

Tectonic Evolution and Hydrocarbon Distribution of Basins in Africa*

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Abstract

African sedimentary basins, with relatively low degree of exploration and huge undiscovered hydrocarbon reserve, are the present hot spots for oil and gas exploration. The African plate mainly experienced three tectonic evolution stages during Phanerozoic, during which the forming, drifting and breaking up of the Gondwanaland led to the development of several types of African basins. Based on our basin study of tectonic evolution and prototype and petroleum geological analysis, the structural characteristics and rules of hydrocarbon accumulation in different types of rifts are determined as follows. The pericratonic basins in north Africa initiated in the early Paleozoic, in which hydrocarbons mainly distributed in the huge dome structures, formed under the compression of the Hercynian movement, and the Paleozoic petroleum system dominated in the pericratonic basins. The continental margin rift basins in north Africa experienced rifting and subsidence after the Hercynian movement, and the differences in subsidence intensity and depocenter led to diversity in hydrocarbon accumulation and resource potential. The passive margin rift basins in the east and west Africa formed during the Pangea paleo-plate breakup and Atlantic and Indian Ocean rifting: In the west, saliferous formations are widely distributed with two petroleum systems developed above and below the saline formations, respectively; in the east, hydrocarbon distribution is heterogenous and controlled primarily by the structural architectures of the basins. The intra-plate central and west Africa rift basins experienced three periods of rifting, i.e., the early Cretaceous, late Cretaceous and Paleogene. The E-W striking basins were uplifted intensely under compression from the collision of the African and Eurasian Plates in the late Cretaceous; as a result, hydrocarbons accumulated primarily in the lower Cretaceous. The NW-SE striking basins, slightly affected by the collision, have hydrocarbon distributions mainly in the upper Cretaceous-Paleogene. Finally, the eastern African rift basins and the Red Sea basin are newly formed Cenozoic basins

with dominant Cenozoic petroleum system. The hydrocarbon in the Cenozoic delta basins is controlled by fan delta sand body distribution and basin architecture.

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Tectonic evolution and hydrocarbon distribution in African basins


By

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Nov. 2018, Cape Town, South Africa

Outline

- 
- Brief introduction
 - Tectonic evolution and hydrocarbon distribution
 - CNPC exploration in Central-West African rift basins
 - Conclusions

❑ **Africa:** Area- $30.2 \times 10^6 \text{ km}^2$. population-1 billion, 56 countries and regions.

❑ **Petroliferous basins:** 55, total area $15.44 \times 10^6 \text{ km}^2$.

➤ 3 group of passive continental margin basin:

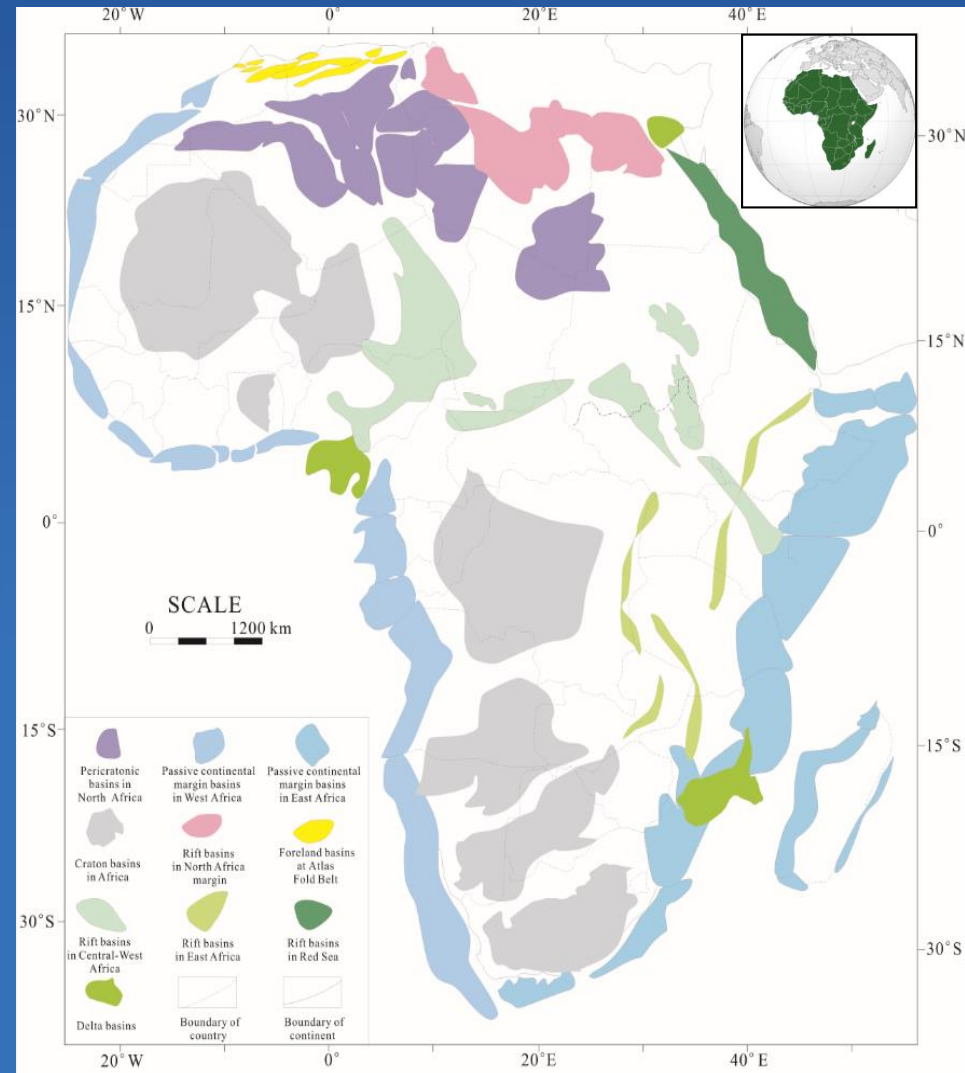
North, East and NE Africa.

➤ 3 group of rift basin: West, Central and East Africa.

➤ 2 group of craton basin: North and South Africa.

➤ 1 group of foreland basin: North Africa.

❑ **Large oil and gas fields:** 161 (2016).



Distribution map of sedimentary basins in Africa (modified after Hemsted T; Zhang Guangya et al, 2018)

Major oil and gas discoveries since 2000 are mainly in West Africa, East Africa, deep sea region of North Africa and Africa onshore.

Passive continental margin basins

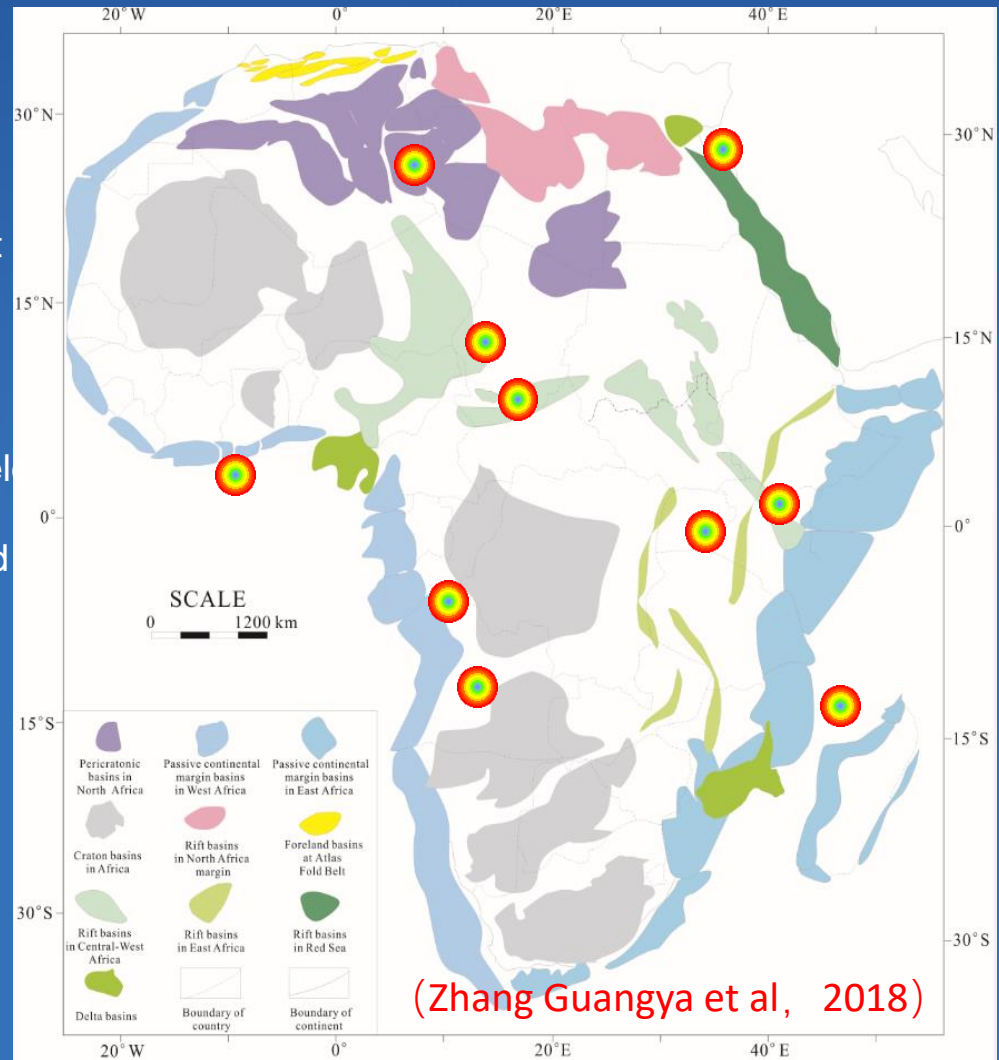
- **Passive continental margin in East Africa:** Huge gas field discovery Rovuma Basin.
- **Deep water region in passive continental margin in West Africa:** pre-salt and post-salt discoveries in salt, deep water discoveries in Niger Delta Basin and Nile Delta Basin.

Intracontinental rifts


- **Rift system in Central Africa:** Palogue Oilfield in Melut Basin, Lower Cretaceous and buried hill discoveries in Bongor Basin, Kome Oilfield in Doba Basin, Cretaceous-Paleogene discoveries in Termit Basin.
- **Rift system in East Africa:** Exploration breakthroughs and discoveries in its west branch and east branch.

Depression basins at craton margin in North Africa

- New discovery in the Ghadames Basin in mature prospect zone (Hassi Touimet Sud1)

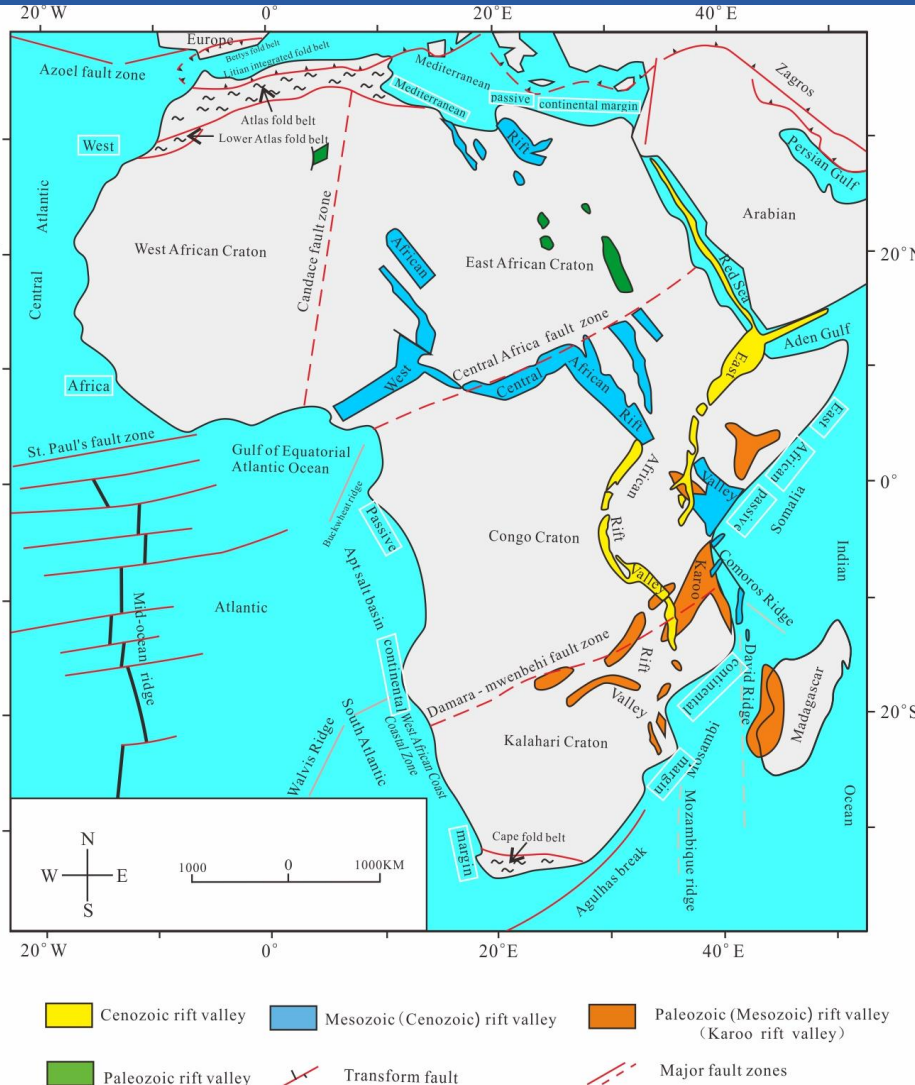


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Tectonic framework of Africa Plate :

- ❑ **Stable paleo continent:** 4 cratons formed the African continent plate during Pre-Cambrian.
- ❑ **3 major rift systems:** Paleozoic rift basins, Mesozoic rift basins and Cenozoic rift basins.
- ❑ **Broad passive continental margin:** west boundary—Central ridge of the Atlantic; east boundary—Central ridge of Indian Ocean.
- ❑ **Folded belts:** two Hercynian folded belts at north and south margins.



Distribution map of tectonic units in Africa Plate (Modified after BUMBY A J, GUIRAUD R, 2005)

The Africa Plate experienced three evolution stages: formation, bulk movement and break-up of Gondwana:



Map of restored plates at about 530 Ma

□ Forming of Gondwana:

Pre-Cambrian — about 530 Ma, pan African orogeny, separate small cratons convergent to form a supercontinent.

□ Bulk movement of Gondwana:

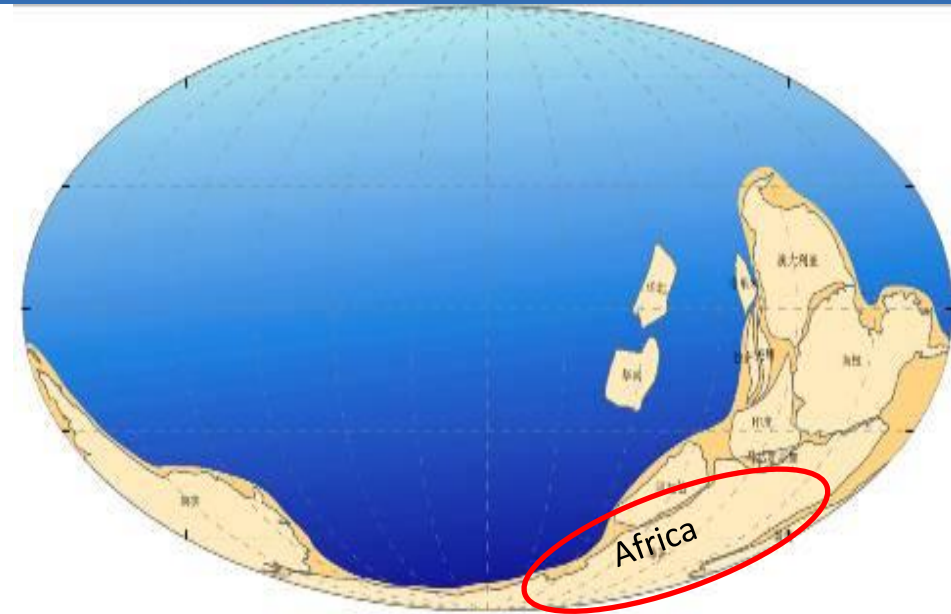
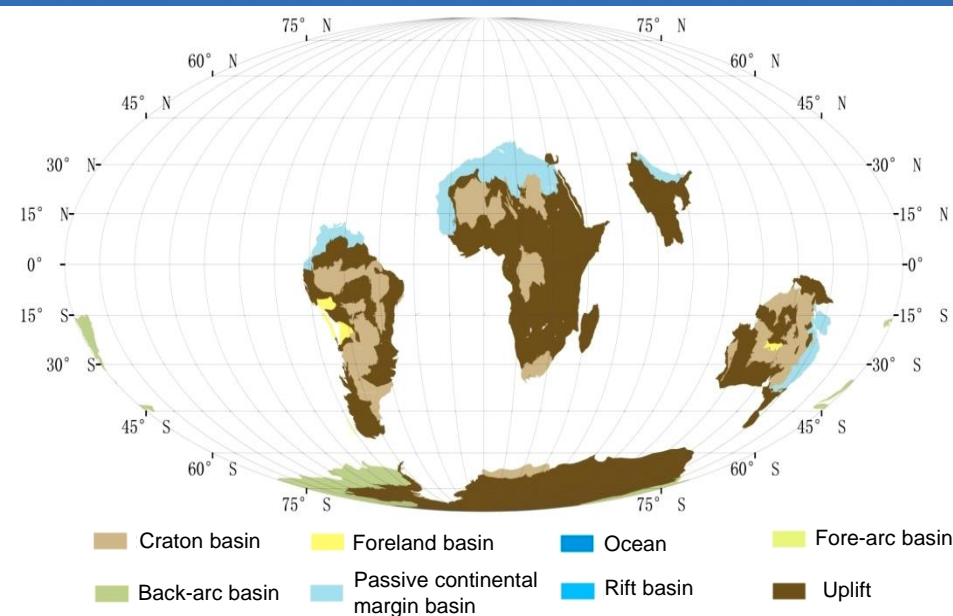
pan African — Triassic, craton margin basins develop in the north, and Karoo rift in SE.

□ Break-up of Gondwana:

Middle-later Jurassic-Present, breakup of Gondwana, African Plate separate from other plates.

□ Silurian (430 Ma)

- The north African Plate was located in the craton margin environment.
- The other parts were in the continental craton environment.
- Paleozoic passive continental margin marine deposits developed in the north.
- Intracraton basins developed inside African Plate.

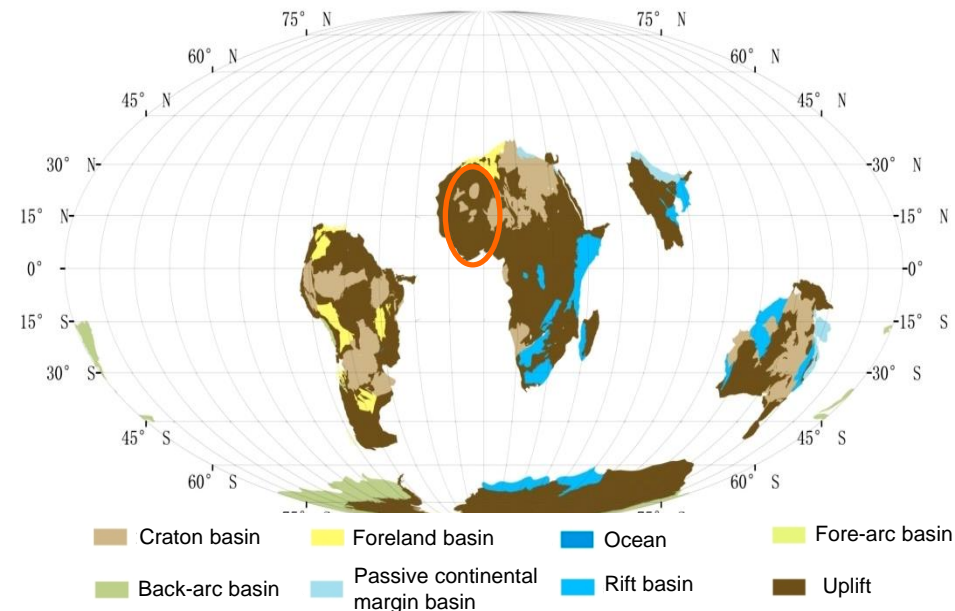


Prototype basin distribution (current position)

Plate tectonic background

□ Permian (270 Ma)

- Rift basins developed in SE due to the Karoo mantle plume extension.
- Craton basins developed under the interior of the continental craton environment.
- Foreland basins developed in north African Plate for Hercynian orogeny during Late Paleozoic,
- The southern Cape fold belt was uplifted and formed.



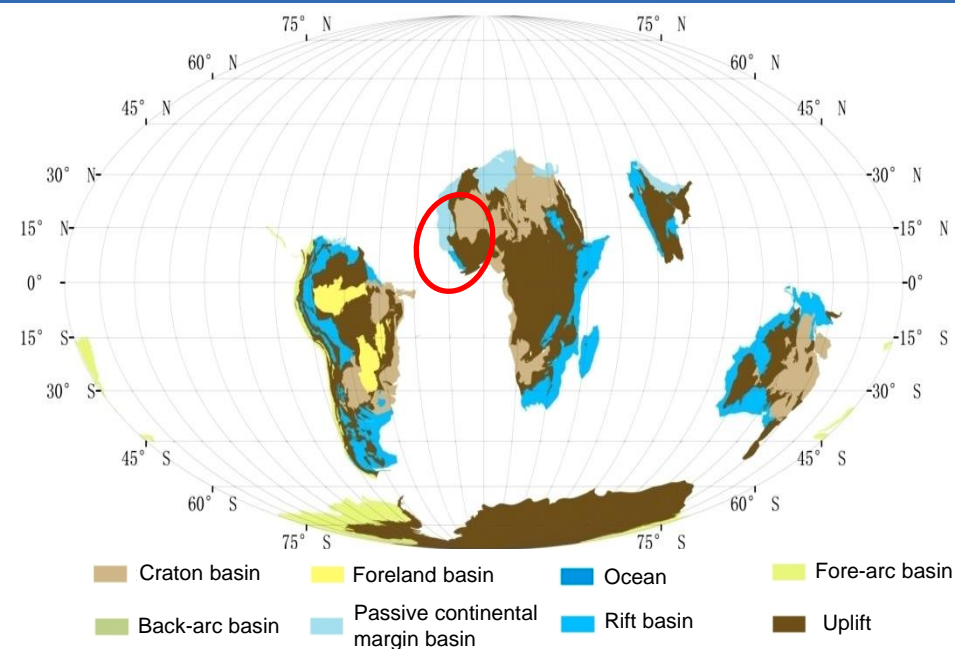
Prototype basin distribution (current position)



Plate tectonic background

□ Jurassic (165 Ma)

- Passive continental margin basins developed in north and NE of the African Plate due to North Africa and North America separation.
- Rift basins developed in SE African Plate under the continuous influence of the Karoo mantle plume.
- Craton basins develop in African Plate under intracontinental cratonic environment.



Prototype basin distribution (current position)

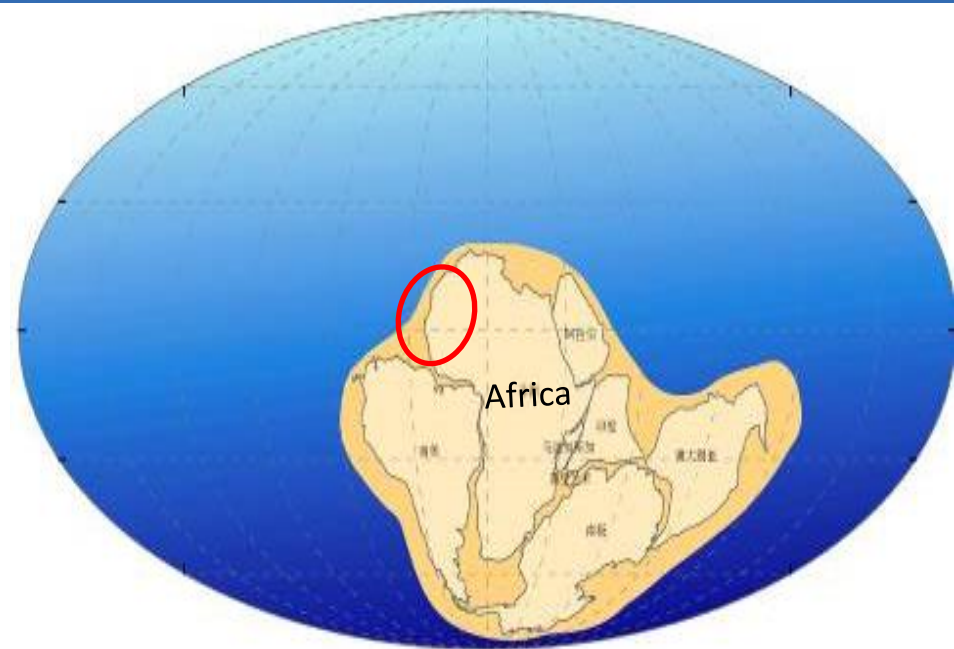
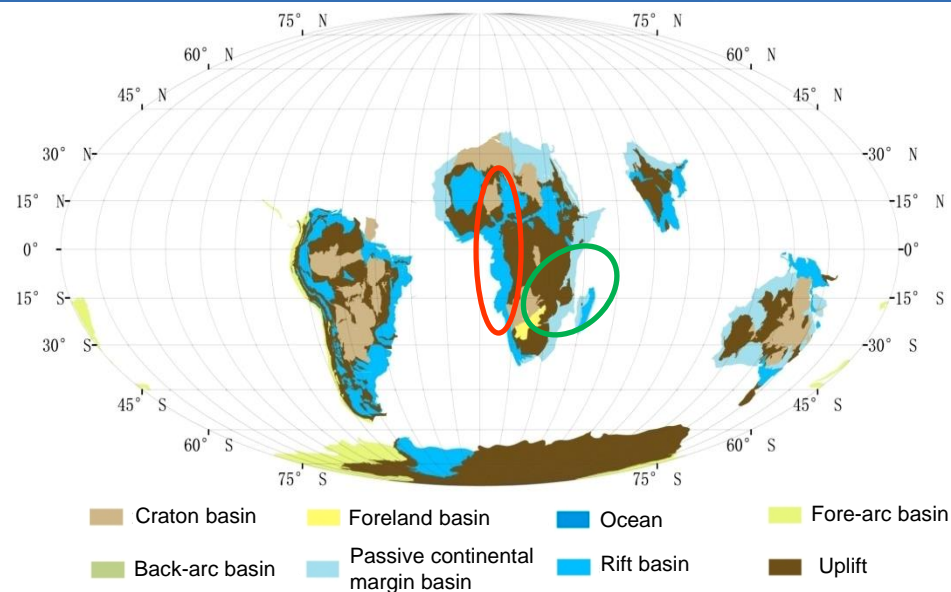


Plate tectonic background

□ Early Cretaceous (125 Ma)

- Passive continental margin basins developed in SE Africa Plate due to Australian-Indian-Antarctic Plate separation.
- passive continental margin basins also developed in west of African Plate due to South American and African Plate separation.
- Rifting happened in Central-West Africa because of Atlantic rifting.



Prototype basin distribution (current position)

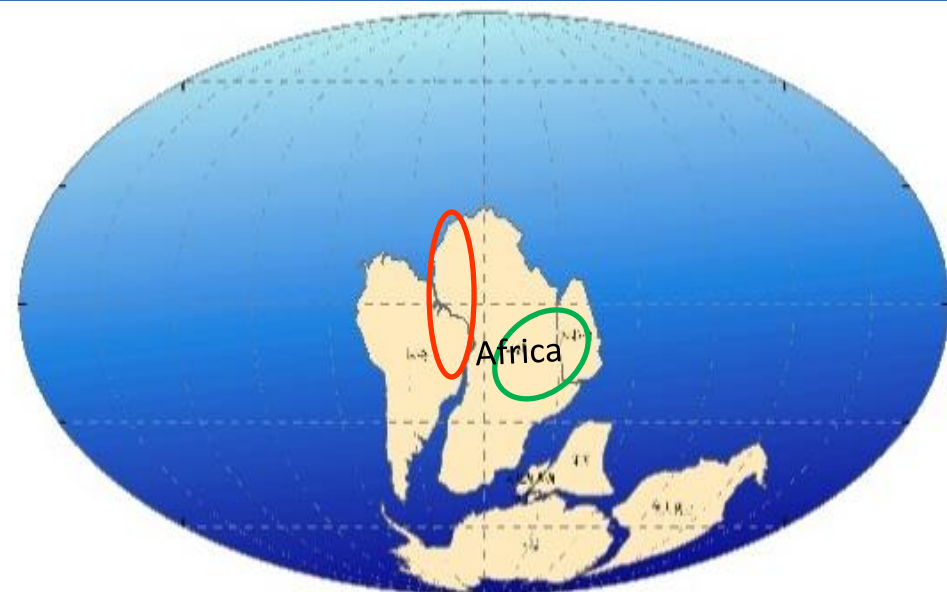
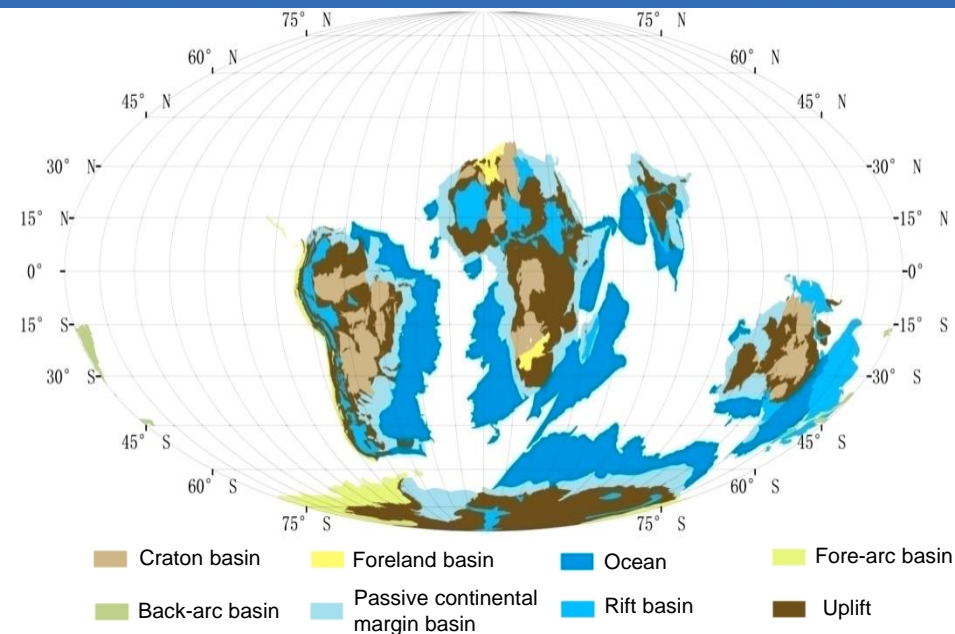


Plate tectonic background

□ Late Cretaceous (90 Ma)

- African Plate was separated from other surrounding plates (except for the Arabian Plate).
- The north and south Africa were affected by the Atlas and Cape orogeny.
- The interior of the continent was in a craton or rift environment.



Prototype basin distribution (current position)

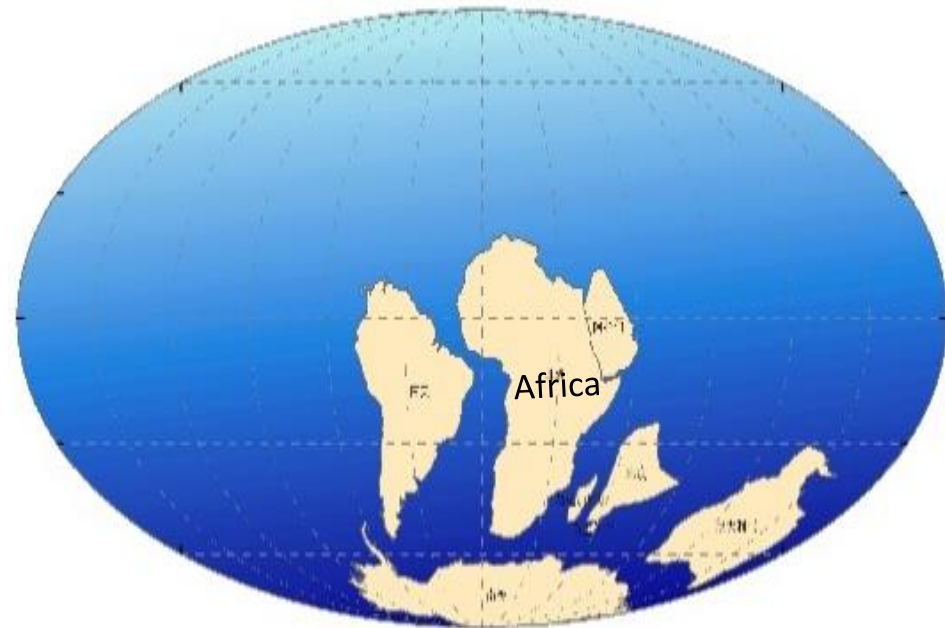
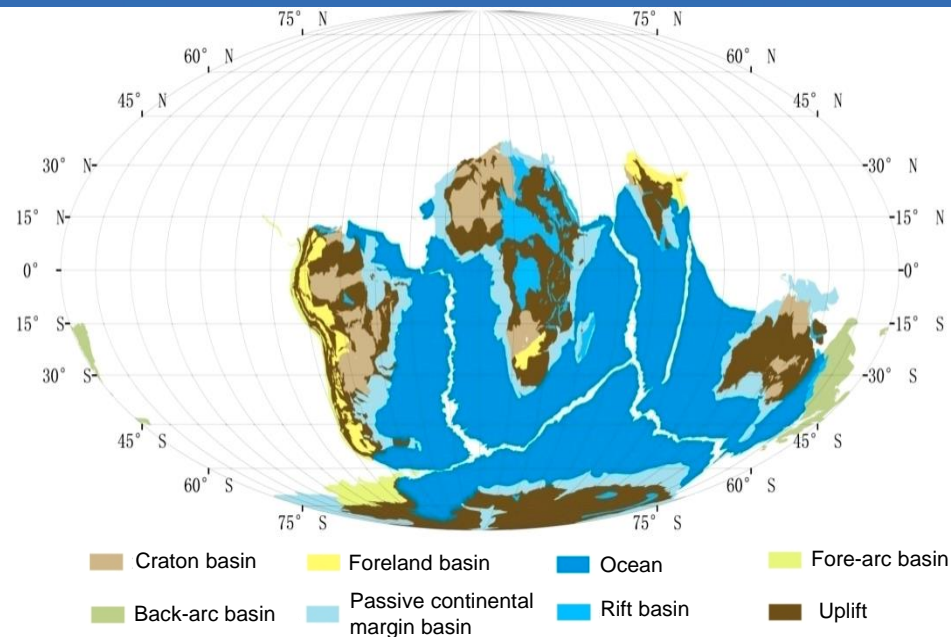


Plate tectonic background

□ Paleogene (40 Ma)

- Africa Plate was separated from the other surrounding plates (except for the Arabian Plate).
- The north and south were affected by the Atlas and Cape orogeny.
- Madagascar was separating from India Plate.
- The interior of the continent was in a cratonic environment.



Prototype basin distribution (current position)

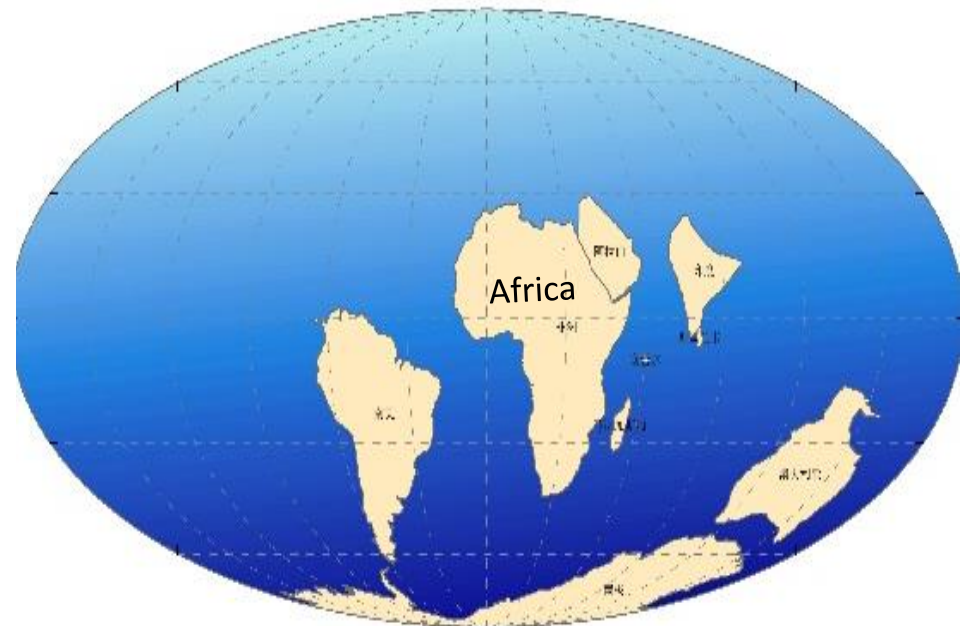
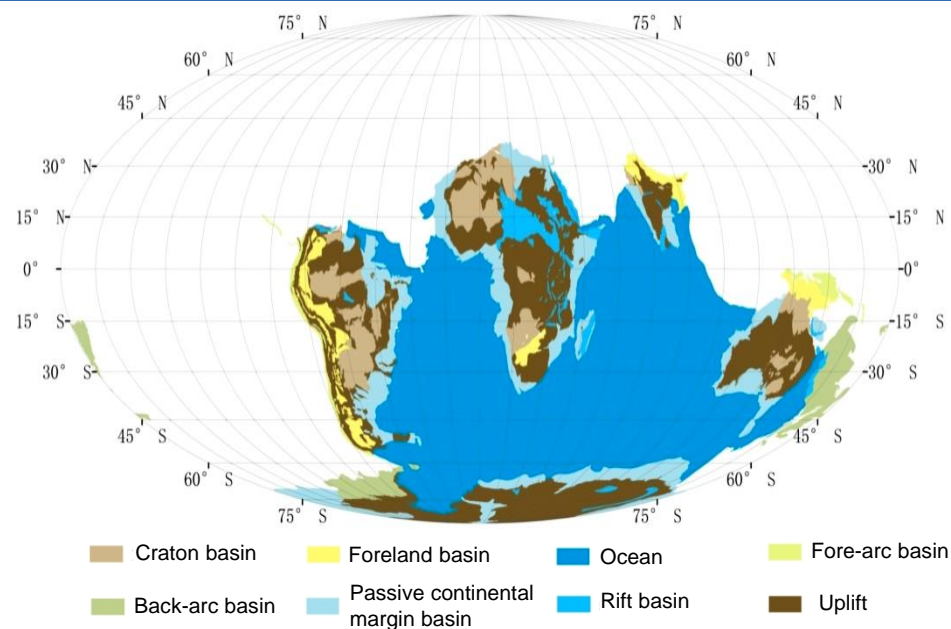


Plate tectonic background

□ Neogene (15 Ma)

- Africa Plate was separated from the other surrounding plates (except for the Arabian Plate).
- The north and south were affected by the Atlas and Cape orogeny.
- Rifting happened in East Africa due to Red Sea rifting.



Prototype basin distribution (current position)

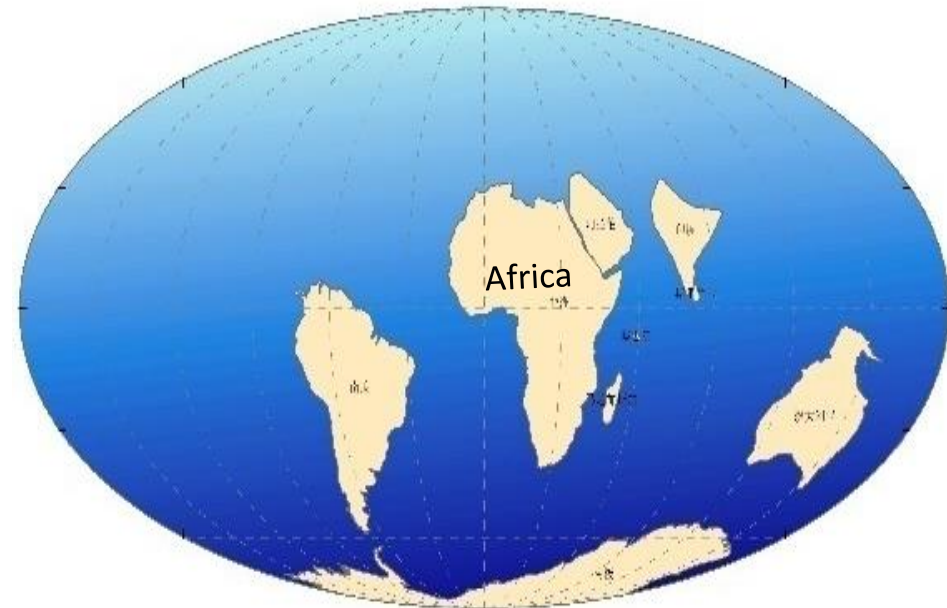
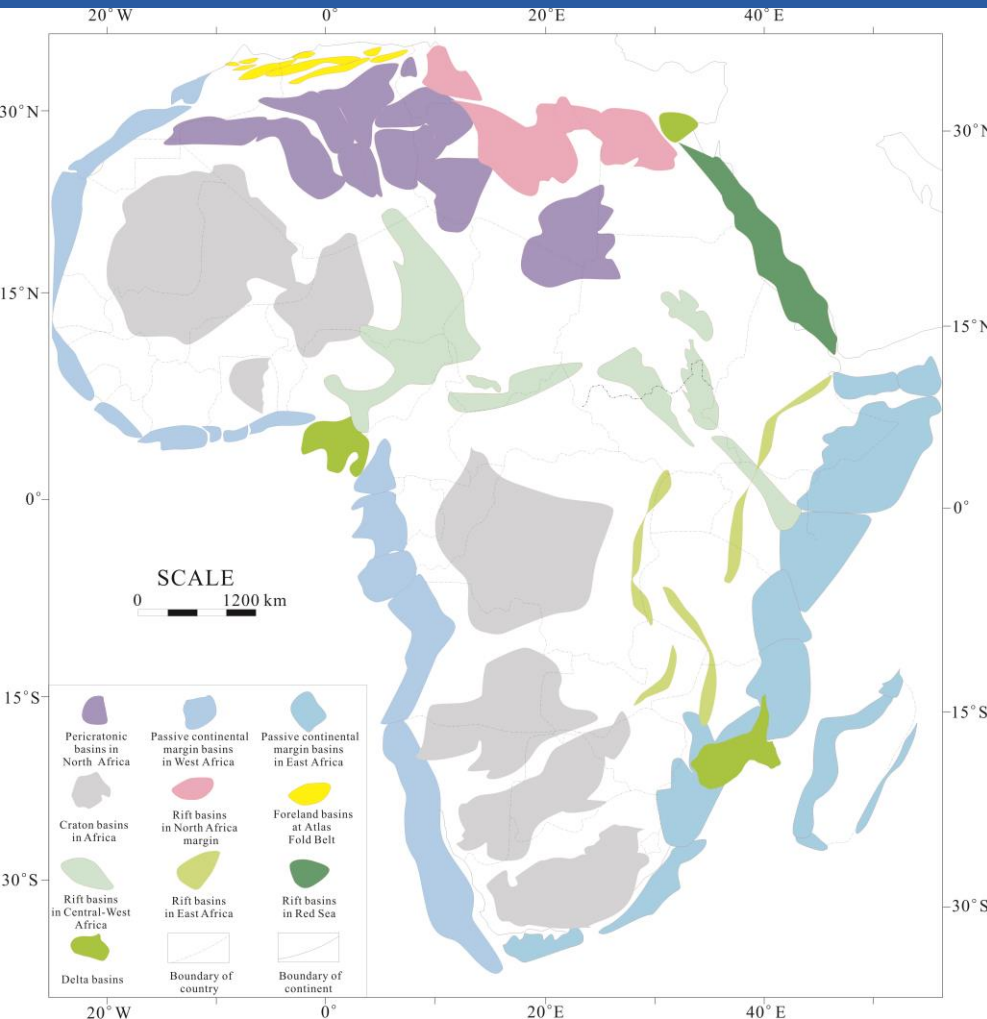


Plate tectonic background

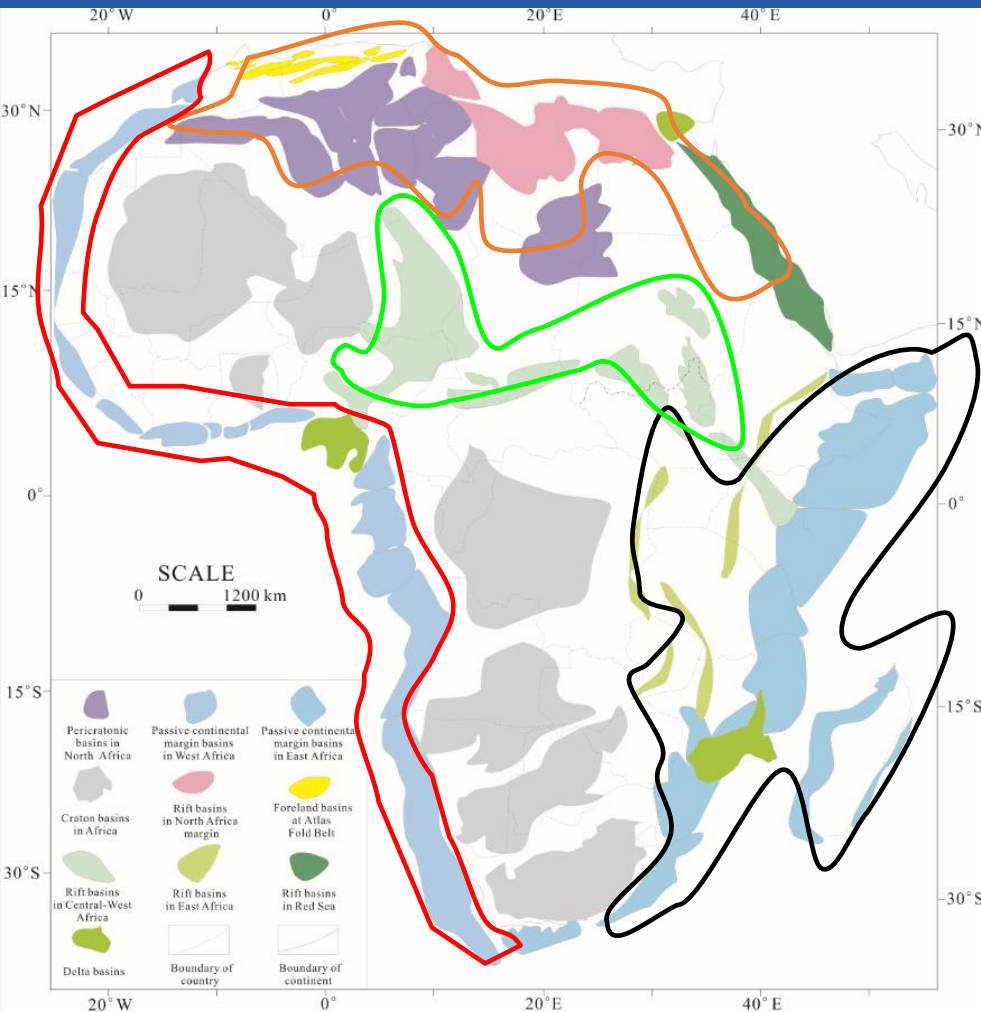


□ 9 types of basins:

1. Craton marginal basins in North Africa
2. Passive continental margin basins in West Africa (including Niger Delta Basin)
3. Passive continental margin basins on the east coast of Africa
4. Intracontinental rift system in Central-West Africa
5. Red Sea rift and the East African rift system
6. The Nile Delta Basin
7. North Africa marginal rift basins
8. Intracratonic basins
9. Foreland basins

Distribution map of sedimentary basin types in Africa
(Modified after Hemsted T)

5 major petroleum provinces:



Distribution map of sedimentary basin types in Africa
(Modified after Hemsted T)

□ Petroleum province in East Africa

- East African continental margin, heavy oil, oil sands and gas.
- East African rift system ,oil.

□ Petroleum province in North Africa

- Cratonic marginal basins ,oil and gas.
- Mesozoic rift basins (Sirte rift) , oil.
- Cenozoic rift basins (Suez Bay Basin and Red Sea Basin) ,oil.
- Cenozoic Nile Delta basin, gas.

□ Petroleum province in West Africa

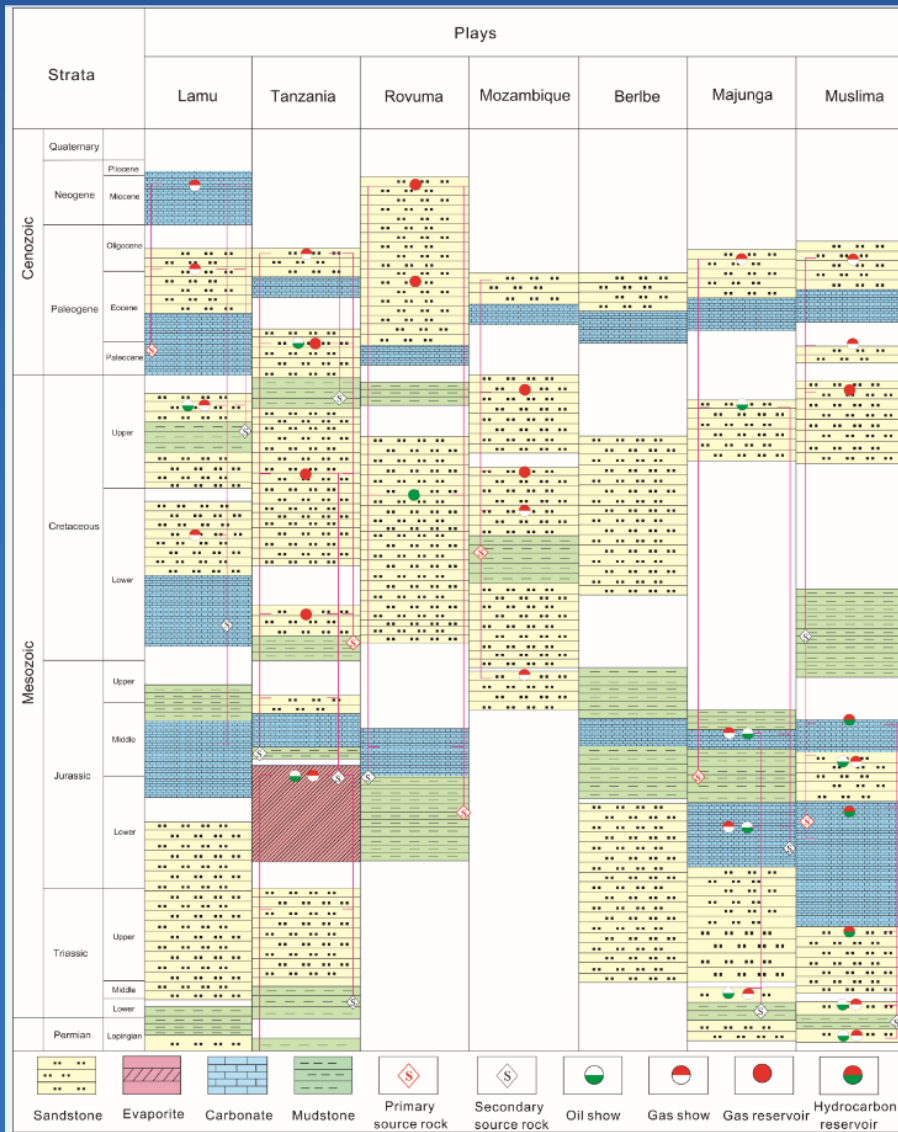
- Passive continental margin basin, oil.
- Niger Delta basin, oil and gas.

□ Petroleum province in Central-West Africa rift

- Meso-Cenozoic rift, oil.

□ Cratonic basin prospect regions

- Paleozoic intracratonic basin in NW Africa, fewer oil and gas discoveries
- Paleozoic inner cratonic basin in SW Africa, no discoveries.



Passive continental margin basins in East Africa:

Several plays, dominant by gas, develop in passive continental margin basins in East Africa.

Regional source rocks:

- Middle-lower Jurassic marine source rocks.
- Upper Carboniferous-Triassic Karoo lacustrine shale.
- Upper Jurassic-Cretaceous marine source rocks.

Reservoirs:

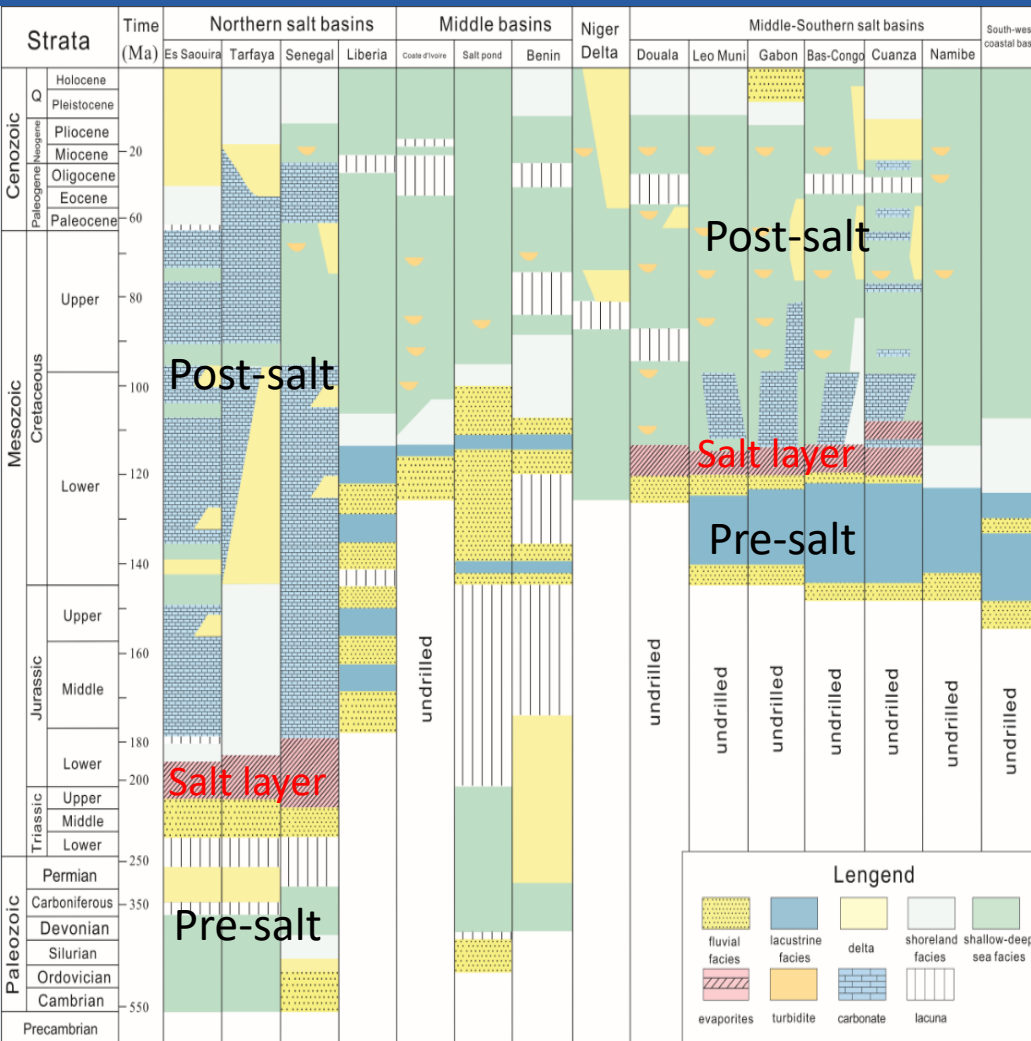
- Fluvial-delta deposits.
- Carbonate deposit.

Cap rocks:

- Marine mudstones during Cretaceous transgression.
- Jurassic evaporite.
- Upper Cretaceous-Paleocene mudstone.

Passive continental margin basins in West Africa:

- ❑ Two plays, post-salt (the major) and pre-salt develop in north segment salt basins.
- ❑ No salt develops in middle segment basins, Cretaceous petroleum system dominant.
- ❑ Niger Delta Basin, Cenozoic petroleum system dominant.
- ❑ Both post-salt and pre-salt plays develop in middle-south segment salt basin.
- ❑ No salt develops in south segment basins, Cretaceous petroleum system dominant.



Sedimentary facies of main basins in West Africa
(Zhang Guangya et al, 2018)



Paleozoic and Mesozoic-Cenozoic basins in North Africa:

Two petroleum systems in North Africa:
Paleozoic and Meso-Cenozoic .

□ Paleozoic petroleum system:

- **Source rocks:** Silurian shale and Devonian mudstone
- **Reservoirs:** Cambrian-Ordovician reservoir, Silurian-Devonian reservoir and Triassic reservoir
- **Cap rocks:** mudstone and evaporite above Triassic

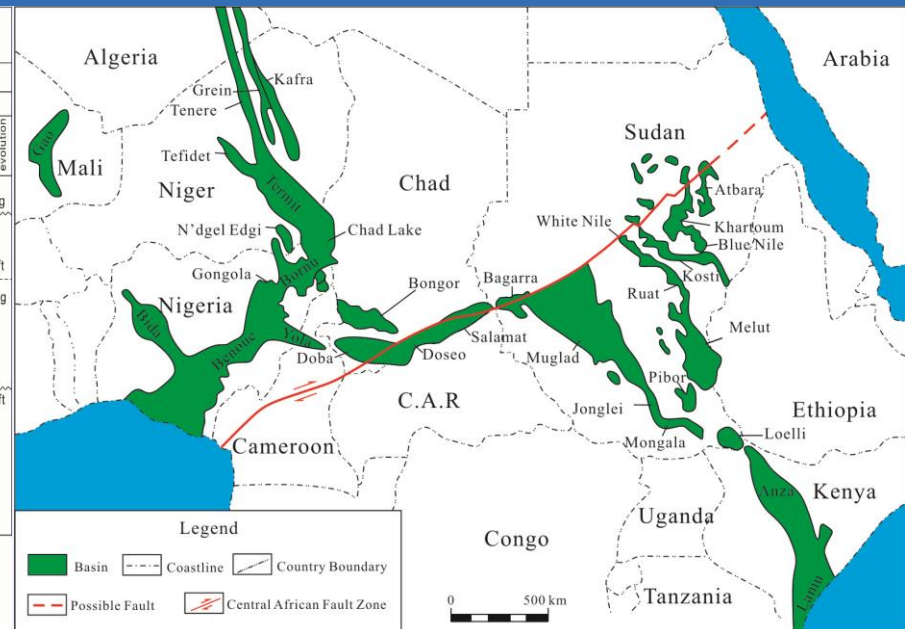
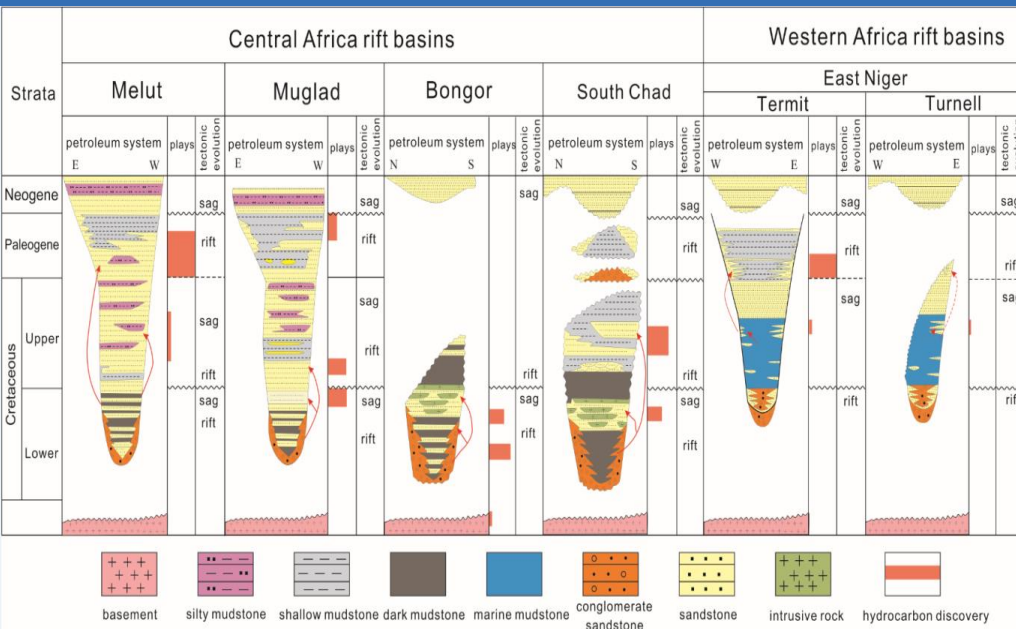
□ Cenozoic petroleum system:

- **Source rocks:** Cretaceous marine mudstone and Paleogene mudstone
- **Reservoirs:** Cretaceous reservoir, Paleogene and Neogene reservoirs
- **Cap rocks:** Meso-Cenozoic mudstone, evaporite and volcanic rock

West and Central African basins: the Africa-Eurasia collision at Late Cretaceous influenced hydrocarbon accumulation.

▣ **W-E trending basins:** oil and gas are mainly in Lower Cretaceous, such as Bongor.

▣ **NW-SE trending basins:** oil and gas are mainly in Upper Cretaceous and Paleogene, such as Muglad and Melut basin.




Petroleum system of the central and west rift basins

(Zhang Guangya et al., 2018)

Distribution of Central and West rift basins

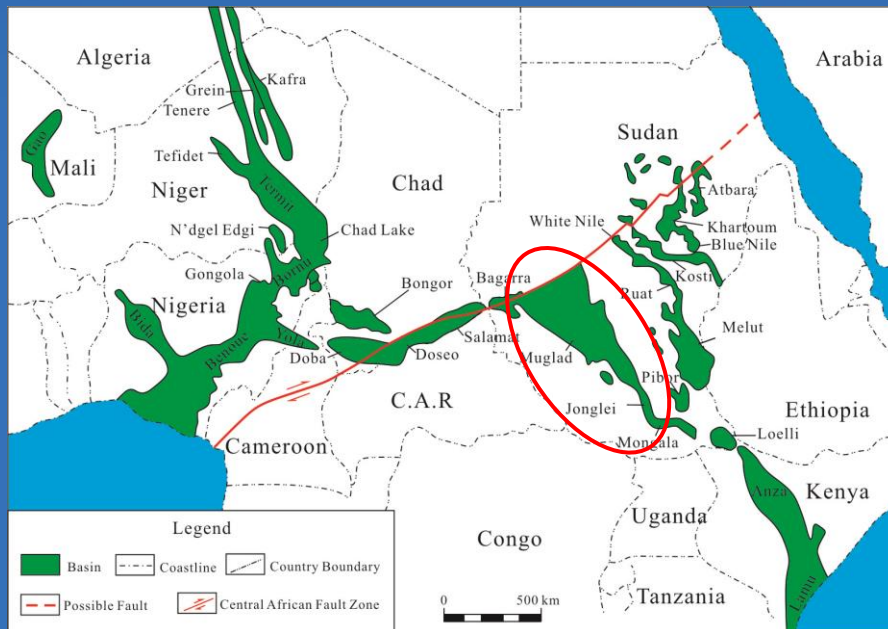
(Genik 1992)

Outline

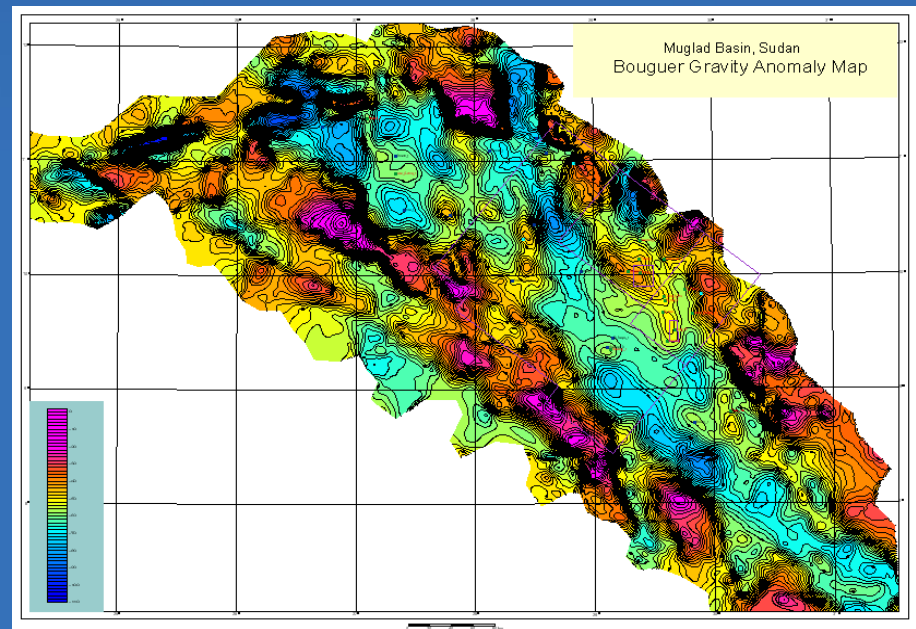
- Brief introduction
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□ Muglad Basin:

- locate in Sudan and South Sudan.
- NE-SE strike, 800 km long, 200 km wide, with an area of 120,000 km².
- maximum sedimentary thickness up to 15 km.



Tectonic location map of Muglad Basin (Genik, 1992)

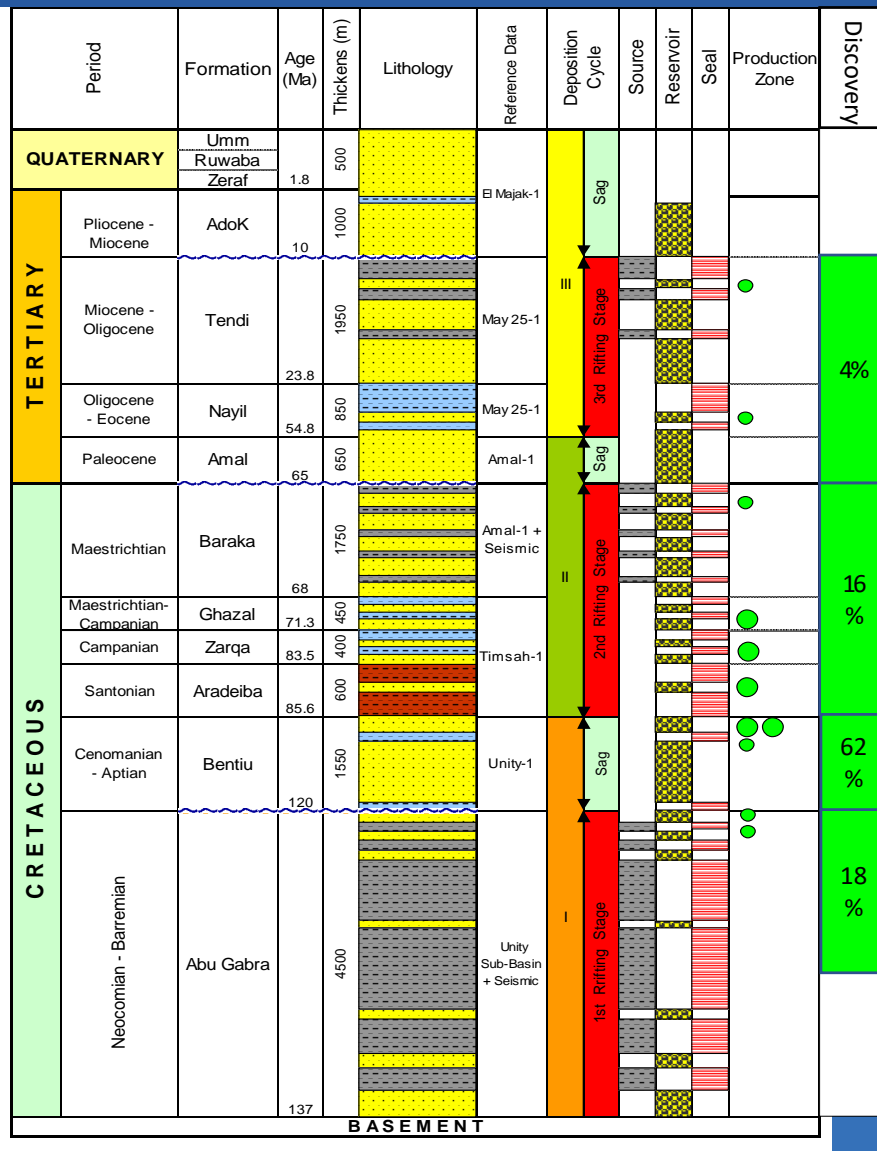


Bouguer gravity anomaly map of Muglad Basin

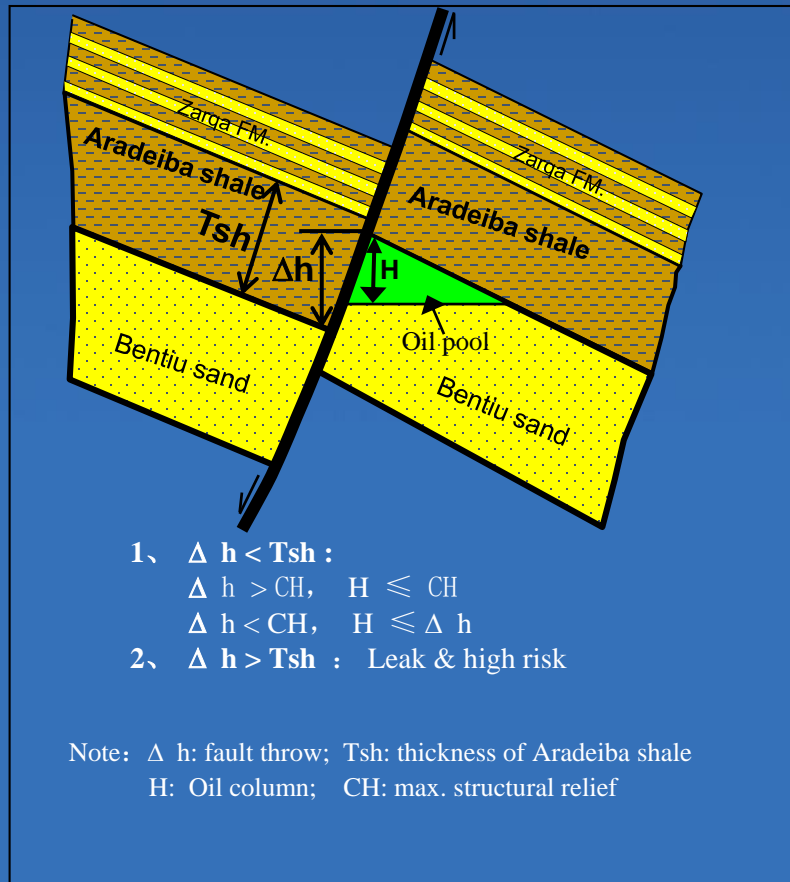
Petroleum System

- **Source:** The organic rich Abu Gabra shale is the main source.
- **Reservoir:** Bentiu sand is the main reservoir, in addition Abu Gabra, Aradeiba, Darfur Group, Amal, Nayil and Tendi sands.
- **Trap:** Structures associated with the First and Second Rifting Cycles
- **Seal:** Top Seal is provided by Aradeiba shale for Bentiu and Aradeiba reservoir and intra-formational shale for the other reservoirs.

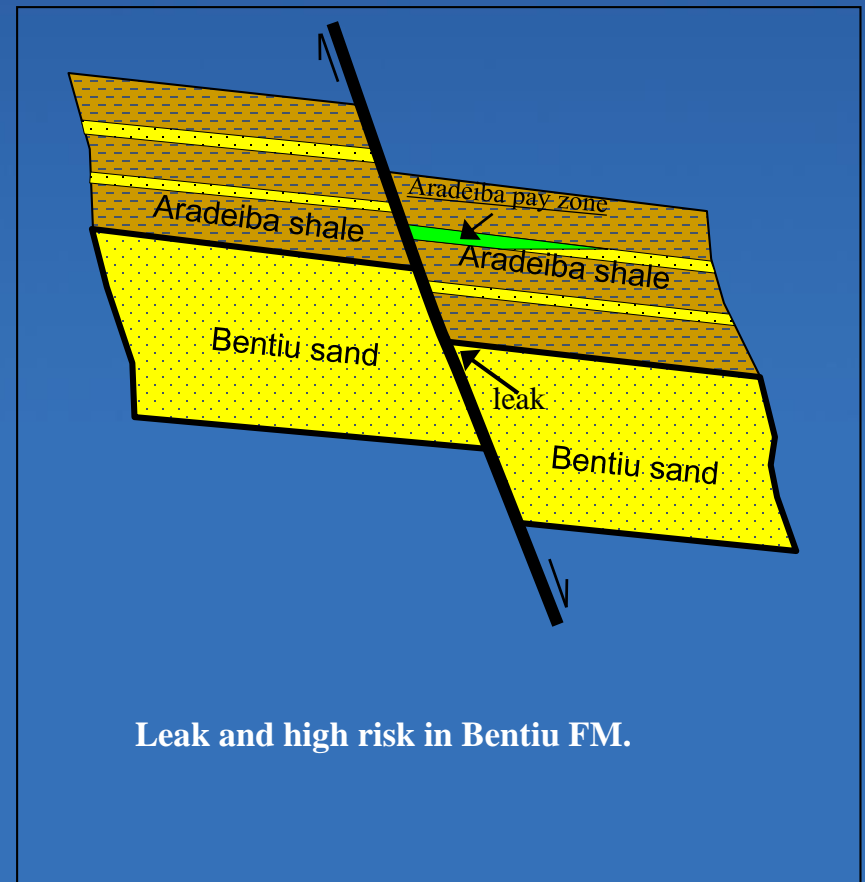
Most of the oil are discovered in Cretaceous.



□ Lateral seal is the most critical factor.



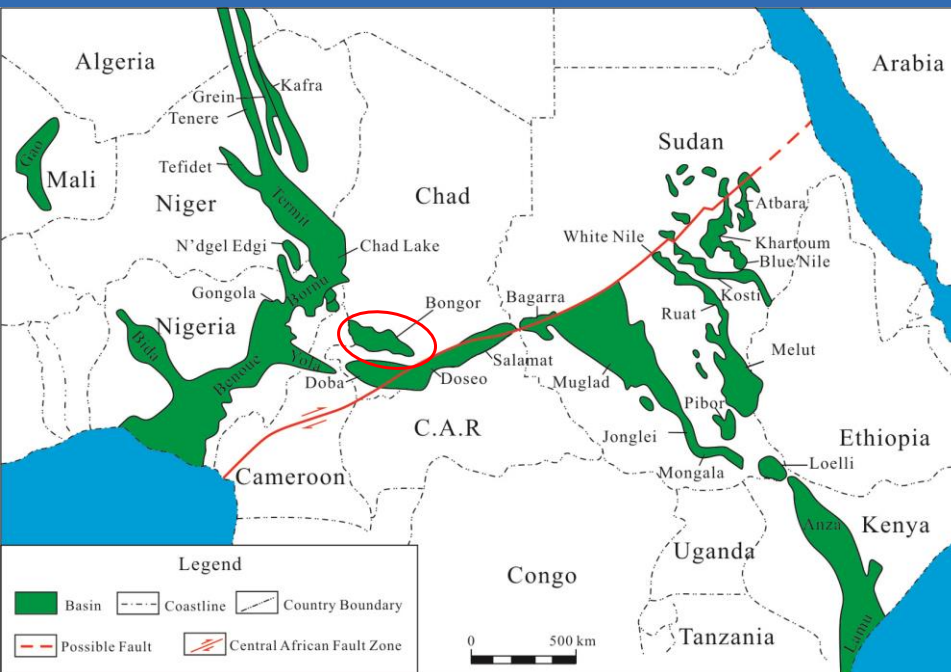
(a) footwall fault block



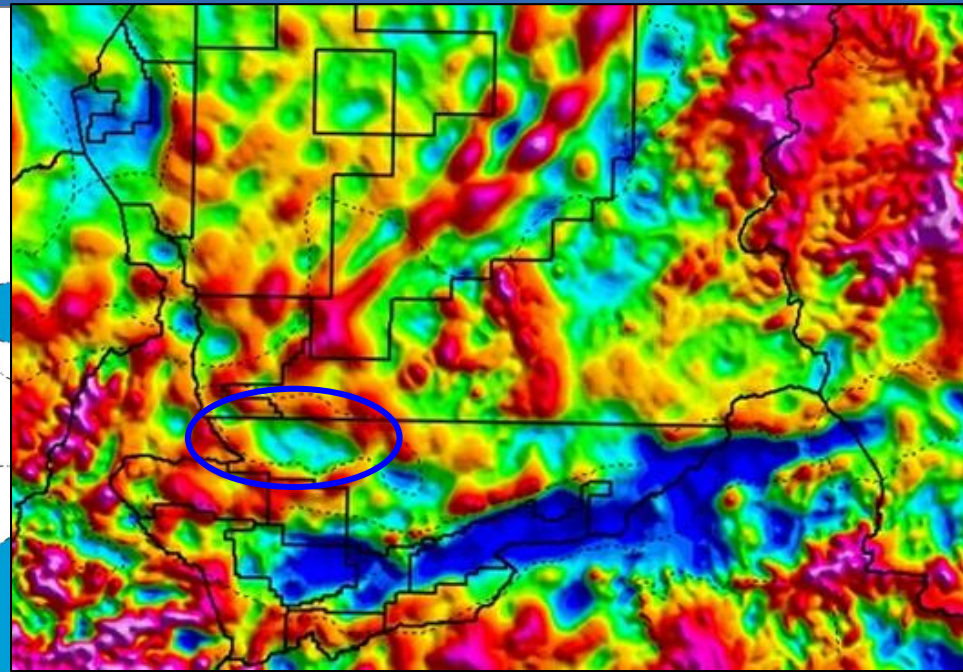
(b) hanging wall fault block

□ Bongor Basin:

- Nearly E-W strike, covering an area of about 16,700 km².
- Meso-Cenozoic intracontinental rift basin.
- Upper Cretaceous missing due to Late Mesozoic inversion.



Tectonic location map of Bongor Basin (Genik, 1992)



Bouguer gravity anomaly map of Bongor Basin

Petroleum System

❑ **Source rock:** Shale and mudstone in P and M Fm.

❑ **Reservoir:**

- Fan Delta and sublacustrine fan sand in P Fm..
- Fluvial channel and fan delta sand in K and R Fm..
- Weathering crust and fractures in basement.

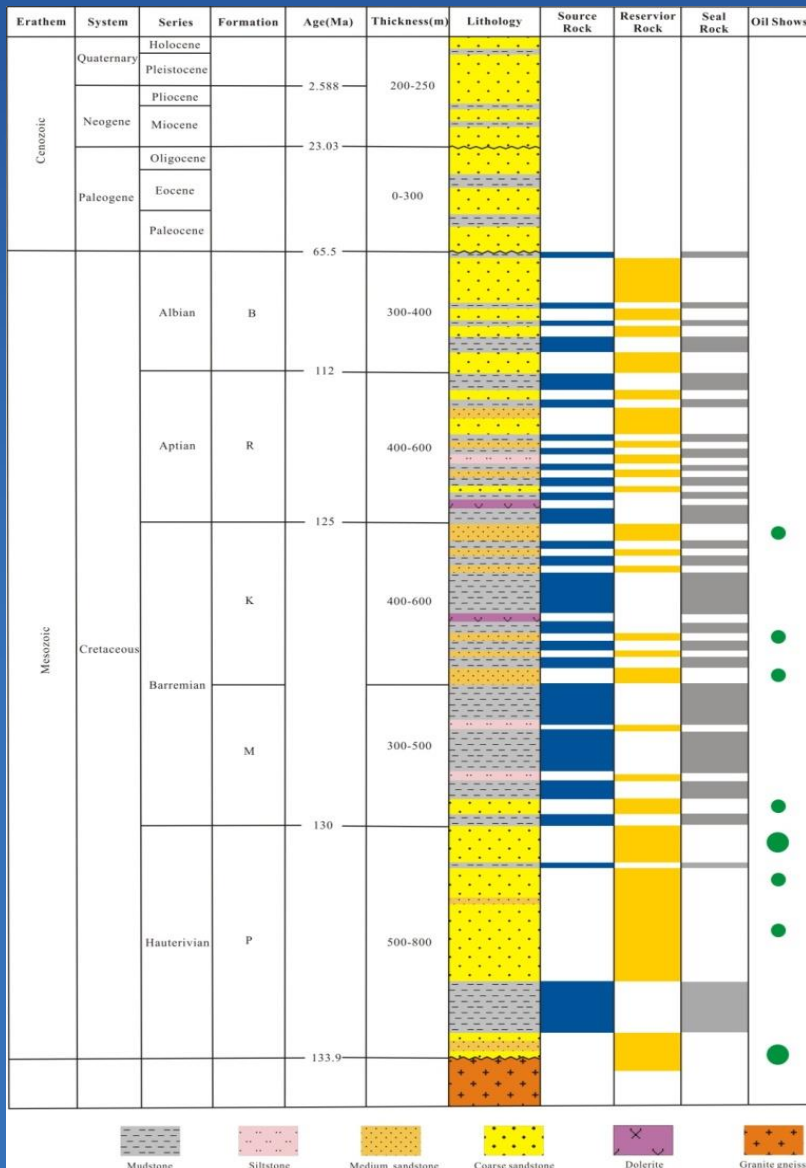
❑ **Cap rock:**

- Primary cap rock: mudstone in M Fm..
- Secondary cap rock: interbedded mudstone layers in K/R/B Fm..

❑ **Play:**

- Upper Play: K/R Fm..
- Lower Play: P Fm. and basement.

❑ **Trap type:** anticline and faulted nose.



Composite column graph of Bongor Basin

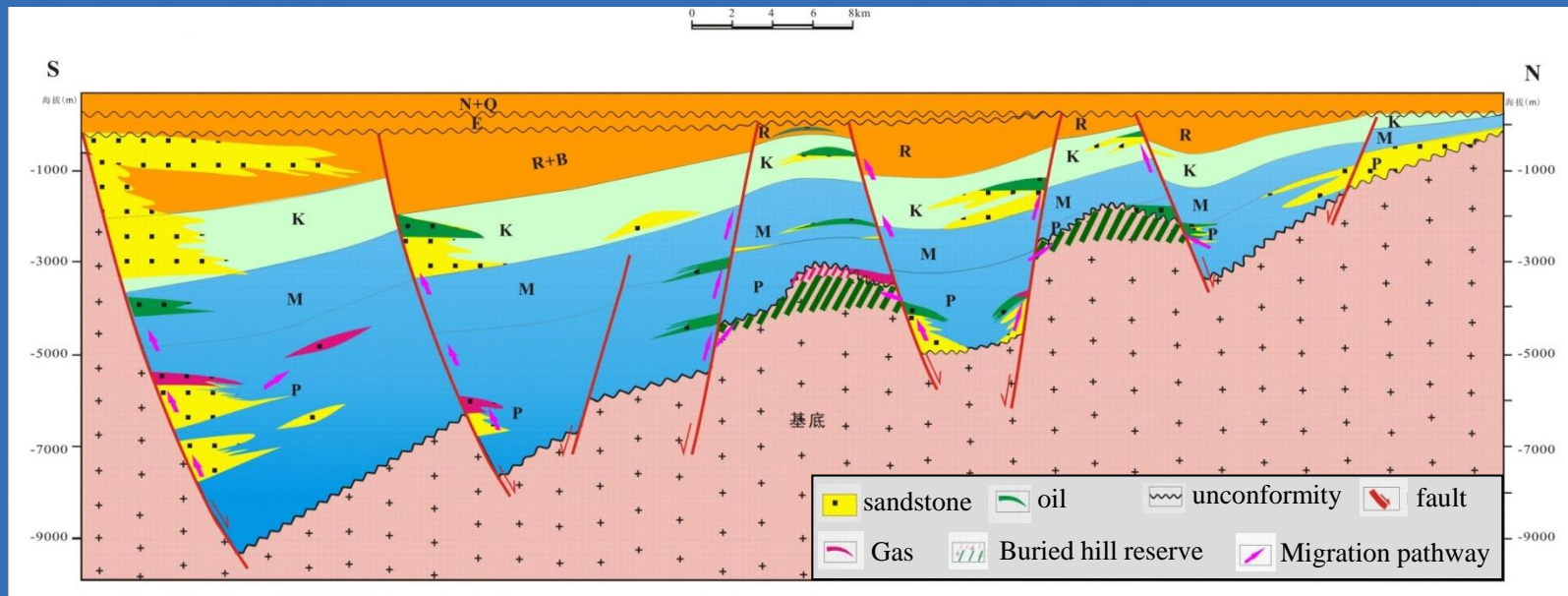
□ Two plays developed in Bongor basin:

□ Upper play (R-K Fm.):

- Structural reservoir.
- Reservoir-caprock is featured with interbedding sand and mud layers.
- Heavy oil and conventional oil.

□ Lower play (M-P Fm. + buried hill)

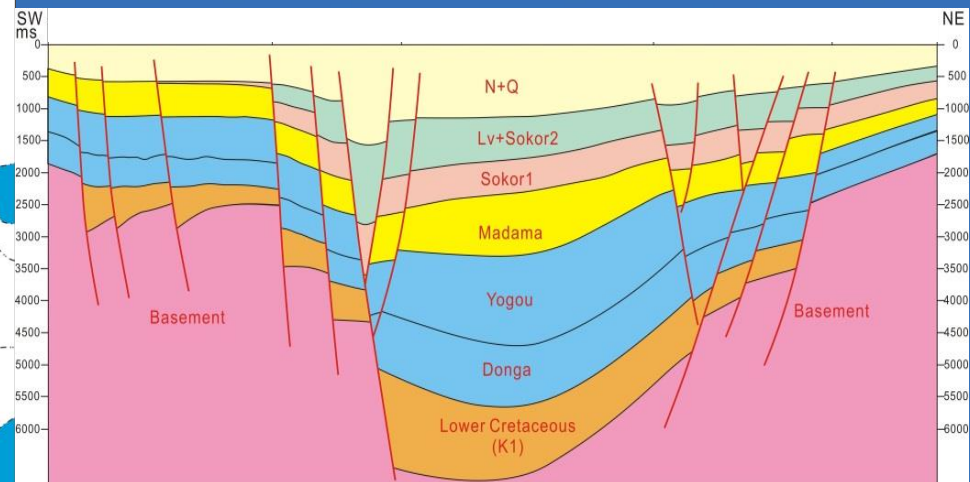
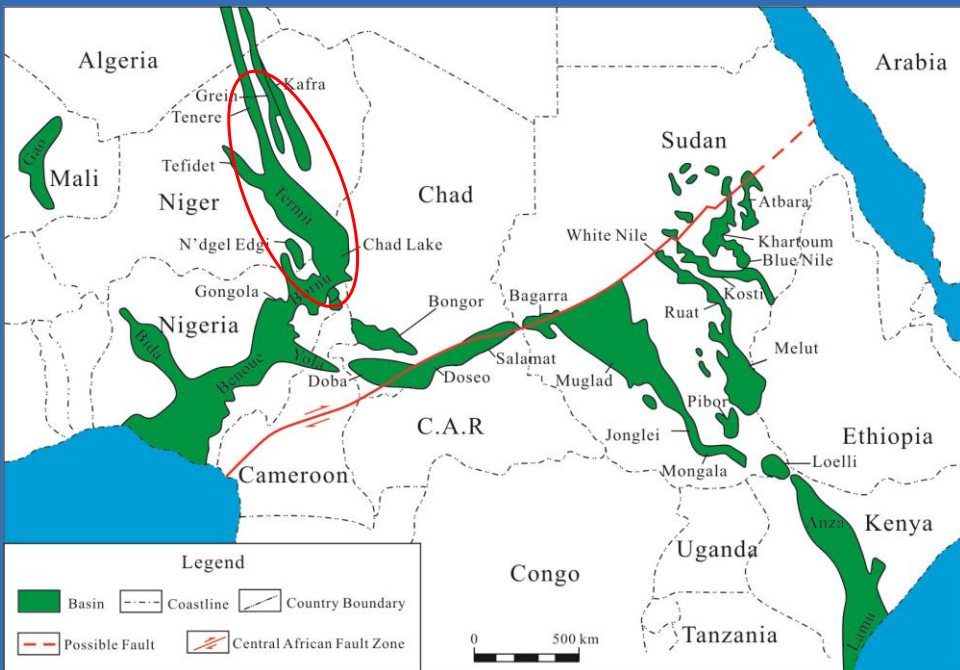
- Structural and lithologic reservoirs.
- thick mudstone seal, middle-coarse sand and granite reservoir (buried hill).
- Conventional, light and condensate oil.



Hydrocarbon accumulation in Bongor Basin(DOU Lirong, et al, 2011)

□ Termit Basin:

- Rifting stage: Early cretaceous and Paleogene.
- Depression stage: Late cretaceous, developing main source rocks (marine facies).
- Weak inversion: Late Cretaceous and Late Paleogene.
- Plays: upper Paleogene and Cretaceous.



Geologic profile of Termit Basin

Basin distribution map in Central-west Africa rift system(Genik,1992)

Petroleum System

□ Source Rock:

- Primary source rock: Late Cretaceous marine shale.
- Secondary source rock : paleogene lacustrine shale.

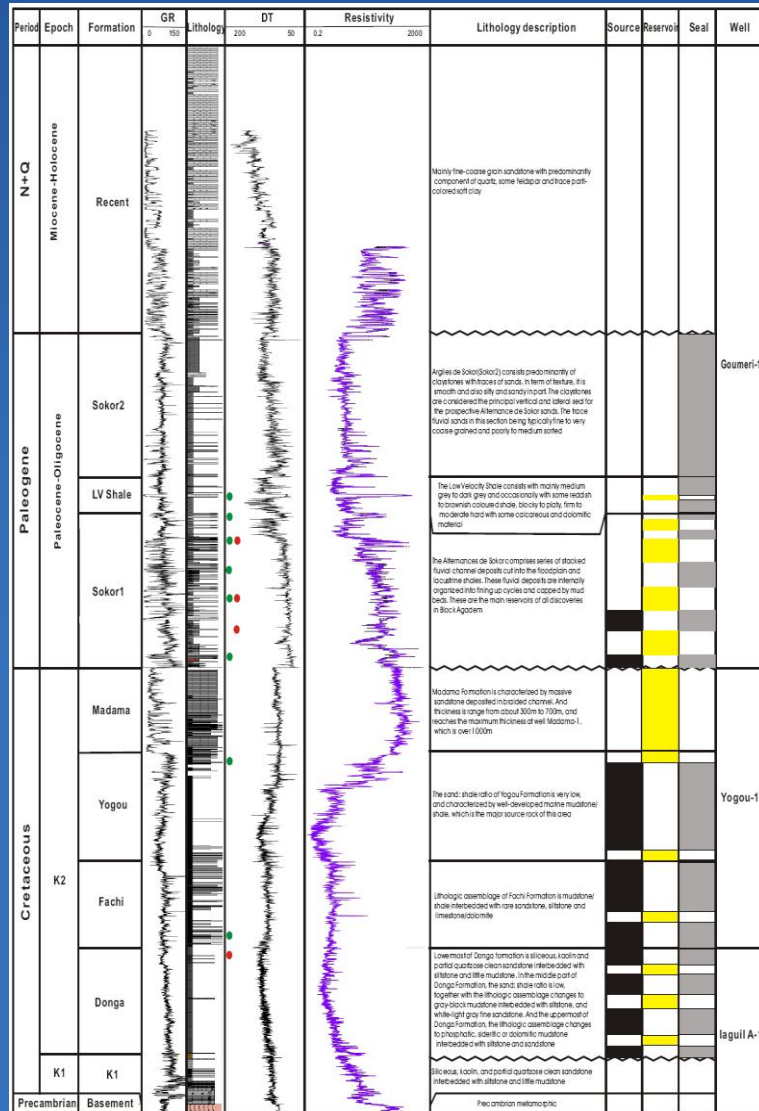
□ **Reservoir:** Paleogene fluvial and fan delta. sandstone;

□ **Cap Rock:** Paleogene lacustrine shale

□ Major Play:

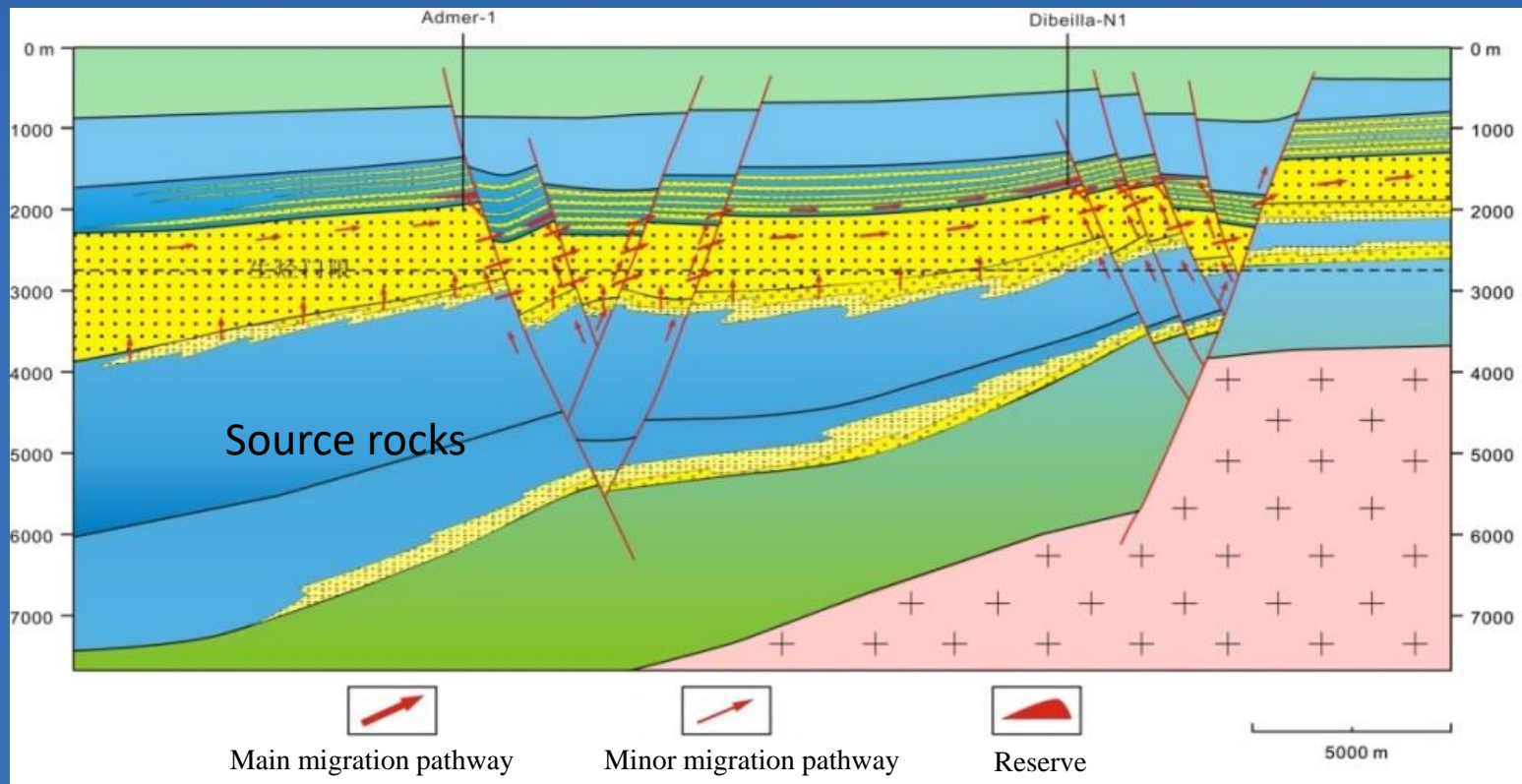
- Paleogene sokor Fm..
- Upper Cretaceous Yogou Fm..

□ **Trap:** antithetic fault block and faulted horst.



Composite column graph of Termit Basin

- Hydrocarbon migrate from Upper Cretaceous marine source.
- The Paleogene reservoirs directly cover on source rock and overlapped by Paleogene lacustrine shale.
- Faults are good migration pathways. Hydrocarbon accumulate in Paleogene traps.



HC migration and accumulation in Termit basin

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The undiscovered oil and gas resources in Africa are mainly distributed in West Africa, East Africa and North Africa.

❑ Oil & gas province in West Africa (undiscovered resources: billion bbls) Niger Delta, Gabon Basin,

Cote d'Ivoire Basin and Lower Congo Basin.

❑ Oil & gas province in East Africa (undiscovered resources: billion bbls) Rovuma Basin,

Mozambique Basin, Tanzania Basin, East African rift system (East and West branches).

❑ Oil & gas province in North Africa (undiscovered resources: billion bbls) Paleozoic craton margin

depression basin group in North Africa, Meso-Cenozoic Sirte Basin, Nile Delta, Cenozoic Suez Bay Basin.

❑ Central-West African rift system (undiscovered resources: billion bbls)

Central Africa rift system—Bangor basin, Dopa Basin, Muglad Basin, Melut Basin; west Africa rift system—Termit Basin.

- ❑ The formation-breakup evolution history of Gondwana resulted in multi-stage rifts and wide passive continental margins, developing 4 types of basins and 10 large basin groups.
- ❑ Important discoveries in recent years are mainly in West Africa, East Africa, deep sea area of North Africa, onshore Central-West African rift systems.
- ❑ The undiscovered oil and gas are mainly in West Africa, East Africa and North Africa.
- ❑ CNPC has made a series of important discoveries in Central-West Africa rift basins such as Muglad, Melut, Bongor and Termit basin.
- ❑ The future exploration areas are mainly in West Africa, East Africa and North Africa, followed by onshore regions of North Africa and Central-west Africa.

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