Republic of Malawi
Ministry of Mining

Final Report of the Project for Establishment of Integrated Geographic Information System (GIS) Database for Mineral Resources

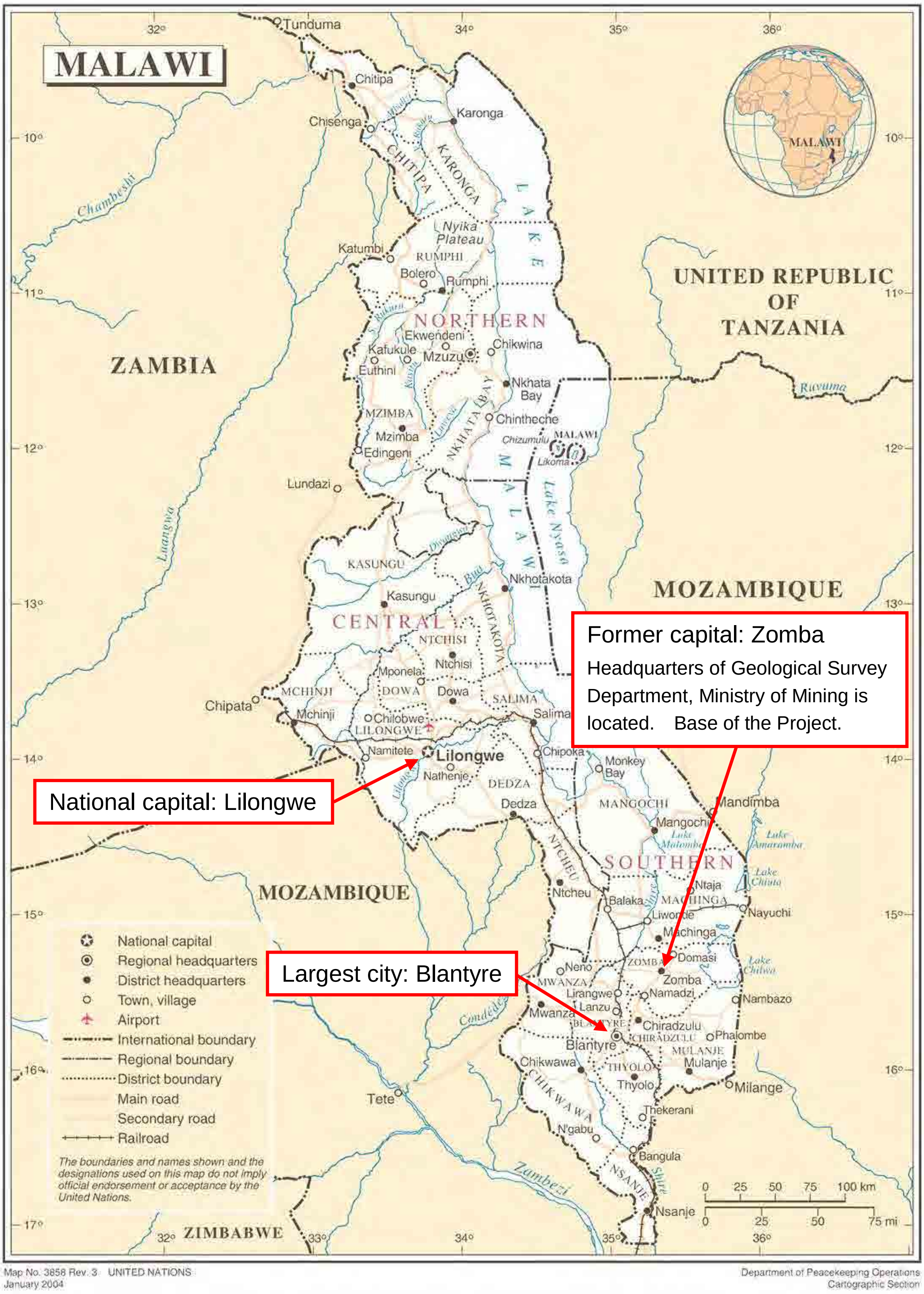
July 2013

Japan International Cooperation Agency
(JICA)

Sumiko Resources Exploration & Development Co., Ltd.

dummy

Frontispiece 1 Map of Malawi



Frontispiece 2　Photos related to geology

Lake Chilwa located in the southeastern part of Malawi and Chisi Island: Chisi Island is composed of syenite.

Upper left: Ilmenite (black sands) deposited on the shore of Lake Malawi

Upper right: Syenite distributed in Chilwa Alkaline Province in the south of Malawi (Cretaceous, Mesozoic)

Lower right: Gneiss of Basement Complex (Proterozoic)

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List of Abbreviations

AIST	National Institute of Advanced Industrial Science and Technology, JAPAN
ArcGIS	ArcGIS for Desktop Basic (software name) / Previous name is ArcView.
ASEAN	Association of South-East Asian Nations
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BGS	British Geological Survey
BRGM	Bureau de Recherches Géologiques et Minières
C/P	Counterpart
DB	Data Base
DEM	Digital Elevation Model
DM	Department of Mines, MALAWI
dpi	dots per inch
EITI	Extractive Industries Transparency Initiative
ENVI	* ENVI is the software name.
EPL	Exclusive Prospecting License
ERSDAC	Earth Remote Sensing Data Analysis Center, JAPAN
FS	Feasibility Study
GCP	Ground Control Point
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
GSD	Geological Survey Department, MALAWI
GSJ	Geological Survey of Japan
HIPC	Heavily Indebted Poor Countries
IMF	International Monetary Fund
IRGS	Intrusion Related Gold System
JICA	Japan International Cooperation Agency
JOGMEC	Japan Oil, Gas and Metals National Corporation
JORC	Joint Ore Reserves Committee
JPEG	Joint Photographic Experts Group
JSS	Japan Space Systems (former ERSDAC)
LOI	Loss On Ignition
MEGS	Malawi Economic Growth Strategy
MEM	Ministry of Energy and Mines, MALAWI
MGDS	Malawi Growth and Development Strategy
MGGSP	Mining Governance and Growth Support Project

MINETEC	International Institute for Mining Technology, JAPAN
MM	Ministry of Mining, MALAWI
M/M	Minutes of Meeting
MNREE	Ministry of Natural Resources, Energy and Environment, MALAWI
MWK	Malawi Kwacha
NDVI	Normalized Difference Vegetation Index
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
PCA	Principal Component Analysis
PGM	Platinum Group Minerals
PGRM	Project of Governance of Mineral Resources
R/D	Record of Discussions
RGB	Red Green Blue (color model)
SADC	Southern African Development Community
SAR	Synthetic Aperture Radar
SRED	Sumiko Resources Exploration & Development Co., Ltd.
SMM	Sumitomo Metal Mining Co., Ltd.
SWIR	Short Wave Infrared Radiometer
TIR	Thermal Infrared Radiometer
UTM	Universal Transverse Mercator
VNIR	Visible and Near-infrared Radiometer
WB	World Bank
XRF	X-ray fluorescence

1. Outline of the Project

1.1 Background of the Project

Malawi is located at the southern end of the Great Rift Valley that traverses longitudinally the eastern part of the African continent. Lake Malawi, elongated in the north-south direction along the eastern edge of Malawi with a total length of 580 km, is characteristic of the Great Rift Valley. The Great Rift Valley has a special geology and geological structures. This area is known for the occurrence of mineral resources which are peculiar to this zone.

The main industry of Malawi is agriculture (tobacco, sugar cane, cotton, tea, etc.), which accounts for 1/3 of GDP and over 90% of export revenues. The economy of Malawi depends upon economic assistance from IMF, the Work Bank and other donors. In 2006, as one of the Heavily Indebted Poor Countries (HIPC), Malawi was approved for debt relief under the HIPC debt relief system. The former president Mutharika, who was elected in 2004, promoted the reduction of poverty through sustainable economy growth as a basic national goal. The Malawi Economic Growth Strategy (MEGS) was formulated in 2004 and the Malawi Growth and Development Strategy 2006-2011 (MGDS) in 2006. The second phase of MGDS, MGDS II 2011-2015, was formulated in 2011 and was approved by President Banda who was assumed on April 2006 and the Parliament.

Background 1: National development plan (MGDS) and mining development

The MGDS 2006-2011 has five main objectives. The first objective "sustainable economic growth" is the highest priority issue to attain the goal of poverty reduction in Malawi. The mining sector is placed as the main "growth sector" in "sustainable economic growth," and the development of this sector is particularly regarded as important.

The MGDS II 2011-2015 has the same objectives as MGDS, and consists of nine priority areas as a means to promote economic growth. The second key priority area is composed of energy, industrial development, mining and tourism. It is described that the development of mining industry can significantly boost economic growth of the country through employment creation and generation of foreign exchange.

Malawi has been actively promoting the entry of private enterprises into the mining sector since the promotion of the mining sector was an important method of economic growth in MGDS and MGDS II. Mining products in Malawi were mainly bituminous coal, precious stones, limestone and construction aggregates, of which only precious stones were produced for export. Kayelekera Uranium mine, which started its production in early 2009, is the only large-scale mine operated in Malawi on an international level. The operation of this mine sharply changed the situation of the mining sector in Malawi.

The mining industry in Malawi had been neglected since independence in 1964. Its contribution to GDP had been less than 3% until 2009, but it increased up to about 10% in 2011 after the operation of Kayelekera Uranium mine. The mineral resources exploration, mine development and investment plans for uranium, rare metals and rare earth elements have been recently implemented by private enterprises based in Australia, China and other countries. The present Mining Law in Malawi is the Mines and Minerals Act, established in 1981. A new Mining Law is now deliberated and is expected to be enacted in 2013.

Background 2: Need of up-to-date geological and mineral resources information

Malawi has only old geological maps which were prepared during the British colonial period, from the 1950s to the 1960s. The geological information has been rarely updated and the mineral resources information is insufficient. As the existing data are not digitalized, it is difficult to store and manage them. GIS data of geology and mineral resources also have not been maintained. These situations seem to be caused by the shortage of equipment, funds and personnel in the mining sector in Malawi.

Background 3: Need of human resources in the counterpart agency

The counterpart agency in the JICA Project is the Geological Survey Department (GSD), which is the agency of the Ministry of Energy and Mines (MEM). The GSD is in charge of the mineral resources exploration, the management of mineral resources information and the promotion of mineral resources development. Equipment of hardware and software for remote sensing and GIS are not sufficient in GSD. Thus, some of GSD staff members have took the training courses of remote sensing and GIS held by JICA and JOGMEC, however, they have currently difficulties to develop their training skills. On the other hand, the problem has occurred, that engineers (in particular, geological engineers and mining engineers) with remote sensing and GIS skills transferred to private enterprises. Therefore, the maintenance and development of such technical personnel and their capacity building are very important issues in formulating future survey plans and promoting investments in the mining sector.

Based on the background described above, the Government of Malawi has requested Japanese government for cooperation in ① collection, processing and analysis of necessary geological information by remote sensing; ② building of GIS ; and ③ capacity development of the GSD. In response to the request, JICA implemented a preliminary study in October 2011 to confirm the relevance of a cooperative project focused on fostering human resources in the mining sector, and signed the Minutes of Meeting (M/M). In November 2011, JICA signed the Record of Discussions (R/D) on "The Project to Establish an Integrated Geographic Information System (GIS) Database for Mineral Resources in Malawi" ("this Project"), for which the counterpart agency is GSD. M/M and R/D are attached in the Report as Appendices.

1.2 Basic concepts of the Project

The basic concepts of the Project implementation are shown in Figure 1.1. The details are shown in section 1.1 and section 1.3 to 1.6.

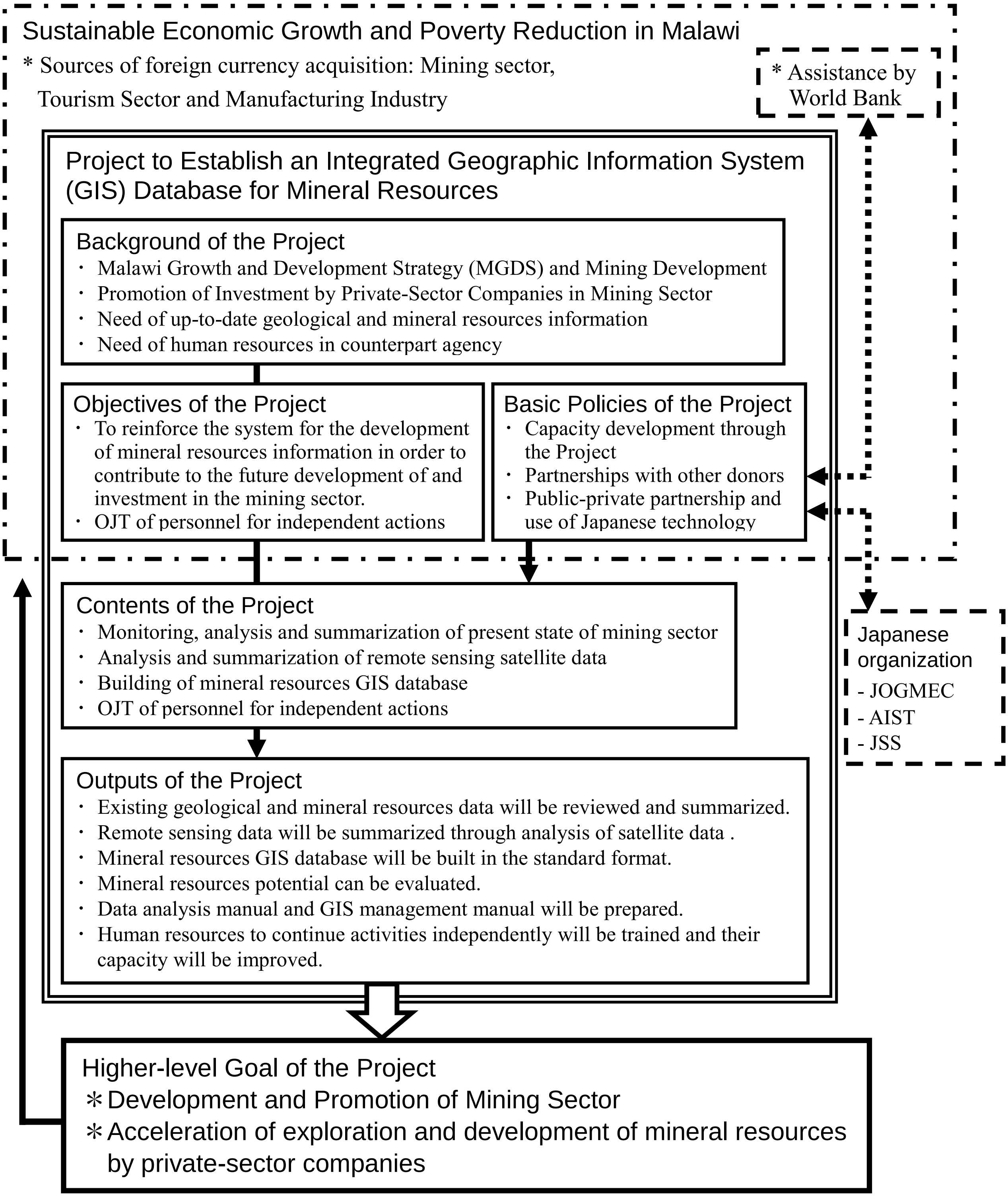


Figure 1.1 Basic concepts of the Project

1.3 Objectives of the Project

Objective 1: To develop management capacity of mineral resources information in order to contribute to the future development and promotion in the mining sector.

Objective 2: To build personnel capacity through on-the-job training (OJT) in order to enable the analysis of remote sensing data and the construction and management of GIS database for mineral resources in a self-reliant and sustainable way.

1.4 Basic policies for implementation of the Project

Policy 1: Personnel training and capacity building by implementing the Project

When implementing the Project in Malawi, the Study Team will undertake the joint work with the C/P in order to achieve technology transfer through OJT. The Study Team will prepare the work manual of remote sensing data analysis and the management manual of GIS database in cooperation with the C/P through the technology transfer.

Policy 2: Implementation of the Project considering the higher-level goal of the Project and understanding fully geology and mineral resources

The higher-level objectives of the Project are the development of the mining sector in Malawi and the promotion of investment by private enterprises. As the development of mineral resources has just begun in earnest in Malawi, the worldwide attention is focused on its high potential of mineral resources, such as uranium, rare earth elements and rare metals. Therefore, the Study Team would fully understand geology and mineral resources in Malawi and report their information in detail and precisely even in order to contribute the higher-level goal of the Project and also to improve the quality of works.

Policy 3: Use of Japanese technology

Remote sensing data obtained by Japanese satellites ASTER and PALSAR will be used. The ASTER optical sensor data features multi-band data of VNIR, SWIR and TIR with high resolution, while the PALSAR SAR sensor data is characteristic of L-band multi-polarization data with high resolution.

Policy 4: Partnerships with other donors and international programs

The World Bank approved “Mining Governance and Growth Support Project (MGGSP)” with a scale of 30 million US dollars as the aid for the mining sector in Malawi in March 2011. The MGGSP includes the program to develop the mining sector, in which geophysical prospecting, geochemical exploration, geological survey and satellite data analysis are implemented, and the capacity development through training is also planned. This JICA Project, therefore, will continuously have the tie-up and cooperation with the WB MGGSP, taking care to avoid the duplication between both projects activities. The trend of Extractive Industries Transparency Initiative (EITI) will be watched closely.

Policy 5: Government and private sectors partnership in Japan

Several geologists of GSD have taken the trainings in JOGMEC Botswana Geologic Remote Sensing Centre. OJT and technology transfer seminar in this JICA Project will be designed with reference to the training curriculum in the JOGMEC Center, through the coordination and consultation with JOGMEC if needed. The information exchange with JOGMEC and AIST projects will be planned.

1.5 Method of project implementation

(1) Monitoring, analysis and summarization of the present state of the mining sector

- Monitoring of position and roles of the mining sector in national development, poverty reduction and economy
- Collection and review of existing materials relating to the mining sector, and analysis of problems
- Collection and review of materials and data relating to geology and mineral resources, and analysis of problems
- Monitoring of the state of personnel system, technical level, equipment and materials of the organizations including GSD, and analysis of problems
- Examination of policies of personnel training for GSD staffs (OJT and seminar in Malawi and training in Japan) and formulation of implementation plans
- Examination and determination of specifications of equipment and materials necessary to implement the JICA Project

(2) Analysis and compilation of satellite data by remote sensing

- Analysis of ASTER and PALSAR satellite data covering the entire land area of Malawi
- Technology transfer through OJT in satellite data analysis method, etc.
- Evaluation and analysis of mineral resources potential
- Preparation of the processing manual to enable the C/P to continue the satellite data analysis on a self-reliant basis
- Selection and procurement of equipment and materials necessary for satellite data analysis
- Field verification study for the results of satellite data analysis

(3) Development of mineral resources GIS database

- Monitoring of existing GIS data and data management system, and identification of problems

・Monitoring of the state of GIS data which agencies other than GSD possess
・Examination of the optimum method for database operation and design of GIS database to allow sustainable database management
・Input of satellite data analysis results and geological and mineral resources data into the GIS database
・Input of various types of data on topography, water systems, infrastructure and administration into the GIS database
・Preparation of the self-reliant management manual of GIS database and submission of recommendations on the optimum system and method
・Arrangement of the website and its contents for dissemination of the basic information obtained in the Project
・Selection and procurement of equipment and materials necessary for construction of the GIS database

(4) Training of personnel to continue self-reliant activities

・Technology transfer through OJT in joint work with C/P personnel in order to enable GSD to continue the works described above in (2) and (3) on a self-reliant basis.
・Technology transfer seminar on the themes of remote sensing and GIS
・Training in Japan of GSD staff for mineral resources database and GIS development
・Drawing up of the Action Plan for the C/P agency's system and personnel training policy for effective utilization of the Project outputs
・Workshop of results presentation by the Study Team and the C/P engineers

(5) Preparation of reports

・Preparation of various kinds of reports describing the work progress and results in the given time schedule

1.6 Outputs of the Project

Output 1: Review and compilation of existing data on geology and mineral resources

・Geological, mineral resources, remote sensing, geophysical prospecting and geochemical data
・Situations of mineral resources exploration and development
・Information on infrastructure and peripheral environment
・Mining Law, investment data by the Investment Promotion Agency, other related laws and regulations, and policies
・Personnel systems and present situation regarding equipment and materials of relevant organizations in the mining sector

・Compliance with the Extractive Industries Transparency Initiative (EITI)
・Trends and status of tie-ups with other donors

Output 2: Compilation of satellite images and analyzed images using remote sensing data analysis

・Collection and analysis of ASTER data for the entire territory of Malawi
・Collection and analysis of PALSAR data for the entire territory of Malawi

Output 3: Building of GIS database for mineral resources in a standard format

・GIS database based on the analysis results of the above remote sensing data
・Input of geological maps and mineral resources data set into the GIS database
・Input of the study results of geology and mineral resources into the GIS database
・Input of various types of data (topography, water systems, mountains, infrastructure, administration, facilities and environment) into the GIS database

Output 4: Evaluation of mineral resources potential

・Creation of mineral resources potential map based on collected and analyzed data

Output 5: Preparation of data processing and database management manuals

・Preparation of the processing manual for satellite data analysis to enable beginners to do works
・Preparation of the GIS database management manual for mineral resources

Output 6: Training to improve the capacity of personnel to undertake the above activities on a self-reliant basis

・Training of personnel by means of technology transfer through OJT in joint works
・Capacity building through technology transfer seminar in Malawi and training in Japan
・Self-reliant and sustainable data analysis and database management by C/P agency resulted from the technology transfer and the manuals mentioned above

1.7 Flow chart of the Project

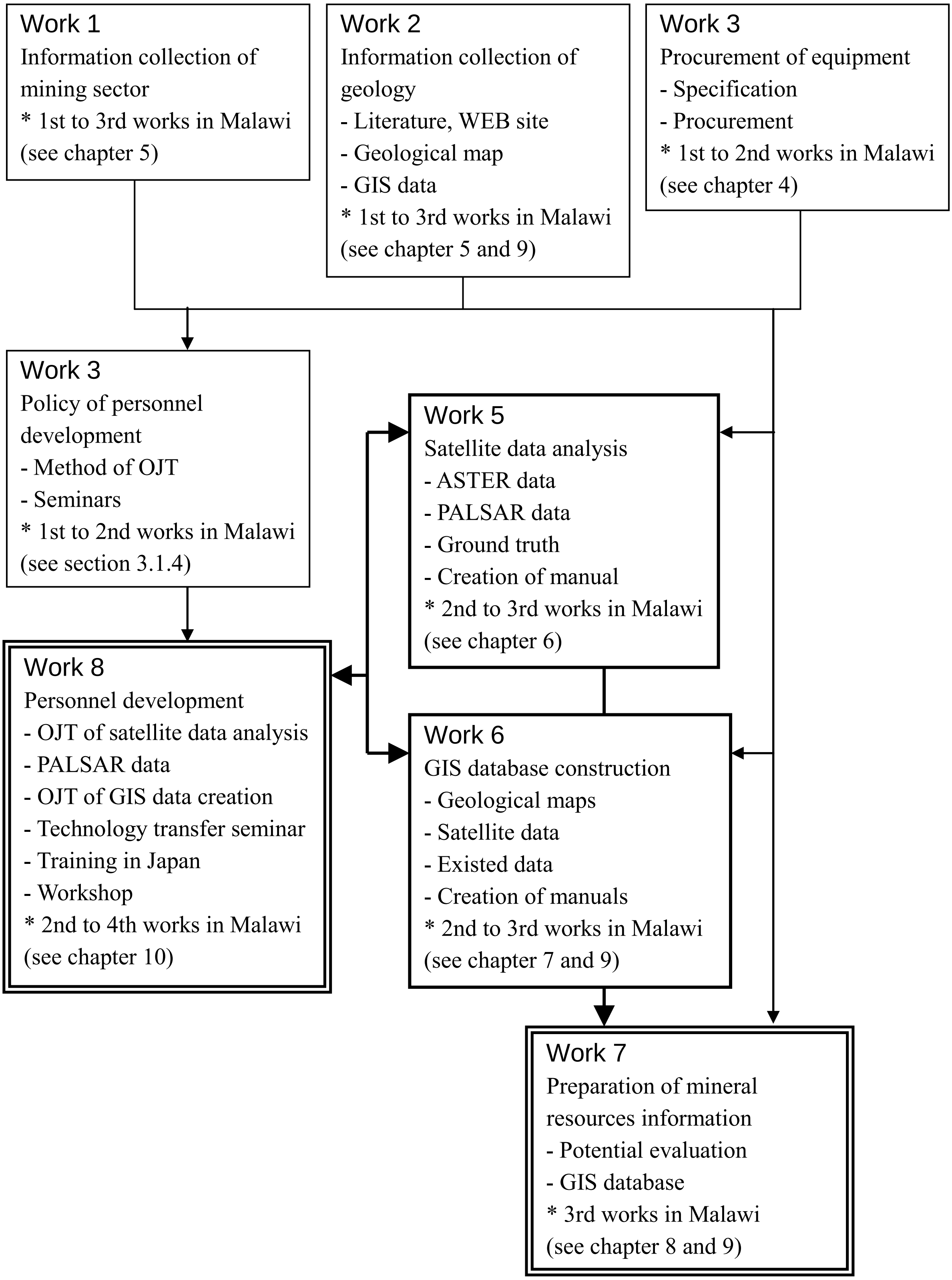


Figure 1.2 Flow chart of the Project

1.8 Organization of the Project

1.8.1 Study Team

The Study Team consists of five members shown in Table 1.1. All of them belong to SRED. Mr. Onuma, Mr. Takeda and Mr. Kobayashi are mainly engaged in works in Malawi. Mr. Ishikawa and Mr. Machida are engaged only in works in Japan. Dispatch schedule and personnel plan are shown in Table 1.2 and Figure 1.3.

Table 1.1 Detail of work assignments of Study Team members

Name	Work assignment	Work description
Takumi ONUMA	Project Management / Related Information Compilation	・General management of the Project and implementation schedule ・Negotiation and coordination with C/P agency and external related agencies ・Collection, organization and analysis of existing geological and mineral resources information ・Trainings in remote sensing and GIS ・Remote sensing data analysis ・Evaluation and analysis of mineral resources potential ・Lecturer in technology transfer seminar ・Preparation for training in Japan and hosting of trainees ・Drawing up of the Action Plan
Masahiro TAKEDA	Remote Sensing / Mapping and Mineral Evaluation	・Procurement of satellite data, equipment and materials ・Setting up of equipment and materials ・Analysis and interpretation of remote sensing data ・Mapping of geological structures and mineralization ・Technology transfer through OJT in satellite data analysis and other technologies ・Support for preparation of the data analysis manual ・Review of geological publications and exploration reports ・Evaluation and analysis of mineral resources potential
Hirohisa KOBAYASHI	Mineral Resources Database / GIS	・Management of collected data ・Design of GIS database ・Construction of GIS database ・Technology transfer through OJT in GIS operation ・Examination of GIS database management and operation methods ・Support for preparation of the database management manual ・Lecturer in technology transfer seminar
Hiromasa ISHIKAWA	GIS	・GIS data creation of geological maps (works in Japan)
Satoshi MACHIDA	GIS	・GIS data creation of geological maps (works in Japan)

Table 1.2 Dispatch schedule of the Study Team

Name / Work assignment	Works in Malawi	Period / Days	Days in total
Takumi ONUMA Project management, Related information compilation	1st 2nd 3rd 4th	31 March 2012～19 April 2012：20 days 4 June 2012～9 July 2012：36 days 26 August 2012～20 September 2012：26 days 27 October 2012～20 November 2012：25 days 23 January 2013～15 February 2013：24 days 18 May 2013～1 June 2013：15 days	146
Masahiro TAKEDA Remote sensing, Mapping and mineral evaluation	1st 2nd 3rd 4th	31 March 2012～19 April 2012：20 days 4 June 2012～1 September 2012：90 days 27 October 2012～7 December 2012：42 days 18 May 2013～1 June 2013：15 days	167
Hirohisa KOBAYASHI Mineral resources database, GIS	1st 2nd 3rd 4th	31 March 2012～19 April 2012：20 days 25 June 2012～20 September 2012：88 days 6 January 2013～15 February 2013：41 days 18 May 2013～1 June 2013：15 days	164

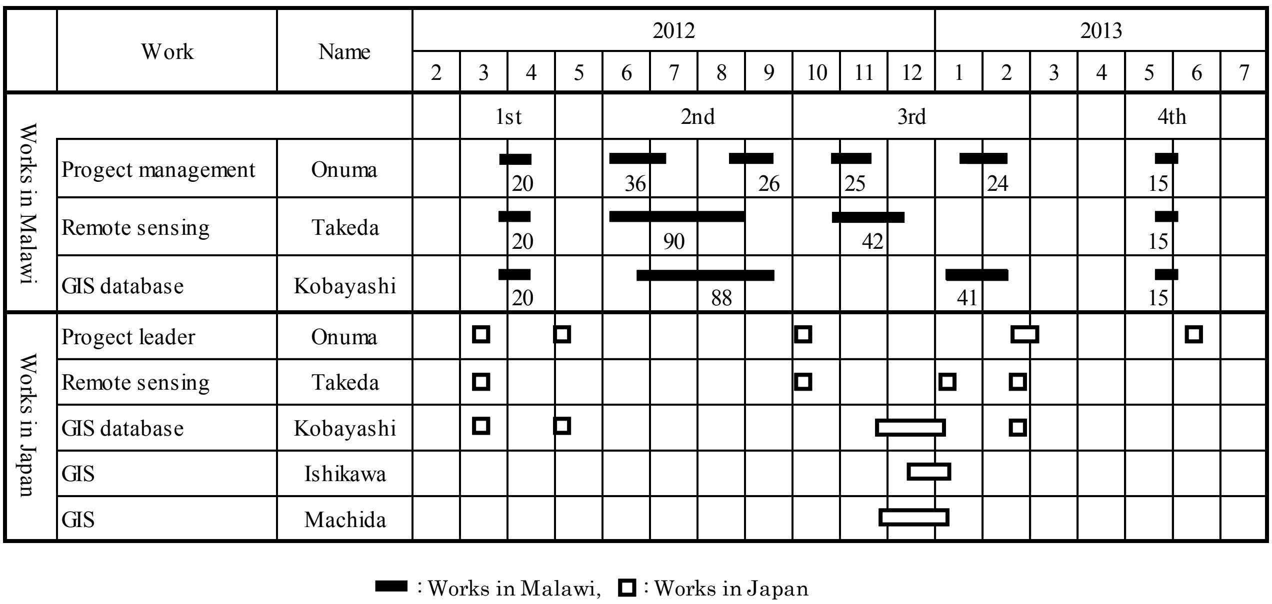


Figure 1.3 Personnel plan of the Study Team

1.8.2 Counterpart agency

The counterpart agency in this Project is the GSD, which is the agency of the Ministry of Mines (MM). The GSD sets up the head quarter in Zomba. Dr. Leonard S. N. Kalindekafe had been the director of GSD for a long time, but was promoted to principal secretary of MM on December 2012. Mr. Jalf Salima, former vice director of GSD, became the director. The GSD has a staff of about 40, including 14 members of geological engineers and 24 members of the other engineers. Organization chart of GSD and staffs directly related to this Project are shown in respectively Figure 1.4 and Table 1.3.

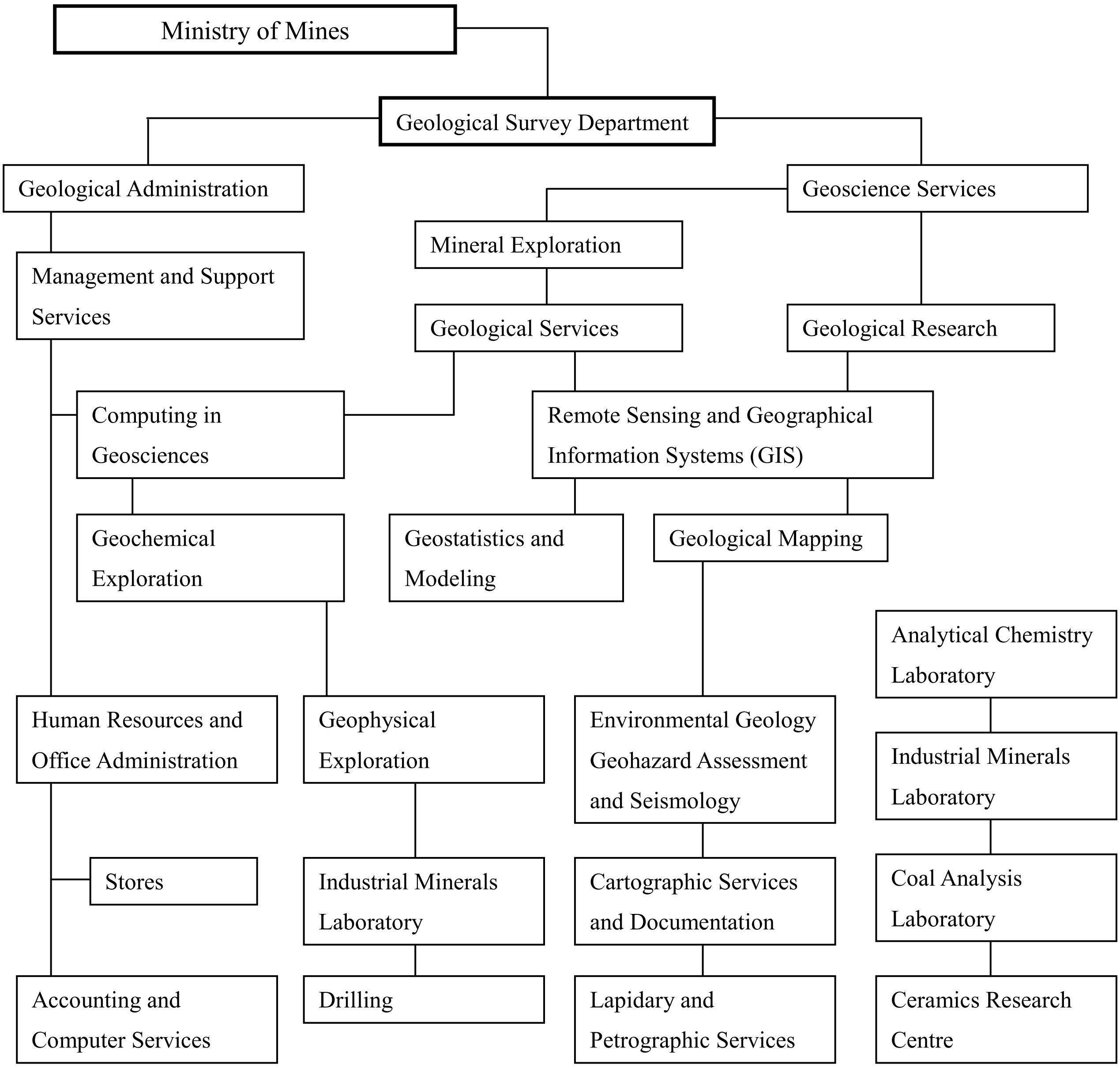


Figure 1.4 Organization chart of GSD

Table 1.3 GSD staffs related to the Project

	Position	Participation
A	Acting Director	Official meetings, Training in Japan
B	Previous Director Principal Secretary in Ministry of Mining	Official meetings, Inception meeting
C	Principal geologist	Training in Japan
D	Principal geologist	Training in Japan
E	Principal geologist	Inception meeting
F	Geologist	Inception meeting, OJT
G	Geologist	Inception meeting, OJT
H	Geologist	Inception meeting
I	Geologist	Inception meeting
J	Geologist	Inception meeting
K	Geologist	Inception meeting
L	Geologist	Inception meeting, OJT
M	Senior seismology technician	Inception meeting
N	Senior geochemist	Inception meeting, Seminar
O	Geological technician	OJT
P	Geological technician	OJT
Q	Cartographer	OJT
R	PC technician	OJT
S	Cartographer	OJT
T	Librarian	OJT
U	Geologist	Seminar
V	Geologist	Seminar
W	Geologist	Seminar
X	Geologist	Seminar
Y	Geologist	Seminar
Z	Geologist	Seminar
AA	Geologist	Seminar
BB	Geologist	Seminar
CC	Geologist	Seminar

1.9 Time schedule of the Project

The Project was started in February 2012 and will be completed in July 2013. The Project contains following four stages of works in Malawi, five stages of works in Japan and once Training in Japan. Five kinds of reports have been prepared and submitted during the Project.

- 1st Work in Japan : From middle March to late March 2012
  Inception Report was submitted in late March.
- 1st Work in Malawi : From late March to middle April 2012
- 2nd Work in Japan : Early May
  Progress Report was submitted in early May.
- 2nd Work in Malawi : From early June to late September 2012
- 3rd Work in Japan : Early October 2012
  Interim Report is submitted in early October.
- 3rd Work in Malawi : From late October 2012 to middle February 2013
- 4th Work in Japan : From late February to early march 2013
  Draft Final report was submitted in early March.
- Training in Japan : From middle April to late April 2013
- 4th Work in Malawi : From middle May to early June 2013
- 5th Work in Japan : From middle to late June 2013
  Final Report was submitted in early July.

2. Works in Japan

The five stage Works in Japan from 1st (March 2012) to 5th (June 2013) were executed.

2.1 The 1st Work in Japan

The 1st Work in Japan was carried out in March 2012 before the 1st Work in Malawi.

(1) Collection and analysis of various types of information about Malawi

Information about the mining sector in Malawi was collected. The basic mining agendas, activities and roles of the mining sector, and issues for the mining promotions and private investment promotions, were grasped. And then, the matters to be considered in the Project were analyzed. The results of these collection and analyses were reflected in the Inception Report.

Information, data and reports about the geology and mineral resources in Malawi were collected. The brief summary of the geology and mineral resources in Malawi were described in the Inception Report.

(2) Consideration of basic policies, methods and schedules of the Project

Basic policies and contents of the Project were considered, and the schedules of the Project were decided. The whole plan of the Project is shown in Figure 2.1 and the schedule of technology transfer seminar and training in Japan is shown in Table 2.1. Human resources development, the method of OJT, and the schedule and contents of the technology transfer seminar and the training in Japan, were plotted out.

(3) Consideration of equipment and materials to be procured

Satellite data, hardware including PCs and software necessary for the execution of the Project were considered to determine the specifications and quantities of those items. As the important software used in OJT of satellite data analysis and GIS database construction, ENVI and ArcGIS were selected based on the actual usage in other donors and neighbor countries.

(4) Preparation of Inception Report

The Inception Report was prepared, in which included basic policies of the Project, study method, work processes, and personnel plan. The contents of the Inception Report were conferred with JICA before the submission, and the Inception Reports were submitted to the GSD during the 1st Work in Malawi.

2.2 The 2nd Work in Japan

The 2nd Work in Japan was carried out in May 2012 after the 1st Work in Malawi.

(1) Preparation of Progress Report

The Progress Report was created, in which results of the Works until the 1st Work in Malawi were described. The contents of the Progress Report were conferred with JICA before the submission. The Progress Reports were submitted to the GSD during the 2nd Work in Malawi.

(2) Procurement of equipment and materials

Satellite data, hardware and software as the equipment and materials necessary for the works in Malawi were ordered to the companies which were selected by the prescribed procedures. The equipment procured is described in chapter 4.

(3) Planning of OJT in the 2nd Work in Malawi

The schedule and contents of OJT during the 2nd Work in Malawi was planned. The early stage program was lecture and OJT of satellite data analysis, and the middle stage program was OJT of satellite data analysis and lecture of GIS data creation, and the late stage program was OJT of GIS data creation.

(4) Approach of capacity building after the 2nd Work in Malawi

The concept to improve the capacity of personnel after the 2nd Work in Malawi is shown in Figure 2.1. The contents of OJT are shown in Chapter 6 and 7, and the contents of technology transfer seminar and training in Japan are shown in Chapter 10.

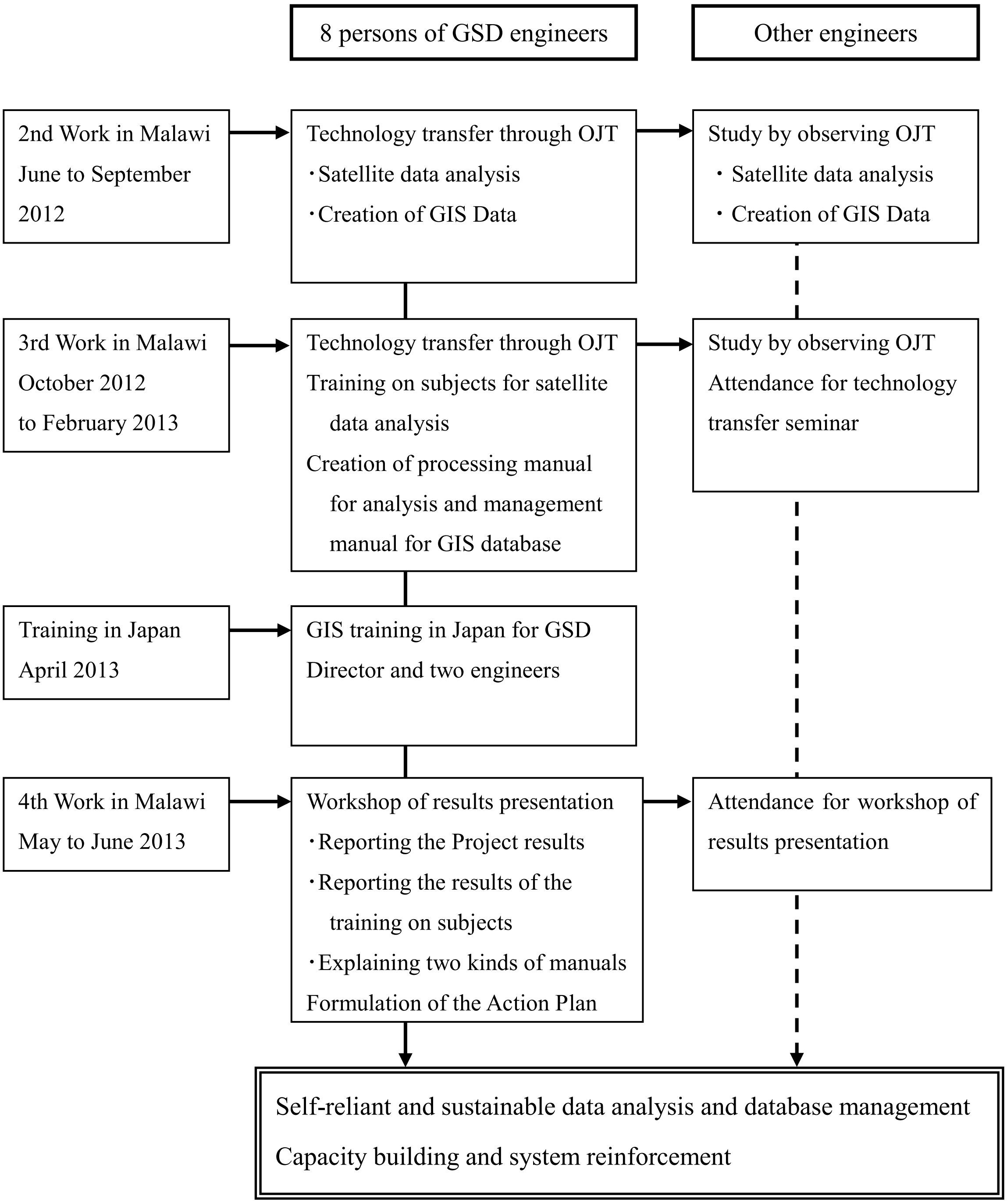


Figure 2.1 Concept for plan of capacity building

2.3 The 3rd Work in Japan

The 3rd Work in Japan was carried out in October 2012 after the 2nd Work in Malawi.

(1) Preparation of Interim Report

The Interim Report was created, in which results of the Works until the 2nd Work in Malawi were described. The contents of the Interim Report were conferred with JICA before the submission.

(2) Planning of OJT in the 3rd Work in Malawi

The schedule and contents of OJT during the 3rd Work in Malawi was planned based on the progress of the 2nd Work in Malawi. The early stage program was OJT of satellite data analysis and the late stage program was OJT of GIS data creation.

2.4 The 4th Work in Japan

The 4th Work in Japan was carried out from November 2012 to March 2013 after the 3rd Work in Malawi.

(1) GIS data creation of geological maps

Twenty sheets of geological maps were digitized from November 2012 to January 2013.
In the same periods which the Study Team was absent in Malawi, C/Ps continued to digitize geological maps by themselves. The Study Team supported them with contact by emails.

(2) Planning of OJT in the 4th Work in Malawi

The schedule and contents of OJT during the 4th Work in Malawi was planned.

(3) Planning of training in Japan

The training in Japan, which would be held on April 2012, was planned for schedule and contents, and was prepared.

(4) Preparation of Draft Final Report

The Draft Final Report was created, in which results of the Works until the 3rd Work in Malawi were described. The contents of the Draft Final Report were conferred with JICA before the submission.

2.5 Training in Japan

The training in Japan was carried out from 12 to 21 April 2013. The schedule is shown in Table 2.1.

(1) Trainees

- Acting director of GSD
- Principal Geologist of GSD
- Principal Geologist of GSD

(2) Schedule

Table 2.1 Schedule of the training in Japan

Date	Time	Contents	Place
12 (Fri) to 14 April (Sat)		Movement from Lilongwe to Tokyo	
15 April (Mon)	10:00~12:00	Briefing of training.	Tokyo International Center of JICA (TIC)
	14:00~15:00	Activities of JICA, Explanation of training.	JICA headquarters
	15:40~16:20	Courtesy call, Explanation of training.	Smiko Resources Exploration & Development Co., Ltd. (SRED)
		Move to Tsukuba	
16 April (Tue)	10:00~12:20	Courtesy call, Activities of AIST, Mineral resources and exploration.	National Institute of Advanced Industrial Science and Technology (AIST)
	13:10~17:30	Non-metal mineral resources, Rare earth elements resources from mineralogy, Remote sensing and exploration.	
17 April (Wed)	10:00~12:00	Observation of mineral analysis equipment.	AIST
	13:00~15:00	Observation of rock specimens.	Geological museum in AIST
		Move to TIC	
18 April (Thu)	10:00~12:00	Activities of JSS, ASTER, PALSAR, HISUI projects. Distribution system of satellite data.	Japan Space Systems (JSS)
	14:00~17:00	Courtesy call, Present exploration and challenges of mineral exploration. Exploration of deep sea mineral resources.	Japan Oil, Gas and Metals National Corporation (JOGMEC)

19 April (Fri)	10:00~12:00	Preparation for reporting.	JICA Global Plaza, Ichigaya
	14:00~15:00	Report of training results, discussion of future plan.	
	15:00~18:00	Seminar of Malawi mining sector: "Investment in mineral sector", "Present status and future prospects"	
	18:00~19:00	Social meetings	
20 (Sat) to 21 April (Sun)		Movement from Tokyo to Lilongwe	

2.6 The 5th Work in Japan

The 5th Work in Japan was carried out in June 2013 after the 4th Work in Malawi.

(1) Preparation of Final Report

The Final Report was created, in which results of entire Works in the Project were described. The contents of the Interim Report were conferred with JICA before the submission.

3. The Works in Malawi

Four stages of Works in Malawi from 1st (March 2012) to 4th (June 2013) were implemented.

3.1 The 1st Work in Malawi

3.1.1 Objectives of the Work

- Explanation of the whole schedule of the Project and discussion of work items
- Consideration of personnel training method
- Collection and analysis of mining-related diverse information
- Consideration and procurement of equipment and materials

3.1.2 Study Team

- ONUMA Takumi : Project management / related information compilation (Team leader)
- TAKEDA Masahiro : Remote sensing / mapping and mineral evaluation
- KOBAYASHI Hirohisa : Mineral resources database / GIS

3.1.3 Schedule of the Work

The 1st Work in Malawi was executed from the 31st of March till the 19th of April. The schedule of the main jobs is shown in Table 3.1. All members worked on the same schedule.

Table 3.1 Schedule of main jobs in the 1st Work in Malawi

Date	Content
2 April (Mon)	Courtesy call on MNREE: Explanation of project plan Meeting at GSD Lilongwe branch: Explanation of project plan
3 April (Tue)	Visit to shops to procure materials: Explanation of procurement, confirmation of estimate Courtesy call with coordinator of World Bank: Explanation of project plan
4 April (Wed)	Movement: Lilongwe－Zomba Meeting at GSD: Explanation of project plan
5 April (Thu)	Inception Meeting at GSD: see 3.1.5 Purchase of goods
10 April (Tue)	Meeting at GSD: Discussion of study policy Conclusion of M/M of Inception meeting
11 April (Wed)	Meeting at GSD: Explanation of the next works in Malawi Movement: Zomba－Lilongwe

12 April (Thu)	Visit to shops to procure materials: Notification of selection result of suppliers, Purchase of goods
13 April (Fri)	Preparation of procurement: Confirmation of specification Courtesy call on Japanese Embassy: Explanation of project plan
16 April (Mon)	Preparation of procurement: Confirmation of specification

3.1.4 Contents of work implementation

(1) Comprehension of information for geology and mineral resources

Geological maps, mineral resources maps and geophysical survey maps, which are printed papers, are available at GSD. The other data are available at the other government agencies.

(a) Existing geological map

- 1/1,000,000 scale geological map (the whole of Malawi, made in 1966) : 1 sheet
- 1/100,000 scale geological map (the whole of Malawi, made in 1960's-1970's) : 40 sheets
- 1/50,000 scale geological map (Ngana Coalfield, Chilwa Island, Tundulu Carbonatite Complex, Nathace Hill, Kangankunde Carbonatite Complex) : 5 sheets

(b) Existing mineral resources data

- 1/1,000,000 scale mineral resources map (the whole of Malawi, compiled in 2000): 1 sheets

(c) Other related survey data

- 1/1,000,000 scale air-borne magnetic map (the whole of Malawi, compiled in 2000) : 1 sheet
- 1/250,000 scale air-borne magnetic map

(d) Other related data

- 1/250,000 scale topographic map (the whole of Malawi) : 10 sheets
- 1/50,000 scale topographic map (the whole of Malawi) : 162 sheets
- Digital data of administrative boundary, infrastructure and etc. (the whole of Malawi)
- Aerial photograph

(2) Comprehension of implementation system and personnel

(a) System and personnel of GSD

- The director was Dr. Leonard S. N. Kalindekafe at that time.
- The organization chart (Figure 1.4) described in M/M of the Project is not changed. As a new president was inaugurated on April 2012, organization was changed later.

・Numbers of the technical experts in April 2012 are as follows.
geologist : 14, seismologist : 1, geochemist : 2, prospector : 3, cartographer : 1, librarian : 1, geological technician : 6, seismological technician : 10
・In July (new fiscal year in Malawi), GSD has plan to recruit ten and more new geologists.

(b) Target persons for technology transfer
・Ten engineers selected for technology transfer are shown in Table 3.2. Their training histories (the training at the JOGMEC Botswana Remote Sensing Center and the JICA Thematic Training Programs at MINETEC, Japan) are shown in Table 3.2. However, the actual persons taking OJT were changed later as Table 3.5.

Table 3.2 List of target persons for technology transfer and their training histories

	Position	JOGMEC Seminar in Botswana Remote Sensing Center	JICA Seminar in MINETEC Kosaka, Japan
A	Principal geologist	5 weeks: Aug to Sep 2010 2 weeks: Jun 2011	—
B	Geologist	5 weeks: Aug to Sep 2010 2 weeks: Jun 2011	5 weeks: Feb to Mar 2010
C	Geologist	5 weeks: Aug to Sep 2010 2 weeks: Jun 2011	—
D	Geologist	2 weeks: Jun 2011	—
E	Geologist	—	—
F	Geologist	—	—
G	Geologist	—	—
H	Geologist	1 week: Jul 2009	5 weeks: Feb to Mar 2011
I	Geologist	1 week: Jul 2009	6 weeks: Feb to Mar 2012
J	Cartographer	—	—

(3) Consideration of personnel training methods

(a) Initial trainings for satellite data analysis using ENVI and GIS data creation using ArcGIS
・The initial trainings were originally planned for four days from 12 June on satellite data analysis and four days from 2 July on GIS data creation. It was agreed that number of days would be changeable according to the experience and ability of trainees.

(b) Technology transfer through OJT
・It was confirmed that there were no problem for overall contents and methods of technology transfer using five PCs which would be provided to GSD.

・Field verification of satellite data analysis was planned for about one week.　However, the Director of GSD requested to increase the target areas and days of ground truth.

・The Study Team replied that it was impossible to increase them in considering primary objectives and schedule of the Project even though the Team understood the importance of ground truth.　Then, the Director agreed it.

・It was agreed that such ground truth or field geological survey would be a matter to be discussed in future.　The field works could be recommended as a new project.

・Though target persons for technology transfer were decided to be ten in total, the Director requested the attendance of observers in OJT in order to bring up as many experts as possible.　The Study Team agreed to accept observers.

(c) Implementation of the examination to estimate the performance of technology transfer

・As main objective is technology transfer, it was confirmed that the examination to estimate objectively the performance was necessary.

(d) Implementation of the training on subjects for satellite data analysis

・C/P appreciated not only OJT but also the way to draw self-reliant work.

・C/P requested to select the target areas near Zomba, and the Study Team agreed it.

・If the areas would be located near Zomba, C/P could visit the areas to verify results of data analysis by themselves.

(e) Reporting at workshop of results presentation

・C/P appreciated the workshop of results presentation, where C/P would report the outputs of technology transfer.

・It was confirmed that all of ten C/P would have presentations.

(f) Implementation of technology transfer seminar

・C/P appreciated that the seminar for satellite data analysis and creation of GIS data would be held for C/P other than ten C/P who would take OJT.

(g) Implementation of the training in Japan

・The schedule and participants of the training in Japan were confirmed.

・The Study Team referred that two participants other than the director of GSD would be basically selected according to the performance on OJT.

(h) General evaluation

・It would be very fruitful for GSD that the number of OJT trainees would be ten at least. It was highly appreciated that many engineers would be able to receive the technology transfer through the observing OJT and technology transfer seminar.

(4) Decision of the policy of procurement of the equipment and setting

・The contents and quantities of equipment provided to GSD were confirmed.　The list of equipment which was finally provided is shown in Table 4.1.

- It was agreed that the present meeting room in GSD would be exclusively used as a room for OJT and that the necessary equipment like PCs, printers and others would be set up in the room.
- It was confirmed that GSD should prepare the necessary facilities like desks, chairs, air conditioners and others except for equipment provided by JICA.
- It was confirmed that the Study Team would use the room next to the present meeting room as an reserved office, in which the user had been absent by a long-term training.
- It was confirmed that GSD should finish the preparation of the room for OJT before the next visit of the Study Team, early June. The hardware procured in Lilongwe would be delivered to GSD during May, and the Study Team would visit Zomba and set up them on early June.
- GSD requested the electric generator to be provided also at the Inception meeting. It was confirmed, however, that the equipment supplying electricity was considered as a necessary facility and GSD should prepare it according to the M/M and R/D of the Project.
- It was confirmed that OJT for the satellite data analysis and the establishment of GIS database would be enabled and the technology transfer could be carried out certainly and effectively when equipment would be set up properly as mentioned above.

(5) Comprehension of problems in GSD (hearing from GSD)

(a) Organization and personnel system in GSD

- An opportunity for training and lecture by experts is necessary, as staffs have not enough technical skills.
- Lack of technical skill makes it difficult to succeed the technology.
- Declination of the number of staffs who got technical skill weakens the system of GSD.
- Lack of IT technology disables the establishment of system.
- OJT by experts is indispensable in order to develop technical skills of staffs.

(b) Facilities in GSD

- To expand facilities for data management is necessary.
- The library has not enough space.
- Facilities to store rock samples and drill cores are insufficient.
- Geological or specimen museum is necessary.

3.1.5 Inception Meeting

The Study Team brought and submitted Inception reports to GSD on the 4th of April 2012. Inception meeting was held at the meeting room in GSD from 10 to 12am on the 5th of April 2012. The list of participants is shown at Table 3.3.

Table 3.3 List of participants of Inception meeting

Name	Position
Geological Survey Department (GSD)	
A	Director
B	Principal Geologist
C	Senior Geochemist
D	Geologist
E	Geologist
F	Geologist
G	Geologist
H	Geologist
I	Geologist
J	Geologist
K	Senior Seismology Technician
Japan International Cooperation Agency (JICA)	
Yoshitaka Hosoi	Senior Advisor, JICA Headquarter
Hiroki Tazawa	Project Formulation Advisor, JICA Malawi office
Michael Malewezi	Programme Officer, JICA Malawi office
Sumiko Resources Exploration & Development Co., Ltd. (SRED)	
Takumi Onuma	Leader of the Study Team, Chief Geologist
Masahiro Takeda	Geophysicist
Hirohisa Kobayashi	Geologist

3.2 The 2nd Work in Malawi

3.2.1 Objectives of the Work

- To report the Progress report
- To procure, inspect and install the equipment
- To collect information and data
- To examine the contents of technology transfer
- To execute the technology transfer through OJT for satellite data analysis and GIS database construction
- To create manuals

3.2.2 Study Team

- ONUMA Takumi : Project management / related information compilation (Team leader)
- TAKEDA Masahiro : Remote sensing / mapping and mineral evaluation
- KOBAYASHI Hirohisa : Mineral resources database / GIS

3.2.3 Schedule of the Work

The 2nd Work in Malawi was executed from the 4th of June till the 20th of September. The schedule of the Work is shown in Table 3.4. The schedule of personnel is different from the Team members as follows.

- ONUMA : 4 June to 9 July, 26 August to 20 September (62 days in total)
- TAKEDA : 4 June to 1 September (90 days)
- KOBAYASHI : 25 June to 20 September (88 days)

Table 3.4 Schedule of main jobs in the 2nd Work in Malawi

Date	Schedule
5 June (Tue)	Procuring equipment, confirmation of specification of new equipment.
6 June (Wed)	Visiting Japanese Embassy: Explanation of this work plan
8 June (Fri)	Meeting with GSD: Explanation of this work plan
9 (Sat) ~13 June (Wed)	Inspection and installation of equipment
14 (Thu) ~24 June (Sun)	Initial training for satellite data analysis OJT of satellite data analysis (details in Table3.6)
25 June (Mon) ~ 12 September (Wed)	Initial training for GIS OJT of satellite data analysis and GIS (details in Table3.6)
17 September (Mon)	Courtesy call on Japanese Embassy: Explanation of work results

3.2.4 Setting up of equipment

The equipment procured in Malawi and Japan was set up in GSD on late June. Though the meeting room would be planned to be used for GSD in the 1st Work in Malawi, GSD requested to use a cartography room when the Study Team visited GSD in early June. As the cartography room was larger than the meeting room, the Study Team accepted this offer. Then, C/P made enough space to set up equipment and cleaned the room.

The Study Team carried the equipment procured in Japan to Malawi as luggage by airplane and brought them to GSD in Zomba. The equipment procured in Lilongwe was delivered directly to GSD. GSD bought new desks and chairs for exclusive use of OJT.

Data and equipment used in OJT is shown in Table 4.1 and photographs of hardware are shown in Figure 4.1 and 4.2. They will be provided to GSD in the end of the Project.

3.2.5 Target personnel for the OJT

GSD selected 13 personnel shown in Table 3.5, who would receive the technology transfer through OJT. As apparent in Table 3.5, however, the attendance rate of C/P who has the experience of technical training is very bad. As a matter of fact, five C/Ps listed upper in Table 3.5 have not received the OJT of satellite data analysis and GIS data creation and are not expected to attend the OJT in the future.

In the initial policy of OJT, 13 C/Ps were divided into two groups, experienced five person's group and inexperienced eight person's group, and the OJT was planned to be held by two groups in the morning session and the afternoon session according to the technical level of two groups. However, as the experienced person's group had not attended the OJT, the inexperienced person's group have been received the OJT in all day from July.

Table 3.5 Target personnel for the OJT and attendance rate

		Position	Experience	Attendance for OJT
1	A	Geologist	Yes	Several days in the beginning
2	B	Geologist	Yes	None
3	C	Geologist	Yes	Several days in the beginning
4	D	Geologist	—	Several days in the beginning
5	E	Geologist	Yes	Only join in September
6	F	Geological technician	—	more than 80%
7	G	Geologist	—	more than 80%
8	H	Geologist	—	more than 80%

9	I	Geological technician	―	more than 80%
10	J	Cartographer	―	more than 80%
11	K	PC technician	―	more than 80%
12	L	Cartographer	―	more than 80%
13	M	Librarian	―	more than 80%

3.2.6 Policy of the OJT

The Study Team considered the OJT policy and plan, and then confirmed that the OJT would be held as follows.

(1) Grouping

Thirteen C/Ps are divided into two groups according to the experience of the technical training (see Table 3.5). Two groups have the OJT alternately in the morning session and the afternoon session as follows.

- Morning session: Group B: 8 inexperienced persons: No.6 to 13 in Table 3.5
- Afternoon session: Group A: 5 experienced persons: No.1 to 5 in Table 3.5

However, as C/P of group A stopped to attend the OJT in the end of June, C/P of group B have attended the OJT in all day from July.

(2) Schedule

The OJT is held in 5 days a week from Monday to Friday except for holidays in Malawi. Timetable of the OJT is basically as follows. The attendance of each C/P is checked every day by the attendance table.

- Morning session: from 9:00 to 10:30 and 10:45 to 12:00
- Afternoon session: from 13:30 to 15:00 and 15:15 to 16:30

The OJT of GIS started in the middle of July. As the delay of GIS data creation became apparent in August, C/P came to perform the OJT in addition to the above time from August on a voluntary basis.

(3) Process

The OJT is held alternately for satellite data analysis and GIS data creation in weekly. The schedule is planned considering both progresses.

(4) Policy

While proceeding the OJT in the first stage, the Study Team recognized the large difference of the technical level among C/Ps. C/Ps seem to be divided into three groups by their work history, technical experience and personal ability. The Study Team gives the jobs adjusted the quality and quantity according to their levels.

3.2.7 Contents of the OJT

The schedule and contents of the OJT executed in the 2nd Work in Malawi is shown in Table 3.6.

Table 3.6 Schedule and contents of the OJT

Date	Satellite data analysis using ENVI	Creation of GIS data using ArcGIS
14, 15, 18 and 19 June	・Theory of spectral and satellite remote sensing data ・Spectral measurement by using spectral meter ・Case study of satellite data analysis relating mineral resources	—
20 June ~ 22 June	・Basic operation of ENVI ・Input and display of satellite data ・Display of data value of image ・Comparison of satellite images ・Creation of mask data	—
25 June ~ 29 June	・Creation of mask data ・Integration of ASTER bands ・Calculation of NDVI ・Creation of masks for vegetation , water, cloud and cloud-shadow areas	—
2 July ~ 5 July	—	・Theory of GIS ・Data kinds used in GIS ・Operation of ArcGIS ・Basics of computer
9 July ~ 13 July	—	・How to use ArcGIS ・Georeference ・Display of coordinate data ・Hyperlink
16 July ~ 20 July	・Creation of color composite image and saving it as GeoTIFF file ・Calculation of band ratio ・Resize of VNIR data ・Creation of integrated mask data	—
23 July ~ 27 July	—	・Operation of pentablet ・How to trace geological maps ・Digital trace of geological maps
30 July ~ 3 August	・Resize of VNIR data ・Integration of VNIR and SWIR data ・Creation of integrated mask data ・Calculation of band ratio ・Creation of color composite image	—

6 August ~ 10 August	—	・Scan of geological maps ・Georeference of geological maps ・Digital trace of geological maps
13 August ~ 17 August	・Creation of integrated mask data ・Calculation of band ratio ・Creation of color composite image	—
21 August ~ 24 August	・Creation of integrated mask data ・Calculation of band ratio ・Creation of color composite image	—
27 ~ 31 August	—	・Digital trace of geological maps
3 ~7 September	—	・Digital trace of geological maps
10 ~ 12 September	—	・Digital trace of geological maps

3.3 The 3rd Work in Malawi

3.3.1 Objectives of the Work

- To report the Interim report
- To collect information and data
- To execute the technology transfer through OJT for satellite data analysis and GIS database construction
- To create manuals
- To hold the technology transfer seminar

3.3.2 Study Team

- ONUMA Takumi : Project management / related information compilation (Team leader)
- TAKEDA Masahiro : Remote sensing / mapping and mineral evaluation
- KOBAYASHI Hirohisa : Mineral resources database / GIS

3.3.3 Schedule of the Work

The Third Work in Malawi was executed twice as the first phase from 27 October to 7 December and as the second phase from 6 January to 15 February 2013. Two schedules are shown in Table 3.7.

The first phase program is composed of the OJT for satellite data analysis, the ground truth for analytical results and the creation of data processing manual. The second phase program is composed of the OJT for GIS data creation, the creation of GIS database and manual, and the technology transfer seminar. The schedule of personnel is different from the Team members as follows.

- ONUMA : 27 October to 20 November 2012, 23 January to 15 February (49 days in total)
- TAKEDA : 27 October to 7 December 2012 (42 days)
- KOBAYASHI : 6 January to 15 February (41 days)

Table 3.7 Schedule of main jobs in the 3rd Work in Malawi

Date	The first phase
29 October (Mon)	Visit JICA and Japanese Embassy
30 October (Tue)	Attend the seminar on forest preservation by the Department of Forestry
1 November (Thu)	Meeting with GSD: Explanation of this work plan

2 (Fri) ～3 November (Sat)	Creation of documents and explanation about OJT (Field verification of satellite data analysis results)
5 (Mon) ～9 November (Fri)	OJT (Field verification of satellite data analysis results)
10 November (Sat) ～4 December (Tue)	GIS database creation, OJT of satellite data analysis (details in Table 3.8)
Date	The second phase
9 January (Wed)	Meeting with GSD: explanation of this work plan
26 (Thu) ～28 January (Mon)	OJT of GIS (details in Table 3.8), GIS database creation Preparation of technology transfer seminar
29 January (Tue) ～1 February (Fri)	Technology transfer seminar (see 3.3.6)
2 (Sat) ～8 February (Fri)	OJT of GIS (details in Table 3.8), GIS database creation
12 February (Tue)	Visit Japanese Embassy: Explanation of work results

3.3.4 Target personnel for the OJT

The same eight C/Ps listed lower in Table 3.5 had received the OJT in the 3rd Work in Malawi.

3.3.5 Contents of the OJT

The schedule and contents of the OJT executed in the 3rd Work in Malawi is shown in Table 3.8. Between the 2nd Work and the 3rd Work in Malawi, from middle September to early November, and between the first phase and second phase in the 3rd Work in Malawi on December, when the Study Team was absent in Malawi, C/Ps have executed the digitization of geological maps by themselves as part of OJT. Twenty sheets of geological maps, which is half amount of all 40 sheets, were consequently digitized by C/P. The rest 20 sheets were digitized by the Study Team during the 4th Work in Japan.

Table 3.8 Schedule and contents of the OJT

First Phase	Date / Week	Satellite data analysis by using ENVI
	5 to 9 November 1st week	・Ground truth for results of ASTER data analysis 5 to 7 Nov. : North, Northwest and West of Zomba 8 to 9 Nov. : Southwest and East of Blantyre
	12 to 16 November 2nd week	・Summary of ground truth ・Summary of ASTER data analysis
	19 to 23 November 3rd week	・PALSAR data analysis ・Extraction of lineament
	26 to 30 November 4th week	・Creation of GIS database ・Creation of data processing manual
Second Phase	Date / Week	GIS database creation by using ArcGIS
	8 to 11 January 5th week	・Summary of GIS data creation ・Correction of polygons ・Creation of geological map
	14 to 18 January 6th week	・Creation of GIS database
	21 to 25 January 7th week	・Creation of GIS data creation manual
	29 January to 1 February 8th week	・Technology transfer seminar (see Table 4)
	4 to 8 February 9th week	・Creation of GIS database management manual ・Methods to manage GIS database

3.3.6 Technology transfer seminar

(1) Participant

The Study Team requested to the director of GSD that the main participants should be new geologists who entered to GSD in 2012. As a result, ten geologists shown in Table 3.9 participated in the seminar

(2) Schedule

- 29 January to 1 February 2013
- AM: 9:00 to 12:00, PM 13:30 to 16:30

(3) Place

- OJT room at GSD
  with 5 PCs provided and used in OJT

(4) Contents

- 1st day: Theory of remote sensing, case study of ASTER data, practice of analysis by ENVI
- 2nd day: Practice of analysis by ENVI
- 3rd day: Theory of GIS, usage of ArcGIS, practice by ArcGIS
- 4th day: Practical data creation by ArcGIS

Table 3.9 Participant list of technology transfer seminar

		Position	Remarks
1	A	Geologist	New face
2	B	Geologist	New face
3	C	Geologist	New face
4	D	Geologist	New face
5	E	Geologist	New face
6	F	Geologist	New face
7	G	Geologist	
8	H	Geologist	
9	I	Senior geochemist	Two days participation
10	J	Geologist	Half day participation

3.3.7 Results completed until the 3rd Work in Malawi

(1) Satellite data analysis

(a) ASTER data (79 scenes)

・Preprocess (creation of mask data and band integrated data)

・Five kinds of band composite image

・Two kinds of band ratio image

・Principal Component Analysis (only in some area)

(b) PALSAR data (64 scenes)

・Mosaic image

・Lineament extraction (only in some area)

(c) Manual

・Data processing manual

(2) GIS data creation

(a) 1/100,000 scale geological map (40 sheets)

・Scan

・Georeference

・Digital trace (20 sheets)

*note: The Study Team completed digital trace works during the 4th Work in Japan.

・GIS geological data (40 sheets)

(b) Manual

・GIS data creation manual

・Creation and printing of maps

(3) Other GIS data

(a) Data collection

・Roads, railways, rivers, lakes, villages

・Administrative boundaries, international boundary

・Topographic contours

・National parks, protected areas

(4) GIS database construction

(a) GIS database construction

・All of results of satellite data analysis, GIS geological data and other GIS data were stored as one GIS database.

(b) Manual

・GIS database management

3.4 The 4th Work in Malawi

3.4.1 Objectives of the Work

・To report the Draft-final report and discuss the contents
・To create an action plan
・To hold the workshop to report the project results

3.4.2 Study Team

・ONUMA Takumi : Project management / related information compilation (Team leader)
・TAKEDA Masahiro : Remote sensing / mapping and mineral evaluation
・KOBAYASHI Hirohisa : Mineral resources database / GIS

3.4.3 Schedule of the Work

The Fourth and last Work in Malawi was executed from 18 May to 1 June 2013. The schedule is shown in Table 3.10. All members worked on the same schedule.

Table 3.10 Schedule of main jobs in the 4th Work in Malawi

Date	Schedule
21 May (Tue)	Meeting with GSD: Report the Project results
22 May ~ 23 May (Wed)	Preparation of Workshop, creation of action plan
24 May (Fri)	Workshop for Project results presentation (see 3.4.5)
27 May (Mon)	Visit the coordinator of World Bank in Ministry of Mining: Information exchange, explanation of project plan. Visit Japanese Embassy: Report the Project results
28 May (Tue)	Visit Principal Secretary of Ministry of Mining: Report the Project results

3.4.4 Action plan

The Study Team created the Action Plan in consultation with C/P; how will GSD make full use of personnel achievements of technology transfer in the Project, how will GSD utilize results of the Project and how will GSD contribute to development of mining sector in Malawi.

3.4.5 Workshop of results presentation

(1) Participant

78 persons: Ministry of Mining, Department of Mines, GSD(each domestic office), private companies, universities, local institutions concerned, newspaper company, JICA Malawi office, JICA Study Team and so on.

(2) Place

Conference room, Masongola Hotel in Zomba

(3) Date and time

20 May 2013 (Monday), from 9:00 to 15:00

(4) Program

- Self introduction of participants
- Opening prayer: AHRMO of GSD
- Opening speech: Acting Director of GSD
- Speech: Deputy Resident Representative of JICA Malawi office
- Summary of the JICA Project: Mr. Onuma, Leader of JICA Study Team
- Remote sensing data analysis and OJT: Mr. Takeda, Member of JICA Study Team
- Coffee break
- GIS database and OJT: Mr. Kobayashi, Member of JICA Study Team
- Results of JICA Project: Mr. Onuma, Leader of JICA Study Team
- Results of OJT: GSD staff
- Results of OJT: GSD staff
- Discussions
- Poster session (satellite images, geological maps): JICA Study Team
- Lunch break
- Impression of JICA Project and OJT: GSD staff
- Impression of JICA Project and OJT: GSD staff
- Impression of JICA Project and OJT: GSD staff
- Results of Training in Japan: GSD staff
- JICA Training Course in Japan: GSD staff
- Discussions
- Closing speech: Acting Director of GSD
- Closing prayer: AHRMO of GSD

4. Equipment to be provided

The equipment necessary for the works in Malawi, which was composed of satellite data, software and hardware, was procured in Malawi and Japan after the companies had been selected according to the prescribed procedures of procurement. The list of data and equipment provided is shown in Table 4.1 and photographs of hardware are shown in Figure 4.1 and 4.2. They will be provided to GSD in the end of the Project.

The Study Team carried the equipment procured in Japan to Malawi as luggage by airplane and brought them to GSD in Zomba. The equipment procured in Lilongwe was delivered directly to GSD. GSD bought 8sets of new desks and chairs for exclusive use of OJT. The Study Team set up the equipment in the cartography room on late June 2012.

4.1 Reason for selection

(1) Satellite data

Because the use of Japanese technology is the basic policy of the Project, remote sensing data of Japanese satellites ASTER and PALSAR were obtained. The ASTER optical sensor data features multi-band data with high resolution. The PALSAR SAR sensor data is characteristic of L-band multi-polarization data with high resolution. Free downloadable data of LANDSAT and ASTER G-DEM were also obtained.

(2) Software

As satellite data analysis software, ENVI of Exelis VIS was selected because it has spread globally and has become a standard particularly in South African countries. As GIS software, ArcGIS for Desktop Basic was selected for the same reason.

As software to make reports and presentations, Office 2010 of Microsoft, Illustrator and Acrobat of Adobe globally used in the world were selected. Kaspersky Anti-Virus of Kaspersky Lab was selected in order to prevent virus from PC, which is widely spread with high valuation.

The Study Team made the license registration of above software.

(3) Hardware

Large size printer and scanner is necessary because large maps are commonly handled in GSD. A0 size printer & scanner of HP which is widely spread with high valuation was selected. A4 size scanner of Canon, which has high scanning speed and is easy to handle, was selected in order to scan and store documents and books like bulletins of geological maps. A3 size color printer of HP which is inexpensive was selected in order to print ordinary documents and simple small maps.

PC and monitor of HP were selected because of global spread and easy procurement. They have higher specification because large amount of image data and GIS data would be treated. Large size pen tablet was installed in order to improve the operation of GIS data creation.

Projector and screen are necessary for OJT and lecture. Projector has higher resolution and higher brightness in consideration of the usage in small room. UPS is indispensable because blackout happens frequently. UPS with high capacity was selected in order to work longer as much as possible. However, the working time using UPS is limited and blackout continued for several hours, then small size and high capacity generator of Ryobi was installed in addition.

External hard disk is necessary for data backup and storing Project results. Two hard disks were prepared for working and backup saving. GPS is necessary to find route for survey site and to obtain position data in ground truthing OJT of satellite data analysis. GPS of Garmin was selected because of global spread and high quality. Ethernet hub is necessary to construct intranet in the OJT room. Five PCs, two external hard disks, A0 size printer & scanner, A3 size printer and PCs of the Study Team were connected by wired LAN.

(4) Consumables

Two sets of each color ink of A0 size printer and one set of print head for reserve were prepared. Three sets of each color ink of A3 size printer were prepared in advance. However, all of them were consumed and these inks were additionally bought as necessary. Each two rolls of matte paper and photo paper were prepared for A0 size printer.

Burglarproof steel chain with keys was prepared to prevent equipment from theft. Steel wires were attached to PCs, PC monitors and projector and fixed to desks

4.2 Equipment provided

The list of equipment provided which were procured according to above reasons and settled at GSD in Zomba is shown in Table 4.1. All equipment were procured and settled in 2012.

Table 4.1 List of equipment to be provided

	Name	Model number, specification	Amount	Procurement
Satellite data	ASTER	L3A product, Ortho data	79 scenes	Japan
	PALSAR	L1.5 product, HH polarization	64 scenes	Japan
	LANDSAT	Free download	12 scenes	WEB
	ASTER GDEM	Free download	One set	WEB
Software	ENVI	Ver.4.8, stand-alone license	5	Japan
	ArcGIS	Ver.10, stand-alone license	5	Japan
	Microsoft Office	Professional 2010	5	Japan
	Illustrator	CS5	5	Japan
	Acrobat	Standard	5	Japan
	Kaspersky	Antivirus 2012, two year license	5	Malawi
Hardware	Desktop PC Keyboard and mouse	HP Elite 7300 MT, 8GB RAM, Windows 7 Professional 64bits	5	Malawi
	LCD monitor	HP, 24 inches, 1,920x1,200 pixels	5	Malawi
	UPS	240V/1kVA, 600W	6	Malawi
	Generator	Ryobi, RG-2700, 2300W, 230V	1	Malawi
	Pentablet	Wacom Intuos 4, 481x304mm	5	Japan
	External hard disk	Baffalo, 4 TB, LAN connection	2	Malawi
	Color printer / scanner	A0 size, HP Designjet T2300	1	Malawi
	Color printer	A3 size, HP Officejet K8600	1	Malawi
	Flatbed scanner	A4 size, Canon, CanoScan LiDE210	1	Japan
	Print server	Planex, MZK-SP300N2, Wi-Fi connection	1	Japan
	Projector	EPSON EB915W, WXGA	1	Malawi
	Projector screen	i-View, Wide 80 inches	1	Malawi
	Eathernet hub	Cnet, 16 ports	1	Japan
	GPS	Garmin GPSmap62S	3	Japan
Consumables	Printer ink	HP72, HP88	One set	Malawi
	Printer paper	A0 size roll paper (mat, photo)	3	Japan
	Printer paper	A3 and A4 size paper	One set	Malawi
	HDMI cable		1	Malawi
	LAN cable		10	Malawi
	Power strip cable	Multi-plug adapter, multi outlets	8	Malawi
	Extension cable		2	Malawi
	Burglarproof chain		One set	Malawi

Figure 4.1 Photo of printers, projector and projector screen

Figure 4.2 Photo of PC, peripheral equipment and UPS

5. Basic information of geology and mineral resources

5.1 National policy related to mining

5.1.1 Policy related to mining

The Malawi Government designed MGDS 2006-2011 in 2005 with a fundamental principles, "The overall objective of the Malawi Growth and Development Strategy is to reduce poverty through sustained economic growth and infrastructure development." The Theme One of the five themes in the MGDS 2006-2011 is Sustainable Economic Growth. It is emphasized that poverty reduction through the sustainable economic growth and infrastructure development is the top priority to create wealth and employment. These include: maximizing the contribution to economic growth through the potential growth sectors. Increasing the contribution of the mining sector to GDP by at least 10 percent annually is one of the Long-Term Goal. Actually, is was about 2 percent in 2009, but rose up about 10% in 2011.

The Key Strategy of maximizing contribution to economic growth through potential growth sectors is as follows;

Big goal

To accelerate the geological and mineral data acquisition and dissemination to strengthen public-private partnerships in infrastructure provision.

Main strategies include:

- Strengthening the institutional capacity of Geological Surveys to effectively promote mining, monitoring and enforcement of environmental safety standards;
- Ensuring compliance by small, medium and large scale miners to environmental and safety standards;
- Supporting small scale miners by integrating them into the minerals market and increasing their value added;
- Increasing investment by private sector companies in medium and large scale mining; and
- Providing up-to-date information and geographical mapping on mineral resources.

The medium term expected outcome for mining is to increase production output and value added by small, medium and large-scale miners, to supply industrial raw materials in the country (import substitution) and to begin exporting minerals. To achieve this, a number of constraints facing the sector need to be addressed. These include; lack of up-to-date information on mineral resources, poorly coordinated institutional setting, high initial investment costs and inadequate incentives for private sector to engage in medium scale mining. In addition, small-scale miners lack skills to add value to mineral products, while electricity disruptions threaten production and safety of miners. Government will work with mining companies to accelerate the geological and mineral data acquisition and dissemination to strengthen public-private partnerships in infrastructure provision. It will continue to provide extension services to small-scale miners to learn value added skills. It will also improve the regulation and monitoring of mining to reduce threats to the environment, enforce safety standards, and reduce smuggling. With development of exploration of the private companies headhunting of administration official, expert about mining by the private companies causes a decrease in management ability of the government for the mining sector. This JICA project establishes the object of maintaining and adapting the human resources related to the mining sector for both quality and quantity because they are regarded as critical issues.

The MGDS II is designed as the second medium term national development strategy formulated to attain the country's long term development aspirations. This is adopted by Mrs. Joyce Banda, president of the republic of Malawi, assumed in April 2012 and National Assembly of Malawi. MGDS II 2011-2015 maintains the same themes as MGDS 2006-2011 and involves 9 key priority areas. Mining included in the theme 1: Sustainable economic growth along with Energy, Industrial Development and Tourism and all that, is situated on the second priority. The Mining is stated in the MGDS II 2011-2015 as follows;

Malawi has abundant mineral resources that can be exploited. These resources include bauxite, heavy mineral sands, monazite, coal, uranium, precious and semi-precious stones, limestone, niobium, dimension stones and rock aggregates. Government recognizes that the development of the mining industry can significantly improve the country's foreign exchange earnings and contribute to economic growth and development. To derive maximum potential of the mining industry, Government will pursue the following goal, expected outcomes and key strategies.

Goal

The goal is to increase production and value addition of mineral resources.

Medium-Term Expected Outcomes

The medium-term expected outcomes include the following:

- Updated geological information system;
- Increased exploration and mining;
- Increased participation by small and medium miners; and
- Improved legal and institutional framework.

Key Strategies

The following are the key strategies for realizing the sector's objectives:

- Producing detailed geological map of Malawi;
- Strengthening institutional capacity of the sector;
- Developing an integrated data management system;

・Strengthening seismic monitoring;
・Promoting both local and foreign investment;
・Enforcing environmental, occupational health and safety in the mining sector; and
・Enforcing legislations on sustainable use and management of mineral resources.

5.1.2 Governmental organization related to mining

In recent years, the Ministry having jurisdiction over the mining sector has changed rapidly, from the Ministry of Energy and Mines (MEM) in a few years ago, through the Ministry of the Environment, Energy and Natural Resources (MNREE), the Ministry of Energy and Mines (MEM), to the Ministry of mines (MM) at present. Being created a separate Ministry of "Mine", the Malawi government regards entirely the mining industry as very important.

The following public organizations in the Ministry of Mines are responsible for the management and regulation of the mining sector.

(1) Office of the Commissioner of Mines
It includes Mineral Rights Office.
Responsible for the handling and delivery of mining license application and enforcement of the Mining Act.
(2) Department of Mines
Responsible for mine development, mine safety and industrial health, reporting and monitoring of mining sector.
(3) Department of Geological Survey
To conduct basic geological mapping and mineral exploration, and publish the results.

5.2 Situation of mining sector

Malawi produces uranium concentrates, coal, gemstones, cement, crushed stones, kaolin, lime and limestone from its mineral deposits at present. Malawi exports only uranium, dimension stone and gemstones among them. Kayelekera Uranium Mine is only large scale mine, which was developed by Paladin Energy Ltd and started production in 2009. Other mining production is from small scale mining

Recent situation of mining production is shown in Table 5.1. Amount of mining production in 2010, total exports was 116 million US$ and national revenue was 1,135,000 US$ in 2010. Kayelekera Uranium Mine started in 2009 greatly distributes to the economy and its monetary value is extremely high and reached about 15% of total exports in Malawi.

Table 5.1 Mineral production and monetary values (2008~2010)

Type	2008		2009		2010	
	Quantity (t)	Value (K US$)	Quantity (t)	Value (K US$)	Quantity (t)	Value (K US$)
Coal	57,477	2,524	59,201	2,600	79,186	4,483
Cement limestone	45,980	213	47,150	219	57,296	277
Agriculture lime	23,495	109	25,900	120	31,790	881
Uranium concentrates	---	---	58,582	9,192	772,622	131,389
Granulated clay	7,023	246	8,050	282	1,020	38
Dimension stones	332	55	240	40	435	99
Rock aggregate	348,080	4,972	970,550	13,864	989,750	14,643
Clay pottery	4,210	---	---	---	---	---
Gemstones	11	46	306	1,811	207	4,329
Terrazzo	10,150	74	12,355	91	4,434	136

< Value is calculated as 1US$=140 MWK>

<Source: Undi and Mtaula, 2011>

Mining activities in Malawi has been mainly for coal, cement limestone, gemstones, precious stones, rock aggregate and industrial raw minerals, almost of which were utilized for small domestic demand. However, Paladin Energy Inc. began to operate Kayelekera uranium mine in 2009, and then the mining industry in Malawi has reached a large turning point. At first, Malawi government revenue from the mine has become a huge amount. In addition, the revenue that the Malawi government has held a 15% stake in the Paladin Energy Inc. occurs. Because the total amount of uranium concentrates that has been produced in the mine is exported, the foreign exchange reserves of Malawi chronically suffering from a lack of foreign currency has been greatly increased. From these points, the Malawi government now recognizes that the mining is essential as a sector of the economy in order to carry out the basic policy of the nation, such as medium-and long-term socio-economic MGDS.

Mineral explorations by foreign and domestic companies have been gradually recovering despite the slowdown due to the global economic recession which began in 2008. In fact, the number of exploration licenses which exploration companies have applied in southern African countries has been increasing due to the global economic recovery, and mineral exploration activities in Malawi have increased rapidly since 2009 compared to 2008. In addition, in the background of factors such as worldwide tight supply and demand of rare earth elements since the autumn of 2010 and the results that the large-scale mine was developed for the first time in Malawi, exploration activities in Malawi by foreign companies have become currently very active. The target mineral species are mainly uranium and rare earth elements, but including rare metals like niobium and tantalum, and also diamond. Main mine developments and exploration projects are shown in Table 5.2.

Table 5.2 Main mine developments and exploration projects

Project	Region/ District	Owned enterprises (ratio %)	Commodity	Remarks
Kayelekera	North / Karonga	Paladin Energy (85%), Malawi government (15%)	U	Produced in April 2009. Production in 2011 : 1,160 t (U_3O_8) Mineral resources : 14,728 t (U_3O_8) Average grade : U 0.081%
Ilombe Hill	North / Chitipa	Resource Star (90%), Nyalihanga Enterprises (10%)	U, Nb, REE	Airborne magnetic survey and soil geochemical survey in 2010
Kanyika	North / Karonga	Globe Metals and Mining (100%)	Nb, Ta, Zr, U	F/S stage at present. Production will start in 2014.
Livingstonia	North / Karonga	Resource Star (80%), Globe Metals & Mining (20%)	U	Provable reserve : 7.7 Mt Estimated average grade : U 0.027%
Kangankunde	South / Balaka	Lynas Corp (100%)	REE	U and Th are low grade. Malawi government approved the acquisition of rights in December 2010.
Songwe Hill	South / Phalombe	Mkango Resources (100%)	REE	Drilling survey in 2011~2012.
Salambidwe	South / Chikwawa	Globe Metals & Mining (100%)	REE	Rock, pit and auger surveys in 2010~2011.
Mulanje	South / Mulanje	Spring Stone (100%)	REE	Exploration license was approved in November 2011.
Machinga	South / Machinga	Globe Metals & Mining (80%), Resource Star (20%)	Nb, Ta, Zr, U, REE	Drilling survey in 2010. HREE mineralization was confirmed.

5.2.1 Active mines

(1) Kayelekera mine

The Kayelekera Mine (KM) is located in northern Malawi, 52km west (by road) of the provincial town of Karonga at the northern end of Lake Malawi. The Central Electricity Generating Board of Great Britain (CEGB) discovered the high grade Kayelekera sandstone uranium deposit in the early 1980's. CEGB spent US$9 million working on the project over an 8-year period, culminating in a full feasibility study in 1991 assessing the viability of a conventional open pit mining operation. This study indicated that the project was uneconomic using the mining model adopted and the low uranium prices prevailing at that time. The project was abandoned in 1992 due largely to the poor outlook for uranium, as well as privatisation of CEGB and resultant pressure to return to its core business.

The Company acquired the Kayelekera Project from Balmain Resources Pty Ltd (Balmain) in February 1998 under a joint venture agreement whereby the Company could earn an 80% interest in the project. In October 1999, the Company acquired a further 10% interest to bring the Company's equity to 90%. In July 2005, the Company announced the purchase of the remaining 10% stake held by Balmain. KM is owned 100% by Paladin (Africa) Limited (PAL) a subsidiary of Paladin. In July 2009, Paladin issued 15% of equity in PAL to the Government of Malawi under the terms of the Development Agreement signed between PAL and the Government in February 2007.

Kayelekera is a sandstone hosted uranium deposit associated with the Permian Karoo sediments and is hosted by the Kayelekera member of the North Rukuru sediments of the Karoo. The mineralization is associated with seven variably oxidised, coarse grained arkoses, separated by shales and chocolate coloured mudstones. Uranium mineralization occurs as lenses within primarily the arkose units and to a lesser extent in the mudstone units. The lowest level of known mineralization currently is at a depth of approximately 160m below surface.

Economic analysis on this Resource has indicated a break-even cut-off grade of 400ppm.

	Ore Reserve Estimate	Grade U_3O_8	Amount U_3O_8	
Proved Reserve	0.62 Mt	1,388 ppm	859 t	1.9 Mlb
Probable Reserve	7.08 Mt	935 ppm	6,614 t	14.6 Mlb
Stockpiles	1.82 Mt	877 ppm	1,598 t	3.5 Mlb
Total Ore Reserve	9.52 Mt	953 ppm	9,071 t	20.0 Mlb

Work in financial year 2012 concentrated at the mine site targeting deep mineralization to the west of the previous resource area and involved 9,554m of drilling in 62 holes. Regional exploration drilling completed 37 holes totaling 6,656m. Drilling was terminated early due to the onset of the rainy season. Regional exploration work continues to expand along the North Rukuru Basin, south of the mine site into the Mazongoni and Nthalire areas. Although only sub-economic uranium mineralization was identified at Mazongoni, geological mapping and ground radiometrics located prospective targets for follow-up drilling in 2012 in the Nthalire area. Scout drilling at Mwankenja, Mlowo and Mpata, all approximately 15km east of the mine site, identified uranium mineralization in two arkose units of up to 10m at 600ppm eU_3O_8 (MP0317).

5.2.2 Exploration activities of mineral resources

Foreign companies doing active exploration in Malawi are from United Kingdom, Australia, Canada and China.

Retail Star Ltd. of UK has carried out explorations for PGM, base metals, radioactive minerals and REE in Mzimba, Kasungu and Lilongwe Valley. Britannia Mining (UK) has done the exploration for iron ore in Mindale area near Blantyre.

Globe Metals & Mining Ltd. of Australia (East China Mineral Exploration and Development Bureau (ECE) held a 52.8% stake in April 2011) has actively carried out explorations for uranium in Livingstonia of northern Malawi, niobium, tantalum, zircon and uranium in Kanyika of central Malawi, rare earths in Machinga and Salambidwe. The Kanyika project is on final FS stage at present and will begin the operation in 2014. Paladin Energy Ltd. (Australia) has actively done the exploration for uranium in Chilongo, Chilumba and Mpata near Kayelekara mine. Lynas Corporated (Australia) is promoting the exploration of rare earths in Kangankunde body in southern Malawi, and it is said to be close to the development stage. Oropa Exploration Inc. (Australia) is exploring radioactive elements and base metals in Mzimba and Kasungu areas. MM Mining Inc. (Australia) is exploring base metals and PGM in Zomba and Kasungu areas.

Mkango Resources Inc. of Canada advances the exploration of rare earths in Songwe body in southern Malawi, and caught the enriched zone of medium and heavy rare earths as dysprosium (Dy), europium (Eu), terbium (Tb), currently at the stage of FS. Gold Canyon Inc. (Canada) is engaged in exploration targeting rare earths in Mulanje alkaline rocks of southern Malawi.

Beijing Zhongxing Joy Investment (ZXJOY) of China has the exploration for heavy mineral sands in Mangochi-Makanjira, the shores of Lake Malawi. Tengani Titanium Minerals has the exploration in Tenigani for rutile and ilmenite contained in the sediment of Shire River.

Lafarge Cement Malawi and Zagaf Cement are domestic companies to explore the limestone in the southern part of Balaka district. Premier Team Work and Batolwe Mining explores coal in the Northern Province of Malawi. Lisungwe Mineral Resources explores pyrite and pyrrhotite in Malingunde near Lilongwe.

Carbonatite is a peculiar igneous rock mainly composed of carbonate (calcite, ankerite and so on) and is distributed in Chilwa alkaline province in the southern Malawi. These carbonatite characteristically include valuable minerals such as rare earths, niobium, tantalum, phosphate and vermiculite. Alkaline rocks like nepehline syenite, which has the potential of the same valuable minerals, are also known to be distributed in many places (Woolley, 2001). "The mineral exploration project in Chilwa-alkaline province" (JICA/MMAJ, 1986~1989) was executed focusing the southern Malawi where many carbonatite bodies are distributed. As a general result including drilling survey, meaningful mineralization (rare earths, apatite and so on) was clarified in several places.

Most mining of gemstones and precious stones have been carried out as a petty small-scale mining. Social protection and relief of these workers are also one of the basic policies of the government, which is also described in MGDS.

5.3 Geology and structure

5.3.1 Geology

The greater part of Malawi is underlain by crystalline rocks of Precambrian to lower Paleozoic age which are referred to the Malawi Basement Complex. In a variety of places, these rocks are overlain unconformably by sedimentary rocks and subordinate alkaline igneous complexes which range in age from Permo-Triassic to Quaternary. The sedimentary rocks belonging to Karoo System range in age from Permian to upper Triassic or lower Jurassic. The alkaline igneous complexes are mainly distributed in the south of the country around Lake Chilwa called Chilwa Alkaline Province. Figure 5.1 demonstrates sedimentary rocks of late Jurassic to Tertiary and Quaternary deposit in addition to three geological domains above mentioned.

(1) Basement Complex

The gneisses and granulites which constitute the greater part of the Basement Complex have undergone medium to high grade metamorphism and polyphase deformation.

The orogenic activities attributed to the genesis of the Basement Complex in Ubendian (2,300~1,800Ma) and Irumide (1,350~950Ma) are limited in northern and central Malawi. The representative lithologies are Songwe biotite-amphibole gneiss, Chambo mica pelitic/semipelitic biotite paragneiss and Jembia River granulite. Rumphi igneous complex and Nyika granite intrudes at the end of Ubendian orogeny. The Basement Complex mainly comprises Muva Supergroup (1,850Ma) in central and southern Malawi. The Muva Supergroup consists of pelitic/semipelitic gneiss containing abundantly amphibole-biotite paragneiss including units of marble, calcsilicate gneiss, quartzite and muscovite schist. Mafingi group in north and Mchinji group in south constitute silicic and clastic metasediments formed during second cycle of orogeny with age 1,400Ma. The metamorphism and deformation occur on these groups at 1,100Ma during Irumide orogeny. Consequently calc-alkaline granite intrude at 1,050~950Ma. The peak metamorphism and deformation on the Basement Complex occur at Mozambique orogeny, a part of Pan-African orogeny. The magmatism and high grade metamorphism associated with Mozambique orogeny in southern Malawi result are related to pyroxene granulite, charnockitic orthogneiss, parthitic complex and small bodies of mafic to ultramafic rocks.

Nepheline syenite intrusions, such as Ilomba and Ulindiin, of early Pan-African (750~710Ma) are distributed in central and northern Malawi. Other intrusions, Mlindi, Little Michuru and Ntonya, outcrop in southern Malawi.

The Basement Complex is important repositories of gem stone (ruby and sapphire), vermiculite, limestone and marble. In addition, barite, fluorite, nepheline syenite, rare-earth metals, phosphate, niobium, tantalum, thorium, uranium and zirconium. They may also be sources of copper, titanium, strontium, and lateritic nickel.

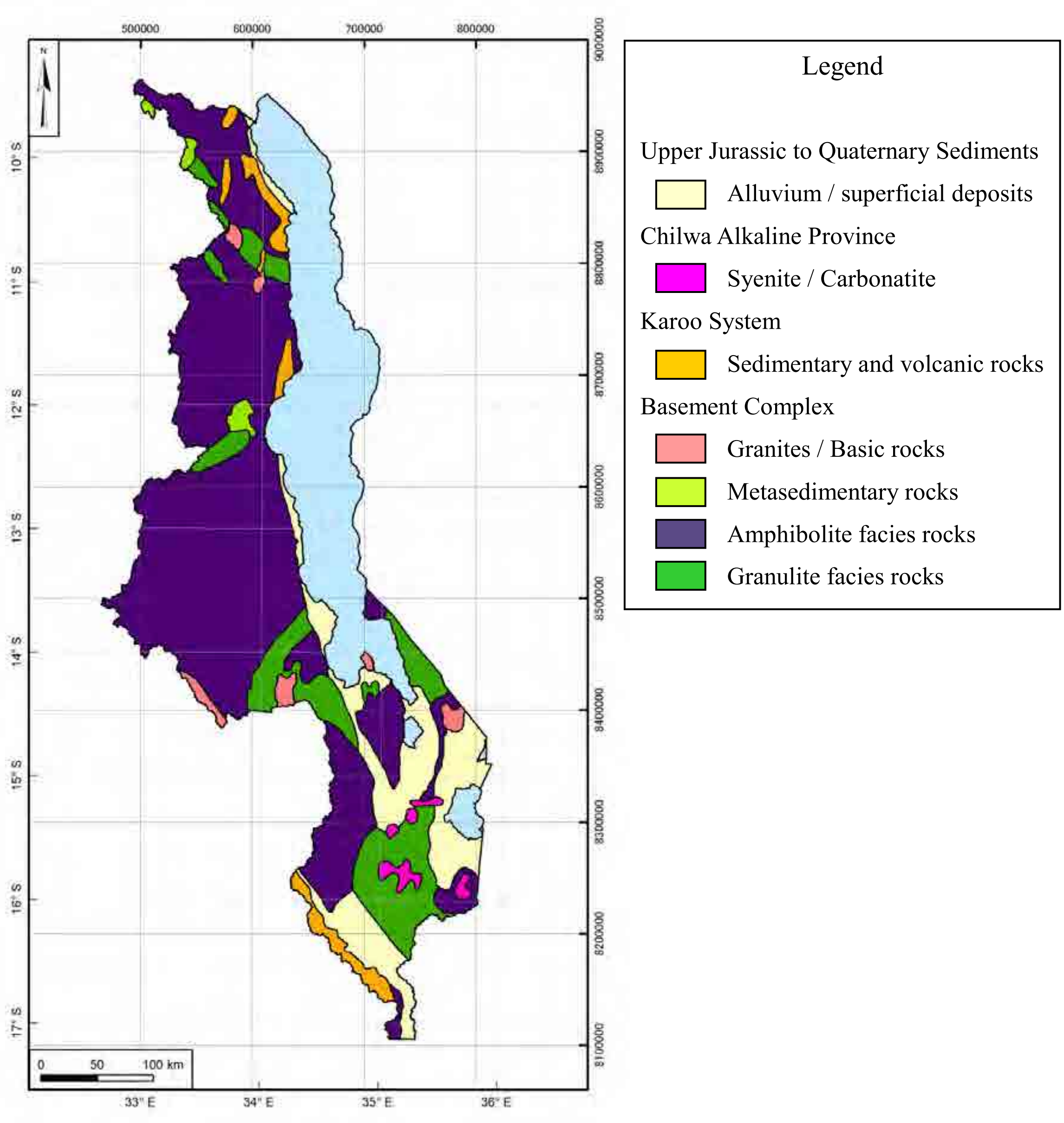


Figure 5.1 General geological map in Malawi

(2) Karoo System

Karoo System sedimentary and volcanic rocks, ranging in age from Permian to upper Triassic or lower Jurassic, crop out in the north of the country and in the south along the Mozambique border to the southwest of Blantyre. Lower Jurassic (Stormberg Series) lavas representative of the uppermost part of the Karoo succession occur within the southern outcrop. The Karoo System and Post-Karoo which is sedimentary rocks of late Cretaceous to Tertiary cover the Basement Complex.

The Karoo system strata are preserved in a number of N-S trending basins and downfaulted troughs and they display both unconformable and faulted relationships to underlying Basement Complex gneisses. The basal beds of the succession consist of conglomerates and sandstones. They are overlain by a coal measure sequence of sandstones, carbonaceous shales and coal seams. The Karoo succession in the north is completed by thick development of arkose and shale and by mudstones, marls and grits.

In southern Malawi the Karoo succession differs in certain respects from that in the north; deposition is believed to have commenced rather later and to have continued longer. Local developments of basal conglomerate are overlain more widely by mudstones, sandstones and thin coal seams. These rocks are succeeded by thick developments of grits, sandstones and shales.

Major faulting during the early Jurassic initiated the eruption of a series of basaltic lava flows, the majority being of fissure type formed under terrestrial conditions. Dolerite dykes and sills form major swarms in Basement Complex of parts of southern Malawi. They are particularly prominent to the south of Blantyre, where they trend predominantly NE-SW. The dykes are also emplaced along fault lines and some acted as feeders for the laver flows.

Although the distributional area of the Karoo System is not major in Malawi, it occupies an important position from the view of deposits of coal and uranium. Kimberlites characteristically intrude in the sedimentary basin of Karoo System.

(3) Chilwa Alkaline Province

The Chilwa Alkaline Province of southern Malawi has an exceptional range of lithologies from carbonatite to alkaline granite and lies at the southern end of the East African rift. The largest plutons consist of syenite and peralkaline granite with smaller intrusions comprising syenite, nepheline syenite, sodalite syenite and carbonatite. Their intrusions occur in the early Cretaceous age (135~113Ma) that related to the rifting of the Gondwana supercontinent. The intrusions sometimes display ring fracturing and cauldron subsidence.

All of the 14 intrusions of carbonatite occur in southern Malawi (Woolley, 2001). The carbonatites commonly include pyrochlore, bastnaesite, monazite phosphate, fluorite and carbonate and have a prospecting potential for economic element such as Nb, Ta, REE, apatite, Sr, Zr, Th.

In northern Malawi, the magmatic activities with the same age as Chilwa Alkaline Province are kimberlitic breccia intruding into the Karoo system in Livingstonia, dolerite, syenite and pyroxenite intrusions.

(4) Upper Jurassic and Cretaceous

Sedimentary rocks of upper Jurassic and Cretaceous age crop in the north of Malawi and near Mozambique border to the southwest of Blantyre. In the north, Dinosaur beds consist of friable sandstones, sandy marls and clays. The beds rest unconformable on the Basement Complex and locally on the Karoo formations. The sedimentary rocks in southern Malawi comprise a sequence of pebble conglomerate, coarse sandstones, sandy shales and marls, all of which tend to be calcareous. These rocks overlie the Karoo formations unconformably.

(5) Tertiary

Tertiary lacustrine deposits occur in a narrow belt aligned parallel to the lakeshore. They are varieties of clastic sediments of coarse sandstone, sandstone, mudstone sand, gravel, calcareous marl, silt, and shell limestone. They conformably overlie the Basement Complex and Mesozoic sedimentary rocks.

(6) Quaternary

Quaternary deposits of lacustrine, alluvial and colluvial type are particularly well developed along the shore of Lake Malawi in the extreme north and to the south. Extensive deposits of this type also occur around Lake Malombe and Lake Chilwa and in the Shire Valley.

5.3.2 Geological structure

The post-Basement Complex structure history of Malawi has been dominated by crustal warping and epeirogenic movements. It is reflected in the development of several major erosion surfaces and in widespread faulting. The chief expression of the latter is the Malawi Rift Valley which forms part of the extensive East African Rift System.

Malawi Rift located on the southern portion of Western branch of the East African rift system has an extension of c.800km. The width and average altitude of the Malawi Rift are 40~90km and 474m, respectively. The topography of Malawi is controlled by the formation of this linear trough (graben) which has been flooded by Lake Malawi and guides its drainage to the south through the Shire Valley. The Malawi Rift consists of horst and half-grabens, their bordering faults, synthetic faults, with altitude of 1200~2500masl, related to the tilted crustal block, and monocline structure. The strike direction of the Malawi Rift varies from NS to NW-SE in the Shire Valley at the latitude 16S and continue to the Urema rift in Mozambique.

The Malawi Rift is largely non-volcanic, with sediments of over 3km in thickness now estimated in the Lake Malawi graben and the Lower Shire Valley. The Malawi Rift Valley remains seismically active to the present day.

5.4 Mineral resources

Type of mineral resources in Malawi is variable. Some are associated with the Basement Complex generated by multi orogeny occurring from Precambrian to early Paleozoic. Others have been producing by the present day rifting at the bottom of Lake Malawi. The genesis of the mineral resources is divided into 4 types on the basis of their related geology. Figure 5.2 displays the distribution of major mineral deposits and resources in Malawi.

(1) Mineral deposits associated with Basement Complex (Precambrian to early Paleozoic)
(2) Mineral deposits associated with Karoo Supergroup and post-Karoo (Permian to Triassic)
(3) Mineral deposits associated with alkaline magmatism
(4) Deposits resulting from residual weathering, placer and rift-related sedimentation (Cenozoic to recent)

Rare earth elements, rare metals such as Nb and uranium resources in Malawi recently attracted. The former two resources are included in the alkaline igneous complex and carbonatite characteristically related to the Malawi Rift. The latter is hosted in the Permian to Triassic sand stone of Karoo Supergroup.

5.4.1 Mineral deposits associated with the Basement metamorphic and igneous rocks

The Malawi Basement Complex, which occupies 85% of the land area, is mainly composed of paragneisses, granulites and felsic to ultramafic (meta-) igneous intrusive rocks. Known deposits include gold. nickel, copper, graphite, limestone/marble, iron sulphide, kyanite, gem corundum/ruby and pegmatite-hosted precious and semiprecious gemstones.

(1) Nickel - Copper - Platinum Group Metals (PGM)

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

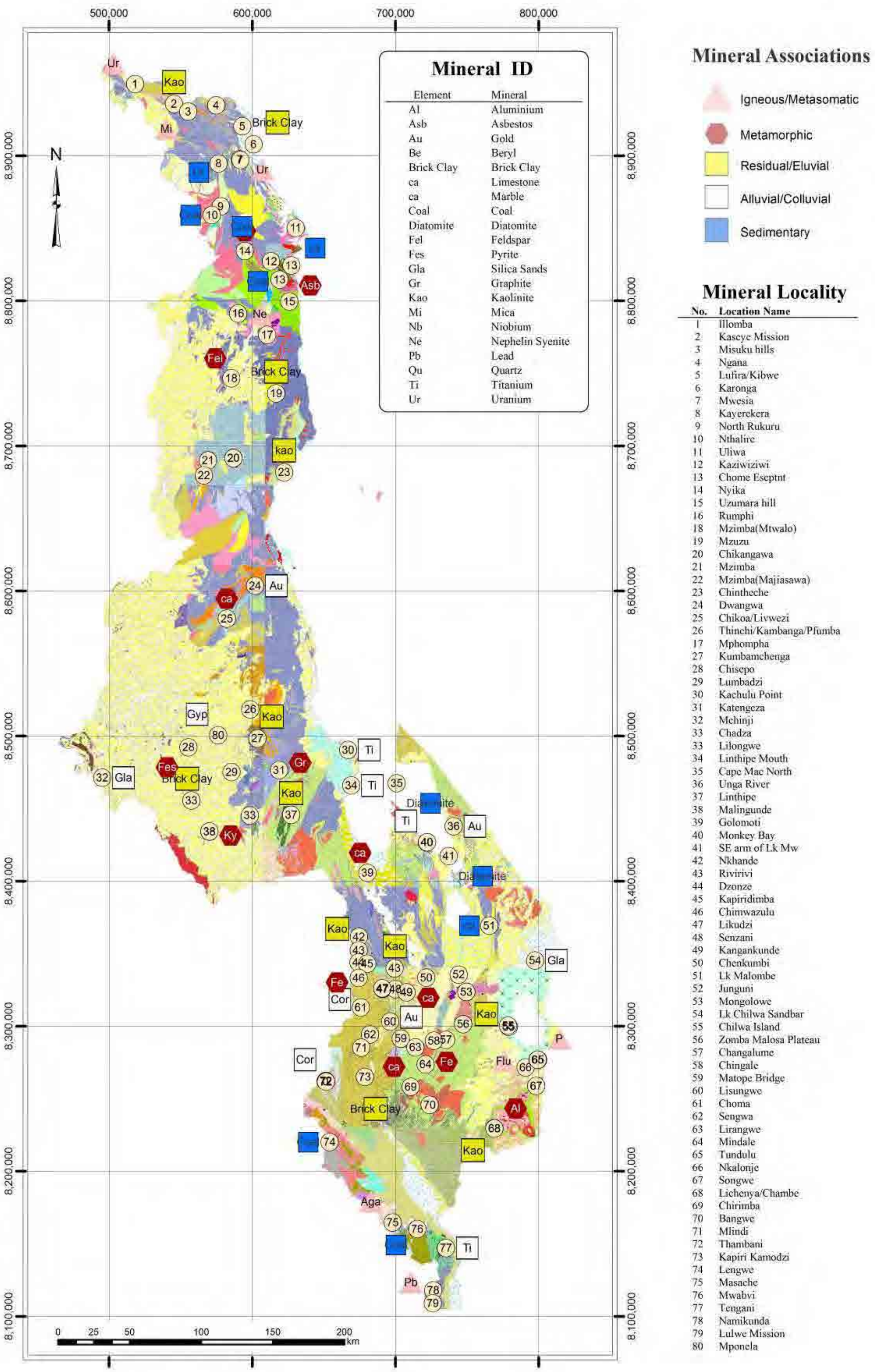


Figure 5.2 Mineral resources map

There are 85 known mafic/ultramafic (or ultrabasic) bodies of significant size with possible nickel-copper mineralization in the Basement Complex in Malawi. These bodies include serpentinised peridotites, pyroxenites and metapyroxenites, biotitites, olivine gabbros, gabbros, norites, anorthosites and amphibolites. Some could be parts of layered intrusions. Several bodies have been investigated by Minex companies and the Geological Survey but economic Ni - Cu deposits have yet to be identified.

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

From geochemical surveys the following bodies show some potential:

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

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

(c) Mpemba, Maperera, Chimwadzulu and Likudzi in the southern region. The Mpenba Hill ultrabasic body registered values up to 6000ppm Ni in the residual soil. At Likudzi an area of serpentinite measuring c. 900×200m yielded values of 2000ppm (max 7000ppm) Ni and 300~500ppm Cu. Anomalous PGM values of up to 420ppb Pd and 104ppb Pt also have been reported by Lisungwe PLC over a strike length >l km. At Maperera and Chingozi there are strong coincident Cu-Ni anomalies over pyroxenite. At Chingozi the Cu-Ni and geophysical anomalies are coincident. At Chimwadzulu and Chimimbe Hill where there are no sulphides and no correlation with the mapped rock types with high nickel values the anomalies are largely attributed to supergene enrichment.

Chromite and Cr magnetite occur in the overburden on Chimwadzulu and Chimimbe hill ultramafic bodies. Chimwadzulu is also characterised by a linear PGM anomaly that closely parallels the base of the intrusion. This suggests that the primary nickeliferous mineralization is associated with cumulate PGM-enriched chromitite layers.

The Mpemba Hill Prospect is located 20km to the SW of Blantyre in southern Malawi is currently being investigated by MM Mining Pty Ltd (75%) in partnership with Albidon Ltd. It comprises a series of pyroxenitic to gabbroic intrusive rocks that contain disseminations and clots of nickel sulphides at many localities plus Ni and Cu soil geochemical anomaly that extends over an area greater than $3km^2$. There are historical reports of rock samples yielding assay results of up to 2.9% Ni and 2.7g/t PGM, along strike to the northwest of the main intrusion.

The mafic-ultramafic body of Mpemba Hill occurs within mafic to felsic pyroxene granulites and banded homblendic gneisses with amphibolites. The ultramafic body is dominantly websteritic locally including olivine. The sulphides are scattered in apparently haphazard patches throughout the whole intrusion as pyrite, nickeliferous pyrrhotite and subordinate chalcopyrite where they typically form 0.5~1% of the rock. The greatest visible concentration of Ni-Cu sulphides (c. 5%) occurs in the Nseche sector in the northwest suggesting that this might be the locus of a feeder at depth. This is comparable with the Mudi River feeder zone where a 100m wide zone with c. 10% pyrrhotite-pentlandite had been previously reported. The sulphides have ratios of po:pn:cp of about 79:9:12, typical of moderate tenor magmatic sulphide mineralization derived from gabbroic rather than picritic or ultramafic magma. The sulphides appear to be orthomagmatic rather than hydrothermal in origin. Ni values from trenches typically averaged 0.2% Ni (maximum of 0.32% Ni) and Cu contents in the region of 0.1%. Pt and Pd levels in soils and mineralized rocks were low and dispel earlier ideas of Platreef-style marginal PGE mineralization at Mpemba. There has been some surficial upgrading of Ni and Cu values although none of the rocks currently exposed at surface exhibit strong lateritic weathering as at Chimwadzulu and Chimimbe.

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

The Ngala Hill Copper prospect was first investigated by Phelps Dodge and Placer and the licence was granted to MM Mining in December 2007. Ngala Hill ultramafic body consists of metapyroxenite, pyroxene amphibolite and hornblendite with a small zone of malachite mineralization. The ultramafic body (2.5km×0.35km) is emplaced into NW-SE striking pyroxene- and hornblende-bearing foliated gneisses of the basement complex. A Cu-mineralized zone is c. 15m wide and 60m long and contains about 2% malachite as coatings on cleavage planes and interstitial sites. Geochemical soil sampling showed separate discrete areas of high Cu (>300ppm), Ni (>400ppm), Cr (>800ppm) and Co (>150ppm). In some parts there is considerable overlap of the Cu and Ni anomalies but, whereas the Ni, Cr and Co values are close to local background, the Cu values are anomalously high. Values of >2000ppm Cu occupy an area of 100m×50m, the long axis being NW-SE. The area includes the zone of malachite staining. Values of >500ppm Cu offer a much larger target. Trenches have registered 64m @0.14% Cu and 1.4g/t PGM and 12m @3g/t with a maximum of 0.75% Cu and 3.8g/t PGM.

(2) Copper

There are a number of copper showings recorded in the Basement Complex but the most significant is at Namikunda Hill in the Nsanje district of southern Malawi. The stratabound primary copper mineralization comprises disseminated pyrrhotite with minor amounts of chalcopyrite arid covellite within thin bands of calcsilicate gneiss. Ferruginous gossans with secondary copper carbonates (malachite and azurite) are developed at surface. The shallow-dipping principal lode, which is 0.6~1.3m thick has been described as a gently undulating shear zone. This has a drill indicated reserve of 1,675t at 3.5% Cu over a strike length of 33m. Very low grade Cu and Zn mineralization has been reported over a 600m thickness and is locally associated with graphitic gneisses.

(3) Gold

Gold has been previously worked in the Kirk Range-Lisungwe valley area in southern Malawi and has been reported in the Dwangwa and Malindi-Makanjira areas. The Kirk Range-Lisungwe valley has been subject to various investigations by the Geological Survey Department (1934~35; 1958~62; 1992~93) and, after re-examination of the UNDP airborne magnetic and radiometric data acquired in 1984~85, is currently drilling some target areas in the Manondo area following a detailed geological and geochemical survey. The gold is mainly hosted in decimetre-scale quartz pyrite lodes and stringer zones up to 1~2 metres thick and enhanced residual concentrations occur in the overlying regolith. The main workings date from the 1930s and include Breeze's, Palula Mine and Peterkin's vein. An inclined shaft sunk to 27 metres depth on a gold mineralized structure at Palula Mine yielded channel sample values of 0.6~11.8g/t (av. 2.7g/t) over a 1.2 metre width. The geochemical survey indicated that the mineralized zone extends NE-SW and appears to be part of the same system as mined at Breeze's, 1.5km to the southwest. The gold is structurally controlled and is now recognized as being associated with the Manondo-Choma thrust. Residual gold contents of 12~42g/t have been reported in the regolith above the bedrock mineralization arid averages at 2.6g/t over a workable area. The northeast-trending gold-bearing Manondo-Choma thrust is 13km long and dips SE. Pelitic gneisses with calcsilicate-rock and marble units and with historical gold workings occur in the hangingwall rocks and pelitic gneisses with metabasic gneisses and amphibolites in the footwall. Old gold workings, Manondo or Breeze's are located at the southwest end of this zone.

A report by ERA-Maptec Ltd. (2000) who carried out a satellite image interpretation and integrated this with other remote sensing (gravity, aeromagnetic, airborne radiometric and EM) and map data indicates gold anomalies and old workings occur in an arcuate belt 40km long and 5km wide surrounding the Lisungwe Anatectic Complex. The anomalies correlate with the Chongwe Schist and its radiometrically interpreted equivalents on the southeast side of the complex. ERA suggested four genetic models for gold deposits in the area:

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

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

Key geological features of IRGS deposits include:

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

(4) Precious and semiprecious stones

A wide range of precious and semiprecious stones are found in the districts of Nsanje, Chikwawa, Mwanza, Ntcheu in the south and Kasungu, Mzimba, Rumphi and Chitipa in the north of the country respectively. The commonest semiprecious stones are aquamarine (blue beryl), emerald, amethyst, gem tourmaline (pink, green and yellow), smoky and rose quartz, sunstone, heliodor, rhodolite (pyrope-almandine) and almandine garnet. Canary yellow tourmalines were first discovered in Malawi in the autumn of 2000 and are highly prized. The Chimwadzulu Hill and Likudzi ultramafic bodies in the Kirk Range district to the south of Ntcheu in southern Malawi have both yielded gem quality ruby corundum. At Likudzi, small pieces of dark red corundum occur in amphibolitic zones within the serpentinite body.

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

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

A swarm of gem-bearing pegmatites occur in the Mzimba district and extend from northern Kasungu through Chikangawa to the Kafukula area on the Zambian border. The host pegmatites range in length up to several hundred metres. They both obliquely crosscut and are concordant with the Basement Complex gneisses which strike predominantly NE-SW. The gems include aquamarine, amethyst some rose quartz and colored varieties of tourmaline. Gem-quality aquamarines (blue beryl) occur in zoned mica pegmatites at several localities in the Mzimba district. The Mphungu pegmatite strikes NE conformable to the schistosity of the host sillimanite-biotite gneisses.

(5) Vermiculite

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

(6) Limestone, dolomitic limestone and marble

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

The largest known deposit occurs at Changalumi, 13km west of Zomba, with an estimated resource of 100Mt. This was exploited by the Portland Cement Co. Ltd. in a 200,000tpa operation up to 2002. The overall poor quality of the marble (85% $CaCO_3$) and large volumes of waste adversely affected the economics of the operation. Deposits of calcitic and dolomitic limestone amounting to >10Mt occur in the Chenkumbi Hills, c. 10km east of Balaka. The marble is variable in texture and composition in which calcite makes up 60~99% and dolomite up to 40%. Parts of the deposit comprise pure dolomitic marble that has been exploited on a small scale for lime burning. Following the ITDG-USAID funded operation in the 1980s the Chenkumbi limeworks, using more efficient vertical shaft kilns, was established in 1991. Lefarge Portland is now commencing a new USD 75 Million limestone project at Chenkumbi Hills.

The Bwanje Valley limestone deposit at the southern end of Lake Malawi was evaluated by Met Chem Inc. of Canada in 1997 for the manufacture of chemical grade lime. 4Mt of calcitic ore grading 52% CaO, 0.99% MgO and 5.2% SiO_2 was delineated. Another block of 14.85Mt with 46.8% CaO and 1.2% MgO was also outlined. 22.4Mt of dolomitic marble reserves occurs in the same area. The Chikowa-Livwezi limestones/marbles have 17Mt of proven reserves with <1.5% MgO but contain abundant silicate impurities. The marbles are interbanded on all scales with garnet-biotite paragneisses, quartzofeldspathic rocks and calc-silicate gneisses. There are, however, substantial bodies of marble with <10% silicates. Marbles with >93% total carbonate grade at 52~54% CaO and 0.2~0.5% MgO. Those with 75~93% total carbonate contain 45.6~46.0% CaO and 0.7~1.5% MgO.

The Shayona Cement Corporation currently produces 150t of cement per day using vertical shaft kiln technology using limestone from Livwezi. There are plans to expand production to 400t/d (>140,000tpa) by the end of 2009. High magnesia dolomitic limestone contains >15% MgO and is mainly used as building lime and in the sulphite paper-making process. Pure dolostone/marble (c. 21.7% MgO) is an important material for the manufacture of refractories. The Lirangwe marble in the Kirk Range is highly dolomitic (>18% MgO). There are two types: <10% calcite and 25~40% calcite. A local lime burning industry has been in operation for many years and reserves appear adequate for this to continue on a small-scale for some time to come. The Matope marble from the same area has reserves of c. 650,000t of highly magnesian marble composed almost entirely of dolomite (54.8~56.7% CaO; 41.8~42.6% $MgCO_3$). It has been also the focus of traditional small-scale lime burning.

(7) Graphite

Deposits of crucible-grade flake graphite occur at Katengeza village in Salima district about 60 km northeast of Lilongwe. A feasibility study carried out in the early 1990s delineated 2.7Mt of graphite ore averaging 5.8% carbon (i.e. total of 157,000t of carbon). It is well located in terms of transport infrastructure. Large resources of flake graphite have also been discovered at Chimutu to the east of Lilongwe. Detailed evaluation of this resource is required but the provisional average grade of the ore is about 10% carbon.

(8) Iron Sulphide

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

10Mt of proven reserves at 10% sulphur occur at Malingunde Hill in the Lilongwe district and a further 34Mt grading at 8% sulphur occur at Nkhanyu Hill in the Chisepo area of the Dowa district. Additional resources of 5.5Mt of pyrite-pyrrhotite grading at 8.9% sulphide have been delineated on Kadamsana Hill in the Chisepoarea. On the Malingunde Hill the disseminated sulphide mineralization is hosted by interlayered kyanite-graphite-muscovite schists, gneisses and metaquartzites that dip at a moderate angle to the ENE. It is probable that there are large unexplored resources in the poorly exposed Lilongwe-Dowa area. Localisation of the Malingundi and Chisepo iron sulphide deposits close to a major north-south structural discontinuity may be significant and is worthy of further investigation. They have been reported to be associated with low angle shear zones. Graphitic iron sulphide belts in Central Malawi have extensive gossan mantles and yield gravity and magnetic anomalies. Elevated values of gold, silver and zinc have been noted at Malingunde Hill. Bodies of disseminated sulphides (mainly pyrrhotite with some pyrite) also occur near Nanzeka Hill in the Nkhotakota district. The sulphide content locally exceeds 25%.

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

5.4.2 Mineral deposits associated with alkaline magmatism

Alkaline magmatism in Malawi has occurred during the early phases of intracontinental rifting events with melt generation by mantle upwellings beneath thinned crust. The main activities of alkaline magmatism in Malawi occurred three times. Alkaline rocks are rich in alkaline component (Na_2O+K_2O) and include feldspathoids and alkali pyroxenes/amphiboles. Alkaline rock types range from felsic to ultramafic and are found in several associations characteristics by distinctive rock types including carbonatites. Alkaline magmatic systems are important repositories of barite, fluorite, nepheline syenite, rare-earth metals, phosphate, niobium, tantalum, thorium, uranium and zirconium. They may also be sources of copper, titanium, strontium, vermiculite and lateritic nickel.

The age of the first alkaline magmatism is Neoproterozoic and occurred in central and northern Malawi. That area called Neoproterozoic North Nyasa Alkaline Province (NNAP) consists of seven intrusions (Kasungu, Chipala, Chikangawa, Mphompha, Telelele Hill, Ilomba and Ulindi) and lie along a north-south trend roughly parallel to the current rift valley. The dominant lithology is nepheline syenite, but alkali syenite and granite occur at Mphompha and pyroxenites outcrop adjacent to, and within the Ilomba intrusion. NNAP plutons were metamorphosed at c. 450Ma during the Pan African event.

The second activity is the late Pan African alkaline ring complexes of southern Malawi including Thambani, Bilila, Chingale, Mlindi, Little Michuru and Ntonya. They typically contain metapyroxenite cores with peripheries of syenite and hybrid rocks. In addition there is a swarm of biotitite bodies that are considered to be metasomatised derivatives of intrusive ultramafic rocks. The Mlindi ring complex, dated at 495Ma (late Cambrian), contains from the centre ourward: pyroxenite, gabbronorite to syenogabbro, gabbro-diorite and syenite. This second activity has no association with carbonatite.

The alkaline magmatism occurred in Chilwa Alkaline Province of southern Malawi in the early Cretacesous (135 to 113 Ma). It lies at the southern end of the East African rift and is unique for its essentially intrusive character ranging from carbonatite and granite. The largest plutons consist of syenite and peralkaline granite with smaller intrusions comprising syenite, nepheline syenite, sodalite syenite and carbonatite. Metamorphosed basanite / nephelinite volcanics are mainly preserved in down-faulted blocks. Extrusion of nephelinitic lavas and emplacement of nepheline and sodalite syenite and syenites at c. 135Ma was followed by nepheline syenites and syenites at c. 126Ma and large syenite-peralkaline granite plutons at c. 113Ma. The major alkaline complexes are Junguni, Mongolwe, Mulanje and Mthache Hill. Chilwa Island, Tundulu, Songwe and Kangankunde are major carbonatite intrusions.

(1) REE

Rare Earth Metals include the 15 elements of lanthanides with scandium and yttrium. The main economic minerals are bastnaesite and monazite.

Monazite occurrences are widespread throughout the Chilwa Alkaline Province and locally form residual concentrations in heavy mineral sands. The Kangankunde Complex consists of roughly concentric zones of agglomerate, breccia, feldspathoid gneisses and fenites surrounding a core of ankeritic and sideritic carbonatite with monazite, strontianite and disseminated manganese oxides. It differs from all the other large carbonatitic centres both in the lack of soviet and the abundance instead of strontianite-rich ankeritic carbonatites. The monazite is reknown for its high Ce content and extremely low thorium and uranium levels. The deposit has an inferred resource of 107,000t of rare-earth oxide (REO) at an average grade of 4.24% REO using a 3.5% REO cut-off grade. Testwork shows that the deposit is amenable to low-cost gravity separation producing a 60% REO concentrate. The Tundulu Complex contains large quantities of REE minerals, mainly bastnaesite, in addition to substantial reserves of apatite. The rocks of Nathache Hill are estimated to contain >3,225,000 tonnes at 2.4% REO per 30 metre depth.

(2) Coltan metals, uranium and zirconium

Nb-Ta-U pyrochlore and zircon mineralization is typically associated with nephelinitic and carbonatite intrusives either as primary magmatic or replacement deposits (intra-intrusive veins or stringer zones, extra-intrusive fenites or veins). The residual weathering accumulations from either deposit type may also be economic.

The Ilomba Hill Alkaline Complex in the far northwest of the country was investigated by surface trenching in the 1950s and returned analyses of up to 2.15% U_3O_8 and 7.50% Nb_2O_5 associated with uraniferous pyrochlore. The total resource amounts to 0.1Mt of Nb_2O_5 at a grade of 0.3% Nb_2O_5. Titanites and eudialytes contain up to 11% Nb_2O_5 and >3.5% Nb_2O_5 respectively which reflects a high Nb activity in the primary melt. The high Nb / Ta ratios are more typical of carbonatites and the nearby presence of the Nachendezwaya carbonatite complex in Tanzania suggests a linkage between these intrusions.

Globe Metals and Mining Ltd. is undertaking a pre-feasibility study of its Kanyika multi-commodity (Nb, U, Ta, Zr) deposit, 55km NE of Kasungu in Central Malawi. The Kanyika mineralization is hosted in a N-S striking intrusive body of nepheline syenite emplaced in basement gneisses that is coincident with a strong airborne radiometric anomaly. The host mineralized alkaline igneous rock has an overall dip of 45~80˚ to the west, is over 3.5km long and up to 300m in width. High-grade ore zones occur immediately adjacent and parallel to the footwall and hangingwall in the central and northern Milenje zone. The inferred Joint Ore Reserves Committee (JORC) resource, defined over 2.1km strike length, and to an average vertical depth of 120m is 56.4Mt at 0.26% Nb_2O_5 (145,000t), 0.007% U_3O_8 (4,000t), 0.012% Ta_2O_5 (6,600t) and 0.48% $ZrSiO_4$ (272,400t) based upon a 0.15% Nb_2O_5 cut-off. Current exploration is focusing on the Milenje zone which is the northern extension of the footwall Chikoka zone further south. Within the broad westerly-dipping high-grade marginal parts of the mineralized intrusion the ore is locally controlled by sub-vertical, S2 foliation-parallel pyrochlore and zircon-rich pegmatitic segregations and veins. These form en echelon arrays which obliquely transect the concordant foliated syenite. Pyrochlore is the dominant ore mineral which contains most of the niobium, tantalum and uranium. It is disseminated throughout the high-grade zones with no apparent diminishment in tenor with depth (max. 300m). The U content of the zircon is 400~800ppm whereas it can reach up to 10% in the pyrochlore. Initial results of 7500m of infill RC and diamond core drilling indicate that the northern Milenje Zone contains a near-surface high grade zone of 14.1 Mt with >1% Nb_2O_5 (52,500t) over more than 200 meters strike length within a broader 1.2km zone. The cut-off is 0.30% Nb_2O_5. Results published in the last quarter of 2008 include 21m @1.03% Nb_2O_5, 0.053% Ta_2O_5, 0.037% U_3O_8 and 17m @1.403% Nb_2O_5, 0.085% Ta_2O_5, 0.059% U_3O_8 including 5m @2.198% Nb_2O_5, 0.100% Ta_2O_5, 0.078% U_3O_8. This near-surface component could be mined by open pit with a low strip ratio of 0.5~0.9 for the first 6+ years of operations which will provide early payback of the capital expenditure. It is intended to produce separate pyrochlore and zircon concentrations. Initial testwork achieved c. 72% recovery but the company is confident that this can be improved.

The Kanyika project, along with a number of other Exclusive Prospecting License (EPL) blocks held by other Minex companies in search of U-Nb-Ta mineralization associated with intrusives in the Basement Complex (Oropa Exploration Pty Ltd. at Chinzani, Chitunde & Mzimba; Mantra Resources Ltd. at Chikangawa, Chintheche & Nanzeka) was first identified from reprocessing the country-wide airborne radiometric and magnetic survey data acquired in 1984/85 by Hunting Geology and Geophysics Ltd. Many of the target radiometric anomalies are circular but the deposit model and search parameters developed by Globe indicate that other geometries/intrusive morphologies may be prospective.

Some of the mineralized carbonatites have significant amounts of pyrochlore which could be extracted as a by-product. Pyrochlore-rich carbonatite at Chilwa Island has indicated reserves of 375,000t at 0.95% Nb_2O_5 whilst the Tundulu carbonatite hosts estimated reserves of 900,000t at 0.37% Nb_2O_5.

(3) Phosphate (apatite)

The Tundulu, Chilwa Island and Kangankunde carbonatite complexes in southern Malawi all contain hard rock phosphate concentrations in the form of apatite. Of these, only the apatite rock at Tundulu in the Mulanje district has any economic potential as a fertiliser raw material.
The Tundulu Ring Complex rises steeply out of the surrounding Phalombe plain to an altitude of 967m and comprises three igneous centres. Centre 1 comprises a circular aureole of fenitization about a 2km diameter plug of syenite. The second carbonatite ring structure

centred on Nathache Hill has a diameter of 500~600m. Wrench faulting prior to emplacement of the third centre displaced the western half of the Nthache Hill ring structure 250m to the north. Centre 3 comprises small plugs and thin sheets of metanephelinite and beforsite. The main apatite deposit forms an arcuate zone (300m N-S and 50m E-W) around the eastern side of the hill.

Drill indicated reserves of 2Mt of rock phosphate with 17% P_2O_5 have been outlined to a depth of 100 meters. Within this block 900,000 tonnes are available averaging 22% P_2O_5 and higher grade rock (28~30% P_2O_5) could be selectively mined. There is potential for increasing the ore reserves by investigating the adjacent areas capped by agglomerate. Met-Chem Canada Inc. evaluated the economic potential of the Tundulu phosphate resources for the Malawi Development Corporation and concluded that recovery of niobium and rare earth resources from the carbonatite could contribute to lowering the P_2O_5 cut-off grade and increase the phosphate reserve. The quantity of phosphate rock and the demand for phosphate fertilisers is, nevertheless, probably too small to justify the establishment of a fertilizer manufacturing plant. Agronomic trials have been carried out on the use of ground Tundulu phosphate rock as a direct application fertilizer for tea. It is deemed not reactive enough for annual crops.

JICA (1989~91) delineated three orebodies on Nthache Hill with a total probable reserve of 1,892,480t at an average grade of 14.4% P_2O_5 using a cut-off of 5% P_2O_5 (i.e. 2.2% P). With a weighted grade of 16.6% P_2O_5 the probable reserves stand at 1,777,688t whereas the reserve estimated for the high grade zone of 22.8% is 805,200t. The drilling indicated continuity of apatite rock to depths >100m. It should be noted that commercial grade rock phosphate usually contains >60% $Ca_3P_2O_5$ (or TPL). In terms of TPL the Tundulu values are fairly low (<50%). It is evident that should the Tundulu phosphate deposit be mined processing will include crushing and flotation to produce a saleable product. However, for direct application the high grade zone may not require beneficiation.

Apatite occurs in biotite-metapyroxenite in the centre of the Basement Complex Mlindi ultrapotassic ring structure and it is only known pyroxenite that has some potential for extraction of phosphate. Most of the exploitable reserves (2.4Mmt @7~14% P_2O_5) occur in the residual soils overlying the metapyroxenite.

(4) Pegmatite Minerals

Malosa Mountain, near Zomba is a site of artisanal exploitation of outstanding pegmatite mineral specimens that are highly prized by collectors. The most celebrated is aegirine associated with smoky quartz, microcline, zircon and other rare species such as parasite, epididymite, fergusonite and eudyalite. The Zomba-Malosa pluton emplaced at c. 113Ma is composed of quartz syenite and peralkaline granite is host to associated NYF (Nb-Y-F enriched) granitic alkaline pegmatites characterised by a unique mineralogy including aegirine, arfvedsonite, Ce-pyrochlore, fluorite, hingganite-(Y), Nb-Ta-Y oxides, niobophyllite-astrophyllite, REE-carbonates, several Na-Be-Zr silicates, xenotime-(Y) and zircon. The pegmatites crop out close to the summit of Mount Malosa (c. 2000masl). They are typically 1.0~1.5m thick, subhorizontal and strongly miarolitic locally with metre-scale cavities or 'pockets'. The rock textures and mineral assemblage indicate crystallisation at shallow depth. Moreover there are large euhedral crystals of rare minerals (e.g. Be silicates) in the cavities that show replacements by REE minerals and Zr-Th silicates. To date about 45 mineral species have been identified including galena.

Nepheline syenite pegmatites with large well developed aegirine crystals also occur in the Chinduzi-Chikala mountain range. The Mulanje mountain massif may also be prospective for the NYF subclass of rare metal pegmatites. At Mwanza, sodic pegmatitic rocks with albite-oligoclase carry bi-pyramidal crystals of brown semi-opaque zircon crystals up to 4cm. Corundum occurs in pegmatites hosted by a biotite Nepheline gneiss to the west and south of Makoko village in Nsanje; a similar environment to that of Thambani in the Mwanza district. Some of the corundum is blue but no gem-quality sapphires have been reposted.

(5) Dimension stone

Azure-blue sodalite syenites are one of the most sought-after dimension stones associated with the alkaline intrusive complexes in Malawi. Sodalite-nepheline syenite of the Ilomba intrusion at Chitipa in north Malawi is quarried for dimension stone by Ilomba Granite of Blantyre and is known under the trademark of 'blue granite'. It occurs in small areas within biotite-nepheline syenite with gradational boundaries. The coarse grained rock predominantly comprises alkali feldspar and sodalite. Biotite, apatite, plagioclase and calcite are present only in minor amounts. The Ulindi hill nepheline syenite intrusion, which lies 6.5km east of Ilomba within the Songwe Syenite, also contains irregular and discontinuous sodalite veins in the summit area. 'Blue granite' also occurs in the Rumphi district.

Sodalite syenite also occurs at Junguni Hill of the Cretaceous Chilwa Alkaline Province in the Balaka diatrict of cental Malawi. This is situated close to the Nacala railway and the major population centres. Sodalite is locally abundant (up to 90%) and occasionally occurs as rounded masses, interstitial patches and in rectangular areas within feldspar prisms.

Amazonite granite, colloquially known as 'Green Granite', occurs in the Ezondweni-Mtwalo area of the Mzimba district of central Malawi and is worked by Granite Ltd. Amazonite is an opaque to translucent bluish-green variety of microcline feldspar that occurs in alkali granites and pegmatites. The green color is largely due to an elevated lead content. Large amazonite crystals are reported from pegmatites on Mount Malosa, near Zomba.

(6) Kimberlites

Kimberlites are a type of potassic volcanic rocks best known for sometimes containing diamonds and they remain the main source of diamonds. Their morphology is the result of explosive diatreme volcanism from mantle sources at depth of 150~450km. Diamonds typically occur in the deep roots of Archaean/Paleoproterozoic cratons from where they are incorporated by the rising kimberlitic magmas. Diamondiferous Kimberlites comprise tabular vertical-dipping feeder dykes that evolve into a volcano with a central vent (commonly referred to as a pipe) within 1.5~2.0km of surface. The diameter of the pipe at surface is typically a few hundred metres to a kilometre but exceptionally can be several kilometres across. Only 1 in 200 kimberlite pipes have economic diamond potential.

The western branch of the East African Rift is characterized by Group II kimberlites which are ultrapotassic peralkaline rocks rich in volatiles that have close affinity to lamproites. The alkaline magmas are derived from deep sources in the mantle plume beneath the continental rift and commonly lead to the genesis of nephelinite-carbonatite and kimberlite-carbonatites. Kimberlitic rocks in the Chapachenga area near Phirilongwe Mountain in Mangochi have a carbonatite affinity. They are currently being investigated by the Geological Survey Department.

It has often been claimed that the geological situation in Malawi-Mozambique is not particularly favourable for the occurrence of diamondiferous kimberlites on the grounds that kimberlites in the vicinity of the East African Rift are barren. However about 50% of these so-called barren kimberlites are reported to carry some diamonds. Although much of Malawi and neighbouring parts of western Mozambique comprises reworked crystalline crust, recent work has shown that older cratonic fragments occur in this geological environment. The kimberlites in north-western Mozambique occur at the north-east extremity of the NE-SW trending transcontinental kimberlite corridor that extends from South Namibia. The Maniamba basin (or graben), which extends NE of Lake Malawi and is infilled with Karoo Supergroup sediments, contains numerous dykes (up to 3m thick) and small pipes (several tens of metres) of primitive Group l kimberlite of Lower Cretaceous age (c. 140Ma). The Mozambiquan diatremes are located at the intersection of the NE- and NNW-trending fault systems within the graben. No kimberlite bodies are found beyond the margin of the Karoo cover. NW-trending kimberlitic zones of Mefululutxe and Fugoe are up to 28km long and located only 4~7km from Lake Malawi. It has yet to be established whether they carry diamonds but it is quite common for barren Group l kimberlite dykes to be associated with diamondiferous pipes.

Kimberlitic dykes are known to occur in the Karoo rocks of the Livingstonia subbasin and the UNDP aerogeophysical survey in the 1980s also indicated targets for diamondiferous kimberlites in the west Chiumba diatreme zone in the Karonga district of northern Malawi. The Chamaliro dislocation zone that borders the Maniamba trough and its northern branch that borders the Rufuru trough and southern margin of the Livingstonia sub-basin are therefore considered prospective zones for kimberlites. Kimberlitic dykes are also reported in the Mwanza River Valley in the districts of Chikwawa and Mwanza. Previous diamond prospect reportedly revealed kimberlite indicator minerals and two microdiamonds in a concentrate taken from the Shire River.

(7) Base metal

Amongst the ring complexes only Mlindi and Chingale have been adequately sampled. Random Cu-Ni anomalies (max 340ppm Cu and 680ppm Ni) and copper minerals have been noted at Mlindi. Isolated soil sample anomalies (max 2,560ppm Cu and 1,600ppm Ni) have been recorded over the biotitites. The Kangankunde carbonatite contains significant accessory amounts of sphalerite, baryte and manganese oxides along with monazite and strontianite. Sphalerite (0.4~0.5%) and baryte (0.6~0.7%) equivalent to 1,654t and 9,250t respectively per 30m depth could be extracted as byproducts of the mining of monazite. There are a number of coincident tin-molybdenum-niobium geochemical anomalies associated with the alkaline intrusions of Phirilongwe (Mangoche), Nkalabe (Nyika), Mbale (Nsanje) and Chekang'ombe (Nkamanga). Potential exists for tin mineralization in association with final phase A-type peralkaline granites and episyenites of the Chilwa Alkaline Province.

5.4.3 Mineral deposits associated with sedimentary and volcanic cover rocks

In Malawi the Permo-Carboniferous to Lower Jurassic sedimentary and volcanic rocks of the Karoo Supergroup and late Cretaceous to Tertiary post-Karoo sedimentary cover overlie an early Precambrian to early Paleozoic Basement Complex. The Karoo Supergroup, along with the Malawi Basement Complex, is cut by Mesozoic alkaline igneous rocks. Ore deposit types range from syngenetic to syr-diagenetic through to late-stage diagenetic and typically include sediment-hosted stratabound deposits of uranium, coal and limestone. The Stormberg volcanics host gem quality blue agate and chalcedony. The Karoo Supergroup also has significant hydrocarbon potential.

(1) Uranium

Kayelekera project

The Kayelekera sandstone-hosted uranium deposit lies within Permian Karoo sedimentary rocks of the North Rukuru basin 52km west of the provincial town of Karonga at the northern end of Lake Malawi and 575 kilometres north of the capital city, Lilongwe. The deposit was discovered and delineated by the Central Electricity Generating Board of Great Britain (CEGB) between 1982 and 1992. In 1998, Paladin Energy Ltd. acquired an interest in Kayelekera through a int venture with Balmain Resources Pty Ltd. and in 2005 acquired the remaining 10% interest held by Balmain. Paladin Energy Ltd, an Australian publicly-listed company, holds a 100% interest in the Kayelekera Project through its wholly owned subsidiary Paladin (Africa) Ltd, but the Company will transfer a 15 per cent shareholding in PAL to the Government of

Malawi under the terms of the Development Agreement signed between PAL and the Government in February 2007. Following environmental approval, Mining Licence ML 152, covering 5,550 hectares was granted in April 2007, valid for a period of 15 years. Construction on the $US200 million development project commenced in June 2007.

The Project is designed to give an annual production of 3.3Mlbs U_3O_8 from the processing of 1.5 Mtpa of sandstone and associated ores by grinding, acid leaching, resin-in-pulp extraction, precipitation and drying to produce saleable product. Meanwhile Paladin has commenced exploration on adjacent blocks to the east, west and south of the Kayelekera Mining Lease i.e. Exelusive Prospecting Licences (EPLs) 168, 169 and 170 granted in December 2005, and EPL225, granted in December 2007, with follow-up on radiometric anomalies identified by the previous helicopter radiometric survey with a view to increasing the resource base and mine life.

The North Rukuru basin contains a >1,500m thick succession of clastic sediments preserved in a semi-graben. This sequence is divided into two distinctly different formations, namely, the glacial and glacio-lacustrine Basal Beds Formation comprising a diamictite (tillite) member with an overlying flaggy sandstone and varved shale member followed by a thick series of alternating arkosic sandstones and mudstones of the North Rukuru Sandstone and Shale Formation which is divided into five members. The Kayelekera uranium deposit is developed in the uppermost Kayelekera Member of the preserved succession which, within the deposit area, has a maximum thickness of c. 150m and contains a total of eight separate arkosic units with intervening mudstones in an approximate 1:1 ratio. The base of the Kayelekera Member is dark grey/chocolate brown mudstone which rests upon the Muswanga Red Beds Member. The Kayelekera member succession indicates cyclic sedimentation within a broad shallow intermittently subsiding basin. Each cyclothem generally passes upwards from coarse reduced facies arkose through oxide facies ‘red-bed’ mudstones into reduced facies carbonaceous silty mudstones locally with thin coaly horizons. Individual arkosic units which may contain several upward-fining sequences, are commonly current bedded and contain carbonaceous debris with associated disseminated pyrite.

Lenses of uranium mineralization occur within the arkose units to a depth of 100m. These vertically stacked lenses are localised approximately parallel to the synclinal axis of the fault-bounded structure. Mineralization is offset but is not confined by faults although it is limited by the surface topography which truncates the host lithologies. Most of the mineralization is contained within six principal lenses in the arkose units although some secondary mineralization also occurs in the mudstones below the mineralized arkose. Three types of mineralization are recognised based on the redox state of the host lithology, namely (i) reduced, (ii) oxidised and (iii) mixed oxide and reduced facies. Coffinite is the primary uranium mineral in the reduced facies often associated with organic debris and/or pyrite. The transitional zone includes uraninite and U-Ti minerals whilst the oxide facies contains several yellow-green secondary uranium minerals dominated by meta-autunite and boltwoodite.

At a 300ppm U_3O_8 cut-off, the total measured and indicated resource is 15.3Mt @0.088% U_3O_8 yielding 13.63Kt of U_3O_8, with a further 3.40Mt @0.06% U_3O_8 yielding 2.04Kt of U_3O_8 as Inferred Resource under the JORC code. The process plant is currently under construction and due for commissioning during the first quarter of 2009. Open pit mining commenced in June 2008 to develop initial stockpiles, with the first blast occurring on 24 July 2008. It will be a conventional open-pit operation with a seven-year life, but processing will continue for a further four years at a steady state rate of 1.5 million tpa to give an annual output of 1,493t U_3O_8 in the first seven years and 530tpa U_3O_8 from stockpiled marginal material grading 0.039% U_3O_8 over the last four year.

Kayelekera is a typical roll-front uranium deposit formed by movement of uranium-enriched oxidising groundwaters down gradient through permeable arkosic sandstones. The uranium, along with other dissolved metals such as molybdenum, vanadium, selenium and arsenic, precipitates out when the groundwaters encounter the oxidation/reduction interface often forming a crescent-shaped ore body. Uranium, being more mobile under oxidising conditions, tends to be leached from the oxidised parts of the deposit. Over time the reduction front will migrate in the direction of groundwater flow. Disseminated pyrite and organic material act as reductants and organic trash pockets in sandstone can result in the additional formation of rich humate-type orebodies. Tabular blanket deposits also may form at the crescent tips of the front. Whilst some deposits are mined by open pit or underground methods, most future mining may be done by in-situ leaching.

These deposits are normally found with radiation detectors although peak to background ratios may be small and can be easily overlooked. The Kayelekera radiometric anomaly was exceptional in being five times background. Complications can arise where there is secular disequilibrium between uranium and daughter products of the decay chain. Uraninite and coffinite may be so newly formed that radioactive daughter products have yet to develop. Such non-radioactive deposits have to be discovered by geochemical methods.

Recognition of economic concentrations of roll-front uranium within the Karoo basins has encouraged increased exploration activity specifically targeting this style of mineralization. Globe Metals and Mining is prospecting for roll-front style uranium mineralization within Karoo sandstones of the Livingstonia sub-basin on the basis of a radiometric anomaly along the eastern escarpment. The first phase of a drilling programme was completed in 2008 at their Chombe, Chiweta and Bunga prospects. Chombe is the most advanced and probably the most promising with intersections of 15m @402ppm U_3O_8 including 4m @864ppm U_3O_8, 10.6m @373ppm U_3O_8 including 3.3m @820ppm U_3O_8 and 8.1m @644ppm U_3O_8 including 3.1m @806ppm U_3O_8. It is a roll-front type of uranium deposit but is much more complex than Kayelekera. Primary ore concentrations appear to be associated with numerous channel fillings as in a braided floodplain environment. Secondary remobilisation has occurred in a number of phases with one superimposed or overprinting an earlier depositional front. There is some deposition of secondary uranium associated with carbonaceous lenses. With Livingstonia being that much closer to the Malawi Rift margin faulting has played a greater role in the localisation of the uranium mineralization although offsets of the mineralized horizon are rarely more than a few metres. Thus the overall geometry is not that of a simple open syncline as at Kayelekera. The main mineralized member is a basal arkosic unit up to 90 metres thick which lies directly above the coal measures sequence. The arkosic sandstones are generally uniform and homogeneous except for a few thin silty interbeds. Proximity to the rift escarpment and other environmental considerations may preclude open pit mining but may be amenable to in situ uranium extraction which has relatively little impact at surface. The natural water table is at a depth of 40 metres but varies somewhat according to the season.

For a roll-front uranium to be amenable to in-situ leaching the uraniferous sandstone must be porous and permeable and confined above and below by imprervious mudstone or shale. The beds must be flat-lying or only gently dipping and must be below the water table or in a confined aquifer. In situ leaching enables economic exploitation of uranium from roll-front deposits that are too deep for surface mining methods.

(2) Coal

Coal is an important and underused source of energy in Malawi. It offers a more reliable source of energy than renewable sources such as hydroelectric power generation which is liable to be affected by drought and could be a substitute for fuelwood/wood charcoal which is subject to increasing environmental and population pressures. Small coal basins with potential for only limited reserves of coal have a local economic and strategic value given the high bulk transportation cost. Malawian coal is currently used in boilers for raising steam, in cement manufacture, curing tobacco and production of pharmaceuticals.

According to available estimates there are 13 coalfields in the northern region and two in the southern part of the country with speculated reserves totaling as a much as 800 million tonnes. The best known deposits occur in the Ngana, Livingstonia, Lufira, Mwabvi, Lengwe, North Rukuru and Nthalire (sub) basins. Malawian coals are sub-bituminous to bituminous, with a high ash content, high volatile and low sulphur contents. They are bi- and tri-maceral humic types rich in inertinite and/or vitrinite and mineral matter, and are typical of other Gondwana coals. The seams so far discovered are mostly <1 metre thick and display rapid vertical and lateral variations. Arkose-related coals appear to be of better quality and more persistent than the coals associated with mudrocks. They offer the greatest potential for economic exploitation in the short to medium term, a point well recognised by the Malawian authorities.

The coal measures vary in thickness up to c. 100m in the north and c. 600m in the south. They comprise interbedded mudrocks and commonly arkosic sandstones and subordinate conglomerates. The argillaceous beds contain thin multiple coal seams. Sandstone-hosted coals are less common but are notable in the Livingstonia basin where they are presently worked. The northern basins exhibit a regional dip to the east and are mostly half-grabens downfaulted to the west along their eastern boundaries. Only in the basins nearest to Lake Malawi is this polarity reversed and the geometry more compatible with the younger Rift Valley tectonics. A considerable thickness of Karoo-Cretaceous deposits occurs beneath the Tertiary to Recent sediments of the northern littoral of Lake Malawi.

The Livingstonia Basin on the southwest side of the Nyika massif represents the southwestern extension of the Ruhuru basin in Tanzania which has been truncated by the Lake Malawi rift. Compared to North Nyika the Livingstonia basin succession was deposited in a deeper water lacustrine environment. It is fault-bounded to the northwest and has a gross geometry consistent with a pull-apart origin in a left lateral transcurrent displacement zone.

Currently there is only one major coal producer, namely Mchenga Coal Mines, which is located in the Livingstonia coalfield and extends over $90km^2$ in the Rumphi district. This coal company operates on a production target of 5000 tons a month and supplies coal to some leading companies in the country as well as supplying 1000tpm to Mbeya Cement in Tanzania. Mchenga Coal is also working on the Chombe coal deposit and the cumulative annual production is likely to touch 96,000 tonnes. Proven reserves in the Mchenga Mine area amount to 1.4 million tonnes. At Mchenga Mine a prominent seam of interbanded dull and bright coal some 1.5~2.7m thick that occurs immediately beneath the K3 basal arkose and has considerable lateral extent is currently being worked. The contact between the coals and roof arkoses is sharp, generally flat-lying and remarkably planar. At their base they rest on carbonaceous micaceous sandstones which show upward fining into the base of the coal. Thinner seams (<0.5m thick) occur above the main seam and show similar roof and floor relationships. There is another small-scale mining operation at Kaziwiziwi that is managed by the Kaziwiziwi Mining Company. The mined Kaziwiziwi 'main seam', which is sandstone-hosted, is 1.5~2.0 metres thick with the best coal occurring in the uppermost 0.75m.

The Ngana coalfield, which covers an area of $60km^2$ and forms the southern extension of the Songwe-Kiwiri Basin in Tanzania, is being evaluated for its opencast potential. The Ngana coal seam is of the order of 15m thick and dips eastwards at 30°. An estimated 50Mt of in-situ coal is within a depth limit of 200 metres. The stripping ratio of overburden to coal is projected to be >10:1 Drill-indicated reserves stand at 182 million tonnes with a recovery of 65%. However, a high proportion of waste is recorded and in view of the high ash/low calorific value of the coals it would require extensive washing to produce a saleable product.

The North Rukuru coalfield covers $190km^2$ and the coal seams range in thickness between 0.5m and 3.0m. The coal resources are inferred at 165 million tonnes with proven reserves of

500,000 tonnes at Kachira in Musisi Forest. The coal may be exploited by open cast or underground mining. The overburden to coal ratio is >15:1.

The Lufira coalfield covers an area of 6km^2 with an estimated coal resource of 1.25Mt. The coal-bearing sequence dips at 16~25° to the east and is 20m thick containing 4~12 seams ranging in thickness from 4mm to 2.45m. Drill indicated reserves stand at 600,000 tonnes. The neighbouring Kibwe coalfield (15km^2) has estimated coal resources of 2Mt. The Lufira and Kibwe Basins form part of the concealed Karonga coalfield with a speculated 300Mt of coal resources.

The coalfields of Lengwe and Mwabvi in the southern lower Shire valley districts of Chikwawa and Nsanje were subject to detailed investigation by BRGM and the GSD in the period 1987~1991. The Mwabvi coalfield extends over 400km^2 and coal seams are in places exposed at surface. The BRGM/GSD drilling campaign identified coal reserves of 2.2 million tonnes at 50m depth and a further 2.5 million tonnes at 100m depth. The quality of the coal improved with depth; coal from shallower levels would require washing. Mining at Mwabvi would be by open cast or underground. The Lengwe coalfield covers nearly 350km^2. 16 drill holes were sunk in a 30km^2 block around Mkombezi wa Fodya River. The coal occurs within mudrocks and is of limited coalification level compared with Mwabvi coal. Further explotation in the Lengwa and Mwabwi areas need not be inhibited by the restricted size of potential mining blocks due to the heavy faulting, provided that reserves can be located at shallow depths to permit easy exploitation. These areas remain the closest potential coalfields to major local markets and this factor alone offers clear advantages.

5.4.4 Deposits resulting from residual weathering, placer and rift-related sedimentation

Superficial deposits (residual to eluvial, colluvial, and alluvial to lacustrine) contain important mineral resources in Malawi. They cover large tracts of the Lake Malawi littoral, the Shire Valley and the Lilongwe-Kasungu and Mzimba plains. Residual and placer deposits developed during the Cenozoic as a consequence of complex evolving geomorphic cycles of weathering, erosion and deposition under varying climatic conditions. Residual deposits include bauxites, clays, saprolitic nickel and gemstones. Dambos are a potential source of gypsum, brick clays and silica sand. Heavy mineral alluvial placers with ilmenite, rutile, monazite, zircon, gold and/or gemstones have largely developed along the major rivers and around the lakes of the East African Rift Valley. They are also a potential source of columbite-tantalite, cassiterite, PGM's, etc. Lacustrine deposits in the Malawi Rift include diatomite, phosphate, and unconsolidated marls. The thick sediment fill of the rift is a target for hydrocarbon exploration.

(1) Rare Earth Element (REE)

The main economic minerals including REE are bastnaesite and monazite. Monazite occurrences are widespread throughout the Chilwa Alkaline Province and locally form residual concentrations in heavy mineral sands.

The core carbonatite of the Kangankunde Complex associates with monazite, strontianite and disseminated manganese oxides. The Tundulu Complex contains large quantities of REE minerals, mainly bastnaesite, in addition to substantial reserves of apatite.

(2) Bauxite

Bauxite comprises variously hydrated aluminium oxides (gibbsite, diaspore, etc) and constitutes the principal ore of aluminium. It forms as a result of intensive surficial weathering on well drained plateaux in regions with wet tropical climates. The process of bauxitisation involves intense leaching of the protolith and/or regolith and dissolution/desilicification of kaolinite. Lateritic (silicate) bauxites comprise >75% of the World's bauxite resources. They can form from various silicate rocks (granite, gneiss, syenite, basalt, shale) but are preferentially derived from lithologies with low silica content, high aluminium content vitreous textures and high porosities.

Bauxite has developed from the prolonged weathering of syenogranitic rocks that form Mulanje Mountain which rises 600~700m above the surrounding Phalombe plain. The Mulanje bauxite resource has been known since 1924 and has been explored by the Anglo American Corporation (1934), the British Aluminium Company (1951~58) and Lonrho (1969~72) amongst others Six extensive bauxite areas have been identified but the best deposits occur on the Lichenya and Linje plateaux at an elevation between 1800 and 2000 metres. The bauxite is a trihydrate gibbsite which overlies kaolinite and has goethite and quartz as the main contaminants. An average analysis yields 43.3% Al_2O_3, 13.3% free quartz, 2.2% combined silica, 14.2% Fe_2O_3, 1.8% TiO_2, <5.0% kaolinite and 28.8% LOI. Total reserves on the mountain are estimated to be >50Mt. Lonrho showed that the two main deposits amount to 28.8Mt using a cut-off grade of 30% Al_2O_3 with an average depth of 4.5 metres. A feasibility study executed by MET-CHEM Canada Inc. on behalf of MIDCOR in 1993 estimated 25.6Mt bauxite at a grade of 43.3% and proposed a mining output of 580,000tpa of bauxite to produce 200,000tpa alumina for an annual production of 100,000 tonnes of aluminium.

The bauxitic outliers on Mulanje Mountain are associated with remnants of the African Surface inherited from the Paleogene (70~40Ma) bauxite-forming event which involved top-down bauxitisation of mature kaolinitic mantles. Bauxite deposits are rare in East Africa which has been influenced by rift-related uplifts. Within the Malawi rift these appear to be preserved at elevations of 1800~2000m.

Bauxitisation was the dominant process on the planated summit of Zomba mountain (2134m) which is at a similar altitude to the Mulanje deposits. Bauxite development up to three metres thick occurs beneath a layer of soil one metre thick. The greatest thickness occurs at the border of the plateau. The bauxite is being supplanted by kaolinitisation under current weathering conditions.

(3) Kaolinitic clays

Substantial resources of kaolinitic clays suitable for the production of ceramic wares occur at Linthipe in the Dedza district and at Senzani and Nkhande in Netcheu district At Linthipe, the clays formed as a result of in situ weathering of a meta-anorthosite body within the Basement Complex. The Linthipe meta-anorthosite, composed of 95% labradorite, forms a negative topographic feature covering 230km^2. The weathering profile passes upward from bedrock through slightly altered meta-anorthosite to kaolinitic saprock and into a saprolite of plastic kaolin on top and overlain by distinctive thin pale grey savannah soils. Four groups of deposits each containing between 1.0 and 3.5km^2 of clay 0.7 to 1.7m thick have been outlined. The total area amounts to 7.6km^2 with indicated reserves of 15Mt. The clays, which consist principally of highly-disordered kaolinite with halloysite, have plasticity indices between 20 and 40. The clay could form the basis for production of earthenware, stoneware, aluminosilicate refractories and sand moulds. Reserves amounting to 0.5Mt and 0.6Mt have been delineated also at Senzani and Nkhande respectively.

(4) Lateritic/saprolitic nickel

Lateritic nickel deposits form by prolonged and pervasive weathering of ultramafic rocks in tropical to subtropical climates. They typically develop from serpentinitic rocks that have a significant background level of nickel (c. 0.3%). Being restricted to the weathering mantle they tend to be tabular, flat and areally large and therefore amenable to low cost open pit or strip mining. Lateritic nickel deposits are estimated to comprise 73% of the worldwide continental nickel resources.

Lisungwe Mineral Resources have identified deposits of nickeliferous saprolite on the Chimwadzulu and Chimimbe ultramafic bodies close to the western border of Malawi with Mozambique and Zambia respectively. Surface pitting indicated that both deposits have estimated non-compliant resources in excess of 3.0Mt of ore grading better than 0.5% nickel. Both deposits are still open along strike, down plunge and at depth. Potentially recoverable quantities of ferro-chrome and magnetite are also present. Chimwadzulu hill is the type locality for Nyala rubies and nickel exploration was suspended upon re-issue of the primary licence to Nyala. Initial exploration work shows Ni grades from 0.3%~1.0% at half metre intervals over a sample depth of two metres. The resource estimate based upon a depth of three metres is equivalent to 12,000t of metallic nickel recovered at 80%.

Chimimbe Hill rises from an extensive peneplain (African surface) about 80km east of Lilongwe and is just 12km from paved highway and railroad access and 6km from a power line. The Chimimbe Hill surface mineralization overlies an east-dipping lenticular ultramafic sheet emplaced into Mchinji sandstones of the Muva Supergroup. The ultramafic body dips at about the same angle as the hillslope and mostly comprises peridotite but there is extensive development of talc schist in the SE part of the hill which may be part of the exposed hangingwall. The sheet is cut by NNE-trending faults. The initial programme of pitting covered an area of 10.5km with some pits reaching a depth of 7 metres. Hand-held XRF analyses indicate grades of 0.3% to 1.3% nickel and 0.3% to 2% chrome. The peridotitic bedrock yields 0.2~0.8% Ni. The explored area remains open at both ends and down-dip to the east. The present phase of rotary air blast (RAB) drilling on an 80-metre square grid to a target depth of 20m to determine the true thickness of saprolite ore grades (typically 10~20m) has yielded encouraging results including the identification of near-surface enrichment zones. Infill holes initially on a 40m grid and possibly deeper holes will be drilled where required. There is an extensive talus apron and colluvial spread on the pediment to the east of the hill which carries not only high Ni-Co but also exploitable ferrochrome. This extends up to 400 metres from the break of slope as two outwash fans. Early metallurgical test work indicates that 85% of the nickel contained in the non-magnetic fraction of the potential ore can be rapidly extracted using hot sulphuric acid at atmospheric pressure. Potentially economic quantities of ferro-chrome and magnetite may also be recovered with simple magnetic/gravity methods of separation. The conservative estimate of 3Mt constitutes in excess of 15,000 tonnes contained nickel. Sulphuric acid will be a significant cost factor and its ready availability may be critical to the viability of this venture.

Numerous ultramafic bodies with elevated Ni values occur within the basement complex. Exploration for lateritic/saprolitic nickel mineralization, which depends upon the preservation of deep weathering mantle, should focus on the African planation surface in the west-central part of the country.

(5) Phosphate

Carbonatites and other alkaline igneous rocks commonly contain elevated phosphate concentrations in the form of fluorapatite. Weathering of these igneous rocks leads to natural enrichment in apatite and other resistant minerals (e.g. magnetite, pyrochlore, monazite) mostly by removal of soluble carbonate minerals and gravitational sorting. Deep weathering profiles overlying and derived from apatite-rich carbonatites can produce economic eluvial deposits. Apatite is an essential raw material that is widely used as a phosphatic fertiliser (either by manufacture of compound phosphate or by direct application) and for the production of phosphoric acid and various other chemicals. According to present practice for apatite to be directly applied to the soil the average P_2O_5 content of the ore should be >16% and the Fe content <5% and it should be free of potential contaminants.

The Kangankunde and Chilwa Island carbonatites, contain only small amounts of primary apatite but the P_2O_5 concentration in residual and eluvial phosphate accumulations range from

1.32 to 8.9% P_2O_5 with an average of 2.5% P_2O_5. Eluvial soils overlying the pyroxenite near Ligowe carry an average of 7.8% chlorapatite, and weathered pyroxenite 1.6km further south contains 12% apatite. Other eluvial phosphate accumulations are reported from the Chingale metapyroxenite (estimated reserves 8.76Mt at 3.76% P_2O_5), the Bilira meta-pyroxenite (mean 1.42% P_2O_5) and the Mlindi ultrapotassic pyroxenite to syenite complex. At Mlindi, two areas with apatite-rich residual soils were delineated overlying the metapyroxenite with estimated probable reserves of 2.4Mt with grades of 7% to 14% P_2O_5.

(6) Alluvial Gold PGM

Alluvial gold has been reported in the Lisungwe river system in the Kirk Range area, the Dwangwa river and its tributaries straddling the districts of Nkhotakota and Nkhata Bay in central Malawi and in the areas of Nathenje and Mwanza.

The Lisungwe River and some of its affluents draining the Manondo gold district contained some of the richest alluvial gold concentrations and have been worked intermittently. The Likudzi River, a tributary of the Lisungwe draining an area of faulted ultramafic sheets additionally carries PGM minerals (e.g. ferroplatinum). The Lisungwe and Likudzi yielded coarse angular gold indicating a proximal source.

The alluvial gold potential is limited but its occurrence is a useful indicator of bedrock sources. In the Nathenje area alluvial gold is spatially related to outcrops of calcsilicate granulites or skarns. The main sources of the gold, however, appear to be shear zone-hosted concordant quartz stringers in the paragneisses and pyritised veins in carbonatised schists. Gold occurrences have been documented for the Malindi-Makanjira area in the Mangochi district also but attempts to trace the gold so far have been inconclusive.

(7) Heavy Mineral Sands

Malawi hosts at least two billion tonnes of mineable heavy mineral sands around the shore of Lake Malawi and along the Shire River. Heavy mineral sand deposits comprise high density minerals (SG>4.2) that occur as disseminated, lenticular or layered concentrations within the sands and most commonly include Ti minerals, gold, cassiterite, zircon, monazite and garnet. By far the most important resource in Malawi is the Ti mineral sand deposits. The high strength-to-weight ratio, corrosion resistance, bio-compatibility and non-toxic characteristics make titanium ideal for strategic and critical applications in the aerospace, military and medical fields. Ti oxide is the main component of white pigments in paints, paper and plastics.

Three heavy mineral sands deposits have been investigated. They include the colluvial deposits at Tengani in Nsanje district, the beach sands in the lakeshore districts of Salima, Nkhotakota and Mangochi and the sand bar at Lake Chilwa in the Zomba district.

In the Tengani area at the foot of the east-dipping Mulaka Hills the reserves of colluvial heavy mineral sands and gravels are estimated at 108Mt with a heavy mineral content ranging from 3.5 to 35% averaging 0.34% rutile and 1~14% ilmenite. Other estimates put the rutile: ilmenite ratio in the heavy mineral fractions in the range 1:12 to 1:4. An assessment by the Geological Survey Dept. in 1997 indicated 2.5Mt of heavy mineral sands grading at 3% ilmenite and 0.3Mt containing 0.3% rutile. Elevated contents of Ti minerals mainly occur on the interfluves between the Nkande and Namyala rivers.

The Mpyupyu Hill colluvial heavy mineral sands contain over 11.9Mt grading at 3.8% ilmenite and 0.01% rutile (MMNRE, 2004). These heavy mineral sands spread across the Lake Chilwa flooplain on which the eastern foothills of the Zomba plateau level off. Between Mpyupyu Hill and the present-day shoreline of Lake Chilwa, two separate sand bodies have been delineated that total of about 15Mt with an average grade of 6.93% ilmenite, 0.38% zircon, 0.02wt% rutile, 0.04% leucoxene and 0.06% garnet (Dill. 2007).

The reserves of beach sands around Chipoka/Salima along the western shore of Lake Malawi are estimated to be 700Mt with an average grade of 5.6% total heavy minerals. The sands contain ilmenite, rutile, monazite, garnet and minor zircon. Other minerals present include amphibole, ortho- and clinopyroxenes, magnetite, titanite, apatite, orthite, epidote and chromite. The exploitable bed is up to five metres thick. Allied Procurement Agency and Mineral Sands Ltd. of South Africa conducted a pilot suction dredging and processing operation along the shoreline to the north of Chipoka in 2006 with the intention of starting large scale exploitation of zircon and rutile. Contained resources of zircon arid rutile at Chipoka Bay amount to 6.7Mt and 3.6Mt respectively.

In the Mangochi district large resources of heavy mineral sands occur at Makanjila on the southeastern lake shore of Lake Malawi. Sand dunes extend 6km inland along a 20km shoreline and up to 100 metres above the current water level of the lake. Reserves are estimated at 800Mt grading at an average of 13.0% total heavy minerals with ilmenite (52%) being the dominant economic commodity.

Millenium Mining Ltd. of Australia have considered the development of the Makanjila and Salima Bay mineral sands deposits with a view to producing 500,000tpa of ilmenite which would have been smelted at Chipoka. A co-product would be high quality pig iron. Development of the smelter with a planned capacity of 250,000t/yr titanium slag would be dependent upon obtaining power supplies from Mozambique.

5.5 Mining law

All minerals are vested in the President on behalf of the people of Malawi. The search for mining and disposal of these minerals is governed by the Mines and Minerals Act (1981). The

Administration of the Act is the responsibility of the Commissioner for Mines and Minerals in the Ministry of Energy and Mining.

The overall policy objective is to maximise the economic benefit to the nation that can be realised from the exploitation of the nation's mineral resources. The government encourages investors to explore, delineate, evaluate and where viable exploit the resource using appropriate technologies.

(1) Reconnaissance Licences (RL)
RL is issued for one year for an agreed programme over an area not exceeding 100,000 km^2 at a fee of K1,000 for the licence and annual charges of K0.1 per km^2. No subsurface operations are permitted unless specifically authorized. However, holders may erect camps and temporary buildings.

(2) Exclusive Prospecting Licence (EPL)
EPL confers exclusive rights to carry out a programme of prospecting operations for specified minerals over a specified area. A detailed programme of exploration, expected expenditures and personal details are required. There must also be a proposal for the training and employment of Malawi citizens in the operations. The licence is issued for a maximum of three years and may be renewed twice for periods not exceeding two years each. Fees payable at issue are K500 and annual charges are is K10.00 per km^2. Fees of K200 are payable for each renewal requested. The maximum area at initial grant is 2,500 km^2 and this is reduced by 50% at each renewal. The holder has the automatic right to apply for and be granted a Mining Licence after recording a final and on submission of a feasibility study report. Progress reports must be submitted to the Minister at the end of each phase including a work programme and cost estima tes for the following phase.

(3) Mining Licence (ML)
ML may be issued to holders of an EPL or non holders. The applicant must give a detailed feasibility report including the anticipated programme of mining operations, an environmental impact assessment, and proposals for the employment and training of Malawians. The licence confers the holders the exclusive right to prospect, mine, produce and sell specified minerals from the designated area. The maximum areas for non holders of EPL is 250 km^2 and for the holders not more than the land subject to the EPL. The ML fee is K1000 per km^2. The initial term for a ML is for a period not exceeding than 25 years or estimated life of the mine, which ever is shorter. It may be renewed for a period of 15 years thereafter. Regular reports on the operation must be made to the Minister.

Three types of licences are issued for small scale mining and prospecting operations. Methods are limited by both financial costs and technical expertise. These licences are:

(a) Mineral Permits are issued to individuals by the District Commissioner of the area for building and other construction materials upon payment of a prescribed fee. The fee depends upon the quantity to be extracted.

(b) Non-Exclusive Prospecting Licences (NEPLs) are issued to individuals or firms who cannot afford large scale prospecting operations but have technical expertise. The holder may conduct prospecting operations in one or more districts for any mineral specified in the licence. The holder may not prospect in an area held under exclusive licence. The initial term of the licence is one year but may be renewed for further one year periods. Applicants must be Malawians or foreign nationals who have resided in Malawi for not less than four years. The holder must seek permission from owners of the land before commencing operations.

(c) Mining Claims are issued to holders of NEPLs after submission of sketches and fees. A claim licence confers the holder exclusive right to prospect mine and sell the product. The maximum area to be pegged for each claim is two hectares and up to three claims may be pegged with one NEPL. All claims expire on 31st March of each year and renewed effective 1st April. Fees payable are K35.00 and K30.00 for grant and renewal respectively. A claim licence does not prohibit the land owner from grazing and farming on the property. A claim may be cancelled where either conditions are not being met or the deposit can be exploited using large scale equipment. Annual reports on prescribed forms must be submitted to the Commissioner of Mines and Minerals.

In addition, the following apply to the following types of Licences:

Reserved Minerals Licence is issued to those wishing to buy and sell precious and metals and precious semi-precious stones. The fee is K300 at each application and duration is one year.

A RML, EPL and ML may only be transferred with the approval of the Minister.

Malawi is preparing a National Environmental Action Plan, however, the Mines and Minerals Act already contains adequate environmental provisions. Potential environmental impacts must be included in applications for exploration and mining and in a mining proposal, suggestions for addressing environment problems, prevention of pollution from mining and mineral treatment and land rehabilitation must be submitted.

6. Satellite data analysis

6.1 Satellite data for analysis

Satellite data for analysis are ASTER data of the optical sensor and PALSAR data of the Synthetic Aperture Radar (SAR) sensor. 79 scenes of ASTER data and 64 scenes of PALSAR data covering the entire land area of Malawi were procured. Figure 6.3 and Figure 6.15 show the location of ASTER data and PALSAR data respectively. The rectangle of about 70km on every side in the figures shows each observation range by satellite. Figure 6.4 shows the ASTER false color image of the whole Malawi and Figure 6.16 shows the PALSAR HH polarized mosaic image of the whole Malawi. ENVI Ver.4.8 software of Exelis VIS and ArcGIS Ver.10 software of ESRI as the provided equipment were used in satellite data analysis of the Project.

The processing and analysis of these satellite data were carried out as OJT. Data files and output images created through the process of satellite data analysis are shown in Table 6.1.

Table 6.1 List of satellite data and created files

data type	file type / data format	Contents of file / example of filename	Process flow # of JOB
ASTER original data	Multi-band data HDF	14 bands data (VNIR, SWIR, TIR) AST3A1_ yymmddhhmmssyymmdd####.hdf	JOB00, 01 JOB02, 09
ASTER processed data	Multi-band data ENVI-img	VNIR resizing data (resolution: 30m) AST_L3A_c01r01_VNIR.img	JOB01
		VNIR&SWIR integrated data (9 bands) AST_L3A_c01r01_BB9.img	JOB02
	Binary data (mask data) ENVI-img	no data area mask data AST_L3A_c01r01_BB9_mask.img	JOB03-1
	Multi-band data ENVI-img	Masked data by no data area mask (9 bands) AST_L3A_c01r01_B1B9_mask.img	JOB03-2
	Grayscale data ENVI-img	Normalized Difference Vegetation Index data AST_L3A_c01r01_NDVI.img	JOB04
	Binary data (mask data) ENVI-img	Vegetation area mask data AST_L3A_c01r01_NDVI_mask.img	JOB05-1
		Water area mask data AST_L3A_c01r01_water_mask.img	JOB05-2
		Cloud area mask data AST_L3A_c01r01_cloud_mask.img	JOB05-3
		Shadow area mask data AST_L3A_c01r01_shadow_mask.img	JOB05-4
	Multi-band data ENVI-img	Multi-band mask data AST_L3A_c01r01_all_mask.img	JOB05-5
	Binary data (mask data) ENVI-img	Integrated mask data AST_L3A_c01r01_integrated_mask.img	JOB05-6
	Multi-band data ENVI-img	Masked data by integrated mask (9 bands) ＊Starting data for analysis AST_L3A_c01r01_masked_B1B9.img	JOB05-7

	RGB color data (band composite image) GeoTIFF	Band composite image (VNIR original data，RGB=B3,B2,B1） AST_L3A_c01r01_B3_2_1_base.tif	JOB00
		Band composite image (RGB=B3,B2,B1) AST_L3A_c01r01_B3_2_1.tif	JOB06
		Band composite image (RGB=B4,B6,B8) AST_L3A_c01r01_B4_6_8.tif	JOB06
		Band composite image (RGB=B4,B6,B1) AST_L3A_c01r01_B4_6_1.tif	JOB06
		Band composite image (TIR data，RGB=B10,B12,B14) AST_L3A_c01r01_B10_12_14.tif	JOB09
		Band composite image (TIR data，RGB=B13,B12,B10) AST_L3A_c01r01_B13_12_10.tif	JOB09
	Grayscale data ENVI-img	Band ratio data (RGB=B4/B8,B3/B8,B3/B1) AST_L3A_c01r01_B4d8.img AST_L3A_c01r01_B3d8.img AST_L3A_c01r01_B3d1.img	JOB07
		Band ratio data (RGB=B7/B6,B3/B4,B2/B1) AST_L3A_c01r01_B7d6.img AST_L3A_c01r01_B3d4.img AST_L3A_c01r01_B2d1.img	JOB07
	RGB color data (band ratio image) GeoTIFF	band ratio image(RGB=B4/B8,B3/8B,B3/B1) AST_L3A_c01r01_B4d8_3d8_3d1.tif	JOB08
		band ratio image(RGB=B7/B6,B3/B4,B2/B1) AST_L3A_c01r01_B7d6_3d4_2d1.tif	JOB08
	PC multi-band data ENVI-img	Result data of Principal Component Analysis AST_L3A_c01r01_masked_B1B9_PCA.img	JOB10
	text data ENVI-txt	Statistics data of Principal Component Analysis AST_L3A_c01r01_masked_B1B9_PCA.sta	JOB10
	Grayscale data GeoTIFF	Single PC band image of Principal Component Analysis AST_L3A_c01r01_masked_B1B9_PC_B#.tif	JOB10
	RGB color data GeoTIFF	PC band composite image of Principal Component Analysis AST_L3A_c01r01_PCB#_#_#.tif	JOB10
PALSAR original data	Grayscale data GeoTIFF	HH polarized band data PASL150yymmddhhmmssyymmdd####.tif	JOB01
PALSAR processed data	Grayscale data ENVI-img	HH polarized band mosaic data PAL_L15_mosaic_Malawi.img	JOB01
	Grayscale data GeoTIFF	HH polarized band mosaic image PAL_L15_mosaic_Malawi.tif	JOB02
	shapefile	Lineament line data lineaments.shp	JOB03
	Grayscale data GeoTIFF	lineament image lineaments.tif	JOB04
G-DEM original data	Grayscale data GeoTIFF	DEM data ASTGTM2_S##E###_dem.tif	-
G-DEM processed data	Grayscale data ENVI-img	elevation mosaic data ASTGTM2_mosaic_Malawi.img	-
	Grayscale data GeoTIFF	elevation mosaic image GDM_mosaic_Malawi.tif	-
	Grayscale data ENVI-img	Shaded relief mosaic data ASTGTM2_mosaic_Malawi_shadedrelief.img	-
	Grayscale data GeoTIFF	Shaded relief mosaic image GDM_mosaic_Malawi_shadedrelief.tif	-

6.2 ASTER data analysis

ASTER has 3 sensors according to the difference of the wavelength. ASTER data has 3 bands in the visible and near infrared radiometer (VNIR), 6 bands in the short wave infrared radiometer (SWIR) and 5 bands in the thermal infrared radiometer (TIR), 14 bands in total and characteristic of multi-band data with high resolution. The ASTER observation range of the wavelength is from 0.52 micrometer to 11.65 micrometer and the observation wavelength of each band increases from band 1 to band 14. The band location of ASTER censor is shown in Figure 6.1.

ASTER L3A data which are orthorectified products (images) were used in the Project. Data format is HDF-EOS. Figure 6.3 shows the location of ASTER L3A data of the whole Malawi.

ENVI software is used for data processing and analysis of ASTER. Lack of data resulting from the difference of the observation range in sensors and missing data need to be masked in data processing. Moreover, the vegetation area, water area, cloud area and shadow area where geological analysis is difficult need to be masked. This pre-processing was carried out to 79 scenes of ASTER data of the whole Malawi. In basic analysis, 5 types of the band composite image and 2 types of the band ratio image were created from these 79 scenes of pre-processed satellite data. In applied analysis, to some parts of the field verification area, principal component analysis (PCA) was executed and PC band composite images were created. The interpretation of geological structures was executed utilizing high resolution of the images, and the mappings of mineral distribution and rock facies were executed utilizing the multi-band SWIR and TIR data.

The process flow of ASTER data is shown in Figure 6.2. Technology transfer through OJT of these data processing and analysis in Figure 6.2 was conducted. The manual of data processing and analysis using ENVI was prepared at the same time, and practical data processing and analysis were carried out based on this manual. Figure 6.5 shows all 14 band grayscale images in 1 scene around Salima, the south-eastern side of Lake Malawi. The image of Figure 6.6~6.12 is the analysis result of this scene.

Details of ASTER data processing and analysis are described according to JOB number in Table 6.1 of Satellite data and creating files list and Figure 6.2 of Process flow of ASTER data as follows. Hereafter, a notation “RGB=B3, B2, B1” means that red color (G), green color (G) and blue color (B) are allocated to band1 (B1), band2 (B2) and band3 (B3), respectively.

6.2.1 Pre-processing

JOB00 : To confirm data quality and outline of observation areas, false color band composite images from original data are created. By using ENVI software, an ASTER L3A product is opened and 14 bands in the product data are loaded. In those data, 3 VNIR bands are selected and a band composite image is created. The combination of bands in the image is RGB=B3, B2, B1.

JOB01 : In ASTER data, resolution of VNIR is 15m and that of SWIR is 30m. To calculate inter-band ratio and create band composite image, VNIR and SWIR should have same resolution. 3 bands of VNIR data are resized to 30m in same resolution as SWIR.

JOB02 : 3 bands of resized VNIR with 30m resolution in JOB01 and 6 bands of SWIR in L3A product which is loaded in JOB01 are selected. The data file which consists of these integrated 9 bands data is created.

JOB03-1 : The data areas are different on both sides of the swath in each band. To create data in the areas where data exist in all bands, a mask which covers the area where no data are in any band is built.

JOB03-2 : The mask built in JOB3-1 is applied to the integrated 9 bands data file created in JOB2 and the masked 9 band data file in the areas where data exist in all bands is created.

By applying the pre-processing mentioned above to 79 scenes, analysis data files (the integrated VNIR-SWIR 9 bands data) are created. The following basic and applied analysis are executed to these data.

6.2.2 Basic analysis

JOB04 : The normalized difference vegetation index (NDVI) is calculated from the analysis 9 bands data created in JOB03. In the Project, band 2 and band 3 of the data were used for calculation of NDVI. The mask data for the vegetation areas according to the NDVI are created.

JOB05-1 : The vegetation mask is built from the distribution of NDVI calculated in JOB04. Specifically, the vegetation mask is built by deciding the threshold of NDVI to separate the vegetation area from the other areas.

JOB05-2 : The water mask is built by using the grayscale image of the band which shows the distribution of water area clearly. In the Project, band 3 of the data was used for build. Specifically, the water mask is built by deciding the threshold of the grayscale value to separate the water area from the other areas.

JOB05-3 : The cloud mask is built by using the grayscale image of the band which shows the distribution of cloud area clearly. In the Project, band 1 of the data was used for build. Specifically, the cloud mask is built by deciding the threshold of the grayscale value to separate the cloud area from the other areas.

JOB05-4：The shadow mask is built by using the grayscale image of the band which shows the distribution of shadow area clearly.　In the Project, band 3 of the data was used for build. Specifically, the shadow mask is built by deciding the threshold of the grayscale value to separate the shadow area from the other areas.　Though the shadow area is made by cloud mainly, the shadow mask is also built about the shadow area made by the condition of steep topography and sunshine.　As soil and rock with dark color show the near value as shadow areas, consideration is needed not to be masked for these analysis areas.　There is a case that it is difficult to separate the areas by using the threshold.　In that case, by drawing manually, the shadow mask was built and the areas out of analysis were masked.

Especially, as data processing which affects analysis results, there is the task of build mask and apply mask.　In build mask, which band is used for build mask or what kind of calculation by using any band is used affect the decision of the analysis area.　The task to select a proper band which shows the characteristic of the region for mask clearly and based on the band, to build the mask to separate outcrops for geological mapping from non-analysis area such as the vegetation area and so on, is needed.

JOB05-5：The integrated mask file which consists of the vegetation mask, the water mask, the cloud mask and shadow mask as the component of bands is created.

JOB05-6：The merged mask is created from the integrated mask file created in JOB05-5.

JOB05-7 : Application of the merged mask created in JOB05-6 to the integrated 9 bands data created in JOB03

JOB06 : Based on the integrated 9 bands data applied the mask to in JOB05-7, various band composite images are created.　The combinations of bands are RGB=B3, B2, B1, RGB=B4, B6, B8 and RGB=B4, B6, B1.

JOB07：Based on the integrated 9 bands data applied the mask to in JOB05-7, the calculation of inter-band ratios is executed.　The calculation of inter-band ratios are B4/B8, B3/B8, B3/B1, B7/B6, B3/B4, B2/B1.

JOB08：Based on the calculation of inter-band ratios in JOB07, various band ratio images are created.　The combinations of inter-band ratios are RGB=B4/B8, B3/B8, B3/B1 and RGB=B7/B6, B3/B4, B2/B1.

JOB09：The band composite images are created by using 5 TIR bands of ASTER original data. The combinations of bands are RGB=B10, B12, B14 and RGB=B13, B12, B10.

6.2.3 Advanced analysis

JOB10-1 : Based on the integrated 9 bands data applied the mask to in JOB05-7, Principal Component Analysis (PCA) is executed. PCA is a mathematical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components and gains a set of new PCA band. Usually important information concentrates to low-order PCA bands, on the contrary, data noise increases as the number of PCA band increases. By using low-order PCA bands instead of the original bands, the distribution of characteristic geology is mapped.

JOB10-2 : Based on PCA bands obtained by PCA in JOB10-1, various PCA band composite images are created. The combination of 3 PCA bands is selected so that geological characteristics in the area for analysis are shown clearly and the PCA band composite image is created. As the geological information which each PCA band shows geological characteristics is different in each scene, which PCA band indicates local geology clearly, or which combination of PCA bands is most available depends on each scene. Generally, the first PCA band (PCA-B1) shows albedo.

6.2.4 Analyzed images

The band composite image and the band ratio image shown in Figure 6.9~6.12 were created by using masked 9 bands data processed in pre-processing and basic analysis.

An example of the band composite image created from original data in JOB00 is shown in Figure 6.6. The combination of bands is VNIR band of RGB=B3, B2, B1. The color distribution is shown in accordance with the observation value even as out of analysis area owing to before pre-processing. Mainly, reddish color indicates vegetation area, dark bluish color indicates water area and brownish color indicates soil or rock.

An example of various masks built in JOB05 is shown in Figure 6.7. Vegetation mask is at upper left, water mask is at upper right, cloud mask is at lower left and shadow mask is at lower right. In all mask images, black area indicates the masked area as out of analysis area. An example of the integrated mask data built from these masks is shown in Figure 6.8.

An example of VNIR band composite image (RGB=B3, B2, B1) created in JOB06 is shown in Figure 6.9. In the Figure, black blank indicates application of mask in masking process and out of analysis area. It is confirmed that masking process is executed properly as vegetation area, water area, cloud area and shadow area indicate black blank in comparison with Figure 6.6. Though the images of Figure 6.6 and Figure 6.9 use the same bands, the tone between these images is different, and the hue in the distribution of soil and rock in Figure 6.9 varies more than that in Figure 6.6. Consequently, it is easier to interpret geological information in Figure 6.9. An example of SWIR band composite image created similarly is shown in Figure 6.10.

The combination of bands is RGB=B4, B6, B8. In the SWIR band composite image of Figure 6.10, existence of minerals including Al-OH group or Mg-OH group is indicated mainly and magenta color series represents different rock facies from blue-green color series. Generally, magenta color series indicates acid clay alteration which consists of Al-OH group and blue-green color series indicates propylitic alteration which consists of Mg-OH group.

An example of band ratio image created in JOB08 is shown in Figure 6.11. The combination of bands is RGB=B4/B8, B3/B8, B3/B1. In the band ratio image of Figure 6.11, existence of iron oxide or basic minerals and tone variations according to the difference of mineral types are indicated.

An example of TIR band composite image created in JOB09 is shown in Figure 6.12. The combination of bands is RGB=B10, B12, B14. In the band composite image of Figure 6.12, difference in content of SiO_2 which exists most abundantly in rock is indicated. Amount of radiation from band 10 to band 12 is low in rock which has relatively more SiO_2, and amount of radiation of band 13 and band 14 is low in rock which has less SiO_2. In consequence, the distribution area of acid igneous rocks shows bluish color and the distribution area of basic rocks shows reddish color.

An example of principal component (PC) band composite image created in JOB10 is shown in Figure 6.13. The area of Figure 6.13 is Palula district. The combination of PC bands is RGB=PCA-B2, PCA-B4, PCA-B6. To compare, the geological map is at the right side of Figure 6.13. In comparison with the geological map, reddish-orangish color indicates biotite gneiss (Xh'), magenta indicates pyroxene gneiss, bluish color indicates pyroxenite (Xup), respectively and the distribution of tone variations is coherent to the geological map.

6.3 PALSAR data analysis

PALSAR is the synthetic aperture radar sensor carried on Japan's latest resource satellite, ALOS and has various observation modes and products (image data) according to the polarity of the microwave to be observed or the resolution. The PALSAR data used in the Project are orthorectified Level 1.5 product. The high accuracy PALSAR L1.5 data covering the entire land of Malawi have 34.4 degree of off-nadir angle and are single polarization data with a ground resolution of about 15m. Data format is GeoTIFF. The location map for the PALSAR L1.5 data covering the whole Malawi is shown in Figure 6.15.

ENVI and ArcGIS software are used by processing and analysis of PALSAR data. After adjusting parameters by using some scenes of PALSAR data to put together each scene of PALSAR data and create the mosaic image of the whole Malawi, the mosaic processing of 64 scenes was executed. Lineaments were extracted and geological structures were interpreted by normal geological photo-interpretation of SAR image. The extraction of the lineament and the circle shape by which Chilwa Alkaline rock district is characterized was executed in the survey area of the field verification.

The process flow of PALSAR data is shown in Figure 6.14. Technology transfer through OJT of these data processing and analysis in Figure 6.14 was conducted. As ASTER data analysis, the manual of data processing and analysis using ENVI was prepared at the same time, and practical data processing and analysis were carried out based on this manual.

Details of PALSAR data processing and analysis are described according to JOB number in Table 6.1 of Satellite data and creating files list and Figure 6.14 of Process flow of PALSAR data as follows.

6.3.1 Creation of mosaic image

JOB01 : After configuring parameters of feathering for overlaid regions by using some scenes of the PALSAR product, mosaic process is executed by using 64 scenes of the PALSAR product and the PALSAR mosaic image file is created.

JOB02 : The grayscale mosaic image (GeoTIFF file) is created by using the PALSAR mosaic image file in JOB01.

Figure 6.16 shows the PALSAT mosaic image of the whole Malawi created by mosaic processing. The fine shadings in the figure are correspondingly expressed by variation of topography and geological formation like as faults form in the geological map Massed dark color presents water area mainly. The PALSAR mosaic image zooming in the southern Malawi is shown in Figure 6.17. The roughness around Mt. Mulanje, the circle shape structures in Machinga area and the NNE-SSW lineament system existing from Zomba to Blantyre can be seen clearly.

6.3.2 Extraction of lineament

JOB03 : Based on PALSAR mosaic image, the lineaments are extracted by normal geological photo-interpretation of SAR data to interpret the geological structure. The PALSAR mosaic image created in JOB02 is registered to the map by ArcGIS and lineaments are traced by using the function of creating polylines. The data of lineaments extracted are saved as shapefile.

JOB04 : The lineament image is created by the shapefile created in JOB03.

As reference data for extraction of lineament, the topographic map of the southern Malawi was created and shown in Figure 6.18. The distribution of lineaments extracted from PALSAR mosaic image and circle shapes by which Chilwa Alkaline rock district is characterized in the southern Malawi is shown in Figure 6.19. The task of Extraction of lineament is executed as OJT. The complex lineament system around Mt. Mulanje, the distribution of circle shapes in Machinga area, the well-developed lineament system around Zomba, the NE-SW lineament system existing widely from Blantyre to Chikwawa can be seen clearly. The lineaments formed by faults in the geological map were clearly confirmed by the lineaments extracted in PALSAR mosaic image.

6.4 Ground truth

The field verification survey for satellite data analysis was implemented as OJT. The objectives of the field verification survey are to improve the accuracy of data analysis and to provide a deeper understanding of the analytical results. The survey areas were selected in which it is deemed necessary to implement checks on rock facies, mineral occurrences and geological structure as well as studies on mineralization areas. However, as a realistic approach, the areas for which one-day trips are possible from Zomba where GSD bases in the southern Malawi or major city Blantyre were selected out as the survey areas. The location of the field verification survey for satellite data analysis is shown in Figure 6.20 and ASTER band composite image (RGB=B3, B2, B1) is shown in Figure 6.21. As field verification survey area, Balaka area (5 sites), Liwonde area (5 sites), Palula area (5 sites), Zomba area (4 sites), Chikwawa area (5 sites) and Mulanje area (5 sites) were selected and the field verification survey was conducted at them.

6.4.1 Survey schedule

The field validation survey was held for 5 days from 5 November, 2012. 3 or 7 C/Ps participated per day according to the arrangement of cars or the capacity. From 5 November to 7 November, the study team had one day excursion from Zomba. As one day trip from Zomba to Chikwawa is difficult, the study team stayed one night on 8 November at Blantyre after the survey of Chikwawa area and on next 9 November, had the survey of Mulanje area. Table 6.2 shows the time schedule of field verification survey and participants.

6.4.2 Survey contents

The analyzed images (scale: 1/5,000~1/10,000) of the satellite data in the area covered by the field verification survey are printed out in advance and are brought to the field. The verification is implemented by comparing the satellite data analysis results with rock outcrops in the field. Rocks of typical outcrops are sampled, and the outcrops and surrounding conditions are photographed. In addition, in data sheets (Figure 6.22) prepared beforehand the details of the field verification survey are described as follows.

- Rock types and main constituent mineral types
- Geological structure, measurement of dip and strike of lineament structure
- Position data acquired by GPS
- Outcrop conditions and vegetation conditions
- Photographing and items of rock sample collection

An example of data sheet for field verification is shown in Figure 6.22. Technology transfer was also implemented for how to acquire GPS data, how to transfer data to PC, and how to input the acquired data into the GIS database.

Results of field verification for satellite data analysis is shown in Table 6.3 and photos of field verification for satellite data are shown in Figure 6.23.

Table 6.2 Schedule of ground truth

Date	Study team	C/P	Field verification area
5 November	Onuma, Takeda	3 person	Balaka (Blk01~04)
6 November	Onuma, Takeda	3 person	Balaka (Blk05), Palula (Pal01~05)
7 November	Onuma, Takeda	7 person	Liwonde (Lwd01~05), Zomba (Zmb01~04)
8 November	Onuma, Takeda	3 person	Chikwawa (Ckw01~03, Len01~02)
9 November	Onuma, Takeda	3 person	Mulanje (Mul01~05)

6.5 Manual of satellite data analysis

The satellite data analysis manual was prepared through OJT to enable the C/P staff to execute the satellite data analysis on a self-reliant basis. The C/P staff has to continue satellite data analysis mentioned above in a self-reliant and sustainable way after the end of the Project and that is the final objective of the Project. For this purpose, the C/P staff took the initiative in preparing the manual. In satellite data analysis, as ENVI software of Exelis VIS is used mainly, the manual was prepared with reference to "A Quick Start to ENVI/ENVI Tutorial" and "Getting Started with ENVI/Manual", which are provided by Exelis VIS to users of the software. As ArcGIS of ESRI was used in a part of satellite data analysis, it is mentioned about how to use ArcGIS in the manual. ASTER data analysis, PALSAR data analysis, G-DEM data analysis and LANDSAT data analysis were mainly described in the manual. The following is the contents of the satellite data analysis manual. Intensive edition of the satellite data analysis manual is shown in Appendix 4.

(1) ASTER data analysis

- Opening and saving data
- Resizing data
- Integration of data and bands
- Calculation of Normalized Difference Vegetation Index (NDVI)
- Build of the mask (no data area, vegetation area, water area, cloud area and shadow area) and application to data
- Creation of the merge mask and application to data
- Creation of the band composite image
- Calculation of inter-band ratios
- Creation of the band ratio image
- Principal Component Analysis (PCA)

(2) PALSAR data analysis

- Opening and saving data
- Process of mosaic
- Creation of the mosaic image
- Extraction of lineaments

(3) G-DEM data analysis

- Opening and saving data
- Process of mosaic
- Creation of ASTER G-DEM color gradient topographic image
- Creation of the shaded relief image

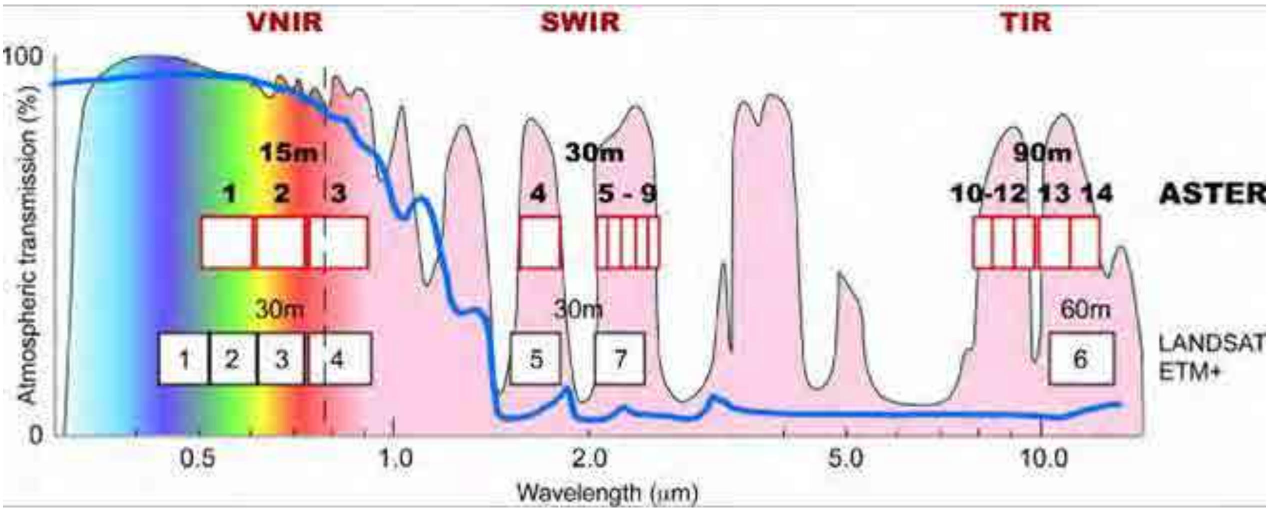
(4) LANDSAT data analysis

- Opening and saving data
- Integration of data and bands
- Calculation of Normalized Difference Vegetation Index (NDVI)
- Build of the mask (no data area, vegetation area, water area, cloud area and shadow area) and application to data
- Creation of the band ratio image
- Creation of the 3-D map

A part of the manual of data processing and analysis using ENVI prepared through OJT of the Project is shown in Figure 6.24. The manual prepared in the Project includes the actual menu screen and images displayed in ENVI, contains visually clear contents so that beginners can operate ENVI easily to accomplish satellite data analysis.

Table 6.3 Results of field verification for satellite data analysis

Site ID	UTM –E (m)	UTM –N (m)	Geologic map code	Rock name (in geological map)	Minerals identified (in situ)	Rock name (in field)	Sample ID	ASTER image column # / row #
Blk01	671,761	8,361,780	Xsy	Perthite Gneiss grading into Perthosite	Plagioclase,orthoclase,biotite	Granite gneiss	Blk01	10 / 2
Blk02	672,321	8,359,612	Xs'	Banded Gneiss	Plagioclase,biotite,almandine	Biotite gneiss	Blk02	10 / 2
Blk03	671,514	8,358,811	Xt	Plagioclase granulite	Almandine,magnetite,plagioclase,Biotite	Biotite gneiss	Blk03	10 / 2
Blk04	674,976	8,363,974	Xgg	Quartzofeldspathic granulite and Gneiss	Magnetite,Biotite,Plagioclase	Granitic gneiss	Blk04	10 / 2
Blk05	698,183	8,355,969	Xna	Augen Gneiss	Quartz,Biotite,Orthoclase,plagioclase	Augen gneiss	Blk05	10 / 2
Pal01	700,828	8,315,703	Xgg	Quartzofeldspathic granulite and Gneiss	Muscovite,Biotite,Quartz	Biotite Muscovite gneiss	Pal01	11 / 3
Pal02	700,963	8,291,482	Xc	Marble	Calcite,dolomite,quartz,feldspar	Marble	Pal03A	11 / 3
Pal03	700,826	8,291,646	Xh'	Hornblende-Biotite Gneiss with Variable amounts of Epidote	Biotite,epidote,plagioclase,Hornblende	Hornblende-Biotite gneiss	Pal03B	11 / 4
Pal04	703,292	8,291,398	Xsy	Anatectic Pyroxene-perthosite-gneiss	Quartz,plagioclase,augite	Pyroxen-gneiss	Pal04	11 / 4
Pal05	704,529	8,290,593	Xup	Meta-pyroxenite	actinolite,augite	Pyroxenite	Pal05	11 / 4
Lwd01	741,077	8,324,245	Pu	Pulaskite and Course pulaskite	Hornblende,feldspar	Syenite	Lwd01A	11 / 3
Lwd02	739,072	8,325,276	Xggs"	Biotite-quartz-feldspar-gneiss	Feldspar,Biotite,quartz	Gneiss	Lwd02	11 / 3
Lwd03	738,154	8,325,242	Xc	Calc-silicate gneiss and granulite	Biotite,feldspar	Calc-silicate gneiss	Lwd03	11 / 3
Lwd04	736,150	8,323,018	Xh'	pyroxene -hornblende-biotite-gneiss,occasionary garnetiferous	augite,hornblende,Biotite,	Hornblende-biotite-gneiss	Lwd04	11 / 3
Lwd05	740,873	8,323,796	Nsy	Nepheline Syenites	Plagioclase,Biotite	Syenite	Lwd01C	11 / 3
Zmb01	747,084	8,299,175	Xk	Charnockitic gneiss and granulite	Biotite,plagioclase,quartz	Biotite-gneiss	Zmb01	11 / 3
Zmb02	748,441	8,299,726	Qmsyp	Porphyritic-quartz-Microsyenite	Feldspar,Biotite,quartz	Syenite	Zmb02	11 / 3
Zmb03	747,074	8,301,702	Sy	Syenites	Biotite,plagioclase,hornblende	Syenite	Zmb03	11 / 3
Zmb04	748,480	8,293,421	Xqsy	Anatectic quartz-syenite	Quartz,hornblende plagioclase	Syenite	Zmb04	11 / 4
Ckw01	672,788	8,212,600	Kt	Massive grits and sandstone with horizon of flaggy sandstone	Quartz,feldspar	Sandstone	Ckw01	11 / 5
Ckw02	673,379	8,212,863	Kt	Massive grits and sandstone with horizon of flaggy sandstone	Quartz,hornblende,biotite,	Conglomerate	Ckw02	11 / 5
Ckw03	682,960	8,213,806	Xh'	Hornblende-Biotite-gneiss	Quartz,plagioclase,Biotite	Hornblende-biotite-gneiss	Ckw03A	11 / 5
Len01	672,430	8,202,538	Km	Grits,sandstone and calcareous shales	Quartz,feldspar	Conglomerate and sandstone	Len01	11 / 5
Len02	672,769	8,202,483	Km	Grits,sandstone and calcareous shales	Quartz,feldspar	Conglomerate and sandstone	Len02B	11 / 5
Mul01	767,072	8,240,579	Sy	Syenite (float)	Quartz,Biotite,plagioclase,hornblende	Syenite	Mul01	13 / 4
Mul02	777,492	8,247,330	Xh'	Hornblende-biotite-gneiss	Biotite,quartz,plagioclase	Biotite gneiss	Mul02	13 / 4
Mul03	782,789	8,259,169	Xsy	Perthite-gneiss	Biotite,plagioclase,quartz	Biotite gneiss	Mul03	13 / 3
Mul04	785,599	8,259,397	Qsy	Quartz-Syenite	Feldspar,syenite	Syenite	Mul04	13 / 3
Mul05	800,523	8,263,231	Nsy	Nepheline Syenites	Quartz,plagioclase,Biotite	Syenite	Mul06	13 / 3



Wavelength zone	Band number	Range of band wavelength (μ m)	Spatial resolution
VNIR	1	0.52 - 0.60	15m
	2	0.63 - 0.69	
	3	0.78 - 0.86	
SWIR	4	1.600 - 1.700	30m
	5	2.145 - 2.185	
	6	2.185 - 2.225	
	7	2.235 - 2.285	
	8	2.295 - 2.365	
	9	2.360 - 2.430	
TIR	10	8.125 - 8.475	90m
	11	8.475 - 8.825	
	12	8.925 - 9.275	
	13	10.25 - 10.95	
	14	10.95 - 11.65	

Figure 6.1 Bands location of ASTER sensors

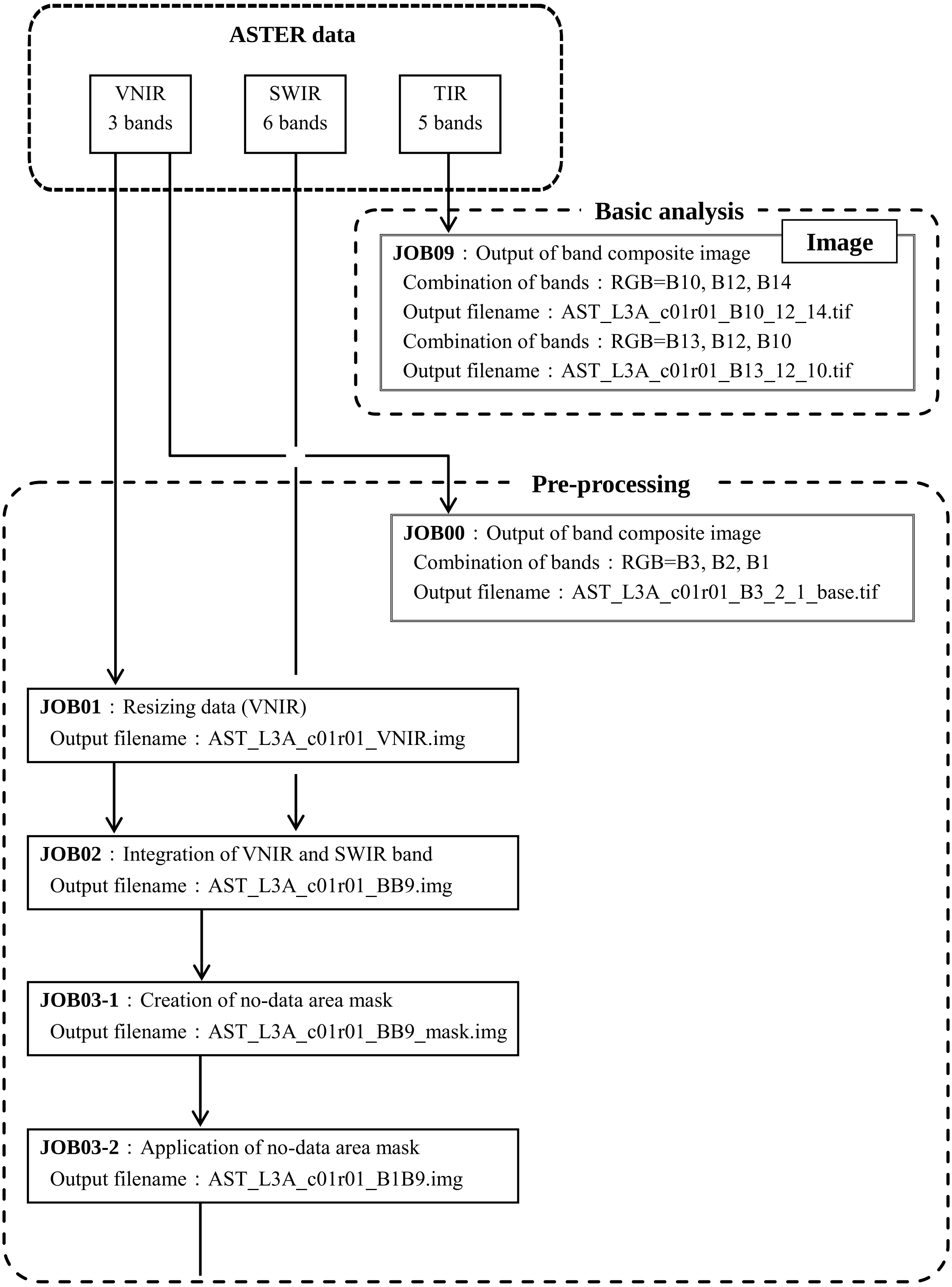


Figure 6.2 Flow chart of ASTER data processing (1/3)

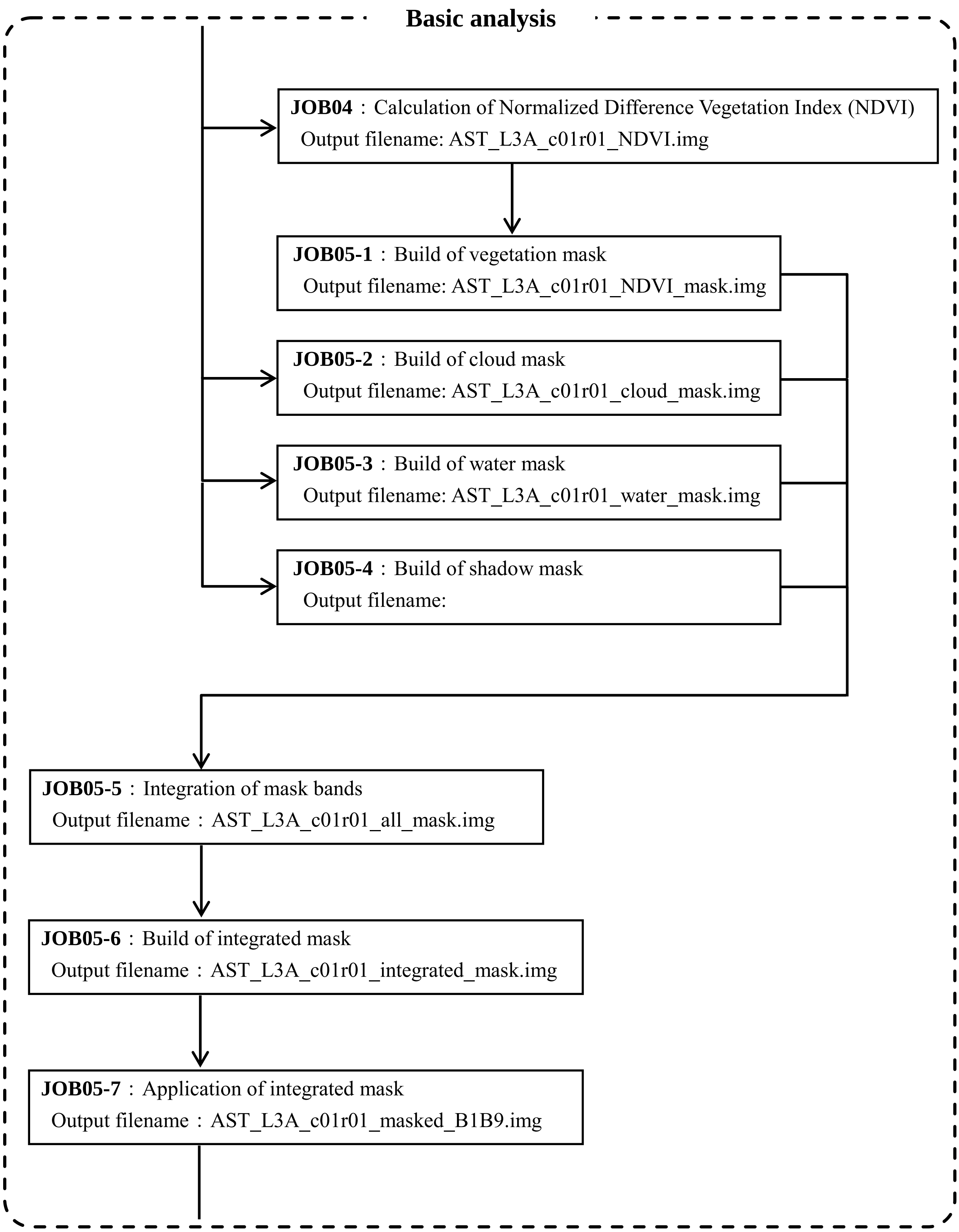


Figure 6.2 Flow chart of ASTER data processing (2/3)

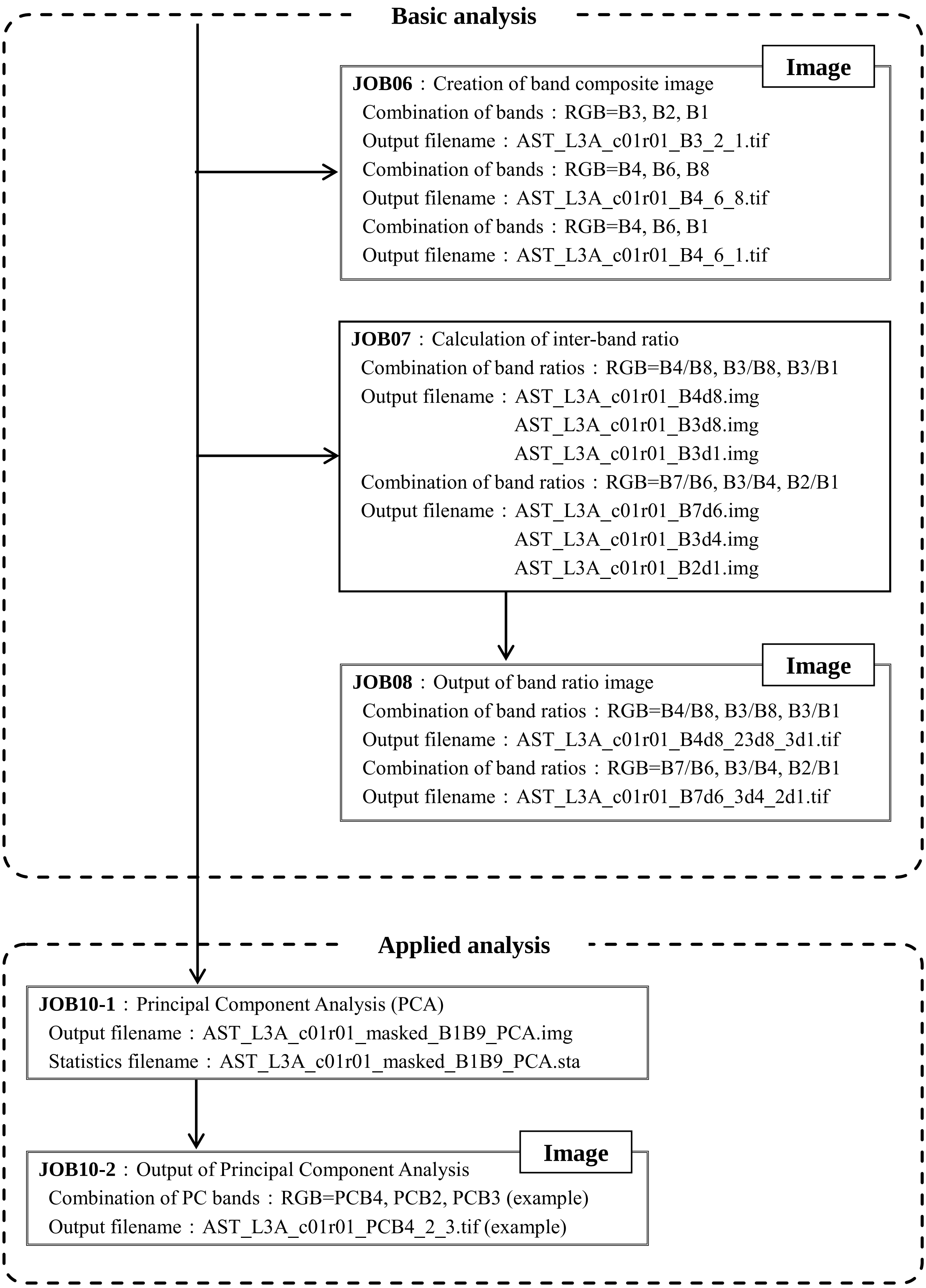


Figure 6.2 Flow chart of ASTER data processing (3/3)

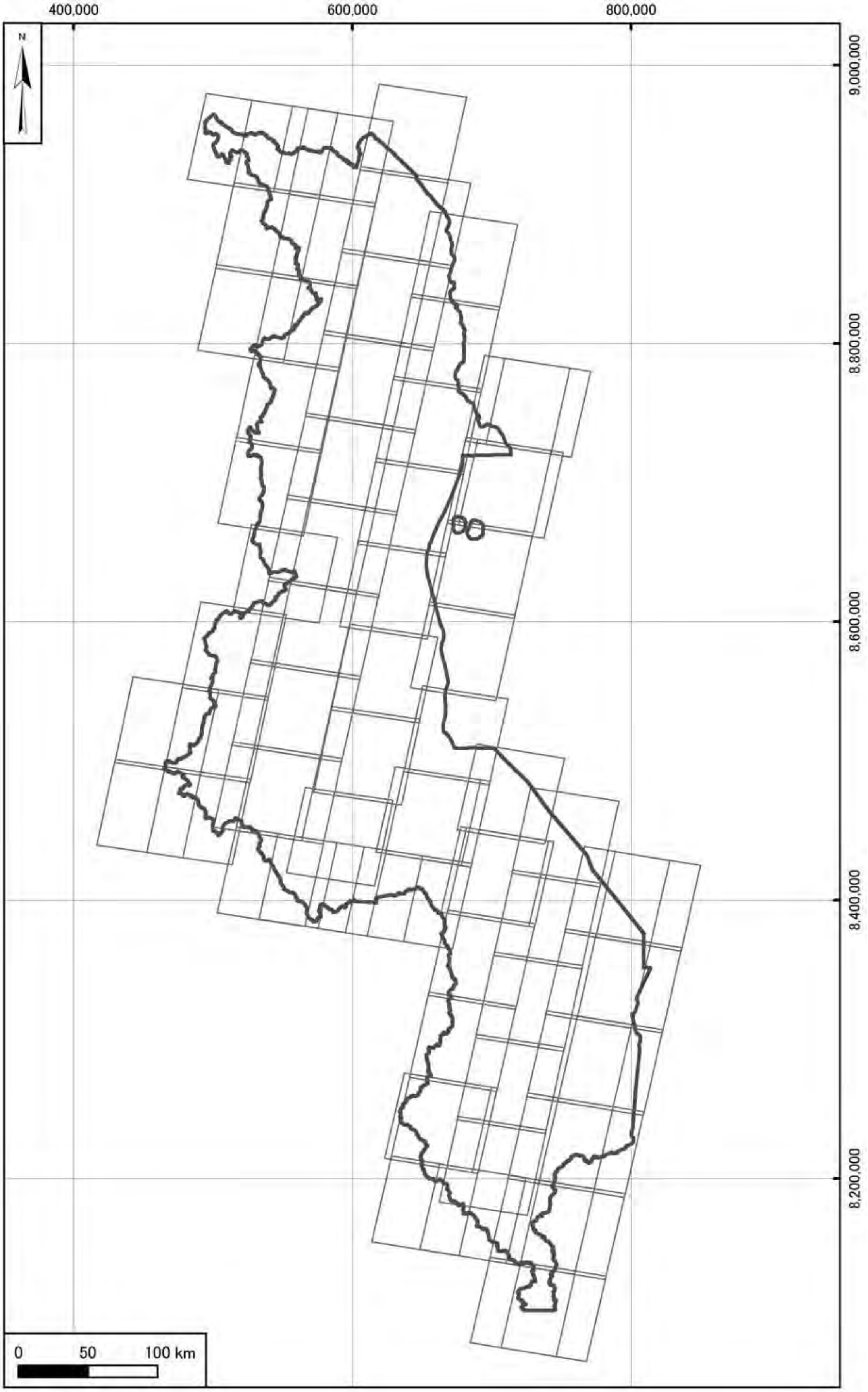


Figure 6.3 Location map of ASTER data

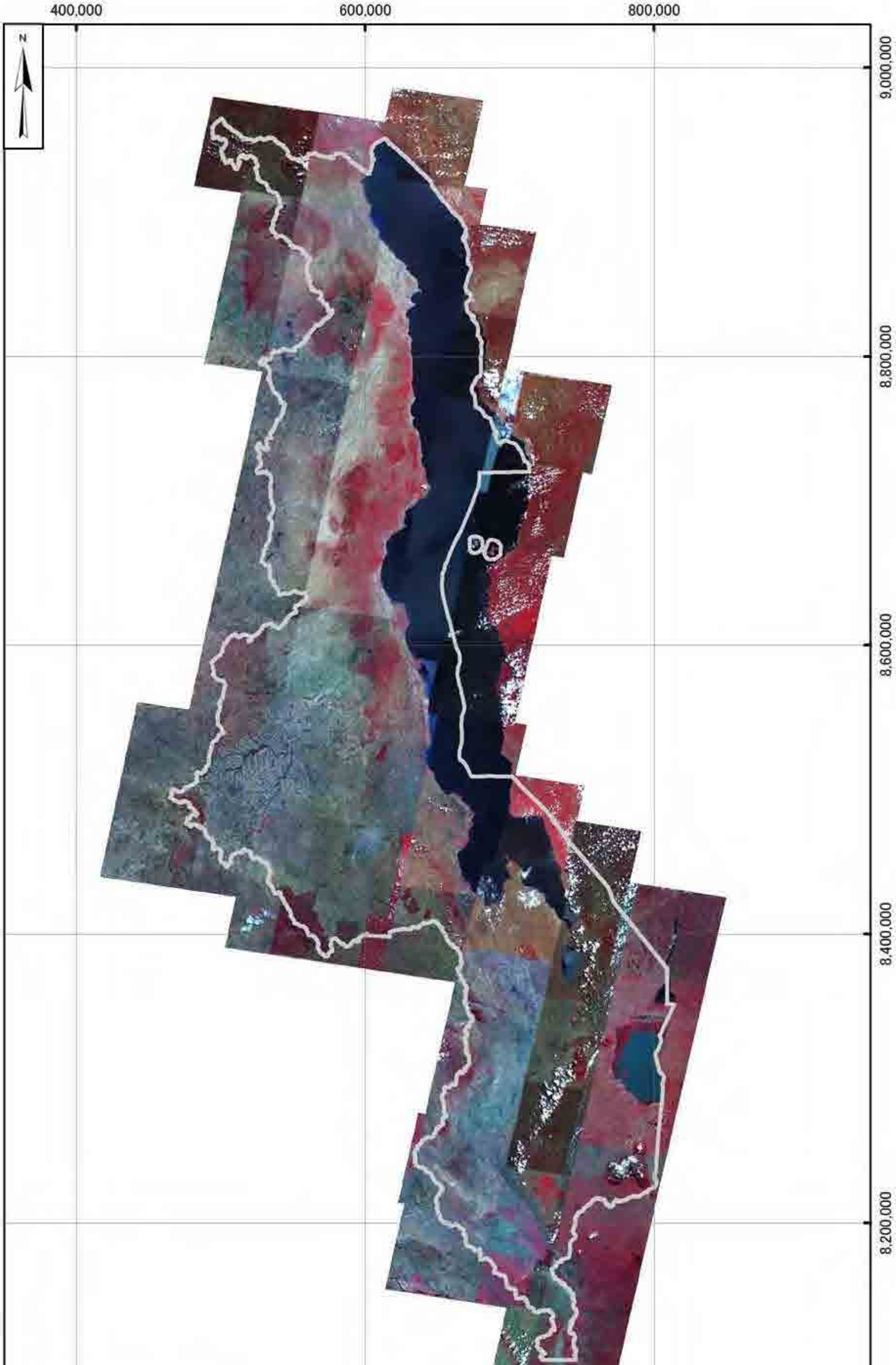


Figure 6.4 ASTER browse image of whole Malawi

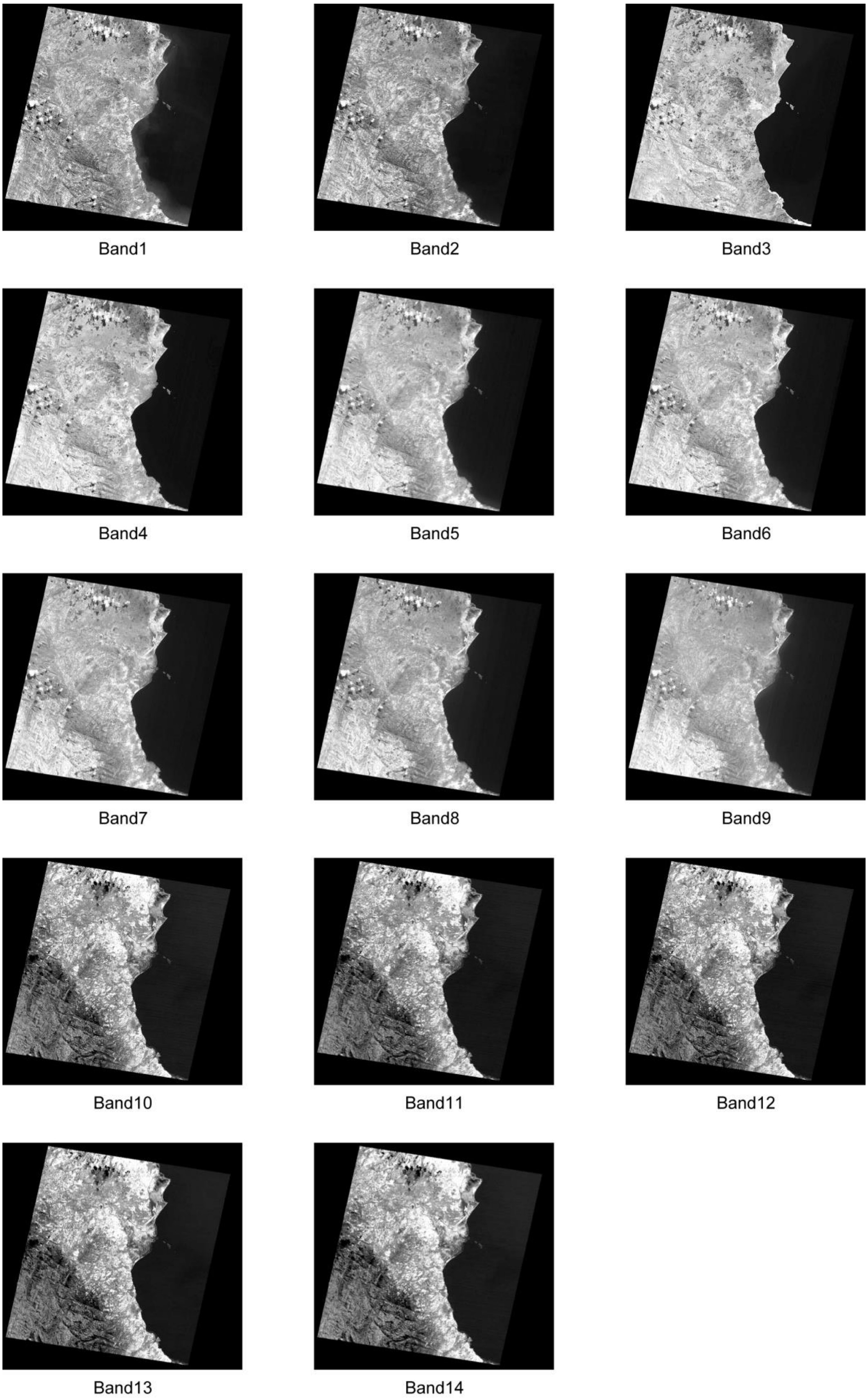


Figure 6.5 All bands images of ASTER data

Figure 6.6 ASTER band composite image (RGB=B3,B2,B1)

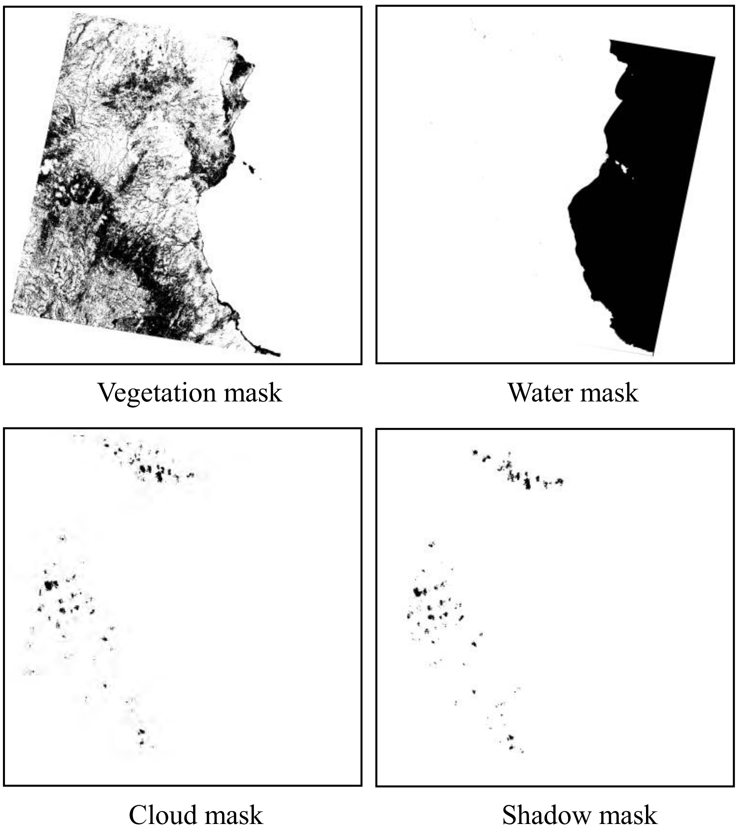


Figure 6.7 ASTER mask data (vegetation, water, cloud, shadow)

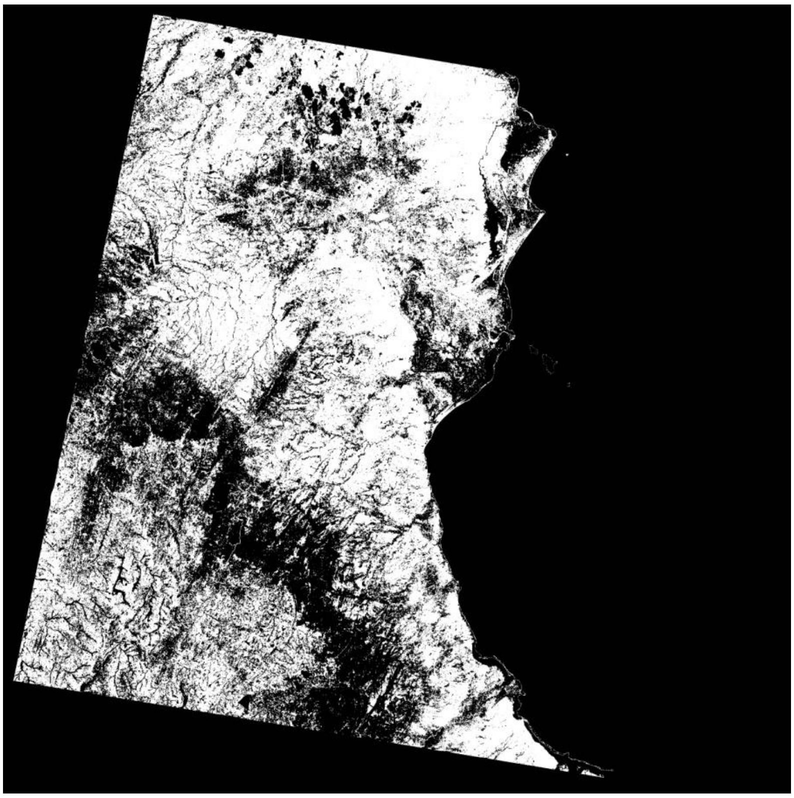


Figure 6.8 ASTER integrated mask data

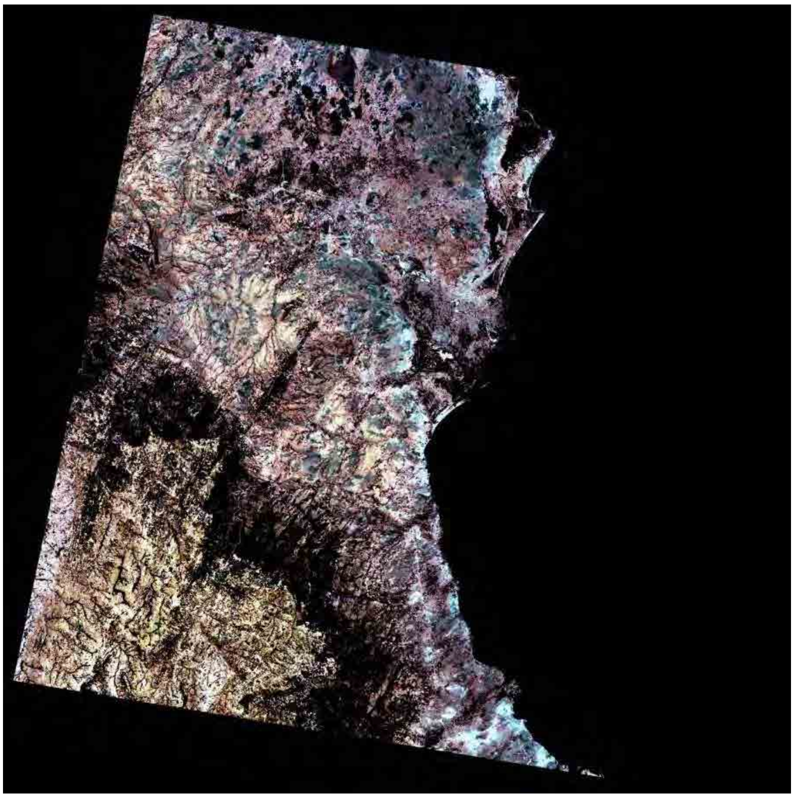


Figure 6.9 ASTER VNIR band composite image (RGB=B3,B2,B1)

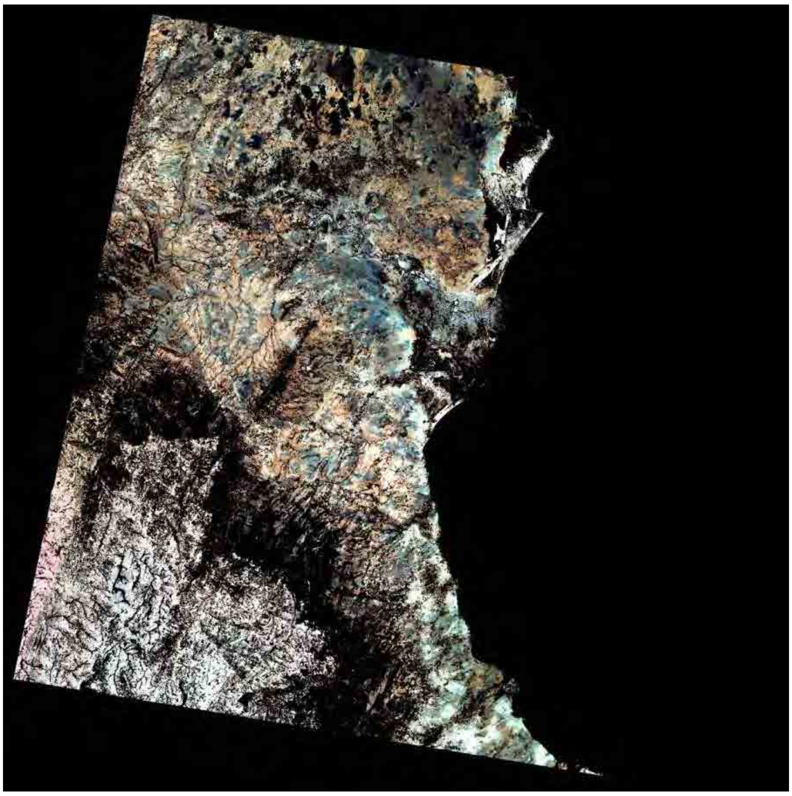


Figure 6.10 ASTER SWIR band composite image (RGB=B4,B6,B8)

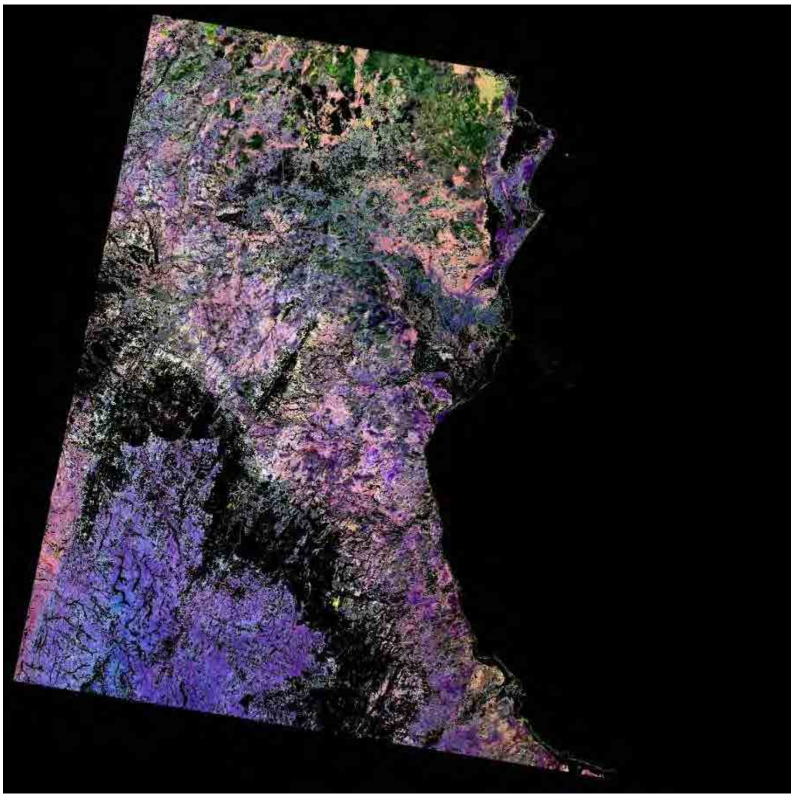


Figure 6.11 ASTER band ratio image (RGB=B4/B8,B3/B8,B3/B1)

Figure 6.12 ASTER TIR band composite (RGB=B10,B12,B14)

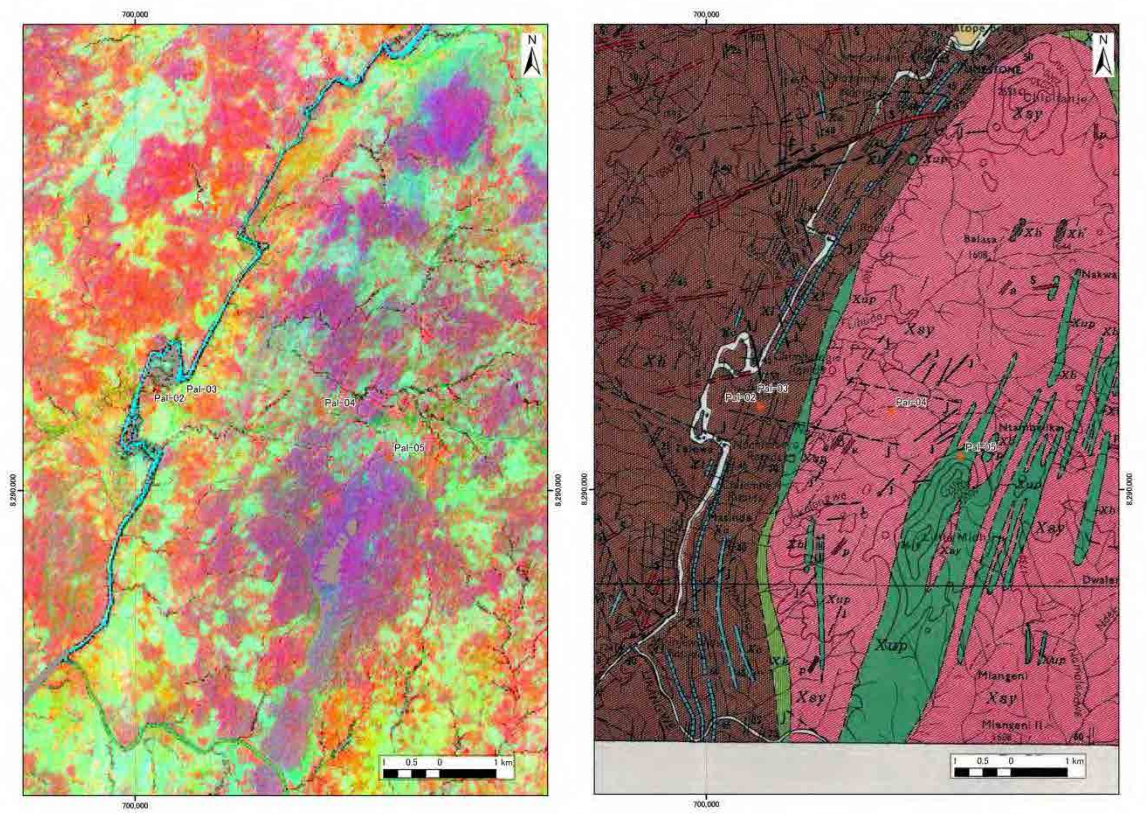


Figure 6.13 ASTER PCA image (RGB=PCA-B2,B4,B6) (left) and geological map (right)

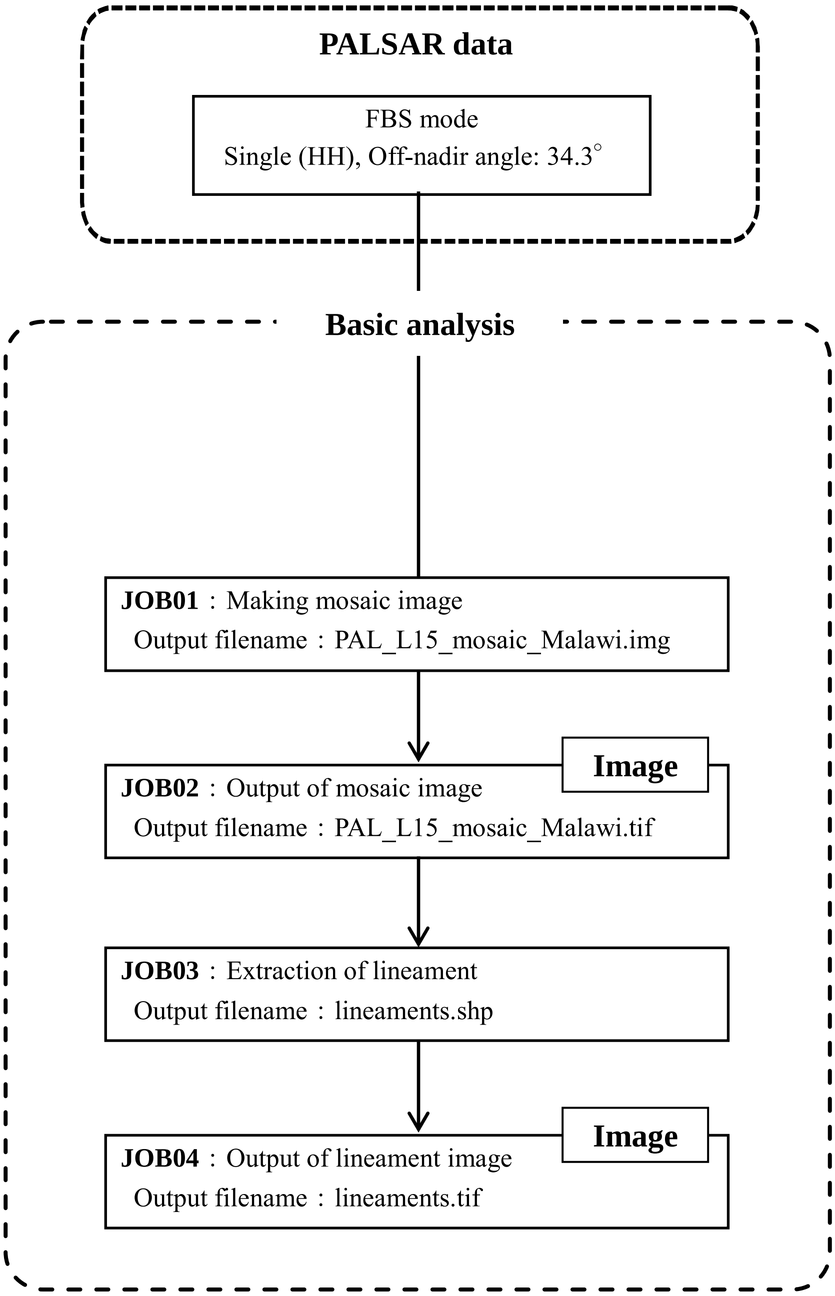


Figure 6.14 Flow chart of PALSAR data processing

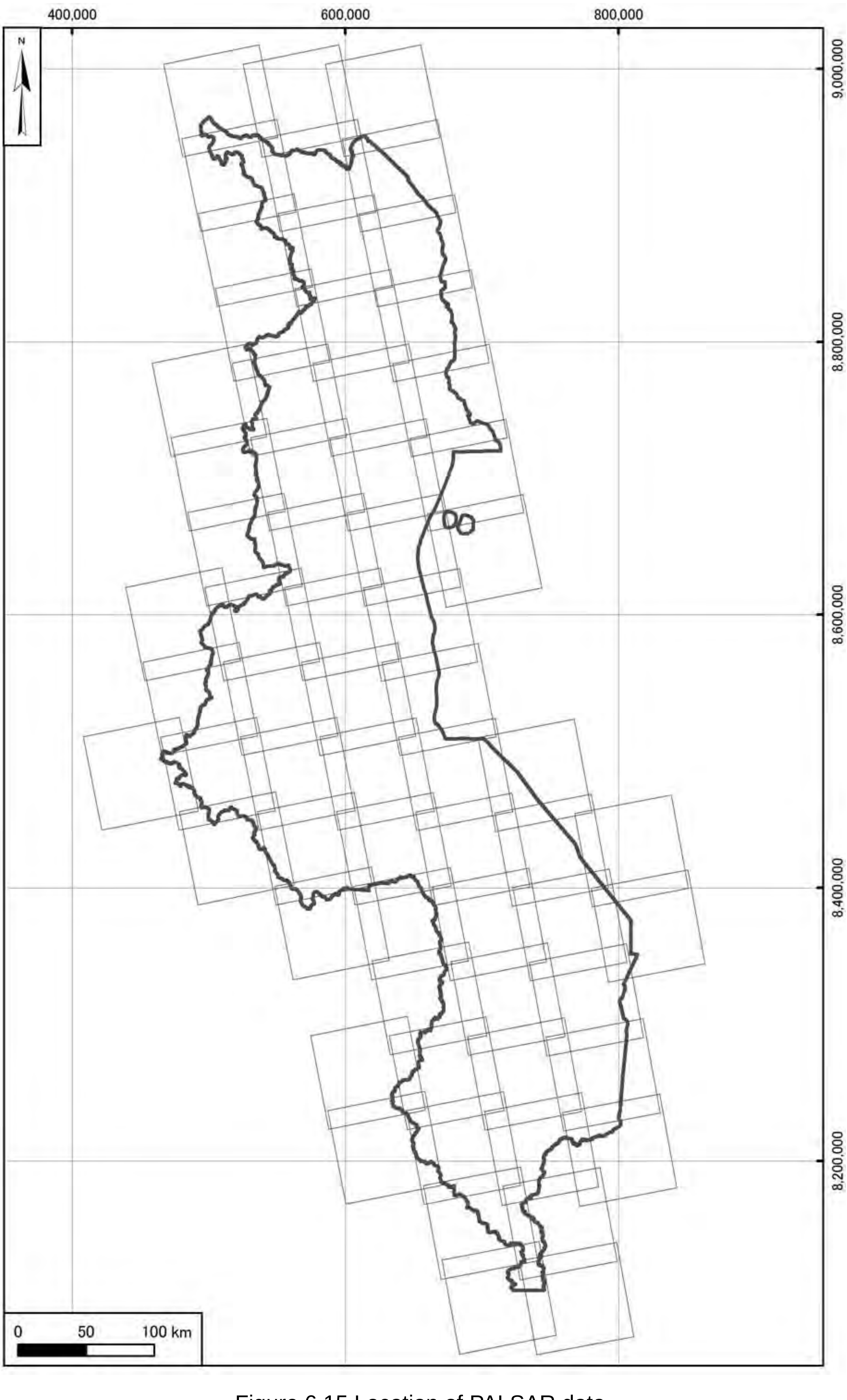


Figure 6.15 Location of PALSAR data

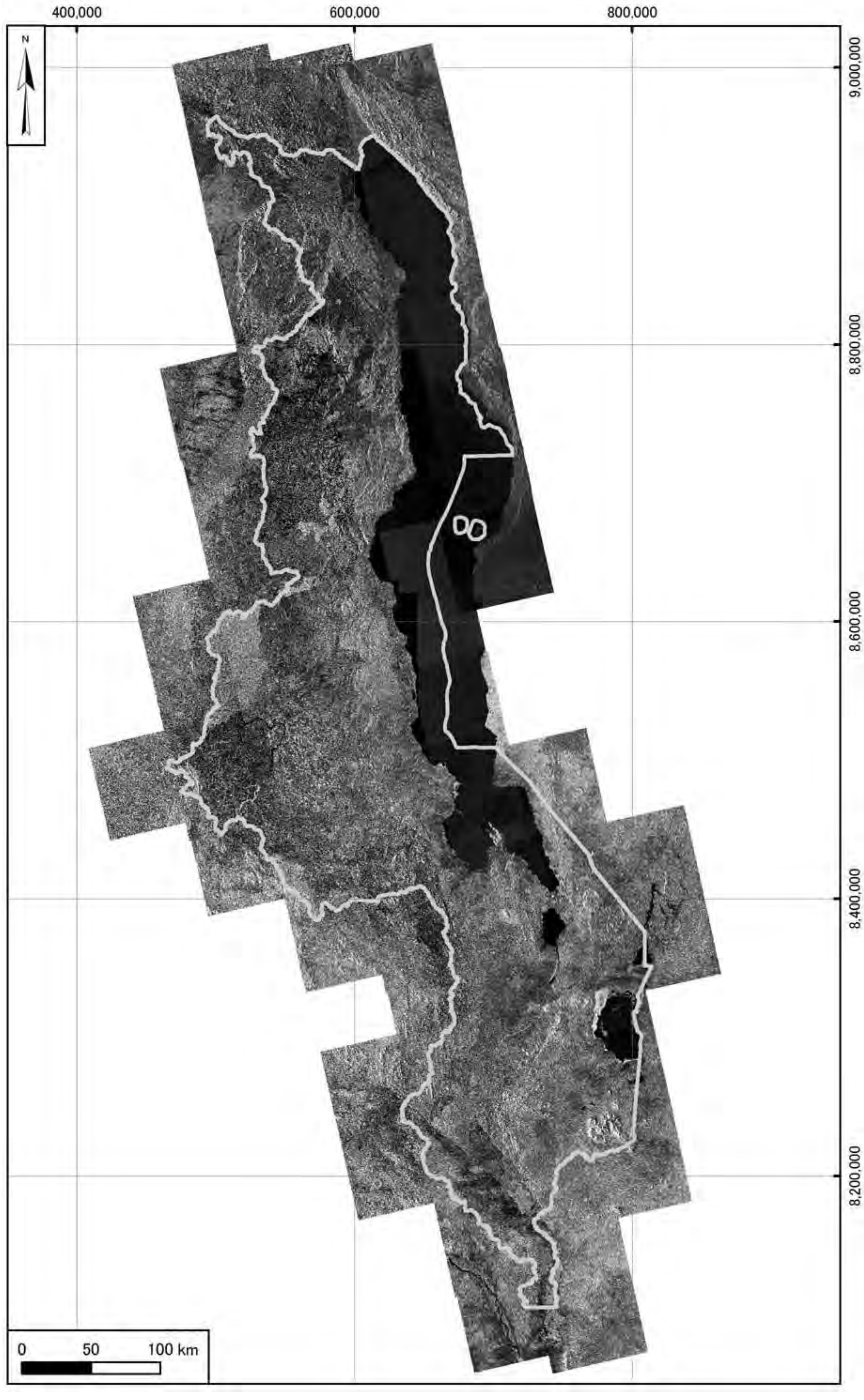


Figure 6.16 PALSAR mosaic image of whole Malawi

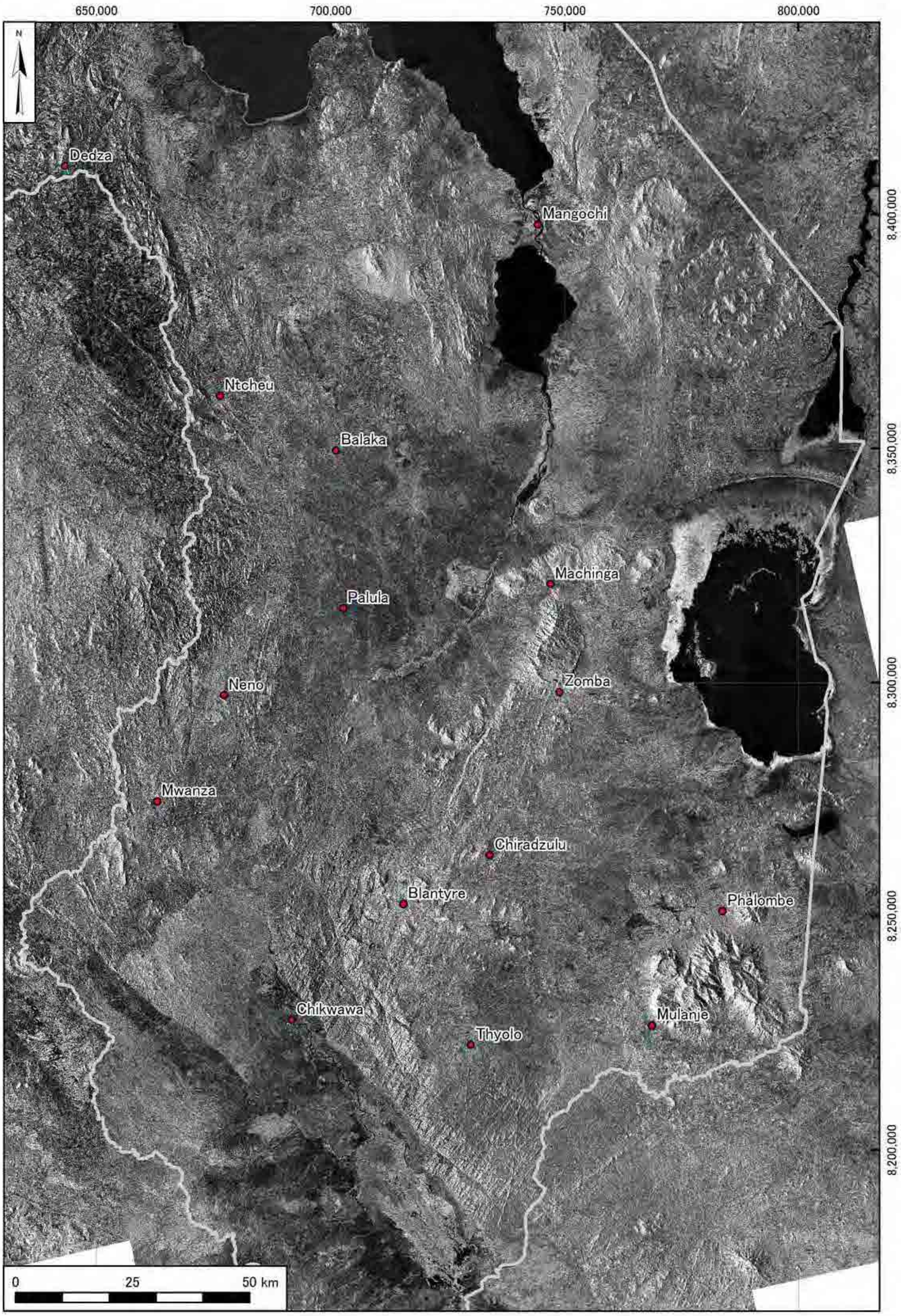


Figure 6.17 PALSAR mosaic image of the southern Malawi

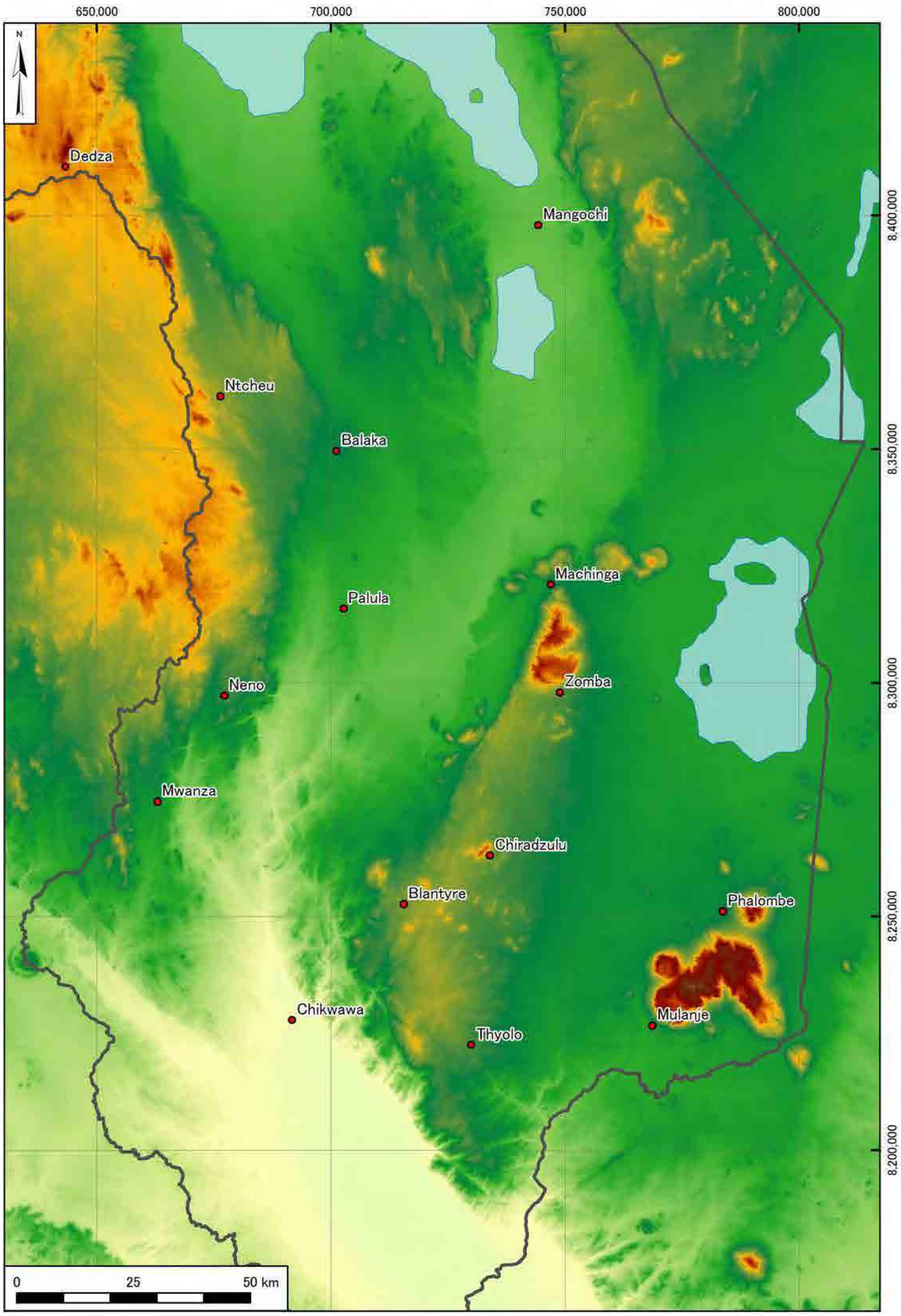


Figure 6.18 ASTER G-DEM color gradient topographic map of the southern Malawi

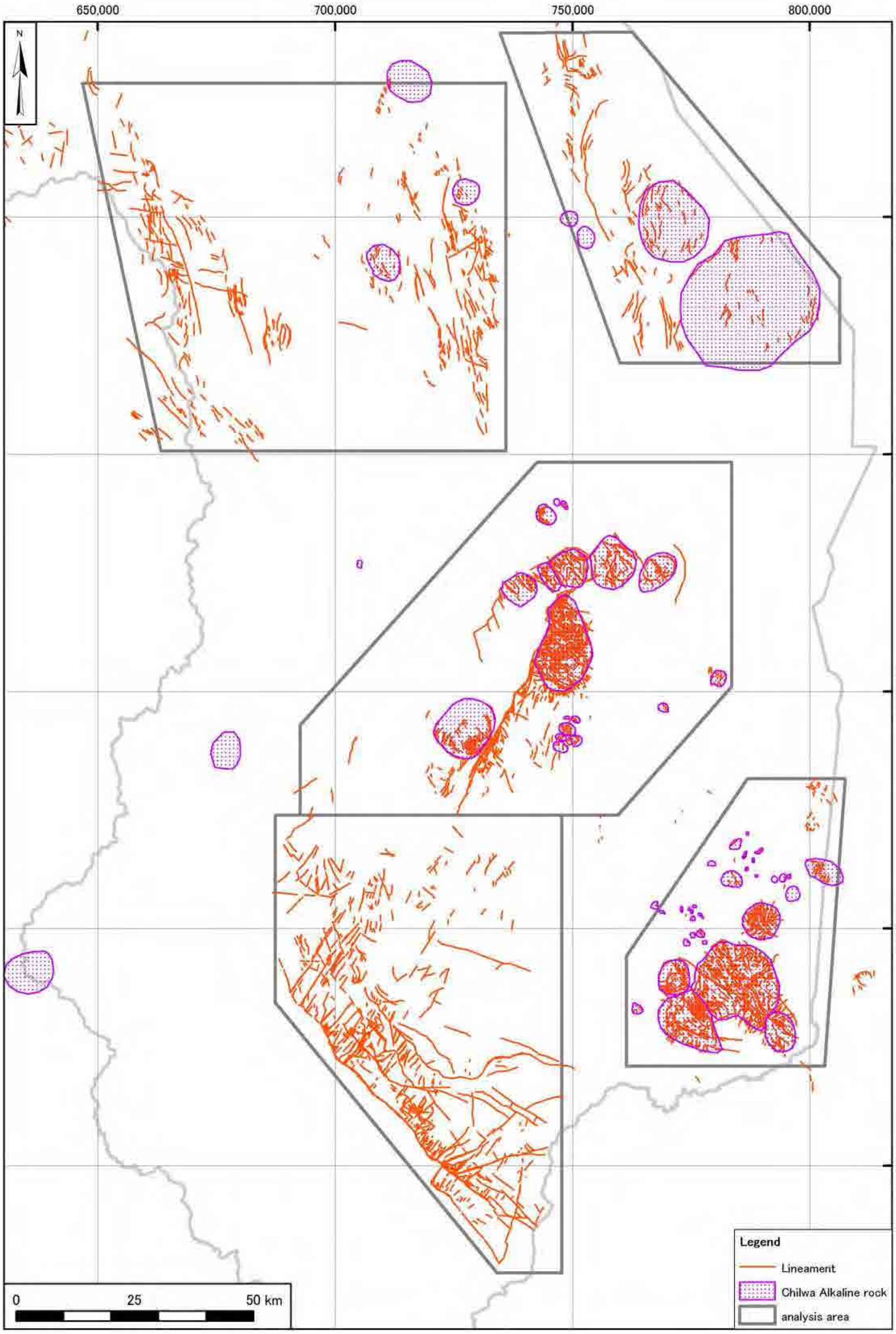


Figure 6.19 Lineament map of the southern Malawi

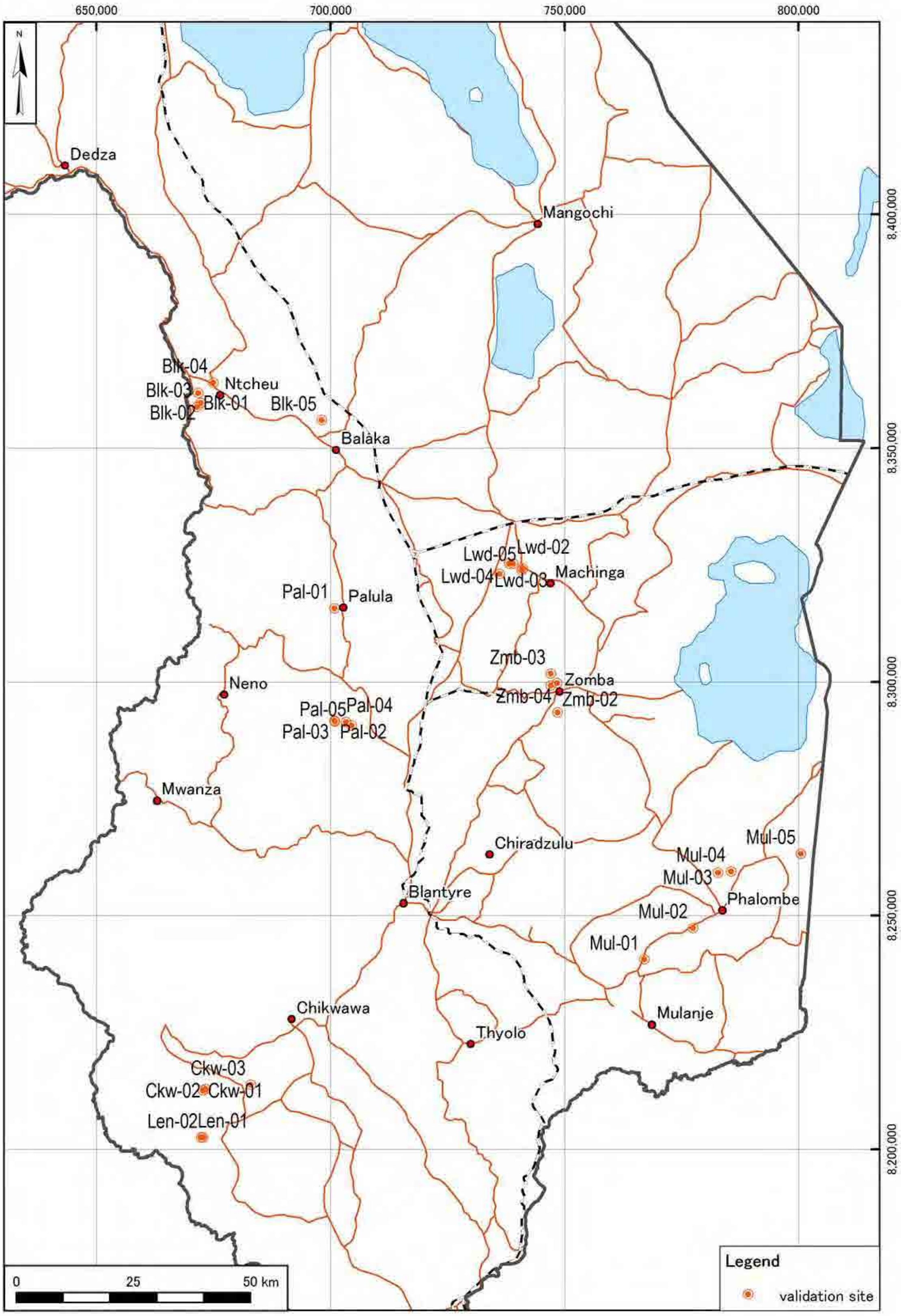


Figure 6.20 Location map of field verification for satellite data

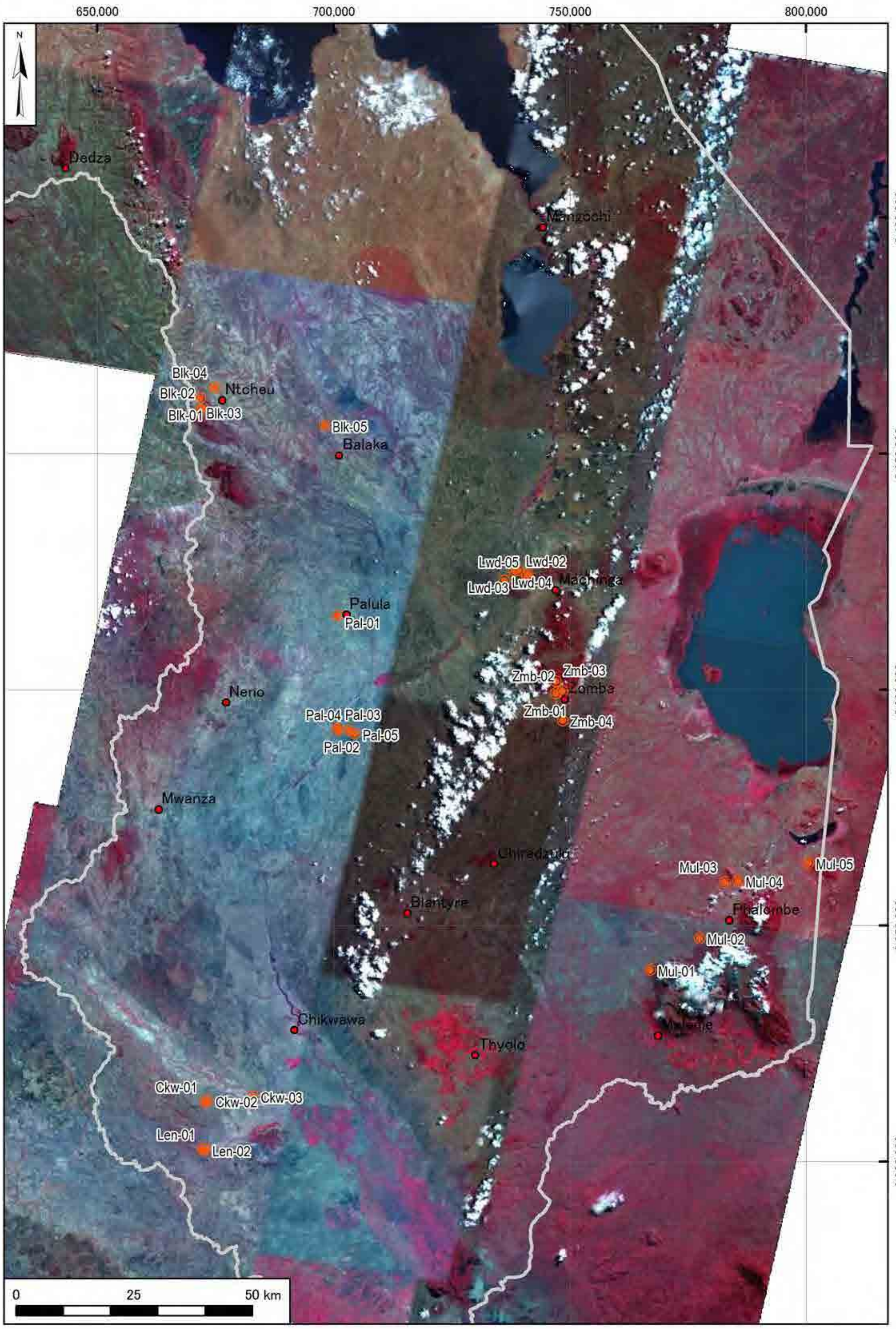


Figure 6.21 ASTER image of field verification area

Site No.: Blk-03	Date: 5^{th} November 2012
Place: west of Ntcheu	
UTM-easting: 671,514	Planned UTM-E: 671,803
UTM-northing: 8,358,811	Planned UTM-N: 8,358,642
Geology: Xt	
Rock name: Plagioclase-granulite.	Color of ASTER images
	-B3,2,1: dark gray
Minerals: Almandine, magnetite, plagioclase, Biotite.	-B4,6,8: dark violet
	-B4/8,3/8,3/1: light gray
	-B13,12,10: dark gray
Geological structure: Trending WNW.	-Remarks:
	Vegetation: Scanty to moderate.
Sample no.: **Blk-03**	
Photo	

Figure 6.22 Example of data sheet for field verification

Blk01

Pal02

Lwd02

Zmb01

Zmb03

Ckw03

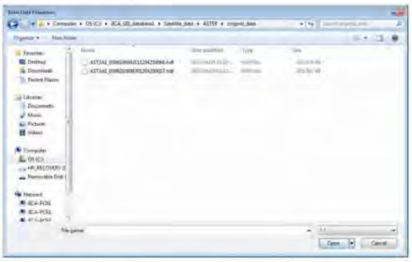
Len01

Mul01

Figure 6.23 Photos of field verification for satellite data

JOB00-1
+ Job content: Create a color composite image (RGB=B3,B2,B1) of ASTER VNIR data
+ Input file folder: C:¥JICA_GIS_database¥Satellite_data¥ASTER¥original_data
+ Input filename: (example: AST3A1_0506100803111204250066.hdf)
"¥" means back slash.

- Click "File" on main menu bar.
- Select and click "Open Image File".
- "Enter Data Filenames" window appears.



- Choose and find the input data folder in the window.
- Select and click the input ASTER data file in the window.
Input file folder: C:¥JICA_GIS_database¥Satellite_data¥ASTER¥original_data
(example: AST3A1_0506100803111204250066.hdf)
- Selected data filename appears in the "File Name" box.
- Click "Open" box in the window.

- Selected ASTER data is read into ENVI and appears in the "Available Bands List" window.

- Click "RGB color" circle shown in lower part of the "Available Bands List" window.
- R/G/B circles and description boxes appear in the lower part of the window.
- When the "R circle" is selected (ticked), click "ASTER VNIR Band3N".
- After the click above, the "G circle" is automatically ticked.
- When the "G circle" is selected (ticked), click "ASTER VNIR Band2".
- After the click above, the "B circle" is automatically ticked.
- When the "B circle" is selected (ticked), click "ASTER VNIR Band1".
- After the click above, the "R circle" is automatically ticked again.

- Make sure that Band3N is shown in the "R box", Band2 in the "G box" and Band1 in the "B box".

- Click "No Display" box in the bottom of the window.
- Select and click "New Display".
- Click "Load RGB" box in the bottom of the window.

- Three kinds of window "Image / Scroll / Zoom" appear.
- A color composite (false color) image (RGB=B3,B2,B1) of ASTER VNIR data is created.

Figure 6.24 ENVI procedure manual for satellite data analysis

7. GIS data creation

7.1 GIS data creation of geological map

GIS data creation is executed to digitize total 40 sheets of 1/100,000 scale geological maps which cover the whole of Malawi (Table 7.1, Figure 7.2). These maps started to be published in 1957 before the independence of Malawi, and were completed in 1984.

GIS data of geological maps were created through OJT using ArcGIS Ver.10.0 of ESRI as provided equipment in the Project. A half of 40 sheets of geological maps were digitized by C/P through OJT. The remaining 20 sheets were digitized by the Study Team as the Work in Japan.

GIS data creation of geological maps is divided into four stages; to capture existing geological maps, to prepare files in ArcCatalog, to create shapefiles in ArcMap and to make map files in ArcMap (Figure 7.1). A series of these tasks was practiced through OJT.

7.1.1 Capture of existing geological map

Existing geological maps need to be scanned and be captured as raster data into ArcGIS because they are printed maps. Capturing maps is composed of three stages; to set up GCP, to scan maps and to make georeference.

・Job01：Set-up of GCP (Ground Control Points)

It is generally necessary in order to digitize a printed map into GIS that many points with coordinate exist on the map. Almost frames of 1/100,000 scale geological maps of Malawi are bounded on the lines of latitude and longitude (Figure 7.2), and there are many GCP on the frames. However, as there are no GCP often inside the maps, GCP were manually drawn on the proper crossing point of latitude and longitude lines (Figure 5.14). Five to ten GCP were set up in each geological map according to the shape and area of the map.

・Job02：Scan of geological map

Printed geological maps with the drawings of GCP were scanned by the large A0 size scanner of provided equipment. The scanned images have 300 dpi resolutions and are stored by JPEG format. The scanner was set up as the scanned image data should be saved into fixed folder in the external hard disk drive. As a file name of saved data was automatically a serial number, the file name was changed to the name of each geological map by checking its image. These files were stored in folders named a short name of each geological map (Table 7.1), which were in “Scan_Data” folder in “Geologic_Map100k” folder.

・Job03：Georeference

The scanned image of geological map was imported into ArcMap file of ArcGIS and the following georeference was carried out. The coordinate values (degrees of longitude and latitude) of all GCP on the geological map were inputted in Georeferencing Tool of ArcMap, and the map image was transformed according to the geographic coordinate system, and the GeoTIFF format file of geological map with coordinate system was newly created and saved in the other folder which were in “Geotiff” folder in “Geologic_Map100k” folder.

Four old geological maps; “The Middle Shire Area”, “The Tambani-Salambidwe Area”, “Chikwawa and Chiromo Sheet1”, “Chikwawa and Chiromo Sheet2”, which are located in the southern part of Malawi, turned out to have old topographic maps which have gaps of topography and river system at the boundary of adjoining geological maps. Since the newer geological maps were confirmed to have the proper topography by the existing data, the location of old four geological maps were simply shifted 1,880m to the east in order to keep the topographical harmony among those maps. The geological map in the southernmost of Malawi, “The Port Herald”, still has a gap of international boundary even after this shift. Therefore, this map was independently georeferenced by setting the following four GCP as the comparable points with the latest topographic map.

GCP location	South latitude (Decimal degree)	East longitude (Decimal degree)
Southeastern end of Malawi border	17.126134	35.295488
Southwestern end of Malawi border	17.128096	35.097519
River inflection point in the south of Nyanthana	16.607728	35.076539
Crossing point of river and rail in the west of Chiromo	16.552201	35.145444

The outside areas of frames of georeferenced geological map were set to be hidden and were saved as GeoTIFF format file in “Geotiff_Subset” folder in “Geologic_Map100k” folder. The geological map of the whole Malawi that these GeoTIFF files of all 40 geological maps were taken into ArcMap is shown in Figure 7.3.

7.1.2 Preparation

It is necessary to create vector data from the captured image (raster data) in the GIS data creation (digitize) of geological map. The vector data is composed of three kinds of data, point, polyline and polygon. The distribution of strata is created as polygon shapefile and the lineation like faults is created as polyline shapefile in the GIS data creation of geological map by ArcGIS. Shapefiles with no data were made by ArcCatalog of ArcGIS as a preparation for creating shapefiles (digital tracing).

・Job04：Preparation in ArcCatalog

Two shapefiles were created in advance by ArcCatalog, which were one polygon shapefile to store the distribution of strata and one polyline shapefile to store the lineation. Coordinate system of shapefiles is set to be UTM Zone 36S WGS 1984. Geo_ID field was created in the attribute table of each shapefile, which would become necessary for later job.

The same numbers of files as strata numbers were created by copying polygon shapefile with Geo_ID field and they were named geological codes. In the same way, polyline shapefiles were copied the numbers of lineation and were named lineation codes. They were empty data files at this moment and data are created and saved through the digital trace described later.

7.1.3 Creation of shapefile in ArcMap (Digital trace)

To create shapefiles in ArcMap is core task in GIS data creation of geological maps, and needs a lot of time and skills. This core task is divided into three following jobs, Job05 to Job07. Job06 and Job07 need enormous amount of work and effect to the accuracy and quality of GIS data. These jobs tend to require a longer time for each trace in order to improve the accuracy and quality. On the other hand, the accuracy and quality tend to decline in order to reduce simply working hours. In general, both of efficiency and accuracy are required in these tasks.

The geological map with lineation of the whole Malawi created by the following procedure is shown in Figure 7.4.

・Job05：Import GeoTIFF file and shapefiles into ArcMap

A new ArcMap file was made and the coordinate system of the file was set to UTM Zone 36S WGS 1984. The GeoTIFF file made in Job03 and the polygon shapefiles of strata distribution and the polyline shapefiles of lineation made in Job04 were imported into ArcMap (Add data).

The GeoTIFF data of geological map was placed in the bottom layer in ArcMap and the polyline shapefiles in the top layer. The polygon shapefiles of strata distribution, which were placed in the middle layers, were combined into one group layer.

・Job06：Digitize the distribution of strata

Polygons of all strata distributions were drawn by tracing carefully each stratum boundary on a PC display using a pen tablet or a PC mouse. Geological code of each stratum (Geo_ID) was inputted in attribute table of the polygon shapefile.

It is not necessary to trace twice the same boundary considering the accuracy of the tracing. Proper tool among “Snapping”, “Clip”, “Merge” and “Auto complete” was selected for efficient tracing. The scale on PC display was set from 1:6,000 to 1:10,000 in order to stabilize the accuracy of polygon drawing.

After creating the polygon shapefiles of all strata in one sheet of geological map, these shapefiles were merged. Gaps and overlaps of polygons in the merged polygon shapefile were checked and repaired. Then, the merged shapefile was saved as “Geology.shp” into a folder named “short name of geological map” (see Table 7.1).

・Job07：Digitize the distribution of lineation

Polylines of all geological lineation were drawn by tracing carefully each lineation on a PC display using a pen tablet or a PC mouse. Each lineation name (Geo_ID) was inputted in attribute table of the polyline shapefile. When a fault line is identical to a strata boundary, both lines were matched on GIS using “Snapping” tool.

After creating the polyline shapefiles of all strata in one sheet of geological map, these shapefiles were merged. Then, the merged shapefile was saved as “Fault_Joint.shp” into a folder named “short name of geological map”.

7.1.4 Creation of map file in ArcMap

To create a map file in ArcMap is a task to create a digital geological map from shapefiles made in Job06 and Job07. This task is divided into two jobs. Job08 is to create a layer file which has data of colors and line type. Job09 is to create a map file which has data of legend, scale bar and others necessary for a geological map. An example of geological map (print layout) which was created by the following jobs is shown in Figure 7.6.

・Job08：Create layer file

The color and line type of polygons and polylines were settled using ArcMap and Microsoft Excel. These settings were saved as a layer file.

The correlation table between geological code and lithology was made by Microsoft Excel, and the table was imported into ArcMap, and then the table was joined to the attribute table of the polygon shapefile (Geology.shp). Every polygons were colored according to its lithology, and the color of each lithology was selected a similar one of the printed geological map.

The line type and width of polylines were set according to its lineation type in the same way. The polygon shapefile (Geology.shp) and the polyline shapefile (Fault_Joint.shp) were combined as one group layer, and the group layer was saved as a layer file into the same folder of shapefiles.

・Job09：Create map file

The print layout was formed by the following procedure in the layout view of ArcMap. This print layout was saved as a new ArcMap file in the prescribed folder (“GeologicMap100k” folder in “GIS_Data” folder).

The size and orientation of document were settled by referring the printed geological map and shown in the layout view of ArcMap. The layer file made in Job08 was imported into ArcMap, and map scale was set to 1:100,000. The layout of geological map was adjusted in the layout view and the grid lines (UTM zone36S WGS1984) were added on the map. The legend, north arrow and scale bar were inserted to right position in the blank area in layout view. The name of geological map was inputted in the title of document properties of ArcMap file. The title was inserted on top of the map and was adjusted its size and position. Other information was inputted as text objects by typing and was settled its size and position. A new data flame in which index map would be created was inserted into the layout view, and was set up its position and size.

7.2 Manual of digitization of geological map

It is necessary that C/P will continue to implement the tasks of GIS data creation by themselves after the completion of this Project. This is one of the goals of OJT in this Project. The Study Team and C/P jointly created manuals as a part of OJT, which is necessary for C/P to create GIS data continuously and autonomously.

The manual is composed of two volumes, “Manual to digitize geological map by ArcGIS” and “Manual to create and print geological map by ArcGIS”. These manuals were created considering beginners of ArcGIS. For example, the recommended work environments were described in the manual and many figures copied from PC display in operation were included. The contents of manuals are follows. Intensive edition of the GIS data creation manual is shown in Appendix 5.

Manual to digitize geological map	
0. Set the environment for drawing 0-1. Start 0-2. Customize toolbars 0-3. Set toolbars 0-4. Customize the scale list 0-5. Set the snapping 0-6. Set small windows of ArcMap 0-7. Set editor options 0-8. Work folders 0-9. Create empty shapefiles 0-10. Set layers **1. Start editing** 1-1. Start 1-2. Start editing window 1-3. Create feature window **2. Draw polygons** 2-1. Start 2-2. Set the position and scale 2-3. Draw polygon 2-4. Draw rectangle 2-5. Draw adjoined polygon 2-6. Save edit **3. Draw polylines** 3-1. Start 3-2. Draw	**4. Edit polygons and polylines** 4-1. Select 4-2. Delete 4-3. Copy and paste 4-4. Edit vertex 4-5. Merge polygons in editor tool 4-6. Cut polygons 4-7. Clip polygons in editor tool **5. Drawing techniques** 5-1. Edge of the map 5-2. Fault 5-3. Major geologic unit in the map 5-4. Out of Malawi **6. Unify to one shapefile** 6-1. Clip the overlapped area 6-2. Open attribute table 6-3. Add field "Geo_ID" 6-4. Field calculator 6-5. Merge in geoprocessing **7. Check and setup polygon** 7-1. Edge of map 7-2. Gap of polygons 7-3. Check the data of "Geo_ID"

Manual to create and print geological map	
0. Set shapefile for the printing 0-1. Set the environment for color setting 0-2. Show and hide the group layer 0-3. Create the relation table between Geo_ID and Lithology. 0-4. Add the relation table 0-5. Join the shapefile and relation table 0-6. Set Symbology **1. Start editing** 1-1. Change the view 1-2. Data Frame 1-3. 2 kinds of Zoom and Pan 1-4. Set the paper size and orientation 1-5. Set the Data frame size and position 1-6. Set the Scale of the data frame 1-7. Set the Grids and the data frame for the Map 1-8. Set the Geo_ID for each geologic unit in the Map	**2. Additional parts of the Layout View** 2-1. Legends for the Map 2-2. North arrow for the Map 2-3. Scale bar for the Map 2-4. Scale text for the Map 2-5. Title for the Map 2-6. Coordinate system for the Map 2-7. Text for the Map 2-8. Picture for the Map 2-9. Additional Data frame **3. Print out** 3-1. Printing method 3-2. Save the data (Export Map) 3-3. Print at the big printer **4. Layer file** 4-1. Outline of the layer file 4-2. Save as a layer file 4-3. Add a layer file

Table 7.1 Name of geological map and its short name

No.	Name of Geologic Map	Short Name	Map_ID
1	The Port Herald	Port_Herald	09
2	The Middle Shire	Middle_Shire	10
3	The Lake Chilwa	L_Chilwa	12
4	The Tambani-Salamidwe	Tambani	13
5	Chikwawa and Chiromo Sheet 1	Chikwawa_N	14N
6	Chikwawa and Chiromo Sheet 2	Chikwawa_S	14S
7	Zomba	Zomba	16
8	Kirk Range-Lisungwe Valley	Kirk_Range	17
9	Shire Highlands	Shire_High	18
10	Ncheu-Balaka	Ncheu_B	19
11	Mlanje	Mlanje	21
12	Cholo	Cholo	22
13	Lilongwe South	Lilongwe_S	23
14	Muchinji-Upper Bua	Muchinji	24
15	Kasungu North West	Kasungu_NW	25N
16	Kasungu South West	Kasungu_SW	25S
17	Lilongwe-Dowa	Lilongwe_D	26
18	Ntchisi-Middle Bua	Ntchisi	27
19	Cape Maclear Peninsula and lower Bwanje Valley	C_Maclear	28
20	Dedza	Dedza	29
21	Salima_Mvera Mission	Salima_M	30
22	Dwangwa	Dwangwa	31
23	Nkhotakota	Nkhotakota	32N
24	Benga-Chia Lagoon	Benga_C	32S
25	Lake Malombe	L_Malombe	33
26	Lake Chiuta	L_Chiuta	34
27	Makanjila	Makanjila	35N
28	Mangochi	Mangochi	35S
29	South Viphya-East	S_Viphya_E	36E
30	South Viphya-West	S_Viphya_W	36W
31	Mzimba	Mzimba	37
32	Nkhata Bay North	Nkhata_N	38N
33	Nkhata Bay South	Nkhata_S	38S
34	Rumphi	Rumphi	39
35	Nyika North	Nyika_N	40N
36	Nyika-South	Nyika_S	40S
37	Uzumara North	Uzumara_N	41N
38	Uzumara South	Uzumara_S	41S
39	Karonga	Karonga	42E
40	Chipita	Chipita	42W

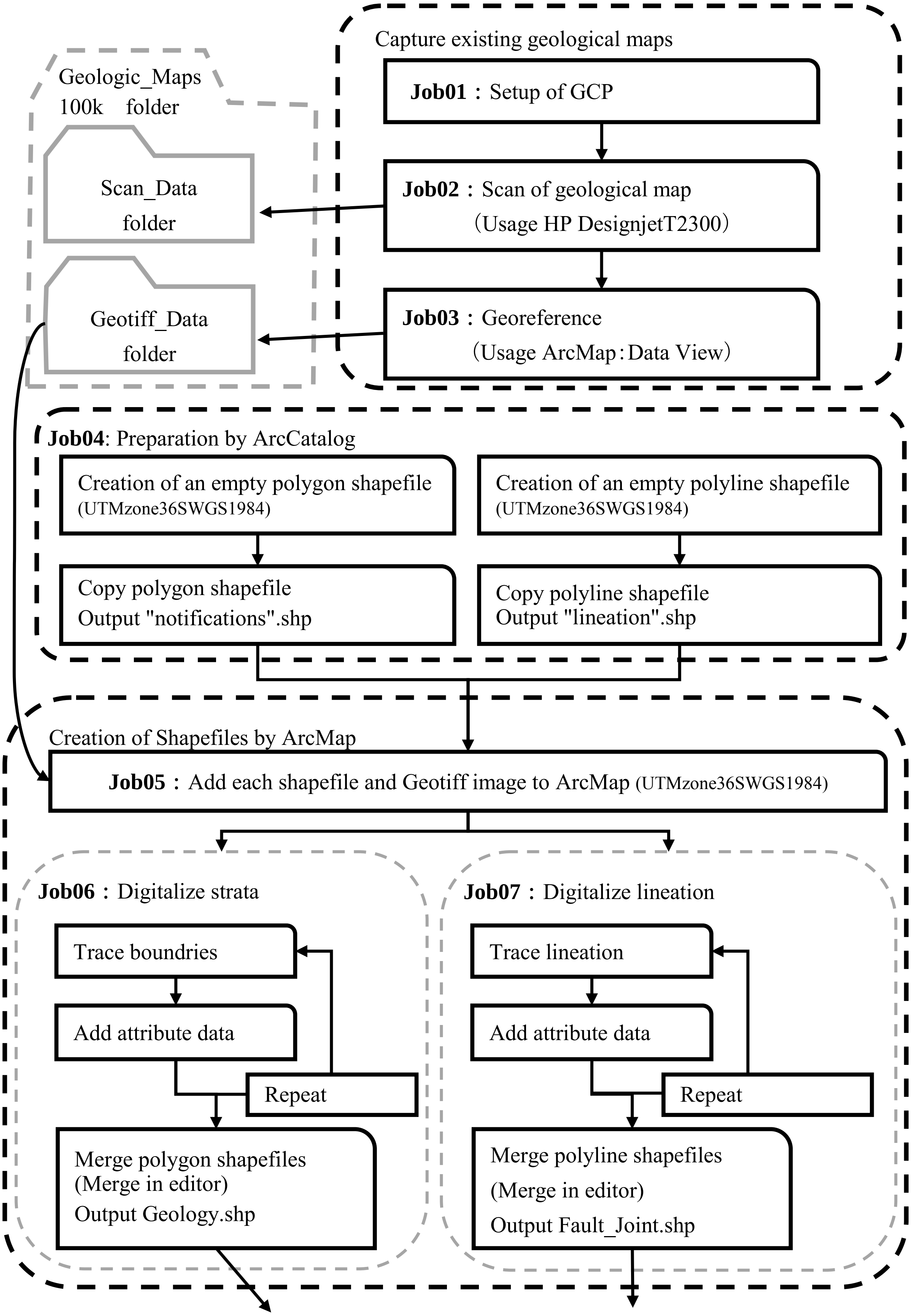


Figure 7.1 Flow chart of GIS data creation of geological map (1/2)

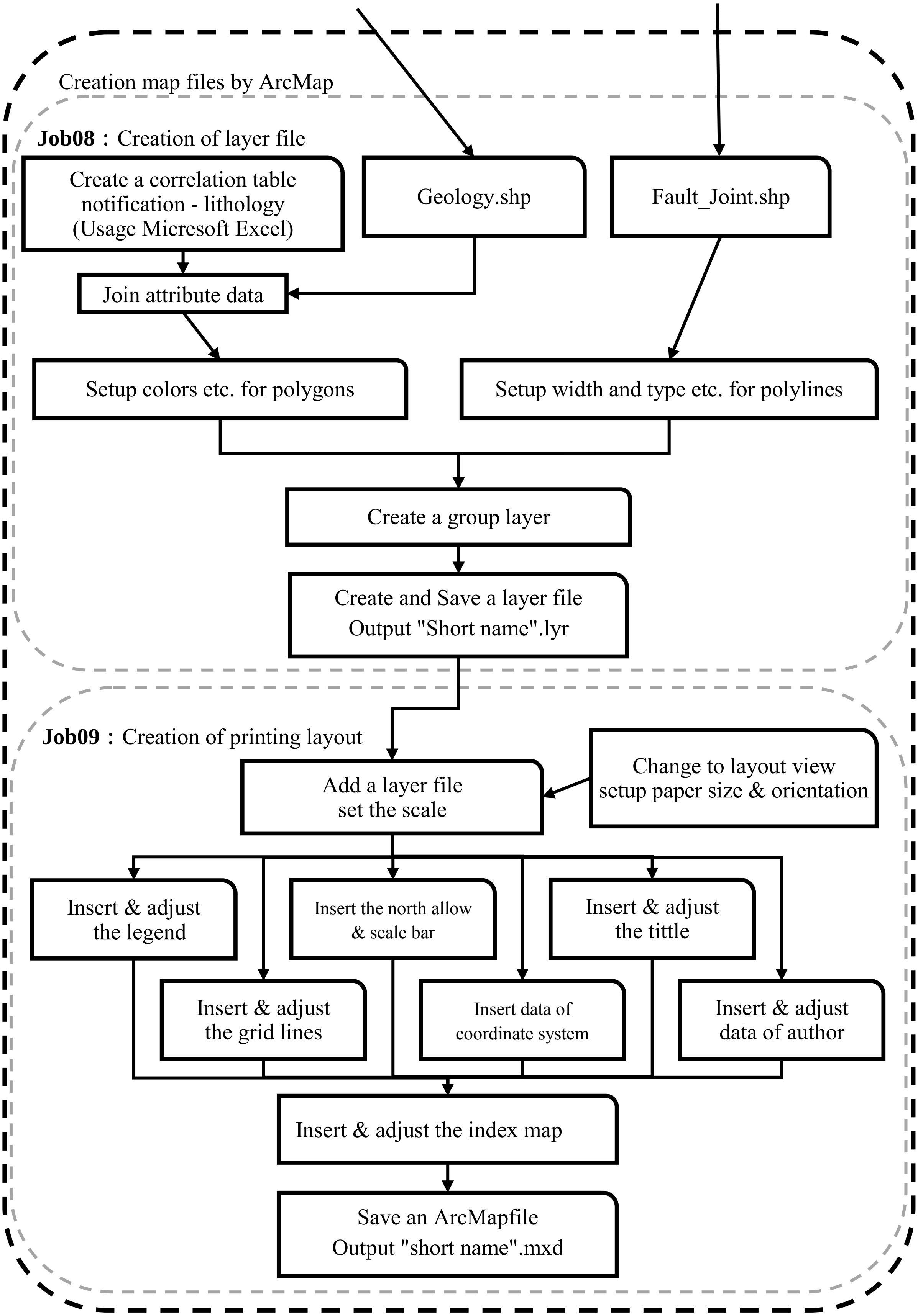


Figure 7.1 Flow chart of GIS data creation of geological map (2/2)

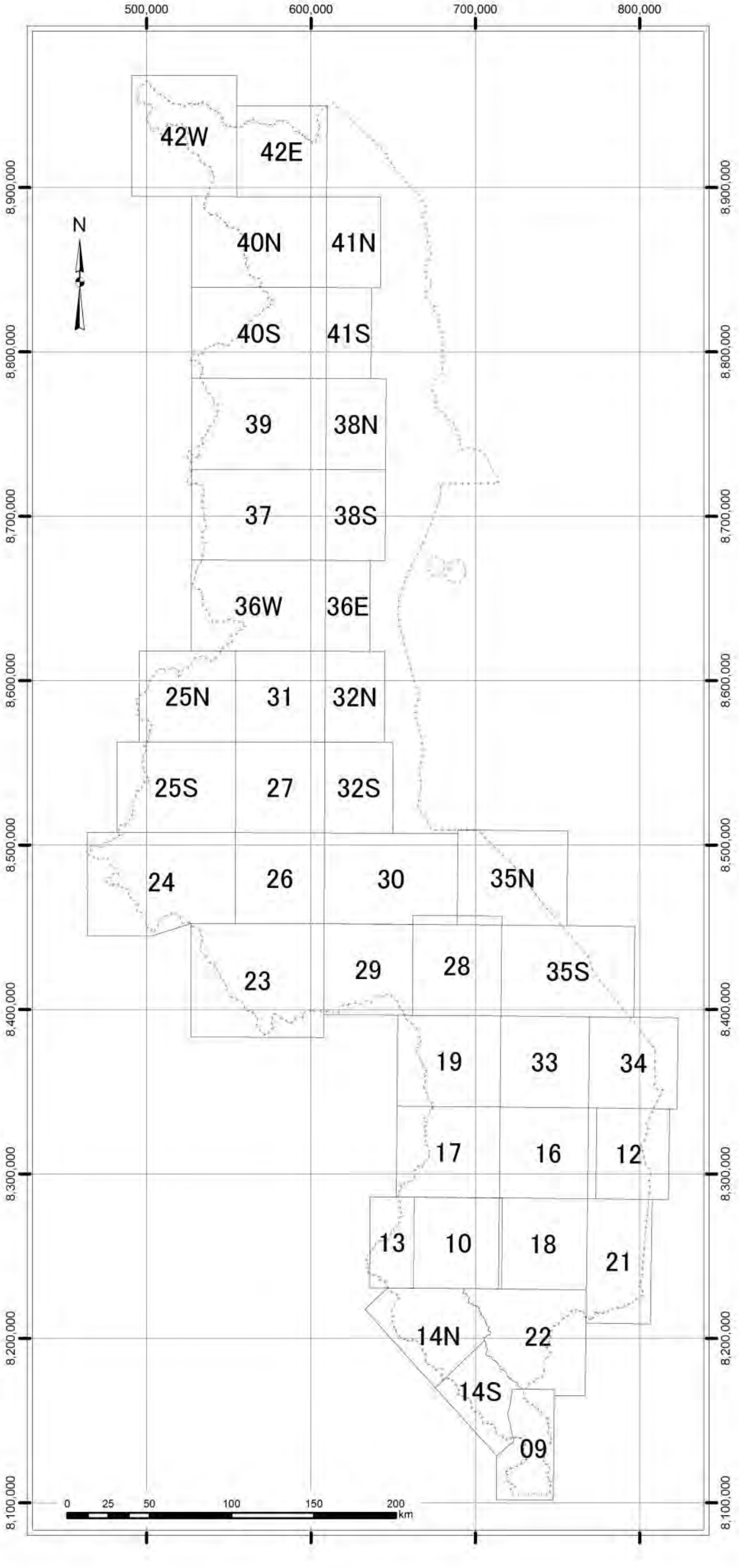


Figure 7.2 Location of 1/100,000 scale geological maps (all 40 sheets)

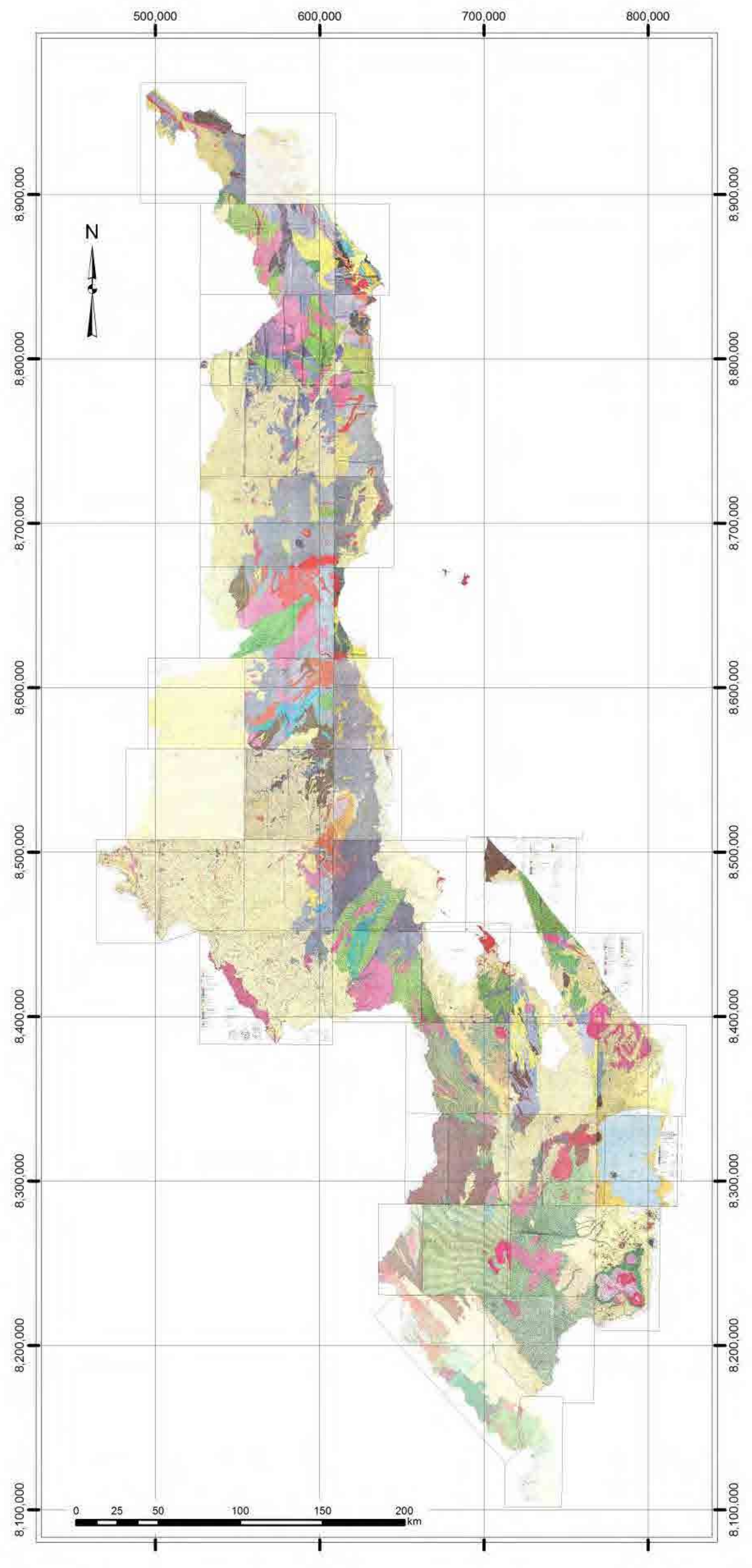


Figure 7.3 Geological maps at 1/100,000 scale of the whole Malawi

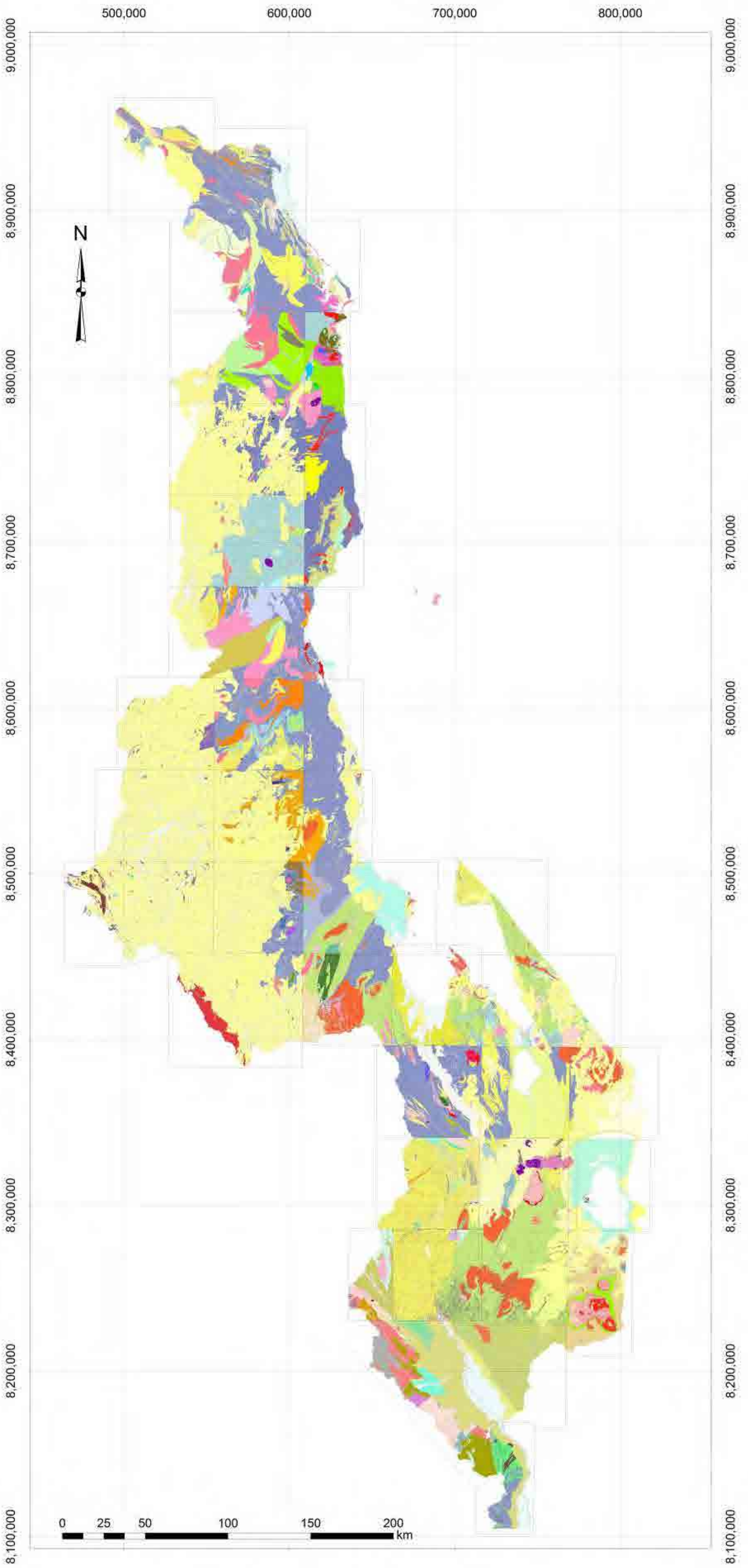


Figure 7.4 Digital geological maps of the whole Malawi(all 40 sheets)

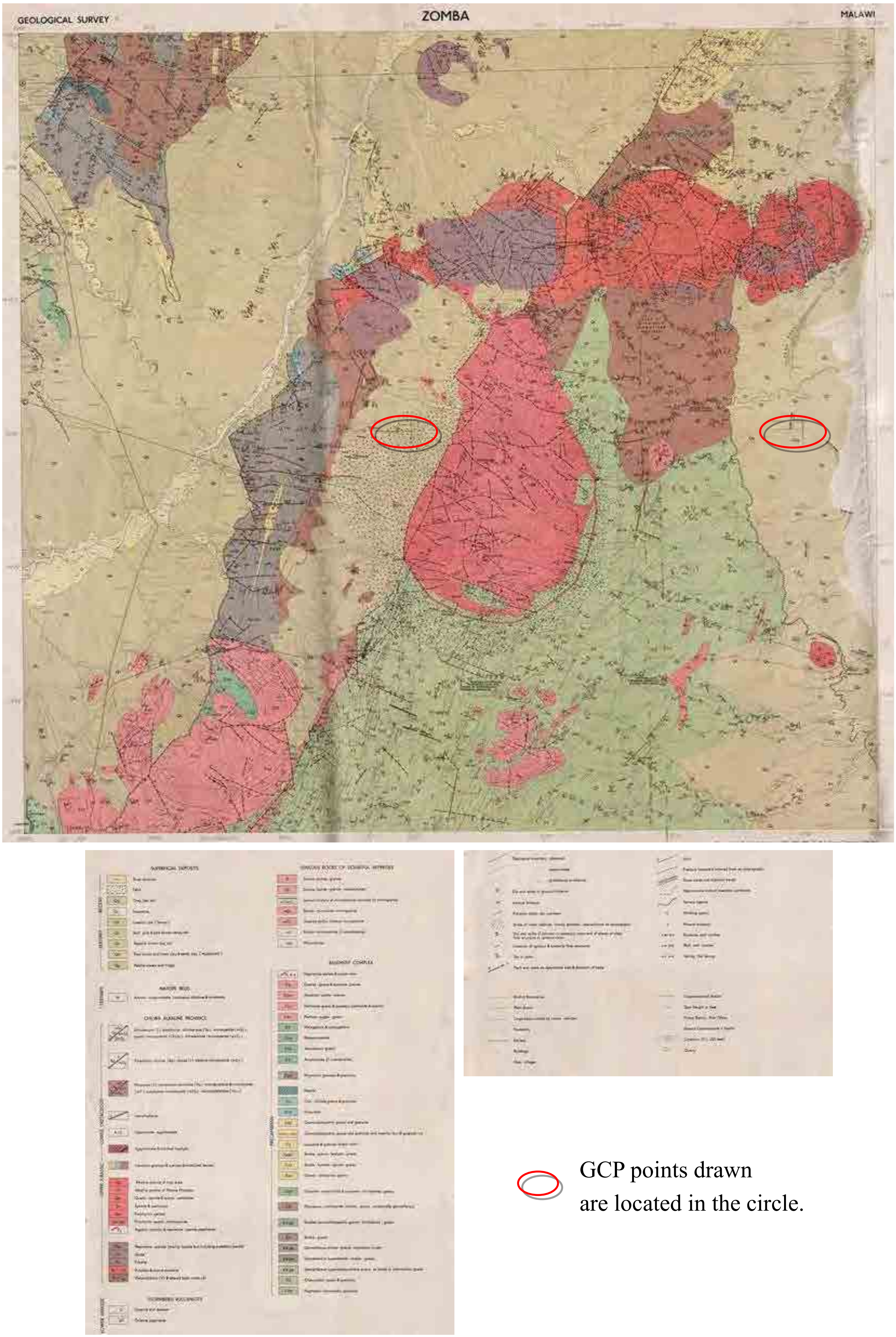


Figure 7.5 Geological map with a scale of 1/100,000 (Sheet no.16: Zomba)

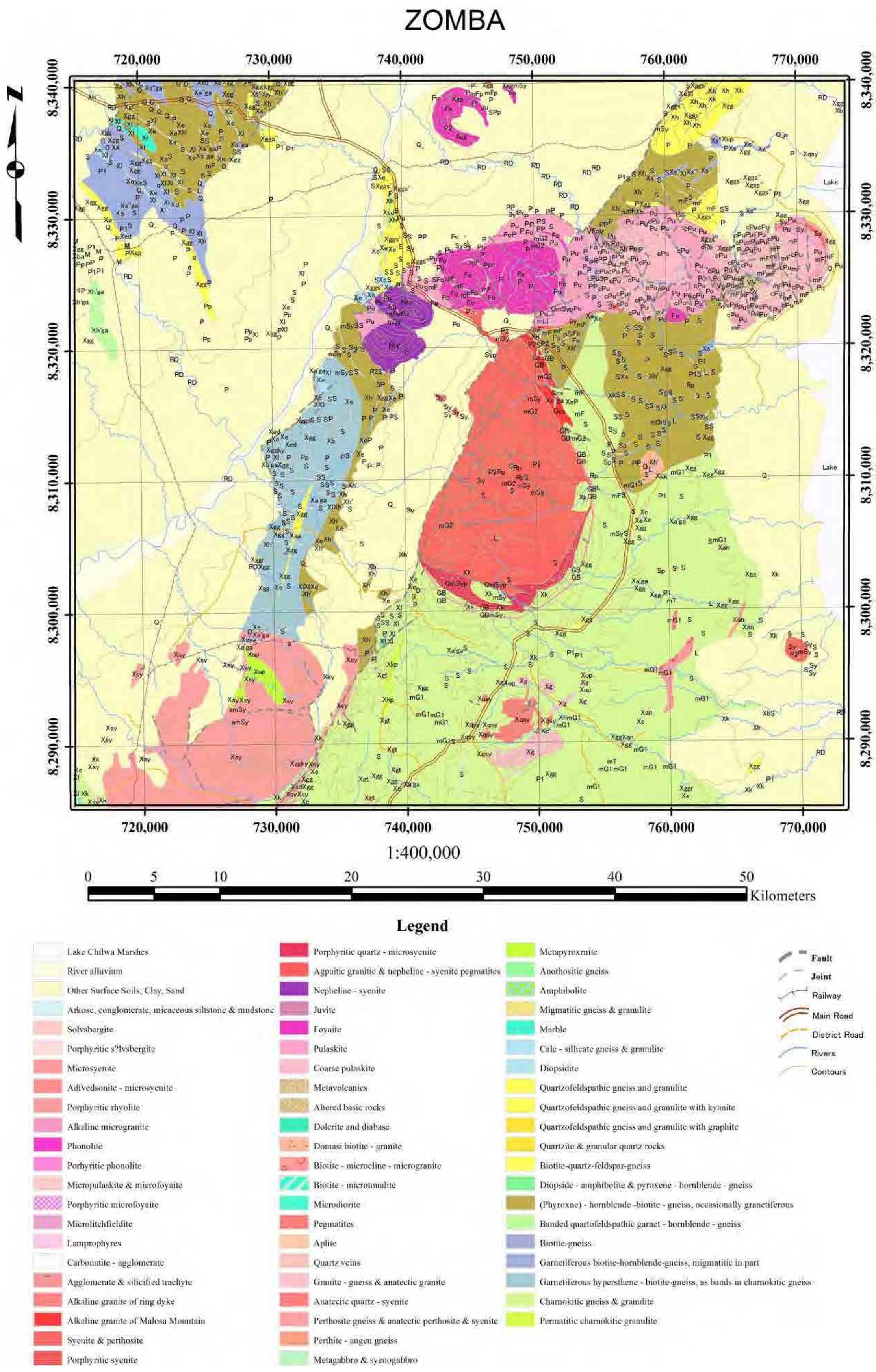


Figure 7.6 Geological map digitized on GIS (Sheet no.16: Zomba)

8. Potential of mineral resources

8.1 Mineral resources map

There is mineral resources map for Malawi at a scale of 1:1 million, which was created in 1980 and updated in 2000. Based on this map and the existed geological maps at a scale of 1:100,000, mineral resources map digitized in this Project is shown in Figure 8.1.
Twenty one kinds of mineral resources are indicated in the map and the number of indications is 80.

- Gold, lead, titanium, niobium, aluminum, graphite, pyrite, beryl
- Coal, uranium
- Limestone, marble, feldspar, nepheline syenite
- Kaolinite, mica, quartz, silica sand, asbestos, fire clay, diatomite

8.2 Potential of mineral resources

Main mineral resources in Malawi are described in section 5.4. Uranium, coal, titanium, niobium, REE and aluminum among them have relatively high potential of mineral resources. The occurrence of these resources has close relationship with geology.

(1) Uranium
Sandstone hosted uranium deposits occur in Mesozoic to Paleozoic sedimentary rocks of the Karoo and post-Karoo in northern part of Malawi. Kayelekera uranium mine which started the production in 2009 is the first large scale mine in Malawi. The uranium exploration has been active in northern part of Malawi where the sedimentary basins of Karoo system are widely distributed. Uranium deposits like Kayelekera are expected there.

(2) Coal
Coal deposits occur in Mesozoic to Paleozoic sedimentary rocks of the Karoo and post-Karoo in northern part and southern end of Malawi. Several small coal mines are operating in the north. It is a bottleneck for the development that coal beds are generally thin, displace largely and occur at deeper underground. However, energy shortages in recent years and mining promotion policy are expected to become a fair wind for the development of coal resources.

(3) Titanium
Titanium deposits occur in lakeside of Lake Malawi and watershed of Shire river as sedimentary heavy sand deposits. Explorations for these resources have been carried out in several areas and this mineral resource is considered to be closest to the development. Though it is the

advantage that mining of heavy sand deposits is easier than other mineral resources, the competitiveness in costs of infrastructure and others is important.

(4) Niobium and REE

There are a lot of intrusive bodies of syenite and Carbonatite in Chilwa Alkaline Province of southern Malawi. Mineral indications of niobium and REE have been known in these bodies. As the exploration for these mineral resources is most active at present in Malawi, their development in near future is expected. However, because the price of REE declines recently, ore grade of each REE, mineral resources, ease of ore dressing and amount of radioactive elements are considered to be major factors to determine the propriety of development.

(5) Aluminum

Bauxite resources are known in the top of Mulanje mountain and Zomba plateau in southern Malawi. Bottlenecks for the development are the situation of infrastructure and electric power supply and environmental problem.

(6) Rare metals and base metals

Mineral indications of magmatic deposits associated with mafic to ultramafic rocks in the basement complex in central Malawi have been known. Large scale deposits have not found yet. There is high possibility to find a new mineral indication by the future explorations. It is expected that some mineral species could be developed for mining.

(7) Precious metals

Main indication of gold is considered to be produced by intrusive activities of igneous rocks and the potential of gold seems to be not high at present. However, value as a small-scale mining cannot be ignored.

(8) Gemstones and precious stones

Gemstones and precious stones are mainly produced by small-scale mining. The quantity and quality of them seem to be not a particularly high level.

8.3 Methods to evaluate mineral resources potential

In general, methods in early stage to evaluate the potential of mineral resources are regional geological maps, geophysical data, geochemical data, satellite data, and statistical data related to mining. When the investigation phase progresses, further information of the same type data is required, and then assay results of various samples and drilling data will be added.

Digital geological maps (GIS data) of the whole Malawi created in this Project are the most basic information in the evaluation of mineral resources. As geological maps were digitized, the usage of maps has become very convenient. Therefore, these GIS data is considered to be used effectively not only in mining sector but also in land use and environmental field.

Though ASTER data used in this Project is effective especially to identify hydrothermal alteration minerals, there are no deposits typically associated with hydrothermal alteration minerals in Malawi. Therefore, ASTER data would be used mainly for the classification of lithology and for the interpretation of geological structure in Malawi. PALSAR data is effective to extract strata and rock bodies with typical structure, because the topographic and geological structures are easily identified in PALSAR images. As part of OJT in the Project, igneous intrusive bodies and lineation were extracted as lineaments in Chilwa Alkaline province (see section 6.3.2 and Figure 6.19). These results will be used effectively to evaluate the potential of mineral resources in early stage.

On the other hand, geophysical data is effective to evaluate such mineral resources which are mentioned above and expected for development in Malawi. Especially, radiometric data is effective for uranium deposits, minerals including REE and heavy sands, and magnetic data is effective for deposits associated with mafic to ultramafic rocks. Regional airborne geophysical survey will be carried out in mining-related project of World Bank starting in 2013 and this survey result is considered to contribute greatly to the exploration of mineral resources in the future.

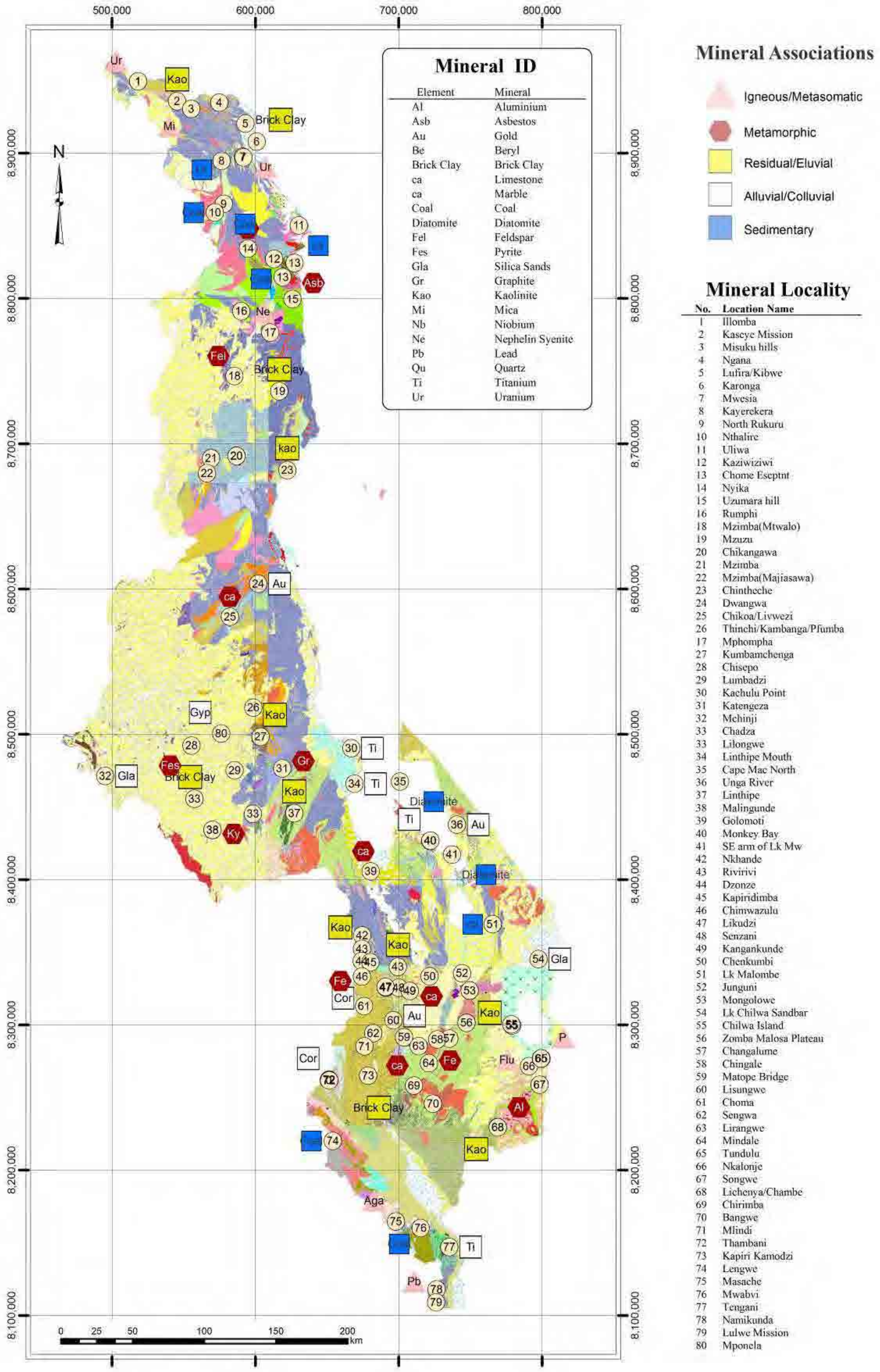


Figure 8.1 Mineral resources map

9. GIS database

9.1 Data collection

The following GIS data on the whole of Malawi has been collected through GSD. These data are managed by Malawi Department of Surveys. The geographic coordinate system of these data is UTM Zone 36S WGS 1984. The main data drawn by ArcGIS are shown in Figure 9.1 and 9.2.

- Roads, railways : Polyline data
- Rivers, lakes : Polyline data and polygon data
- Administrative boundaries, international boundary : Polygon data
- Villages : Point data
- National parks, protected areas : Polygon data
- Topographic contours : Polyline data

9.2 GIS database creation

The GIS database is stored in the external hard disk drive of provided equipment with LAN connection. The tree directory structure of the database is shown in Figure 9.3.

The name of root directory (top folder) is “JICA_GIS_database”. There are three sub directories, “GIS_Data”, “Geologic_Maps100k” and “Satellite_data” under the root directory.

In “GIS_Data” folder, GIS data digitized 40 sheets of 1:100,000 scale geological map and GIS data collected are stored.

In “Geologic_Maps100k” folder, each type of image data for 40 sheets of 1:100,000 scale geological map are stored.

In “Satellite_data” folder, each satellite data of ASTER, PALSAR and LANDSAT and their analyzed images, G-DEM data and its analyzed data are stored.

9.3 Manual to manage GIS database

The GIS database is stored in two hard disk drives with LAN connection. The usage of two drives has the purpose to prevent the data form accidental deleting or unexpected changing. One drive is for saving and another is for backup. Only one drive for saving is usually turned on and used. Only the administrator who is nominated by the director of GSD can update GIS database in the drive for saving and immediately has to copy the update data to another drive for backup. The database users have to copy necessary data from the drive for saving to each PC and then will process the data or create maps.

The manual which contains maintenance, management and operating procedures of GIS database is prepared. The contents of the manual are follows. Intensive edition of the GIS database management manual is shown in Appendix 6.

1. Equipment
2. Structure of directories
3. Operating
   3.1 Outline
   3.2 Management of hard disk
   3.3 Usage of database
   3.4 Update database
   3.5 Restore database

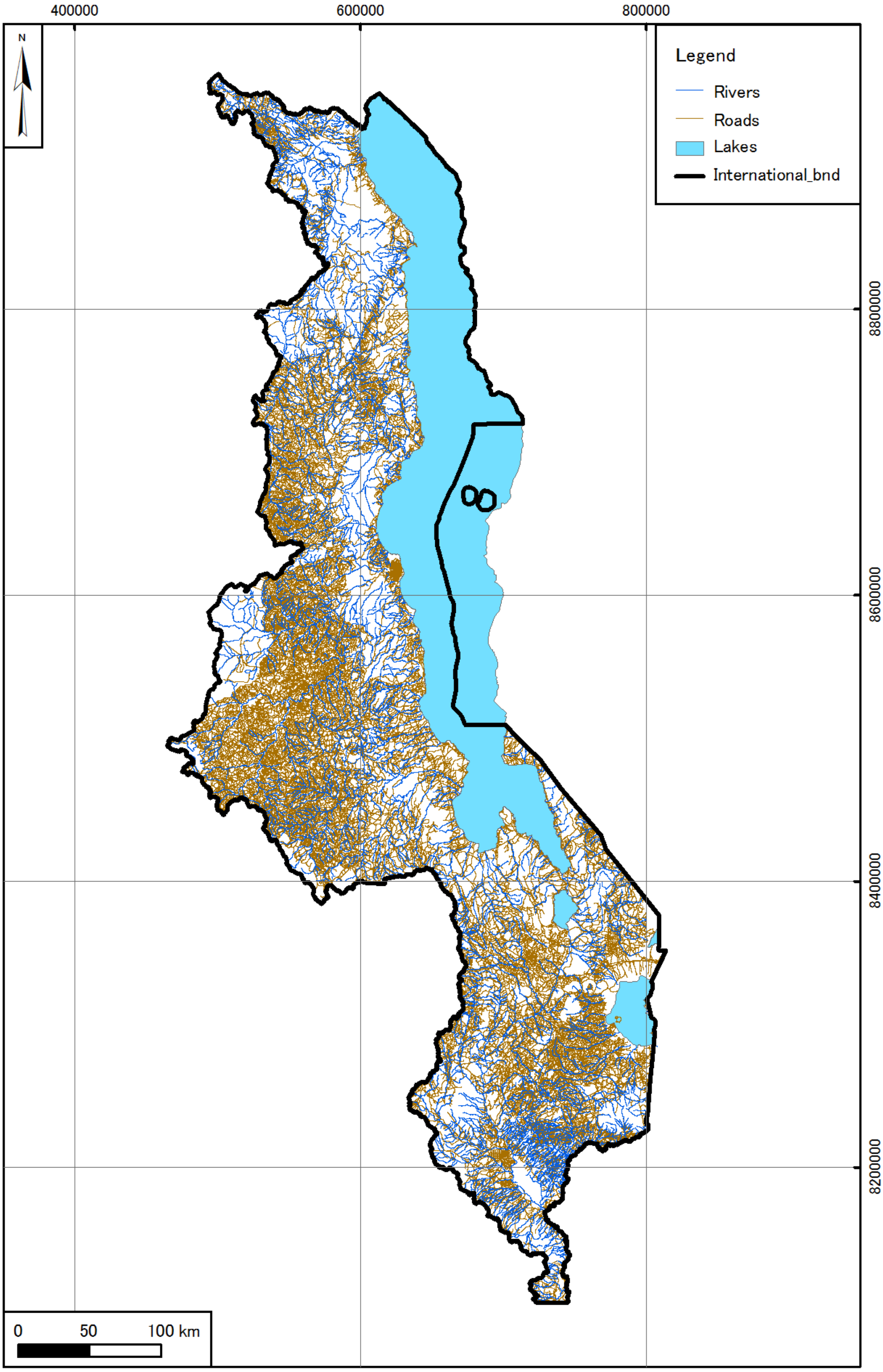


Figure 9.1 GIS map of geographic data

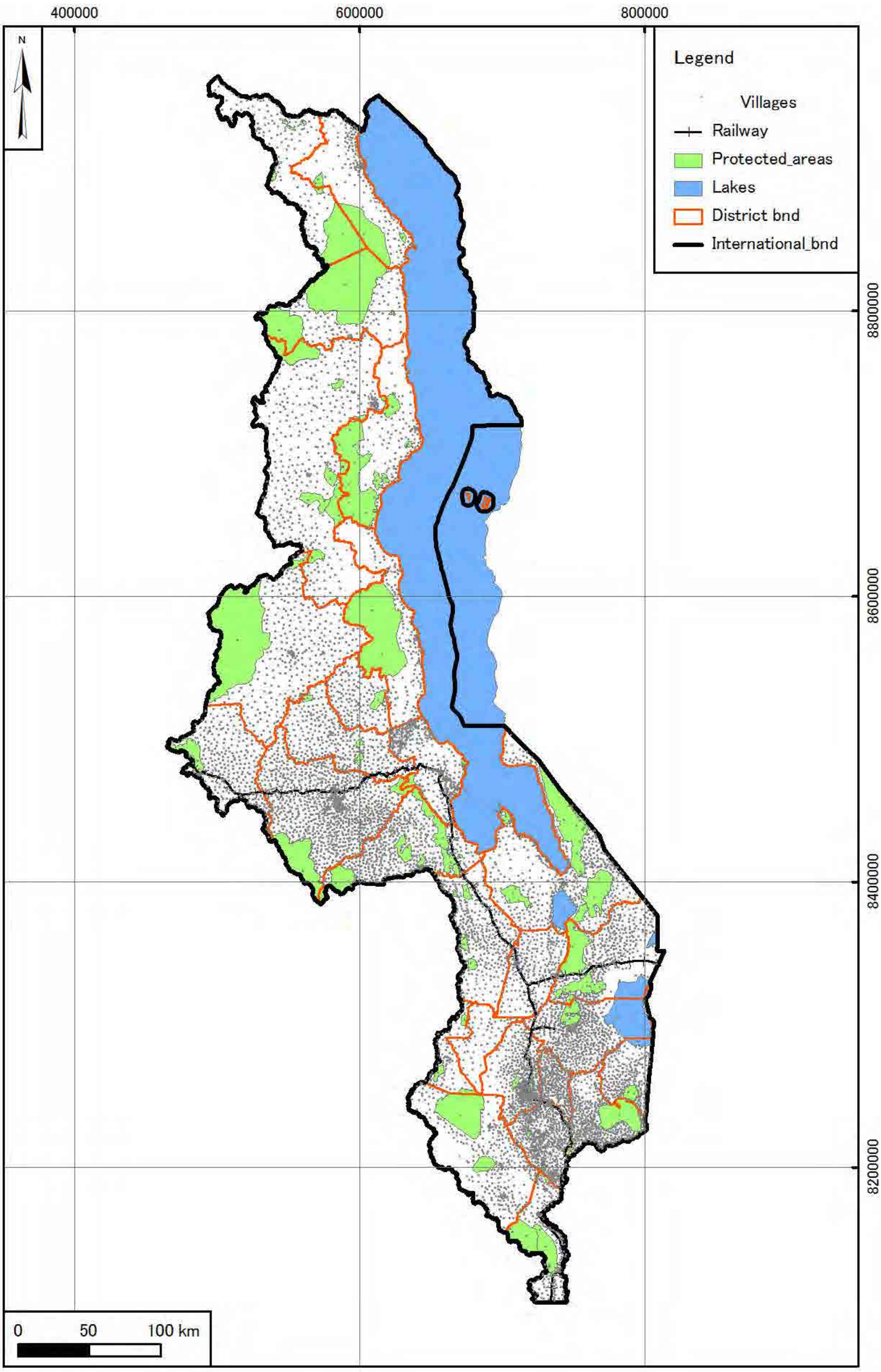


Figure 9.2 GIS map of administrative data

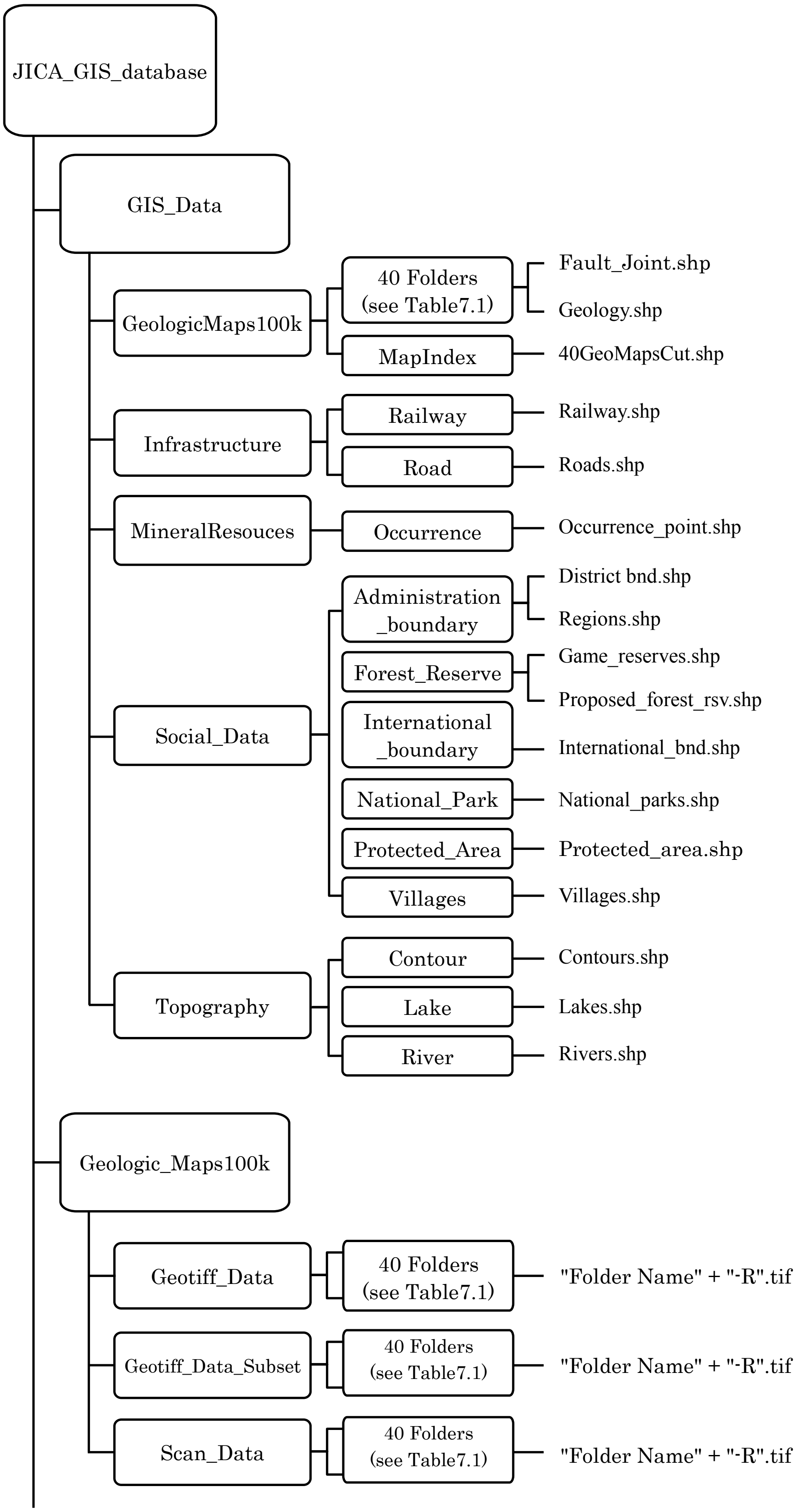


Figure 9.3 Tree directories of GIS database (1/2)

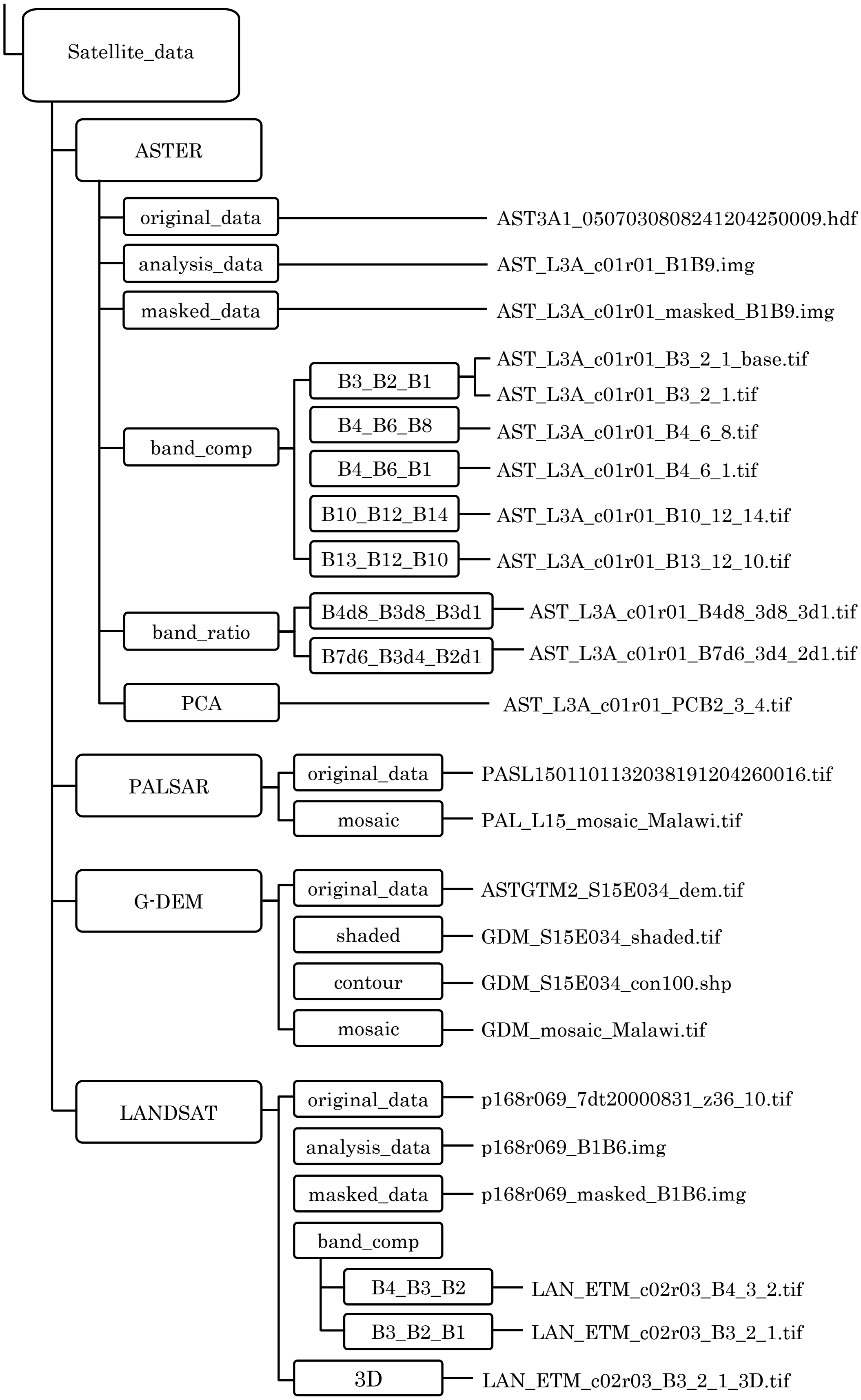


Figure 9.3 Tree directories of GIS database (2/2)

10. Personnel training

10.1 Program of personnel training

Personnel training is composed of technology transfer through OJT for satellite data analysis and GIS data creation, technology transfer seminar, training in Japan and workshop of Project results presentation.

Technology transfer through OJT was executed during the 2nd and 3rd Works in Malawi and technology transfer seminar was held in the late of 3rd Works in Malawi. Training in Japan was executed in Japan after the 3rd Works in Malawi and the end of the Project. Workshop of Project results presentation was executed in the 4th Work in Malawi. List of the participants in the personnel training is shown in Table 10.1.

Table 10.1 List of GSD staffs participated in personnel training program

		Position	Participating Program
1	A	Acting Director	Training in Japan, presentation in Workshop
2	B	Principal geologist	Training in Japan
3	C	Principal geologist	Training in Japan, presentation in Workshop
4	D	Geologist	OJT
5	E	Geologist	OJT, presentation in Workshop
6	F	Geologist	OJT
7	G	Geological technician	OJT, presentation in Workshop
8	H	Geological technician	OJT
9	I	Cartographer	OJT, presentation in Workshop
10	J	Cartographer	OJT
11	K	PC technician	OJT, presentation in Workshop
12	L	Librarian	OJT, presentation in Workshop
13	M	Senior geochemist	Seminar
14	N	Geologist	Seminar
15	O	Geologist	Seminar
16	P	Geologist	Seminar
17	Q	Geologist	Seminar
18	R	Geologist	Seminar
19	S	Geologist	Seminar
20	T	Geologist	Seminar
21	U	Geologist	Seminar
22	V	Geologist	Seminar

10.2 OJT of satellite data analysis

10.2.1 Method of OJT

The satellite data analysis by using ENVI software of Exelis VIS mainly was executed as OJT. The data for analysis are ASTER data (79 scenes), PALSAR data (64 scenes) and G-DEM data (84 scenes). The OJT was conducted for pre-processing, calculation of bands, creation of band composite image and band ratio image and principal component analysis as ASTER data analysis, process of mosaic and extraction of lineaments as PALSAR data analysis, process of mosaic and creation of topographic map as G-DEM data analysis. Moreover, the field verification survey was conducted as OJT for verification of analysis results of satellite data. In the field verification survey, at 29 sites around GSD selected based on results of satellite data analysis, rock outcrops were observed and rock facies, mineral types and geological structure were confirmed as OJT.

10.2.2 Contents of OJT

The lecture about the theory of remote sensing and the outline and case study of satellite data analysis was held at the beginning in OJT (Figure 10.1, upper and middle photos). For the task of satellite data analysis, the whole task was separated to some parts of job and the work manual for each part was prepared. At the beginning of the training, a demonstration of the job was given in accordance with the work manual. Each job is done repeatedly by C/P staff to be understood sufficiently. Personal instruction was conducted depending on the need or the situation so that all C/Ps present accomplish all jobs. In this way, OJT training was conducted so as to enable C/P staff to master the skill for a series of data processing and analysis by himself referring the manual

10.2.3 Evaluation of technology transfer

As a result of evaluation for technical level of each C/P in practical jobs and exercises of OJT, C/Ps were classified into 3 groups as follows.

(1) Group A

They understand well the contents of satellite data analysis. They are able to execute the data processing and analysis by themselves according to the processing manual.

(2) Group B

They understand roughly the contents of satellite data analysis. They are able to execute most of the data processing and analysis by themselves according to the processing manual. However, they need instructor’s advice in some parts of works.

(3) Group C

They do not really understand the contents of satellite data analysis. They have difficulties to execute the data processing and analysis without instructor’s directions.

Furthermore, mini tests were carried out 3 times in order to grasp degree of intelligibility and acquirement in OJT works and to maintain technical level of C/P. The mini tests were composed of questions which understanding level on technical terms, contents and procedure of data analysis would be evaluated by. Results of mini tests were harmonic very well to the evaluation described above and C/Ps were classified into the same 3 groups.

The technical skills acquired through OJT works are shown according to group as follows.

(1) Group A

ASTER data analysis

- Opening and saving data
- Resizing data
- Integration of VNIR and SWIR band
- Build of no data area mask and application to data
- Calculation of Normalized Difference Vegetation Index (NDVI)
- Build of the vegetation, water, cloud and shadow mask and application to data
- Integration of multi-band mask data
- Creation of the merge mask and application to data
- Creation of the band composite image
- Calculation of inter-band ratios
- Creation of the band ratio image
- Saving images as GeoTIFF file
- Principal Component Analysis (PCA)

PALSAR data analysis

- Opening and saving data
- Process of mosaic
- Creation of the mosaic image
- Saving images as GeoTIFF file
- Extraction of lineaments

G-DEM data analysis

- Opening and saving data
- Process of mosaic
- Creation of ASTER G-DEM color gradient topographic map
- Creation of the shaded relief image
- Creation of ASTER G-DEM shaded relief map
- Saving images as GeoTIFF file

(2) Group B

ASTER data analysis

・Opening and saving data
・Resizing data
・Integration of VNIR and SWIR band
・Build of no data area mask and application to data
・Calculation of Normalized Difference Vegetation Index (NDVI)
・Build of the vegetation, water, cloud and shadow mask and application to data
・Integration of multi-band mask data
・Creation of the merge mask and application to data
・Creation of the band composite image
・Calculation of inter-band ratios
・Creation of the band ratio image
・Saving images as GeoTIFF file

PALSAR data analysis

・Opening and saving data
・Process of mosaic
・Creation of the mosaic image
・Saving images as GeoTIFF file

G-DEM data analysis

・Opening and saving data
・Process of mosaic
・Creation of ASTER G-DEM color gradient topographic map
・Creation of the shaded relief image
・Creation of ASTER G-DEM shaded relief map
・Saving images as GeoTIFF file

(3) Group C

ASTER data analysis

・Opening and saving data
・Resizing data
・Integration of VNIR and SWIR band
・Build of no data area mask and application to data
・Calculation of Normalized Difference Vegetation Index (NDVI)
・Creation of the band composite image
・Saving images as GeoTIFF file

PALSAR data analysis

・Opening and saving data
・Saving images as GeoTIFF file

G-DEM data analysis

・Opening and saving data
・Creation of ASTER G-DEM color gradient topographic map
・Saving images as GeoTIFF file

10.3 GIS data creation

10.3.1 Contents of OJT

The OJT was executed for digital trace of 1/100,000 scale geological maps and creation of geological map for printing by using ArcGIS software. Eight C/Ps acquired skills to trace geological maps and methods to draw polygons and polylines, to save data, to express data and to draw and print maps.

The lecture about the theory of GIS and the methods of ArcGIS usage was held at the beginning in OJT. The actual OJT was executed one by one for GIS data creation of geological maps and creation of maps for printing to repeat following three steps. The goal of the practice is that C/Ps should implement these jobs by themselves, and tutorial was executed according to the situation and need. Short lectures or reviews were additionally carried out about the subjects that many C/Ps mistook or met with a setback. The Study Team tried to grasp their skills by small examinations once a week.

・Lectures
・Demonstrations on the screen
・Practices referring the manual

The detailed contents of GIS data creation in OJT are shown in chapter 7.

10.3.2 Evaluation of technology transfer

As a result of evaluation by the Study Team for technical level of each C/P in practical jobs and exercises of OJT, eight C/Ps were classified into following three groups.

(1) Group A

They understand the summary to create and print GIS data. They are able to digitize the geological data into GIS with almost enough accuracy by themselves, and also guide other C/P in simple works. They acquired the following skills.

- Adjust the environment of whole jobs
- Georeference
- Use properly coordinate system
- Effective creation of shapefiles
- Add data to shapefiles

- Save files
- Setup the paper size and orientation
- Setup the grid lines
- Setup the legend
- Print out
- Find large problems
- Simple guidance

(2) Group B

They understand the main works to create GIS data. They are able to execute most of works to digitize the geological data by themselves according to the digitizing procedure manual. However, the accuracy and speed of digitizing are unstable and they need instructor's advice in some parts of works. They acquired the following skills.

- Adjusting the environment of drawing jobs
- Setup the coordinate system
- Creation of shapefiles
- Save files
- Setup simple the paper size and orientation
- Setup simple grid lines
- Setup simple legends

(3) Group C

They do not understand enough the works to create GIS data. They have difficulties to digitize the geological data into GIS without instructor's directions. The speed and accuracy of works are insufficient. They acquired the following skills.

- Creation of simple shapefiles
- Save files

10.4 Summary

OJT had executed for satellite data analysis and GIS data creation through practice using each exclusive software. Eight C/Ps were classified into three groups above mentioned according to the intelligibility of the OJT works and the acquirement of software operation. However, the grouping between satellite image analysis and GIS data creation is different in parts. Person in group A are common in both grouping, but others are different from both grouping based on their specialty, experience of PC operation and personality.

It is evaluated that group A has acquired skills to execute satellite data analysis and GIS data creation in a self-reliant and sustainable way. Group B is able to execute continuously those works like group A under the assistance of group A. Group C is required to improve the technical level of operation, especially speed and accuracy of operation, by repeating OJT works.

10.5 Technology transfer seminar

(1) Participant

The Study Team requested to the director of GSD that the main participants should be new geologists who entered to GSD in 2012. As a result, ten geologists shown in Table 10.1 participated in the seminar

(2) Schedule

- 29 January to 1 February 2013
- AM: 9:00 to 12:00, PM 13:30 to 16:30

(3) Place

- OJT room at GSD
  with 5 PCs provided and used in OJT

(4) Contents

- 1st day: Theory of remote sensing, case study of ASTER data, practice of analysis by ENVI
- 2nd day: Practice of analysis by ENVI
- 3rd day: Theory of GIS, usage of ArcGIS, practice by ArcGIS
- 4th day: Practical data creation by ArcGIS

(5) Results

Young geologists could touch latest technology to process geological data and had a lot of interest in contents of seminar. However, most participants desired longer seminar because the seminar was executed in a short period as explanation of summary and simple practice.

10.6 Training in Japan

(1) Trainees

・Acting director of GSD
・Principal geologist of GSD
・Principal geologist of GSD

(2) Schedule

・12 (Fri) to 14 April (Sat) : Movement from Lilongwe to Tokyo

・15 April (Mon)

/ 10:00~12:00 : Tokyo International Center of JICA (TIC)
Briefing of training

/ 14:00~15:00 : JICA headquarters
Summary of JICA activities, Mineral resources in Japan, Objectives of training

/ 15:40~16:20 : Smiko Resources Exploration & Development Co., Ltd. (SRED)
Courtesy call, Explanation of training

/ 16:20~ : Move to Tsukuba

・16 April (Tue)

/ 10:00~12:20 : National Institute of Advanced Industrial Science and Technology (AIST), Geological Survey of Japan (GSJ)
Courtesy call, Summary of AIST/GSJ activities, Mineral resources and exploration

/ 13:10~17:30 : AIST/GSJ
Non-metal mineral resources, Rare earth elements resources from mineralogy, Remote sensing and exploration

・17 April (Wed)

/ 10:00~12:00 : AIST/GSJ
Observation of mineral analysis and mineral processing equipment

/ 13:00~15:00 : Geological museum in GSJ

/ 15:00~ : Move to TIC

・18 April (Thu)

/ 10:00~12:00 : Japan Space Systems (JSS)
ASTER, PALSAR, HISUI projects, Project for Mining Geology Database, Data management system of ASTER and PALSAR

/ 14:00~17:20 : Japan Oil, Gas and Metals National Corporation (JOGMEC)
Courtesy call, Summary of JOGMEC activities, Mineral exploration investment challenges of industry and government, Development of mining system for seafloor massive sulfide (SMS) in Japan

・19 April (Fri)

/ 10:00~12:00 : JICA Global Plaza, Ichigaya
Preparation of reporting

/ 14:00~15:00 : JICA Global Plaza, Ichigaya
Report of training results

/ 15:00~18:00 : JICA Global Plaza, Ichigaya
Seminar of Malawi Mining Sector

/ 18:00~19:00 : JICA Global Plaza, Ichigaya

Social meetings

・20 (Sat) to 21 April (Sun) : Movement from Tokyo to Lilongwe

10.7 Workshop of Project results presentation

(1) Participant

78 persons

Ministry of Mining, Department of Mines, Geological Survey Department, Private companies, Colleges, Local officials, Newspaper company, JICA Malawi office, JICA Study Team, and so on.

(2) Place

Masongola Hotel in Zomba, Conference room

(3) Date and Time

24 May 2013 (Friday), from 9:00 to 15:00

(4) Program

- Self introduction of participants
- Opening prayer: AHRMO of GSD
- Opening speech: Acting Director of GSD
- Speech: Deputy Resident Representative of JICA Malawi office
- Summary of the JICA Project: Mr. Onuma, Leader of JICA Study Team
- Remote sensing data analysis and OJT: Mr. Takeda, Member of JICA Study Team
- Coffee break
- GIS database and OJT: Mr. Kobayashi, Member of JICA Study Team
- Results of JICA Project: Mr. Onuma, Leader of JICA Study Team
- Results of OJT: GSD staff
- Results of OJT: GSD staff
- Discussions
- Poster session (satellite images, geological maps): JICA Study Team
- Lunch break
- Impression of JICA Project and OJT: GSD staff
- Impression of JICA Project and OJT: GSD staff
- Impression of JICA Project and OJT: GSD staff
- Results of Training in Japan: GSD staff
- JICA Training Course in Japan: GSD staff
- Discussions

- Closing speech: Acting Director of GSD
- Closing prayer: AHRMO of GSD

10.8 JICA training in Japan

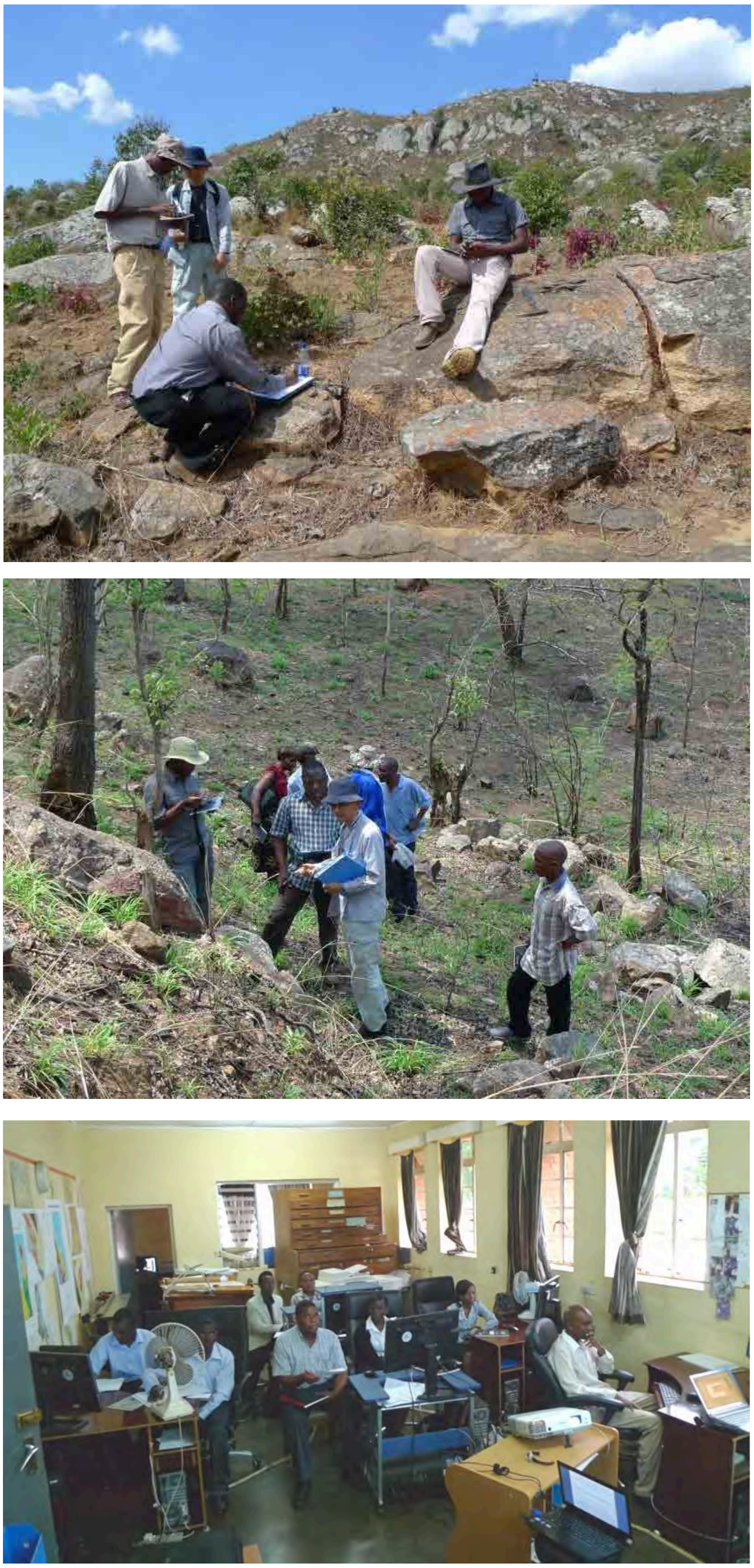
JICA's "Area focused training course" for African countries has been held every year from early February to late March, mainly composed of lecture in MINETEC located at Kosaka town in Akita prefecture. Two geologists who received OJT in the Project participated in this JICA training course from February to March 2013 during the Project. When GSD selected the participants of the Course, Mr. Onuma of the Project leader actually recommended two persons. These two had additionally the knowledge and skill about mineral resources, remote sensing and GIS in the long term Course in Japan and then improved their technical capabilities. Mr. Onuma, Project leader, had the lecture in the Course for two days at Kosaka and several days at Tokyo, and tried to support them.

Upper photo: Lecture about remote sensing (former GSD Director attended.)

Middle photo: Spectral measurement of rocks by a spectral meter

Lower photo: Explanation of data process of satellite data

Figure 10.1 Photos of technology transfer through OJT (1/2)

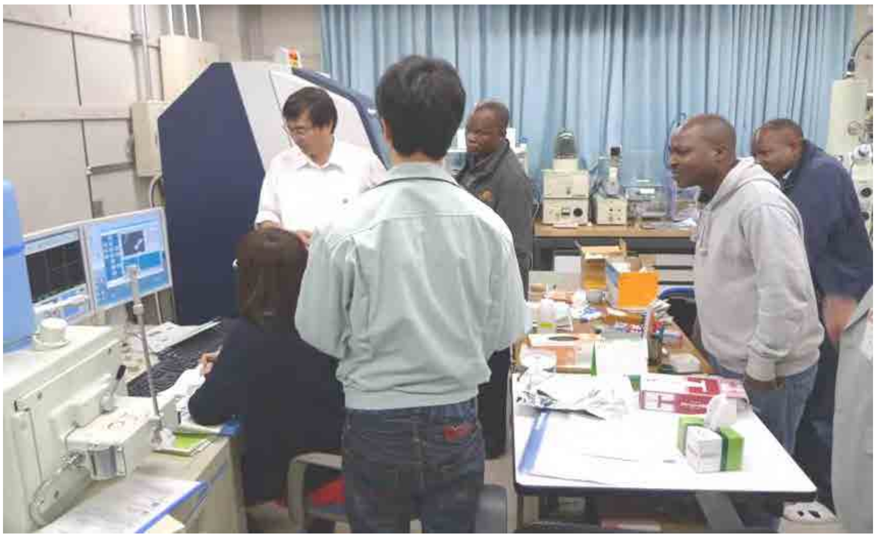


Upper photo: Ground truth of remote sensing analysis (obtaining GPS data)

Middle photo: Ground truth of remote sensing analysis (teaching what to describe)

Lower photo: Lecture in technology transfer seminar

Figure 10.2 Photos of technology transfer through OJT (2/2)



Upper photo: Observing mineral analysis equipment in the Training in Japan (at AIST/GSJ)

Middle photo: Opening speech in the Workshop (Acting Director, GSD)

Lower photo: Posters displayed as a part of results in the Workshop (explained during poster session)

Figure 10.3 Other photos of personnel training

11. Problems and recommendations

11.1 Problems

Although some geologists who had the experience of training expected to participate in OJT in the beginning of the Project, they did not actually participated in OJT. Therefore, the progress of OJT works had serious problem. However, it was the maximum result that two geologists had obtained the general skills about remote sensing data analysis and GIS data creation through the OJT. Other C/Ps also certainly improved their skills through the OJT. The Survey Team believes that this result lead to technical development of GSD in the future.

It is necessary that the technical experts who acquired the high skill in this Project continue to keep their technical level. At the same time, it is requested that these experts and others who had the regular skill in other trainings will not leave GSD and will continue to inherit skills and experience to the other staffs. For its execution, it is desired that projects for geological survey and mineral exploration will be carried out continuously by foreign donors and private companies as Japan. However, the data of geology and mineral resources in Malawi is not enough for private companies. It is essential to prepare and manage more detailed and attractive data.

In terms of facilities, necessary and sufficient hardware and software were provided to GSD in this Project. However, to secure electric power is most critical because blackout happens frequently. Periodical updates of hardware and software are also necessary. At present, however, GSD has to rely on such supports to foreign donors.

11.2 Recommendations

Considering the promotion of mining in Malawi and the investment promotion of private sector, it is considered that the following data, research, and management system are necessary.

(1) Seamless geological map of whole Malawi

GIS database created in this Project is composed of data with immediate demand. However, 40 sheets of digitized geological maps are not necessarily convenient for users because they are stored and managed separately. In other words, when all 40 sheets of geological maps are compiled into a single seamless geological map, the utility value as geological map could increase.

Geological map of Malawi were created in different age. There are many places where the geological boundaries between maps do not connect. It is necessary to correct such problems in a geological point of view and to create a more accurate seamless geological map. However, this procedure is not a simple task, and must require a lot of effort and time for compilation based on the topography and satellite data by geological understanding.

(2) Geochemical map of whole Malawi

Basic data required when starting the exploration of mineral resources is geological map, geochemical and geophysical data and satellite data. In this Project, geological maps were digitized and unified with satellite data into GIS database. Geophysical data will be obtained by MGGSP of World Bank in 2013. However, geochemical data has not been prepared yet. Therefore, geochemical data covering whole Malawi is desired to be obtained.

The creation of geochemical map has objectives to recognize geological and geochemical background data in natural and to extract anomalous data indicating mineral deposit and environmental anomalous data. Survey method is to collect stream sediments in main rivers, to serve them for chemical analysis and to calculate statistically assay results. Then, statistical anomaly data is extracted from statistical analysis results and is drawn as a map on GIS.

Such geochemical map leads to extract easily promising area of mineral resources and becomes very useful information for mineral exploration.

(3) Management of database

It is necessary that the database should be expanded to add data which would be obtained from surveys of World Bank and etc. However, to maintain properly and systematically the database becomes important when the data kinds and amount would increase. In the future, the various data related to geology and mineral resources should be managed centrally with high security as digital data, and a system to sell data in request should be built.

11.3 Action Plan

An action plan, which has targets to continue the personnel training and system strengthening as the policies of this Project, is set as follows.

(1) Objectives

- To attempt to maintain and improve technical skills by using the existed satellite data
- To try to accumulate related data
- To maintain and manage the database appropriately

(2) Contents

- Do a self-study of data processing regularly by using the existed satellite data

- Process satellite data in the region of interest
- Do a self-study for processing satellite data and creating GIS data according to the existed manuals
- Create GIS data of past survey results as necessary
- Create maps by GIS based on satellite data and geological maps of new survey area
- Create GIS data of new survey results certainly
- Take GIS data newly created and survey data of World Bank and etc. into the existed database properly
- Take a backup of the database regularly and manage the database continuously and properly
- Pay attention always to safety management that unauthorized use of the database and damage and theft of hardware do not occur

(3) Expected results

- More engineers can learn technical skills of satellite data processing and GIS data creation.
- Technical capabilities of GSD will be maintained.
- The database will be managed properly and be developed.

(4) Necessary equipment

- It is enough for the moment to use the set of equipment provided in this Project.

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