	0.484	0.418	-0.005	0.337	0.782	0.344	0.728	0.233	0.370	0.853	0.308	0.518	0.945	0.763	0.777	1								
Ho_ppm	-0.114	-0.075	-0.088	0.328	0.359	0.557	0.182	0.109	-0.070	0.350	0.620	0.267	0.341	0.270	0.315	0.065	0.601	0.274	0.516	0.024	0.347	0.560	0.369	0.637	0.250	0.424	0.995	0.403	0.470	0.979	0.980	0.638	0.866	1							
Lu_ppm	-0.244	-0.042	-0.172	0.383	0.366	0.221	0.127	-0.030	-0.067	0.318	0.259	0.220	0.309	0.356	0.327	-0.048	0.456	0.052	0.550	0.054	0.367	0.284	0.339	0.426	0.202	0.435	0.866	0.456	0.382	0.755	0.937	0.339	0.543	0.860	1						
Nd_ppm	0.107	-0.021	0.229	0.174	0.093	0.933	0.212	0.274	0.007	0.322	0.976	0.207	0.361	0.279	0.393	0.195	0.547	0.546	0.381	0.046	0.372	0.829	0.343	0.698	0.238	0.357	0.709	0.307	0.522	0.831	0.605	0.792	0.956	0.723	0.369	1					
Pr_ppm	0.122	-0.010	0.248	0.178	0.085	0.937	0.186	0.260	-0.009	0.295	0.988	0.222	0.345	0.278	0.399	0.176	0.510	0.570	0.373	0.025	0.376	0.845	0.319	0.703	0.208	0.366	0.677	0.289	0.535	0.806	0.571	0.773	0.942	0.692	0.337	0.996	1				
Sm_ppm	0.077	-0.048	0.161	0.183	0.153	0.883	0.210	0.255	-0.010	0.328	0.947	0.218	0.354	0.257	0.359	0.179	0.573	0.521	0.399	0.037	0.347	0.810	0.352	0.717	0.250	0.367	0.778	0.314	0.514	0.889	0.679	0.797	0.985	0.792	0.449	0.988	0.980	1			
Tb_ppm	0.008	-0.058	0.029	0.247	0.253	0.765	0.171	0.168	-0.061	0.318	0.836	0.250	0.331	0.228	0.323	0.104	0.586	0.444	0.453	-0.016	0.342	0.742	0.345	0.733	0.226	0.392	0.916	0.322	0.523	0.982	0.843	0.747	0.988	0.927	0.641	0.909	0.889	0.953	1		
Tm_ppm	-0.226	-0.062	-0.156	0.390	0.391	0.304	0.160	0.020	-0.058	0.339	0.344	0.248	0.321	0.337	0.321	0.001	0.526	0.101	0.552	0.066	0.360	0.342	0.354	0.477	0.232	0.436	0.925	0.458	0.392	0.833	0.979	0.429	0.632	0.923	0.983	0.460	0.424	0.539	0.726	1	
Yb_ppm	-0.248	-0.059	-0.174	0.388	0.380	0.240	0.155	0.003	-0.051	0.338	0.272	0.231	0.322	0.355	0.326	-0.014	0.488	0.053	0.555	0.073	0.365	0.288	0.353	0.427	0.229	0.438	0.881	0.469	0.370	0.771	0.949	0.363	0.558	0.875	0.995	0.386	0.351	0.465	0.656	0.991	1

Figure 3-49 Correlation matrix

	F1	F2	F3	F4	F5	F6	F7	Initial communality	Final communality	Specific variance
Au_ppm	-0.004	-0.059	**0.343**	0.009	0.011	0.301	0.123	0.292	0.227	0.773
Ag_ppm	0.011	-0.137	0.083	-0.204	-0.034	0.122	**0.367**	0.356	0.219	0.781
Ba_ppm	0.118	0.170	0.441	-0.371	-0.345	**-0.486**	-0.114	0.808	0.743	0.257
Be_ppm	0.304	0.424	-0.211	-0.399	**-0.547**	-0.084	0.137	0.811	0.801	0.199
Bi_ppm	0.271	0.193	-0.298	-0.035	**-0.444**	0.339	-0.147	0.637	0.534	0.466
Ce_ppm	**0.780**	0.144	0.511	-0.001	0.043	-0.026	0.126	0.938	0.908	0.092
Co_ppm	0.416	**-0.841**	0.063	0.094	-0.199	0.166	-0.008	0.962	0.961	0.039
Cr_ppm	0.358	**-0.688**	0.274	0.156	-0.172	0.293	-0.165	0.944	0.843	0.157
Cu_ppm	0.135	**-0.724**	0.115	0.039	-0.279	0.162	0.206	0.764	0.704	0.296
Fe_%	0.579	**-0.762**	-0.029	-0.046	0.091	0.116	-0.044	0.964	0.942	0.058
La_ppm	**0.800**	0.247	0.503	0.087	0.070	-0.010	0.093	0.990	0.976	0.024
Li_ppm	0.216	0.484	-0.081	-0.160	**-0.566**	0.201	0.216	0.756	0.720	0.280
Mn_ppm	0.576	**-0.668**	0.016	-0.116	0.150	-0.010	0.115	0.896	0.827	0.173
Mo_ppm	**0.515**	-0.485	-0.039	-0.408	0.042	-0.147	0.130	0.789	0.708	0.292
Nb_ppm	0.601	-0.346	0.072	**-0.614**	0.246	-0.106	0.113	0.980	0.947	0.053
Ni_ppm	0.296	**-0.759**	0.224	0.207	-0.352	0.221	-0.009	0.965	0.929	0.071
P_ppm	**0.681**	-0.312	-0.051	0.253	-0.255	-0.306	-0.075	0.815	0.791	0.209
Pb_ppm	0.358	**0.646**	0.407	-0.216	-0.258	0.010	-0.064	0.861	0.829	0.171
Sn_ppm	**0.631**	-0.033	-0.203	-0.439	0.031	0.057	-0.049	0.767	0.640	0.360
Sr_ppm	0.180	**-0.559**	0.033	0.038	-0.406	-0.540	-0.207	0.801	0.847	0.153
Ta_ppm	0.595	-0.235	0.012	**-0.643**	0.251	-0.040	0.053	0.976	0.891	0.109
Th_ppm	**0.689**	0.494	0.390	-0.120	0.086	0.147	-0.084	0.942	0.921	0.079
Ti_%	0.592	**-0.637**	-0.033	-0.151	0.259	-0.015	-0.257	0.935	0.914	0.086
U_ppm	**0.667**	0.582	0.137	-0.137	-0.038	0.172	-0.234	0.925	0.906	0.094
V_ppm	0.466	**-0.803**	0.004	0.088	-0.017	0.146	-0.246	0.964	0.952	0.048
W_ppm	**0.568**	0.081	-0.082	-0.522	-0.088	0.278	-0.197	0.734	0.732	0.268
Y_ppm	**0.872**	0.233	-0.342	0.240	0.010	0.000	0.011	0.990	0.990	0.010
Zn_ppm	0.591	**-0.621**	-0.173	-0.178	-0.053	-0.052	0.232	0.913	0.856	0.144
Zr_ppm	**0.540**	0.487	0.107	-0.363	0.100	0.096	-0.253	0.802	0.755	0.245
Dy_ppm	**0.913**	0.255	-0.142	0.259	0.048	0.016	0.019	0.995	0.989	0.011
Er_ppm	**0.841**	0.177	-0.475	0.152	0.019	-0.027	0.029	0.995	0.990	0.010
Eu_ppm	**0.786**	-0.220	0.260	0.267	-0.063	-0.245	0.014	0.924	0.870	0.130
Gd_ppm	**0.904**	0.252	0.171	0.267	0.080	0.002	0.044	0.994	0.990	0.010
Ho_ppm	**0.888**	0.216	-0.323	0.222	0.028	-0.004	0.017	0.993	0.991	0.009
Lu_ppm	**0.695**	0.124	-0.672	0.004	0.030	-0.048	0.029	0.991	0.953	0.047
Nd_ppm	**0.867**	0.205	0.398	0.181	0.059	-0.044	0.065	0.995	0.994	0.006
Pr_ppm	**0.848**	0.224	0.432	0.148	0.063	-0.033	0.078	0.994	0.990	0.010
Sm_ppm	**0.891**	0.221	0.297	0.232	0.057	-0.022	0.036	0.993	0.990	0.010
Tb_ppm	**0.915**	0.267	0.033	0.264	0.070	0.013	0.036	0.993	0.986	0.014
Tm_ppm	**0.760**	0.139	-0.616	0.076	-0.003	-0.042	0.021	0.993	0.985	0.015
Yb_ppm	**0.713**	0.109	-0.668	0.026	0.004	-0.044	0.017	0.992	0.969	0.031

Values in bold correspond for each variable to the factor for which the squared cosine is the largest



Eigenvalues:

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	16.199	7.961	3.830	2.750	1.795	1.362	0.810
Variability('	39.511	19.418	9.341	6.708	4.377	3.322	1.977
Cumulative	39.511	58.928	68.269	74.977	79.354	82.676	84.653

Figure 3-50 Factor analysis results (above) and Eigen values (below)

3.8.4 Interpretation of geochemical survey results

Interpretations of geochemical maps are preferable from the following two approvals;

a) quantitative method/ statistical factor analysis results: including considerations between anomalies and correlative geological factors, such as lithology and faults
b) qualitative method/ field description based consideration: on site observations of lithology, sediment composition and mineralization style

The former might be correspond to macro-scale interpretation (regional, 1km-10km order, geological map scale), and latter to meso-scale interpretation (0.1-1 km order, detailed route map-outcrop scale), conceptually. It is appreciated to adjust these two way results for better interpretations.

Established geological map, sometimes, is not fit for our field scale observation (e.g. boundary shape accuracy or dominant lithology identification etc.). In the field campaign of geochemical survey, detailed optical observations by optical and hand-lens (loupe) used to be done to fill the description sheet format and to recognize local lithological variety, trace of Cu mineralization (e.g. characteristic green Cu oxide and sulphide coexistence), skarnization (particular mineral assembly of skarn), and confirmation of heavy mineral distribution (magnetite, garnet, zircon, apatite etc. in sediments) or mixing of lateritic crust fragments etc. and are described for better understanding on geochemical anomaly interpretations.

(1) Chitipa area (GC01-02)

In northernmost Chitipa area (GC01-02), Cu-Co and Cr-Ni broad anomalies are recognized (Figure 3-51) and confirmed 7 weak Cu oxide occurrences in field campaign (Figure 3-52).

These all sites are correspond to the lithological homogeneity to amphibole gneiss (light brown area in the figure), which were identified in outcrops especially associated with the altered amphibolite intrusion (pale green area in the figure) and posterior fine felsic intrusion (granite-quartz) by occurrences of Cu-oxide rimmed Cu sulphide and pyrite dissemination. Additionally relatively thinner residual soil cover was observed in the area, so it is highly probable as source anomaly in the case of Cu anomaly in Chitipa area (GC01). This Cu mineralized area is firstly documented by this survey. However it is not so high, the anomaly value (over 50 ppm) is approximately twice as much as upper continental crust average.

Locally Nb+Ta anomaly (threshold 550ppm) is also identified along the Ilomba hill syenite-Songwe syenite (North Nyasa alkaline rocks) associated with Mugesse shear zone (figure 3-53), which seems to be correlate with magnetite sand occurrence (probably pyrochlore also, Figure 3-54). Ilomba hill syenite is well known as locality of sodalite bearing syenite and its Nb concentration. Malawi Resource Star (2011) reported several sites over 2% concentration of Nb-oxide by soil geochemical survey based on aero-radiometric survey (Figure 3-54). Our survey results show a probability of its external extension along the Songwe syenite.

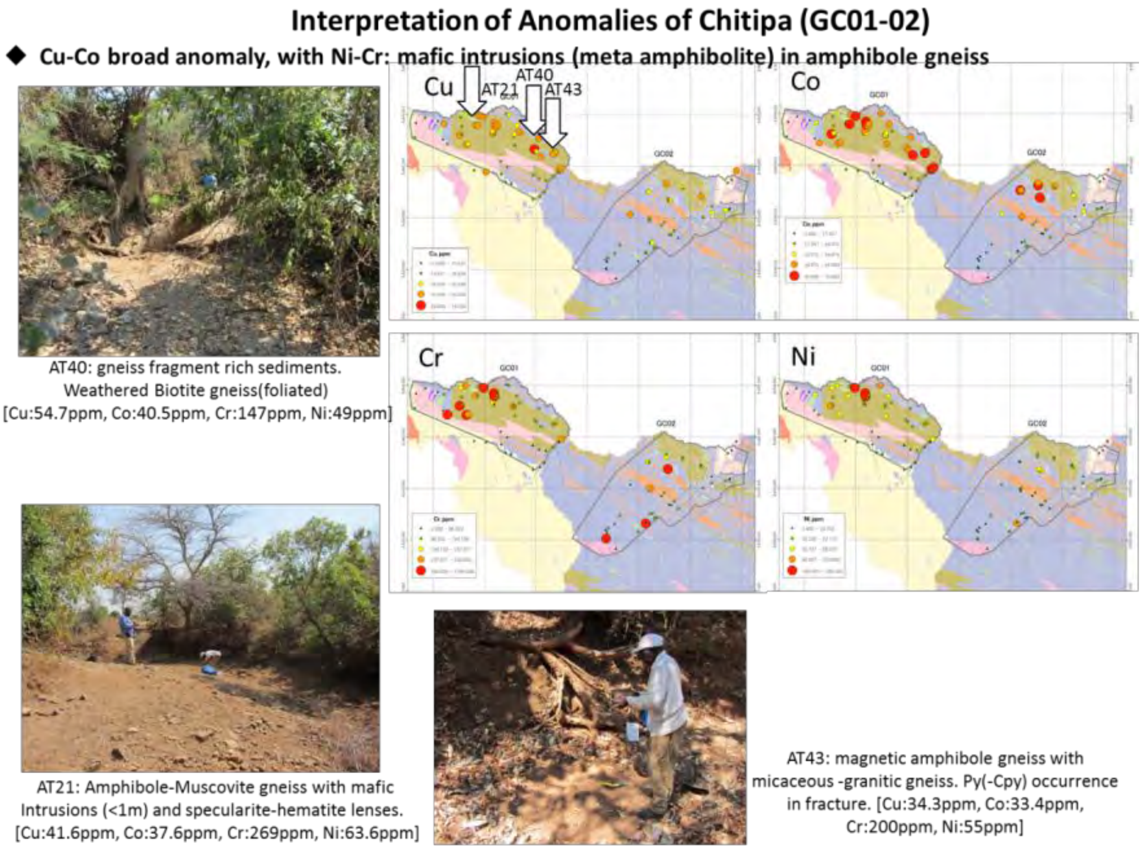


Figure 3-51 Cu-Co anomaly site (Chitipa area)

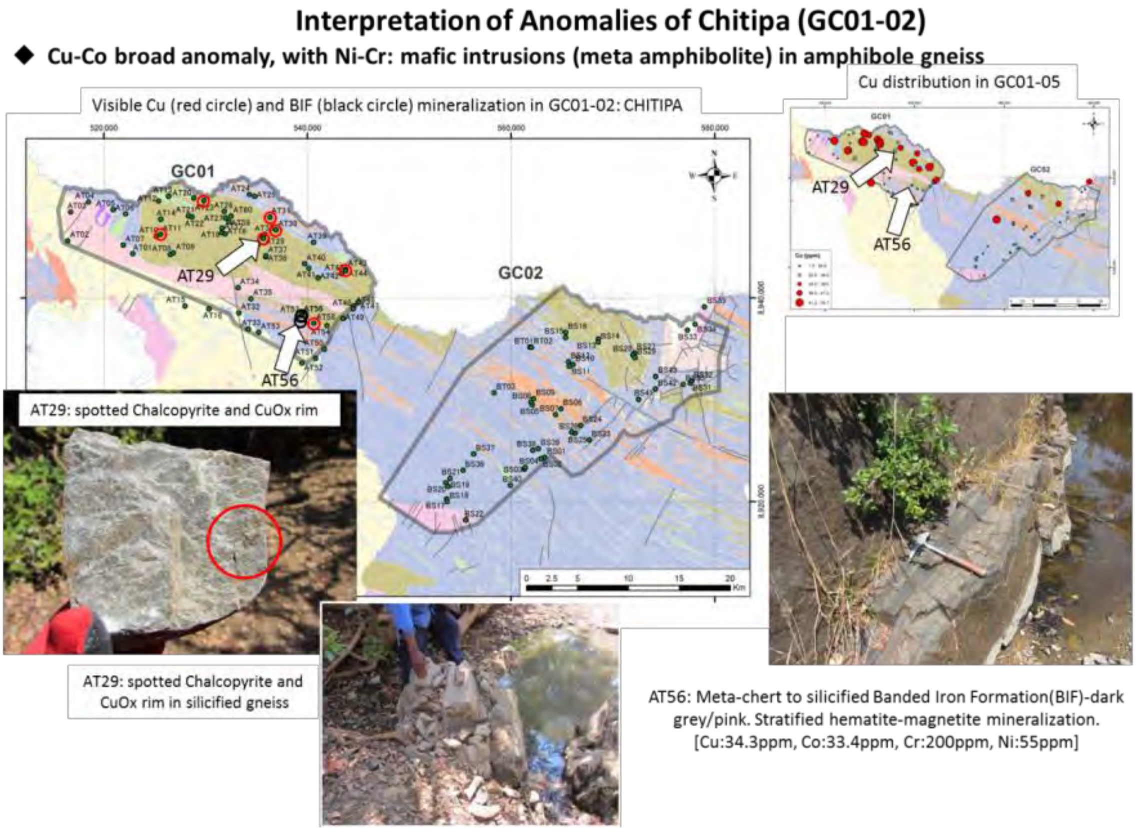


Figure 3-52 Cu (red-circle) and BIF (black-circle) occurrences (Chitipa area)

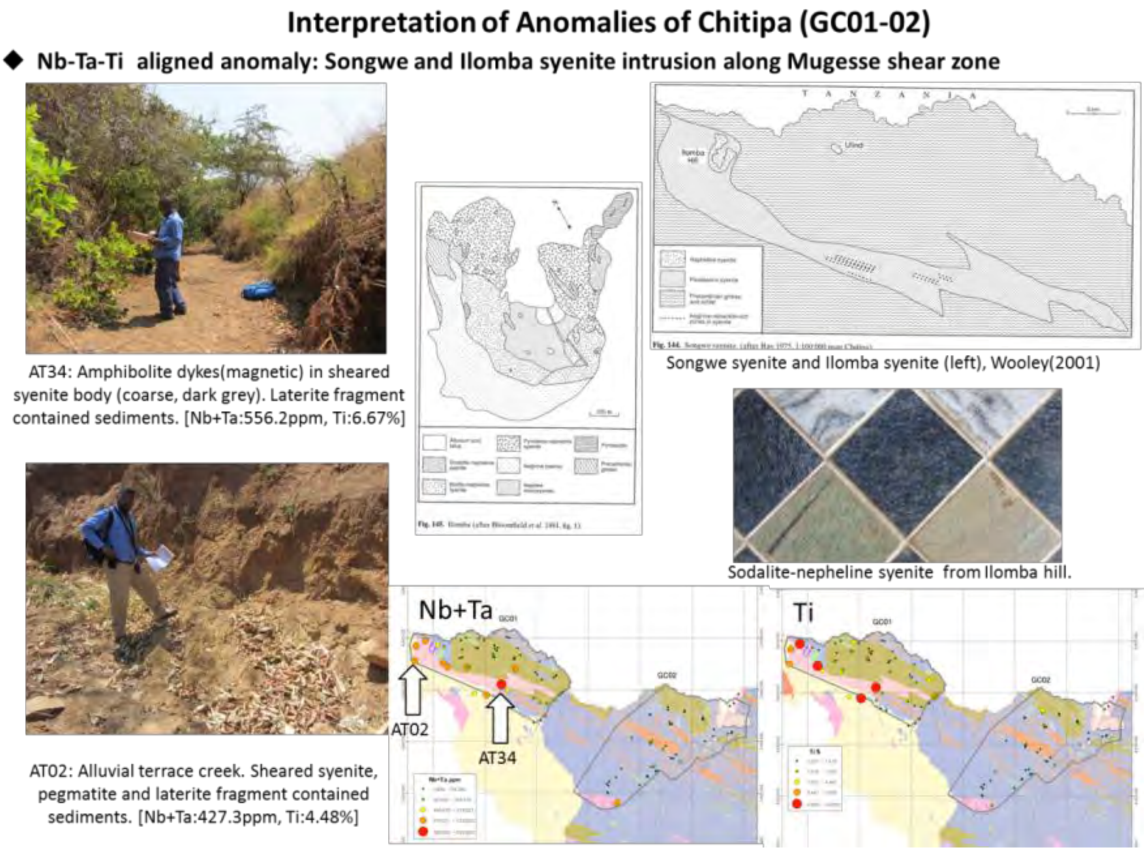


Figure 3-53 Nb-Ta anomaly site (Chitipa area)

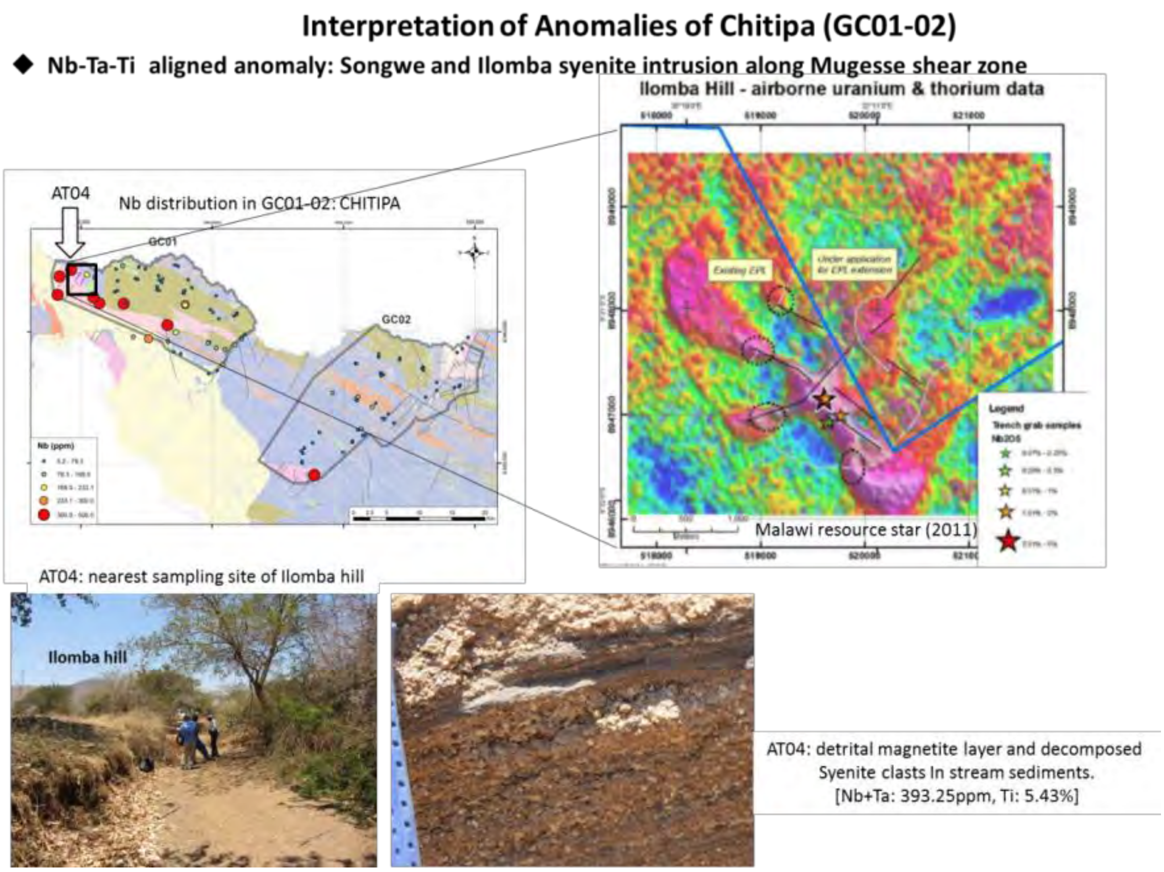


Figure 3-54 Nb-Ta anomaly site with magnetite layer occurrence (Chitipa area)

(2) Rumphi area (GC03-04)

Rumphi area (GC03-04) in northern region, Nb-Ta-Zr anomalies (Nb+Ta: Over 550ppm) are identified associated with nepheline syenite bodies (Telelele hill, Nkonjera, Mphompha) in granitic complexes (Figure 3-55). Figure 3-55 shows east-west sensed chained nepheline syenite intrusive area (pale violet-brown) in granite complexes (pink). In field campaign, anomalous sites are recorded the abundance of magnetic particles and clay/soil particles (Figure 3-55). This Nb-Ta anomaly is also as source anomaly as well as GC01-02

In Nkonjera syenite, former geochemical survey also recorded the anomalous Nb concentration from heavy mineral sample (max.3000ppm). Our survey documented again the anomalous distribution in more broad area, probably from every syenitic body.

Sr-Ba-Ag(-Pb) anomaly also is identified in similar contoured area, highly probable from syenite.

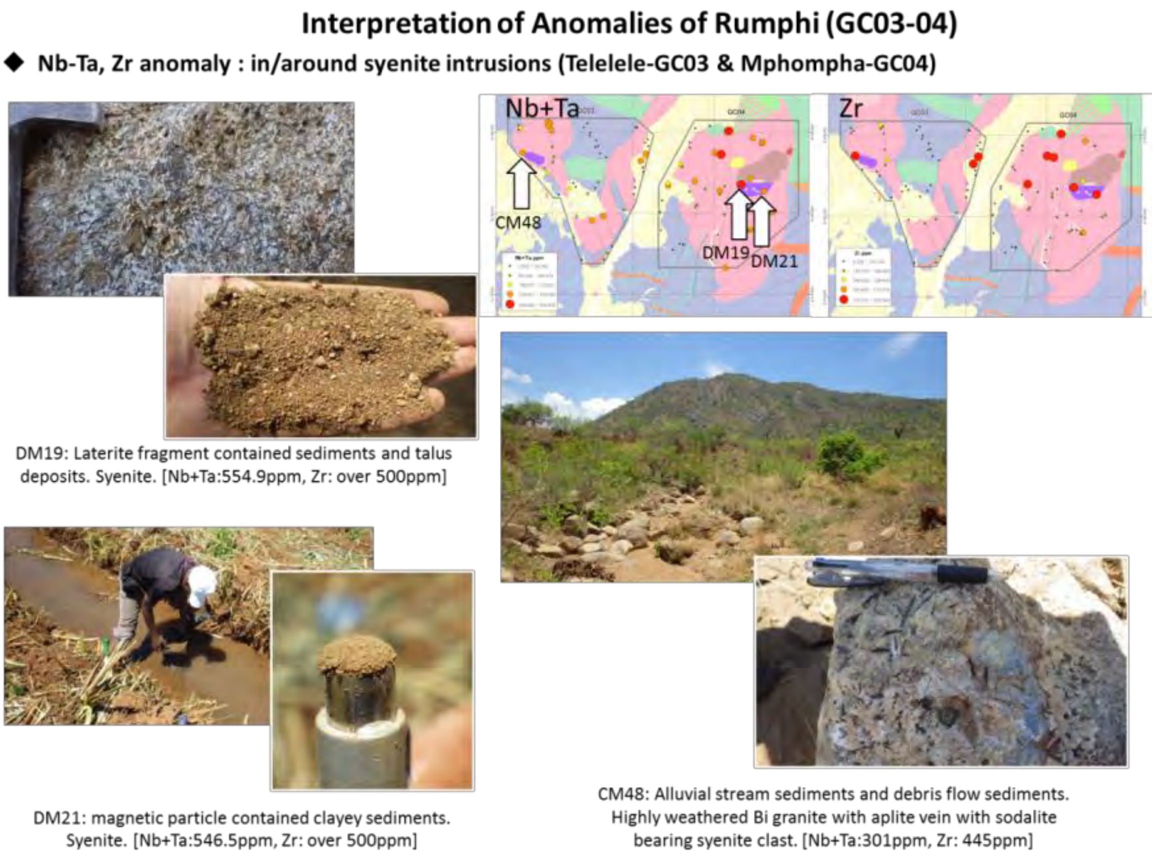


Figure 3-55 Nb-Ta anomaly site (Rumphi area)

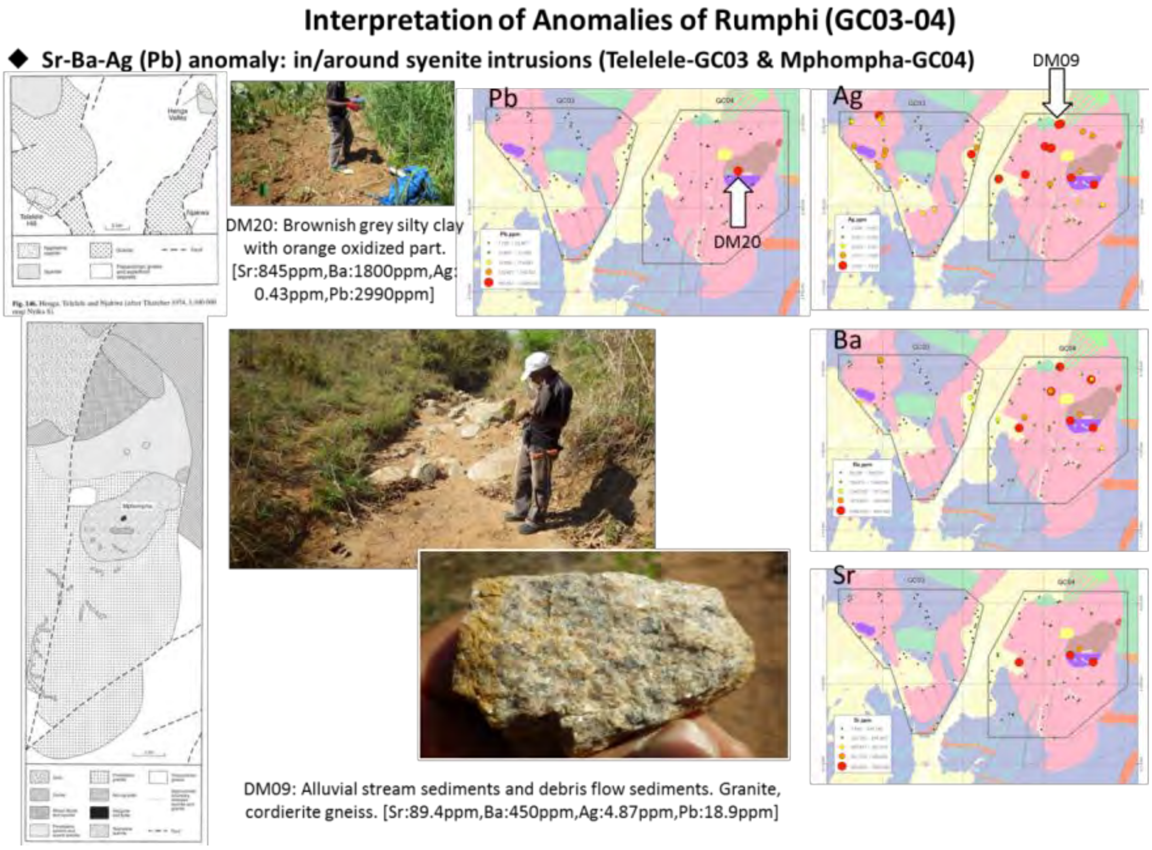


Figure 3-56 Sr-Ba-Ag(Pb) anomaly site (Rumphi area)

(3) Mzimba area (GC05)

Mzimba area (GC05) is characterized by REE and nuclear metals (U+Th) abundance associated with pegmatite occurrences as mentioned above.

Figure 3-57 shows broad anomalies centered in survey area of LREE (over 2000ppm), HREE (over 150ppm), U+Th (over 950ppm) and Zr (over 373ppm). Maximum value of total REE is reached to 5000-10000ppm. Sediment and geology of anomaly detected sites is characterized by fragments of pegmatite/muscovite/laterite, and frequently observed quartz-pegmatite veinlets in weathered basement (Figure 3-41), which seems to be origin of their REE anomaly. Particularly observed coexistence of REE and U+Th anomaly suggest possible origin mineral contains monazite-pyroclore.

Comparing with world-class REE deposit data by Takagi (2013) with stream sediment data of Mzimba area (GC05) shows the comparable concentration in LREE values and 10-50% leveled concentration in HREE of Chinese ion-absorbed type regolith hosted REE mines (Figure 3-58).

Private company OROPA (2008) is exploring norther part of our survey area for Uranium in Mafingi quartzite, it seems to be totally deferent sedimentation age and process (Figure 3-57).

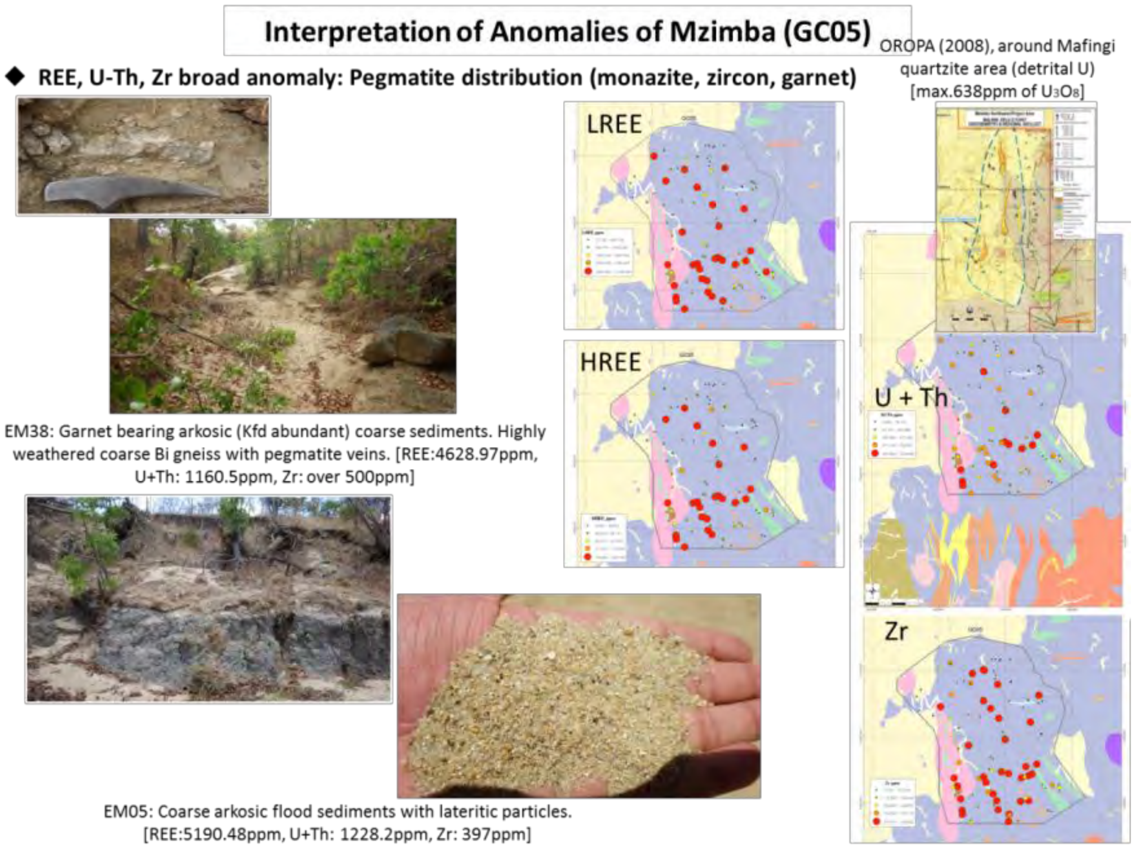


Figure 3-57 REE, U-Th anomaly site (Mzimba area)

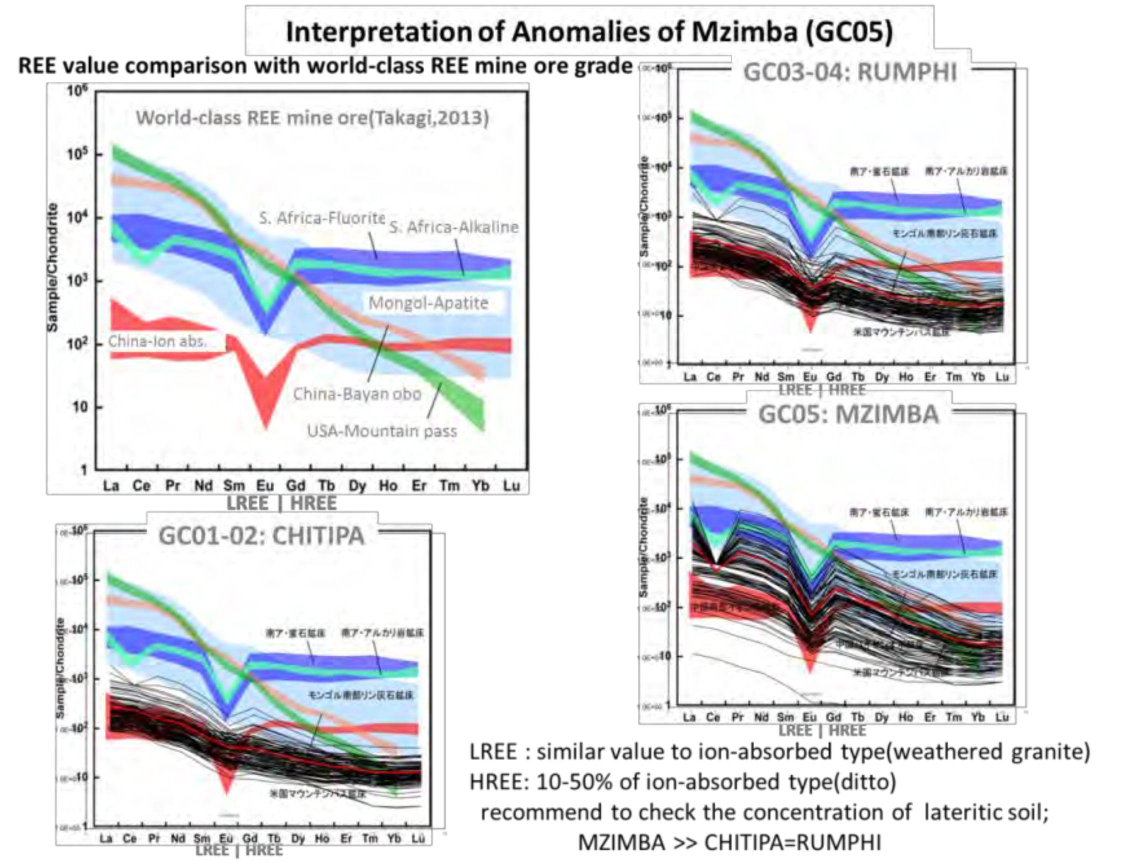


Figure 3-58 REE pattern comparison with world class mine (Chitipa, Rumphi, Mzimba areas)

(4) Kasungu area (GC06)

In Kasungu area of central region detected only spotted anomalies of Cu-Au and Ti-Zr, by means of complicate and segmented geology.

Cu-Au anomalies are located in/around calcareous and quartzose gneiss area associated with felsic vein and dykes and some alteration (Figure 3-59). Visible Cu-Au occurrence was not detected, but along fracture small scale skarn vein or lenses were observed. In former geochemical survey before 1973 by GSD also detected some Au anomaly, our survey documented again the occurrence of Cu-Au.

Ti-Zr anomalies are located just along granitoids including porphyroblastic gneiss, which contains 10cm (maximum) diameter porphyroblast of K-feldspar (Figure 3-60) by high temperature motamorphism. This porphyroblastic gneiss always belong high magnetism up to 40x10E-3 Si and magnetite sand layer also (possibly with zircon). Ti anomalous content is probably derived from magnetite (Figure 3-60).

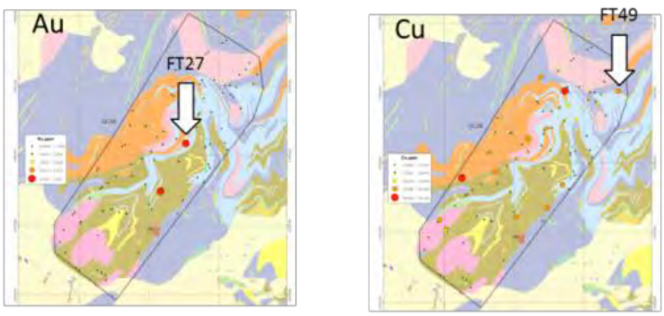
Interpretation of Anomalies of Kasungu (GC06)

◆ **Cu, Au spotted anomalies: <u>skarnization-alteration by granitic intrusions along calcareous gneiss</u>**

FT27: calcareous-siliceous gneiss with felsic vein and epidote-K-feldspar veinlet [Au: 0.133ppm, Cu:17.6ppm]

FT49: banded calcareous (white, centered: actinolite-biotite-calcite)-siliceous(Qz-Fd) gneiss, deformed, with meta-gabbro (dark greenish gray, below left) [Au: 0.001ppm, Cu: 33.6ppm]

FT27: incised meandering terrace-weathered basement with large clasts (placer situation)



Calcareous-siliceous gneiss expressed by sky blue

Figure 3-59 Cu, Au anomaly site (Kasungu area)

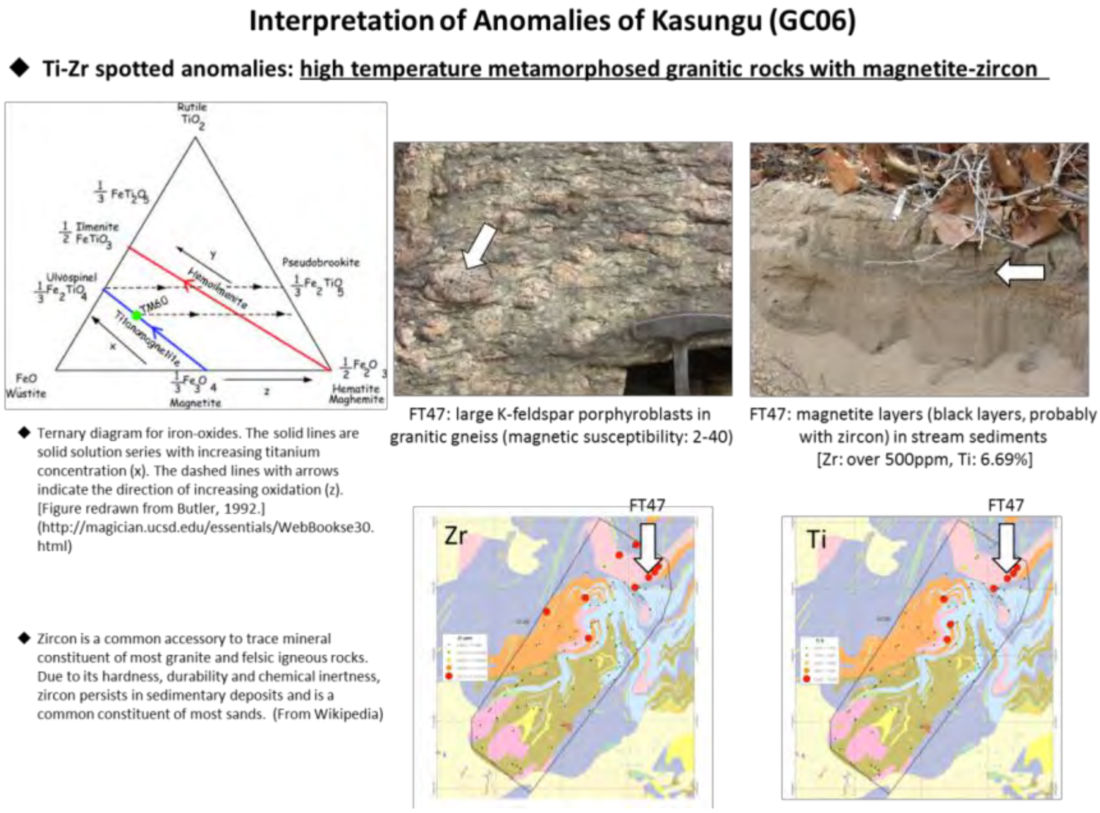


Figure 3-60 Ti-Zr anomaly site with magnetite layer occurrence (Kasungu area)

(5) Lilongwe area (GC07)

In Dzalanyama area of central region, detected only two of broad Zr anomaly (over 373ppm) and spotted W anomaly (over 22ppm) as shown in Figure 3-61.

Dzalanyama granite is classified a two type with leucoclatic granite and coarse alkaline granite in established geological map, and Zr anomaly distribution is coincide to the latter lithology by original zircon abundance.

Spotted W anomalies are probably associated with quartzose schist lenses (partly hydrothermal altered lens) because of common occurrences of quartz-calcite veinlets around the area (possibly with rare scheelite as W bearing carbonate). Dzalanyama granite totally obtained mylonitic shear with a NW trend foliation, is the just same direction with mentioned lens.

At the beginning of survey plan, an occurrence of gold was expected concerning with the shear zone, but not detected any anomalous value. Therefore gold occurrence of Au rich Malingunde pyrite zone in basal complex, which located NE of Dzalanyama is the probable origin.

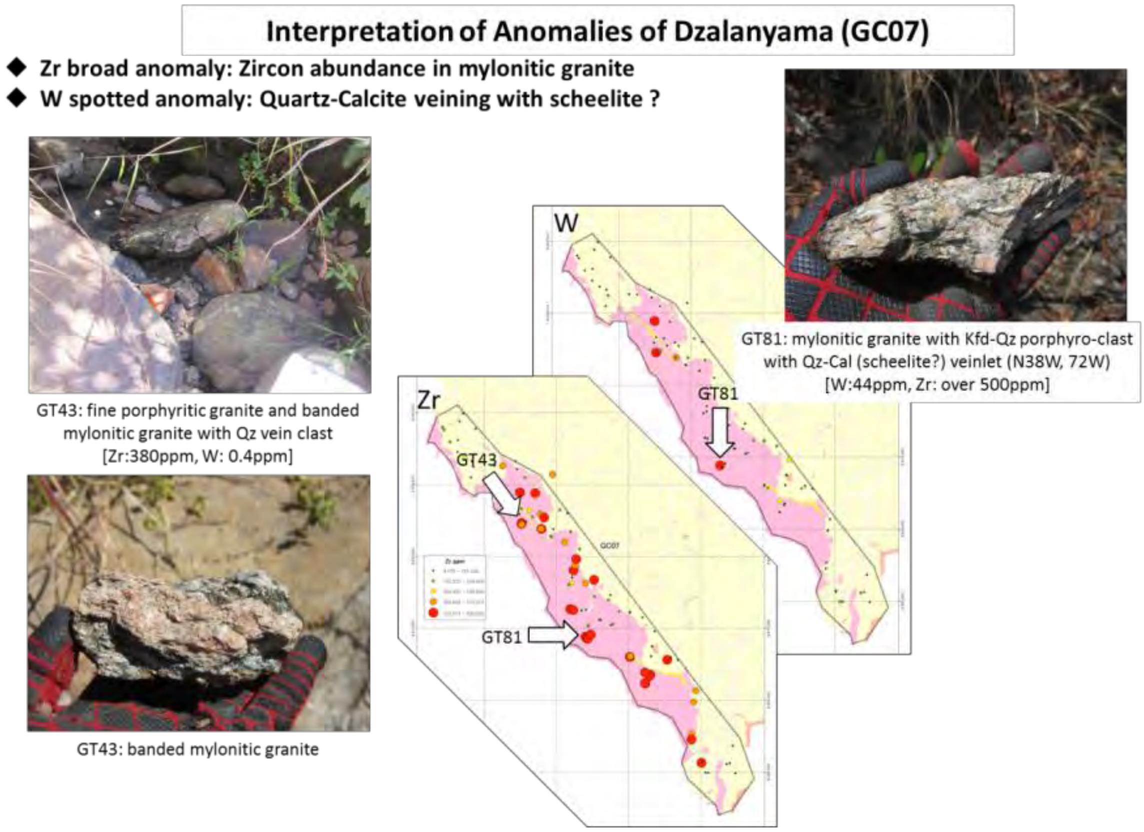


Figure 3-61 Zr-W anomaly site (Lilongwe area)

(6) Mangochi area (GC08)

In Mangochi area of southern region, various anomalies of Mo-Zn-W, REE, U-Th, Zn, Nb-Ta, Fe-Ti are detected in association with the multiple varied intrusions and rift fault systems.

Mo-Zn-W anomalies (Mo: over 6ppm, Zn: over 300ppm, W: over 22ppm) are located surrounding carbonatite complex of the Lake Malombe vents (Figure 3-62). Abundant magnetite occurrence in stream sediments is remarkable. The concentric duplicate Mo-Zn anomaly is known by the other carbonatite vent in Malawi (e.g. Kangankunde), associated with sideritic carbonatite (Peters, 1973).

REE and U-Th anomaly shows the aligned distribution in lowland valley along the NNW rift fault systems (Figure 3-62). Sediments contain dense magnetite, garnet and lateritic fragments. It seems the secondary hydraulic anomaly.

Zn, Nb-Ta, Fe-Ti anomalies tend to locate broad area eastern lowland part. Sediments is characterized by variety of heavy minerals (zircon, magnetite, ilmenite, garnet and apatite). It seems also by secondary hydraulic anomaly (Figure 3-64).

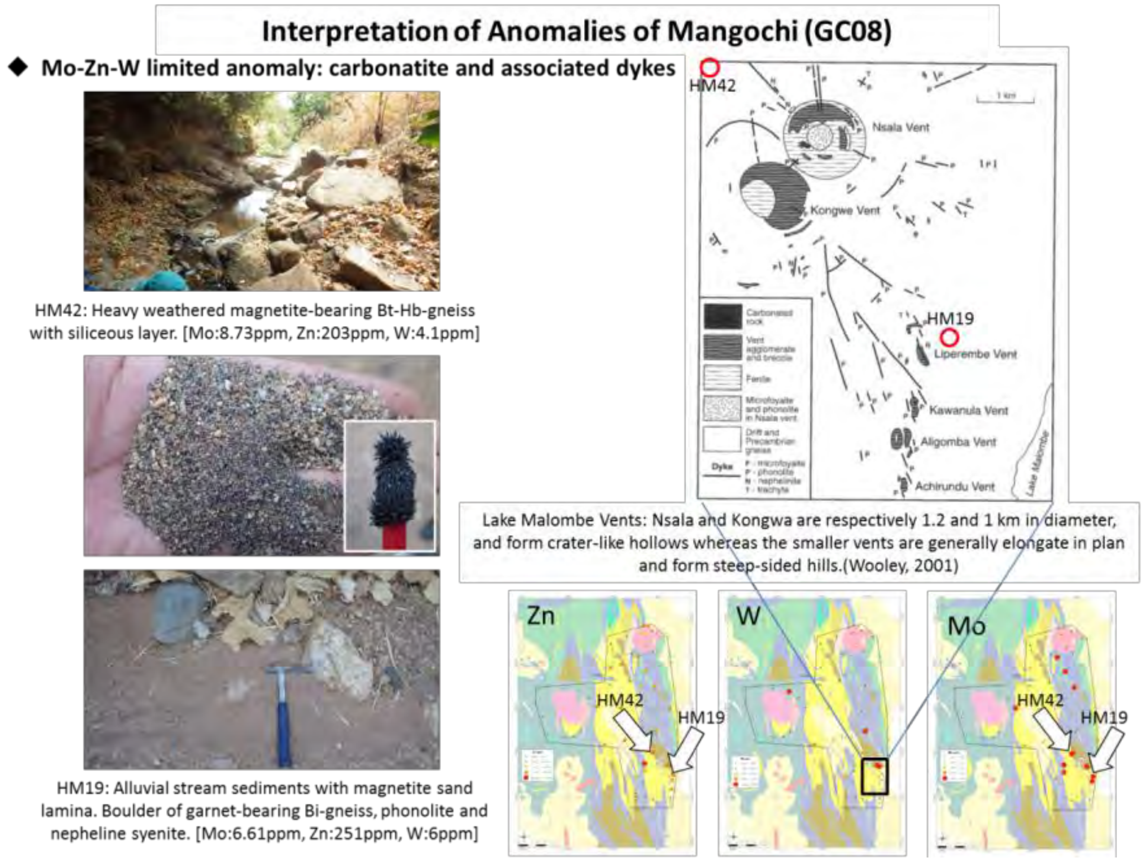


Figure 3-62 Mo-Zn-W anomaly site (Carbonatite) (Mangochi area)

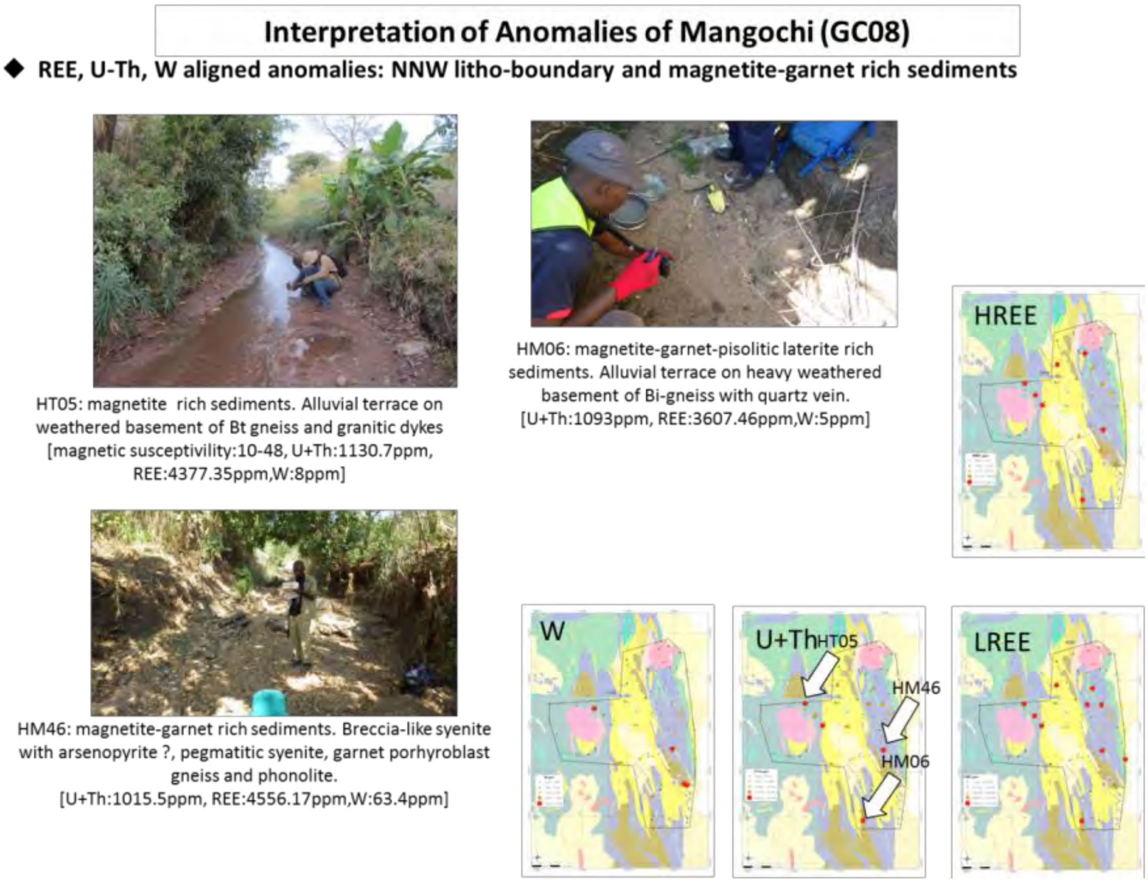


Figure 3-63 REE,U-Th, W anomaly site (Mangochi area)

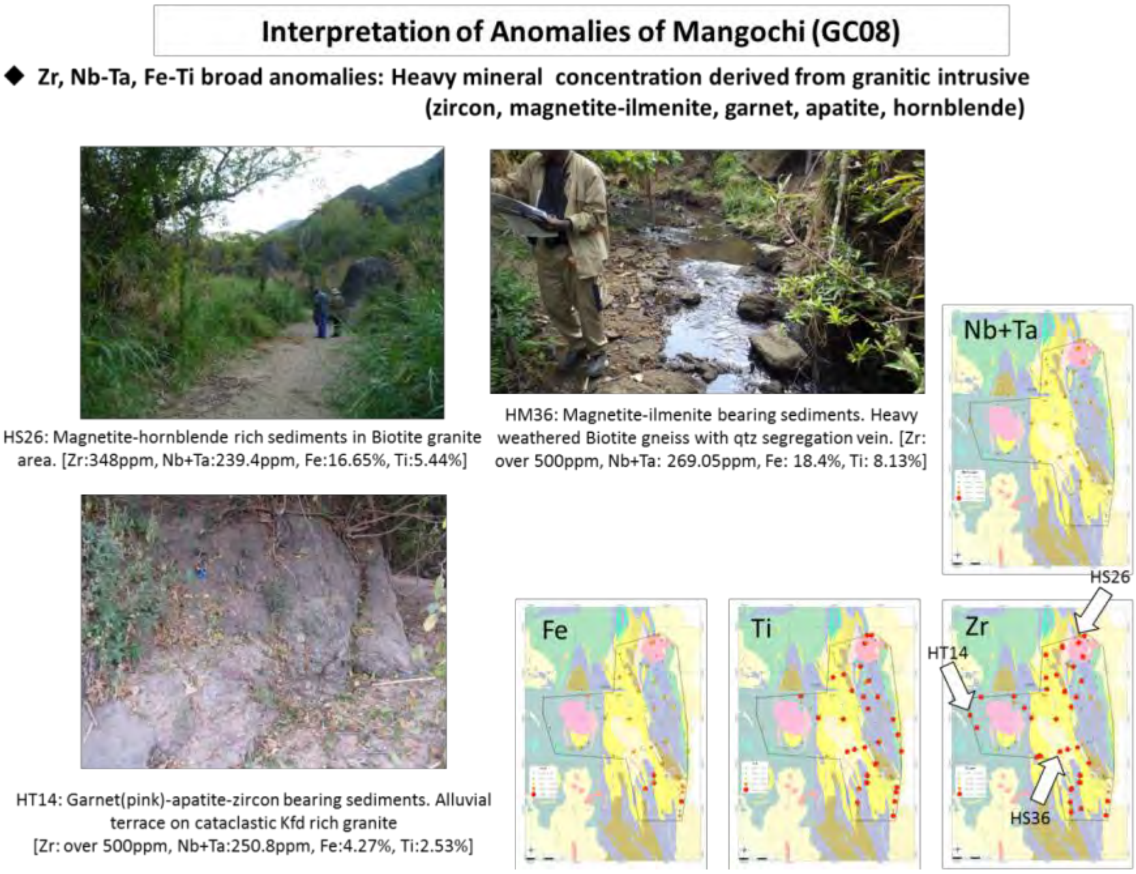


Figure 3-64 Zr, Nb-Ta, Fe-Ti anomaly site with heavy minerals (Mangochi area)

(7) Balaka area (GC09-10)

In Balaka-Mwanza area of southern region, varied anomalies (Fe-Ti, Cu-Co-Ni-Cr, REE, Nb-Ta, Zn-Mo, Sr-Ba, P) are detected by mean of multiple intrusive, ring structures and rift faults.

Fe-Ti anomalies (Fe: over 28%, Ti: over 5%) are more remarkable in Balaka area (GC09) along Shire valley. It seems a hydraulic anomaly with abundant magnetite and ilmenite (Figure 3-66).

Cu-Co-Ni-Cr anomalies are laid particularly on ultramafic rock and carbonatite, and a calcrete crust is observed at sampling site. So this is a source anomaly (Figure 3-66).

Also REE, Nb-Ta, Zn-Mo anomalies are located around Kangankunde carbonatite (Source anomaly). Peters (1973) indicated the Zn-Mo concentric anomaly centered with carbonatite body. In addition, Nb exploration of Kangankunde started in 1960's or before (Wooley, 2001). Our survey result documented again the distribution pattern (Figure 3-68).

Sr-Ba and P anomaly distribution is similar to the Cu-Co-Ni-Cr anomaly (correlation with ultramafic and carbonatite) pattern, but more extensive. It means of correspondence of whole ring structures of Mlindi (GC10 south) and of Lisungwe fault (GC09, south) involving ENE sorvergite dyke swarm nested between the two ring structures (Figure 3-69, Source anomaly).

Especially the P anomaly of Mlindi ring structure is documented in BGS (2009), as a high grade (7-14%, P_2O_5) phosphate concentration in residual soil laid on meta-pyroxenite. Mlindi complex is also detected by aeromagnetic survey (Figure 3-65).

Our survey results suggest the probability of extension of P anomaly beyond Mlindi ring structure to east.

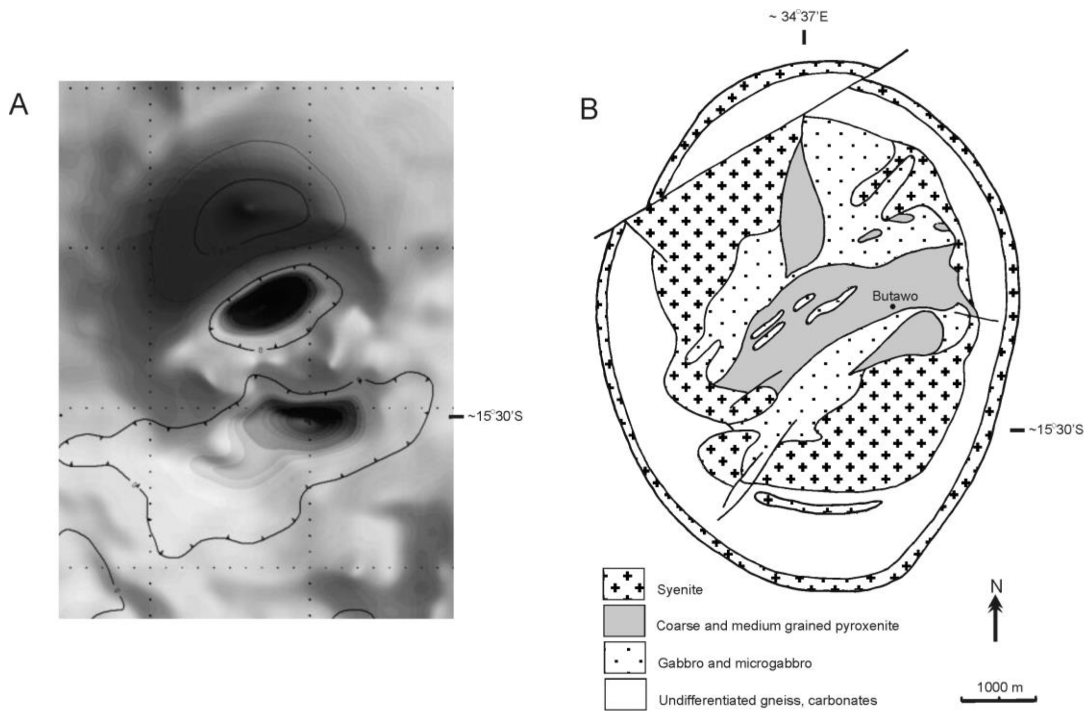


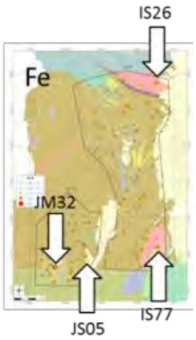
Figure 3-65 Aeromagnetic field of Mlindi ring structure and geology (Balaka area)

Interpretation of Anomalies of Balaka-Mwanza (GC09-10)

◆ **Fe-Ti broad anomalies: Heavy mineral concentration derived from felsic-mafic multiple intrusive (zircon, magnetite-ilmenite, garnet, pyroxene)**

IS26: Garnet-magnetite rich sediments. Perthite augen-gneiss. N40W40E: gneissosity [Fe:16.05%, Ti: 8.13%]

JS05: Red-brown magnetite rich sandy colluvium, boulders of Qz-feldspathic rock > Solvsbergite [Fe:16.4%, Ti: 6.74%]



IS77: Fine magnetite-ilmenite bearing sediments. Granite/syenite and Gabbro (magnetic susceptibility: 10-40) [Fe: 22.5%, Ti: 7.77%]

JM32: Magnetite-pyroxene rich sediments. Boulder of Bi-syenite(high magnetism), Kfd-bearing Bi-metapyroxenite and calcrete? cementing of sand and gravel. [Fe: 34.1%, Ti: 1.945%]

Figure 3-66 Fe-Ti anomaly site and heavy minerals (Balaka area)

Interpretation of Anomalies of Balaka-Mwanza (GC09-10)

◆ **Cu-Co, Ni-Cr broad anomalies: Lateritic crust-soil of mafic-ultramafic or carbonatite intrusion**

JM33: Lateritic fragment-magnetite rich sediments. Calcrete of gravel: Bi--metapyroxenite, solvsbergite, Qtz fragment. [Cu: 55ppm, Co: 45.9ppm, Ni: 194ppm, Cr: 428ppm]

IS44: Sandy sediments, covered by Black soil (Dambo) Magnetite and Mn coated fenite bearing. [Cu: 52.2ppm, Co: 25.1ppm, Ni: 34ppm, Cr: 47ppm]

IS69: Black clayey soil (Dambo) of flood plain. [Cu: 74.2ppm, Co: 39.1ppm, Ni: 132ppm, Cr: 166ppm]

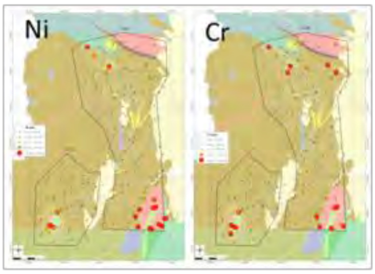


Figure 3-67 Cu-Co, Ni-Cr anomaly site with laterite formation (Balaka area)

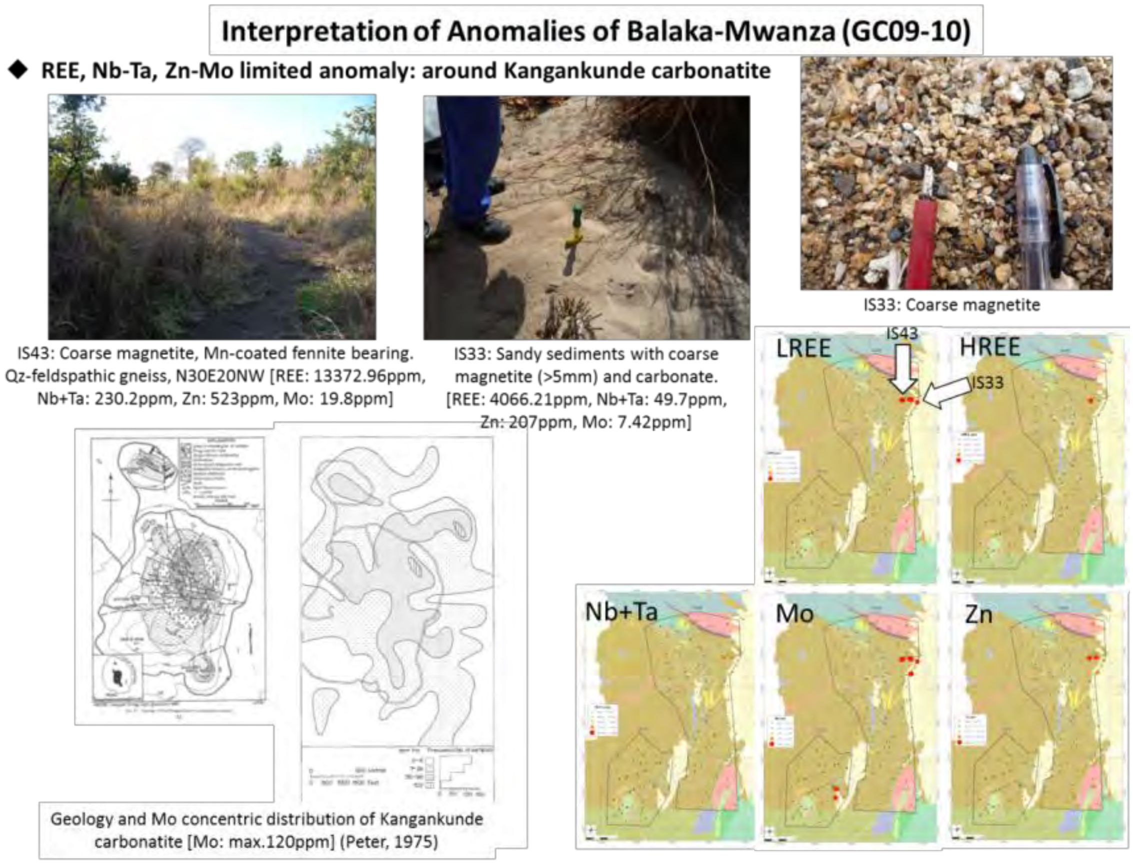


Figure 3-68 REE, Nb-Ta, Zn-Mo anomaly site (Carbonatite) (Balaka area)

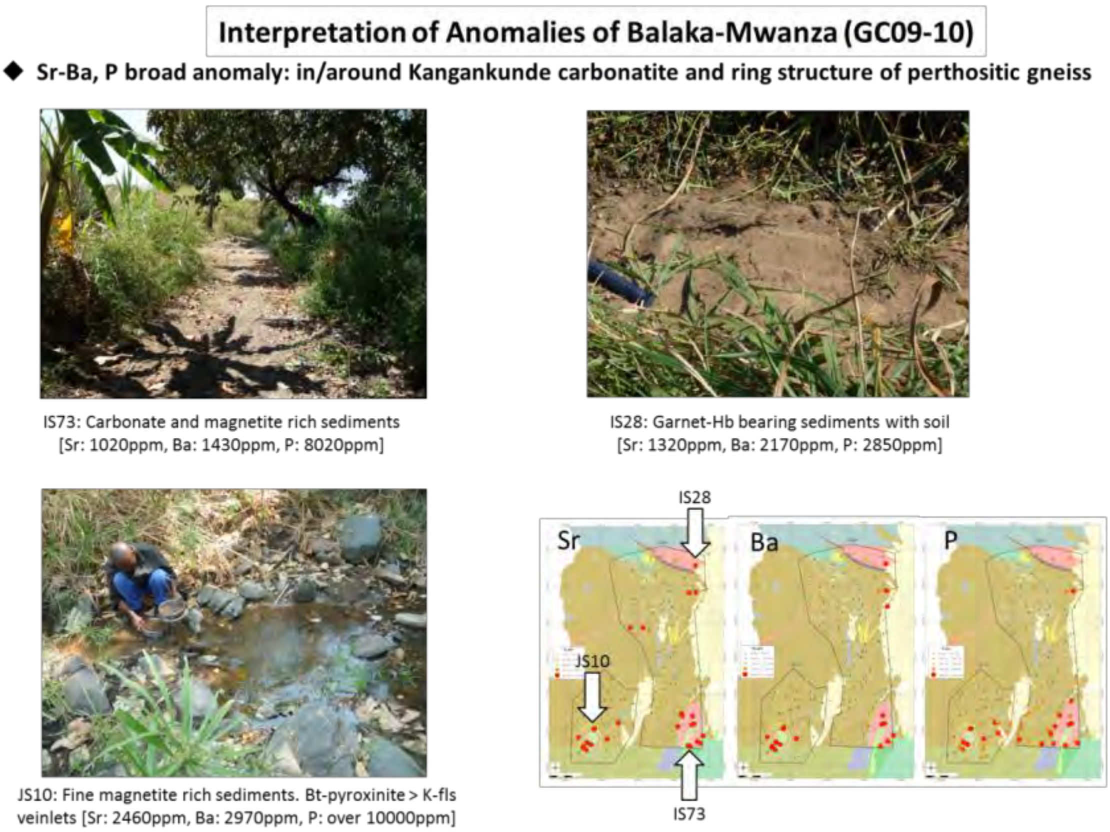


Figure 3-69 Sr-Ba, P anomaly site (Balaka area)

(8) Nsanje area (GC11)

In Nsanje area of southernmost region, varied anomalies of Cu-Co-Cr-Ni, Au, REE, U-Th, Nb-Ta, Zn, Zr are recorded by the reason of complexity of multi-phased intrusions and folded and faulted deformed basal complex.

Cu-Co-Cr-Ni anomalies show the NE trending linear distribution in southern part of Nsanje area, probably associated with NE fault system and related felsic dykes with acidic alteration halo (Figure 3-70). In some sites hematite-limonite gossan (crust) was collected and observed, and also visited a 1960's excavated Cu oxide pit (Figure 3-70).

Spotted Au anomalies are detected in heavy mineral concentrated sites, where located in some marble-skarnized vein area. It seems to derived from such alteration area some particle of Au and settled as a placer (Figure 3-71).

REE, U-Th, Nb-Ta, Zn, Zr anomalies are distributed in downstream of nepheline bearing gneiss area (Figure 3-72), and variable heavy minerals (garnet, magnetite, zircon etc.) are assorted. It seems to be a hydraulic anomaly.

In the former geochemical survey before 1973, Cu-Mo occurrence was recorded in Nsanje south part, but not detailed especially positioning data. Our survey confirmed the approximate distribution again. However Cu weak occurrence was detected in Karoo dolerite dykes also (Figure 3-73). Taking into account the variety of Cu source, detailed geochemical survey might be recommendable to estimate the Cu mineralization scale and style.

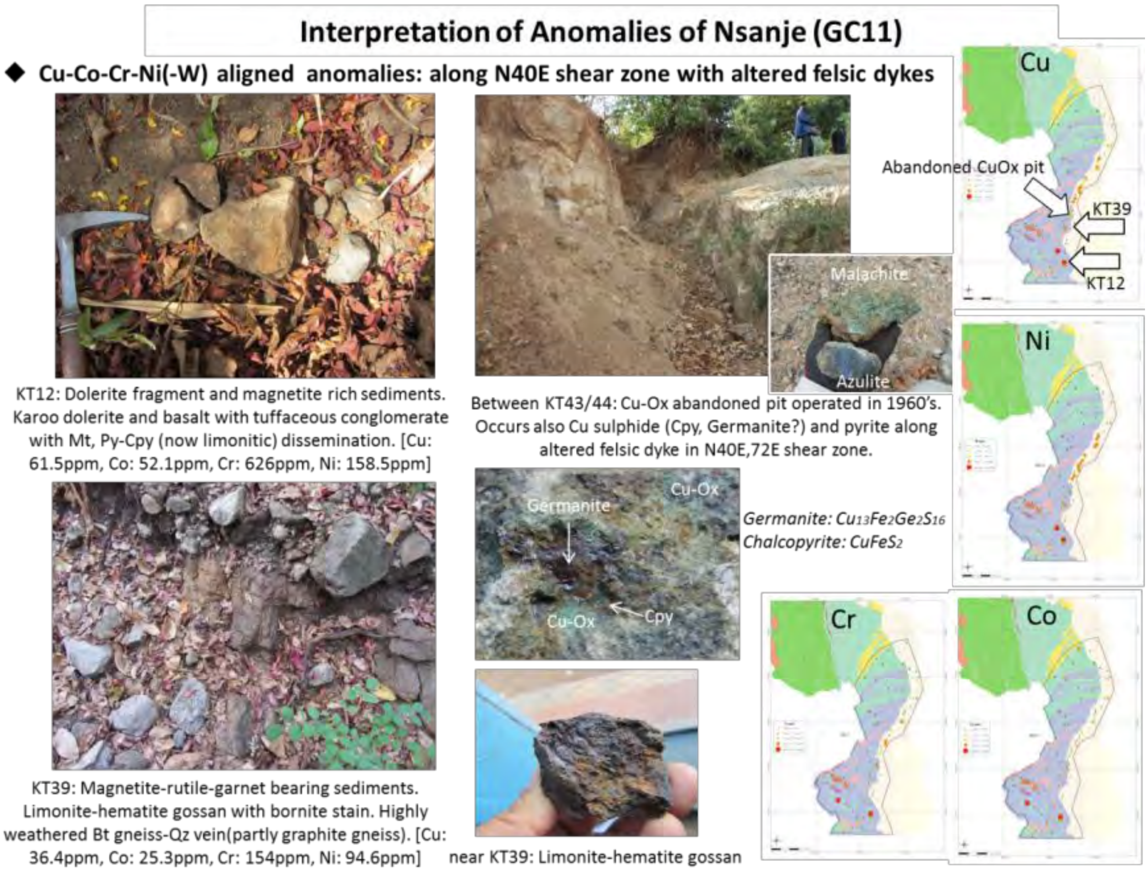


Figure 3-70 Cu-Co-Cr-Ni(-W) anomaly site and Cu occurrence (Nsanje area)

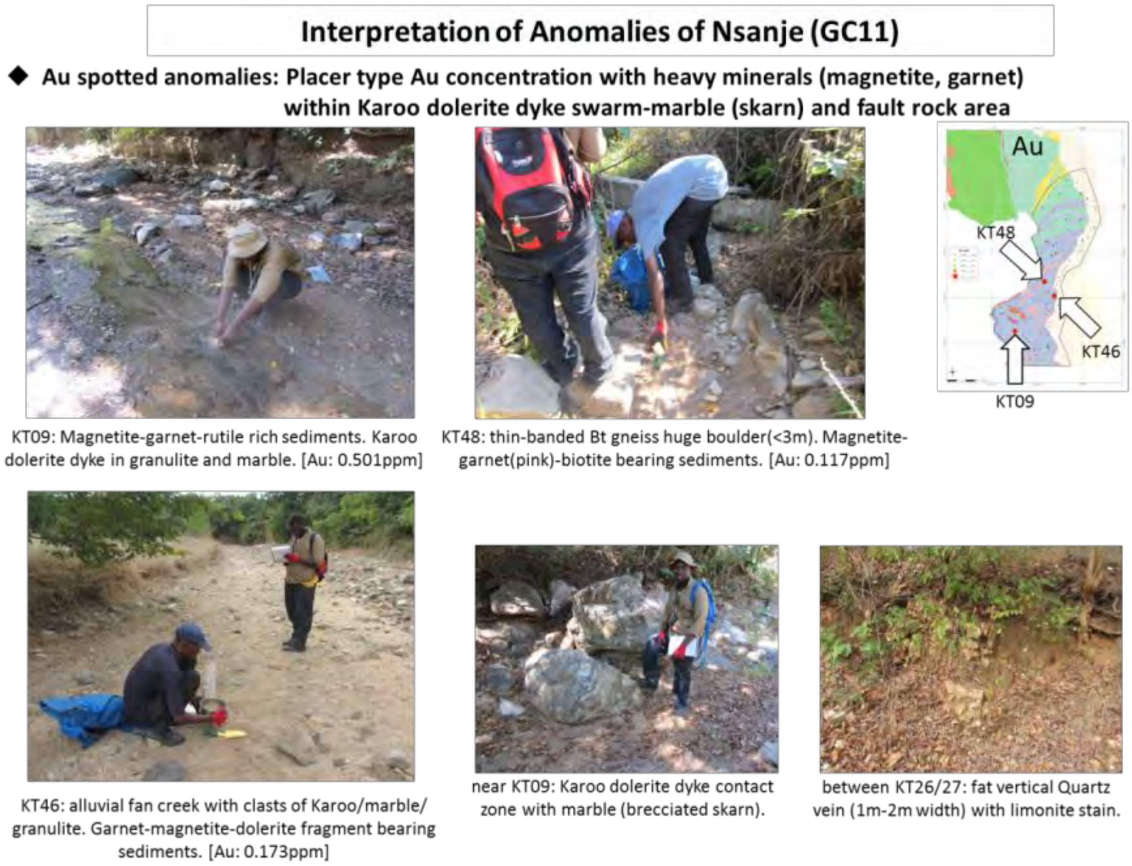


Figure 3-71 Au anomaly site with heavy minerals (Nsanje area)

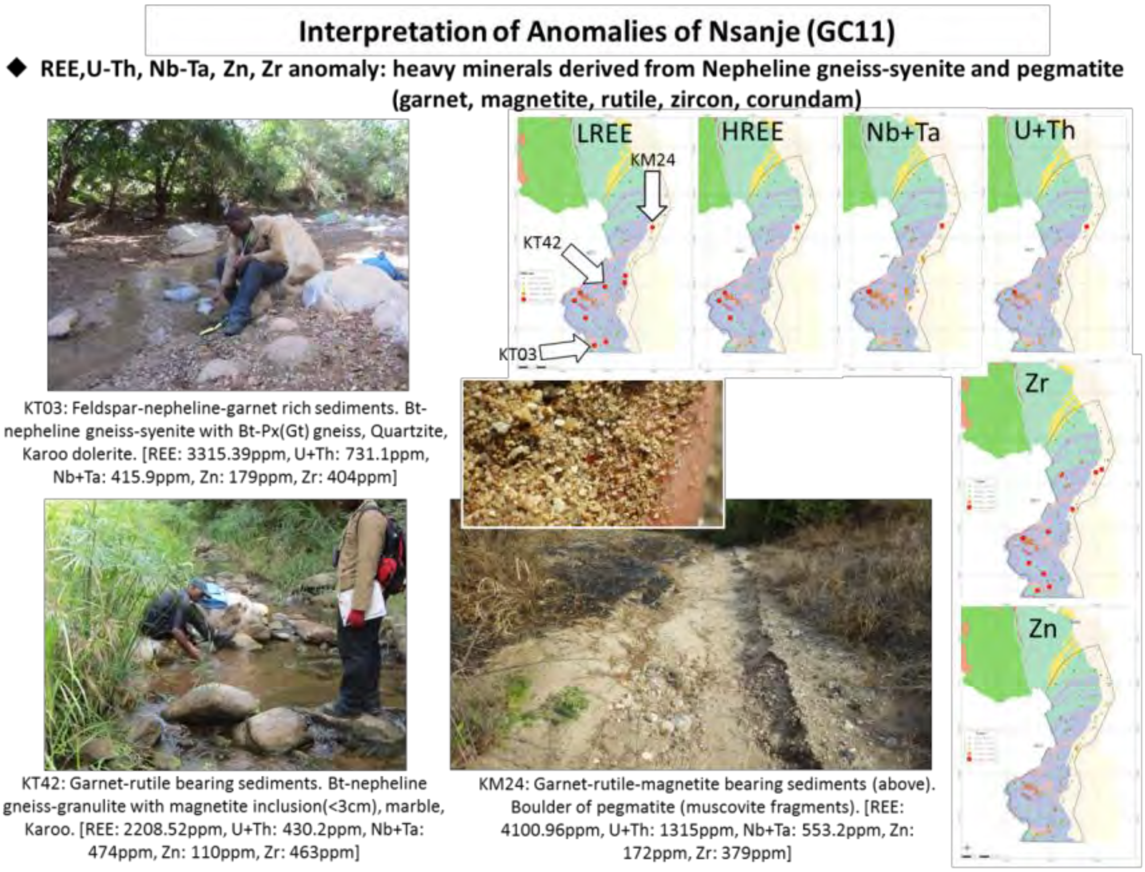


Figure 3-72 REE, U-Th, Na-Ta, Zn, Zr anomaly site with heavy minerals (Nsanje area)

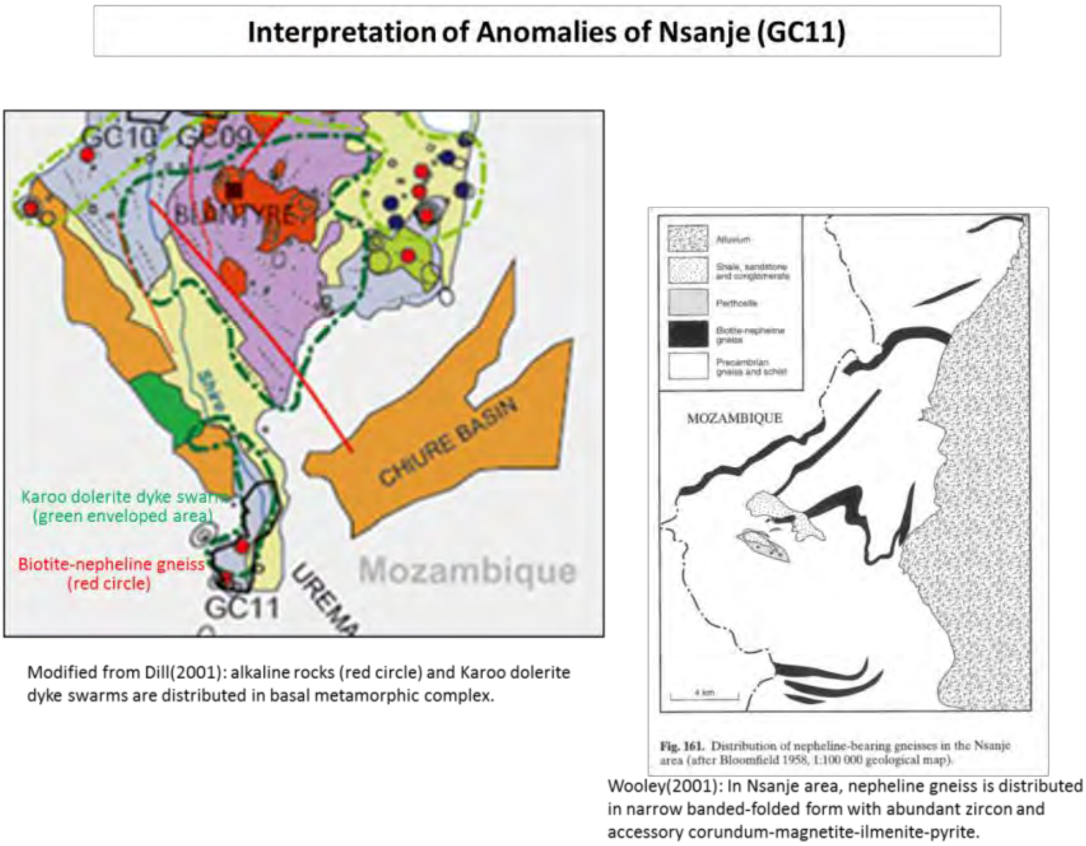


Figure 3-73 Sr-Ba, P anomaly site (Nsanje area)

3.8.5 Evaluation and proposal based on the geochemical survey results

Table 3-5 shows the generalized results of all 11 survey areas (GC01-11). It shows primarily targeted commodity is changeable by systematic geochemical survey results with repeatable evidence of chemical analysis. It means also systematic and attentive survey can reveal the prospective area.

The following four areas with broad evaluable anomalies are extracted to plan a detailed survey, which are shown in Figure 3-74.

- REE in Mzimba area
- P, Cu-Co (REE) in Balaka area
- Cu-Co in Chitipa area
- Au, Cu in Nsanje area

These four areas are prospective with detailed geological and geochemical survey, including soil and rock geochemical survey, to understand the mineralization style-formation process-economical value, and to delineate the most fertilized zone.

Table 3-5 Summary of geochemical survey results

Target	Survey area	Location	Area	Occurrences	Detected anomalies (**Bold**: broad/strong anomaly)	Further exploration recommendable
REE	GC05	Mzimba	455 km^2	Be,Nb,Ta,U	**REE, U-Th, Zr**	**YES** (Pegmatite)
	GC08	Mangochi	750 km^2	-	**Nb-Ta**, REE, **Ti, Zr,** U-Th, W, **Mo-Zn**	
	GC09	Balaka	360 km^2	REE	**P-Ba-Sr, REE, Mo-Zn, Cu-Co-Ni-Cr, Ti**	**YES** (Carbonatite-dyke & meta-pyroxinite)
Au	GC03 GC04	Rumphi	454 km^2	-	**Nb-Ta, Ag, Zr,** Ba-Sr	
	GC06	Kasungu	573 km^2	Nb, Ta, U, Au	Au, Cu, Cr, Ti-Zr	
	GC07	Dzalanyama	530 km^2	Au-placer	**Zr,** W	
	GC10	Mwanza	1,010 km^2	Au (Lisungwe)	**P-Ba-Sr,** Cu-Co-Ni-Cr, Ti	**YES** (Carbonatite-dyke & meta-pyroxinite)
Base Metals	GC01	Chitipa and Misuku	647 km^2	Nb, U	**Cu-Co-Cr-Ni, Nb-Ta, Ti**	**YES** (amphybolite-felsic dykes)
	GC02				**Cu-Co**	
	GC11	Nsanje	500 km^2	Cu, Pb	**Au, Cu-Co-Cr-Ni-W, REE, U-Th, Sr, Nb-Ta**	**YES** (Karoo dykes, Quartz vein, syenite
Total	11 areas		5,279km^2			remain 89,000km^2

However the most important issue is maintenance of learned survey skill in practical geochemical survey for C/P and assistants, from plan to report with organization skill.

For that purpose, several options can be proposed; 1) other model area survey, 2) detailed survey in recommended four areas, 3) nation-wide geochemical survey.

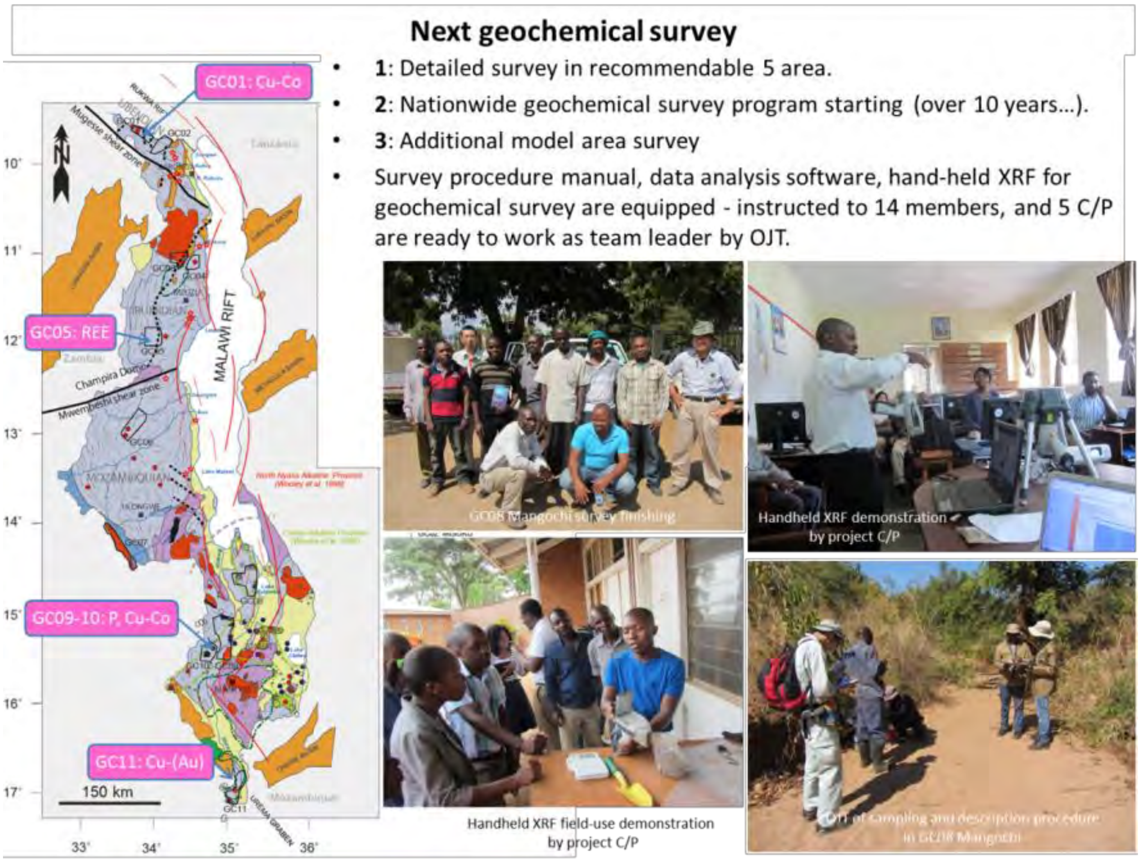


Figure 3-74 Proposal of detailed survey area

3.9 Plan of nationwide geochemical survey

3.9.1 Preliminary plan

The total area of Malawi is 118,484 km², including 24,404 km² of water surface. The land area of Malawi is 94,080km^2. According to the geological maps in Malawi shown in Figure 3-75, superficial deposits like alluvium are widely distributed up to about 40 % of the land area (light yellow color parts in Figure 3-75). It means that the effective area for geochemical survey is about 56,400 km^2. In this Project, geochemical survey is implemented in the selected model areas, which have about 5,000 km^2 in area. Therefore, the rest area is about 51,400 km^2.

The plans of nationwide geochemical survey on stream sediments in Malawi are described below.

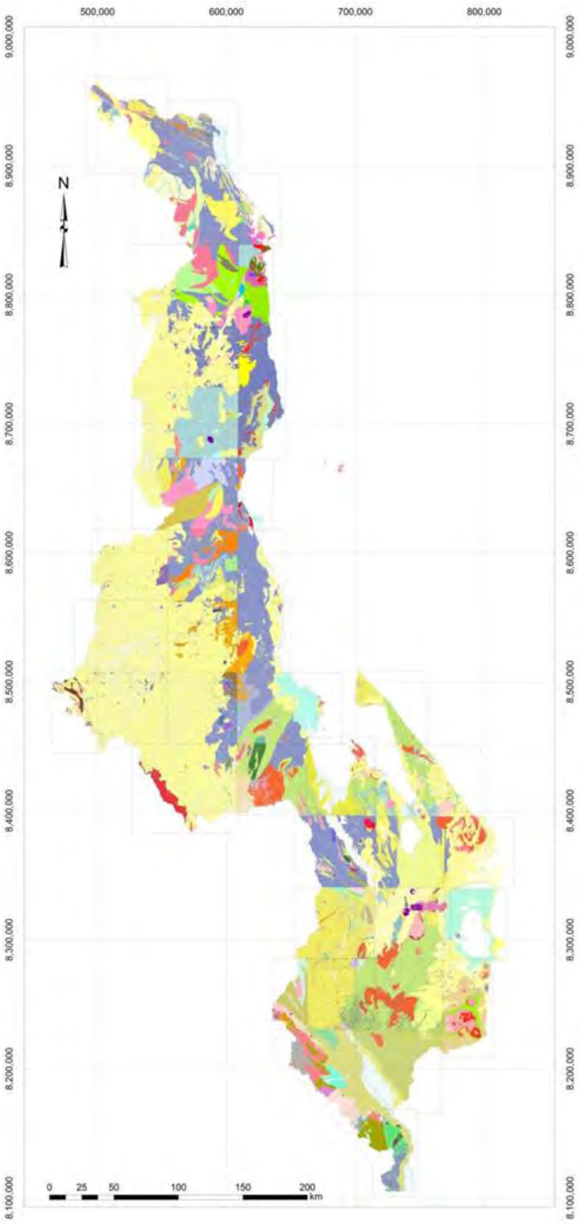


Figure 3-75 Geological map of Malawi (digital map by the previous JICA Ptoject)

(1) Plan A

(a) Condition

- Work period: 18 weeks during middle May to middle October, dry season.
- Sampling density: 1 sample per 5 square kilometers (0.2 sample/km^2)
- Total number of samples: 10,280
- Sampling efficiency: 30 samples per week (6 samples/day, 5 working days/week)
- Number of survey team: 4

(b) Formula

$56400\ km^2 \times 0.2\ sample/km^2 \div 30\ samples/week \div 18\ weeks/year \div 4\ teams$

$= 5.22$ year

(c) Conclusion

It will take more than 5 years to complete the nationwide geochemical survey under the condiotion described above. However, it may not be easy to realize this condition. Especially, it seems to be difficult that four teams implement the field work continuously through 18 weeks.

(2) Plan B

(a) Condition

- Work period: 18 weeks during middle May to middle October, dry season.
- Sampling density: 1 sample per 25 square kilometers (0.04 sample/km^2)
- Total number of samples: 2,056
- Sampling efficiency: 20 samples per week (4 samples/day, 5 working days/week)
- Number of survey team: 3

(b) Formula

$56400\ km^2 \times 0.04\ sample/km^2 \div 20\ samples/week \div 18\ weeks/year \div 3\ teams$

$= 2.09$ year

(c) Conclusion

It will take 2 years to complete the nationwide geochemical survey under the condiotion described above. This plan can be realized.

The biggest difference between plan A and B is that the sampling density in plan B becomes five times. When the sampling density becomes larger, the sampling efficiency per day should decrease. The plan B is to enhance the feasibility by decreasing the number of working teams.

3.9.2 Updated plan

Based on the experiences of drainage geochemical survey of 11 model areas, revised nation-wide survey plan is proposed. Principally geochemical survey consists of five following steps, 1) Pre-field campaign planning with field equipment preparation, 2) Official survey permission by stakeholders, 3) Field campaign with stream sediment sampling, 4) Analytical sample preparation and dispatching, and 5) Interpretation and reporting of whole survey data. More detailed procedure of every step is follows.

1) Pre-field campaign stage

Using registered GIS database of GSD-HQ, arrange the geological and topographical base map for field campaign with sample planning sites, followed by GPS uploading and printing for all survey team to be participated. Sample site numbering is determined cautiously by cartographic sheet number with numerical extension number for user's convenience and to avoid some confusion.

2) Receiving permission by stakeholders

Sending GSD official letters to request for permission to conduct geochemical survey to responsible personnel, in advance of survey team presence, of district office, police office, department of forestry, district hospital etc., and prepare its hard copies and summarized survey area maps. When we will be introduce officially to above mentioned personnel, show it with precise explication of our purpose and duration of survey to be aware of our presence to local people, and know some practical information of dangerous area and need to obtain Traditional Authorities phone number and address to make appointment of meet directly for our better security in field campaign (Figure 3-76).

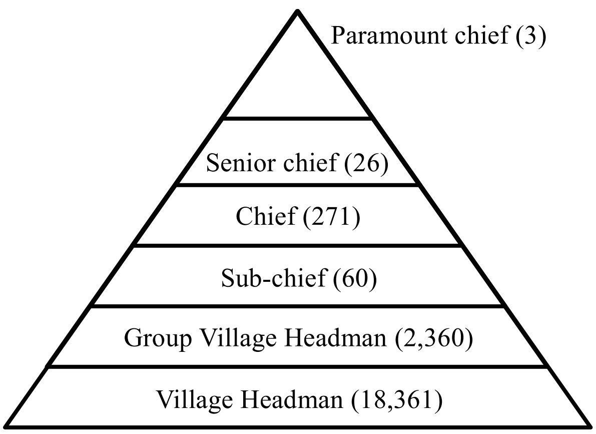


Figure 3-76 Hierarchy of TA (Traditional Authority) in Malawi (Kojima, 2014)

3) Field campaign stage

After all preparation procedure, field campaign can be carried out. Before starting team survey, team leaders check your own survey equipment of sampling, which contains a shovel, sieve set, plastic bags, rucksacks, plastic container to store etc., of description, which consist of digital camera, GPS, hummer, clip folder and description sheets with base map, and of daily food stuff. Then need to share information of the delineation of team survey area, daily start-finish time and schedule. After daily return to lodge, need to list up the total sampling number and discuss a plan of the next day. Two days a week are holidays, but one half day use to collation and drying-quartering the sample.

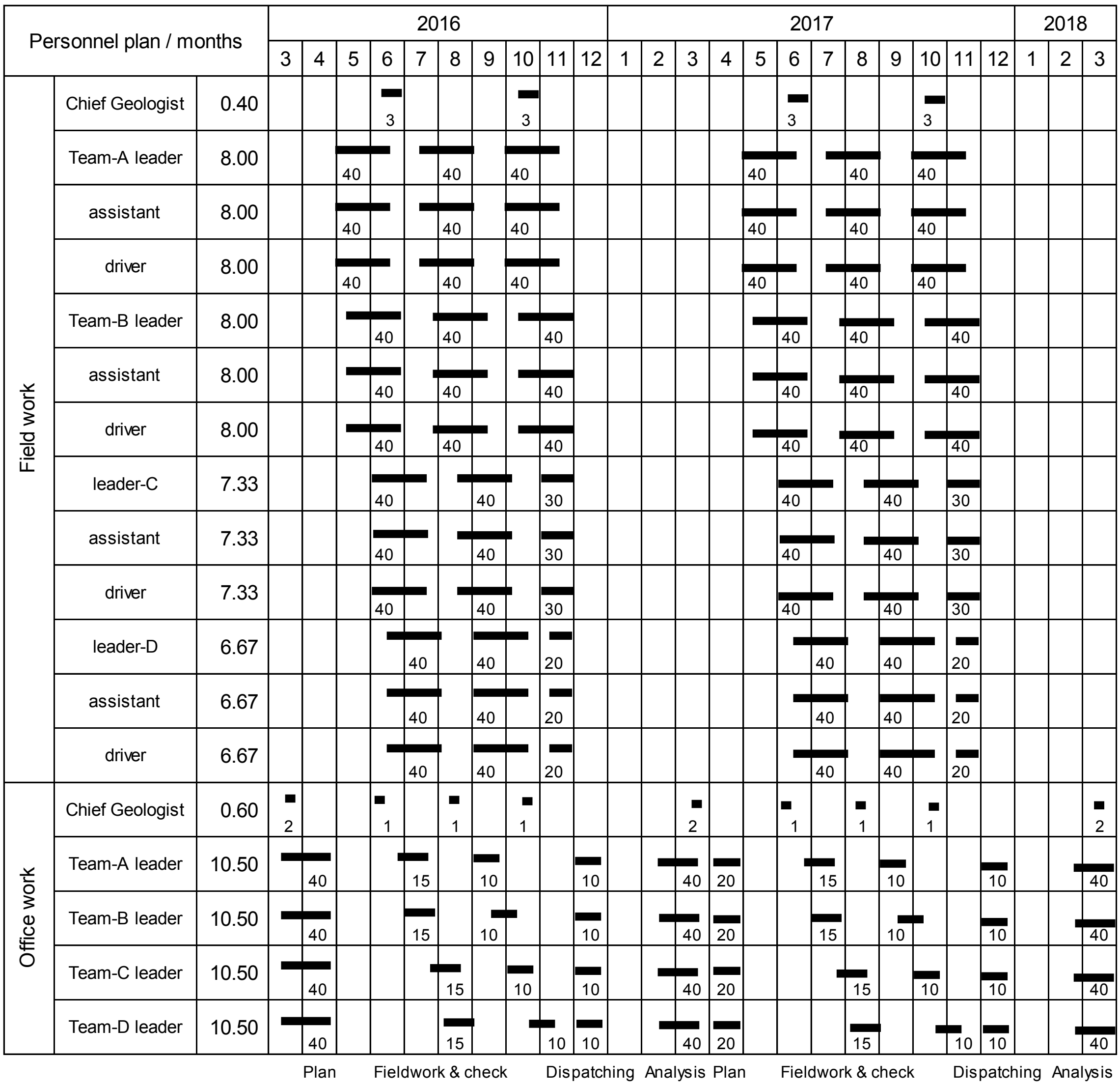
4) Analytical sample preparation and dispatching

As mentioned above, analytical sample prepare once a week during daytime of holiday and after covered one cartographic area check off the obtained samples and analysis sample, then store temporarily in GSD branch office etc. After all field campaign dispatch packages of analysis samples to laboratory, in case of transport to other country with EXPORT PERMISSION by MINEM.

5) Interpretation and reporting of whole survey data

After all above procedures successfully, team leaders need to integrate and interpret whole analysis results and description data, particularly positioning and geological description, using statistical analysis software and GIS mapping to edit report, then save it to database in GSD.

Revised nation-wide drainage geochemical survey plan shows in Figure 3-77. Basic concept of 2100 samples with a density of sample/25 sq.km in two year duration is to cover whole outcropping area in Malawi. It considers three teams in field campaign (1 spare team) during field campaign, and four team leaders are exclusive to the survey from preparation to reporting including administrative and fiscal works. Practical discussion for next geochemical survey is appreciated, up to vehicles reservation and fuels amount estimation.



	transport	holiday	permission	working days	daily sample	sample number
40 days fieldwork / team:	2	10	3	25	4	100
30 days fieldwork / team:	2	8	3	17	4	68
20 days fieldwork / team:	2	6	3	9	4	36

samples per year: 1104

samples per 2 years: 2208

Figure 3-77 Updated nationwide geochemical survey plan in Malawi

3.10 Training of measurement by handheld XRF analyzer

In this Project, two handheld XRF analyzers were donated to GSD for the purpose that GSD will efficiently implement the nationwide geochemical survey and mineral exploration in the future. The specification of the analyzer is shown below.

- Manufacturing company：Thermo Scientific
- Model name：Niton^{TM} XL3t 950 GOLDD+
- X-Ray Tube：Ag anode (6-50 kV, 0-200 µA max)
- Detector：Geometrically Optimized Large area Drift Detector (GOLDD)
- Integrated CCD camera
- Dimensions (L x W x H)：244 x 230 x 95.5 mm
- Weight：1.3kg
- Portable Stand (No. 420-032)

Portable XRF Analyser：Niton XL3T (from WEB site of Thermo Scientific)

The training how to use the Niton's Portable XRF Analyser was carried out at the Headquarter of GSD, Zomba, on 31 October 2014, in the middle stage of the 2nd On-site Works in Malawi. The technical trainer, who belongs to United Spectrometer Technologies company at Cape Town South Africa, was invited, and taught the theory of XRF, how to use the analyzer safely and how to measure and trained the measurement by using real analyzers. The photos of the training and documents used in the training are shown respectively in Figure 3-78 and Appendix 3-5.

Lecture for the specification and usage of the Analyser

The cover page of PowerPoint used in the lecture

Training: The lecturer is instructing how to use and measure.

Training: Each engineer of GSD is measuring rock samples by himself/herself.

Figure 3-78 Training of the Niton's Protable XRF Analyser

3.11 Roadmap to upgrade geochemical laboratory

The study team creates the roadmap to upgrade the geochemical laboratory in GSD HQ as follows. The team selects the necessary equipment, considering that GSD will be able to maintain them easily.

(1) Current situation of equipment

The main and relevant equipment which have been installed in GSD HQ up to now are as follows.

- ✓ Atomic Absorption Spectrometry (AAS): In operation: Elements to be analyzed are Au, Zn, Mn, Cu, Co, Pb and Ni.
- ✓ Ultra-violet and visible spectrophotometer: Connecting PC is out of order: Elements to be analyzed are Si and Al.
- ✓ X-ray diffractometer (to identify minerals) : In operation
- ✓ Electronic scale: One is in operation. Many are out of order.
- ✓ Draft chamber: Out of order.
- ✓ Automatic oven: In operation
- ✓ Jaw crusher: In operation
- ✓ Ball mill: Out of order. Parts are broken.
- ✓ Rock cutter: In operation
- ✓ Polishing machine: Out of order
- ✓ Portable XRF analyzer: In operation/ Two analyzers are donated in this Project.

Though ASS is in operation, chemicals which are used to dissolve samples are lacking. As the draft chamber is out of order, it is dangerous to use harmful chemicals.

(2) Necessary equipment

- ✓ X-ray Fluorescence Spectroscopy (XRF)
  XRF is a typical analytical method for solid materials. Sample preparation and measurement of XRF are easy compared to other analytical methods. Models with multiple detector system at a wavelength dispersion type can analyze simultaneously about 40 elements. XRF machinery needs to pay attention to the exposure of X-ray. After being crushed and pulverized, samples are pressed in sample holder and then analyzed. XRF is recommended because of easy usage and maintenance.

- ✓ Draft chamber
  As liquid analytical sample is created by dissolving solid sample in acids for AAS analytical method, ventilation system is necessary for safety. However, the draft chamber is out of order, new one should be installed.

- ✓ Uninterruptible Power Supply (UPS)
  Sudden power outage and voltage drop may cause equipment failure of analytical machine and PC. Therefore, in Malawi where power supply is unstable and power outage happens frequently, the UPS is essential equipment to use desktop PCs, communications equipment and control equipment. When large scale analytical equipment and connecting PC are installed, not small UPS for PCs which was provided in the previous JICA Project but the UPS with larger capacity should be installed.

- ✓ Jaw crusher
  As the jaw crusher in GSD HQ is so old and small, new one with high capability to crush and easy maintenance should be installed.

- ✓ Ball mill
  As the ball mill in GSD HQ is very old and out of order, new one with high capability of milling and easy maintenance should be installed.

(3) System related quality control

Not only the quality (precision) management but also the quality control on sample preparation is important and required for chemical analysis. For example, measures to prevent contamination of the sample are important. If GSD will implement the analysis requested from a third party, it should provide the reliable analysis with high quality and the following items should be realized.

- ✓ Management system, personnel and facilities for quality control
- ✓ Maintenance on chemical analysis machines
- ✓ Maintenance of standard samples and supply of consumables
- ✓ Facilities for sample preparation, ventilation system and cleaning equipment
- ✓ Draft chamber and cleaning equipment for sample treatment

(4) Other facilities

Facilities for working safety, waste disposal and environmental protection should be installed.

(5) Capacity building

In order to upgrade the chemical laboratory describe above, the following capacity building is necessary.

- ✓ Chemical analysis: sample preparation, analytical technique, machine maintenance, quality control

- ✓ Laboratory facility maintenance: quality control, environmental management, safety management

(6) Flow of laboratory upgrading

- ➢ STEP1: detailed study of current equipment and facilities, machine selection, plan of facility improvement
- ➢ STEP2: Facility renovation, equipment purchase, installation of equipment and machinery
- ➢ STEP3: Training for equipment usage, safety education, management education
- ➢ STEP4: Implementation of chemical analysis through OJT, quality control, environmental management
- ➢ STEP5: Planning and education for sustainable and self-reliant management on geochemical laboratory

4 Integration of GIS database

4.1 Geochemical database creation

The geochemical survey database created in this project is composed of field survey data, assay data, raster data of statistical quantitative analysis and GIS data of geochemical maps. The geochemical survey database is stored in "Geochemical_survey_data" directory and is composed of three subdirectories; "Geochemical_data", "Geochemical_maps" and "Geochemical_survey_manual". The tree type directory structure of the database is shown in Figure 4-1, and data list being stored is shown in Table 4-1.

Original data used for preparation of GIS data are stored and existed in "Geochemical_data" directory, and description data in each sampling site, photographs on field sites, geochemical assay data, statistic quantitative analysis data and analytical value data by handheld XRF analyzer equipment are stored.

Geochemical maps of each survey area, field survey data used for geochemical maps, shape files of geochemical assay data and statistic quantitative analysis data, and raster data of topography are stored in "Geochemical_maps" directory.

Manuals on methods and procedures of geochemical exploration carried out in this project are stored in "Geochemical_survey_manual" directory.

In addition, data newly obtained from the official organization of Malawi are listed below, and these data are also stored in the database of this project.

- Data on rivers and streams: Polyline data (Procured from Survey Department)
- Topography maps: Raster data scanned from printed matter (maps owned by GSD)

This geochemical database is unified by ArcMap (ver.10.2) as GIS Software provided in the previous JICA project. The description data at sampling sites in each survey areas and assay data can be browsed as the attributive data in ArcMap. Also, it is possible to display the geochemical map of each element in each survey area. Examples on display of attributive data are shown in Figure 4-2 and Figure 4-3.

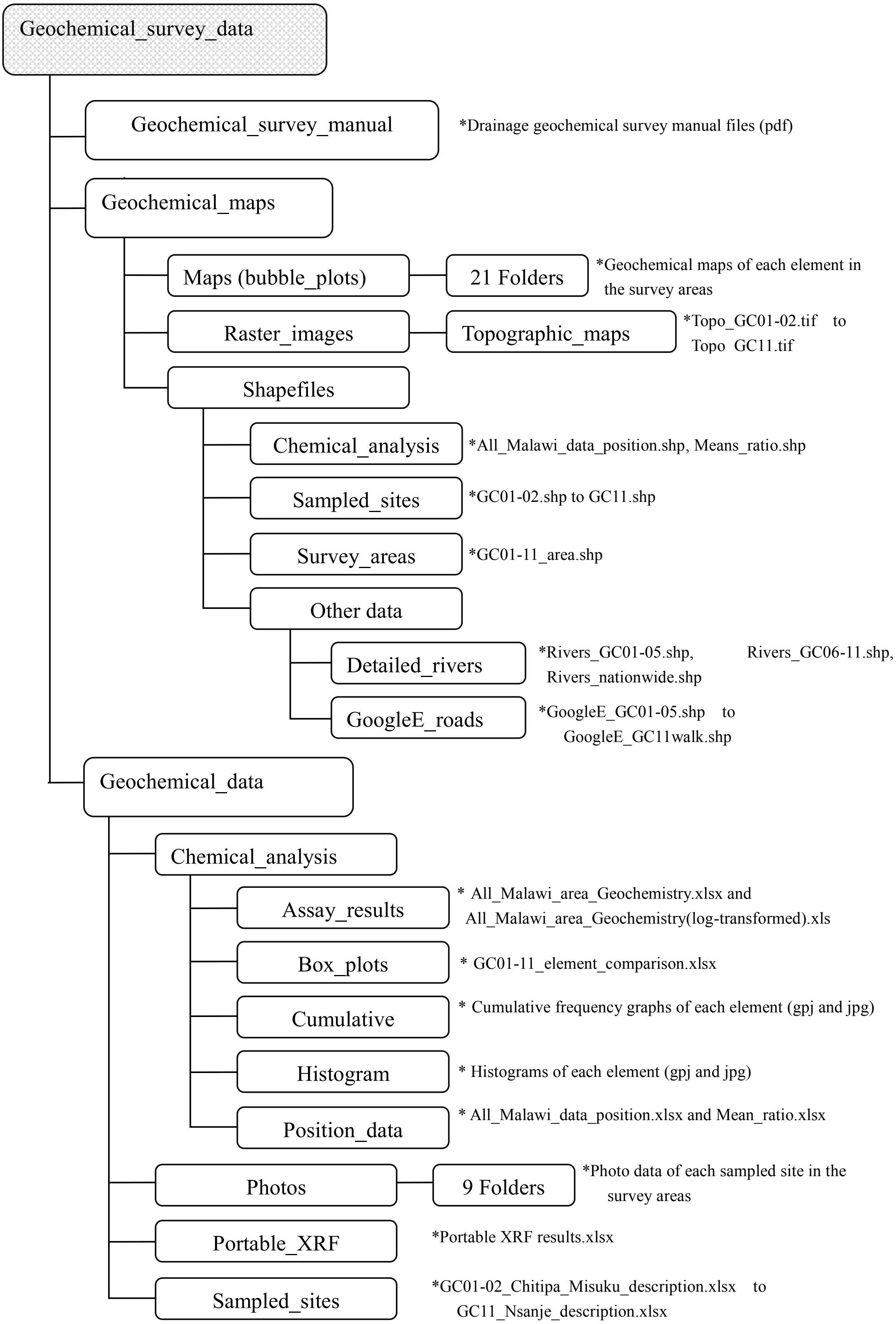


Figure 4-1 Tree directory structure of geochemical database

Table 4-1 Data list of geochemical database

Category	Data	Data type	File name	Data_format	Attribute	Remarks
Geochemical survey	Geochemical maps	ArcGIS	MWResult2015_v10.1.mxd	mxd (v10.1)	–	
		ArcGIS	MWResult2015(Nation_wide)_v10.1.mxd	mxd (v10.1)	–	
		Raster	***_***.png	png	–	***_***: area_elemnt symbol
	Assay results	Vector	All_Malawi_data_position.shp	shp (point)	Number, Sample_ID, Elevation(m), East, North, Au_ppm, Ag_ppm, Ba_ppm, Be_ppm, Bi_ppm, Ce_ppm, Co_ppm, Cr_ppm, Cu_ppm, Fe_%, La_ppm, Li_ppm, Mn_ppm, Mo_ppm, Nb_ppm, Ni_ppm, P_ppm, Pb_ppm, Sn_ppm, Sr_ppm, Ta_ppm, Th_ppm, Ti_%, U_ppm, V_ppm, W_ppm, Y_ppm, Zn_ppm, Zr_ppm, Dy_ppm, Er_ppm, Eu_ppm, Gd_ppm, Ho_ppm, Lu_ppm, Nd_ppm, Pr_ppm, Sm_ppm, Tb_ppm, Tm_ppm, Yb_ppm, Major Industrial_ppm, Precious_ppm, Nuclear_ppm, Documented_ppm, LREE_ppm Σ HREE_ppm, REE_ppm, REY_ppm, Selected REE_ppm, Pegmetite_ppm, Coltan_ppm	
		Table	All_Malawi_data_position.xlsx	xlsx	–	–
	Means ratio of assay data	Vector	Means_ratio.shp	shp (point)	Areas, East, North, Au_ratio, Cu_ratio, Ni_ratio, Co_ratio, Cr_ratio, LREE_ratio, HREE_ratio, U+Th_ratio, Coltan_ratio, P_ratio, Ti_ratio, Fe_ratio, Mo_ratio,	–
		Table	Mean_ratio.xlsx	xlsx	–	–
	Description data of sampled sites	Vector	GC01-02.shp	shp (point)	Description record of sampled sites in GC01-02	–
		Vector	GC03-04.shp	shp (point)	Description record of sampled sites in GC03-04	–
		Vector	GC05.sph	shp (point)	Description record of sampled sites in GC05	–
		Vector	GC06.shp	shp (point)	Description record of sampled sites in GC06	–
		Vector	GC07.shp	shp (point)	Description record of sampled sites in GC07	–
		Vector	GC08.shp	shp (point)	Description record of sampled sites in GC08	–
		Vector	GC09.shp	shp (point)	Description record of sampled sites in GC09	–
		Vector	GC10.shp	shp (point)	Description record of sampled sites in GC10	–
		Vector	GC11.shp	shp (point)	Description record of sampled sites in GC11	–
		Table	GC01-02_Chitipa_Misuku_description.xlsx	xlsx	–	–
		Table	GC03-04_Rumphi_description.xlsx	xlsx	–	–
		Table	GC05_Mzimba_description.xlsx	xlsx	–	–
		Table	GC06_Kasungu_description.xlsx	xlsx	–	–
		Table	GC07_Dzalanyama_description.xlsx	xlsx	–	–
		Table	GC08_Mangochi_description.xlsx	xlsx	–	–
		Table	GC09_Balaka_description.xlsx	xlsx	–	–
		Table	GC10_Mwanza_description.xlsx	xlsx	–	–
		Table	GC11_Nsanje_description.xlsx	xlsx	–	–
	Survey areas	Vector	GC01-11_area.shp	shp (polygon)	name, sqkm	–
	Photos of sampled sites	Raster	******.png	jpg	Photos of sampled sites in GC01-02	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC03-04	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC05	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC06	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC07	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC08	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC09	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC10	*******: photo No.
		Raster	******.png	jpg	Photos of sampled sites in GC11	*******: photo No.
	Portable XRF results	Table	Portable XRF results.xlsx	xlsx	–	–
Statistics analysis	Assay_result (no coordinates)	Table	All_Malawi_area_Geochemistry.xlsx	xlsx	–	–
		Table	All_Malawi_area_Geochemistry(log-transformed).xls	xlsx	–	–
	Box_plots	Table	GC01-11_element_comparison.xlsx	xlsx	–	–
	Cumulative frequency graphs	Grapher	******.gpj	gpj (v11)	–	******: element symbol
		Raster	******.jpg	jpg	–	******: element symbol
	Histograms	Grapher	******.gpj	gpj (v11)	–	******: element symbol
		Raster	******.jpg	jpg	–	******: element symbol
	Position_data	Table	All_Malawi_data_position.xlsx	xlsx	–	–
		Table	Mean_ratio.xlsx	xlsx	–	–
Topography	Topographic maps	Raster	Topo_GC01-02.tif	geotif	–	scanned image of topographic map owned by GSD
		Raster	Topo_GC01-02_Border.tif	geotif	–	
		Raster	Topo_GC03-04.tif	geotif	–	
		Raster	Topo_GC05.tif	geotif	–	
		Raster	Topo_GC06.tif	geotif	–	
		Raster	Topo_GC07.tif	geotif	–	
		Raster	Topo_GC08.tif	geotif	–	
		Raster	Topo_GC09.tif	geotif	–	
		Raster	Topo_GC10.tif	geotif	–	
		Raster	Topo_GC11.tif	geotif	–	
Road	Road interpretation in GoogleEarth	Vector	GoogleE_GC01-05.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC06car.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC06walk.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC07car.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC07walk.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC08car.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC08walk.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC09-10car.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC09-10walk.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC11car.shp	shp (polyline)	GM_TYPE, Length_Km	–
		Vector	GoogleE_GC11walk.shp	shp (polyline)	GM_TYPE, Length_Km	–
River	Drainage data	Vector	Rivers_nationwide.shp	shp (polyline)	name, id	purchases from Survey Department
		Vector	Rivers_GC01-05.shp	shp (polyline)	name, id	
		Vector	Rivers_GC06-11.shp	shp (polyline)	name, id	

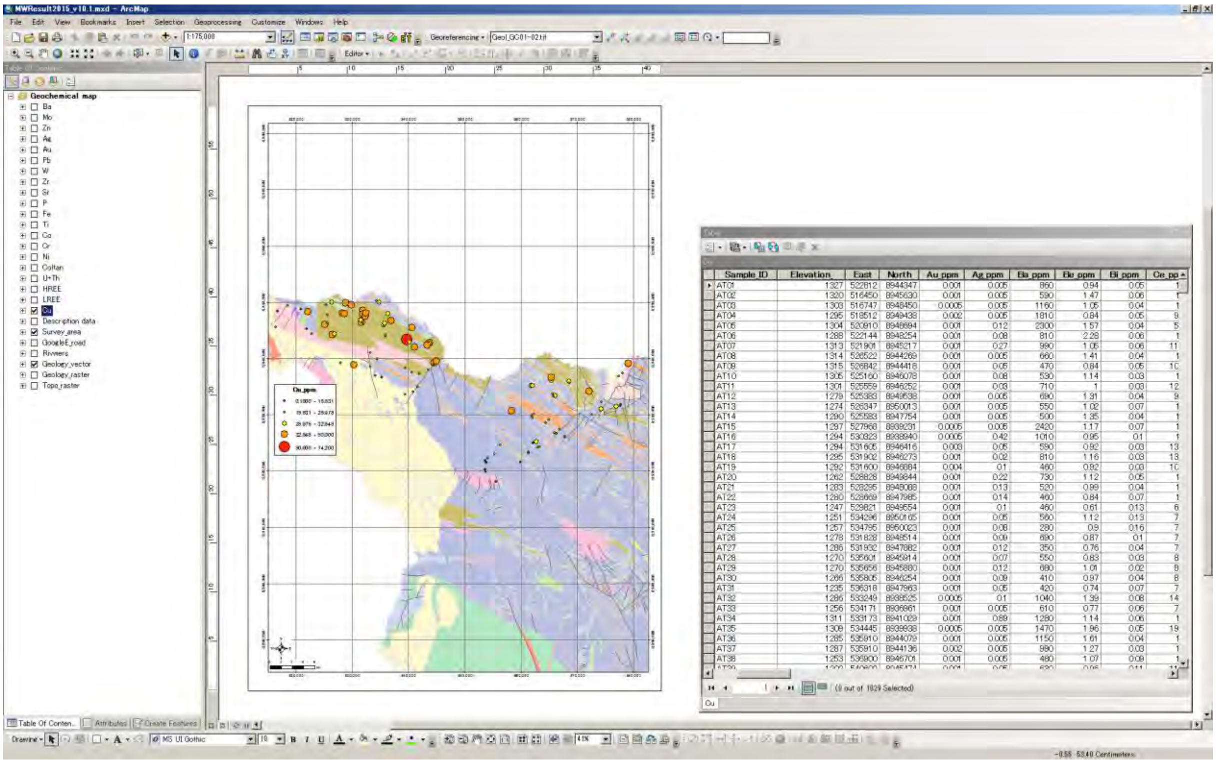


Figure 4-2 Indication of chemical analysis data of geochemical database

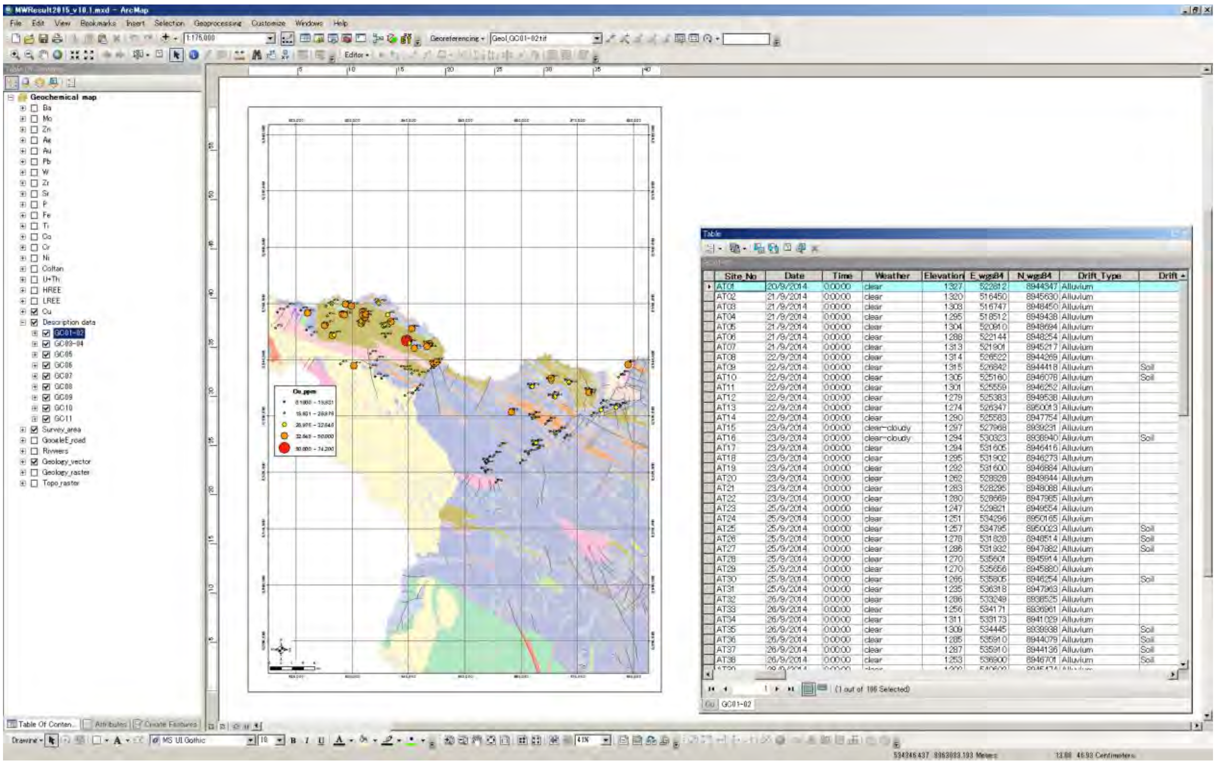


Figure 4-3 Indication of description data of geochemical database

4.2 GIS database integration

(1) Plan for integration of GIS database

The name of “Root Directory” (the top folder) of the GIS database created in the previous JICA project is “JICA_GIS_database”. This is composed of three sub-directories; “GIS_Data”, “Geologic_Maps100K” and “Satellite_data”.

“Geochemical_survey_data” directory, in which the geochemical survey database created in this project is stored, is integrated into the root directory as a sub-directory corresponding to these sub-directories as above mentioned. Therefore, “JICA_GIS_database” after integration is to be composed of four sub-directories. The tree type directory structure of “JICA_GIS_database” integrated is shown in Figure 4-4.

Integrated GIS database is to be newly unified in ArcMap (ver. 10.2), and the new analytical map can be prepared by using geochemical data of this project and satellite images prepared in the previous project. The examples on display of the integrated database are as shown in Figure 4-5 and Figure 4-6.

In addition, in case that the geochemical survey in whole country will be carried out in future, GIS database will possibly be renewed by storage of those new GIS data into corresponding sub-directories respectively. Also, preparation of new map and analysis of the same will possibly be done by adding new GIS data into the map file (.mxd) of ArcMap.

(2) Integration of GIS database

In the fifth On-site Works in Malawi, as the result of trying to integrate the geochemical survey database to the LAN connection external hard disk which is the equipment provided at the previous JICA project, the JICA study team found that this external hard disk was broken. This breakage of external hard disk may presumably be occurred due to the fact that electric power stoppages were frequently occurred since the disk was disconnected from UPS and was directly connected to an electrical outlet plug in the room. Accordingly, after returning to Japan, the JICA Study team should integrate GIS database, store the database in USB connect type portable HD, and provide it to GSD. This USB connect type portable HD is to be possessed and controlled by the director of GSD, and staffs of GSD shall be able to utilize the GIS database upon the receipt of an approval from the director of GSD.

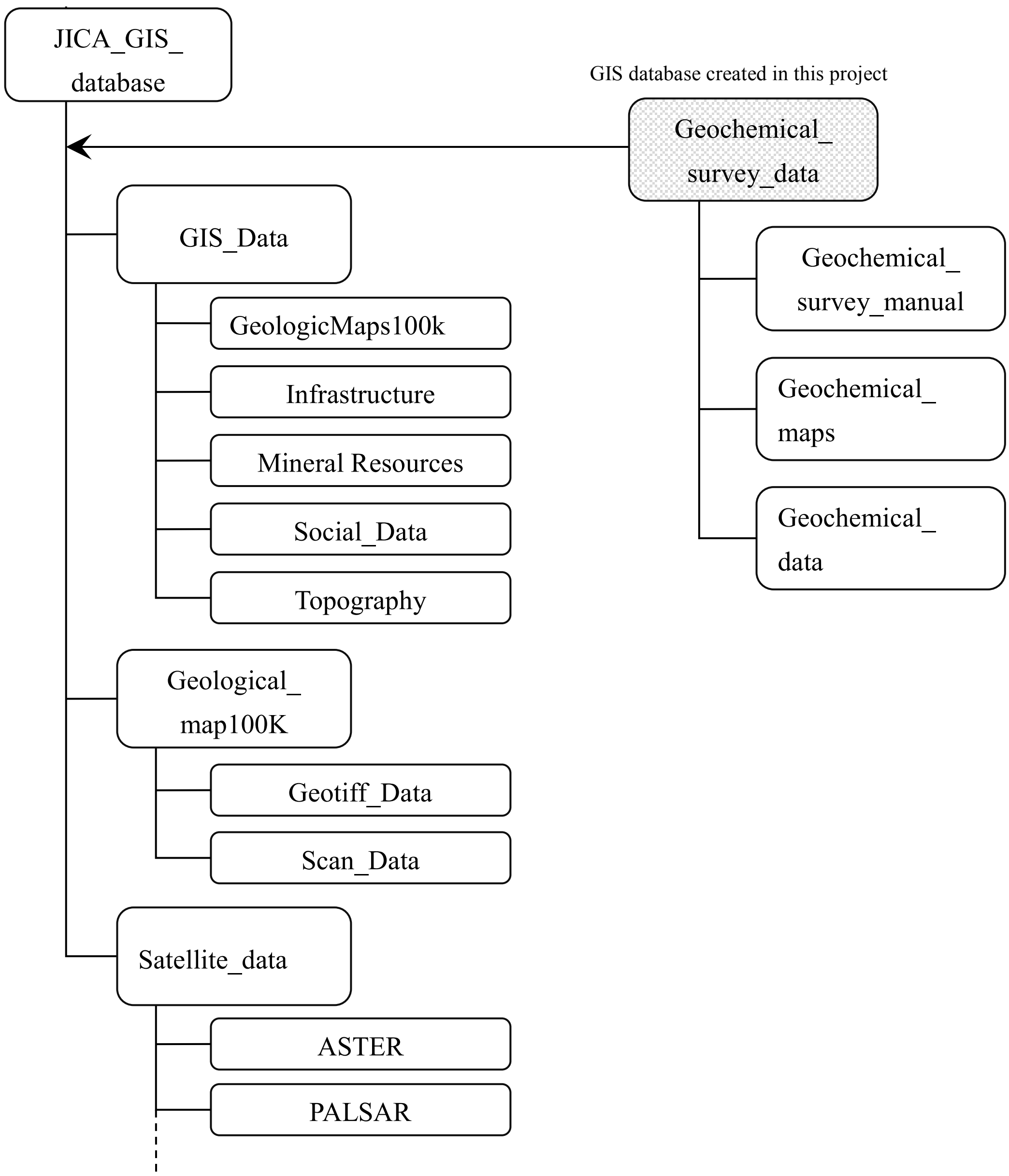


Figure 4-4 Tree directory structure of GIS database integrated

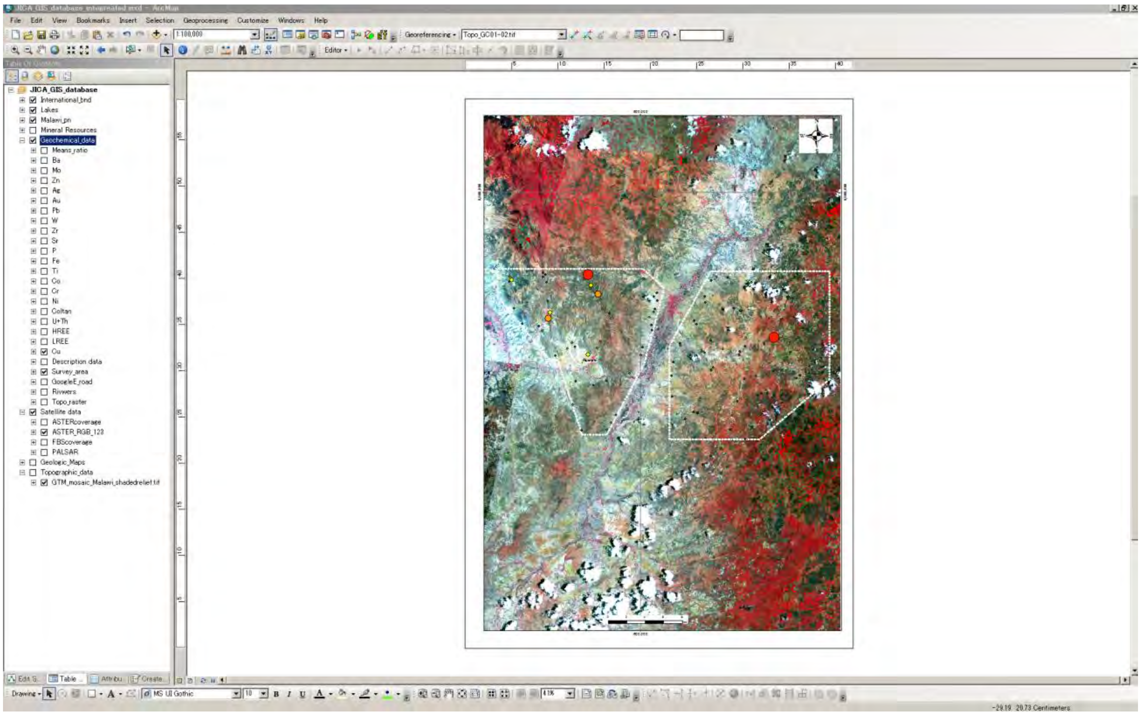


Figure 4-5 Geochemical map (Rumphi area) and ASTER image

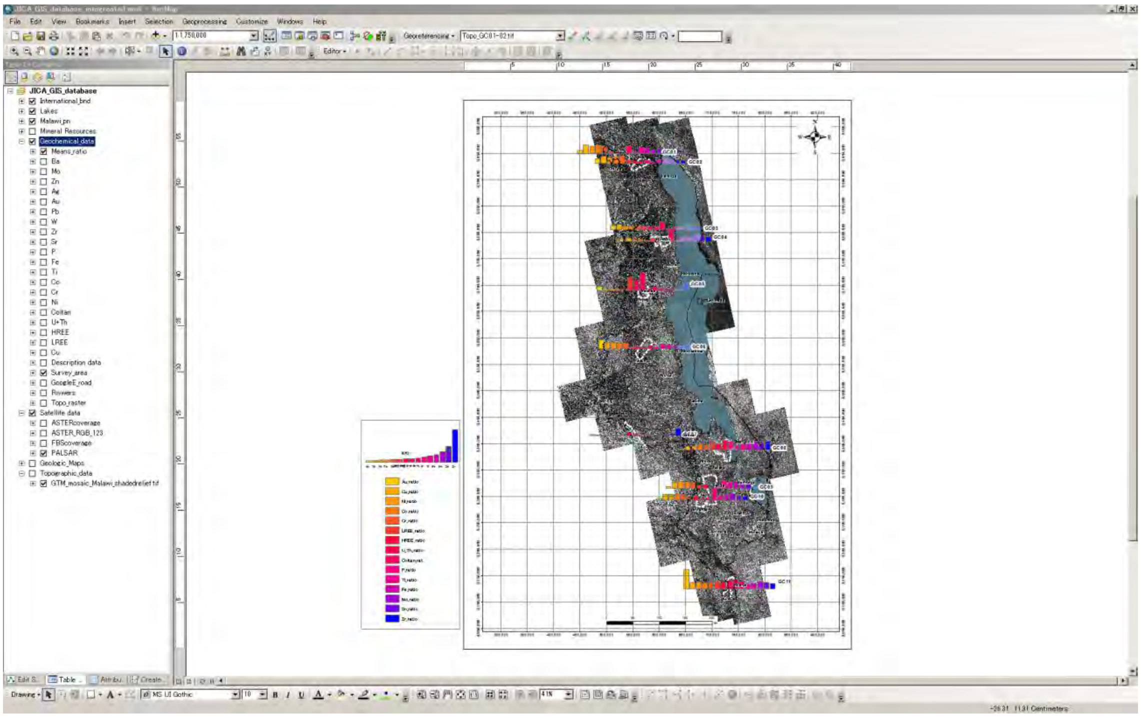


Figure 4-6 Statistical analysis graphs and PALSAR mosaic image

4.3 Manual for GIS database integration

Integration manual of GIS database for methods of integration for new GIS database and control standards as well as procedures for utilization were prepared. Outlines of this manual are as shown in the following, and this manual is shown in Appendix 4-1.

Integrated GIS database "JICA_GIS_database" is stored in USB connect type portable HD provided in this project. Only the person in charge of administration who obtained an approval from the director of GSD can make access to this database, and the manager is to borrow the portable HD and is to carry out the work by using desktop PC which is the provided equipment and materials in the previous project. At the time of renewing data and of integrating new GIS data in regard to geochemical survey, new GIS data corresponding to the sub-directory of "Geochemical_survey_data" directory are to be stored respectively. New GIS data are to be added on ArcMap, and they are to be possibly displayed and perused. Successively, "JICA_GIS_database" is to be copied and backed up in the backup directory of desktop PC immediately after renewal for control.

GSD staffs who utilize this database are to carry out the work such as data treatment, preparation of drawing, etc. by copying this database into other PC through the administrator.