ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

CHARACTERIZATION OF PERMIAN TO TRIASSIC FORMATION WITHIN OGADEN RESERVOIR ETHIOPIA, IMPLICATION OF SOURCE RESERVOIR INTERACTION

A Thesis Submitted to Addis Ababa Institute of Technology
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In Partial Fulfillment of the Requirement for the Degree of Master of Science in Petroleum Engineering

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DECLARATION

I, the witnesses, hereby declare that this thesis is my original work performed with the supervision of Samuel Getnet(PhD.) has not been presented as a thesis for MSc degree program in any other university and all sources of materials used for the thesis work has been fully approved.

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This thesis has been submitted for examination with my approval as a university advisor.

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ABSTRACT

The Ogaden region is located on the Somali Plateau, in southeast Ethiopia. Originally a clanbased term, the Ogaden is now commonly used for the entire region below about 1,500 m a.s. l., an area of some 350,000 km2 that encompasses most of the Somali Regional State and includes the southwest portion of Oromia**.** The Northern Ogaden Basin is underlain by Precambrian basement rocks and Phanerozoic rocks consist of Paleozoic – Mesozoic sedimentary rocks and Cenozoic volcanic and cover rocks. The Phanerozoic of northern Ogaden Basin is formed on an exhumed rift-related, NW-to WNW trending basin that formed as a result of the NE-SW extension that began in Paleozoic. The oldest rocks in the basin are represented by the deposition of Paleozoic-Early Jurassic succession, which is made of continental clastic sediments (Wayu Sandstone and Adigrat Sandstone). They are deposited within grabens bounded by NW-trending and northeast-and southwest-dipping normal faults, which are developed above a top-to-northeast detachment fault. They are un conformably overlain by Middle – Late Jurassic sediments comprised of mainly limestone with minor interbeds of shale and marls (Hamanlei, Urandab and Gabredarre Formation) that pass upward into the Garbeharre Formation, which consists of sandstone, mudstone, shale with minor interbeds of limestone at the base of the succession. The climate is hot, arid to semiarid, corresponding to the Ethiopian bereha and kolla climatic zones. Three basic physiographic provinces are recognized: the Genale and Shebele drainage basins and the Eastern Slope and Plains. The two drainage basins include spectacular upstream canyons that witness the vertical movements that have accompanied the succession of rifting events in the Ethiopian Rift, Afar, and the Gulf of Aden. In strong contrast, the Eastern Slopes and Plains is dipping less than 0.4° on average over hundreds of kilometers to the southeast and is mantled by red sands. Several remarkable Oagden landforms are described and analyzed, including volcanic, fluvial, and gravitational features, some having few equivalents in other areas on Earth.

ACKNOWLEDGMENT

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ABBREVIATION AND ACRONYM

GM	Gamma ray
API	American Petroleum Institute
Dep Envt	Depositional environment
API	American Petroleum Institute
DT	Sonic log
PAULESI	Pan African University Life and Earth Sciences Institute
Geochron	Geochronology
GR	Gamma ray
ILD	Deep resistivity log
RHOB	Density log
SNP	Sidewall neutron porosity log
SP	Spontaneous potential
SSTVD	Subsurface true vertical depth

CHAPTER ONE

INTRODUCTION

1.1. General statement

The Ogaden Basin is a large frontier sedimentary basin in Ethiopia and, despite the discovery of hydrocarbon as early as the 1970s; it remains one of the underexplored basins in eastern Africa. The basin has an area of approximately 350,000 sq. km and an estimated sediment thickness in excess of 7 km in the basin center(Catuneanu et al., 2005) .The Ogaden Basin, according to (EMS, 2023) started to develop in the Permian as a tri-radial rift system known as Karoo Rift and evolved as a passive margin starting from Jurassic intermittently affected by regional tectonics.

The stratigraphy of the basin can be broadly divided into two main intervals .a lower sequence primarily composed of terrigenous clastics of Permian to Triassic/earliest Jurassic age which accumulated in the Karoo rift, and the overlying mega-sequence of Jurassic to Tertiary age, composed of predominantly carbonates and evaporites formed in a passive margin setting(Oljira et al., 2020).The Karoo section in the Ogaden, with the exception of the top Adigrat Formation, is completely subsurface and previous studies of the section have been based on hydrocarbon exploration wells. Around 50 exploration wells have been drilled to date with four gas field discoveries of an estimated reserve in excess of 6 TCF and numerous oil and gas shows in the Karoo section(Worku & Astin, 1992). Moderately thick sequences of coarse sandstone and conglomerate in a rift are likely to be alluvial deposits. The moderate sorting, reasonably well developed bedding, including crude horizontal bedding, point to stream-flood-dominated alluvial fan or plain sediments(EMS, 2023)

1.2. Location and accessibility

The study area is found in the Somali region in the southeastern part of the country. The study area borders Djibouti to the north, Somalia to the east and north-east, and Kenya to the south and the west, it borders Oromia Region and, to the north-west the Afar Region(Alemu & Corporation, 2018). From the Somalia region the study area is found in nine administrative wereda: Shinile, Jijiga,Fik,Degahbur, Korahe, Warder, Gode, Afder and Liban (fig.1). 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 and one domestic airport in Jijiga.

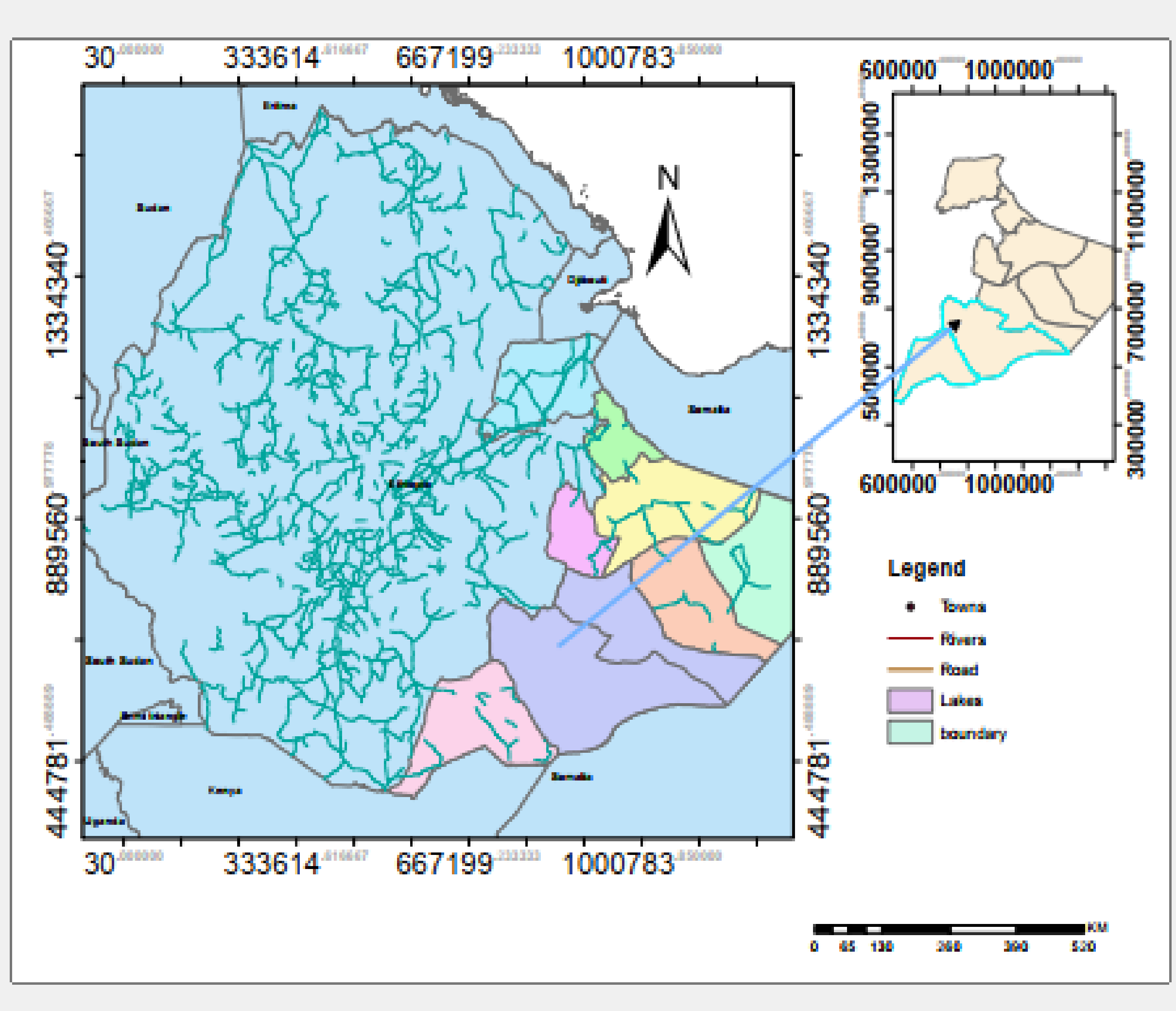


Figure 1.1. Location map of Ogaden basin showing all boundaries with Kenya, Djibuti, Somalia and Oromia Regio

1.3. Physiography and Drainage

1.3.1. Physical Geography

The digital elevation model of south eastern Ethiopia (Figure 3) shows the main features of the Ogaden landscape and the clear subdivision into highly dissected western and subdued eastern regions. The boundary is relatively abrupt, along the eastern side of the uplifted Marda Range, a prominent NW/SE-trending structure thought to have formed by Phanerozoic multiphase reactivation of a Precambrian shear zone(Mège et al., 2015b). From fig 4.the western Ogaden, the high plateau rises to the rift margin rim and is dissected by the steep canyons of south- and east-draining rivers, creating a rugged topography. The steep river canyons and profiles are evidence of the recent relative uplift along the plateau rim. These rivers join the Wabe Shebele, which flows southeast across the central Ogaden into Somalia, its valley slowly diminishing from a steep-walled high canyon to a broad flood plain. Pronounced NW-trending features, such as the Marda Range complex, are clearly seen. By contrast, the eastern Ogaden is a very gentle slope, on average dipping less than 0.4° to the southeast, with no major rivers or high topographic features. Comprehensive geomorphological studies remain to be conducted.

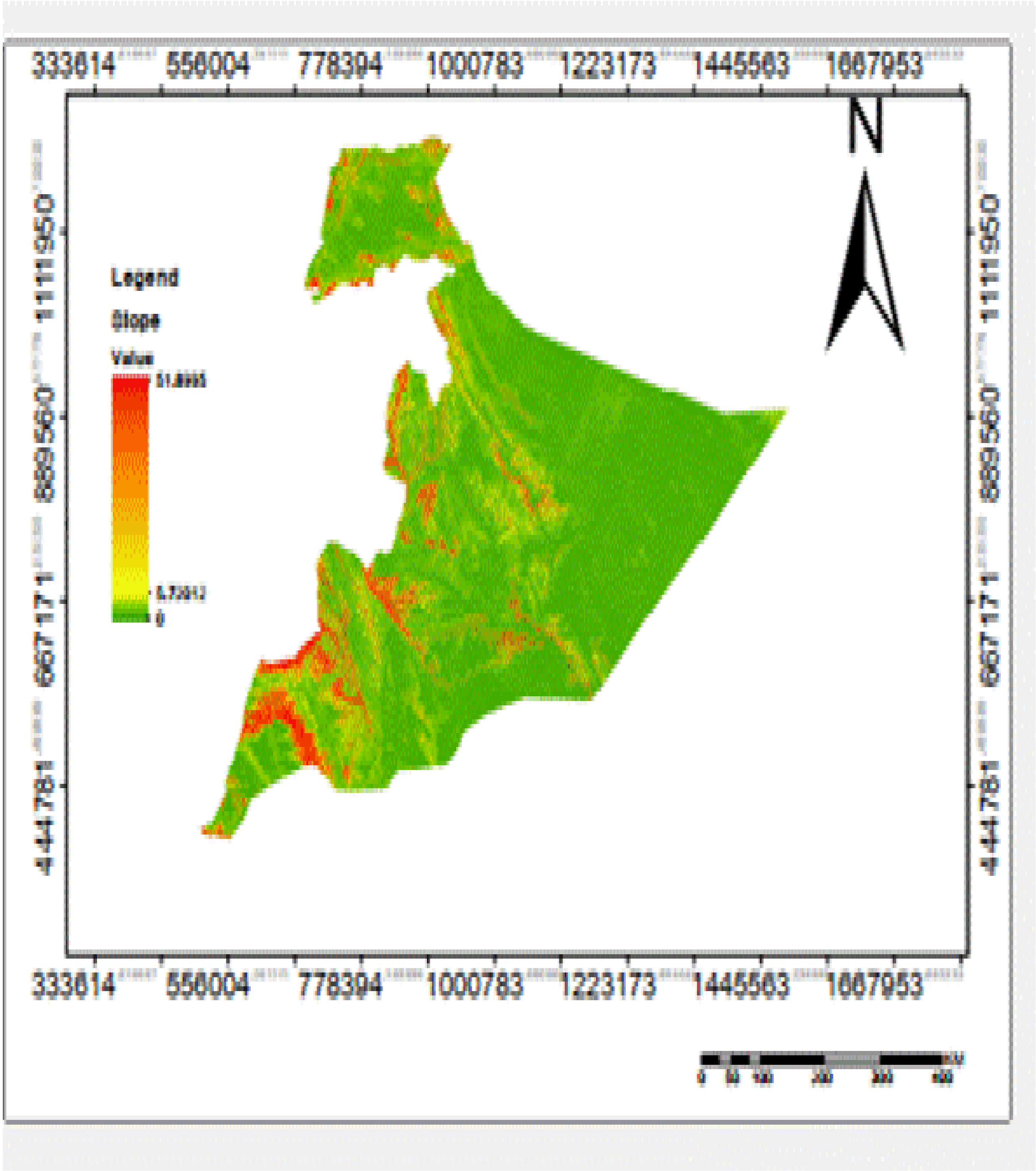


Figure 1.2 Map showing the slope of the Somalia Region

The Ogaden region contains two vast drainage systems, the Wabe Shebele basin in the northeast and the Genale basin in the southwest, as shown in Fig.4 below Both systems drain into the Indian Ocean. The Wabe Shebele (Somali, River of Leopards), known as the ‘Second Nile’ to early Arabian geographers, is over 1,300 km long in Ethiopia (about 2,000 km overall) and has a catchment area of over 205,000 km2 . The river rises in the Arsi highlands in the west and flows initially northeast in spectacular deep canyons, reaching over 900 m deep near the ancient town of Sheik Hussein, before abruptly swinging southeast and meandering across the Ogaden into Somalia. Near Mogadishu, it is deflected southwestward by coastal dunes and, in the wet season at least, joins the Juba River and enters the ocean near Kisamayo. The main tributaries of the Wabe Shebele are the Galeti, Ramis, Erer, and Dakota rivers, rising in the north in the Ahmar Mountains and cutting deep narrow gorges in the northern slopes of the plateau, as discussed further in. The easternmost major river in the region is the Fafan, which, with its main tributary, the Gerer (or Yerer), flows southeast along the Marda Range and then southward, drying into the desert, except in heavy wet seasons when it flows into the Wabe Shebele. The Genale catchment area covers about 168,000 km2 and contains three main rivers, the Genale, Weyb (or Webi Gestro), and Dawa, all of which meet near Dolo on the Somalia border and continue south as the Juba River.The scattered low basaltic hills, has been undertaken and is discussed in Rock outcrops are relatively rare and the plain is covered with alluvial and eolian red sand, commonly a few meters thick but locally as deep as 13 m, based on the results of oil and water bores (Feakins et al., 2013).The main physiographic provinces and features of the Ogaden are shown in Fig4 below shows the basic subdivision recognizes the main provinces of the Wabe Shebele and Genale watersheds and the Eastern Slopes and Plains.

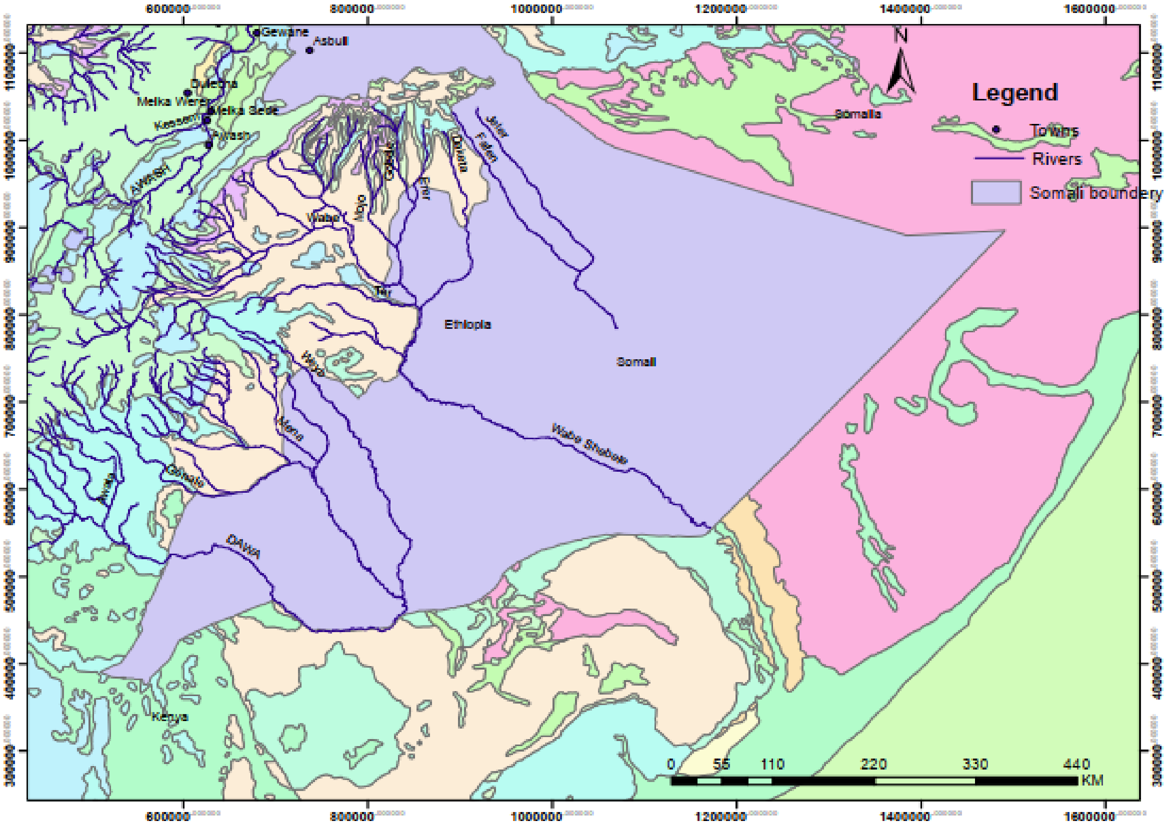


Figure 1.3 Drainage system map of Ogaden the rivers are in blue

1.3.1. Elevation

The Somali Plateau has its highest elevation along the uplifted faulted margins of the Afar Depression and the Main Ethiopian Rift (MER), reaching 2340m m a.s.l. in the Arsi and Bale mountains in the west and over 2300 m a.s.l. in the Chercher and Ahmar mountains in the north/northwest. Except in the west, the areas above 2,3,00 m in elevation occur only relatively near the plateau edge and, in all areas, are associated with volcanoes or thick Tertiary basalt flows. The elevation declines to the south and east and is below 400 m along the Somalia border (Fig. 4). The present elevation of the Somali Plateau is the result of geodynamic events that produced vertical movements of the crust over the Cenozoic(Mège et al., 2015b). The Ogaden is located at the edge of a dynamic mantle plume, upwelling for more than 30 million years in eastern Africa and western Arabia (Eric Donselaar et al., 2015).Flood lava eruption in the Ethiopian-Yemenite province, which peaked at 30–29 Ma (Hofmann et al. 1997), was accompanied by vertical displacements in the region, though whether and where it resulted in uplift or subsidence depends on an interplay of parameters (Olson 1994), details of which are limited by the scarcity of adequate geological observations .On the northern side of the Ogaden, rifting of the Gulf of Aden ([Nature Vol. 261 Iss. 5561] PURCELL, P. G. - The Marda Fault Zone, Ethiopia (1976) [10.1038_261569a0] - Libgen.Li, 1976)started as early as Late Eocene, while uplift peaked at 20–18 Ma and stopped around 16 Ma, when oceanization started([Nature Vol. 261 Iss. 5561] PURCELL, P. G. - The Marda Fault Zone, Ethiopia (1976) [10.1038_261569a0] - Libgen.Li, 1976; Bosworth, 1994). Northward propagation of the Main Ethiopian Rift and initiation of the southern Afar started at 11–10my (Alemu & Corporation, 2018; Hunegnaw et al., 1998; Mège et al., 2015b), and rifting has proceeded until the present. Rift-flank uplift at the western edge of the Ogaden is thought to have occurred during this interval. The overall southeastward slope of the Ogaden seems primarily a consequence of the topographic evolution of this tectonism along the northwestern edge of the Somalia Plate, although it does appear that the region.

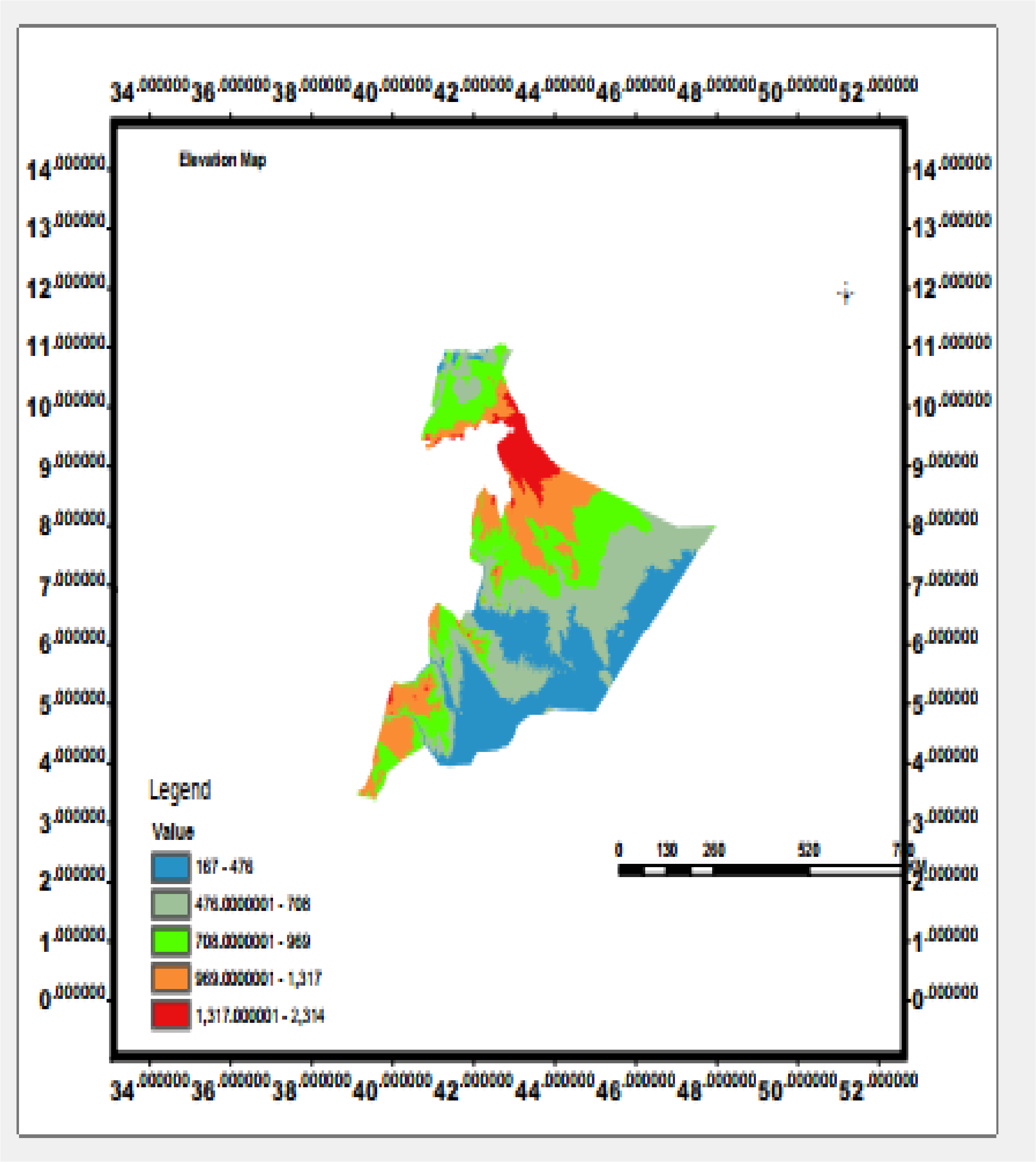


Figure 1. 4 The Map shows the slope of the Ogaden Basin

1.4. Objective

1.4.1. Main objective

The aim the current study is to evaluate the formations and characterize the reservoir in Calub gas field, in terms of its geological structure and petrophysical properties for optimal hydrocarbon estimation.

1.4.2. Specific objectives

- ✓ Petrophysical estimation of reservoir rocks
- ✓ Integrated seismic interpretation of Calub fields.
- ✓ Estimating porosity, permeability of the Calub field
- ✓ Geological and drainage mapping

1.5. Scope of the study

The following scope of work was earmarked towards realizing the study objectives:
Gather and QC all available data and subsequently identify the major subsurface uncertainties in respect of the reservoir and carry out 3-D seismic interpretation, detailed correlation, generate top structure map and quantify the impacts of these uncertainties by evaluating the range of Gas Initially in place (GIIP) in the reservoir.

1.6. Research justification

A fundamental goal of reservoir characterization practices is to form accurate predictions of stratigraphic deposits that cannot be fully “seen”. Remote using seismic acquisition is typically limited by insufficient resolution to resolve important stratigraphic heterogeneity. Seismic signal attenuation due to depth and complexity of overlying sections degrades the ability to image deeply buried deposits at a high-enough resolution to accurately characterize the reservoirs and optimize well planning. High-resolution vertical well data can be gathered, but these methods are costly and the ultimate lateral resolution of this observation method is lacking. The difference in scale between these two observation methods—well and seismic data—can significantly influence the accuracy of subsurface predictions To fill the voids left by available observation methods, exploration and development geologists often predict the spatial distribution of reservoir characteristics based on knowledge gained from well-studied stratigraphic deposits (analog cases), such as well-exposed outcrops. However, stratigraphy is exceedingly variable, and relying on the relatively limited number of available, measurable “analog cases” to formulate production plans is insufficient. To limit exposure to significant uncertainty, companies desire access to expansive sets of system-scale analogs that match observed well data and fit within the geologic context interpreted from available seismic data. The use of system-scale analogs helps predict stratigraphic facies and plan appropriate well programs.

CHAPTER TWO

LITERATURE REVIEW

2.1 Exploration History of Ogaden Basin

Century of Exploration History East African O&G exploration actually began in Ethiopia, in 1921, when Anglo American's expedition to 'Abyssinia' arrived and conducted several local geological surveys amid controversy and intrigue over who held and could award the concessions. The first systematic petroleum exploration was by AGIP in the late 1930s, predominantly in the northern Ethiopia on the Cusp A guest article by Jane Whaley, Editor in Chief, GEO ExPro Magazine and eastern Ogaden, before WWII disrupted exploration. In 1945 Sinclair Petroleum obtained an exploration license covering all Ethiopia, undertaking surface mapping before spudding the first oil well in the country, Gumboro-1, on 17 May 1949, which proved to be dry. The company drilled a series of 'structural' holes looking for regional structures – a technique successful in Saudi Arabia but which failed to identify any Ghawar-type structures in the Ogaden Basin. The 1955 Galadi well had encouraging oil shows in the Jurassic and Triassic. Sinclair supply plane, 1948. After Sinclair left in 1956, more companies entered the arena and 43 wells were drilled in the Ogaden Basin between 1950 and 1995,the high point being the Tenneco's discovery of the country's first two fields: Calub (1973) and Hilala (1974).There were also good oil shows in 1972 in the El Kuran wells in the south-west part of the Ogaden Basin. The military coup in 1974 which overthrew Emperor Haile Selassie was followed by years dominated by civil unrest and war with neighboring Somalia, although extensive geophysical prospecting and appraisal drilling was carried out by Russian organisations.US companies Hunt Oil and Maxus arrived in 1990 and explored for several years, with Hunt drilling the Ganale-1 well in the SW Ogaden. As the oil A country that has long held fascination in the west, Ethiopia is rich in history and culture as well as minerals, but after 100 years of hydrocarbon exploration it is only now close to commercial oil and gas production. @africaoilweek | #africaoilweek price surged early in the 21st century, interest in Ethiopia revived. Petronas began work in the Gambela Basin in 2003, later expanding into Ogaden, and by 2009 it was reported that virtually all areas thought to have potential had been leased; over 30 blocks, with up to ten companies involved. At the time of writing at least five companies have leases in the country, predominantly in the Ogaden Basin.

2.2 Ogaden Basin Discoveries

Ogaden Basin Discoveries As previously mentioned, the first discoveries in Ethiopia were Calub, located 1,200 km southeast of Addis Ababa, and Hilala, 80 km further west. These were found by Tenneco, with partners Texaco and Chevron. Several other wells drilled by the group in the same area were unsuccessful and they relinquished the concession in 1977. A number of companies have since held interests in the blocks containing these discoveries. In the 1980s, the USSR Petroleum Exploration Expedition undertook geophysical studies and drilled further wells on both the Calub and Hilala fields and conducted successful production tests on several Calub wells. After they withdrew in 1991, the Calub Gas and Oil Corporation commissioned ZPEB of China to conduct a well completion programme on the fields. Several other companies held interest in the area but no progress was made until Petronas was awarded the blocks in 2006; after drilling several appraisal wells, they relinquished them in 2010.

2.3 Geological Setting and Basin Evolution

The Ogaden basin is bounded to the north and northwest by the Ethiopian portion of the Miocene-Quaternary East African Rift, and to the west and southwest by basement complex ~~[~~and to the south, east and northeast (Fig 6). *In* Ethiopian, Ogaden Basin adjoins a sedimentary basin in Somalia, which developed in the same regional context The Ogaden basin has a total sediment thickness of 10,000 m and presents an economically viable hydrocarbon deposit The Ogaden basin is said to have a maximum sediment thickness (at deeper parts) of 7 km at the central and southwestern part of the sub-basin around Bodle deep with an aerial extent of about 75,000 km2 .The development of the Ogaden Basin is related to the break-up of Gondwanaland .The source of the sedimentary fill is mainly the Tethys Sea during the Mesozoic times, the cross-river channels, and lacustrine depositional environments

From Permian to Jurassic times, a tri-radial system of north-south, NE-SW and NW-SE trending grabens developed as a consequence of the opening of the North Atlantic and Proto-Indian Oceans In Ogaden basin, sediments deposited are associated with different phases of deformation i.e. the pre-rift sediments (Calub Formation), initial rift sediment (Bokha and Gumburo Formation),early rift sediment (Adigrat sandstone Formation and Lower Hamanlei

Formation), Syn-rift sediments (Middle Hamanlei) and post-rift sediments (Antalo Limestone and Ambaradam Formation) (Figure). The stratigraphy of Ogaden basin from oldest to youngest is Calub Formation,Bokha Formation,Gumburo Formation, Adigrat sandstone Formation, Hamanlei Formation, Uarandab Formation, Gabredarre Formation, Antalo limestone Formation andAmbaradam Formation .Geologically, Ogaden basin comprised non-marine to deep marine clastics,very thick, shallow to deep marine carbonates (in complex association with argillaceous clastics) and evaporites. Ogaden basin is characterized by enormous lithologic heterogeneity in both lateral and vertical extensions derived from a range of paleo environmental settings ranging from late Paleozoic to Mesozoic deduced the depositional environment of the basin as it ranges from continental alluvial fan, fluviatile and deltaic clastics to lacustrine argillaceous types palynological analysis. Later calculated time-temperature indices of rock maturation using Lopatin Model and suggested the presence of favorable environments for generation of petroleum, especially gas, in the Paleozoic and Mesozoic rocks of the Ogaden Basin. On this note, he suggested that the Bokha Shale and the Hamanlei Formation could be potential hydrocarbon source rocks. Suggested that the potential source within the Ogaden basin could be the organic-rich Bokh Shale, transition zone and Urandab Shales with fair to good petroleum potential up to 20 kg HC/ton rock. Reported that sandstones facies of the Calub formation and Adigrat Sandstone Formations as well as the carbonate’s facies in the Hamanlei Formation can serve as reservoir.

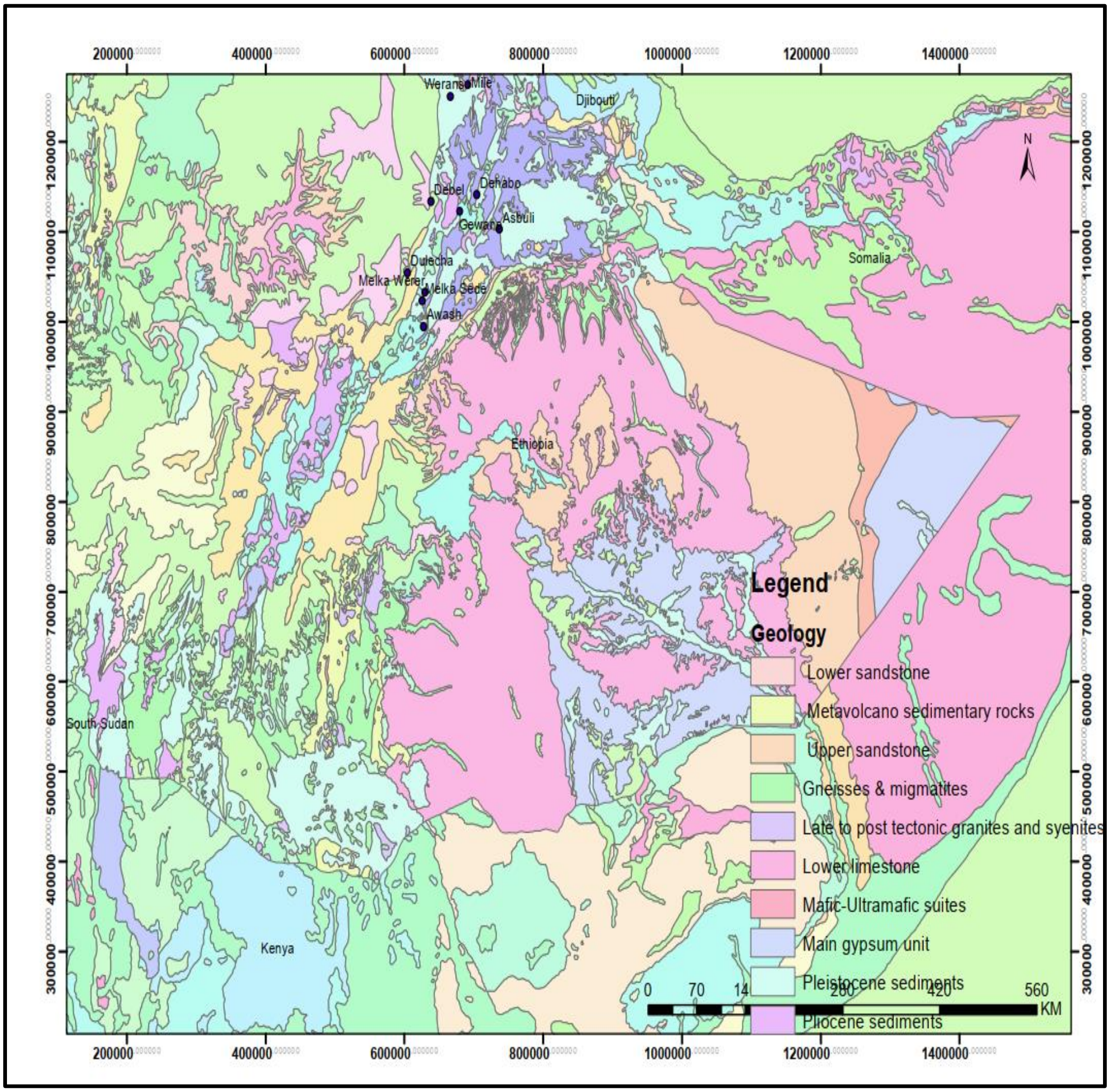


Figure 2.1 Geological map of Ogaden basin and structures aligned in different directions

2.3.1 Paleozoic – Mesozoic Sedimentary Rocks

The Paleozoic – Mesozoic sedimentary rocks in the northern Ogaden Basin is characterized by ~1200 m thick horizontal to sub-horizontal successions of both continental clastic and marine carbonate rocks. From oldest to youngest they are divided into: - (i) Paleozoic – Early Jurassic Sediments, (ii) Middle – Late Jurassic Sediments, and (iii) Cretaceous Sediments; separated from each other by hiatuses and unconformities .Paleozoic – Early Jurassic Sediments Paleozoic-Early Jurassic sediments are continental clastic sedimentary rocks, which un conformably overlying the Precambrian rocks. In the northern Ogaden Basin these sediments are represented by Wayu Sandstone and Adigrat Sandstone .The term Karoo Sediments is preferred to encompass both the Wayu Sandstone and the Adigrat Sandstone, following the usage elsewhere in East Africa, where all continental sediments below the widespread Mesozoic marine transgression are included in the Karoo (cf. Worku and Astin, 1992). The Wayu Sandstone (Berhe, 1985) is exposed only in Wayu valley south of Soka village. It is characterized by flat and rolling topography and consists of 100-150 m interstratified mudstone, siltstone, sandstone and conglomerate, which underlie the Adigrat Sandstone along an angular unconformity. The Wayu Sandstone is represented by three lithofacies. From bottom to top these are: - (i) medium to coarse grained, grayish green to brownish yellow and compacted sandstone, (ii) interbedded mudstone, shale and sandstone in which individual beds are measured in thickness from 10 cm to 1 m, and (iii) grayish yellow, medium grained, compacted and less porous sandstone, which constitutes most of the unit. The sedimentary beds are commonly inclined and folded with open folds trending east-north-east and plunging northwest. The Adigrat Sandstone is named after a town Adigrat in northern Ethiopia for continental clastic sediments underlying the marine carbonates (Blanford, 1870). In the northern Ogaden Basin it is exposed in the uplifted central north and northeast corner of the basin, and within the deeply cut river valleys of Galete, Jerjertu, Ramis, Gobele rivers and their tributaries (Fig.6. It unconformably overlies the Precambrian metamorphic basement. The contact with the overlying Middle – Late Jurassic carbonates is sharp and marked by erosional unconformity. The thickness of the Adigrat Sandstone is measured between 10 and 120 m, but in Bedesa area the maximum thickness of the unit is estimated to be more than 200 m (Tadesse and Tura, 2008). The Adigrat Sandstone is commonly red in color with minor gray and grayish yellow interbeds, less compacted and friable. It displays cyclical deposition of the sediments in upward fining manner. Typical cycles started by conglomeratic sandstone, then cross bedded coarser sandstone overlain by beds of laminated medium- to fine- grained siltstone and mudstone. Generally the Adigrat Sandstone seems to be fluviatile sediment formed by meandering stream, in which, the conglomerate represented the channel lag sediments, the sandstone mark point bar deposits and the interbedded mudstone and siltstone are characteristics of over bank deposits. At place, along Adele – Kurfa Chelle road close to Dawe village the Adigrat Sandstone is observed to include some interlayers of volcanic rocks. The volcanics are represented by interlayers of trachyte and pyroclastics measured in thickness up to 5 cm. Late basalt/doleritic dikes are seen cutting the succession. At this particular outcrop the sandstone is deformed by thrust fault and fold (cf. OWWDSE, 2008).

2.3.2 Middle – Late Jurassic Sediments

The Middle – Late Jurassic sediments are represented by four lithological units, which are related to the marine transgression and regression that affecting the Ogaden Basin. From oldest to youngest, these are:-

1. Hamanlei Formation
2. Urandab Formation
3. Gabredarre Formation
4. Garbeharre Formation

The type section for the Hamanlei Formation (Lower, Middle and Upper) was defined by Migliorini (1956) after the village of Hamanlei in southeastern Ogaden basin. The Hamanlei formation in the northern Ogaden basin is correlatable to the Upper Hamanlei of Migliorini (1956). It represents the first marine sediment formed by the flooding of the sea in the area. In the uplifted central and northern part of the area it underlies plains and ridges commonly overlie the Adigrat Sandstone, but at places around Hakim Gara and Kombolcha it rests directly on the Precambrian basement rocks. Its contact with the underlying Adigrat Sandstone is an erosional surface due to the advancement of the sea; however, its contact with the overlying Urandab Formation is a flooding surface that record sudden deepening of the sea. The Hamanlei Formation is showing thickening from northeast to southwest. It attains a thickness of 317 m at Hakim Gara section, where the base of the formation is exposed, but at Dhungeta section, where the base of the succession is not exposed a thickness of 400 m is measured (Fig.). Lithologically, it is divided into: - (i)) Lower unit, consists of mixed carbonate-clastic sediments, and (ii) Upper unit, comprised of pure limestone. The boundary between them is gradational. The lower unit is characterized by relatively steep slope topography and commonly yellow and grayish yellow color and attains a thickness of 242 m. The unit is comprised of calcareous sandstone, sandy limestone, silty limestone and carbonate mudstone. The upper unit represents the dominant part of the formation is forming plains and flat-topped ridges. The thickness of the unit is increasing from northeast to southwest and a maximum exposed thickness of 400 m measured at Dhungeta section (Fig.2a). The unit comprises storm sequence in the lower part and grainy limestone with intercalations of mudstone in the upper part. At places, interbeds of cherty limestone measured in thickness up to 10 m are observed. The cherty limestone is commonly medium to thickly bedded with frequent development of stylolites along bedding plane. The Hamanlei Formation exhibits tidal flat environment condition that progressively getting more near shore sediments, ranging from upper intertidal to beach.

2.3.3 Urandab Formation

The name Urandab Formation is named after its type section near the village of Urandab, which is located between Kebrhidar and Degehabur (Hunegnaw et al., 1998).In its type section, it is 55 m thick, gray, brown and greenish gypsum-bearing shale intercalated with grey argillaceous limestone in the middle and shale in the lower part(Hankel, 1994; Mège et al., 2015a) .The Urandab Formation in the northern Ogaden basin is formed plains, ridges, local hills and river and stream beds. The formation is thickening towards the southwest, which attains an exposed thickness of 257 m at Shanan – Mechara section, however, in the northeast at Hakim Gara section the formation is not deposited (Fig.6). It is generally horizontally bedded, but at places in the southwestern part of the area along Shanna–Mechara road the beds are inclined and gently folded by monoclinal flexure fold dipping to the northwest (cf. OWWDSE, 2008). It is affected by two sets of fractures/joints; an early northwest to west-northwest striking and the late northeast striking, which formed ladder patterns. Around Mechara-Gelemso and Bedesa area, the formation is represented by: - (i) thin to very thinly bedded limestone in the southwestern part of the area in the deep cut valleys of Dhungeta, and Shannan Rivers, and (ii) coralliferous limestone, burrowed limestone, brachiopod-gastropod bearing limestone and ammonite bearing limestone, in northeastern part of the area around the upper course of Ramis, Galete and Mojo Rivers. The environment of deposition of Urandab Formation is interpreted to be current deposited sediments along the floor of the sea under subtidal environments. The sharp change of near shore facies of Hamanlei to a deeper facies of Urandab confirms a sudden deepening of the sea. The deepening of the sea, continued during the whole Urandab period and reach its maximum at the end, which is marked by a condensed section represented by shaly layer (1.5 m thick), which is limonitized in places at its contact with the overlying Gabredarre Formation. The coral bearing and burrowed limestones confirm a gradational deposition of sediments from a depth where corals can exist to a relatively deeper condition that sunlight and oxygen ceased and only bottom organisms can exist.

2.3.4 Gabredarre Formation

Gabredarre Formation is named after its type locality at Kebrhidar in southeast Ogaden Basin (Migliorini, 1956). At its type locality, the formation consists of thinly bedded alternating olitic and marly limestone with gypsum-bearing shale in its lower part. The thickness of the formation at its type locality is 410 m (Alemu & Corporation, 2018)and decrease northwards, which attains a thickness of less than 100 m. In the northern Ogaden basin, the Gabredarre Formation stands prominently on the underlying Urandab Formation forming a small, but continuous cliff forming escarp, or small table lands. It is separated from the underlying Urandab Formation by a condensed section consists of shaly layer, but its contact with the overlying Garbaharre Formation is gradational characterized by outcrop of mixed carbonate and clastic rocks. Commonly, it is characterized by karst topography with the development of sink holes and cavernous. It is composed of massive to thickly bedded and fossiliferous limestone, oolitic limestone, sandy and silty limestone, which attains a maximum thickness of 247 m at Shanna–Mechara section (Fig. 2a). The sediments of Gabredarre Formation seem to represent open sea sediments. Garbaharre Formation The type area of the formation is exposed in southwestern Somalia on both side of the Lugh syncline. Barberi, 1968 (cited in Merla et al., 1979), distinguished a lower member of sandstones, dolomitic limestones, biostromal and micritic limestones (Busul Member) and an upper member of alternating limestones and dolomites, sandstones, shales and anhydrite. The thickness varies from 100 m in southern Somalia to a maximum of 670 m in the Mandera-Lugh basin. According to Barberi, 1968 (cited in Merla et al., 1979) the age of the formation extend from Portlandian to early Cretaceous. However, Joubert, 1960 (cited in (Hunegnaw et al., 1998)) suggests Tithonian to early Cretaceous age.

In the northern Ogaden basin this succession has previously been mapped as Cretaceous Sediments, which is referred to as Amba Aradom Formation /Upper Sandstone/,by geological survey(Alemu & Corporation, 2018). However investigations made by Tadesse and Tura (2008) and OWWDSE (2008) suggested that this succession marks the last phase of sedimentation by Jurassic sea on its regression, forming a thick deposition of siliciclastics, having a gradational contact with the underlying Gabredarre Formation. Its mixed nature and basin ward termination with progressive decrease in thickness and texture reveals that it is contemporaneous with the Gabredarre (Blanc, 1990). during the course of their mapping at Harer and Dire Dawa area, identified the stratigraphic relationships between the Cretaceous Sediments (Amba Aradom) and the underlying Gabredarre sediments to be unconformable. 6th Ethiopian Geosciences and Mineral Engineering Association (EGMEA) Congress, November 8 – 9 2008. Earth Sciences for Society in the context of the UN proclaimed International Year of the Planet Earth 2008. 9 Therefore, it is difficult to correlate the Garbeharre Formation with the Cretaceous Upper Sandstone/Amba Aradom Formation as thought before by previous workers. Tadesse and Tura (2008) were the first to adopt the name Garbeharre Formation for the last sandstone succession found in the northern Ogaden basin conformably overlying the Gabredarre Formation from(Hunegnaw et al., 1998), who mapped similar sediments as basin margin clastic unit in the southwest Ogaden basin. The Garbeharre Formation is extending south from Bedesa Basin to Mechara-Shannan-Shek Hussien road. South of Wabi Shebele River, between Beltu and Sawena the formation characteristically forming discontinuous outstanding ridges and hills with development of Mesas. As seen on Fig. 7, the formation limits the western extension of the Middle- to Late Jurassic sediments in the northern Ogaden Basin. This might suggest that the formation is marking the last position of the Jurassic sea shoreline. The formation attains a maximum thickness of 300 m at Shanan-Mechara section (Fig.8) and overlies the Gabredarre Formation with a gradational lower contact. This lower contact is characterized by outcrop of mixed carbonate and clastic rocks. The formation is divided into lower and upper units. The boundary between them is gradational. The upper unit is dominantly represented by outcrops of sandstone generally, characterized by reddish to reddish brown color, cross bedded and rippled. The lower unit is characterized by a wide development of shale, mudstone, siltstone, fine - medium grained sandstone with interbeds of thin (bottom. The Lower member, 70 m thick is dominantly fine to medium grained sandstone with interbeds of shale and mudstone with coal seams.

2.3.5 Garbaharre Formation

The type area of the formation is exposed in southwestern Somalia on both side of the Lugh syncline.(Blanc, 1990; Mège et al., 2015b), distinguished a lower member of sandstones, dolomitic limestones, biostromal and micritic limestone (Busul Member) and an upper member of alternating limestones and dolomites, sandstones, shales and anhydrite. The thickness varies from 100 m in southern Somalia to a maximum of 670 m in the Mandera-Lugh basin. According to Hunegnaw.A (Hunegnaw et al., 1998) the age of the formation extend from Portlandian to early Cretaceous.

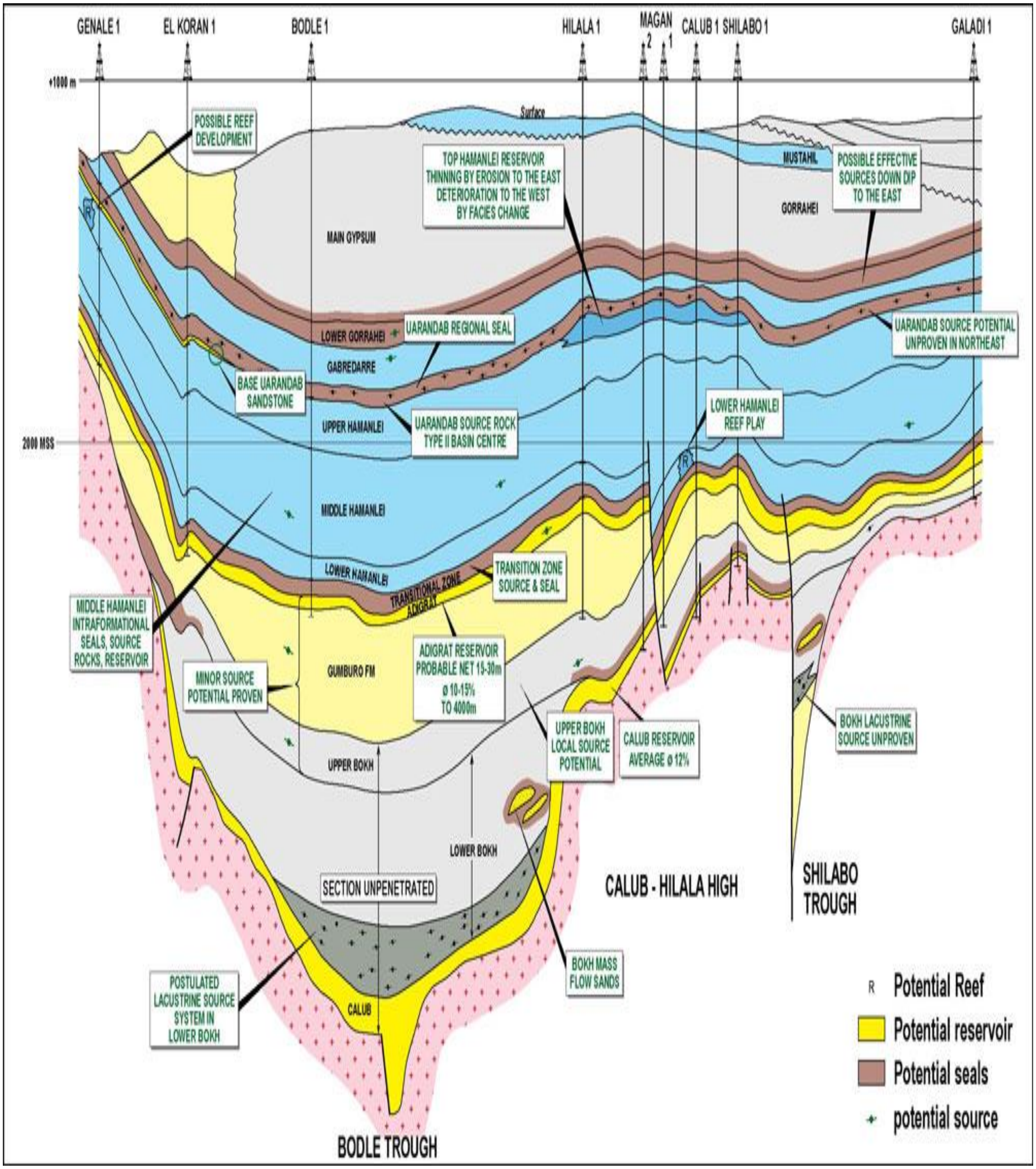


Figure 2.2 Geological cross-section P and R Geological consultants.

2.3.6 Cenozoic volcanic and superficial deposits

The Cenozoic volcanic rocks in the area are divided into Tertiary and Quaternary volcanics and associated superficial deposits. The Tertiary volcanics are divided into: - (i) Pre-Rift (trap) Series, and (ii) Rift-Series, following the classification of Zanettin (1992) for the Cenozoic Volcanic Provinces of Ethiopia. The Pre-Rift series are represented by; (i) Alaji Basalt, and (ii) Termaber Basalt. The Alaji basalts are extending from Chercher mountain chain in the west to Kulubi area in the east. In the southern part of the area they characteristically forms step-like terraces and occupy flat, low-lying areas. In the northeast and central part of the area around Ejersa Goro, south Dogu and Grawa villages they occur as isolated outcrops forming ridges and hills. At places, between Upper Daketa and Fafem rivers they occur as discontinuous ridges aligned in northwest-southeast direction following the regional structures. The basalts generally formed of aphyric to locally porphyritic basalt measured in thickness up to 800 m. K-Ar age determinations place the Alaji basalts between 28 and 25 Ma. (Kuntz et al., 1975). Termaber basalt is comprised of up to 600 m thick succession of aphyric, pyroxene and plagioclase-phyric basalts forming outstanding ridges like Gara Muleta. The Rift series are represented by Arba Guracha silicics consist of basalt interlayered with trachyte and ignimbrite. The Quaternary volcanics are represented by Ginir basalt, which is composed of olivine- rich basalt, usually platy and columnar jointed, commonly aphanitic to fine-grained, black to dark green and grey, and weathers to brownish yellow and reddish brown. It is invariably interlayered with scoriaceous olivine-phyric basalt and characterized by amygdaloidal and vesicular texture.

2.4 Structural Evolution

2.4.1 Precambrian structures

The Precambrian structures are divided on the basis of their geometric characteristics, principles of superposition and crosscutting relationships into three phases of deformation designated as D1, D2, and D3. D1 deformation is represented by folding and thrusting(Alemu & Corporation, 2018). The folds are NE- to ENE-trending open to tight and isoclinals (Fig. 3b and c)(Alemu & Corporation, 2018), formed by folding of metamorphic or compositional layering (migmatitic layering and gneissic banding)(Alemu & Corporation, 2018). The thrust fault is east-northeast to northeast-trending and varies in width from few meters up to kilometer. It structurally separates the underlying gneiss and migmatites from the overlying pelitic and psammo-pelitic schists in the Boye Domain. The structures developed during D2 deformation is related to northeastand east-northeast- trending strike-slip shear zones and NW- to WNW-trending strike-slip faults(Mège et al., 2015a). The mylonitic foliation is well-developed within the shear zone, generally east-northeast-trending and dips moderately to steeply (40° to 80°) to north-northwest and northwest and contains shallow plunging stretching lineation. The shear zone is characterized by asymmetric winged feldspar clasts, south and south-southeast verging minor folds and asymmetric boudins, which suggest sinistral sense of shearing (Fig.4). Minor component of dextral strike-slip shearing is seen by dragging of migmatitic layering/gneissic banding, steeply plunging folds with Z-asymmetry, and asymmetry of rotated mafic boudins and porphyroclasts (Mège et al., 2015a) D3 deformation is characterized by low-angle normal-slip fault/shear zone (detachment). Shear sense indicators in the shear zone include; σ- and δ- K-feldspars porphyro clasts and S-C fabrics show top- to-the north east and east-northeast sense of shearing (Alemu & Corporation, 2018)

2.4.2 Phanerozoic structures

Most of the Phanerozoic structures are the result of reactivation of Precambrian structures, which are mainly characterized by extensional deformation. However, compressional deformations are recorded at places related to uplifting and closure of the basins. The earliest deformation is related to the development of northwest- southeast striking and northeast- dipping, high-angle normal faults. These faults are formed above the hanging wall detachment fault to accommodate extension of the Precambrian basement rocks (Fig. 2b). They appear to be root and/or terminate into the detachment faults, and evolved as asymmetric graben forming a basin for the deposition of the Paleozoic-Early Jurassic Sediments (Wayu and Adigrat sandstones). These sediments are commonly accumulates on the downthrown side of the fault, which passes upward from conglomeratic to fine-grained facies. Late compressional deformation is witnessed by reactivation of the normal faults as reverse faults, and development of folds and thrust faults on Wayu sediments. The folds are mainly open folds trending northeast- to east-north-east and plunging to northwest at low angle. They closely approximate the geometrical characteristics of those of concentric or parallel folds and characterized by very small amplitude relative to wavelength. This might suggest that the folds are formed under low strain conditions. This stage of deformation is followed by rifting occurred from Middle Jurassic to Early Cretaceous, and was more widespread in its effect. It was initiated by the formation of northwest trending and west and southwest dipping normal faults, which formed rift basin for the deposition of Middle – Late Jurassic sediments. The increase in thickness of the Jurassic carbonates (Hamanlei and Urandab Formations) from northeast to southwest in the down thrown side of the fault suggesting that the normal faults were active during sedimentation and appear to be syn-depositional They display right-stepping relay geometry on map outline Dhungeta and Saketa rivers and lower course of Ramis and Mojo rivers follow the trend of these structures .These faults are overlapped to the southwest by deposition of sediments (Gabredarre and Garbeharre Formations), indicating both activity and cessation of displacement on individual faults during basin subsidence .This might suggest that the basin opened progressively from northeast to southwest. The last stage of Phanerozoic deformation in the basin is marking a regional unconformity between the Jurassic sediments and the Cretaceous sediments, and characterized by uplifting and associated rifting. Uplifting in the area is delineated by Tefe – Senbeti upland plain and Wabi Shebele River bend. This uplifting is accompanied by the development monocline flexural folding; define by dip of sedimentary beds to northwest with shallow to moderate angles. The fold is cut by late west-northwest- to northwest-trending and northeast-trending faults. The northeast-trending faults well developed at the hinge of the monoclinal flexure fold and steepened the early shallow beds. At place, along Sawena – Beltu road steep dip (80º) was measured on sandstone beds of Garbeharre formation. Though no conclusive field streams. During Cenozoic the basin is affected by regime of extensional tectonics, which is resulted in the development of major normal faults with associated strike-slip faults.

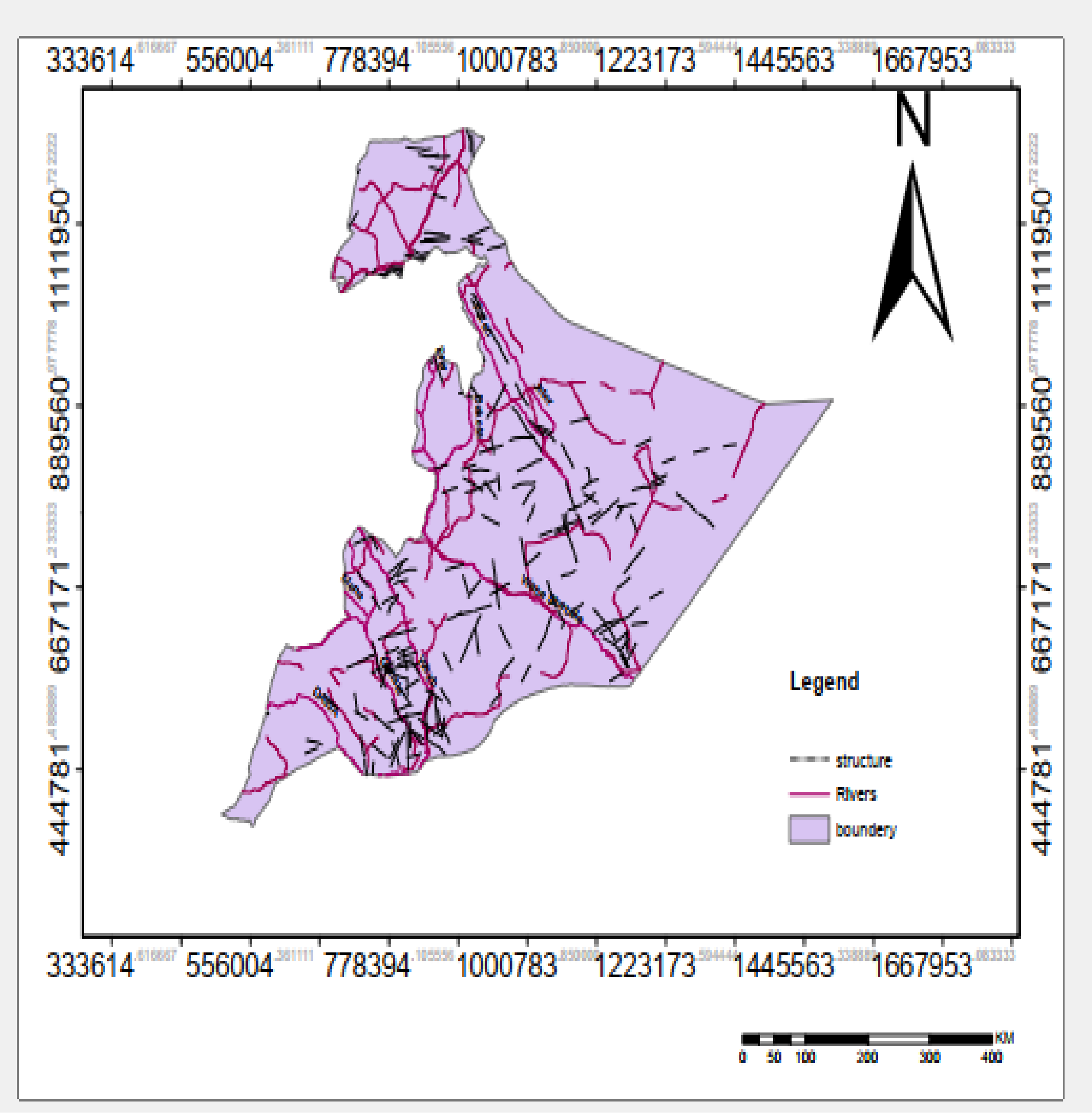


Figure 2.3 Structure map of Ogaden Basin

CHAPTER THREE

METHODOLOGY

3.1 Data Acquisition

The data set for the study is made up of well-logs and and Topo map Data Ministry of Mines, Addis Ababa, Ethiopia. Data from wells used in this study included gamma ray, effective porosity, and resistivity logs from eight wells: Calub 5, Calub 6, calub7,Calub 8,Calub9 and Calub 10,Hilala3 and Hilala5.

3.2 Methods of Analysis

(a) Data collection, digital Wire line logs data(in LAS) well deviation data in (ASCIfile),well header information check shot survey data(used to calibrate the relation between time calculated from sonic log well depths .

(b) Petro physical Analysis: The following petro physical analysis will be carried out for certain reservoir sand bodies within the 8 wells in the area of study from wireline logs by using petro physical calculation (Archie, 1942; Asquith and Krygowski, 2004): Net-to-cross (N/G), Porosity (p), Permeability (K), Volume of Shale (Vsh), Formation factor (g), Water saturation (Sw), Irreducible water saturation (Swirr), Bulk Volume Water (BVW) and Hydrocarbon saturation (SH).

c) Use of wire line log data is to guide and aid the sediment logical interpretation of the cored sequences employed.

d) Software used and its application

Schlumberger's Petrel software, version 2009, interpreted well-logs and well-log correlations Interactive petro physics, ArcGIS 10.7 is Use it to make maps, to analyze data,

3.3 porosity

Porosity can be estimated from the log curve of *flushed zone* resistivity *Rxo*. Since the drilling mud invades the zone closest to the borehole wall, it displaces most of the hydrocarbons, so the local hydrocarbon saturation in such small zone can drop easily to around 20% or less.

The Archie equation can be applied then to this invaded zone —for now let's assume that the rock matrix is clean, non-clayey, and non-conductive—. Replacing the deep, true far field un invaded resistivity Rt with the flushed zone resistivity Rxo, and replacing the formation water resistivity Rw with the mud filtrate resistivity Rmf (which has to be corrected to the depth temperature), and solving for the porosity φ:

$$\emptyset \cong \left(\frac{\propto.\mathrm{Rmf}}{\mathrm{Sxo}^2.\mathrm{Rxo}}\right)$$

Sxo≅0.8 for hydrocarbon pay zone

Sxo = 1 for water zone

$\propto \cong 1, \mathrm{m} \cong 2.0, \mathrm{n} \cong 2$ depending on reservoir

$\emptyset =$ Denotes the porosity, Rm = the electrical conductivity of the fluid saturated rock, Rxo =represents the electrical conductivity of the aqueous solution (fluid or liquid phase), is the water saturation,

f =formation factor

Provided that a good quality curve for Rxo is available in a good quality and stable borehole —occasionally MSFL yields good results—, and Rmf is accurately measured and converted to the depth temperature, the estimator for porosity is useful. This φ estimate is independent of the classics density porosity, neutron porosity, and sonic porosity. It is based only on resistivity and provides yet another in situ estimate, valuable either for validation or even estimation on its own right.

3.4 permeability

It has been proposed that permeability, water saturation, and rock resistivity have a relationship. When the other two are known, this connection can be used to interpret any one of the three parameters. When water saturation is known, the relationship, for instance, can be used to infer permeability from resistivity logs. The electrical measurements of core samples with various permeability provide the foundation for this work. Rock permeability was expressed using brine saturation and the related rock resistivity. The rock resistivity was represented by an apparent formation fact Of Fa, which is the ratio of the partially sati- rated rock resistivity to the brine resistivity. In order to eliminate the brine-resistivity influence.

Mathematical Expressions for permeability and Porosity

$$F = \frac{R_o}{R_w} = \frac{\tau}{\phi}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Resistivity of a partially brine-saturated rock, Q, is a function of *F*, brine resistivity, @, water saturation, , and saturation

$$R_t = F\frac{R_w}{S^n}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$S_w^n = \frac{R_t}{R_w}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Eq.2 can be rewritten as F =Apparent formation factor, >a • expresses the rock resistivity for any brine saturation. This parameter is a constant for each brine saturation and does not change when different salinity brines are used.

Fq is defined as the ratio of F =

From Eq, 3 and Eq. 4, the following equation can be derived:

F = F.S ....(5)

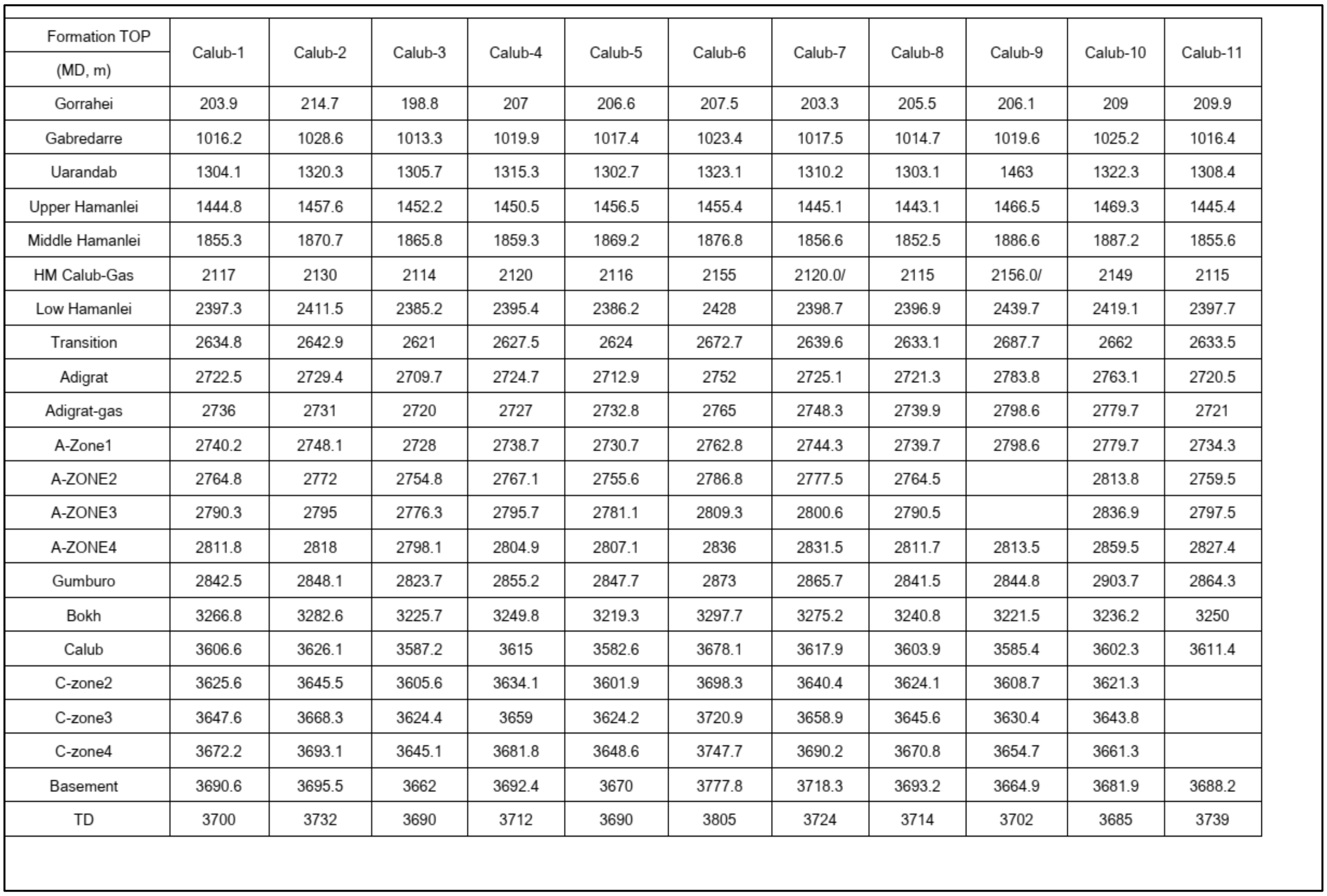
Eq. 5 defines a rational relation of the apparent formation factor (N = $FS,,$ ° •) with respect to, for all rocks having the same F value. For rocks with a different value, another curve will be defined.

Eq. 5 explains formation factor F as a function of apparent formation factor, Fg, water saturation, and saturation exponent, n. For a given R, if water saturation and rock resistivity are known, then F can be calculated. Because Fts a function of porosity and tortuosity, permeability, k, should be a function of F. Eventually, if permeability ability can be represented as a function of N, it also can be represented as a function Of F_a and S'' according to Eq. 5, namely:

k = f(Fq, S•,)...(6)

After establishing the relationship in Eq. 6, the permeability of a rock can be calculated from resistivity and water-saturation data. The relationship between k and F was not used directly, because F cannot be calculated from resistivity logs in hydrocarbon zones. Estimation of F from

Porosity.



Formation TOP (MD, m)	Calub-1	Calub-2	Calub-3	Calub-4	Calub-5	Calub-6	Calub-7	Calub-8	Calub-9	Calub-10	Calub-11
Gorrahei	203.9	214.7	198.8	207	206.6	207.5	203.3	205.5	206.1	209	209.9
Gabredarre	1016.2	1028.6	1013.3	1019.9	1017.4	1023.4	1017.5	1014.7	1019.6	1025.2	1016.4
Uarandab	1304.1	1320.3	1305.7	1315.3	1302.7	1323.1	1310.2	1303.1	1463	1322.3	1308.4
Upper Hamanlei	1444.8	1457.6	1452.2	1450.5	1456.5	1455.4	1445.1	1443.1	1466.5	1469.3	1445.4
Middle Hamanlei	1855.3	1870.7	1865.8	1859.3	1869.2	1876.8	1856.6	1852.5	1886.6	1887.2	1855.6
HM Calub-Gas	2117	2130	2114	2120	2116	2155	2120.0/	2115	2156.0/	2149	2115
Low Hamanlei	2397.3	2411.5	2385.2	2395.4	2386.2	2428	2398.7	2396.9	2439.7	2419.1	2397.7
Transition	2634.8	2642.9	2621	2627.5	2624	2672.7	2639.6	2633.1	2687.7	2662	2633.5
Adigrat	2722.5	2729.4	2709.7	2724.7	2712.9	2752	2725.1	2721.3	2783.8	2763.1	2720.5
Adigrat-gas	2736	2731	2720	2727	2732.8	2765	2748.3	2739.9	2798.6	2779.7	2721
A-Zone1	2740.2	2748.1	2728	2738.7	2730.7	2762.8	2744.3	2739.7	2798.6	2779.7	2734.3
A-ZONE2	2764.8	2772	2754.8	2767.1	2755.6	2786.8	2777.5	2764.5		2813.8	2759.5
A-ZONE3	2790.3	2795	2776.3	2795.7	2781.1	2809.3	2800.6	2790.5		2836.9	2797.5
A-ZONE4	2811.8	2818	2798.1	2804.9	2807.1	2836	2831.5	2811.7	2813.5	2859.5	2827.4
Gumburo	2842.5	2848.1	2823.7	2855.2	2847.7	2873	2865.7	2841.5	2844.8	2903.7	2864.3
Bokh	3266.8	3282.6	3225.7	3249.8	3219.3	3297.7	3275.2	3240.8	3221.5	3236.2	3250
Calub	3606.6	3626.1	3587.2	3615	3582.6	3678.1	3617.9	3603.9	3585.4	3602.3	3611.4
C-zone2	3625.6	3645.5	3605.6	3634.1	3601.9	3698.3	3640.4	3624.1	3608.7	3621.3	
C-zone3	3647.6	3668.3	3624.4	3659	3624.2	3720.9	3658.9	3645.6	3630.4	3643.8	
C-zone4	3672.2	3693.1	3645.1	3681.8	3648.6	3747.7	3690.2	3670.8	3654.7	3661.3	
Basement	3690.6	3695.5	3662	3692.4	3670	3777.8	3718.3	3693.2	3664.9	3681.9	3688.2
TD	3700	3732	3690	3712	3690	3805	3724	3714	3702	3685	3739

Table 3.1 showing well detail from calub well 1 to 11

CHAPTER FOUR

RESULT AND DISCUSSION

The porosity (volume of pore spaces) and permeability (capacity for transmitting fluids) of carrier and reservoir beds are important factors in the migration and accumulation of oil. Most conventional petroleum accumulations have been found in clastic reservoirs (sandstones and siltstones).

4.1. Horizon interpretation

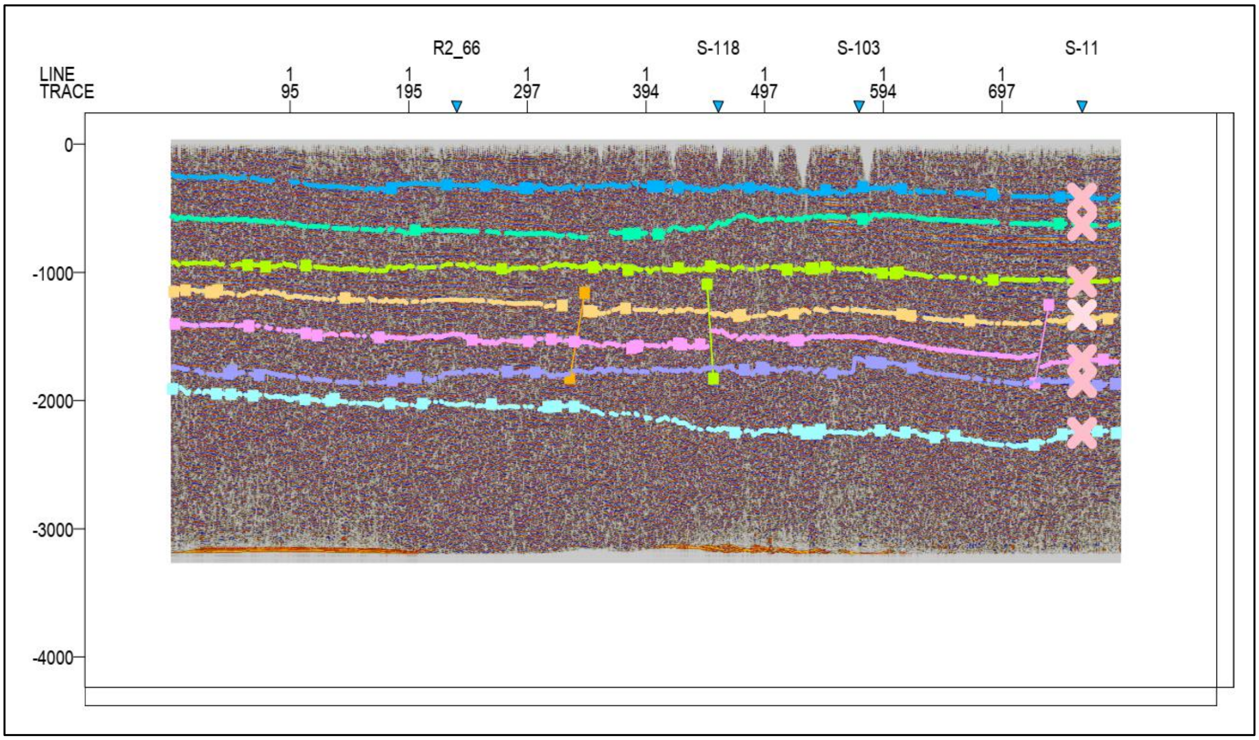


Figure 4.1 Figure shows the horizon interpretation, which shows horizons of Calub formation, Gorahei formation, Gumburo formation and structures, observed on calub and Gorahei formation.

4.2. Porosity

The porosity (volume of pore spaces) and permeability (capacity for transmitting fluids) of carrier and reservoir beds are important factors in the migration and accumulation of oil. Most conventional petroleum accumulations have been found in clastic reservoirs (sandstones and siltstones). In in calub field the porosity of the calub formation is increased from the South West to North East direction.

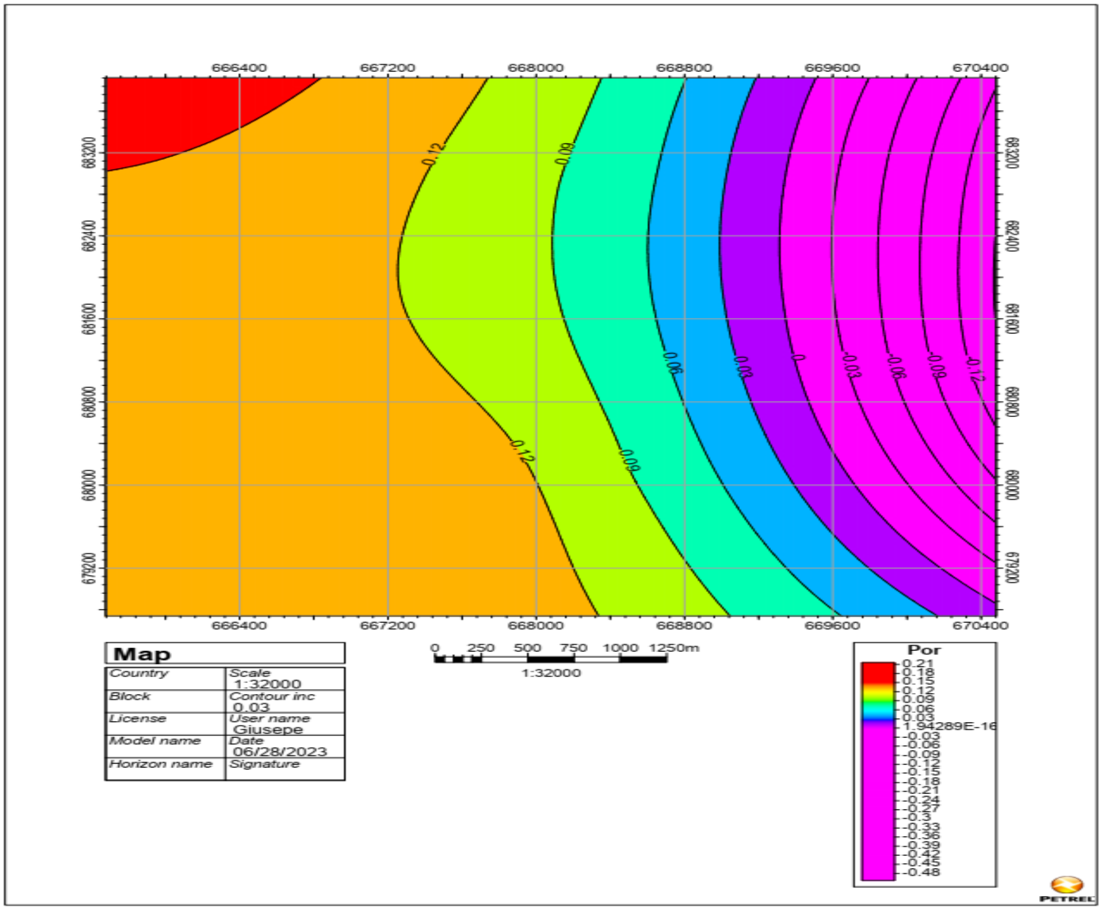


Figure 4.2 porosity map of Claub formation which is increasing to the North East Direction

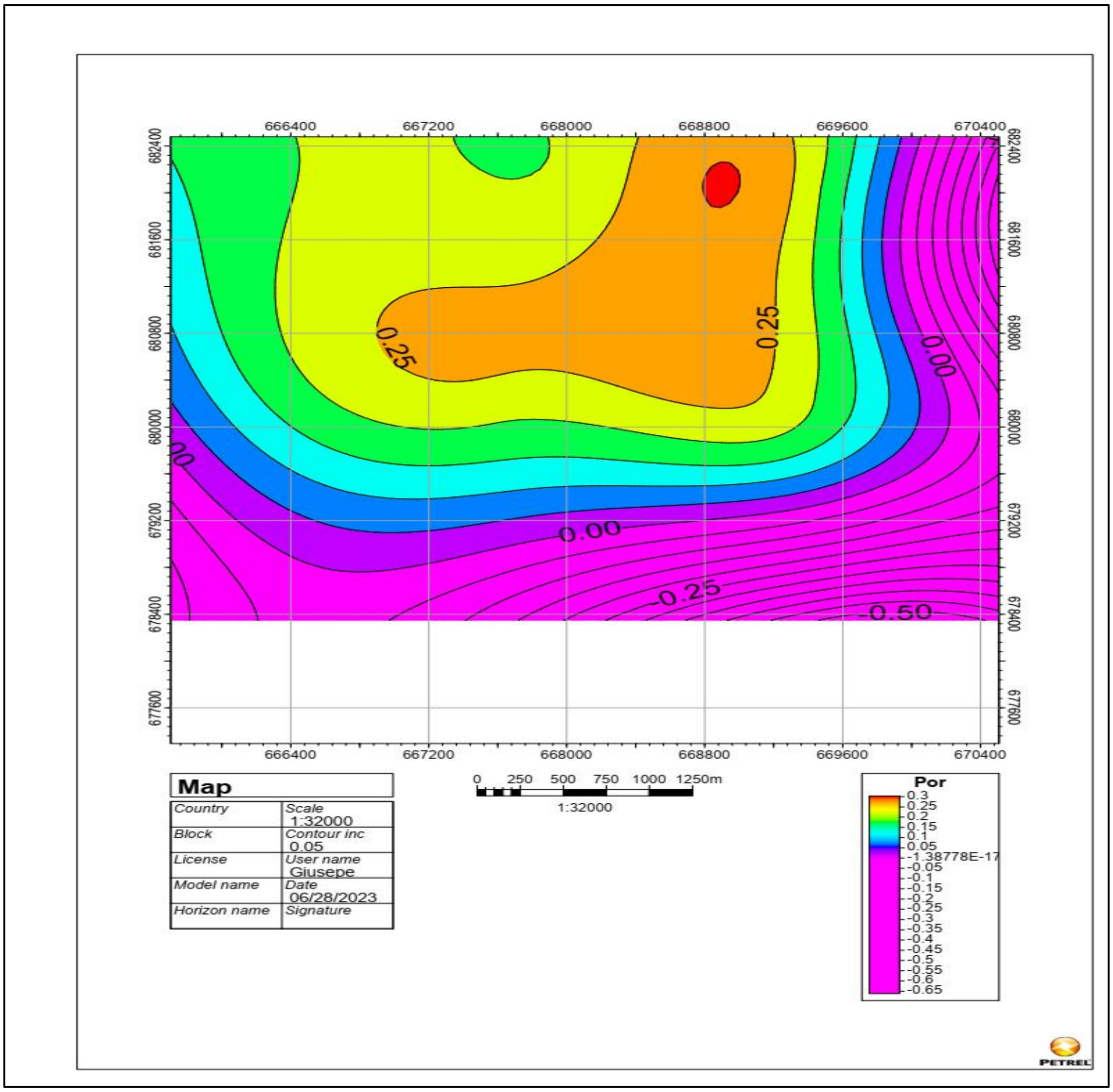


Figure 4.3 Figure shows the porosity of Gorahei formation which is increasing to south west

From the figure above the porosity of Gorehi formation is increasing to the south East that indicate the shale content is also increasing to south east and the sand is dominated to west direction.

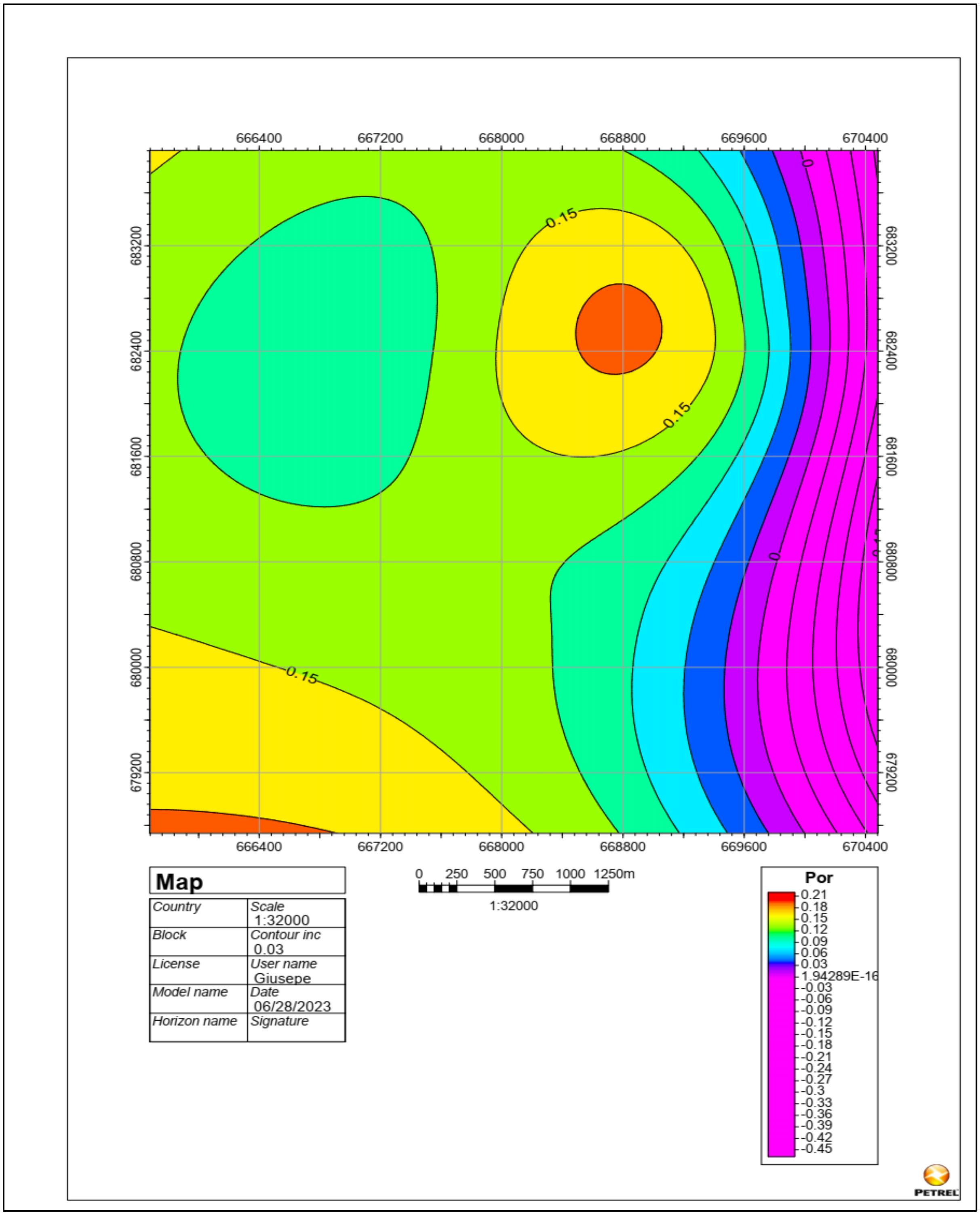


Figure 4.4 shows the porosity of Gumburo formation which is increasing to south East

From the figure above the porosity percentage of Gumburo formation is increasing to south East that means the shale content is also relatively increasing.

4.3. Permeability of the Ogaden Basin

Permeable zones (sands) were differentiated from non-permeable zones Using GR, SP and Based on this, tops and bases of Reservoir X were delineated in all the 4 wells. From the permeability map below the formation permeability is increasing from East to west direction which implies the sand content or the sand ratio also increasing to the west direction.

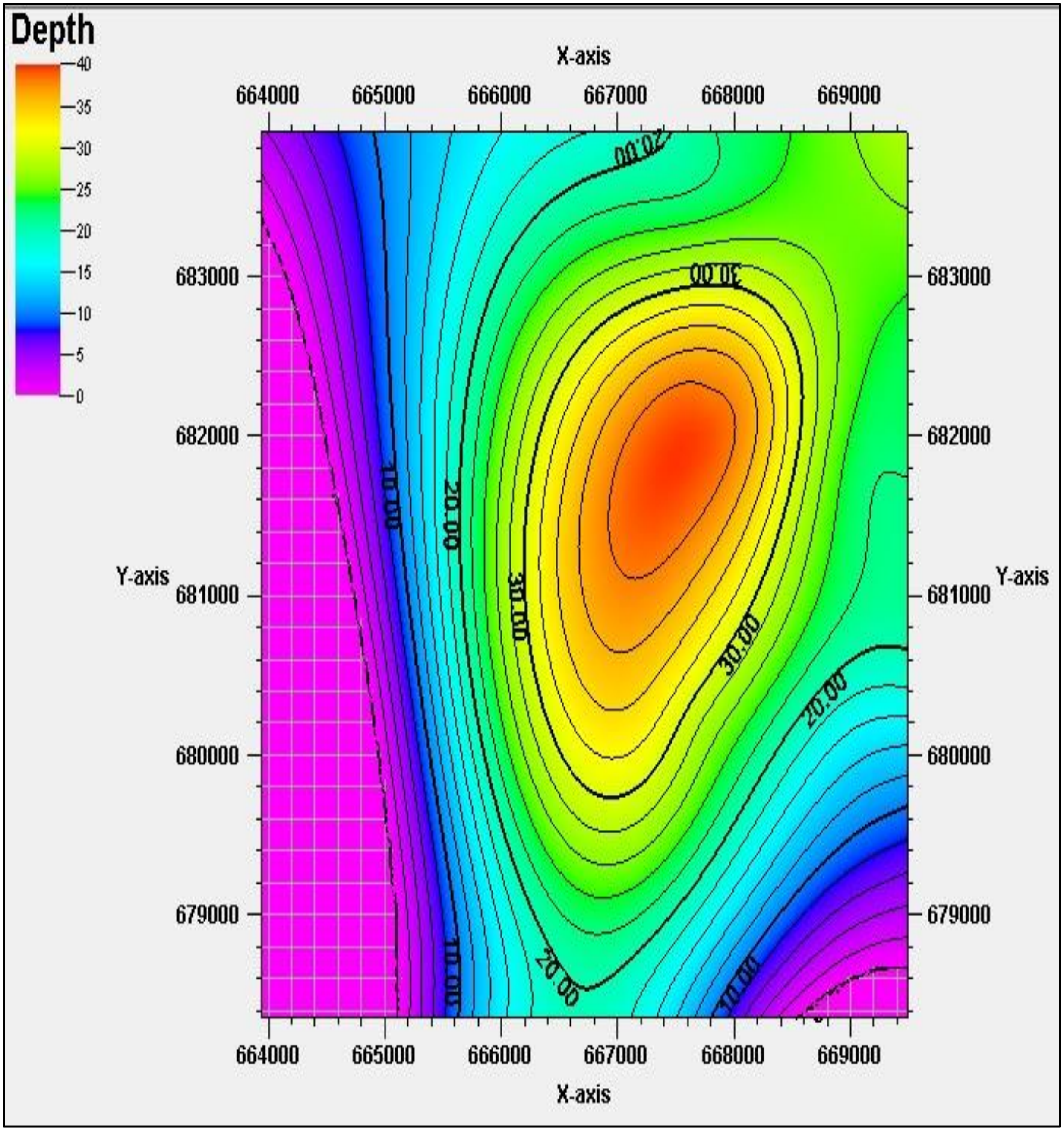


Figure 4.5 shows which increases from South East North West the permeability value of Gorahei

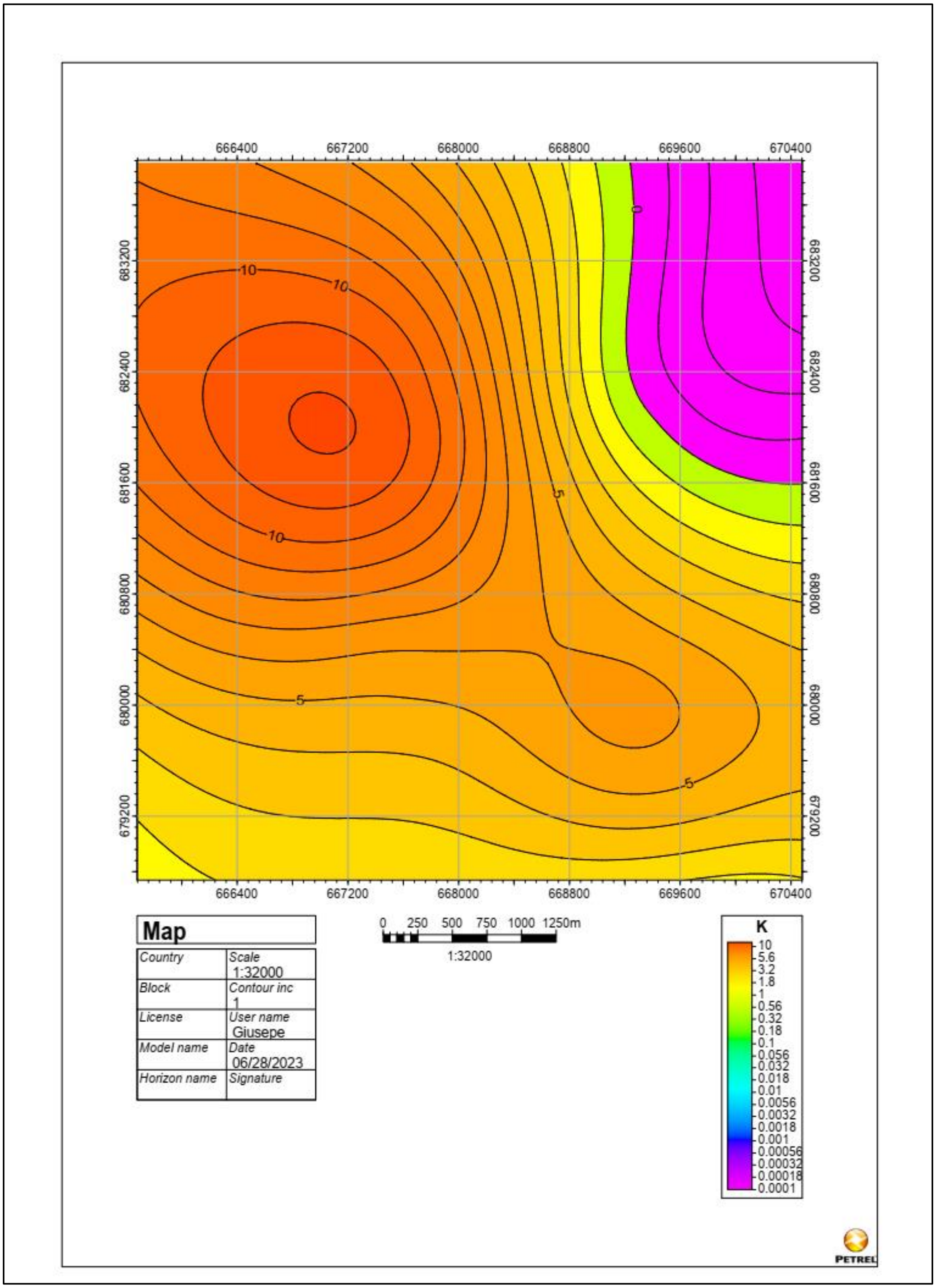


Figure 4.6 Figure shows which increases from South East North West the permeability value of Gorahei formation

The above figure of Gorahei formation the permeability is increasing to north west margin which is sand ratio also increasing

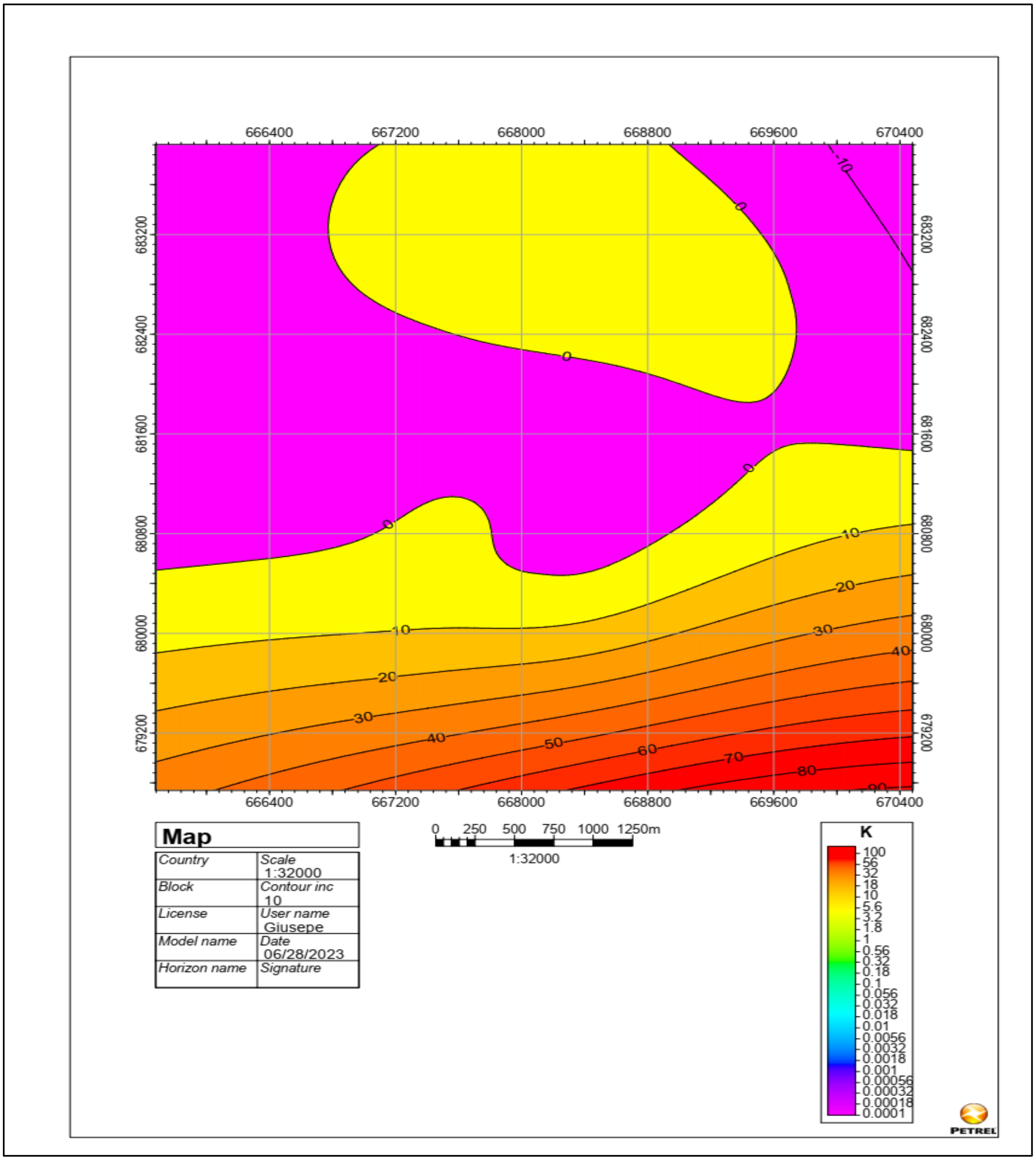


Figure 4.7 permeability of Gumburo formation which increase from north to south East

From above figure the permeability zone of the formation is the southern margin as shown on the permeability contour map that means the southern part is dominated by sand stone than shale.

4.4. Depth of Formation

The thickness of formations may range from less than a meter to several thousand meters. In other words, a formation is a series of beds that is distinct from other beds above and below, and is thick enough to be shown on the geological maps that are widely used to estimate in Calub the depth of the formation is estimated from seismic well log data.

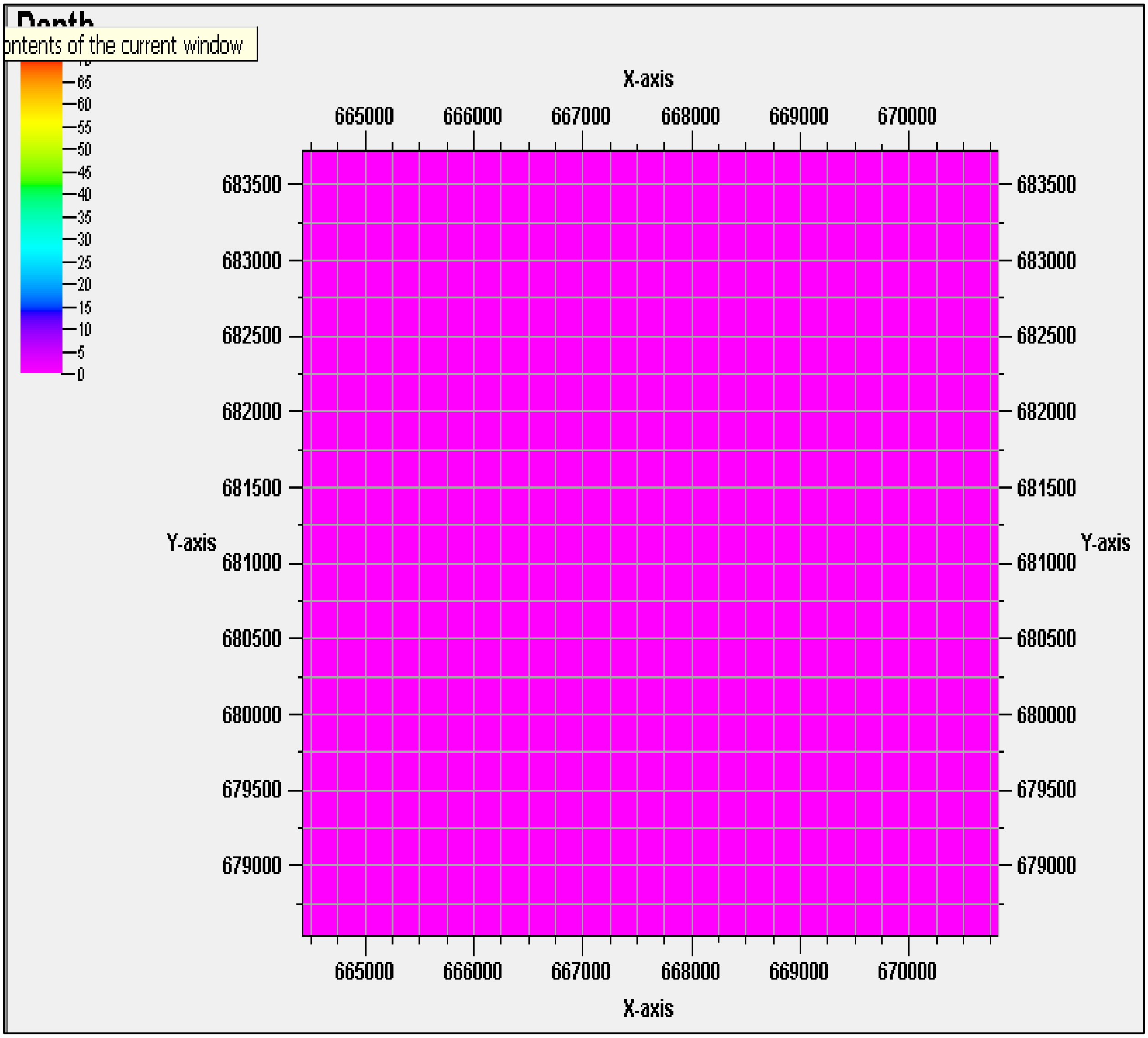


Figure 4.8 shows almost there is no shale observed in club formation which is mapable at this scale

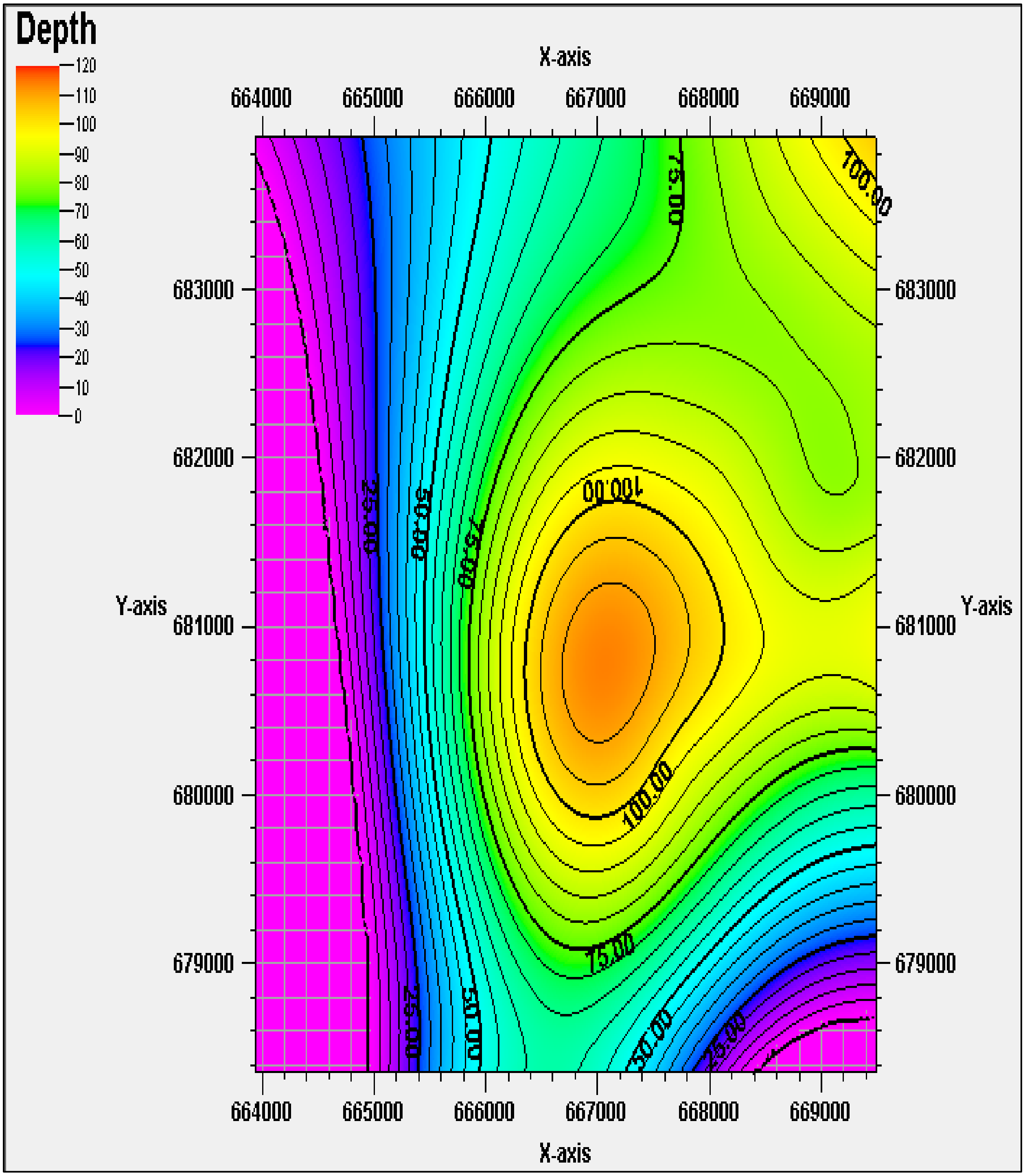


Figure 4.9 Gorahei formation thickness is increasing towards the margin of south.

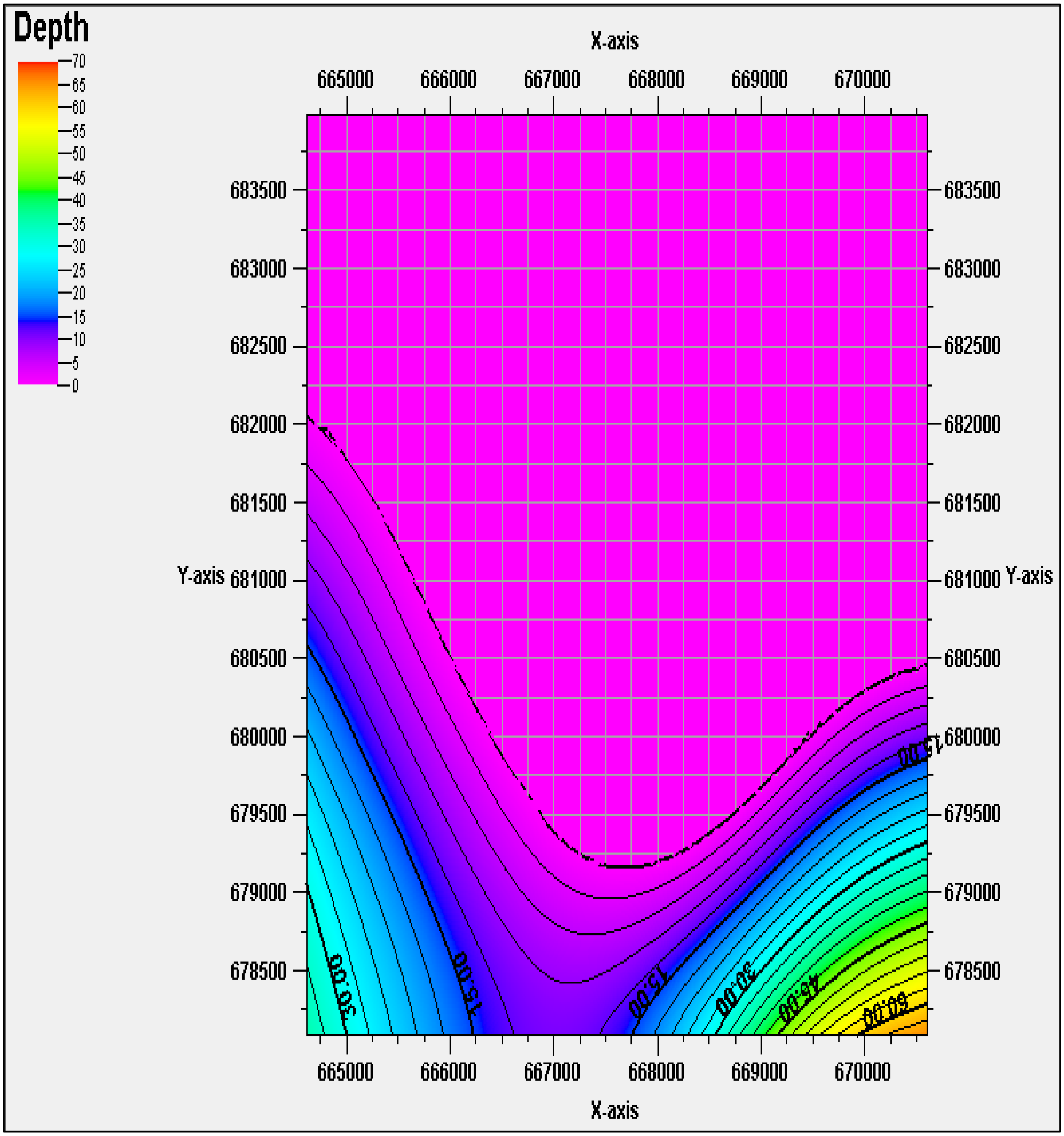
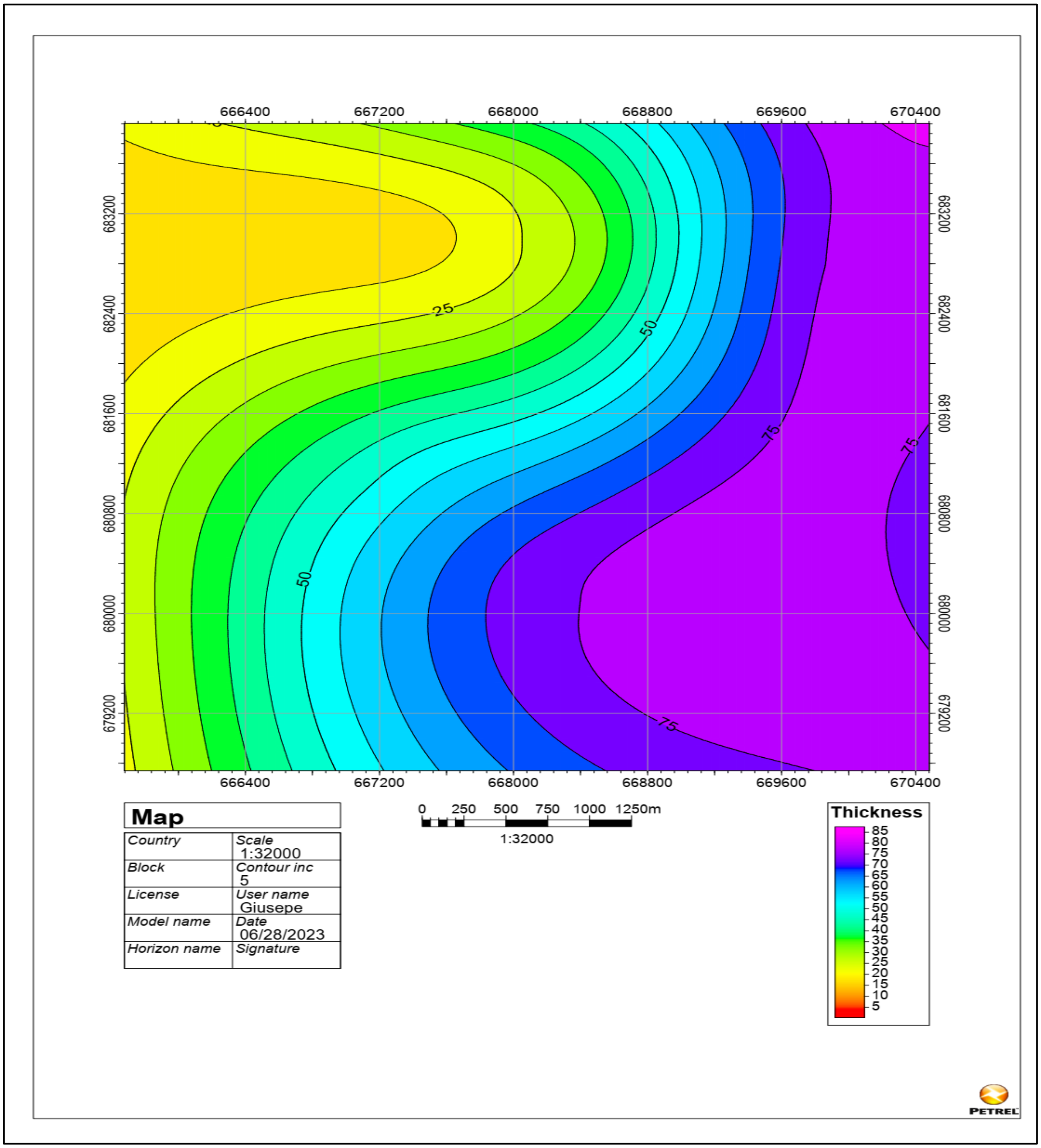


Figure 4.10 As figure above shows the thickness of shale thickness increasing to the margin of south west that implies also the area of low permeability.

4.5. Horizon thickness



Map

Country	Scale 1:32000
Block	Contour inc 5
License	User name Giusepe
Model name	Date 06/28/2023
Horizon name	Signature

Figure 4.11 Figure shows the horizon thickness of Calub Formation which increases from West to East Direction

From the above figure the thickness of the calub formations is observed toward western and south part.

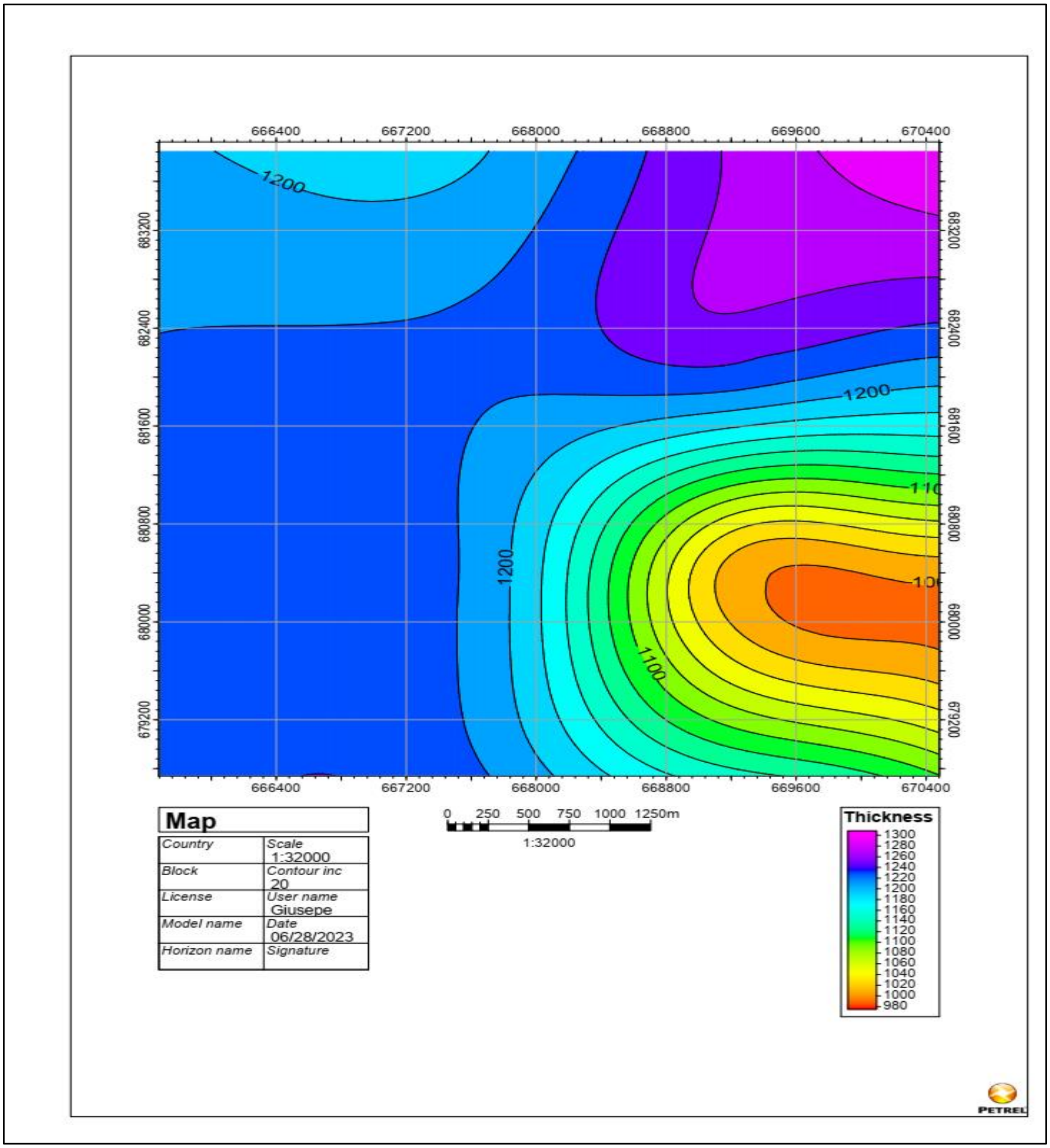


Figure 4.13 shows the horizon thickness of Gorahei-Upper Hamanlei which is increasing from North West to south East

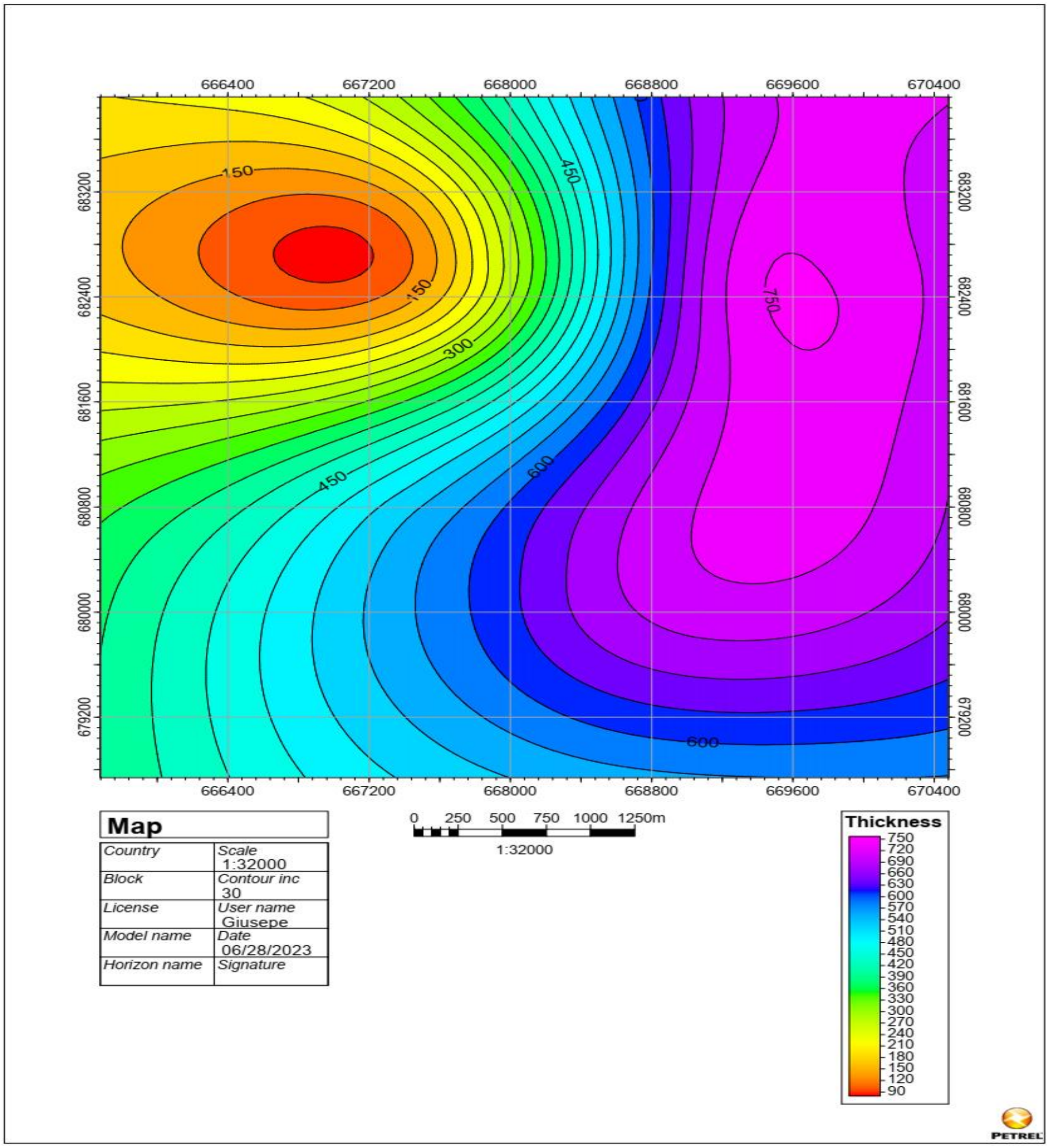


Figure 4.14 The Map shows the Horizon thickness of Gumburo Calub which is increasing from West to East direction

4.6. The Depth of the formation

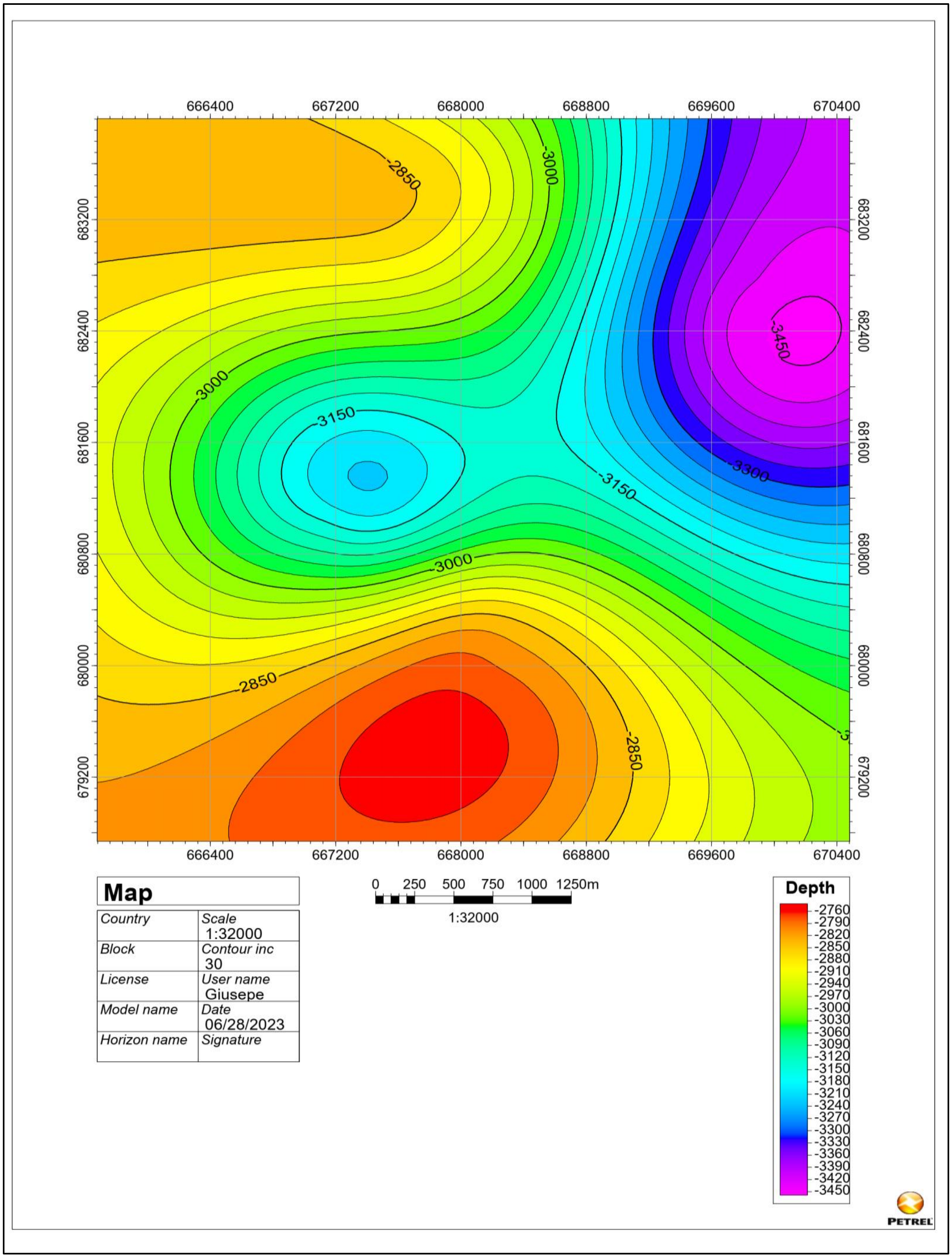


Figure 4.15 shows the depth of calub formation increases from West to North East

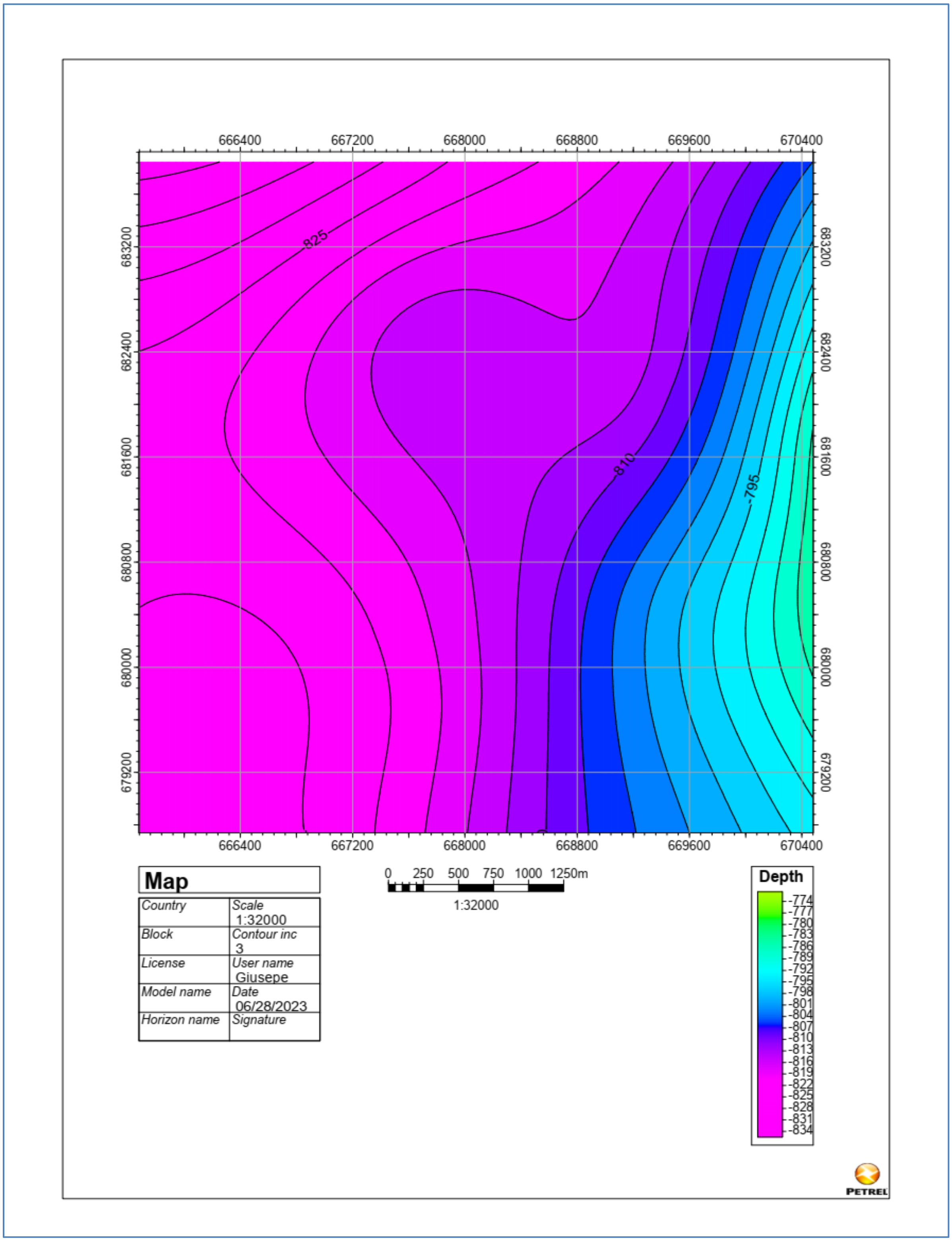


Figure 4.16 shows the Depth of Gorahei formation increases from south East to North direction

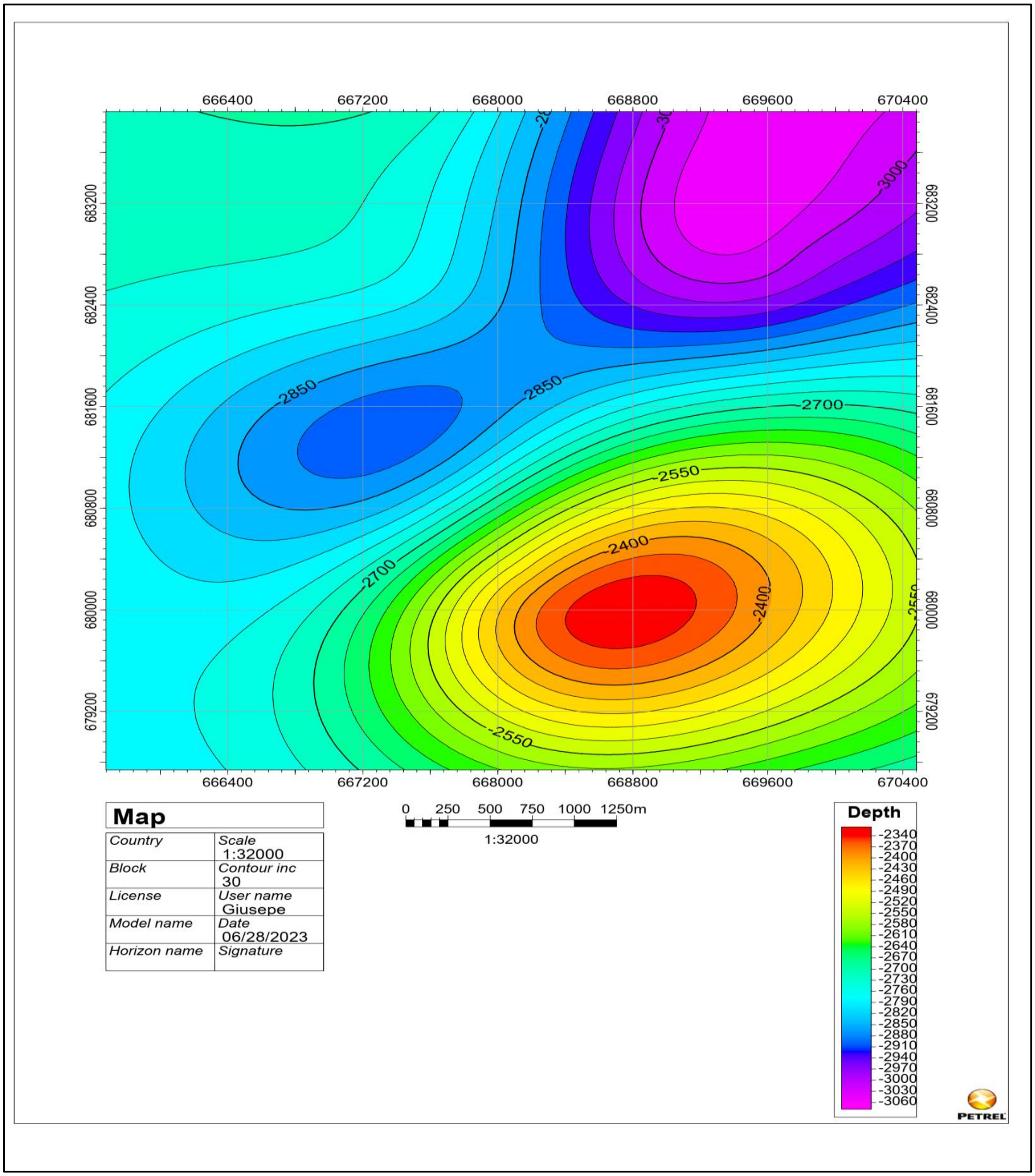


Figure 4.17 shows the Depth of Gumburo increase South East to North West

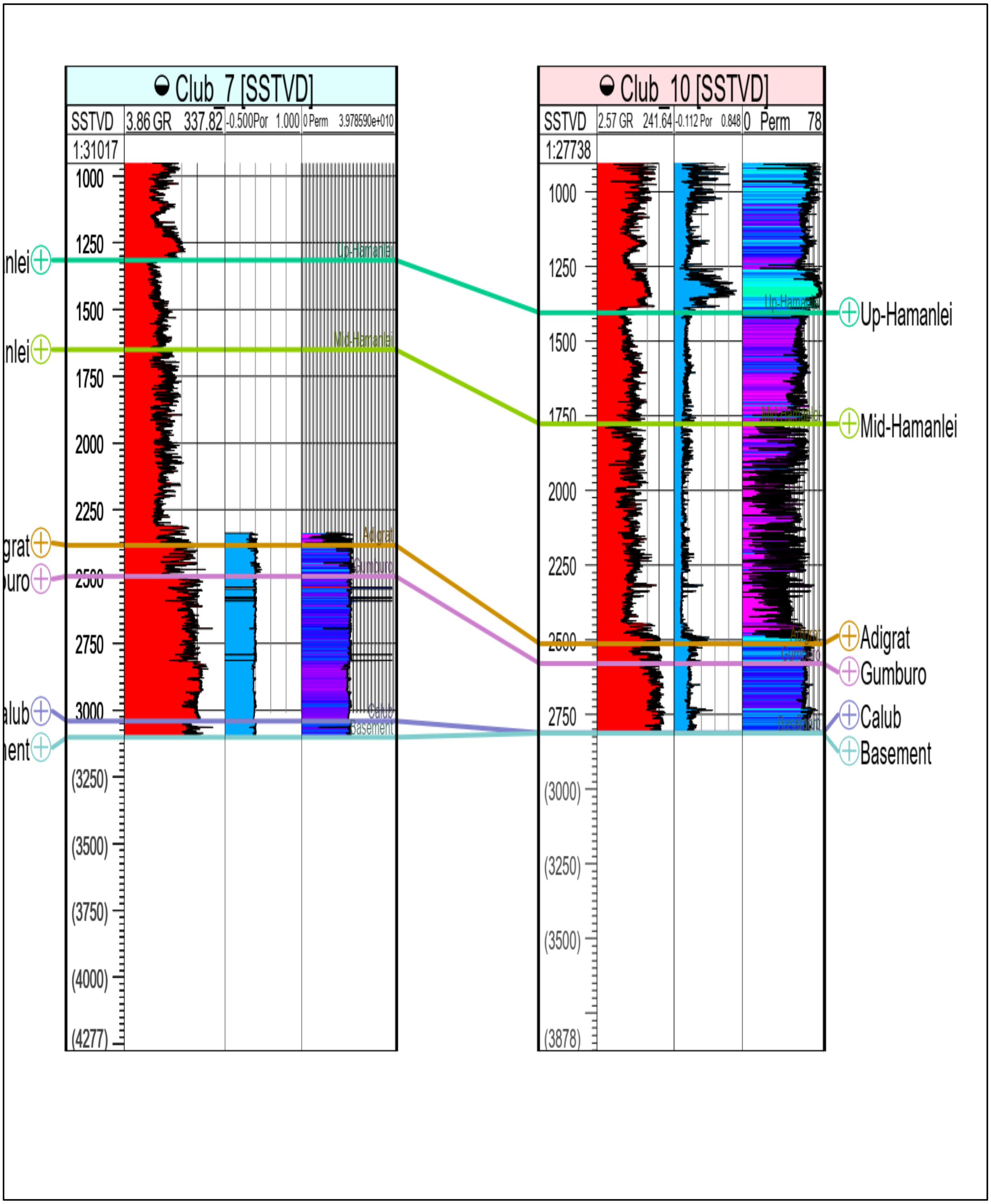


Figure 4.18 Figure well log interpretation of well 7 and 10which shows gamma ray log and spontaneous log with their correlation

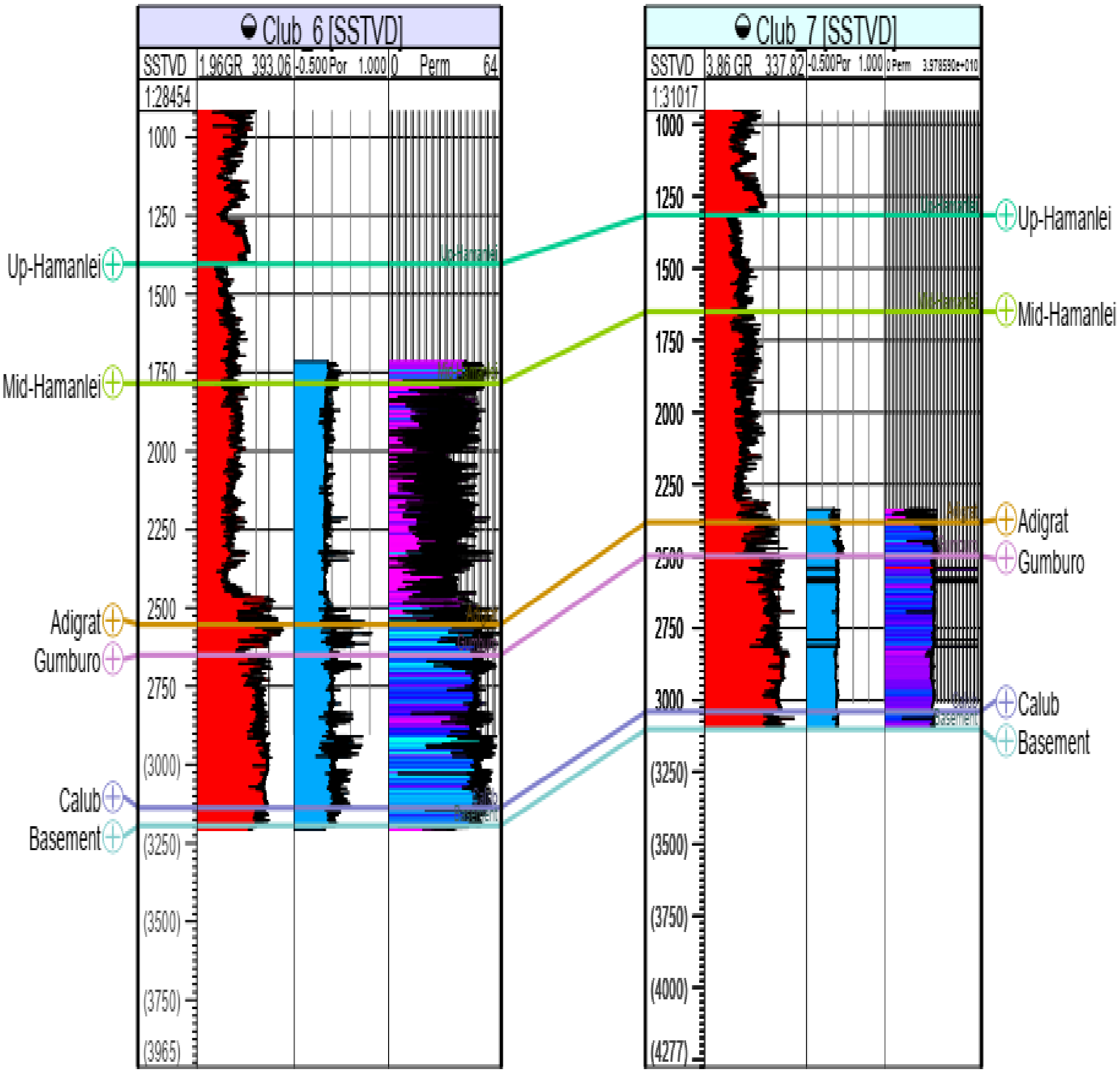
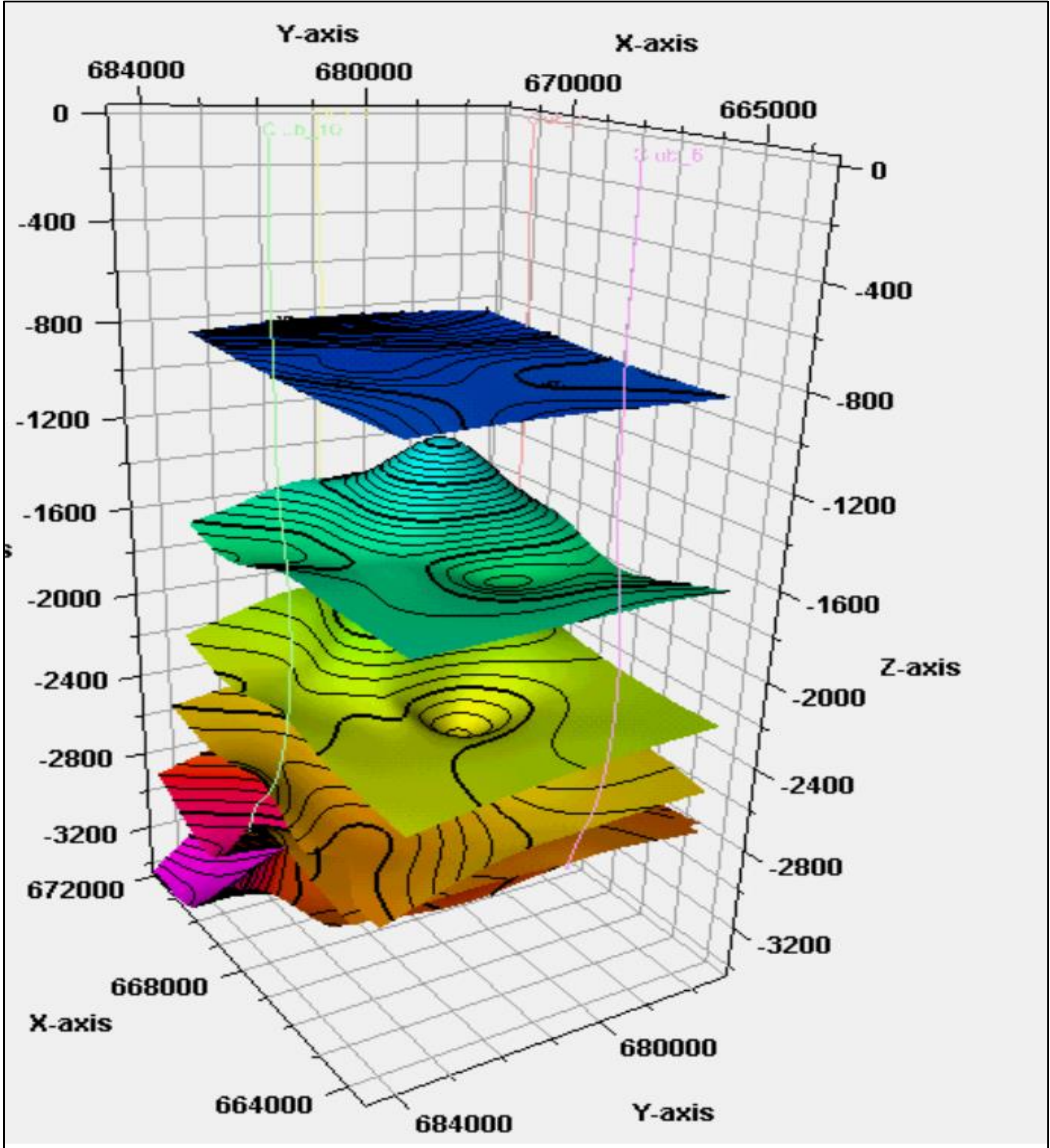


Figure 4.19 Figure Log of well 6 and 7 which shows gamma ray log and spontaneous log

4.7. Well and surface in 3D



Figures 4.20 Well and surface in 3D

Table 4.1 showing the summary of formation characterstics

	Strata	Porosity%	Permeability Micro10-^{3} micro m^{3}	Horizon thickness in (m)	Depth (m) variation
1	Calub	3-20	0.1-40	8-55	2700-3450
2	Gorrahei	5-25	1.6-10	10-120	774-890
3	Gumburo	5-21	1.8-100	10-60	2300-3000

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1.Conclusion

From the mentioned above the shale with high porosity is found in all formation is thicker from west to eastern direction of the field. The calub and and Gumburo Formation are the best reservoir due to best Permeability in the study area and good r Figure shows sand thickness of Gorahei formation increasing to the center reservoir rock at the depth. The porosity in Calub and Gumburo formation is less than 20% and the permeability value is 800mD.

5.1.Recommendation

During this research since there data consistent ,I didn't model the three model of the formation characterization ,so I recommended to work on the 3d modeling and observe the variation of properties such as permeability, porosity, thickness, and sand continuity influence both oil recovery and its distribution in the field ,. It is therefore highly recommended that a robust and holistic 3-D studies be done.

During primary production areal variation of properties such as permeability, porosity, thickness, and sand continuity influence both oil recovery and its distribution in the field. It is therefore highly recommended that a robust and holistic 3-D studies be done. This will further validate the inferences drawn from the 2-D regional line since an accurate internal, three-dimensional (3-D) variation of reservoir rock properties description is essential to effective reservoir management

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