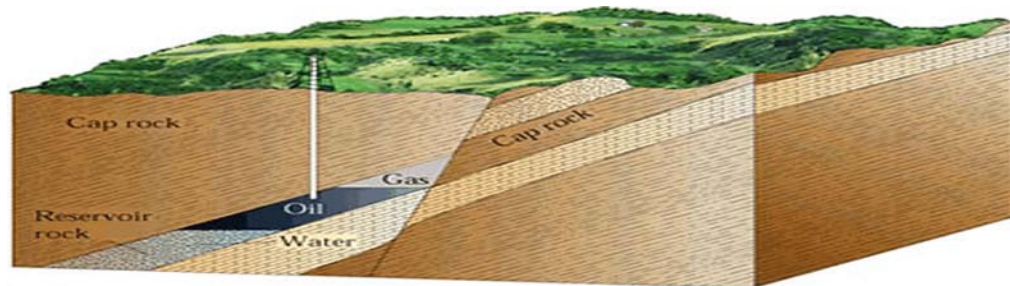


Addis Ababa
University
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APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM FOR PETROLEUM EXPLORATION IN OGADEN BASIN: ETHIOPIA



**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
SCIENCE IN REMOTE SENSING AND GEOGRAPHIC INFORMATION SYTEM**

**BY
BERESSA EDESSA
July, 2008**

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
SCIENCE FACULTY
DEPARTMENT OF EARTH SCIENCES**

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INFORMATION SYTEM**

**July 2008
Addis Ababa, Ethiopia**

DECLARATION

I hereby declare that the thesis entitled “APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR PETROLEUM EXPLORATION IN OGADEN BASIN: ETHIOPIA” has been carried out by me under the supervision of Dr. Bekele Abebe from the Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2007-2008 as a part of Master of Science program in Remote Sensing and Geographic Information System. I further declared that this work has not been submitted to any university or Institution for the award of any Degree. All sources of material used for the thesis have been duly acknowledged.

Place: Addis Ababa University, School of Graduate Studies, Addis Ababa, Ethiopia

Date: July, 2008

(Beressa Edesa)

This is certified that the thesis entitled “APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR PETROLEUM EXPLORATION IN OGADEN BASIN: ETHIOPIA” is a benefited work carried out by Beressa Edessa under my guidance and Supervision. This is the actual work done by Beressa Edessa for the partial fulfillment of the award of Degree of Master of Science in Remote Sensing and Geographic Information System (GIS) from Addis Ababa University, Addis Ababa.

Dr. Bekele Abebe,

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Examiner

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Acronym

ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer
DEM	Digital Elevation Model
DEM	Digital Elevation Model
DPPB	Disaster Prevention and Preparedness Bureau
DTMs	Digital Terrain Models
EIGS	Ethiopia Institute of Geological Survey
EMA	Ethiopia Mapping Authority
EMS	Electromagnetic Spectrum
EOR	Enhanced Oil Recovery
ERDAS	Earth Resources Data Analysis system
ESRI	Environmental System Research Institute
ETM+	Enhanced Thematic Mapper plus
FCC	False Color Composite
GCP	Ground Control Point
GIS	Geographical information system
GPS	Geographic positioning system
GSE	Geological Survey of Ethiopia
HIS	Hue Intensity Saturation
IDW	Inverse Distance Weighted
IRS	India Remote sensing service

MME	Ministry of Mines and Energy
NE	North East
PC	Principal Component
PCA	Principal Component Analysis
RGB	Red Green Blue
SCUK	Save the Children United Kingdom
SPEE	Soviet Petroleum Exploration Expedition
SRTM	Shuttle Radar Terrain Model
SW	south west
SWE	SouthWest Energy
USGS	United States Geological Survey
USSR	United Socialist Soviet Republic
WGS	World Geodetic System

Abstract

Petroleum Exploration requires the analysis of different types of data such as satellite imagery, seismic surveys, surface geology studies, subsurface and cross section interpretations and images, well locations, and existing infrastructure information. In this thesis the greatest advantage of Remote Sensing; the synoptic view that it provides, a regional and integrated perspective of interrelations between various land features it gives, the availability of multi-spectral data as well as the advanced capabilities of digital image processing techniques along with the potential of Remote Sensing in generating enhanced and interpretable image is used in delineating the lithological contacts and geological structure in great details with better accuracy than it was. In this thesis GIS is used as a decision support system to demonstrate its with capabilities of efficient data storage and overlay analysis of spatial data from diverse sources, in order to relate all of the data sets (remote sensing, seismic, gravity, geochemical and other ancillary data) to each other, allowing overlying, view, and manipulate the data in the form of a map to thoroughly analyze the potential for understanding or extending play potential in the study area. So With the application of remote sensing and GIS capability, Exploration can be done more accurately, faster, and for less cost.

Key words: remote sensing, GIS, gravity, seismic, geochemical,

CHAPTER ONE

Introduction

1.1 General Introduction

The Ethiopian energy sector is one of the least developed in the world. At present, the country is heavily dependent on traditional fuels consisting mainly of wood, crop residues and animal waste. Without access to modern energy sources, the poor people in the country will not be able to grow beyond subsistence level.

Economic factors dictate that Ethiopia must increase oil and gas exploration in its five known sedimentary basins and identify new exploration target areas. At the end of 2005, Ethiopia was totally dependent upon imports to meet its demand for petroleum, Ethiopia's petroleum consumption was estimated at 32,000 barrels per day (bbl/d) in 2005 (Yager, 2007).

Ethiopia's current proven hydrocarbon reserves are minimal, but the potential to increase reserves to commercial viability is seen as promising. The country's geology is similar to that of its oil-producing neighbors to the east (on the Arabian peninsula) and the west (Sudan).

For various historical reasons, there has been little petroleum exploration activity in Ethiopia. Hunegnawu et. al., (1998) reports that only 46 exploration wells have been drilled in the Ogaden basin, and most of this activity has centered on the southern and eastern parts of the basin.

Sedimentary rocks cover more than 30% of the country that includes the Mekele, Abbay (Blue Nile), Gambela, Southern Rift and the Ogaden basins. However, in the past minimal exploration activities have been limited to the Ogaden basin, which is located in the eastern part of the country. The other basins are either unexplored or lightly explored due to geologic complexity and logistics problems (Tadesse, 2007). Currently the Abay basins and Gambela basins are getting a good attention.

Hydrocarbon exploration in Ethiopia's Ogaden Basin began over 80 years ago (Standard Oil in 1920). The Ogaden basin is located in the eastern and southern parts of the country. This basin covers approximately one – third (1/3) of the country.

Petroleum exploration is considered as an art in which many geological variables are gathered, using expensive and sophisticated methods. The selection of effective exploration targets is an important step to achieve success in oil exploration. The selections are dependent on studies of basic petroleum geological conditions on the surface. Petroleum geologists generally consider basins to be a basic geological unit of petroleum exploration and their main tasks is to find and determine various sedimentary basins.

The greatest advantage of Remote Sensing, is the synoptic view that it provides a regional and integrated perspective of interrelations between various land features It gives, the availability of multi-spectral and high resolution data as well as the advanced capabilities of digital image processing techniques, in generating enhanced and interpretable image has further enlarged the potential of RS in delineating the lithological contacts and geological structure in great details and with better accuracy for petroleum exploration.

The capability of GIS to Input and store spatial and attribute data captured through GPS and digitization, make different analysis on input data to produce intermediate and final potential maps, integrate data from different sources (remote sensing, existing geophysical maps & field survey), produce output thematic layers.

In the geophysics and geology integration the study shows general petroleum potential area to carry on drilling program in the area, in the central part of the study area, there is a possible petroleum potential basin is delineated.

1.2 Objectives

1.2.1 General objectives

The main objective of this work is to apply Remote Sensing and GIS in the petroleum exploration industry in the Ogaden basin with special focus on detailed lithological and structural mapping;

1.2.2 Specific objectives

- Interpretation and Mapping of different lithology found in the study area using remote sensing.
- Use combined image processing and get information about the underground geological structures and features, including the extent of depression, second-order structural zones and large local structures.
- Generate modified Geological and structural maps using integrated remote sensing and GIS techniques.
- Predict potential oil field area in the given blocks; 9A, 9 and 13 by integrating different types of secondary data.
- Relate the Geophysical data with the modified geological map and propose well drilling sites in the future.

1.3 General description of the study area

The Ogaden Basin is located in south east Ethiopia between latitude 4° and 10° N and longitude 40° and 48° E. The basin may hold significant reserves of crude oil and gas (http://en.wikipedia.org/wiki/Ogaden_Basin). It covers an area of about 350, 000 km² (135,000 square miles) and contains up to 4,000 m of late Paleozoic to Tertiary sediments. It has geological similarities to other hydrocarbon-rich basins in the Middle East. Most of the region is

plain with elevation ranging from 300m to 600m, with a steady rise to north, west and southwest to more than 1km above sea level (Assefa, 1998).

1.3.1 Location of the study area

The study area is found in the Somali region in the north eastern part of the country. The study area borders Djibouti to the north, Somalia to the east and north-east, and Kenya to the south. To the west, it borders Oromiya Region and, to the north-west the Afar Region. From the Somalia region the study area is found in nine administrative wereda: Shinile, Jijiga, Fik, Degahbur, Korahe, Warder, Gode, Afder and Liban.

The study area (according to southwest energy - SWE websites -http://www.sw-oil-gas.com/ogaden_basin_overview.htm); is found in the SouthWest Energy concession, which consists of blocks 9, 9A and 13, located at the northern end of the Ogaden Basin in Eastern Ethiopia immediately south of the Border with Somalia Fig1.1. These blocks cover 28,873 square kilometers in an 'oil prone' part of Ogaden Basin between longitudes of 42°E to 45°E & North of 8°N to 10°N. The area measure approximately 220km E to W and 193 km N to S. These blocks have a high prospect for oil and gas which makes it possible that due to potential Karoo age source rocks found still in the oil window.

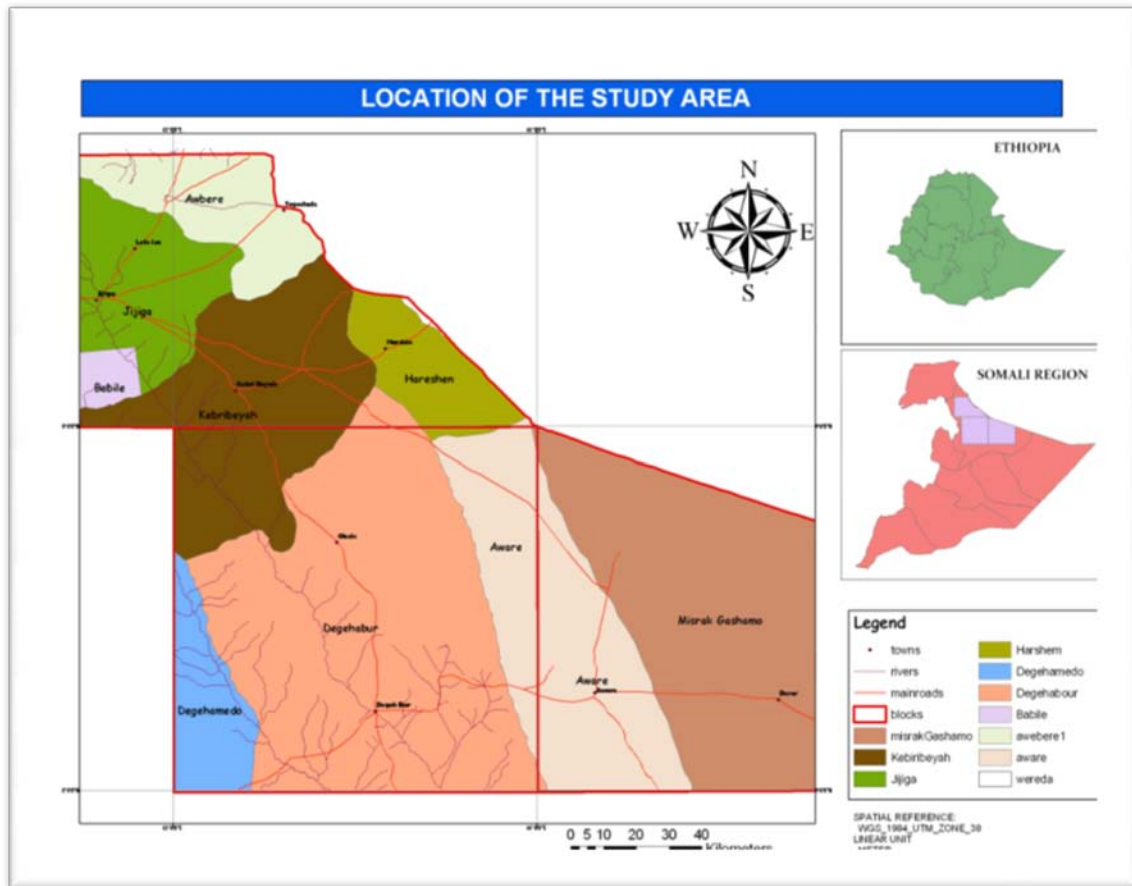


Figure 1 Location map of the study area and administrative wereda's

1.3.2 Infrastructure and Accessibility of the study area

Roads and access to health, education and water – is poor throughout the region. There is a major asphalt road 620km from Addis Ababa to the study area – through Adama/ Nazreth – Harer- Jijiga covers about 620km. There are also major all weather roads totaling about 300km, starting from Jijiga – Kebribeyah - Dgahabour – Aware up to Gode. Another road from is Jijiga to Togochale to the Somaliland Border which is about 60km. And there are many dry weather roads in the study area. There is one domestic airport in Jijiga.

1.3.3 Climate, drainage and water supply

According to SUCK/ DPPC, 2004, report **Climate** is mostly arid/semi-arid in lowland areas, cooler/wetter in the higher areas. Annual rainfall ranges from 150 to 1,000mm per year. Temperatures range is from 19°C (Jijiga Zone) to 40°C (the southern zones, particularly the Shabelle, Dawa and Ganale river basins). The major rivers in the area include the Fafan, Jerer and Dakhata rivers (in Jijiga, Fik, Degahbur and Korahe Zones),

Water sources of the area are mainly rivers, shallow/deep wells, natural ponds, *berkads* (artificial reservoirs) and boreholes. Shallow wells (mostly in seasonal river-beds) are found in all zones of the region; their yields and quality decline in the dry seasons. *Berkads* are found mainly in the *Hawd* areas (Warder, eastern Korahe, eastern Degahbur and Jijiga Zone) where permanent water sources do not exist. Other sources include natural depressions (*valleys*) which collect rain water, or hand-dug ponds. Water quality is often a problem for all sources – boreholes are better but are very few. Water scarcity is an endemic problem in most areas, particularly those with no permanent water points.

1.3.4 Seasonality in Somali Region

The region can be divided into two areas based on the seasons of the year: Shinile and Jijiga Zones to the north, and the remaining seven zones to the south. The rainfall pattern for both is bimodal but the timings differ slightly, as illustrated below:

In Degahbour area the climate is generally hot and dry. Annual rainfall is 300 – 400mm, falling during two rainy seasons - *Gu* (Apr - Jun) and *Deyr* (Oct – Dec).

Table 1 Wet and dry season in Somali region, adapted from SCUK/DPPB,2004.

Administrative Zones	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Fik, Degahbur, Korahe, Warder, Gode, Afder, Liban (and Harshin District of Jijiga Zone)	Jilaal dry season	Gu rains: Mid Apr-end June			Hagaa dry season: early Jul - end Sep			Deyr rains: (early Oct-late Dec)		Jilaal dry season: Jan – mid-Apr		
Jijiga and Shinile Zones excluding Harshin of Jijiga Zone	Jilaal dry season	Diraa (Gu) rains: late Mar-late May		Hagaa dry season: late May - late Jul		Karan (Gu) rains: late Jul- Sep		Jilaal dry season: six dry months with possibility of 2-4 days hais rains in Shinile and parts of Jijiga				

1.3.5 Phsiography and vegetation type of the study area

The vegetation type in the area is a combination of hilly, browse-rich (thick, thorny bush) areas good for camels and goats; and shrub / grassland / plains with grazing for sheep and cattle, and where crops may be grown (particularly near rivers). Some areas are rich in trees that produce gums and resins (eg Filtu and Dolow-Ado). Dagahbour Zone is predominantly semi-arid lowland: the east (all Harshin, Gashamo and most of Aware) is characterised by flat, treeless plateaus, few rivers and mountains; treeless plains are gradually increasing.

The altitude in the area ranges from 200m in the southern/central parts, to 1,800m in Jijiga Zone. Medium altitudes consisting of hilly terrain and plateau are found in parts of Liban, Degahbur, Fik and Shinile Zones.

Soil fertility of the area is high around rivers (permanent and seasonal) which flood seasonally. These areas are cultivated by agropastoralists and riverine communities. Most of the *Hawd* area has sandy soils which are very porous and does not support crop production. Many parts are rocky and hilly.

1.3.6 Livelihood

According to SCU/DPPB, (2004) Four generic livelihood types exist in the region: Pastoralism, Agropastoralism, Farming (sedentary and riverine) and Urban. Pastoralism is the most prevalent, comprising about 60% of the region's rural population. Agropastoralism comprises about 25% of the total rural population, and is a mixture of extensive livestock rearing and rain-fed crop production; some may be better described as pastoralists with opportunistic farming. The remaining 15% of the rural population comprises sedentary (Jijiga) and riverine (Shabelle and Dawa-Ganale) farmers.

1.4 Methodology

1.4.1 Methodology description

First, topographical maps of the study area with scale of 1:250,000 were scanned then Georeferenced. Next the different toposheets were mosaicked using ERDAS Imagine 9.1 software. Settlements, main roads, trails, drainage, topographic contours and other geographic information were digitized from this mosaic of topographical maps. The geological map of Ethiopia with scale of 1: 2 million obtained from the Geological Survey of Ethiopia, is scanned and georeferenced, with the appropriate projection system. Satellite images of the study area were acquired, whose Meta data is given on the next section of this thesis and are all orthorectified to the appropriate projection system.

Since the area is covered by four scene of Landsat ETM+, which was acquired on different dates and different season, it needs to be mosaicked. But due to poor quality of the mosaicked image, all the process is done separately on each individual scene. In addition to Landsat ETM+, to use

the seamless mosaic of Geocover image, geocover of N_38_5_200 is used mainly for the lithological interpretation and structural analysis.

By combining Bands 2, 4 and 7 of the satellite image, a false color composite (FCC) were generated. Spatial, radiometric and spectral enhancement techniques have been done on the image. To take advantage of the spatial resolution (panchromatic, Band 8) and spectral resolution of the satellite images, both images are “resolution merged” together to obtain a multi-spectral image having higher spatial resolution. All the above preprocessing techniques are carried on ERDAS Imagine 9.1 software.

Digital Image Processing is also then carried out in ERDAS Imagine 9.1. All the informations in the Georeferenced geological maps (lithological boundaries as polygon features, faults as polyline features) are digitized in ArcGIS 9.2. The road networks, settlement, drainage of the region are also updated using the merged satellite image with additional data are extracted from Ethio - Gis data and automatically extracted drainage network.

In order to magnify some topographic feature for 3D views and to get an idea about the topography and their orientation, 30m resolution USGS SRTM DEM data is used. First the data is loaded to 3dem software to fill the Gap or missing information in the data through iteration of patching process. After the missing gap is filled the data is imported to ArcGIS9.2 by converting DEM to raster data. Next the raster data is used to generate slope map and hillshade map of the study area. In order to generate Digital Terrain Models (DTMs), multi spectral, PAN and merged images are draped over the DEM. These analyses were carried out in ArcGIS9.2 using the 3DAnalyst module. After analysis of the image and manual extraction of lineament and drainage network of the study area relatively modified geological map of the study area is produced. To locate possible petroleum basin in the study area, surface information has to be supported with the geophysical data that are acquired at different time. Secondary geophysical data (seismic

lines, gravity gradient and geochemical result data) are georeferenced to the same projection system to match with the rest of the data. Some of the data were in TNTmpis file and are exported to shapefile format to do the analysis and mapping, and then all of this data are overlaid.

Based on the X-Y coordinates, Magnetic data, gravity and seismic lines were imported and overlaid on top of all the other layers to identify the possible potential area in the basin, in order to propose the possible drilling site for the future. This step is also carried out in ArcGIS 9.2 software.

1.5 Data used

Reliable data is necessary to realize the designed objectives. The study was based on both primary and secondary data. In addition to the available data, field work and observation was done together with the GPS readings to generate primary information. In order to accomplish this work the following data were used.

1.5.1 Satellite imagery

ORIGIN of the image for the entire scene is "Image courtesy of the U.S. Geological Survey". The ETM+ sensor image has 9 bands of which 6 are multi-spectral (Bands 1, 2 & 3 visible, band 4 is NIR, and bands 5 & 7 are SWIR) having spatial resolution of 30m, 1 panchromatic (band 8) having spatial resolution of 15m & and 2 thermal (bands 61 and 62) high and low gains respectively and having spatial resolution of 60m. The raw ETM+ sensor image has an absolute positional accuracy of 50m.

In addition to ETM+, Geocover N_38_5_2000 and SRTM 30m DEM data are used for different geological data analysis mainly for geological map generation.

1.5.2 Methodology Flow diagram

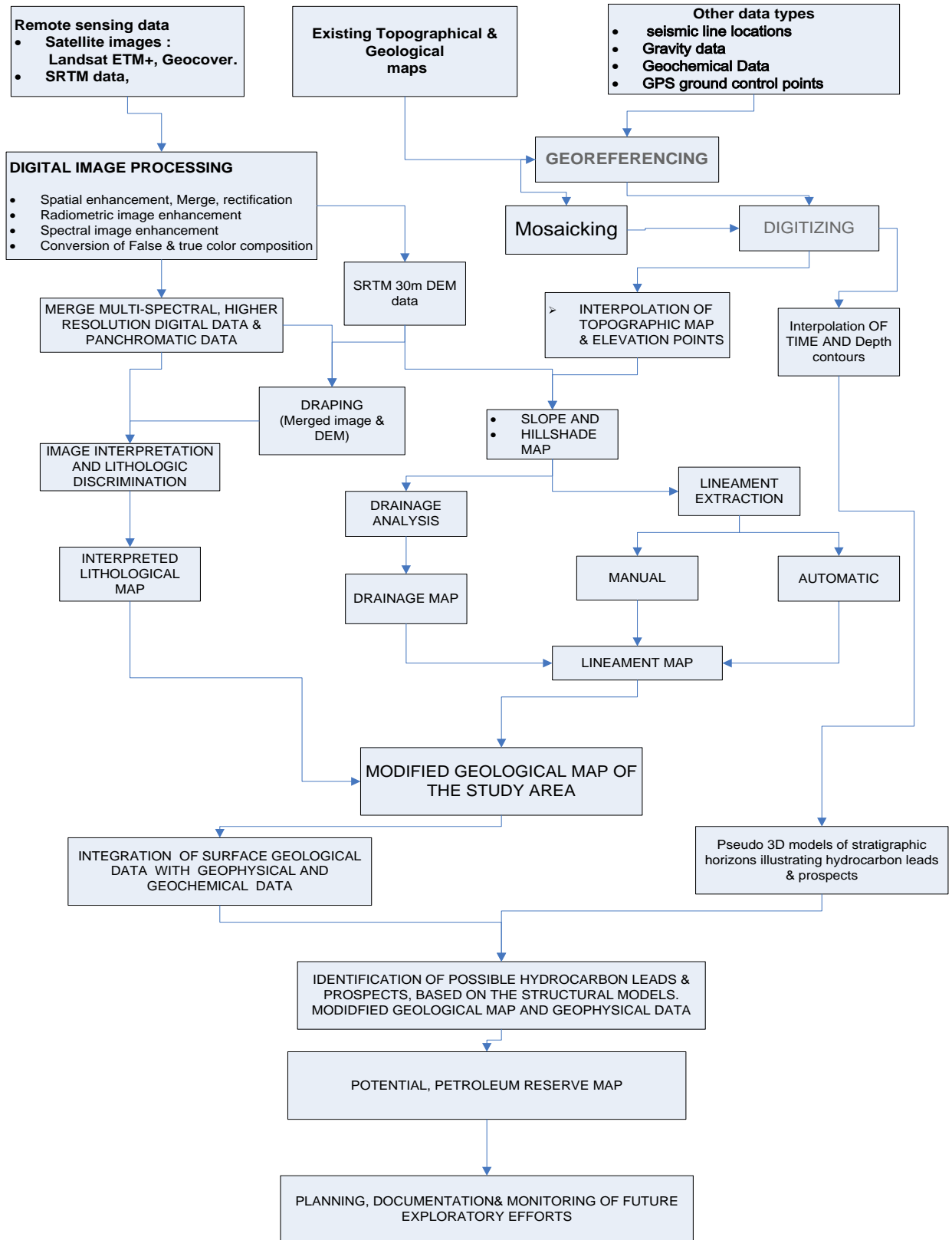


Figure2 Methodology flow diagram.

General information of the satellite images

SPACECRAFT_ID = "LANDSAT7"; SENSOR_ID = "ETM+"; REFERENCE_DATUM = "WGS84"; REFERENCE_ELLIPSOID = "WGS84"; MAP_PROJECTION = "UTM"
 ZONE_NUMBER = 38

Table 2 satellite image Meta data

Satellite scene	ACQUISITION_DATE	WRS_PATH	STARTING_ROW
1	2003-04-04	166	54
2	2003-04-04	166	53
3	2003-03-12	165	54
4	2003-04-04	165	54

1.5.3 Other secondary data

The following are secondary data obtained from southwest energy. This data are used for the purpose of showing the petroleum potential area along with are data.

Table 3 other secondary data table

Data type		Author /owner
Geophysical data	Seismic data	Maxus Ethiopia,INC,1993/SWE
	Gravity data	
	Magnetic data	
Geochemical data	Geochemical data	GMT/SWE

1.5.3.1 Topographic maps

Table 4 topographic data table

NO	INDEX NO.	DESCRIPTION /TITLE	SCALE	AUTHOR
1	NC38-9	HARAR, ETHIOPIA	1:250000	EMA,
2	NC38-13	CHO'BA, ETHIOPIA	1:250000	EMA
3	NC38-14	DEGAHABOUR, ETHIOPIA	1:250000	EMA

1.5.3.2 Geological map of Ethiopia
Table 5 Geological map table

NO	DESCRIPTION /TITLE	AUTHOR
1	GEOLOGICAL MAP OF THE OGADEN AND SURROUNDING AREA	BEICIP/MME
3	GEOLOGICAL MAP OF ETHIOPIA	GSE
4	GEOLOGICAL MAP OF ETHIOPIA AND SOMALIA	CONSIGLIO NAZIONALE DELL RICERCHI,ITALY.1973

Data collection methods

Different methods are employed during the study for data collection to acquire required data.

1.5.4 Preliminary, simple observation:

A preliminary survey has been conducted to get a general overview. The objective of this investigation stage is to develop a clear understanding of the petroleum potential rocks and the petroleum habitat of the area, previous work that has been done, effort employed, exiting situation of the area etc. This is done through informal interviews and focus group discussions.

1.5.5 Reviewing literature:

Maximum effort has been employed to get some valuable information from previous research papers done on similar geological formation, from Internets, and/or other resources. Unpublished documents, data, and works have been reviewed to get general overview.

1.5.6 Satellite images and topographic maps:

In addition with the above-mentioned methods of data gathering in this research majority of the data were extracted from the Satellite images and top sheet which are relevant for the study. Appropriate satellite images (Landsat ETM⁺) and image processing is done on the individual

features and targets of the studies. Other secondary geophysical data like seismic lines and gravity data are used.

1.5.7 GPS Readings:

Since it was difficult to identify all the lithologic units only by interpreting satellite images, ground truth data collection through fieldwork was conducted. In addition, to locate and verify the different geological and non-geological features in the study area, GPS readings were taken. This was done systematically by taking representative areas of interest by selecting traverses across and along some exposures.

1.6 Software and materials used

Table 6 table showing software and materials used

Softwares	ERDAS imagine 9.1, ArcGis 9.2, TNTmpis, Global mapper 9.0, 3DEM, PCI Geomaticav9.1
Materials used	GPS /geographic positioning system/, Clinometers Compass, Geological hammer, Digital camera, Laptop and desktop computer

CHAPTER TWO

2. Literature Review

Petroleum (rock- oil, from the Latin *petra*, rock or stone and *oleum*, oil) occurs widespread in the earth as gas or, liquid, semi-solid, or solid or in more than one of these states at a single place (Levorsen, 1954). Chemically any petroleum is an extremely complex mixture of hydrocarbon (hydrogen and carbon) compounds with minor amounts of nitrogen oxygen and sulfur as impurities. Liquid petroleum which is called crude oil to distinguish it from refined oil, is the most important commercially. Petroleum gas commonly called natural gas to distinguish it from manufactured gas consists of the lighter paraffin, hydrocarbons, of which the most abundant is methane gas (CH_4). The semi-solid and solid forms of petroleum consist of the heavy hydrocarbons. They are called asphalt, tar, pitch, albertite, gilsonite, or grahamite (Levorsen, 1954).

Because of its wide occurrence and its unique appearance and character, petroleum has always been readily observed by man, and is repeatedly mentioned in the earliest writings of nearly every region of the earth (Boverton, 1922).

From the earliest times recorded by man, petroleum is frequently mentioned as having an important part in the religious, the medical and even the economic life of many regions. The use of petroleum spread slowly in what has been called the “Kerosene age” (1859-1900), but the development of internal-combustion engine, near the beginning of the twentieth century, set off a phenomenal growth of the petroleum industry, a growth that has not yet shown any sign of slackening. Petroleum has, in short, become one of the most important natural resources of modern civilization (Levorsen, 1954). Ever since, E.L Darke drilled the first well for oil in

Pennsylvania in 1859, and especially, of course, since 1900, the geology of petroleum has assumed growing importance as a special economic application of geology.

Exploration is the term used in the petroleum industry for oil hunting (Landes, 1976). It is pre-discovery phase; post- discovery activities are classified under exploration, or development and production. The outstanding direct indication of the presence of oil or gas in the rock is a seep at the surface (DeGolyer, 1940).

Ye and Qui, (1990) stated that, Oil and gas exploration is moving into increasingly remote, complex, and poorly-understood regions of the world. Most Obvious structures have long since been drilled, and the remaining structural traps are revealed by subtle clues at the surface. Remote sensing technology presents these subtle geomorphic indicators to the geologist; he must then discern hydrocarbon traps among all the surficial features.

There are several aspects to structural geomorphology. The first is to understand the rock types being viewed. There are colors, tones, textures, weathering features, common associations, and deformational styles that suggest specific rock types. Recognizing Lithology is important because each rock type expresses structure to different degrees (Sabins, 1997). Another aspect is recognizing dip, which allows one to map anticlines and other traps in areas of outcrop. In areas where outcrops are scarce or non-existent, one may interpret drainage patterns, soil color, tone, and textural patterns, vegetation distribution, moraine patterns, and sand cover to predict the location of "blind" structures. Lithologic mapping based on drainage texture (course in sandstones; fine in shales) has been used successfully to locate folds in the Ucayali basin, Peru (Doeringsfeld and Ivey, 1964). Domed, stratified uplifts are characterized by radial and annular drainage. The deflection of parallel streams in opposite directions can be evidence of a subtle

buried structure. There are several types of faults that play important roles in creating hydrocarbon traps. Each fault type is associated with a set of distinct landforms (prost, 1992).

Work on geologic image interpretation is reported less frequently (Ray 1960; Miller and Miller, (1961); Drury, 1987; Campagna, and Lavadowski, 1991; Gupta, 1991 ;) and techniques for assisting petroleum exploration are rarely reported (Posamentier, 1989). Most remaining undiscovered resources are located where traps have no obvious surface expression; they are buried by alluvium or soil, sand, till, vegetation, swamps, or other cover. Much work has been done on processing imagery to enhance information content.

As stated by Yu, Xiaoping, and Zou (2001) the most established market in remote sensing is in the area of natural resources in exploration of oil, gas, and minerals. Satellite and airborne Remote Sensing technology aids in the selection and development of oil and gas exploration areas around the World as well as in the areas of oil spill mitigation and remediation. Oil spills and natural oil seeps can be detected using remote sensing techniques, and GIS can be used to determine the location of the hydrocarbons (Rauschkolb, 2003).

Lineaments are significant lines of landscape caused by joints and faults revealing the architecture of rock basement (Hobbs, 1904) as cited in Sander (2007).

Lineaments perceived in remotely sensed images are reliable indicators of geologic structure. Mapping of lineaments is one of the key factors in understanding structural traps for the occurrence and movement of oil and gas. Lineaments can be recognized on satellite images by image color, texture, tone, pattern, break of slope, abrupt change in stream course, lithology, vegetation, etc.

Meanders will develop on the lower gradient, and the stream will straighten downstream of the fold as the gradient increases. Foster and Soeparjadi (1974) used this technique to map oil-

bearing pinnacle reefs in the Salwati basin, Indonesia. One may observe alluvial ponding and braided streams as the gradient decreases.

As stated by Gülcan (2005) and reference therein, Remote Sensing Techniques have opened a new era in mapping lithology. The Landsat Enhanced Thematic Mapper data are extremely useful. In the past, the geological maps are prepared from conventional ground surveys based on field observations. Since the development of remote sensing technology, mapping procedures have undergone continuous change. Now remote sensing techniques play an important role in mapping programs. Mapping of lithology and alteration zones in inaccessible mountain and forest terrain has always posed a challenge. Vast area to be surveyed and its inaccessibility, forbids physical investigation of every outcrop. At this juncture, the potential of RS is appreciable. The existing multi spectral satellite systems are designed to investigate natural resources with special focus on vegetation coverage, lithology and mineral exploration. The wide area coverage of the data in connection with their long-term availability allows analysis of the spatial dynamics within larger areas. Most applications of RS in geology involve the delineation of structures, discrimination of different rock and soil types and resource exploration (Kruse and Dietz 1991). Following the launch of LandSat Thematic Mapper (TM) in 1982, geologists gained access to better spatial (30m) and spectral resolution (Abrams, 1984), compared to the Multi spectral Scanner (MSS) used, for detailed geological studies (Podwysocki et. al.. 1983). Many geological studies have employed TM and ETM+ data to discriminate the various lithologies, lineaments and minerals by using hyper-spectral laboratory (Abrams, 1984). In the regions where bed rock is exposed multi-spectral RS is useful for mapping lithology and alteration zones.

According to samih, 2006 and references therein, Subsequent Studies, in south-west USA and elsewhere have confirmed that areas of hydrothermal alterations may be distinguishable using the

ratio of TM band 5 and 7. Also it is evident that the spectral characteristics of TM bands are suitable for mapping lithology.

2.1.1 Remote sensing and Structural Traps

Anticlines, domes, and horsts are important structures in the search for oil and gas (Prost, 1992). The shape of these structures ranges from circular, as in salt domes, to elliptical, to plunging "noses," to a gentle change in strike. The anticline is commonly expressed as a topographic high at the surface. Just as commonly topography may be inverted, with the resistant layers breached by erosion and the core layers exposed as a valley.

Anticlines: Anticlines are formed by horizontal compression at right angles to the fold axis. These folds may also form as a result of salt movement, sediments draping over the edge of a faulted block, or by compression in a thrust sheet.

2.1.2 Remote sensing and structures associated with faults

Normal and reverse faults: Normal and reverse faults are often near-vertical at the surface, are characterized by a linear trace, and are frequently indistinguishable. They are identified by an escarpment, offset landforms, by juxtaposition of differing lithologies, or an abrupt change in strike or dip across the trace. Where there are no outcrops, or they are covered by vegetation, near-vertical faults may appear as vegetation or soil tone alignments, often because of near surface groundwater. Linear stream segments or linear valleys extending several kilometers suggest fault control, since the broken rock in the fault zone is readily eroded into valleys. Alignments of springs reveal groundwater ponding against a fault.

Prost, 1992 & reference therein, Listric normal faults tend to be arcuate or scoop-shaped in plain view. Faults concave toward the downthrown side are probably listric. Rotation of bedding and

continued faulting leads to a sequence of steep to shallow dips as one proceeds basin ward. Growth faults, a type of listric fault, are characterized by dip reversal into the fault (rollover).

Reverse faults

Reverse faults bound many uplifts. A linear mountain front with parallel zones of fractures and faults within the uplift suggest the uplifted block is bounded by reverse faults and overhangs the basin. These parallel zones are probably relaxation features that developed following uplift (Price, 1959). The fault and uplifted basement can form an updip seal ("overhang play").

1) Strike-slip faults

Prost, 1992, and reference therein Strike-slip faults are recognized by a consistent lateral offset of units, streams, alluvial fans, roads, etc. En echelon folds develop at 30-450 to the fault and perpendicular to the maximum horizontal compression. The Newport-Inglewood trend in the Los Angeles basin has produced much oil from en echelon folds. Strike-slip faults can also be recognized by pull-apart basins or sag ponds at releasing bends, and by buckle folds and "flower" structures at restraining bends. Pull-apart basins can form depocenters that accumulate source and reservoir units; flower structures often contain folds that trap hydrocarbons.

As stated in Edgar, (1975) In the early days of petroleum prospecting most oil finds were the result of digging or drilling near known oil and gas seeps, as Lyne T. Barret did in 1866 at Oil Spring in Nacogdoches County, or of accidental finds while drilling for water, as with George Dullnig's 1886 strike in Bexar County or the discovery of oil in Corsicana in 1894. Because of abundant seeps, guesswork and good luck were sufficient for finding oil. But now a day's Exploration requires the analysis of different types of data such as satellite imagery, aerial photography, seismic surveys, surface geology studies, subsurface and cross section interpretations and images, well locations, and existing infrastructure information. In the

subsurface, geological features may be perceptible from boreholes, cuttings and/or surface geophysics methods (Kheiralla et. al, 2006).

The magnetic methods have long ago played a secondary role in oil exploration, such as helping to define the basement structures that control emplacement of hydrocarbon in overlying sedimentary basins (Edgar, 1975). In recent years, based on researches on magnetic minerals accompanied in the processes of formation of oil and gas deposits, specialists have a new look on the applying abilities of the magnetic method for the purpose of hydrocarbon exploration.

GIS is an efficient tool for manipulating and storing large volumes of data, integrating spatial and nonspatial information in a single system, offering a consistent framework for analyzing the spatial variation, allowing manipulation of geographical information and allowing connection between entities based on geographical proximity. Integrated GIS and remote sensing technology has modernized the study of natural resources. Remote sensing provides multispectral, multi-temporal, multisensor and multivariate data of the Earth's surface. GIS has emerged as a decision support system with capabilities of efficient data storage and convergent analysis of spatial data from diverse sources. There is a strong synergy between remote sensing and GIS, as remote sensing data are a major source of spatial information in GIS analysis and GIS data can be used as ancillary information to support remote sensing data interpolation. The synergism between these two technologies is a major advantage in the use of an integrated approach (;Saraf and Choudhury 1998).

An integrated approach of remote sensing and GIS technologies provides better opportunities not only for geological mapping, but also for geological interpretation and implementation of exploration programs in difficult terrains with greater accuracy and in a cost-effective manner (Saraf et. al. 2002).

CHAPTER THREE

3. Regional geology of the study area

3.1 Regional geology

Any rock that is porous and permeable may become a reservoir. But these properties are most commonly exhibited in sedimentary rocks, especially sandstone and carbonates. A trap is usually formed by the deformation of the reservoir rock, which may be accomplished by faulting, folding, or both, either in simple episodes. But trap is not always formed by deformation; it may be formed by stratigraphic variation in the reservoir rocks (Levorsen, 1954).

Sedimentary rocks are widespread in Ethiopia and occur in five distinct basins (Tadesse, 2007) , namely: Ogaden (350,000 sq. km), Abay River (63,000 sq. km), Gambela (17,000 sq. km), Southern Rift (15,000 sq. km) and Mekelle (8,000 sq. km) (Hunegnaw, 2007).

All the basins are related to the extensional stresses which have affected the region intermittently since the Late Paleozoic and especially during the Cretaceous when associated wrench tectonics occurred (Hunegnaw et.al, 1998).

3.1.1 The development of Ogaden basin

As stated by Hunegnaw (1998), the development of the Ogaden Basin is related to the break-up of Gondwanaland. From Permian to Jurassic times, a tri-radial system of north-south, NE-SW and NW-SE trending graben developed as a consequence of the opening of the North Atlantic and Proto-Indian Oceans (Beicip-Franlab, 1985, 1998).

3.1.2 Hydrocarbon source and reservoir of the Ogaden basin

In terms of hydrocarbon source and reservoir rocks, pre- syn- and post-rift rocks are all of potential importance. The Calub Formation of Permian age (or possibly Ordovician to Silurian, Assefa, (1988)) consists of pre-rift sandstones and conglomerates deposited in a glacial-to-fluviatile environment unconformably on basement. The overlying Bokh Formation (Permian to Lower Triassic) comprises organic-rich, black-to-brown shales and laminated sandstones, and corresponds to initial rift-phase deposits laid down in a lacustrine environment. The overlying Gumburo Formation (Middle to Upper Triassic) consists of sandstones with black shales and interbedded red-to-green siltstones, deposited in a deltaic to fluviatile environment. These formations belong to the Karoo System and vary widely in thickness (Hunegnaw, 1998).

According to Assefa, (1988), the fluviatile Adigrat Formation (Upper Triassic to Lower Jurassic) unconformably overlies the Karoo sequence. It comprises fine- to medium-grained sandstones with intercalated shales, and represents deposition during the early rift phase. A transition to a shallow-marine depositional environment is recorded in the uppermost part of the formation.

The overlying Lower, Middle and Upper Hammanlie Formations represent an Early Jurassic to Callovian syn-rift marine sequence, and consist of the following lithologies: limestone with intercalated shales (in the lowermost section); anhydrite, dolomite and limestone with local oolitic and stromatolitic beds (in the middle section); and bioclastic oolitic lime stones (in the uppermost section).

The Uarandab Formation corresponds to the maximum flooding sequence deposited during the break-up transgression (Callovian- Oxfordian), and is composed of dark, laminated marls and limestone containing a pelagic marine fauna. The Gabredarre Formation (Upper Jurassic) represents a passive-margin sequence comprising bioclastic, locally oolitic and reefal limestone; these limestones were deposited in offshore bars and small reefal build-ups.

Opening of the South Atlantic Ocean was initiated during the Cretaceous, and a number of shear zones were developed along and within the East African continental margin. A series of intracratonic troughs were formed along the Central African Shear Zone. NW-SE trending grabens were generated, and shear movements occurred along NE-SW trending faults. During this post-rift period, regressions and transgressions alternated over the Ogaden platform area and the related sedimentary rocks are represented by the Gorrahei, Mustahil, Ferfer, Belet Uen and Jesomma Formations.

The Tertiary section is composed of the thin Palaeocene-Eocene Auradu and Taleh Formations in the eastern Ogaden Basin, by the Oligocene-to-Pliocene Trap Series (mainly volcanic flows) in the northern and western parts of the Ethiopian Plateau, and thicker sedimentary deposits in the Red Sea area to the NE.

3.1.3 Structure of the basin

As stated by Worku, and Astin, 1992 and references therein, The East African region has been affected by two major phases of rifting. The first phase was the widespread rifting in Karroo times (Late carboniferous) to the formation of the East African rift system (Cenozoic to Recent). The earlier phase of extension has been identified throughout eastern Africa, stretches from Ethiopia to South Africa and corresponds to the initiation of the break-up of Gondwanaland. Unpublished seismic sections of the Ogaden Basin show that further subsidence took place without significant associated faulting, through the rest of the Mesozoic and into the Tertiary. This subsidence, combined with sea-level fluctuations, produces cyclic patterns of shallow marine carbonates, shales, evaporates and minor clastic deposits. Compressional structures are present, including reverse faults and localized folds, some of which may be related to the opening of the Indian Ocean and some to uplift of the basin during the tertiary (Kent, 1974).

The second phase of rifting began in the Gulf of Aden area and was followed during the early Miocene by the formation of the Red sea and the Ethiopian rift system (Shackleton, 1978). Both periods of rifting are considered to be a reactivation of existing tectonic lineaments that were first active during the pan-African.

The Ogaden Basin has several structural highs and lows separated by normal faults (Kent, 1974). Oil company drilling and seismic studies have revealed two major lows' the NE-SW trending El kuran trough and the NW-SE Abred trough, separated by the calub saddle. The Gerni and Mibio uplifts in the northeast of the refion are monoclimal structured. Unpublished seismic sections suggest that all the principal tectonic elements in the basin originated in the later palaeozoic to Triassic, but with considerable evidence of reactivation of many of the major lineaments throughout the Mesozoic, especially by wrench movements o previously normal faults.

Assefa, 1998, and reference therein states that structurally the basin belongs to the well developed East African system of NNE-trending troughs which started to form in the Paleozoic. This system which often takes the form of graben and half graben is considered to be a rift stages basin of the East African continental margin (Purcell, 1981). From the Paleozoic to lower Miocene, this part of Africa was strongly affected by the vertical differential movement of the Mosaic of the Precambrian blocks bound by NW- trending fracture zones. The first phase of the vertical movement, the strongest in the region, took place in the Karoo times. Others, of relatively minor scale, developed at the end of the cretaceous, the Eocene, and the Oligocene to the Lower Miocene (Kent, 1974).

The Ogaden basin thus appears to have been initiated in Paleozoic time as part of the above mentioned regional trough. It is dominant, like similar basins in NE Africa, by non-compressional tectonics. Two main fracture zones, known as "Marda fracture Zone" and the "Kuran fracture Zone" dominates its structural framework.

3.1.3.1 Marda Fault

The Marda fault zone in the south-Eastern Ethiopia was first recognized in the Marda Range near Jijiga and was called Marda Hills line (Purcell, 1976). The “linear NW-SE arrangement of basalt capped summits with basaltic plugs” and the associated Bouger anomaly were considered indications of a major “Volcanic-tectonic” lineament. Subsequently the fault zone was described as a complex of NW-SE trending fault, down through to the NE and possibly extending 200km in to the Ogaden Basin (Purcell, 1976).

Subsequently the fault zone was described as a complex of NW-SE trending faults, down thrown to the NE and possibly extending 200km into the Ogaden basin. Recent studies have indicated that the fault zone extends over 400 KM beyond the Marda range to the Belet Uen area in Somalia.

These indications of a zone of faulting from the southern margin of the Afar depression southeast to the Indian Ocean define a length for the Marda fault zone of more than 900KM. The feature must therefore be recognized as a major structural element in the Horn of Africa.

Purcell, (1976) states that the ERTS imagery clearly shows the outcropping volcanic and Hamanlei formation sediments in the Marda range, the linear valleys of the fafan, gerer and Wabshebelli Rivers, and numerous linear between 10 and 100 KM long, several of which near Jijiga have been proved to be wrench faults. Numerous NE-SW linears are also seen, which in the southern Ogden seem to offset the zone. Similar cross-faulting has been mapped on the ground near Jijiga. Structural form lines determined from air photography consistently swing to the right near the zone suggesting dextral displacement on the faults zone.

3.1.4 Stratigraphy

As stated by Worku et.al, 1991 and reference therein, the general stratigraphy of the Ogaden basin sedimentary sequence is has been developed from studies by several oil companies and Ethiopian institute of Geological surveys.

As stated by Assefa (1988) and reference therein; the lithologic subdivisions indicated are essentially the same as those adopted by the earlier investigators. The early history of the basin was characterized by continental Karroo deposition (evidenced by the sub surface by wells drilled in the basins) that lasted from early Paleozoic to Late Triassic or earliest Jurassic times.

Within this Paleozoic sequence, three formations (Calub sandstone, Bokh shale, and Gumburo sandstone) have been distinguished. Their age was considered to be either Permian (Kmen-Kaye, 1978; Purcell 1981) or lower Paleozoic (Elwerath, 1967).

3.1.4.1 Calub sandstone

Hunegnaw, (1998) states that The Calub sandstone was penetrated first in Tenneco's calub-1 wildcat. The Calub sandstone is known from the eastern and central parts of the basin. The formation thickness is from 61 to 225 m in the central Calub area adjacent to the Calub saddle, and is about 300 m in the Bokh-1 well in the eastern part of the basin. It rests unconformably on precambrian crystalline basement (metamorphosed granite/ granodiorite and quartz-feldspar schist) and has a rapid transition into the overlying Bokh shale. The sediments are mainly arkosic coarse sandstones with some granular conglomerate and minor beds of reddish brown siltstone.

The average sandstone composition is 63% feldspar, 17 % quartz, 9 % rock fragments, being mainly chert. In the Bokh-1 well, some beds of lithic sandstone, rich in basic volcanic clasts, are present in association with beds of intermediate to basic volcanic tuff. These are the

first evidence found for localized volcanism within the karoo of Ethiopia. Sandstones and conglomerates are moderately finer well sorted, and well bedded. Some scattered pedogenic calcite concretions occur in the sediments.

Table 7 Key features of the Karoo stratigraphy in the Ogaden Basin adapted from Worku et.al, 1991.

Formation	Approx. Age	Basal contact	Average thickness (m)
Adigrat sandstone	Early jurassic	Transitional	100
Gumburo sandstone	Late Triassic?	Transitional	290
Bokh shale	Early Triassic	Transitional	300
Calub sandstone	Permian?	Unconformity	120

3.1.4.2 Bokh shale

The Bokh shale is named after Elweraths' Bokh-1 wildcat (7^o29.78' N, 46^o56.58'E) (Elwerath, 1967). This formation varies in thickness from 300 to 400 m and is confined to the graben.

It is characterized by predominantly dark grey and minor dark green to reddish brown shales with interbeds of siltstone and fine sandstone. About 30 m of dolomicrites occur at the base of the formation in the Bokh-1 well. The sandy beds increase in thickness up to a maximum of about 40 cm and in abundance towards the top of the formation. Sand beds are usually massive with sharp bases and tops, sometimes showing some fining upwards. The transition to the overlying Gumburo sandstone is marked by sandy micaceous sediments with some bioturbation by vertical and U-shaped burrows.

The dark shale has variable organic carbon contents (up to 5 %) and is locally pyrite rich. It is typically finely laminated. The organic maturity varies widely, with the Bokh area having more compact and indurated shale. Articulated fish and bivalves have been found in cores from the

calub area, together with coalified wood. One palynological sample has given an approximate age of lower Triassic (Carnian to Norian).

3.1.4.3 Hammanlie formation

Lower, Middle and Upper Hamanlei Formations represent an Early Jurassic to Callovian syn-rift marine sequence, and consist of the following lithologies: limestone with intercalated shales (in the lowermost section); anhydrite, dolomite and limestones with local oolitic and stromatolitic beds (in the middle section); and bioclastic oolitic limestones (in the uppermost section) Hunegnaw, (1998).

Hamanlei formation is a shallow-marine to lagoonal and deltaic deposit that consists of organic-rich carbonate and evaporites with subordinate shale and sandstone. Carbonates assigned to this formation may act as reservoir rocks, and thin interbedded shales as source rocks and seals.

3.1.4.4 Urandab formation

According to Hunegnaw (1998) and references therein The Urandab formation (Callovian - Oxfordian) is composed of shale, sandstone, marl, cherty and oolitic limestone, as well as dolostone deposited in a pelagic to shallow-water marine environment, which are 30- to 120-m thick. The Urandab formation is interpreted to be a neretic deposit. The Urandab source rock is located between the Upper Hamanlei limestone reservoir and the Gabredme carbonate reservoirs. In both cases, the structural deformation (mainly Late Jurassic - Early Cretaceous) occurred prior to oil generation and migration (Late Cretaceous to Recent). An example is the accumulation in the Hilala structure.

The organic matter is Type II kerogen and the petroleum potential varies from 2 kg HC/ton rock (Faf-1 well), to 8.6kg HC/ton rock (Hilala well) and up to 20kg HC/ton rock (Gherbi-Z well).

3.1.4.5 Karroo sediments

The oldest sediments in the basins are continental Karroo sediments. “Karoo” is a broad term applied to mainly continental rift sediments deposited widely in what was eastern Gondwana land from the late Paleozoic to the early Jurassic. The type locality is the Karroo basin in the South Africa. Similar sediments also occur in a connected set of rifts both at outcrop and in the Subsurface, in Zimbabwe, Mozambique, Tanzania, Madagascar, Kenya, Somalia and Ethiopia (Worku, and Astin, 1992 and references therein).

As stated in Worku et. al (1992); In the Ogaden basin the Karroo sediment can be subdivided into four formations, all confined to the subsurface. From oldest to youngest these are the Calub sandstone, the Bokah Shale, the Gumburo Sandstone, and the Adigrat sandstone.

Before worku et. al. (1992), the name “Karoo” has been limited in Ethiopia to sediments deposited prior to the Adigrat sandstone (Mohr, 1963). Up to 300 m of conglomerate and overlying unfossiliferous sand stone have been recognized as Karoo. These have been correlated with permo carboniferous continental sediments from the coastline of Kenya and Tanzania (Elwerath, 1967).

3.1.4.6 Gumburo formation

Beicip - Franlab (1998) states that Gumburo Formation (Middle to Upper Triassic) overlying Bokh shale consists of sandstones with black shales and interbedded red-to-green siltstones, deposited in a deltaic to fluvial environment. These formations belong to the Karoo System and vary widely in thickness.

3.1.4.7 Adigrat sandstone

According to Assefa (1988) The Adigrat sandstone, previously defined as being post-Karoo, is much more widely distributed than the older sediments. It is the last widespread marine

transgression in the Jurassic which led to the deposition of marine carbonates of the Hammanlie Formation. In the Ogaden Basin there is a complete gradation from pre-Adigrat sediments (Gumburo sandstone) to the Adigrat sandstone.

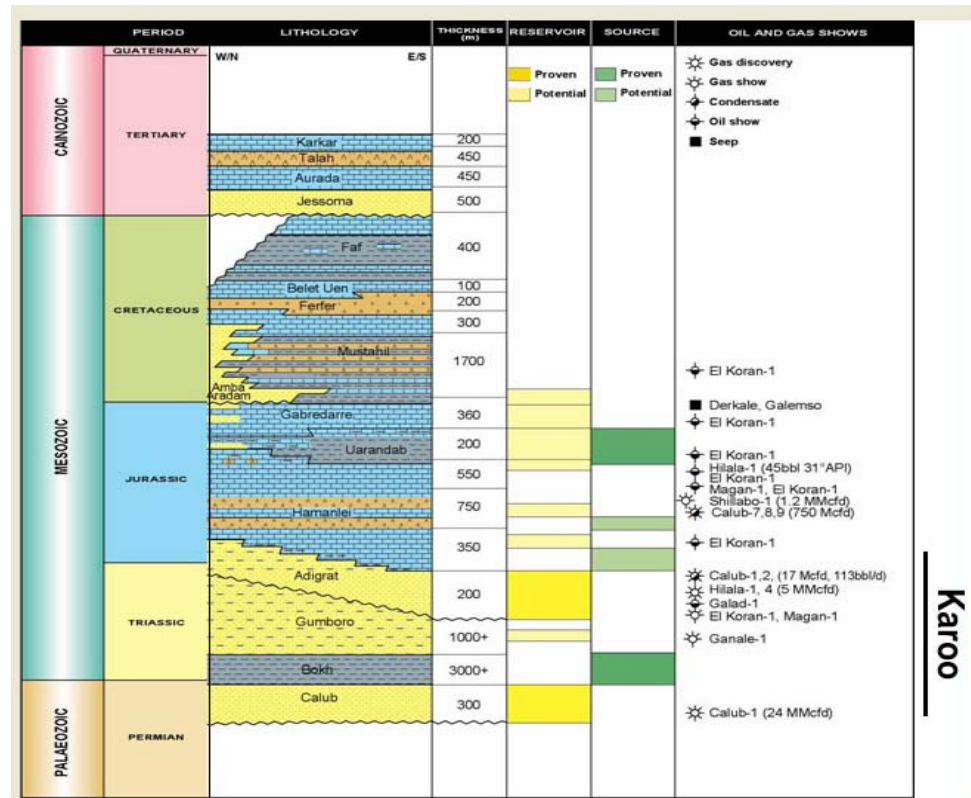


Figure 3 Chart showing petroleum systems in the Ogaden Basin used with permission from SWE Continental clastic deposition was continuous until terminated by lower to middle Jurassic carbonate deposition. The Adigrat sandstone is likely to be diachronous, probably being older in the Ogaden Basin in the south, and becoming younger to the north where it outcrops in the Mekele, Harar and Central Ethiopia regions.

A thickness of over 10,000m of sedimentary rocks is present in the deepest (southernmost) part of the Bodle Deep, which has a steeply-dipping western flank deformed by northsouth and NNE-

SSW trending faults and a gentler eastern flank. The floor of the basin rises progressively northwards; the depth to basement is around 6,100m at the Bodle-I well, and 5,000m at the junction of the tri-radial rift system.

The North Shillabo half-graben progressively deepens from north to south, with a maximum sedimentary thickness of 7,500m next to the major ENE-WSW trending Shillabo fault which separates the half-graben from the Calub Saddle. The Calub Saddle comprises a “deep” zone adjacent to the Bodle Deep, where the basement is about 5,500-m deep; a steeply-dipping flexure zone; and a relatively high area to the south, where basement depths range from 4,200 to 2,500 m in the direction of the Bur High(Hunegnaw, 1998).

3.1.5 Petroleum habitat

Three conditions must be present for oil reservoirs to form: first, a source rock rich in organic material buried deep enough for subterranean heat to cook it into oil; second, a porous and permeable reservoir rock for it to accumulate in; and last a cap rock (seal) or other mechanism that prevents it from escaping to the surface. Within these reservoirs fluids will typically organize themselves like a three-layer cake with a layer of water below the oil layer and a layer of gas above it, although the different layers vary in size between reservoirs.

3.1.5.1 Potential source Rocks in the region

As stated in Assefa (1998); the most likely oil and Gas source rock in the sedimentary rock of the Ogaden basin are the Bokh shale, the Hammanlie, and the Urandab formations. The Bokh shale comprises black shale, siltstone and silty sandstone with a few dolostone, coarse sandstone and conglomerate intercalations.

Numerous geochemical analyses (Robertson Research, 1986; Beicip-Franlab, 1998) have reached the conclusion that the most important potential source-rock intervals are the Bokh Shales, the Transition Zone (top Adigrat-base Lower Hamanlei), and the Uarandab Formation.

3.1.5.2 Potential reservoir rocks in the region

Based on core analyses and log studies (Beicip-Franlab, 1985 and 1998), two main groups of potential reservoir rocks have been defined: sandstones in the Calub and Adigrat Formations; and Carbonates in the Hamanlei Formation. Potential reservoirs units in the Calub (Permian) and Adigrat (Late Triassic –Early Jurassic) Formations consist of fine to very coarse-grained sandstones, with average porosities of 8 to 12% and fair to good permeability.

The Calub Sandstones have been penetrated in five structures. In the Culub field, they have a maximum cumulative thickness of 95m and porosities ranging from 7 to 19.4%. The Adigrat Sandstones are medium to coarse-grained, with maximum porosity and permeability values of 20% and 100mD, respectively. In the Culub field, the Adigrat Sandstones have a maximum total effective thickness of 39m with porosities ranging from 7.6 to 14.4%.

Carbonates in the Middle and Upper Hamanlei Formations essentially comprise syn-to post-rift grainstone/packstones and dolomites. Good petrophysical characteristics are found in non- or lightly cemented limestones and in dolomitized intervals (mainly in the uppermost part of the Upper Hamanlei Formation) (Hunegnaw, 1998). Maximum porosity and permeability values reach 23% and 1D, respectively.

3.1.5.3 Traps

A range of potential structural, combination and stratigraphic traps have been identified (Beicip-Franlab, 1985 and 1998): (i) Folded and faulted structures related to transpressional wrench tectonics (drag folds, flower structures along the ENE and NW fault trends); (ii) Basement-

related features, such as broad, relatively flat domal structures; (iii) Fault traps on the flanks of deep grabens; (iv) The pinch-out of the Calub Formation reservoir against basement; (v) Deep turbiditic fans within the Calub Formation and in the deepest part of the Shillabo half-graben; (vi) Sand lenses, sand bars and channels in the Calub and Adigrat Formations; reefal, oolitic and high-energy facies, as well as zones of dissolution or dolomitization, and zones of local fracturing in the Hammanlie Formation limestone.

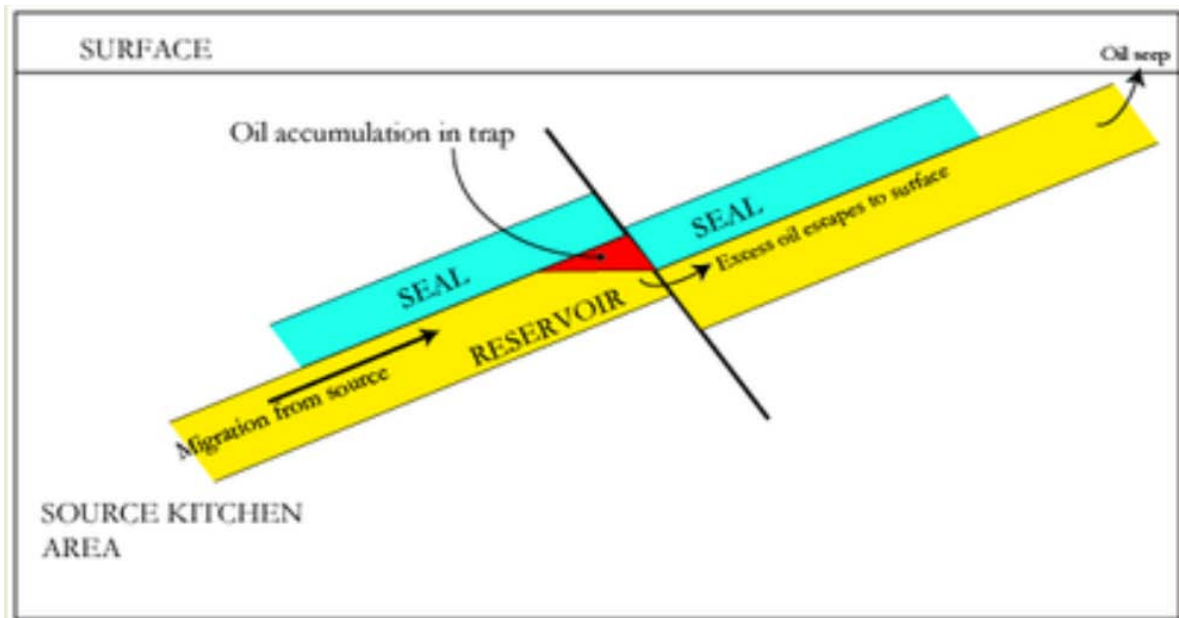


Figure 4 Structural traps, where a fault has juxtaposed a porous and permeable reservoir against an impermeable seal.

3.1.5.4 Seals

As stated by Hunegnaw (1998) and reference therein The Calub, Adigrat, Middle and Upper Hamanlei reservoir units are respectively sealed by the Bokh Shales, the Transition Zone, the Middle Hamanlei and Uarandab shales (and anhydrite for the Middle Hamanlei seal). These formations have a regional extent, and have an excellent sealing capacity with thicknesses ranging from 30 to 450 m.

3.1.6 Plays and prospects

As stated by Hunegnaw (1998) a number of leads (often seen on only one profile) have been defined, and several plays and corresponding prospects have been identified in relation to the recognized petroleum systems (Beicip-Franlab, 1998).

3.1.6.1 Adigrat plays and prospects

As stated by Hunegnaw (1998) Unlike the Calub Formation which is confined to small areas, the Adigrat Formation (Upper Triassic- Lower Jurassic) exists throughout the Ogaden Basin. Although it pinches-out on the northernmost flank of the basin. It is a continuous, sandstone reservoir of fairly good quality (especially in the lower part), with porosities ranging from 10-16% (up to 20%) and permeability up to 100mD. The maximum net thickness reaches 135m.

3.1.6.2 Middle Hammanlie plays and prospects

The Middle Hammanlie Formation (grainstones, packstones and dolomites of Early- Middle Jurassic age) occurs throughout the basin, but the unit's reservoir characteristics are best in the Calub Saddle and eastern part of the basin. Reservoir quality is rather poor in the Bodle Deep. The best reservoirs are the dolomitic beds with porosities ranging from 1 to 26% and permeabilities from 5 to 60mD. Net thickness reaches 100m in the Cuhb area and 195m in the Bokh area(Hunegnaw 1998).

Traps may be stratigraphic (permeability barriers within the carbonates), mixed and structural (gentle anticlines in the Calub saddle, and in the easternmost part of the basin).

3.1.6.3 Upper Hammanlie plays and prospects

As stated by Hunegnaw (1998) Carbonate reservoirs in the Upper Hammanlie Formation are uncemented grainstones and packstones located in the upper part of the formation. Porosities

range from 10 to 23% and permeabilities from 10mD to 1Darcy. Net thickness is significant in the Calub Saddle (40-135m) and in the eastern part of the basin (90-105m).

The carbonates are overlain by the dark, organic-rich shales of the Uarandab Formation (providing source rocks and seals) which are 30- to 120-m thick and contain Type II kerogen. Their petroleum potential reaches 20kg HC/ton rock and they are considered to be the best potential source rocks in the basin (Beicip-Franlab, 1998).

3.1.7 Exploration History of the Basin

According to Hunegnaw, 1998, Exploration of the Ogaden Basin was initiated in 1945 by the Sinclair Petroleum Co. Sinclair carried out aerial photography, surface geological surveying and mapping, and gravity, magnetic and reflection seismic surveys. Two deep exploration wells were drilled - Gumburo-I (3,087m) and Guludi-I (2,769m) in 1949 and 1952, respectively. The Guludi-I well encountered an oil show at the top of the Adigrat Sandstone.

Between 1954 and 1957, Sinclair drilled 15 wells in the eastern part of the Ogaden Basin. Elwerath, a German oil company, farmed-in during 1959 and carried out an aerial photographic survey with further geological mapping. Between 1961 and 1963, Elwerath shot 1,925 line-km of reflection seismic profiles. Gravity and magnetic surveys were also carried out, and they drilled Abred-1 (3,104 m) and Bokh-1 (3,061 m) in 1963 and 1965, respectively, but no significant oil or gas shows were encountered. A seismic survey of 1,963 line-km and gravity/magnetic surveys were carried out in 1965 and 1966.

Tenneco Oil Co., having obtained a license to explore the Ogaden Basin in 1969, carried out aerial photographic studies and geological surveying. The company reinterpreted the available geological and geophysical data while running an aeromagnetic survey that covered an area of

75,000 sq. km. In 1972 and 1973, Tenneco drilled three exploratory wells: ElKuran-1(3,189m), ElKuran-2 (2,015m) and the Calub-1 (3,685m) gas discovery.

Oil and gas were reported in several intervals throughout the entire section of both the ElKuran wells. Seismic acquisition was also carried out (7,850 line-km). Between 1973 and 1974, Tenneco drilled five further wells (Magan-1: 3,575m; Callafo-I: 3,242m; Bodle-1: 3, 91 lm; Hilala-1: 4,116m; and Gherbi-I: 1,976m), of which only Hilala-1 encountered significant oil and gas shows.

In 1973, the Whitestone Petroleum Co. and the Voyager Group (Voyager Petroleum Ltd., Polar Bear International Petroleum Ltd., Houston Oil Ltd. and the Cardinal Petroleum Co.) were awarded blocks in the northern and SW parts of the Ogaden Basin. They conducted aerial-photographic, geological and gravity surveys over large areas. The Whitestone gravity survey covered 77,000 sq. km, and that by the Voyager Group 5,400 sq. km. In addition, Whitestone carried out an aeromagnetic survey covering 16,000 sq. km in 1976.

An agreement between the Ministry of Mines and Energy of Ethiopia and the USSR Ministry of Geology was signed in 1979. The USSR group of experts studied and reinterpreted all the previously acquired data. In accordance with the agreement, the Soviet Petroleum Exploration Expedition (SPEE) was established in 1980 to explore the area between Shillabo and Hilala in the central Ogaden Basin. SPEE shot 1,544 line-km of seismic profiles and drilled four wells: Shillubo-1 (2,900m), Hilala-2 (2,400m), Hilala-3(1,760m) and South Culub-1 (1,700m). Oil and gas shows were reported in the first three of these wells. An intensive seismic survey (2,777 line-km) was carried out by SPEE between 1984 and 1987, and during the same period, five further wells were drilled: Fafl (3,446m), Mugun-2 (4,306m), Culub-2 (3,732m), Calub-3 (3,690m) and Tulli-I (4,010m).

The earlier Culub-1 gas discovery was confirmed by Culub-2, which tested gas at a rate of 19.5 x 10³ cu. m/d from the Calub Formation. After renewal of the agreement, the SPEE continued its operations and drilled seven appraisal wells on the Culub field (Culub-4 to Culub-10).

In 1990, Maxus Energy and Hunt Oil Co. were awarded exploration acreage in the NE and SW of the Ogaden Basin, respectively. In 1995, Hunt Oil drilled a dry well (Genule-I) near the Genale River oil seep in the west of the basin, and Maxus relinquished its concession after conducting seismic work (1,160 line-km). At the present time, 14 blocks are open for exploration in the Ogaden Basin.

Petronas Carigali Overseas Shd. Bhd. of Malaysia explored for crude petroleum at Block G in the Gambella Basin. In August 2005, the company was awarded three concessions in the Ogaden Basin. Wal-Wal and Warder covered 36,796 square kilometers (km²); Kelafo, 30,611 km²; and Genale, 25,571 km².

In October 2005, Pexco Exploration of Malaysia was awarded a concession that covered 29,865 km² at Abred and Ferfer in the Ogaden Basin. Pexco planned to spend \$5 million on exploration over 4 years beginning in 2006. In October, Afar Exploration Company of the United States was negotiating with the Government over a concession and production-sharing agreement that covered 18,000 km² in northern Afar Regional State (Bekele, 2005).

Currently The Ogaden basin has been divided into 21 blocks, and exploration rights have been awarded for many of them. Companies with concessions in the basin include Netherlands registered Pexco Exploration, Petronas (Malaysia), Lundin East Africa (Sweden), South West Energy (Hong Kong), and Afar Explorer (USA).

CHAPTER FOUR

4. Data Analysis and geological interpretation

4.1 Image processing

Most of the information for this project was extracted from satellite images. As raw satellite data contain significant distortion they can't be used as maps. Hence, to extract maximum information from the satellite images, it is necessary to compensate for the distortion introduced during image acquisition. Image restoration (pre-processing) processes are designed to recognize and compensate for errors, noise, and geometric distortions introduced into the data during the scanning, transmission and recording processes. The objective is to make the image resemble the original scene (Sabins, 1987).

The ETM+ images were obtained in "tiff" file formats and orthorectified. Only 6 bands (multispectral bands,) were layer staked using ERDAS Imagine 9.1 software.

Various image enhancements techniques are used to extract different thematic information. In addition color composites were generated using the staked layers to get high quality image. The enhancement techniques and band combinations are used to extract thematic layers such as lineament. In remote sensing, tonal anomalies and subtle changes in information content are used as important indicators when applying imagery for oil and gas exploration.

4.1.1 Image Enhancement

Enhancement is the process of improving the visual interpretability of an image by increasing the apparent distinction between the features in the scene (Lillesand et. al., 2004).

Various types of enhancements were applied to the raw Landsat images to increase their visual interpretability. The major enhancements performed were spatial (non directional edge,

convolution and resolution merge), radiometric (histogram equalization, haze reduction), and spectral (principal component, decorrelation stretching and RGB to IHS, IHS to RGB).

Non-directional edge and convolution were applied for detecting lineaments. In order to improve the spatial resolution of the multi-spectral bands, the high resolution panchromatic band (band 8) of ETM+ sensor was resolution merged with the multi-spectral bands of ETM+ sensor images. The resulting image has got spatial resolution of that of the panchromatic band which is 15m. The resolution merged images are used in the interpretation of non-changing parameters like lineament.

4.1.2 Contrast enhancement

This method highlights the information contents of the geological features and pick up color anomaly by enhancing and transform methods. Due to the sparse vegetation cover of the Ogaden basin it encounters low image saturation; the three channels of color composite image data have strong correlation.

Linear and non-linear transform of color composite imagery of 7, 4, 2 as RGB were followed by enhancement of brightness, and color and saturation space. This resulted in a significant improvement of contrast information and better saturation of the image data.

4.2 Combination of remote sensing imagery and DEM data for geologic discrimination

The basic premise of remote sensing (satellite images) is that different objects do have different reflectance properties at different EMS (electromagnetic spectrum) interacting with them since all objects vary with internal structure, morphology, and chemical composition (Lililand and keifer, 2004).

The advent of readily available, low-cost Landsat 7 imagery has provided new opportunities for the application of remote sensing to geologic investigations (David et. al.. 2001). Improved resolution from band 8 15-m resolution panchromatic image data allows creation of sharp photographic-quality images at scales as large as 1:100,000 (100K) to 1: 50,000 (50K). Band combinations using Landsat bands 7-4-2 as RGB color images, with color infrared band 4 assigned green for vegetation, generate true-color appearing images. Enhanced lithologic content in the red band results from use of the short-wave infrared bands 7. According to James, (2001), this combination provides a "natural-like" rendition, while also penetrating atmospheric particles and smoke. Healthy vegetation will be a bright green and can saturate in seasons of heavy growth, grasslands will appear green, pink areas represent barren soil, oranges and browns represent sparsely vegetated areas. Dry vegetation will be orange and water will be blue. Sands, soils and minerals are highlighted in a multitude of colors. This band combination provides striking imagery for desert regions. It is useful for geological, agricultural and wetland studies.

Form the satellite image with Band combination of 7-4-2 as RGB, the area is generally divided in to two with the NW – SE trending structure dividing the area. A western region dominated by the outcropping gray colored Hammanlie formation and an eastern region dominated by reddish to the north eastern and gray and vegetation covered in the south eastern of Jassoma units. The dividing line between the two regions is marked by the major NW-SE trending Marda fault Zone/system. To the south eastern extreme of the study area there area are surface expression of the more or less parallel drainage pattern Fig5 below.

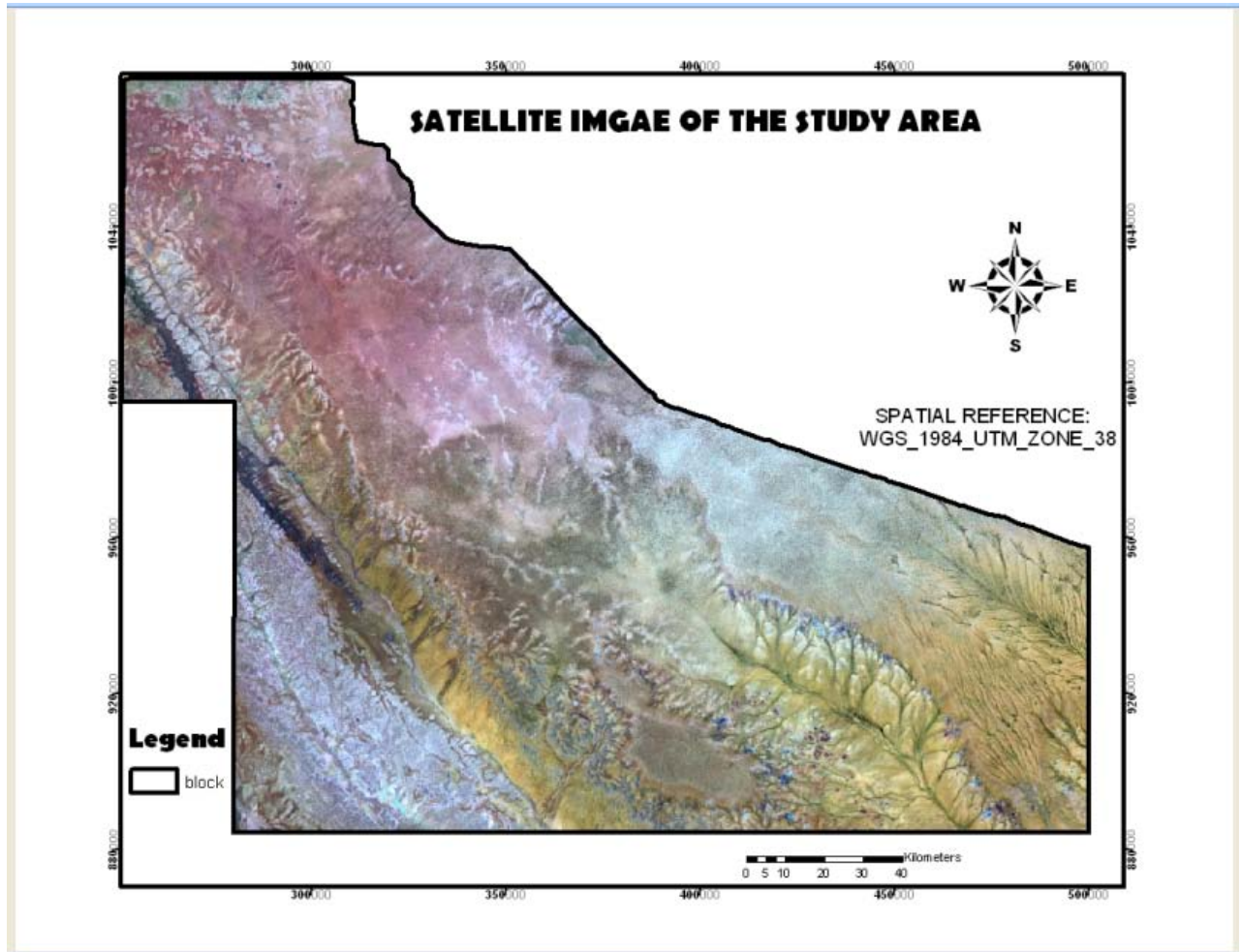


Figure 5 satellite image of the study area

4.2.1 Application of DEM data

The most direct way to display DEM data in a raster format is to color each pixel according to its elevation, using a standard eight-bit (256 values) scale (Fig6).

The application of surface DEM (digital elevation model) data can eliminate the geometric distortion in remote sensing imagery caused by terrain relief, improve the positioning accuracy of remote sensing imagery and create a realistic 3D imagery, providing precise geographic coordinate for surface survey. The digital elevation data can provide with valley and trench map and drainage map. In this study 30m SRTM DEM data is used for the analysis.

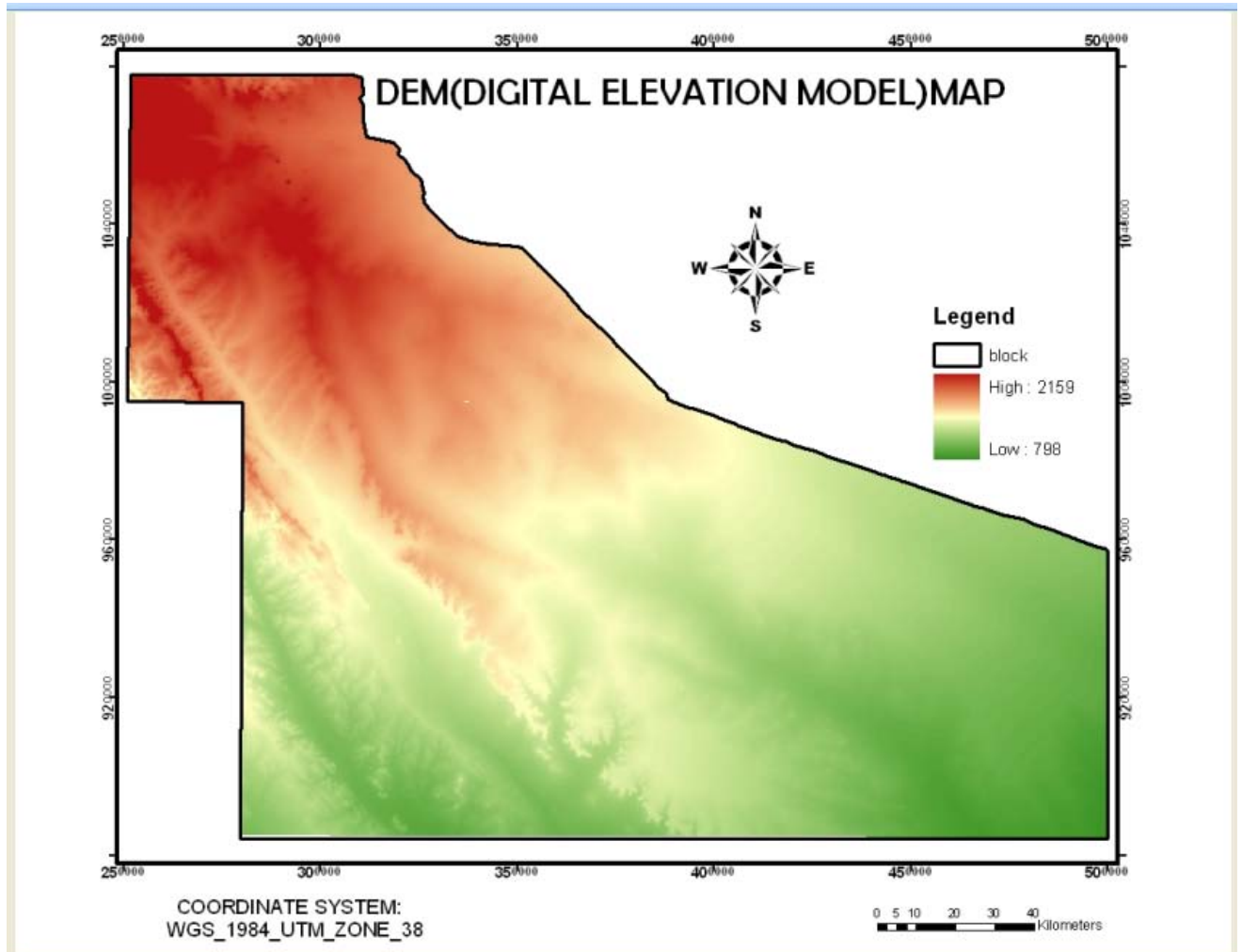


Figure 6 Digital elevation model map and slope map of the study area

And from the DEM data analysis the northern and NW part of the study area have very high elevation ranges of 1645m to 2159m which is the highest in the area. To the NE extreme and to the middle it is characterized by high elevation ranging from 1436 to 1645m. and again to the south the elevation is decreasing and have an elevation of 1085 to 1436m. to the SE and SW corner of the study area is characterized with very low elevation having an elevation ranging from 798m to 1065m.

4.2.2 Slope

Slope map is generated by ArcGis9.2 using the spatial analyst surface analysis to derive slope from the 30m SRTM data to give surface slope change of the study area. Abrupt Changes in slope across the landscape are indication of structural features and lineaments seen in slope maps may represent fault scarp localities. To the western and extreme north the area has high slope and toward south eastern it is decreasing (Fig7).

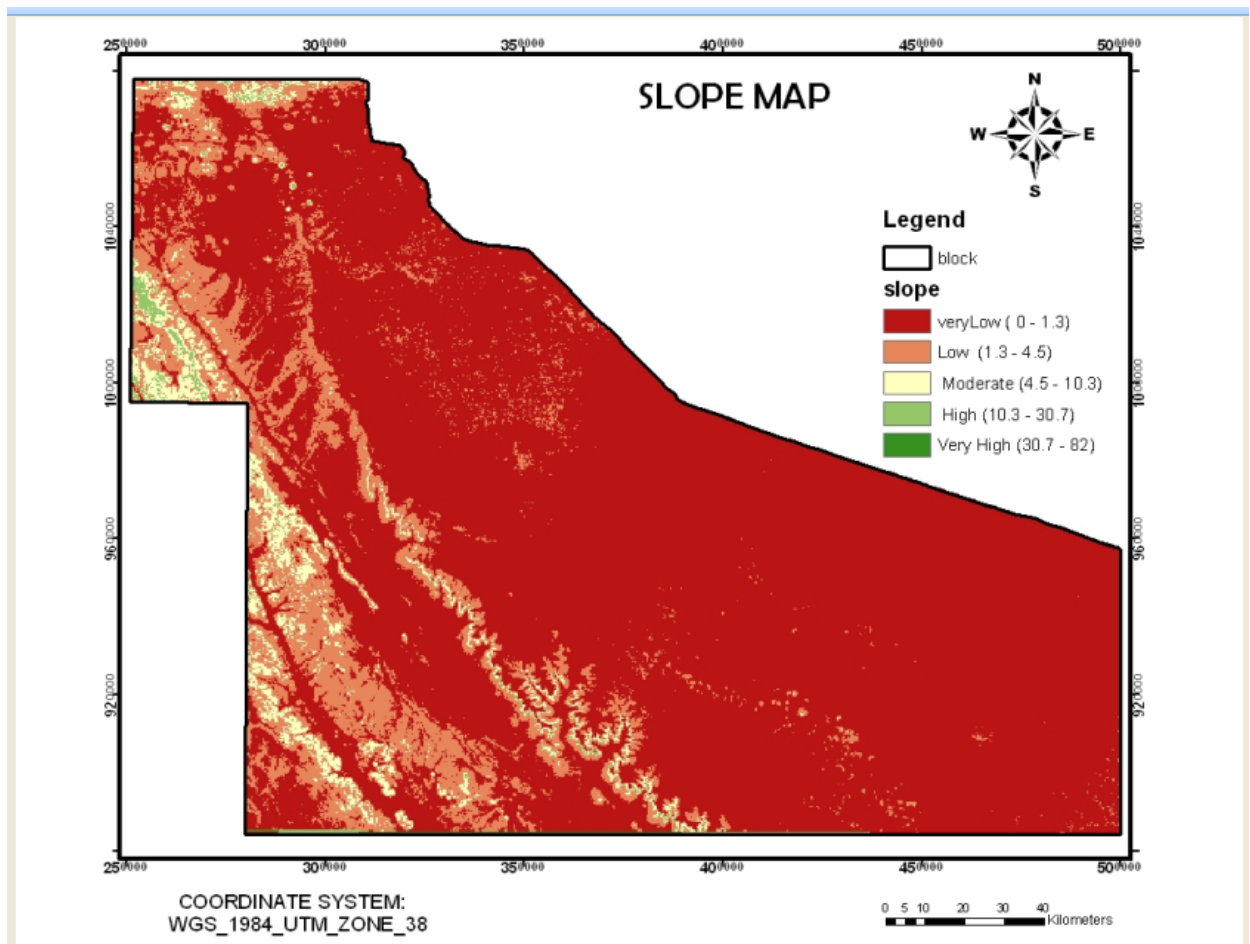


Figure 7 slope map of the study area

The output image contains slope values which range from 0° to 82°. In the study area slope map, it is noted that a linear break in slope angles exists that has a value of around 10°. This is manifested by the red to yellow colour transition in Figure (Fig7). It is also noted that this

systematic break in slope angles matches with the elevation change across the tonal geomorphic evidence (e.g. lineaments).

4.2.3 Shaded relief

The DEM were processed so that shaded relief images were produced using various illumination conditions in order to study the long-term evolution of landforms in the study area. From shaded relief, we can visualize geomorphic evidence such as V shaped valleys and tilted footwall areas along strike of major faults (Pike, 2003). For the shaded relief image in Figure (Fig8), histogram equalization stretching, is used to enhance the visualization to digitize large lineaments. From Fig5, we can trace the major faults and we can infer their dip direction, because there are numerous northwest- southwest on the western side and NNE-SSW trending valleys on the eastern side of the study area. The existence and parallel arrangement of the footwall valleys are inferred by the linear shape of the shadows. This shaded relief map is used mainly to manual lineament extraction, combined with pan sharpened satellite image with different false color composite, to have high accuracy of the linear feature.

In addition, the other major use of the shaded relief is for visual interpretation and study of drainage patterns in the study area; from the shaded relief map (Fig8 below) There are major structures controlling features which are dictating the flow direction of the streams, as it is shown on the drainage map Fig10.

4.3 Drainage analysis

As stated in Prost (1992) Streams in alluvial terrain may show a marked angularity over buried structures. Fractures propagating up section due to reactivation, or caused by bending due to drape, exert control on stream channel erosion forming abrupt, nearly right-angle bends.

4.3.1 Automatically generated drainage system

In recent years, automatic extraction of drainage network from DEM with the help of Geographical Information System (GIS) has become possible and is now being practised the world over for hydrological studies (Saraf, et.al, 2004).

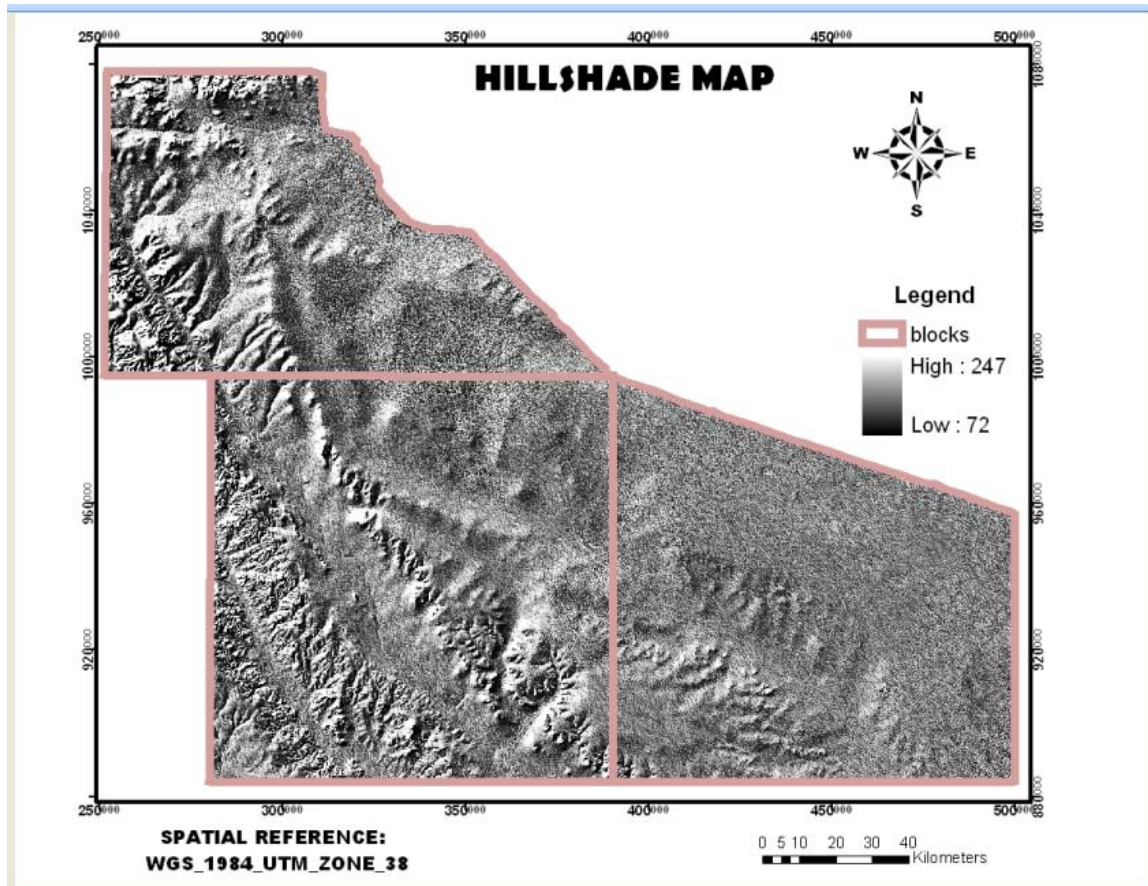


Figure 8 shaded relief map of the study area

The ArcGIS Hydro data model (ESRI, 2002), often shortened to ArcHydro was used to obtain the drainage network from the DEM. During the processing, potential problems with the terrain representation can be identified, thus preventing the DEM errors from propagating to the later stages of the analysis. The purpose of terrain preprocessing is to perform an initial analysis of the terrain and to prepare the dataset for further processing. Since DEM always contain some depressions, which hinder the flow routing, a depression-less DEM is created through

neighbourhood analysis. The steps involved in automatic extraction of drainage network including preprocessing of the digital elevation data are; removal of artificial depressions (sinks) by iterative process. To do so the depressions should be removed first by patching the missing data using 3dem software and then convert the DEM data to raster data set by importing the data to ArcGIS 9.2 by using conversion tool. The sinkfill function in ArcGIS9.2 ArcHydro module fills sinks in a grid by modifying the elevation value.

After preprocessing the data, series of processing procedures are followed to generate flow direction from each individual cell.

The series of procedures in terrain processing of ArcHydro extension is shown in Fig9 below; flow direction – flow accumulation – stream definition - stream segmentation – catchment grid delineation – catchment polygon processing — drainage line processing. The flow direction is the direction in which water flows out of individual pixel (or cells). The output of this series of process gives the drainage network of the area which can convey information about the underlying controlling structure which in turn gives an insight to see the overall structure of the area.

The drainage clearly follows NW- SE trend in the whole area Fig10. Generally the flow direction of the area is structurally controlled. In the eastern part of the study area there is more or less parallel drainage pattern. In the middle of the eastern part the major N- S drainage shows a change in course in to the NW- SE near Obole town which would be related with the offsetting underlying fault, a correlation of this change is also noted with the image interpretation and the integration of the Maxus data. In the northern part of the study area, in block 9A, a clear radial drainage pattern is observable from the topographic high in the centre.

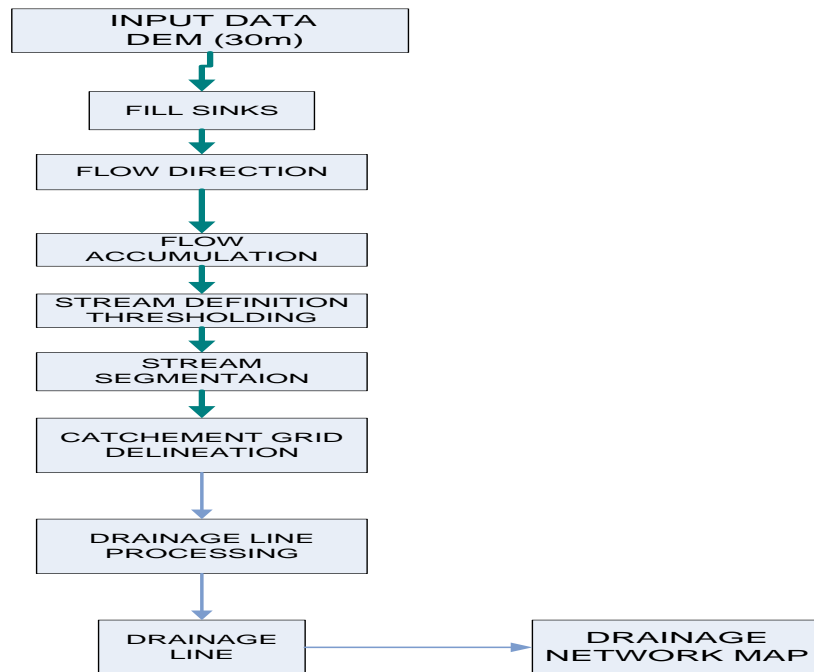


Figure 9 Automatic drainage extraction flow chart.

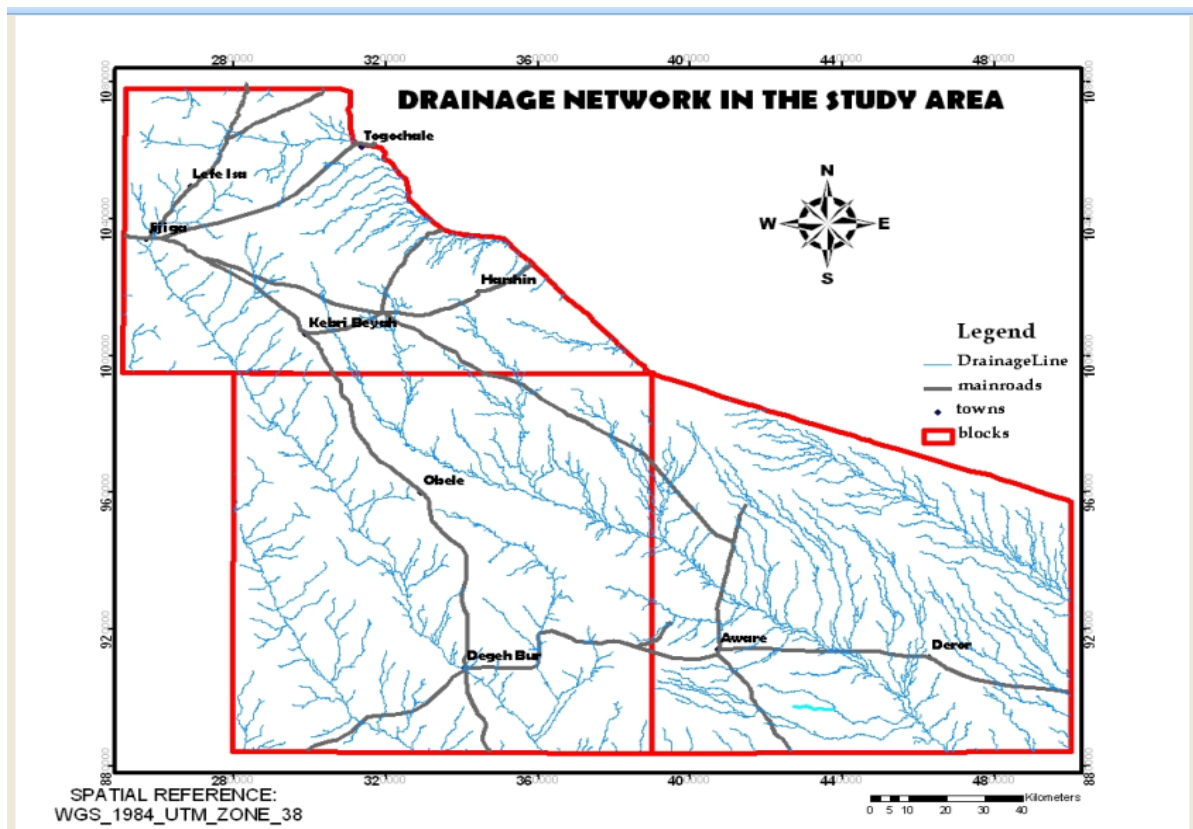


Figure 10 Automatically generated drainage network

In addition to Archedro TNTmpis (NPA, 2007) is used for drainage analysis to extract drainage lines from DEM data and the data is manually edited to get the output.

4.4 Lineaments and related features in the study area

Lineament is defined as a mappable simple or composite linear feature of surfaces, whose parts are aligned in straight or slightly curving relationships, and which are differs distinctly from the pattern of adjacent features and presumably reflects a sub surface phenomenon (O’Leary, Friendman and Phon 1976)

According to Sabins, (1997), the surface feature making up a lineament may be geomorphic (caused by relief) or tonal (caused by contrast difference). The surface feature may be landforms, the linear boundaries between different types of terrain, or breaks within a uniform terrain. Straight stream valleys and aligned segments of valleys are typical geomorphic expressions of lineament. Lineaments may continuous or discontinuous. In discontinuous lineaments the separate feature are aligned in a consistent direction and are relatively closely spaced.

Lineaments may be simple or composite. Simple lineaments are formed by a single type of feature, such as a linear stream valley or aligned topographic escapements. Composite lineaments are defined by more than one type of feature, such as an alignment of a linear tonal feature, stream segments, and ridges.

4.4.1 Lineament extraction and mapping techniques

Lineament extraction and analysis is one of the routines in mapping large areas using remotely-sensed data, most of which is the satellite images (SÜZEN, TOPRAK V, 1998). Mapping of lineaments can be carried out from topographic maps, digital elevation models (DEM), satellite images and aerial photographs. High resolution satellite images like Quick Bird and IKONOS are

best images for mapping lineament accurately. Medium resolution Landsat, SPOT, IRS and ASTER missions are the most commonly used imageries in lineament mapping (Gezahegn, 2007).

In this study lineament extraction is performed in two ways:

- Manual lineament extraction
- Automated lineament extraction

As indicate by Flow chart in Fig11, the manual lineament extraction is carried by using pan sharpend ETM+ satellite image and DEM data(Hillshade). To extract the lineament with better accuracy and to pick all the linear features from the satellite image, filtering operation, principal component analysis/PCA/, band rationing and color composite processing area carried out with ERDAS Imagine9.1.

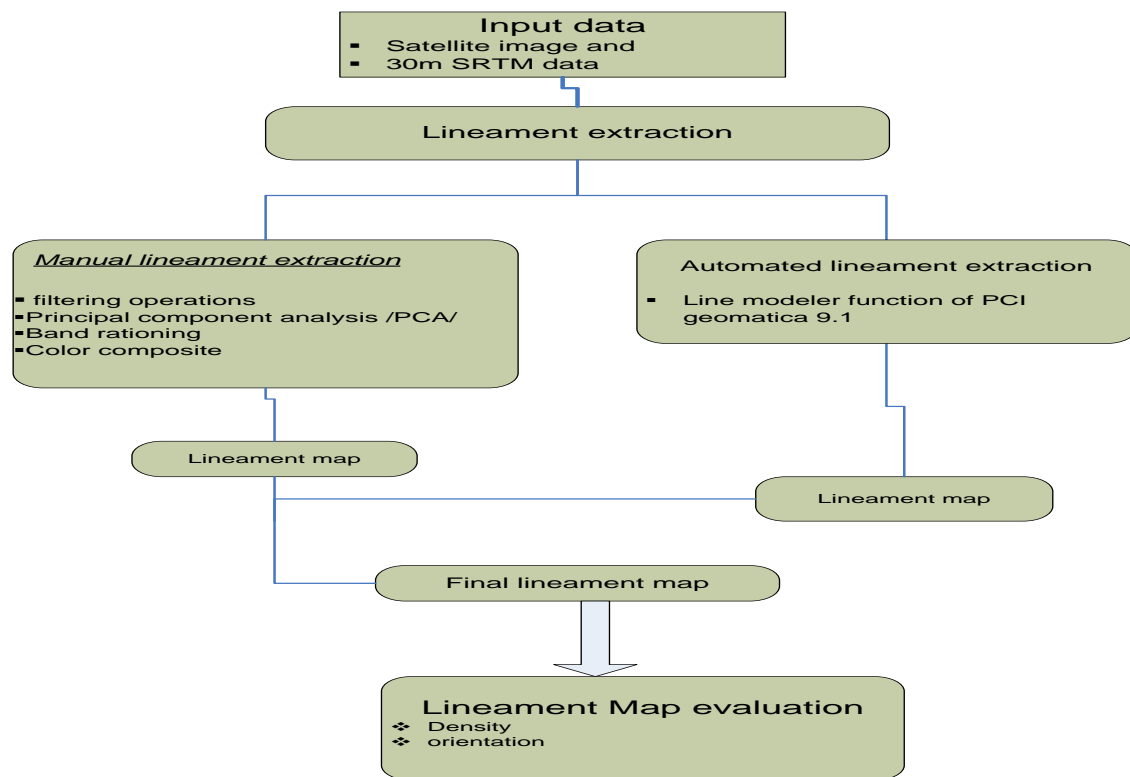


Figure 11 Lineament extraction flow diagram

4.4.2 Manual Lineament Extraction

In manual extraction method, the lineaments are extracted from satellite image by using visual interpretation. The lineaments usually appear as straight lines or “edges” on the satellite images which in all cases contributed by the tonal differences within the surface material. Some general features that help to identify the lineaments can be listed as follows: Topographic features such as straight valleys, continuous scarps, Straight rock boundaries, Systematic offset of rivers, Sudden tonal variations and Alignment of vegetation.

At the beginning, lineaments indicated on the geologic map of the study area were digitized and draped over the satellite image to have idea about lineament on the satellite images.

There are several image enhancement techniques that can contribute to manual lineament extraction. In this study four of commonly known techniques are used in the preparation of the final lineament map. These are filtering operations, Principal Component Analysis (PCA), spectral rationing and the color composites.

Various edge detection and enhancement algorithms and non directional and directional filters applied for recognition of lineament. Principal Components Analysis (PCA) is a spectral enhancement which can be used to compress the information content of a multi-spectral data set (Sabins, 1987). PCA uses mathematical algorithms to transform n bands of correlated data into n principal components which are uncorrelated, such that the coordinate axes of the components are mutually orthogonal (corner). The first principal component (PC-1) describes most of the variation of the brightness values for the pixels of the original bands (Jensen, 1986). Subsequent components explain less and less of the data, with the final PC usually corresponding to atmospheric noise in the data rather than any ground features (Sabins, 1987). Only 1st, 2nd and 3rd principal components and their false color composite in RGB order are used to pick major lineament features.

Thematic layers generated using different enhancement techniques and band combinations were draped over individual principal component image and their false color composites to identify similar features which were not clearly visible on the original image.

In addition to Landsat ETM⁺ sensor Images in this thesis manual lineament mapping was done using and 30m SRTM DEM data, with visual observation .

4.4.3 Automated Lineament Extraction

Lineaments are extracted from satellite images using automated extraction techniques in order to compare with the manually extracted lineaments. The main advantages of automated lineament extraction over the manual lineament extraction are its ability to uniform approach to different images; processing operations are performed in a short time and its ability to extract lineaments which are not recognized by the human eyes.

The automated lineament extraction in this study is performed by the LINE module of PCI Geomatica Version 9.1 software applying on Landsat ETM+ scene. This information is provided from the Geomatica users' manual (2001). Band 7 of the image with a spatial resolution 30*30 meter is selected for automated lineament extraction because this band is useful for discrimination of lineaments and other geological features such as mineral and rock types and is also sensitive to vegetation moisture content (Sabins, 1996).

The extraction process is manipulated changing the six parameters. Several lineament maps are generated using different threshold values. The most suitable threshold values are selected (RADI=100; GTHR=100; LTHR=100; FTHR=5; ATHR=3; DTHR=80) considering these lineaments as fault lines. General properties of faults are taken into consideration such as the length, curvature, segmentation, separation and so on in order to determine the threshold values.

Although, the extraction of the automated ones is performed with different threshold values, the one presented here is the best output considering these lineaments as fault lines.

The final automated lineament map generated is overlaid with the satellite image and drainage map and those that correspond to the main roads, trails, major drainage line and image boundary are erased manually (Figure 12).

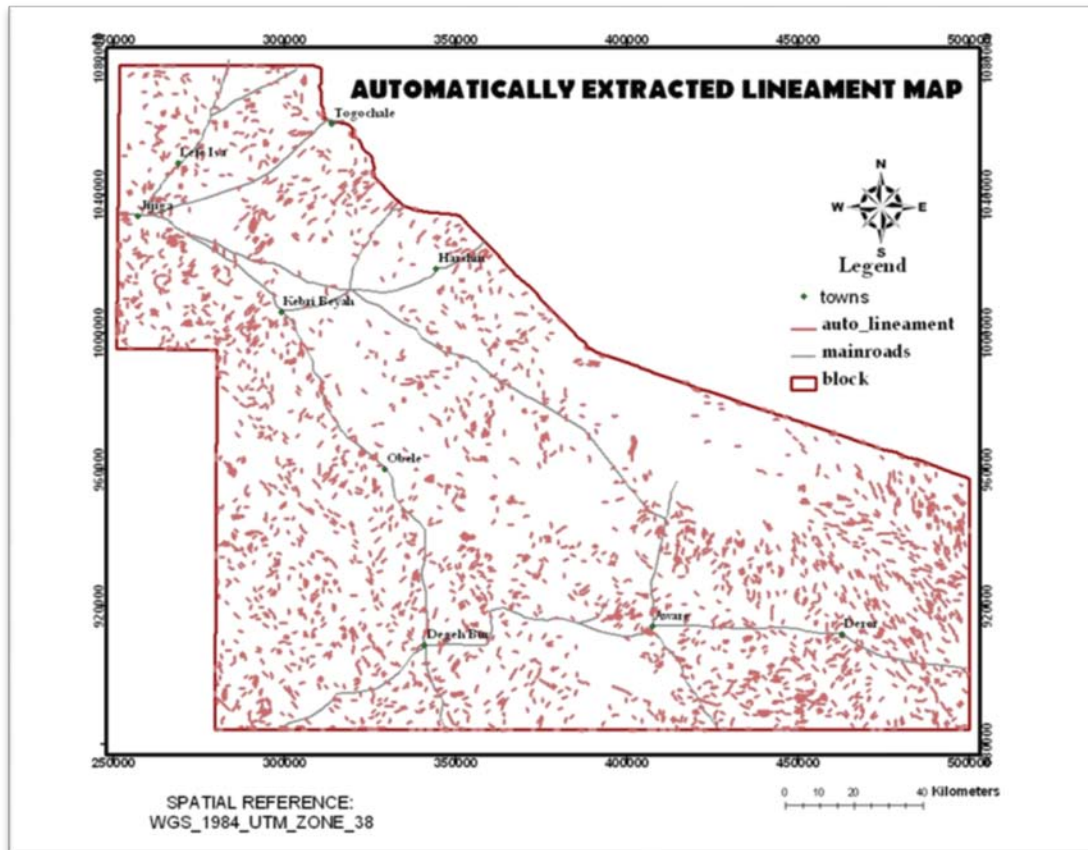


Figure 12 automatically generated lineament map

After completing the manual digitization of lineaments from the satellite images and SRTM data they were overlaid with the geologic map to see the consistency. It was found that the majority of the bigger linear features identified from the satellite images and SRTM data were also indicated on the geologic map. But there were many newly mapped lineaments especially those smaller in length.

Comparison of two maps indicates that the manually extracted lineament map is more reliable in terms of length of the lineaments, their segmentation, their spatial distribution and their orientation. Because it is found that the manual extraction produces better results, For this reason the output of the manual lineament is taken as the final lineament map, the automated one is not be considered in the rest of the thesis.

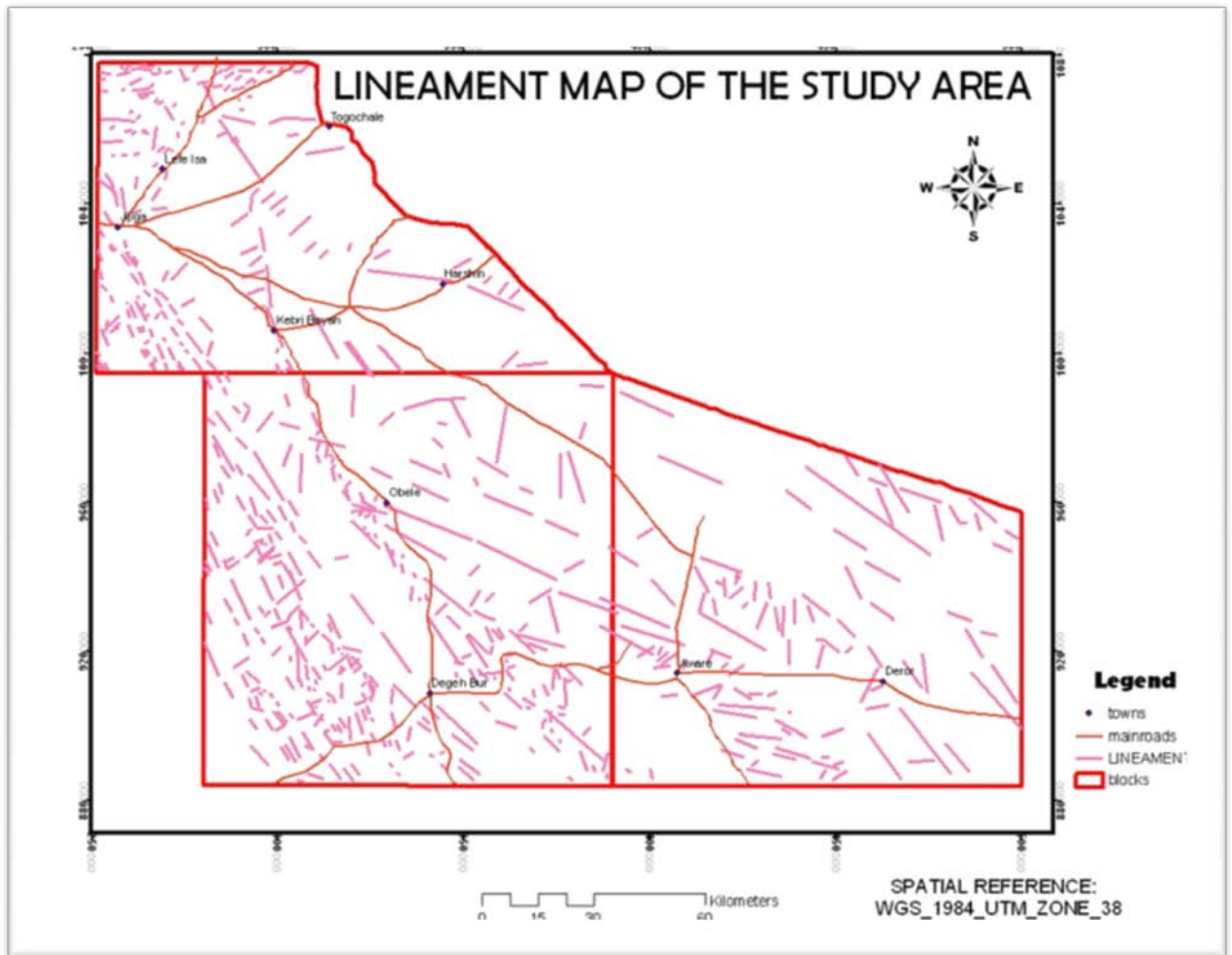


Figure 13 Lineament map of the study area

In order to distinguish anthropogenic linear features such as foot path which is dominant in the study area the mapped lineament vector map was overlaid on the scanned old topographic map of

the study area after which the non-geologic linear features were omitted. The final lineament map was overlaid with the drainage map digitized from the topographic map and automatically extracted drainage map and it was found that most of the mapped lineaments correspond to the drainage line which confirms that the drainages are structurally controlled (Figure14).

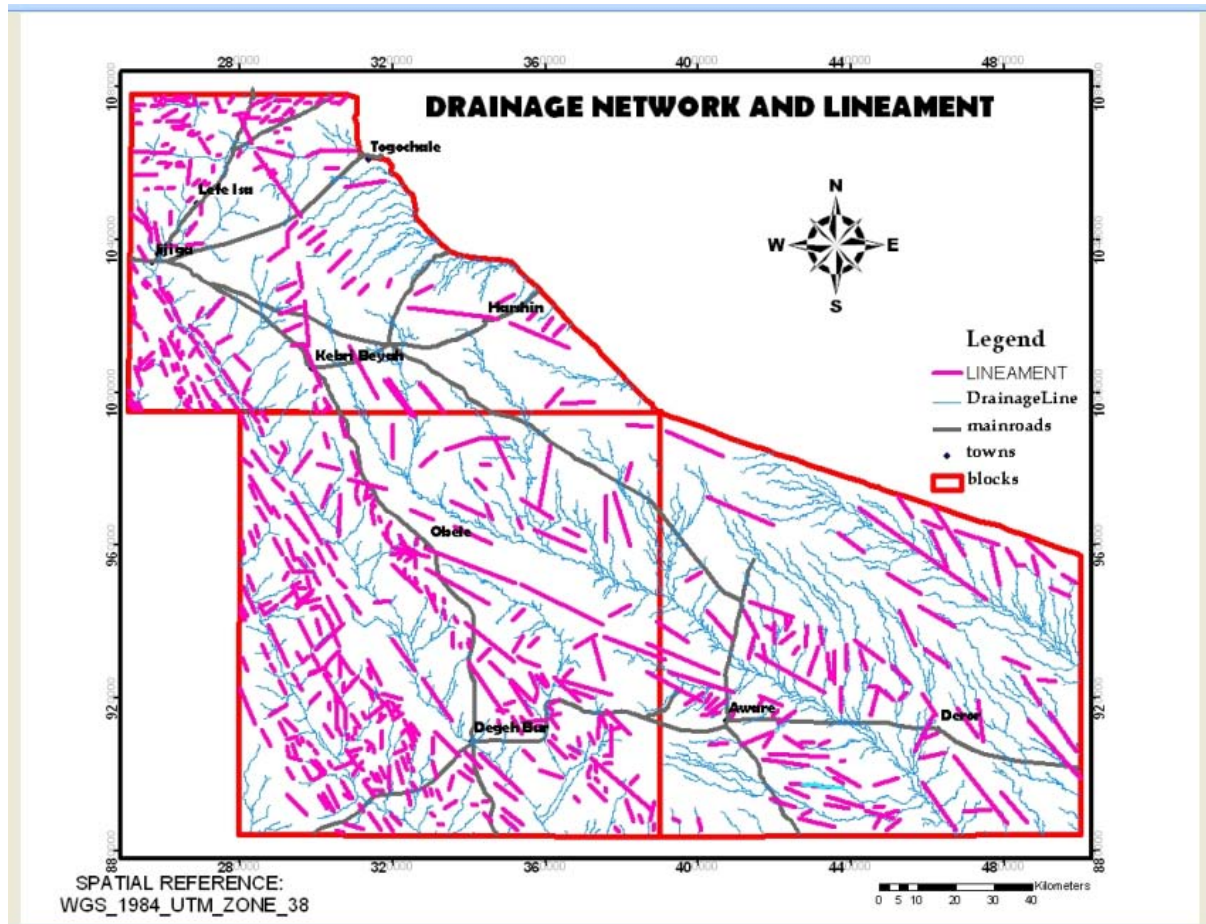


Figure 14 Map showing Drainage and lineament showing that drainage is structurally controlled.

4.4.4 Lineament map interpretation

The northern border of the study area, where the basement rock is outcropped, sees a switch in structural trend to approximately E-W direction. The fault trend mapped on all of the data-sets is dominantly NW-SE (Marda) to the western of the study area, with the ENE-WSW (Karoo), in the

SE of the study area, being localised to the south and east of the block. The faults are curvi-linear in nature and suggest that they are listric in section. No strike-slip movement is apparent from the faults mapped though there is likely to be some offset present, even though it didn't confirmed by field-checking. The sandstone escarpment has two main trends; NW-SE & WNW-ESE which is clearly shown on the sandstone outcrop. The NW-SE trend is clearly related to the Marda fault system.

4.4.5 Lineament Density map

The digitized lineament map was imported to ArcGIS where lineament density was calculated with spatial analyst tool. The purpose of the lineament density analysis is to calculate frequency of the lineaments per unit area. This is also known as lineament-frequency (Greenbaum, 1985). Accordingly this analysis produces a map showing concentrations of the lineaments over the area.

From the Figure below (Figure 15) noted that there are several fault zones in the area. in general the faults are exposed in the form of straight line that extends in NW-SE direction along the Marda fault, several sub-zones (or fault sets) are distinguished in the area to the eastern and northern and SE of the study area.

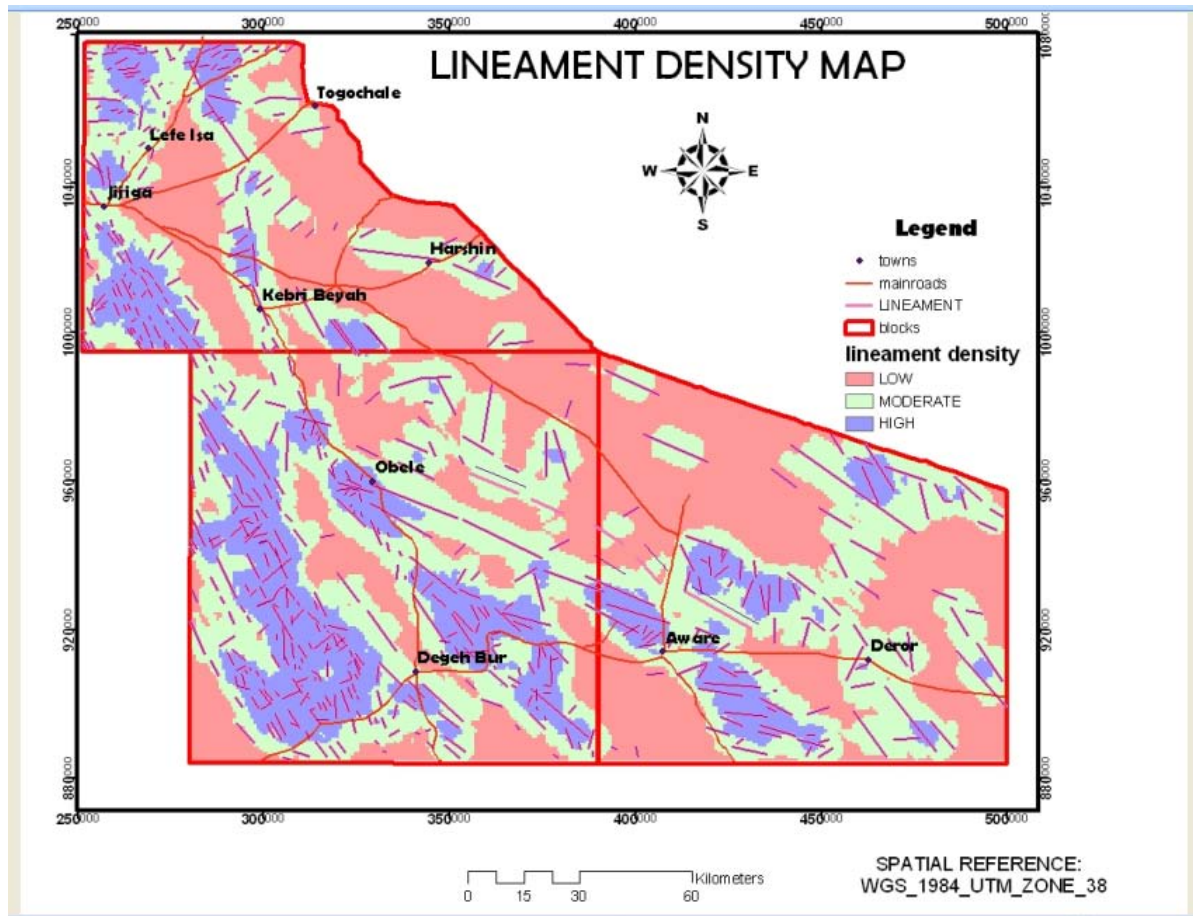


Figure 15 Lineament density map

4.5 Geological interpretation of the study area from satellite images

Remote sensing techniques have great utility in lithologic discrimination and production of geological maps at different scales. As stated in Qari, 2008 and references therein, Landsat data has been utilized by several authors for lithologic discrimination.

Interpretation methods for Landsat images and other forms of remote sensing imagery are determined by the objective of the interpreter (Sabins, 1997). In geological remote sensing the two application fields which benefit most from information extracted from satellite imagery are lithological and structural mappings (Kheiralla K. M.et. al, 2006).

Methods of aerial photograph interpretation and Remote sensing multispectral analysis can be used for stratigraphy studies in areas where strata have favorable exposure and Lithology, and where current climate conditions are suitable (Maria S. et. al., 1995).

It is usually possible to group surface units into categories based on color, texture, vegetation cover, etc. Since intrusive and metamorphic rocks are of little interest to the petroleum geologist (Prost, 1992), except as areas to be avoided, sedimentary units are considered as a suitable Lithology for petroleum exploration.

In this thesis the Landsat images (Fig6) were chosen for their large spectral resolution and their appropriate spatial resolution. The Enhanced Thematic Mapper plus images have been used after being digitally processed in order to achieve maximum lithological differentiation. For investigating the lithology in the study area, the use of some spectral processing techniques was necessary to prove the efficiency of R.S. in this Field. A linear contrast stretch with haze reduction, was used to make full use of the 256-output value. Enhanced images of single band or false-color images comprising three contrast stretched bands can then be interpreted geologically.

To achieve this goal principal component analysis and IHS to RGB and RGB to IHS transformation are applied separately. Due to the limitation of mosaicking output of the four scene satellite image of the study area, Geocover image is used for comparison.

4.5.1 The use of Principal Component Analysis for investigating lithology

The Principal Component (PC) Analysis process allowed the extraction of new information. It shows the directions of grey levels distribution in feature space. In general, PC analysis is a statistical technique widely used in RS to choose the suitable bands and to show spectral differences which helps to display clearly the correlation of the spectral values between the

different channels. Due to the large number of spectral bands, much information was acquired from Landsat ETM+ images, especially in the infrared region of the spectrum. As result, these data were very useful for lithology, soil and terrain pattern differentiation. After Principal Component transformation, using linear and nonlinear adaptive stretches, visual inspection of the PC color composites indicates that the composite containing the first three PCs 1st, 2nd and 3rd PC are found to be the most effective and gives much information.

4.5.2 The use of IHS transformation for investigating the lithology

For cover type discrimination, the IHS transformation has been successfully applied to ETM+ data; it presents colors more nearly as they are perceived by humans (Buchanan 1979). It is a system based on the color sphere in which the vertical axis represents Intensity, the radius represents saturation, and the circumference represents hue. The intensity represents brightness variations, saturation represents the purity of color or amount of white, and hue represents the dominant wavelength of color. IHS image was prepared from ETM+ bands 7, 4 and 2 for the study area. From the above analysis on the image the geological map is become modified as shown on Fig22.

After the image is analyzed in the Laboratory field work has been conducted by choosing traverse which could give access to all the lithologies present. And the following lithologies are identified.

4.6 Field Works and identified Lithology

4.6.1 Basement rock

The northern extreme part of the study area is characterized by the Alge group which is biotite and hornblende gneiss, granulite and migmatite with minor metasedimentary gneiss. It is of Archean age. Gneiss with banding of black and white minerals, there is a vein with an orientation of E – W direction the vein is mica (Muscovite) and calcite (Quartz). There is a dipping of the gneiss in NW – SE direction with the dip of 60° , there are a number of veins with different orientation NW – SE.



Figure 16 gneiss rock showing banding and veins

4.6.2 Hammanlie formation

To the western of the study area on and behind the Marda Fault there is a Hammanlie formation of oxfordian limestone and dolomite with gypsum and shale interbeds. This Limestone is partially massive and sometimes thinly bedded, sometimes cherty and oolitic.

It forms an uplifted topography which is prominent feature in the area. At base of these features there are surface exposures of calcareous limestone with Very thin bed of extensive size, with few cm of thickness. The limestone is calcareous and conglomeratic. The size of the conglomerate is very coarse and very hard. Locally it is more oolitic limestone with dominant intercalation of sandstone. It is also calcareous, vesicles and highly weathered on the top of the

outcrop. In most cases the Size of the exposure is extensive laterally but vertically limited to few centimeter. The limestone is more fossiliferous and harder with dominant thickness. The limestone is lighter and porous.

Carbonates tend to be resistant to physical weathering. They are often ledge-formers, and are easily fractured. In arid areas, they form sinkholes, have thin soils and steep-sided valleys. In humid climates they develop buttes as well as sinkholes, and the topography is rounded. Drainage patterns are considered "deranged" as a result of ending suddenly in sinkholes. Carbonates can be either source or reservoir for hydrocarbons (prost, 1992).



Figure 17 Fractured and oolitic limestone



4.6.3 Jassoma formation

The study area as it is digitized from 1 to 2 million Ethiopia geological map of Geological survey of Ethiopia is mainly dominated by jassoma formation. This formation is late cretaceous Paleocene sandstone (Mengesha et. al, 1990, EIGS, 1996,).Sandstones tend to be resistant and ledge-forming. The high porosity in sandstones and their resultant soils causes low runoff and widely-spaced drainage. Sandstones are resistant and brittle and display fracture systems prominently. Gullies have steep sides and flat bottoms. Sandstones exposed around a basin margin can reveal the distribution of a hydrocarbon reservoir deeper in the basin, and may contain seeps. It is locally Quartzitic, with shale and gypsum and has a total thickness of about

425m (Assefa, 1988). It is very dominant and covers approximately 70% of the study area. It is locally conglomeratic, coarse grained, and has general trend of the bedding in NW – SE.



Figure 18 Sandstone



Figure19 Sandstone with cross bedding

There is a cross bedding of the sandstone and conglomeratic beds (Figure below xxx). There are few cracks which are parallel joints there is infilling of secondary materials in the cracks, Parallel cracks

4.6.4 Auradu formation

During the field work in the area there are extensive lateral out crop of this formation with dominance of limestone on the way from Obole to Harshim about 7 km from Obole to the east. This outcrop is more oolitic limestone with dominant intercalation of sandstone, It is also calcareous, vesicles on the top of the outcrop Size of the exposure is extensive laterally but few centimeter of vertical thickness. On the upper topmost part of the formation Late Paleocene – Early Eocene limestone with iron-stained cherty concretions and basalt flows.

4.6.5 Shale

Shale erodes easily because of their small grain size. They form badlands (arid) or gentle valleys (temperate or humid Climate). High runoff leads to closely spaced drainage. Joints are not well expressed because the units are more ductile.

Shales are found as an intercalation with the limestone in the Hammanlie formation in the NW part of the study area and in the limestone exposure near Jijiga.



Figure 19 shale and limestone layers

Thin layers of shale are intercalating the limestone with irregular intervals, different layer thickness, hardness and property. It is very soft at the top and harder toward the bottom. There is very minor intercalation of sandstone at the bottom. The thickness increases downward and becomes darker and black.

4.6.6 Basalt/ Ashangi formation:

There are small patches of volcanic mountains (of Ashangi formation, Mengesha T. et. al, 1990, EIGS, 1996,) which is highly weathered alkaline and transitional basalt flows with rare intercalation of tuff, often tilted (include Akobo basalts of southwest Ethiopia).

Weathered, massive rocks of basalt, Hard and fine grained. General orientation of the Mountain is in NW-SE direction. At the base of these mountains, there is again calcareous limestone with big conglomerates. The size of the clasts is boulders of different Lithology and the possible explanation is the depositional environment is at the beginning of eruption. There are breccias

In addition there are continuous mountainous exposure of basalt in the western side of the study area are on top of the limestone. They are the highest topography in the study area. The sharp contact between the basalt and limestone shows the dipping of the limestone toward the basalt beds in SE direction. The basalt is highly jointed with columnar jointing with orientation of NW – SE direction. The depositional environment is assumed to be post – tectonic eruption on the side of the plane of weakness. I.e. after the faulting of sedimentary and basement rocks, the volcanic is erupted.

There are alternating beds of sandstones and basalt intercalated or interbedded: basalt – sandstone – basalt – sandstone. The sandstone is agglomerate with big boulder of clasts. Locally at the southern end of volcanic exposure there is dyke and sills.

Depositional environment is volcanic environment with bigger clasts of volcanic affecting the normal horizontal sedimentary bedding. It is a kind of pyroclastic eruption.



Figure 4.18 a) basalt with columnar jointing



Figure 4.18 b) dyke and sills in the sandstone

4.6.7 Quaternary alluvial deposits

There are also undifferentiated quaternary alluvial and Lacustrine deposits: sand, salt, clay, diatomite, limestone and beach sand between the high elevation volcanic and Hammanelie limestone and the lower elevation Jassomma formation. This formation is the second aerially dominant next to the Jassomma formation.



Figure 20 Quaternary alluvial deposits

From both satellite image interpretation and field work the following lithological map is produced.

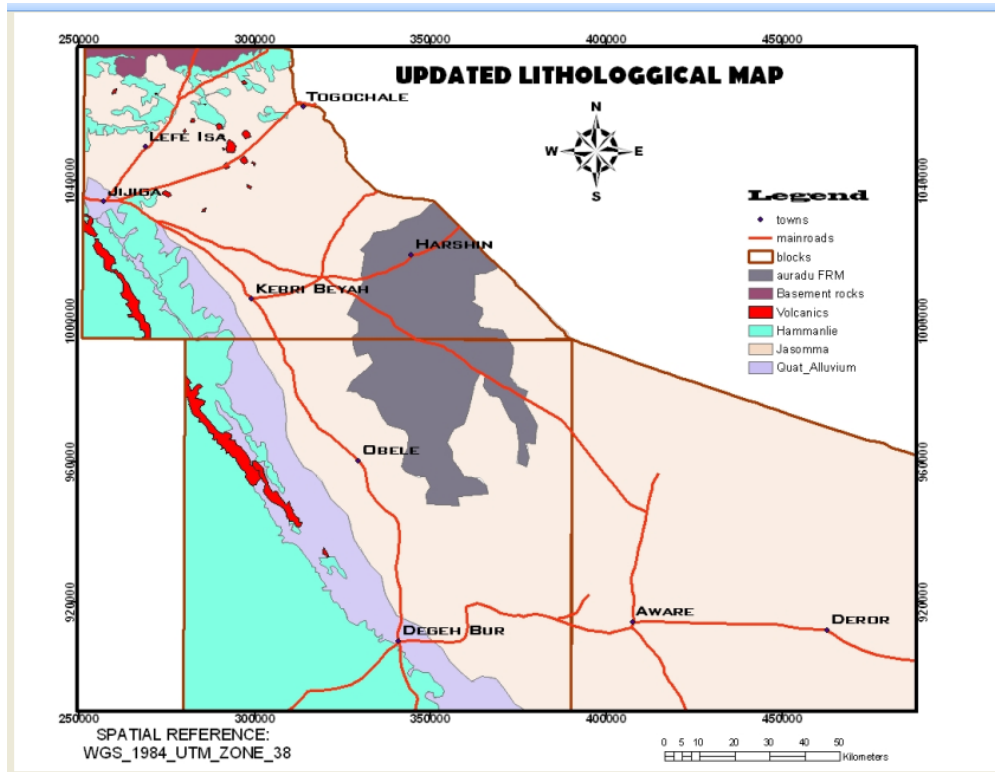


Figure 21 interpreted geological map

In this research remote sensing data was used for the identification of lineament, for lithological mapping to identify different lithologies from Landsat ETM+. Remotely sensed data due to its wide area coverage and multi-spectral nature help in identification and mapping of these factors with selective ground checks. The parameters generated from remote sensing images were combined with other petroleum potential indicator parameters like lithology, drainage density, and slope derived from existing maps and geophysics data such as gravity, seismic data interpretations helps to produce the petroleum potential map of the study area.

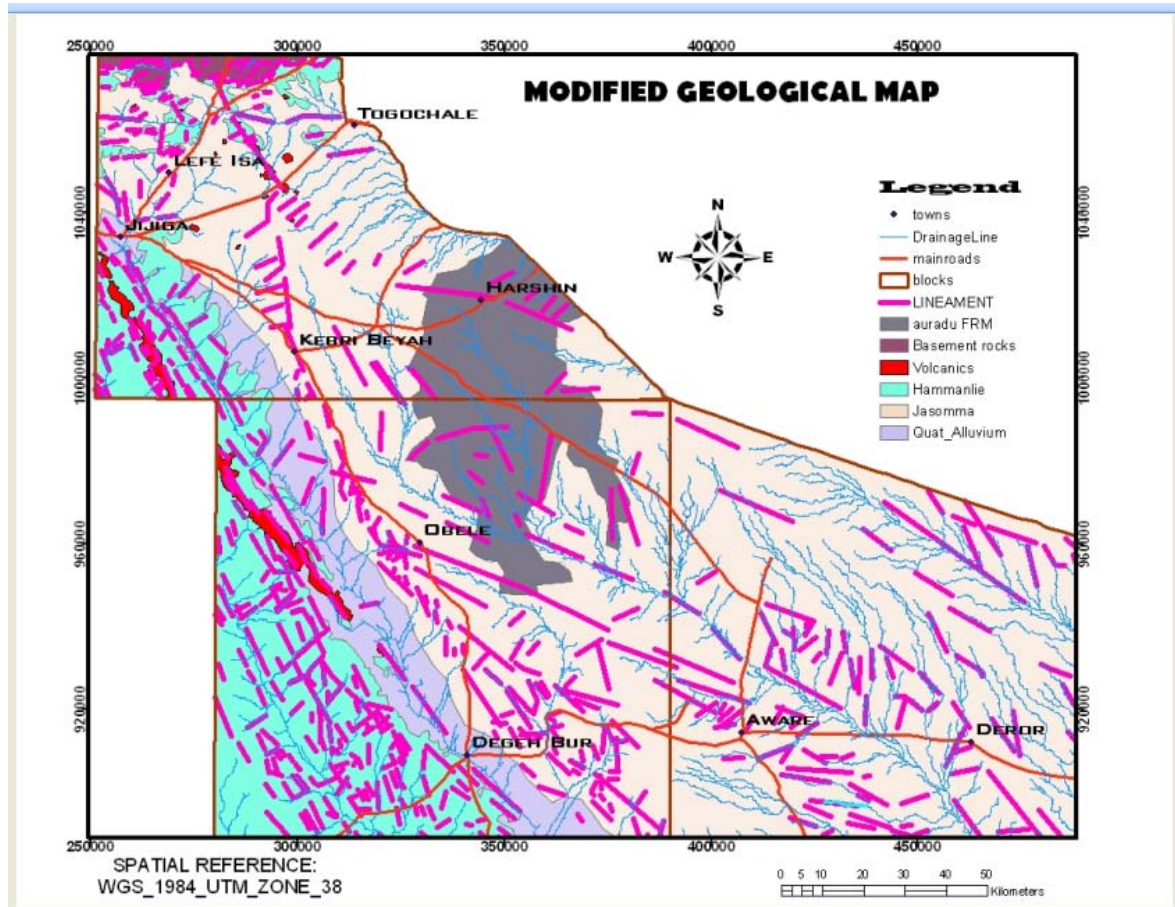


Figure 22 modified detailed geological map

4.7 Local geology

As indicated in Mengesha et. Al., (1990) and EIGS, (1996,) there are six major Lithology are identified in the study area. Namely Jassoma formation, Hammanlie formation, quaternary alluvial deposit, Auradu formation, Alge group, Ashanghi formation.

Jassoma formation: This formation is late cretaceous Paleocene sandstone (It is locally Quartzitic, with shale and gypsum and has a total thickness of about 425m (Assefa, 1988). This Lithology is very dominant and covers approximately 70% of the study area.. There are also undifferentiated quaternary alluvial and lacustrine deposits: sand, salt, clay, diatomite, limestone and beach sand between the high elevation volcanic and Hammanlie limestone and the lower

elevation Jassomma formation. This formation is the second dominant next to the Jassomma formation. There are small patches of Ashangi formation which is deeply weathered alkaline and transitional basalt flows with rare intercalation of tuff, often tilted (include Akobo basalts of southwest Ethiopia).

The northern extreme part of the study area is characterized by the Alge group which is biotite and hornblende gneiss, granulite and migmatite with minor metasedimentary gneiss. It is of Archean age. This constitutes the lower basement.

To the western of the study area on and behind the Marda Fault there is a Hammanlie formation of oxfordian limestone and dolomite with gypsum and shale interbeds. The Limestone is partially massive and sometimes thinly bedded, sometimes cherty and oolitic. Lower, Middle and Upper Hamanlei Formations represent an Early Jurassic to Callovian syn-rift marine sequence, and consist of the following lithologies: limestone with intercalated shales (in the lowermost section); anhydrite, dolomite and limestones with local oolitic and stromatolitic beds (in the middle section); and bioclastic oolitic limestones (in the uppermost section).

Hamanlei formation is a shallow-marine to lagoonal and deltaic deposit that consists of organic-rich carbonate and evaporites with subordinate shale and sandstone. Carbonates assigned to this formation may act as reservoir rocks, and thin interbedded shales as source rocks and seals.

The Marda fault zone in the south-Eastern Ethiopia was first recognized in the Marda Range near Jijiga and was called Marda Hills line (Purcell, 1976). The “linear NW-SE arrangement of basalt capped summits with basaltic plugs” and the associated Bouger anomaly were considered indications of a major “Volcanic-tectonic” lineament. Subsequently the fault zone was described as a complex of NW-SE trending fault, down through to the NE and possibly extending 200km in to the Ogaden Basin (Purcell, 1976).

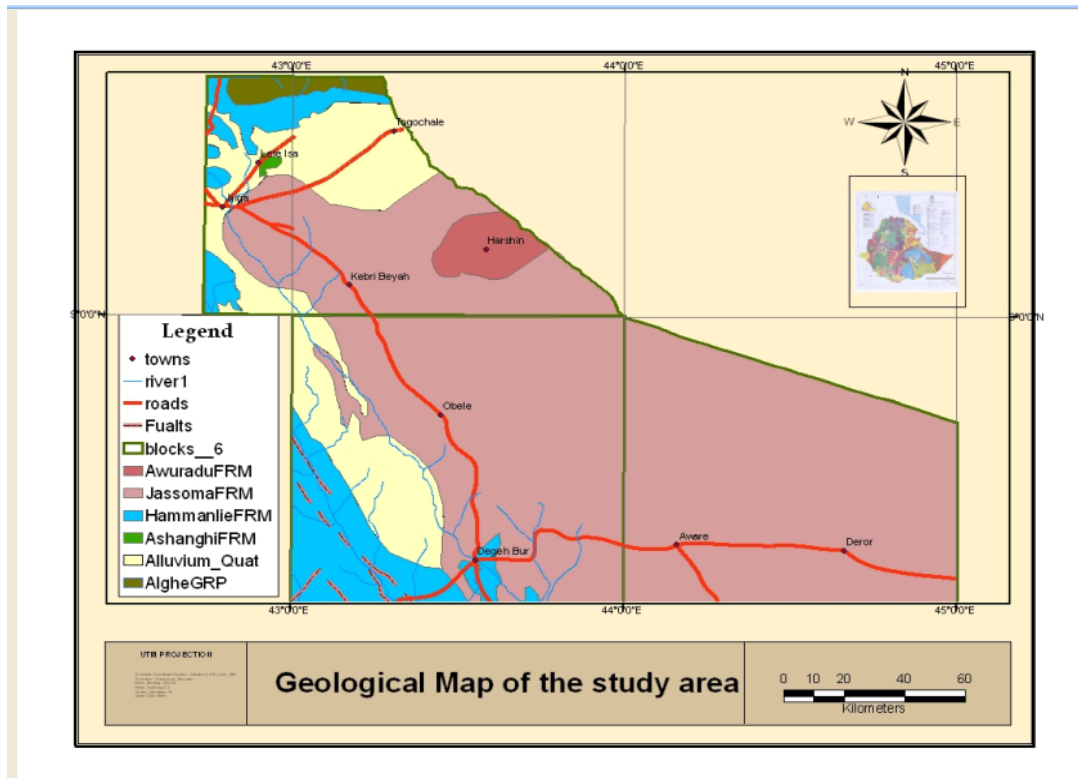


Figure 23 geological map of the study area before modification as it is digitized from 1:2Million geological map of Ethiopia.

Structural form lines determined from air photography consistently swing to the right near the zone suggesting dextral displacement on the faults zone.

The local Geology and the interpreted geological maps area fits with respect to the lithology except the absence of Basalt in the old geologic map north of Marda fault. The modified one much advanced than the old geologic map with respect to lithological details, structural details, orientation and frequency of the linear feature. The drainage network of the area is modified in a very detailed way to give the structural trend in the area.

CHAPTER FIVE

5. Integration of Geophysics with Remote Sensing and Geographic Information

System for petroleum exploration

Geophysics is a science that applies different tools and methods of physics to explore the first few miles of the earth's crust. It attempts to identify rock types and delineate their gross structure. The ability to do this has proved to be invaluable in the exploration for oil and gas, and in the mining and construction industries.

Maxus Energy, Inc. has spent approximately four years investigating the petroleum potential of the northern Ogaden in southeastern Ethiopia (Maxus Ethiopia, INC, 1993). During the four years multiple field geological surveys, two separate gravity field surveys, a magnetic field survey, 1160 km line of seismic survey and remote sensing surveys were undertaken. Additional data from previous work was acquired, reprocessed and integrated into the interpretation.

The purpose of this effort was to investigate the possibility of the existence of a Mesozoic basin capable of generating and trapping commercial quantities of hydrocarbons.

5.1 Seismic

The central physical property upon which seismic prospecting is established is the variation in speed of the transmission of elastic earth waves or sound waves through different geological structures measured by time (Society of Exploration Geophysicists, 1948, 1956). The speed of transmission of the waves through different geological structures is proportional to the density or compactness of the formation. Unconsolidated formations such as sands and shales transmit waves with a low velocity, weak sandstones and limestones with higher speeds, and massive crystalline rocks such as limestones, rock salt, schists, and various igneous rocks with very high

speeds. The refraction method aids petroleum explorers in locating salt domes that transmit elastic earth waves at high rates of speed. The reflection method of seismic exploration is based on the echo of sound waves off layers of varying density rock, which are reflected at a high angle back to the surface. In 1931 Petty Geophysical Engineering Company of San Antonio invented and implemented the reverse profile method of reflection shooting (Olive, 1976) that became the standard method of shooting throughout the industry. Now most seismologists, instead of using dynamite to make shock waves, use a machine called a thumper to produce elastic shock waves.

Reflection seismology, or 'seismic' as it is more commonly referred to by the oil industry, is used to map the subsurface structure of rock formations. Seismic technology is used by geologists and geophysicists who interpret the data to map structural traps that could potentially contain hydrocarbons. Seismic exploration is the primary method of exploring for hydrocarbon deposits, on land, under the sea and in the transition zone (the interface area between the sea and land).

5.1.1 Seismic work in the study

Maxus Energy, Inc. has spent approximately four years investigating the petroleum potential of the northern Ogaden in southeastern Ethiopia (Maxus Ethiopia, 1993). Western Crew 720 finished the recording of 1160 kilometers (Fig24) of 60 and 120 fold Vibroseis data on January 1993.

5.1.1 Seismic result obtained

The Maxus 'Seismic Basement map' provided has little detail mapped in the north of the block. Only in the south are E-W trending basement faults and structural highs/synclinal axes mapped. There is little outcrop present in this region to relate with any structures. But when integrated with the gravity data there is some correlation between the synclinal axes and the gravity lows.

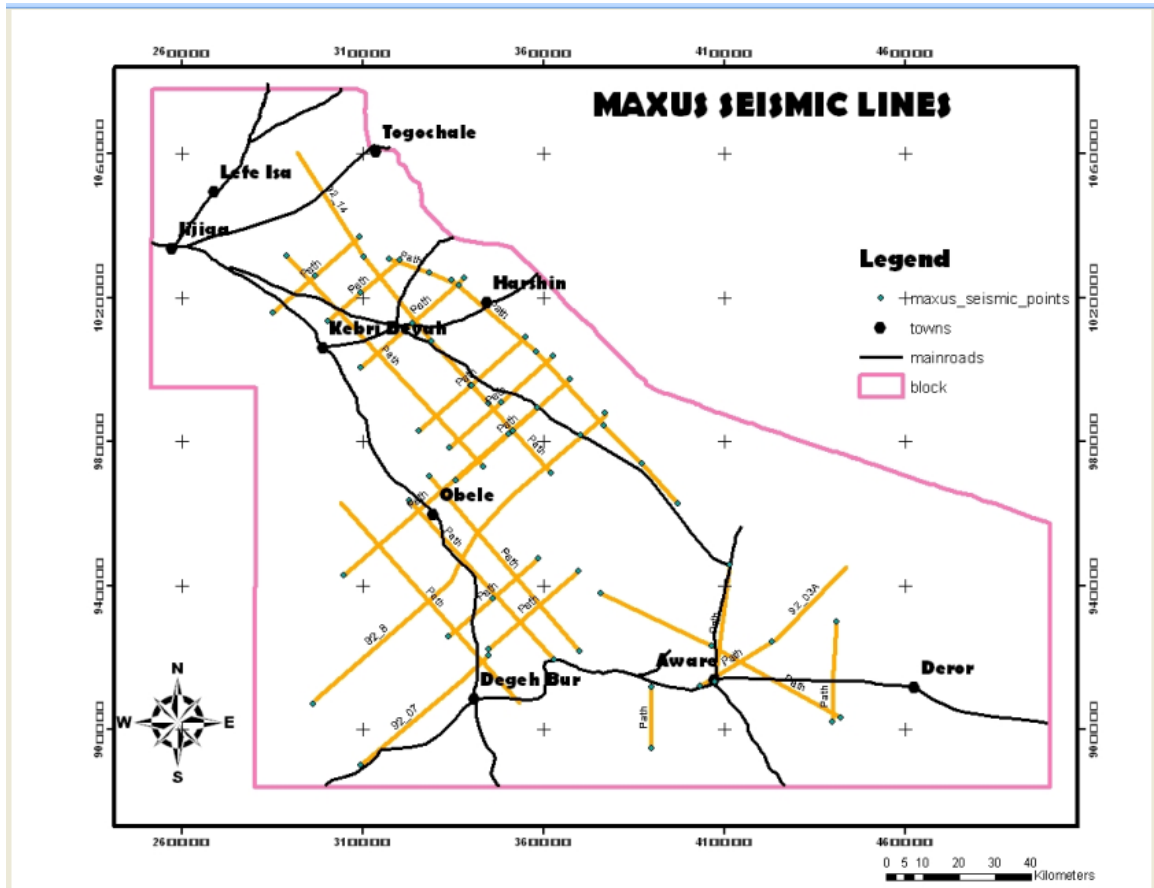


Figure 24 seismic lines location done by maxus

The Maxus ‘Seismic Basement map’ outlines two trends: ENE-WSW (red), Fig25 these are basement faults that have not been reactivated and WNW-ESE/NW-SE trending faults (blue), these are basement inverted faults with Mesozoic movement. The former have no surface representation, whereas the latter clearly tie-in with faults and linears mapped on the image interpretation. The faults are sub-parallel to the Marda trend which is more NW-SE. The relationship between the faults mapped on the escarpment and those in the Jurassic section and on the margins of the Marda is not clear. It maybe that the faults splay from the Marda system,

though their curvature (towards the SW) suggest that they are not strike-slip related splays (these would curve away from the main fault zone towards the NE).

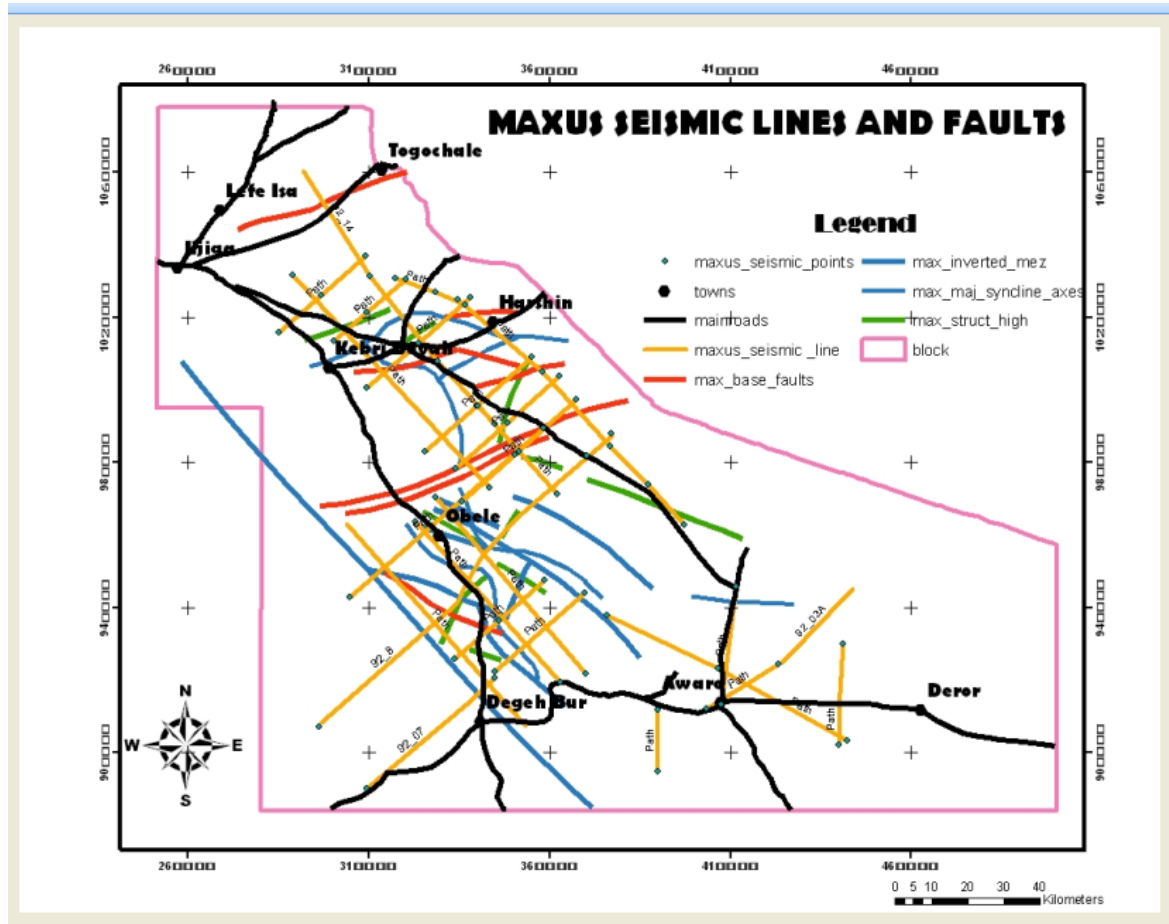


Figure 25 seismic line and faults that are generated from Maxus

The Maxus data-set only marginally covers the block. The structures mapped in block 9 can be extrapolated into block 13 and there is some coincidence of the WNW-ESE features mapped on the surface with the inverted faults on the Maxus data. However, within block 13 only the Mesozoic graben contour (>2.5 km depth) is mapped on the Maxus data. This E-W trending graben does tie-in with the residual gravity which also has an E-W trend (see Figure 26). There is

an 'indent' in the south of the graben contour that looks like it should tie-in with the large circular high seen on the gravity, perhaps this has been poorly mapped on the original Maxus map.

The ESE striking Marda fault, interpreted on seismic and magnetic data and visible on Landsat imagery defines the southern limit of the Tertiary Mesozoic Grain. To the south of the Marda fault, Jurassic rocks are mapped on the surface.

5.2 Gravity and magnetic

5.2.1 Gravity work in the study area

As stated in Maxus Ethiopia, INC, (1993) report, Nortech Surveys (Calgary, Alberta, Canada) took gravity and magnetic reading along all the 20 seismic lines with the exception of line 1 Fig24. Station spacing for most of the project was 250 meters. Parts of some of the lines were sampled with a station spacing of 500 meters. These residualized gravity profiles along with the magnetic profiles were displayed at the same scale as the processed seismic lines and attached to the bottom of the time migrated sections.

South of Degehabour, a positive Bouguer anomaly of $\sim 40 \times 10^{-5} \text{ m/s}^2$ trends NE – SW on the eastern side of the Marda lineaments and east – west on the western side (Purcell , 1976). Profile analysis of the Degahabur anomaly defines a residual anomaly of almost $5 \times 10^{-5} \text{ m/s}^2$, which may indicate superbasement structure. This is supported by a negative magnetic anomaly of 10^{-2} T coincident with the gravity anomaly. The main anomaly may be interpreted in terms of crustal structure similar to the Bouguer gravity anomaly on the zone near Jijigga.

Black et. al., (1974) defined a Tertiary age for the zone, evidenced by the abrupt contact of Mesozoic and Tertiary outcropping units across the zone, the displacement of Mesozoic sediments by NW-SE faults near Jijiga and the volcanics of the Marda range which locally

overlie the cretaceous Amba Aradam sediments. Mesozoic activity on the zone is, however, evidenced by structural thinning of the lower Jurassic Hamanlie series on the basement structures, confirmed by reflection seismic surveys, and the thinning of upper Jurassic limestones west of Jijigga. The large bouguer anomalies on the zone and the basic change in character of the regional bouguer field across the zone have been interpreted as indirect evidence of Precambrian tectonism.

The residual gravity data of the study area (see Figure 5.3 above) map two gradient trends; NW-SE and ENE-SW. The former is thought to be related to the Marda trend with the latter being related to the Karoo rift trend (NPA, 2007).

The gravity data clearly shows an ENE-WSW trending low that has been associated with Palaeozoic Karoo tectonics. From the Mesozoic onwards the main trends present are associated with the NW-SE trending Marda. The outcropping Jurassic section in the west is clearly also affected by NW-SE trending extensional tectonism. Both the Bouguer and residual gravity outline this block as what is thought to represent the eastern 'arm' of the Karoo tri-radial rift system at the middle.

On the eastern side of the study area, the residual gravity clearly outlines an E-W trending gravity low through the centre of the block that extends east ward, with E-W trending highs both to the north and south. A large circular high exists in the centre of the E-W trending low near Aware town. Integrating the gravity with the image interpretation and the ancillary data supplied shows that structurally the block is complex. Magnetic minerals may directly indicate the presence of oil and gas deposits, therefore magnetic methods are applied to hydrocarbon exploration in oil-bearing sedimentary basins (PHAN, 1999).

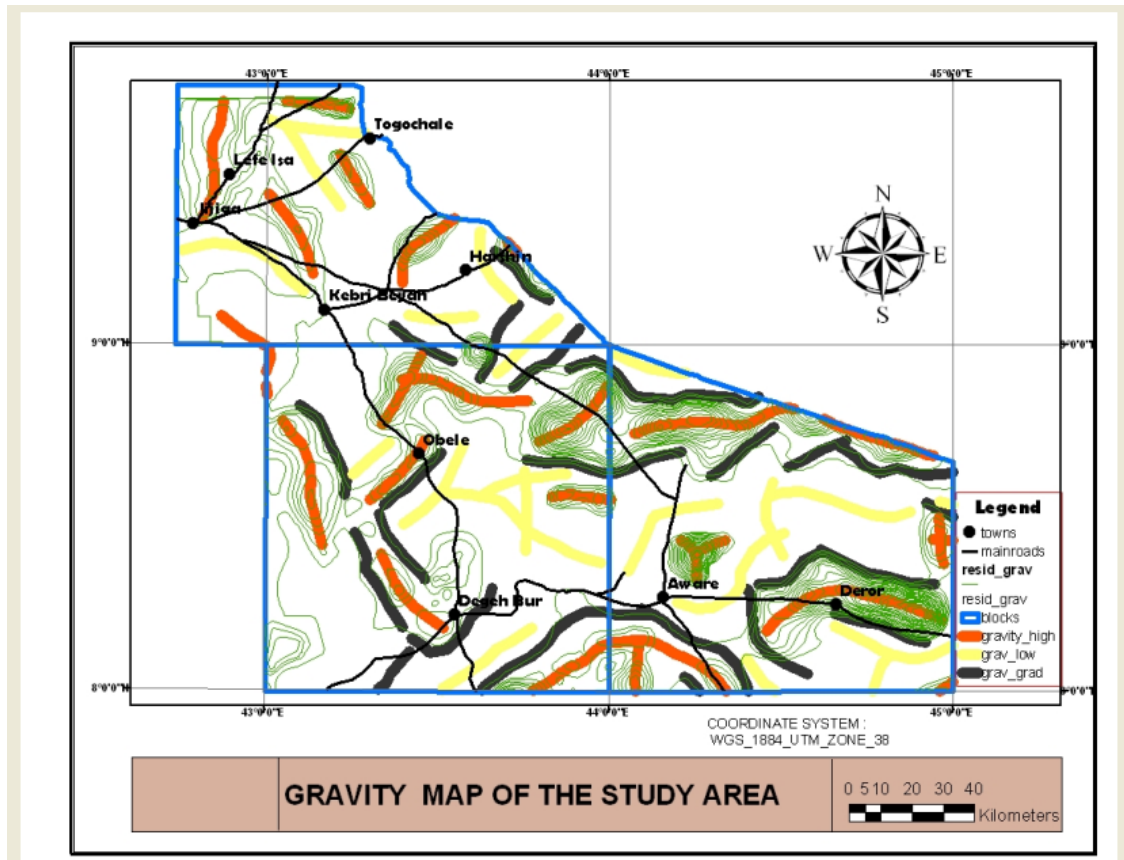


Figure 26 Gravity map of the study area

5.3 Potential petroleum basin delineated from gravity and seismic

According to Maxus Ethiopia, INC (1992) unpublished report modeling these magnetic and residual gravity profiles along selected key seismic lines produced a plausible interpretation of a basin up to 8 kilometers deep, filled with sediments largely composed of limestone and evaporates with a significant contamination by volcanics in some areas. The corresponding magnetic and residual gravity profiles, attached to the bottoms of the seismic sections (Figure27), served to aid and constrain the seismic interpretation. The potential fields data indicated a much shallower economic basement than would have been interpreted using the seismic data alone.

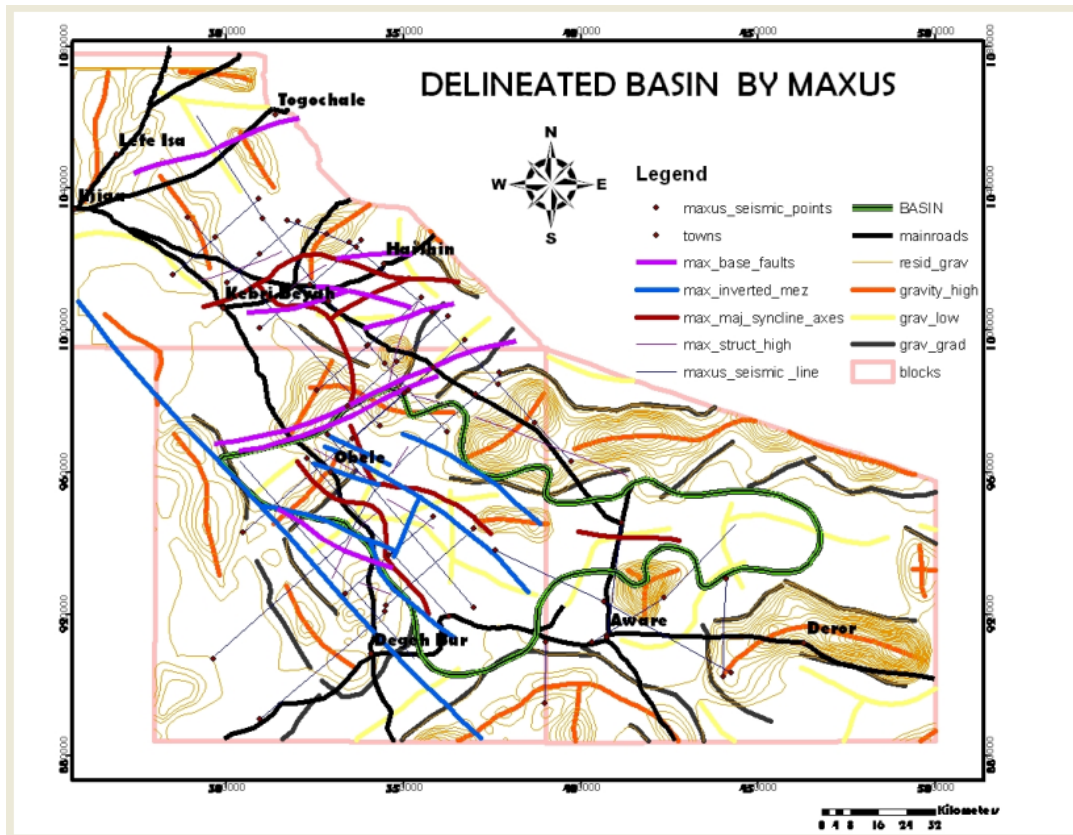


Figure 27 potential petroleum basin delineated by Maxus based on gravity and seismic result

5.4 Geochemical data

According to unpublished report of Geo-Microbial Technologies, Inc.2007 and the references therein, the successful application of surface and near-surface geochemical techniques in petroleum exploration requires careful acquisition, interpretation and integration of surface and subsurface data. Hydrocarbon microseepage data, such as the soil geochemical data, can provide the explorationist with the means to screen large areas -- or individual leads and prospects -- rapidly, economically, and qualitatively for their overall hydrocarbon potential.

According to unpublished report of Geo-Microbial Technologies, Inc.2007, data collection for, analysis and interpretation of 716 Microbial Oil Survey Technique (MOST) samples and 76 Sorbed Soil Gas (SSG) samples for the purpose of oil and gas exploration and reservoir source

characterization in the approximately 2500 square kilometer Blocks 9 and 13 in the Ogaden region of Ethiopia, south west energy block is taken. With the objective of reconnaissance hydrocarbon microseepage survey to evaluate the widespread survey area and determine -- based on the microbial and soil gas results -- if there are any significant hydrocarbon signatures and then which part warrants additional geological, geophysical, or geochemical study (see Figure28 below).

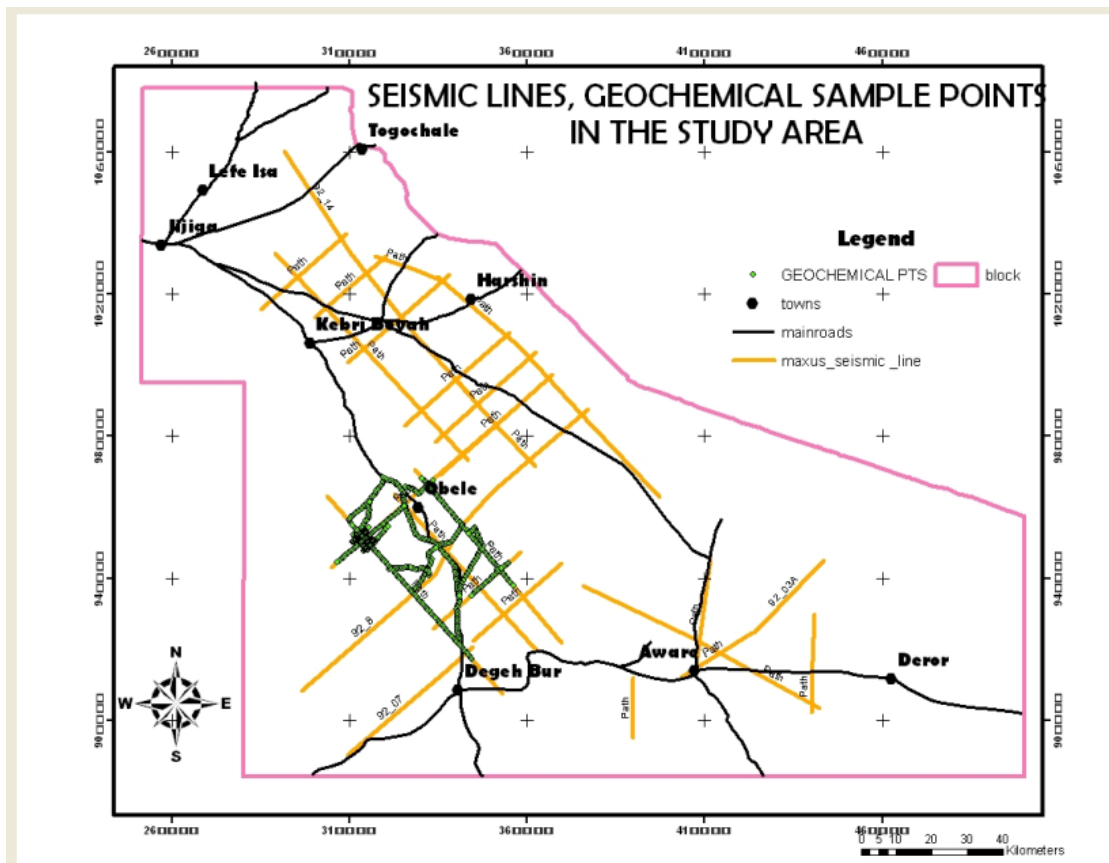


Figure 28 geochemical sample points taken for analysis (the data is used with permission from SWE)

5.4.1 Geochemical result obtained

According to unpublished report of Geo-Microbial Technologies, Inc.2007 The results of the microbial analysis reveal that there are three areas of interest indicated with red (Fig29): (1) a

large anomalous region at the east central margin of the study area based on several intersecting groupings of high MOST samples, (2) at smaller trend of separate anomalies associated with the more detailed sampling at the western margin of the block, and (3) two sharp but isolated linear anomalies found extending in the south line of samples. Each anomalous area displays very positive hydrocarbon microseepage signatures. Furthermore, for reconnaissance discrimination purposes, large portions of the prospect area show very low microseepage values and consequently are not favorable for oil and gas exploration. There are no analog drill sites within the study area. Several of these MOST anomaly areas were confirmed by the Sorbed Soil Gas analyses as having predominately oil micro seep sources.

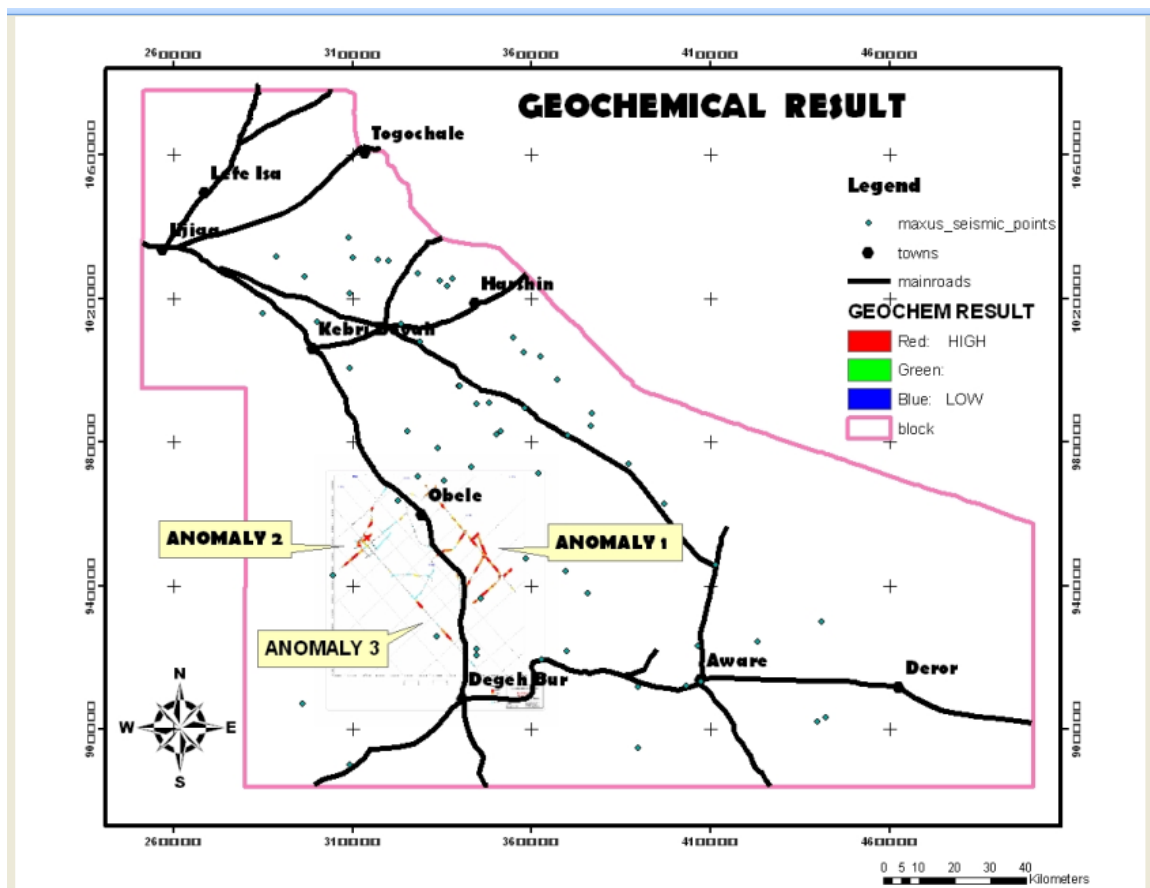


Figure 29 Geochemical result obtained the red shows positive result and the blue one showing negative result (the data is used by permission from SWE)

As cited by Gezahegn, 2007 and reference therein GIS is a process that contains a set of procedures that facilitate the data input, data storage, data manipulation and analysis and data output for both spatial and attribute data to support decision making activities. In this study, Input and store spatial and attribute data captured through GPS and digitization, to make different analysis on input data to produce intermediate and final factor maps, integrate data from different sources (remote sensing, existing maps & field survey), produce output thematic layers were utilized.

5.5 The integration of all the results of available data

The Figure below shows the area of positive result from the combination of all the available geological, structural, geophysical and geochemical data. The geophysical data is coupled with the geochemical data and shows positive result in three locations.

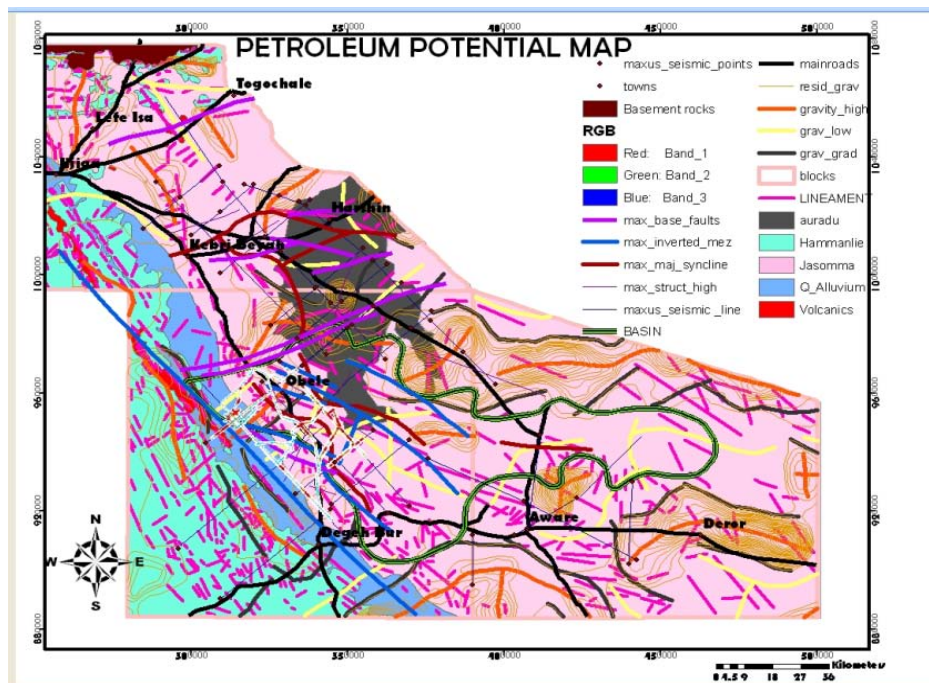


Figure 30 petroleum potential map

CHAPTER SIX

Result and discussion

6.1 Satellite image

The satellite imagery shows that the study area can be broadly divided into 2 regions; a western region dominated by the outcropping Hammanlie formation and an eastern region dominated by Jassoma units. The dividing line between the two regions is marked by the major NW-SE trending Marda fault Zone/system. The satellite image shows there are agricultural lands with shrub covered land and some outcrop of the Jassoma sandstone Fig6.1 below. The western part of the study area is dominated by Hammanlie formation and hilly outcrop of Basalt Mountains following the same orientation with the Marda fault system. In the northern extreme there is basement exposure. On the eastern at the border with Somalia there is surface out crop of Auradu formation, which was proved during field work. Geological map of the area is more refined and detailed with respect to the lithology and structures.

The eastern part of the study area, east of Marda fault, is characterized by a mixture of recent sediments and agriculture cover with small outcrop on the surface and on the escarpment of sandstone. These are mainly Jassoma units though there are Tertiary igneous plugs mapped to the northern extreme. The plugs have a possible structural control for their location, as they have a rough NW-SE trend and mirror Marda trend to the west. The presence of scattered Tertiary volcanic outcrops (though there is a rough NW-SE Marda parallel trend) indicates recent extensional activity in the centre of the block. Basement units are obviously at a shallow depth in the northern part of the study area and the extreme NW corner is characterized by Jurassic units. Further to the south east the main trends of the Jassoma are related to the erosional escarpments and the drainage analysis shows that it forms more or less parallel drainage pattern. Outcrops are

generally small and sparse in the south eastern part of the study area, though those that do occur are either in clusters or along strike from each other.

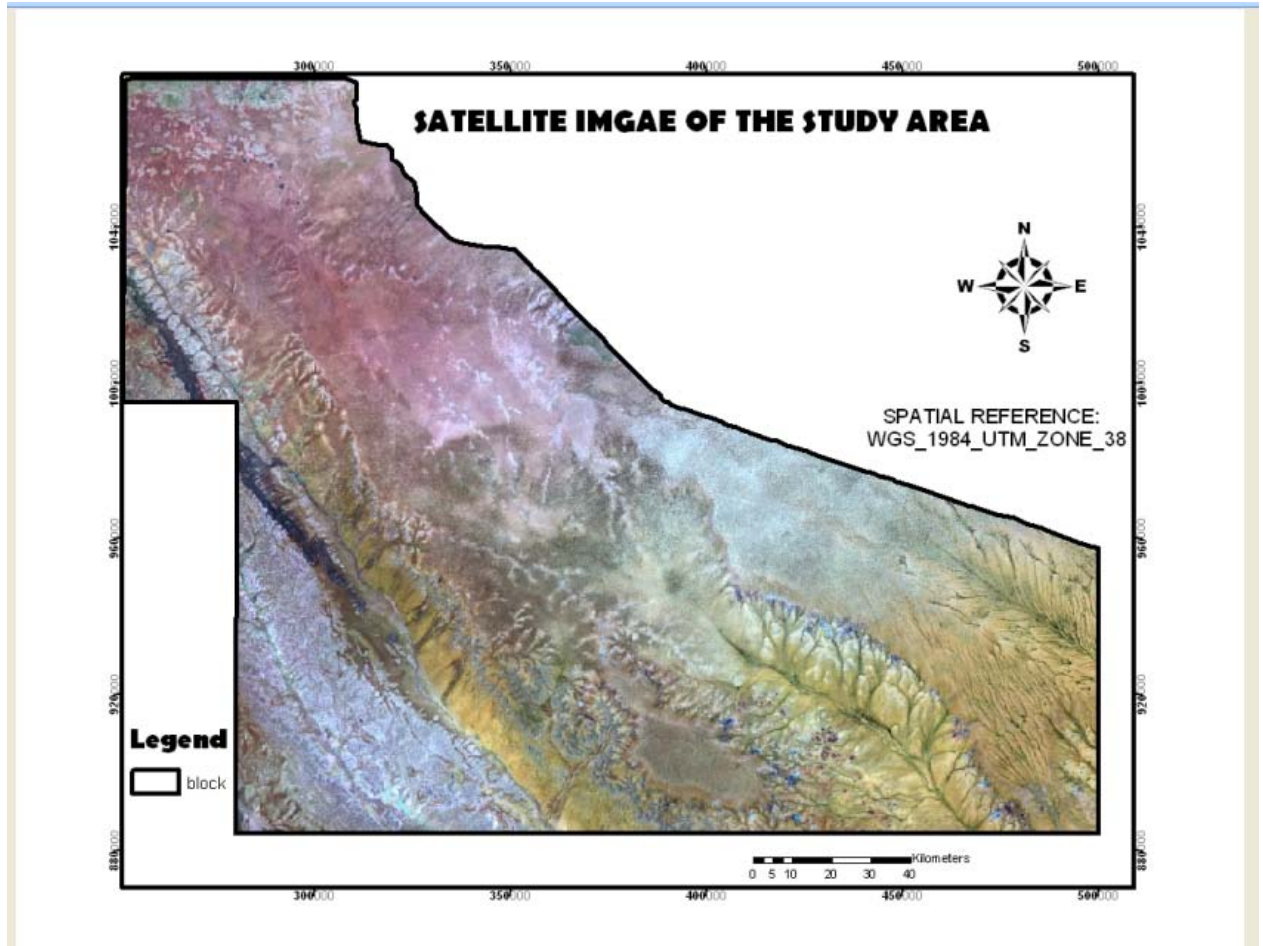


Figure 31 Satellite image with Marda fault dividing the area

The Marda fault zone is the surface expression of the Fafen Arch, a NW-SE trending pre-existing Precambrian zone of crustal weakness (NPA, 2007). The Marda fault zone is a complex series of NW-SE trending faults, With significant throw on faults associated with the Marda it is likely that the hanging wall marginal to the fault-system may provide a good kitchen area with possible migration 'up-dip' to structural traps in the east.

From the DEM data analysis generally the northern and NW part of the study area have very high elevation . and to the south the elevation is decreasing and have an elevation to the SE and SW corner of the study area is characterized with very low elevation havin an elevation as low as 798m.

The shaded relief map, combined with pan sharpened satellite image with different false color composite, is used mainly to manual lineament extraction, to have high accuracy of the linear feature. In addition, the other major use of the shaded relief is for manual extraction and study of drainage patterns in the study area; from the shaded relief map (Fig32) There are major structures controlling features which are dictating the flow direction of the streams, as it is shown on the drainage map Fig4.6.

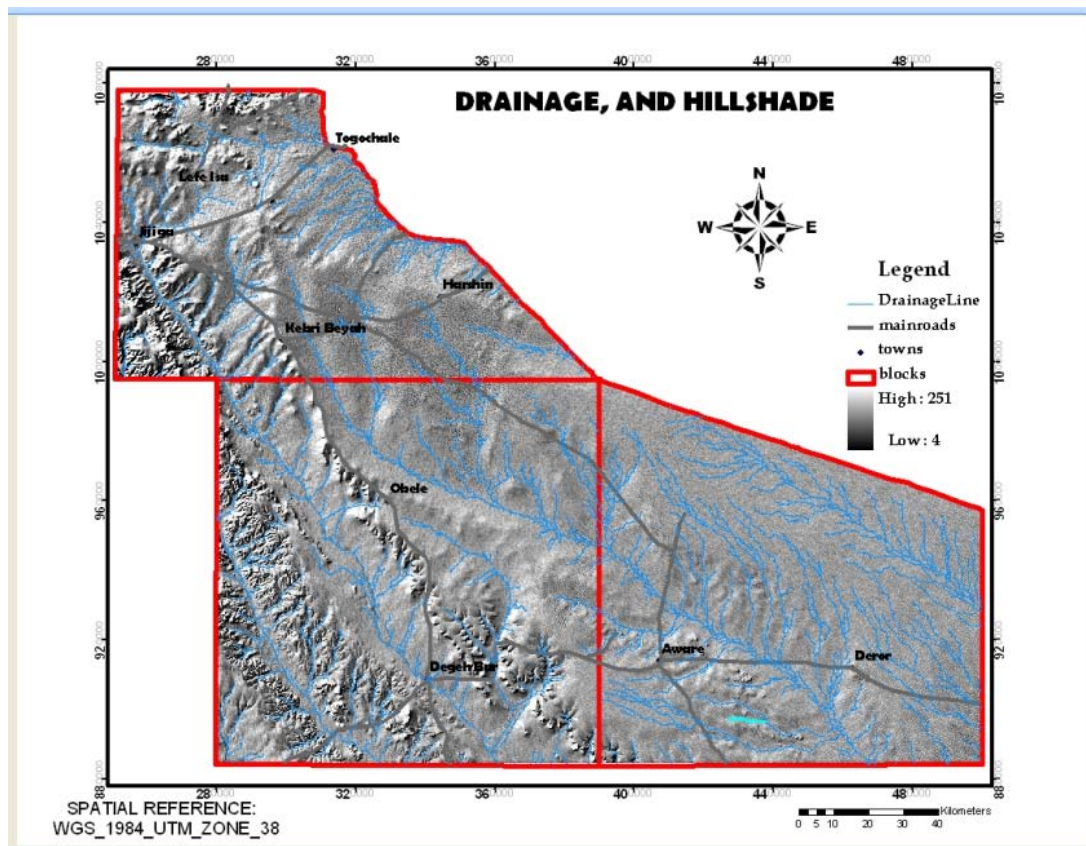


Figure 32 Hillshade and drainage network map

The drainage clearly follows NW- SE trend in the whole area Fig4.6. Generally the flow direction of the area is structurally controlled. In the eastern part of the study area there is more or less parallel drainage pattern. In the middle of the eastern part the major N- S drainage shows a change in course in to the NW- SE near Obole town which would be related with the offsetting underlying fault, a correlation of this change is also noted with the image interpretation and the integration of the Maxus data. In the northern part of the study area, in block 9A, a clear radial drainage pattern is observable from the topographic high in the centre.

From the lineament map extracted both manually and automated, Comparison of two maps indicates that the manually extracted lineament map is more reliable in terms of length of the lineaments, their segmentation, their spatial distribution and their orientation. Because it is found that the manual extraction produces better results, For this reason the output of the manual lineament is taken as the final lineament map, the automated one is not be considered in the rest of the thesis.

The northern border of the study area, where the basement rock is outcropped, sees a switch in structural trend to approximately E-W direction. The fault trend mapped on all of the data-sets is dominantly NW-SE (Marda) to the western of the study area, with the ENE-WSW (Karoo), in the SW of the study area, being localized to the south and east of the block. The faults are curvilinear in nature and suggest that they are listric in section. No strike-slip movement is apparent from the faults mapped though there is likely to be some offset present, even though it didn't confirmed by field-checking. The sandstone escarpment has two main trends; NW-SE & WNW-ESE which is clearly shown on the sandstone outcrop. The NW-SE trend is clearly related to the Marda fault system.

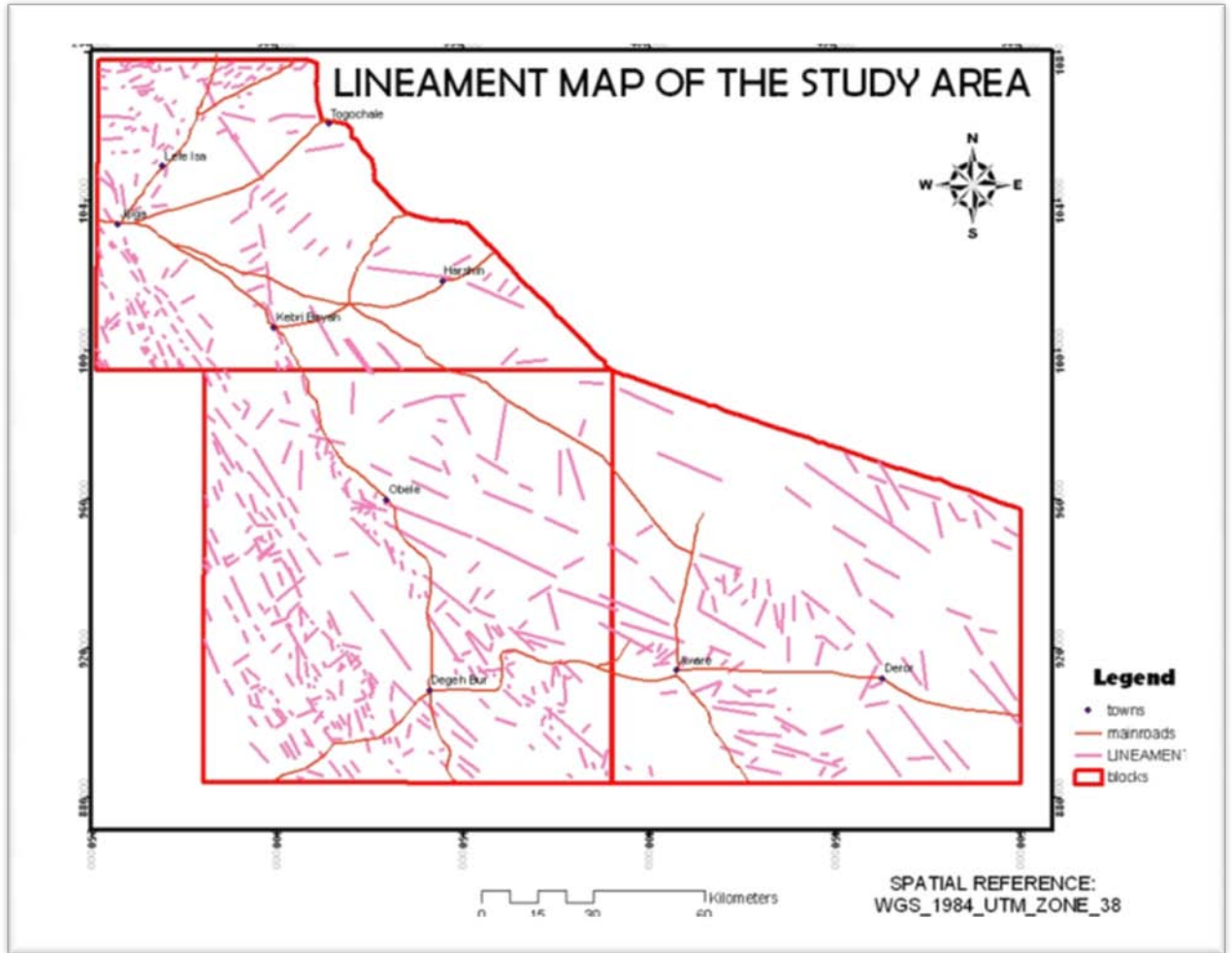


Figure 33 final lineament map

In the Figure (Figure 33) noted that there are several fault zones in the area. in general the faults are exposed in the form of straight line that extends in NW-SE direction along the Marda fault, several sub-zones (or fault sets) can be distinguished in the area to the eastern and northern and SE of the study area.

From both satellite image interpretation and field work the following lithological map is produced.

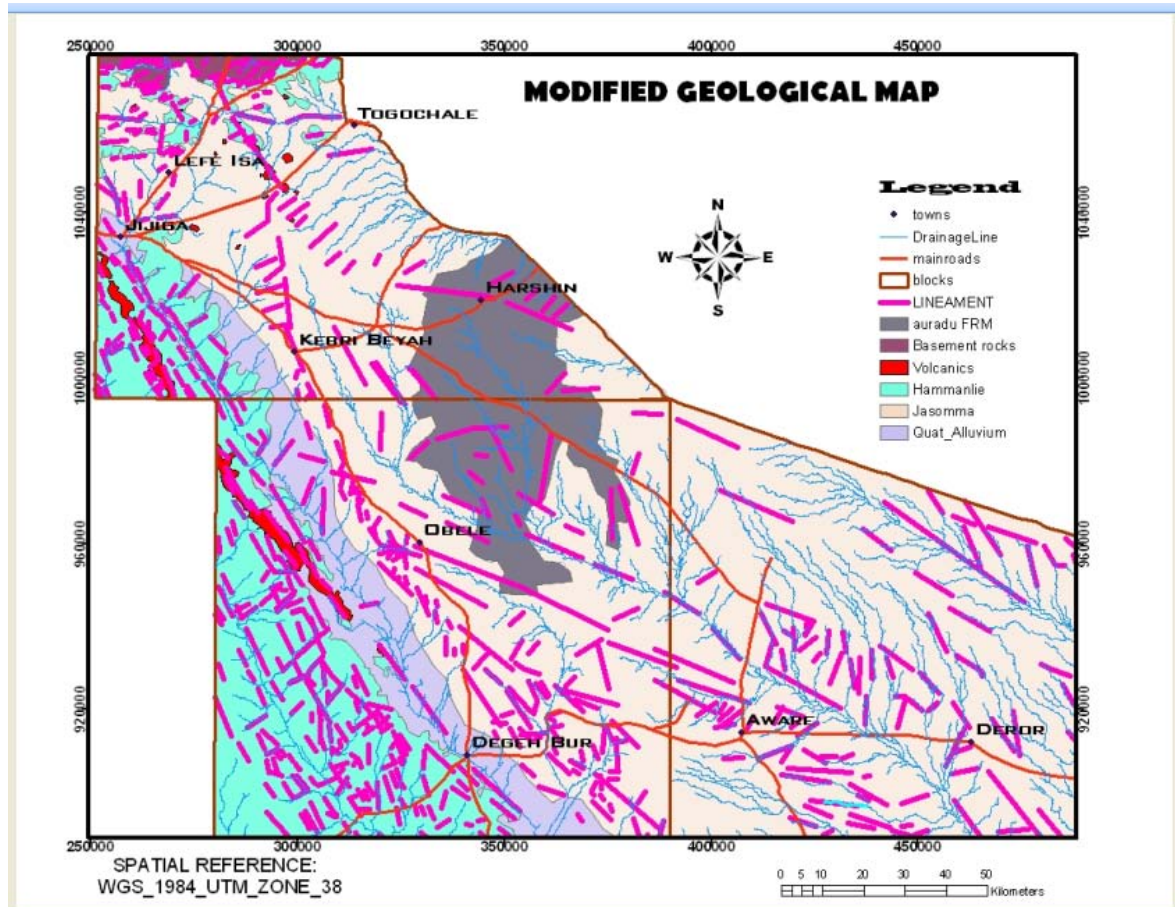


Figure 34 modified final geological map of the study area.

6.2 Geophysics

In the geophysics and geology integration the study shows general petroleum potential area to carry on drilling program in the area. From the previous work of magnetic, gravity and seismic, in the central part of the study area, there is gravity low, possible dip-sited structural trap from the seismic interpretation, a possible petroleum potential basin is delineated Fig35.

There is little outcrop present in this region to relate with any structures. But when integrated with the gravity data there is some correlation between the synclinal axes and the gravity lows.

The Maxus 'Seismic Basement map' outlines two trends: ENE-WSW (red), Fig35 According to Maxus, these are basement faults that have not been reactivated and WNW-ESE/NW-SE trending

faults (blue), these are basement inverted faults with Mesozoic movement. The former have no surface representation, whereas the latter clearly tie-in with faults and linears mapped on the image interpretation. The faults are sub-parallel to the Marda trend which is more or less NW-SE. The relationship between the faults mapped on the escarpment and those in the Jurassic/Hammanlie section and on the margins of the Marda is not clear.

And as it is on the Geological map, the eastern extent of the graben is inferred from potential field data due to NR seismic data in the eastern part of the survey. The graben is defined to the north by E-W trending faults as well as south dipping seismic events. The ESE striking Marda fault, interpreted on seismic and magnetic data and visible on Landsat imagery defines the southern limit of the Tertiary Mesozoic Grain. To the south of the Marda fault, Jurassic rocks are mapped on the surface. To the west the grain is defined as basically downthrown to a series of NNE striking faults interpreted as Karroo aged faults reactivated in the Mesozoic. The deepest parts of this Tertiary-Mesozoic aged grain are interpreted to overlie a Karroo aged grain east of the above described faults (Figure35).

The gravity data clearly shows an ENE-WSW trending low that has been associated with Palaeozoic Karroo tectonics. From the Mesozoic onwards the main trends present are associated with the NW-SE trending Marda. The outcropping Jurassic section in the west is clearly also affected by NW-SE trending extensional tectonism. Both the Bouguer and residual gravity outline this block as what is thought to represent the eastern 'arm' of the Karroo tri-radial rift system at the middle.

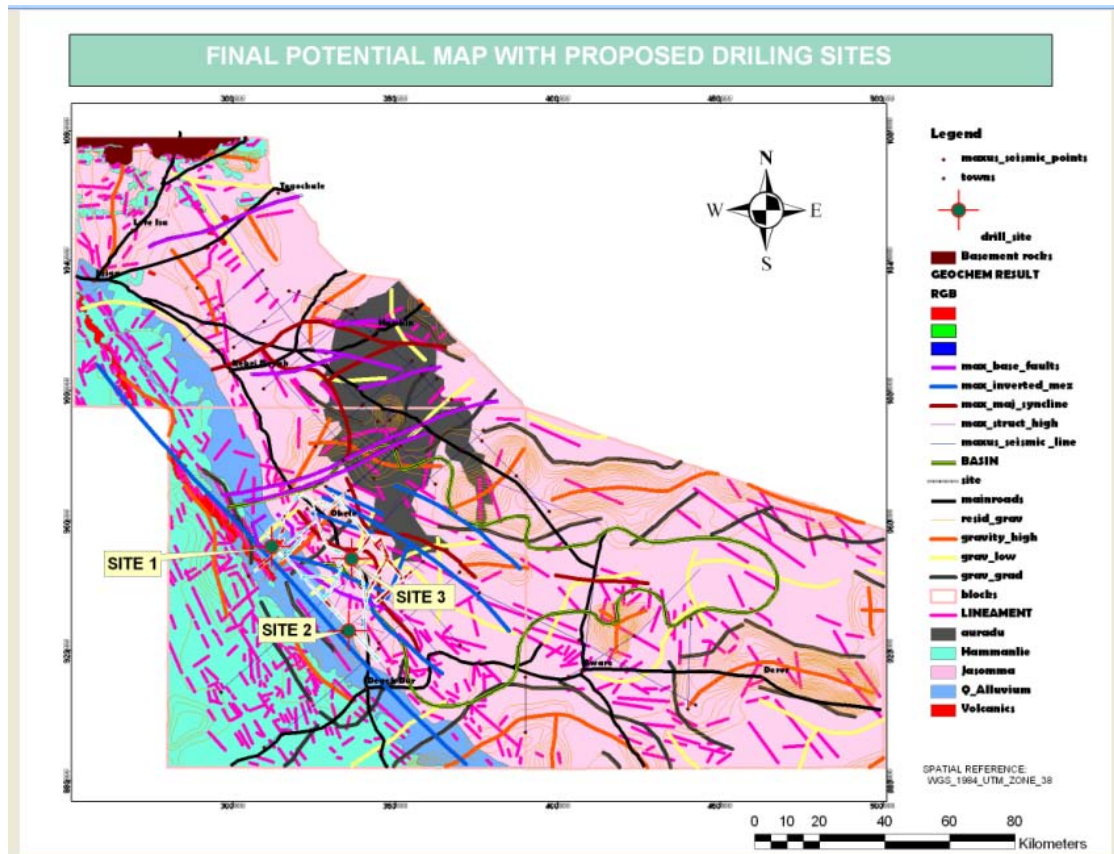


Figure 35 final petroleum potential map with proposed drilling sites

On the eastern side of the study area (block 13), the residual gravity clearly outlines an E-W trending gravity low through the centre of the block that extends east ward, with E-W trending highs both to the north and south. A large circular high exists in the centre of the E-W trending low near Aware town. Integrating the gravity with the image interpretation and the ancillary data supplied shows that structurally the block is complex.

From the geochemical data According to unpublished report of Geo-Microbial Technologies, Inc.2007 The results of the microbial analysis reveal that there are three areas of interest indicated with red (Fig35): (1) a large anomalous region at the east central margin of the study area based on several intersecting groupings of high MOST samples, (2) at smaller trend of separate anomalies associated with the more detailed sampling at the western margin of the

block, and (3) two sharp but isolated linear anomalies found extending in the south line of samples. Each anomalous area displays very positive hydrocarbon microseepage signatures. Furthermore, for reconnaissance discrimination purposes, large portions of the prospect area show very low microseepage values and consequently are not favorable for oil and gas exploration.

GIS Analysis, used in this thesis to facilitate the data input, data storage, data manipulation and analysis and data output for both spatial and attribute data to support decision making activities. In this study both the fundamental and advanced capabilities of the system such as; Input and store spatial and attribute data captured through GPS and digitization, make different analysis on input data to produce intermediate and final factor maps, integrate data from different sources (remote sensing, existing maps & field survey), produce output thematic layers were utilized.

CHAPTER SEVEN

Conclusions and recommendations

7.1 Conclusions

- Exploration can be done More accurately, faster, and for less cost by interpreting remote sensing imagery with consideration of subtle Signs of structure because Structurally trapped petroleum accumulations often occur in remote, rugged, or poorly-mapped terrains which gives numerous clues to structure that can be observed both directly (e.g., fault offsets, dips) and indirectly (e.g., drainage alignments, vegetation and soil tone changes).
- One of the efficient methods of imagery processing is false color composite with different band combination and principal component; as the remote sensing imageries for oil exploration study band 7-4-2 is a suitable band combination. On the basis of primary composition analysis, IHS transform can provide good false color copmposite imagery.
- Geographic Information Systems (GIS) is used as an important tool for complete and accurate analysis of large volumes of geographic information to integrate data from different sources (remote sensing, existing maps & Geophysics), to produce output thematic layers.
- Geological map and geophysical seismic interpretation and use of orthorectified satellite images, provides insight on the selection of areas to plan 2D or 3D seismic surveys for an exploration drilling program. Currently the capabilities of remote sensing and its necessity in the oil industry are much greater when compared with the tradition way of exploration.
- Remote sensing and GIS provides the oil industry with fast, efficient, methods of exploration which are superior to the traditional technique.

7.2 Recommendation

- Use of high resolution image like IKONOS and ASTER terra image for further geological investigation on some area is appropriate.
- Detailed geological field work is required to see for some surface expressions of the off-setting faults.
- High resolution grid 2D and 3D seismic lines and further interpretation of the existing data.
- Acquisition of better gravity and Magnetics.

REFERENCES

- A. Hunegnaw, L. Sage and R. Gonnard, 1998, "HYDROCARBON POTENTIAL OF THE INTRACRATONIC OGADEN BASIN, SE ETHIOPIA", *Journal of Petroleum Geology*, Vol. 21(4), October 1998, pp. 401-425.
- Akira Hirano, Roy Welch, and Harold Lang, 2003 "Mapping from ASTER stereo image data: DEM validation and accuracy assessment" *ISPRS Journal of Photogrammetry & Remote Sensing* 57 (2003) 356– 370.
- American Association for Petroleum Geologists, 1975 "A History of Exploration for Petroleum" (vol.2, Tulsa, Oklahoma).
- BEICIP-FRANLAB, 1998, "Petroleum potential of Ethiopia " Ministry of Mines and Energy, Petroleum Operations Department, petroleum exploration promotion project, Addis Ababa, Ethiopia; Beicip-Franlab petroleum consultants, (unpublished report).
- David A., MULLINS, Kevin, DOHRENWEND, John, and ISBRECHT, Jo-Ann, 2001, "ANALYSIS OF LANDSAT 7 IMAGERY FOR GEOLOGIC MAPPING IN NEW MEXICO" GSA Annual Meeting, November 5-8, 2001, Paper No. 123-0
- Edgar, 1975, "Trek of the Oil Finders: A History of Exploration for Petroleum" American Association for Petroleum Geologists, 1975
- Ethiopia Country Analysis Brief. Energy Information Administration. Retrieved on 2008-02-28 from http://www.eia.doe.gov/emeu/cabs/Horn_of_Africa/Ethiopia.html
- ERDAS (2001). ERDAS Imagine® Configuration Guide. Atlanta, Ga.: ERDAS Inc.
- Folyd F. Sabins, 1977, fundamentals of image interpretation, La Habra, California.
- G. Assefa, 1988; "Potential hydrocarbon-Generating Rock units within the phanerozoic Sequence Of the ogaden Basin, Ethiopia: A preliminary assessment using the LOPATIN Model." *Journal of petroleum Geology*, 11(4), 1988, pp. 461-472.

- Geo-Microbial technologies, INC.,2008 “reconnaissance Hydrocarbon Microseepage survey Microbial oil Survey Technique(MOST) sorbed soil Gas analysis, Methane & Ethane carbon Isotopes Analysis from ‘SSG’ Extractions: block 9 and 13, Ogaden Region, Ethiopia prepared for SouthWest Energy(HK) Ltd” Geo-Microbial Technologies,Inc. Ochelata, Oklahoma, USA, 2008. (Unpublished report).
- H. Ranjbar, H. Shahriari, 2003, “Comparison of ASTER and ETM+ data for exploration of Porphyry copper mineralization: A case study of Sar Cheshmeh areas, Kerman, Iran” <http://www.gisdevelopment.org>, retrieved on April 2008.
- Hooper, D.M., Bursik, M.I., Webb, F.H., 2003. “Application of high resolution interferometric DEMs to geomorphic studies of fault scarps, Fish Lake Valley, Nevada–California, USA” *Remote Sensing Environment* 84, pp. 255– 267.
- I.Levorsen, 1954, *Geology of petroleum*, by W. H. Freeman and Company, inc. Library of congress catalogue card number: 54- 7502
- James W. Quinn, 2001, “band combination of landsat 5 (tm sensor) and landsat 7 (etm+ sensor).
- Jay Rauschkolb, 2003, “Using GIS and Satellite Imagery to Locate Hydrocarbons” Presented at the ESRI International User Conference, San Diego, California July 7 - 10, 2003
- John Fell, Kim Long, Erin Payton, 2004, *GIS Technology in the Petroleum Industry: Current State of Affairs* GISC 6383 fall 2004
- Kent, P.E., 1974. Continental Margin of East Africa – a region of vertical movements. In: BURK, A. and DRAKE, C.L (Eds.). *The Geology of Continental Margins*. Springer – Verlag, New York, 313 - 320
- Kheiralla K. M, Richard G., Mahmood S. Amer, 2006, “Multisource Geophysical Data and DEM

for Lineaments Analysis of the Muglad Rift Basin Sudan, IEEE-ICET 2006 2nd
International Conference on Emerging Technologies Peshawar, Pakistan, 13-14
November 2006

K. Saraf et. al..2004” GIS based surface hydrological modelling in identification of
groundwater recharge zones” International Journal of Remote Sensing, ISSN 0143-1161

Print/ ISSN 1366-5901 online # 2004 Taylor & Francis Ltd

Lillesand, T. M., & Kiefer, R. W. (1994). Remote Sensing and Image Interpretation (3
rd ed.). New York : John Wiley & Sons, Inc.

Margia S. et. al., 1995, Stratigraphic correlation by integrating photostratigraphy and Remote
Sensing Multi- spectral data; an example from Jurassic- Eocene strata, Northern Somalia,
AAPG Bulletin V.79, No. 11, p 1579- 1589.

McClay K. and Bonora M. 2001, Analog models of restraining step over in strike slip faults
system; the American Association of petroleum Geologists, AAPG bulletin, V.85, No. 2 pp
233-260

NPA, 2008, “Ethiopia: Blocks 9A, 9 & 13 Satellite Interpretation Study.”(Unpublished
document)

O. Catuneanu et. al., 2005 “The Karoo basins of south-central Africa” Journal of African Earth
Sciences 43 (2005) 211–253

Olive Scott Petty, 1976” Seismic Reflections: Recollections of the Formative Years of the
Geophysical Exploration Industry” (Houston: Geosource, 1976).

P.G. Purcell, 1976, “The Marda Fault Zone, Ethiopia “White stone Ethiopia Petroleum Company,
nature Vol.261 1976.

- Premanand M., Sagar N., 2005. "Using Remote Sensing and GIS technologies as an aid for hydrocarbon exploration in the Assam-Arakan fold-thrust belt", GISdevelopment.net
- PHAN K.1999, "magnetic data processing for the purpose of hydrocarbon exploration" Institute of Geological Sciences, NCNST, Hoàng Quốc Việt Road, Hư Néi
- Samih et. al.2006, « The use of Remote Sensing Technology in geological Investigation and mineral Detection in El Azraq-Jordan » european Journal of geography , article no. 358
- SCUK/DPPB, 2004, "Somali Regional State, Ethiopia: Livelihood Zone (LZ) Map", Food Security Monitoring and Early Warning Program, Addis Ababa, Ethiopia
- SÜZEN M. L.; TOPRAK V, 1998, "Filtering of satellite images in geological lineament analyses : An application to a fault zone in Central Turkey", International journal of remote sensing ISSN 0143-1161 Coden Ijstedk, 1998, vol. 19, no6, pp. 1101-1114.
- Tadesse, K.et. al., 2007," A New Regional Assessment of the Petroleum Potential in Ethiopia" University of Texas at El Paso, El Paso,
- Worku T. and Astin T.R, 1992. The karoo sediments (late Paleozoic to Early Jurassic) of the Ogaden basin, Ethiopia. *Sediment Geol.*, 76: 7- 21
- Ye H. and Cao X., collections of reports on new Theory, New method, new techniques in Petroleum Exploration. Application of Remote Sensing in petroleum Exploration in Dongpu Sag Ocean Press, Beijing, PP 150, 1989
- Ye H. and Qui X., Petroleum Analysis of remote Sensing Images in Liaohe Basin and its Vicinities. National resource remote sensing studies Vol. PP 13, 1990.
- Yu Wuyi, Qi Xiaoping, Zou Liqun, 2001, "evaluation of Multi-sensor remote sensing data applied oil and Gas exploration in the loess highlands, Ordos plateau, China." Paper presented at the 22nd Asian conference on remote sensing, 5-9 November 2001, Singapore