Tectonic Evolution Control on Hydrocarbon Accumulation in Fractured Basement: A Case Study from Melut Basin in South Sudan and Bongor Basin in Chad*

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Abstract

The Melut Basin in south Sudan and the Bongor Basin in Chad are two Late Cretaceous to Tertiary rift basins distributed, respectively, along the south and north side of Central African Shear Zone(CASZ). Hydrocarbons hosted in fractured basement reservoir have been found in both basins, but the hydrocarbon accumulation models of them are different. The objective of this study is to discuss the effects of tectonic evolution on hydrocarbon accumulation in fractured basement, which involves basement lithology, source rock development, hydrocarbon-generation history, caprock distribution, and accumulation. The analysis of regional tectonic evolution indicates that, from the Late Precambrian to the Carboniferous, the entire Africa plate experienced a relatively quiet phase, culminating in the collision of Gondwana and Laurentia during the Carboniferous. The basement adjacent to the rift areas is predominantly Precambrian granitic and metamorphic rocks. The two basins have similar basement lithology, which can be proved by core, log, and microscopic characteristics. The effect of basin evolution on large-scale fractures in basement is studied with seismic attributes (Ant-tracking) to indicate the relationship between the change of stress field and fracture distribution. The comparative study on the impact of structure and tectonic evolution on hydrocarbon accumulation was/is conducted according to stratigraphic framework, hydrocarbon-generation history, caprock development, related faults, and structural-framework evolution. The result shows that the two basins have experienced differences in tectonic evolution. The Bongor Basin experienced a relatively constant rifting-sagging stage during Early Cretaceous, and the whole basin suffered tectonic inversion in Late Cretaceous as a result of the collision of African plate and Eurasian plate. Whereas, the Melut basin experienced three phases of the rifting-sagging cycle, which was stronger in Early Cretaceous and Paleogene and weaker in Late Cretaceous. There tectonic inversion occurred only in local areas. The research on hydrocarbon-generation

history has shown that hydrocarbons accumulated in Early Cretaceous in Bongor Basin and in Late Cretaceous in Melut Basin. This difference in evolution led to different accumulation conditions for basement reservoirs in terms of caprocks, hydrocarbon charge and preservation, and accumulation.

Selected References

Dou, L., C. Shrivastava, C. Dai, J. Wang, N. Hammond, C. Anakwe, M. Siddick, and B. Xu, 2014, Deciphering an unconventional African reservoir: Geological characterization of granitic basement from Bongor Basin, Chad: Search and Discovery Article #10673 (2014). Website accessed April 25, 2016, http://www.searchanddiscovery.com/documents/2014/10673hrivastava/ndx_shrivastava.pdf.

Dou, L., C. Shivastava, W. Jingchun, N. Hammond, C. Anoliefo, D. Lei, and M. Siddick, 1914, Understanding the interplay of fractues, stresses and Facies in unconventional reservoirs - Case study from Chad granites (abstract): EAGE Conference and Exhibition, Amsterdam, The Netherlands. Website accessed April 25, 2016, http://www.slb.com/~/media/Files/technical_papers/eage/eage2014_tu-d201-04.pdf.

Genik, G.J., 1992, Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and the Central African Republic(C.A.R.): Tectonophysics, v. 213, p. 169–185.

P'An, C-H, 1982, Petroleum in basement rocks: AAPG Bulletin, v. 66, p.. 1597-1643.

Wang, X., L. Dou, Y. Zhao, D. Mao, Q. Zhang, and X. Wei, 2015, Fractured granite basement reservoir discoveries in the Bongor Basin of Chad (abstract): Search and Discovery Article #90216 (2015). Website accessed April 25, 2016, http://www.searchanddiscovery.com/abstracts/html/2015/90216ace/abstracts/2090846.html.

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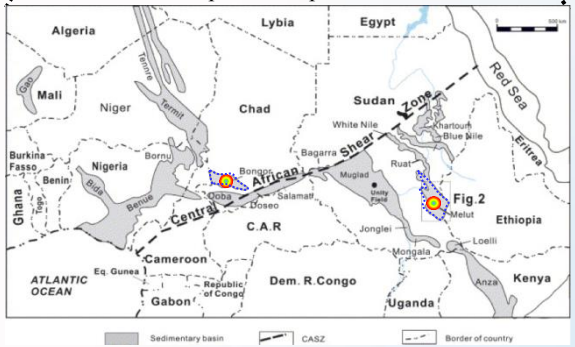
Outline

Basement Reservoir Exploration in Africa

- **Basement Reservoir widely developed in Africa, but essentially non-commercial to date**

Simplified Map of Africa



Mesozoic-Tertiary Rift Systems of CASZ

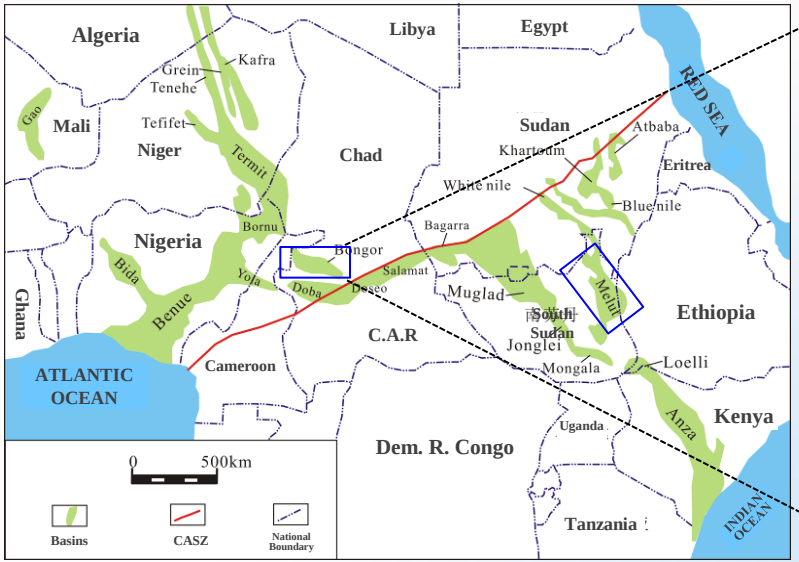
North Africa	Algeria：Cambro-Ordovician quartzitic sandstones （Hassi Mesaoud Oil Field、Saharan Area）
	Egypt：Precambrian igneous and metamorphic rocks （Hurghada Oil Field、Zeit Bay Oil Field）
	Libya：Precambrian igneous （Nafoura-Augila Oil Field）
	Morocco：Precambrian granite and Paleozoic metasediments （9 Oil Fields，Produced more than 3.75 million barrels of oil since discovery in 1947 (P'An, 1982)
South Africa	Namibia:(Kudu Oil Field)
East Africa	Kenya：Clastic volcanic rocks (Turkana Depression)
West Africa	Angola: (Onshore Cabinda, about 600,000 barrels)
CASZ	Melut Basin：Precambrian igneous and metamorphic rocks (very few wells with oil in fractured basement)
	Bongor Basin：Precambrian igneous and metamorphic rocks (5 Buried-hill structures with oil flows)

Basement Reservoir Distribution in Africa

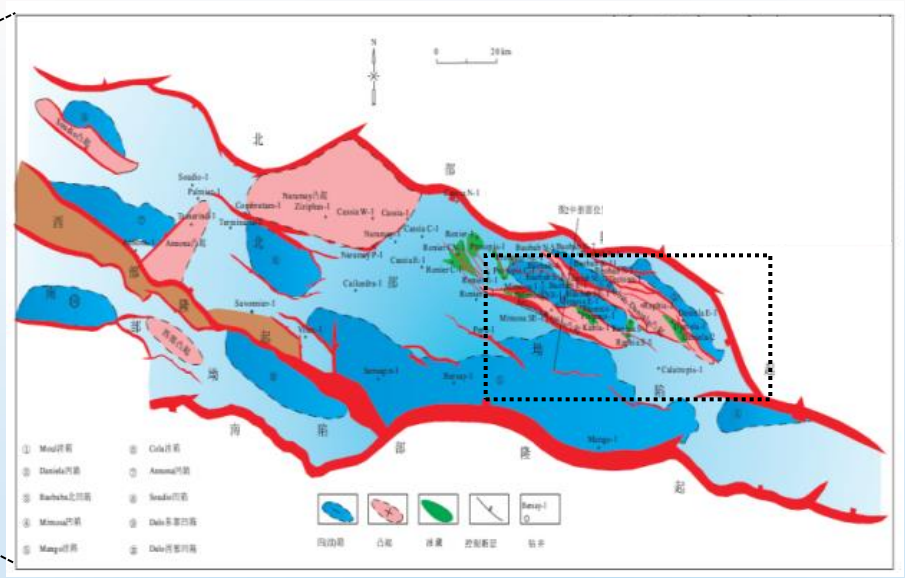
Basement Reservoir Exploration in Bongor Basin

Exploration Situation in Bongor Basin

- Oil potential of naturally fractured basement reservoirs in Bongor basin is manifested by the discovery of Lanea-1 in early 2013.
- Eight "buried hill" belts have been recognized on the north slope, aligned along the sub-parallel NW-SE trends; and five of them have been targeted as hydrocarbon-bearing reservoirs by drilling.



Location of Bongor Basin

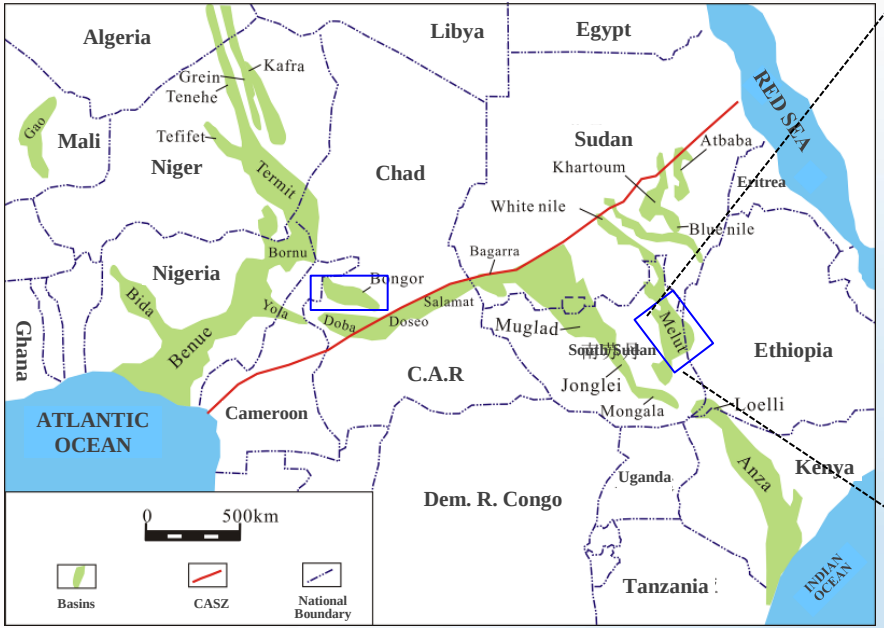


Structure of Bongor Basin

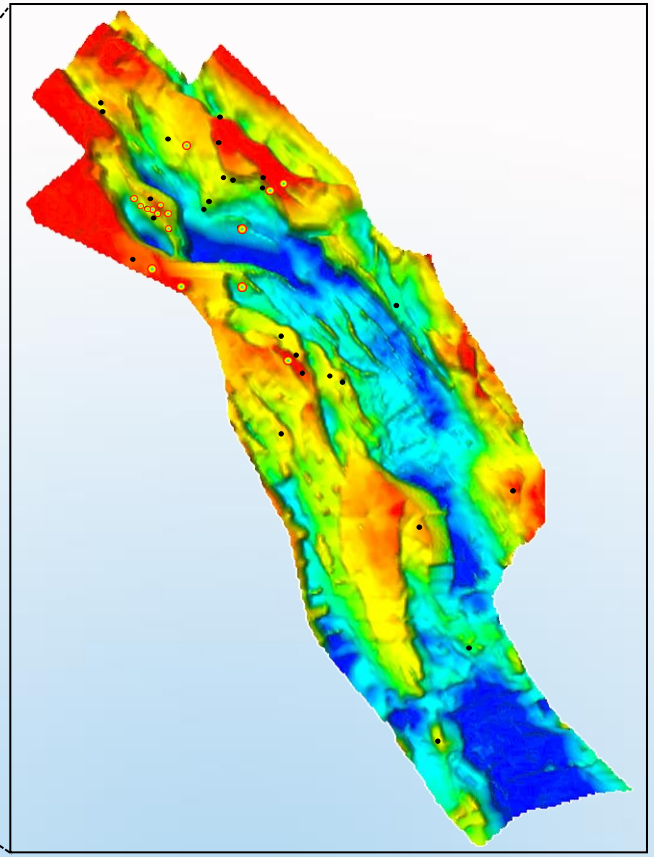
Basement Reservoir Exploration in Melut Basin

Exploration Situation in Melut Basin

- About 40 wells have penetrated basement in Melut Basin.
- The hydrocarbon shows in basement are mainly distributed in Ruman Uplift, but only 2 wells with oil flows.



Relationship of Melut Basin with Central Africa



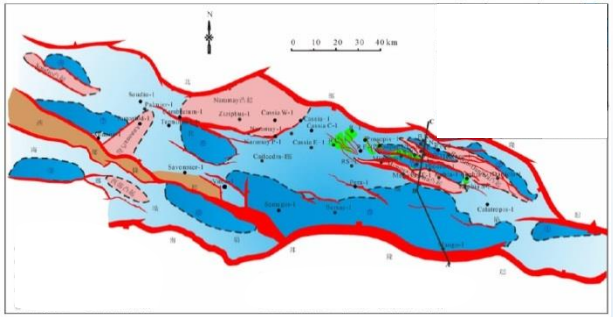
Wells That Penetrated Basement in Melut Basin

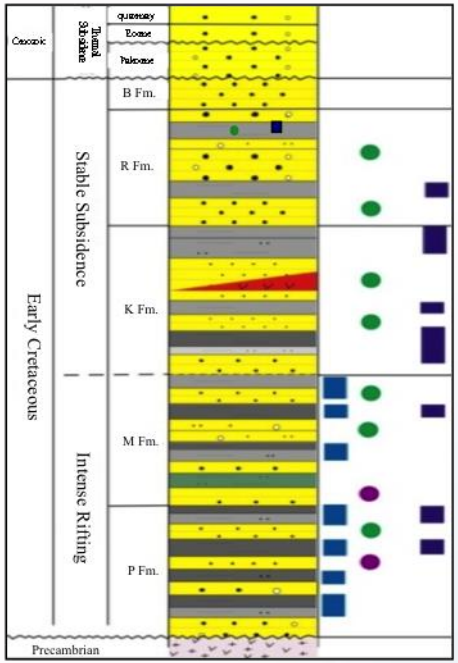
Outline

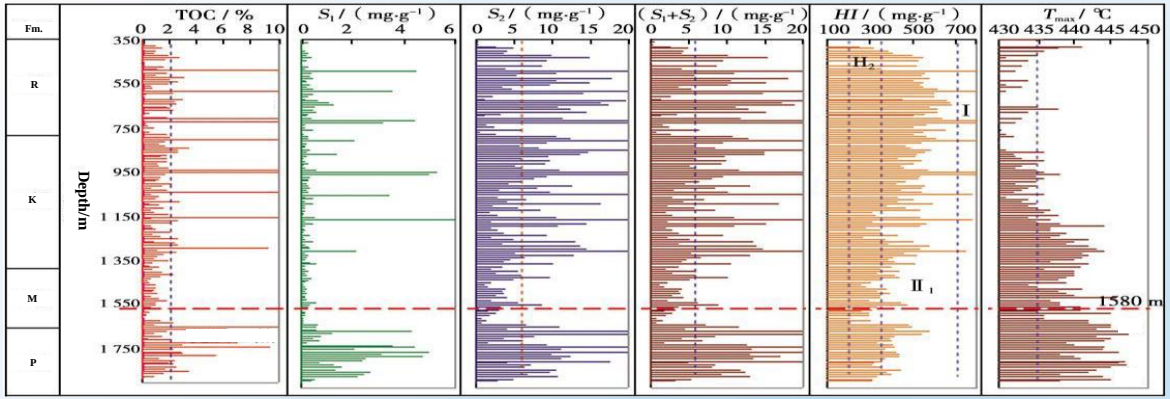
Geological Setting of Basement Reservoir in Bongor Basin

1. Oil Source Rock – P and M Fms. are the major source rocks in Bongor basin.

- P and M Formations have high TOC values with an average of 3.5%. The organic matter is mainly of I-type kerogen and in mature stage.
- Several sub-basins are developed which provide good oil source for buried hills.





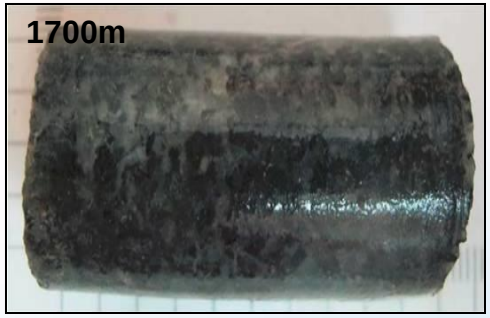


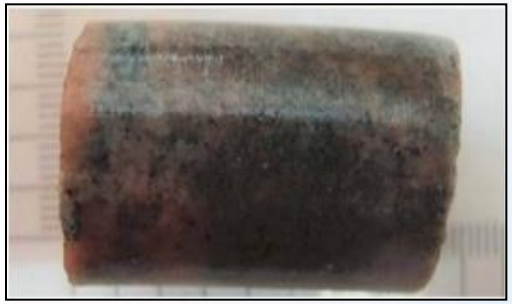
Geochemical Profile of Mimosa-2, Bongor Basin（Dou Lirong，2011）

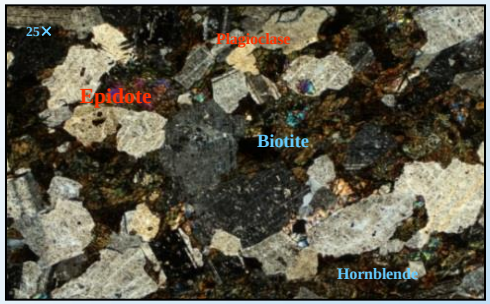
Geological Setting of Basement Reservoir in Bongor Basin

2.Reservoir — ①The lithology of granite and granitic gneiss basement is favorable for formation of fractures.

➢ The lithology of basement is mainly composed of granite and granitic gneiss with minor occurrences of other igneous rocks and gneiss.







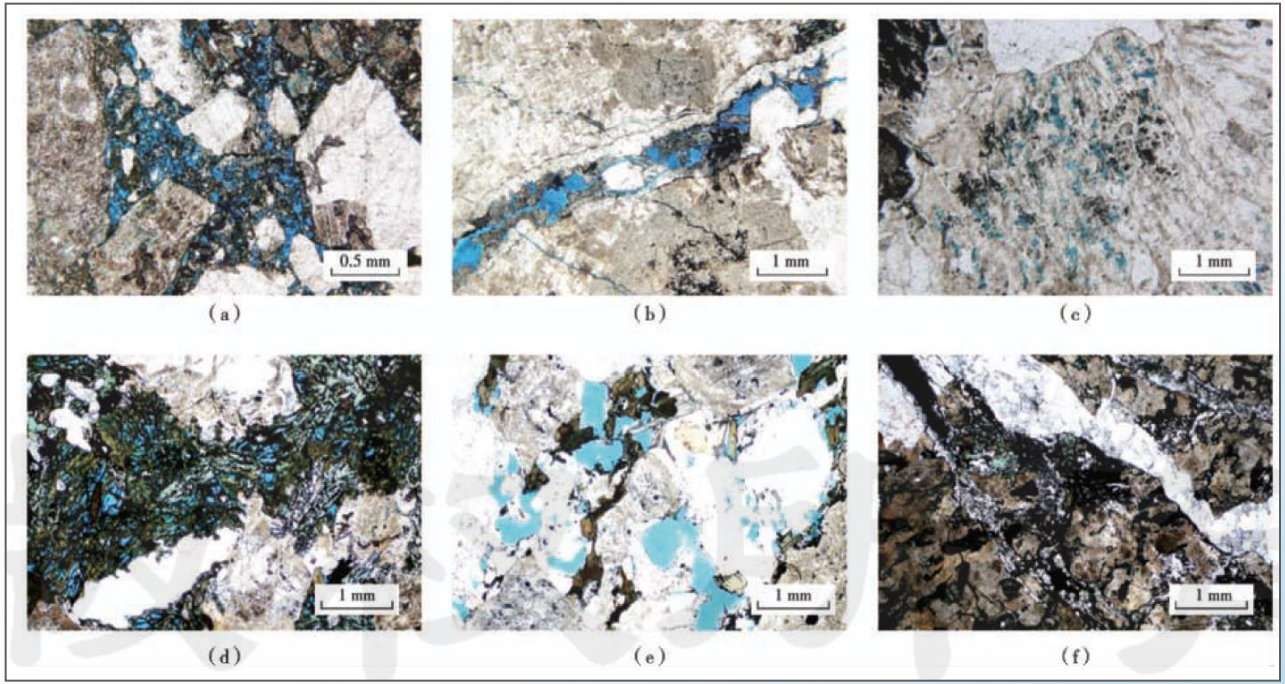
Well-1

Well-2

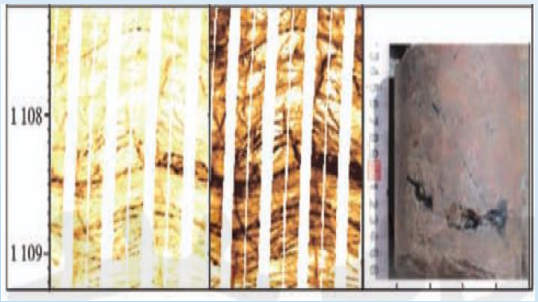
Geological Setting of Basement Reservoir in Bongor Basin

2. Reservoir — ② The basement reservoirs are well developed.

- Two reservoir space types: pore-type and fracture-type



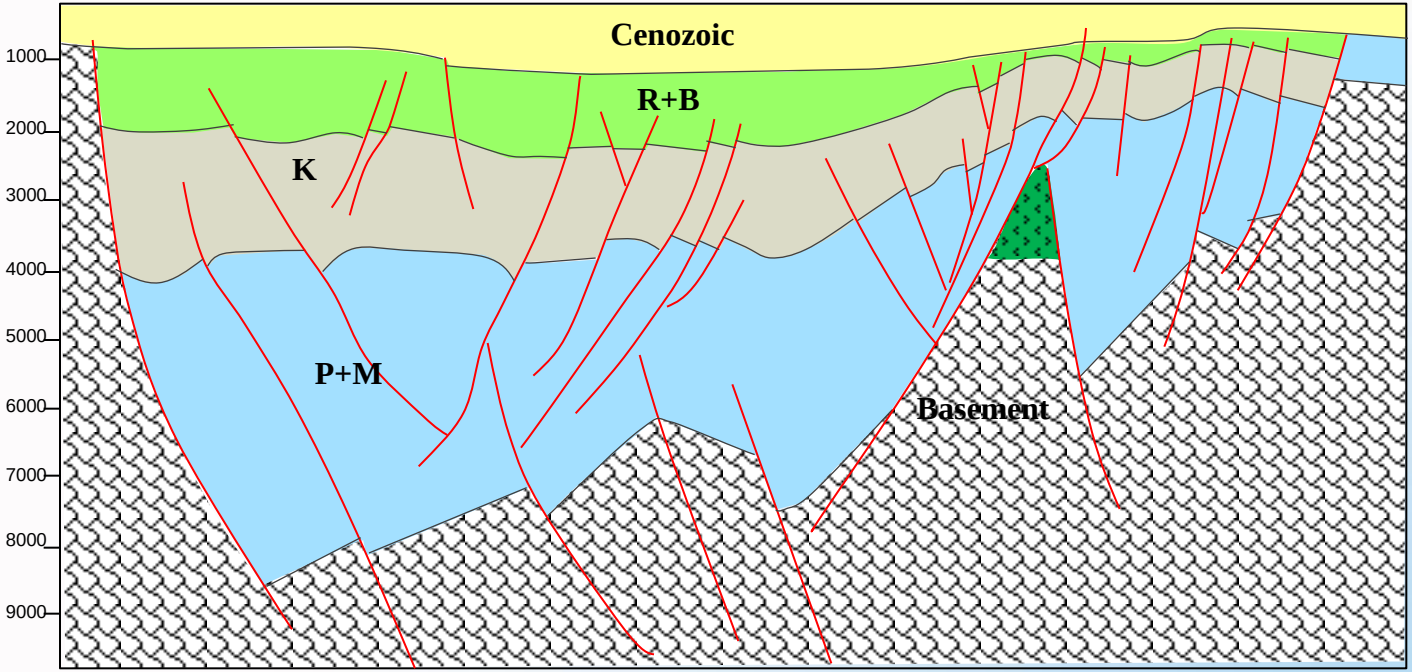
Characteristics of pores within basement buried-hill reservoirs（Dou Lirong，2015）

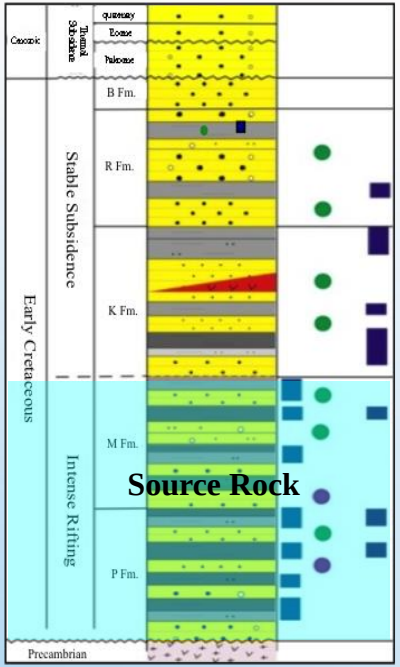


Core photos and FMI of two types of granitic buried-hill reservoir（Dou Lirong，2015）

Geological Setting of Basement Reservoir in Bongor Basin

3. Caprocks — P and M Formations are both oil source rocks and caprocks for basement.

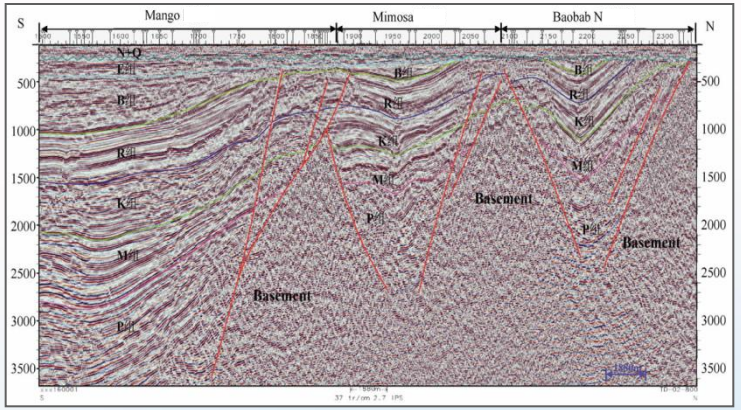


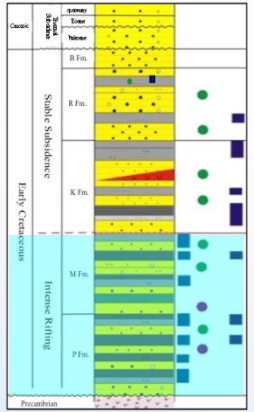


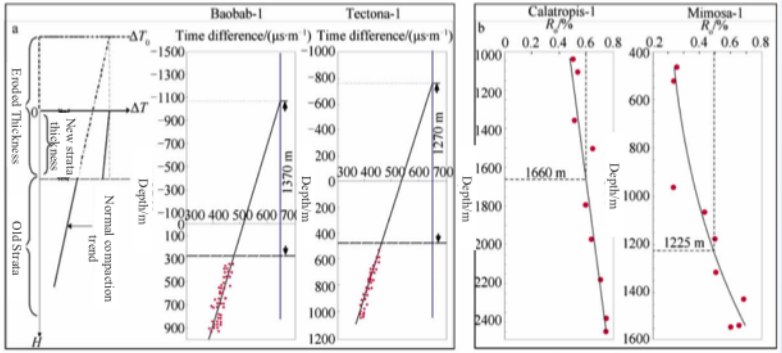
Geological Setting of Basement Reservoir in Bongor Basin

4. Structure –Intensive structural inversion resulted in regional basinal uplift.

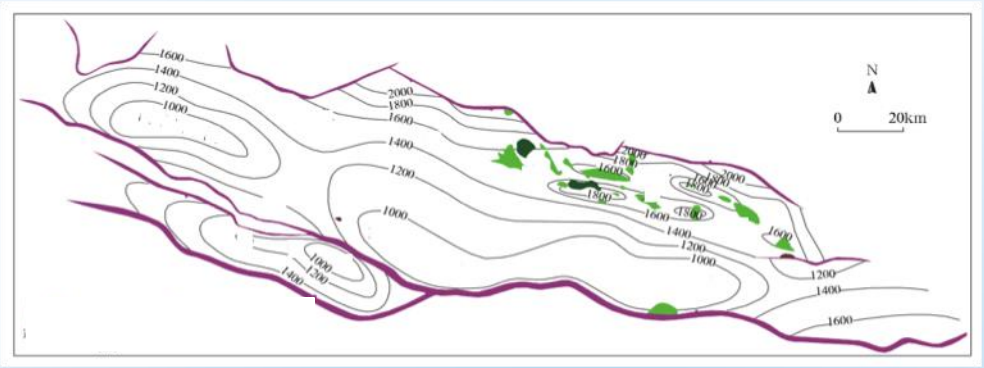
- The Lower Cretaceous is directly overlain by Cenozoic; Mesozoic erosion ranged from 600 to1600m.
- The deeply buried basement was uplifted in Late Cretaceous.
- The drilling depth of basement is mostly about 2000m.







Restoration of Erosion Using Ro and Acoustic Logging Data (Xiao Kunye, 2015)

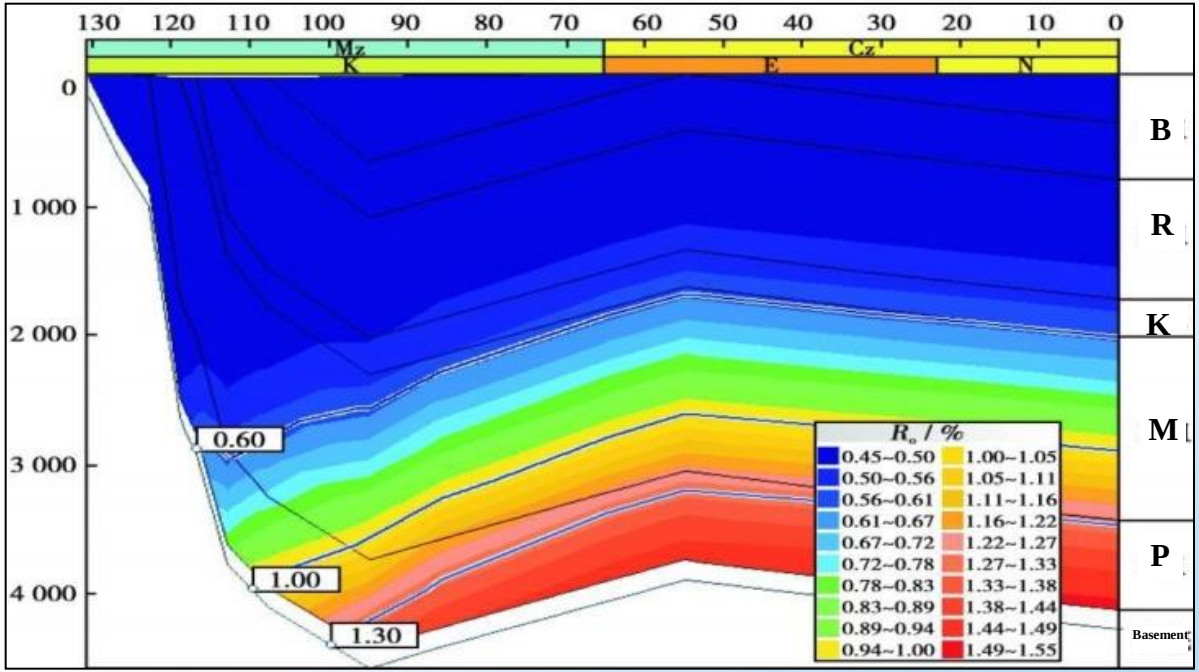


Estimate of Mesozoic Erosion in Bongor Basin (Yu Zhaohua, 2013)

Geological Setting of Basement Reservoir in Bongor Basin

5. History of Hydrocarbon Generation – Hydrocarbon accumulated in late Early Cretaceous

➢Oil from basement is about 25-33API.

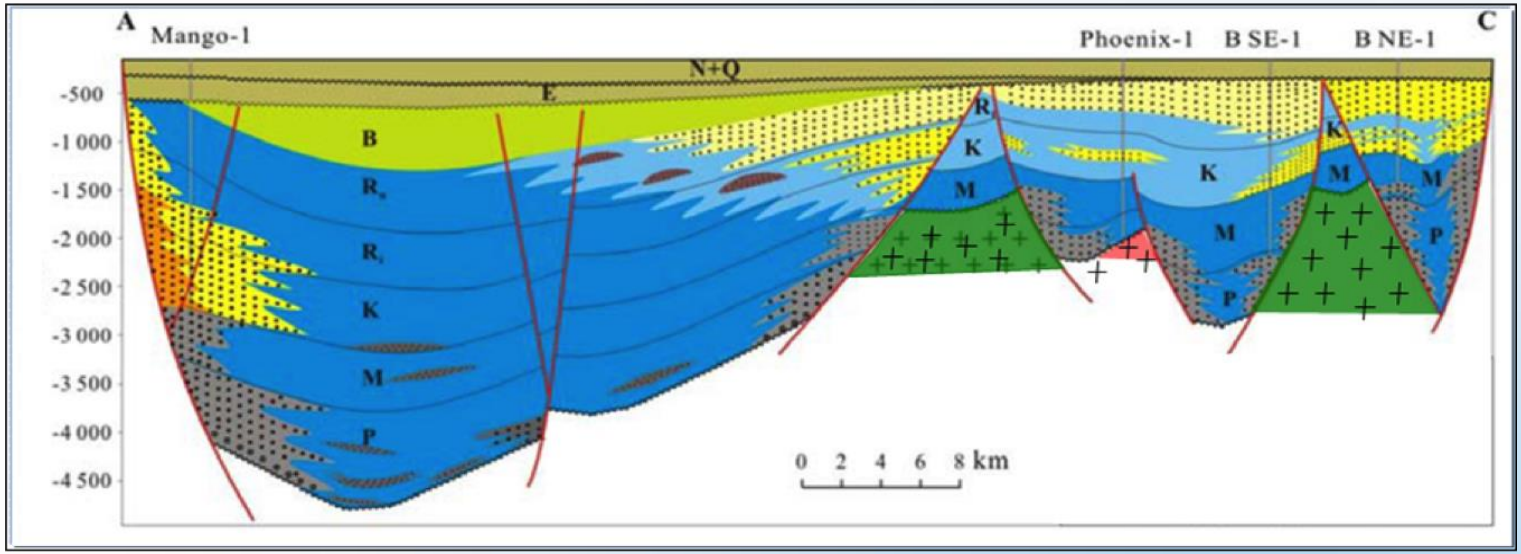


One Dimensional Basin Modeling of Bongor Basin

Geological Setting of Basement Reservoir in Bongor Basin

Key Geological Features of Basement Reservoir in Bongor Basin

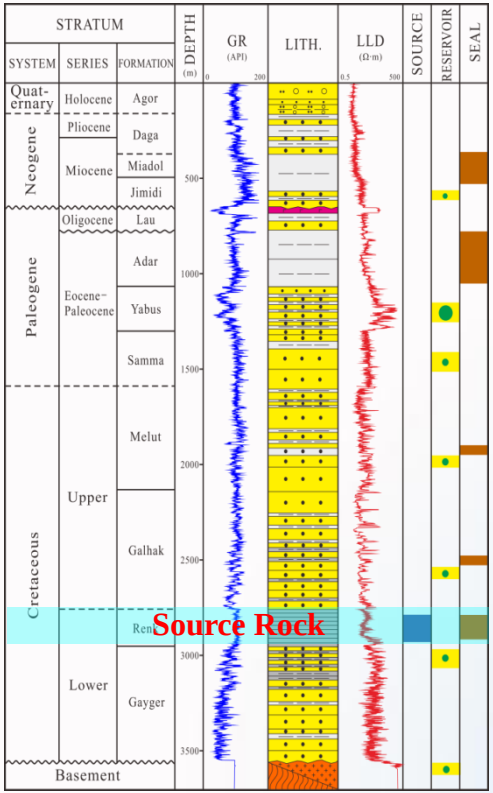
- Oil Source: the development of several sub-basins provides good oil source rock for buried hills in Bongor basin.
- Caprock: the overlying source rocks of basement provide good caprock
- Reservoir: the lithology of granite basement is favorable for fracture formation; the basement reservoirs are well developed in Bongor basin.
- Structural Inversion: the deeply buried basement, underlying the source rock, was uplifted to a shallow position.
- Oil that accumulated in basement in late Early Cretaceous was not affected by the regional uplift in Late Cretaceous.

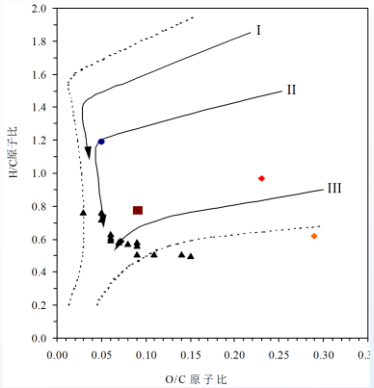


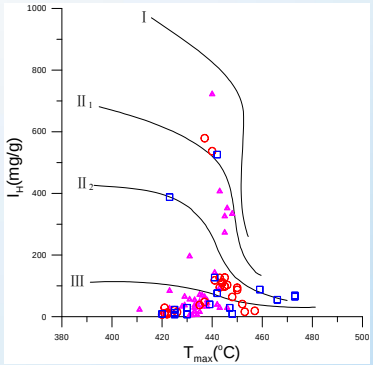
Outline

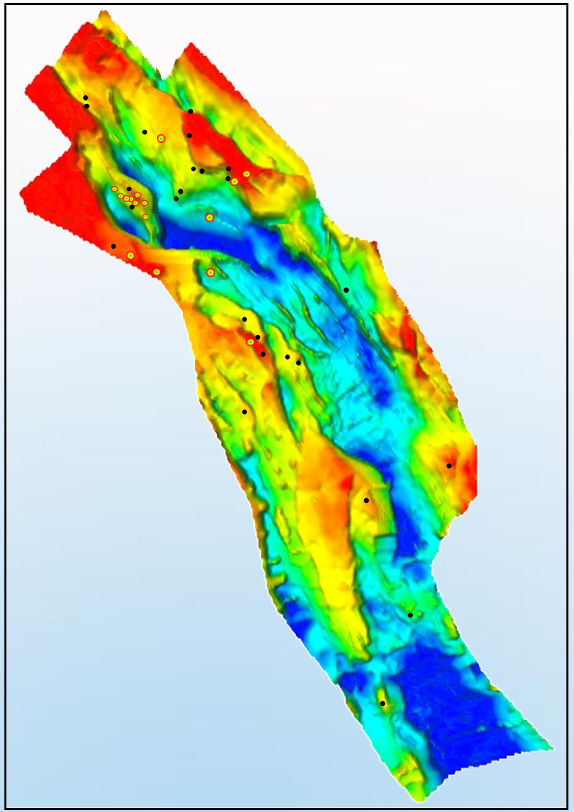
Comparison of Geology of Basement Reservoir between Bongor and Melut Basins

1. Oil Source Rock – Renk Fm. (Lower Cretaceous) is the major source rock of Melut Basin





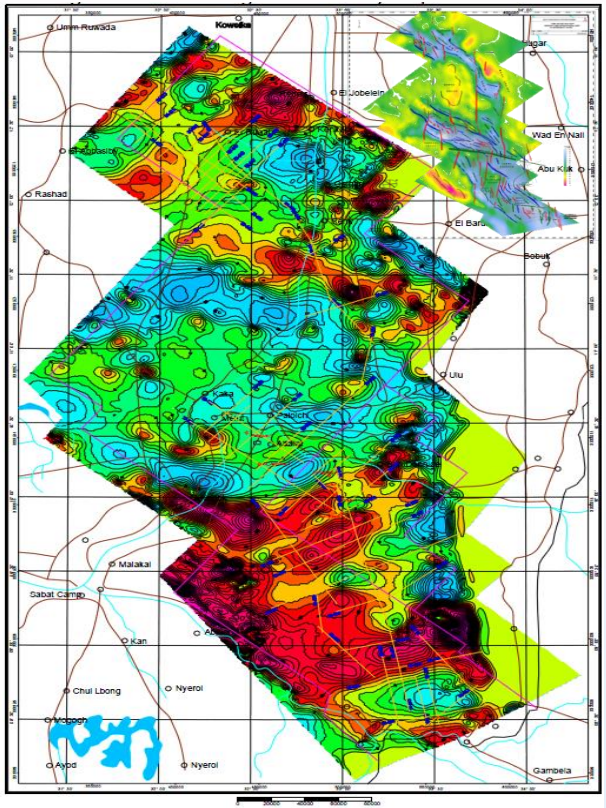




Wells That Penetrated Basement in Melut Basin

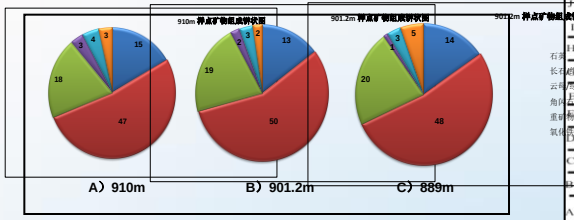
Comparison of Geology of Basement Reservoir between Bongor and Melut Basins

2.Reservoir — ①Similar lithology of granite and granite gneiss basement

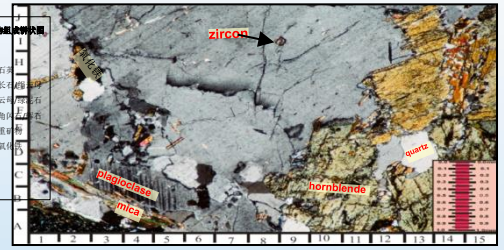


Residual Magnetic Anomaly Map of Melut Basin

- The lithology of basement in Melut basin is different from North to South.
- The mineral of basement in North is mainly composed of feldspar, mica, and quartz, with minor hornblende and pyroxene.

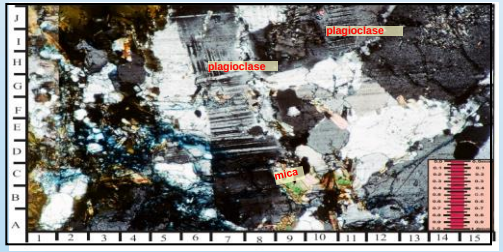


A）Ruman N-2：910m



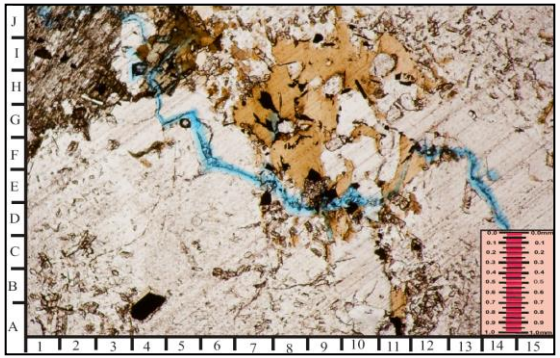
B）Ruman N-2：901.2m

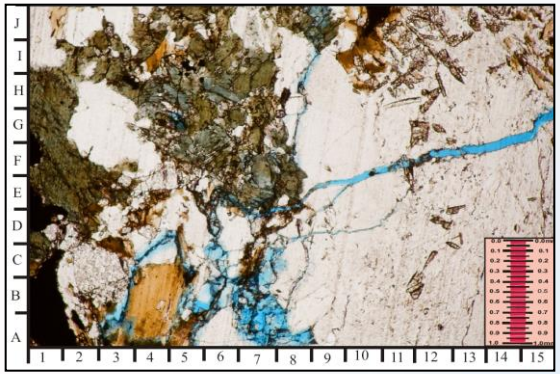
C）Ruman N-2：889m

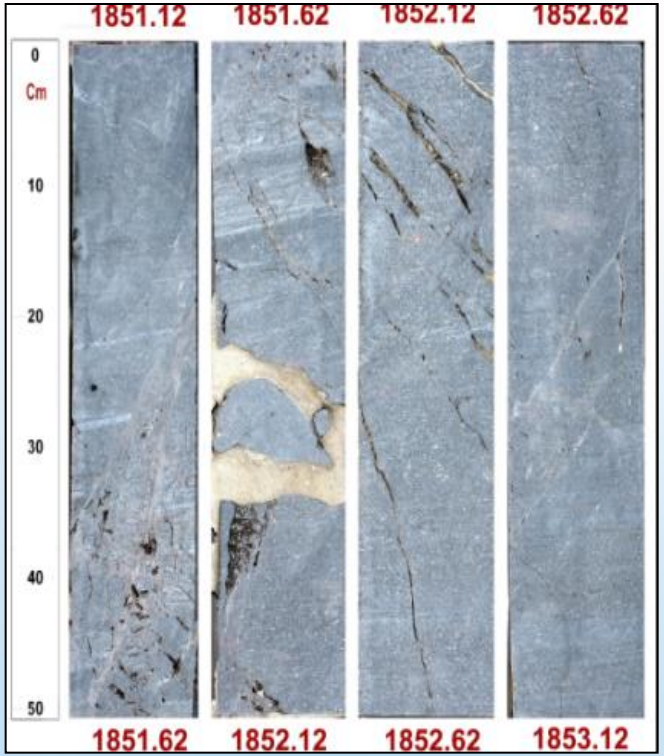


Comparison of Geology of Basement Reservoir between Bongor and Melut Basins

2. Reservoir — ② The basement reservoirs are also well developed.







Comparison of Geology of Basement Reservoir between Bongor and Melut Basins

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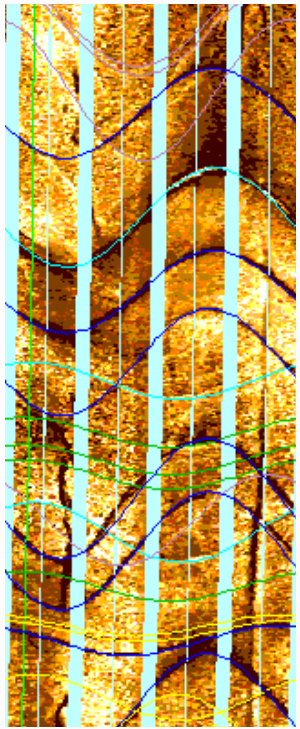
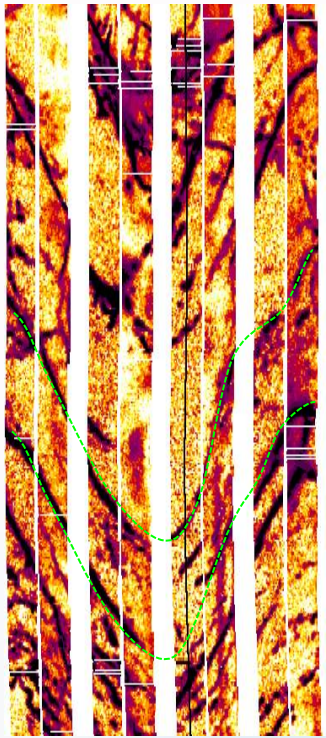


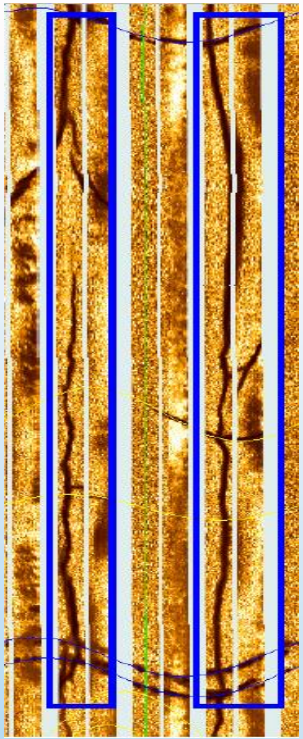
Continuous Conductive Fractures



Discontinuous Conductive Fractures

Continuous Resistance Fractures

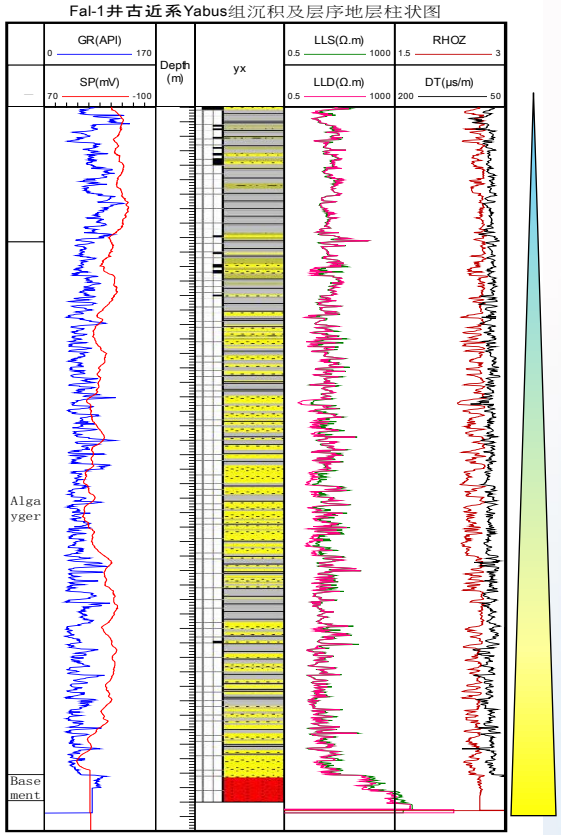
Dissolution-Enhanced Fractures

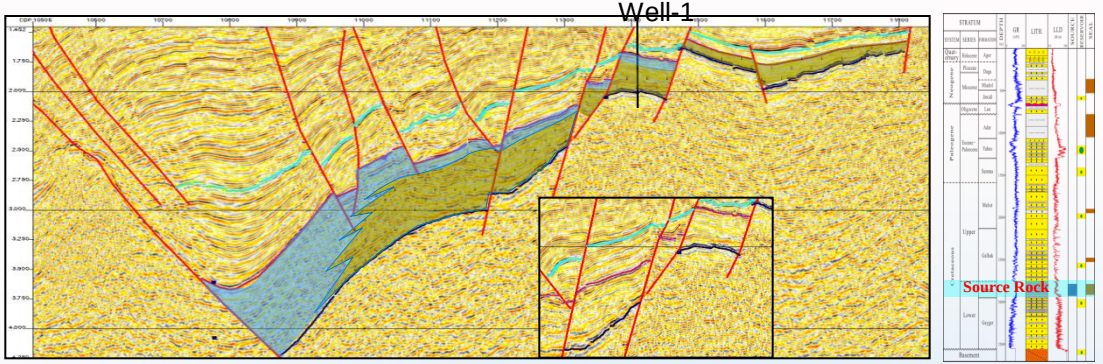


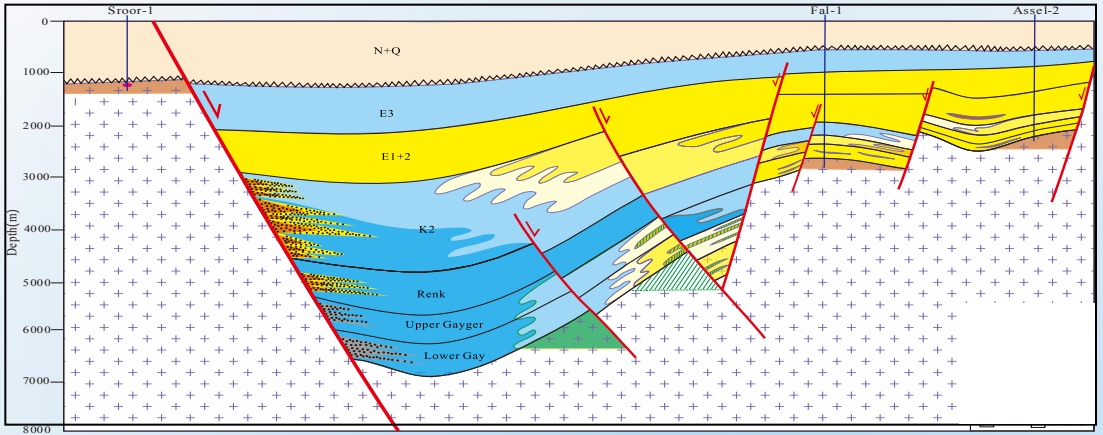
Inductive Fractures

Comparison of Geology of Basement Reservoir between Bongor and Melut Basins

3. Caprocks — The overlying Gayger Fm. of basement is composed of sandstones in higher positions.

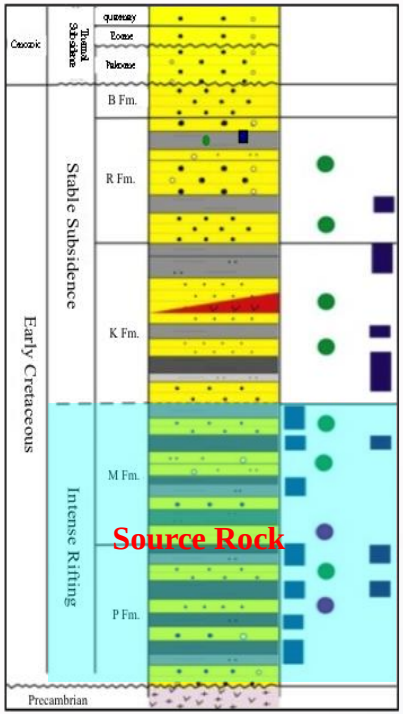




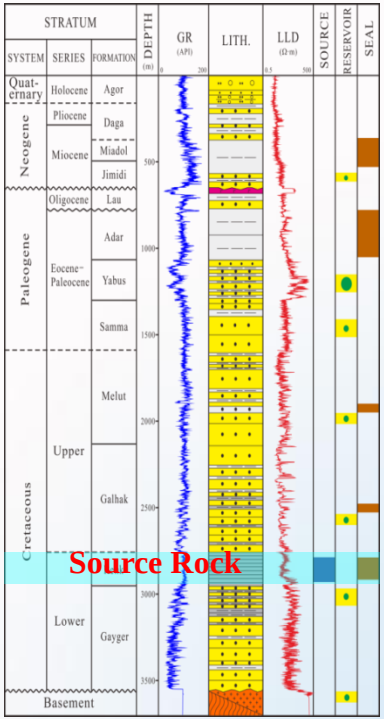


Comparison of Geology of Basement Reservoir between Bongor and Melut Basins

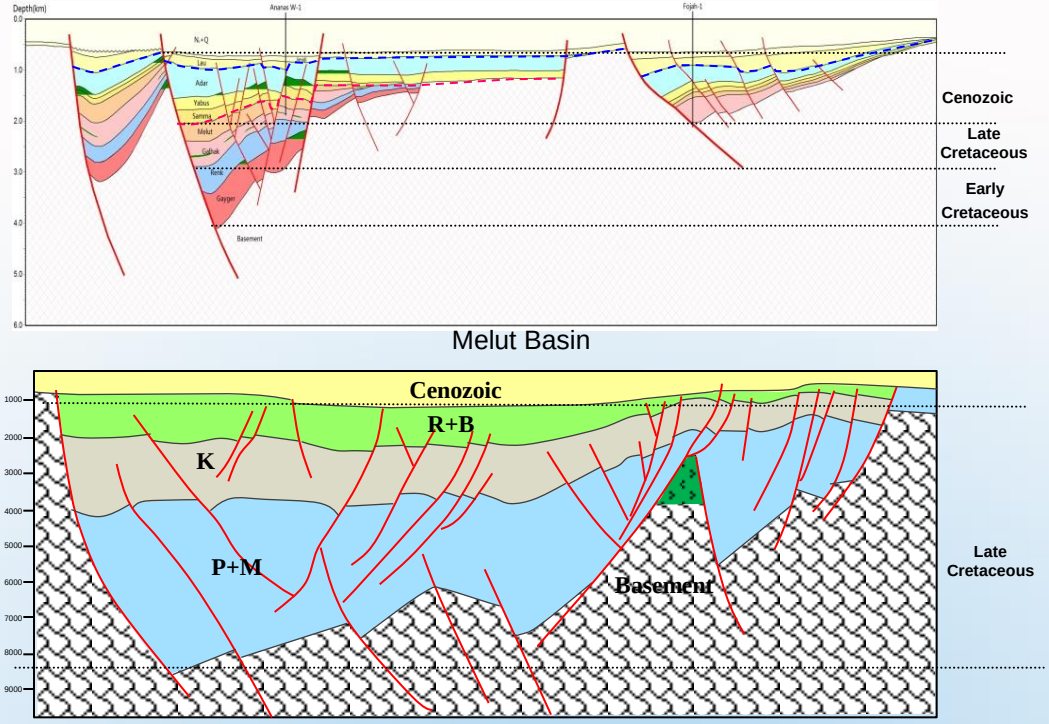
4. Structure — The buried hill of Melut basin is an inherited uplift.



Bongor Basin



Melut Basin



Bongor Basin

Comparison of Geology of Basement Reservoir between Bongor and Melut Basins

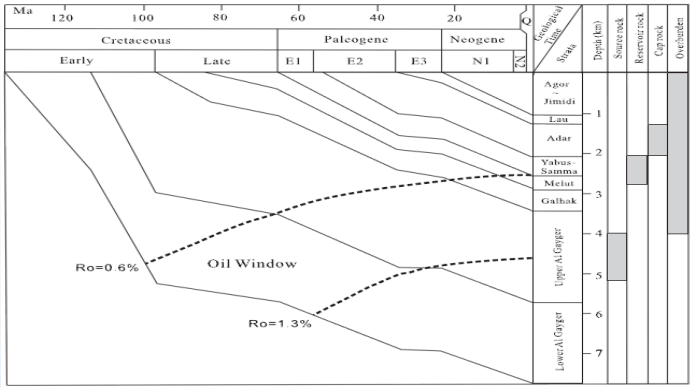
5. Hydrocarbon Generation and Expulsion

Melut Basin – HC generated in Eocene to Oligocene.

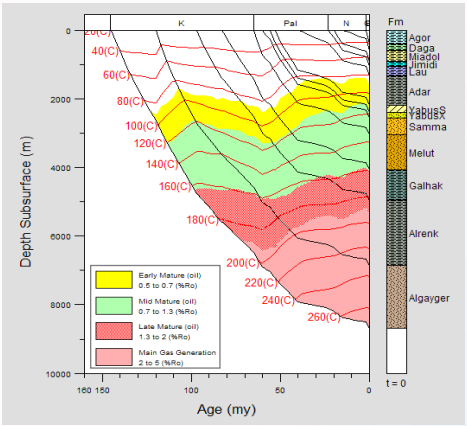
- The low geothermal gradient (2.94) caused the source rocks to mature late.

Bongor Basin – HC generated in late Early Cretaceous

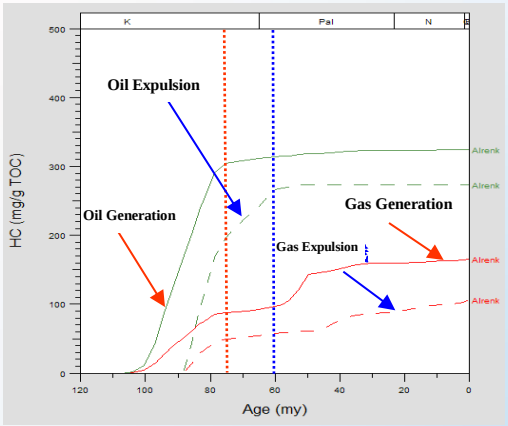
- The HC generation ceased in Late Cretaceous.
- The geothermal gradient ranges from 2.9-4.9.



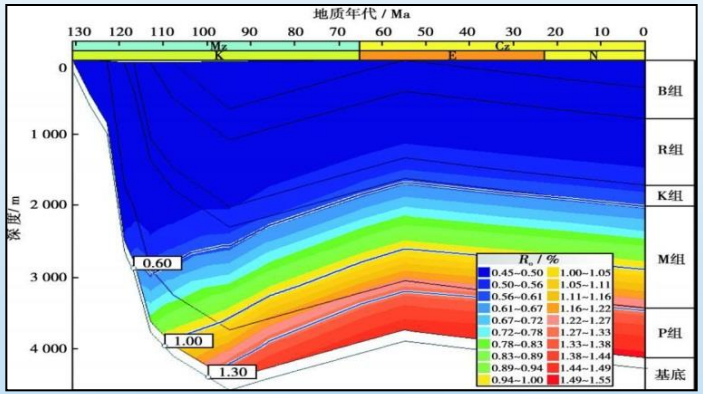
Hydrocarbon Generation History of Melut Basin



Burial History of Well in Melut Basin



Hydrocarbon Generation and Expulsion History of Renk Fm.



Hydrocarbon Generation History of Bongor Basin

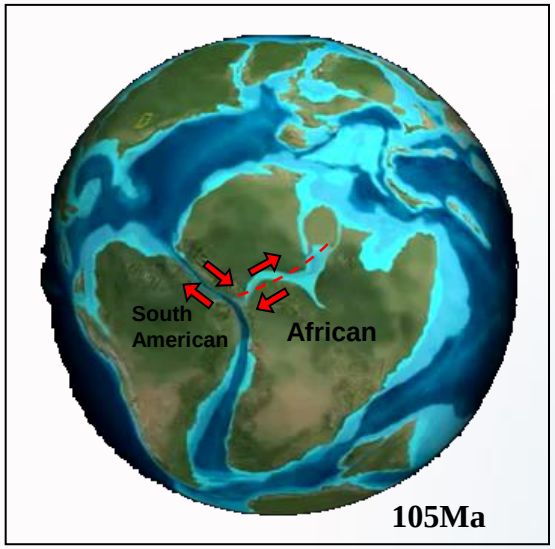
Outline

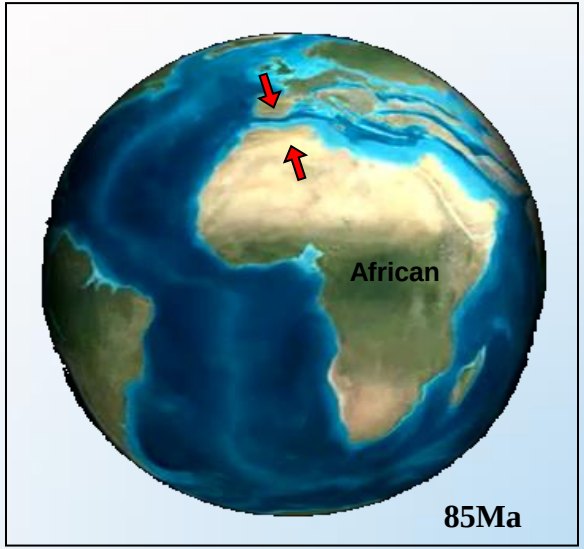
Control of Structure and Tectonic Evolution on Hydrocarbon Accumulation in Fractured Basement

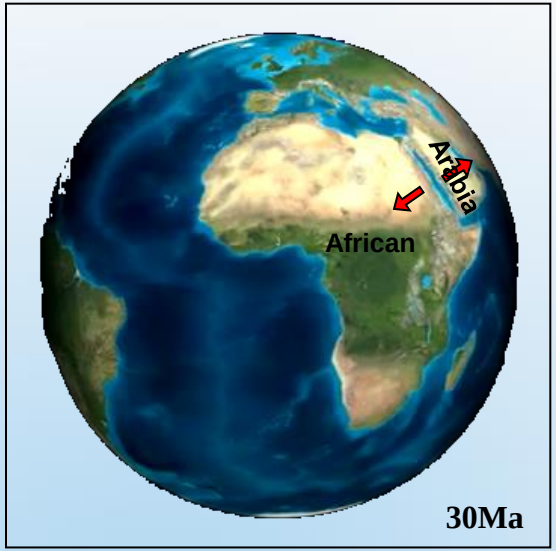
Tectonic Evolution of CASZ

Three stages since Pan-Africa movement

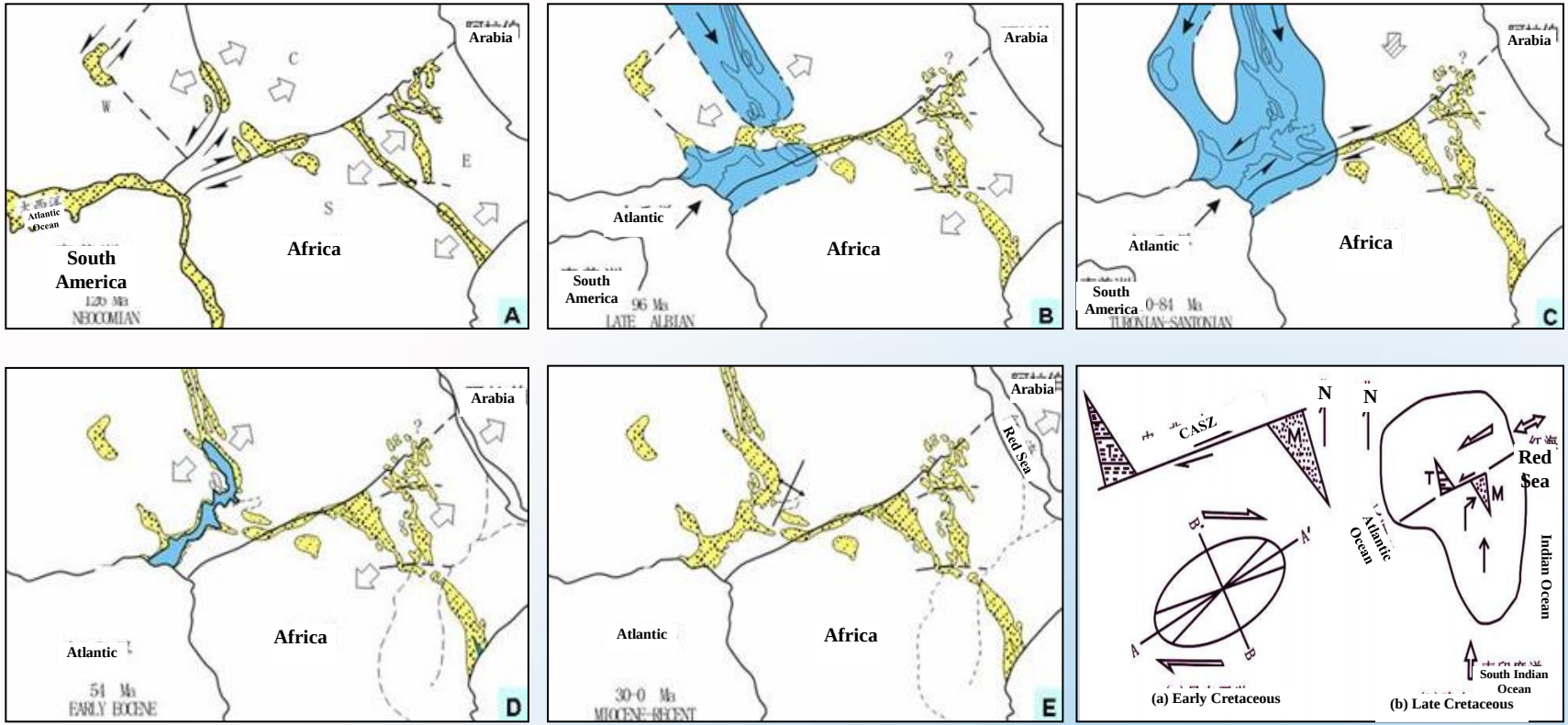
- 550Ma～130Ma. The entire Africa plate experienced a relatively quiet tectonic phase.
- 130Ma~20Ma. Gondwana breakup and South Atlantic Ocean opening; the CASZ formed.
- After 30Ma. The activity of CASZ ceased; the Arabian began to rift away from the African to form the Red Sea.





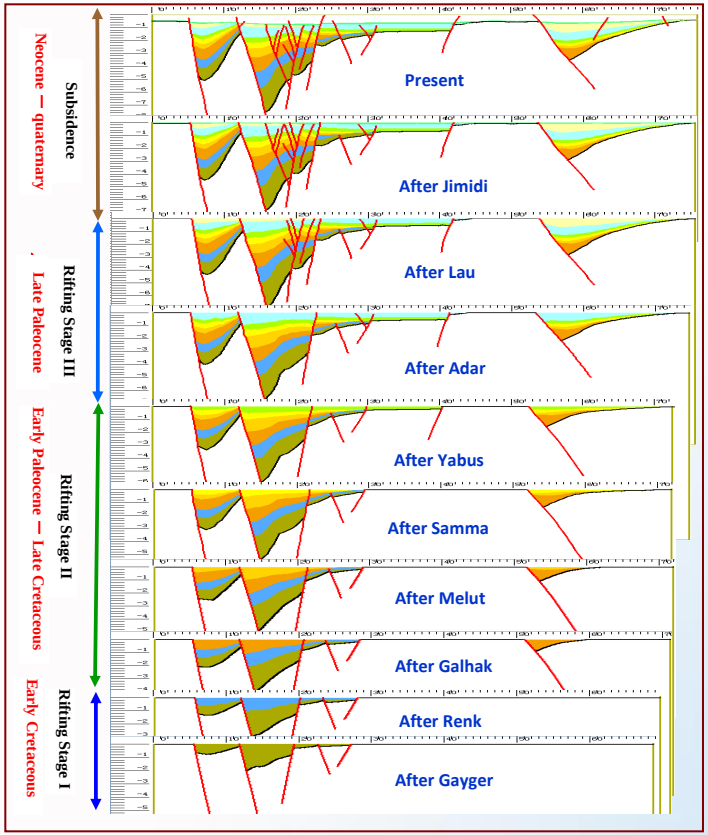


Control of Structure and Tectonic Evolution on Hydrocarbon Accumulation in Fractured Basement

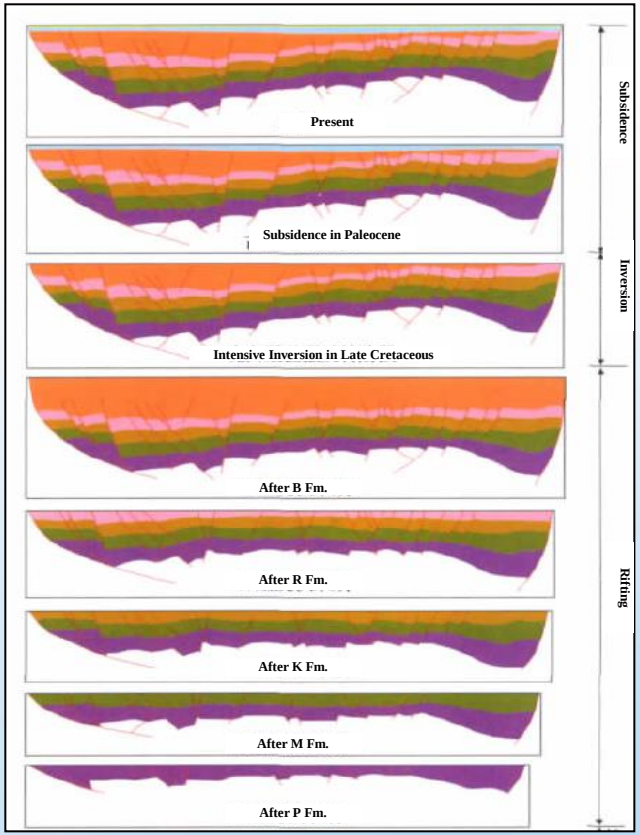


(Modified after J. G. Genik, 1992)

Control of Structure and Tectonic Evolution on Hydrocarbon Accumulation in Fractured Basement



Profile of Tectonic Evolution of Melut Basin



Profile of Structural Evolution of Bongor Basin

Conclusions

- **Both of these two basins have good oil source rocks for basement reservoir.**
- **The P&M formations are both oil source rock and caprock for basement in Bongor Basin. The Gayger Fm. overlying basement in Melut basin includes sandstone in higher positions. The favorable caprock for basement is everywhere at deeply buried depths.**
- **These two basins have similar basement lithology of granite and granitic gneiss, which is favorable for fracture formation; core data, FMI data, and microscopic examination also proved reservoir development.**
- **The different evolution history led to different accumulation conditions for basement reservoirs in terms of caprocks, hydrocarbon charge, and preservation. The Bongor Basin experienced a relatively constant rifting-sagging stage during Early Cretaceous, and the whole basin suffered a tectonic inversion in Late Cretaceous. Melut basin experienced three phases of the rifting-sagging cycle, which was stronger in Early Cretaceous and Paleogene and weaker in Late Cretaceous. Tectonic inversion occurred only locally.**

Thanks !