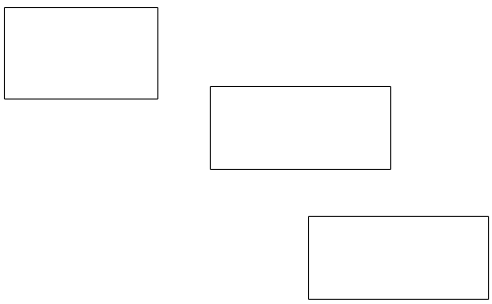
CHAPTER THREE

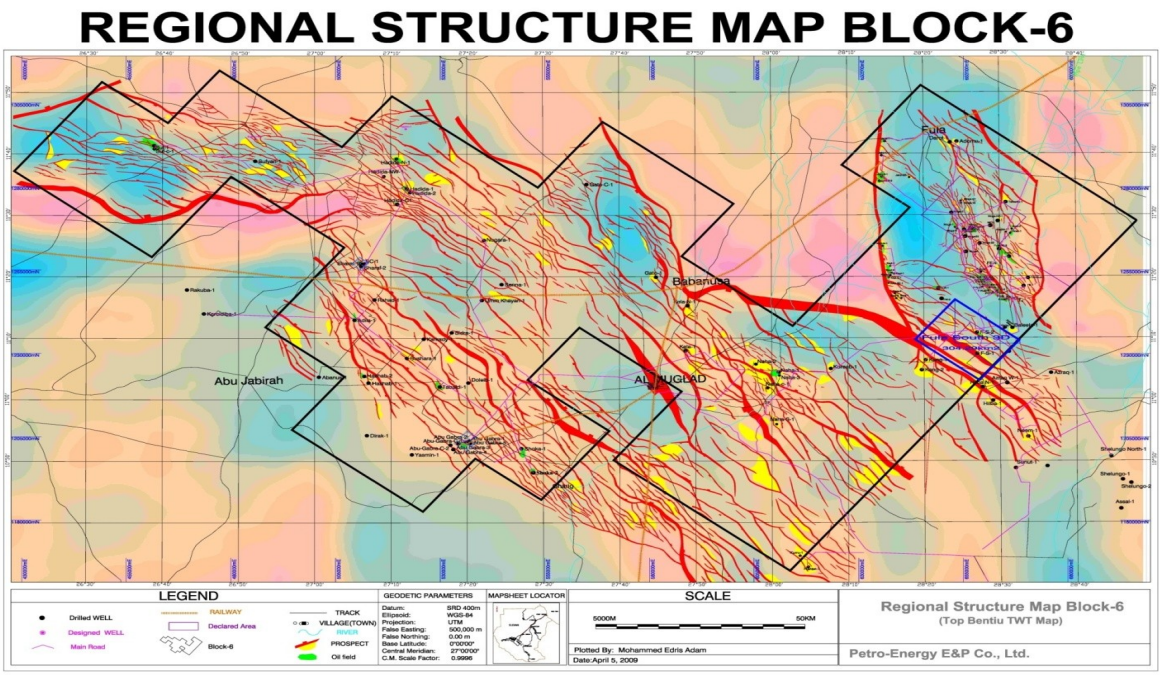
Geology Background

3.1 Structural Setting

Block VI is located in the southwest of Sudan, in the northwest of the Muglad basin, and covers an area of 59,000 sq. km. Hadida Field is located in the northwest of Block6 (Fig.3.1) between Nugara and Sufyan field.



Geology Background



(Fig.3.1) Hadida Position in Block VI (Petro Energy E&P, 2014)

The Muglad is the major sedimentary basins in the Sudan and is likely to have been affected by tectonic events (Fig.3.2) creating rifts. These rift events consist of:

i-Early rifting:

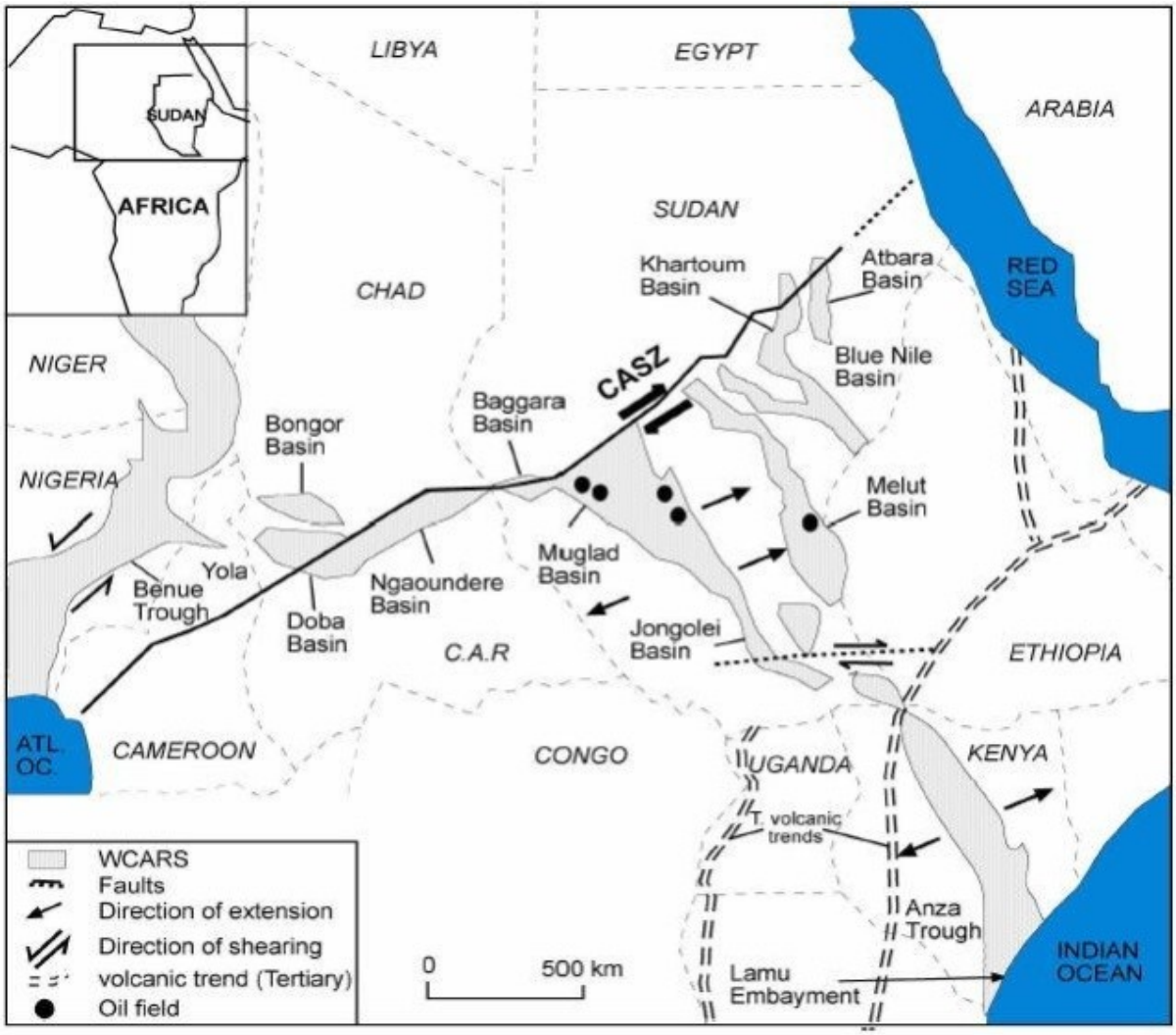
Which occurred in late Jurassic to early Cretaceous (130-150 Ma). It was the strongest phase of rifting and lasted until near the end of the Albian ere.

ii- Intermediate rifting:

Which took place in the Senonian to Turonian (late Creteous-early Tertiary) and resulted in the development of rift lakes and deposition of lacustrine and floodplain sediments of the Aradeiba Formation with associated minor volcanic rocks.

iii- Late rifting:

Which occurred in late Eocene to Oligocene, probably related to the opening of Red Sea and East African Rift.



Tectonic model of the West and Central African Rift System from Fairhead (1988)

Fig. (3.2) Tectonic Model of CASZ Rift System (Petro-Energy E&P, 2014)

3.2 Hadida Traps and wells:

3.2.1 Hadida Traps:

In Muglad basin and the study area, the general structural system is mainly the NNW-SSE striking faults with different throws. This orientation

is the overall result of the Central African Shear Zone reactivation resulting in creation of a complex system of linked extensional and trans-tensional sub-basins. The faults assembled into different patterns such as Y-shaped, fan- shaped as well as step-wise pattern giving rise to good oil-trapping tilted blocks.

The Hadida Main (HM) Field is faulted anticline trap located in the uplift between Nugara north and Sufyan sub-basin, HM field located in the middle of Hadida 3D. It is 9.5km to the northwest of well Hadida North-1.
Based on the analysis of structural evolution and burial history undertaken previously by the Exploration Dept., the trap of Abu Gabra was formed before Bentiu deposition. The source rocks of the mid-Abu Gabra in the eastern area is within generation threshold in early Amal deposition. Therefore the prospect is an effective trap for oil and gas accumulation, the same fact which has been confirmed later by testing results.

3.2.2 Hadida wells:

The Hadida-1 well proposed as a vertical exploration well to test a prospect on the Hadida structure. The primary reservoir target is the upper Abu Gabra Formation, and the secondary target is the Bentiu Formation.
The Hadida-2 proposed as a vertical appraisal well to test the prospect on Hadida structure. The primary objective was to test oil-water contact of Abu Gabra Formation and test Bentiu Formation as secondary target.

3.3 Stratigraphic and sedimentary setting:

3.3.1 Rifts in Hadida:

i-Rift Phase One:
Is characterized by deep lacustrine, deltaic front and flood plain environments leading to
deposition of mainly mudstones in Abu Gabra Formation and mainly braided Bentiu thick sands.

ii-Rift Phase2:

Witnessed deposition of the semi-deep lacustrine and meandering channels fine sediments of Darfur Group ending up with mainly braided massive, sandstone of Amal Formation (Palaeocene).

iii-Rift Phase3

Accompanied by development of the Tertiary deposits, Kordofan Group, of mainly fluvial, flood plain and shallow lacustrine. Hence, based on the studies of former researchers, the stratigraphic sequence in the study area from bottom to top can be summarized as follows:

- Abu Gabra Formation (Neocomian).
- Bentiu Formation (Aptian-Cenomanian).
- Aradeiba Formation (Turonian -Santonian).
- Zarqa Formation (Campanian).
- Ghazal Formation (Campanian- Maastrichtian).
- Baraka Formation (Maastrichtian).
- Amal Formation (Paleocene-Eocene).
- Senna-Tendi Formation (Oligocene-Miocene) and
- Adok-Zeraf Formation (Pliocene-Pleistocene).

Fig. (3.3) shows other elements of stratigraphy such as formation top, thickness, lithology boundary ...etc. In this Study, attention was paid to Abu Gabra Formation, Bentiu Formation and Aradeiba Formation, being the main reservoirs in which, Abu Gabra contains light oil and gas, and Bentiu and Aradeiba contain heavy oil.

3.3.2 Hadida formations:

There are three mainly formation in Hadida; Abu Gabra, Bentiu and Aradeiba Formations.

3.3.2.1. Abu Gabra Formation:

i-Sequence C (SC):

The lithological type is mainly dark brown, light to moderate grey, blocky mudstone and shale, which indicates a shallow to semi-deep lacustrine environment. It acts as the main source rock layer.

ii-Sequence D (SD):

The lithological type is mainly dark grey blocky mudstone inter bedded with white to light grey sandstone and oil shale. A coal layer can be found in local areas in the block. The sandstone is deposited in delta front facies. The mudstone is deposited in semi-deep lacustrine environment, and acts as the main source rock layer.

iii-Sequence E (SE):

Light-grey siltstone, coarse sandstone inter bedded with grey clay stone layers. Its sandstone deposited in meandering stream environment.

The sandstone in Abu Gabra reservoir formation was interpreted to have deposited in shallow lacustrine and deltaic environment as a meandering system. The sandstone layer and mudstone inter beds comprise the optimal reservoir-cap layer association.

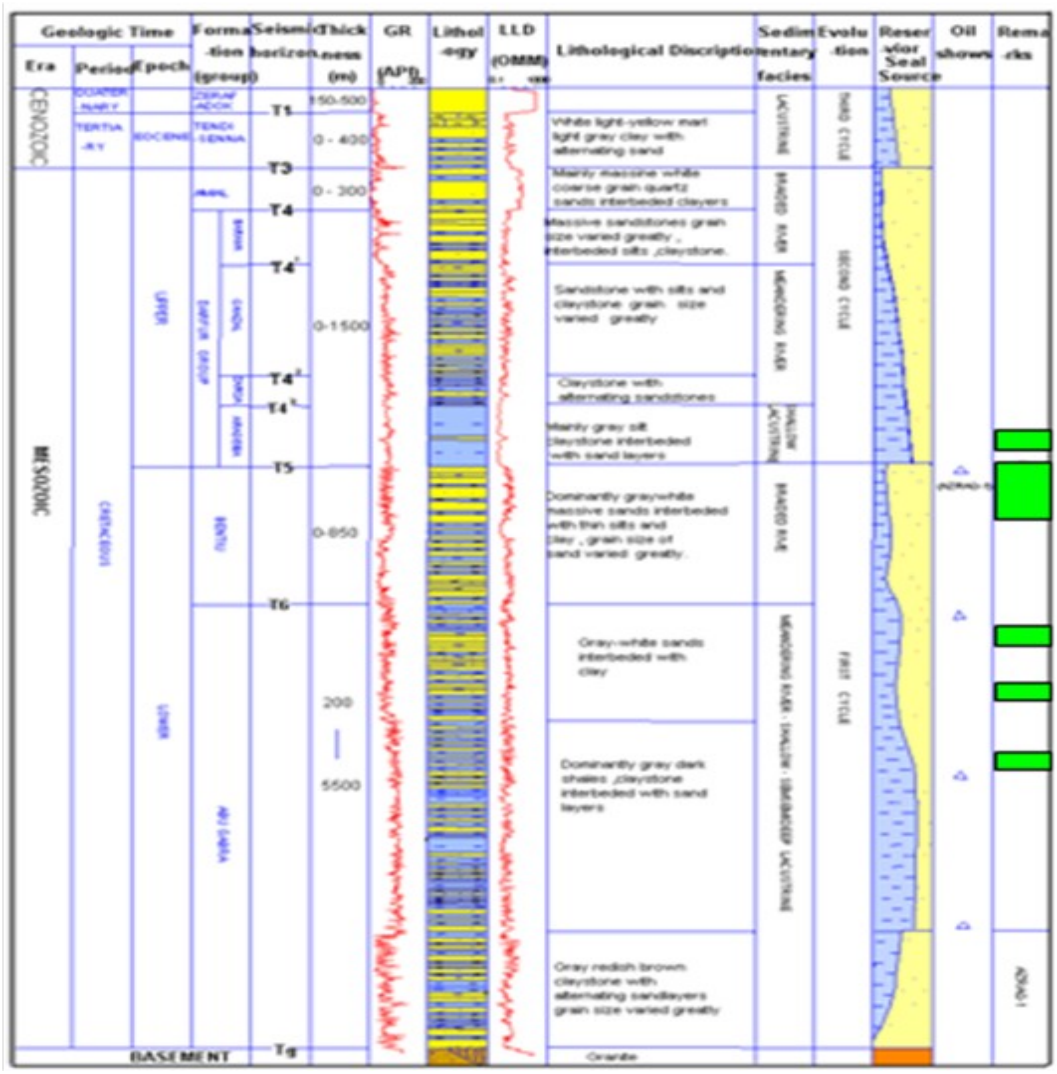


Fig. (3.3) Stratigraphic Column (Mohammad Zaid and others 1999)

3.3.2.2 Bentiu Formations:

Sequence F (SF):

Bentiu Formation is a major oil bearing sandstone reservoir in the Muglad rift basin of interior Sudan. Subsurface litho facies analysis allows the subdivision of Bentiu Formation into lower, middle, and upper parts. Each part is characterized by distinct facies assemblage and different depositional pattern. The lower part indicates deposition in moderately deep mixed-load high sinuosity stream showing transition to lacustrine delta. The middle part suggests deposition in low sinuosity braided sand-

bed dominated streams. The upper part which is dominated by gravel sandstone and sandstone facies indicates deposition in outwash plain of low sinuosity braided shallow channels.

3.3.2.3 Aradeiba Formations:

Sequence G (SG):

Aradeiba Formation was not part of the field reservoir formations. Since the key stratigraphic surfaces are concerned, the thick sequences of shales above and below the reservoir were used in picking the top and base of the reservoir. The picks were taken at the point where the shaliness in the cycle as observed from the log record is at its maximum. The environmental interpretations are based on the well data, previous studies and regional geology interpreted litho facies into litho facies associations. The interpreted depositional framework enabled the reconstruction of the reservoir architecture and sand body geometries for use in 3D geological modelling.

3.4 Reservoir subdivision and Correlation:

The depositional sequences and boundaries between Aradeiba and Bentiu, Bentiu& Abu Gabra are very clear. Reservoir sequences then have been subdivided into correlatable units (Fig. 3.4). This was based on the recognition of clearly defined depositional cycles in each of the sequences which are characteristically bounded at the base and top by thin but field-wide correlatable shale or fine-grained intervals, higher order sequence boundary surfaces. Each correlatable unit represents a para sequence set, comprising a number of individual para sequences with uniform depositional patterns.

The lithology of Aradeiba is clay-stone intercalated with thin sandstone. The features of log curves are high GR, low RT, high DT and low RHOB. For Bentiu, the lithology is massive sandstone interspersed with thin clay stone, log curves have low GR, high RT, medium-low DT, high RHOB. Abu Gabra has the lithology of stratified sandstone and shale, high GR, low RT and low DT in log curves. Therefore, based on the log response, Aradeiba, Bentiu and Abu Gabra are easily distinguishable.

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Stratigraphic compartmentalization and well correlation are based on sequence division, cycle of sedimentation, shale markers and log curves features. Abu Gabra Formation is divided into AG1 and AG2, and 6 sand units are identified in AG1, that is, Abu Gabra, AG1A, 1B, 1C, 1D, 1E, and AG1F.

AG1 sand units are the main oil-bearing zones.

Fig. (3.4) Log Curve Feature at Reservoir Intervals (Well H-1) Stratigraphic Column

3.5. Reservoir Lithology:

Reservoir targets are mainly Abu Gabra 1A sands. Abu Gabra formation is composed mainly of medium grey to dark grey clay stones inter bedded with very fine to medium grained sandstones and dark grey shales. The clay stones form 50% of the deposit. According to the mud logging data in wells, there were 68 observed zones as shown by the test.

The sandstone is translucent to transparent, trace to minor light grey, light grey, poorly consolidated to well consolidated, very fine to medium grained, sub-angular to rounded, well sorted, occasionally to minor argillaceous matrix, rare to common kaolinitic cement, trace calcareous cement, rare to trace micaceous, poorly to good porosity (Fig. 3.5.1) and (Fig. 3.6.1).

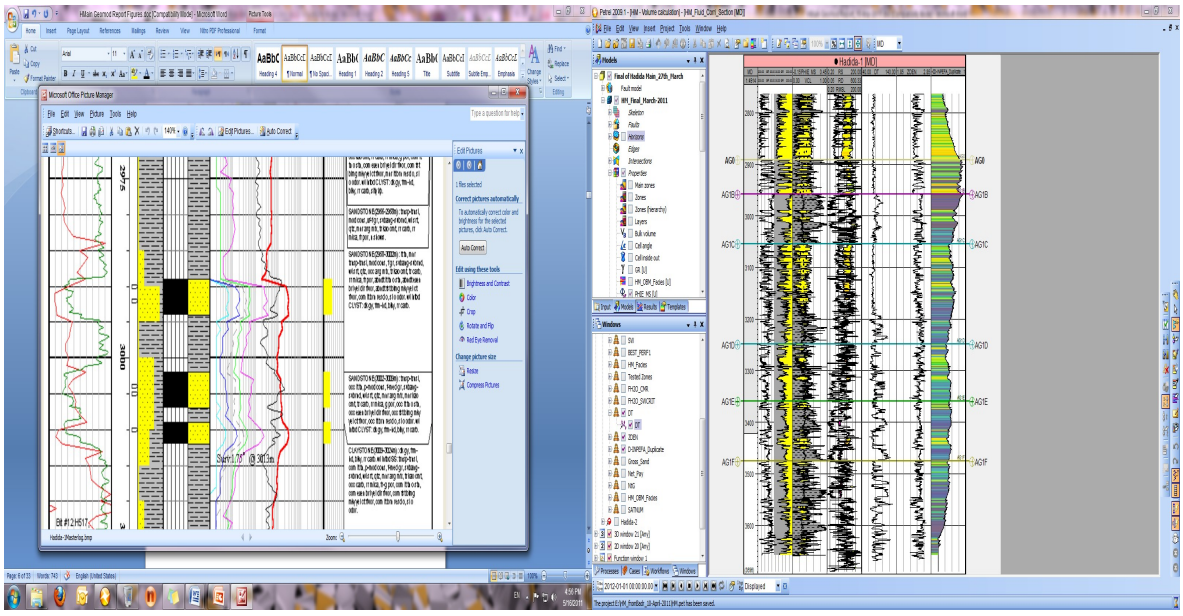

Fig. (3.5)Abu Gabra1B Reservoir Lithology from Field Lithology Log

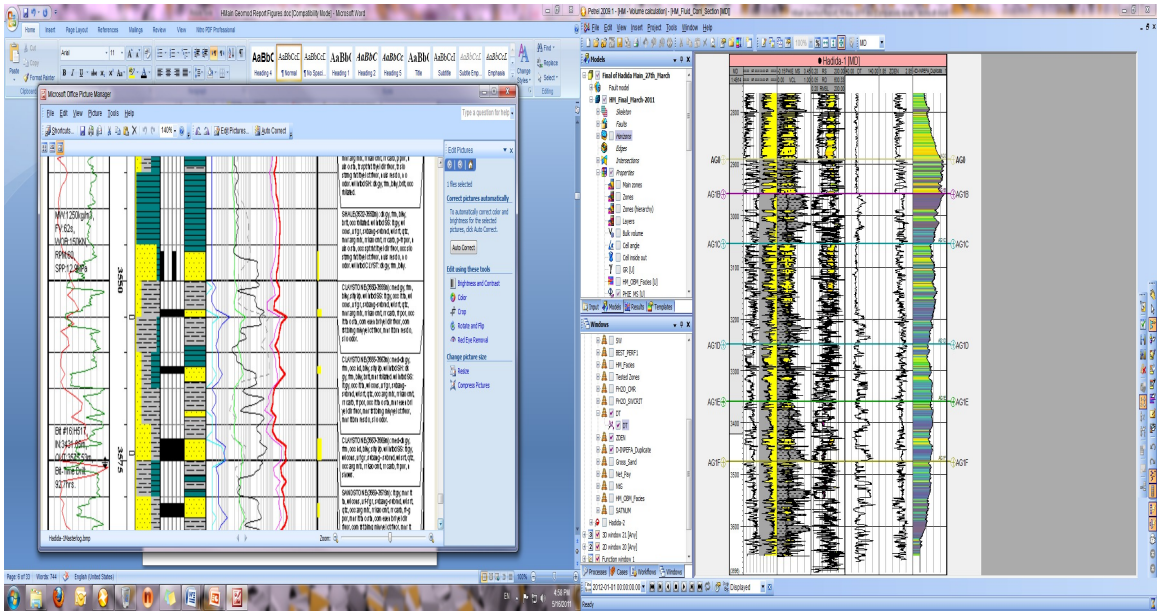

Fig (3.6) Abu Gabra 1E Reservoir Lithology from Field Lithology Log