Forming Conditions, Types and Characteristics of Lithological Reservoirs in Melut Basin: Implications for Hydrocarbon Exploration in Mature Rift Basins of Africa*

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Abstract

African rift basins develop rich hydrocarbon resources, and after decades of exploration, the mature basins are facing challenges of discovering new plays and new prospects. Against this background, the latest research and exploration progress on lithological reservoirs in Melut Basin will be presented, which will give an implication for African mature basins. Melut Basin is located in central Africa with an area of 33,000 km^2, and most structural prospects have been drilled over the past years, so it is particularly urgent to carry out lithological reservoir exploration for new discoveries. With the wire-logging, mud-logging, and coring data from near 200 wells and 4,000 km^2 3D data, the source rock evaluation, sedimentary facies, and fault features were researched, which indicated that Melut Basin has the lithological oil reservoir forming conditions. The research guided the exploration deployment and breakthrough of lithological oil reservoirs, and three types of lithological reservoirs were discovered: beach-bar reservoir, fan delta reservoir, and structural-lithological reservoir. The first two types of lithological reservoirs developed in the Cretaceous Galhak Formation with good oil source conditions as the in-source lithological reservoirs, and the structural-lithological reservoirs developed in the upper member of the Paleogene Yabus Formation as the above-source lithological reservoirs. Due to the deeper burial depth, the reservoir quality is the main risk for in-source lithological traps, so the prediction and evaluation of the reservoir determines the success rate. In contrast, the above-source lithological traps usually have better reservoir quality with shallow burial depth, and the oil source is the main risk due to being far away from the Cretaceous oil kitchen, so it is very important to study vertical migration pathway and hydrocarbon charging. The practices showed that the exploration deployment of above-source lithological traps should be conducted in mature areas with deep understandings on hydrocarbon accumulation rules, and the structural-lithological traps controlled by oil-source faults are more favorable than sandstone lens traps. The researches and discoveries in Melut Basin indicated that the lithological oil reservoir exploration may promote step-out exploration and upgrade reserves of highly-explored areas. So, it is a good attempt to carry out lithological reservoir research and exploration for new discoveries in other African mature rift basins.

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Forming Conditions, Types and Characteristics of Lithological Reservoirs in Melut Rift Basin

Implications for Hydrocarbon Exploration in Mature Rift Basins of Africa

By Zhongsheng Shi

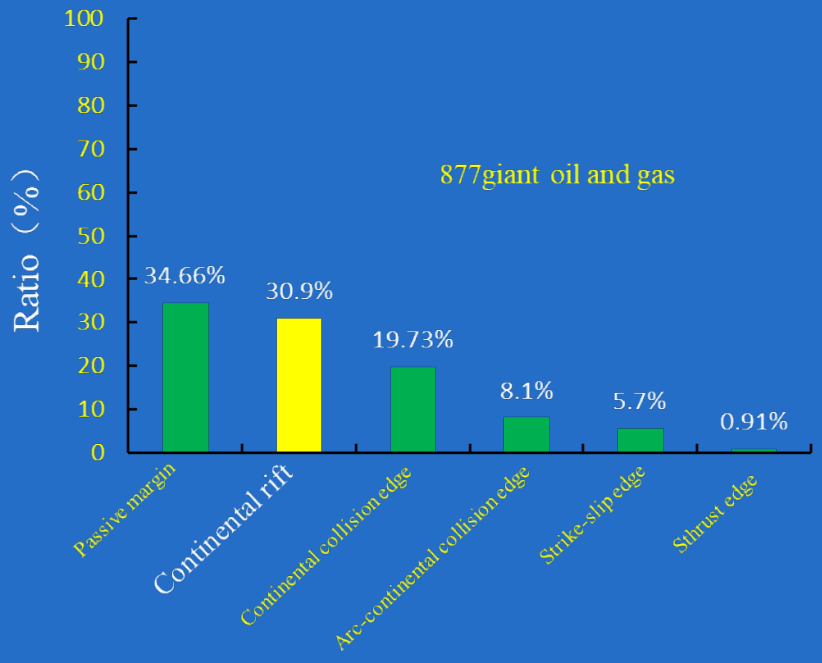
Cape Town

Outline

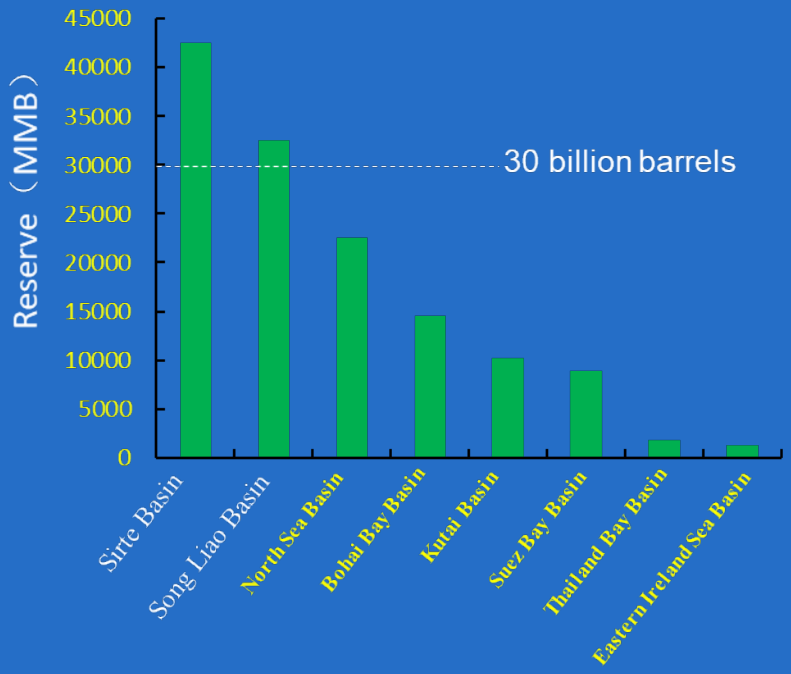
- Rift Basin and Hydrocarbon Exploration
- Lithological Reservoirs Characteristics in Melut Basin
- Conclusions and Implications for African Rift Basins

Rift Basin and Hydrocarbon Exploration

- The rift basin developed rich oil and gas resources
  - The giant oil and gas fields in rift basins account for nearly one-third
  - Some basins discovered huge HC resources



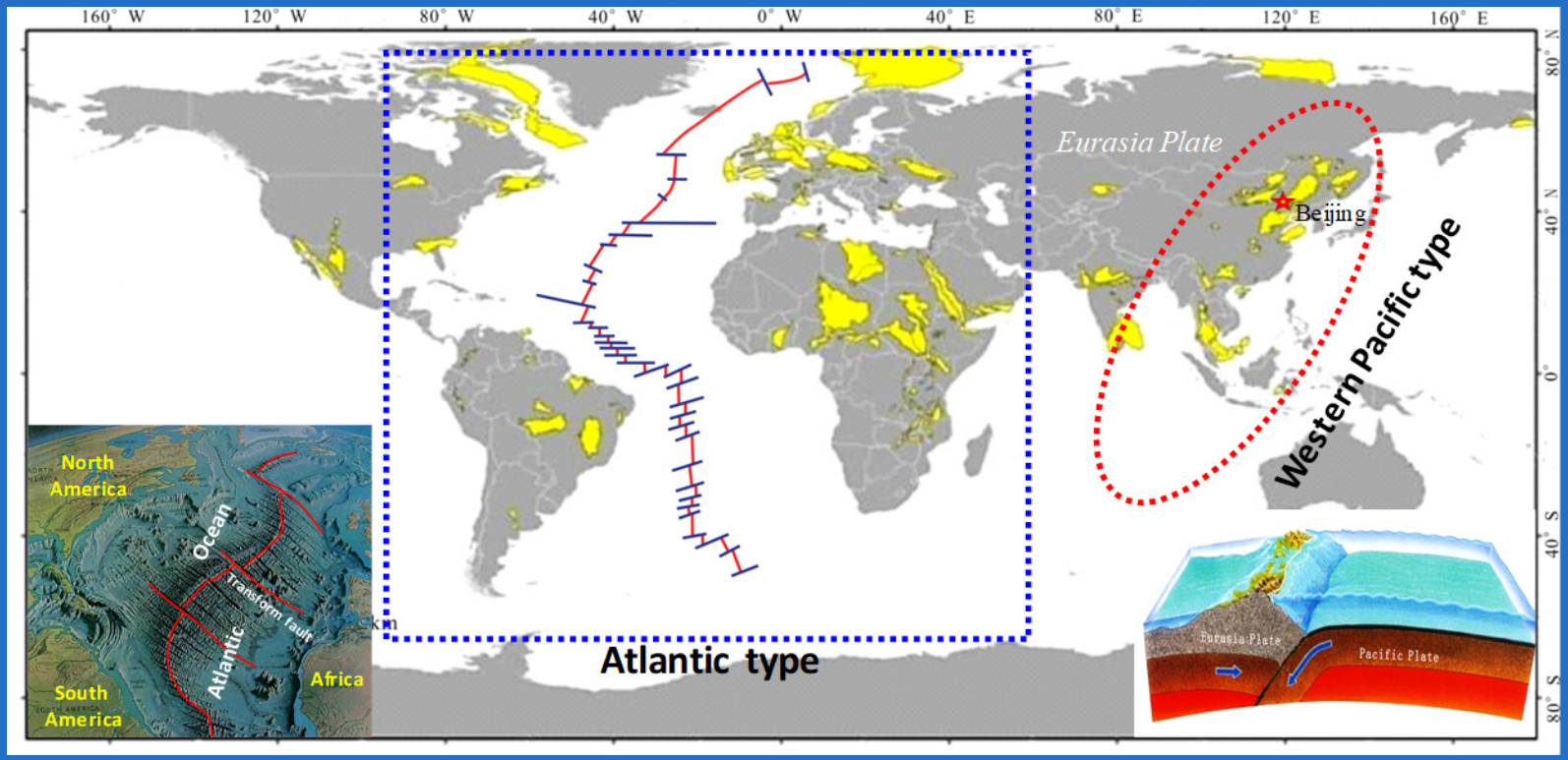
Proportion of global giant oil and gas fields under different tectonic settings
（Mann et al., 2003; Jia et al.,2011）



Sorting map of oil and gas reserves in typical rift basins
（Mann et al., 2003）

Rift Basin and Hydrocarbon Exploration

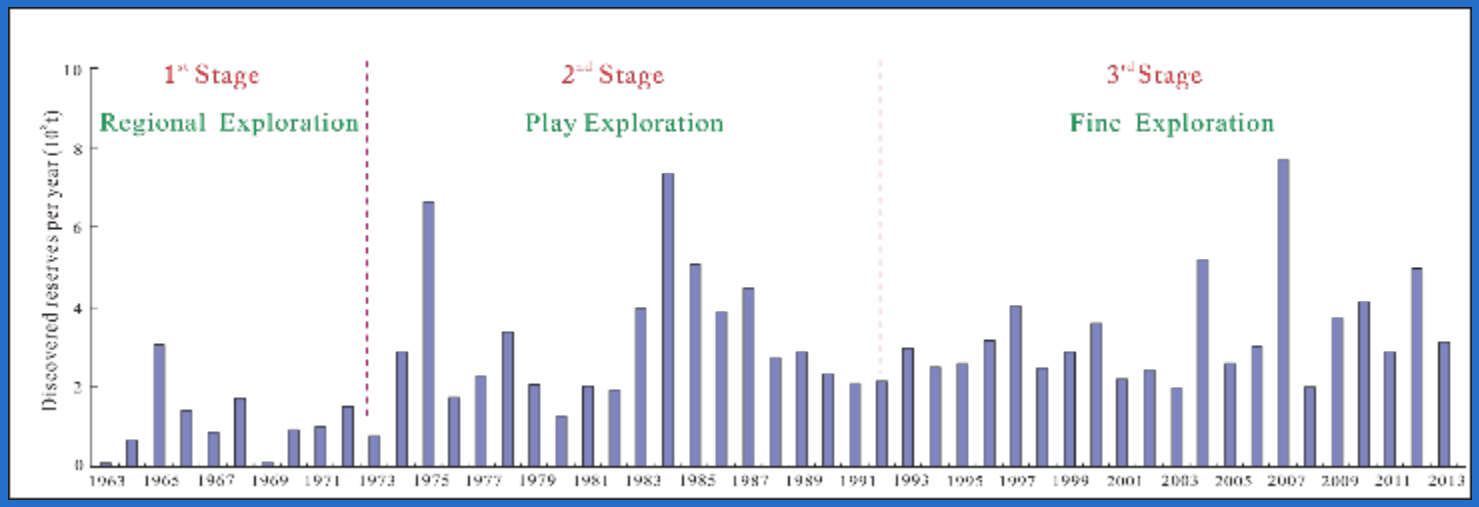
- The rift basin can be divided into two types according to dynamic mechanisms
  - **Atlantic type:** **R**elated to the Atlantic Ocean extension , and rift basins are mainly located on both sides of the Atlantic Ocean
  - **Western Pacific Type :** Related to the subduction of the Pacific Plate, and rift basins mainly developed in the eastern Eurasia Plate



Distribution of global rift basin

Rift Basin and Hydrocarbon Exploration

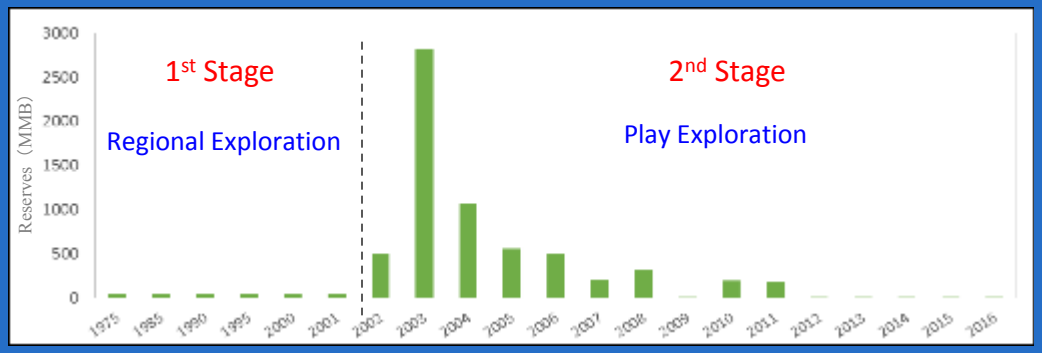
- Petroliferous rift basins usually experienced three exploration stages
  - In the Regional and Play exploration stage, structural traps are main exploration targets
  - After the 1st and 2nd stages, most structural traps have been drilled and the basin will enter into Fine Exploration stage, and lithological reservoirs will become the main drilling targets.
  - In the Fine Exploration stage, lithological reservoir exploration can also discover considerable reserves



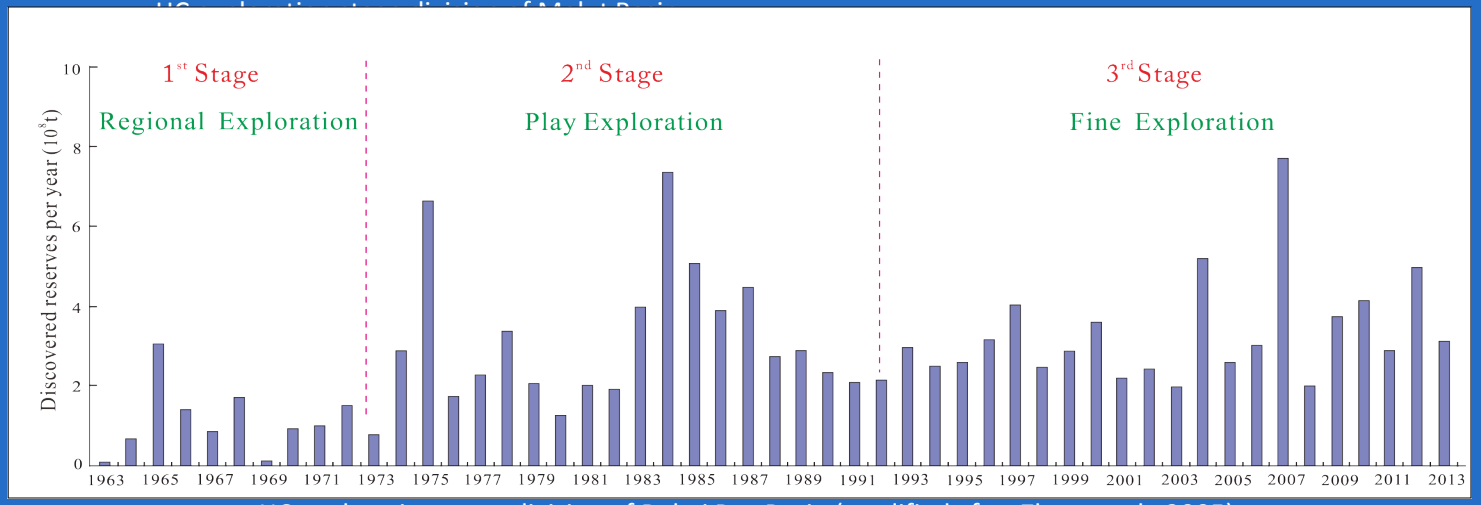
HC exploration stage division of Bohai Bay Basin (modified after Zhao et al., 2005)

Rift Basin and Hydrocarbon Exploration

- Melut Basin and most other African rift basins are facing the transition from Play Exploration to Fine Exploration



- Compared with rift basins in China, Melut Basin and most other African rift basins are at a low exploration level
- Lithological reservoirs will be important targets for future exploration and reserve growth



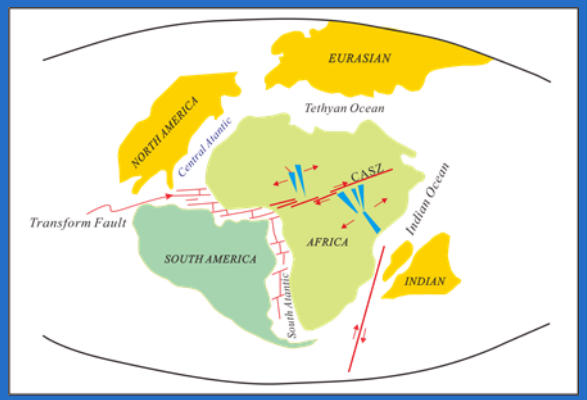
HC exploration stage division of Bohai Bay Basin (modified after Zhao et al., 2005)

Outline

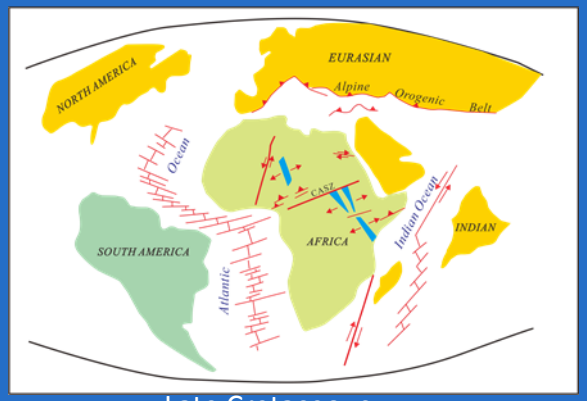
- Rift Basin and Hydrocarbon Exploration
- Lithological Reservoirs Characteristics in Melut Basin
- Conclusions and Implications for African Rift Basins

1.Regional Geological Setting of Melut Basin

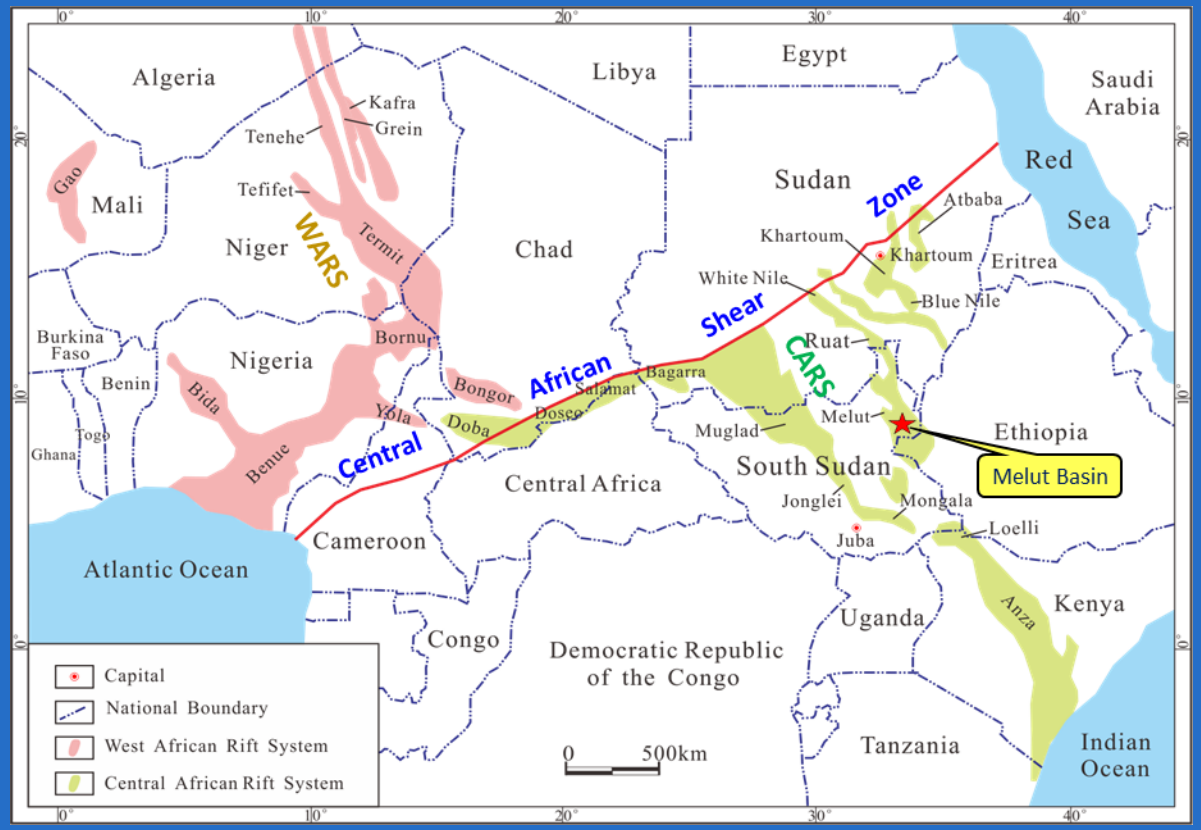
- Melut Basin is a passive rift basin controlled by the Central African Shear Zone（CASZ）
- The CASZ was related to the expansion of Atlantic Ocean since Late Jurassic.
- African continent developed central and western rift systems, with a large number of rift basins
- Melut Basin belongs to the CARS，with an area of 33,000 km^2



Late Jurassic to late Cretaceous



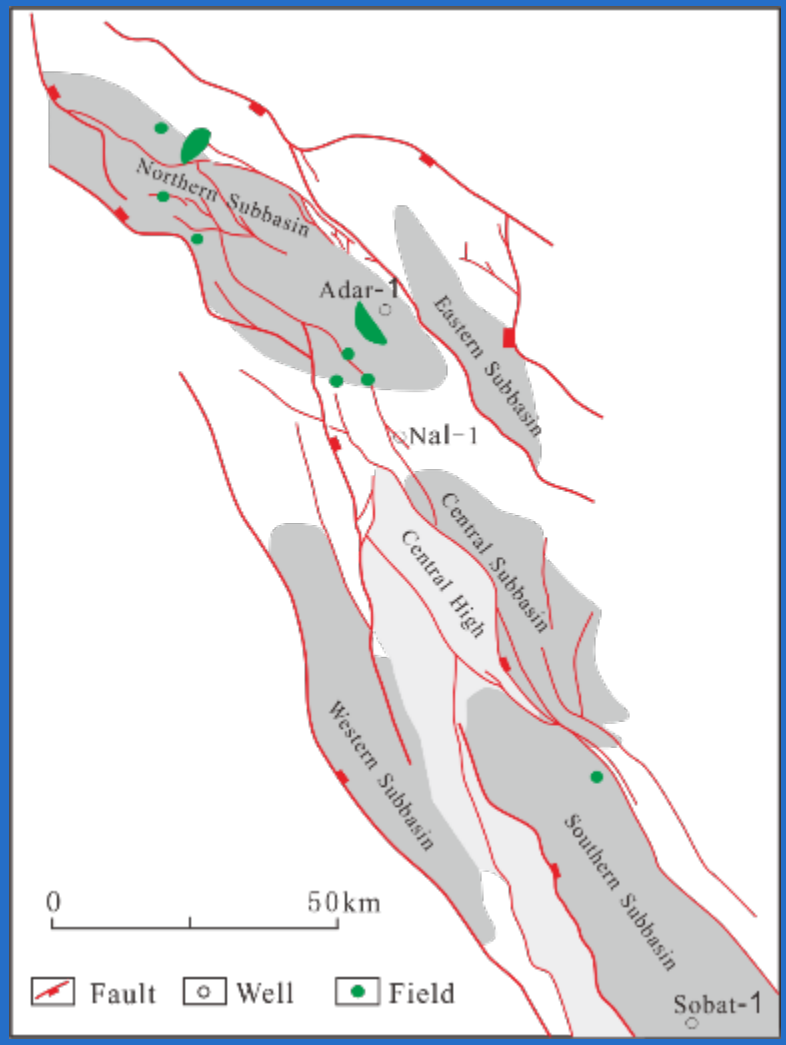
Late Cretaceous
（Modified after Bumby and Guiraud, 2005）



Central Africa Shear Zone and Location of Melut Basin (Modified after Genik, 1993)

1.Regional Geological Setting of Melut Basin

- Five sub-basins and one central uplift
- The Northern Sub-basin is the main exploration area, with a large number of discoveries .
- With the deepening of exploration, most structural traps have been drilled, and the NMSB is facing transition from structural reservoir exploration to lithologic reservoir exploration.



Structure unit and oil discoveries of Melut Basin
(Dou et al., 2007)

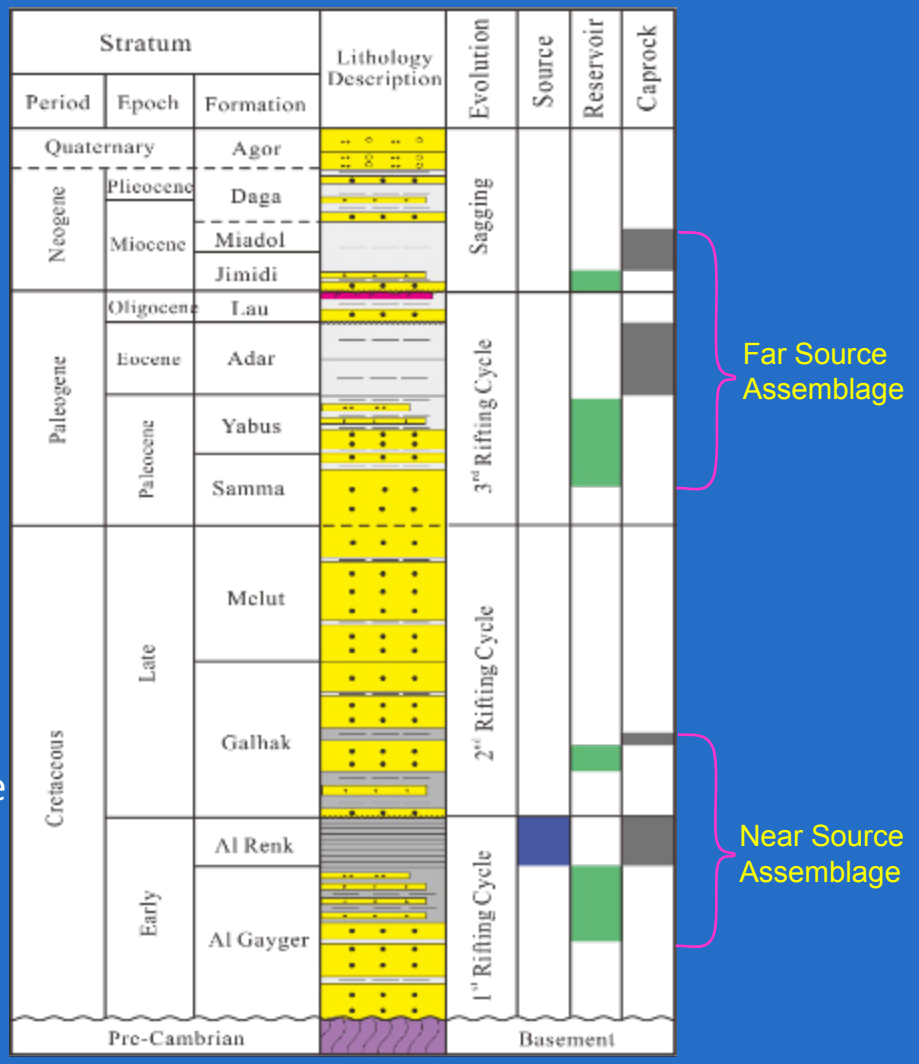
1.Regional Geological Setting of Melut Basin

- Developed 3 rifting cycles
  - The 1st and 3rd cycles developed strong tectonic activities with thick mudstone deposition acting as source rock and regional caprock
  - The 2nd rifting cycle is weak and deposited hundreds of meters sand-rich stratum
- Two types of reservoir-caprock assemblage
  - Near source reservoir-caprock assemblage

    Galhak sandstone & inner Galhak mudstone assemblage； Al Renk & Al Gayger assemblage
  - Far source reservoir-caprock assemblage

    Adar & Yabus assemblage

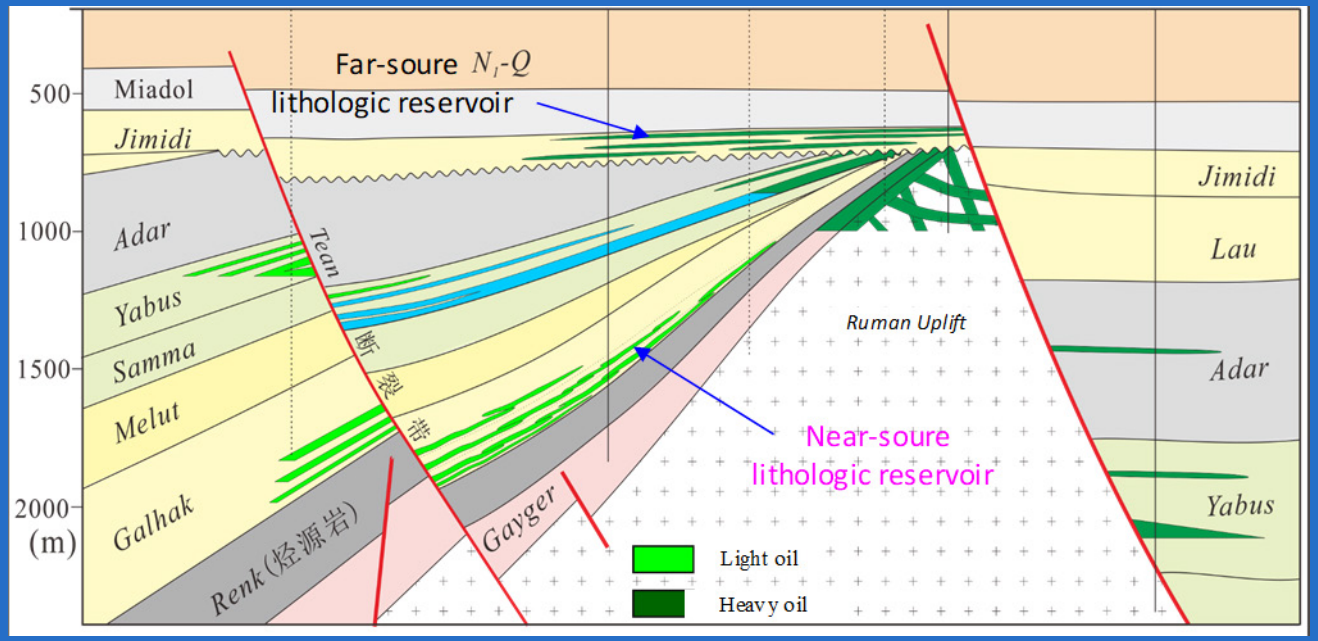
    Miadol & Jimidi assemblage



Generalized stratigraphic column for the Melut Basin

2.Lithologic Reservoir Characteristics of Melut Basin

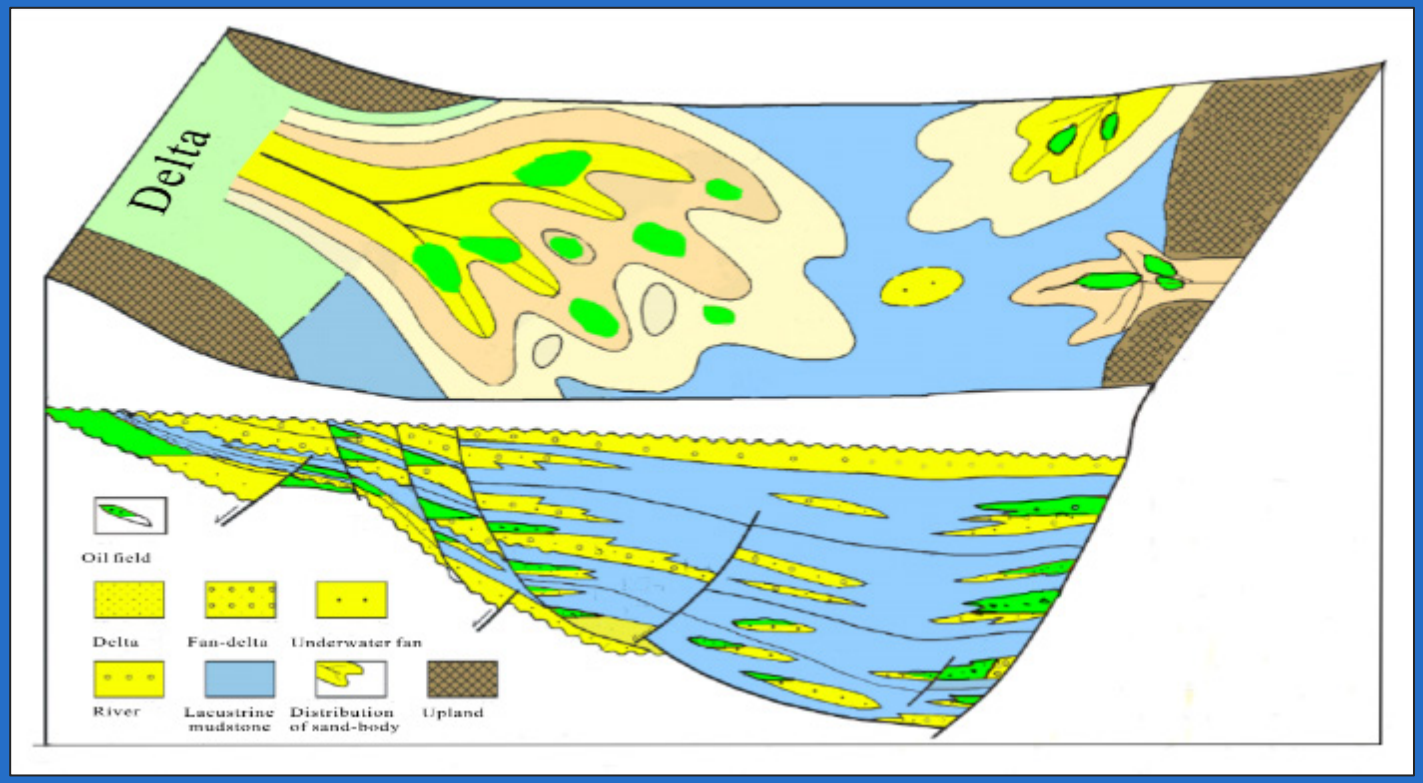
- Developed 2 types of lithologic reservoirs
  - Near-source lithologic reservoirs
    - ✓ Close to source rock and has good oil source condition
    - ✓ Usually deeply buried, and the porosity and permeability is the big risk
  - Far-source lithologic reservoirs
    - ✓ Shallow buried depth, with good reservoir quality and high productivity
    - ✓ Far from source rock, and HC charging is the big risk



HC accumulation model of Melut Basin

(1) Characteristics of near-source lithologic reservoirs

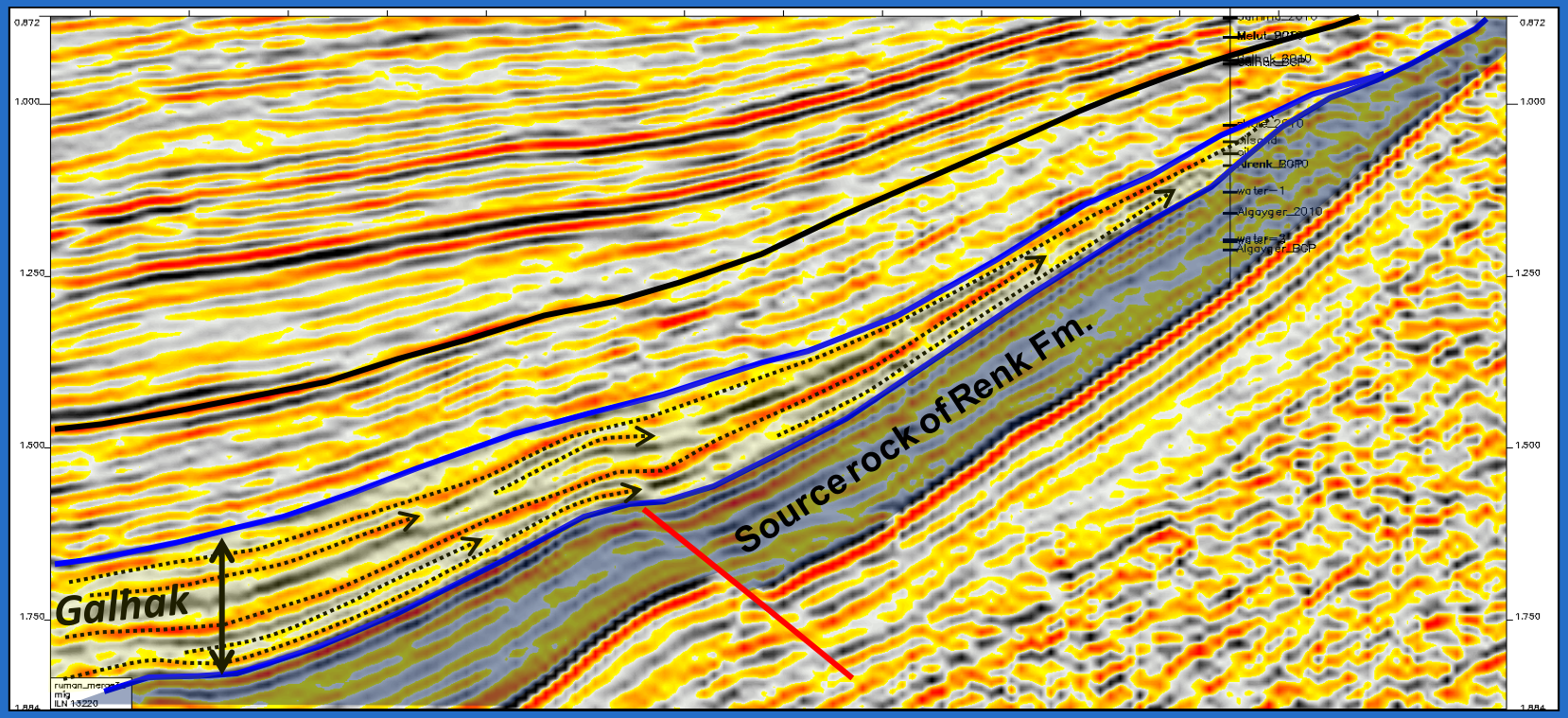
- Beach-bar lithologic reservoirs in gentle slope
- Fan delta and subaqueous fans lithologic reservoirs in steep slope



HC accumulation model of lithologic reservoir in rift basin
(Modified after Jia et al., 2007)

Beach-bar lithologic reservoirs in gentle slope

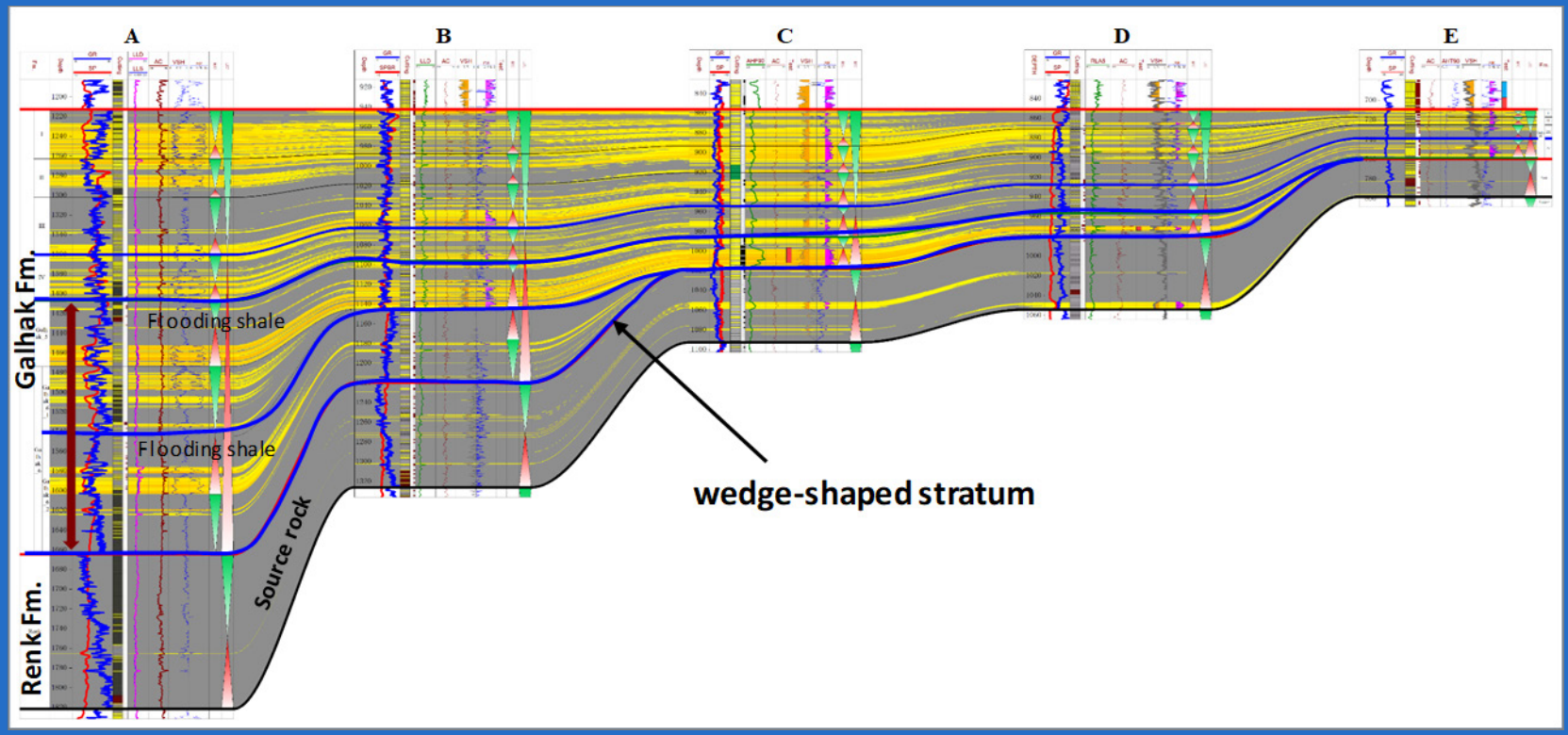
- Beach-bar lithologic reservoirs developed in wedge-shaped stratum in gentle slope
- The wedge-shaped stratum is adjacent to source rocks, with good oil source condition
- A large number of updip pinch-out reflections developed, which created conditions for forming stratigraphic-lithologic traps



Seismic reflection of wedge-shaped stratum in Ruman gentle slope

Beach-bar lithologic reservoirs in gentle slope

- The wedge-shaped stratum deposited after source rock, with interbedded sediments of sandstones and mudstones, and developed good reservoir-caprock condition

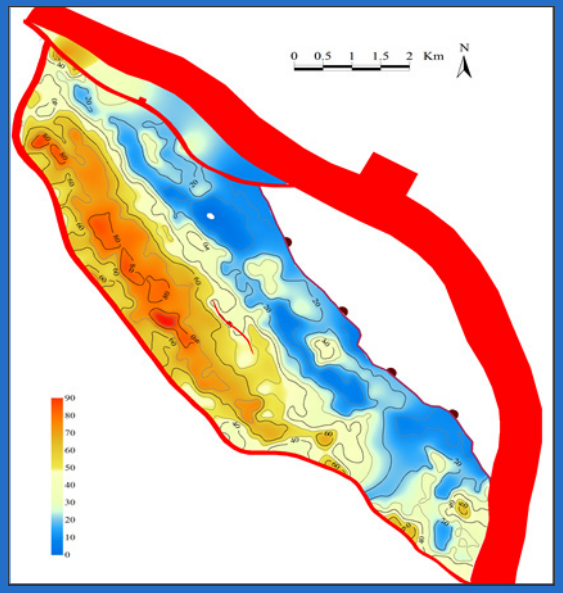


Reservoir-caprock assemblage of wedge-shaped stratum in Ruman gentle slope

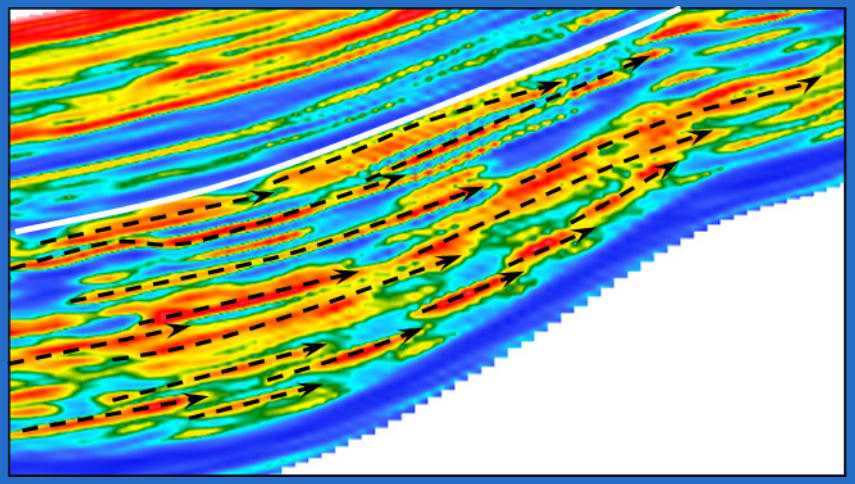
Beach-bar lithologic reservoirs in gentle slope

Sedimentary features of beach bar

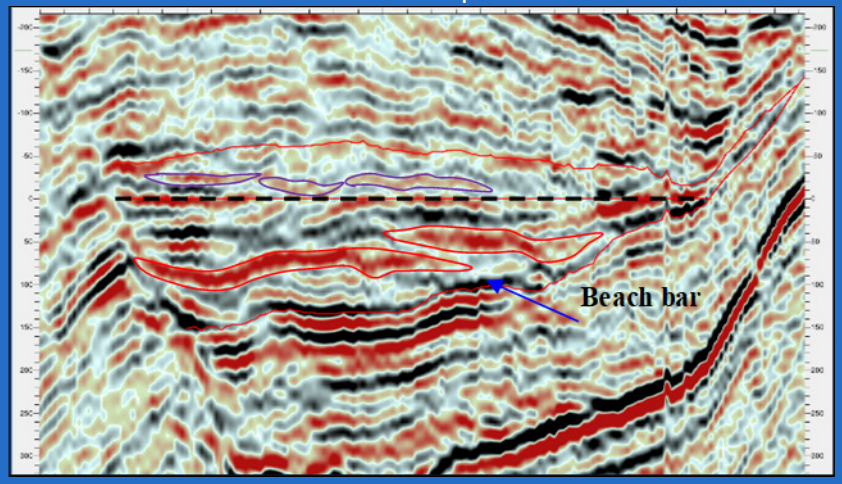
- ✓ In lithology inversion and layer flattening seismic sections, the beach bars are discontinuous strong reflection and overlapped each other, and each beach bar is about several kilometers in width
- ✓ In plane, the strike direction of beach bar is parallel to the shoreline



Thickness map of beach bars



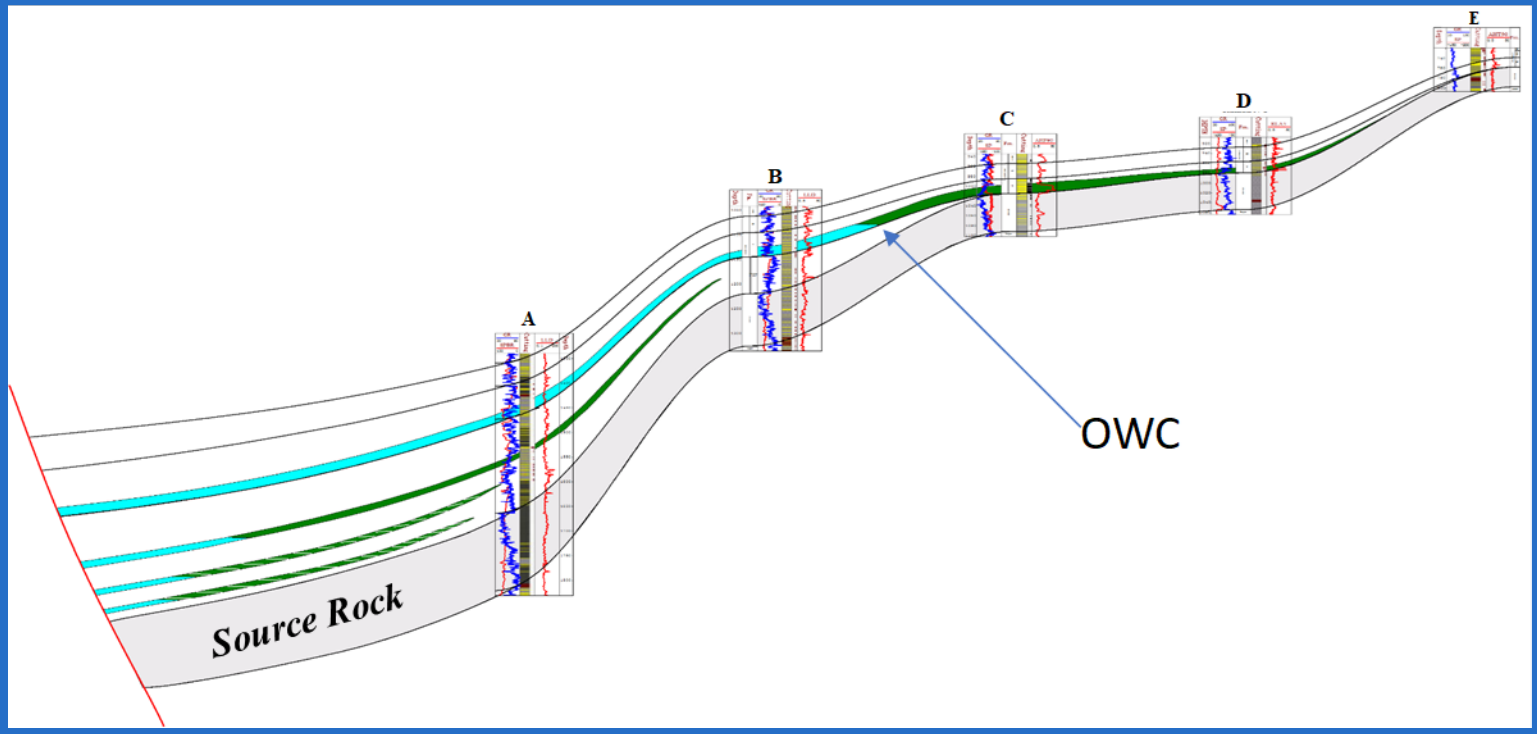
Beach bars in lithology inversion section



Beach bars in layer flattening seismic section

Lithologic reservoir characteristics of gentle slope

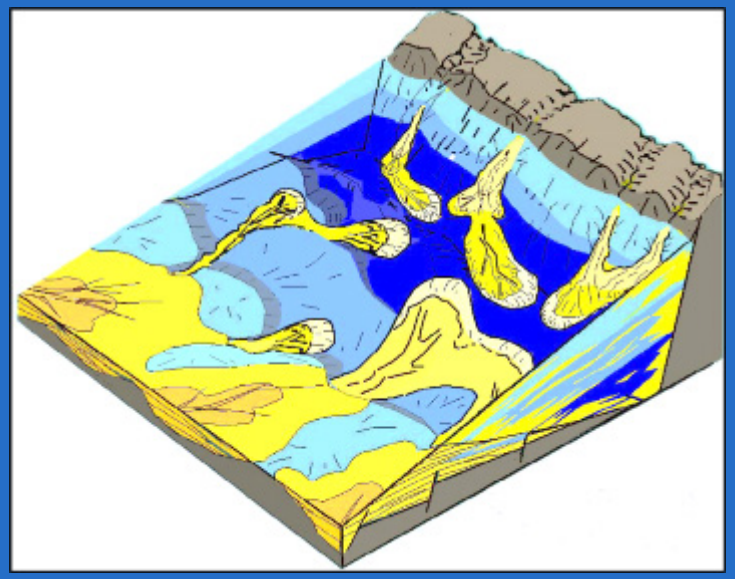
- In the wedge-shaped stratum, each updip pinch-out sand body has independent OWC
- Even if the upper pinch-out sand body encountered water, the lower pinch-out sand body may still develop oil reservoirs.
- Lithologic reservoirs greatly increased the exploration potential of gentle slope



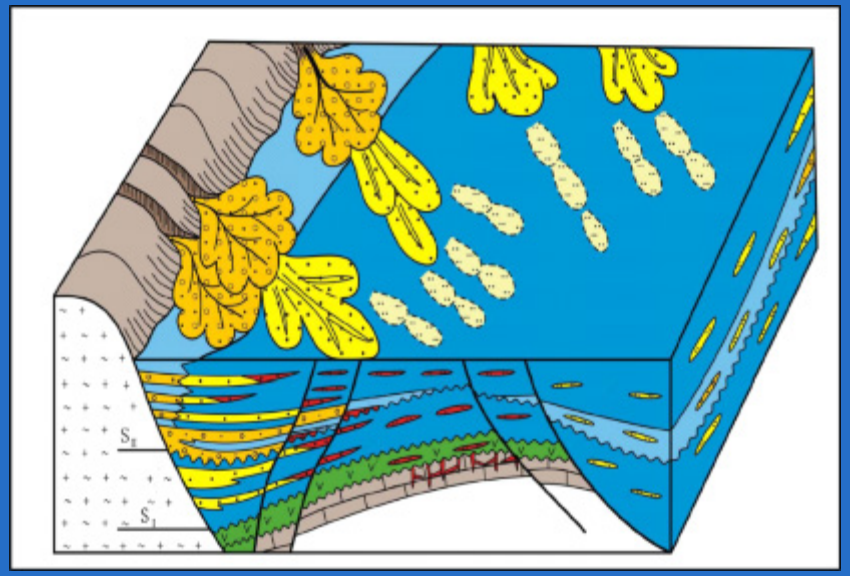
HC accumulation model of lithologic reservoir in gentle slope

Lithologic reservoirs of steep slope fan in Melut Basin

- In the steep slope of rift basin, usually developed some subaqueous fans or fan deltas
- The steep slope fans generally deposited in rifting stage, with good oil source and sealing condition
- The steep slope fans are important exploration targets in rift Basin



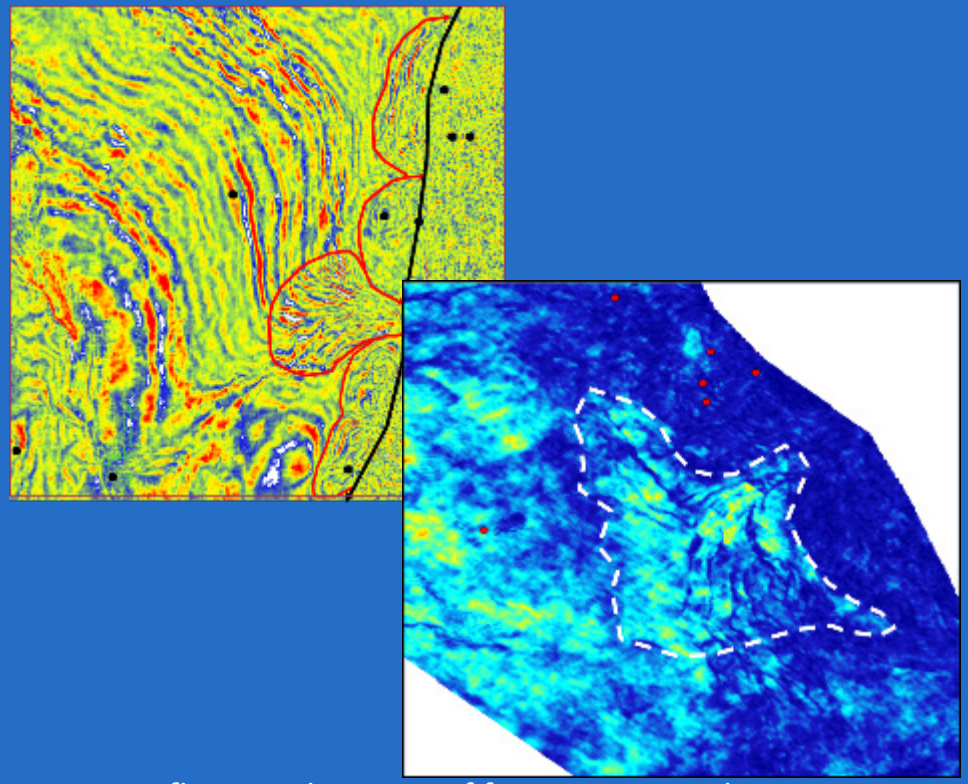
Sedimentary model of rifting stage in rift basin
(Jia et al., 2008)



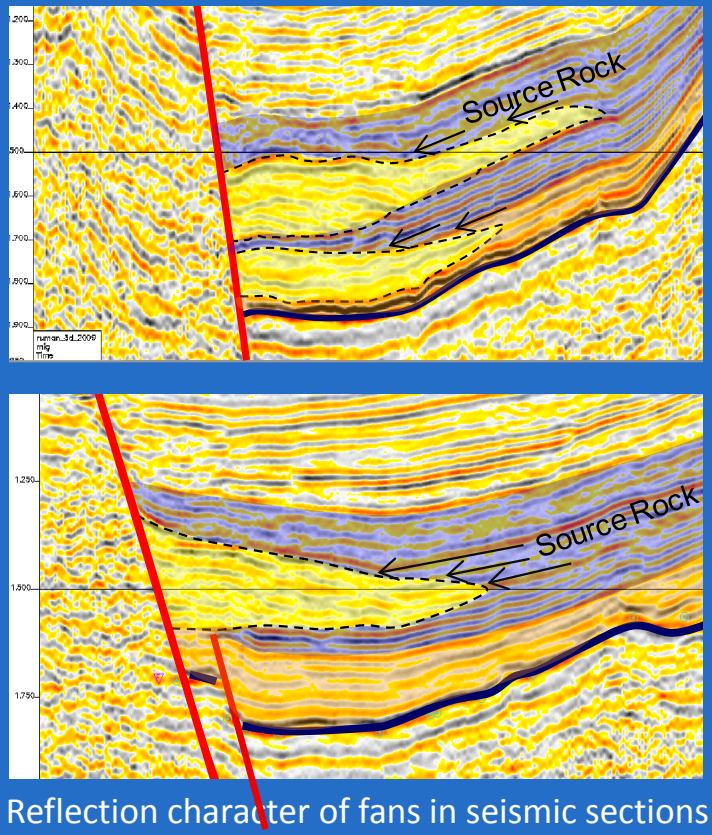
Steep slope Sedimentary and accumulation model
(Jia et al., 2008)

Lithologic reservoirs of steep slope fan in Melut Basin

- A series of subaqueous fans and fan deltas were identified in Melut Basin
- The fans directly contacted with source rocks
- In section, the fans are wedge-shaped bodies, with clear reflections of outline and internal structure
- In slice, the fans distribute along the boundary fault with an area of several to tens of sq kilometers



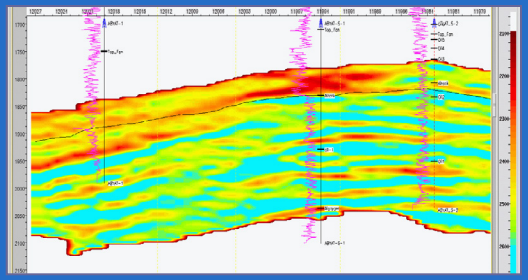
Reflection character of fans in seismic slice



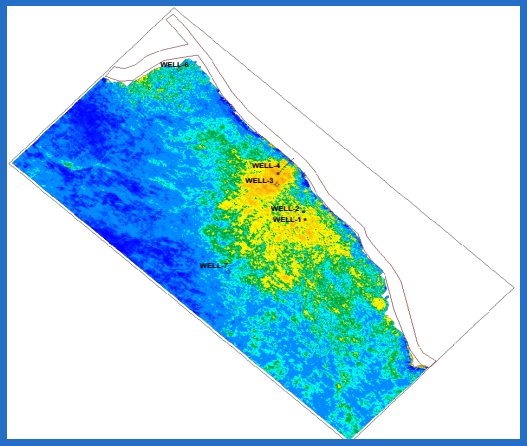
Reflection character of fans in seismic sections

Lithologic reservoirs of steep slope fan in Melut Basin

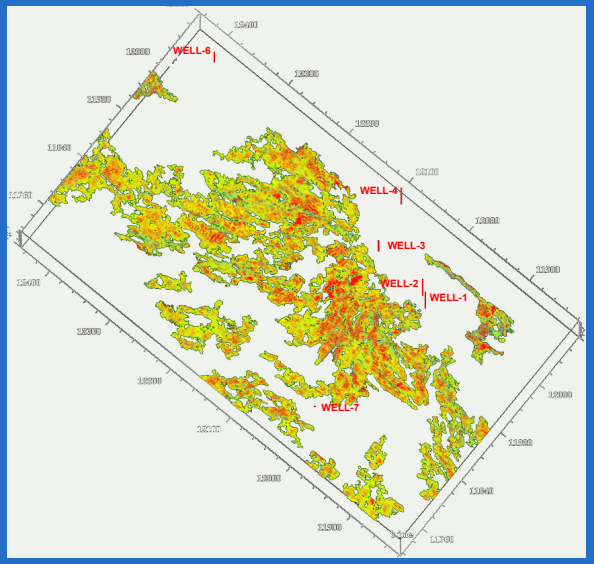
- The sandstone of steep slope fans usually have poor sorting and rounding due to short distance transportation
- It is necessary to carry out prediction and evaluation on sandstone distribution and reservoir quality by different methods to increase the reservoir evaluation accuracy



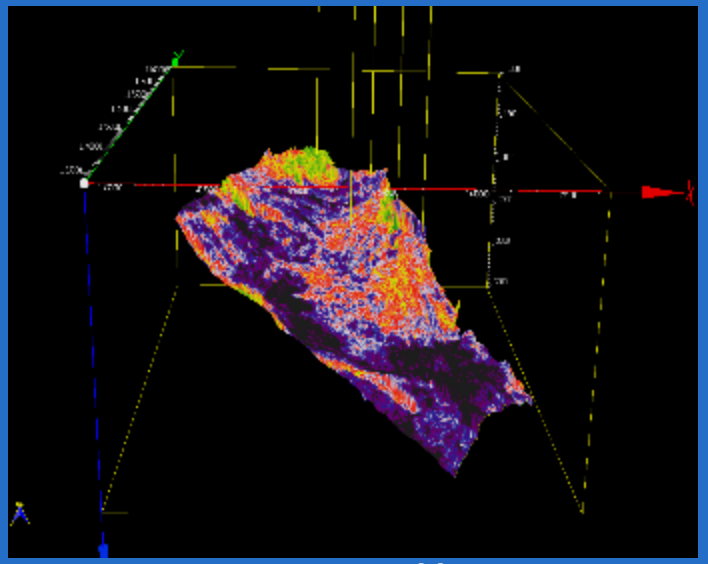
Lithology inversion section



Seismic attribute analysis



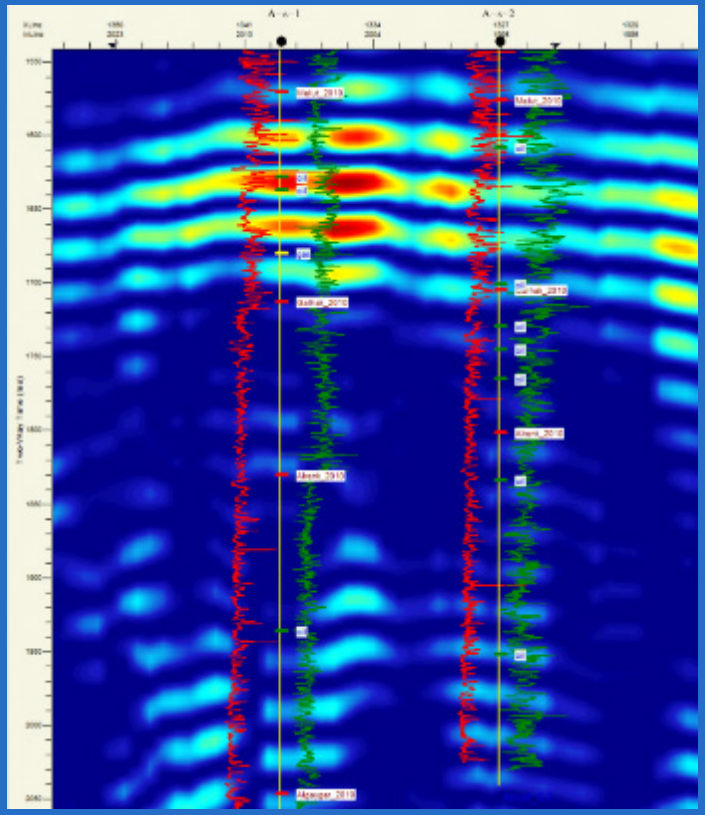
Channel sandstone distribution



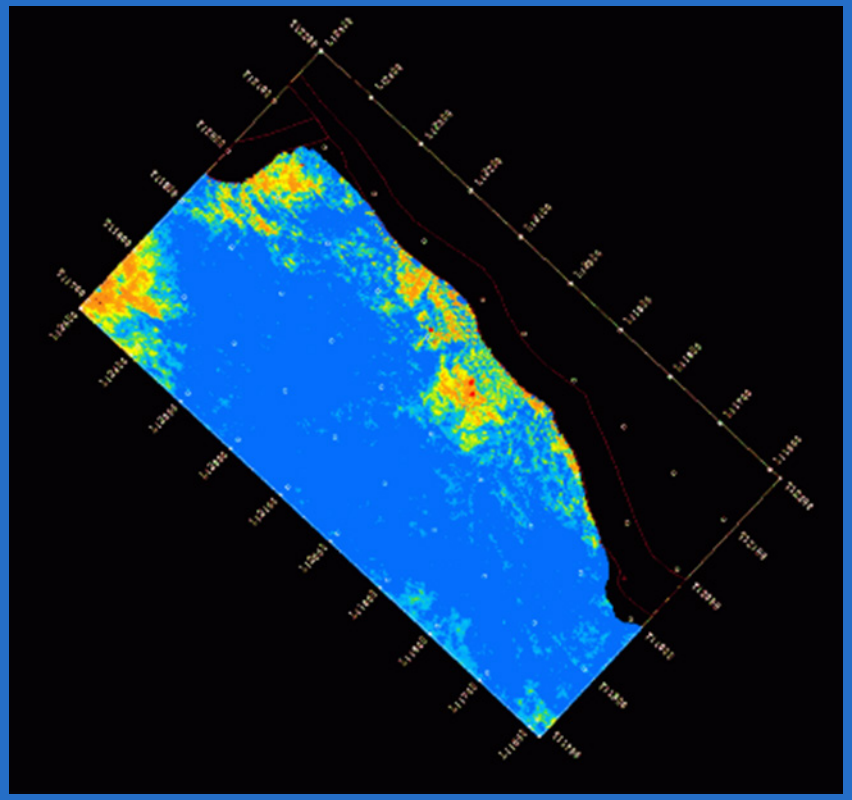
3D view of fan

Near-source lithologic reservoirs of steep slope

- It is very necessary to conduct hydrocarbon detection to reduce the exploration risk
  - ✓ Time-frequency analysis
  - ✓ Fluid density prediction analysis



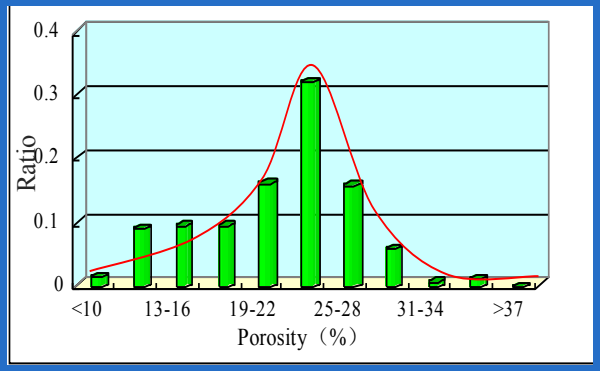
Time-frequency analysis



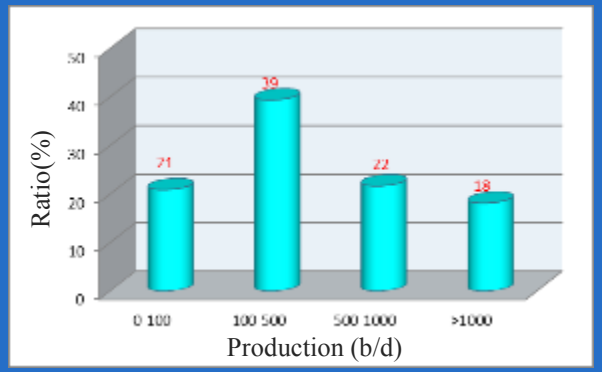
Fluid density prediction analysis

(2) Characteristics of far-source lithologic reservoirs

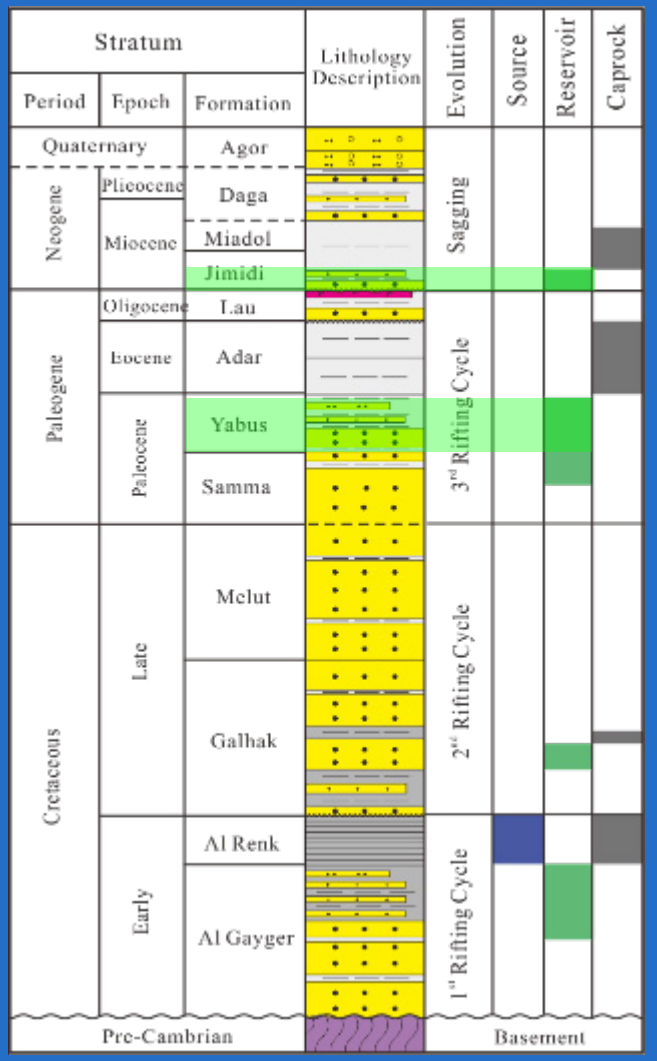
- Discovered 2 types of far-source lithologic reservoirs
  - Related to braided delta front sediments of Yabus Fm.
  - Related to braided river deposits of Jimidi Fm. in Neogene
- Shallow buried depth, good reservoir quality, high productivity
  - the porosity of sandstone is generally above 20% in Yabus Fm.
  - the high-yield oil layers with more than 500 barrels per day account for 40%.
- Far from source rock, and HC charging is the big risk



Porosity of Upper Yabus Fm.



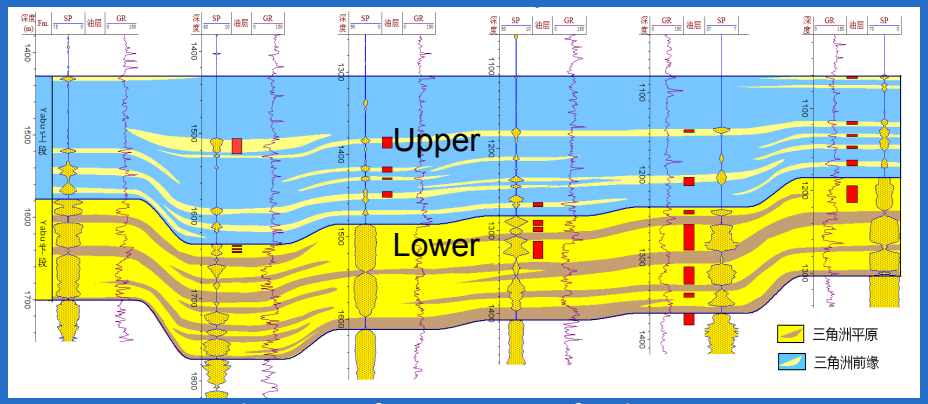
Productivity of Upper Yabus Fm.



Generalized stratigraphic column for the Melut Basin

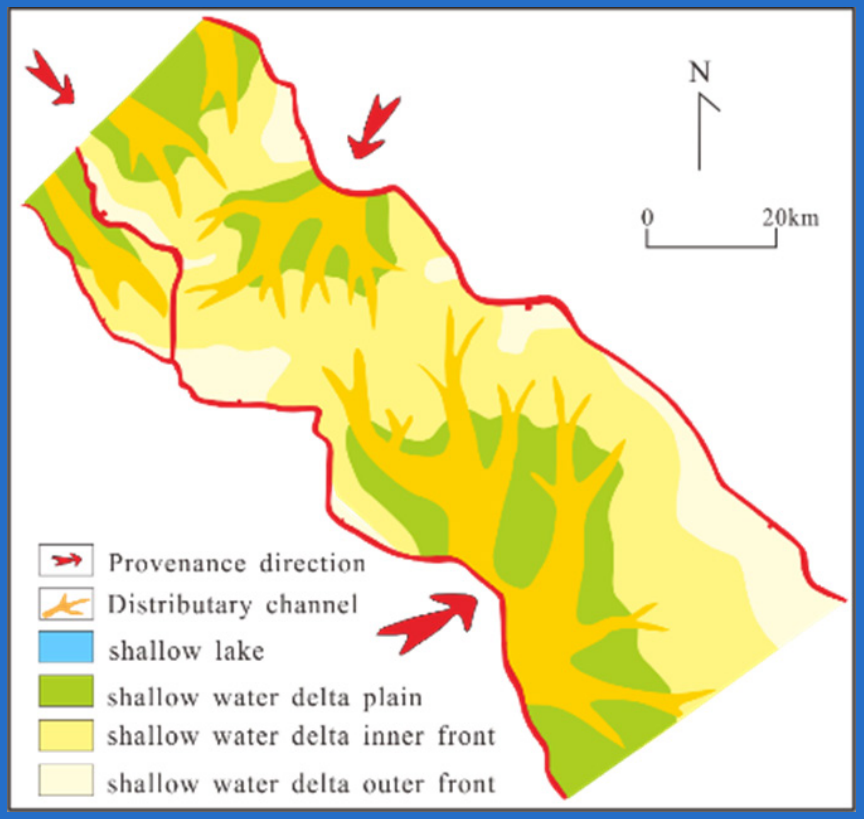
Lithologic reservoirs of Yabus Fm. in Paleocene

- The Yabus Fm. is a set of shallow water delta deposition, and the lower and upper part have different sedimentary features
- The lower part deposited broad braided delta plain, with extensively massive channel sandstones
- Structural traps are the primary drilling targets



Sedimentary facies section of Yabus Fm.

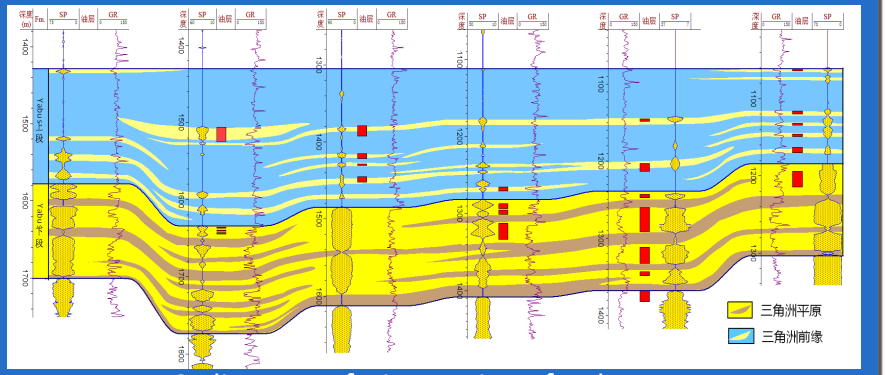
HC reservoir section of Lower Yabus Fm.



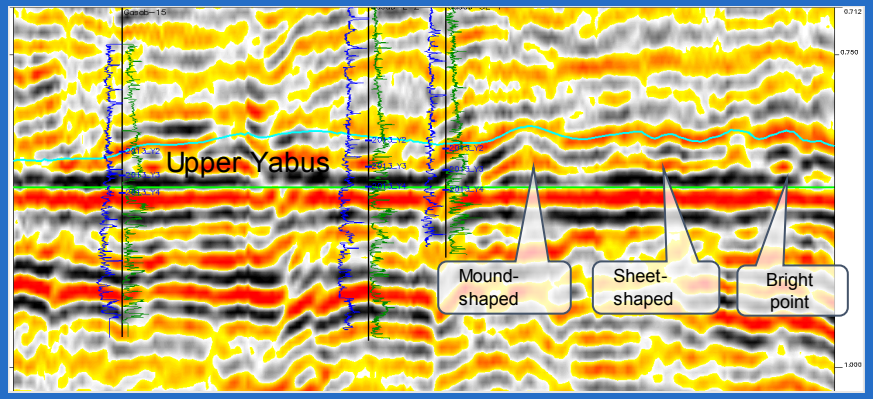
Sedimentary facies map of Lower Yabus Fm.

Lithologic reservoirs of Yabus Fm. in Paleocene

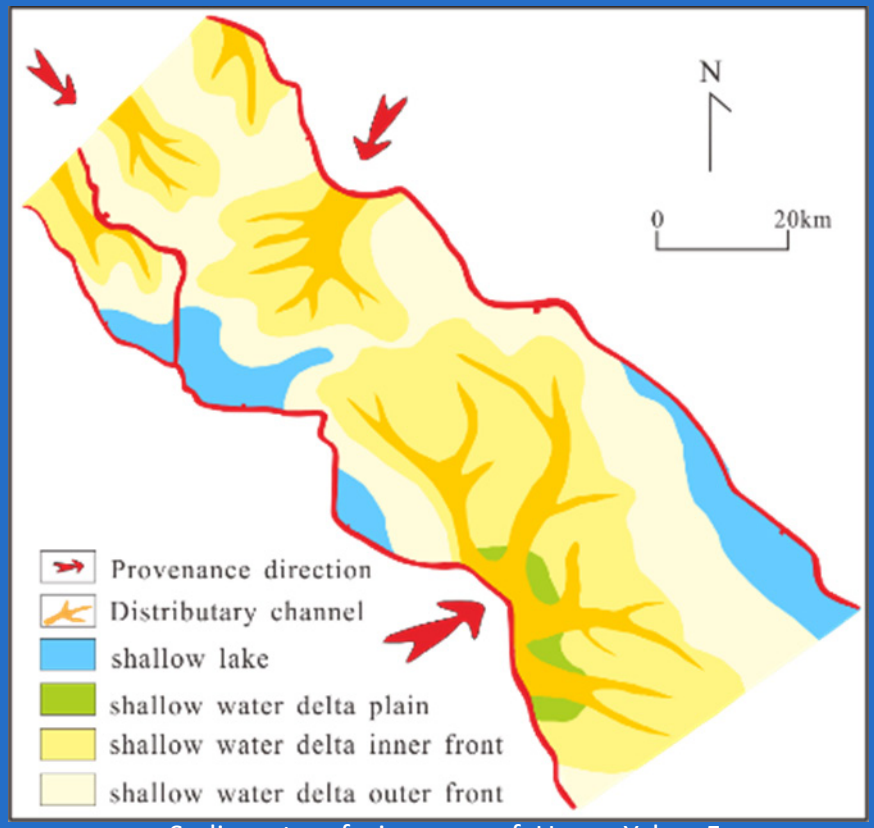
- The Upper Yabus Fm. deposited wide delta front, with “sand wrapped by mud ” depositional feature, which is easily to develop lithologic traps
- Distributary channels and mouth bars are favorable reservoirs
- In flattening section, the Upper Yabus Fm. are characterized by mound-shaped, sheet-shaped and bright point reflections



Sedimentary facies section of Yabus Fm.



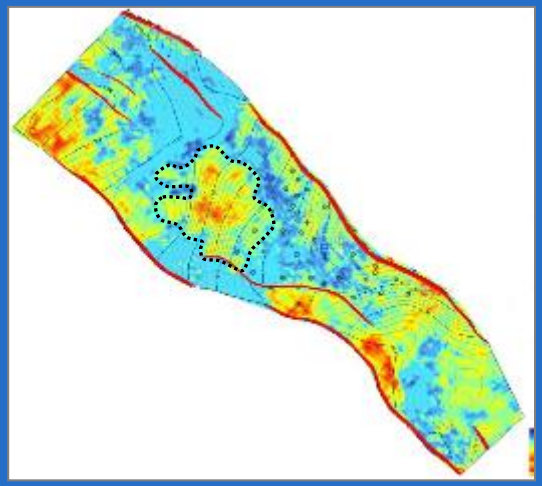
HC reservoir section of Upper Yabus Fm.

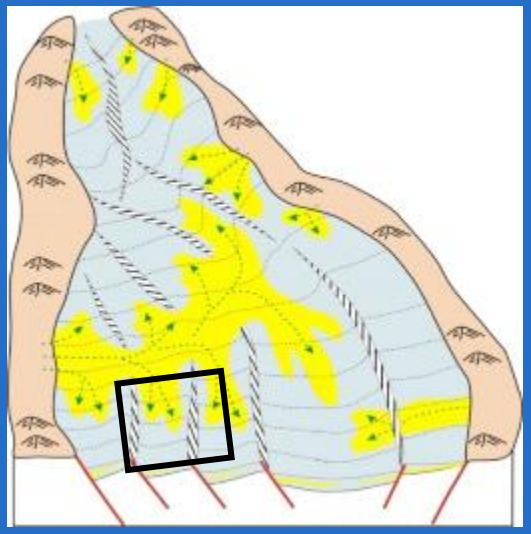


Sedimentary facies map of Upper Yabus Fm.

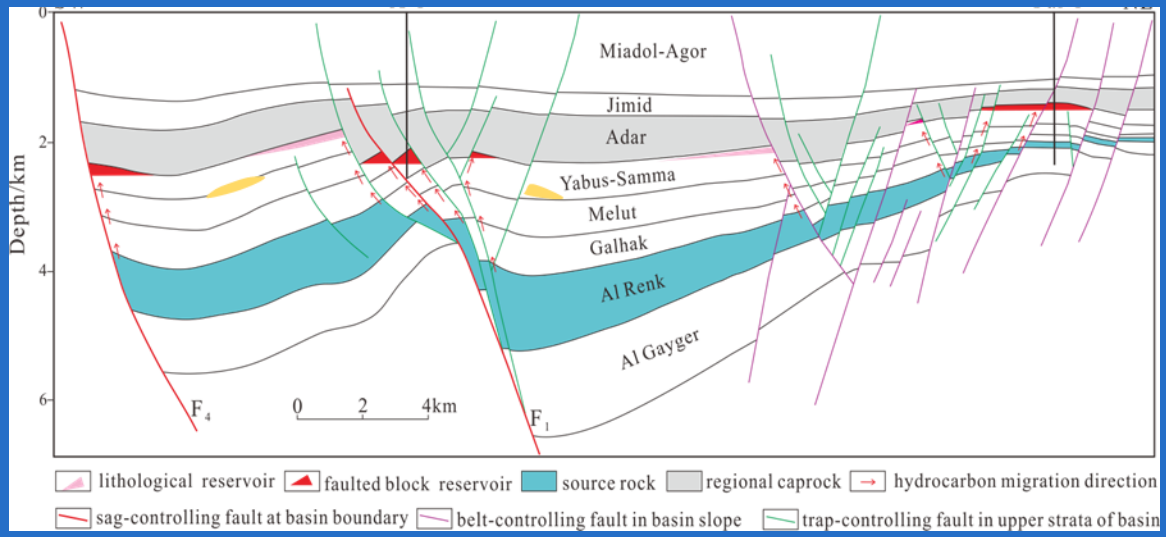
Lithologic reservoirs of Yabus Fm. in Paleocene

- Since the Upper Yabus Fm. is far from the Lower Cretaceous source rock, HC charging is the great risk
- Lithologic traps controlled by oil-source fault and delta front sandstones may reduce the risk of HC charging
- Sand lens and lithologic traps far from oil-source fault have high risk





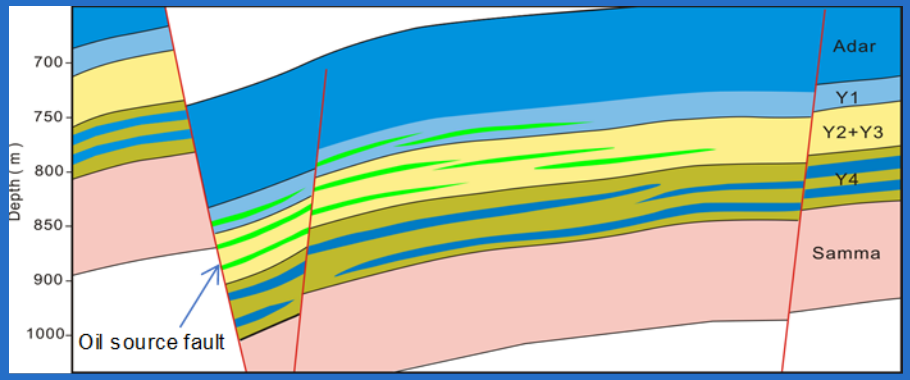
Provenance direction and sedimentary model of Yabus

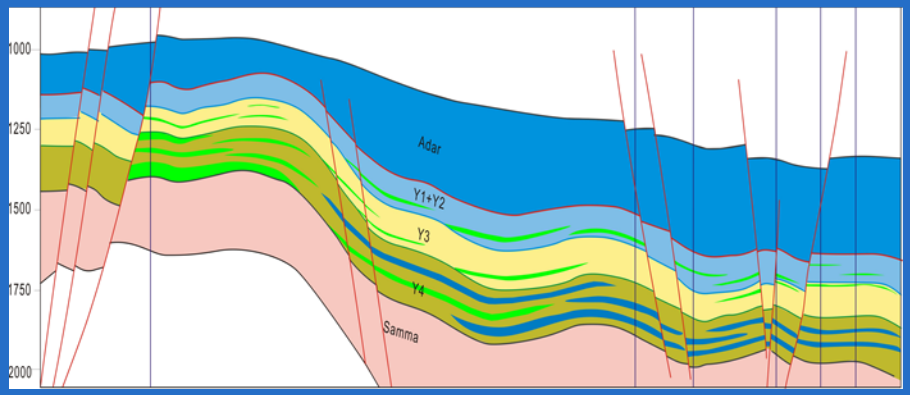


HC accumulation model of Yabus

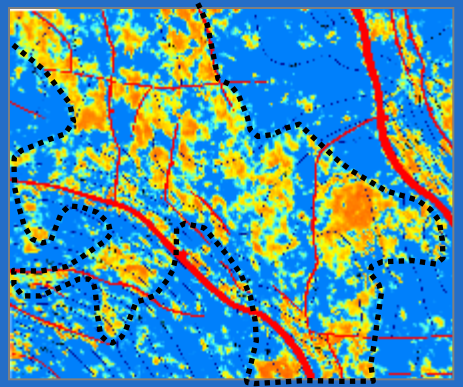
Lithologic reservoirs of Yabus Fm. in Paleocene

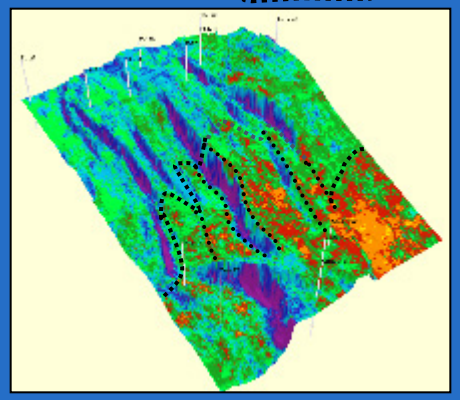
- Two types of favorable lithologic traps are identified
  - ✓ Subaqueous distributary channel sandstones combine with oil-source faults
  - ✓ Wedge-shaped sand deposits in slope of uplift combine with oil-source faults
- The lithologic reservoirs greatly increased the exploration potential of Yabus Fm.





Structural-lithologic hydrocarbon accumulation model

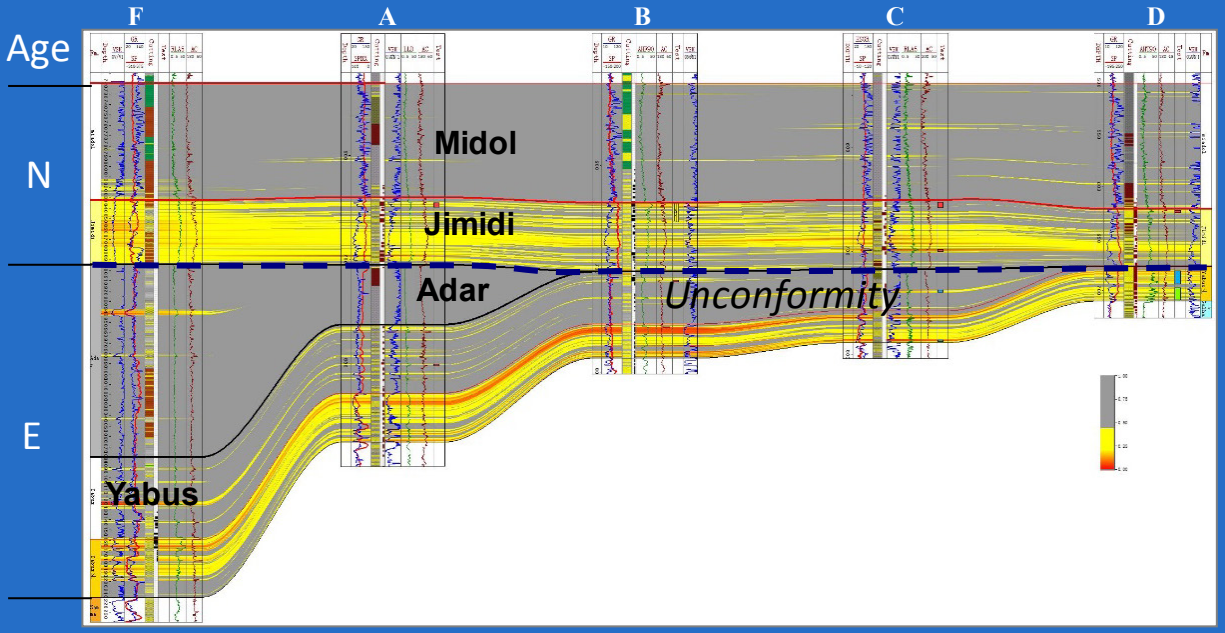




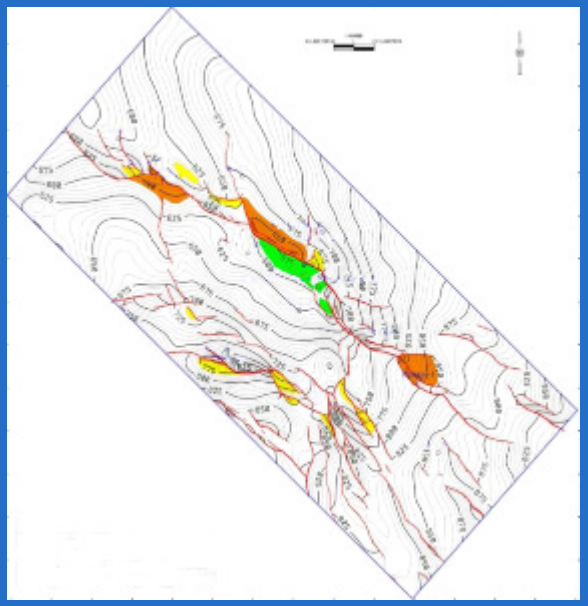
Structure-stratigraphic trap model

Lithologic reservoirs of Jimidi Fm. in Neogene

- Jimidi Fm. is a set of braided river deposits, with shallow depth and good reservoir quality
- Under the sealing of regional mudstones of Miadol Fm., some fault block oil reservoirs have been discovered in previous exploration



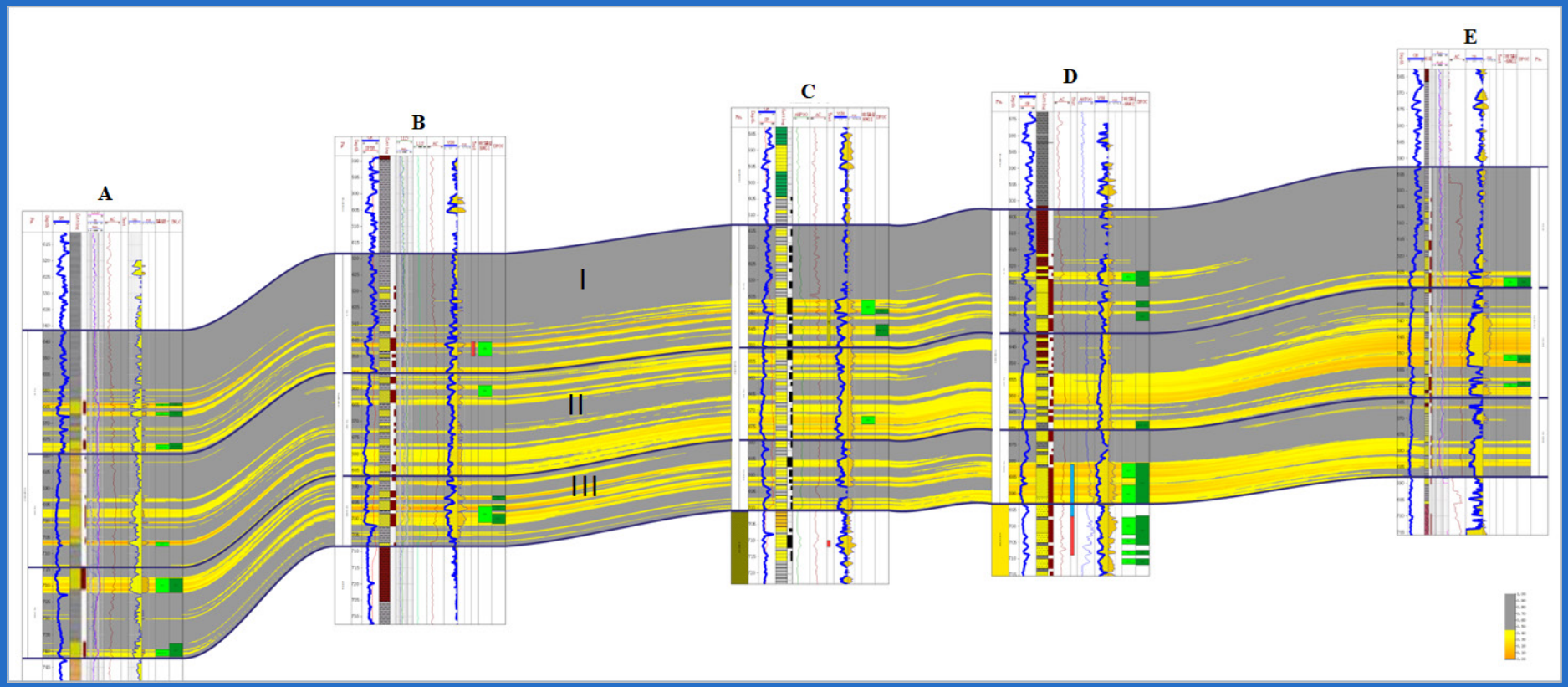
Reservoir-caprock feature of Jimidi Fm.



Fault block reservoirs of Jimidi Fm.

Lithologic reservoirs of Jimidi Fm. in Neogene

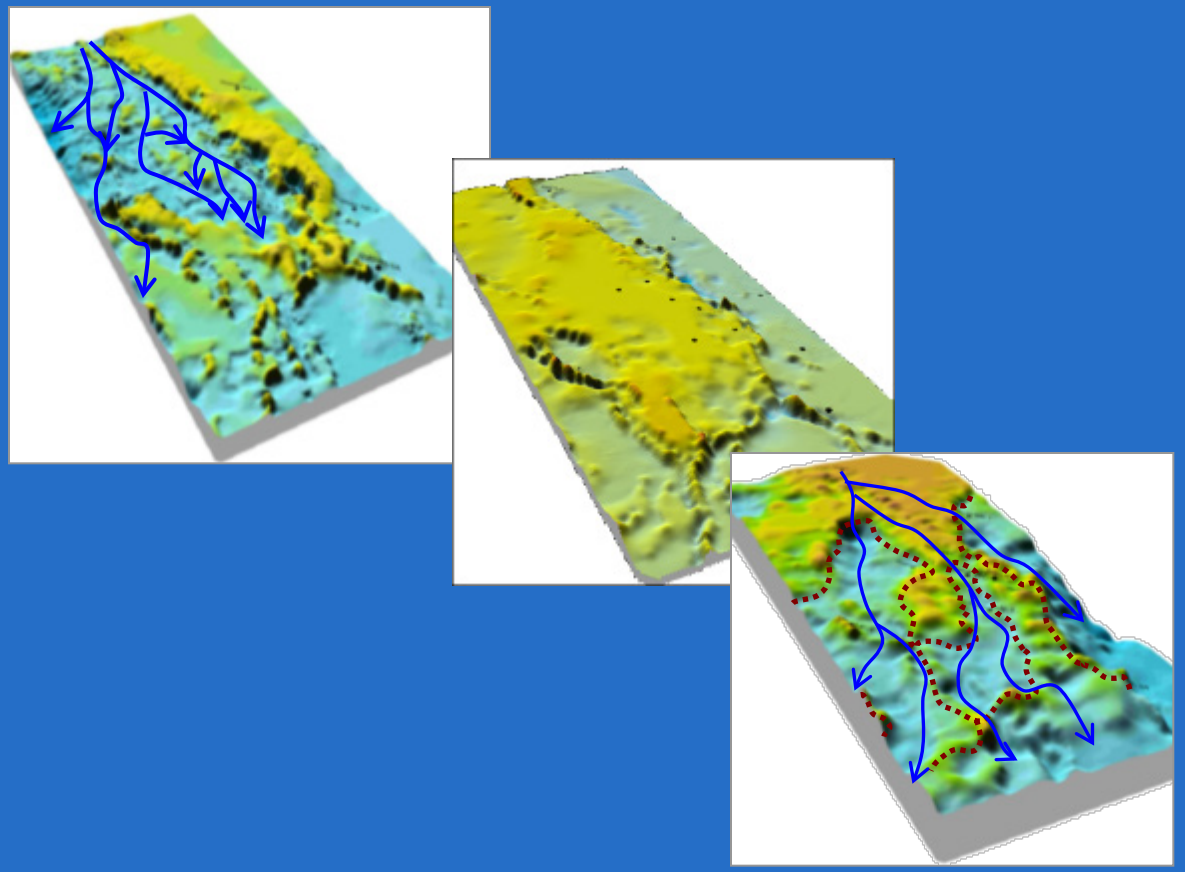
- Actually the reservoirs of Jimidi Fm. are structure-lithologic reservoirs
- The channel sandstones are discontinuous in lateral and vertical, and is not a set of thick massive sandstone



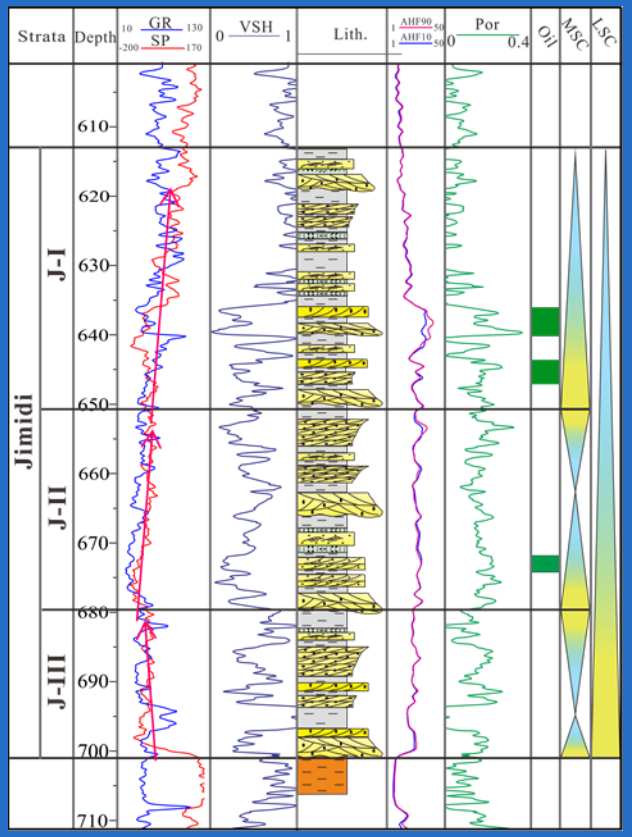
Sandstones and oil layers distribution in lithology section of Jimidi Fm.

Lithologic reservoirs of Jimidi Fm. in Neogene

- The paleotopography study indicated that the channel shape and type made a fast change from the bottom to upper part of Jimidi Fm., which made the channel sandstones be discontinuous and develop lithologic reservoirs



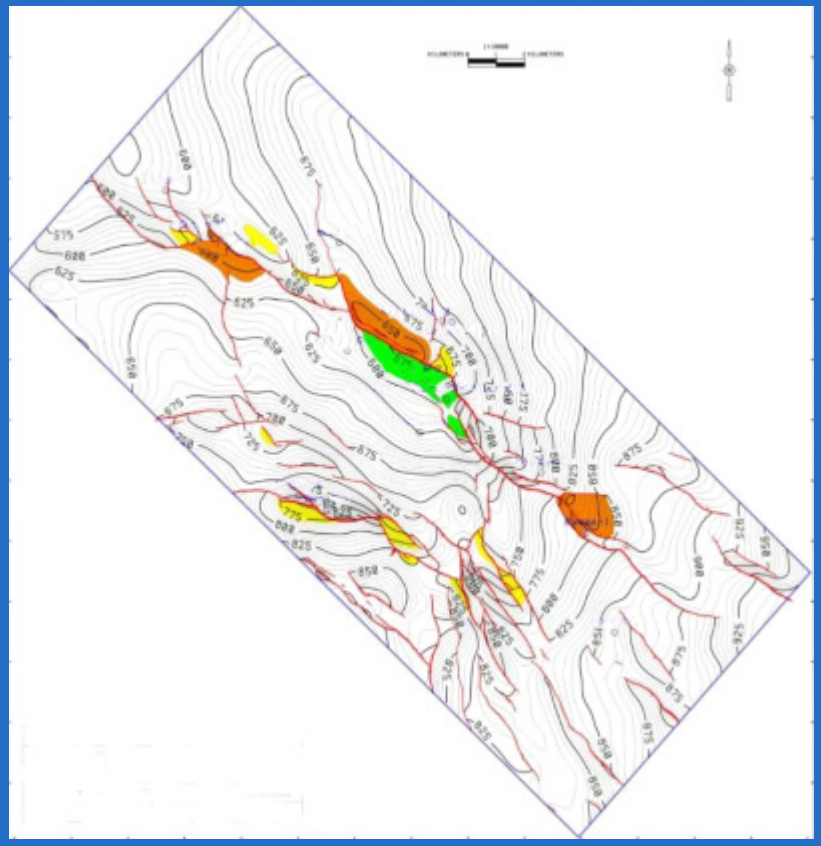
Paleotopography of lower, middle and upper part of Jimidi Fm.



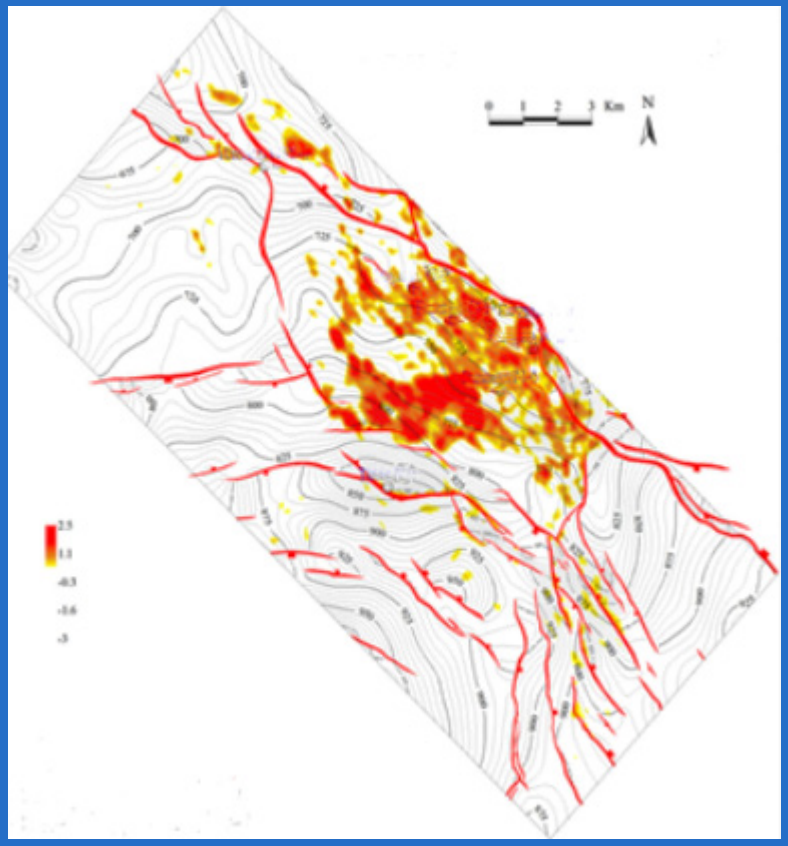
Logging facies and mud logging of Jimidi Fm.

Lithologic reservoirs of Jimidi Fm. in Neogene

- Lithologic reservoirs of channel sandstones greatly expanded the oil-bearing area and exploration potential of Jimidi Fm.



Fault block reservoirs of Jimidi Fm.



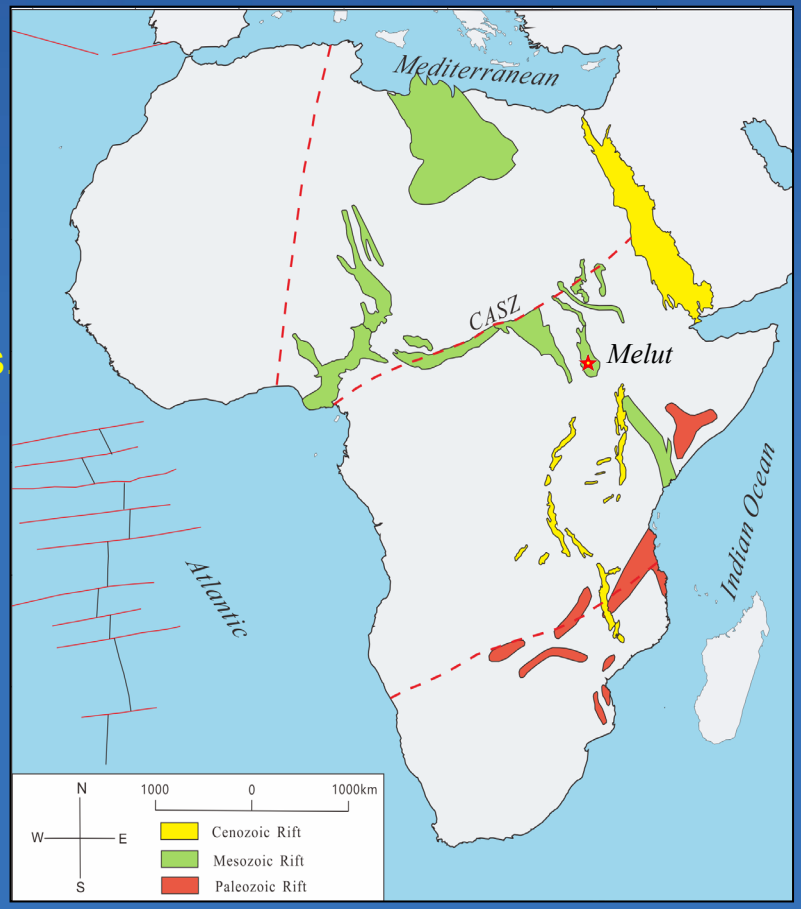
Structure-Lithologic reservoirs of Jimidi Fm.

Outline

- Rift Basin and Hydrocarbon Exploration
- Lithological Reservoirs Characteristics in Melut Basin
- Conclusions and Implications for African Rift Basins

Conclusions and Implications

- African continent developed numerous rift basins with similar tectonic setting and sedimentary filling features, and most basins are facing exploration transition from exploring structural trap to exploring lithologic trap.
- Melut Basin developed multiple types of lithologic reservoirs, and lithologic reservoirs have great exploration potential.
- Near-source and far-source lithologic traps have different accumulation features and evaluation focus
  - Near-source lithologic traps are close to source rock, with good oil source condition, and the reservoir quality is the big risk due to deep depth;
  - Far-source lithologic traps have good reservoir quality with shallow depth, and HC charging is the big risk due to long distance migration.



Rift basin of African continent
(Modified after Daly,1988;Fairhead at al., 1989)