ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

CENTER FOR ETHIO MINES DEVELOPMENT

DEPARTMENT OF PETROLEUM ENGINEERING

Title: Biostratigraphy, Burial History and Thermal History of Gambella Basin, Ethiopia; Implications for Source-Reservoir Interaction and Hydrocarbon Generative Potential

BY

CHANGKUOTH DHAN DENG

A Graduate Project submitted to the Addis Ababa Institute of Technology, Center for Ethio-Mines Development in partial fulfillment of the requirements for the Degree of Master of Engineering in Petroleum Engineering

Advisor: Dr. Samuel Getnet

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Addis Ababa, Ethiopia

ADDIS ABABA UNIVERSITY

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DECLARATION

"I, the undersigned, declared that this research work entitled "**Biostratigraphy, Burial History, and Thermal History Evaluation of Gambella Basin, Ethiopia**" (**Implication for Source-reservoir interaction and Hydrocarbon Generative Potential**) is an original and has not been submitted for a degree to any other Universities.

All Source of data (primary and secondary) used for the project work has been duly acknowledge where required.

This research work submitted to Center for Ethio-Mines Development, Addis Ababa Institute of Technology in Partial fulfillment of degree of Master of Engineering in Petroleum Engineering

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This Research Work submitted for the examination with approval from the university Supervisors

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ABSTRACT

The Gambella Basin, located in southwestern Ethiopia, near the Sudan border, covers an area of about 15,350 sq.km. It has a NW-SE elongated outline, and it is presumed to be the southeastern extension of the Melut Basin of South Sudan. Geological data review indicates that sedimentation in the interior Basins of the South Sudan is controlled by intermittent rifting phases that continued up to Mid Miocene.

Biostratigraphy, Burial history and Thermal history evaluation of Gambella area, analysis include the Palynological and Paleoenvironment analysis on 104 cuttings samples and 16 sidewall cores from the interval of 60-3500 mKB in Jekow well and carried out on seventy 70 ditch cuttings from the interval 745-3250 in Jacaranda well (PCOB report, 2007).

The exploration wells, Jekow (in the East) and Jacaranda (in the West) Gambella, Ethiopia which have penetrated the target zone of Sothern Melut Basin extension of the South Sudanese rift Basin. The source rock screening, Thermal Maturity, zonal layer, geologic section, the vitrinite reflectance and the age have target the interest of burial history and the hydrocarbon generative of the Basin. A one-dimensional modeling of Burial history and Thermal history was performed in Jekow and Jacaranda locations using one PetroMod 1-Dimensional modeling of Integrated Exploration Systems of Gesellschaft mit beschränkter Haftung, (GmbH-IES), Germany.

However, due to unsuccessful exploration campaign in South Melut Basin where Gambella Basin is extended and in addition to the poor quality seismic data implied that the risk for the petroleum system in the West Gambella Sub-basin is still very high.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

TOC----- Total organic carbon

GP-------- Generation Potential

OI --------Oxygen Index

Tmax---- Maximum Temperature

HI-------- Hydrogen Index

PI ---------..Production Index

FIS-------..Fluid Inclusive Stratigraphy

FIT………Fluid inclusive Technology

BSR--------Bacterial Sulfate Reduction

TSR-----…Thermal Sulfate Reduction

MoME…..Ministry of Mines, Ethiopia

PCOB……Petronas Carigali Overseas

PCE ……..Petronas Carigali Ethiopia Team

DST …….Drill Stem Testing

SGR …….Shale Gouge Ratio

CHAPTER ONE

1. INTRODUCTION

1.1 GENERAL STATEMENT

There are five distinct sedimentary basins in Ethiopia, these are the Ogaden Basin, Abay Basin, Mekele Basin, Gambella Basin, and South Omo Basin. The sedimentary basins of Ethiopia cover a significant area of the nation. The majority of these Basins were formed as a result of the extensional tectonic episodes that occurred sporadically starting in the Late Paleozoic and continuing into the Tertiary. Three distinct sedimentary basins that make up the thick succession of Palaeo-Mesozoic sediments that cover 25% of Ethiopia's landmass are the Ogaden Basin (350,000 km2), Blue Nile or Abay Basin (63,000 km2), Gambella Basin (15,350 km2), Mekele or Adigrat Basin (8,000 km2), and Southern Rift Basins (South Omo basin, N-S striking) (Assefa, 1988). The breakup of Gondwanaland in the Upper Paleozoic is thought to have caused extensional forces that resulted in the formation of the Ogaden, Abay, and Mekele basins, which are intra continental rift basins. The Gambella Basin is a seismic exploration area that covers approximately 15,350 square kilometers in south-western Ethiopia. The formation of the Basin is linked to the Early Cretaceous, Paleogene, and Late Cretaceous, with the latter being less significant. Source rocks are lacustrine shales from the Lower Cretaceous, whereas reservoirs and seals are both Paleogene and Upper Cretaceous in age. An intra-continental Cretaceous to Tertiary rift system known as the West and Central African Rift System (WCAS), which is made up of the West African Rift Subsystem (WAS) and the Central African Rift Subsystem (CAS), both strike-slip and extensional Basins were primarily formed by the mechanical separation of the African crustal block during the Early Cretaceous age (Fairhead, 1988), (Fairhead, 1986). Exxon, Chevron, and Conoco among others extensively investigated this region in the 1970s and 1980s. Only one massive oil field, the Sudan's Unity Field, which was discovered in 1980 and has 900 million barrels of reserves, was discovered between 1975 and 2000 (Paul et al., 2003). The Muglad Basin in South Sudan, the Doba, Doseo, and Lake Chad Basins in Chad, as well as the Termit Basin in Niger, have all seen the discovery of numerous smaller fields (Schull, 1988); (Giedt, 1990); (Genik, 1993).Oil pay zones include the Lower Cretaceous strata in the Doba and Doseo Basins in Chad, Muglad Basin in South Sudan, Upper Cretaceous in the Muglad Basin of

South Sudan and Termit Basin in Chad, and Paleogene in Termit Basin of Niger. A concession agreement spanning 516,000 km2 was signed by Chevron and the Democratic Republic of Sudan in November 1974. The block contained Muglad and Melut, two sizable rift basins. Operations for exploration started in 1975. Data on magnetic fields, gravity, and seismic activity were gathered. The Muglad Basin, where numerous oil fields had been found since 1979 (Schull, 1988; Dou et al., 2002; Tong et al., 2004), was the site of the majority of drilling operations.Only one tiny oil field, the Adar-Yale field, was discovered in the Melut Basin by the end of 2000 after four exploration wells and one appraisal well had been sunk there (Schull, 1988). Aspects of the petroleum exploration of the interior rift Basins are covered in earlier studies, most notably those by (Schull, 1988) and (Genik, 1993). Papers by Fairhead (1988), Guiraud and Maurin (1992), and McHargue et al. (1992) discussed the tectonic history and structural types of the Basin. Wycisk et al. (1990) and Wilson and Guriaud (1992) both provided descriptions of the volcanic activity for a larger area. In South Sudan, the Muglad Basin has received the most attention. On the other hand, there hasn't been much written on the Melut Basin's petroleum geology and hydrocarbon exploration. Because the Melut Basin (Figure 1) is farther from the Central African Shear Zone (CASZ) and closer to the East African Rift System (EAS) than the Muglad Basin, the influences of the strike-slip of Central Africa Shear Zone, the Senonian Basin inversion rejuvenation of rifting (Guiraud and Bosworth, 1997) had relatively weaker impact on the Gambella Basin (Melut). Therefore, the basin formation and evolution, structural styles and petroleum system are to some extent different from the Muglad Basin. Since 2000, the Melut Basin has been widely explored, including 10,000 km of 2D seismic, more than 2000 km2 of 3D seismic and more than 50 exploration wells. This paper presents the petroleum geoscience and oil & gas discovery of the Gambella Basin. The Basin has a NW-SE elongated outline, and it is presumed to be the southeastern extension of the Melut Basin (White Nile Rift) of South Sudan. Geological data review indicates that sedimentation in the interior basins of the Sudan is controlled by intermittent rifting phases that continued up to Mid Miocene. The sedimentary thickness in Gambella Basin is estimated from 6 to 8 Km. the prospectively of the Gambella area for hydrocarbons needs to be viewed in relation with the South Central Sudanese Basins, which are renowned for oil pool discoveries. Intermittent rifting and sedimentation in Tertiary resulted in the deposition of lacustrine shale and mudstone and fluvial sandstones each of which served a great role in formulation of the petroleum system.

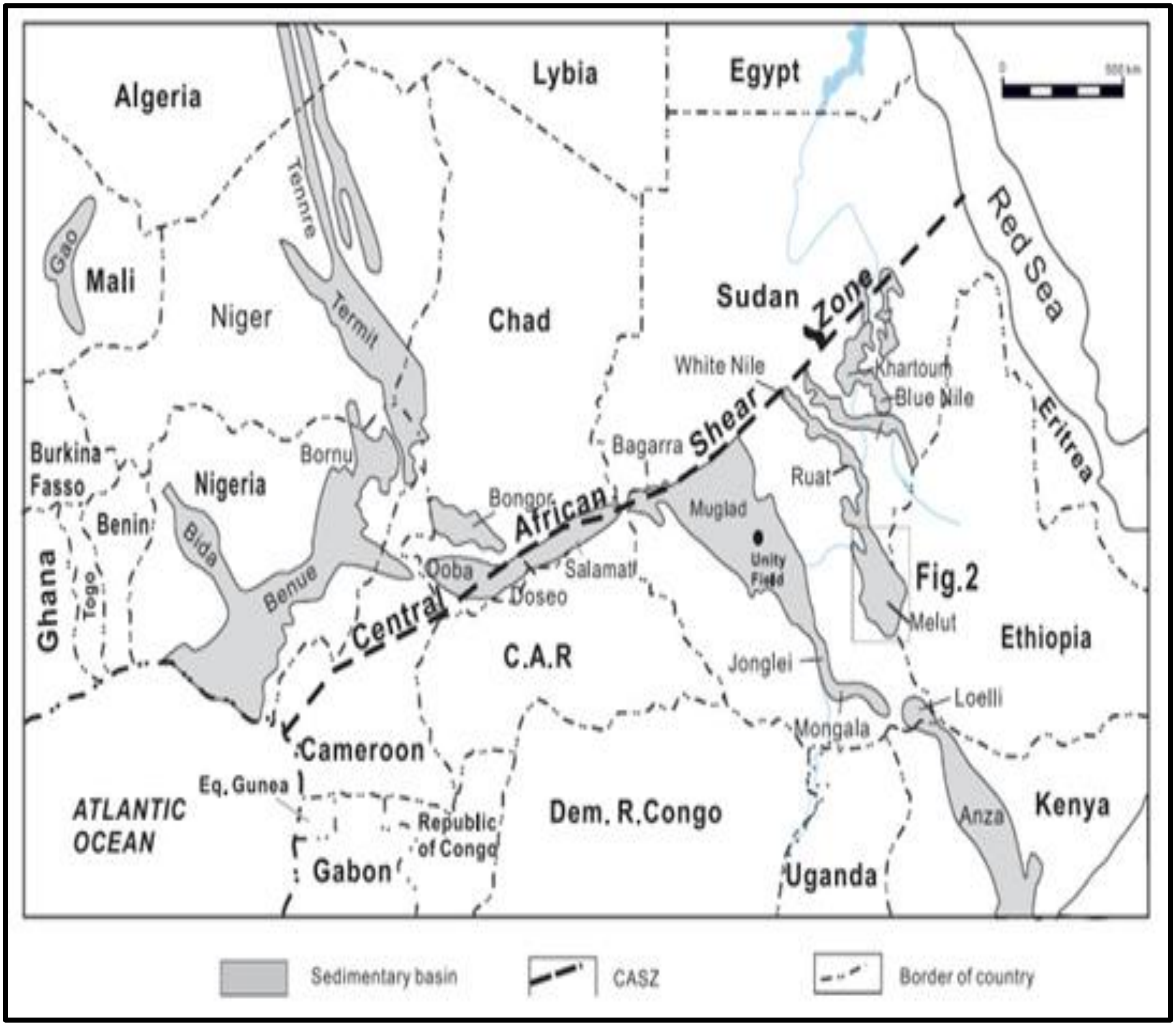

Figure 1. General map of the Central African Rift System (modified from Fairhead, 1988; McHargue et al., 1992) highlighting the principal characteristics addressed in the text and the position of the Melut Basin.

1.2 LOCATION AND ACCESSIBILITY

1.2.1 Geographic location of the Gambella Region

Gambella study area is located in the west of Gambella region. It is a boundary between Ethiopia and Sudan, about 80 Km away from main town. Gambella Regional State is located in the South West of Ethiopia bordering with the South Sudan in the West, South and North, the state of Southern nation, nationalities and people of South and the East with the state of Oromia in the North and East at 80^0 and 15^0 respectively and North latitude at 34^0, 55^0 East longitudes. It's about the 766 km from the Ethiopia Capital city Addis Ababa. The state of Gambella lying between two rivers Baro and Akobo and also officially known as Gambella Peoples' National Regional State (GPNRS). It's the nine ethnic divisions of Ethiopia. The Region has three Zones with twelve Woredas, one special Woreda and one town administration. The terrain of this working area is flat, covered with many bushes and deep grass, and the elevation in southeast is higher than that in northwest in this area. The elevation range is from 396.07 m to 420.08m, and its difference is about 14m. There are some villages in the working area, which are connected by many paths and small traces. The traffic in the working area is not convenient. Besides, most of the roads are rugged and snaky. There are many rivers and canals crossing each other in the working area. And most of the working area is swamp, and there are many thick woods in the middle of the working area. Southwest seismic lines were designed and deployed according to the contract signed between Petronas and ZPEB. The operation length of the designed lines is totally 317.95 km, including 5667 source points and 12724 receiver points. The detailed maps are shown on figure below and the detailed seismic line are shown on the chapter four of this work. The line location was between 7°50'08.29008"N to 8°26'17.87962"N and between 33°12'23.10998"E to 33°39'59.75045"E in WGS84 coordinates system (report).)

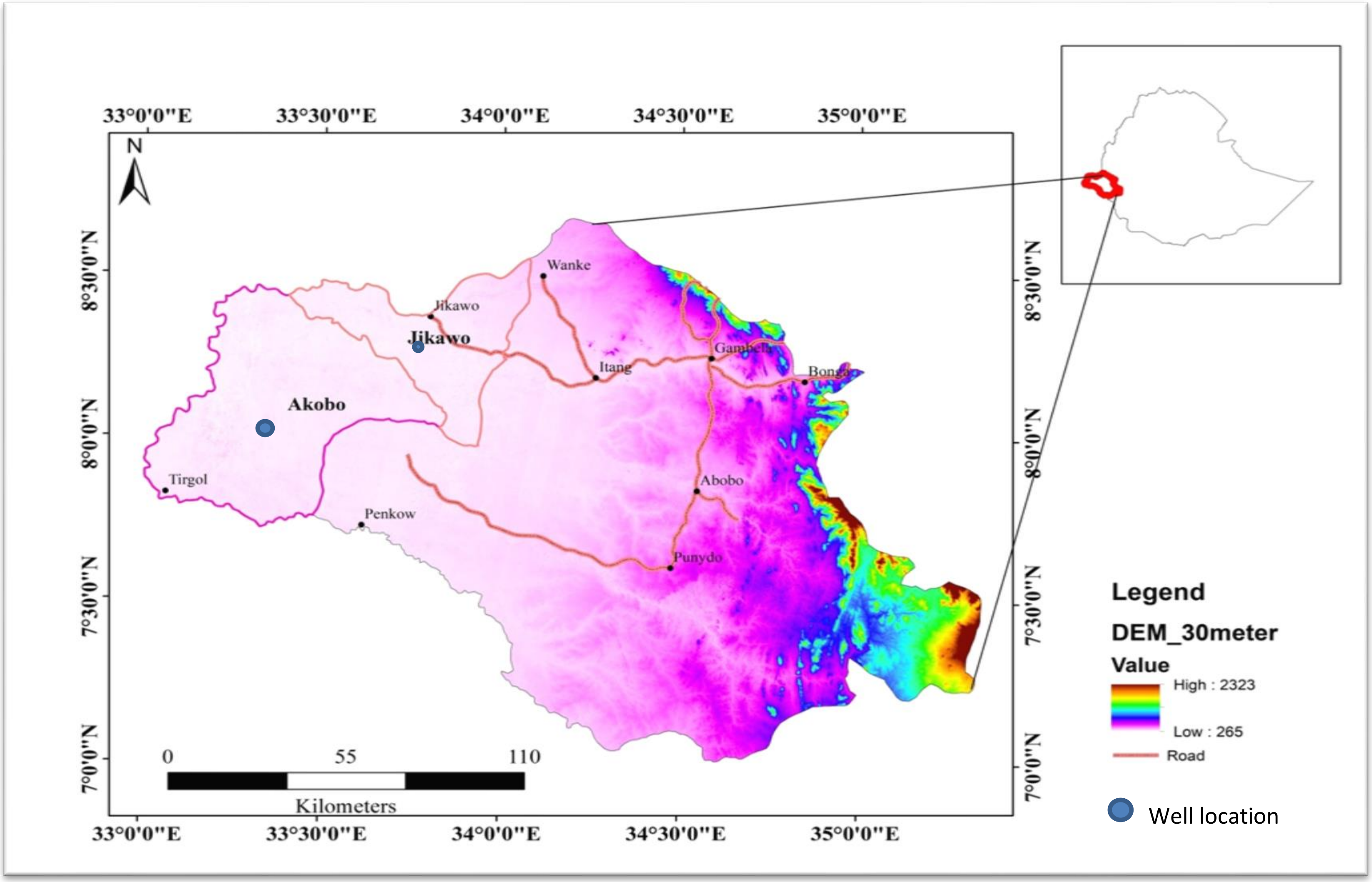

Figure 2. Location Map of Gambella Basin showing study of the area (Extracted from geographical Map using Arc GIS software)

1.2.2. CLIMATE AND VEGETATION

Gambella area is flat and its climate is warm and humid**.** Annual rainfall averages about 600 mm while the minimum/ maximum temperatures are approximately 21.1^{0}C and 35.9^{0}C respectively. The vegetation covers of the region is mostly green environment. The State has an undulating land feature dissected by the Omo river basin into western and eastern parts. The lowest area and highest peaks in the State is recorded near Lake Rudolf in South Omo and at Mount Goge in North Omo, respectively. About 56 % of the total areas of the State are found below 1,500 meters elevation, which is categorized largely as hottest low land ("Kolla"). The rest 44% is found in the temperate climatic zone. The mean annual rainfall of the State ranges from 500 – 2,200 mm. Its intensity, duration and amount increases from South to Northeast and Northwest. The mean annual temperature of the State in general ranges from 21.1°C to 35.9°C.

1.2.3 PHYSIOGRAPHIC FEATURES AND DRAINAGE

The study area occupies a topographically low land adjacent (Figure 3) to the uplift basement blocks of the highland weine dega in the northeast and the Blue Nile in the northwest. Apart from some isolated sandstone outcrops east of Muglad town, the Melut Basin and the surrounding areas are essentially flat land covered by superficial deposits of Quaternary age. The area has a mean ground elevation of about 400 m above sea level, and the difference between the highest and the lowest places is less than 15 m. The drainage system is generally towards the northwest, of which the White Nile and its tributaries represent the main drainage elements. Tectonics is highly complicated through faulting and dominated by a series of NW-SE trending faults of different episodes. Seismic data indicates several sub-basins. All of the sub-basins in the Melut including Gambella Basins are half graben type rifts.

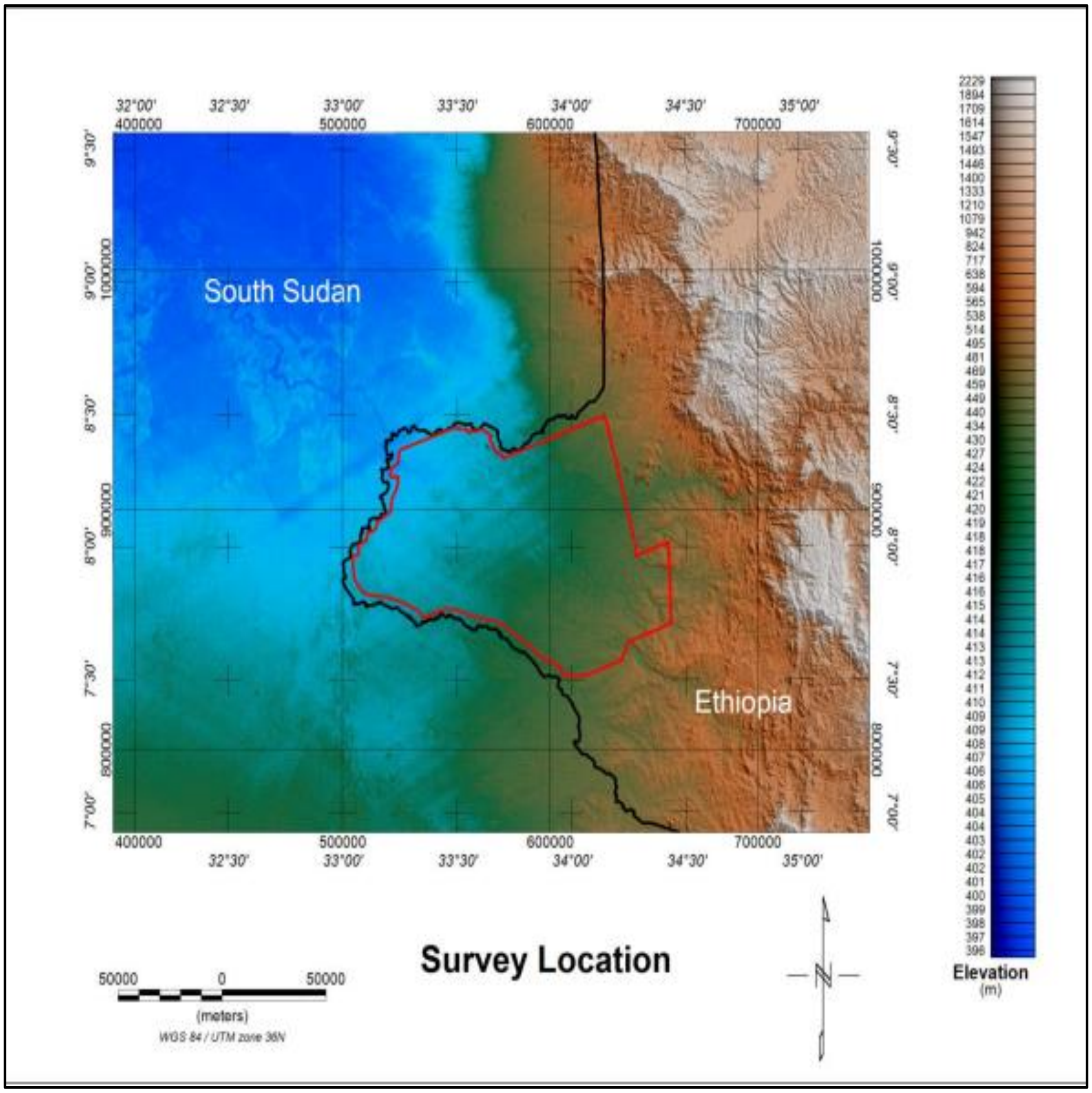

Figure 3. Physiographic Map showing the study area location of Gambella Basin, Western Ethiopia

1.3 EXPLORATION HISTORY

Exploration for oil and Gas in the Gambella Basin was first attempted by Chevron Overseas Petroleum Inc. in 1983 following exploration of Muglad and Melut Basin of South Sudan in 1975. Gravity Survey was carried out in Gambella area covered Thirty-Four survey lines with 1012 gravity station surveyed which produced a map of final bouguer gravity measurement (report). As CHEVRON signed concession agreement made with government of Ethiopia in 1983, Gravity and Magnetic surveys were done followed by seismic investigations which were carried out in an area covering the NW-Gambella by PCOSB in 2004 to 2007 Acquiring good results from the geophysical surveying. Two explorations well were drilled in the area, Jekow in the North East the Jacaranda in the South West. In 2013 South West Energy carried out Magnetic survey in the region, accepted coverage was obtained for 17,772.3 of the planned 17906.7 line km (99.2%) and the sorbed soil analysis were analyzed.

1.4 OBJECTIVE OF THE STUDY

1.4.1 General objective

The objectives and purpose of the study is generally intended to evaluate the Burial History, Thermal History, Hydrocarbon potential and to understand the existence of a Petroleum System (source – reservoir) rock interaction within Gambella area and also to confirm the existence of active petroleum in Gambella Basin.

1.4.2 Specific Objective

The specific objectives of the study are;

- ✓ To Evaluate Burial History of the Basin
- ✓ To Determine thermal maturity history of the Basin
- ✓ To Investigate Maturity History within the Basin
- ✓ To Indicate the Migration Path Way
- ✓ To Reveal Seal and Trap
- ✓ To Understands the Existence of oil and gas System within the Basin

1.5 SCOPE OF THE STUDY

The study area dealt with evaluation of each formations existed layer within the Gambella Basin, the biostratigraphy, the burial history and thermal history of the Gambella basin. The penetrated target layer zone like shale evaluated the amount of organic constituents source rock has, type of organic matter shale is made of and, thermal maturity level at which organic matter was transformed to the organic compound. The study has also assigned the possible category of generative potential of the source rock within the basin.

CHAPTER TWO

2. REGIONAL GEOLOGICAL SETTING AND BASIN EVOLUTION

2.1 REGIONAL GEOLOGICAL SETTING

In the broad context of the geology of the South Sudan, (Whiteman, 1971)and (Vail, 1978) discussed the regional geology of the study area and the other surrounding areas. In the last three decades, the study region has been the focus of in-depth geological research since it is a target for hydrocarbon development. Prior to Chevron's exploration effort in Sudan from 1975 to 1985, it was widely accepted that the Precambrian basement rocks in the central Sudan were uniformly overlain by shallow basins covered with thin sedimentary cover. Later, the results of Chevron's geophysical study that revealed the presence of thick non-marine Mesozoic and Cenozoic sequences connected to the Central African Shear and deep rift structures that were filled with these sequences changed this idea. A description of South Sudan rift geology and regional tectonics is appropriate, as the GAMBELLA area of interest (AOI) represents the southernmost extension into Ethiopia of the South Sudanese Basin (Figure 4). Exploration prospects and production occur in a series of rift basins, bounded by shears and faults, resulted from the dislocation continent of the African between the Late Cretaceous and Early Tertiary. The Melut Basin is part of a trend of Cretaceous age sedimentary rift basins which traverse Central Africa from the Benue Trough in Nigeria through Chad and Central African Republic into Sudan. Evidence of extension further toward the southeast is masked by recent uplift associated with the Tertiary age rifts in Ethiopia and Kenya. Air magnetic and gravity data interpretation shows that as much as 6 km of sediments where deposited in the Melut Basin and 8 km of sediments in Gambella Basin. Tectonics is highly complicated through faulting and dominated by a series of NW-SE trending faults of different episodes. Seismic data indicates several sub-basins. All of the sub-basins in Melut and Gambella Basins are half graben type rifts. (Figure 4) Regional stratigraphy indicates three major rifting episodes followed by a sag period in Africa: 1) Triassic / Jurassic (Karoo) (TAMRAT, 1992) affecting mainly East Africa, and proven in the nearby Kenya rifts ((Rudolf and Anza Troughs). Cretaceous extending all across Central Africa (Figure 1), related to opening of the South Atlantic Ocean. 3) Tertiary creating the present day East African Rift System (related to the Afar Plume). Based on present information from seismic data, the Gambella Basin is identified to have Cretaceous origin like the South Sudan Basins.

According to the sedimentlogical model in Sudan, the early rift sediments are dominated by coarse continental clastics, with some lacustrine or fluvial sediment likely to have been deposited. During the continuous rifting stage, the basin continued to widen and lacustrine sediments with interbeds of coarser rift clastics sediment derived from surrounding basement highs dominated the stratigraphy. This sedimentary regime continued through Tertiary times. The Gambella Basin is getting close to the present day position of the Afar Plume with its related volcanic surface expression (mountainous, basaltic region dominating central Ethiopia), The igneous rocks penetrated in Adar-1 (basalt) and Sobat-1 (basalt) shows similar alkaline parentage that suggest some relation with the Tertiary basalts. Although present, limited information does not clearly indicate the impact of the Afar Plume on the hydrocarbon habitat of the Gambella Basin; the contrary must not be fully excluded at this time. The Afar Plume has pinned the entire African Plate for many millions of years, and the related uplift has caused erosion over a wide spread area (and initiation of the Nile River System). This may have affected the sedimentology in the Gambella Basin (sealing capacity, reservoir development in an immature facies). In addition, extreme cases of elevated heat flow could have destroyed both reservoir and source maturity (report 2007).

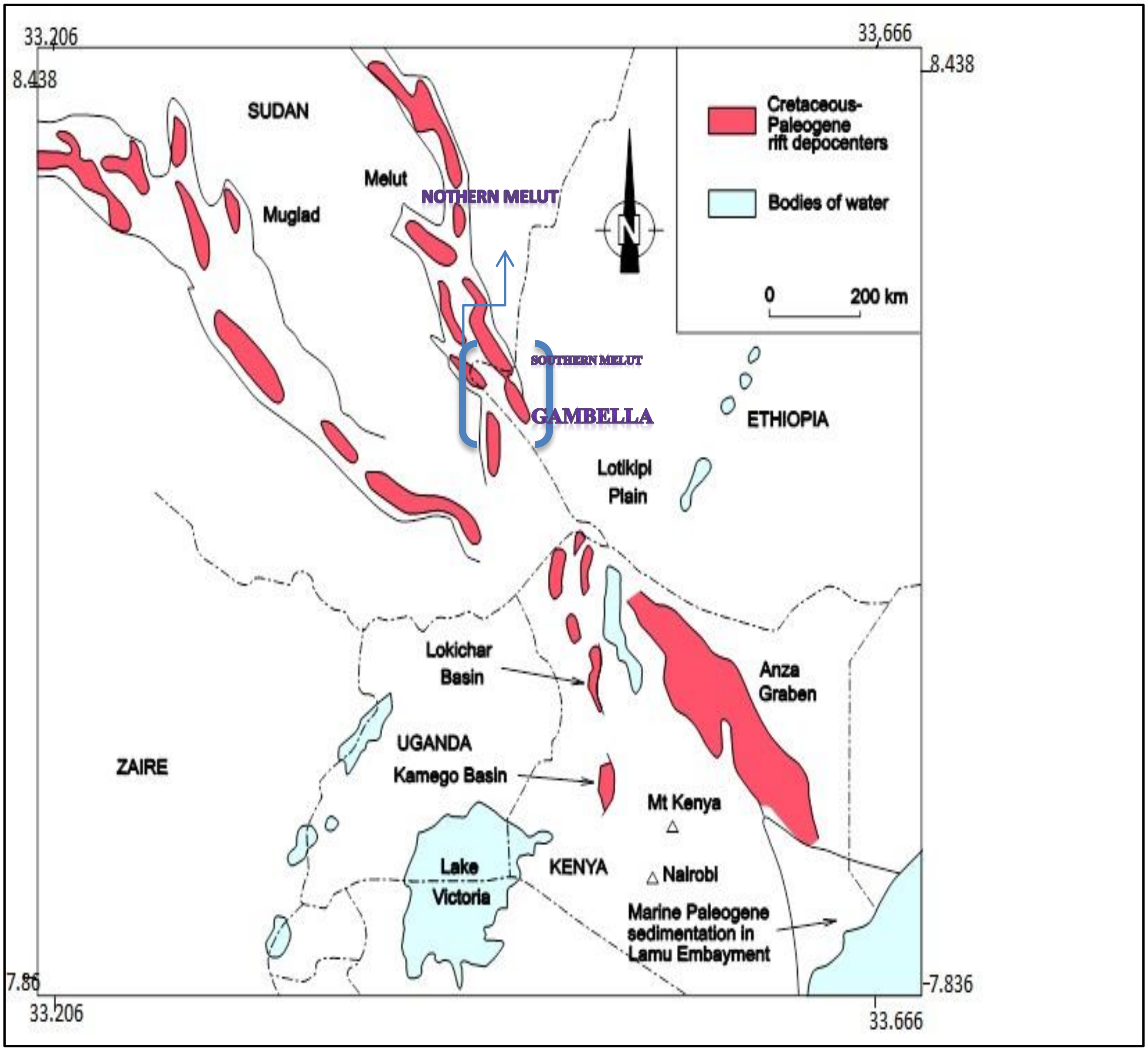

Figure 4. Regional Geology map of Gambella, Melut Basin, (After MoM)

2.1.2 MELUT RIFT SYSTEM

The Africa continent has experienced a long and complex history of rifting phase that began in the Proterozoic but became particularly heightened during the Mesozoic forming the Western and Central African passive rift system (of which the Sudan rift system and its extension into Ethiopia are a part), and, during the Cenozoic forming the East African active rift system (Figure 4). The central position within Gondwana land has ensured that Africa has recorded within its landmass much evidence of the complex plate interactions, which have progressively fragmented the Gondwana supercontinent since the Early Mesozoic. The current understanding is that the difference of opening rates of Central and Southern Atlantic Ocean rifts were sufficient to generate crustal shear stresses that were implicated in the development of West and Central African Rift system. This stress sought a dissipation mechanism, which was largely provided by the transmission of net right to lateral shear movement along the CASZ, which was ultimately transformed into the distal intra-continental rifts of Sudan ((Fairhead and Binks, 1991). The syn-Atlantic rift phase of intra-continental basin development continued until about 87 Ma (Santonian), by which time Africa and South America had been physically separated for approximately 10 Ma. The sedimentary Basins of (interior) Sudan are characterized by thick clastic sequences of nonmarine Late Jurassic-Cretaceous and Tertiary age. Over 13700 m of sediment has been deposited in the deepest trough. Other large basins areas are underlain by more than 6000 m of sedimentary rock (Schull, 1988) Depositional sequences include thick lacustrine shales and clay stones, floodplain clay stones, and lacustrine, fluvial and alluvial sandstones and conglomerates. The lacustrine clay stones were deposited in a suboxic environment and therefore can provide good oil-prone source rocks. Reservoir sandstones have been found in a wide variety of non-marine sandstone facies. Major fault movements occurred intermittently into the Miocene. Various phases of fault movement have led to the formation of several deep fault bounded troughs, major inter basinal highs, and complex basin flanks, creating a variety of structures, many of which have been found to be effective hydrocarbon traps.

2.1.3 STRUCTURAL TRENDS

Studies of gravity and magnetic data within the Melut-Gambella rift system have been performed using qualitative and quantitative interpretation methods; the former method helps to identify and map the overall basin architecture and structural elements, this qualitative understanding was used as a basis for detailed refinement using quantitative study. This combined interpretation shows that the Melut rift system, of which the Gambella rift represents the southernmost limit within Ethiopia, is essentially controlled by two main sets of structural features: a NNW-SSE trending fault set and a sub N-S trending fault set, in essence forming a skewed and compressed letter ″x″. The NNW-SSE set is dominant, however N-S trends are prominent along a narrow band, revealed intermittently within the NNW-SSE rift corridor and also immediately outside the NNW-SSE rift corridor to the north and south. In general, integrated interpretation of these potential field data identified three main sub-basins with in the Gambella basin. The Tori-Biel sub-basin represents the principal structural low within the Gambella AOI and is of considerable interest in terms of its sedimentary thickness. Unlike the Melut rift elements to the north, the origin of the Tori-Biel structure would appear to be tensional, lying as it does in the lee of the AbwongSobat fault (Figure 5). Circumferential domal stress, related to Tertiary Ethiopian doming, may be partly responsible for its accentuated depth. With no seismic control or well data currently available it is difficult to determine to what degree Tertiary rifting might have played a part in the development of what is otherwise regarded as a principally Cretaceous structure. In detail, it is hypothesized that a large part of the Melut rift system was formed as a result of right-lateral movements along a series of early Cretaceous sub E-W to ENE-WSW trending wrench faults, W1-W6 closely allied to and extending from the CASZ (Central African shear zone) in the north and progressing in en echelon fashion southeastward through Sudan and terminating upon the Ethiopian Dome periphery, within the Gambella region of Ethiopia. Right-lateral trans tension along these wrench faults (with subsequent magmatic intrusion - as the stress field presumably changed - thus revealing the lines of fracture) appears to have provided the principal means by which the NNW-SSE trending sub basin elements of the Melut rift system were formed. Wrench faults W2-W6 appear to be truncated to the west by a single NW-SE trending fracture (again magmatically intruded) lying along the western margin of the rift system. The right-lateral Trans tension would appear to have been decoupled along this fracture, insulating the region to the west, and south of wrench fault W1 from this type of rifting mechanism. This fracture with accompanying magmatic intrusion would appear to be responsible for the coincident Abwong-Sobat Uplift (Petronas-provided name) and therefore for the purposes of this report is named the Abwong-Sobat fault. ("Structural Trends Map on Figure 5).

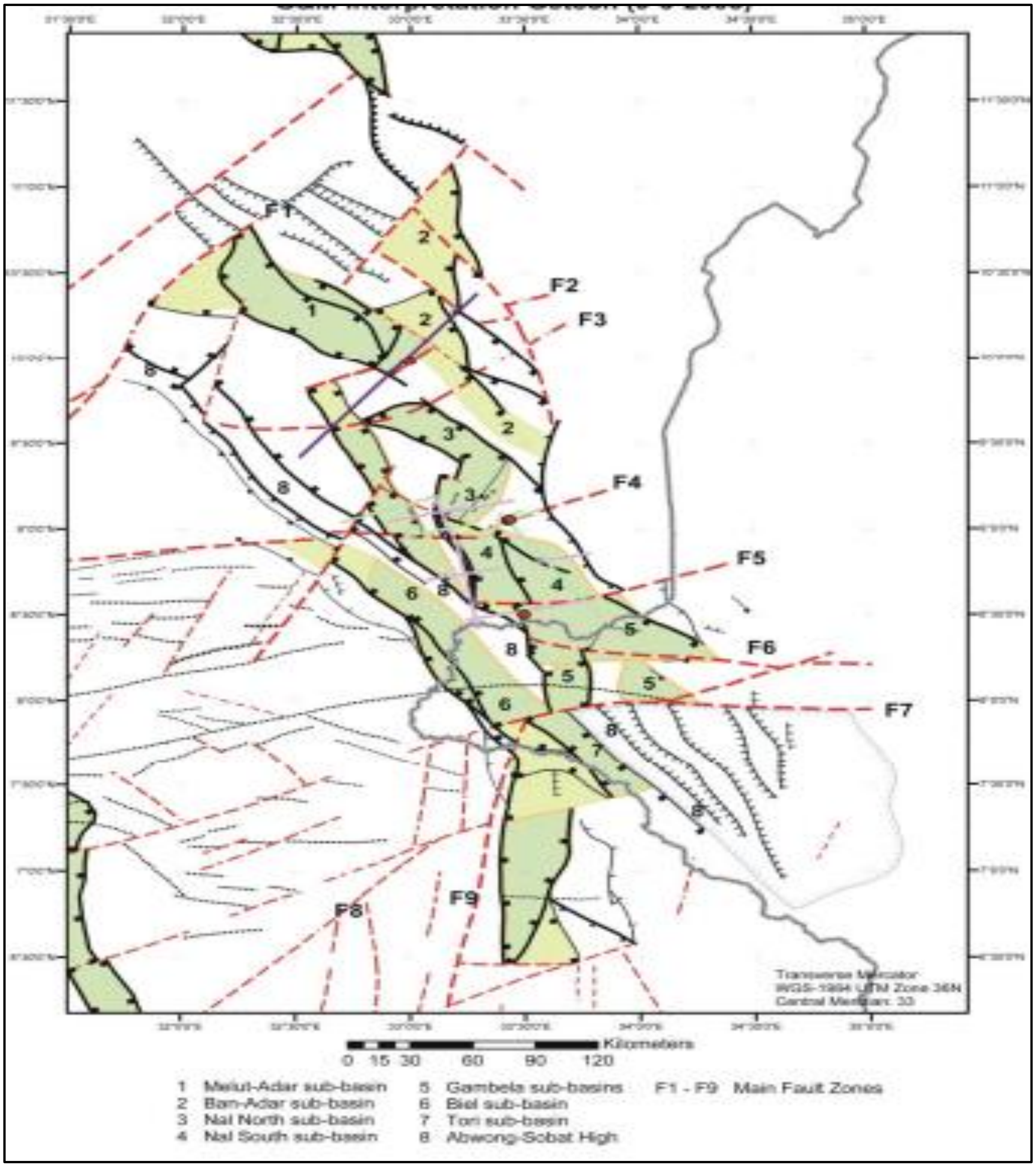

Figure 5. Structural trend map of Gambella Basin, G & M interpretation (After MoM)

2.2 REGIONAL TECTONIC SETTING AND BASIN EVOLUTION

In this part, the main structural characteristics of the Melut Basin and its surroundings are discussed and illustrated in (Figure 6). (Schull, 1988) Provides a thorough, illustrative explanation of the underlying structure of the southern Sudanese basins. The Anza Rift in Kenya appears to continue northwestward into the Melut and Muglad Basins, which are the major interior rift basins in Sudan (Figure 6). Two significant basins, primarily the Khartoum and Blue Nile Basins, are recognized in the east-central Sudan. Regional studies (Fairhead, 1986); (Bosworth, 1992)) link the early break-up phase of the South Atlantic and the split of Gondwana during the Jurassic (?)-Early Cretaceous to the initial rift basin development in central and West Africa. Numerous graben and half-grapen structures, including those in Sudan, were produced in Africa as a result of the incident's significant shear and extensional forces (Figure 6). The Central African Shear Zone (CASZ), a significant fault zone, appears to stop parts of these rift basins' northwest extension. But analysis of gravity data (Ibrahim et al, 1996)) indicated the existence of at least seven sedimentary basins northwest of the CASZ. The Bagbag Basin, which is located 150 km west of Khartoum, has sediments with a thickness of around 3000 m, according to the gravity models presented by (Osman, 1998) (Figure 6). (Browne et al, 1985) And (Bosworth, 1992) claim that the Pan-African mobile belts' weak lineaments were reactivated by Mesozoic-Tertiary motions, which in turn caused the tectonic evolution of the Sudanese interior rift basins. According to (Schull, 1988), the tectonic evolution of Sudan's Interior Rift Basins can be split into a pre-rifting phase, three rifting phases, and a sag phase. The Early Cretaceous (130–160 Ma) to Late Jurassic (?) rifting phase began and ended close to the Albian boundary. The second rifting phase occurred between the Turonian and Late Senonian, coinciding with the deposition of lacustrine, floodplain clay stones, and siltstones as well as some modest volcanic activity. This stage of rifting may be connected to andesitic basalt found in the Northern Melut that is dated as (Campanian (RRI & GRAS,, 1991). Deposition of an increasingly sand-rich series, which culminated in the Yale Formation's massive Paleocene sandstone layer, marks the end of this phase. In the Late Eocene to Oligocene, the last rifting phase started. The Adar Formation's thick succession of lacustrine and floodplain clay stones and siltstones exhibit this phase. The region has seen mild sinking with little to no faulting since the Mid-Miocene. (Browne et al, 1985)

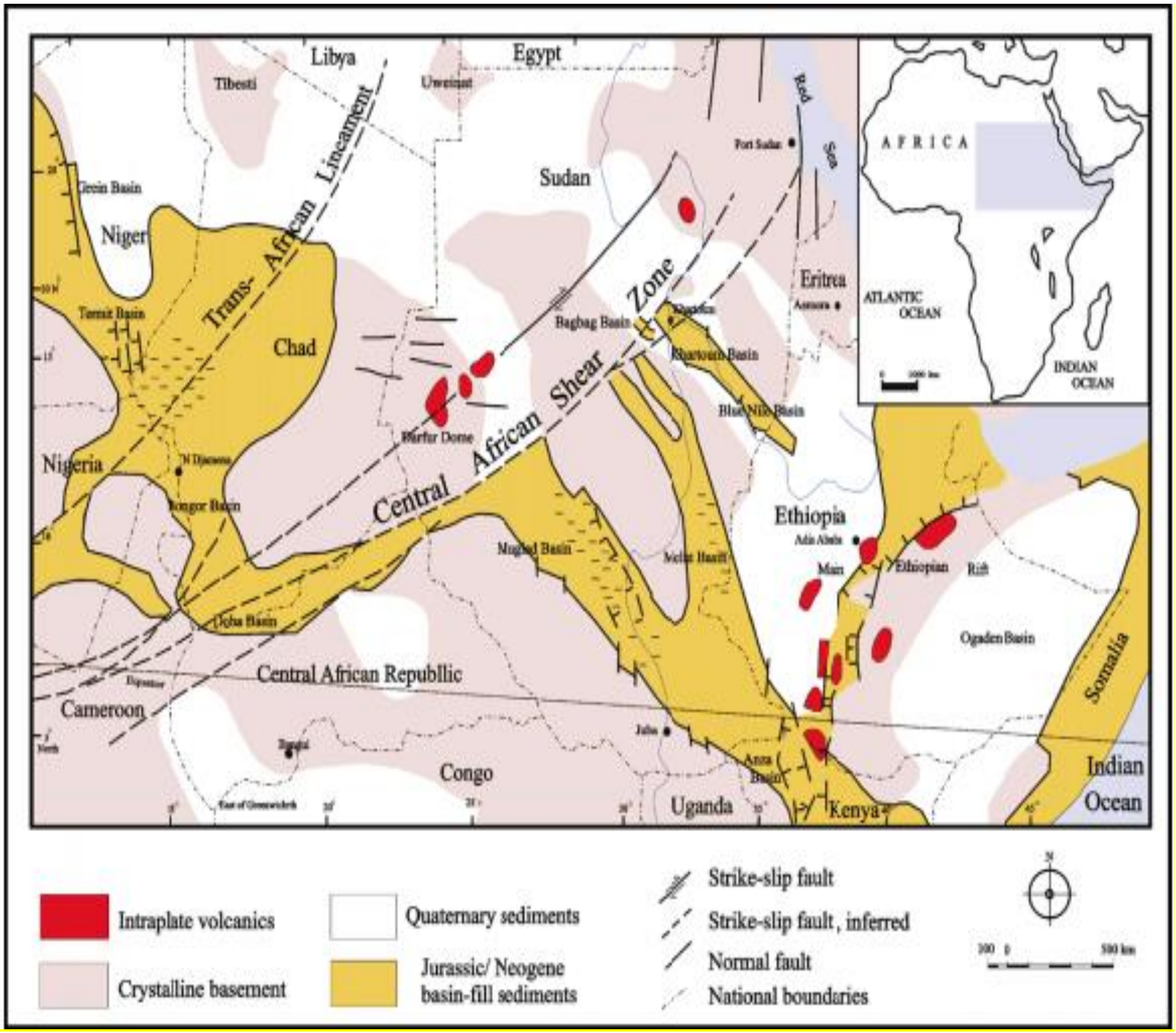

Figure 6. Map of the CASZ's primary rift basins and those of the neighboring nations (adapted from Pudlo et al., 1997).

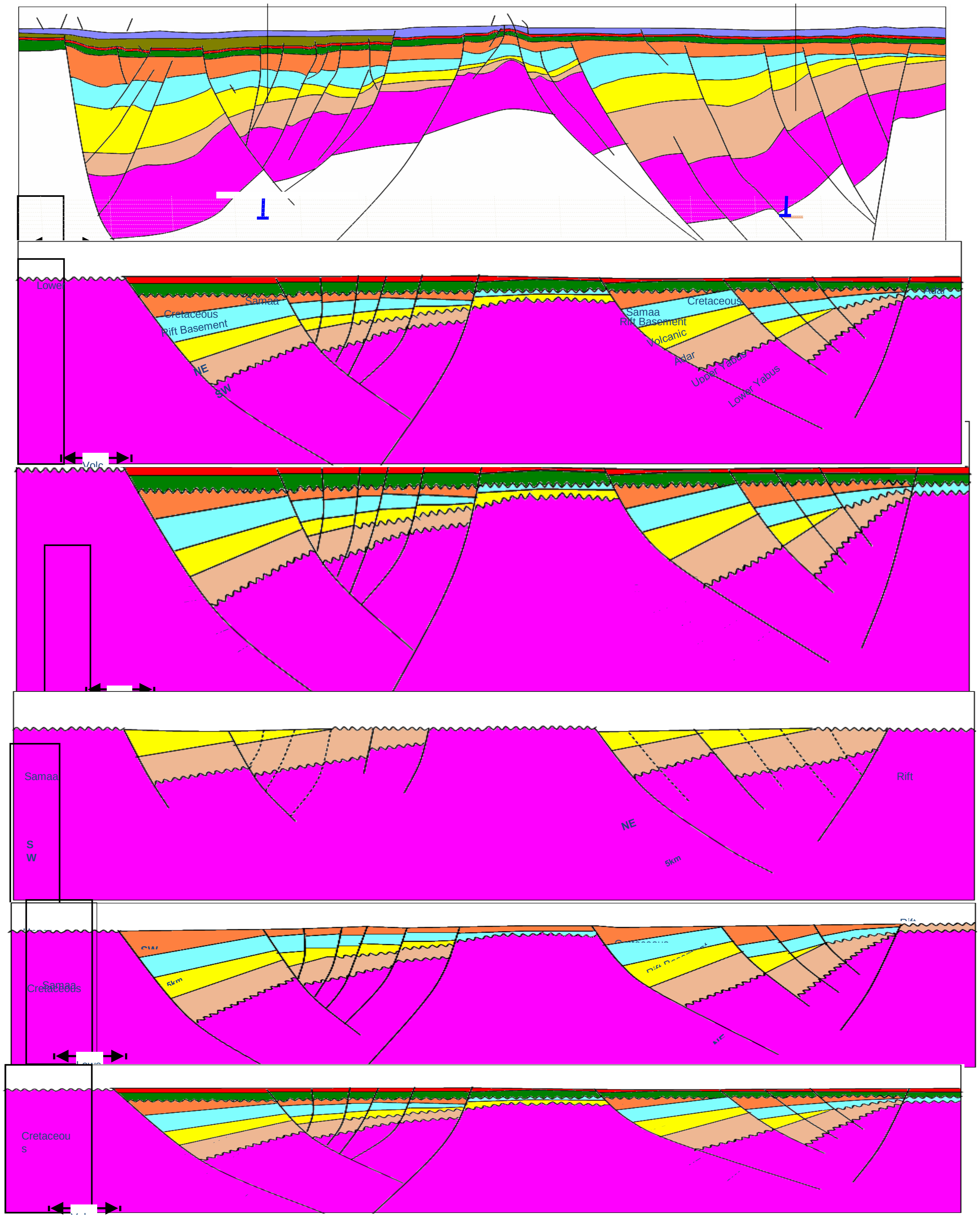

Figure 7. Showing basin evolution of the studied area (After MoM)

Initial syn-rift (Early-Later Cretaceous): Graben and horst development, rapid subsidence, developed shaly prone Al Gayger to Al Renk that believes the main source rock of the basin.

Sag (Late Tertiary to present): the basin experienced a sag development Most of the faults were stop after Late Tertiary. Some basement involved faults were reactive associated with the right lateral wrench movement.

Later rifting-early sag (Oligocene): Extrusive active, the volcanic covers all South Melut including Gambella Basins, and the volcanic pinch out in North part of South Melut basin

2nd rifting (Late Cretaceous-Early Tertiary): Half graben development start, the master (boundary) faults continue to grow and the other side is “locked”, erosion may occurred in the edge of hanging wall and supply rework materials. More sediment supplies in the later stage, accumulated sand prone Melut-Samaa formation. Initiated the synthetic fault and anti-synthetic fault in the hanging wall.

3th syn-rift (Paleocene-Eocene): The master fault continues to grow and the other side keeps “locking”. The synthetic and anti-synthetic fault continues to develop. However, the relief of paleo-topography was smaller than previous stage in the basin and surrounding area. The sediments on lapped to the previous high and cover the basement in the surrounding area while development of fining upward Yabus and Adar Formations

Early sag (Early Miocene): Subside in Southwest and uplift in Northeast. Deposited Lau formation in West Gambella Sub-basin and depositional hiatus in East Gambella.

2.3 TECHTONO STRATIGRAPHIC DEVELOPMENT OF GAMBELLA BASIN

In any un-drilled Basin, such as the Gambella Basin, a sequence stratigraphic approach would form the Basis for determining the sedimentary framework for the basin. The quality of the seismic in the Gambella Basin however did not allow such approach. For this reason, reference is made to the stratigraphy in the Melut Basin (Figure 8), which shows some results from a sequence stratigraphic study on the Melut Basin). From the above, stratigraphic, chrono-stratigraphic correlations and recent seismic data, the Gambella Basin is likely to be dominated by similar sedimentary sequences like the Melut Basin. These sequences consist primarily of non-marine clastics deposited over Precambrian Basement.

2.3.1 Basement

The Precambrian metamorphic and igneous Basement rocks are the oldest rocks found in the Melut Basin. The Gambella Basin should experience something similar (Figure 8).

2.3.2 Pre-Cretaceous

Based on regional tectonic considerations, it cannot be excluded that the basement in the Gambella Basin is overlain by (Karoo) Jurassic deposits (figure 8).

2.3.3 Early Cretaceous

The Early Cretaceous silt is thought to have accumulated under primarily non-marine conditions during the early stages of rifting, analogous to the Melut Basin. Depocenters (lakes), the main source rock in the Melut Basin, accumulated mud-prone facies when subsidence surpassed sedimentation rate or clastic input decreased (Figure 8).

2.3.4 Late Cretaceous

The Late Cretaceous strata in the Melut Basin comprise two formations, the Galhak and Melut (Campanian to Maastrichtian age) (Figure 8). Overall, the Late Cretaceous succession comprises a weakly retro gradational succession with thinly bedded sandstones prevailing. The depositional setting is dominated by fluvial conditions with brief, periodic phases of lacustrine conditions.

2.3.5 Paleocene - Eocene

Three formations make up this section of the Paleogene succession; they are the Samma, Yabus, and Adar formations, as seen in Figure 8. In essence, the Samma and Yabus formations date from the Paleocene and Eocene periods. The entire Adar Formation is Eocene in age. The Samma and Yabus Formations indicate a subsequent syn-rift phase, with the renewed influx of coarse clastics caused by the tectonic rejuvenation of bordering highs. The Late Cretaceous is incongruous with the Paleocene. Only locally preserved and deposited, the Samaa Formation most likely reflects the early infilling of a post-Late Cretaceous terrain. There are large sub aerial oxidative stages and predominant fluvial and overbank facies. In several places, the Yabus Formation directly overlies Late Cretaceous silt, showing more widespread deposition throughout the basin. The Lower Yabus Sandstone Member, which is regionally correlative and whose upper surface defines a good seismic reflector, is defined by the channel sandstones that make up the initial deposits. The Sandstone Member has a variety of stacking patterns, and wireline log profiles indicate a complicated interaction of channel, mouth bar, and crevice splay deposits. The Upper Yabus is a fining upward sequence that extends from the top of the Yabus Formation to a maximum flooding surface in a high-stand system. On top of the Yabus Formation, the Adar Formation appears to be in conformance. The overbank/crevasse splay/flood plain facies are more common and represent a late rift phase, which is represented by the Adar Formation. Additionally, lacustrine phases grew persistent. However, sub aerial oxidation remained considerable. The Adar Formation, located in the Sobat-1 well in the southern part of the Melut Basin, consists of two extrusive basalts that are 28 and 21 meters thick, respectively. This extrusive phase is thought to be the first release of the Ethiopian Plateau Basalts (Afar Plume). They are broadly distributed over the southern portion of the basin, according to seismic evidence, but they pinch out immediately south of the Miyan-1 well in Sudan.

2.3.6 Oligocene - Early Miocene

A significant phase of structuring separates the Adar Formation from the overlying Lau/Jimidi formations of Oligocene age (Figure 8). Unfortunately due to limited information, precise dating cannot be achieved and the duration of the break is unknown. The seismic data suggests that no Lau Formation was deposited in the East Gambella Basin, but the thickness of this formation reaches up to 1000m in the West Gambella Basin. In the Melut Basin, the Lau Formation comprises relatively fine-grained sediments, implying that this formation has been deposited in the early stage of the sag period. Overbank/flood plain facies are considered to have prevailed, but with occasional lacustrine phases. The succeeding Jimidi Formation is a markedly on lapping unit, which is readily co relatable across the entire basin. The basal part of the formation is characterized by stacked, essentially retro gradational sandstones that probably represent channel sandstones introduced into lacustrine environments.

2.3.7 Middle Miocene – Quaternary

The Daga formation (Figure 8) is currently interpreted to comprise middle Miocene-Pliocene age strata, deposited as predominantly flood plain sediment deposited in a humid, tropical/sub-tropical type climate. The succeeding Agor formation was deposited under drier condition relative to the Daga formation.

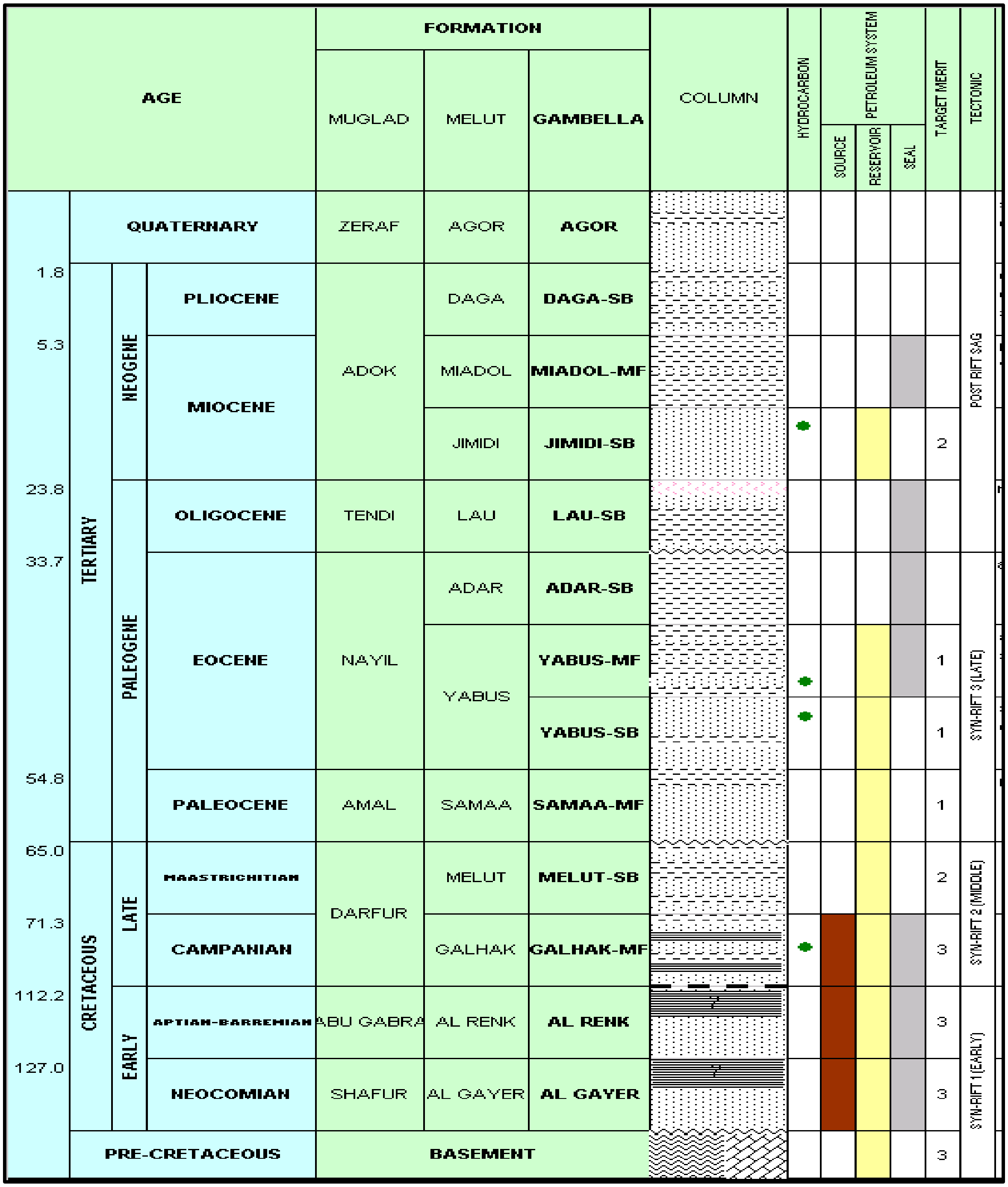

Figure 8. Regional stratigraphic correlation of the Phanerozoic strata from NW Sudan to SW, Ethiopia (PCE).

2.5 STRATIGRAPHIC FRAME WORK

2.5.1 CRETACEOUS

Mainly composed of Claystone, Interbeded Igneous rock, Metamorfic sediment (3051m – 3278.8m MDDF)

2.5.1.1 Claystone (181.8m, 80%): dark brownish red, trace greyish green, rare varicolored with white spot, firm, locally soft, subblocky, common blocky, earthly lustre, slightly washed out, intermixed with trace pyroclastic or tuffaceous material, trace dark mafic material(pyroxene or amphibole), trace calcite filled in vein or microfracture, rare powdered calcite.

2.5.1.2 Igneous rock (27m, 11%): grey to dark grey, minor dark grey, firm, minor hard to very hard, minor dense, subblocky, minor irregular shape, very fine crystalline, dominant plagioclase and feldspar, trace pale green olivine and amphibole, trace white quartz and calcite filled in vein or microfracture, locally amygdaloidal structure, occasionally tuffaceous, trace white powdered calcite, rare volcanic ash.

2.5.1.3 Metamorphic (18m, 9%): greyish green, trace varicolored with white spot, firm, soft in part, earthy lustre, altered of igneous rock, with olivine grain mineral(?), greenish and greyish rock fragment, locally altered, become soft, calcite secondary filling in vein or microfracture(?), trace dark grey mafic material(pyroxene or amphibole), rare powdered calcite, trace altered of feldspar material.

2.5.2 MELUT *(GALHAK)* FORMATION

In Jekow-1, the MELUT Formation is composed of fine to medium grained sandstones interbeded with brownish red and grey claystones. The sandstones form 70% of this formation; the claystones form 30% of this formation.

2.5.2.1 SANDSTONE: light grey to off white, occasionally clear, translucent, transparent and rare pale yellow, loose to friable, moderately hard in part, dominantly fine to medium grained, occur very fine grain, moderately sorted, argillaceous matrix, kaolinitic in part, poor to fair cemented with siliceous , fair to good inferred porosity.

2.5.2.2 CLAYSTONE: dominant medium brownish red , soft to firm, minor moderate hard, amorphous, rare sub blocky, earthy luster, sticky and very wash out, non-calcareous.

2.5.3 VOLCANIC FORMATION

Mainly composed of Predominantly Basalt in upper part interbeded with Claystone and Sandstone (1491 m – 1681 m MDDF);

2.5.3.1 Basalt (98m, 55%): very dark grey to black, with rare white spot, fresh surface, hard to very hard, dense, irregular shape, very fine crystalline, dominant ultramafic material, occasionally pale green olivine, occasionally white quartz or feldspar, rare calcite filled in vein or microfracture.

2.5.3.2 Claystone (59m, 33%): brownish red, light grey to dark grey, moderately hard, common firm, subblocky, trace blocky, earthy lustre, non-calcareous.

2.5.2.3 Sandstone (22m, 12%): light grey to off white, trace Transparent to translucent, soft, very fine to fine grained, trace medium grained, subrounded, well sorted, quartz, occasionally.

2.5.4 SAMMA FORMATION

In Jekow-1, the Samma formation is composed of fine to medium grained sandstones interbeded with brownish red and grey claystones. The sandstones form 68% of this formation; the claystones form 32% of this formation.

2.5.4.3 Sandstone: Quartz, trace argillaceous matrix, occasionally to minor kaolinitic cement, occasionally translucent to transparent, poorly to moderately consolidated, fine to medium grained, trace coarse to very coarse grained, subangular to subrounded, poorly to moderately sorted, and fair porosity.

2.5.4.4 Claystone: brownish red, occasionally grey, trace brownish yellow, moderately hard, subblocky. There were no fluorescent shows observed in this formation.

2.5.5 LOWER YABUS FORMATION

Mainly Interbeded Claystone and Sandstone

2.5.5.1 Claystone (260m. 63%): light grey to reddish grey, commonly soft, locally firm, soluble, sticky, occasionally amorphous, subblocky, trace blocky, earthy lustre, washed out, earthy luster, non-calcareous, silty inpart, locally slight calcareous.

2.5.5.2 Sandstone (152m, 37%): commonly light grey to off white, transparent to translucent, friable to soft, occasionally brittle, poorly consolidated, predominantly fine to medium grain, minor very fine grained, traces coarse grained, rare very coarse grained, subangular to subrounded, moderately sorted, non to slight calcareous cemented, loose quartz, argillaceous matrix, occasionally kaolinitic material, poorly to fairly visible porosity.

2.5.6 UPPER YABUS FORMATION

The Upper Yabus is mainly composed of Interbeded Claystone and Sandstone

2.5.6.1 Claystone (358m, 51%): light grey to reddish grey, commonly soft, locally firm, soluble, sticky, occasionally amorphous, subblocky, trace blocky, earthy lustre, washed out, earthy luster, non-calcareous, silty inpart, locally slight calcareous.

2.5.6.2 Sandstone (344m, 49%): commonly light grey to off white , Transparent to translucent, friable to soft, occasionally brittle, poorly consolidated, predominantly fine to medium grain, minor very fine grained, traces coarse grained, rare to coarse grained, sub angular to subrounded, oderately sorted, non to slight calcareous cemented, loose quartz, argillaceous matrix, occasionally kaolinitic material, poorly to fairly visible porosity.

2.5.7 ADAR FORMATION

The Adar formation in Jacaranda well-1 is composed of Interbeded Claystone and Sandstone

2.5.7.1 Claystone (185m, 55%): light grey to dark grey, commonly firm, locally soft, soluble, sticky, occasionally amorphous, subblocky, trace blocky, earthy lustre, washed out, earthy luster, non-calcareous, locally slight calcareous.

2.5.7.2 Sandstone (153m, 45%): commonly off white to milky white, Transparent to translucent, friable to soft, occasionally brittle, unconsolidated to poorly consolidated, predominantly fine to medium grain, minor very fine grained, traces coarse grained, rare very coarse grained, subangular to subrounded, moderately sorted, non to slight calcareous clay material cemented, quartz, argillaceous matrix, occasionally kaolinitic material, poorly to fairly visible porosity.

2.5.8 LAU FORMATION

2.5.8.1 Sandstone (125m, 36%): Transparent to translucent, loose, medium grained, occasionally fine grained, trace coarse grained, subangular to subrounded, moderately sorted, quartz, trace argillaceous matrix, minor kaolinitic material, good visual porosity.

2.5.8.2 Claystone (207m, 61%): greyish brown, occasionally light grey-grey, soft, sticky, amorphous, earthy luster very washed out, non-calcareous.

2.5.8.3 Siltstone (11m, 3%): light grey, moderately consolidated, subrounded, well sorted, quartz, minor argillaceous matrix, poorly porosity.

2.5.9 JIMIDI FORMATION

In Jekow-1, the JIMIDI Formation is made up of fine to medium grained sandstone that is interbedded with light to dark grey and brownish red claystones, as well as basalt near its base. The claystones make up 35% of this formation, followed by the sandstones (33%), and the basalt (32%).

2.5.9.1 SANDSTONE: translucent to transparent, trace light grey, unconsolidated, fine to medium grained, occasionally coarse grained, trace very coarse grained, subrounded to rounded, poorly sorted, quartz, trace argillaceous matrix, good porosity.

2.5.9.2 CLAYSTONE: light to dark grey, occasionally brownish red, trace dark brown, moderately hard, occasionally firm, subblocky to blocky.

2.5.9.3 BASALT: dark grey to black, very hard, compact, blocky, occasionally flaky, dark mineral. There were no fluorescent shows observed in this formation.

2.5.10 MIADOL FORMATION

The Miadol formation in Jacaranda well-1 is Dominantly Clay stone and interbeded with Sandstone and Siltstone.

2.5.10.1 Clays tone (192m, 73%): dominantly light grey, dark grey, brown, light brown, occasionally greenish grey, red, trace greyish yellow, firm, soft in part, sub blocky to soluble, amorphous in part, earthy luster, lightly washed out, rare carbonaceous, non-calcareous.

2.5.10.2 Sand stone (56m, 22%): Transparent to translucent, occasionally light grey, loose, poorly Consolidated in part, very fine to fine grained, trace medium grained, subrounded, poorly well sorted, quartz, occasionally argillaceous matrix, fair porosity.

2.5.10.3 Siltstone (14m, 5%): grey, moderately consolidated, subrounded, well sorted, quartz, minor argillaceous matrix, poorly visual porosity.

2.5.11 AGORDAGA FORMATION

The Agor Daga formation is Mainly Clay stone interbeded with Sandstone and Siltstone.

2.5.11.1 Clay stone (445m 61%): dominantly grey, brown, with variety of colours yellowish, purple reddish greenish, soft to firm hardness, sticky, sub blocky to blocky , amorphous, washable, earthy luster, occasionally waxy luster, trace carbonaceous, non-calcareous.

2.5.11.2 Sandstone (259m 35%): dominantly Transparent-translucent, light grey to grey, light brown to brown, yellowish brown, loose, poor consolidate sand, fine to medium grained, coarse grained, and traces of granule-pebble, sub angular to subrounded, moderately to well sorted, poorly sorted, quartz grain, trace of argillaceous matrix, poor to good visual porosity.

2.5.11.3 Siltstone (26m, 4%): brown, grey, occasionally greenish, poor consolidated, soft, subrounded, well sorted, quartz, minor argillaceous matrix, poorly visual porosity**.**

Table 1. Formation Tops based on Jacaranda well-1 correlated based on Lithology to the nearest well Jekow-1 well

Horison	**Prognosis mMMDF**	**Prognosis** mTVD DF	**Prognosis mTVD SS**	**Actual mMD DF**	**Actual mTVD DF**	**Actual mMD DF**	+Hi / - Lo (m)
AgorDaga	-	-	-	-	-	-	-
Miadol	739	739	327.6	745	745	333.6	6
Jimidi	962	962	550.6	1007	1007	595.6	45
Lau	1109	1109	697.6	1160	1160	748.6	51
Volcanic	1434	1434	1022.6	1491	1491	1079.6	57
Adar	1554	1554	1142.6	1681	1681	1269.6	127
Upper Yabus	1885	1885	1473.6	2020	2020	1608.6	135
Lower Yabus	2439	2439	2027.6	2393	2393	1981.6	-46
Samma	2717	2717	2305.6	2805	2805	2393.6	88
Melut	2907	2907	2495.6	-	-	-	-
Cretaceous	-	-	-	3051	3051	2639.6	-
TD	4000	4000	3588.6	3278.8	3278.8	2867.4	-721.2

CHAPTER 3

3. MATERIALS AND METHODS

3.1. MATERIAL

To carry out the research work, the material acquired are; Borehole data and cutting samples used in this study were provided by the Ethiopian Ministry of Mines((PCOB report, 2007). Material for this study include final geological reports prepared by Chevron (1982), post drills report for two well, FIS report, analysis on 104 cuttings samples and 16 sidewall cores from the interval of 60-3500 mKB in Jekow well and carried out on seventy 70 ditch cuttings from the interval 745-3250 in Jacaranda well ((PCOB report, 2007)). The exploratory wells, located in the Gambella Basin, Western Ethiopia (Figure 2). The wells (Jekow and Jacaranda) were drilled by Petronas Carigali Overseas Petroleum Inc. from February 2006 to April 2007. Composite logs of the scale 1: 500 of the scale 1:1000 were produced by Company. This research will be carried out on the two exploration well drilled by PCOB as they are noted below;

Table 2. Table showing well locations used for the study

S/N	Well	Coordinates					
		X(UTM)	**Y(UTM)**	**Top depth**	**Bottom depth**	**KB (m)**	**Symbol**
1	Jekow	08 16'42.509''N (915153)	33 42'24.679''E (577843)	400 m	3500 m	9	4
2	Jacaranda	08º 06’ 27.969” N(896231.4M)	33º 22’ 43.866” E(541738.4M)	402.4 m	3278.8 m	9	4

3.2 METHODS

3.2.1 Data Acquired

Contour and Base-Map Maps of the study area, well locations, structural elements, well deviation data, biostratigraphy and palynology data, well header information, check shot survey data (used to calibrate the relationship between time calculated from sonic log well depths and, core photographs, seismic data (SEGY), and organic geochemical data are all included.

3.2.2 Software used for data analysis

PetroMod petroleum systems modeling software simulates the development of a sedimentary basin by integrating seismic, well, and geological data. The PetroMod program can determine whether and how a reservoir has been charged with hydrocarbons, as well as the source and timing of the generation, the migratory paths, the amounts, and the type of hydrocarbons in the subsurface or at the surface. Users of PetroMod 1D

:• A quick 1D analysis tool

• A calibration tool for 3D models giving access to all modeling features including statistics,

• A 1D viewer along wells and single cells of interest with sophisticated plots and multi-plot handling, and

• A teaching tool for beginners with a well-structured workflow.

The PetroMod 1D modeling system is fully incorporated into the PetroMod 2D and 3D modeling systems, or it can be used as a standalone tool. Wells and pseudo-wells can be imported via the Well Editor, imported from scratch, or directly extracted from PetroMod 2D and 3D models. The 2D/3D Simulator can then employ calibrated wells with calibration findings such as heat flow trends. All calibration process is expedited as a result. PetroMod 1D combines input, simulation, and output in one application. The output allows users to choose between overlays, depth, time, burial and deviated plots. Users can display input and output next to each other, making it much easier to prepare presentations.

A software platform called Petrel is employed in the petroleum industry's exploration and production division. It gives users the ability to analyze seismic data, carry out accurate correlation, create reservoir models, view the outcomes of reservoir simulations, compute volumes, create maps, and plan development strategies to maximize reservoir exploitation1. Techno guide, a firm in Norway, created the Petrel software. Former workers of Geomatic, including some important programmers involved in the early development of RMS, created Techno Guide in 1996. Petrel, which was created especially for PCs and the Windows operating system, went on sale in 1998.

Interactive Petro physics: IP offers potent functionality as standard that competing products charge extra for. Principle calculations like clay volume, porosity/water saturation, cut-off and summation, pulsed neutron analysis, organic shales and NMR interpretation are all part of the package. Together, they create an industry-leading deterministic petrophysical workflow built for efficiency and collaboration.

Procedures: The primary images that were provided were of wells. Two wells (Jekow and Jacaranda) will be examined, observed, and documented starting at the bottom. observantly examining the core images and noting the overall traits and geological sequence. Each core section's boundaries shall be identified. Geological structures will be studied, taking note of characteristics like thermal history, burial history, and biostratigraphy. Using the lithofacies classification methodology, the lithofacies types will be identified and interpreted based on descriptions, lithology and grain size, and dominating sedimentary structures. Core/log To characterize the well logs for calibration, core information will be used. Geochemical and organic data Petroleum reservoirs' organic components commonly exhibit observable vertical and lateral compositional changes, both inside and between wells. The geological position of the reservoir, which affects how migratory petroleum fills the reservoir from one or several source kitchens, controls the pattern of variance. The calcilutite, which is rich in organic materials, serves as both a source rock and a reservoir, making it a significant exploration target.

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Research Flow Chart

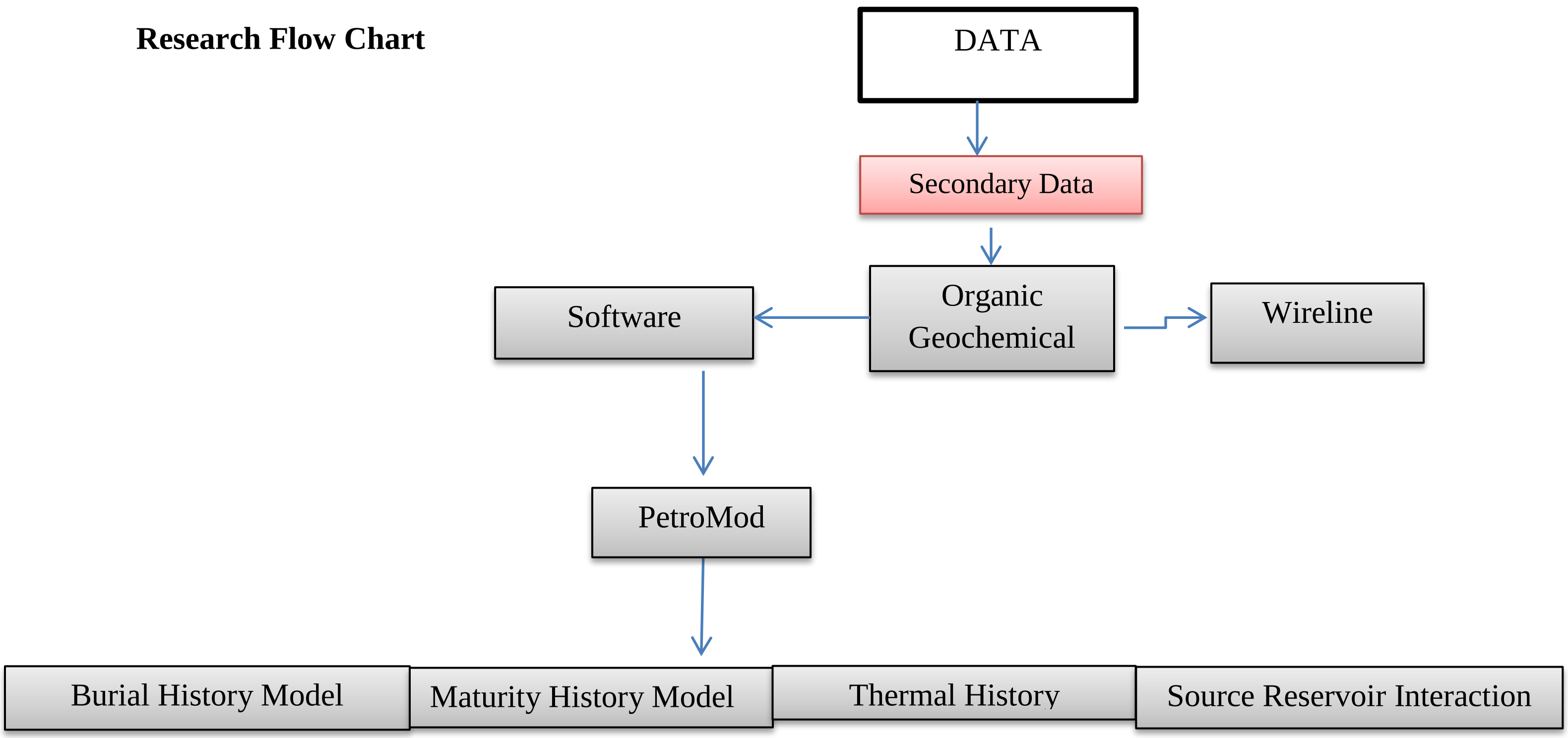


Figure 9. Showing flow chat of methodology followed for the current study

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. PETROPHYSICS

In 1983 CHEVRON carried out gravity survey in Gambella with the permission from Ethiopia's Ministry of Mines. Thirty-Four survey lines containing 1012 gravity stations were surveyed in the Gambella area of Ethiopia. The results of a gravity study are displayed in the Gambella gravity map, which was represented part of the information used to design the surface hydrocarbon micro seepage survey. That map shows that there is in the Gambella area a dominant northwesterly grain which parallels the regional tectonic trend. It is characterized by a series of linear highs and lows bounded by strong gravity gradients which are indicative of faulting; the anomaly pattern, and associated faulting, is suggestive of extensional tectonics (horst and graben structures). In general strong alignment of NW-SE trend is identified on both the residual and Bouguer anomaly maps. NE-SW trending gravity lows are interpreted as basin depocenters where there is thick accumulation of sediments, whereas NWSE trending gravity highs are interpreted either as areas affected by faults or where the basement is high. Generally these interpretations are conformable with the forward models performed on arbitrary lines with in the basin. (See 3D Gravity Inversion Map inset on next pages (Figure 4.1). Following the Gravity and magnetic survey in Gambella area, Seismic survey was also carried using the 3D model in the picture below Formation data available consist of Gamma Ray (GR), Resistivity, Density, Neutron, Sonic, mudlogs and SWC samples. The SSS model developed by Crocker Petrolog Software was used in which porosity and saturation values were derived using the density- neutron cross plot and the modified Waxman-Smits Equation respectively. Mudlogs and log interpretation showed that no hydrocarbon was present in any of the sands. All the sands in Jikawo-1 were interpreted as water. Average total porosity of the sands ranged from 21%b.v to 34%b.v.

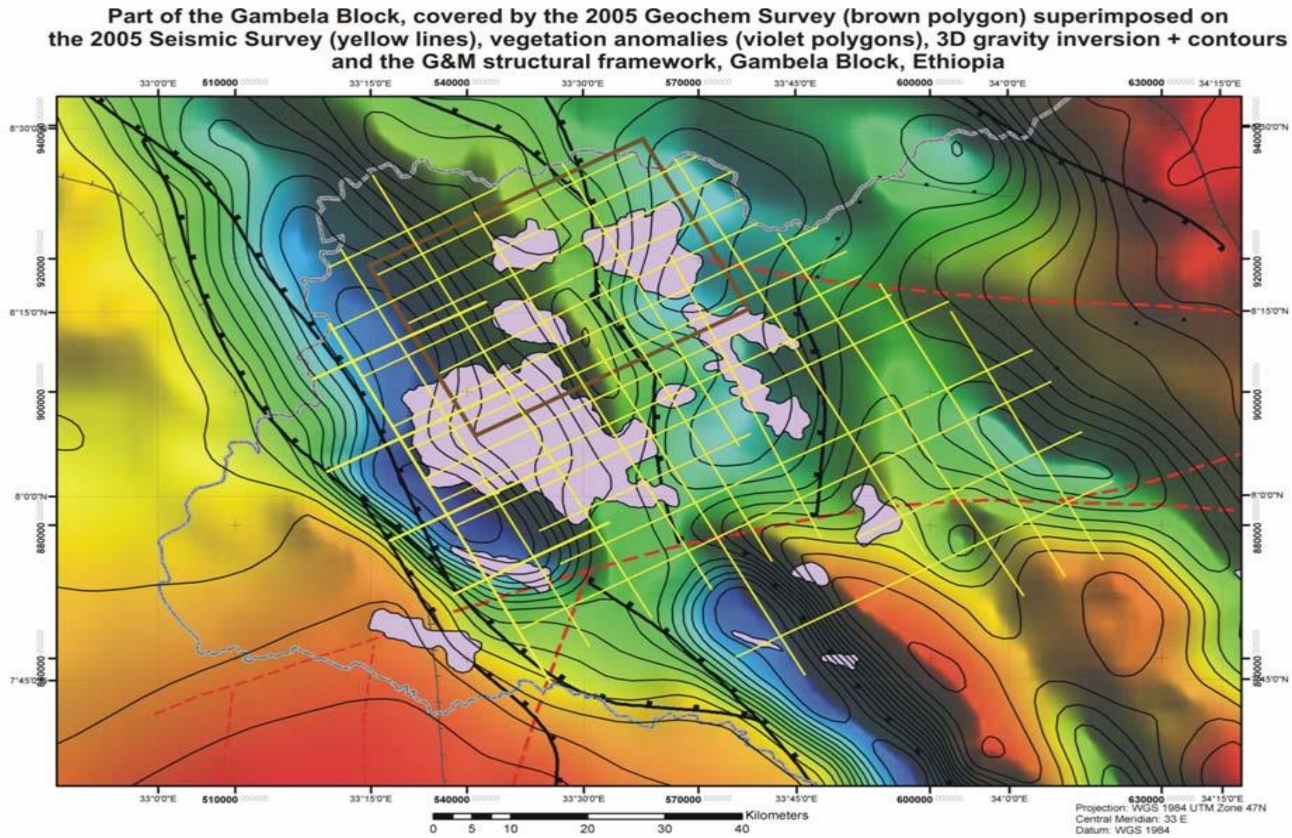
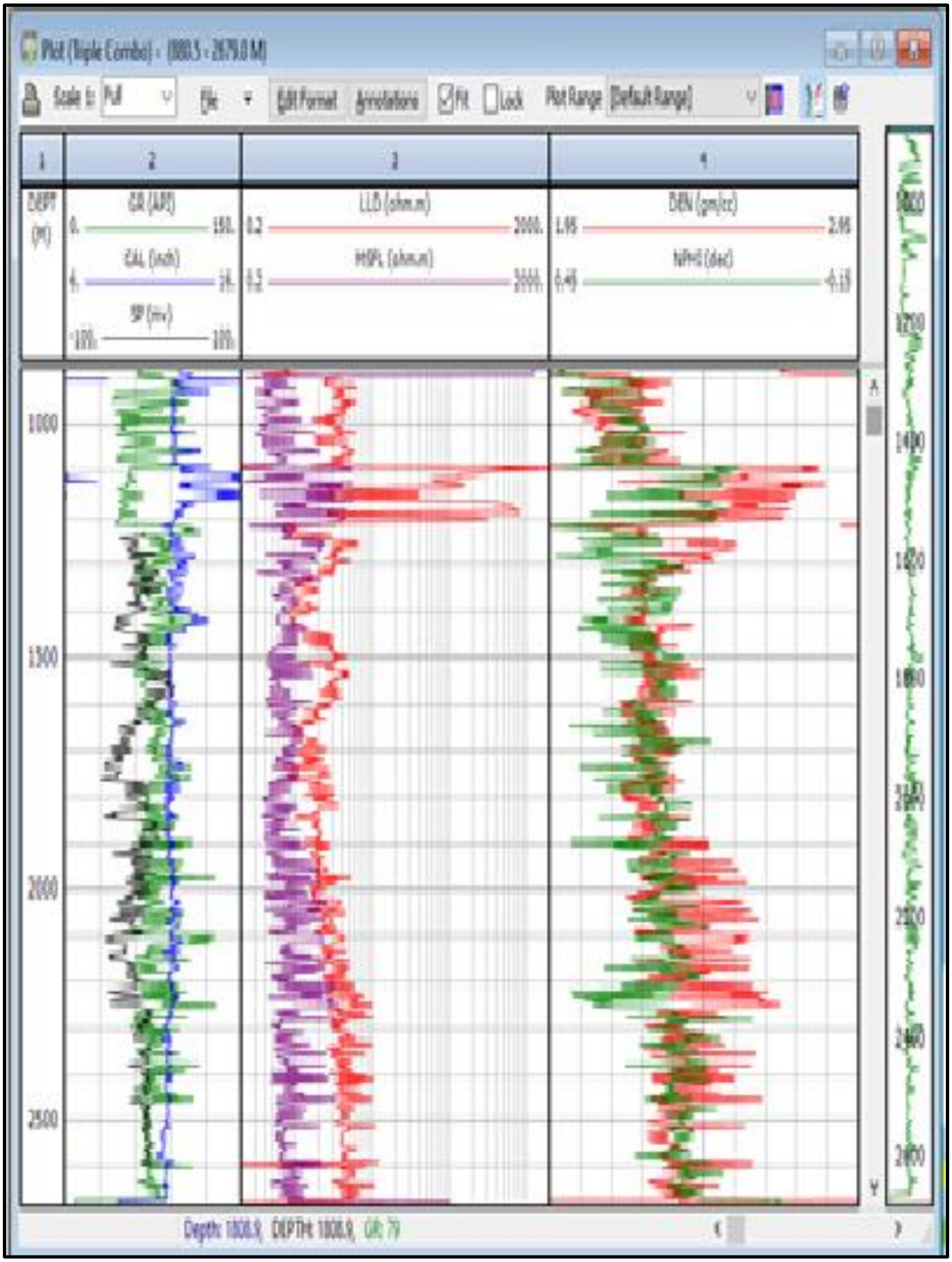


Figure 10. Gravity map of Gambella Basin using 3d gravity inversion, G & M structural frame work (After MoM)

4.1.1 WELL LOG FACIES

By analyzing the lithology, as well as the physical and mechanical characteristics of the sedimentary rocks, well-log analysis can be utilized to determine the vertical succession of the borehole. This aids in understanding the lithology and depositional environment as well as in the analysis of reservoir properties including porosity, permeability, and particle size. Shale was recognized as a source rock and sandstone was identified as a reservoir rock in the Gambella Basin using Gamma Ray as a logging technique. According to the log, the shale is medium hard, well indurated, subfissile to fissile, subblocky to blocky, subplaty to platy, and dark grey to light grey in color. The Siltstone also depicts white grey, greenish grey, dark greenish grey, grey, dark grey, light green, at times blackish grey, and brownish grey, firm to medium hard, subblocky, at times blocky, and at other times subplaty as on the log (Figure 11).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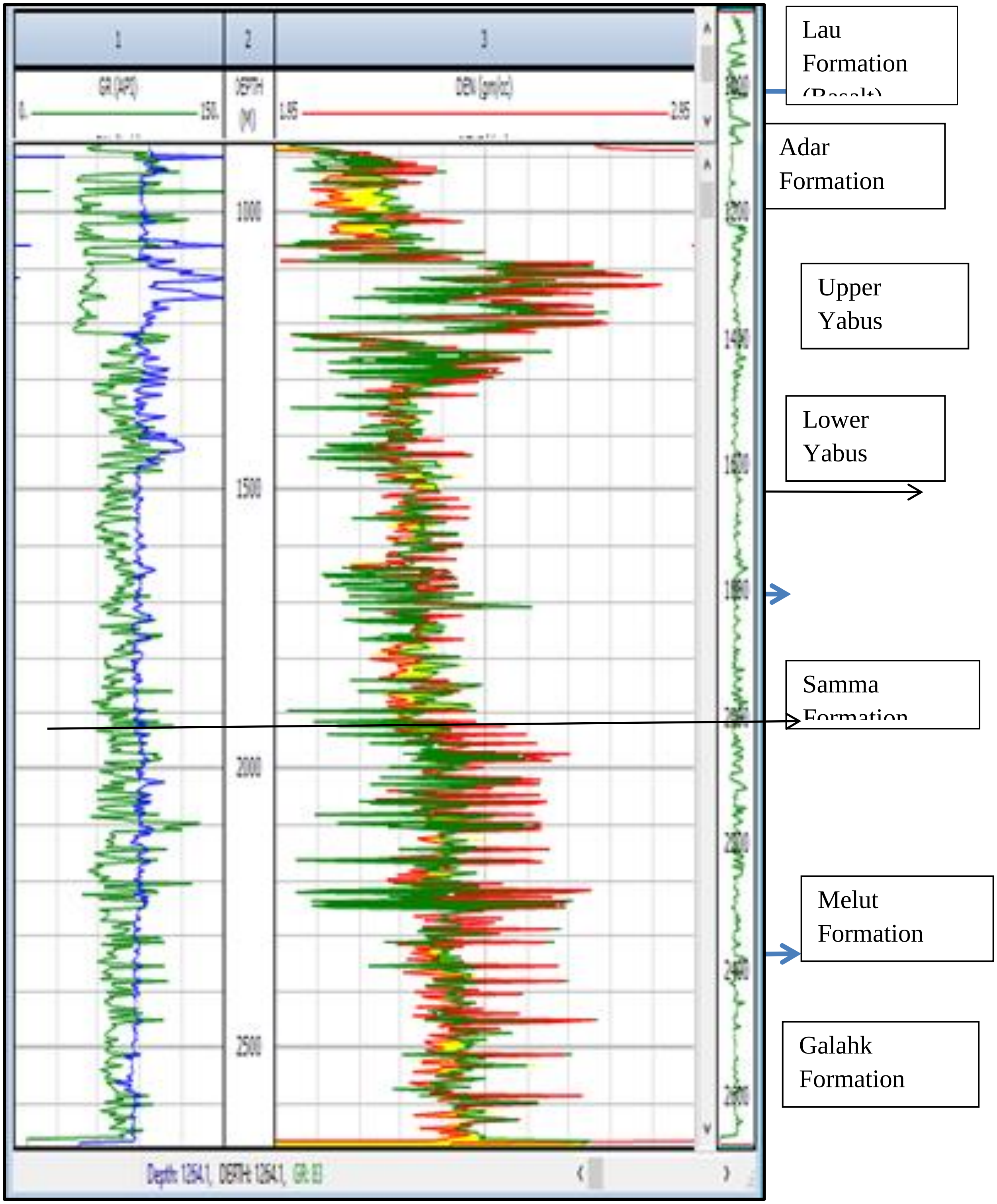
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2
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GR (API)
DEPTH (M)
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Lau Formation
Adar Formation
Upper Yabus
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Samma Formation
Melut Formation
Galahk Formation

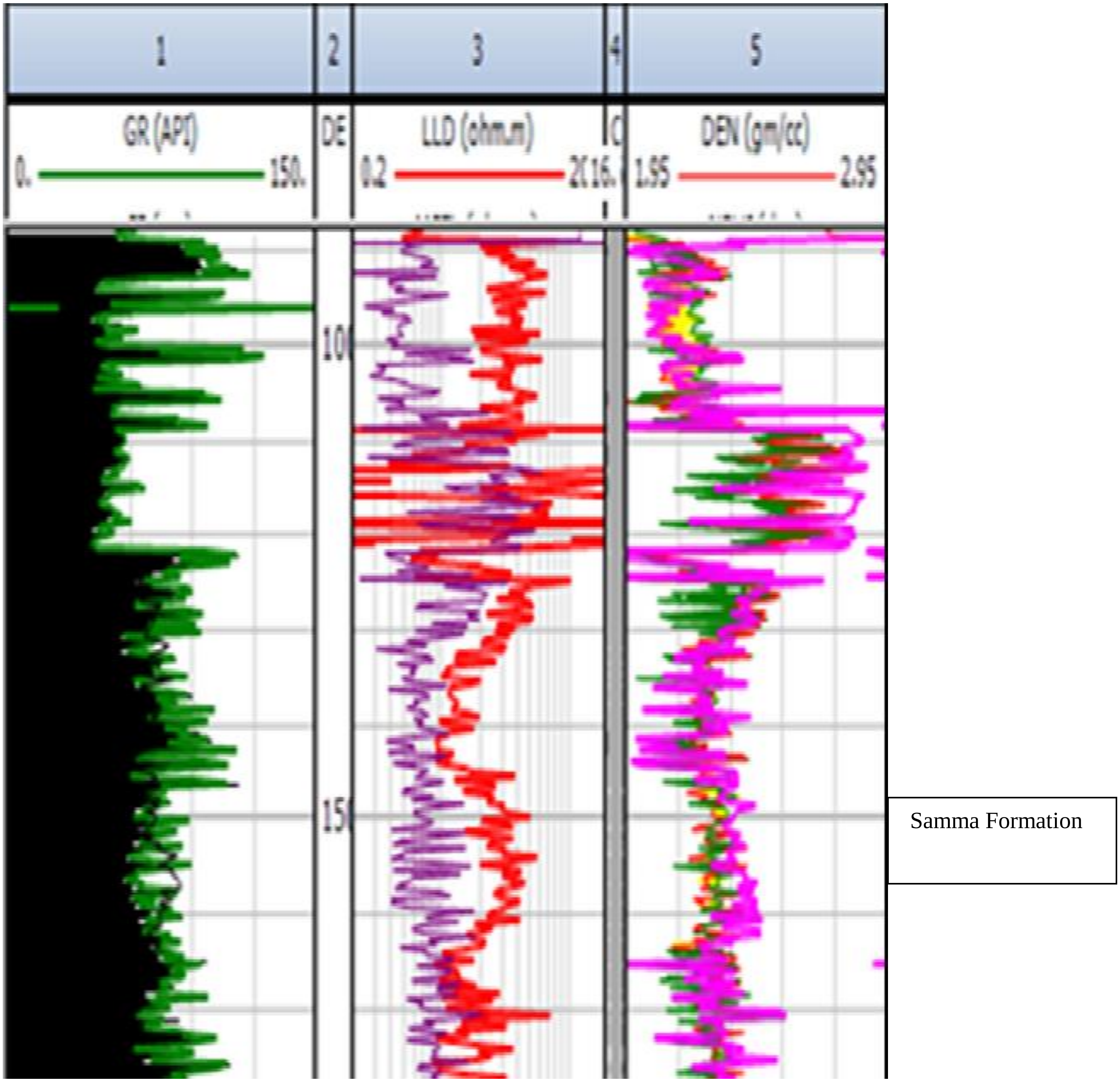


Figure 11. Well log facies generated with Interactive Petrophysic of Jekow Well-1 showing Gamma ray reflection, Density lo, and Resistivity, Gambella Basin, Ethiopia

4.1.2 STRATIGRAPHIC IDENTIFICATION AND CORRELATION

Prognosis depth was predicted from the seismic interpretation based on the existing and reinterpreted gravity and magnetic maps. Besides, correlation with nearby offset well in South Melut Basin was also taken into consideration (report, 2007). Generally, the dataset quality is poor to fair; therefore making an interpretation is difficult. The actual formation tops is given in (Table 5 below). These actual depths were interpreted from the wireline logs together with mudlogs and other parameters i.e. rate of penetration, formation pressure and lithology descriptions. This formation top was picked prior to Biostratigrapical results. In general, the reservoirs prediction depth was good. The actual depth of most sand appeared to be slightly deeper than prognosis. Both objectives, Lower Yabus and Melut were encountered in Jikawo-1 well (on Table 5). Differences of actual and prognosis depth in the objectives ranging from 50m to 98m 9 (on the table below). Such differences were perhaps caused by the volcanic layers which gave strong reflector and masked the energy during the seismic job. The well correlation between Jekow-1 and Sobat-1 is showed in seismic interpretation in figure 4.3

Table 3. Jekow-1 Formation Tops based on Jekow well horizon

Ground Level (m)	400.00				
Drill Floor Elevation (m)	9.00				
Formation Top	Actual Depth (m)		Prognosis Depth (m)		Diff (m-TVDSS) +Hi/-Lo
	MDDF	TVDSS	MDDF	TVDSS	
Miadol	616.58	207.58	600.00	191.00	16.58
Jimidi	927.39	518.39	920.00	511.00	7.39
Lau (Basalt)	1090.00	681.00	1100.00	691.00	-10.00
Adar	1217.54	808.54	1190.00	781.00	27.54
Upper Yabus	1447.43	1038.43	1470.00	1061.00	-22.57
Lower Yabus	1768.70	1359.70	1867.00	1458.00	-98.30
Samaa	2216.00	1807.00	-	-	-
Melut	2670.80	2261.80	2620.00	2211.00	50.80
Galhak	3097.42	2688.42	-	-	-

4.1.3 SEISMIC INTERPRETATION AND HORIZON DELINEATION

For the well to seismic match of Jekow-1 well, the following data was used: Sonic, density, gamma ray, deep resistivity and VSP data. Seismic dip line GE04-2D24 was selected to have the matching processes. However, due to difference frequency contents, matching between seismic and the VSP were considerably inadequate. Synthetic seismogram is then used as help and also to understand the lithology seismic response from the well. The strongest and continuous reflection of the volcanic was used as the key matching reference. By using all those data, a good well to seismic match was reasonably established for all identified markers. Seismic interpretation was performing on a LINUX work station using landmark seiswork software. Due to the seismic quality, seismic interpretation over parts of the area has to be taken to a certain extent as conceptual, the following horizon was interpreted and map generated:

Top Jimidi sand

Top Adar shale

Top Melut formation

Basement

Seismic interpretation allow the identification of three prospect and four leads of which only one prospect is located in west Gambella sub-basin. The structure in the west sub-basin would be ideally located with respect to reservoir and charge, however, present seismic coverage does not permit to define it to a drillable prospect. For this reason, initial priority is given to east Gambella sub-basin. From the identified prospect and leads, Jekow –A prospect is ranked highest for its best structural definition. The structure is mapped on 3 dip line and 1 strike line. The fault definition and reflector continuity delineation the prospect are fair in dip line and the delineation of the anticline reflection on the strike line is fair good. Based on the regional seismic map prospect-A was identified in the hanging wall of the East Gambella sub-basin with horizon closures in the lower Yabus Top and Melut top horizon

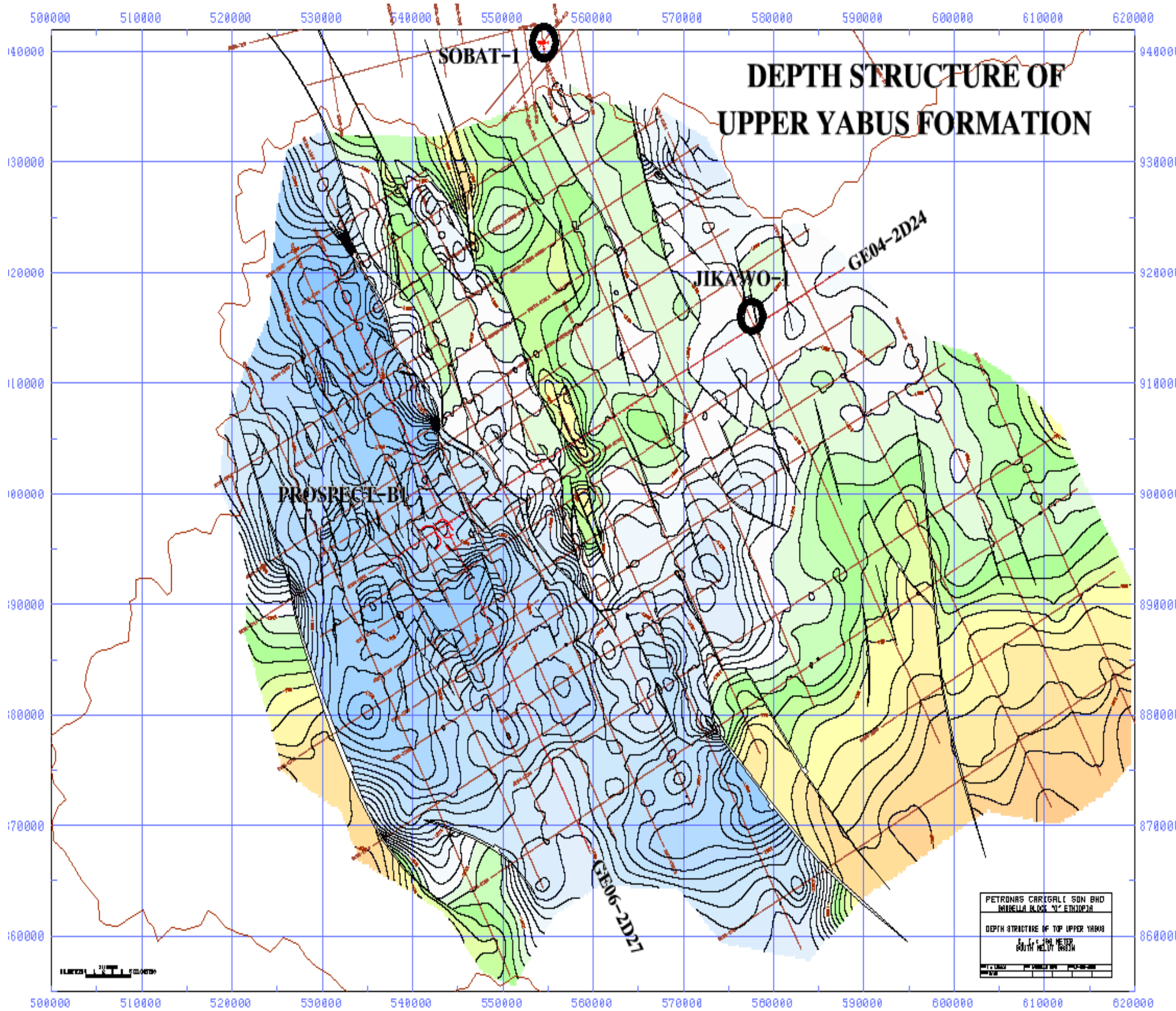


Figure 12. Seismic identification of Upper Yabus (2D) of Jekow well-1.

4.2 BIOSTRATIGRAPHY

Biostratigrapical Analysis was carried out by Fugro Robertson Limited (UK). This Biostratigrapical analysis include the Palynological and Paleoenvironmental analysis on 104 cuttings samples and 16 sidewall cores from the interval of 60-3500 mKB in Jekow Well and on seventy (70) ditch cuttings from the interval 745-3250 in Jacaranda well and radiometric dating was carried out on two (2) samples at 1580-1610 and 3250-3270. Table 6 lists the analyses. Only palynological analysis was requested by PCE because the entire series under analysis was dug in sediments that were thought to have been deposited in a non-marine environment. Freshwater ostracods and other microfossils were checked for in the washed residues of the samples used for palynology analysis, but none were found. The results of caving below 745 are questionable because no palynological analyses were requested for samples from the surface to 745, making it impossible to determine the date for that time period. Samples from the bottom of the well 3250-3275 were not palynologically analyzed because the hole was drilled in volcanic rocks. The distribution map of the detected palynomorphs is provided, along with summaries of the analysis' findings in (Table 6) In order to represent intervals with volcanic rocks, ditch cuttings at 1580 and 1610 and 3250 and 3270 were subjected to potassium/argon (K/Ar) radiometric dating. The whole report is presented (Table bottom 6), however the results are summarized and discussed below.

Table 4. Summary of Jekow-1 Biostratigrapical Result (After MoM).

Intervals (mKB)	Age	Formation	Paleoenvironment
760-890	Pliocene	Miadol	freshwater
890-921	Lower Miocene	Miadol	freshwater
921-1087	Oligocene	Jimidi	freshwater
1087-1217	Oligocene	Lau	-
1579	Eocene	Yabus	-
2770	Mid Eocene	Yabus	-
2875	Early - Mid Cretaceous	Galhak to Al Renk	-
3430	Early Cretaceous	Al-Renk	-

Table 5. Biostratigraphic analyses of Jacaranda well, West Gambella Basin

Sample Type	Numbers of Analyses		
	Conventional micropalaeontology	**Calcareous nannofossils**	**Palynofacies**
Ditch Cuttings	**0**	**0**	**70**
Sidewall Cores	Na	Na	na
Conventional Core	Na	Na	na
Totals	**0**	**0**	**70**

na = non available

4.2.1. PHOTOMICROSCOPY

Microscopic studies of sedimentary organic matter are used for palaeoenvironmental interpretations (Batten, 1982) for refining biostratigraphic correlations of the strata, which lack other biostratigraphic markers, and for the analysis of source rock and kerogen typing (Batten, 1983). Thin sections were prepared from Jacaranda-1 (FIT report)samples at depths warranting further examination following preliminary assessment of the FIS analytical results. The sections were then examined under a petrographic microscope using a variety of fluid inclusion techniques (e.g., UV-fluorescence, micro thermometry, etc.) in order to verify the presence of petroleum bearing inclusions in the rock samples and to explore textural relationships that may yield additional information on the timing of hydrocarbon migration or generation. Petrographic examination is also necessary to verify that petroleum-bearing fluid inclusions present in the samples and responsible for the observed mass spectra are not relict features (i.e., that they were not already present in the mineral grains prior to deposition). The following figures 13 contain photomicrographs representative of samples from Jacaranda 1 at the depths indicated.

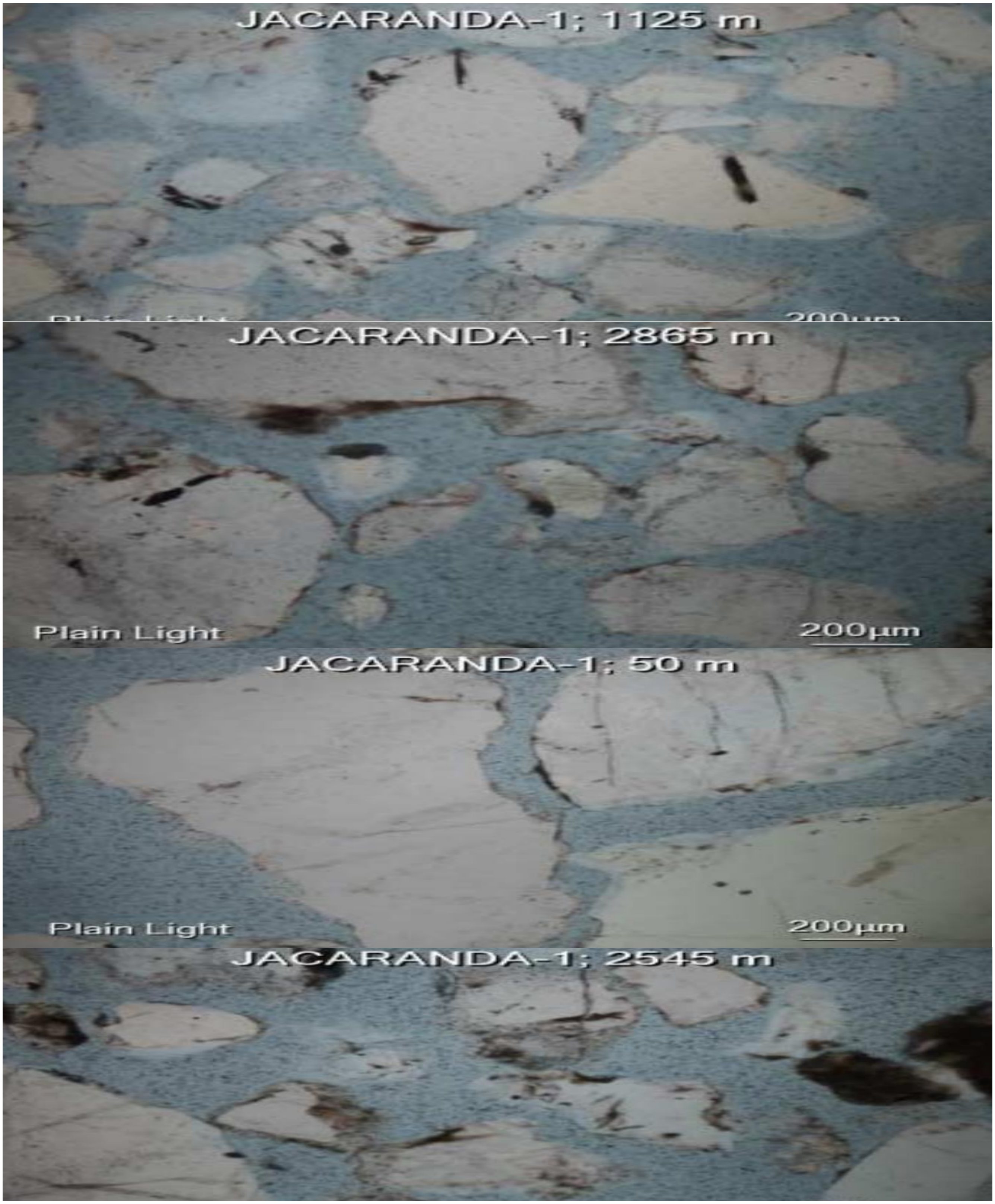


Figure 13. Photomicrographs from Jacaranda well-1 of west Gambella Basin, Ethiopia

4.2.2 PALYNOLOGICAL ANALYSES

4.2.2.1 Dating & Zonation

Dating of the sequence analyzed by palynology is tentative, but the palynomorphs recorded appear to indicate the following breakdown:

Table 6. Indicating the Age of the formation of Jacaranda well, west Gambella Basin

745	-	**880**	**Late Oligocene**
885	-	**990**	**Late – Early Oligocene**
995	-	**1620**	**Early Oligocene**
1855	-	**1915**	**Late Eocene**
2085	-	**3250**	**Age Indeterminate** [samples mainly barren: Eocene or older]

The sample analyzed was specifically selected by *PCE* over the interval 745-3250. Very few detailed palynological zonation studies have been published that relate to the northeast African region, particularly covering the Tertiary. The regional palynological zonation scheme of (Germeraad, Hopping & Muller , 1968)] is only broadly applicable as it was based primarily on Nigerian Paleogene data. A revision of the available data for Africa was provided by (Salard-Cheboldaeff , 1990) but it also only gives broad age relationships for some of the key species. Many of the species observed here proved to have different distributions to those of (Salard-Cheboldaeff , 1990) and many other species that are present do not appear to have been recorded before. (Kaska, [1989]) Published a summary of results from drilling in central and southern Sudan and subdivided the Paleogene into two zones. Recently (Eisawi & Shrank, [2008]) published on the palynology of four 4 wells from Southeast Sudan recognizing five [5] zones in the Tertiary. Most of the results of analyses carried out on the non-marine Tertiary sequences of Sudan and Ethiopia remain unpublished. The assemblages recorded in the well were subdivided into a sequence of *Local Palynological Zones* that may be used to correlate with other wells in the region in the future. Four 4 main units and eleven (11) subunits have been recognized based on the appearances and disappearances of particular palynomorphs, abundances and/or changes in total yields. Direct correlation to the zones of (Eisawi & Shrank, [2008])was not possible, but some species were common and allowed comparison

Table 7. Indicating Summary of palynological dating & zonation of Jacaranda well

Sample Depths *meters*		**Local Palynological Zone**	**Key Events**	**Age**	**Remarks**
Top	**Bottom**				
995	**1000**	**JPF 2.4**	LDO *Magnastriatities howardii*	**Early Oligocene**	LDO of *M. howardii* [JPF 2.4] is regarded as no older than Oligocene.
1195	**1200**				
1215	**1220**				
1285	**1290**				
1300	**1305**	**JPF 2.3**	LDO *Quillonipollenites* sp.		JPF 2.3 is a very lean interval and records LDO *Quillonipollenites* sp. but this may be due to caving.
1315	**1320**				
1325	**1330**				
1335	**1340**				
1385	**1390**				*Cicatricosisporites dorogensis* is regarded as occurring from Late Eocene to Oligocene. The species is very rare.
1485	**1490**				
1555	**1560**	**JPF 2.2**	LDO *Cicatricosisporites dorogensis*		*Radiometric dating at 1580 indicates an Early Oligocene age*
1615	**1620**				

Sample Depths *meters*		Local Palynological Zone	Key Events	Age	Remarks
Top	**Bottom**				
1855	**1860**	**JPF2.1**	LDO *Proteacidites bellus*	**Late Eocene**	*Proteacidites bellus* is regarded as a Late Eocene marker species. Only two very poor specimens, at 1620 and 1915, were observed in very lean assemblages. Also apparent LDO *P. usmensis*.
1875	**1880**				
1910	**1915**				
2085	**2090**	**JPF1**	Barren interval	[Eocene or older, based on age of the interval above]	Samples virtually barren with no age diagnostic taxa. *See radiometric dating*
2205	**2210**				
2285	**2290**				

4.2.3 POLLEN AND SPORES

(Combaz, 1964) Introduced the term Palynofacies for all organic material excluding clearly identifiable microfossils. This term is now used for all acid resistant organic remains, including microfossils such as spores and pollen. Since then, and particularly in the last decade, the interest in palynofacies studies has increased considerably. The apparent absence of foraminifera and other calcareous marine fossils, in washed residues of Lithologies, is a tentative indication that the interval analyzed was deposited in a non-marine environment. Palynological analyses yielded very occasional specimens of marine or brackish water palynomorphs, but in general all of the palynomorphs recorded are derived from organisms living on land or in standing bodies of freshwater, such as lakes. In the upper part the presence of the freshwater alga *Pediastrum* and

Botryococcus is an indication of at least sporadic lacustrine conditions. In the lower part the absence of palynomorphs, together with the presence of varicoloured claystones is an indication of an arid or semi-arid environment, where there were few plants growing and where plant material was exposed to the effects of oxidation.

The depositional environments indicated by palynomorphs alone are listed Table 10, but when taken in conjunction with lithological evidence the following broad Assemblage subdivision can be made.

Assemblage one: 745-1220 Continental, alluvial, lacustrine, fluvial.

Periodic well established lakes, where freshwater algae were abundant [very rare dinoflagellates in two samples in the upper part tentatively indicate brackish or marine incursions, if they are not caved or reworked]

Assemblage Two: **1220-1285** Gap between analyses

Assemblage Three: 1285-1490 Continental, alluvial and / or fluvial

Palynomorphs are very rare, compared with interval above, and it is not entirely certain whether lacustrine indicators, *Pediastrum* and *Botryococcus*, are in place**.** The absence of brackish and marine taxa, suggests a continental regime, which is tentatively supported by the presence of an alternation of sands with red, brown claystones.

Assemblage Four 1490 – 1555 Gap between analyses

Assemblage Five 1555 – 1620 Extrusive volcanicity

Lithologies mainly extrusive volcanic rocks, possible interbeded clays and sandstones.

Assemblage Seven 1620 – 1855 Gap between analyses

Assemblage Eight 1855 -1915 Continental, alluvial and / or fluvial

Similar comments to 1285-1490

Assemblage Nine 1915 - 2085 Gap between analyses

Assemblage Ten 2085 – 3050 Continental, alluvial and / or fluvial, probably arid-semi arid. Mainly barren of palynomorphs. Sandstone appears to be dominant according to composite log, indicating that higher energy conditions were more prevalent.

Assemblage eleven 3050-3105 Gap between analyses

Assemblage Twelve 3105-3250 Continental, alluvial and / fluvial,

Probably arid-semi arid, Extrusive volcanicity in lower part Varicoloured, often red-brown, claystones, with palynomorphs more or less absent. Lower energy conditions prevalent, Pencontemporaneous extrusive volcanic activity and reworking of volcanic rocks especially in the lower part of the basement.

Analyses of well logs [which were not available for this study] in conjunction with palynological data should provide a more definitive interpretation of depositional environments. The Composite Log suggests that sandstones are a significant part of the sequence and it must be assumed that they contain relatively few palynomorphs, as compared with the claystone, are were probably deposited in variously alluvial and fluvial [meandering and / braider stream] environments.

Table 8. Depositional environments as indicated by palynological analyses, Jacaranda Well

Depth	Palynology	Key Palynomorphs
745-1220	Lacustrine, Continental, alluvial, lacustrine, fluvial	*Pediastrum* & *Botryoccus* Two dinoflagellates specimens & abundant *Pediastrum*
1285-1490	Lacustrine Continental, alluvial and / or fluvial	Rare *Pediastrum*, very lean, very degraded & oxidised, coally.
1555 – 1620	Extrusive volcanicity	Some *Pediastrum*, sapropelic, very lean.
1855 -1915	Continental, alluvial and / or fluvial	Barren, very degraded & oxidised
2085 – 3050	Continental, alluvial and / or fluvial, probably arid-semi arid.	No fluorescing organic matter and some are Barren
3105-3250	Continental, alluvial and / fluvial, probably arid-semi arid	Barren, Some vitrinite with fluorescing lamalginite but this could be from the lignosulphonate, others are barren.

4.3 ORGANIC GEOCHEMISTRY

A series of cuttings samples from interval 310 m 3250 m of Well Jacaranda-1 (Table 11), drilled in Block G, Gambella Region, Melut Basin, Ethiopia, were subjected to geochemical screening and maturity analysis. Cuttings were heavily contaminated with glycol and polymer mud additives, which proved difficult to completely remove, even after detergent washing and 72 hour solvent extraction. Occasional high hydrogen indices, and almost ubiquitously high oxygen indices, production indices and suppressed Tmax values are most likely a result of incomplete removal of these contaminants. No considerable source potential is seen in any samples, despite the presence of residual mud contamination, with the exception of one sample from the Jimidi Formation (1095–1100 m), which had a TOC of 2.64%. This sample has a moderate HI of 121, which indicates that it will be gas-prone until it reaches maturity. Due to the presence of persistent mud contamination, Tmax measurements are abnormally low and essentially useless for evaluating maturity. The typical "oil window" (c. 0.7% Ro. vit.) is estimated to peak at roughly 2700 m in the well according to a vitrinite reflectance analysis, which also produced a satisfactory maturity profile. There has been little to no erosion of Late Tertiary sediments from the area where the vitrinite reflectance profile crosses the surface at 0.17% Ro. According to PCE, the Agor Dagar, Miadol, Jimidi, Lau, Volcanics, Adar, Upper and Lower Yabus, and Cretaceous Formations in Melut cuttings samples from the interval 310 to 3250m were screened for source rock and evaluated for maturity in this report. The impact of glycol and/or polymer additives on Rock-Eval data was a key issue because the well was drilled using a water-based KCl/glycol/polymer mud combination. A thorough cleanup program was implemented, consisting of a first stage of detergent washing and a second stage Soxhlet extraction lasting 72 hours using a solution of 93% dichloromethane (DCM) and 7% methanol [MeOH] combination. Establishing the source potential and maturity of the sequence, as well as making comments on any lingering contamination by glycol and/or polymer additions from the water-based mud, were the goals of the geochemical analysis.

Table 9. Geochemistry analysis of Jacaranda well-1 of Gambella Basin, West Ethiopia

Analyses	Number
Sample preparation	46
Detergent washing	46
Soxhlet extraction, 72 hours	46
Total organic carbon [TOC]	46
Rock-Eval pyrolysis	46
Vitrinite reflectance	20

4.3.1 ORGANIC MATTER TYPE AND SOURCE ROCK ANALYSES

4.3.1.1 Source Potential

Forty-six (46) cuttings samples from the interval 310-3250 were subjected to detergent washing and solvent extraction (Soxhlet for 72 hours) in an attempt to remove polymer and/or glycol based contamination, indicate particularly high production indices [OPI], high oxygen indices [OI], low Tmax, and occasional anomalously high hydrogen indices [HI] indicating that the clean-up was not entirely successful. Almost all sediments were very lean with < 1% TOC, (Figures 14 & 15). Only three 3 cuttings samples approached or exceeded 1% TOC, including one sample from the Agor Dagar Formation, 715-720, one 1 from the Miadol Formation, 890-895, and one 1 from the Jimidi Formation, 1095-1100. Lithological descriptions of the washed residues of the samples analyzed confirm that the sediments contained very little carbonaceous debris (Figure 14).

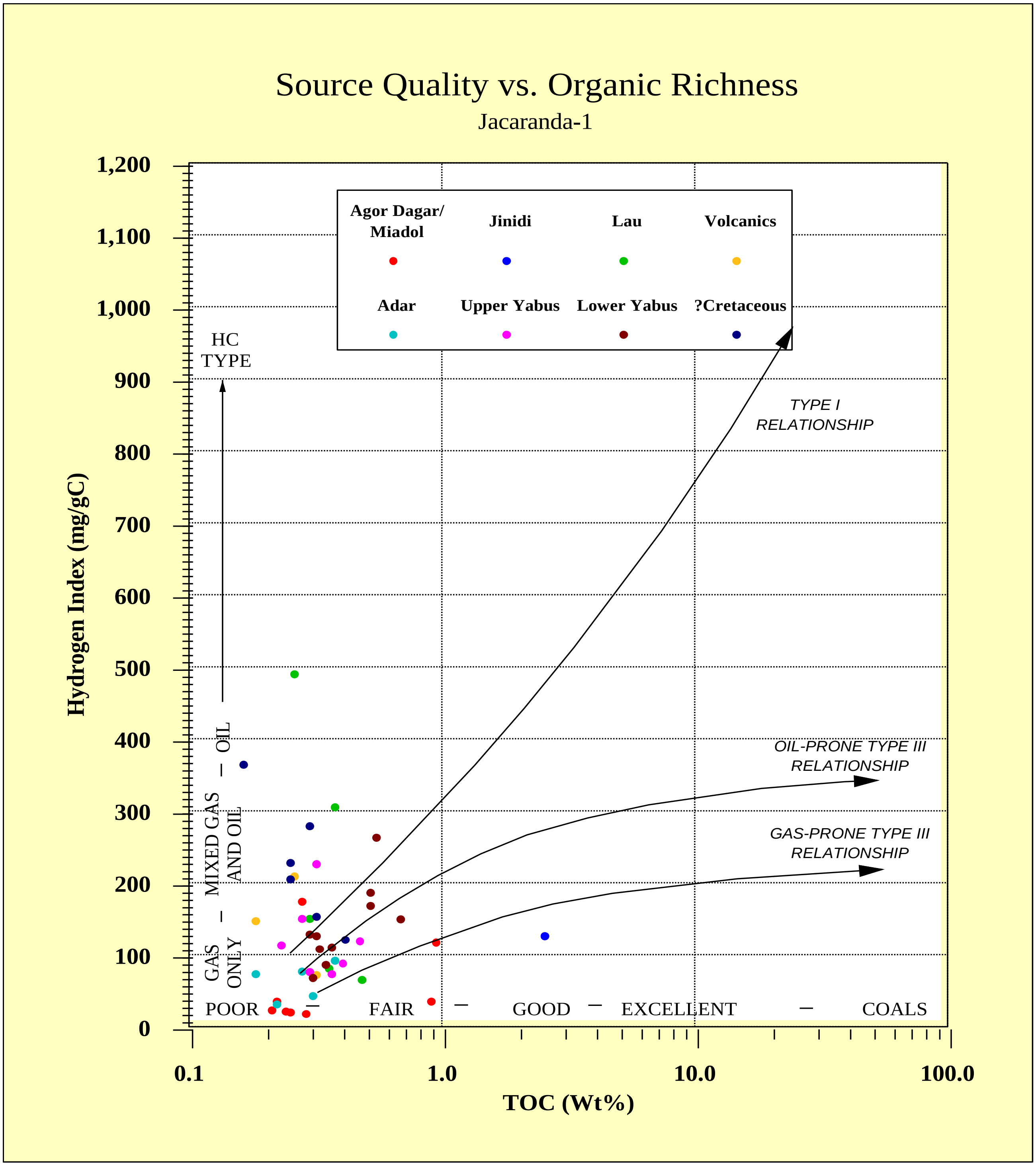


Figure 14. Source quality and Organic Richness, Jacaranda well-1

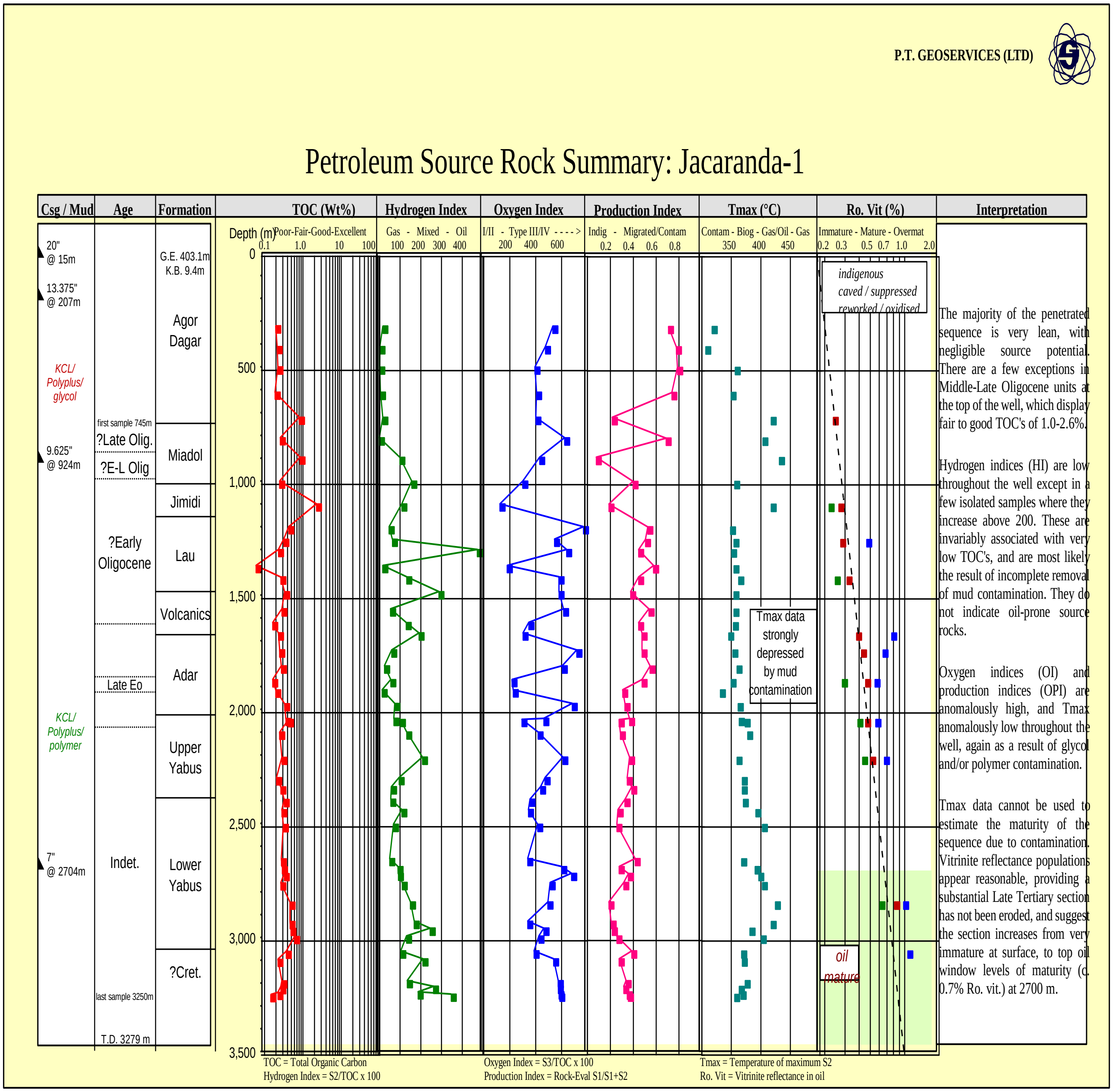


Figure 15. Well jacaranda-1 Petroleum Source Rock Summary

The richest sample in the entire well was a single cuttings sample from the Jimidi Formation, which contained 2.64% TOC. It has a moderate HI of 121, a high OI of 145, a moderate Tmax of 422°C, and a moderate OPI of 0.21, which coupled with the sample's moderate HI and OI values and high OI show that it has a lower residual mud contamination level than the bulk of the leaner samples in the well. It is immature right now, but as it reaches maturity, it will make a fair to good gas-prone source rock.

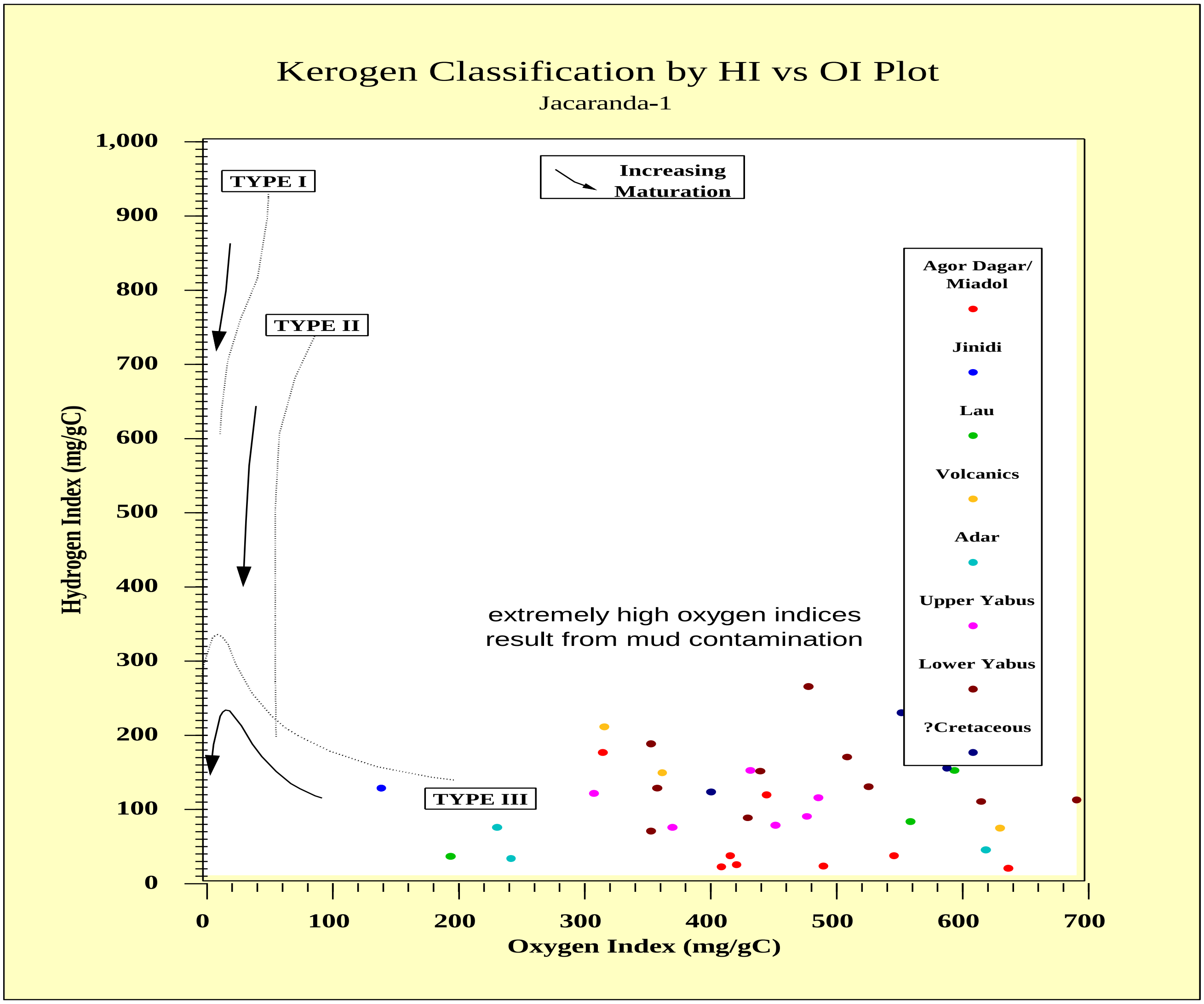


Figure 16. Hydrogen Index and Oxygen Index Modified Van Krevelen Diagram, Jacaranda Well Hydrogen indices remain below 200 kg/t for the most part, consistent with a gas-prone kerogen, Figures 15 & 16, however almost all samples in the well are considered to be too lean to be effective source rocks, other than for biogenic gas. Occasional high HI in very lean samples, such as 1295-1300, 1480-1485, 3245-3250, is considered to be the result of residual glycol/polymer contamination, rather than oil-prone kerogen. This is supported by production indices, which remain high throughout much of the well, Figure 17. The reason for the step change in OPI at about 190, or the trends in Tmax below 2100 is not known. In addition to high

production indices, extremely high oxygen indices, Figure 17, are probably indicative of residual glycol and/or polymer contamination.

4.3.1.2 SOURCE MATURITY

With the exception of samples from the Lower Yabus Formation and sporadic samples from the top of the well, Tmax from Rock-Eval, (Figure 17), is abnormally low in the vast majority of samples. Low Tmax may be the result of poorly formed S2 peaks or, more likely, residual polymer/glycol contamination since higher Tmax is related with higher Rock-Eval S2 values. An immature sequence is consistent with even the largest Tmax values.

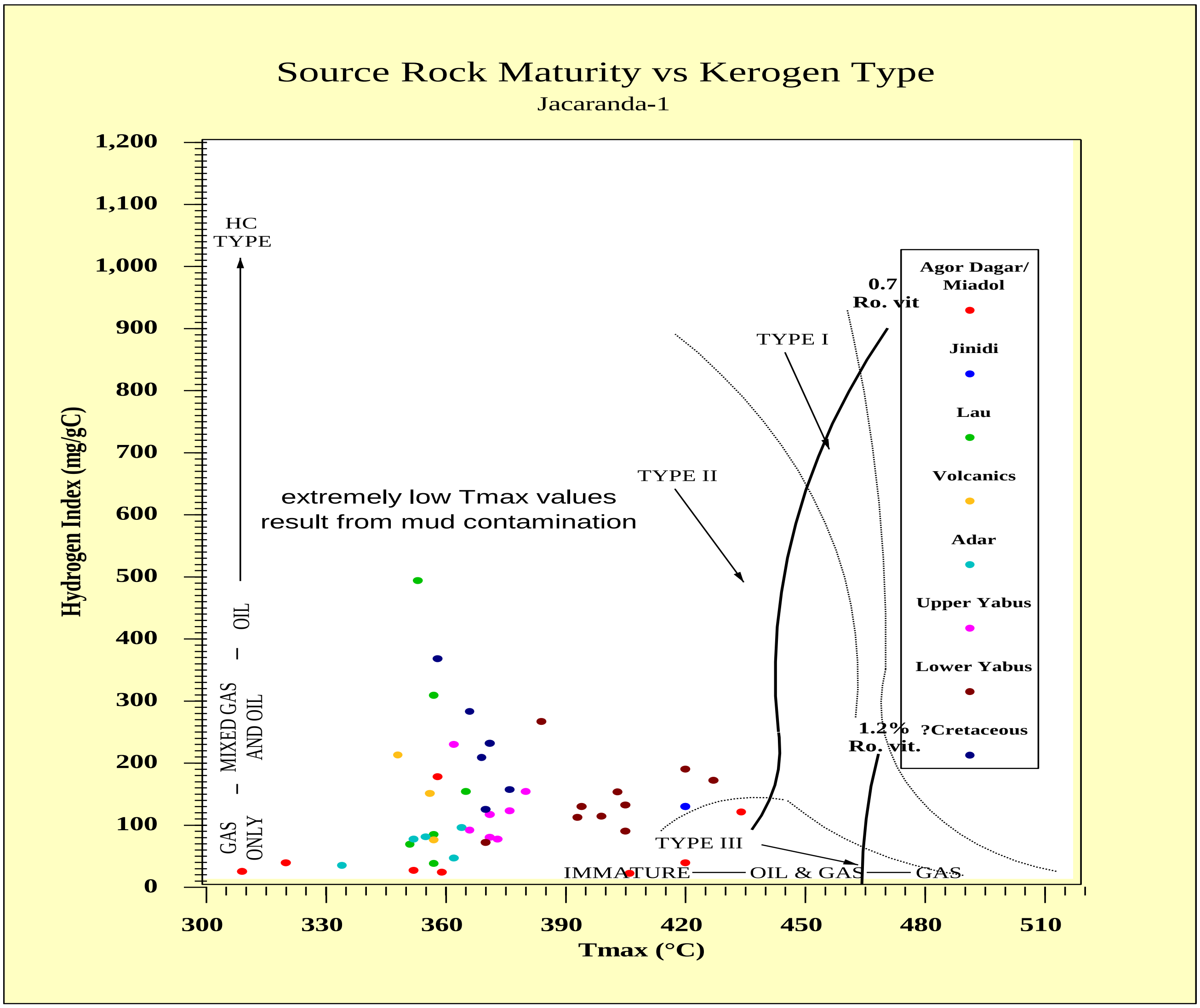


Figure 17. Source Rock Maturity and Kerogen type, Jacaranda well-1

Vitrinite reflectance analysis was performed on twenty [20] cuttings samples from 310 to 3240. Several of these were barren, but samples that contained indigenous vitrinite material yield a reasonable looking maturity trend, Figure 18 [right]. This suggests that the top of the conventional "oil window" lies at about 2700 in this well. One caveat, however, is that the vitrinite trend intersects the surface at about 0.17% Ro. This is very reasonable if the surface sediments are of late Tertiary age and there has been little or no uplift, however, if there are relatively old Tertiary sediments at surface, there may have been some uplift and erosion, which is not adequately reflected by the interpreted vitrinite trend. A cross plot of mean indigenous vitrinite reflectance vs. Tmax clearly indicates where Tmax is suppressed by contamination on (Figure 18).

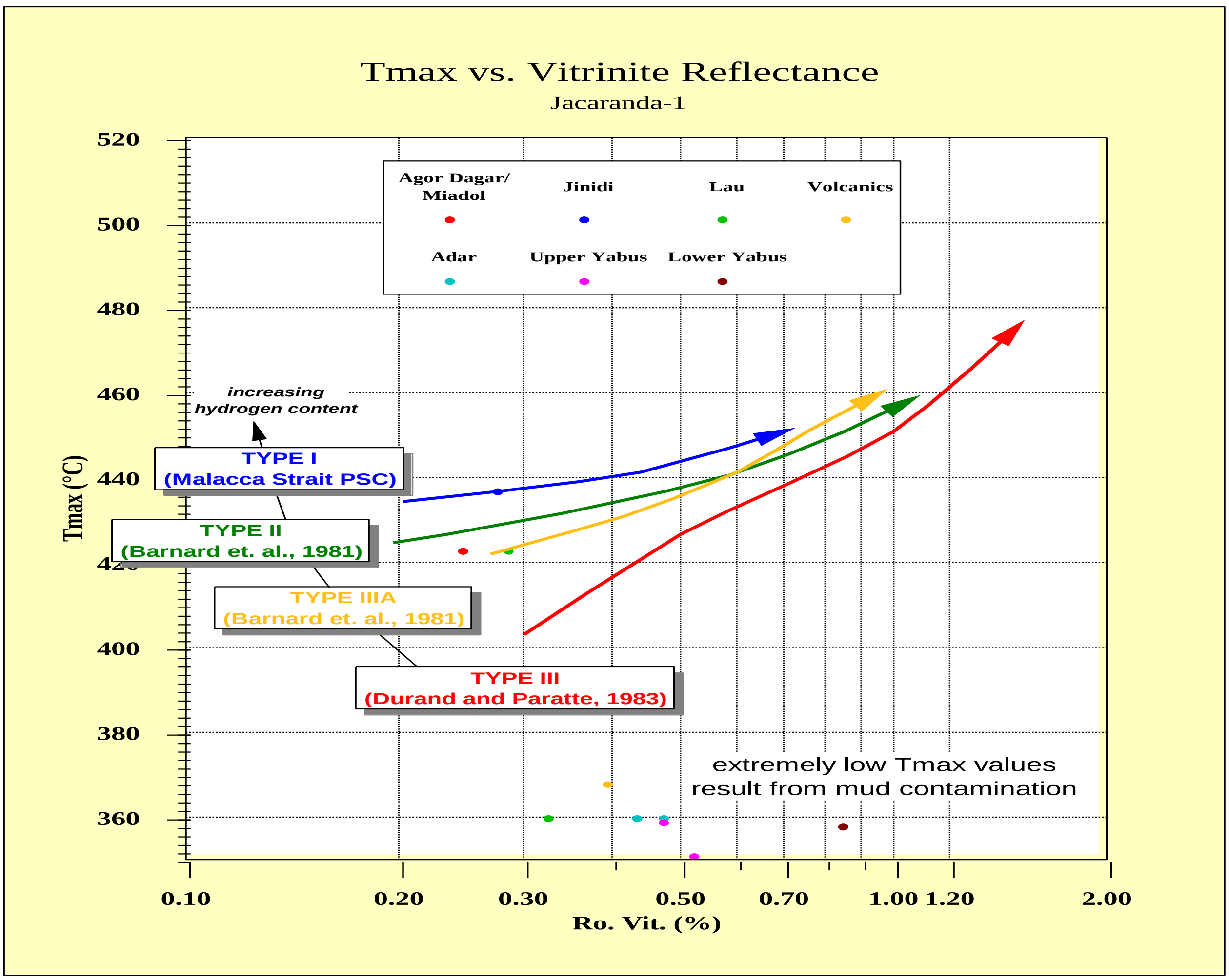


Figure 18. Tmax and vitrinite réflectance of Jacaranda well-1

4.4 BURIAL HISTORY

PetroMod 1-Dimensional modeling of Integrated Exploration Systems of Gesellschaft mit beschränkter Haftung, (GmbH-IES), Germany, was used to model the burial history and thermal maturity of the Gambella Area of Interest (AOI) at the locations of two wells (Jekow and Jacaranda) (Figure 19). The wells' locations were chosen in order to continue exploring Gambella Melut basin and determine whether hydrocarbons are present because To confirm whether Gambella represent the same geologic settings as neighboring South Sudan, they (1) drilled to a depth that penetrated a significant portion of the geologic section of interest, (2) measured vitrinite reflectance, and (3) collected downhole temperature data to assist in calibrating maturation models. Geologic time (age), lithology, and thickness are some of the geological parameters that help determine the burial history. Techno stratigraphy displays the age, thickness, and generalized lithologic data that were utilized to create the burial-history curves below.

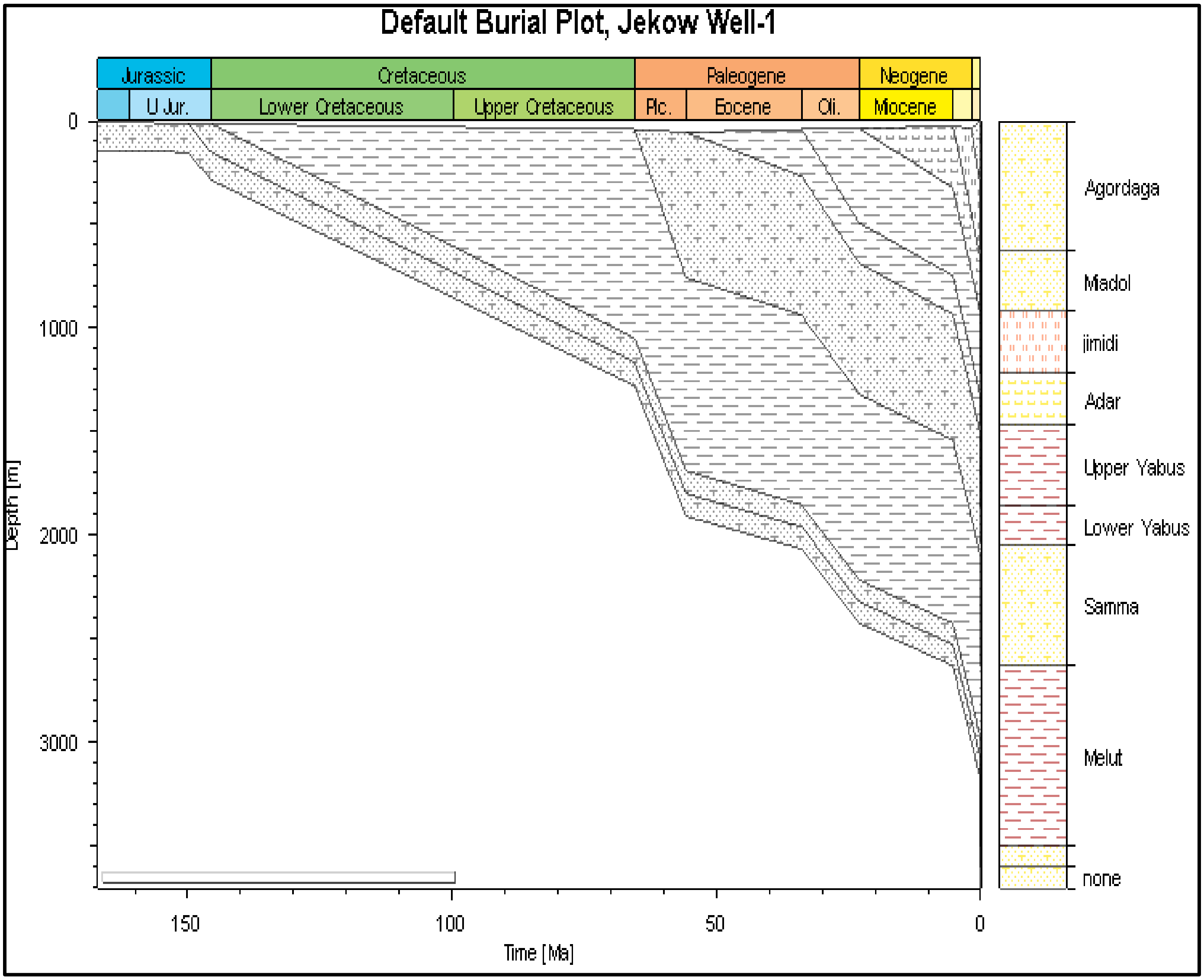


Figure 19. Burial-history model for Jekow well around the East and West Gambella Basin

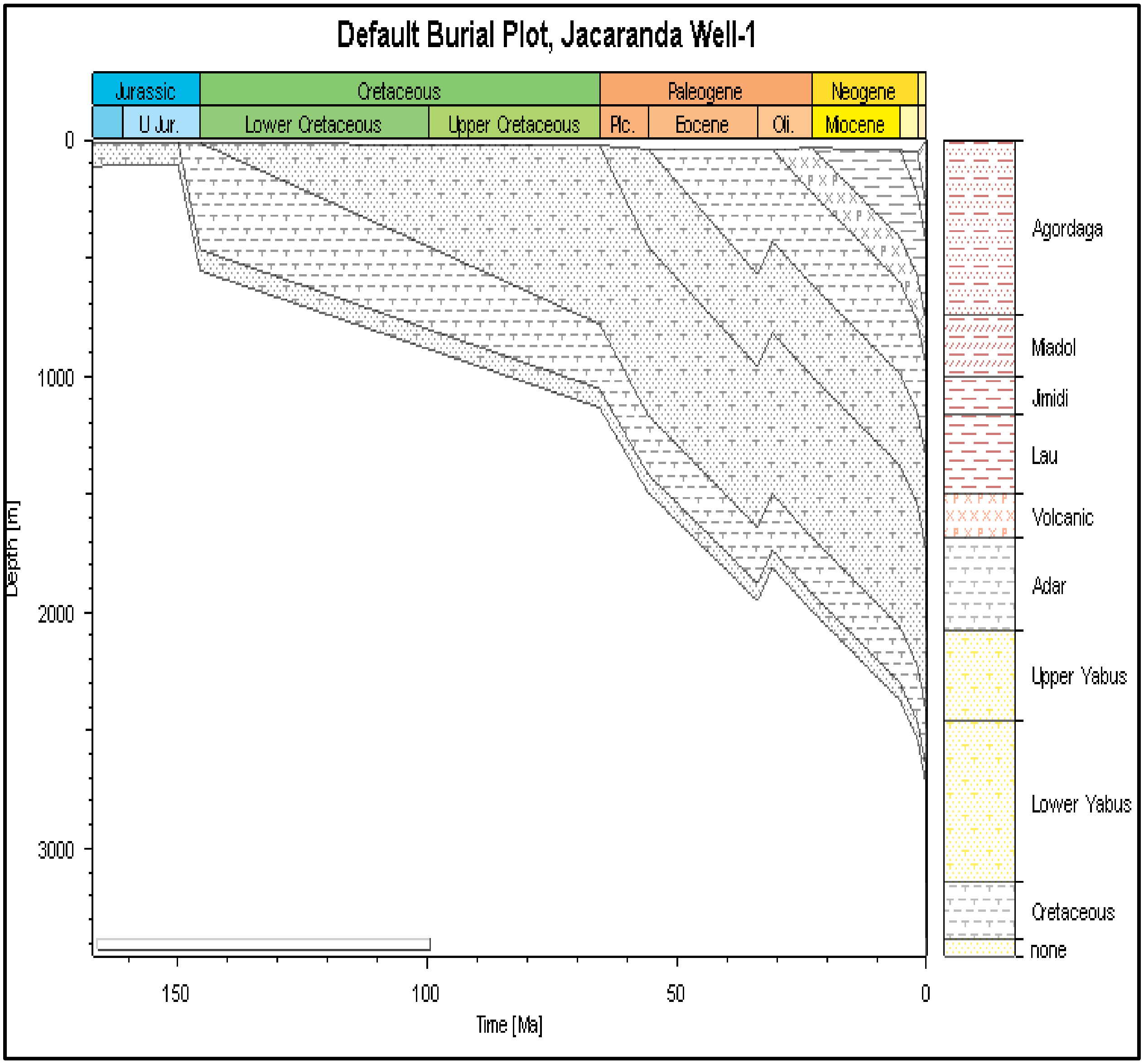


Figure 20. Burial-history Model for Jacaranda well around West Gambella Basin.

4.4.1 Geologic Time-Age

Using (Love and others, 1993) as a reference for the generalized ages of stratigraphic formation units and ages of regional unconformities throughout the Melut, geologic ages of stratigraphic formation units were determined (Table 12). To the south of CASZ is the Melut Basin (Figure 1). It is an intra-continental Cretaceous-Tertiary rift basin that developed on the consolidated craton during the Early Cretaceous as a result of strike-slip and associated pull-apart along the CASZ (Binks and Fairhead, 1992); (Guiraud and Maurin , 1992); (Genik, 1993). It suggests that the basin is a passive rift formed by lithologic thinning and crustal extension (Jorgensen and Bosworth, 1997; Wilson and Guriaud, 1992).In accordance with the 1999 Geologic Time Scale (Geological Society of America, 1999), the ages at system and series boundaries were modified. According to (Sohn, 1979) and (Litwin and others , 1998), the Jurassic/Cretaceous boundary's age.

4.4.2 Burial history- Thickness and Lithology

Geophysical logs were used to interpret the thickness of the stratigraphic formation units in the subsurface, or tops of the units recorded by the PCE team by ZPEB drilling Sub Company were used to determine thickness. In order to obtain thickness information for the lower units that were not penetrated in the well that had produced vitrinite reflectance data, it was essential to drill to the sites (Tables 12 and 13). Unconformities in the subsurface that represent the thickness of eroded sections were interpreted using cross sections made from geophysical logs or modified from published studies (Law, 1981); (Shuster, 1986); (Dickinson, 1989); (Dutton and Hamlin, , 1992). For modeling purposes, lithologies of the stratigraphic units were also generalized for interpretation from geophysical logs (see details in Tables 12 and 13).

4.4.3 Burial history- Stratigraphy

Regional stratigraphy shows that a significant East Africa Rift basin with a structural axis aligned with Rudolf Trough in Kenya occurred in the Early Jurassic. The failing Muglad Rift Basin appears to have split into the Gambella Basin (Melut). Although some lacustrine or fluvial sediment has been deposited, the coarse continental clastics are likely to dominate the early rift material. The Rift Basin kept growing throughout the late Jurassic. The main rock created may have been lacustrine sediment with interbeds of coarser rift clastics originating from nearby basement blocks. In the Chevron concession, only the Sudan has reached Jurassic sediment to date. interior Basin may have been formed at this time. The stratigraphic succession of each rift-related depositional cycle of Jacaranda well begins near the rift margins with basal sand, followed upwards by a shale-dominated interval, reflecting the deepening of the basin. This well is in the flank junction of Muglad and Melut Basin as the indicated of hydrocarbon show on the gamma ray log. Unlike Jacaranda, Jekow well which is located toward the Eastern Basin also target the same similarity with Sobat-1 well as it penetrated the Yabus, Jimidi and Galhak formation of Melut Basin. Shale-dominated in Jacaranda well sediments accumulated during periods of active rifting when subsidence was Maximum. Sand-dominated sediments accumulated when rates of subsidence were relatively low, especially during the thermal sag phases. Syn-rift deposits of the first cycle (Abu Gabra Formation) with similar identity to Jacaranda, is dominated by extensive lacustrine shales. We can concluded that the lake water depth was apparently sufficient for the accumulation and preservation of organic-rich kerogenous shales that are the main source rocks for the oils show found in this basin.

Table 10. Data generated from PetroMod 1-D modeling Indicating Jacaranda well lithology and thickness

Layer	Top [m]	Base [m]	Thick. [m]	Eroded [m]	Depo. from [Ma]	Depo. to [Ma]	Eroded from [Ma]	Eroded to [Ma]	Lithology
Agordaga	0	745	745		0.01	0.00			SHALE&SAND
Miadol	745	1007	262		1.80	0.01			SHALE&SILT
Jimidi	1007	1160	153		5.30	1.80			SHALE
Lau	1160	1491	331		23.00	5.30			SHALE
Volcanic	1491	1681	190		30.90	23.00			Basalt (weathered)
Adar	1681	2020	339	120	55.80	33.90	33.90	30.90	Shale (organic lean, typical)
Upper Yabus	2020	2393	373		65.50	55.80			Sandstone (typical)
Lower Yabus	2393	3051	658		145.50	65.50			Sandstone (clay rich)
Cretaceous	3051	3278	227		150.00	145.50			Shale (organic rich, typical)
	3278	3350	72		170.00	167.00			Sandstone (typical)
						170.00			

Table 11. Data generated from PetroMod 1-D modeling Indicating the Jekow well lithology and thickness

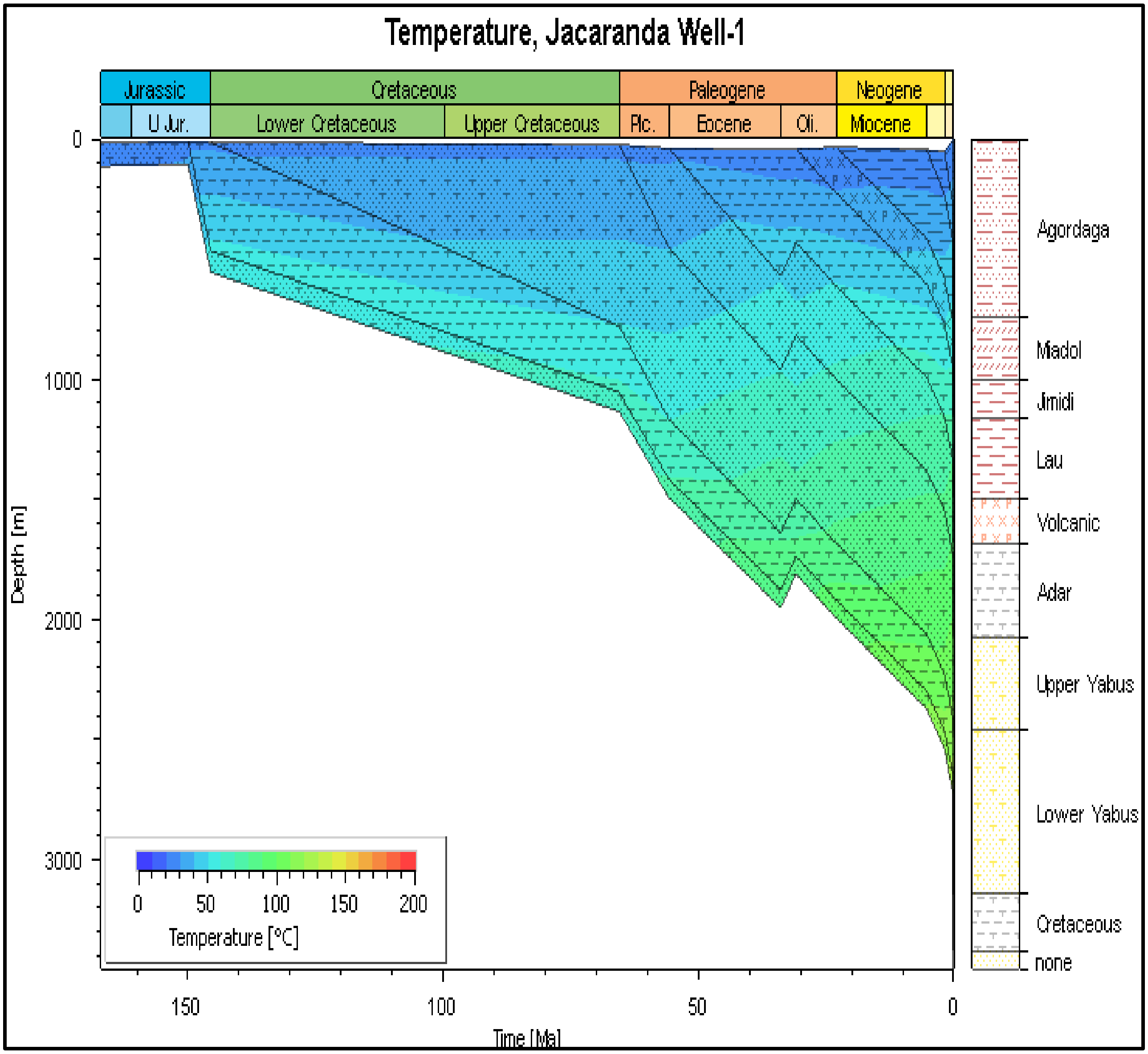
Layer	Top [m]	Base [m]	Thick. [m]	Eroded [m]	Depo. from [Ma]	Depo. to [Ma]	Eroded from [Ma]	Eroded to [Ma]	Lithology
Agordaga	0	624	624		0.01	0.00			Sandstone (subarkose, clay rich)
Miadol	624	921	297		1.80	0.01			Sandstone (clay rich)
jimidi	921	1217	296		5.30	1.80			Tuff (basaltic)
Adar	1217	1470	253		23.00	5.30			Sandstone (arkose, quartz poor)
Upper Yabus	1470	1862	392		33.90	23.00			SHALE
Lower Yabus	1862	2043	181		55.80	33.90			SHALE
Samma	2043	2627	584		65.50	55.80			Sandstone (quartzite, typical)
Melut	2627	3500	873		145.50	65.50			SHALE
	3500	3600	100		167.00	145.50			Sandstone (typical)
	3600	3700	100		170.00	167.00			Sandstone (typical)
						170.00			

4.4.4 Unconformity

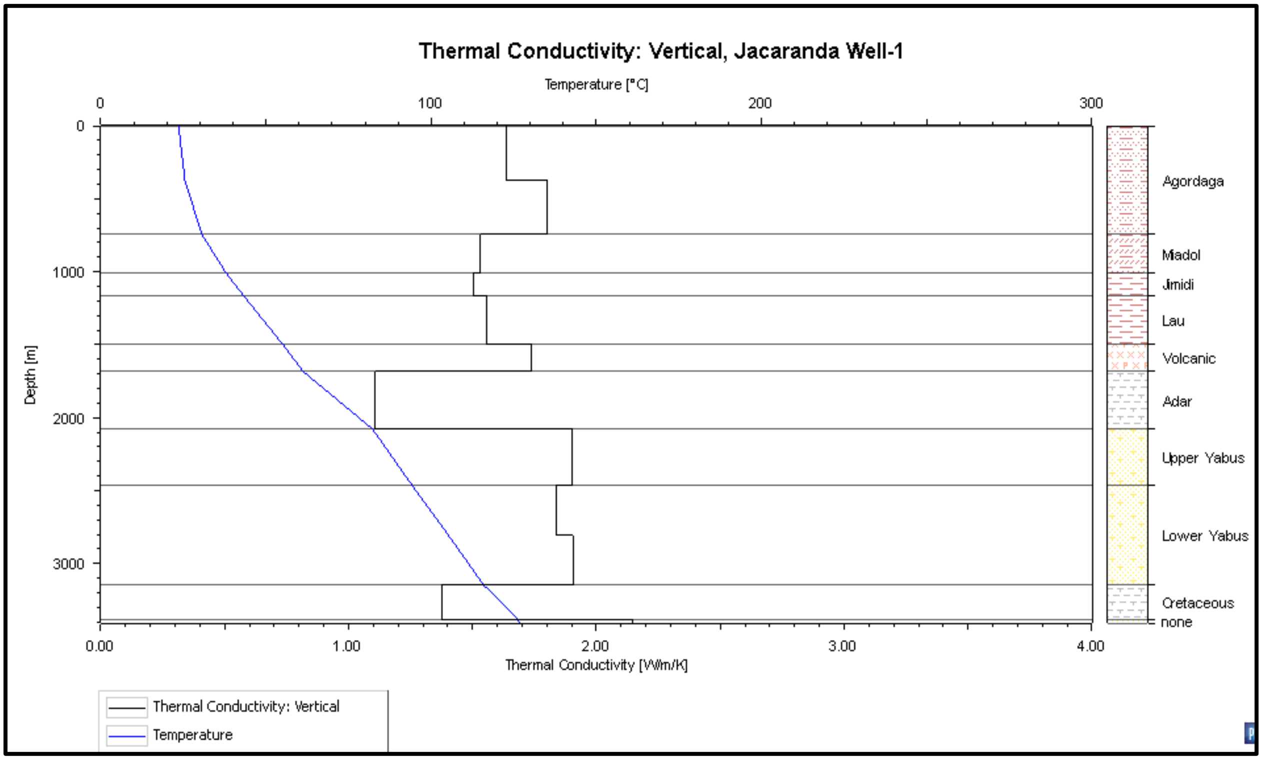
A buried erosional or non-depositional surface that separates two rock masses or strata with varying dates is called an unconformity, and it shows that sediment deposition was not continuous. However, the phrase is used to characterize any pause in the sedimentary geologic record. In general, the older layer was exposed to erosion for a period of time before the younger layer was deposited. An unconformity develops across four primary stages, which are as follows: Uplifting and weathering, denudation and transportation, subsidence and redeposition, and recurrent diagenesis are the first four processes. (Wu et al., 2013) (Figures 20 and 21 from the burial model)

4.5 THERMAL HISTORY

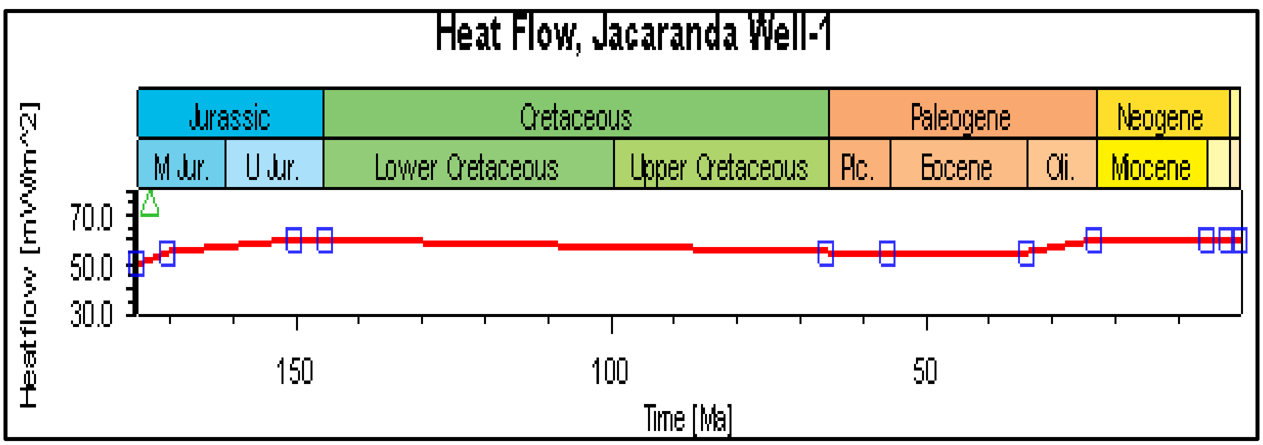
Thermal models were calibrated for each burial-history site using bottom-hole temperatures, vitrinite reflectance data, and presumptive Paleosurface temperatures. The bottom-hole temperatures were derived from data on the individual well log headers used in the modeling process or from nearby well headers. According to the American Association of Petroleum Geologists (AAPG) correction table (Kehle, 1972; Meissner, 1978), the temperatures were adjusted.Twenty (20) cuttings samples, ranging in size from 310 to 3240, were subjected to a vitrinite reflectance examination (Table 13). Many of these were bare, but samples that contained native vitrinite material produced a maturity trend that appeared realistic. This means that the typical "oil window" in this well is at its peak at around 2700. However, the vitrinite trend does intersect the surface at around Maturation history is based on predicted and measured vitrinite reflectance (%Ro) for each point of the burial history. Selected %Ro ranges are placed on the burial-history curves in Figures 22 and 23. As was previously mentioned, the recommended start to peak of gas generation from humic coals is between 0.17 and 1.25% Ro. The %Ro numbers of 1.10 and 1.35, which are intermediate maturities between the peak (%Ro) and end (2.0%Ro) of gas generation, were added solely for informational purposes. Since the Agor Daga Shale of the uplift, the Melut Shale (and analogs), and the Upper Yabus Formations are thought to be gas-prone source rocks, vitrinite reflectance (%Ro) can be used to gauge the degree of gas generation. The dates (Ma) that the source rocks reached the %Ro values of 0.17, 1.10, and 2.64, as well as their depths and temperatures at each %Ro maturity level, are summarized in (Tables 22 and 23). Therefore, to make a direct comparison of burial history and timing of hydrocarbon generation described in a previous study conducted in Melut Basin the average annual surface The following temperature assumption was made for all the burial-history sites: starting in the Pliocene, when the first units were deposited, Jimidi, the richest formation from the Jacaranda well with a TOC of 2.64%, is projected to have a temperature range of up to 4200 C. A burial and temperature history investigation in the vicinity of the west Gambella Sub basin used potential alternative Paleosurface temperatures, which were typically warmer. The PetroMod1D program's input parameter for the heat-flow value is employed for the reconstructions of burial histories (Figures 22 and 23). Utilizing the observed downhole temperatures (adjusted), the current temperature, and the posited paleosurface temperature, the PetroMod1D algorithm was used to calibrate to obtain a current-day heat-flow value at the base of the stratigraphic column at each modeled point. The estimated erosion amounts that could affect the calibration weren't changed. Although it is likely that heat flow varied with time (Laura N.R. Roberts, Michael D. Lewan, and Thomas M. Finn), making assumptions wasn't essential.



A)

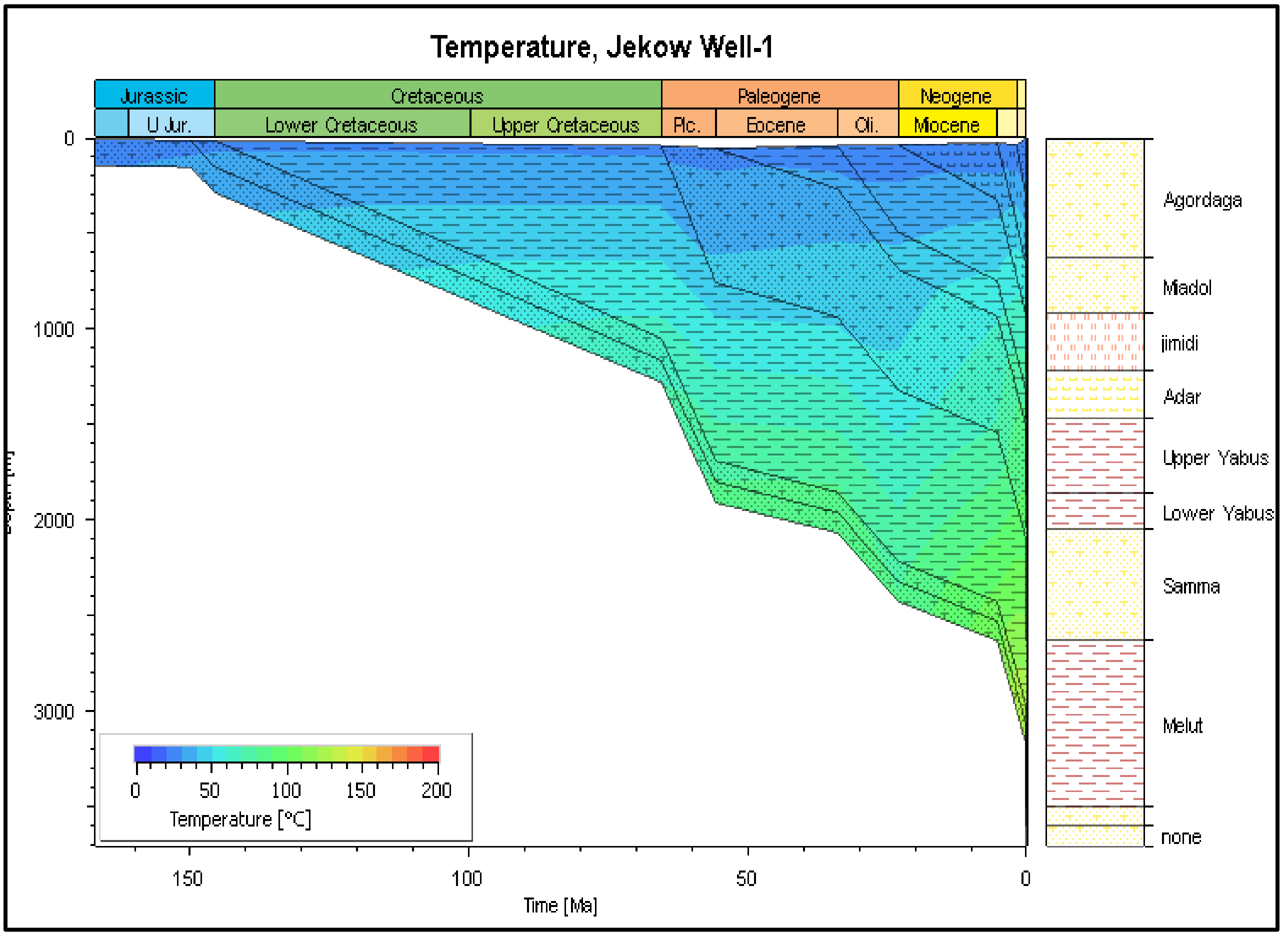


B)



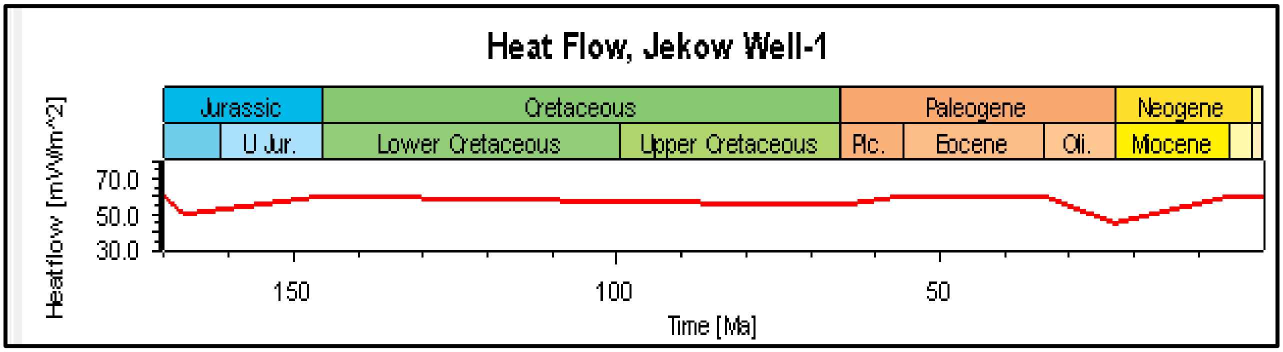
C)

Figure 21. (A,B,C) Model for Thermal-history curves of Jacaranda well around the East and West Gambella Basin, Heat flow and thermal gradient used to calibrate model are given for each location.

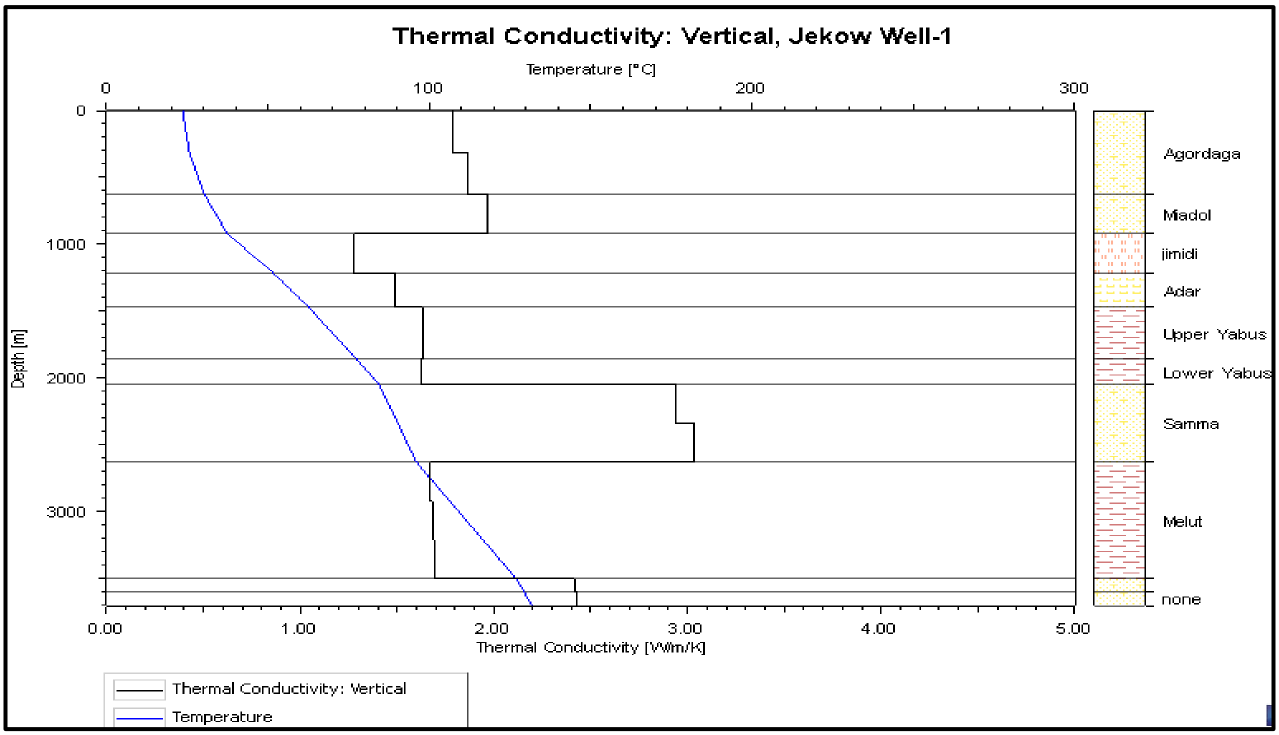


Temperature, Jekow Well-1
Jurassic
Cretaceous
Paleogene
Neogene
U Jur.
Lower Cretaceous
Upper Cretaceous
Plc.
Eocene
Oli.
Miocene
0
1000
2000
3000
150
100
50
0
Time [Ma]
0
50
100
150
200
Temperature [°C]
Agordaga
Miadol
jimidi
Adar
Upper Yabus
Lower Yabus
Samma
Melut
none

A



B)



C)

Figure 22. Thermal history of Jekow well around the Eastern and West Gambella. Heat flow and thermal gradient used to calibrate model are given for each location Indicated on A, B, C.

4.6 HYDROCARBON GENERATIVE POTENTIAL

These Sandstones' burial diagenesis determines that the Upper Cretaceous pay zones are relatively low in porosity and permeability while the Paleogene pay zones are high in both. This showed that lower and higher Cretaceous were when the hydrocarbon was created. Oil and gas production from the prescribed source rocks began at a depth of 2627 meters during the Cretaceous (145.5–65.5 Ma), representing the earliest timing and greatest extent of petroleum generation in the identified source-rock intervals. The period at which petroleum generation occurs will be later and the amount of petroleum generation will be less updip from these places. Oil-prone source rocks, such as the Upper and Lower Yabus Formation, often consist of marine carbonate- or chert-dominated rocks and contain Type-II and III Jacaranda wel-1 kerogen, which produces gas more than the remainder of the formation. On the other hand, marine clastic source rocks such as the Samma Formation, which are oil-prone source rocks, generally include Type-II kerogen, which produces volatile oil. The start of oil generation for the base of the Yabus Shale, a mix of Type-II and Type-III kerogen, occurred from 55.8 to 33.9 Ma and ended at all locations by 30 Ma, where generation of oil is a possibility today. The formation of gas from the cracking of oil began in the early Cretaceous, within about 145 Ma of the end of oil generation at 30 Ma, in the deepest regions of the province, the Melut Petroleum Systems and Geologic Assessment of Oil and Gas in the Sudan Interior Basin. At these deep places, gas production from oil cracking came to a halt around 30 Ma. Around 55.8 Ma to 33.9 Ma, the Samma's gas-producing source rocks first started to produce gas. Gas production from the Samma has peaked everywhere but in the Melut formation. Oil production started 55.8 Ma ago for the Type-II kerogen-containing Yabus Formation at Jekow well-1 and stopped 33.9 Ma ago at several sites in the west and east Gambella subbasin. Oil cracking started at the deeper basin locations 5.3 Ma after the end of oil generation and was finished by 65 Ma, but it hasn't happened at the shallower location

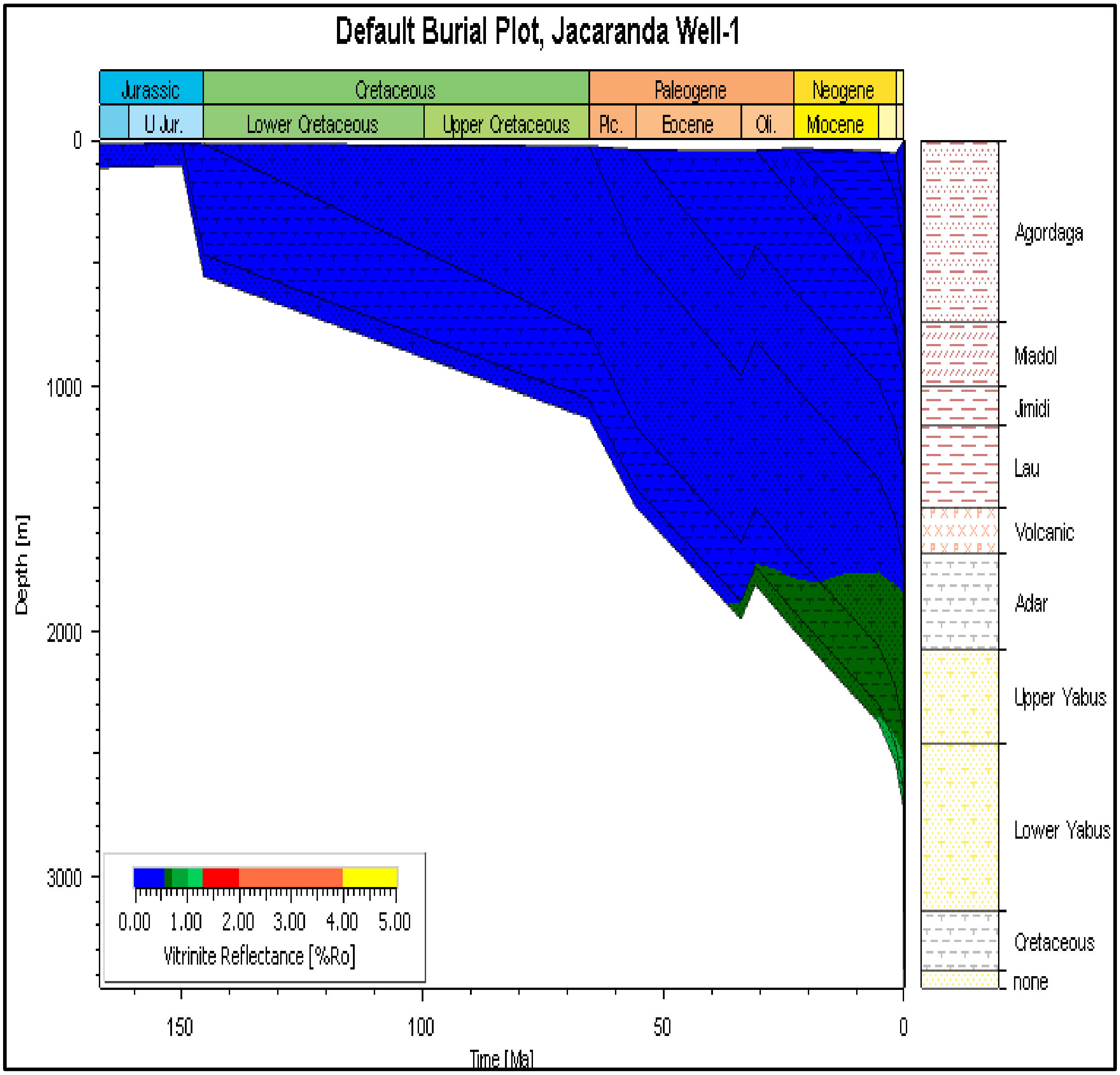


Figure 23. Hydrocarbon generative potential of Jacaranda-well 1 around western Gambella Basin.

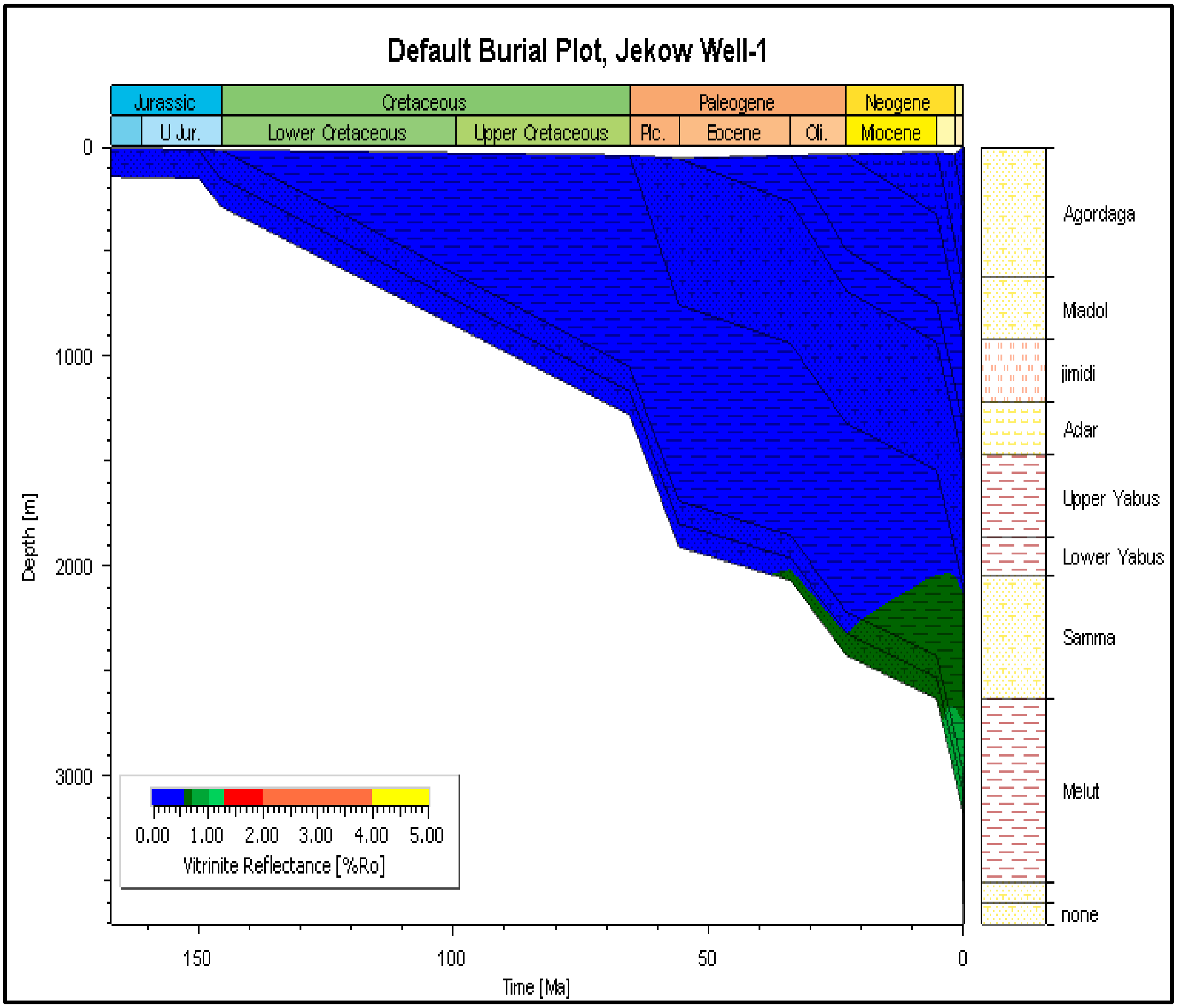


Figure 24. Hydrocarbon generative potential and vitrinite reflectance of Jekow-well 1 around Eastern Gambella Basin.

4.7 PETROLEUM SYSTEM

"Is there any evidence for present or past petroleum in this borehole?" is the most fundamental query that FIS can answer. Documentation of a FIS hydrocarbon anomaly typically answers this question in the affirmative, however it may also point to other processes. While Gambella Basin is located in South Melut Basin, North Melut Basin currently holds the majority of the hydrocarbon discoveries. Similar to South Melut Basin offset wells, this basin's lithology is distinct from that of the North Melut Basin. In South Melut Basin and Gambella, the shale is predominantly reddish brown in color, whereas in North Melut Basin, the shale is grayish in color. Could it be a result of the different depositional ages or the different sedimentary environments? Want to learn more? The structure of the East and West Gambella Basin is genuine and advantageous to the petroleum system, according to the earlier view. This was supported by studies on a number of wells drilled at North Melut Basin which penetrated the cap rocks and reservoirs. While in Jekow well, formation evaluation results indicate that there is an absence of hydrocarbon. Hence Fluid Inclusion Study (FIS) has been introduced to analyze the samples from Jekow and Jacaranda well. The concept behind this analysis is to identify any hydrocarbon that probably trapped inside the micropore right before diagenesis process. The Fluid Inclusion Study (FIS) indicates that there seems no charged in the Jekow area and probably less sign indicated in Jacaranda well of west Gambella. However, this FIS result might not confirm that there is inexistence of source rock at Jekow. Either the source rock is presence but the hydrocarbon did not charge or the source rock is totally absence remain as a main concern.

4.7.1 Source rock, generation and migration

The source rock may be lacustrine shale from the Early Cretaceous, according to earlier research from well findings in the North Melut and South Melut Basins. From 1.6% to 5.6% of Total Organic Content (TOC) is rich in organic material. The hydrocarbon was believed to be migrated vertically through faults and laterally along sand prone horizons. However, Jekow-1 well was not deep enough to reach the Early Cretaceous Formation. Therefore, no directly primary source rock in the formations will be available. The deepest formation encountered was Galhak formation of the Late Cretaceous age. In Galhak Formation, there are indications of organic materials and carbonaceous which is the sign for lacustrine environment. From the geochemical analysis, the Total Organic Content (TOC) results range from 0.35-1.38%. At 3310 mKB which is suspected to be the equivalent source rock, the TOC value is 1.14%. Base on the available data, the source rock might not exist at East Gambella Sub-basin in which Prospect A depend on. Since Jikawo-1 well was proposed in the hydrocarbon migration fairway, the hydrocarbon would be trapped if there was any hydrocarbon generated. Moreover, FIS was conducted on the sample from the Jekow-1 well. The sample was analyzed and the result shows low hydrocarbon levels and/or dry gas responses in the penetrated section (Figure). It is suspected that the dry gas is biogenic. The FIS indicates that there seems no charged in the Jekow area. Nevertheless, the FIS result does not confirm that the source rock is totally absence. Perhaps the occurrence of no charged in Jekow area as indicate by FIS may be due to the sealed hydrocarbon migration pathway?

4.7.2 Reservoir

The primary target of this well is Early Tertiary Yabus sandstone which is expected to be developed in a low stand fluvio-lacustrine system. Generally, the overall quality of the Yabus Sand drilled is moderate to good. The prediction was accurate about the consolidation of Yabus sand. This sandstone is unconsolidated to moderate consolidate. From the section drilled, Yabus sand has a fining upward sequence which could represent channel system. Based on the petrophysic analysis, the average porosity of the sand is 23%. The sorting is moderate to poor with some traces of Lithic and Kaolinite which characterize an immature environment. The Yabus shale is reddish to brown in color in which indicate an oxidation environment. Lower Yabus formation has a net sand of 339m with net to gross ratio higher than predicted. Generally, preliminary results show that the primary reservoir quality is moderate to good. In the other hand, the secondary objective is Late Cretaceous Melut and Galhak Formations. The paleoenvironment both was expected to be dominated by fluvial conditions with brief periodic lacustrine environment. However, based from the lithology of these two formations, deposition of Melut formation was dominated by fluvial environment and Galhak was dominated by lacustrine environment. Cutting samples for both formation show that the sandstones are moderate to well sorted. Porosity for Melut and Galhak ranging from 13%-20% with average porosity of 15% and both were interpretated to be wet. Melut and Galhak formation have poor to moderate consolidation of sandstone. However, Melut Formation is sandier compared to dominantly shally formation in Galhak. Net sand for Melut is 230m and Galhak is 127m. Overall, Melut formation is more likely to be a good reservoir compare to Galhak formation.

4.7.3 Migration without trapping

A migration pathway may be indicated when FIS responses are low or moderate, when contamination and recycled inclusions can be discounted, when quoted visual petroleum inclusion abundances are \rare" or \several" and when no other petrographic or log evidence of current petroleum charge is identified in the zone. There are a number of factors that influence inclusion abundance and, consequently, raw FIS response strength, including geologic setting, extent of diagenesis, rock type and permeability. However, it has been demonstrated that both visual petroleum inclusion abundance and FIS strength within many porous reservoir rocks is proportional to hydrocarbon saturation or Paleo saturation in a relative sense. Because migration occurs at average bulk-volume petroleum saturations below those encountered in charged reservoirs, FIS signal strength and visual inclusion abundance are generally lower along migration pathways than in charged reservoirs from the same area.

4.7.4 Seals

Late Eocene age of Adar and Upper Yabus Lacustrine Shales are the seals for the reservoirs. Previous study concluded that the effectiveness of the lateral seal depend on the juxtaposition of Adar and Upper Yabus lacustrine shales with interbeded sandstones. The drilling results indicate that Adar formation is less shally than estimated. It consists of 50% shale and 50% sandstone interbedded with each other. While the gross thickness of Adar formation is 229m. Even though it has reasonable thickness, the effectiveness of the seal is still poor. This is because the interbedded sequence of sandstone and shales might affect the seal quality. While in Upper Yabus, the lacustrine shale is less than expected. Cutting samples of Upper Yabus show that the percentage of sandstone is higher compare to Adar formation. Fault plane analysis showed that most of the seals for both Yabus and Melut reservoir are moderate to poor. It seems that the reservoirs for Yabus and Melut are juxtaposed with the other sand reservoirs on the other fault block. Therefore the lateral sealing capability for both reservoirs may not be very effective However, the existence of clay smear or slickenside may improve the lateral sealing capability for the reservoir. Since Jekow-1 did not penetrated any of the faults, clay smear analysis i.e Shale Gouge Ratio (SGR) value could not be estimated. Therefore the actual lateral sealing capability may range between poor to good.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

At two locations in the Gambella Basin, models for biostratigraphy, burial history, thermal maturity, and timing of petroleum generation have been developed for several petroleum source-rock strata. According to the findings, Melut, a nearby South Sudanese Basin, is most likely comparable to Melut in terms of burial history, thermal maturity, and time of petroleum formation. The Gambella Block "G" of the Gambella People's National Regional State (GPNRS) in Ethiopia is home to the Jekow-1 well, a wildcat well. The primary objective reservoirs are sandstones of the Early Tertiary Yabus Formation. The secondary target is the sandstones of the Late Cretaceous age Melut formations. This kind of information is crucial for identifying petroleum production zones and estimating the amount of untapped petroleum in the Gambella areas. The period of the beginning of oil generation happened within a relatively small range, according to results for the base of the Melut Formation, a source rock made up of Type-I&II kerogen. An intra-continental Cretaceous-Tertiary rift basin called Melut was created by strike-slip and the pull-apart that went along with it along the CASZ. In the Melut Basin, three major phases of extensional tectonism are recognized: the "Early Cretaceous," lasting roughly 140-95 Ma; the "Late Cretaceous," lasting 95-65 Ma; and the "Paleogene," lasting 65–30 Ma. The polyphased geologic evolution of the Melut rift Basin (Gambella) during the Cretaceous and Tertiary has resulted in the superimposed tectonic episodes, with stronger extension and more shales sediments during the Early Cretaceous and Paleogene and relatively weaker tectonism and sandy sediments during the Late Cretaceous. The black lacustrine shales of the Lower Cretaceous deposited during the peak lacustrine period are the major source rocks, those deposited during the Paleogene are the regional seal. The Paleogene sandstones are mainly sub arkoses and sublitharenites, while the Upper Cretaceous ones are arkoses.

The results of the geochemical analysis support the following conclusions and interpretations: An active petroleum system is present in the Gambella block. The composition of the migrating hydrocarbons is principally thermo genic dry gas, however, about 15% of the samples have compositions typical of oil-associated gases.

The burial diagenesis of these Sandstones decides that the Paleogene pay zones are of high-porosity and high permeability and the Upper Cretaceous are of medium to low porosity and permeability. The results show that the Yabus reservoir was deposited during Eocene which is similar to earlier predicted age of Melut.

Large-scale anticlines in Paleogene sequences and synthetic and antithetic normal fault-blocks in the Upper Cretaceous are the dominant structural types. The Great Palogue Field, a large, highly faulted anticline that contains a giant hydrocarbon accumulation of world-class proportions that is characterized by a large gross hydrocarbon interval and good- to excellent-quality lacustrine-fluvial reservoir sands, suggests that the Paleogene pay zone is the main exploration target, in contrast to the Muglad basin where the Lower Cretaceous Bentiu is the main pay zone. The highest hydrocarbon production occurred during the Late Paleogene because of the overriding of active rifting sequences on the passive rifting sequences of the Cretaceous, which generated a temperature gradient that was substantially lower during the Cretaceous and higher during the Paleogene. Oil and gas moved vertically and horizontally through extremely thick Upper Cretaceous sandstones before accumulating in Paleogene reservoirs. The areas of each half-graben where petroleum can accumulate are the gentle slopes. While the antithetic fault-blocks in the Upper Cretaceous periods represent a volumetrically less significant trapping mechanism, the anticlines within the Paleogene syn-rift sequences serve as the primary trap types.

5.2 RECOMMENDATION

The seismic prediction on the Early Tertiary Yabus sand and Late Cretaceous Melut sand are consistent with the actual formation depth. Even though with poor quality of seismic data, the forecast is still acceptable. Differences in the prognosed thickness and actual thickness of the formations are probably due to the screening effects of volcanic rock in Lau formation. The gravity and magnetic survey showed that the sedimentary thickness is about 7 km. Even though the thickness of the sediment accumulated in this area is thick enough, the basin might have been filled up with immature sediment derived from basement high. Without a good dataset, it is hard to carry out the sequence stratigraphy and sedimentary study. The reconstructions of paleoenvironment and regional material supply for each formation are very important to guide the next exploration activity. The absence of Hydrocarbon in the Jekow area is generally believed due to the nonexistence of the source rock. The FIS result indicates that there was no hydrocarbon charge in Jekow area. Either the source rock is presence but the hydrocarbon did not charge or the source rock is totally absence remain as a main concern. Because of this, it can be concluded that Prospect-A of East Gambella Sub-basin might not be favorable to petroleum system. The drilling results indicate a weakly presence of Petroleum System in East Gambella Sub-basin. Therefore the leads identified in East Gambella Basin, which are dependent on a similar Petroleum System, will be downgrade. Nevertheless the prospect identified in West Gambella Sub-basin, which is dependent on a different petroleum system, is still worth to explore. In order to interpret West Gambella Sub-basin, data set from Jekow-1 combining with dataset from offset wells in South Melut Basin will be used. Reconstruction of the Paleo environment and regional material supply need to be established in order to predict the source of sediment supply to West Gambella Sub-basin. By mapping the thickness and percentages of the shale at South Melut Basin the path of sediment supply could be estimated. In addition, seismic inversion correlation will be carried out between the well data and the seismic data to predict the lithology of potential well location in West Gambella Sub-basin. Besides, screening effect of the volcanic sediment need to be discriminate to get a better observation on the quality of West Gambella Sub-basin. However, due to unsuccessful exploration campaign in South Melut Basin, in addition to the poor quality seismic data implied that the risk for the petroleum system in the West Gambella Sub-basin is still very high.

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