

Republic of Malawi
Ministry of Mining

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

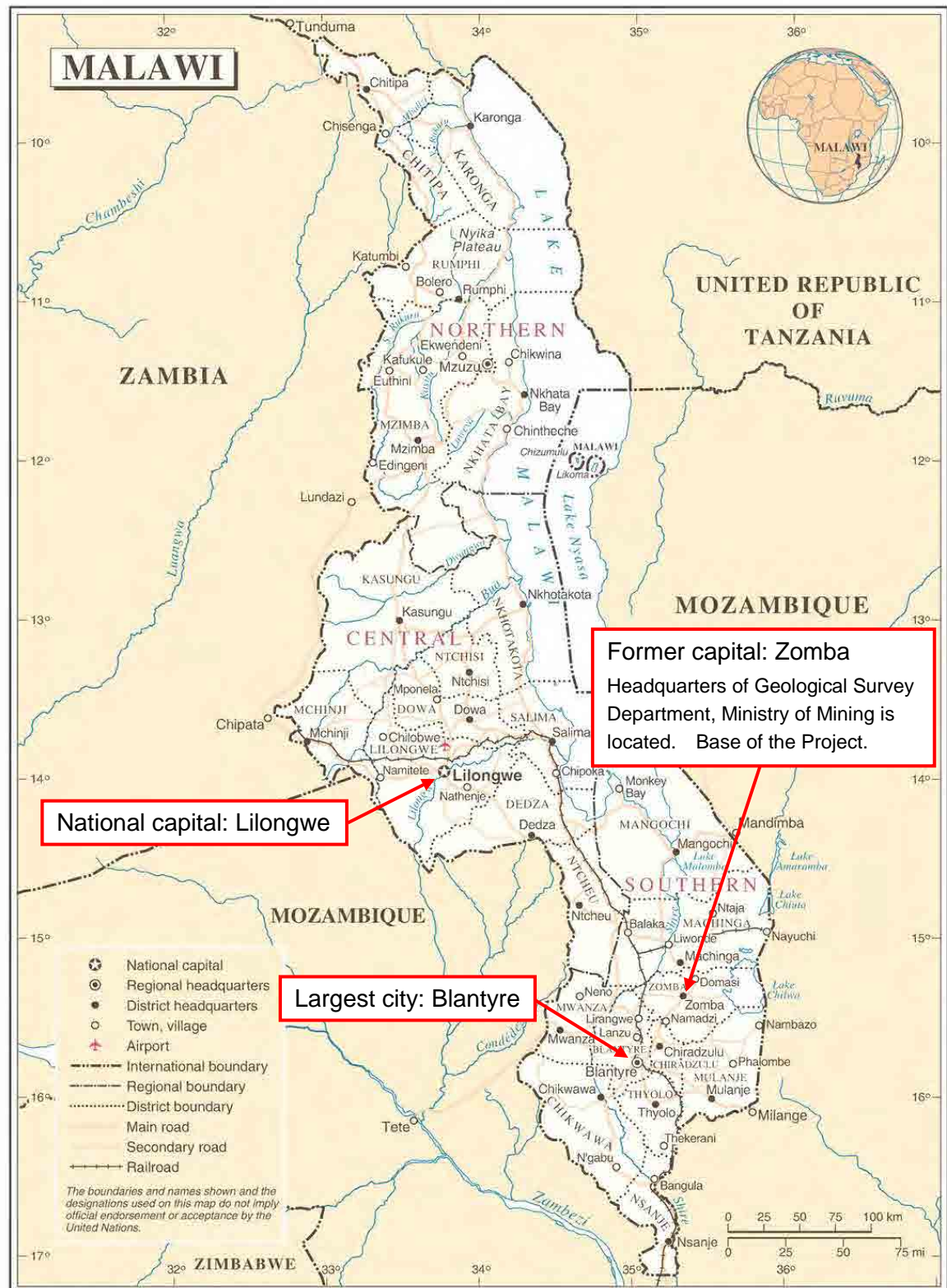
Abridgment

July 2013

Japan International Cooperation Agency
(JICA)

Sumiko Resources Exploration & Development Co., Ltd.

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
GSJ	Geological Survey of Japan
GSD	Geological Survey Department, MALAWI
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 World 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.

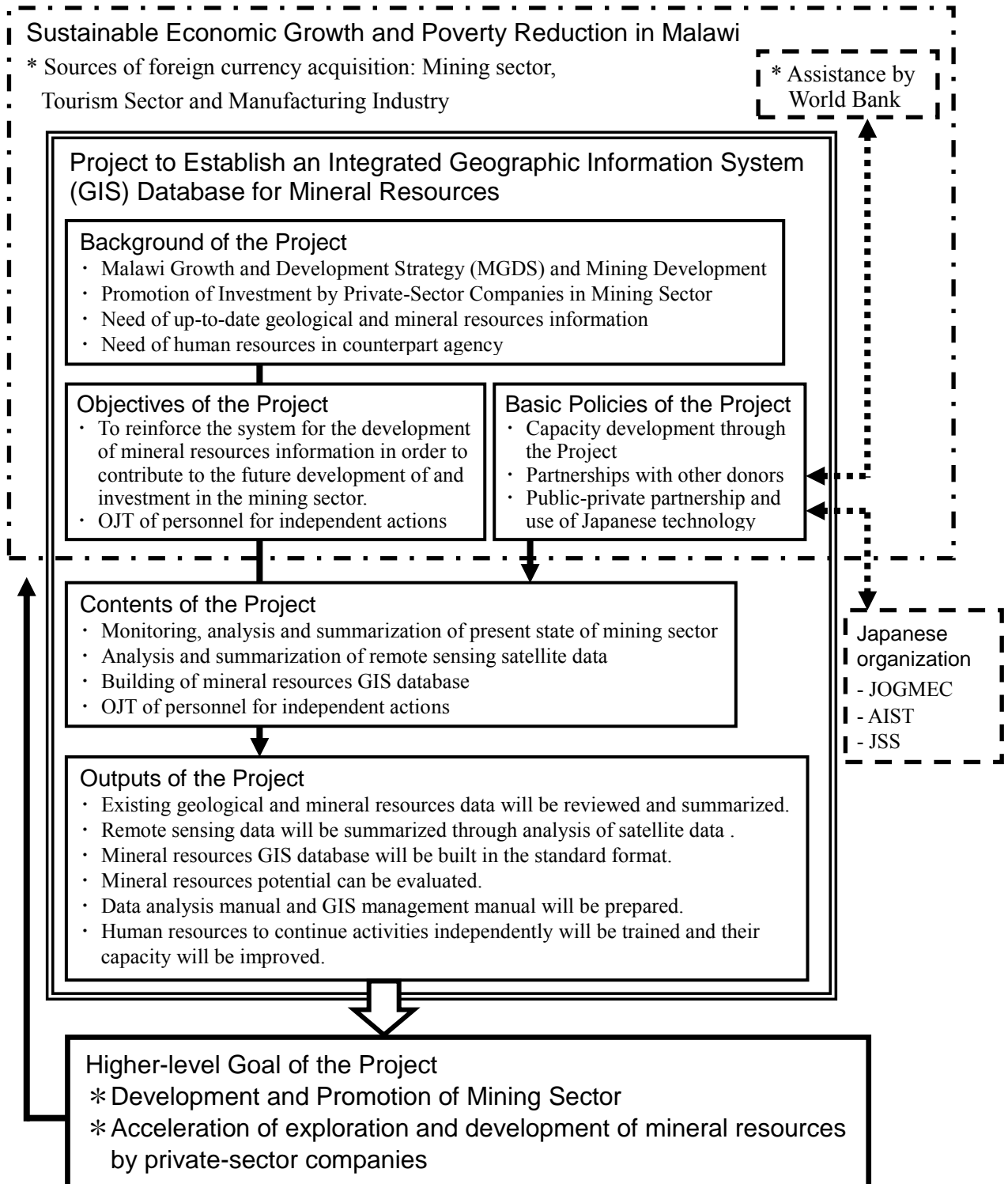


Figure 1.1 Basic concepts of the Project

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

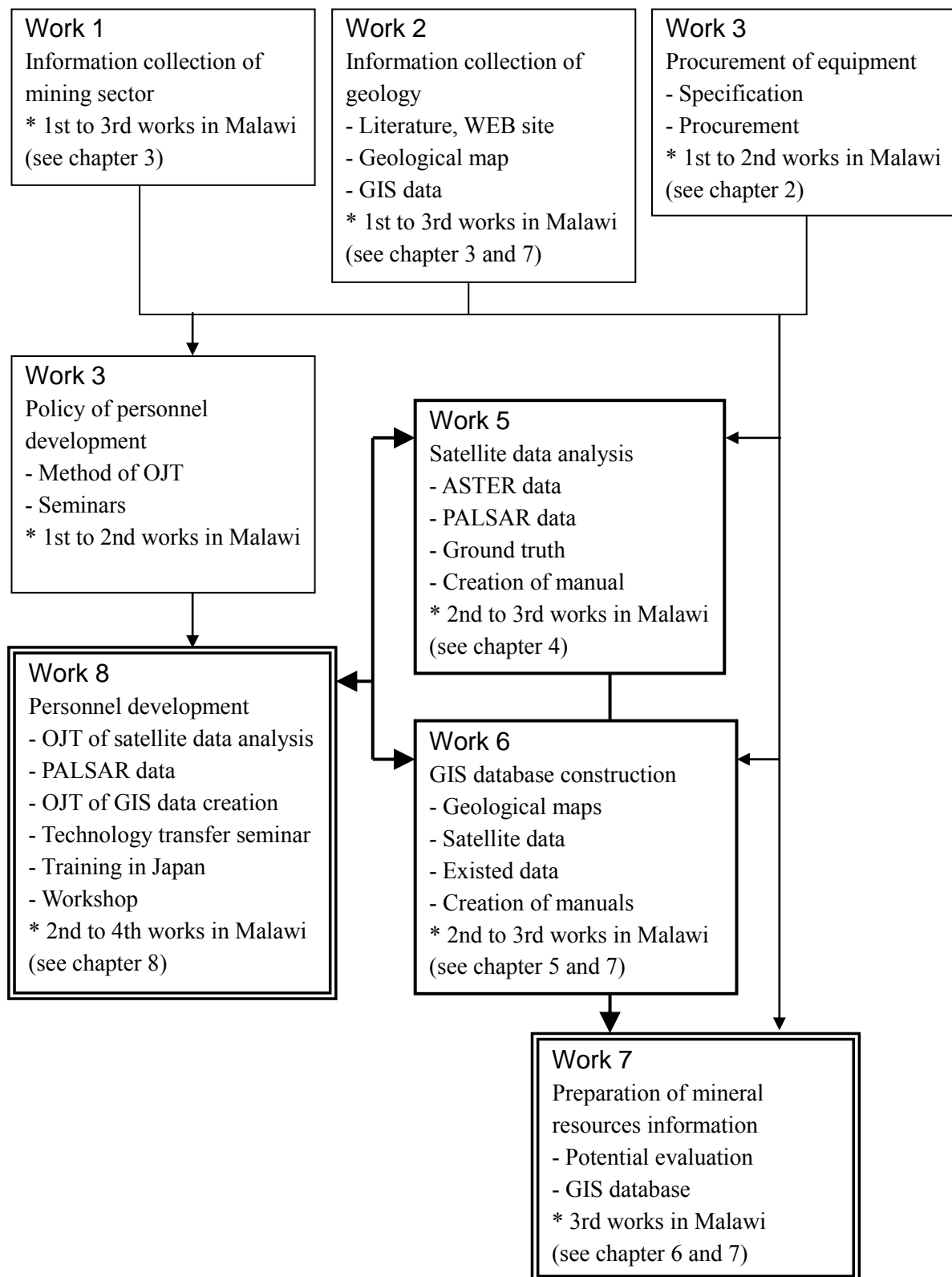


Figure 1.2 Flow chart of the Project

1.8 Organization of the Project

1.8.1 Study Team

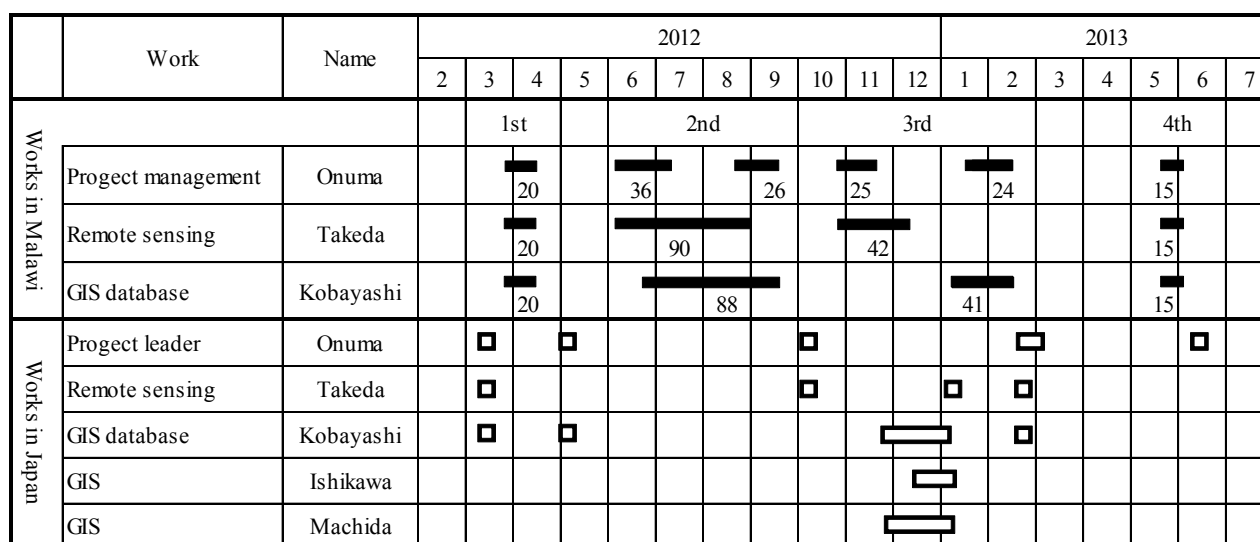
The Study Team consists of five members shown in Table 1.1. All of them belong to SRED. Mr. Onuma, Mr. Takeda and Mr. Kobayashi are mainly engaged in works in Malawi. Mr. Ishikawa and Mr. Machida are engaged only in works in Japan. Dispatch schedule and personnel plan are shown in Table 1.2 and Figure 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • GIS data creation of geological maps (works in Japan)
Satoshi MACHIDA	GIS	<ul style="list-style-type: none"> • 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 19 May 2013~2 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 19 May 2013~2 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 19 May 2013~2 June 2013 : 15 days	164



■ : Works in Malawi, □ : Works in Japan

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.

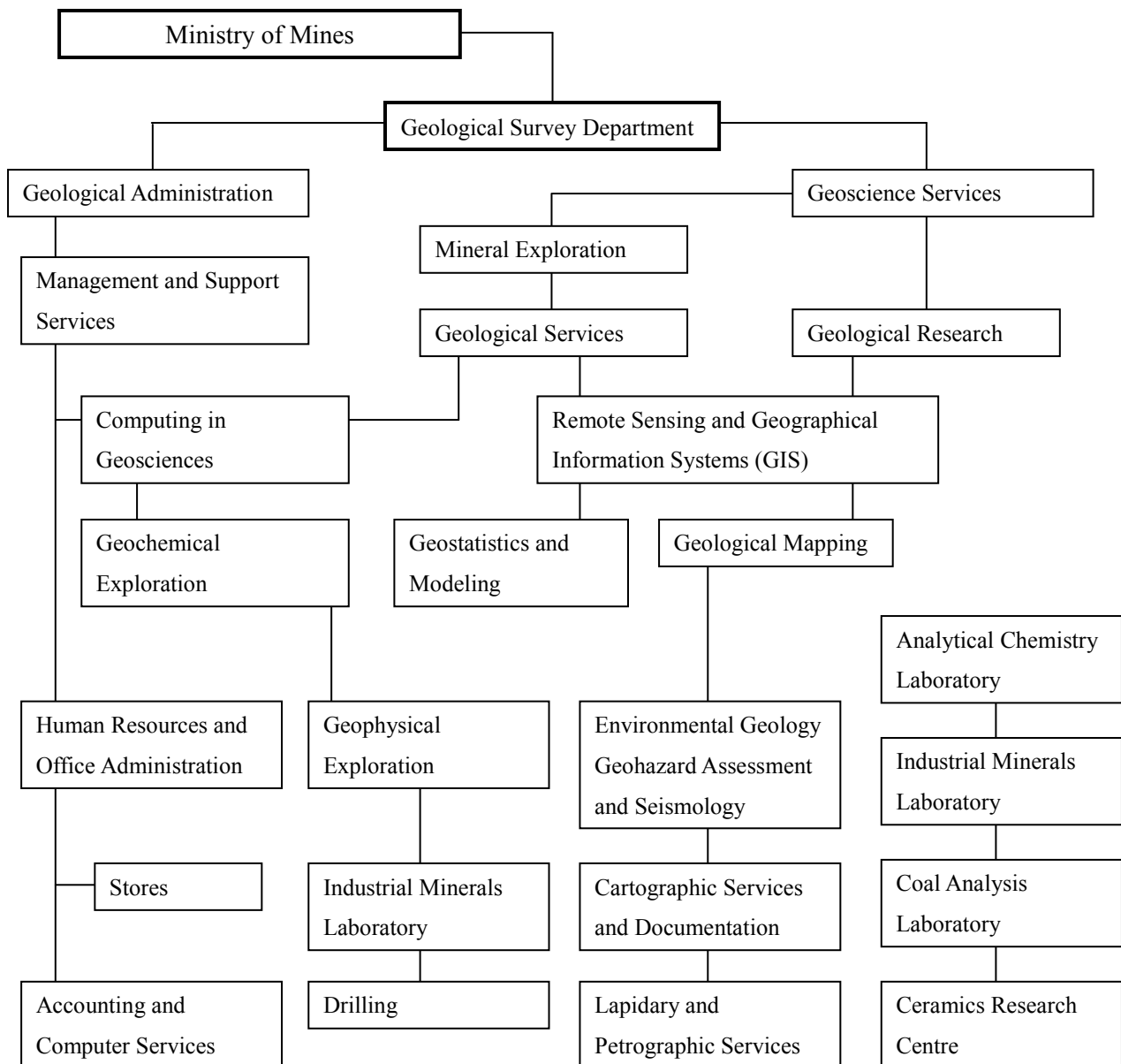


Figure 1.4 Organization chart of GSD

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. 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 2.1 and photographs of hardware are shown in Figure 2.1 and 2.2. 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.

2.1 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

2.2 Equipment provided

The list of equipment provided which were procured according to above reasons and settled at GSD in Zomba is shown in Table 2.1. All equipment were procured and settled in 2012.

Table 2.1 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
	Pentablat	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

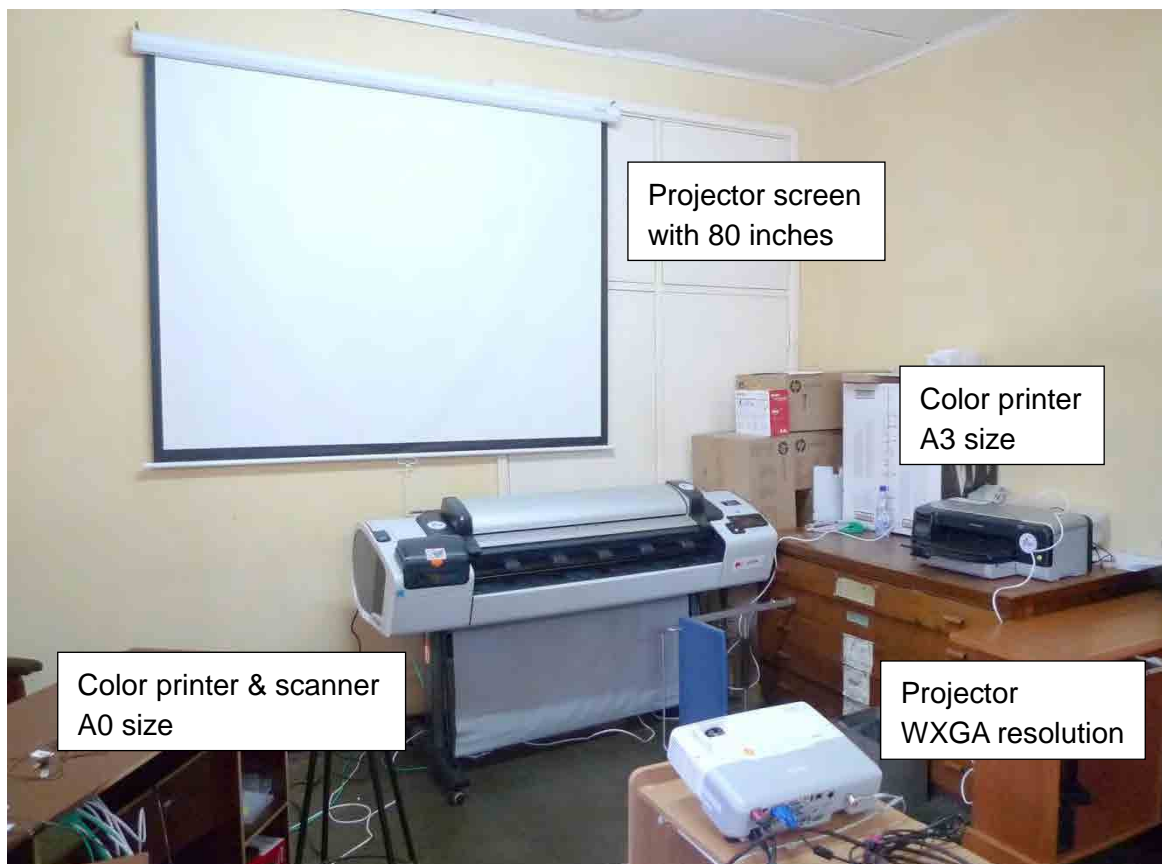


Figure 2.1 Photo of printers, projector and projector screen

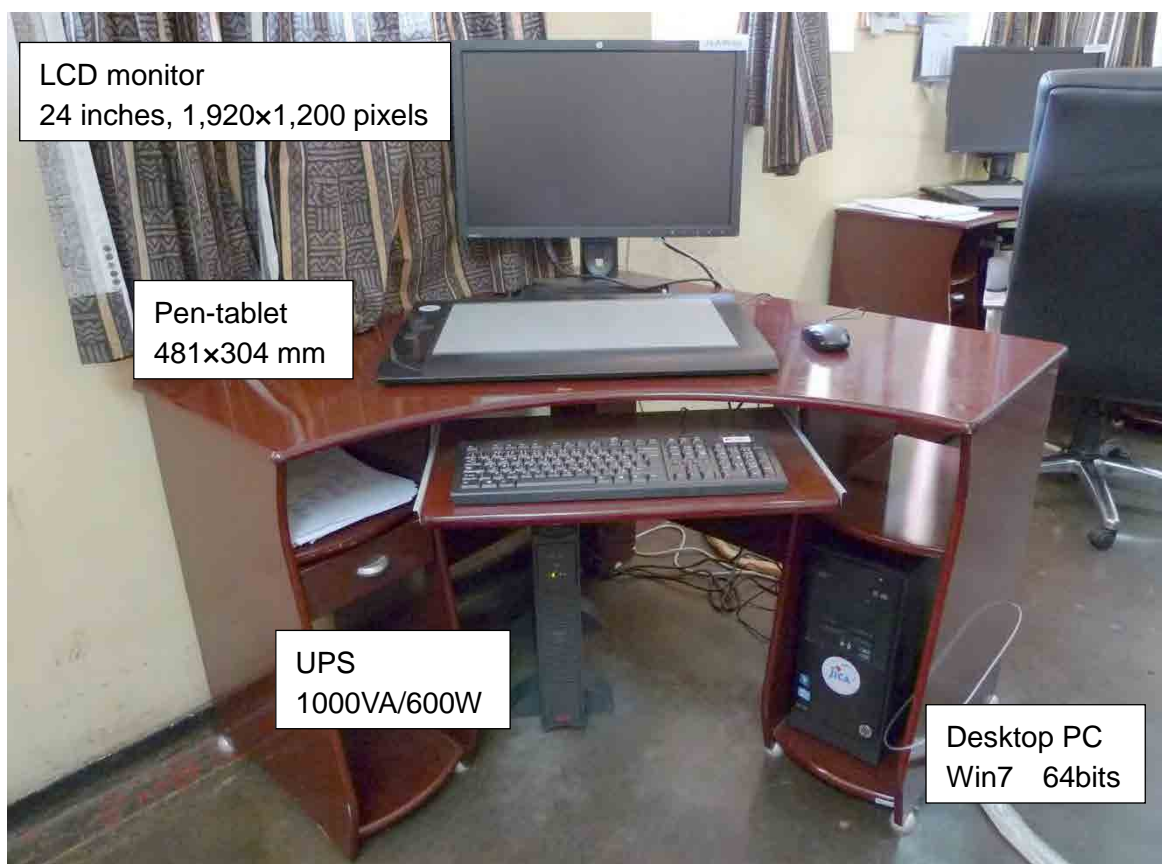


Figure 2.2 Photo of PC, peripheral equipment and UPS

3. Basic information of geology and mineral resources

3.1 National policy related to mining

3.1.1 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, it 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.

3.1.2 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.

3.2 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 3.1. 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 3.1 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 3.2.

Table 3.2 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 ₃ O ₈) Mineral resources : 14,728 t (U ₃ O 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.

3.2.1 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. CEEB 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 CEEB 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 ₃ O ₈	Amount U ₃ O 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).

3.2.2 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.

3.3 Geology and structure

3.3.1 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 3.1 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.

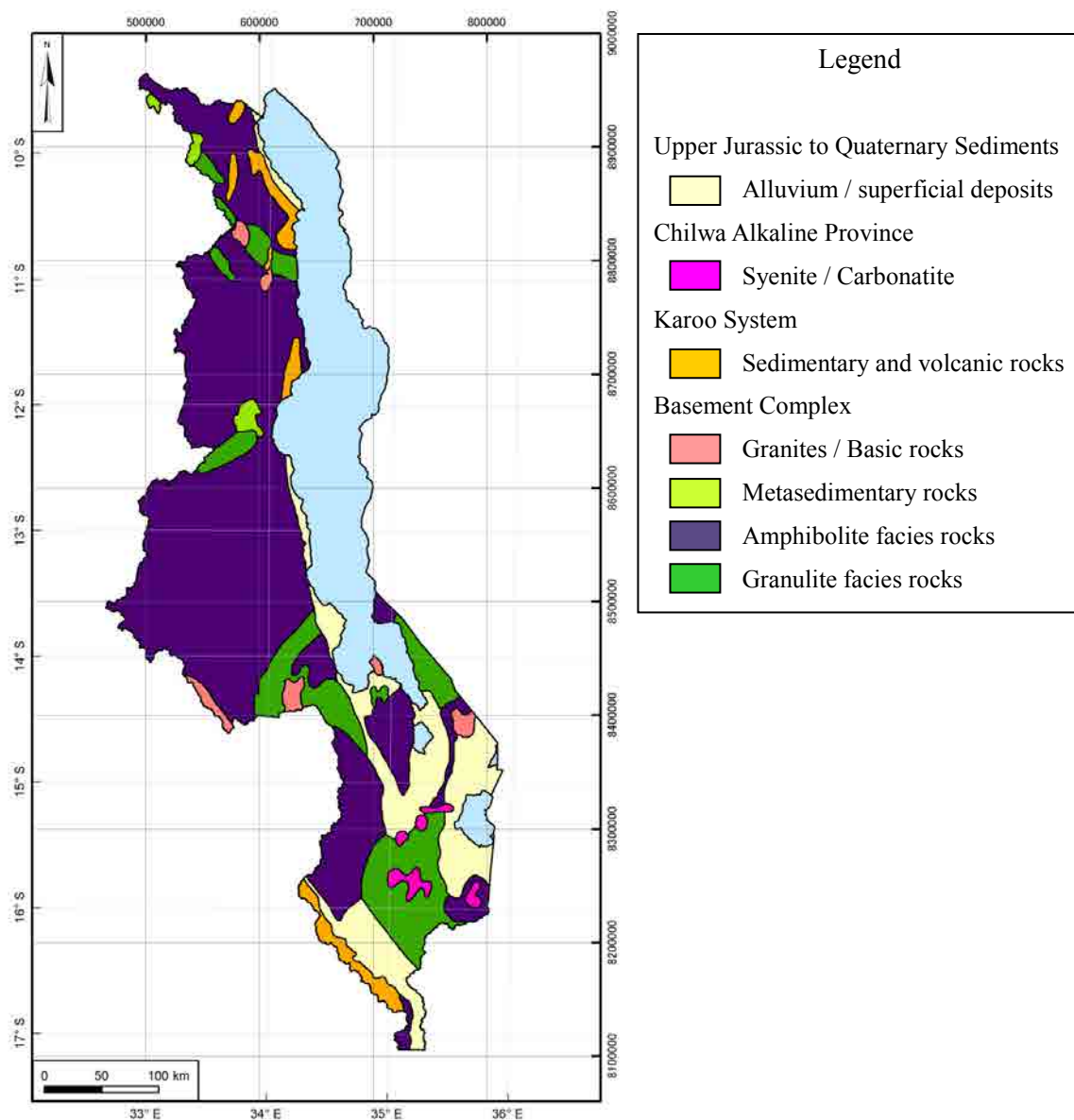


Figure 3.1 General geological map in Malawi

(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 lava 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.

3.3.2 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.

3.4 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 6.1 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.

(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.

(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 ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) 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.

(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 syngenetic 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.

(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.

3.5 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 km² at a fee of K1,000 for the licence and annual charges of K0.1 per km². 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 K10.00 per km². Fees of K200 are payable for each renewal requested. The maximum area at initial grant is 2,500 km² 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 estimates 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 km² and for the holders not more than the land subject to the EPL. The ML fee is K1000 per km². 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.

4. Satellite data analysis

4.1 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 4.3 and Figure 4.15 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 4.4 shows the ASTER false color image of the whole Malawi and Figure 4.16 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 4.1.

Table 4.1 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_yymmddhhmmssymmdd####.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/B8,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 PASL150ymmddhmmssymmdd####.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	-

4.2 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 sensor is shown in Figure 4.1.

ASTER L3A data which are orthorectified products (images) were used in the Project. Data format is HDF-EOS. Figure 4.3 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 4.2. Technology transfer through OJT of these data processing and analysis in Figure 4.2 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 4.5 shows all 14 band grayscale images in 1 scene around Salima, the south-eastern side of Lake Malawi. The image of Figure 4.6~4.12 is the analysis result of this scene.

Details of ASTER data processing and analysis are described according to JOB number in Table 4.1 of Satellite data and creating files list and Figure 4.2 of Process flow of ASTER data as follows. Hereafter, a notation “RGB=B3, B2, B1” means that red color (R), green color (G) and blue color (B) are allocated to band1 (B1), band2 (B2) and band3 (B3), respectively.

4.2.1 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 JOB03-1 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.

4.2.2 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.

4.2.3 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.

4.2.4 Analyzed images

The band composite image and the band ratio image shown in Figure 4.9~4.12 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 4.6. 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 4.7. 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 4.8.

An example of VNIR band composite image (RGB=B3, B2, B1) created in JOB06 is shown in Figure 4.9. 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 4.6. Though the images of Figure 4.6 and Figure 4.9 use the same bands, the tone between these images is different, and the hue in the distribution of soil and rock in Figure 4.9 varies more than that in Figure 4.6. Consequently, it is easier to interpret geological information in Figure 4.9. An example of SWIR band composite image created similarly is shown in Figure 4.10.

The combination of bands is RGB=B4, B6, B8. In the SWIR band composite image of Figure 4.10, 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 4.11. The combination of bands is RGB=B4/B8, B3/B8, B3/B1. In the band ratio image of Figure 4.11, 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 4.12. The combination of bands is RGB=B10, B12, B14. In the band composite image of Figure 4.12, difference in content of SiO₂ 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 SiO₂, and amount of radiation of band 13 and band 14 is low in rock which has less SiO₂. 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 4.13. The area of Figure 4.13 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 4.13. 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.

4.3 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 4.15.

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 4.14. Technology transfer through OJT of these data processing and analysis in Figure 4.14 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 4.1 of Satellite data and creating files list and Figure 4.14 of Process flow of PALSAR data as follows.

4.3.1 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 4.16 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 4.17. 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.

4.3.2 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 4.18. 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 4.19. 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.

4.4 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 4.20 and ASTER band composite image (RGB=B3, B2, B1) is shown in Figure 4.21. 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.

4.4.1 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 4.2 shows the time schedule of field verification survey and participants.

4.4.2 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 4.22) 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 4.22. 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 4.3 and photos of field verification for satellite data are shown in Figure 4.23.

Table 4.2 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)

4.5 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.

(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

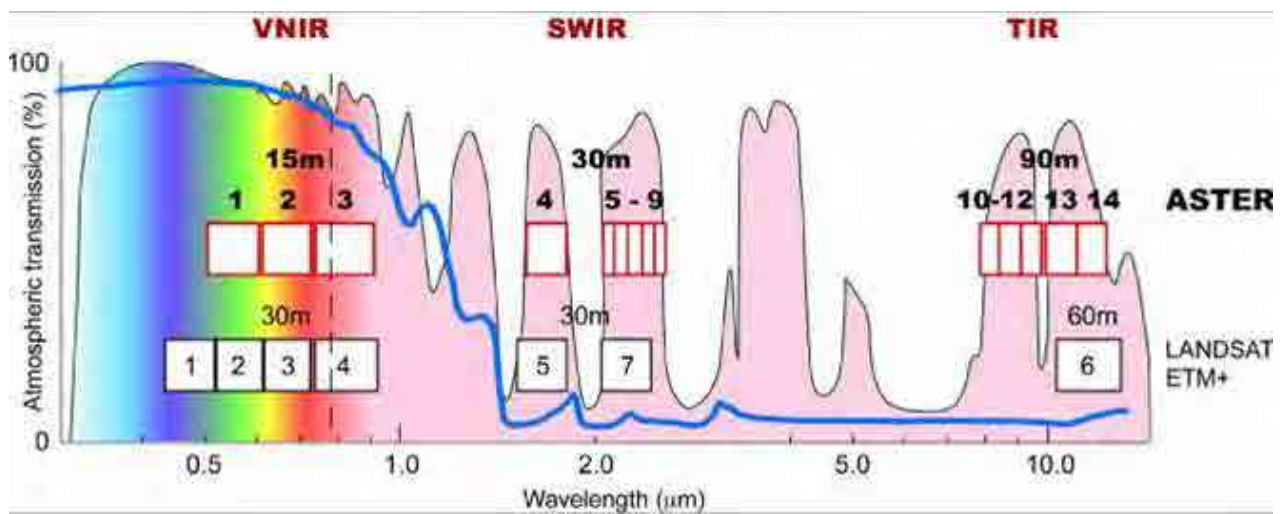
(4) LANDSAT data analysis

- 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 4.24. 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 4.3 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	Pyroxene 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,occasionaly 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 4.1 Bands location of ASTER sensors

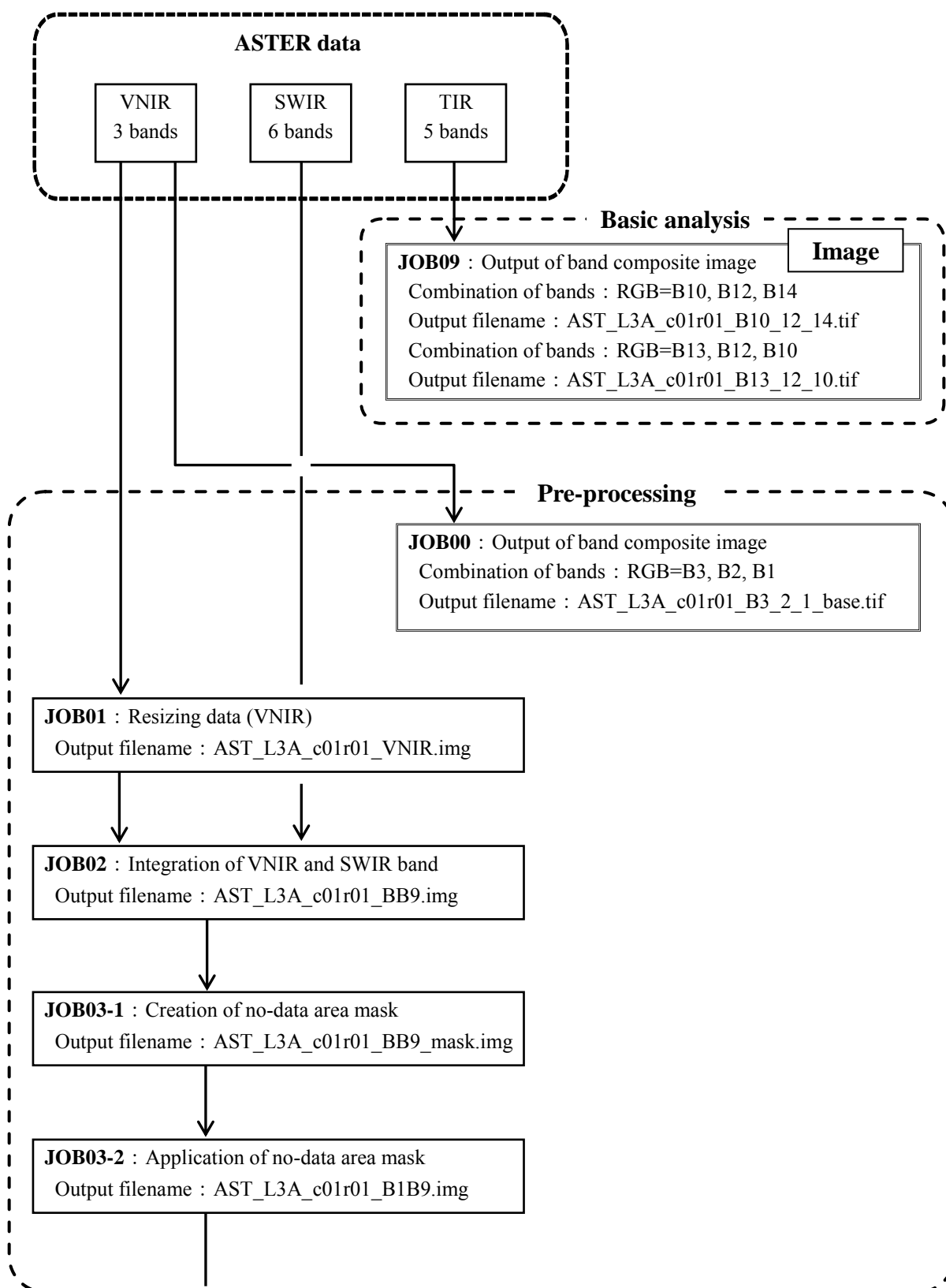


Figure 4.2 Flow chart of ASTER data processing (1/3)

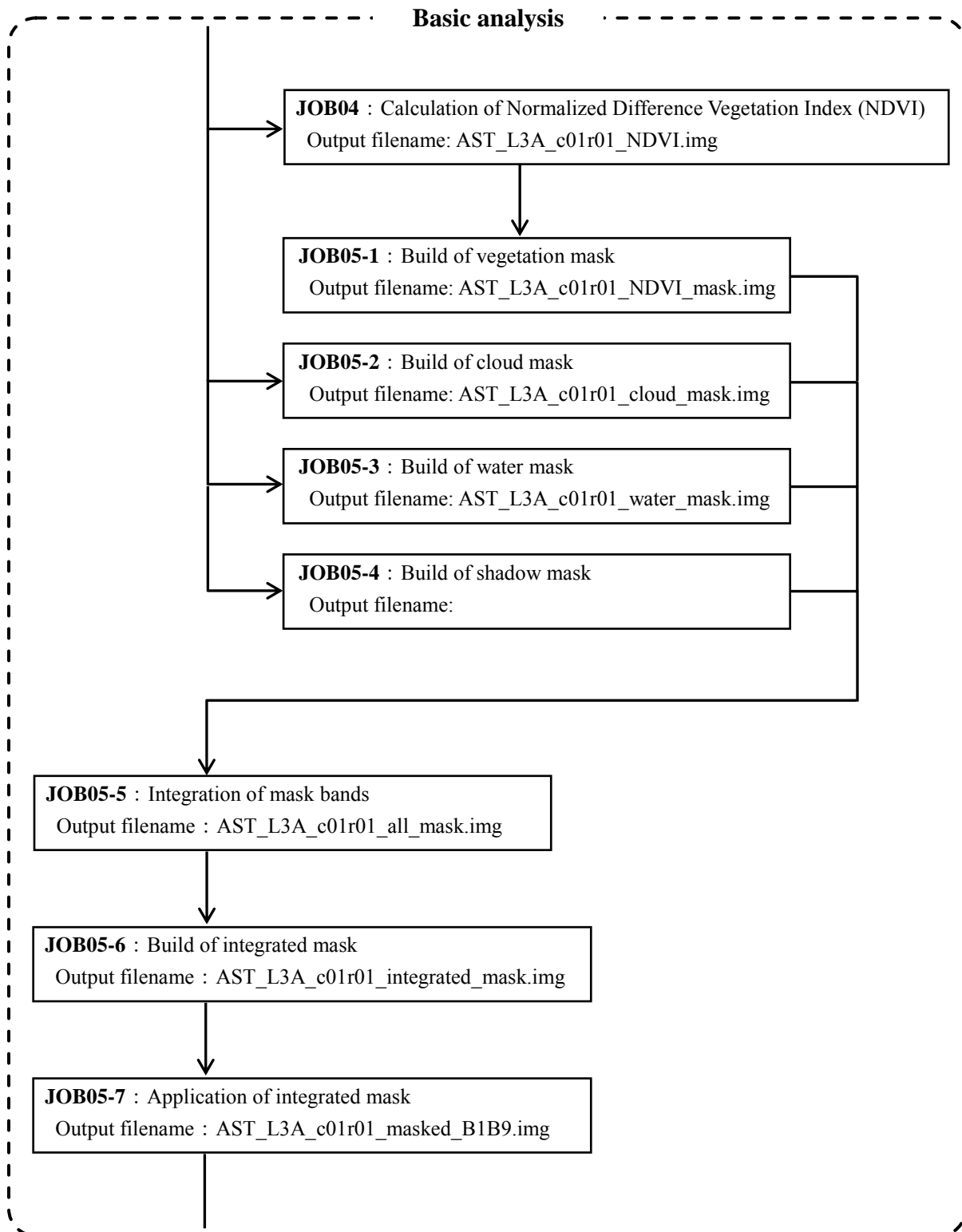


Figure 4.2 Flow chart of ASTER data processing (2/3)

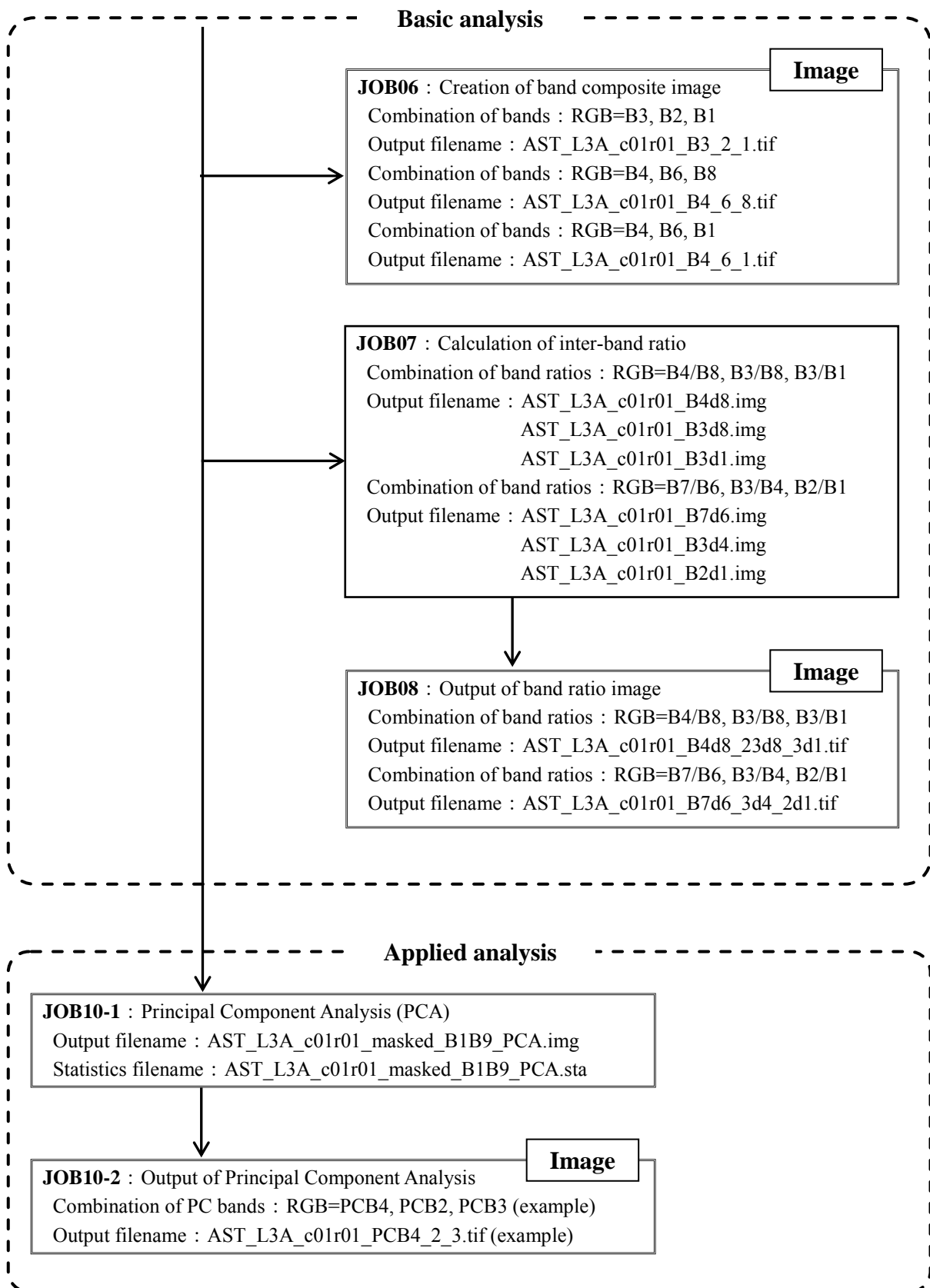


Figure 4.2 Flow chart of ASTER data processing (3/3)

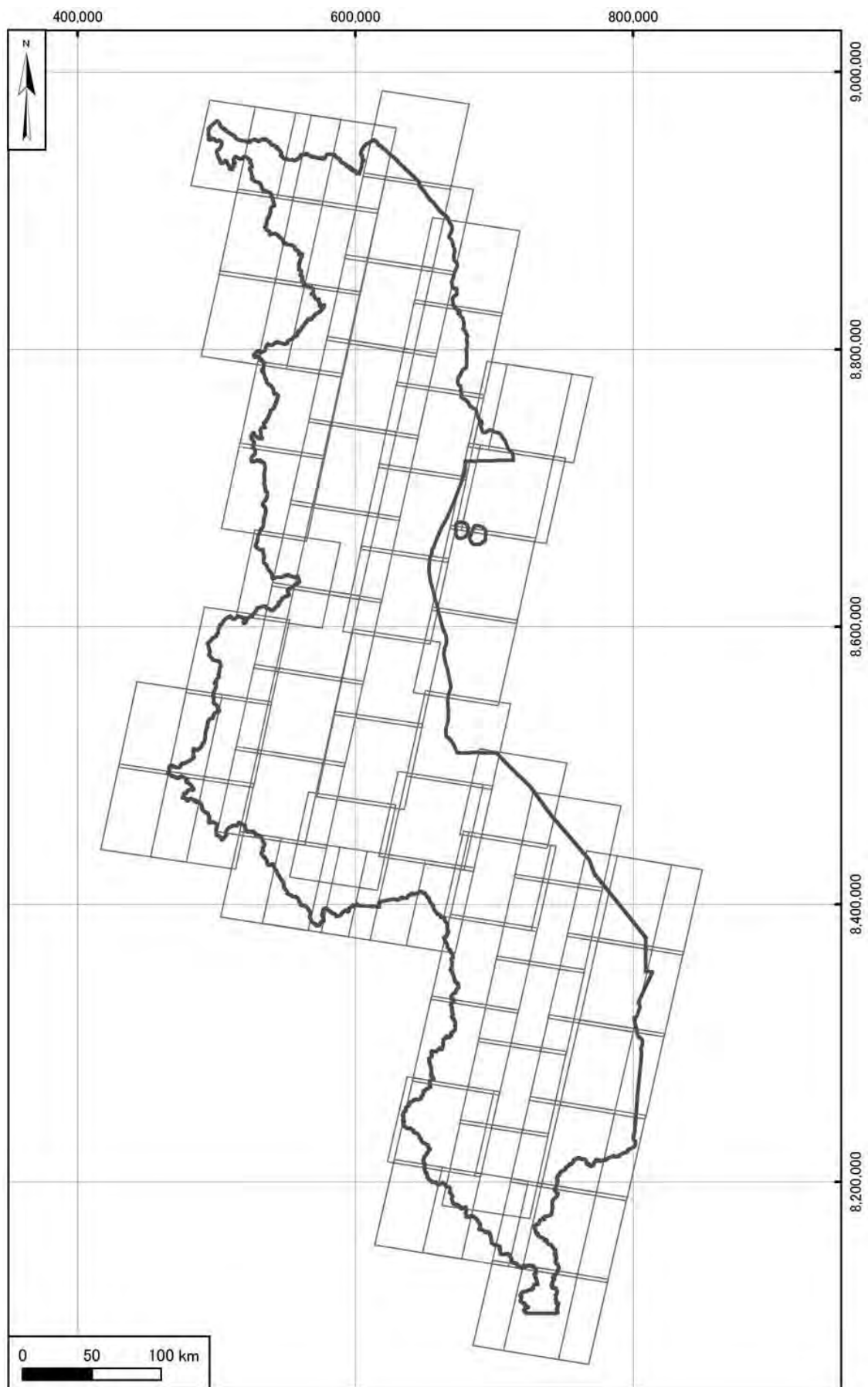


Figure 4.3 Location map of ASTER data

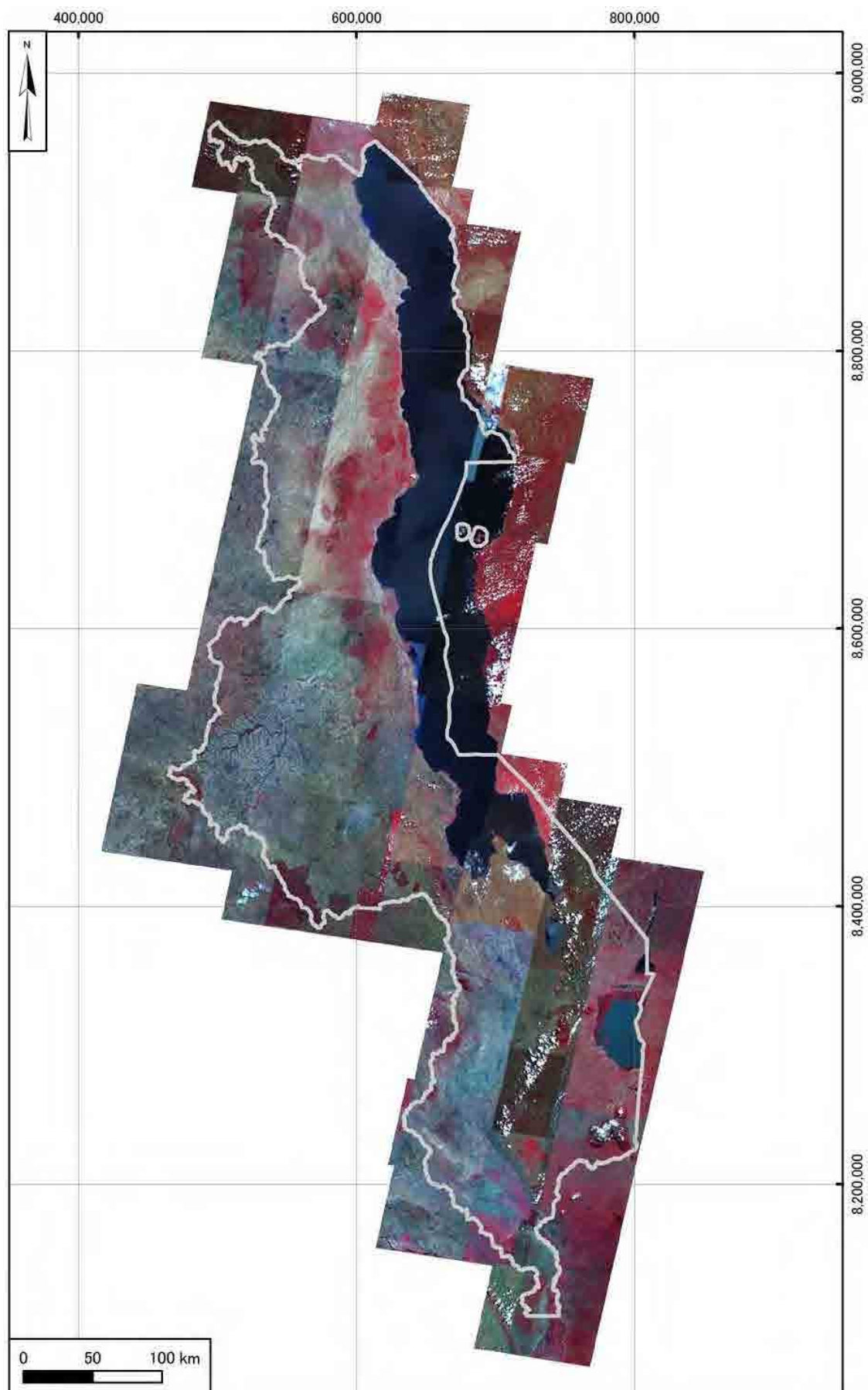


Figure 4.4 ASTER browse image of whole Malawi

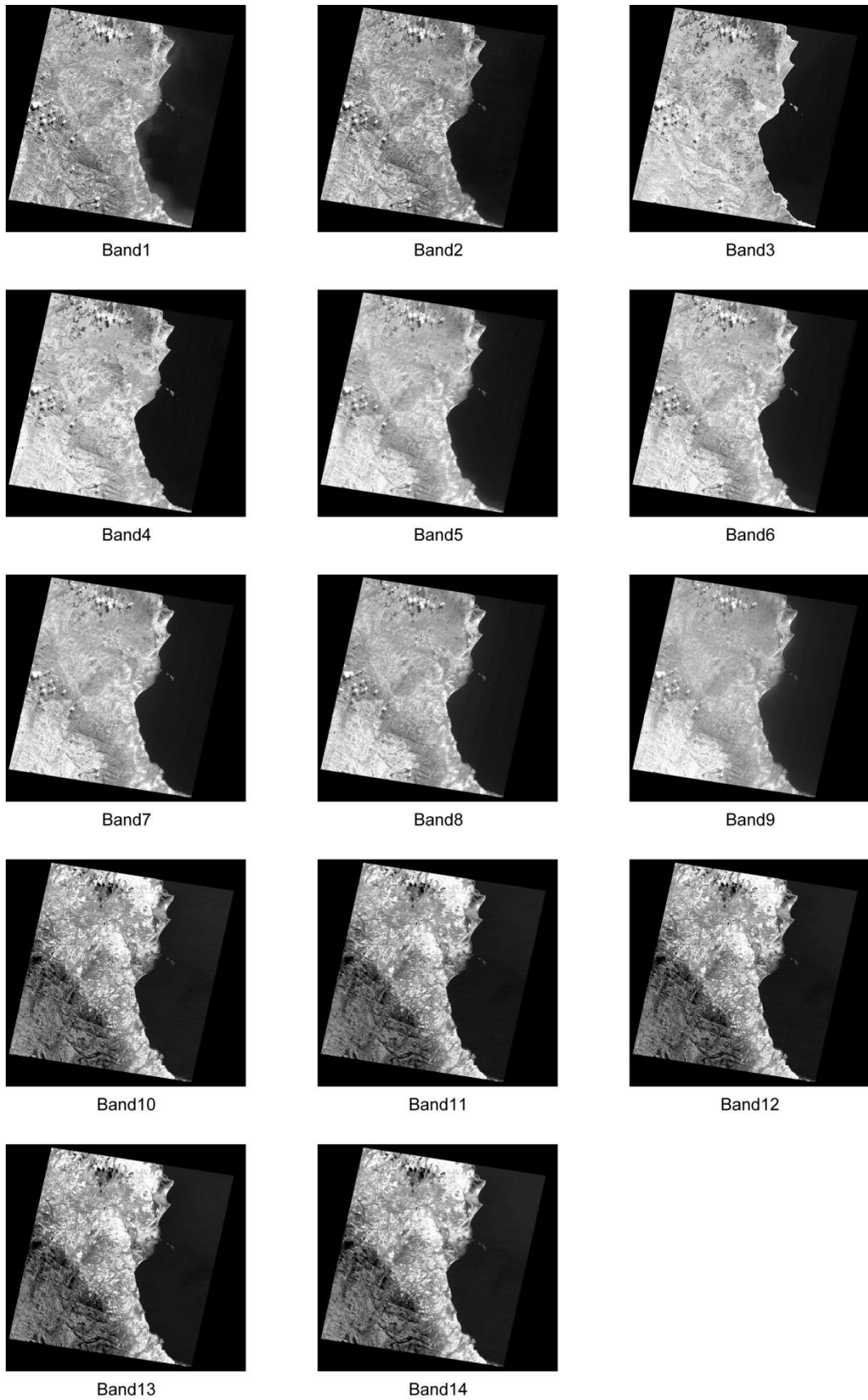


Figure 4.5 All bands images of ASTER data



Figure 4.6 ASTER band composite image (RGB=B3,B2,B1)

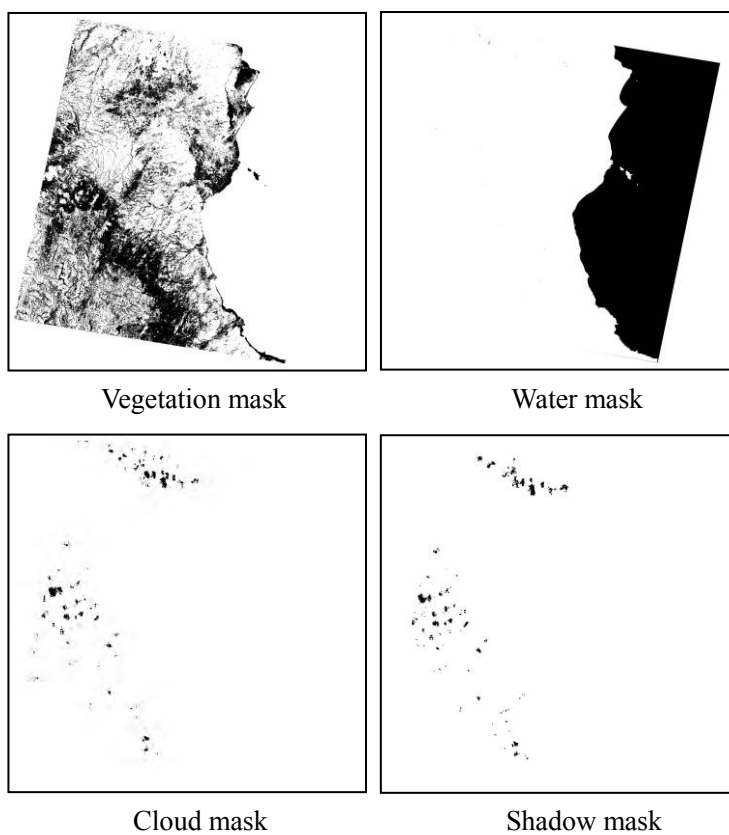


Figure 4.7 ASTER mask data (vegetation, water, cloud, shadow)

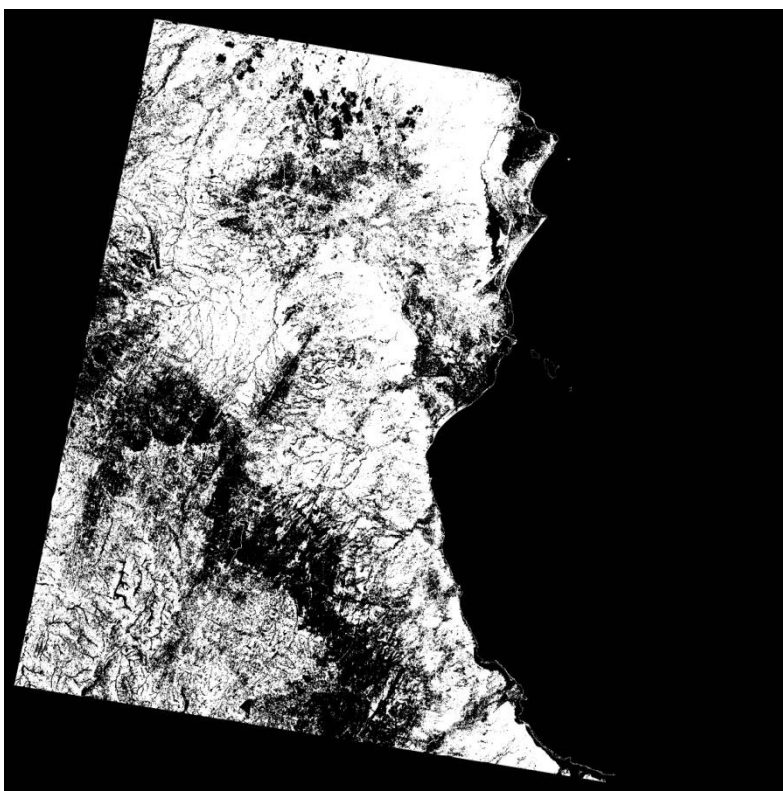


Figure 4.8 ASTER integrated mask data

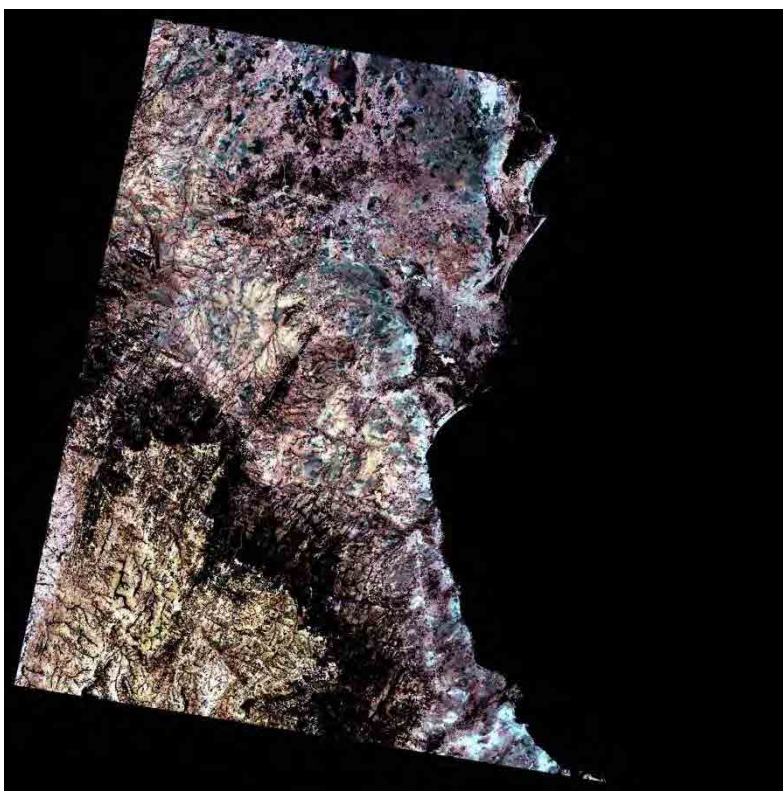


Figure 4.9 ASTER VNIR band composite image (RGB=B3,B2,B1)

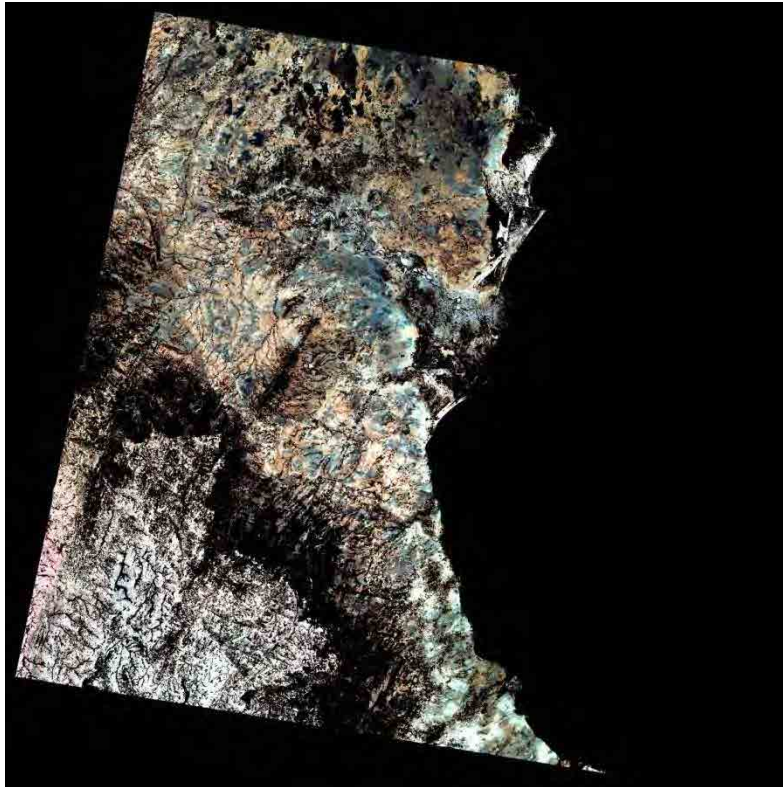


Figure 4.10 ASTER SWIR band composite image (RGB=B4,B6,B8)



Figure 4.11 ASTER band ratio image (RGB=B4/B8,B3/B8,B3/B1)



Figure 4.12 ASTER TIR band composite (RGB=B10,B12,B14)

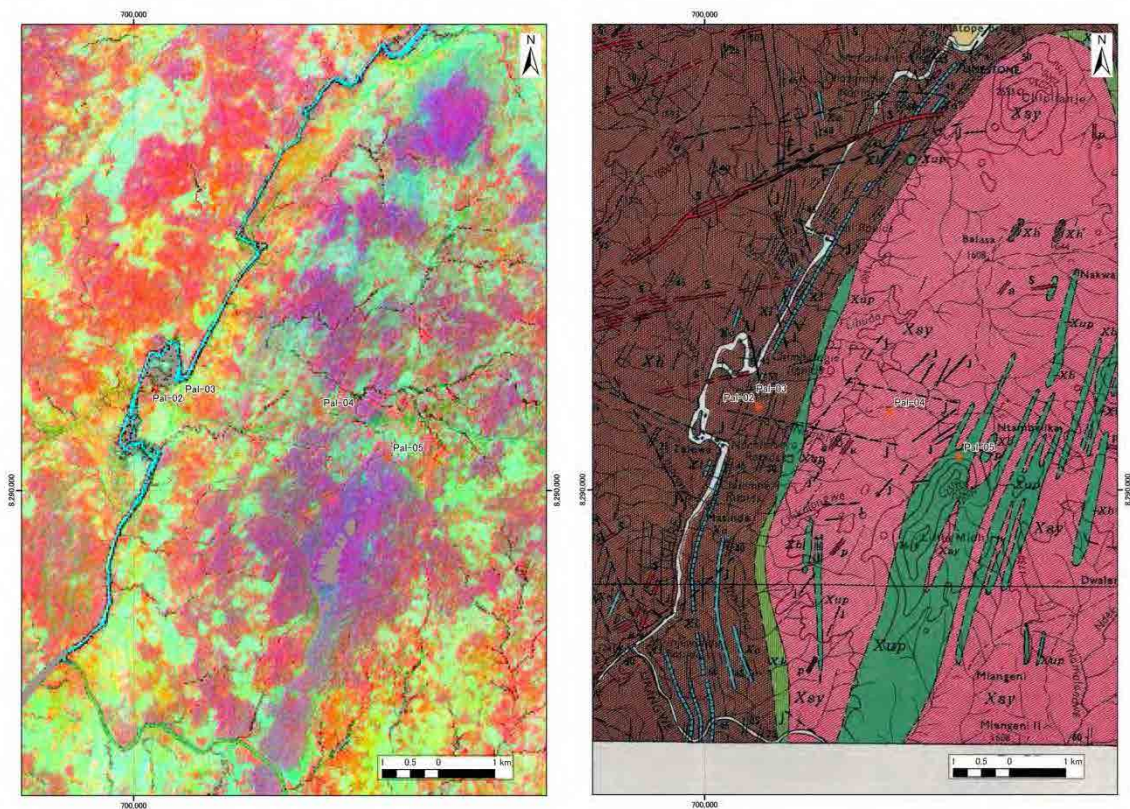


Figure 4.13 ASTER PCA image (RGB=PCA-B2,B4,B6) (left) and geological map (right)

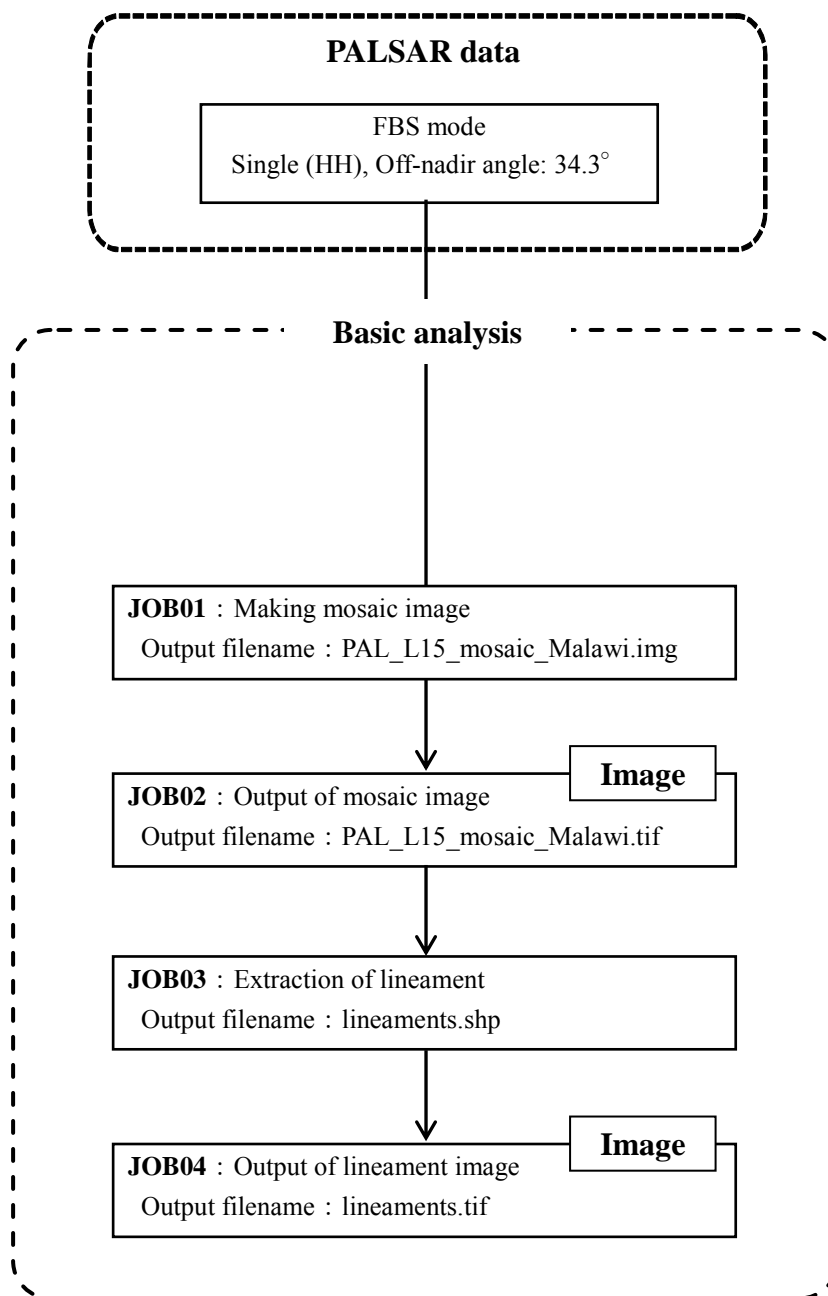


Figure 4.14 Flow chart of PALSAR data processing

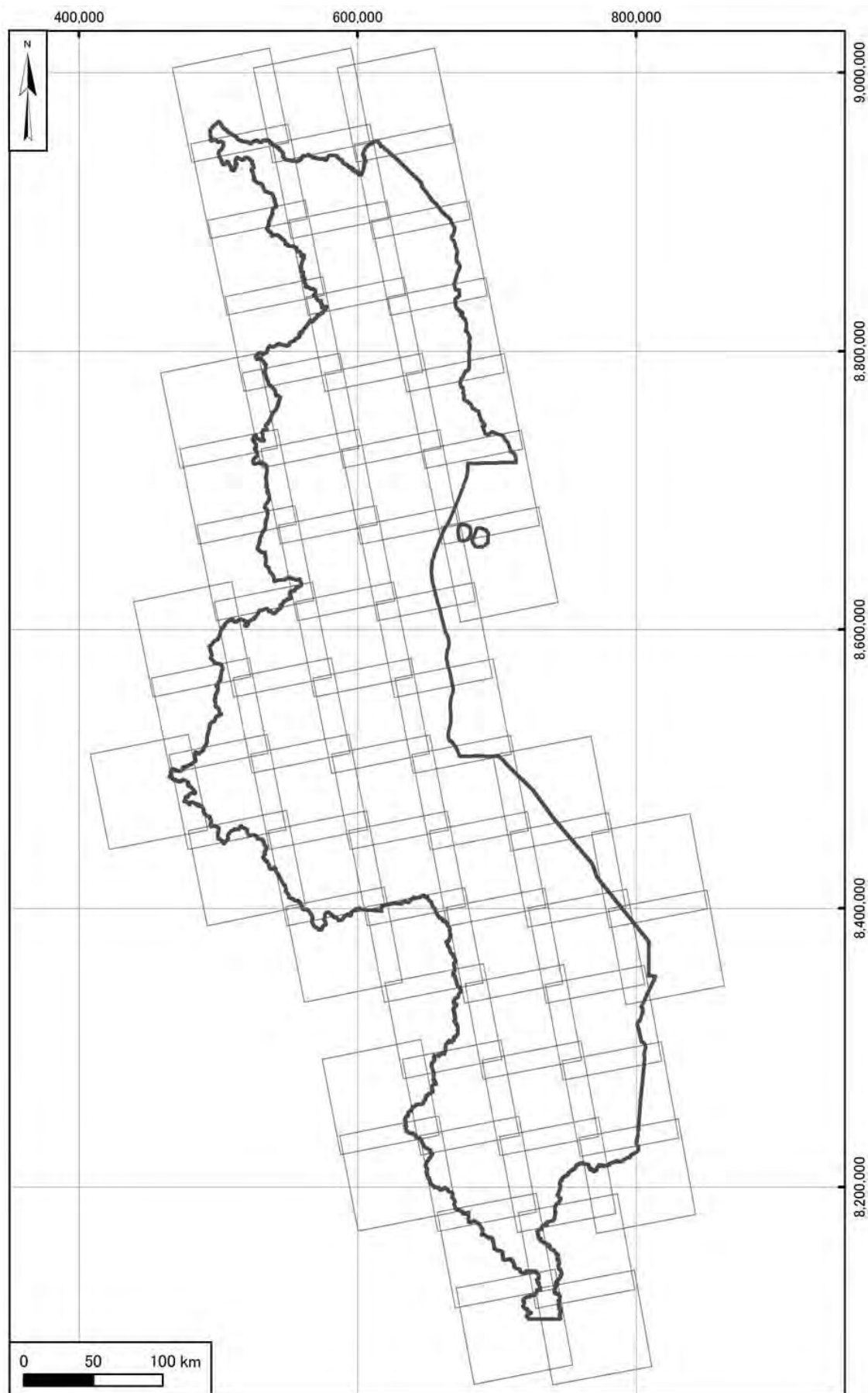


Figure 4.15 Location of PALSAR data

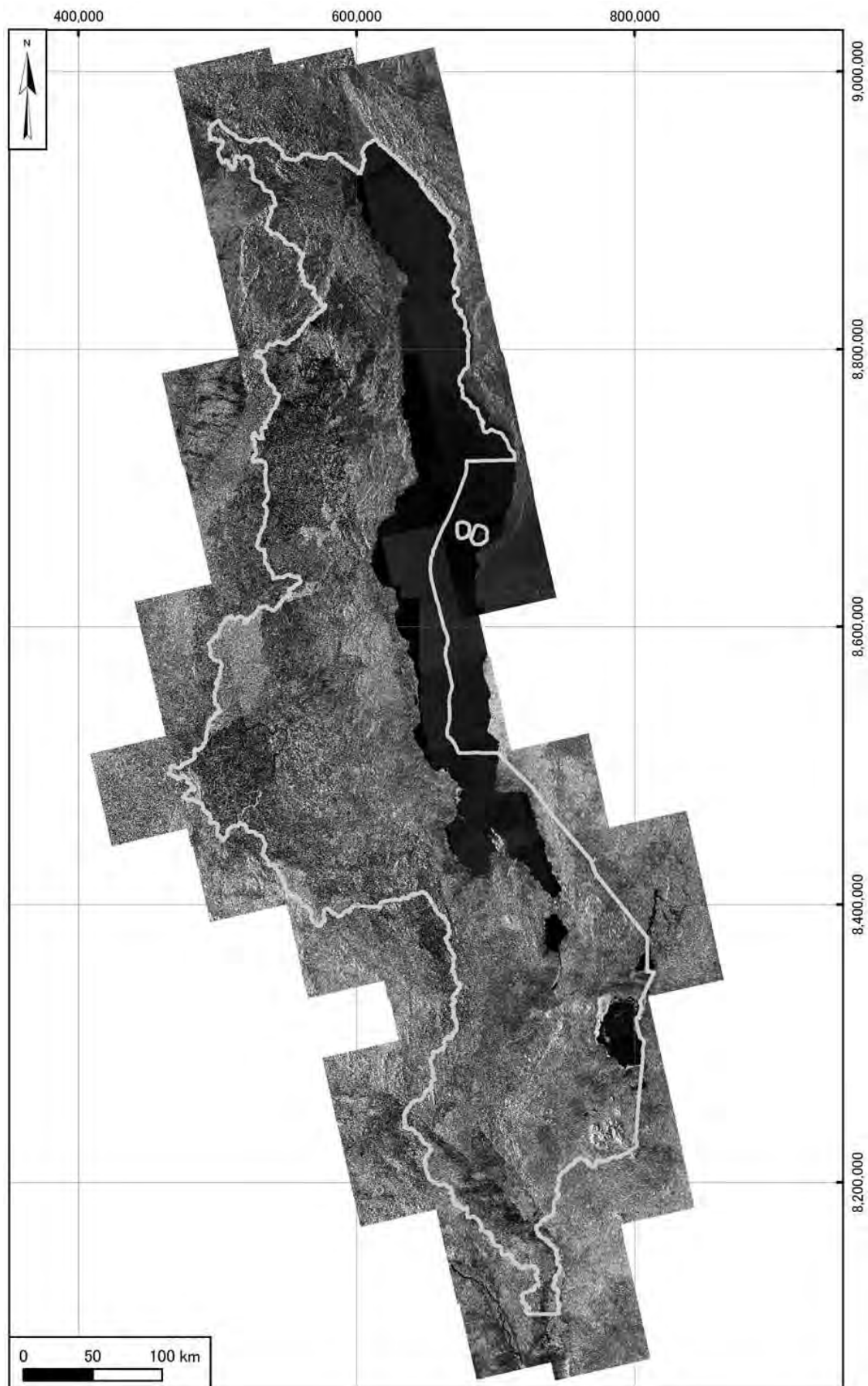


Figure 4.16 PALSAR mosaic image of whole Malawi

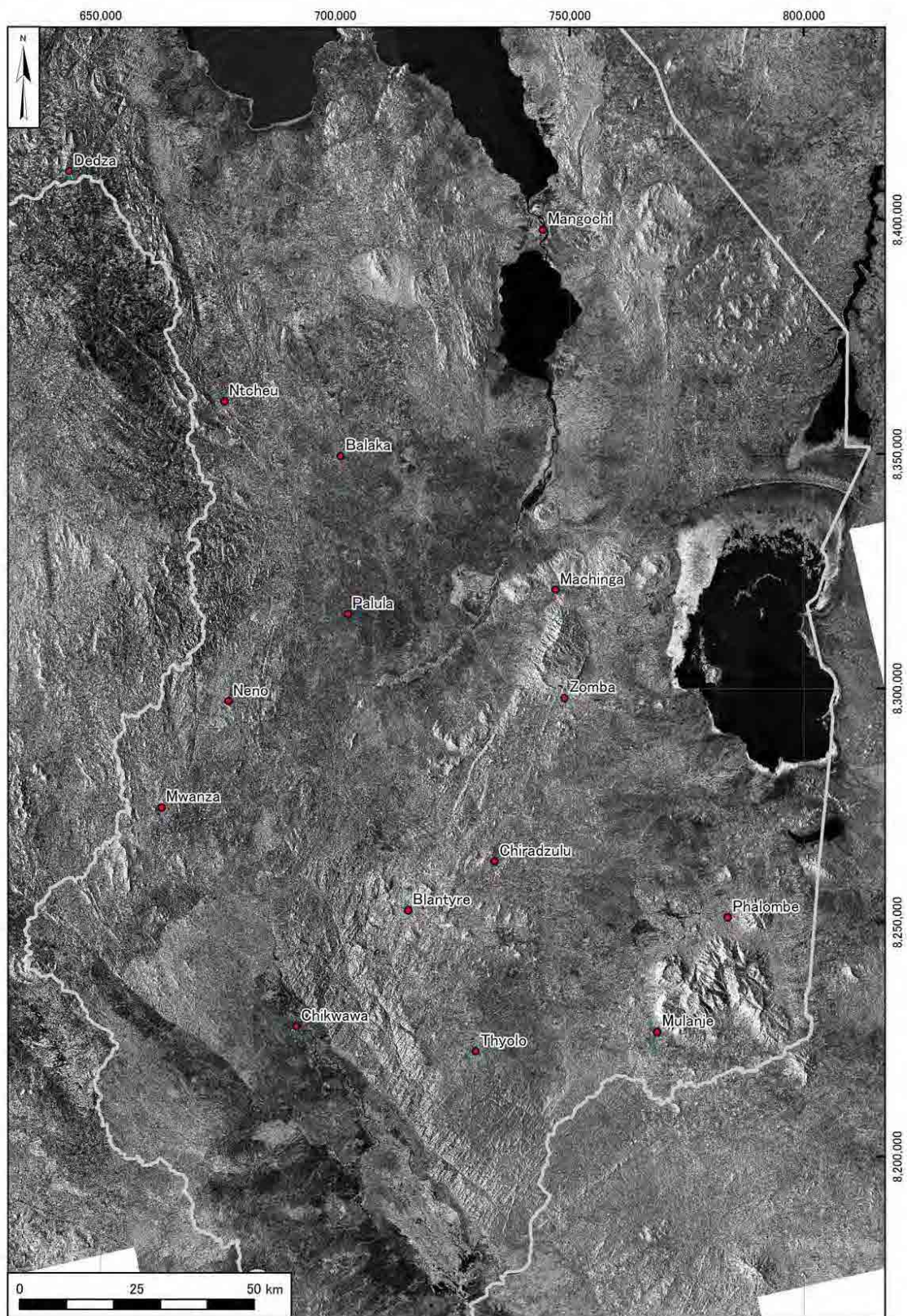


Figure 4.17 PALSAR mosaic image of the southern Malawi

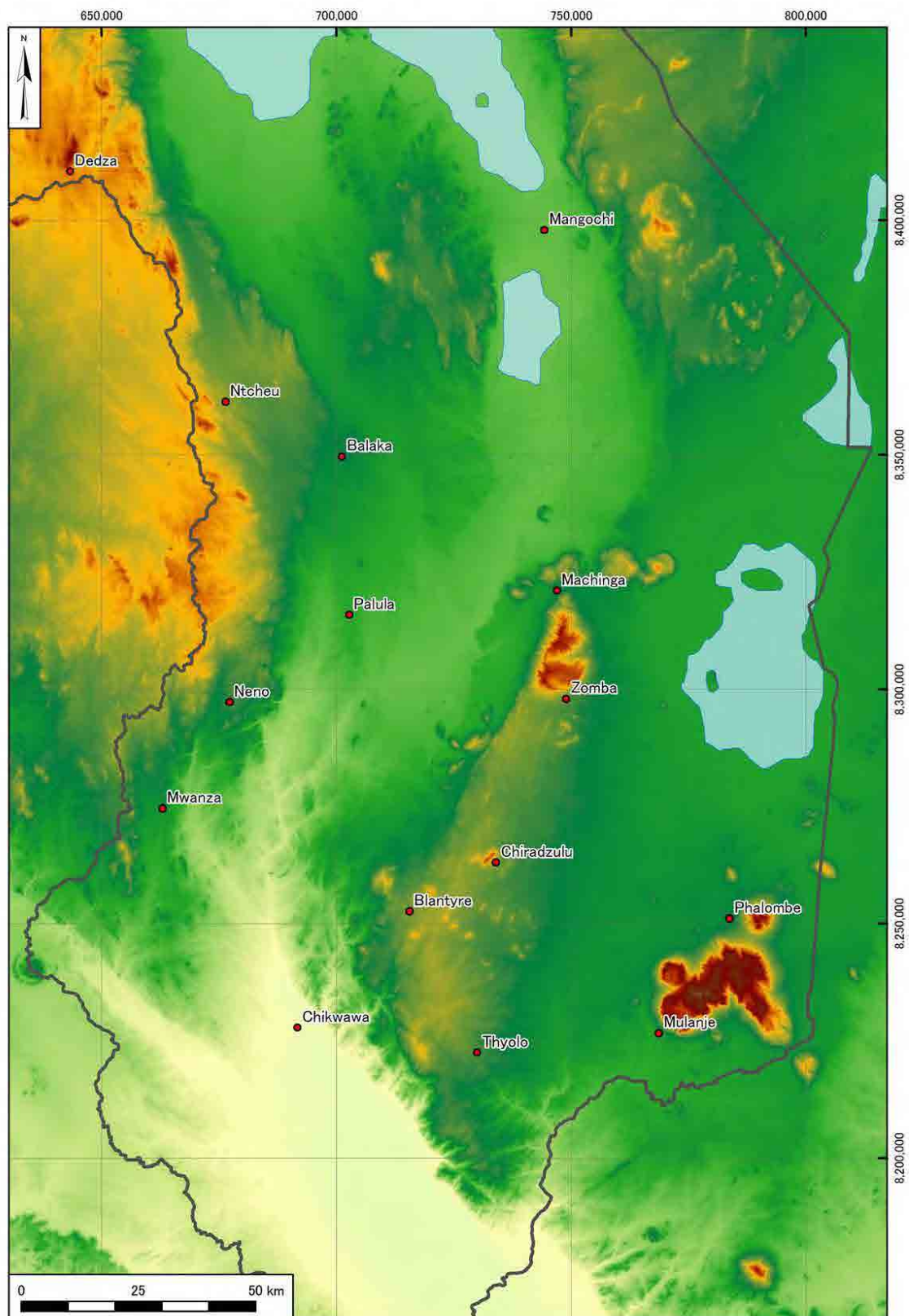


Figure 4.18 ASTER G-DEM color gradient topographic map of the southern Malawi

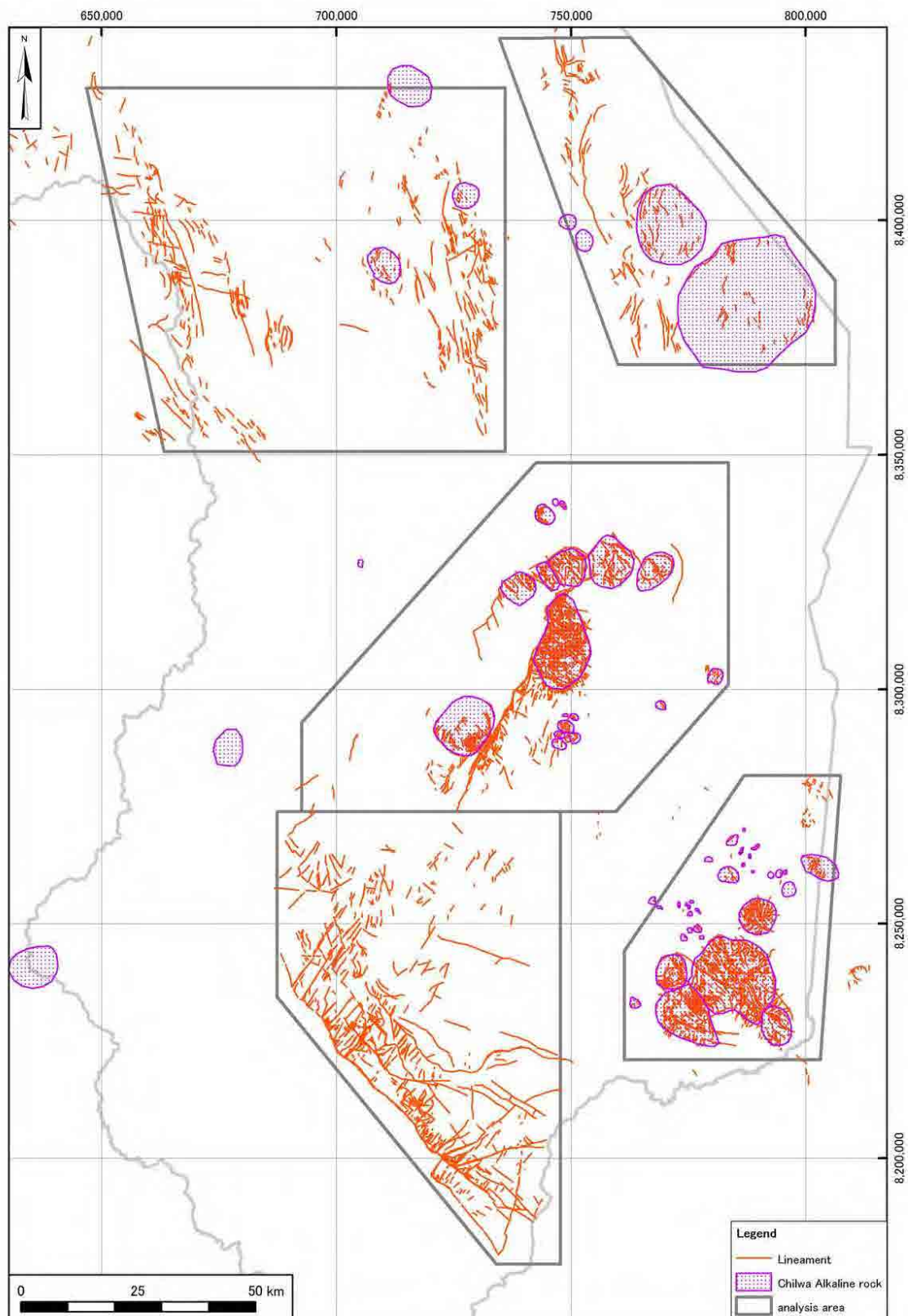


Figure 4.19 Lineament map of the southern Malawi

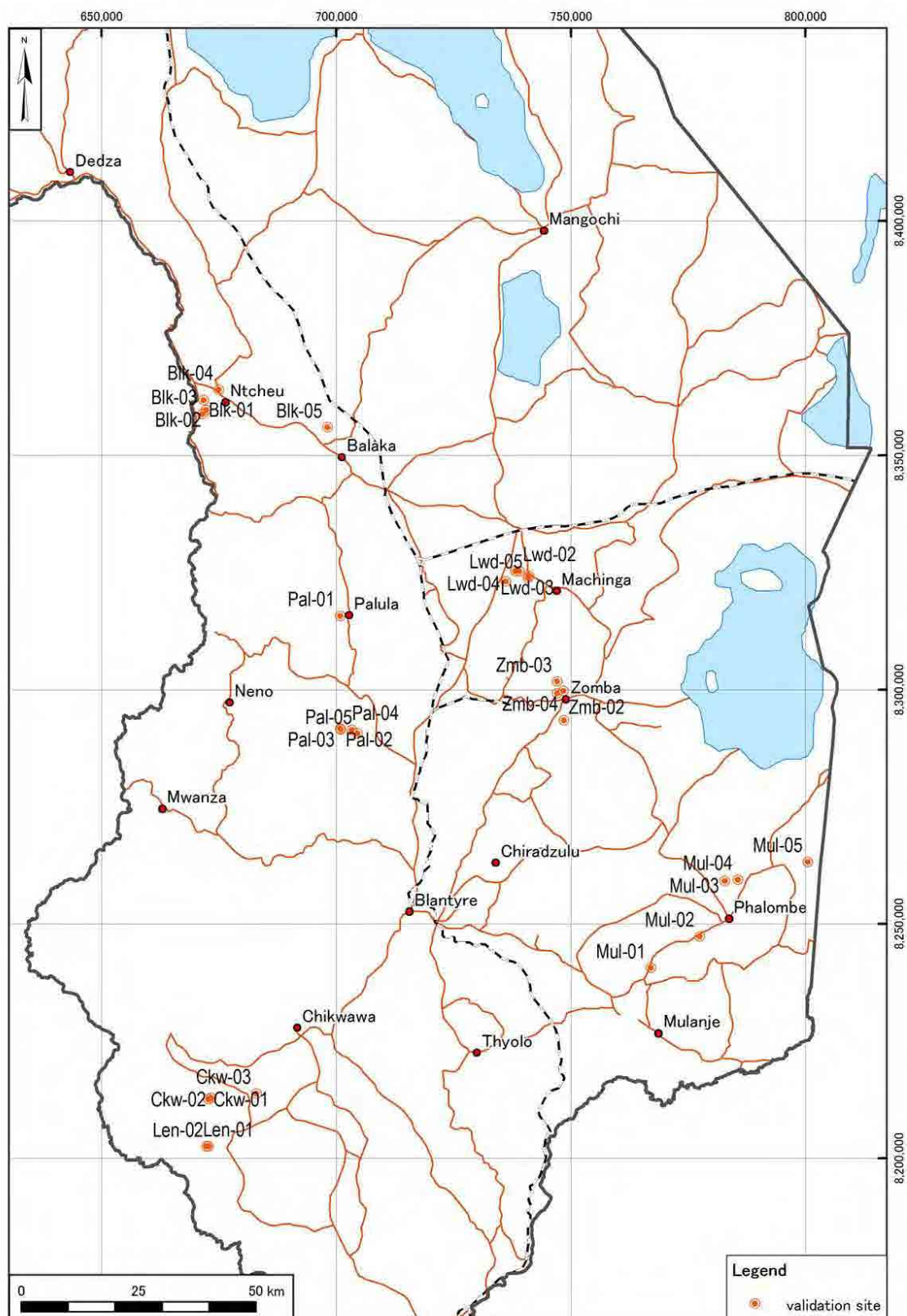


Figure 4.20 Location map of field verification for satellite data

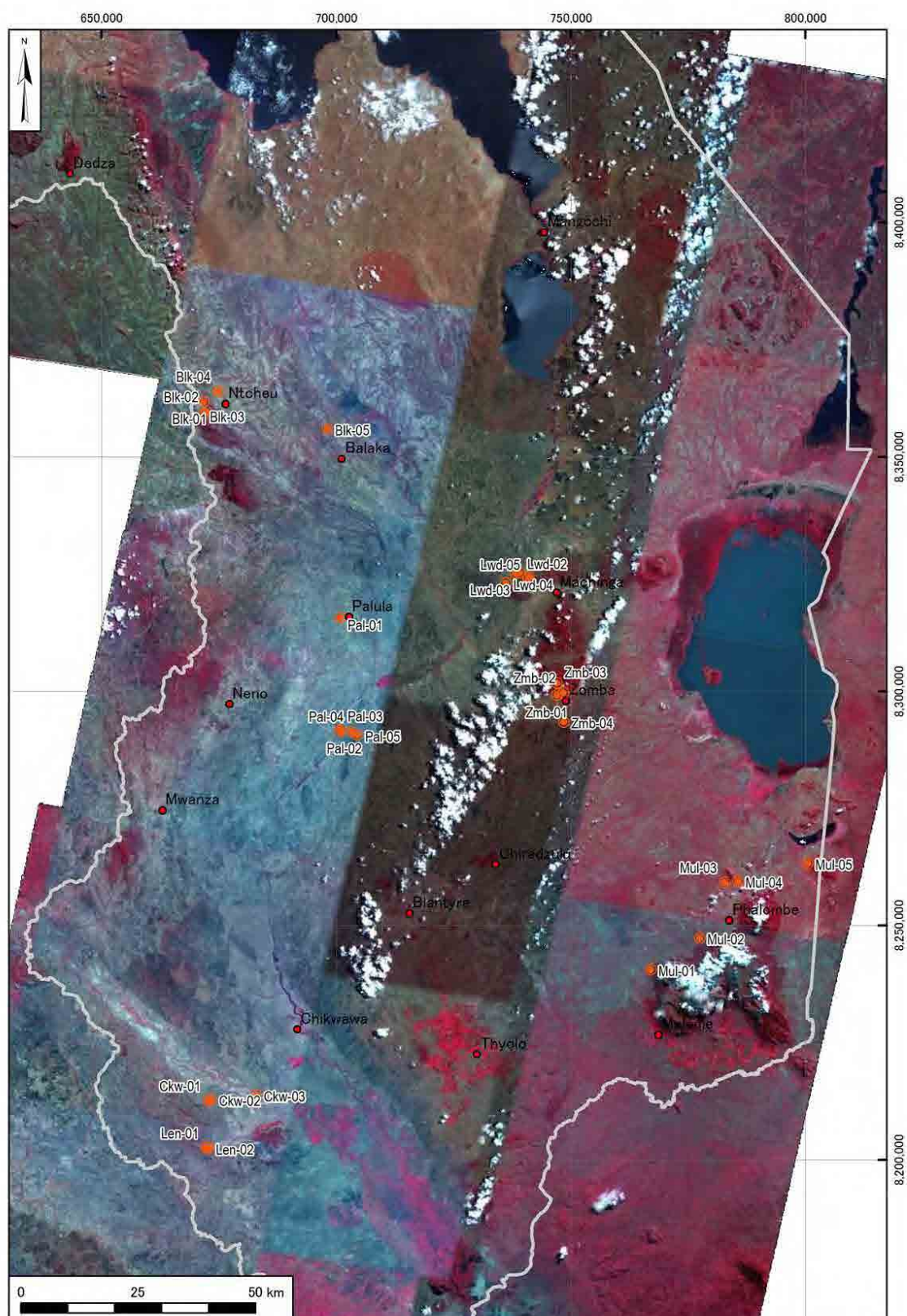


Figure 4.21 ASTER image of field verification area


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	
<p>Photo</p> 	

Figure 4.22 Example of data sheet for field verification



Blk01



Pal02



Lwd02



Zmb01



Zmb03



Ckw03



Len01



Mul01

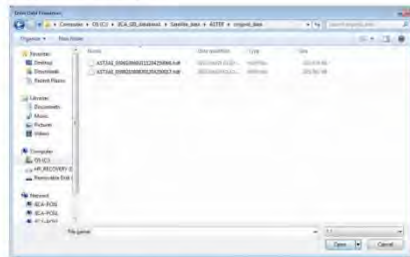
Figure 4.23 Photos of field verification for satellite data

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_050610080311204250066.hdf)

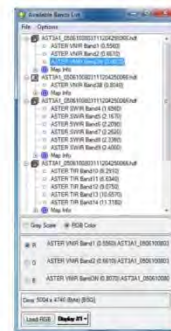
"V" means back slash.

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



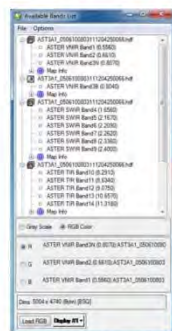
- Choose and find the input data folder in the window.
- Select and click the input ASTER data file in the window.
- Input file folder: C:\JICA_GIS_database\Satellite_data\ASTER\original_data (example: AST3A1_050610080311204250066.hdf)
- Selected data filename appears in the "File Name" box.
- Click "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 4.24 ENVI procedure manual for satellite data analysis

5. GIS data creation

5.1 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 5.1, Figure 5.2). 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 5.1). A series of these tasks was practiced through OJT.

5.1.1 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 5.2), 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 5.5). 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 5.1), 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 5.3.

5.1.2 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.

5.1.3 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 effort 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 5.4.

- 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 5.1).

- 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”.

5.1.4 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 5.6.

- 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 frame in which index map would be created was inserted into the layout view, and was set up its position and size.

5.2 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.

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 5.1 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

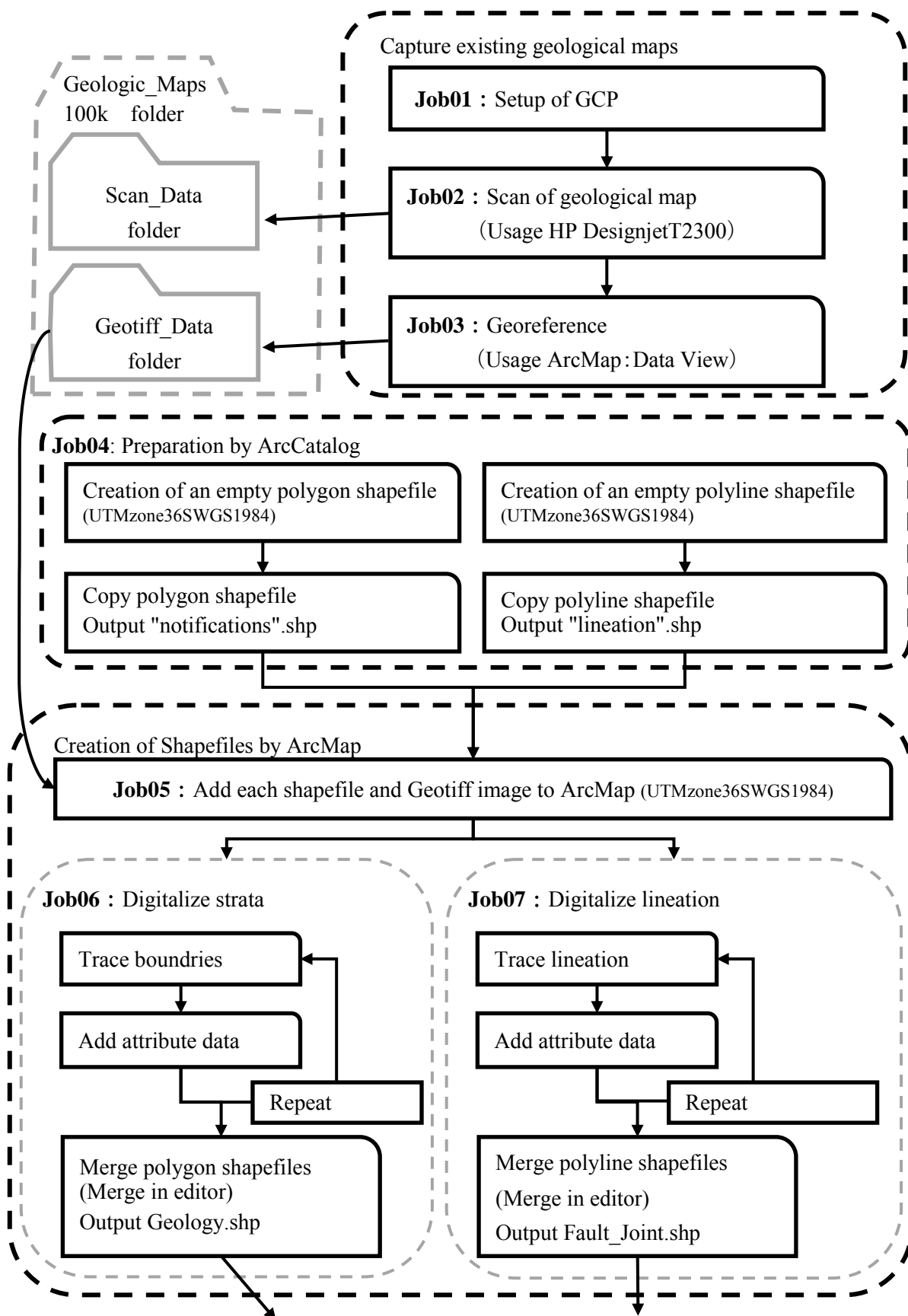


Figure 5.1 Flow chart of GIS data creation of geological map (1/2)

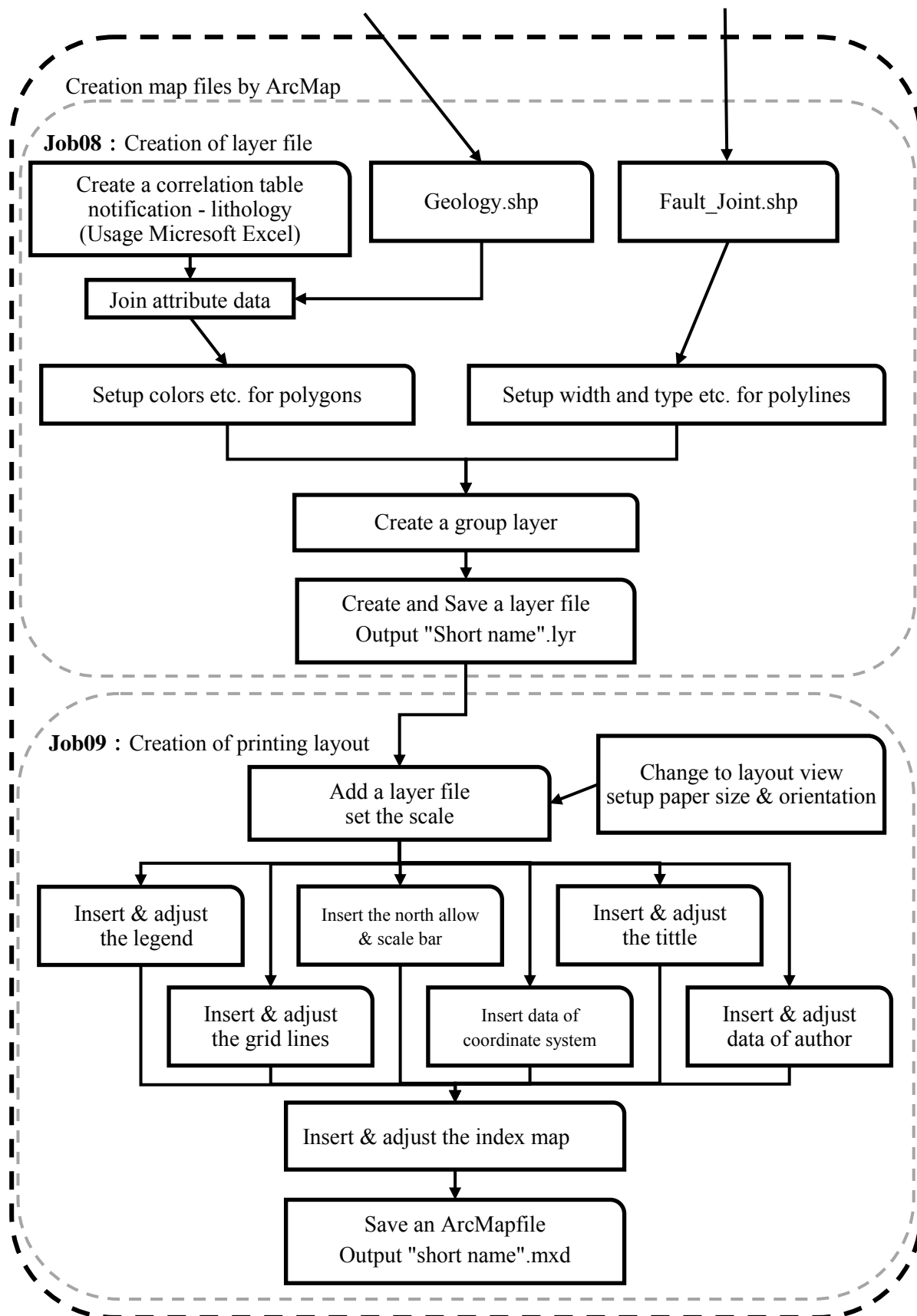


Figure 5.1 Flow chart of GIS data creation of geological map (2/2)

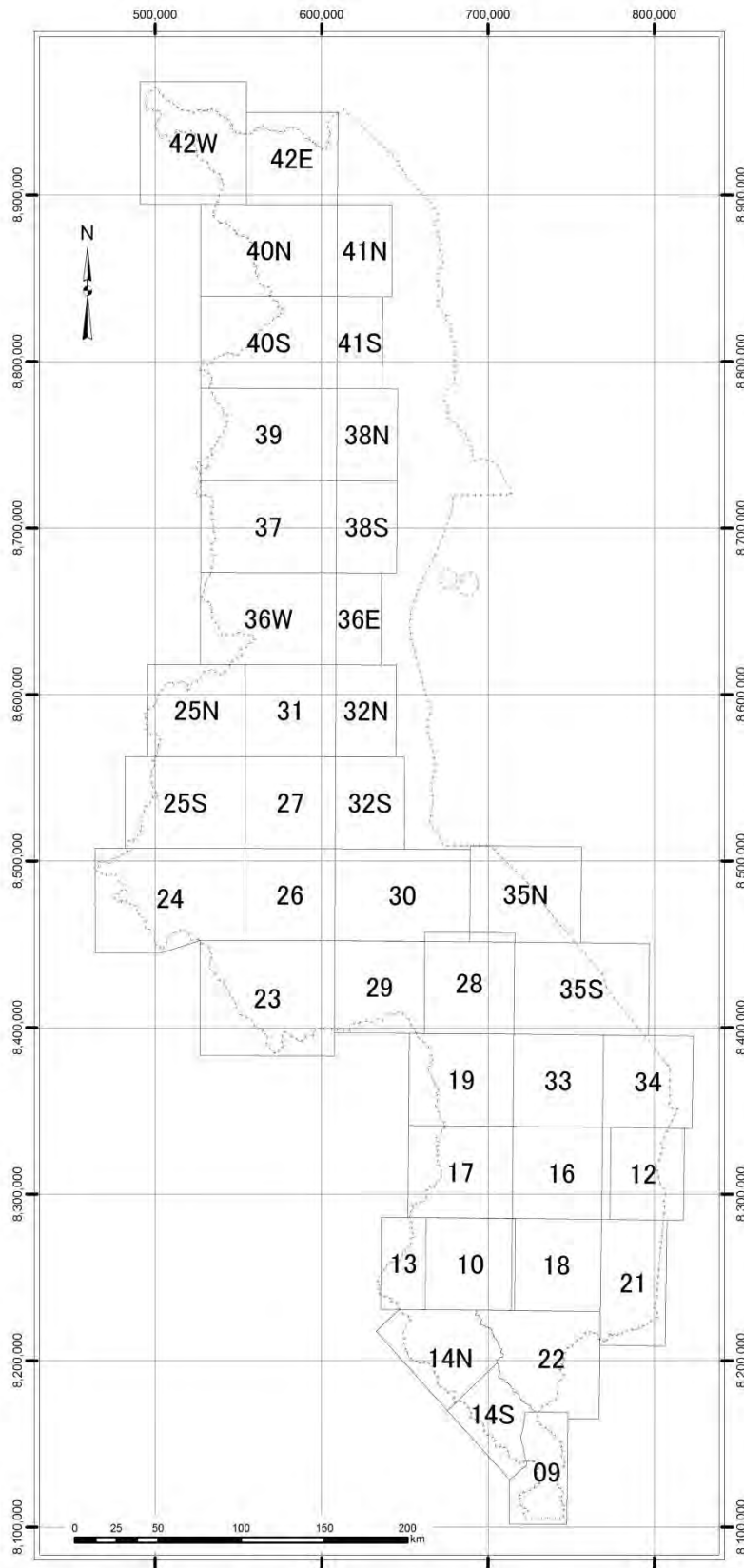


Figure 5.2 Location of 1/100,000 scale geological maps (all 40 sheets)

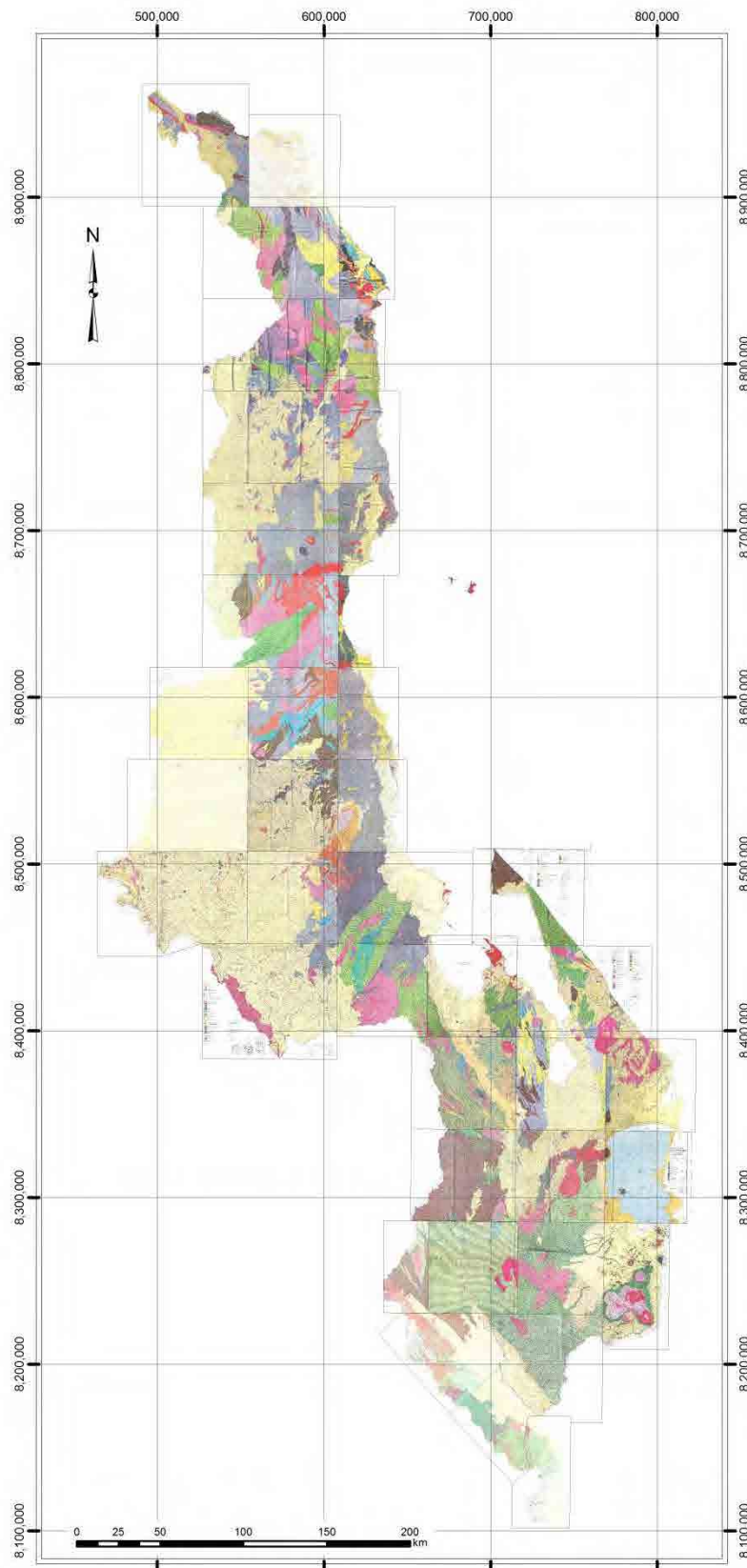


Figure 5.3 Geological maps at 1/100,000 scale of the whole Malawi

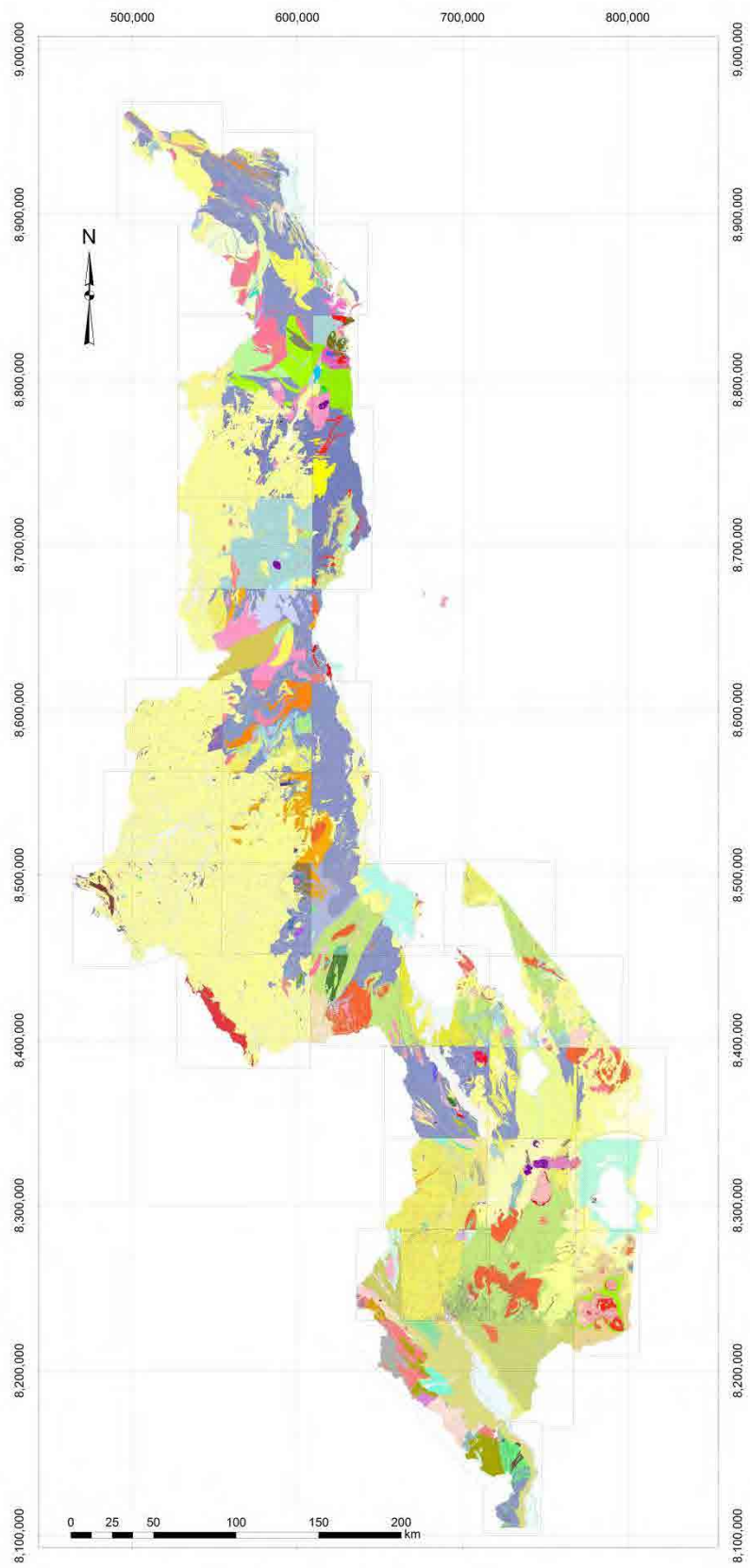


Figure 5.4 Digital geological maps of the whole Malawi(all 40 sheets)

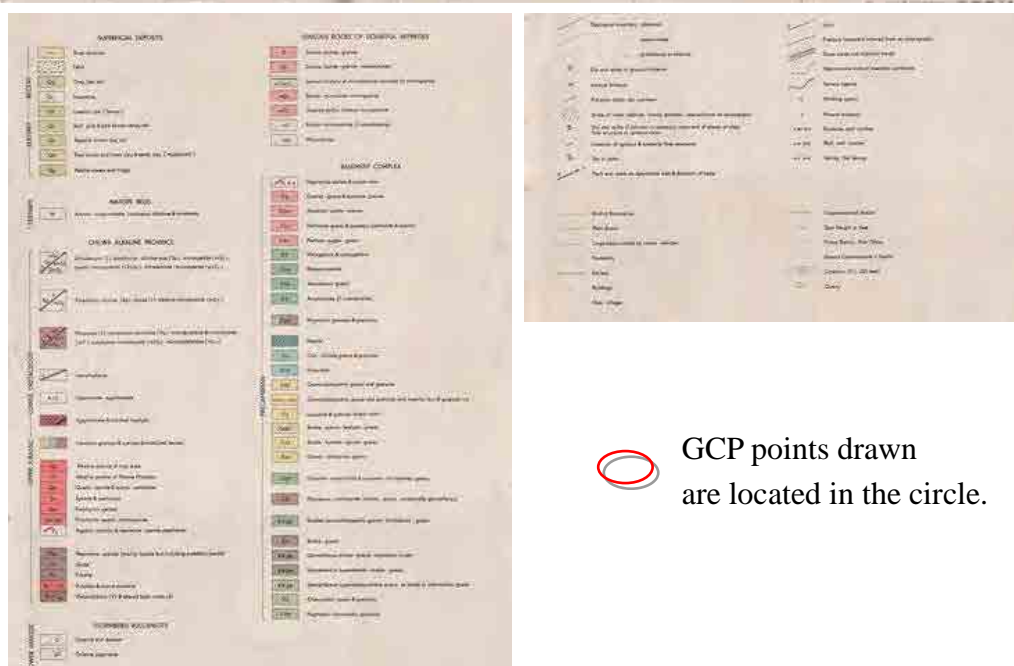
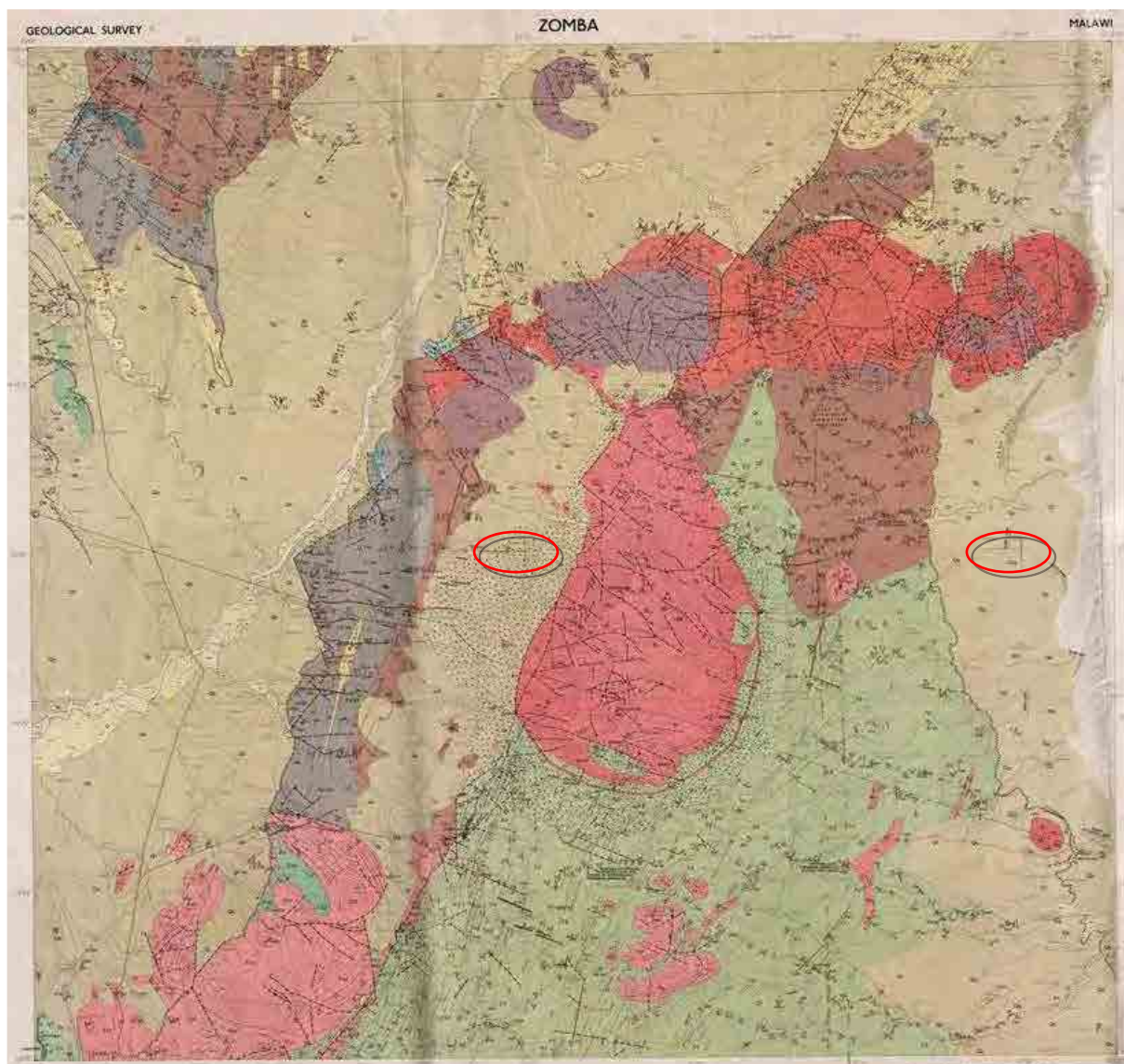


Figure 5.5 Geological map with a scale of 1/100,000 (Sheet no.16: Zomba)

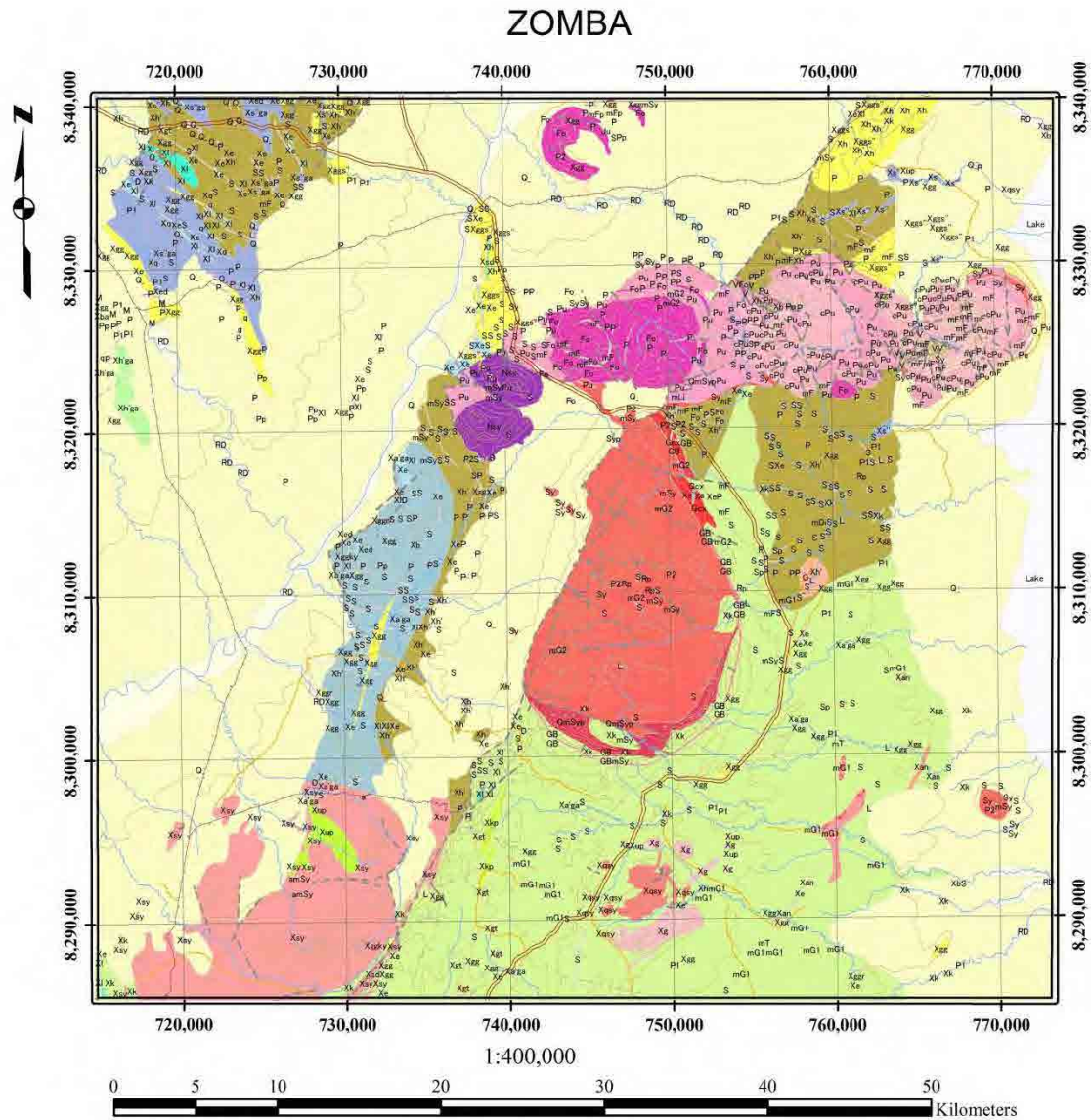


Figure 5.6 Geological map digitized on GIS (Sheet no.16: Zomba)

6. Potential of mineral resources

6.1 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 6.1.

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

6.2 Potential of mineral resources

Main mineral resources in Malawi are described in section 3.4. 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.

6.3 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 4.3.2 and Figure 4.19). 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.

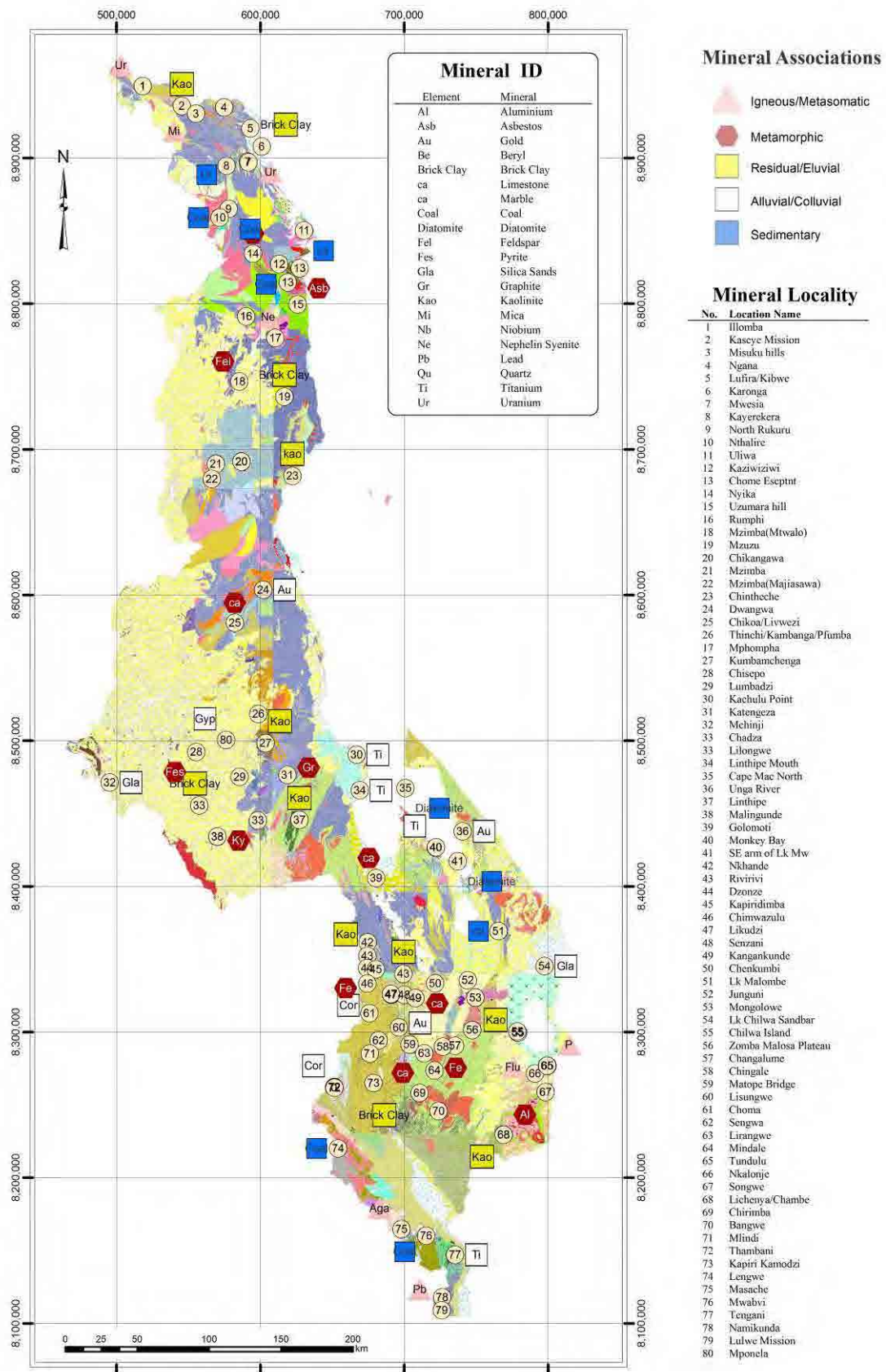


Figure 6.1 Mineral resources map

7. GIS database

7.1 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 7.1 and 7.2.

- 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

7.2 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 7.3.

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.

7.3 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 from 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.

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

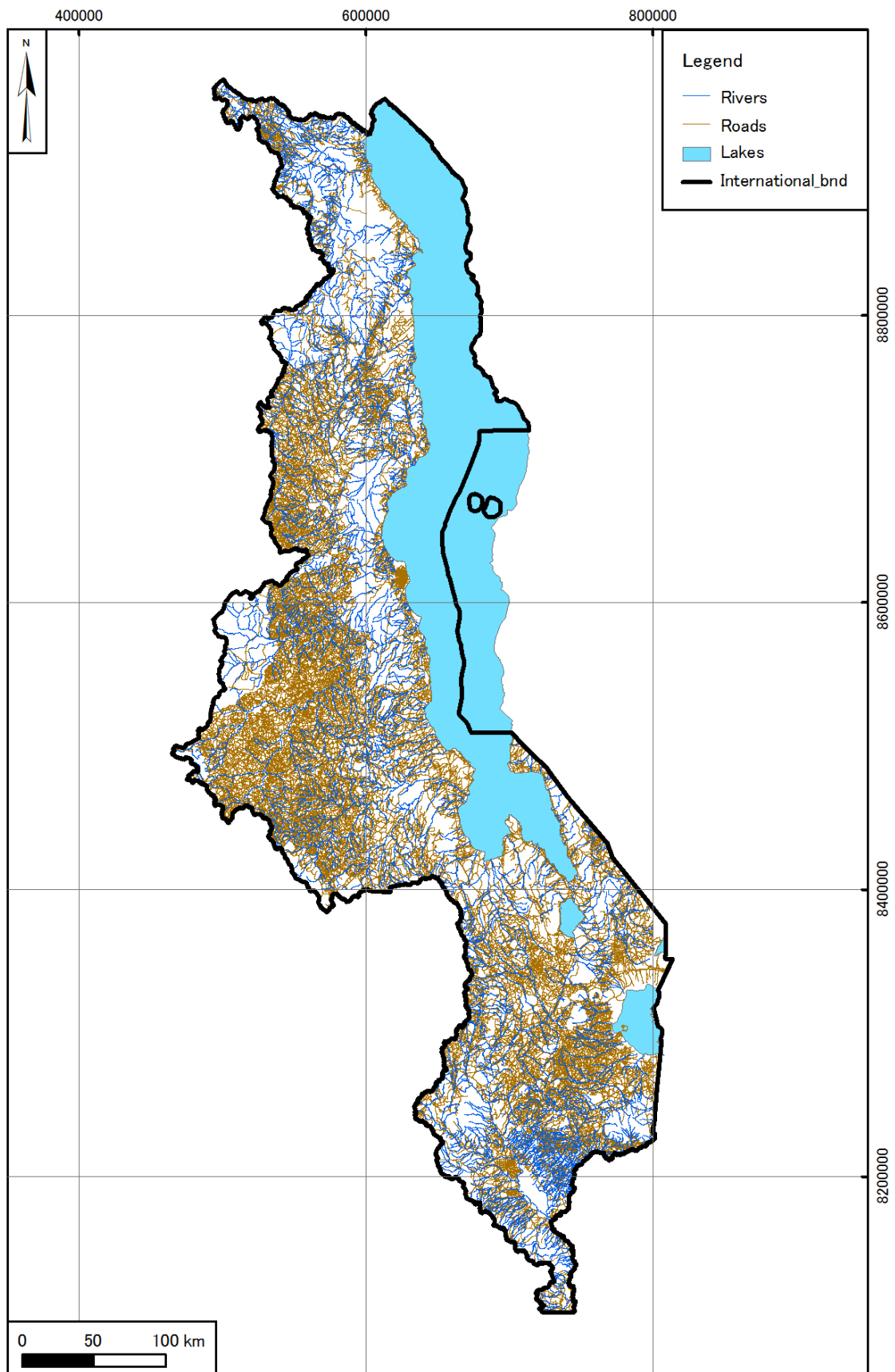


Figure 7.1 GIS map of geographic data

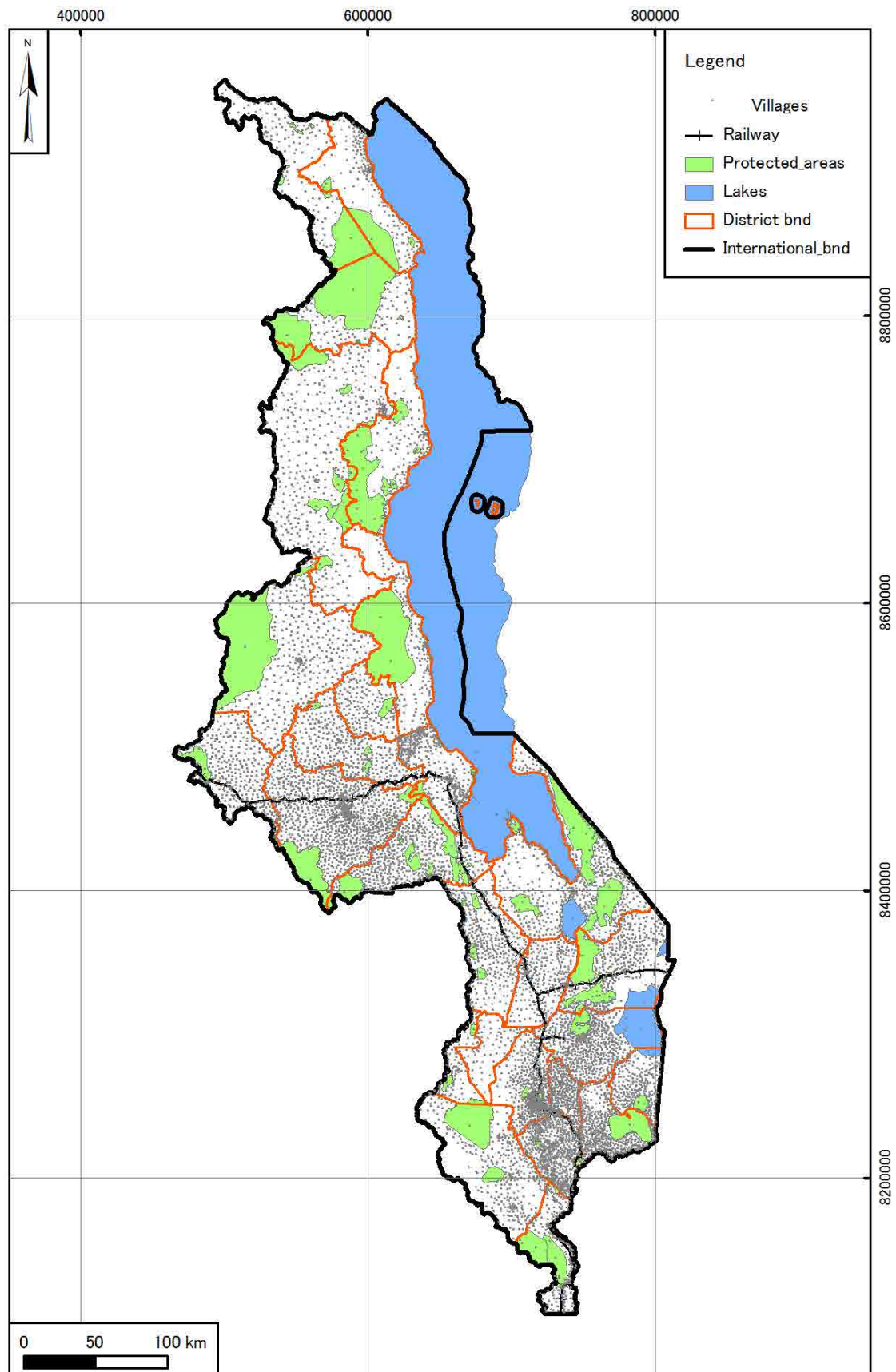


Figure 7.2 GIS map of administrative data

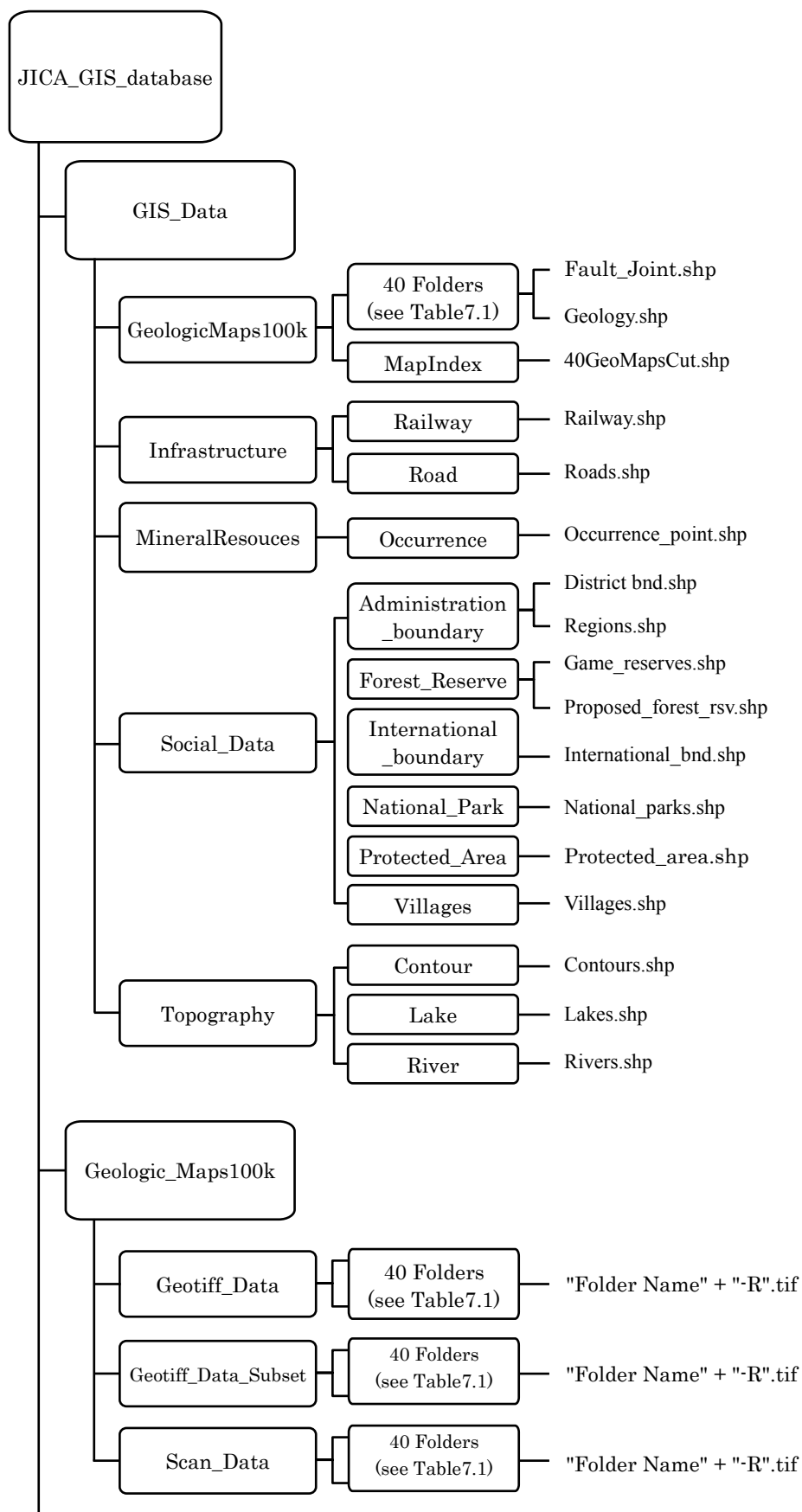


Figure 7.3 Tree directories of GIS database (1/2)

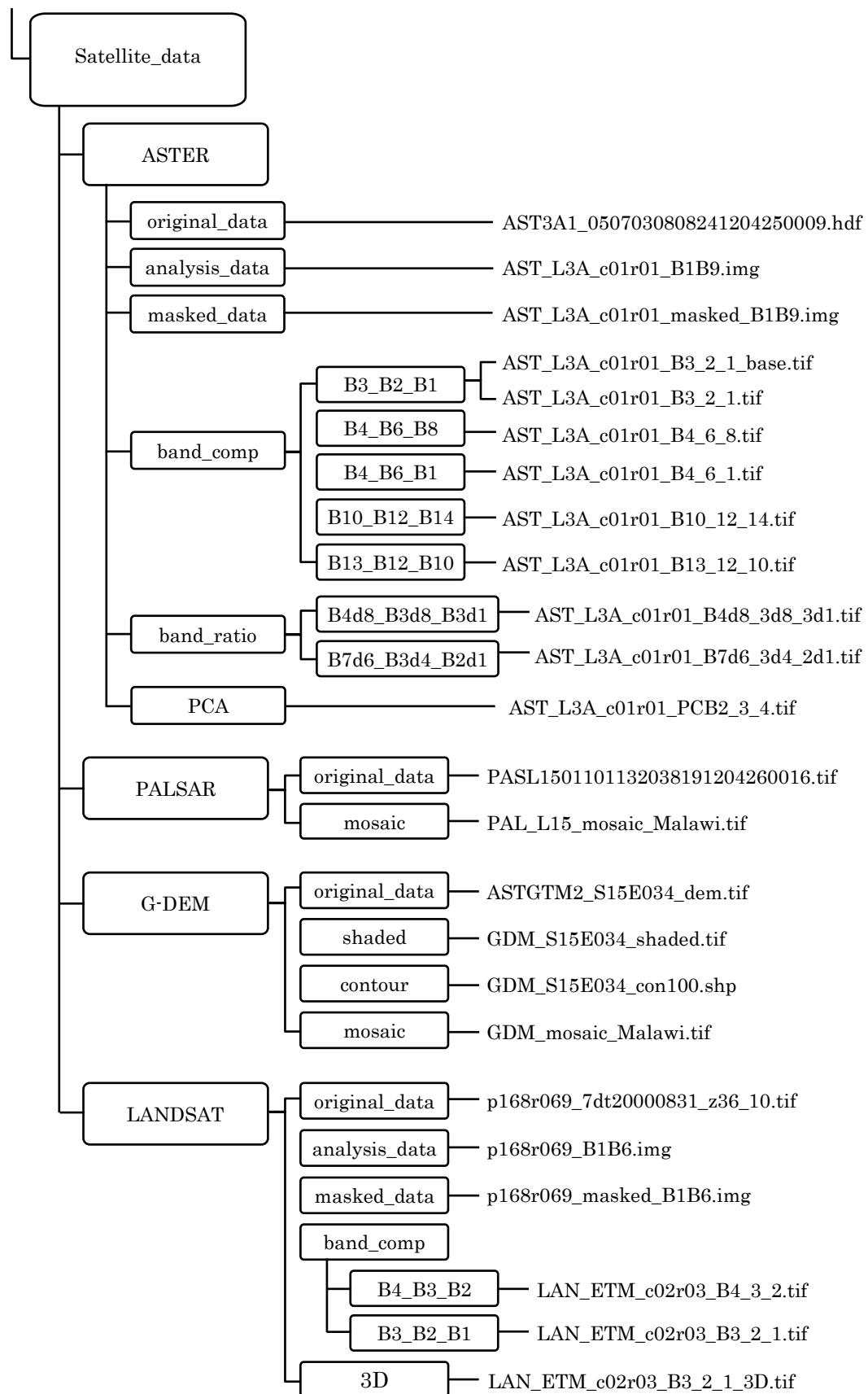


Figure 7.3 Tree directories of GIS database (2/2)

8. Personnel training

8.1 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 8.1.

Table 8.1 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

8.2 OJT of satellite data analysis

8.2.1 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.

8.2.2 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

8.2.3 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

8.3 GIS data creation

8.3.1 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.

8.3.2 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

8.4 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.

8.5 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.

8.6 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

8.7 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

8.8 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 8.1 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 8.2 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 8.3 Other photos of personnel training

9. Problems and recommendations

9.1 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.

9.2 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.

9.3 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.

10. References

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