The Federal Democratic Republic of Ethiopia
Ministry of Water, Irrigation and Electricity

THE PROJECT FOR GROUNDWATER RESOURCES ASSESSMENT IN THE MIDDLE AWASH RIVER BASIN IN THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

FINAL REPORT
GEOLOGICAL AND HYDROGEOLOGICAL MAPS

December 2015

Japan International Cooperation Agency
Kokusai Kogyo Co., Ltd.

Composition of the Report

Executive Summary

Main Report

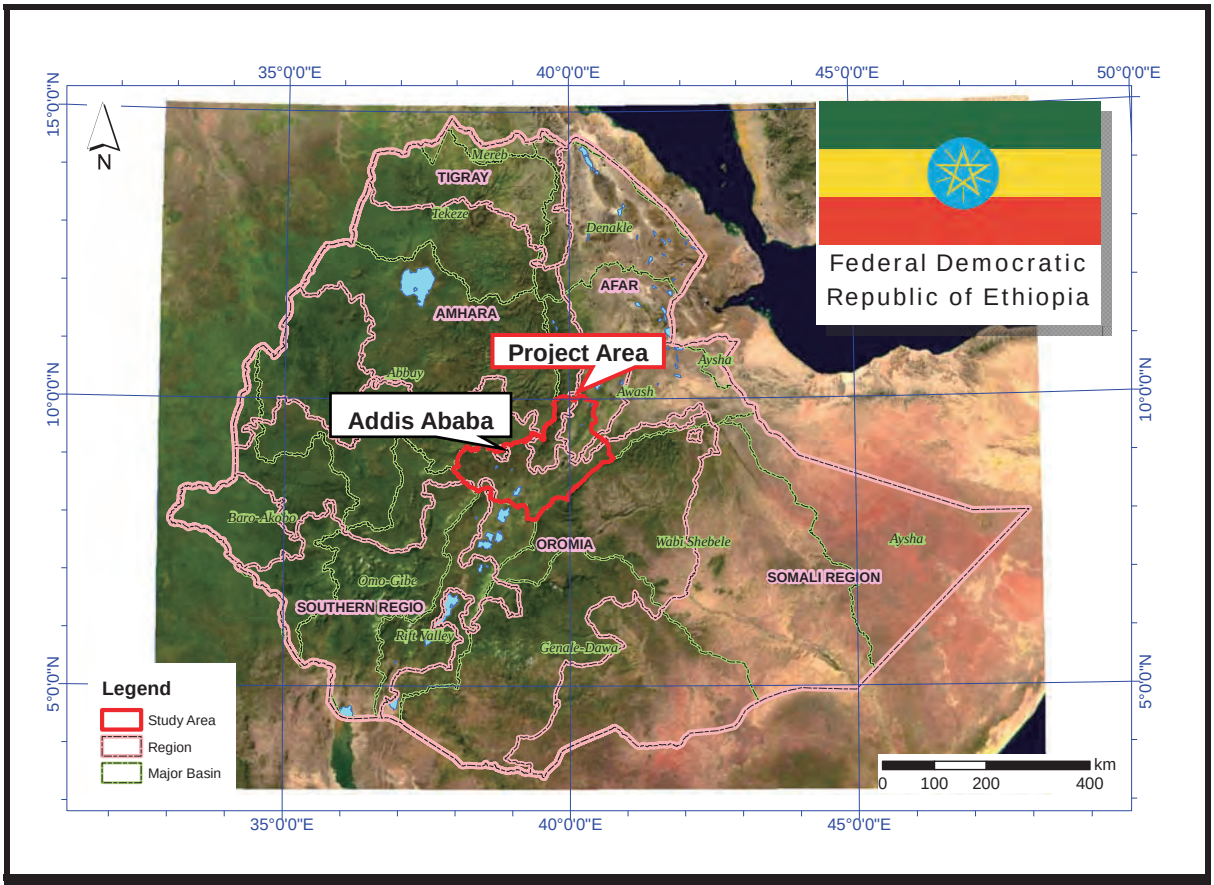
Supporting Report

Data Book

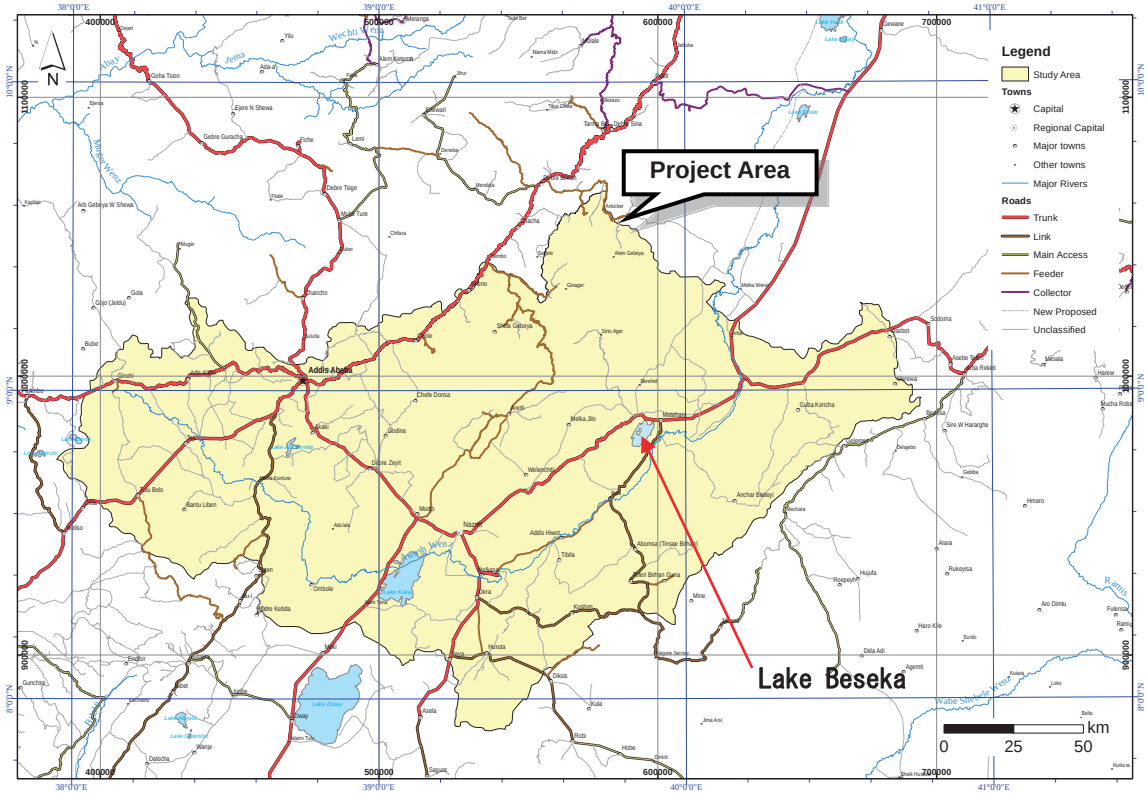
Geological and Hydrogeological Maps

This Report is prepared based on the price level and exchange rate of July 2015.
The exchange rate is:

US$1.0 = ETB20.6298 = JPY123.80



Location of the Study Area



The Middle Awash River Basin

LOCATION MAP

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Abbreviations

AAU	Addis Ababa University
AGRAP	Alidge Groundwater Resources Assessment Project
AIDS	Acquired Immune Deficiency Syndrome
ALOS	Advanced Land Observing Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTER-GDEM	ASTER-Global Digital Elevation Model
BFI	Base Flow Index
CAD	Computer Aided Design (System)
CDE	Center for Development and Environment, Ministry of Agriculture
CFC	Chloride Fluoride Carbon
CREC	China Railway Engineering Corporation
CSA	Central Statistical Agency
CSE	The Conservation Strategy of Ethiopia
C/P	Counterpart (organization or personnel)
DB	Datebase
DCI	Ductile Cast Iron
DEM	Digital Elevation Model
DF/R	Draft Final Report
DTH	Down-the-hole Hammer
DWL	Dynamic Water Level
EA	Environmental Assessment
EC	Electric Conductivity
EEPCO	Ethiopia Electric Power Corporation
EGRAP	Ethiopian Groundwater Resources Assessment Program
EIA	Environmental Impact Assessment
EIGS	Ethiopian Institute of Geological Survey, now renamed as Geological Survey of Ethiopia (GSE)
EL	Elevation
ELC	Elc electroconsult milano and Geotermica italiana pisa, Italia (an Italian Consultant)
ELSA	Equilibrium Lake Surface Area
EMA	Ethiopia Mapping Agency
ENGDA	Ethiopian National Groundwater Database
ENGWIS	Ethiopian National Groundwater Information System
EPA	Environmental Protection Agency, now renamed as Ministry of Environment and Forest (MEF)
EPC	Environmental Protection Council
ERA	Ethiopian Road Authority
ERC	Ethiopian Railway Corporation
ESA	Ethiopian Standard Agency
ESIA	Environmental and Social Impact Assessment
ET	Evapotranspiration
EWCA	Ethiopian Wildlife Conservation Authority
EWTEC	Ethiopia Water Technology Center, now renamed as Ethiopia Water Technology Institute (EWTI)
EWTI	Ethiopia Water Technology Institute, formerly known as Ethiopia Water Technology Center (EWTEC)
F/R	Final Report
FAO	Food and Agriculture Organization of the United Nations
FAO-AGLW	FAO Water Resource, Development and Management Services

FDM	Finite Difference Method
FEM	Finite Element Method
GD	Groundwater Directorate (of MoWIE)
GDP	Gross Domestic Product
GHB	General Head Boundary
GIS	Geographical Information System
GL	Ground Level
GNI	Gross National Income
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
GSP	Galvanized Steel Pipe
GTP	Growth and Transformation Plan
GWR	Groundwater Recharge
HIV	Human Immunodeficiency Virus
IAEA	International Atomic Energy Agency
IC/R	Inception Report
IEE	Initial Environmental Examination
IMF	International Monetary Fund
INGEIS	Instituto de Geocronología y Geología Isotópica (Institute of Geochronology and Geology, Argentine)
ISO	International Standard Organization
ISODATA	The Iterative Self-Organizing Data Analysis Technique
IT/R	Interim Report
ITCZ	Inter-tropical Convergence Zone
JICA	Japan International Cooperation Agency
LEL	Local Evaporation Line
LMWL	Local Meteoric Water Line
M&E	Monitoring and Evaluation
M/M	Minutes of Meeting
MCM	Million Cubic Meter
MDGs	Millennium Development Goals
MEF	Ministry of Environment and Forest, formerly known as Environmental Protection Agency (EPA)
MER	Main Ethiopian Rift
MOA	Ministry of Agriculture
MoWR	Ministry of Water Resources, now renamed as Ministry of Water, Irrigation and Electricity (MoWIE)
MoWE	Ministry of Water and Energy, now renamed as Ministry of Water, Irrigation and Electricity (MoWIE)
MoWIE	Ministry of Water, Irrigation and Electricity, formerly known as Ministry of Water, Irrigation and Energy(MoWIE), Ministry of Water and Energy (MoWE) or Ministry of Water Resources (MoWR)
MSE	Metehara Sugar Estate
MWL	Meteoric Water Line
NASA	National Aeronautics and Space Administration, USA
NGI	National Groundwater Institute
NGO	Non-Governmental Organization
NMA	National Meteorology Agency
OLEPB	Oromia Land and Environmental Protection Bureau
ORP	Oxidation and Reduction Potential
O(R)WMEB	Oromia (Regional) Water, Material and Energy Development Bureau
OWNP	One WASH National Program
OWWDSE	Oromia Water Works Design and Supervision Enterprise

P/R	Progress Report
PA	Preliminary (Environmental) Assessment
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
PC	Personal Computer
PPP	Purchasing Power Parity
PRSP	Poverty Reduction Strategy Paper
PVC	Polyvinyl Chloride
R/D	Record of Discussions
REA	Regional Environmental Agencies
RESTEC	Remote Sensing Technology Center of Japan
RVLB	Rift Valley Lakes Basin
SC	Steering Committee
SCM	Steering Committee Member or Steering Committee Meeting
SDPRP	Sustainable Development and Poverty Reduction Program
SEA	Strategic Environmental Assessment
SFGS	Streamflow Gauging Station
SP	Spontaneous potential
SPOT	Satellite Pour l'Observation de la Terre (French Satellite for Earth Observation)
SRTM	Shuttle Radar Topography Mission
SS	Suspended Solids
TDS	Total Dissolved Solids
TEM	Transient (or Time-domain) Electromagnetic Method
TIR	Thermal Infrared
TM	Thematic Mapper
TOR	Terms of Reference
TU	Tritium Unit
TWSSO	Town Water Supply Service Office
TWSSSE	Town Water Supply and Sewerage Service Enterprise
UAP	Universal Access Program
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children’s Fund
uPVC	Unplasticized Polyvinyl Chloride
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
UTM	Universal Transversal Mercator
VES	Vertical Electrical Sounding
VIP	Ventilation Improved Pit
WASH	Water Supply, Sanitation and Hygiene Program
WB	World Bank
WC	Water Committee
WFB	Wonji Fault Belt
WHO	World Health Organization
WSDP	Water Sector Development Program
WSSM	Water Supply and Sanitation Master Plan
WWDSE	Water Works Design and Supervision Enterprise
WWMEO	Woreda Water, Mineral and Energy Office
ZWMEO	Zonal Water, Mineral and Energy Office

Chapter 1

Survey Summary

1 Survey Summary

1.1 Objective and area of the project

a. Objective of the project

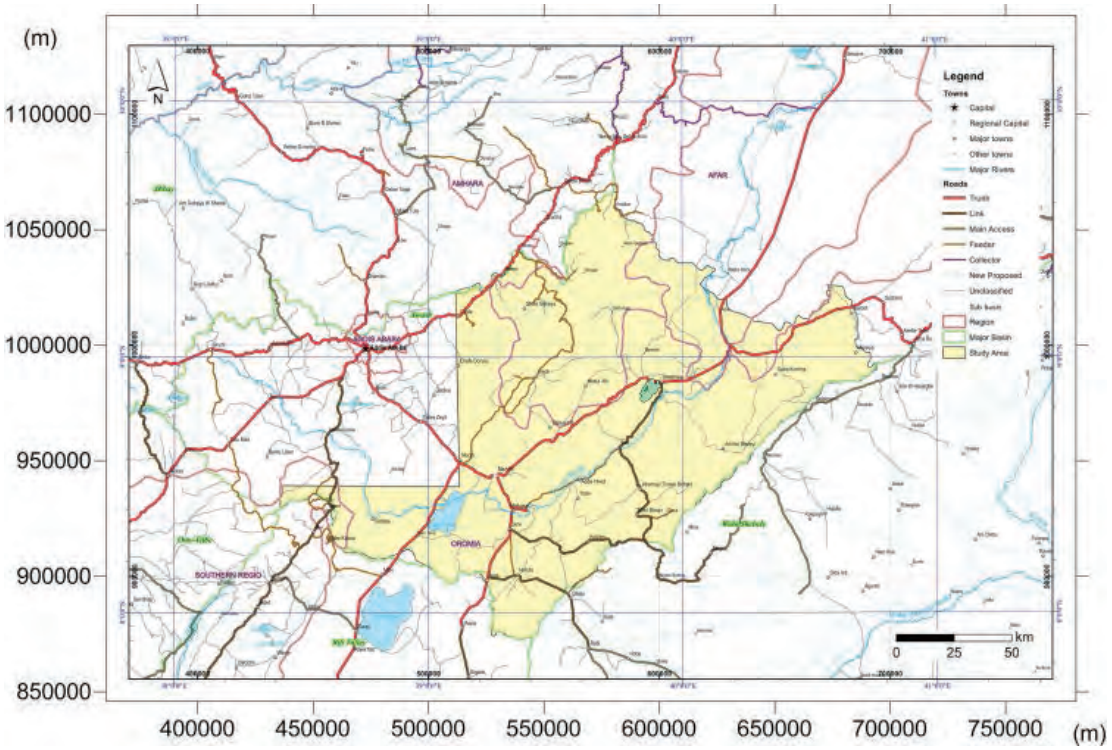
The geological and hydrogeological study was executed as a part of the Project of "Groundwater Resources Assessment in the Middle Awash River Basin in the Federal Democratic Republic of Ethiopia (hereafter, the Project)" based on the results of the record of discussions (R/D) agreed and signed by the Federal Democratic Republic of Ethiopia and Japan International Cooperation Agency (JICA) on 27 May 2013. The objective of this geological and hydrogeological study is to create the geological map and hydrogeological map in the Middle Awash River Basin based on the results of the analysis of geology, hydrogeology, and water quality and to discuss the groundwater potential through the use of the geological and hydrogeological map.

b. The Project schedule

The Project started in May 2013 and was confirmed to end in December 2015.

c. Area of the Project

The area of approximately 20,000km^2 in the Middle Awash River Basin covered by the geological and hydrogeological maps is shown in Figure 1.1.1 below;



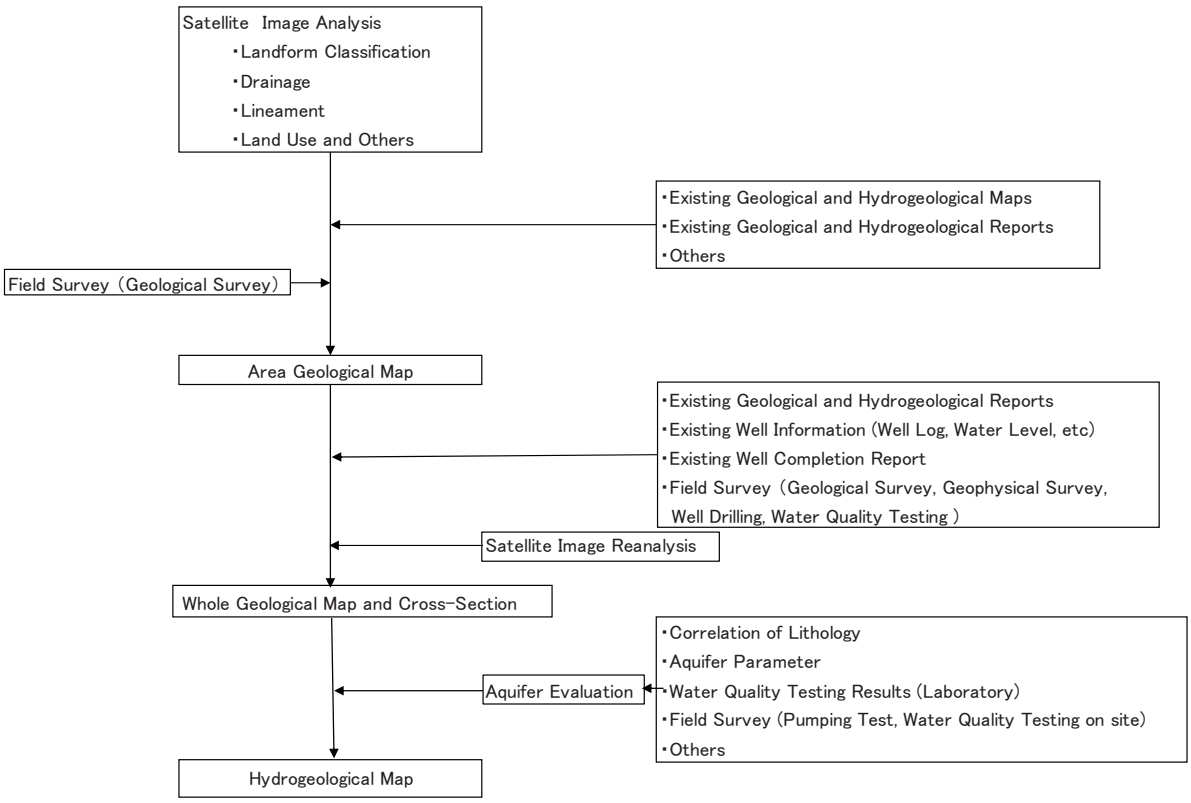
Source: the Project Team, Data: Production by Project member

Figure 1.1.1: Area Covered by the Geological and Hydrogeological Maps

1.2 Methodology of the Project

a. The Project flow

The Project flow was shown in the following Figure 1.2.1; The geological and hydrogeological maps were created mainly by five works, namely satellite image analysis (for example land classification, lineament analysis), classification of geological units based on the existing geological maps and reports, geological field survey, arrangement of existing well data, and evaluation of hydrogeological units.



Source: the Project Team, Data: Production by Project member

Figure 1.2.1: The Project Flow

b. Satellite image analysis

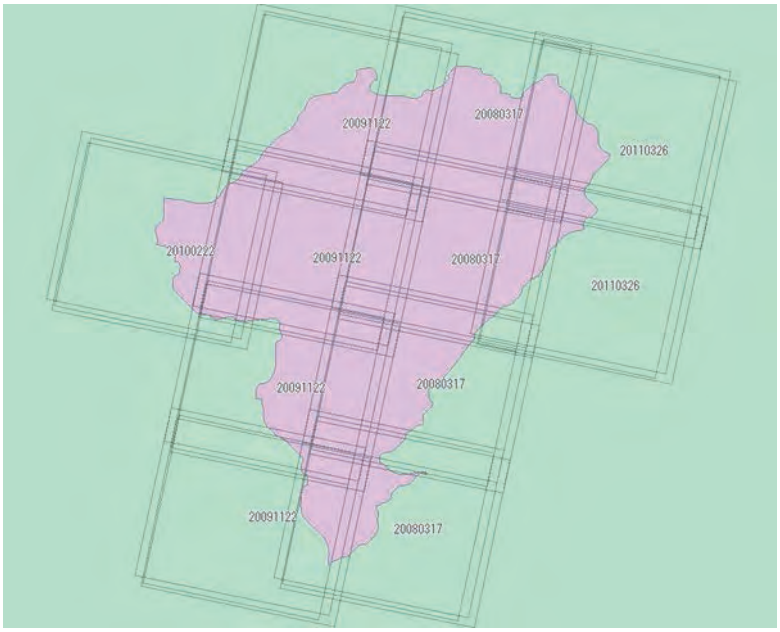
b.1 Satellite image

The interpretation of surface information on satellite imagery to grasp the volcanic geographical condition and geological structure for the basic data of hydrogeological condition was conducted using the following satellite imagery (refer to Table 1.2.1).

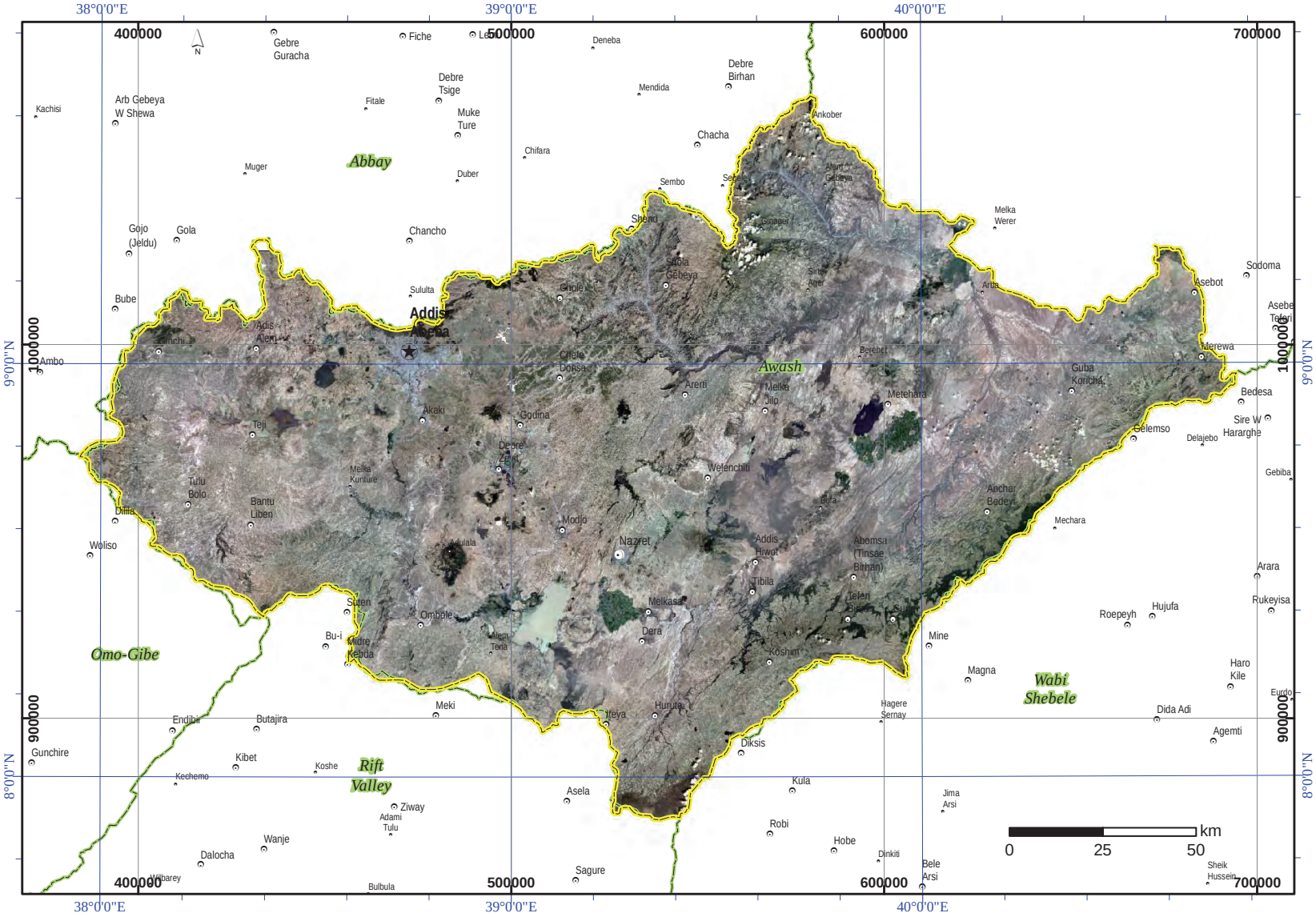
Table 1.2.1: Satellite Image for Interpretation

Satellites	Shooting data and information	Main purpose
SRTM	1994-, resolution, 30m	Extract DEM to create contours
SPOT	2006-2007, Pacromatic, 0.5m resolution	（high accuracy）, Lineament, Geological structure, Topography, Vegetation, Collection of land use information
ASTER	2006, 3 bands, ortho-rectified	Extract DEM, Interpretation on 3D model
ALOS	2008-2011,resolution, 10m	Elevation map, Hydrology information map, Wide-area topography, vegetation, Collection of land use information

（ALOS: Purchasing area for the shooting and shooting data）

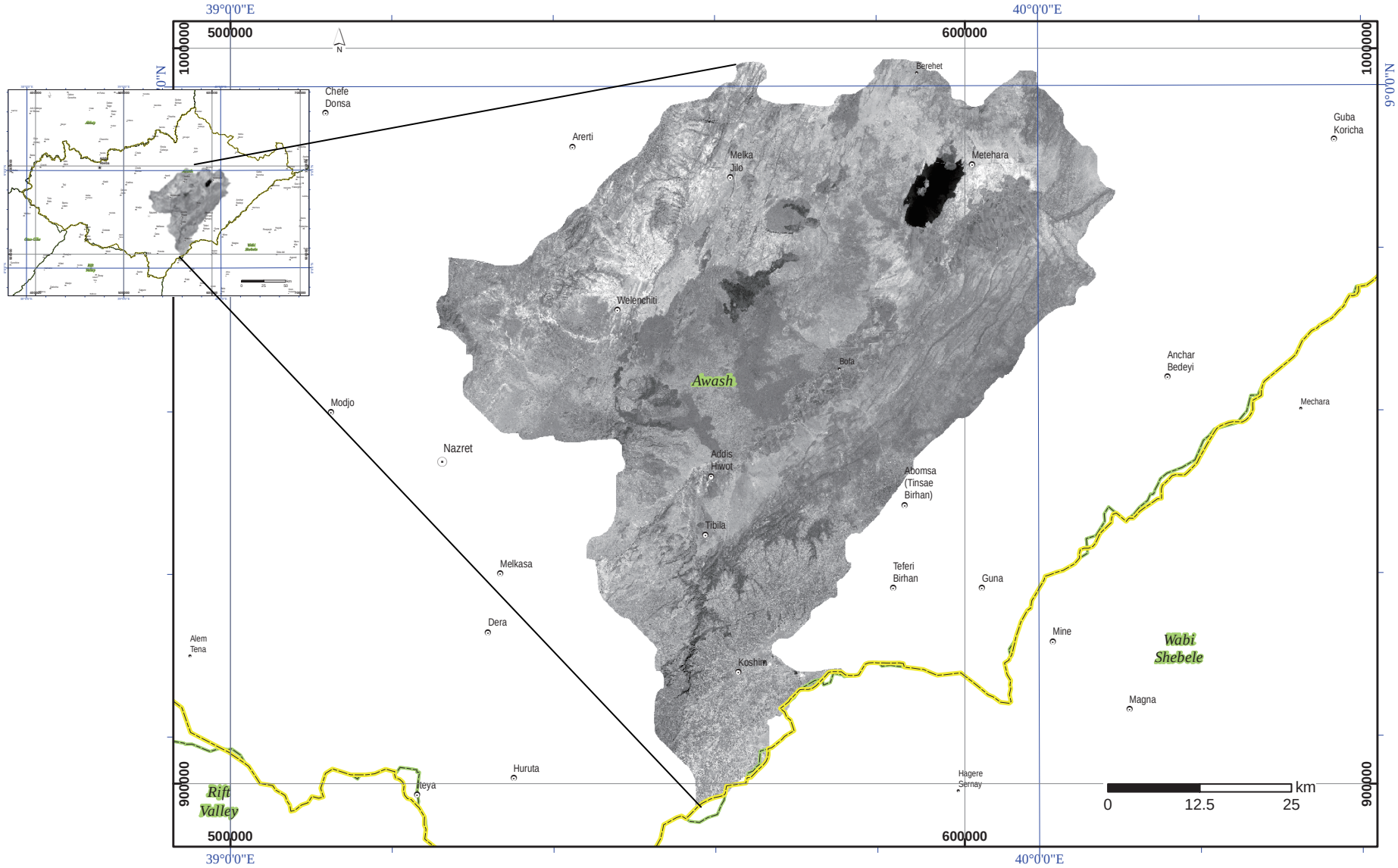


The SOPT and ALOS satellite imagery have been shown in Figure 1.2.2 and Figure 1.2.3.



Source: the Project Team, Data: SPOT

Figure 1.2.2: SPOT Satellite Image



Source: the Project Team, Data: ALOS

Figure 1.2.3: ALOS Satellite Image

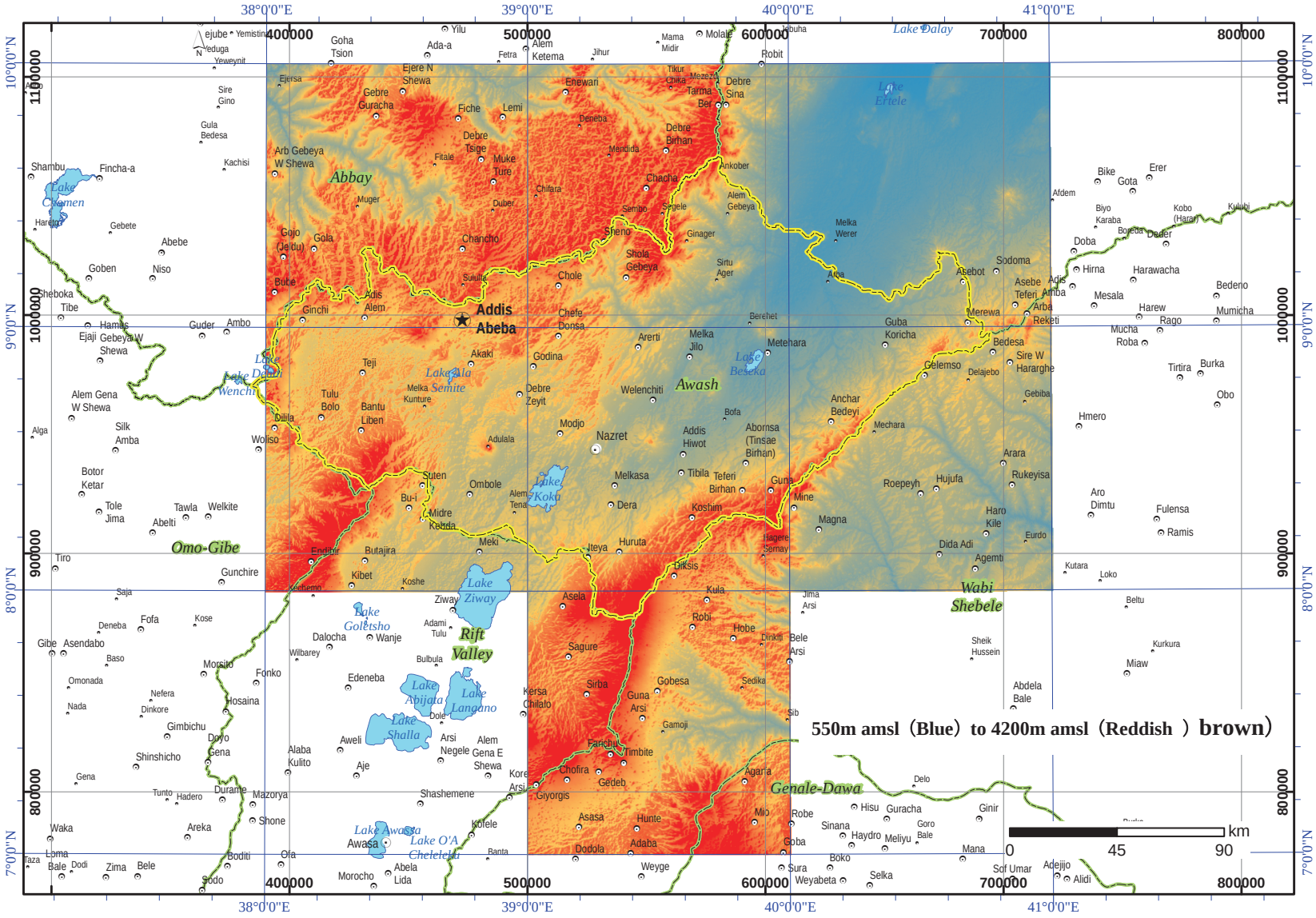
c. Surface interpretation

The Digital Elevation Model (DEM) has been generated from the SRTM for shaded relief model and Aster Satellite imagery (refer to Figure 1.2.4). The data has been applied to create contours and shaded relief model to understand the surface characteristics of the Study area. The shaded relief model has been utilized to assess the lineaments and other geomorphological marks (such as volcanic craters and bodies) to support the structural evidence in relation to its geological setting and history. The major faults, lineaments and volcanic topographic aspects are presented in Figure 1.2.5 for using the shaded relief model, SPOT and ALOS imageries.

The geological structures in this area are characterized by the MER distributed from Rift Valley Lakes Basin (hereafter refer to as “RVLB”) and the Southern Afar Rift lied next to the northeast of the MER. The MER extends from the southern Afar margin to the Lake Chamo area in RVLB, whereas the South-western Ethiopian Rift (hereafter refer to as “SWR”) is located to the west and represents roughly N-S trending basins related to the Kenya Rift. The Gregory rift of Kenya links to the north with Chew Bahir rift. In accordance with Halcrow 2008, the character of the faults in the two rifts is explained

In a large sense, the central MER direction has been changed from NNE-SSW in the southwest Study area to NE-SW in the main Study area, and the western and eastern rift escarpment run in NE-SW direction (refer to Figure 1.2.5).

This area is called as northern MER, and the northern MER continues to run to the south Afar Rift in NE-NNE direction. The east rift escarpment come to the rift floor as the step faults in the east rift of the Study area, but the west escarpment is unclear. The rift floors, plain area bounded by the both side escarpment, lie in the grabens from the northern part of RVLB to the northeast of the Study area. The scablands have distributed continuously in the rift floor, and runs to the south Afar Rift. These volcanic bodies have lined from the Corbetti, Aluto volcanos (the Aluto is active volcano) in the central MER of RVLB to the Tullu Move, Gedemsa, Boset, Kone and Fantale volcanoes in NE-SW direction in the eastern MER, and have accompanied with caldera and rhyolitic pyroclastic flows largely. There are lots of scoria pyroclastic cones in surrounding volcanic lines. The floor of northern MER is dissected by clear, fresh NE-SW to NNE-SSE trending faults known as the WFB, and WFB can be traced to the southern Afar Rift.



Source: the Project Team, Data: ASTER

Figure 1.2.4: ASTER DEM

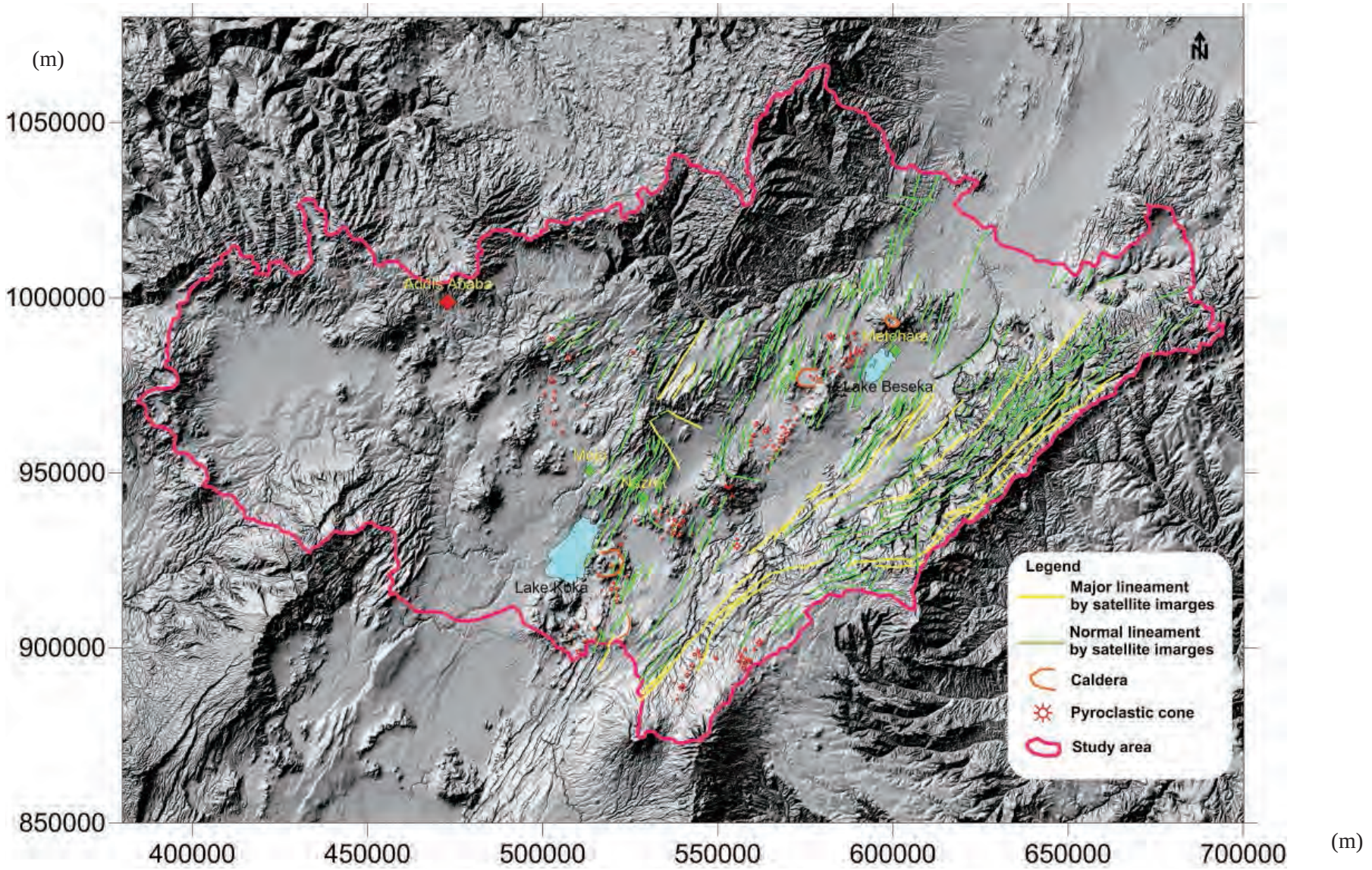


Figure 1.2.5: Topographical Information Map by Satellite Images

Source: the Project Team, Data: SRTM+ Result of survey in this project

d. Creating of the geological map

The main existing geological maps in the Project area and its surrounding areas are as follows;

- Geological map of Nazret, Ethiopian Institute of Geological Surveys (EIGS), 1978
- Geology and Developing of the Nazret area, northern Ethiopia rift, Kazmin etc. EIGS 1978
- Geological map of Dire Dawa, EIGS, 1985
- Geological map of Debre Birhan, Geological Survey of Ethiopia (GSE), 1993
- Geology of Debre Birhan area, Daniel Mesheha etc. compiled, GSE, 2010
- Geological map of Akaki Beseka area, GSE, 1997
- Geology of Akaki Beseka, Efrem Beshawered compiled, GSE, 2010
- Geology of Addis Ababa map sheet, GSE, 1997
- Geology of Addis Ababa city, Getahun assigned, GSE, 2007

A reliable hydrogeological map was created based on a detailed geological map. Therefore, in the preliminary survey of geology in the field, the middle Awash River Basin was divided into four areas in accordance with the aspects of geology and distribution. The strata of each area were correlated based on the specific geology (a key bed), and the correlation chart was described. Finally, the stratigraphy in the entire area was created and the geological map was completed in the middle Awash River Basin (Map scale of 1:250,000 in the entire area and 1:100,000 in Lake Beseka area).

Chapter 2

Summary of Geography and Geology

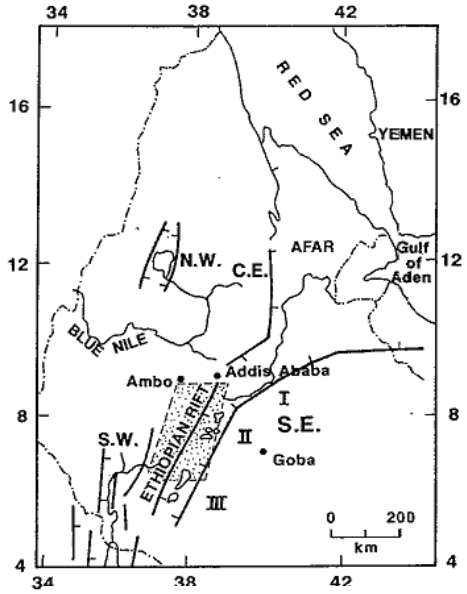
2 Summary of Geography and Geology

2.1 Summary of geography

a. Landform

The Study area is located in the northern sector of the Main Ethiopian Rift (hereafter referred to as "MER"), and the Study area of the northeast broadens northward into the Afar Rift (refer to Figure 2.1.1: Ⅰ: Northern; Ⅱ: Central and Ⅲ: Southern of MER respectively). The geological tectonic direction in the rift escarpment of MER has been changed from NE-SW to ENE-WSW between Ⅱ and Ⅰ (refer to Figure 2.1.1), and it made an aperture at the Aden junction in the Afar Rift.

The Study area is bounded by the western rift escarpment along the northwest highlands heading towards Addis Ababa, and the altitude of the highlands ranges from 1500m to 2600m above mean sea level (hereafter refer to as "amsl"). The graben in MER runs in NE-SW direction. The altitude of the lowlands in the Study area changes from 1750m amsl of Tuluri Mountain in the southeast, to 1000m amsl at Awash area in the east. The rift floors are subjected to recent volcanic activities from Moye volcano (altitude 2349m amsl) in the southwest, to Fantale volcano (altitude 2007m amsl) in the east. In between of the two volcanoes, several volcanoes and pyroclastic cones are distributed continuously. In Arsi zone, located in south and southwest in the Study area, the rift escarpment is located between the central rift of MER to the west and the Arsi plateau to the east. The altitude of this escarpment ranges from 1500m amsl to 2500m amsl. The Arsi plateau bounded by the lowland in the east and the altitude of the lowland changes from 1000m to 1900m amsl. The Arsi plateau elevation ranges from 2000m amsl at Sire to 3625m amsl at Arba Gugu Mountain.



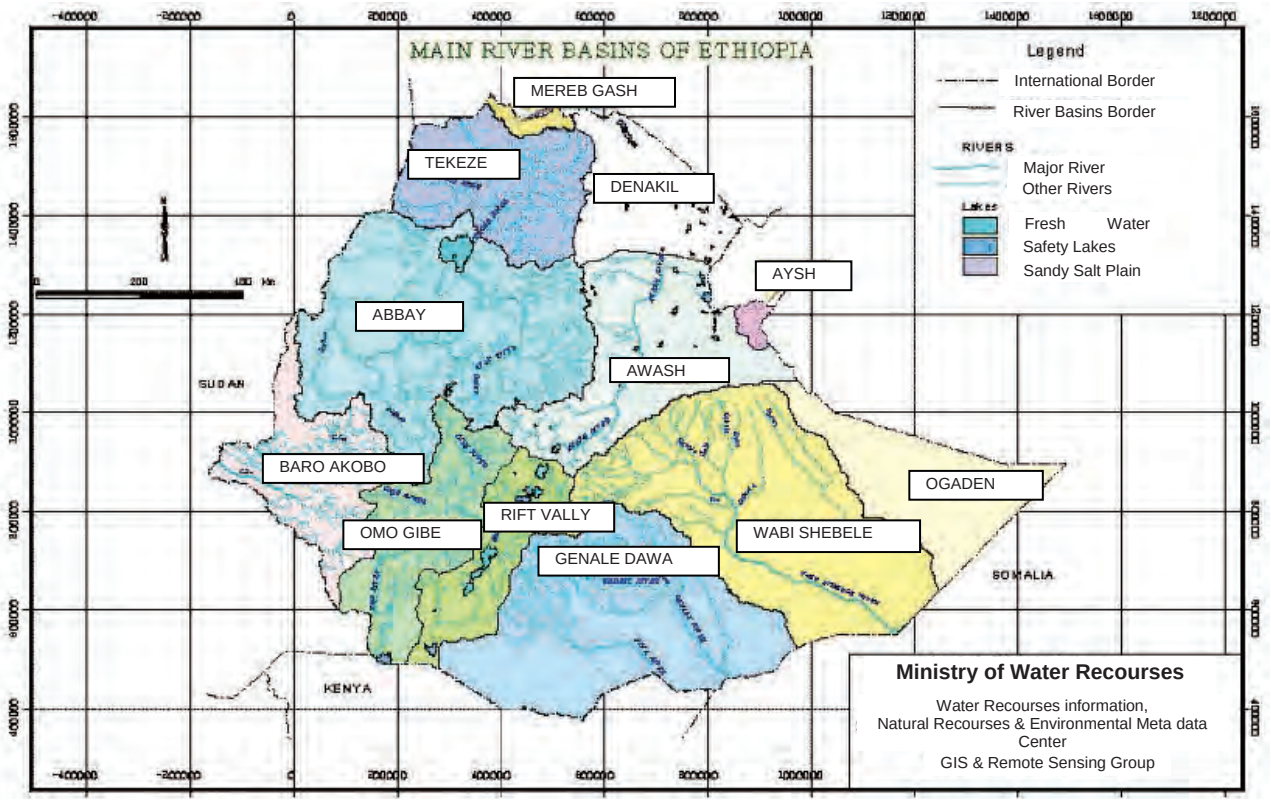
Source: G. Woldegabriel, 1990

Figure 2.1.1: The Central Sector of the MER

b. Watershed classification

In Ethiopia, there are 12 major basins and each is subdivided into minor sub-basins (divided by the Ministry of Water Resources (hereafter refer to as "MoWR") (old name) refer to Figure 2.1.2). The Study area lies next to the northeast of Rift Valley Lakes Basin and the topographical elevation decreases toward the northeast in general. The Awash River flows

toward the northeast, in which direction the elevation of topography also decreases, and its flow direction changes to the north in its middle area.



Source: Ministry of Water, Irrigation and Electricity: MoWIE

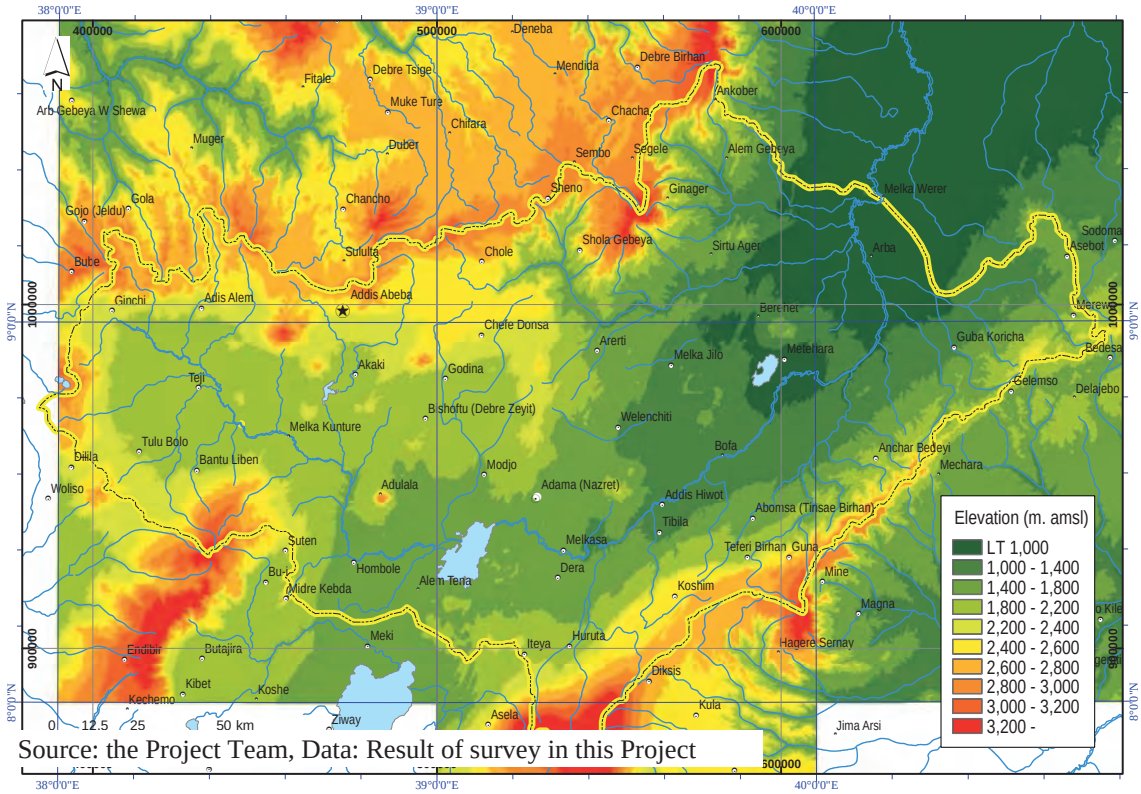
Figure 2.1.2: Major Basins in Ethiopia

c. Hydrographic system

The Awash River source is Mt. Warque in the west of Addis Ababa. The river runs toward south-eastern direction for around 130 km and then changes its direction to the northeast at around Mt. Zuqualla. After passing through the Awash National Park, the Awash River is being joined by the Kesem River, the biggest tributary, from its left bank side. The river finally flows into Lake Abbe located on the national boundary with Djibouti. Since Lake Abbe has no water outfall, the Awash River Basin forms a closed water area. The total length of the Awash River is 1,200 km and the total catchment area is 112,700 km^2.

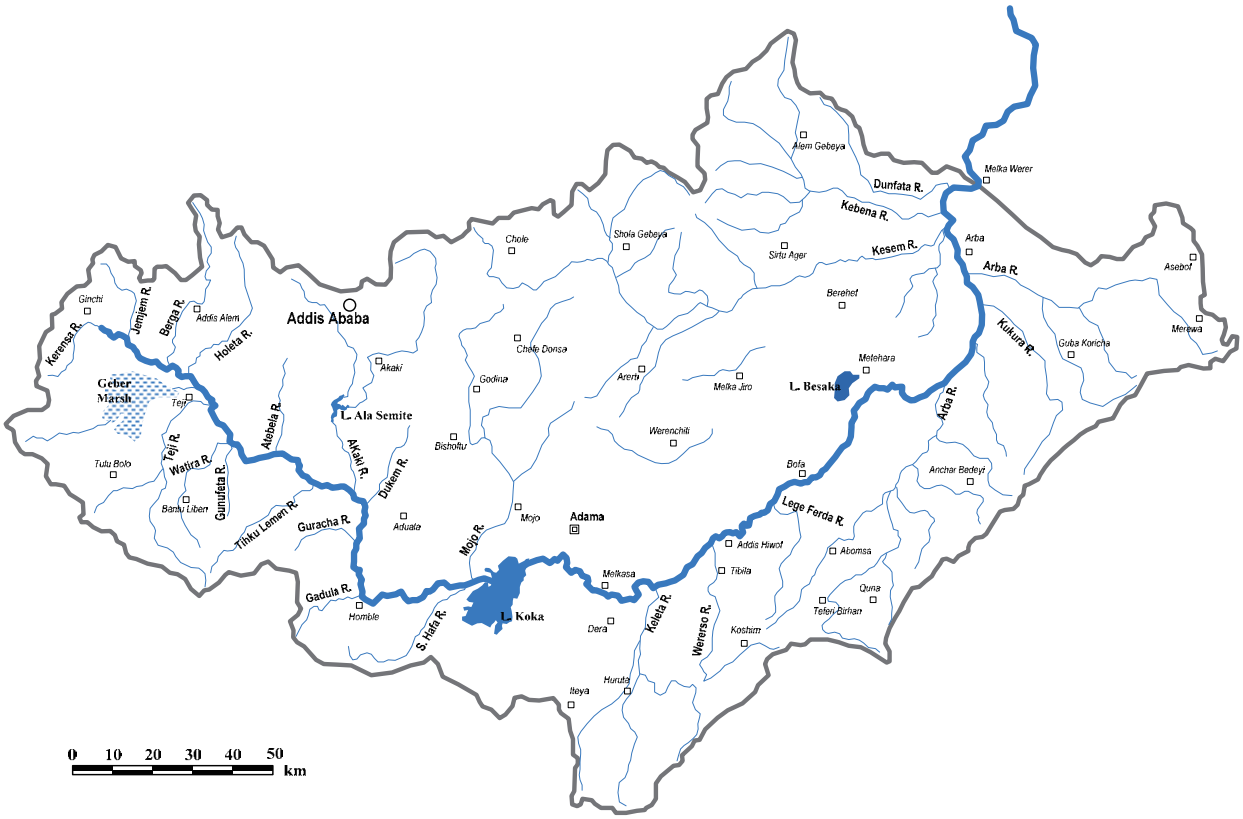
The Middle Awash River Basin is defined by the Ministry of Water, Irrigation and Energy (MoWIE) as the watershed area upstream Melka Werer town in Afar Region. Total catchment area of the Middle Awash is 29,280 km^2 according to the measurement by the JICA Study Team with available Digital Elevation Models (DEMs). The length of the Middle Awash reaches around 380 km.

General topographic view and river system of the Middle Awash River Basin are shown in Figure 2.1.3 and Figure 2.1.4, respectively.



Source: the Project Team, Data: Result of survey in this Project

Figure 2.1.3: Digital Elevation Model of the Middle Awash River Basin



Source: the Project Team, Data: Result of survey in this Project

Figure 2.1.4: River System of the Middle Awash

2.2 Regional geological and tectonic setting

a. Regional geological setting

The study area belongs to northern part of the **Main Ethiopian Rift (MER)**. MER developed over a span from the Oligocene to the Quaternary. During that period, major volcanic episodes are recognized in Oligocene, middle Miocene, late Miocene, early-middle Pleistocene and Holocene (WoldeGabriel et al. 1990). An overview of the history of MER development is as follows;

The oldest volcanic activities are basalt and rhyolite flows in Oligocene, exposed in and around the rift margins (e.g. Blue Nile gorge), which formed lava plateau in the surrounding area. By middle Miocene, the rift was formed in some parts with containment basaltic flows. In Pliocene, a huge pyroclastic flow covered the northern part of study area. This characteristic pyroclastic flow deposit is currently observed at the depth of around 2100m in the basin floor by geothermal well, indicates a minimum of 2km of downthrown in the rift basin since its eruption (WoldeGabriel et al. 1990, WoldeGabriel et al, 2000).

In Pleistocene, Wonji Fault Belt (WFB), which is the main spreading axis of MER, is formed at the rift floor, and floor basalt and rhyolite are erupted along WFB. The volcanic activities are characterized by peralkaline fissure basaltic eruptions and rhyolitic eruptions which make volcanoes and calderas. MER was formed as symmetrical depression zone in this period and many lakes appeared and disappeared by obstruction of volcanic deposit and/or climate change.

b. Regional tectonic setting

The initial stage of MER formation is closely related to that of the Red Sea and Aden Sea. In Mesozoic time, north – central MER was bulged. That is deduced by the existence of thick Mesozoic sediments in Kella horst (North of Butajira) and the Blue Nile gorge.

In Oligocene, large and huge volcanic activity created a lava plateau. In early Miocene, three radial rifts might have been formed in the plateau. After that, two rifts spread open and were downthrown to the sea, which became the Red Sea and Aden Sea. The other rift, which was not spread well, became the MER.

Such kind of tectonic activity is considered to have occurred in the initial stage when the continent started splitting, and caused by rising of hot plumes from the mantle (refer to Figure 2.2.1).

Structural and stratigraphic relations of volcanic rocks along both rift escarpments of MER indicate a two-stage rift development. The early phase started during late Oligocene – early Miocene and was characterized by a series of alternating and opposed half grabens. The half-grabens evolved into a symmetrical rift during the late Miocene. The area also was characterized by active rifting during Plio-Pleistocene, around 2000m of subsidence was estimated (WoldeGabriel et al, 1990).

The rift floor is nowadays covered by lakes, lacustrine sediments, basalts from fissure eruptions, and silicic tephra from the nearby Quaternary volcanoes.

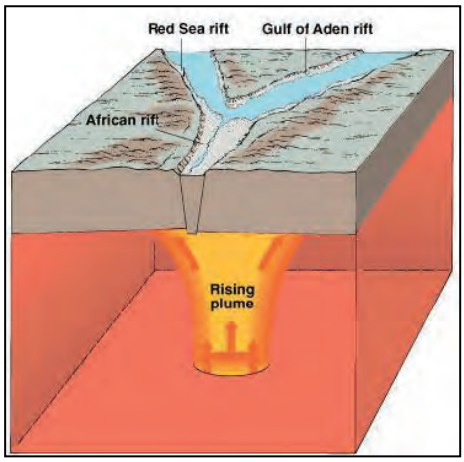


Figure 2.2.1: Schematic Diagram for Development of Red Sea Rift and Aden Sea Rift, and failed African Rift (MER), (Source: http://www3.interscience.wiley.