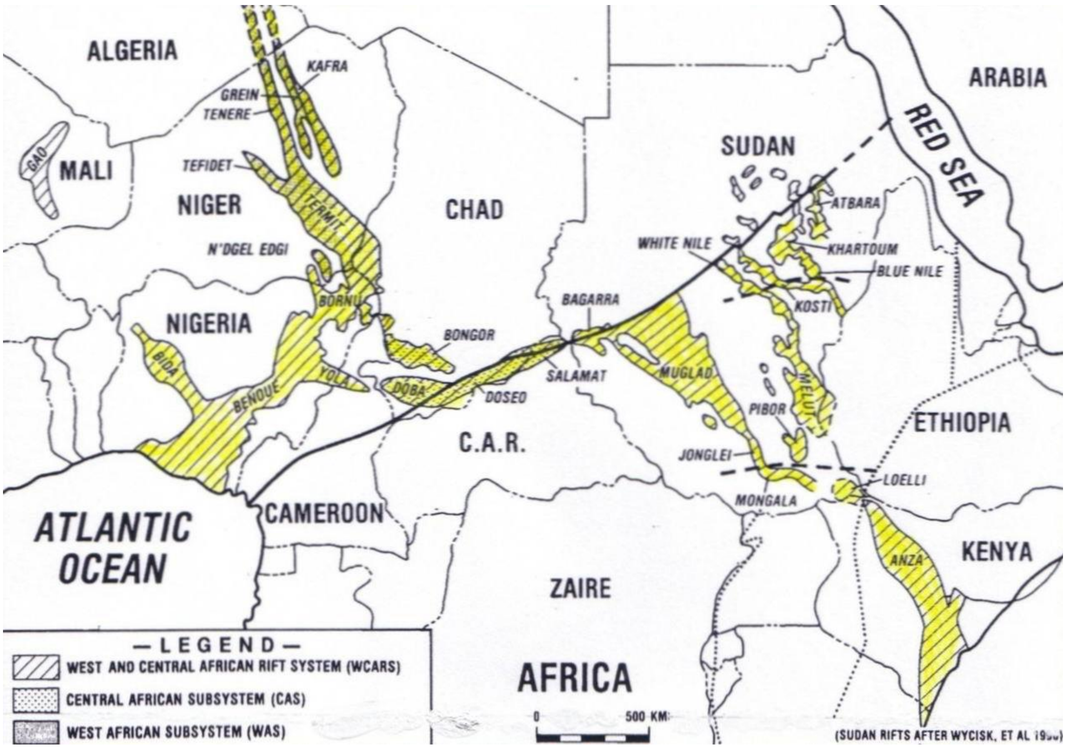
Chapter 2

Geological Review

2.1. Introduction:

In Sudan, five NW-SE trending continental rifts are known. They define together an extensional province, which has a wide of 1000 km and a length of at least 800 km parallel to the strike direction (Figure 2.1) (Fairhead, 1988). From North to South, these rifts are referred to as:

- The Atbara rift.
- The Blue Nile Rift (Khartoum and Khartoum South).
- The White Nile Rift (Melut or Bara and Kosti).
- The Muglad-Abu Gabra Rift (the Muglad-Abu Gabra and Bahr el Arab rifts are collectively referred to as the Southern Sudan rift). The Muglad is the best known and is the largest of the Sudan rift basins.
- The Bagarra Basin.



Figure(2.1): shows the tectonic model of the West and Central African Rift System (Fairhead,1988).

In the northwest, the Sudan rift basins terminate along the transcurrent fault zone in continental scale, the Central African Shear Zone (Figure 2.1). The Central African Shear Zone is envisioned to link the Sudan rift basins with the Lower and Upper Cretaceous rift basins in Chad and Niger (Fairhead,1988). The south-eastern terminations of the Sudan rifts are more complex (Schull 1988).

2.2. Muglad Basin:

The Muglad basin is rift basin of Meso-cenozoic, which caused by the shear zone of middle-Africa and developed on the firm basement of Precambrian(Vail, 1978; Whiteman, 1971). There are three superimposed rift formations of different periods in Muglad area since Early Cretaceous(Fairhead, 1988). The first one is Abu Gabra Fm - Bentiu Fm of Lower Cretaceous, the second one is the Darfour group of Upper Cretaceous–Paleocene of Paleogene, and the third is Eocene of paleogene–Neogene. There are immense differences in the position of main extensional faults of the three rifts, the early rift was cut and changed by the later rift (Fairhead, 1988).

The major rift formation in discoveries Abu Gabra and Sharif belong to the first and second periods, deposition formation of the third period is very poor. The rift sign of main extensional fault system of the first period is indistinct for the reason of datum. The generation of second period rift resulted mostly from the action of dextral slip of share zone of middle-Africa, the direction of main faults in work area is NW.

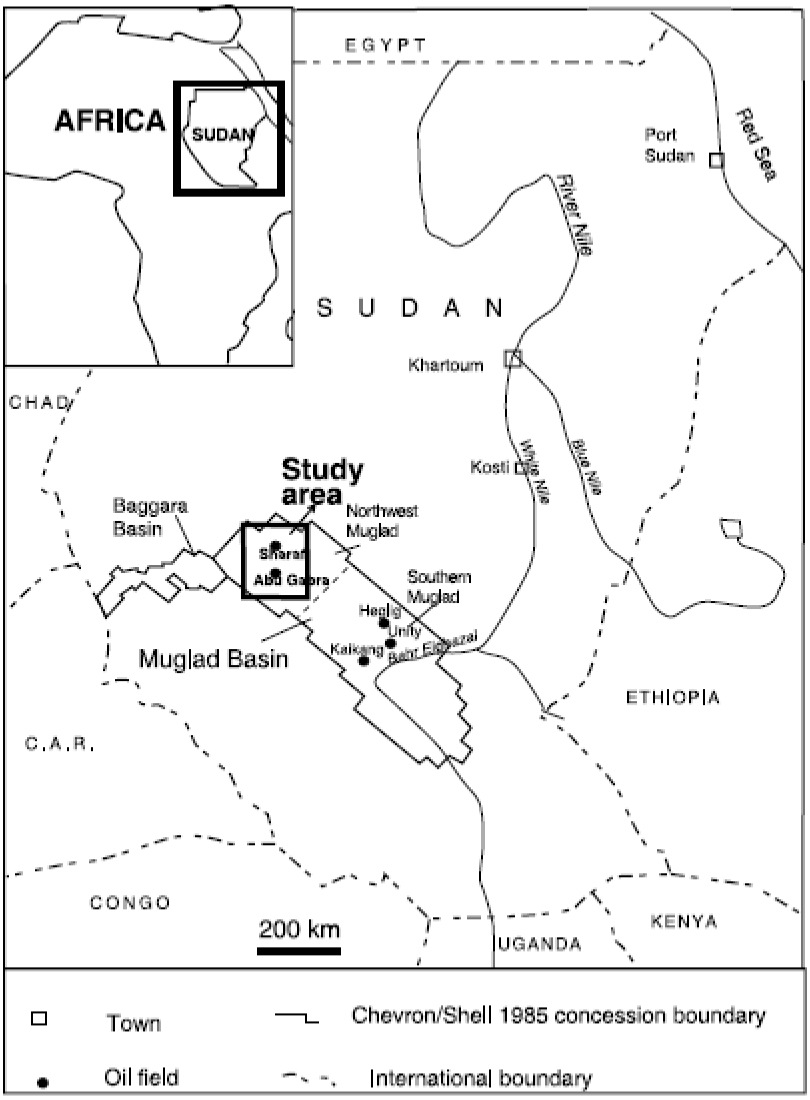
Though the deposition of third period rift in work area is thin, it changed the early rift obviously. The third period rift was under the control of series action of East African Rift Valley (Schull 1988; Kaska 1989)

The initiation of rifting in southern Sudan might be directly related to Jurassic rifting in northern Kenya (Anza Trough) or to the older Karoo rifts known in Eastern Kenya and Madagascar. Possible evidence for the timing of the rift initiation is the Jurassic sedimentary sequence encountered in the Blue Nile well or older sediments .encountered in the deep Muglad and Melut basins.(Schlull,1988).

The second rifting phase began during the Coniacian-Santonian times and continued until the end of Cretaceous(Schull 1988).

Changes in the opening of the South Atlantic account for a Late Cretaceous period of shear movements on the West and Central African rift system (Santonian shear in the Benoue trough) (Fairhead ,1988).

The third rifting phase is recorded in a thick accumulation of over 3960 m of sediments. The intensely faulted section of the Early Tertiary of the southern Sudan basins indicates that this final rifting phase was a significant tectonic event(Lowell & Genik 1972). The initiation of this rifting phase is synchronous to the initial phase of the opening of the Red Sea and East African rifting: the Muglad, Melut, and Blue Nile basins are sub-parallel to the Red Sea(Schull,1988).



Figure(2.2): Shows the area of study in the Muglad Basin , Sudan and the main oil fields discovered (Mohamed et al. (2001)).

2.2.1. Tectono-Stratigraphic Development:

The tectonic development of this area can be divided into a pre-rift phase and three rift phases, while each rift phase is followed by a sag phase. These evolutionary stages are well documented by geophysical data, well information, and regional geology (Schull,1988).

2.2.1.1. Pre-Rifting Phase:

By the end of the Pan-African orogenese (550 ±100 Ma), the region became a consolidated platform. During the Paleozoic and Early Mesozoic, this highland platform provided the sediments for the adjacent subsiding areas. The nearest preserved Paleozoic rocks are continental sediments in northwest Sudan, close to the Chad and Libyan borders. (Schull,1988).

2.2.1.2. Rifting phases:

As mentioned above, three distinct periods of rifting occurred in response to crustal extension, which provided the isostatic mechanism for subsidence. Subsidence was accomplished by normal faulting parallel and sub-parallel to the basin axes and margins. The multiphase tectonic history of the Muglad rift includes three discrete major extension phases: an Early Cretaceous (145 to 93.5 Ma), a Late Cretaceous (93.5 to 58 Ma) and an Eocene-Oligocene (58 to 23.8 Ma) rift phase, resulted in an accumulation of up to 5400m, 4200m and 5400m of sediments, respectively. Each phase consists of a rift-initiation phase, an active rifting phase and a thermal sag phase(Browne and Fairhead 1983; Schull,1988).

2.2.1.2.1. The Initial Rifting Phase :

Cannot be dated precisely. In the case where the basement was penetrated by wells in the north-western Muglad basin, it is overlain by Neocomian- Barremian lacustrine siltstones and claystones attributed to Abu Gabra Formation. Seismic shows that the Abu Gabra is not a monolithic formation, but has a basal member affected by half graben tectonic(Schull,1988). This basal member rests unconformably below an upper member, which is usually conformable with the overlying Bentiu Formation. Based on well and seismic data, it is suggested that the rifting begun during the Jurassic or Early Cretaceous (160-130 Ma.) and lasted until the end of the Aptian. The termination of the initial rifting without volcanism in Sudan is Stratigraphically marked by basin wide deposition of the thick sandstones of the Bentiu Formation (Bussert, 2002).

- **Bentiu Sag Phase:**

Up to 3500 m of sands attributed to Bentiu Formation were deposited during the first sag phase. The average thickness of the Upper Bentiu, present all over the graben, is about 2000m. Whereas two local thickenings in the North Kaikang and South Kaikang troughs at the base of the formation (Lower Bentiu) amount 1500 m (Browne et al., 1985).

2.2.1.2.2. The Second Rifting Phase:

Occurred during the Coniacian up to Campanian-Maastrichtian (Darfur Group, Baraka Formation). Stratigraphically, this phase is seen in a widespread deposition of lacustrine and floodplain claystones and siltstones (Aradeiba shaly Formation) with minor volcanism in the northwestern part of the Muglad basin and in the central Melut Basin. The end of this phase is marked by the deposition of an increasingly sand-rich sequence that concluded with thick Paleocene sandstone deposition of the Amal Formation (sag phase)(Schull,1988).

2.2.1.2.3. The Final Rifting Phase:

Began in the Late Eocene-Oligocene. This phase is reflected in the sediments by a thick sequence of lacustrine and floodplain claystones and siltstones with minor volcanism in the southern Melut block. After this rift period deposition became more sand-rich throughout the Late Oligocene-Miocene (Schull, 1988).

- **Adok Upper Sag Phase:**

During the middle Miocene, the basinal areas entered into an intra-cratonic sag phase of very slow subsidence accompanied by small or no faulting. This phase is marked by the deposition of 3000 m of sandy sediments and locally minor volcanism.

In the Late Tertiary, the regional stress regime changed resulting in the termination of the southern Sudan rifting during the middle Miocene. A maximum of 762 m sediment thickness accumulated in these basins during the post-rift sag phase, the direction of the faults in work area is NNW.

2.2.2.Stratigraphic Column:

The Stratigraphy of the northwest area and generalised in Figure(2.3). Three continental sedimentary depositional cycles are defined by three rifting episodes which occurred in the Early Cretaceous (140–90 Ma), Late Cretaceous and Lower Tertiary (90–60), and the Tertiary to recent respectively.

Stratigraphic sections of the Muglad Basin published by Schull (1988), McHargue et al. (1992) and Kaska(1989).

2.2.2.1. Sharaf And Abu Gabra Formations:

The early graben-fill clastics are sediments derived from the basement and are associated to the first-cycle. During the early phase of rifting, Late Jurassic to Neocomian, claystones, siltstones, and fine-grained sandstones of the Sharaf Formation were deposited in fluvial-floodplain and lacustrine environments. Towards the basin edges and in areas of major sediment influx these sediments graded to coarse alluvial clastics. The maximum penetration of this unit is approximately 365 m in the Muglad basin; however, on the seismic the unit is indicated to be much thicker in the deep center of the troughs.

The Neocomian to Barremian Abu Gabra Formation represents the period of greatest lacustrine development. Several thousands of feet of organic-rich lacustrine claystones and shales were deposited with interbedded fine-grained sands and silts. The nature of this deposit was probably the result of a humid climate and the lack of external drainage, indicating that the basins were tectonically sealed. The lacustrine claystones and shales are the most important source rock of the basins. In the northern part of the Muglad basin, several wells encountered oil in the Abu Gabra sands.

2.2.2.2. Bentiu Formation:

During the Aptian, shales with interbedded fine-grained sands and silts up to 1000-1500 m were deposited in the deepest part of the basin. This facies with lacustrine influence shows similarities to the underlying Abu Gabra Formation.

During the Albian-Cenomanian, a predominantly sandy sequence was deposited.

The alluvial and fluvial-floodplain environments expanded, probably due to a change from internal to external drainage. This unit, which is up to 2000-2500 m thick, typically shows good reservoir quality. These sandstones are the primary reservoirs of the Heglig field.

2.2.2.3. Darfur Group:

The Darfur Group is up to 2600 m. The Senonian to early Maastrichtian period was characterized by a cycle of fine to coarse-grained deposition. The initial deposits, Aradeiba and Zarqa Formations, predominantly claystones, shales, and siltstones, followed the first rifting phase. Floodplain and lacustrine deposits were widespread. These units may represent a time when the basins were partially silled. Throughout the basin, the Aradeiba and Zarqa Formations are an important seal. The floodplain, lacustrine claystones and red to brown shale, are interbedded by several fluvial/deltaic channel sands generally 3 m to 21 m. These sands are significant reservoirs in the Unity field.

In the Ghazal-Lower Baraka Formations, the sand-shale alternating intervals present a more regular vertical distribution corresponding to a floodplain environment.

The Cretaceous ended with the deposition of increasingly coarse grained sediments of the Middle –Upper Baraka Formation. This Formation was deposited in sand-rich fluvial and alluvial fan environments, which prograded from the basin margins.

2.2.2.4. Amal Formation:

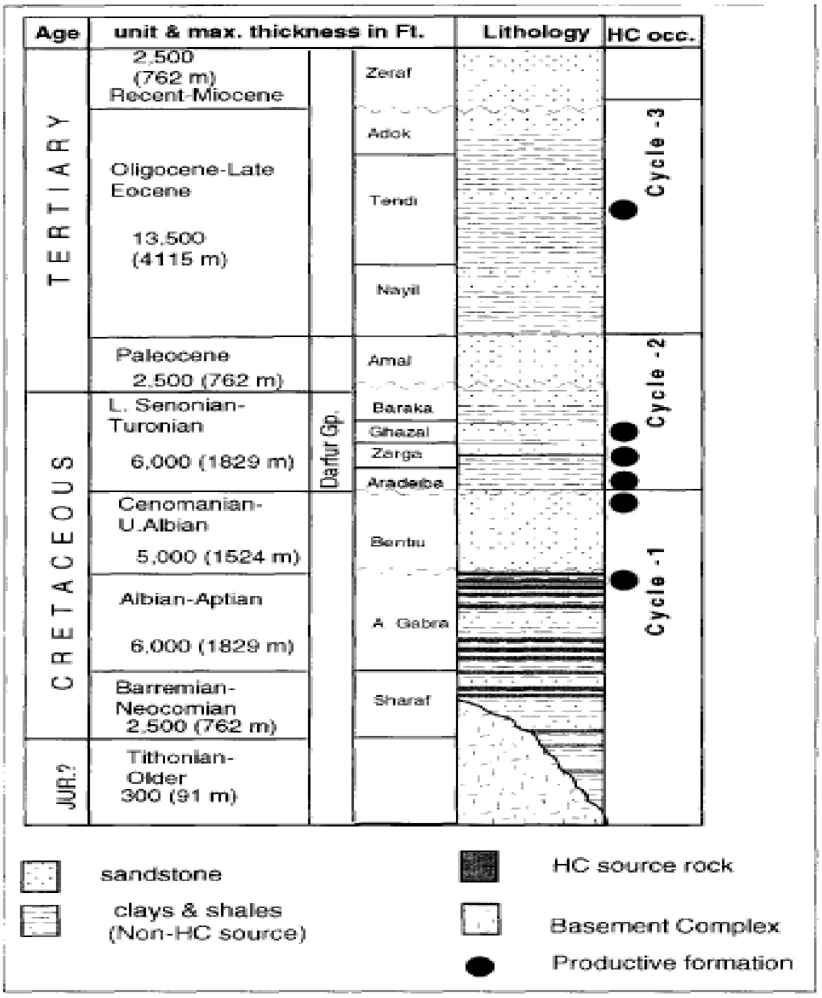
The massive sandstones of the Paleocene, which are up to 762 m, are dominantly coarse-grained sandstones. The unit represents a high energy deposition in alluvial-plain environment with coalescing braided streams and fluvial fans. These sandstones are potentially excellent reservoirs.

2.2.2.5. Nayil And Tendi Formations:

These sediments represent a coarsening-upward depositional cycle that occurred from late Eocene to middle Miocene. The lower portion of the cycle is characterized by fine-grained sediments related to the final rifting phase. The deposits represent an extensive fluvial-floodplain and lacustrine environment. These lake deposits appear to have only minor oil source potential; however, they offer an excellent potential as a seal overlying the sandstones of the Amal Formation.

Upward, this unit is generally characterized by interbedded sandstone and Claystone with increasing sand content. The fluvial-floodplain and limited lacustrine environments gave way to the increased alluvial input reflected in the sand-rich braided stream and fan deposits of the Pliocene Adok and Quaternary Zeraf Formations.

In the eastern Sudan, the first orogenic movements leading to the uplift of the Ethiopian plateau started in the Upper Eocene and induced intense faulting and latter volcanic intrusions (basaltic dykes, mounds and flows). Next to these Upper Eocene intrusions, exist more recent volcanics dated Miocene.



figure(2.3): simplified stratigraphic column of the sedimentary fill of Muglad basin (adapted from Schull (1988), Kaska (1989) and Giedt (1990)).