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RESERVOIR CHARACTERIZATION OF ADIGRAT SANDSTONE AROUND CALUB WITHIN OGADEN BASIN, ETHIOPIA

A thesis submitted to the Center of Ethio-Mines Development in partial fulfillment of the requirements for the degree of Master of Petroleum Engineering

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Declaration

I hereby declare that this thesis is my original work and has not been, presented, for a degree in any other university, and that all sources of material used for the thesis have been duty acknowledged,

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ABSTRACT

The sedimentary Basins of Ethiopia cover a significant portion of the country and there are five distinct sedimentary basins. Ogaden Basin is located in the southeastern part of the country and covers an area of about 350,000 sq. km. The Reservoir characterization of Adigrat sandstone of Calub Ogaden Basin Ethiopia using seismic and well-log data is the focus of this work. The data used for the study consisted of seismic lines, well logs, and published reports to achieve the aim and objectives of the work. Data from wells Calub-1, Calub-2, Calub-3, and Calub-4 were deployed. Software including Petrel, Eclipse, Interactive Petrophysics, and ArcGIS was used. A petrophysical analysis was carried out to determine porosity, permeability, water saturation, and other reservoir parameters. The methods used for analysis involved petrophysical analysis, geostatistical analysis, and reservoir modeling.

The Calub wells had relatively consistent porosity and permeability slightly lower values. Based on these results, further exploration and production activities are recommended, but additional data collection and analysis are necessary to fully characterize the reservoir properties and optimize production. This includes conducting well tests, seismic surveys, and reservoir modeling to better understand reservoir behavior and optimize production strategies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYM

2D	Two Dimension
3D	Three Dimension
API	American petroleum institution
BP	British Petroleum
E&P	Exploration and Production
EPE	Ethiopian Petroleum Enterprise
K	Permeability
LAS	Landing Assist system
MoME	Ministry of Mines Ethiopia
NE	North East
NTG	Net-to Gross
SEG-Y	Society of Exploration Geophysics
SPEE	Soviet Petroleum Exploration Expenditure
Sw	Water saturation
SW	South West
SWE	South West Energy
Vsh	volume of shale
Φ	porosity

CHAPTER ONE

INTROCUTION

1.1. General statement

The sedimentary Basins of Ethiopia cover a significant portion of the country and there are five distinct sedimentary basins; namely: Ogaden, Blue Nile, Gambela, Mekele and Southern Rift Basins .Ogaden Basin is located in the southeastern part of the country and covers an area of about 350,000 sq. km. The basin is part of the southeastern section of the lowlands of the Horn of Africa and includes the Somalian region and part of northeastern Kenyan (Mandera basin). The basin is characterized by gentle rolling relief decreasing towards the south and southeast and drained by Dawa, Genale, and Wabi Shebelle rivers

Early geologic works in the region are local geological studies, which were reported and discussed by many workers including; (Gortani, M., Binachi, A. , 1937), (Mullen, 1937), (Brown, 1943), and (Migliorini, 1956). (Dainelli, 1943) In his class, master precedence about the geology of the Horn of Africa discussed briefly the geology of the Ogaden Basin, More systematic geologic works in the regions were conducted since the early 1970s. These include; (Greitzer, 1970), (Merla et al., 1973, 1979), (Purcell P. , 1981), (Gebreyohannes, 1989), (Gebreyohannes , 1990), (Worku, T., Astin, R., 1992), (Geleta, 1998), (Bosellini, 1999) and (Bosellini et.al, 2001).

"Geology and Petroleum Potential of the Ogaden Basin, Ethiopia" by (Mulugeta, 2007), "Sedimentology and Stratigraphy of the Jurassic-Cretaceous Succession in the Ogaden Basin, Ethiopia" by (Yohannes Hailemichael, 2009). Geological and Geophysical Investigation of the Ogaden Basin, Ethiopia" by (Dereje Ayalew, 2011), "Tectonic Evolution and Hydrocarbon Potential of the Ogaden Basin, Ethiopia" by (Ahmed yosuf, 2014), "Petroleum System Analysis of the Ogaden Basin, Ethiopia" by (Tadesse, K.et. al..,, 2007).

"Geological and Petrophysical Evaluation of the Calub and Hilala Reservoirs Ogaden Basin. Ethiopia" by (Tadesse, 2005). "Reservoir Characterization of the Calub and Hilala Fields, Ogaden Basin, Ethiopia" by (Mulugeta, 2007), "Sedimentology and Diagenesis of the Calub Formation, Ogaden Basin, Ethiopia" by (Yohannes Hailemichael, 2009), "Structural and Stratigraphic Analysis of the Hilala Field, Ogaden Basin, Ethiopia" by (Dereje Ayalew, 2011), "Integrated Reservoir Characterization of the calub and Hilala Fields, Ogaden Basin, Ethiopia" by (Ahmed yosuf, 2014). Several reservoir-characterizing studies have been undertaking, especially to tackle production challenges associated with Geochemical

Characteristics and Hydrocarbon Generation Modelling of Early Triassic to Late Cretaceous Formations within Ogaden Basin, Ethiopia (Samuel Getnet Tsegaye, 2018).

Geology and Petroleum Potential of the Ogaden Basin, Ethiopia" (Tadesse Alemu and Mulugeta Atnafu , 2007)."Stratigraphy and Depositional Environment of the Adigrat Sandstone, Ogaden Basin, Ethiopia" (Yohannes Hailemichael, 2009), "Tectonic Evolution of the Ogaden Basin, Ethiopia" by (Dereje Ayalew, 2011). "Reservoir Quality and Porosity Prediction of the calub Formation, Ogaden Basin, Ethiopia" by (Ahmed yosuf, 2014), "Sequence Stratigraphy and Petroleum System Analysis of the Ogaden Basin, Ethiopia" by (Tadesse Alemu and Mulugeta Atnafu, 2016).

Reservoir characterization is crucial for the successful exploration and production of hydrocarbons in the Ogaden Basin. It involves the analysis and interpretation of geologic data to understand the properties of the reservoir rocks, such as porosity, permeability, and fluid saturation. This information used to identify potential hydrocarbon reservoirs, estimate their volume and quality, and optimize drilling and production strategies. Accurate reservoir characterization can also help reduce exploration and production costs and minimize environmental impact by avoiding unnecessary drilling or production activities. Therefore, the works mentioned above play a significant role in advancing our understanding of the geology and petroleum potential of the Ogaden Basin and providing valuable insights for reservoir characterization.

Reservoir characterization of the Adigrat sandstone around Calub and Hilala in the Ogaden Basin of Ethiopia has been a focus of exploration activities in the area. The Adigrat sandstone believed to be a potential reservoir for oil and gas, and several exploration wells have been drilled to evaluate its properties.

The reservoir characterization involves the use of various techniques such as seismic data interpretation, well log analysis, and core analysis to determine the reservoir properties such as porosity, permeability, and fluid saturation. The data obtained from these techniques is used to build a geological model of the reservoir, which is then used to estimate the reserves and plan for production.

Multiple layers of sandstone characterize the Adigrat sandstone is a complex reservoir with varying properties across the basin. The reservoir with varying thickness and quality, the sandstone is also interbedded with shale, which affects its permeability and fluid flow,

1.2. General description of the study area

The Ogaden Basin is located in south east Ethiopia between latitude 40 and 100 N and longitude 400 and 480 E. The basin may hold significant reserves of crude oil and gas (http://en.wikipedia.org/wiki/Ogaden_Basin", n.d.)". 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, Lithostratigraphy and environment of deposition of the Late Jurassic - Early Cretaceous sequence of the central part of Northwestern Plateau, Ethiopia. N.Jb.Geol.Paläont.Abh. 182, 255-284, 1998).

Calub and Hilala are located in the Ogaden Basin in the Somali Region of Ethiopia. The region is generally remote and remote access is limited. The closest major city is Jijiga, located about 80 kilometers away. Access to the region can be difficult due to poor road infrastructure and lack of public transportation. The region is not easily accessible by air, and the closest airport is around 400 kilometers away. The region can be easily accessed by foot with roads and pathways connecting the towns in the Ogaden Basin.

1.2.1. 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-oilgas.com/ogaden_basin_overview.htm); is found in the SouthWest Energy concession, which consists of blocks 11 and15, located at the northern end of the Ogaden Basin in Eastern Ethiopia immediately south of the Border with Somalia Fig1.1

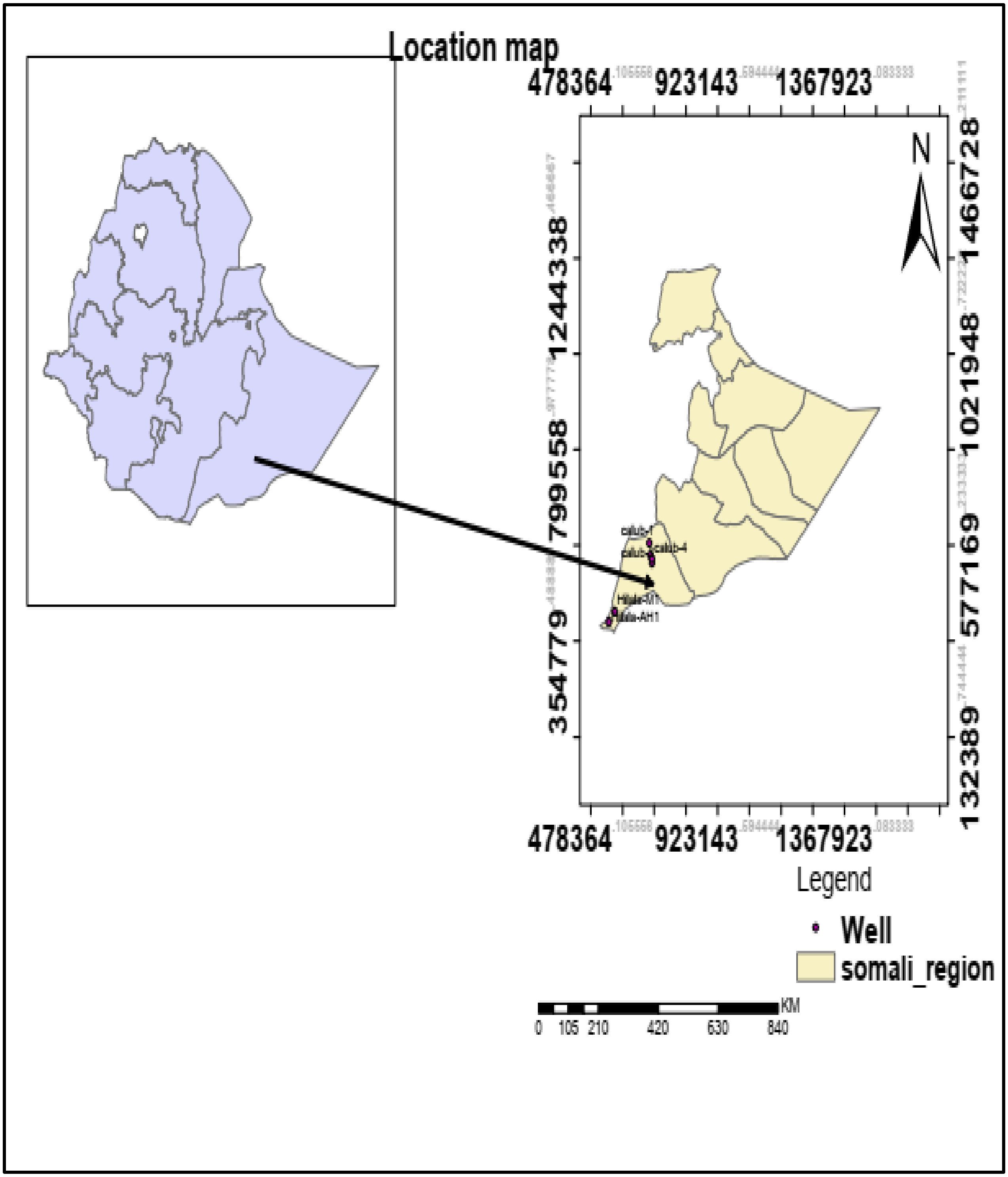


Figure 1.1: Location Map of Ogaden Basin plotted using Global Mapper 22.0 software

1.2.2. 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. In addition, there are many dry weather roads in the study area. There is one domestic airport in Jijiga.

1.2.3. 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 riverbeds) 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.

The Ogaden Basin is located in the southeastern corner of Ethiopia. It has a semi-arid climate with long, hot summers and short, mild winters. The average annual temperature is 22°C (72°F).

1.2.4. 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.

The vegetation of the Ogaden Basin is dominated by thorny acacia trees, grasses, and shrubs. There are also patches of evergreen and deciduous forests near the rivers. Other plants found in the area include Cypress trees, Juniper trees, and Wild Olive trees.

The Ogaden Basin is a large sedimentary basin located in eastern Ethiopia. The basin is characterized by flat terrain, with a number of shallow depressions and a few seasonal rivers. The Ogaden Basin is drained by the minor Dawa and Ganale Rivers, which merge to form the larger Shebelle River. The Shebelle ultimately empties into the Gulf of Aden in Somalia. A dry lakebed, known as Lake Abhe, is located in the northeast corner of the basin.

1.3. Exploration History of Ogaden Basin

The Ogaden Basin, located in eastern Ethiopia, has a long history of exploration dating back to the 1930s. The first oil exploration activities in the area were carried out by the British Petroleum Company (BP), which conducted geological and geophysical surveys in the region. However, no significant discoveries were made at that time.

In the 1950s and 1960s, several international oil companies, including Shell, Mobil, and Chevron, conducted further exploration activities in the Ogaden Basin. These efforts included seismic surveys, drilling of exploratory wells, and geological mapping. However, no commercial discoveries were made, and most companies eventually abandoned their operations in the area.

In the 1980s, the Ethiopian government established the Ethiopian Petroleum Enterprise (EPE) to oversee the country's oil and gas exploration and production activities. EPE carried out further exploration activities in the Ogaden Basin, including the drilling of several exploratory wells. However, these efforts also failed to yield any significant discoveries.

In recent years, the Ethiopian government has been actively promoting investment in the country's oil and gas sector, including the Ogaden Basin. In 2013, Chinese firm Poly-GCL Petroleum Group Holdings Limited signed an agreement with the Ethiopian government to explore and develop natural gas reserves in the Ogaden Basin. The company has since drilled several exploratory wells in the area and reported significant gas discoveries.

Overall, while the Ogaden Basin has a long history of exploration, commercial discoveries have been limited so far. However, recent developments suggest that the area's petroleum potential may be significant, and further exploration activities are likely to continue in the coming years.

1.4. Objectives

The main objective of this study is Reservoir characterization of Adigrat sandstone around Calub within Ogaden Basin, Ethiopia.

1.4.1. Specific objectives

- To Predict and quantify porosity
- To Predict and quantify permeability
- To indicate seal and Traps

1.5. Scope of the study

The scope of this study of reservoir characterization of the Adigrat sandstone around Calub in the Ogaden Basin of Ethiopia is to understand the rock properties, reservoir characteristics, and flow properties of the formations. Data collection will include petrophysical analysis, log analysis, seismic interpretation, and reservoir modeling. The ultimate goal of this research is to develop an integrated understanding of the Adigrat sandstone in the Ogaden Basin so that effective development strategies can be realized.

1.6. Research justification

Reservoir characterization of the Adigrat Sandstone around Calub wells in the Ogaden Basin of Ethiopia is important for a better understanding of the hydrocarbon potential of this area. Characterizing the Adigrat Sandstone around Calub would provide a better understanding of the overall structure, composition, and fluid characteristics that can have an impact on future exploration and production activities. Additionally, a better understanding of the Adigrat could provide insight into nearby formations that may have similar characteristics, allowing for better exploration and production efforts in the region. This data could also improve our understanding of the regional subsurface hydrology, helping us to better assess the resources available in this area.

1.5 Limitations

As this study is focused exclusively on well logs data and is conducted in a limited period and resources, The absence of core data from the reservoir is a major uncertainty in the study, core samples is important petrophysical parameters. Lack of bio stratigraphic data for better inter well correlation and to ascertain environment of deposition was another challenge.

CHAPTER TWO

REGIONAL GEOLOGY OF THE STUDY AREA

2.1.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, 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, K.et. al..,, 2007) , namely: Ogaden (350,000 sq. km), Abay Basin (63,000 sq. km), Gambela (17,000 sq. km), Southern Rift (15,000 sq. km) and Mekelle (8,000 sq. km) (Hunegnaw, 1998). 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, 1998)

2.2. Basin Evolution

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).

2.3.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, “Potential hydrocarbon-Generating Rock units within the phanerozoic Sequence Of the ogaden Basin, Ethiopia: A preliminary assessment using the LOPATIN Model.), 1988, , 1988) consists of pre-rift sandstones and conglomerates deposited in a glacial-tofluviatile 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, “Potential hydrocarbon-Generating Rock units within the phanerozoic Sequence Of the ogaden Basin, Ethiopia: A preliminary assessment using the LOPATIN Model.), 1988, , 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 ini/tiated 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.

2.4.Structure of the basin

As stated by (Worku, and Astin,, 1992) and references there in, 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 of previously normal faults.

(Assefa, Lithostratigraphy and environment of deposition of the Late Jurassic - Early Cretaceous sequence of the central part of Northwestern Plateau, Ethiopia. N.Jb.Geol.Paläont.Abh. 182, 255-284, 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 P. , 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.

2.4.1. 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.

2.5.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, Lithostratigraphy and environment of deposition of the Late Jurassic - Early Cretaceous sequence of the central part of Northwestern Plateau, Ethiopia. N.Jb.Geol.Paläont.Abh. 182, 255-284, 1998) 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 or lower Paleozoic. (Kmen-Kaye, ; Purcell , 1978,1981)

2.5.1. 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 1.1: 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

2.5.2. Bokh shale

The Bokh shale is named after Elweraths' Bokh-1 wildcat ($7^0$29.78' N, $46^0$56.58'E) (Placeholder1). 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).

2.5.3. 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 organicrich carbonate and evaporaites with subordinate shale and sandstone. Carbonates assigned to this formation may act as reservoir rocks, and thin interbedded shales as source rocks and seals.

2.5.4. 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 Uarandab 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).

2.5.5. Karroo sediments

The oldest sediments in the basins are continental Karroo sediments. “Karroo” 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, T., Astin, R., 1992) and references therein).

As stated in (Worku et.al,, 1991); 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,, 1991), 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 (Bosellini, 1999).

2.5.6. Gumburo formation

(Beicip-Franlab, 1985, 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 fluviatile environment. These formations belong to the Karoo System and vary widely in thickness.

2.5.7. Adigrat sandstone

According to (Assefa, Lithostratigraphy and environment of deposition of the Late Jurassic - Early Cretaceous sequence of the central part of Northwestern Plateau, Ethiopia. N.Jb.Geol.Paläont.Abh. 182, 255-284, 1998) 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.

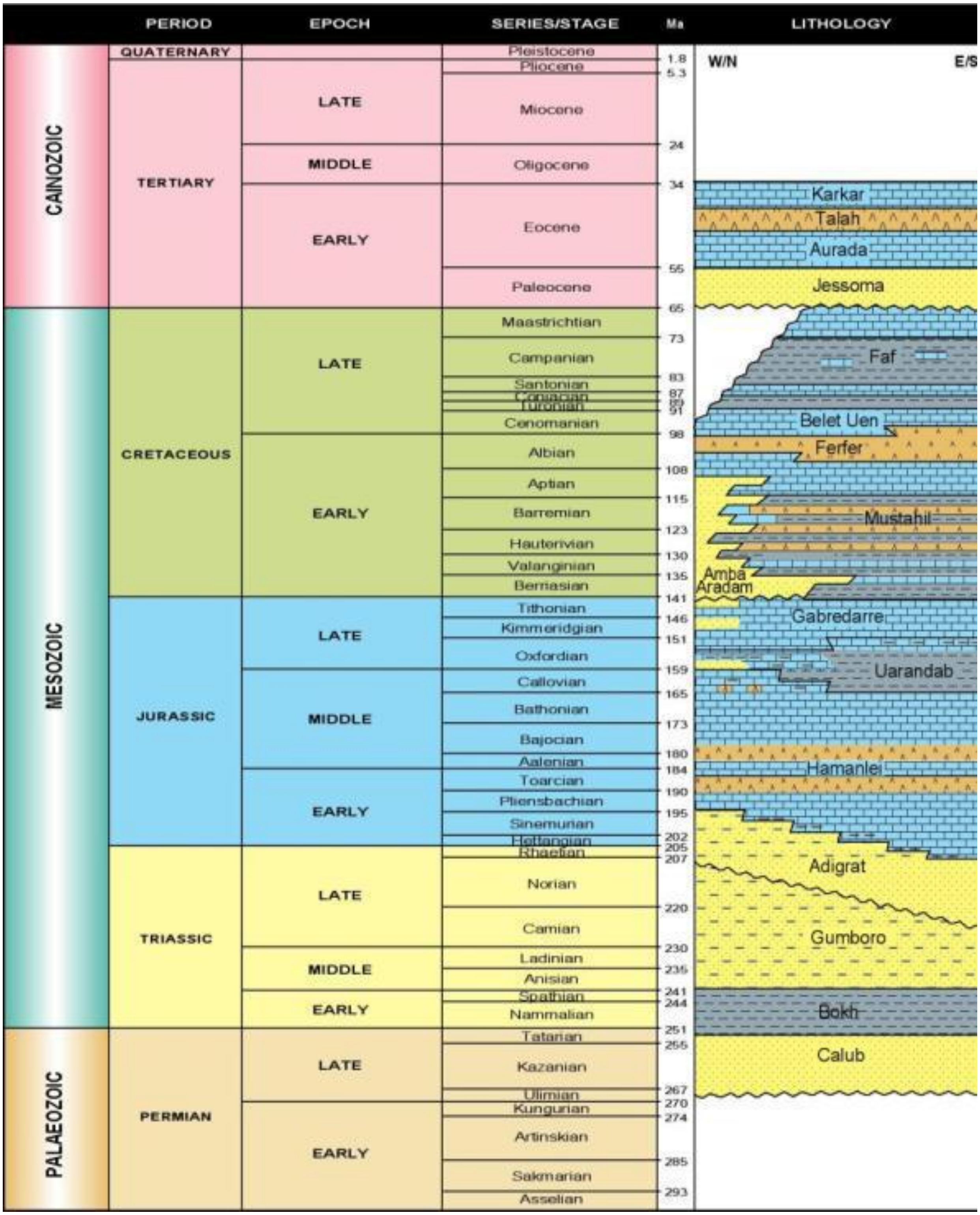


Figure 2.1: Chart showing petroleum systems in the Ogaden Basin After (Worku et.al,, 1991)

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 Boodle Deep, which has a steeply dipping western flank deformed by north south and NNESSW 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 Boodle-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 Boodle 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).

2.6.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.

2.6.1. Potential source Rocks in the region

As stated in (Assefa, Lithostratigraphy and environment of deposition of the Late Jurassic - Early Cretaceous sequence of the central part of Northwestern Plateau, Ethiopia. N.Jb.Geol.Paläont.Abh. 182, 255-284, 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 (Beicip-Franlab, 1985, 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.

2.6.2. Potential reservoir rocks in the region

Based on core analyses and log studies (Beicip-Franlab, 1985, 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.

2.6.3. Traps

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

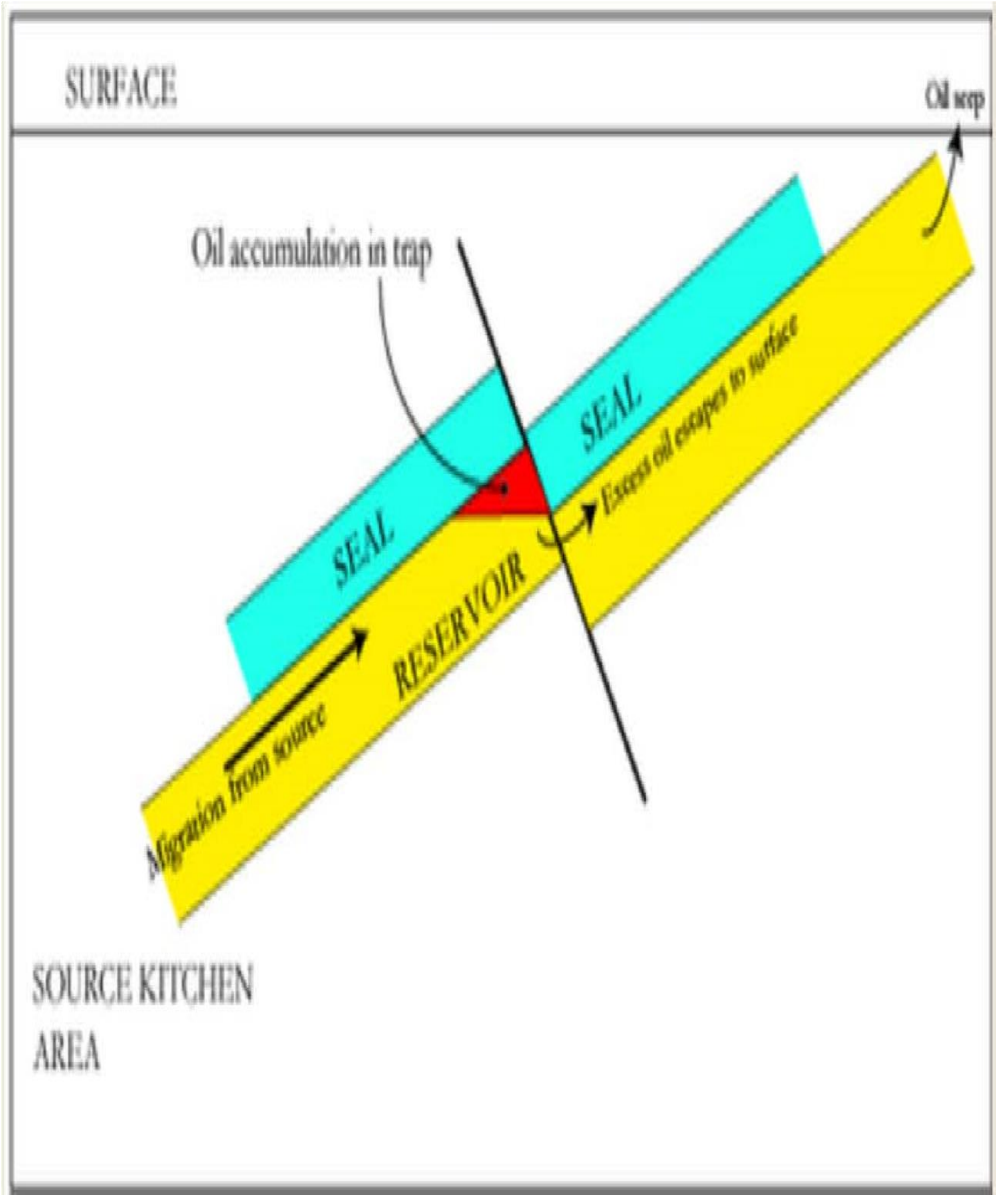


Figure 2.2: Structural traps, where a fault has juxtaposed a porous and permeable reservoir against an impermeable seal. (Beicip-Franlab, 1985, 1998)

2.6.4. 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.

2.7.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, 1985, 1998).

2.7.1. 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 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.

2.7.2. Middle Hammanlie plays and prospects

The Middle Hammanlie Formation (grain stones, pack stones 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 permeability's 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).

2.7.3. 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 the best potential source rocks in the basin (Beicip-Franlab, 1985, 1998).

2.8.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-l (2,769m) in 1949 and 1952, respectively. The Guludi1 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 drilledAbred-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-l (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-1encountered 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 (2,90Om), Hilala-2 (2,40Om), 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 Calub-2, which tested gas at a rate of 19.5 x l03 cu. m/d from the Calub Formation. After renewal of the agreement, the SPEE continued its operations and drilled seven appraisal wells on the Calub 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). Now, 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 km^2; and Genale, 25,571 km^2.

In October 2005, Pexco Exploration of Malaysia was awarded a concession that covered 29,865 km^2 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 km^2 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 THREE

MATERIAL AND METHODS

3.1. MATERIALS

This chapter focuses on the methods and theoretical background, which is utilized to conduct this study,

3.1.1. Data acquisition

The data acquisition used for reservoir characterization of Adigrat sandstone around Calub in the Ogaden basin, Data collected from the Ministry of Mines, Addis Ababa, and Ethiopia. This study utilizes a suite of six well data of the Ogaden basin, Ethiopia. One of the early challenge is to get familiar with the well log data sets, learning the different geological and geophysical softwares (eg. Interactive Petrophysics, Petrel) used in this study to handle different data formats are also challenging. It is very important to know what exactly the softwares are calculating/estimating behind the scene. This data format includes-

- Well data in LAS format for Calub wells
- Seismic SEGY data in SEGY format
- Map and report

3.1.1. Well logs –

Well logs they include data on lithology, porosity, permeability, and fluid saturation, among others. Log data are available for four (4) wells (calub-1, calub-2, calub-3, and calub-4, in the field. The log types used for quantitative analysis in this study are the gamma ray, resistivity, density, and neutron logs.

3.1.2. Seismic data from Calub

Seismic data is a geophysical method used to image the subsurface. It provides detailed information on the structure, geometry, and properties of the rock formations.

3.1.3. Geological and geophysical maps of the study area

These maps obtained from the Ministry of Mines, Addis Ababa, Ethiopia. They provide valuable data on the lithology, stratigraphy, structure, and geological history of the area.

3.1.4. Academic literature –

Relevant academic literature such as journal articles, books, and conference proceedings can provide additional insight into the geology, stratigraphy, and reservoir properties of the study area.

3.1.5. Soft wares

This study utilizes different software packages. Microsoft Office 2007 (Excel, Word and PowerPoint), is used to handle the data, writing thesis and making presentations for final thesis defense. Interactive Petro physics software provided by Synergy is used for most of the petro physical analysis. Petrel provided by Schlumberger used for the correlation study of the source, reservoir and cap rocks units. It also used to generate the contours maps to understand subsurface ogaden basin.

3.2. Methods

Available Well log data from sonic, gamma ray, matrix density and resistivity logs from four wells data were used in the analysis. The ability of rocks to conduct electrical current is primarily a function of the quantity and salinity of the pore fluid. A highly resistive permeable bed is therefore indicative of high hydrocarbon saturation (Dresser Atlas, 1982). The resistivity logs were therefore first used to identify hydrocarbon or water-bearing zones and hence indicate permeable zones. The various sand bodies were then identified on the gamma ray logs. From these logs also were determined the gamma ray index I_{GR} needed for the computation of shale volume in the identified sand bodies.

Using the bulk density and sonic logs, the shale corrected Φ_{cc} of the sand bodies were estimated using the following relations:

$$\Phi cc = \frac{\Delta t - \Delta tma}{\Delta tf - \Delta tma} - V_{sh}\left(\frac{\Delta tsh - \Delta tma}{\Delta tf - \Delta tma}\right) \text{ ---------- } (1)$$

$$\Phi cc = \frac{\rho ma - \rho b}{\rho ma - \rho f} - V_{sh}\left(\frac{\rho ma - \rho sh}{\rho ma - \rho f}\right) \text{ ---------- } (2)$$

Where

Δt =formation interval transit time;

Δt_{ma} = formation matrix interval transit time;

Δt_{sh} = interval transit time for adjacent shale;

Δt_f = interval transit time for interstitial fluid = 189 μs/ft;

ρ_{ma} = matrix bulk density = 2.65 gm-cm^{-3};

ρ_b = formation bulk density;

ρ_f = fluid density = 1.01 gm-cm^{-3}; and

ρ_{sh} = bulk density of adjacent shale.

The shale volume V_{sh} in the sand bodies was estimated using the equation (3) below which is valid particularly for Tertiary sediments.

$$Vsh = 0.083\left(2^{3.7}\ IGR - 1\right)3 \text{------------------------------------ (3)}$$

$$IGR = \frac{GRlog - GRmin}{GRmax - GRmin} \text{-- (4)}$$

Where

GR_{log} = gamma-ray log value for shaley sand;

GR_{min} = gamma-ray minimum value for clean sand; and

GR_{max} = gamma-ray maximum value for shale zone

To estimate the formation water saturation S_w, the true formation resistivity R_t from the deep reading resistivity log is first obtained and the formation water resistivity as supplied by the company noted.

Then using the modified Archie's equation (5) (Dresser Atlas, 1982) we have that

$$S_w = \sqrt[n]{\frac{aRw}{\Phi_{cc} m R_t}} \text{-- (5)}$$

Where

R_w = resistivity of formation water;

a = tortuosity = 0.81;

m = cementation factor = 2.0 and

n = saturation exponent usually taken as 2.0.

A formation is at its irreducible water saturation when its bulk volume water B_{vw} is constant. This value is obtained from equation (6) below.

$$B_{vw} = s_w \Phi\text{c} - \text{(6)}$$

At the irreducible water saturation, the Timur's equation is applied to determine the formation permeability K, which is given as

$$K_{(mD)} = \frac{0.136\Phi^4\text{cc}^4}{s^2{}_w} \text{-- (7)}$$

3.2.1. Petrophysical analysis:

This involves the examination of the physical properties of the rock such as porosity, permeability, resistivity, and saturation using well logs. This analysis is fundamental to understanding the reservoir characteristics of the Adigrat sandstone.

3.2.2. Geological analysis:

This involves the study of the depositional environment, stratigraphy, and sedimentology of the Adigrat sandstone. This analysis enables an interpretation of the geological processes and the formation of the reservoir.

3.2.3. Geochemical analysis:

This involves the study of the chemical composition of the rock and its impact on reservoir properties such as porosity, permeability, and saturation. It also involves the analysis of the molecular properties of the hydrocarbons.

3.2.4. Reservoir simulation:

This involves the use of numerical models to simulate the behavior of the reservoir under different conditions. The simulation involves the input of data from the petrophysical, geological, and geochemical analyses to produce a comprehensive model of the reservoir.

3.2.5. Production data analysis:

This involves the study of production data from existing wells in the Adigrat sandstone reservoir. This analysis is essential in understanding the production behavior of the reservoir, determining its productivity, and optimizing recovery.

3.2.6. Well Log Analysis:

Well-log analysis can be used to analyze the vertical sequence of the Adigrat Sandstone around Calub wells by examining the lithology and the physical and mechanical properties of the sedimentary rocks. This helps to understand the depositional environment and lithology, as well as to analyze the reservoir characteristics such as porosity, permeability, etc.

Table 3.1:.Data of availability Calub studied wells (source: MoM 2021)

Well / Formation	Calub-1	Calub-2	Calub-3	Calub-4
	Formation tops	Formation tops	Formation tops	Formation tops
Gorrahei	203.9	214.7	198.8	207
Gabredarre	1016.2	1028.6	1013.3	1019.9
Uarandab	1304.1	1320.3	1305.7	1315.3
Upper Hamanlei	1444.8	1457.6	1452.2	1450.5
Middle Hamanlei	1855.3	1870.7	1865.8	1859.3
HM Calub-Gas	2117	2130	2114	2120
Low Hamanlei	2397.3	2411.5	2385.2	2395.4
Transition	2634.8	2642.9	2621	2627.5
Adigrat	2722.5	2729.4	2709.7	2724.7
Adigrat-gas	2736	2731	2720	2727
A-Zone1	2740.2	2748.1	2728	2738.7
A-ZONE2	2764.8	2772	2754.8	2767.1
A-ZONE3	2790.3	2795	2776.3	2795.7
A-ZONE4	2811.8	2818	2798.1	2804.9
Gumburo	2842.5	2848.1	2823.7	2855.2
Bokh	3266.8	3282.6	3225.7	3249.8
Calub	3606.6	3626.1	3587.2	3615
C-zone2	3625.6	3645.5	3605.6	3634.1
C-zone3	3647.6	3668.3	3624.4	3659
C-zone4	3672.2	3693.1	3645.1	3681.8
Basement	3690.6	3695.5		
TD	3700	3732	198.8	207

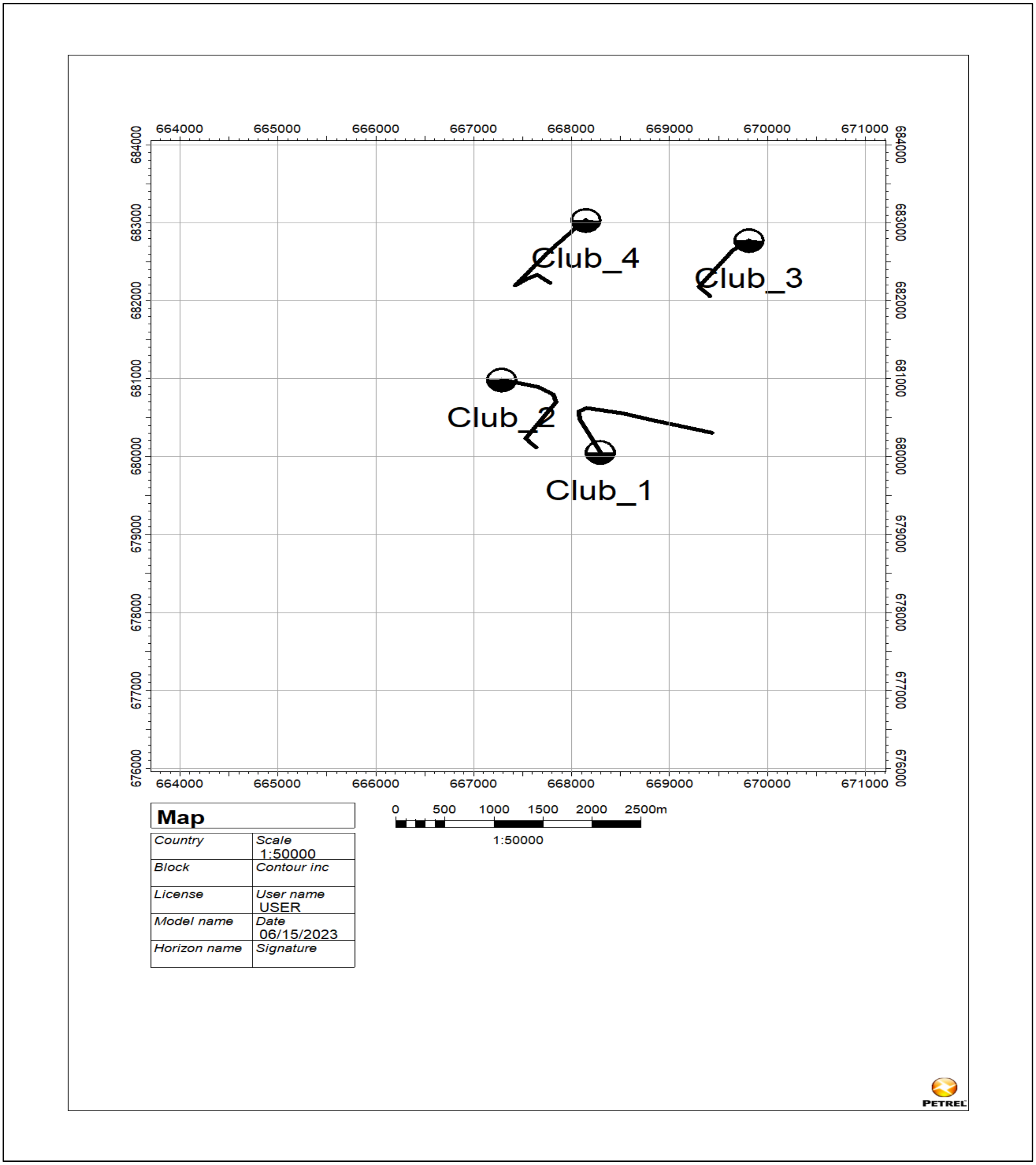


Figure .3.1: Well location map used for the study plotted using Petrel TM 2009 software

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1.Correlation of the Wells:

4.1.1. Calub- 1 and Calub-2 wells

The Gamma ray log was a useful tool in determining the lithology at that depth which was considered before selecting the reservoir with high sand thickness, the resistivity log shows a in the reservoir formation of Adigrat formation.

In well calub-1 well Reservoir Adigarat formation was delineated with well tops at depth of 1600 m as the top of reservoir and at 2000 mts as the base. (Figure 4.1).

In well calub-2 well Reservoir Adigarat formation was delineated with well tops at depth of 1750 m as the top of reservoir and at 2500 m as the base. (Figure 4.1).

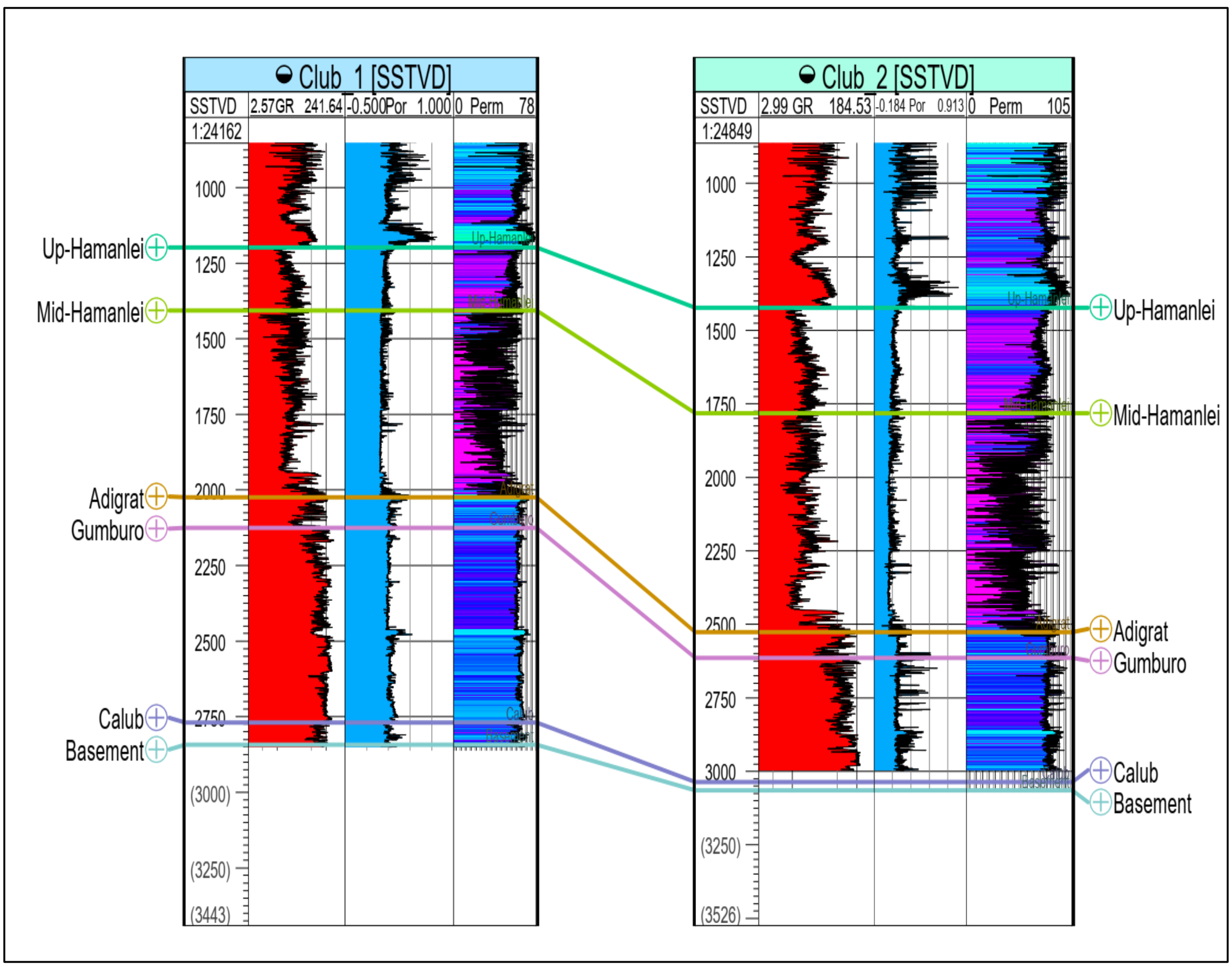


Figure 4.1: Well composite log and well correlation of calub-1 and calub-2

4.1.1. Well calub-3 and calub-4 wells

In well calub-3 well Reservoir Adigarat formation was delineated with well tops at depth of 1000 m as the top of reservoir and at 1300 m as the base, as shown by the well tops markers (Figure 4.2).

In well calub-4 well Reservoir Adigarat formation was delineated with well tops at depth of 1000 m as the top of reservoir and at 1250 m as the base. as shown by the well tops markers (Figure 4.2).

The Gamma ray log was a useful tool in determining the lithology at that depth which was considered before selecting the reservoir with high sand thickness.

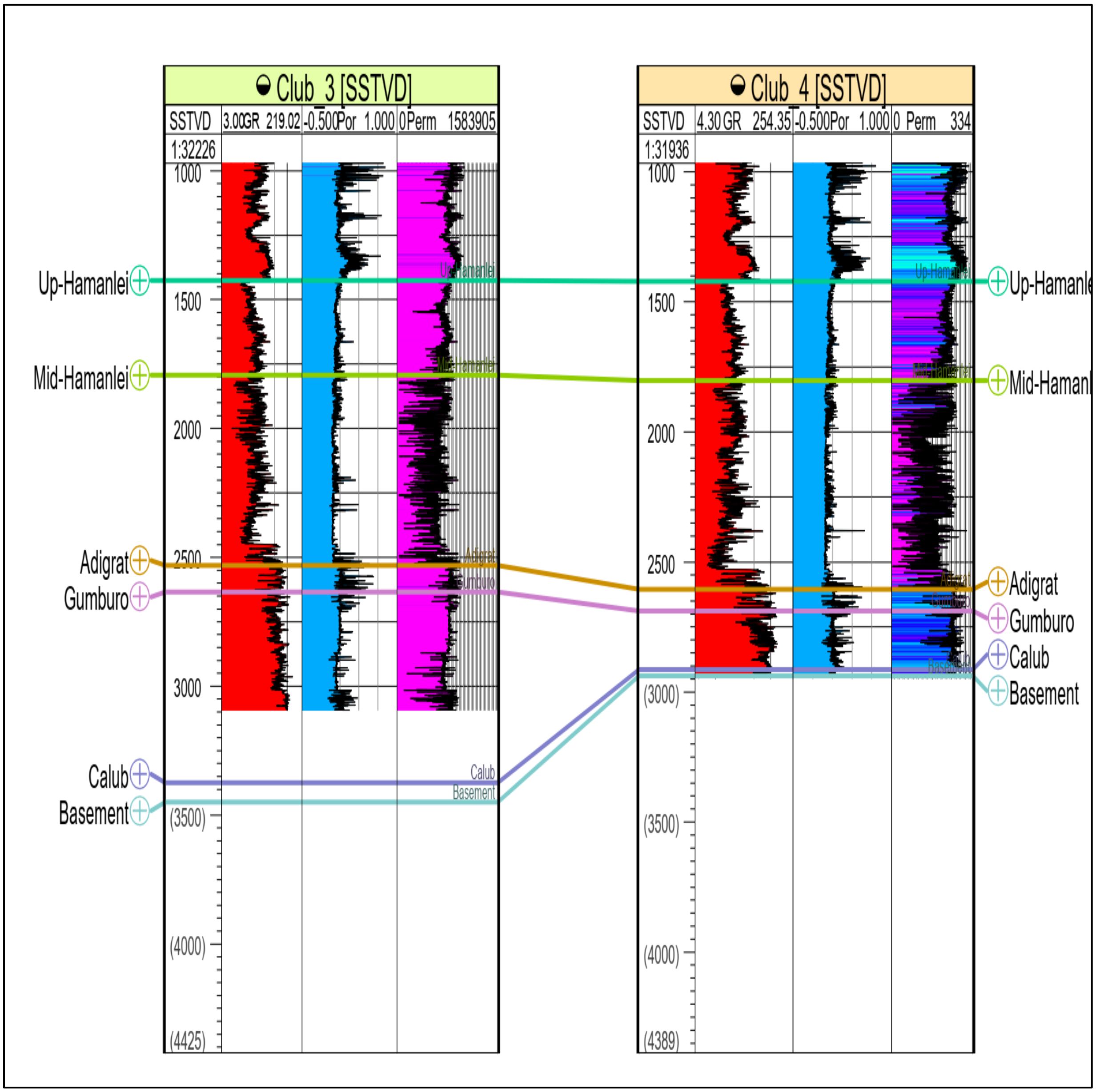


Figure 4.2: Well composite log and well correlation of calub-3 and calub-4

4.2.Stratigraphic verification and well log facies

This has already been carried out earlier on, using log correlation to delineate the reservoir architecture and continuity. A field and reservoir wide (for the modelled levels) correlation exercise was carried out as a means of validating the reservoir tops and bases, to ensure consistency of the reservoir picks, and to correlate the reservoir. This was done within the established sequence stratigraphic framework.

4.2.1. Property Modelling

This is the process of filling the cells of the grid with discrete (facies) or continuous (Petrophysical) properties including facies, Porosity and Permeability. The first thing was to import into Petrel all the property logs prepared in well log data. These logs were then scaled up. Scale up of well logs involves sampling property values from well logs into the 3D grid in such a way that each grid cell will have a single value for each property. Having assigned property values (both facies and petrophysical) to each grid cell at well locations, the next thing was to distribute properties in the inter-well grid cells in order to realistically preserve the heterogeneity of the studied reservoir.

This was achieved in Petrel by first performing Data analysis and then modelling the properties. Data analysis was done in order to identify trends in the data; remove the identified trends; apply transformations on the residual property data, and eventually define Variogram model that describe the data and serve as input into property modelling process.

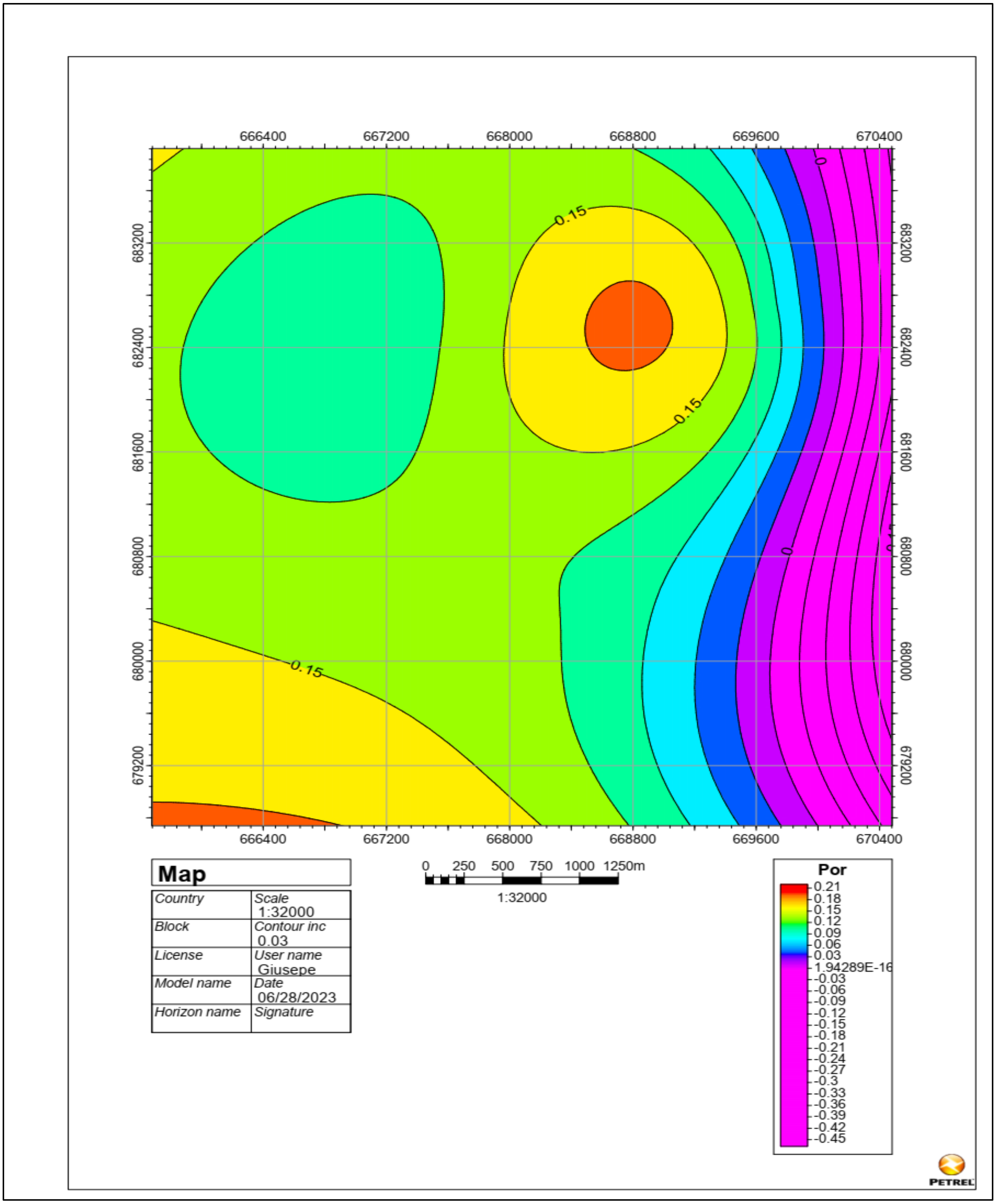


Figure 4. 3: Variogram map for Porosity of Adigrat Formation

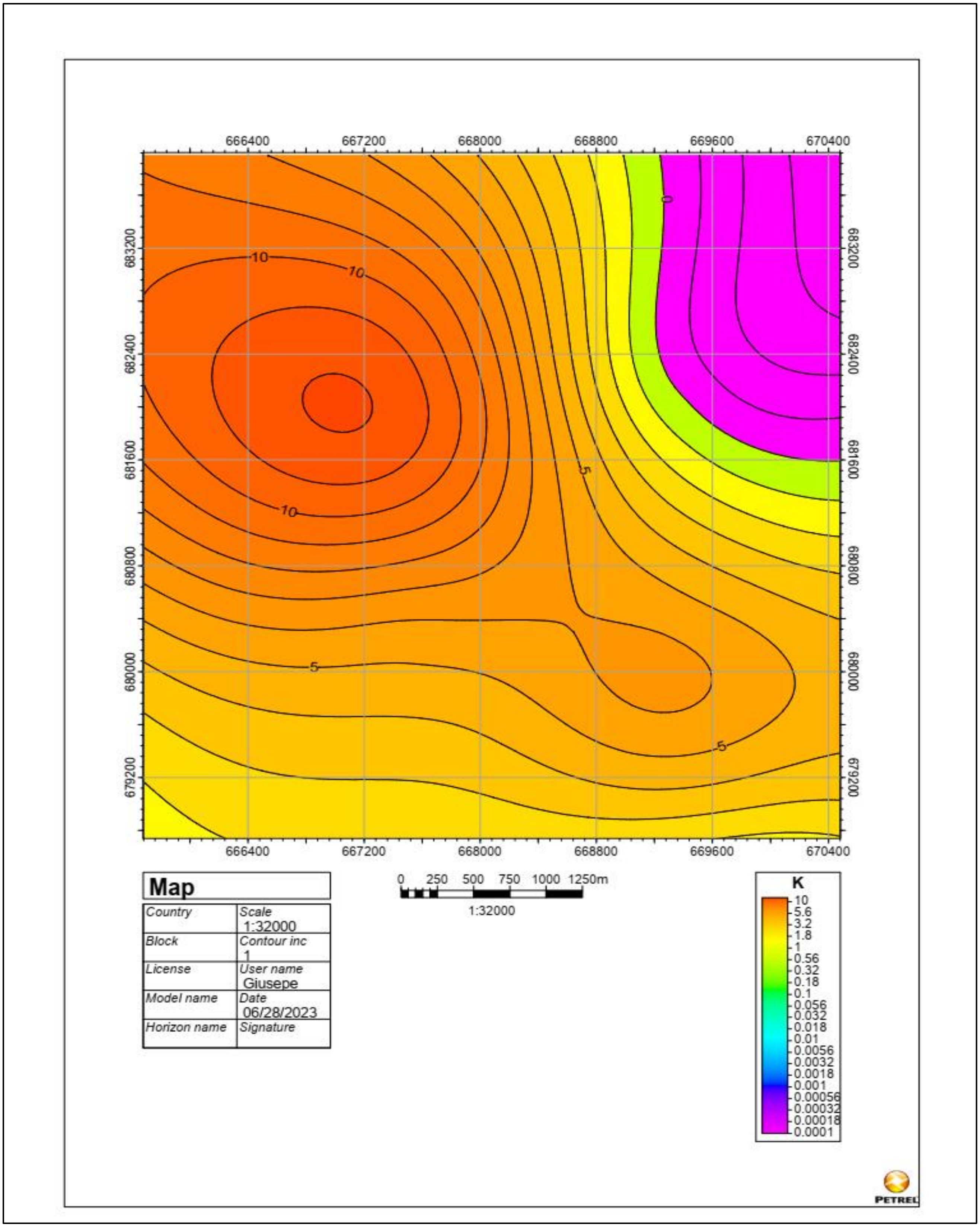


Figure 4.4: Permeability map of Adigrat Formation

4.3.Formation Thickness

Correlation formations, reveals that the reservoirs in the Adigarat formations. It also reveals that each of formation extends throughout the field and varies in thickness with some units occurring at greater depth than their adjacent unit does. As can be seen in Figure 4.2: Adigrat Formation attained a thickness of 300 mts in north –South and in south-west, it becomes shallow depth.

In order to indicate the deposit centers and their migration along with the basin evolution, thickness maps of Adigrat formations are mapped from figure 4.1-4.3, the depar the north East and shallow at north weast

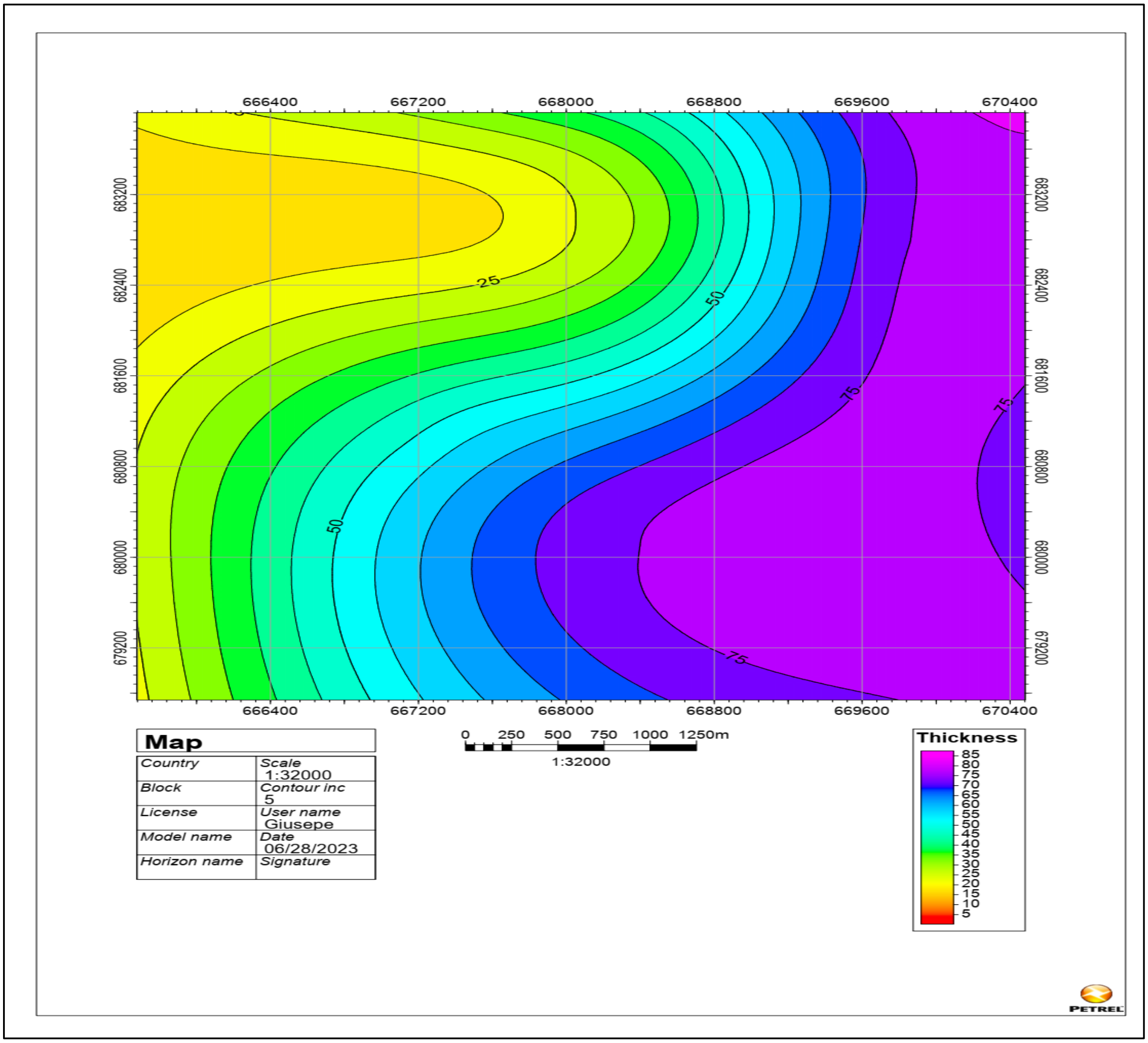


Figure 4.5: Horizon thickness of Adigrat Formation .

4.4. Seismic Interpretation

Seismic interpretation is typically used in oil and gas exploration to identify potential reservoirs. The process of seismic interpretation involves analyzing the complex patterns of reflections and refractions in the seismic data to identify faults, folds, and other geologic features. Interpreters use a variety of tools, including seismic sequences, horizon maps, and cross-sections to build models of the subsurface structures.

4.3.1. Seismic to well tie

A synthetic seismogram was generated for the only well that has checkshot data and this was used to tie seismic to well data. Being that the field is a mature field with many wells, an arbitrary line was taken across the field inside the seismic to calibrate the seismic to well data. Both methods produced the same results (Figures 4.6 and 4.7).

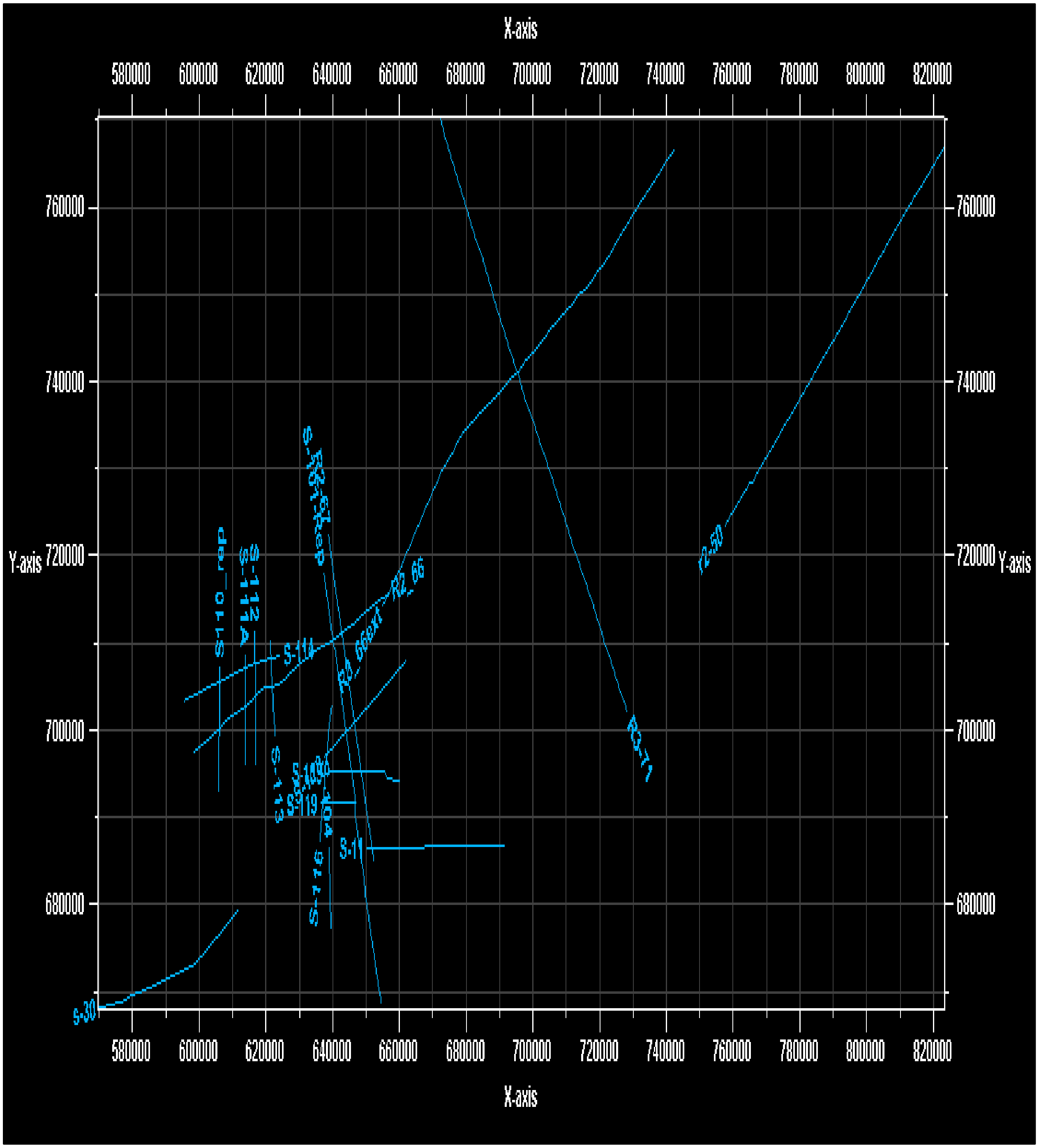


Figure 4.6: Seismic profile map before tied with wells within Ogaden Basin used for the current study

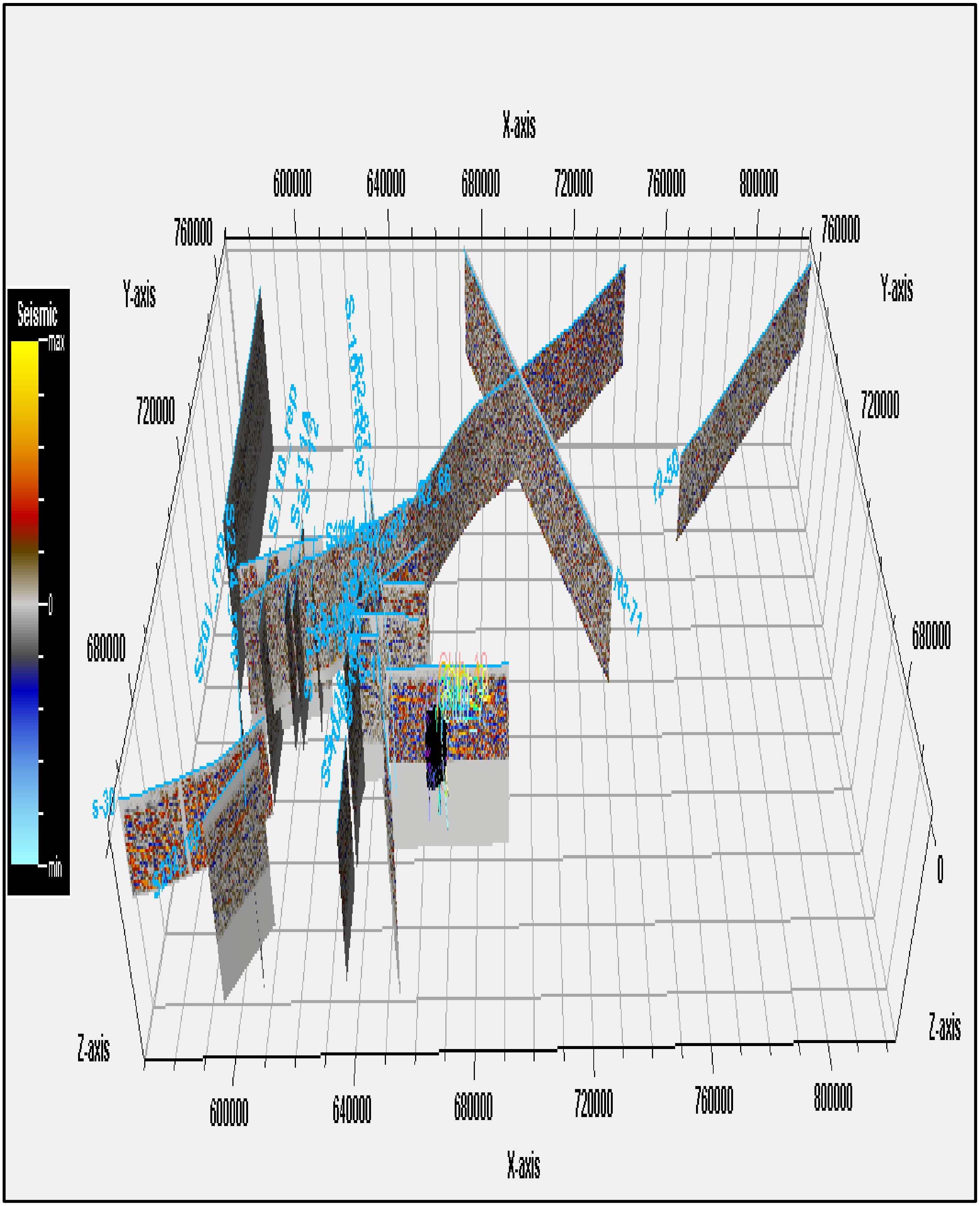
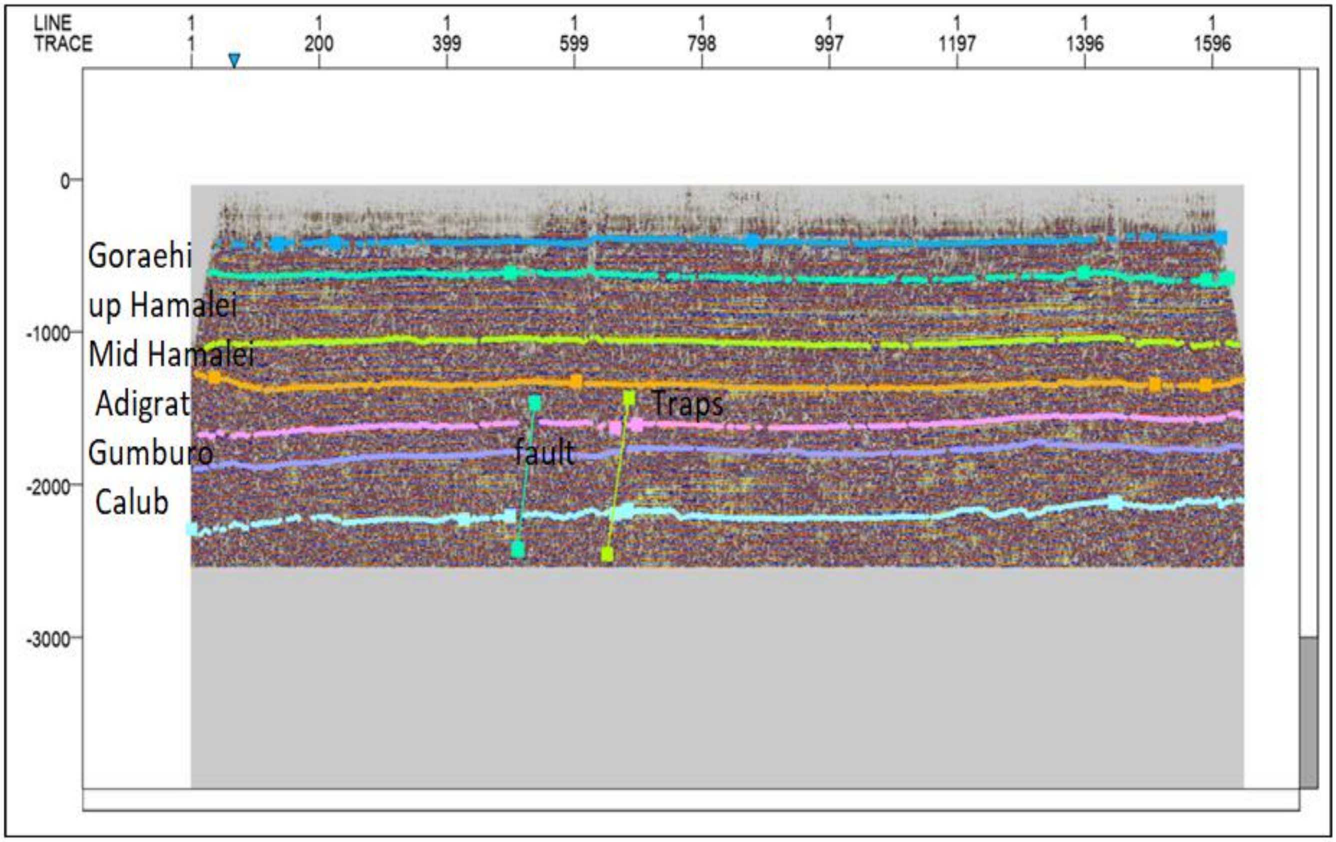


Figure 4.7: Seismic profile map tied with wells within Ogaden Basin used for the current study used pertrel softawere 2009

4.5. Horizon delineation

Figure below shows the horizon interpretation, which shows horizons Adgrata formation as can be seen in the 2D 2D seismic of Adigrata formation interpretation (Figures 4.13 the deepest part of the basin is observed to be towards south eastern part of the study area. This result is also arrangement with the 2D seismic sections interpreted faults and seal traps.



Figures: 4.8:2D seismic of formation interpretation

As it can be seen from the above figure, Reservoir Adigrat formation is a Rollover anticline structure bounded to the North by the major (E-W trending) regional synthetic growth fault and to the Northwest by the East-west boundary fault with dip closures to the East and South. There is no occurrence of intra-reservoir faults.

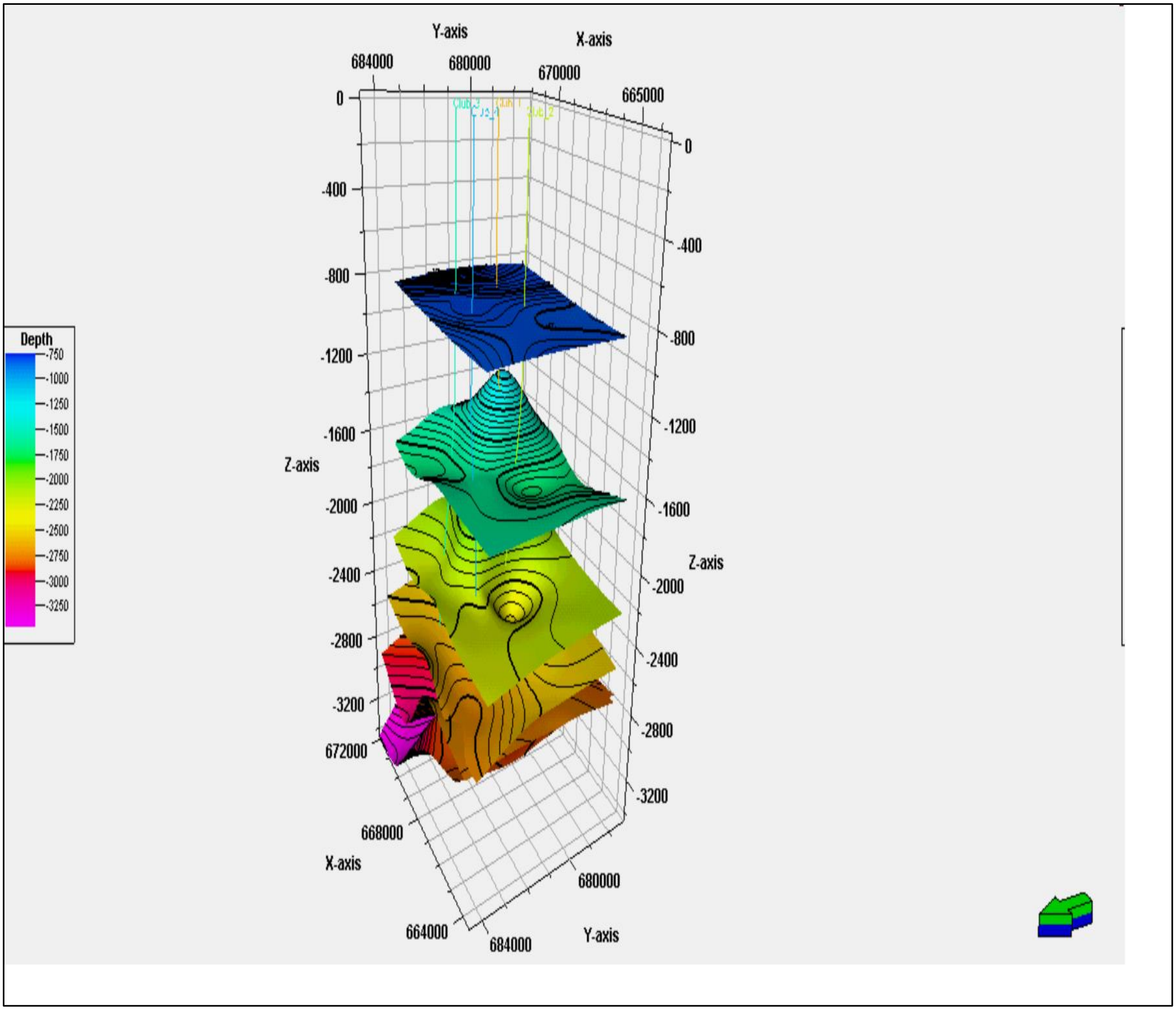


Figure 4.9: Isochore map Depth in 3D of Calub-1, Calub-2, Calub-3 and Calub-4 using petrel software 2009

An isochore map of Wells with different formation indicates the variation in thickness or depth of different geological formations in the subsurface. It shows the distribution of rocks with similar physical properties and ages, which can be useful in identifying potential hydrocarbon reservoirs. The map can also help in understanding the structural geology of the area and the history of sedimentation and tectonic activity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The study focuses on reservoir characterization of Adigrat Sandstone in Calub wells in Ogaden Basin, Ethiopia, using secondary data. The lithological and petrophysical properties of the sandstones were analyzed to determine the reservoir permeability, porosity, and trap interpretation. The results revealed that the Adigrat Sandstone has good reservoir properties; with moderate to high porosity, the reservoirs were identified to be moderate to highly productive, with adequate potential for oil and gas accumulation. The study recommends that more detailed analysis and geological studies should be undertaken using well-related data for improved reservoir characterization of the Adigrat Sandstone in the Ogaden Basin.

5.2. Recommendation

Based on these results, further exploration and production activities are recommended, but additional data collection and analysis are necessary to fully characterize the reservoir properties and optimize production. This includes conducting well data , seismic surveys, and reservoir modeling to better understand reservoir behavior and optimize production strategies.

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