The Prospectivity of Offshore Madagascar

Ben Sayers
Project Developer – Africa, Mediterranean & Middle East
25th January 2016

Legal Notices

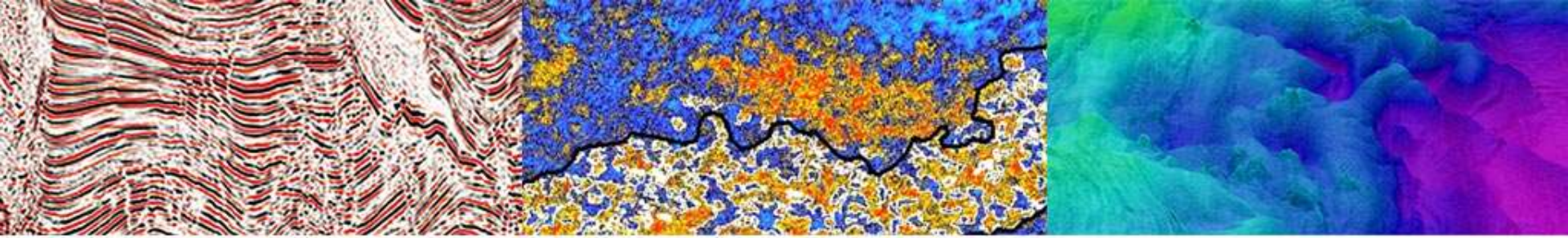
- By viewing this document made available to you by TGS-NOPEC Geophysical Company ASA (“TGS”), you hereby acknowledge and agree that: (i) TGS owns all copyrights for the document; (ii) TGS is providing you with access to the document, provided that you do not distribute, in any medium, to a third party without TGS’s prior written consent; and (iii) you are viewing the document solely for your internal use.

- The images in this document shall not be scanned or loaded to any PC/workstation that makes the data image capable for manipulation or transformation back into commercially viable information.

- All images in this presentation have had the quality reduced. For a higher resolution data room, please contact TGS.

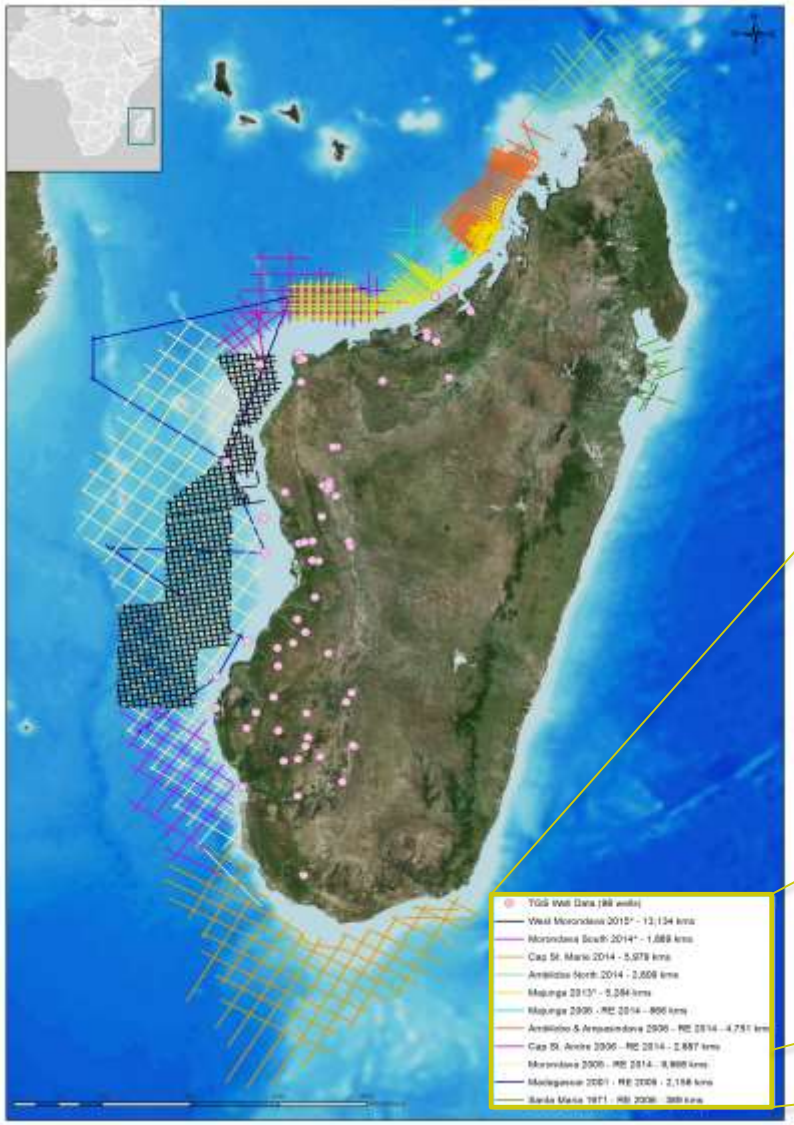
Agenda

- Multi-Client Database
- Tectonic Development and Basin Distribution
- Petroleum System Elements
- Basin Tour
  - Cape St Marie
  - West Morondava
  - Majunga
  - Ambilobe North
- Concluding Points



Multi-Client Database

Madagascar Multi-Client Database

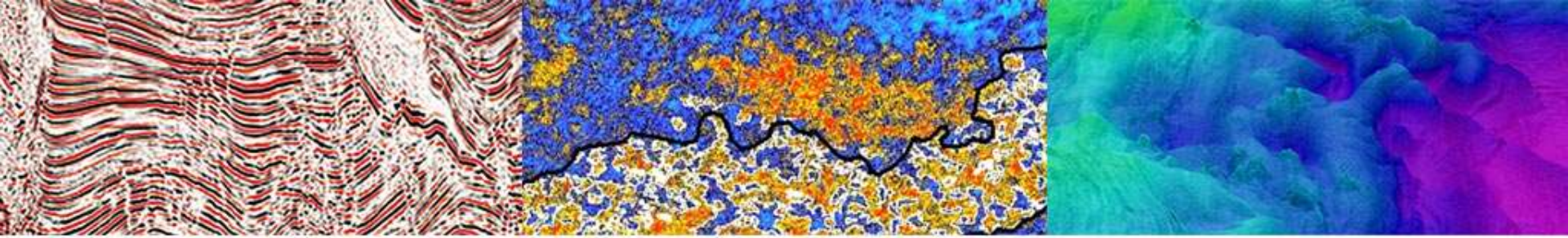


c.**50,000** line kms of 2D seismic and marine gravity/magnetic data available in Madagascar plus **98** wells, of which 11 are offshore and all in shallow water depths.

Integrated interpretation studies are nearing completion.

- TGS Well Data (98 wells)
- West Morondava 2015* - 13,134 kms
- Morondava South 2014* - 1,889 kms
- Cap St. Marie 2014 - 5,979 kms
- Ambilobe North 2014 - 2,809 kms
- Majunga 2013* - 5,284 kms
- Majunga 2006 - RE 2014 - 866 kms
- Ambilobe & Ampasindava 2006 - RE 2014 - 4,751 kms
- Cap St. Andre 2006 - RE 2014 - 2,887 kms
- Morondava 2005 - RE 2014 - 9,668 kms
- Madagascar 2001 - RE 2005 - 2,158 kms
- Santa Maria 1971 - RE 2006 - 389 kms

* in partnership with BGP



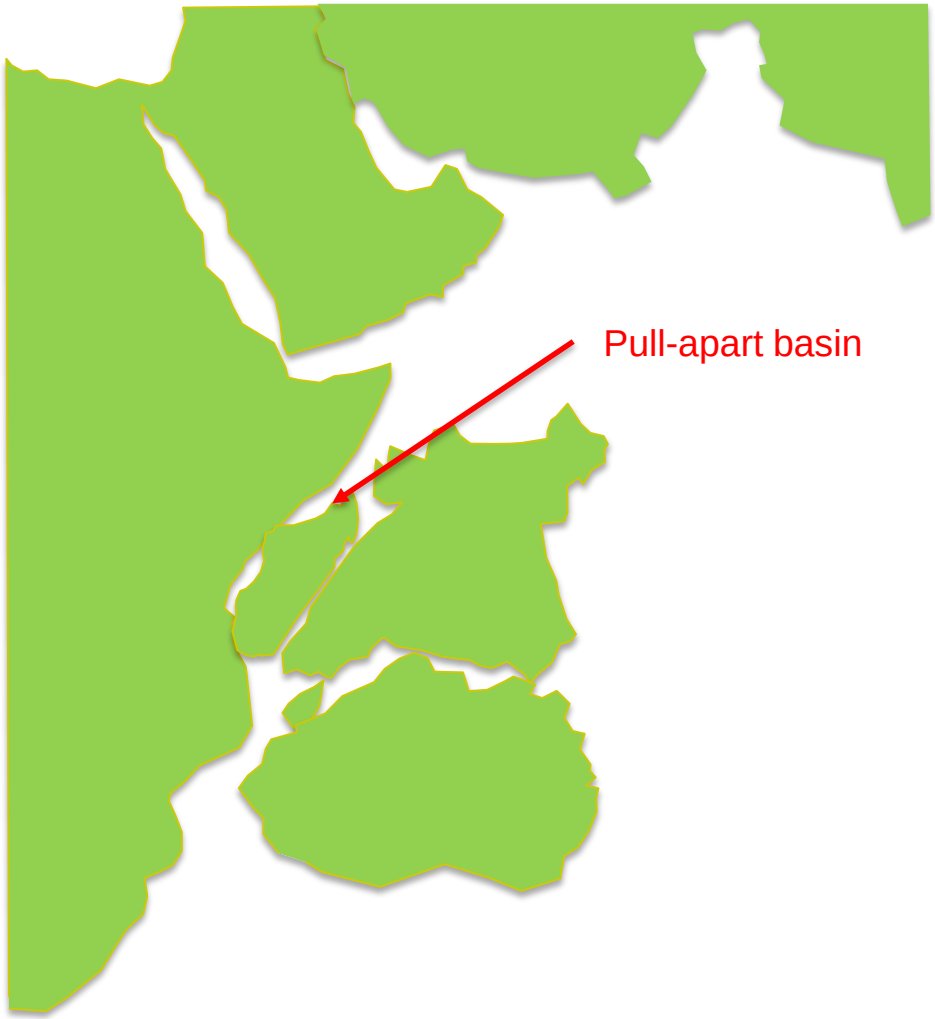
Tectonic Development and Basin Distribution

Tectonic History

Karoo event lasted from Carboniferous to Lower Jurassic

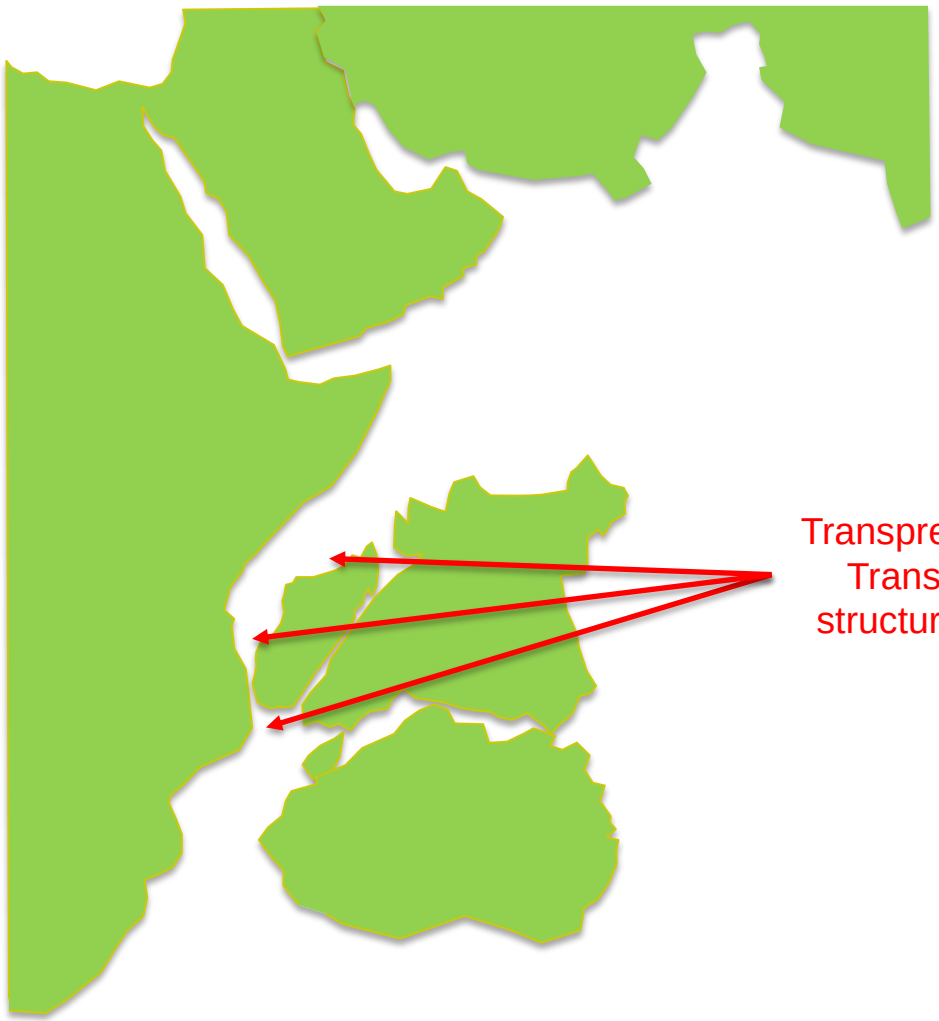
Sketch map purely for Karoo trend discussion and no paleo-reconstruction has been performed

Tectonic History



Middle Jurassic

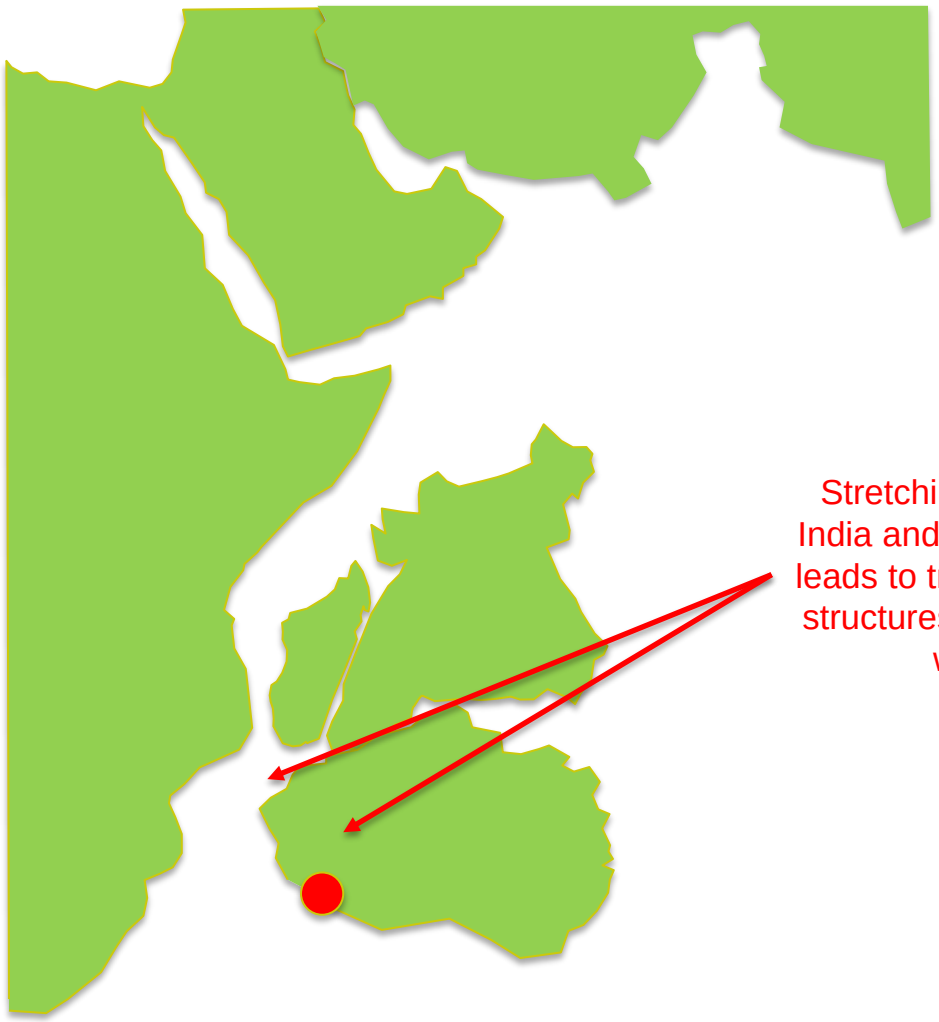
Tectonic History



Upper Jurassic

Transpressional and
Transtensional
structures develop

Tectonic History

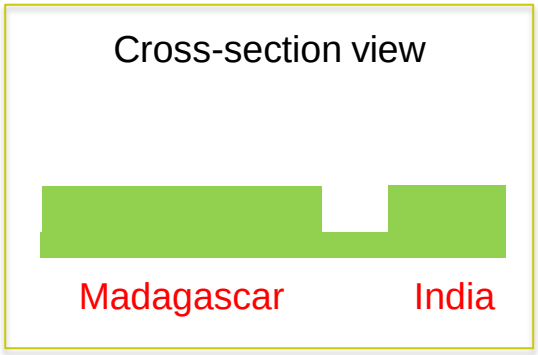


Upper Cretaceous

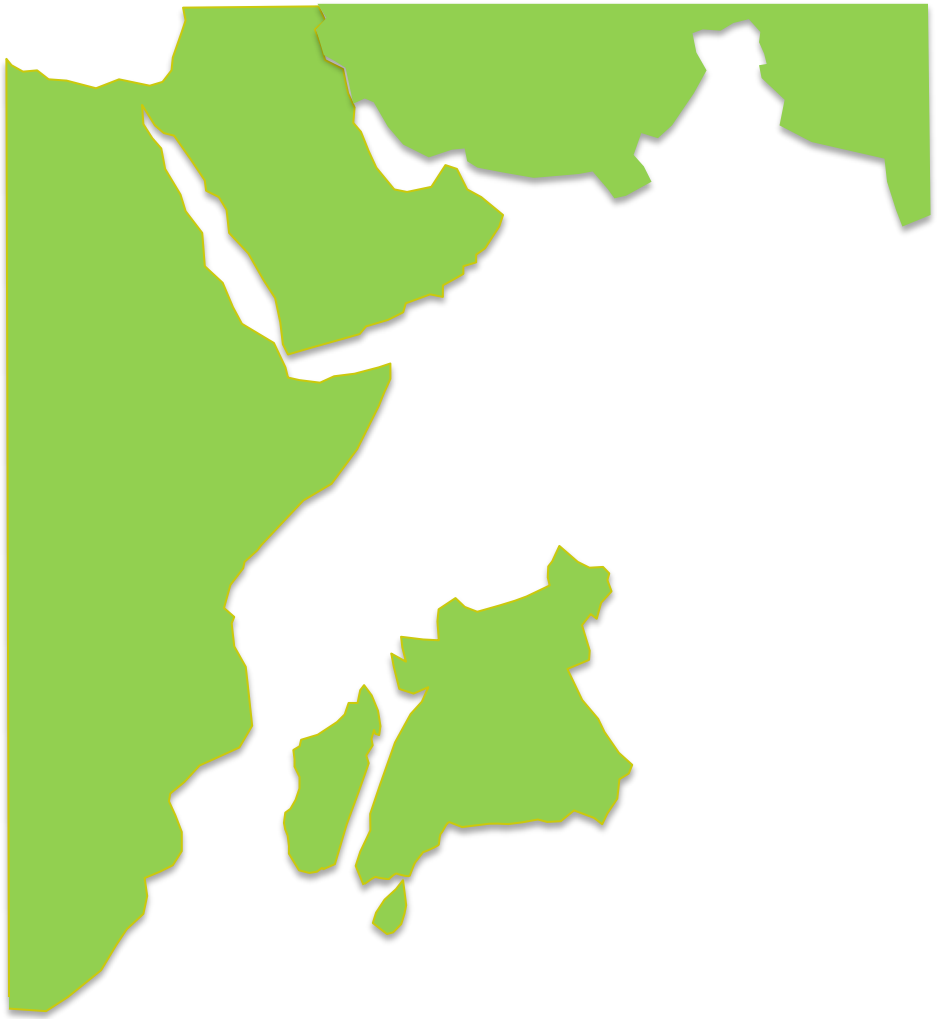
Stretching between India and Madagascar leads to transtensional structures develop on west

Tectonic History

Upper Cretaceous



Tectonic History

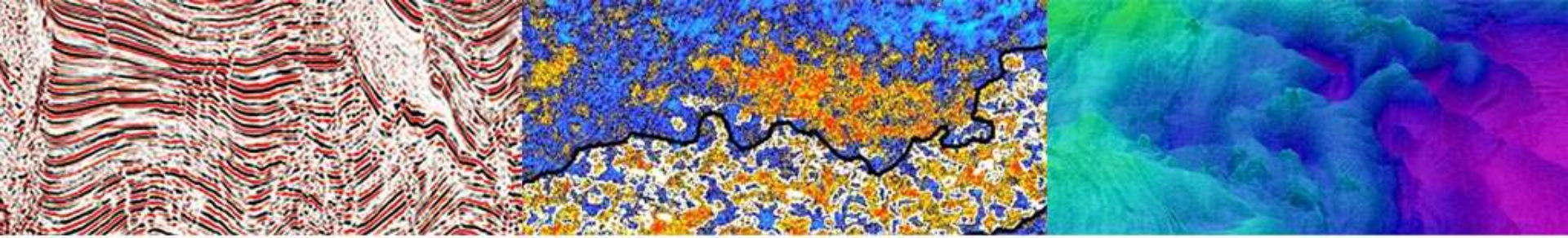


Upper
Tertiary
Cretaceous

Tectonic History

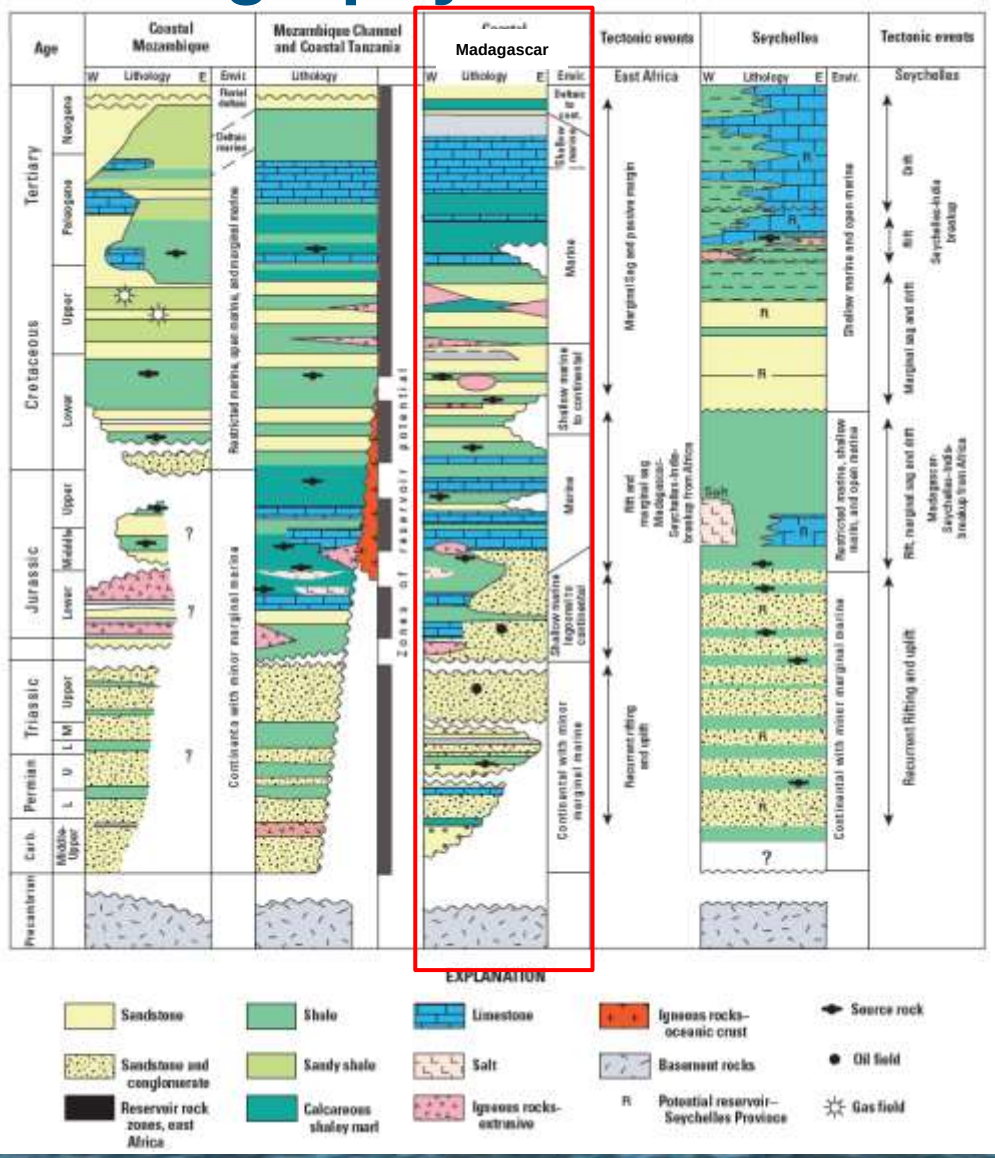
Present Day

1. Permo-Triassic (Karoo) failed rift
2. Jurassic rifting of Madagascar from East Africa
3. Turonian rifting of India from Madagascar



Petroleum System

Stratigraphy



Source rocks:

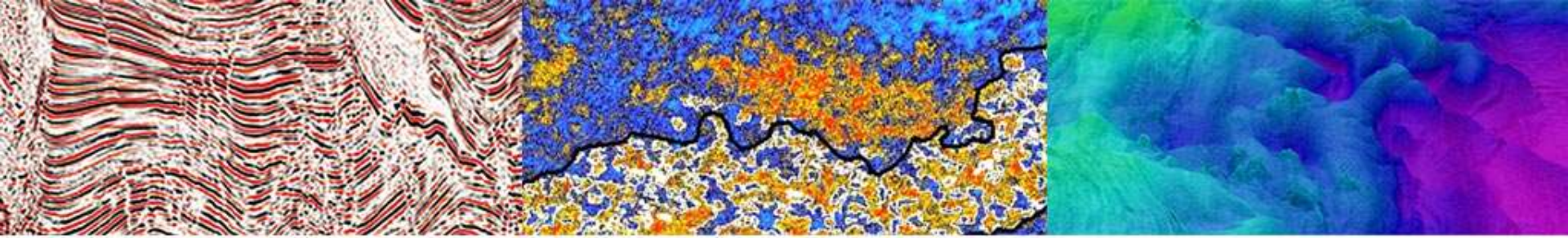
- Lower Triassic – Sakamena formation;
- Lower to Middle Jurassic: shallow marine shales and marls;
- Upper Jurassic shales;
- Cretaceous and Tertiary source rocks

Reservoir rocks:

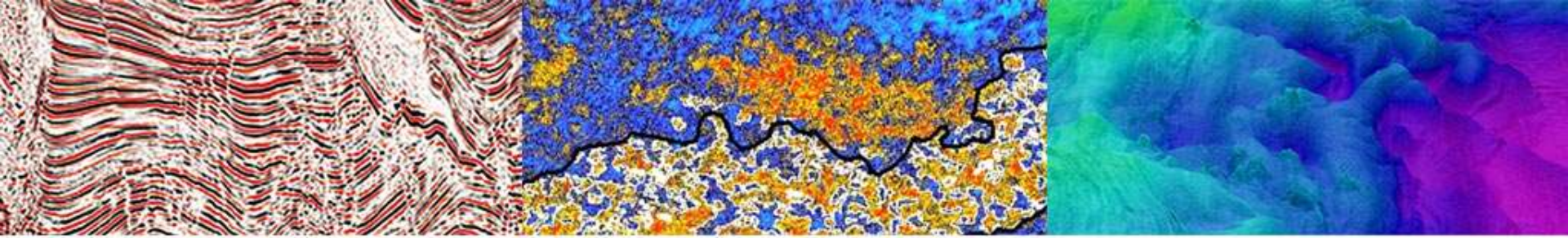
- Triassic-Lower Jurassic: Isalo group sandstones;
- Middle Jurassic shallow marine biogenic limestones,
- Lower Cretaceous and Upper Cretaceous deltaic sandstones, deep water fan and channel sandstones
- Tertiary sandstones and nearshore limestones.

Seals:

- Thick marine shales in Cretaceous and Tertiary sequences

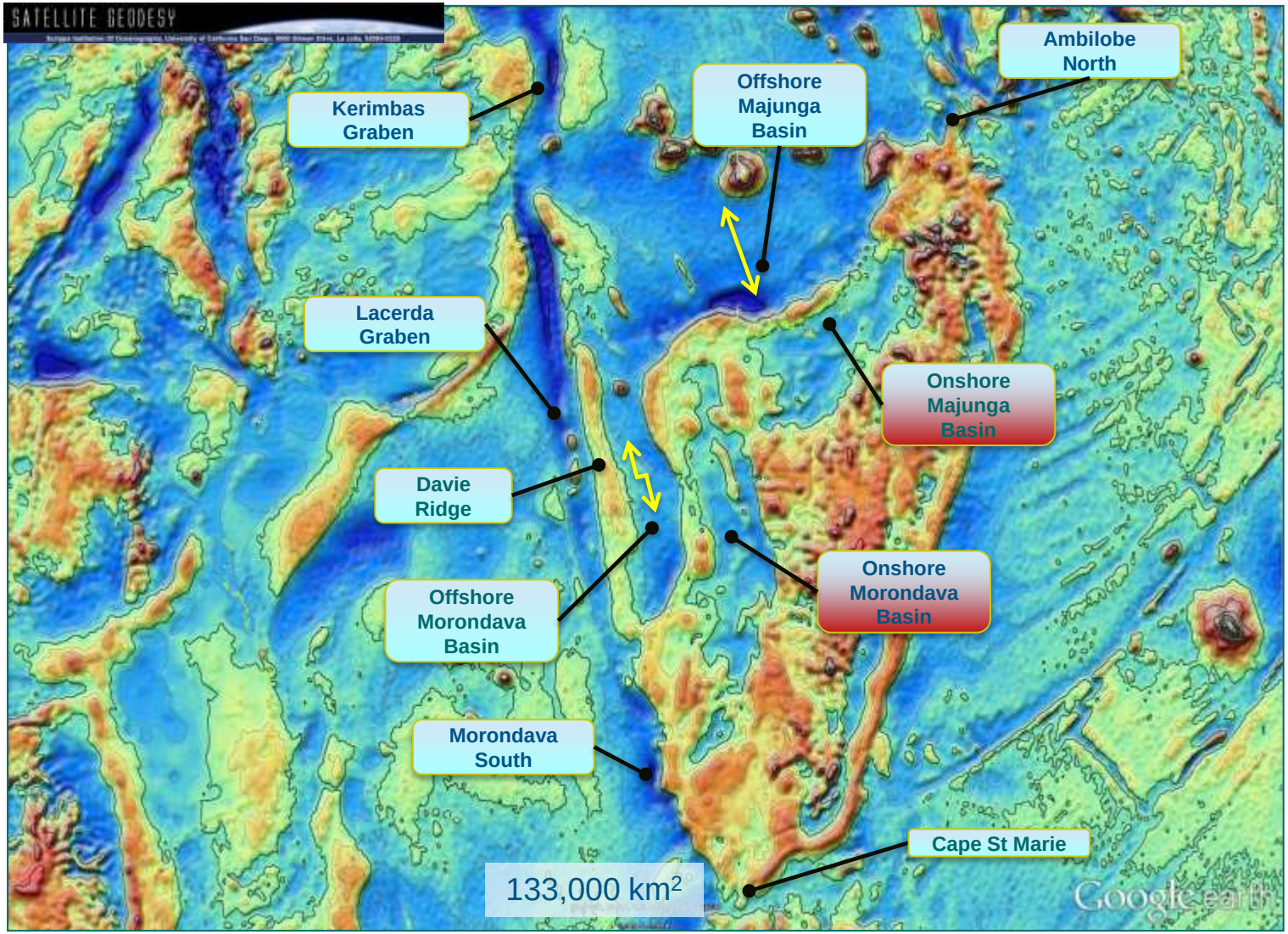


Basin Tour

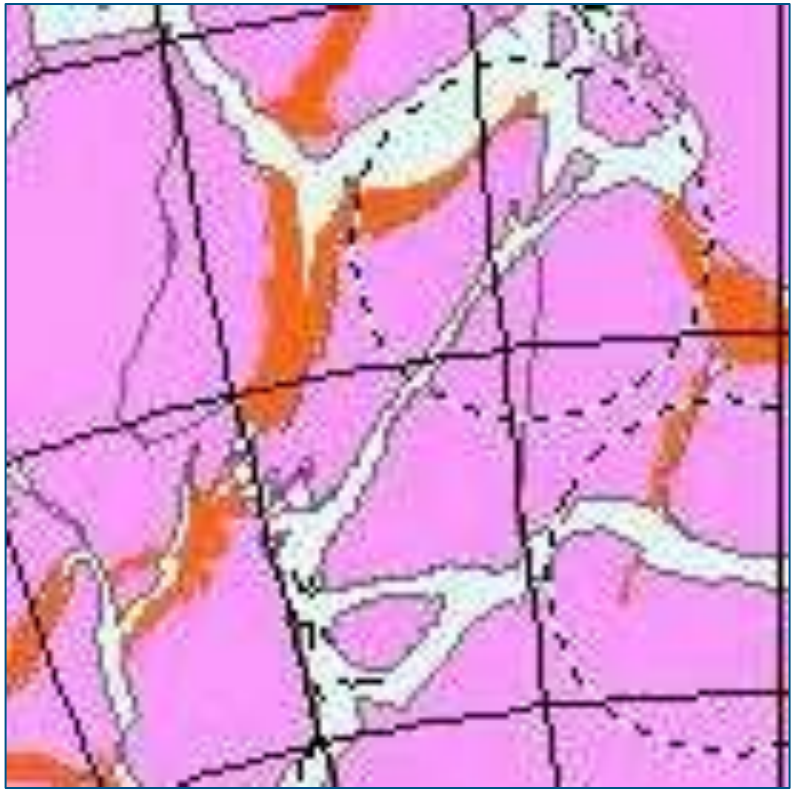


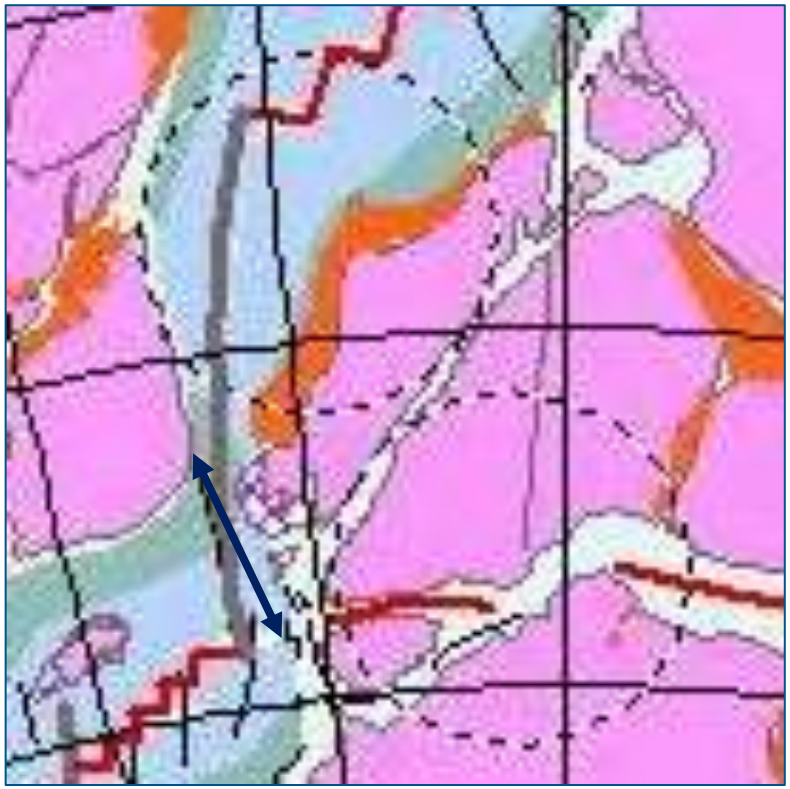
Basin Tour: Cape St Marie

Location Map and Free Air Anomaly



Development of the Basin

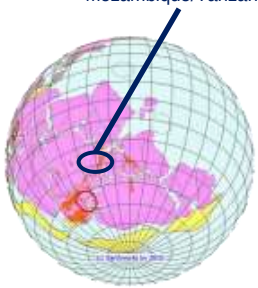




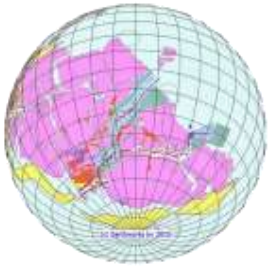
Early Jurassic [184 Ma]
(Toarcian)
At the fit position the western edge of the Cap St. Marie area was connected to the Mozambique/Tanzania

The Karoo basin (orange) trend can be seen running down the present day western coast.

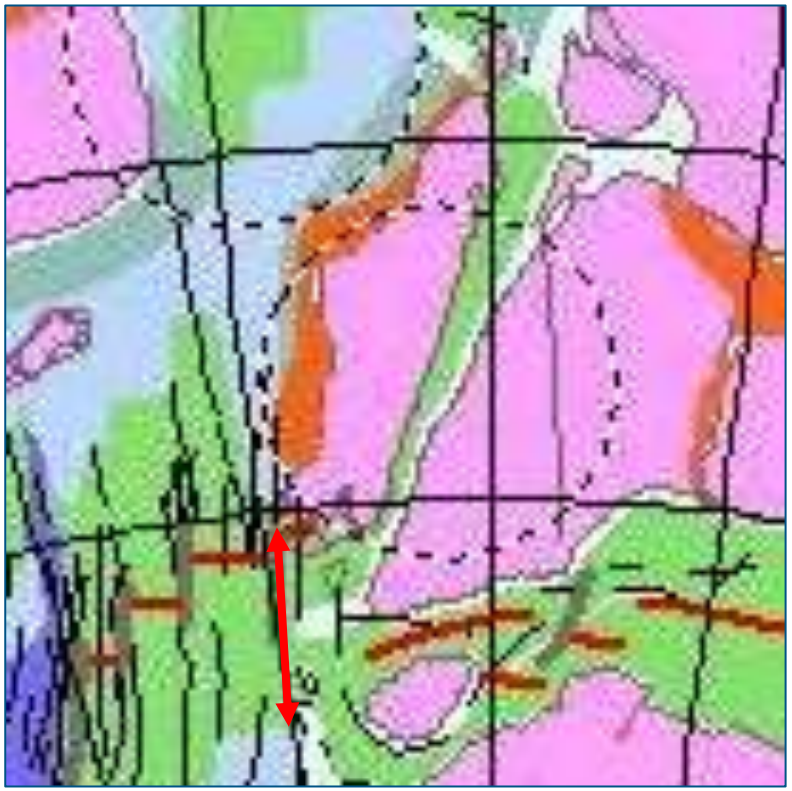
Connected to Mozambique/Tanzania



Late Jurassic [146 Ma]
(Tithonian)
Rifting that started in the Early Jurassic had opened up the Cap St. Marie area with a NW-SE trend. Creating shallow marine conditions.

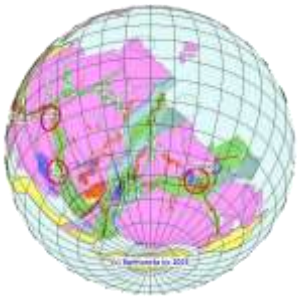


Development of the Basin



Early Cretaceous [120 Ma]
(Early Aptian)

Rifting had rotated to a N-S trend extending the ocean between Antarctica.

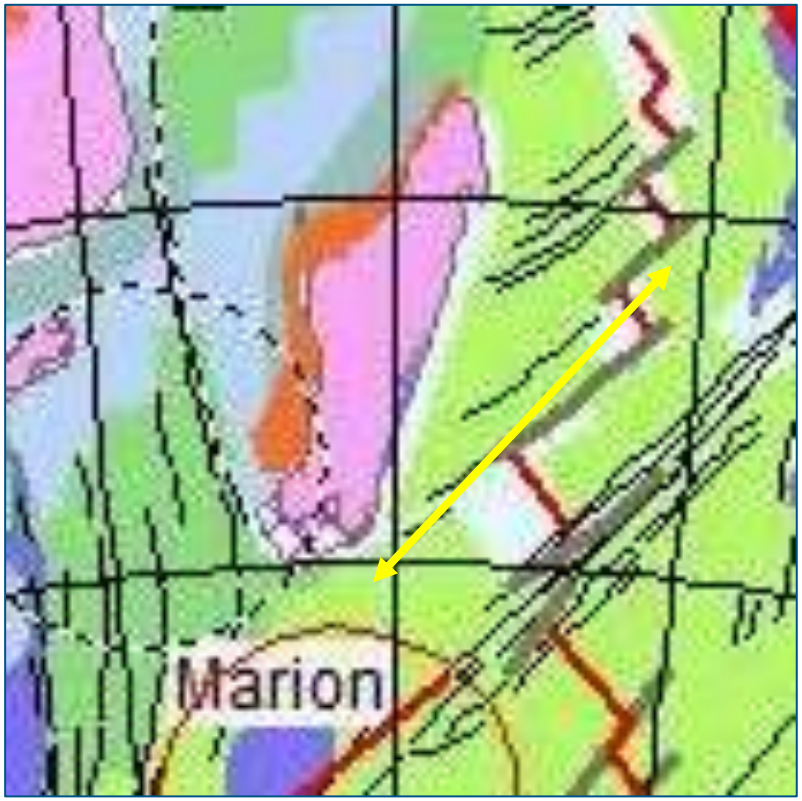


Late Cretaceous [88 Ma]
(Late Turonian)
Rifting between India and Madagascar began creating accommodation space for sediments in CsM

The Marion Hotspot led to output of volcanic material The higher heat flow led to uplift in the Cap St. Marie area.

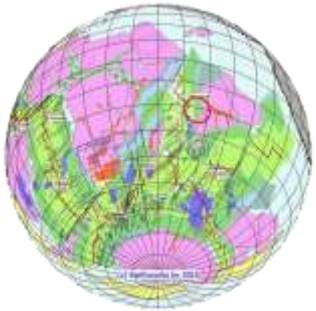
During the tilting of Madagascar sediments filled the western side of the CsM basin and created extension structures to the east.

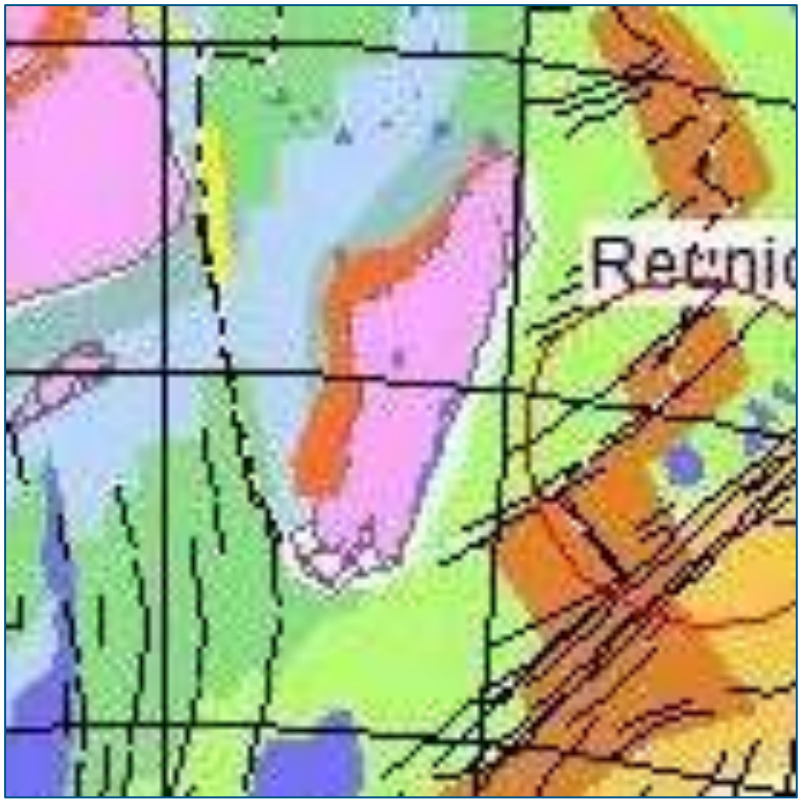
Development of the Basin



Late Cretaceous [66 Ma]
(Maastrichtian)
Following rifting to the east and west and uplift from the hotspot a natural central high developed.

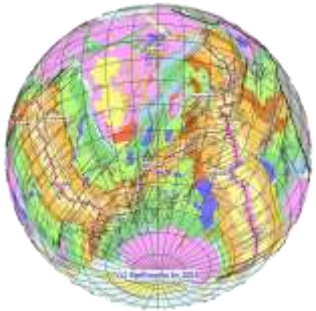
Tilting following the India rift focused sediments to the west





Present Day

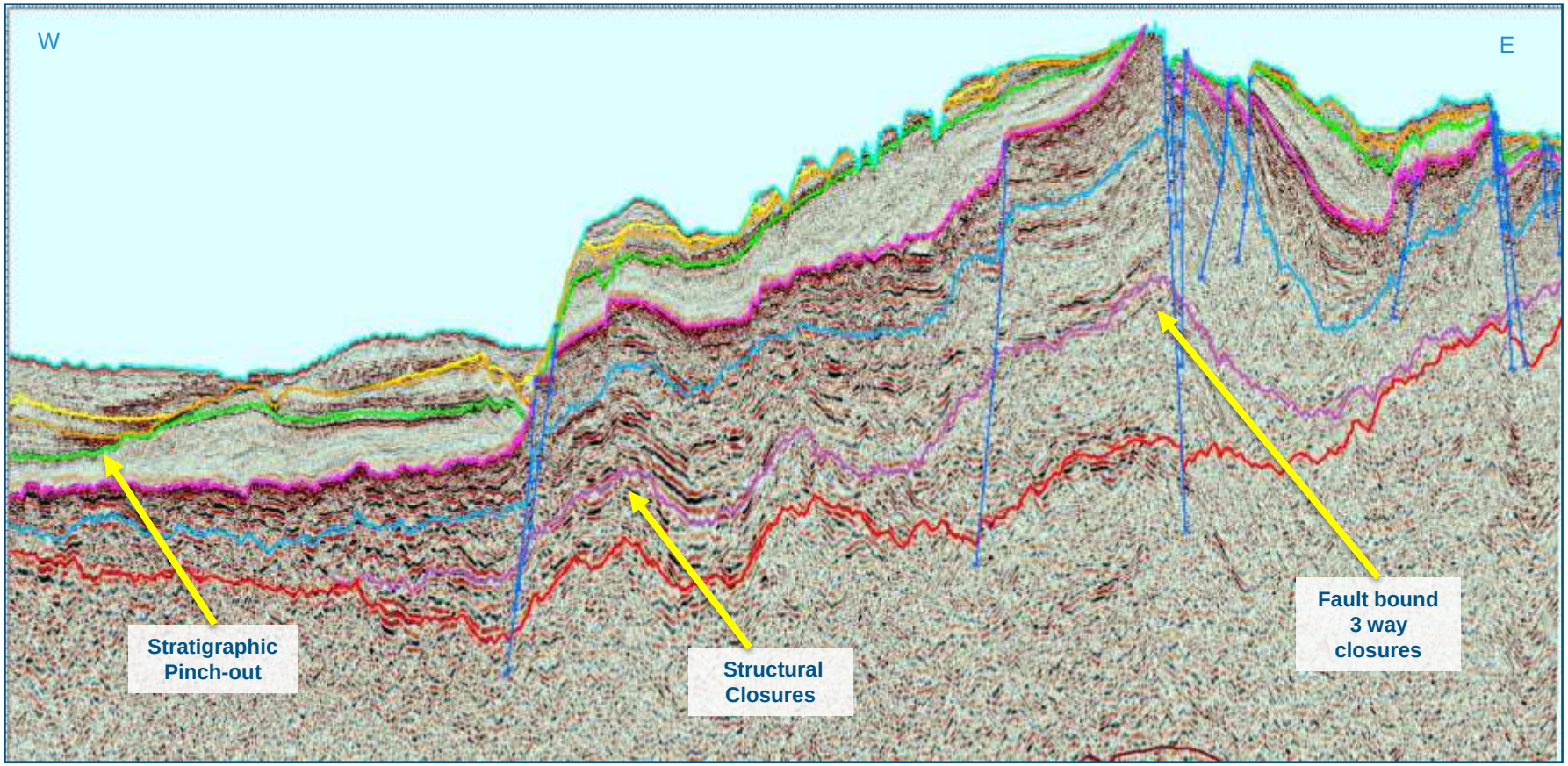
Continued passive margin.



Petroleum Potential

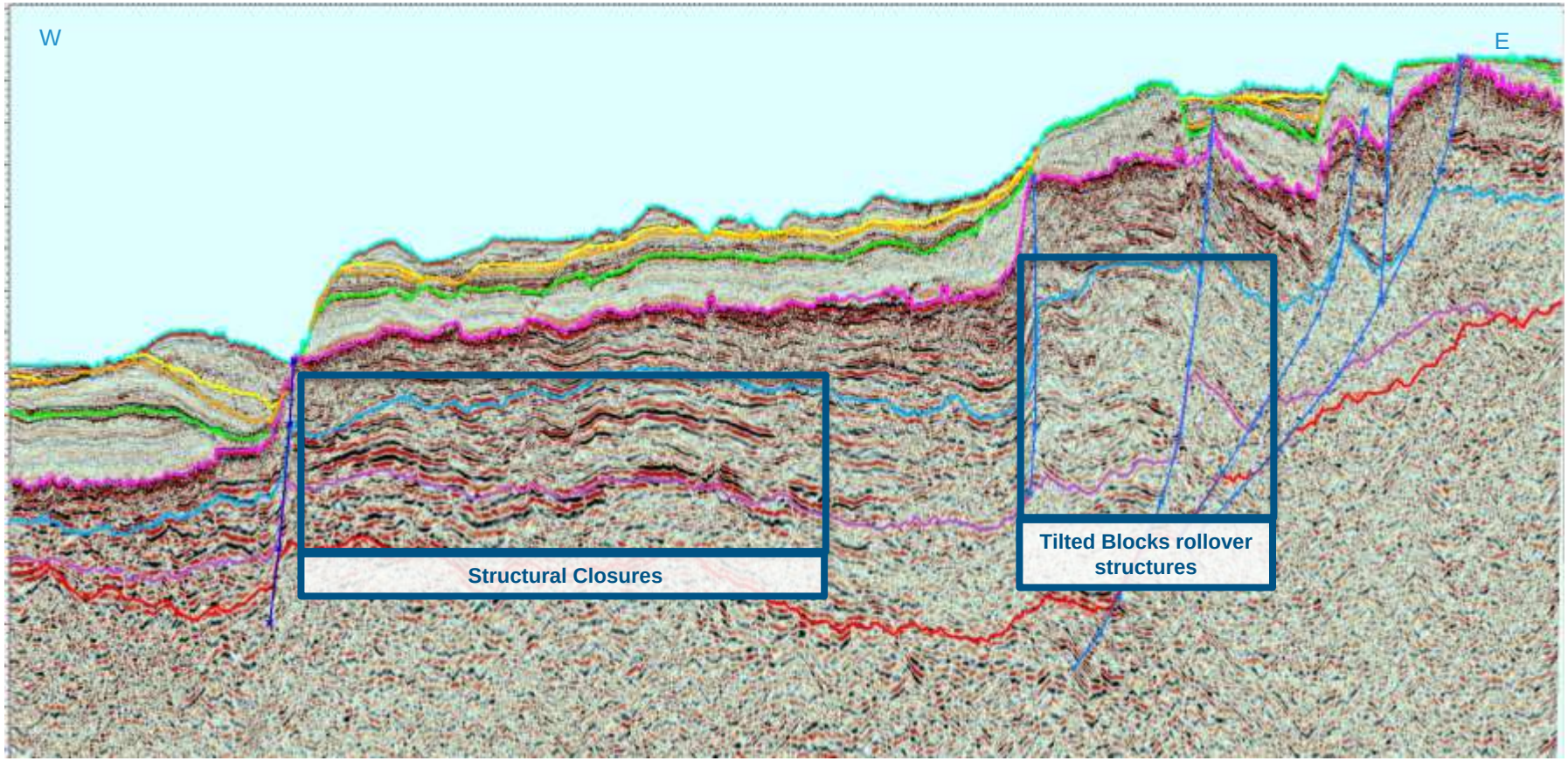
- The offshore Cape St. Marie area has had a number of tectonic events that produce a number of large structural closures and potential fault related structures;
- Untested frontier area with an interpreted thick Lower Cretaceous to Lower Jurassic interval with potential for good source rock deposition;
- The appearance of the Marion hotspot (c. 90Ma to 80Ma) would have a regional effect on the thermal maturity of the area.

Play Types: Example 1



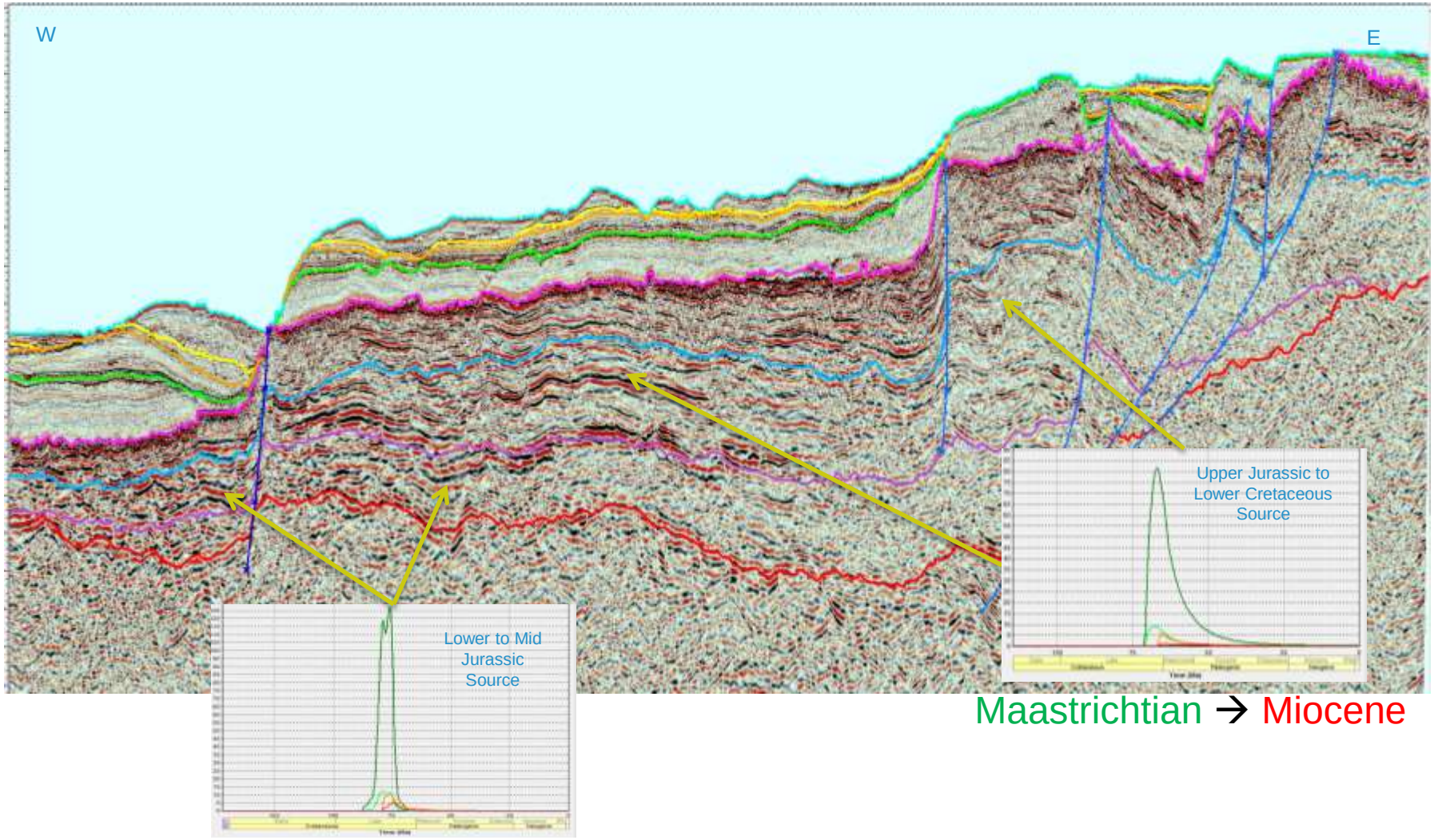
- Horizons below Santonian (Pink)
  - Jurassic to Lower Cretaceous (Blue)
  - Middle / Lower Jurassic (Purple)

Play Types Example 2



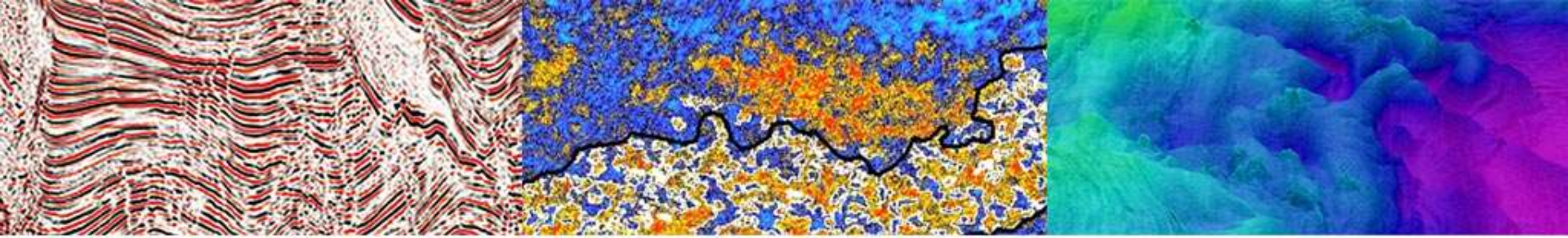
- Horizons below Santonian (Pink)
  - Jurassic to Lower Cretaceous (Blue)
  - Middle / Lower Jurassic (Purple)

Source Rock Expulsion



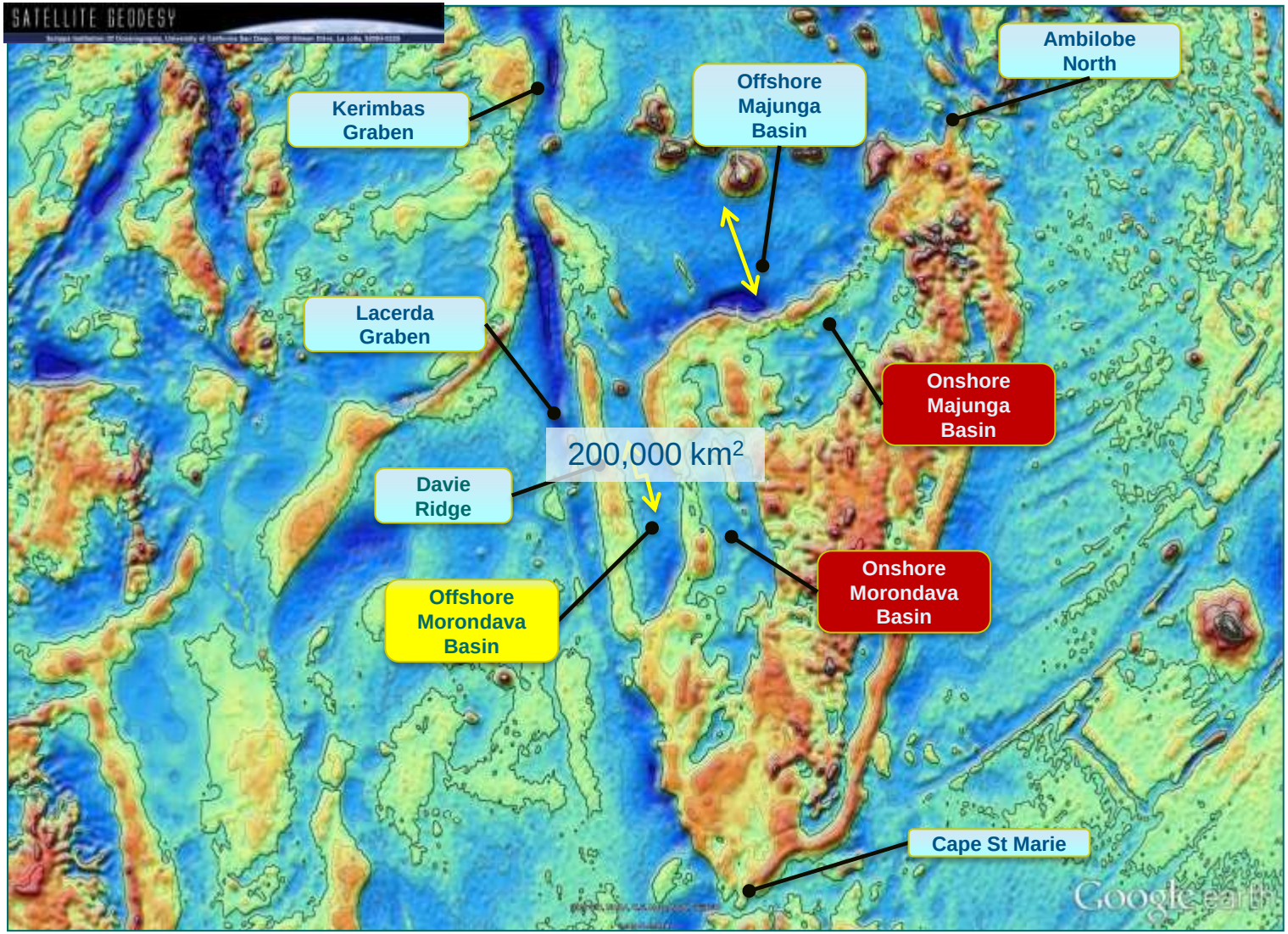
Maastrichtian → Miocene

Santonian → Maastrichtian

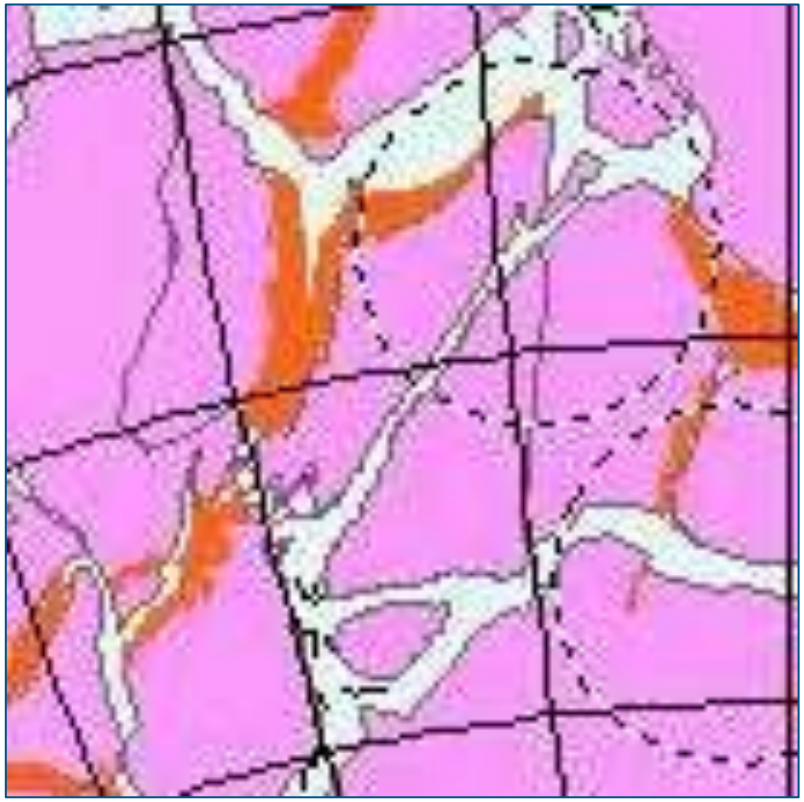


Basin Tour: Morondava

Location Map and Free Air Anomaly



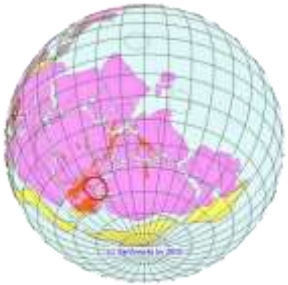
Development of the Basin

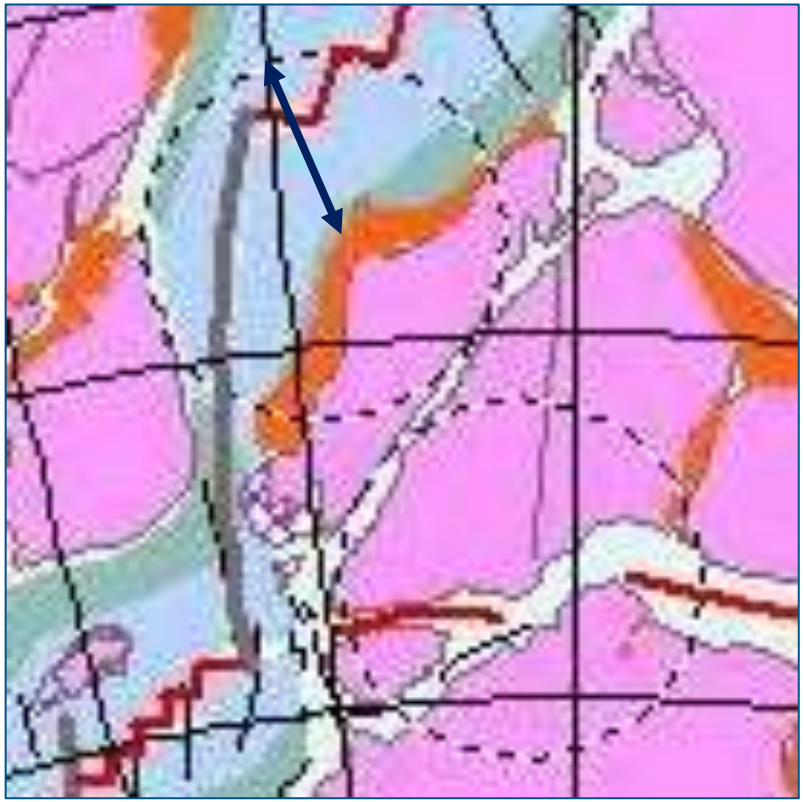


A. Early Jurassic [184 Ma]
(Toarcian)

The ‘fit’ position, Morondava is located is still conjugate with Mozambique, Tanzania and Kenya.

The failed karoo sag basins were accumulating sediments since Permain

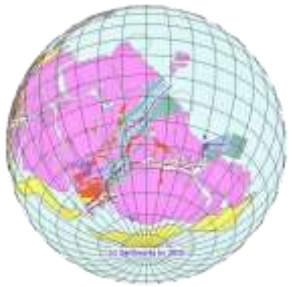




B. Lower Cretaceous [144 Ma]
(Berriasian)

Rifting that started in the Early Jurassic had opened up the Morondava basin with a NW-SE trend, creating shallow marine conditions with active biogenic limestone production creating reefs

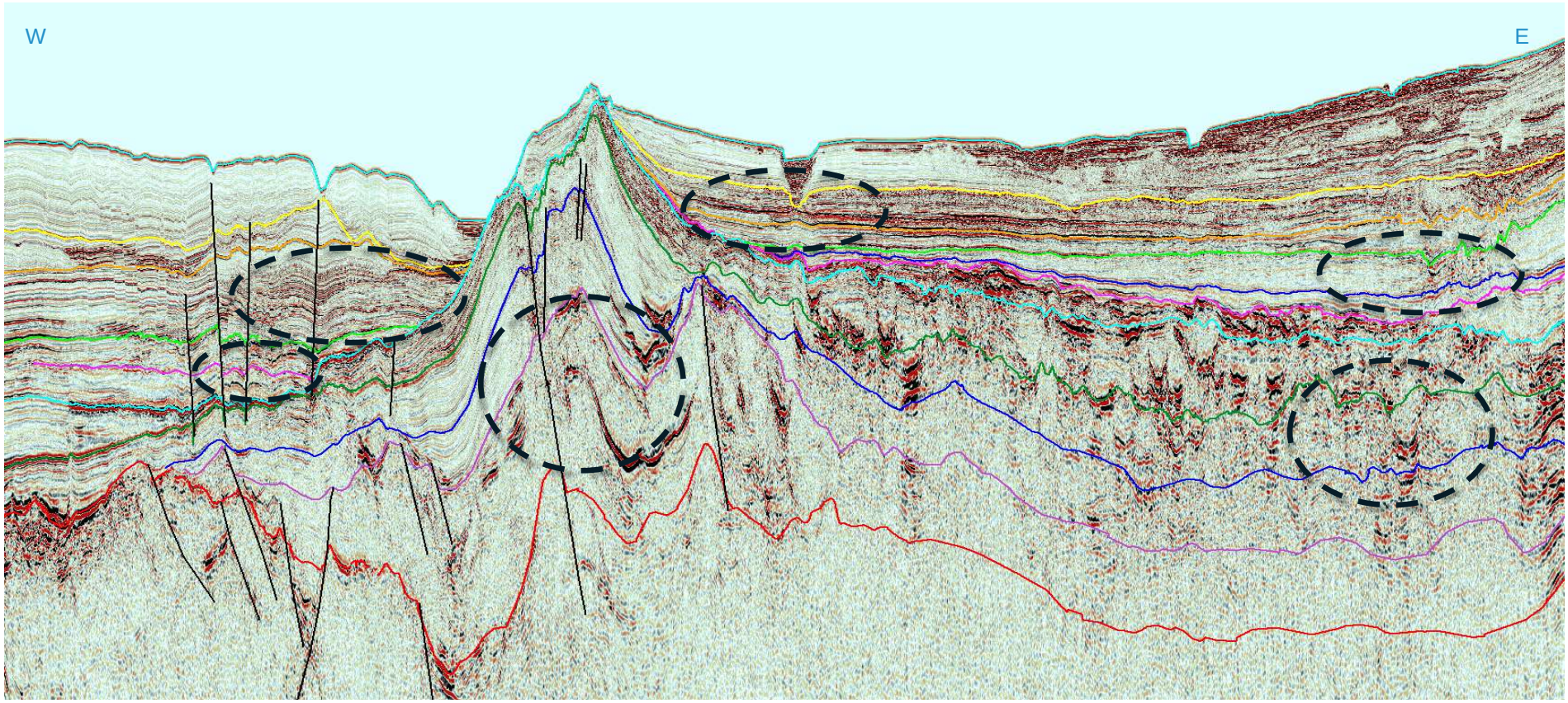
Madagascar was still connected to India so there is a large hinterland for sediment supply.



Petroleum Potential

- Potential for oil mature Jurassic source rocks and Jurassic syn-rift plays;
- Potential reservoirs and seals throughout the Jurassic to Tertiary sequence with local amplitude support;
- Structural closures, faulted traps and stratigraphic pinch out and combination trapping potential;
- Potential inverted basin play within the Davie Fracture Zone.

Morondava Basin – Example Play Types



Inside the DFZ with fault bounded closures and 4-way dips

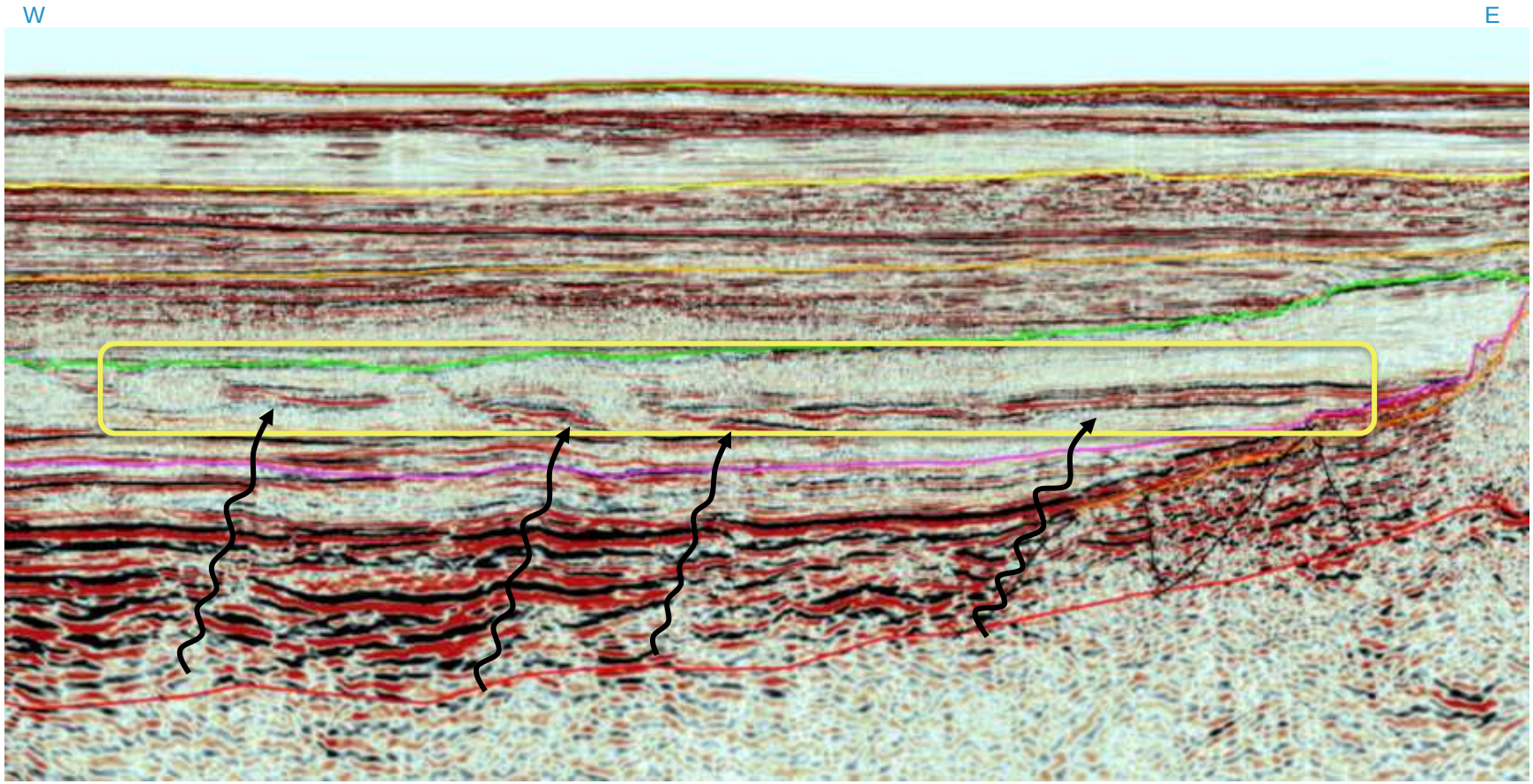
Lower Cretaceous / Upper Jurassic fault blocks

Upper Cretaceous stratigraphic pinch-outs

Anticlinal transpressional structures outboard of the DFZ

Pinching out against DFZ

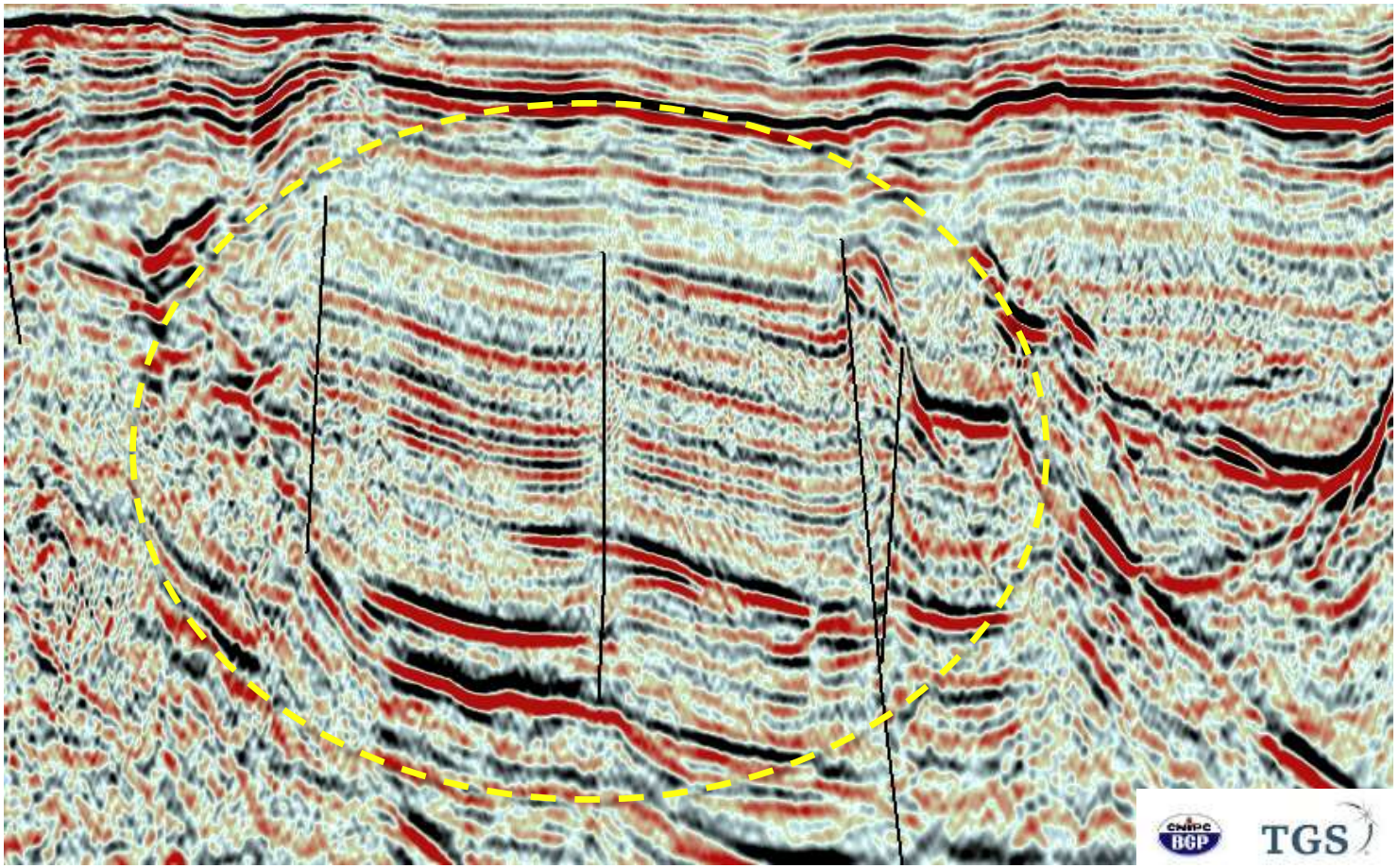
Channel Sands



Clear channels outboard
of the DFZ

Lower Cretaceous Fault Blocks

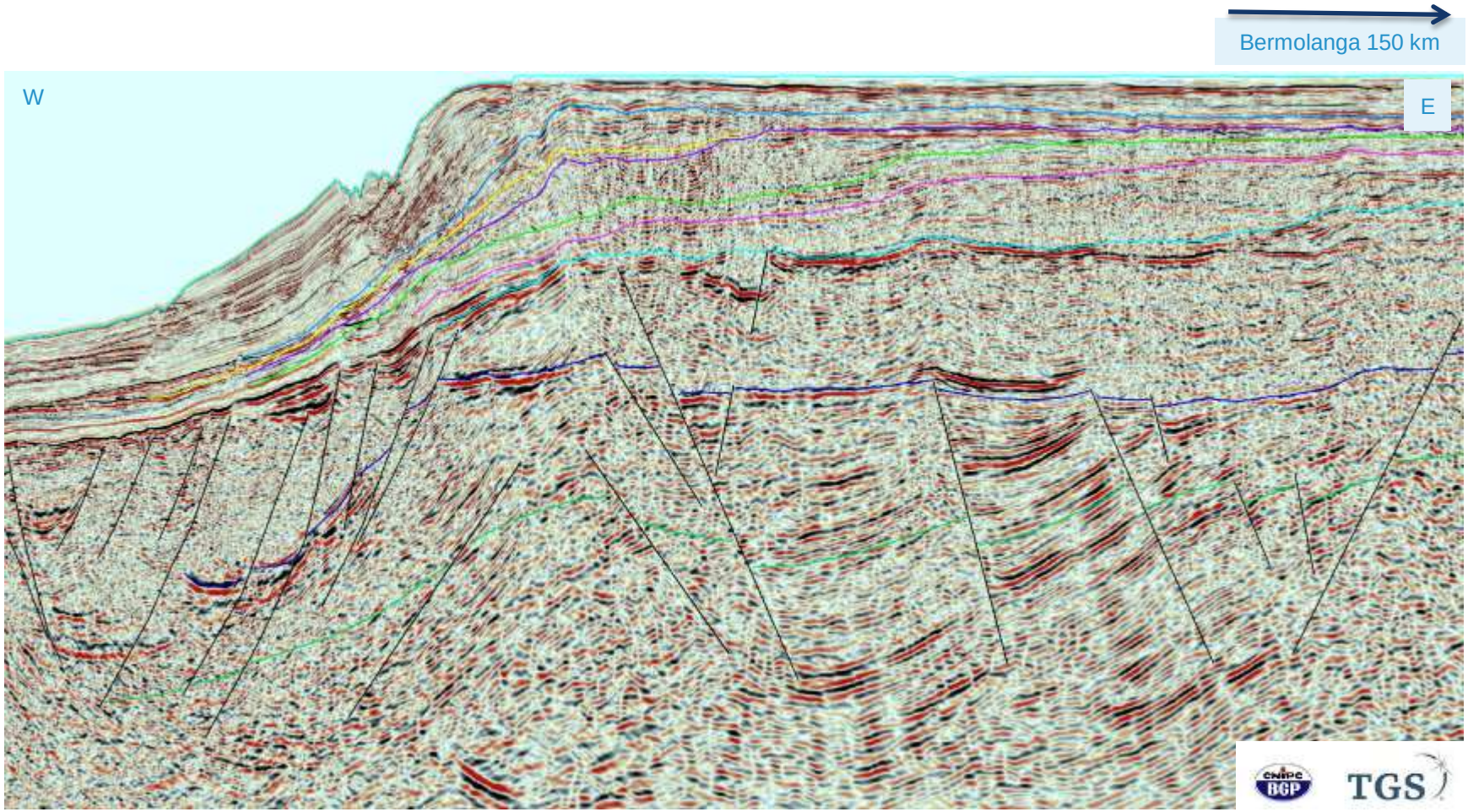
W



E

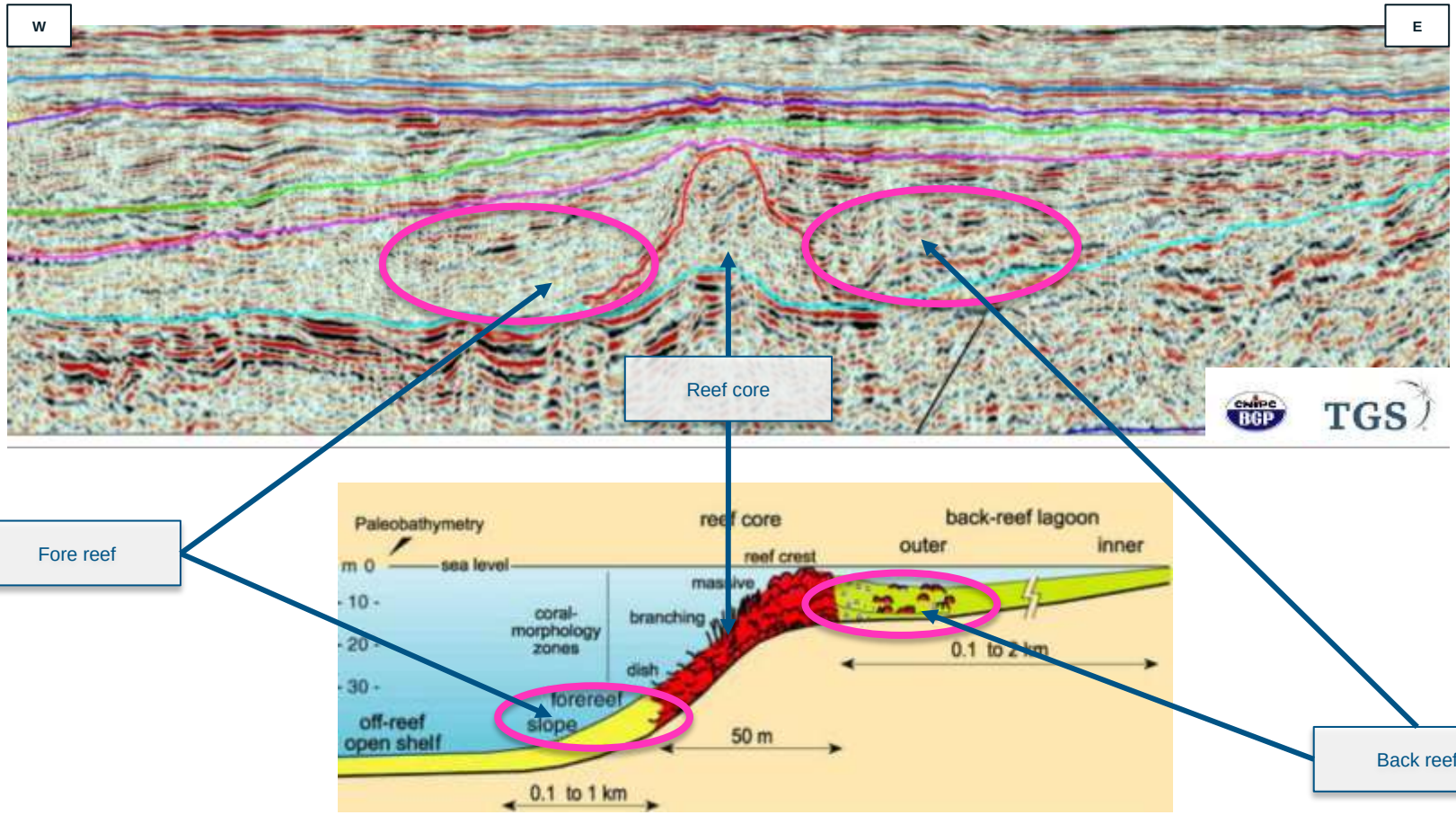
Rotated during the transpressional movement along the DFZ and during the microplate rotation.

Rotated Fault Blocks on Morondava Shelf

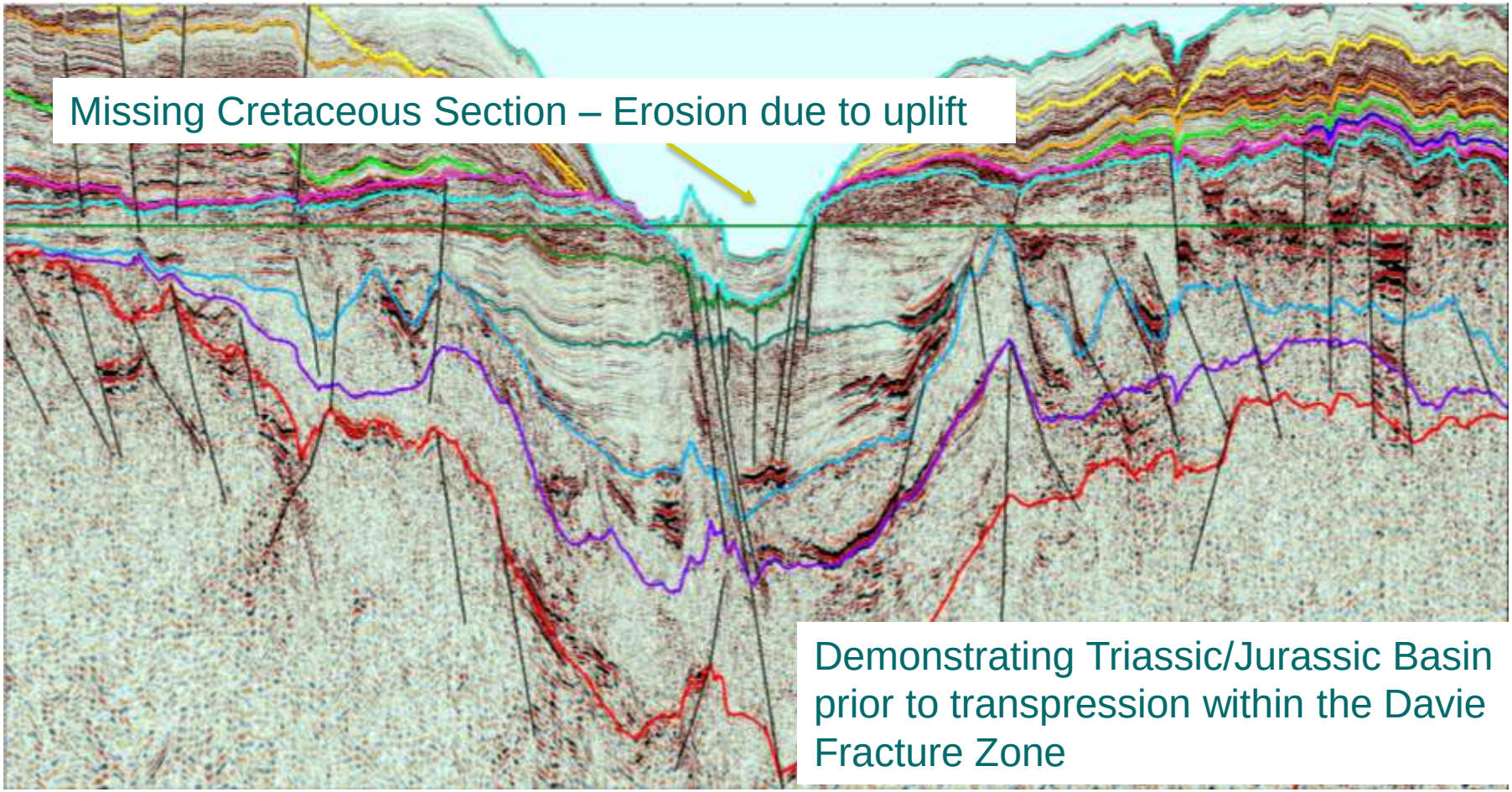


Karoo sediments rotated during Jurassic.

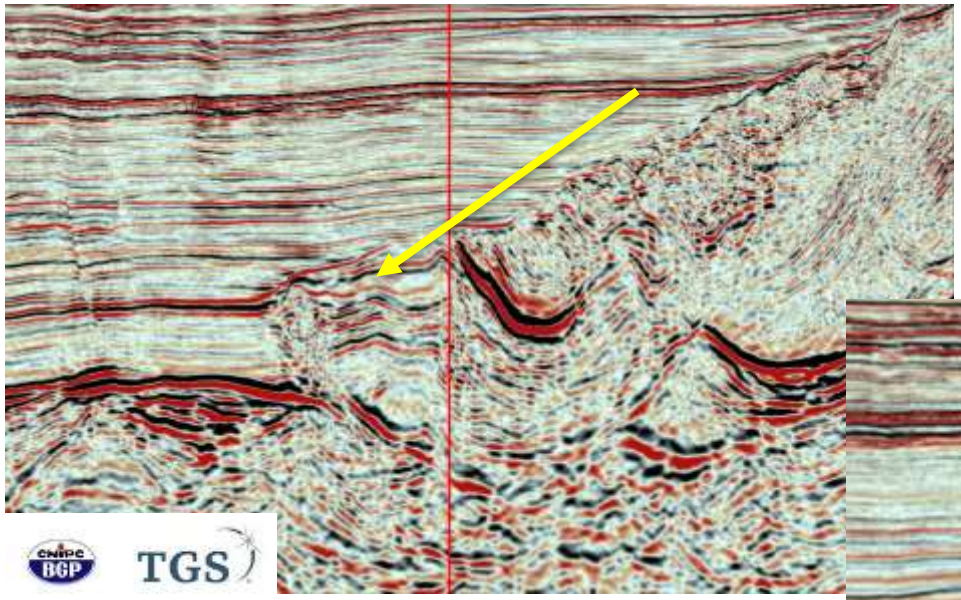
Cretaceous Reefs

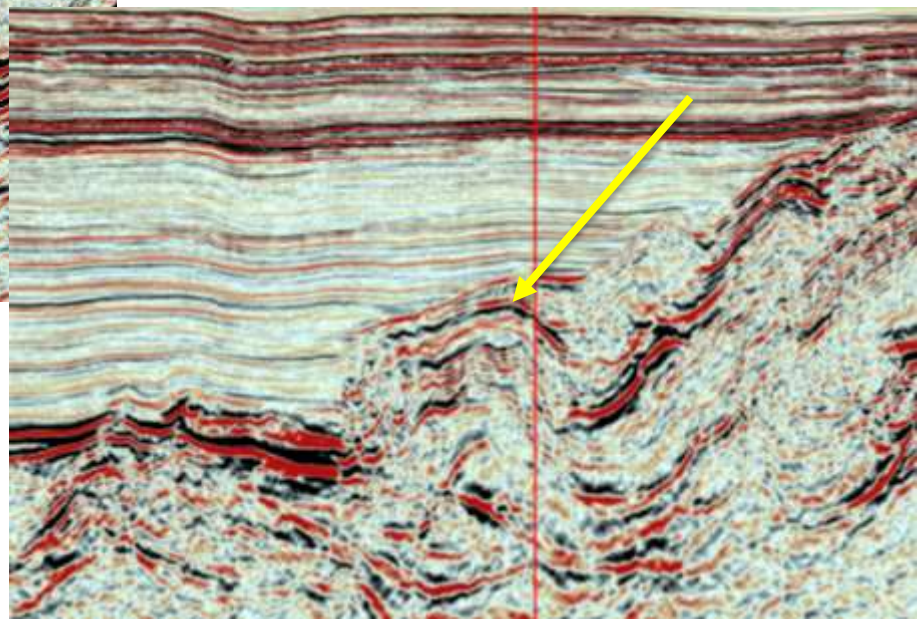


Data Flattened on Intra-Lower Cretaceous



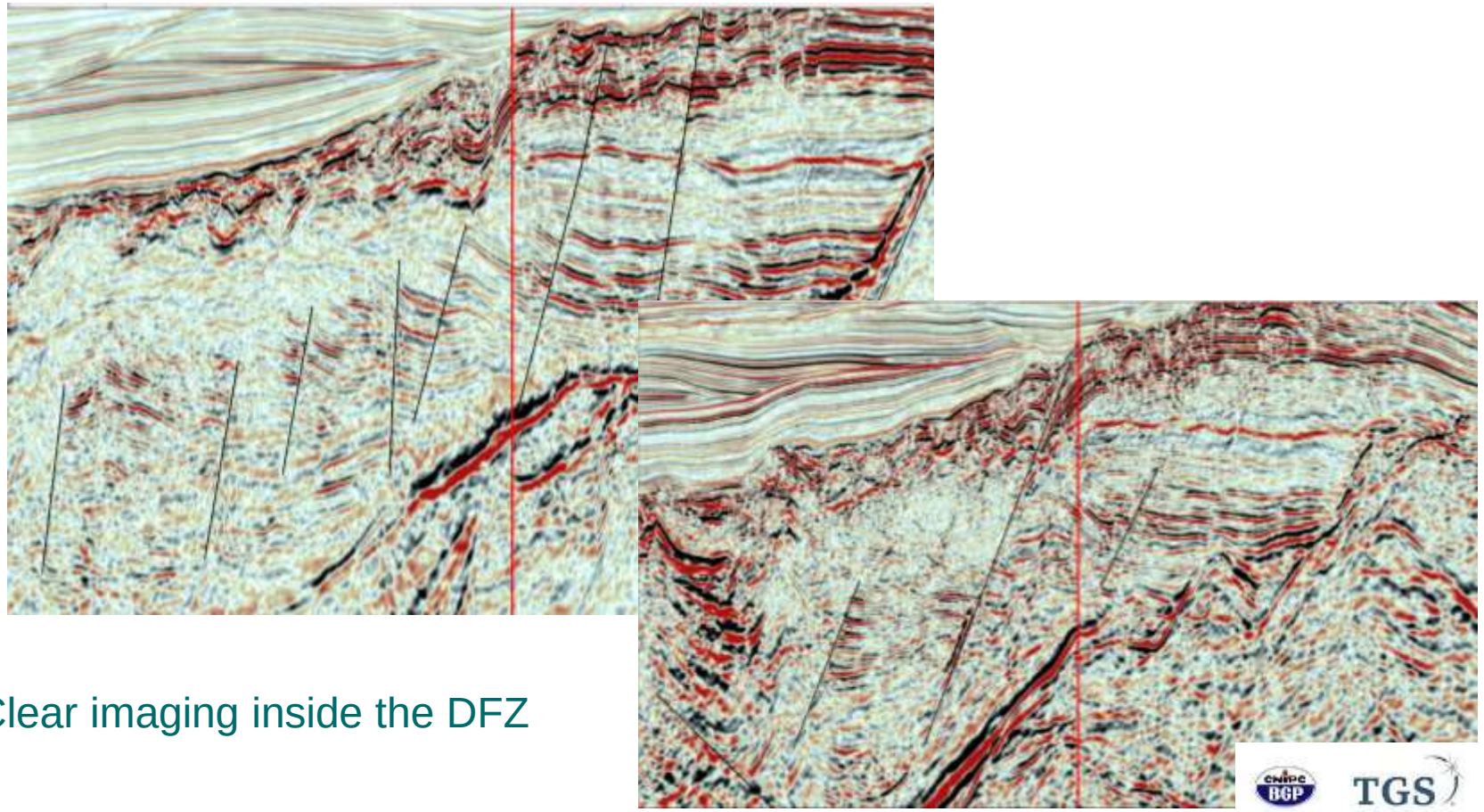
Lower Cretaceous Transpressional Structure





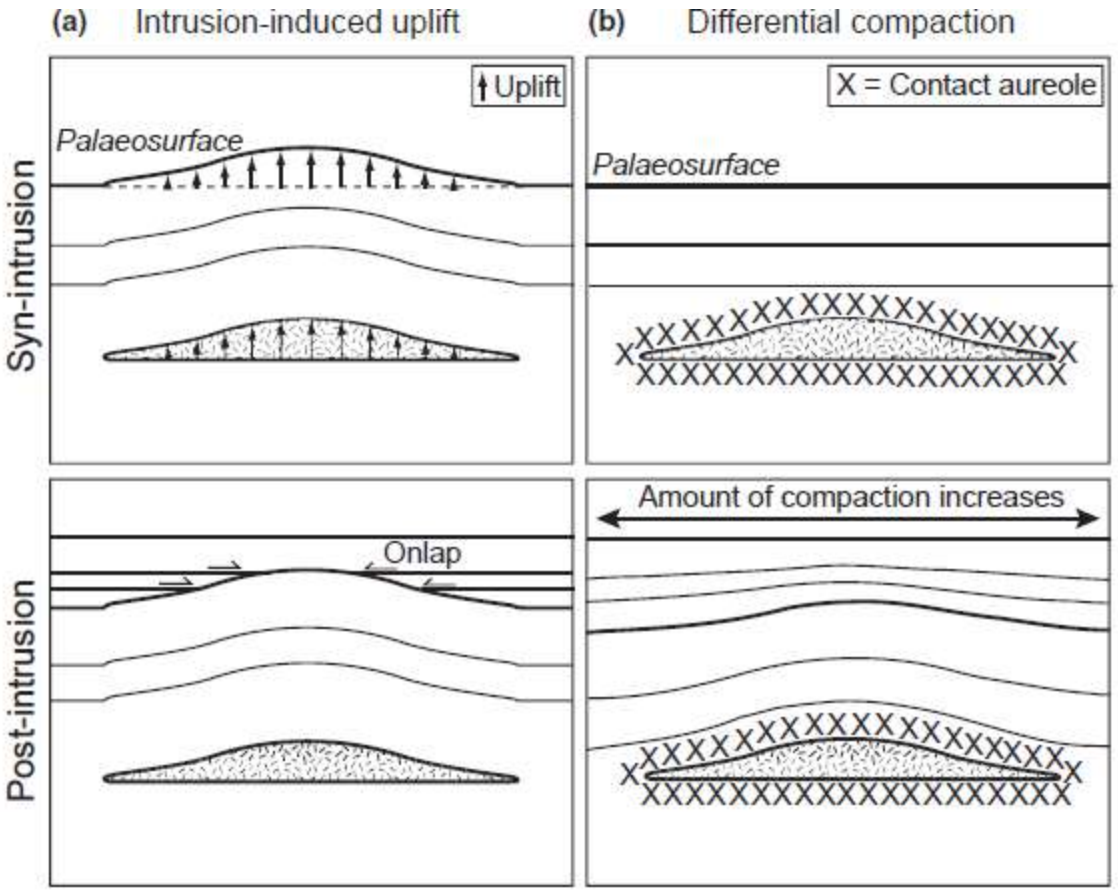
Transpressional structures created with movement along the DFZ and during the microplate rotation.

Upper Cretaceous Tilted Fault Blocks Within the DFZ



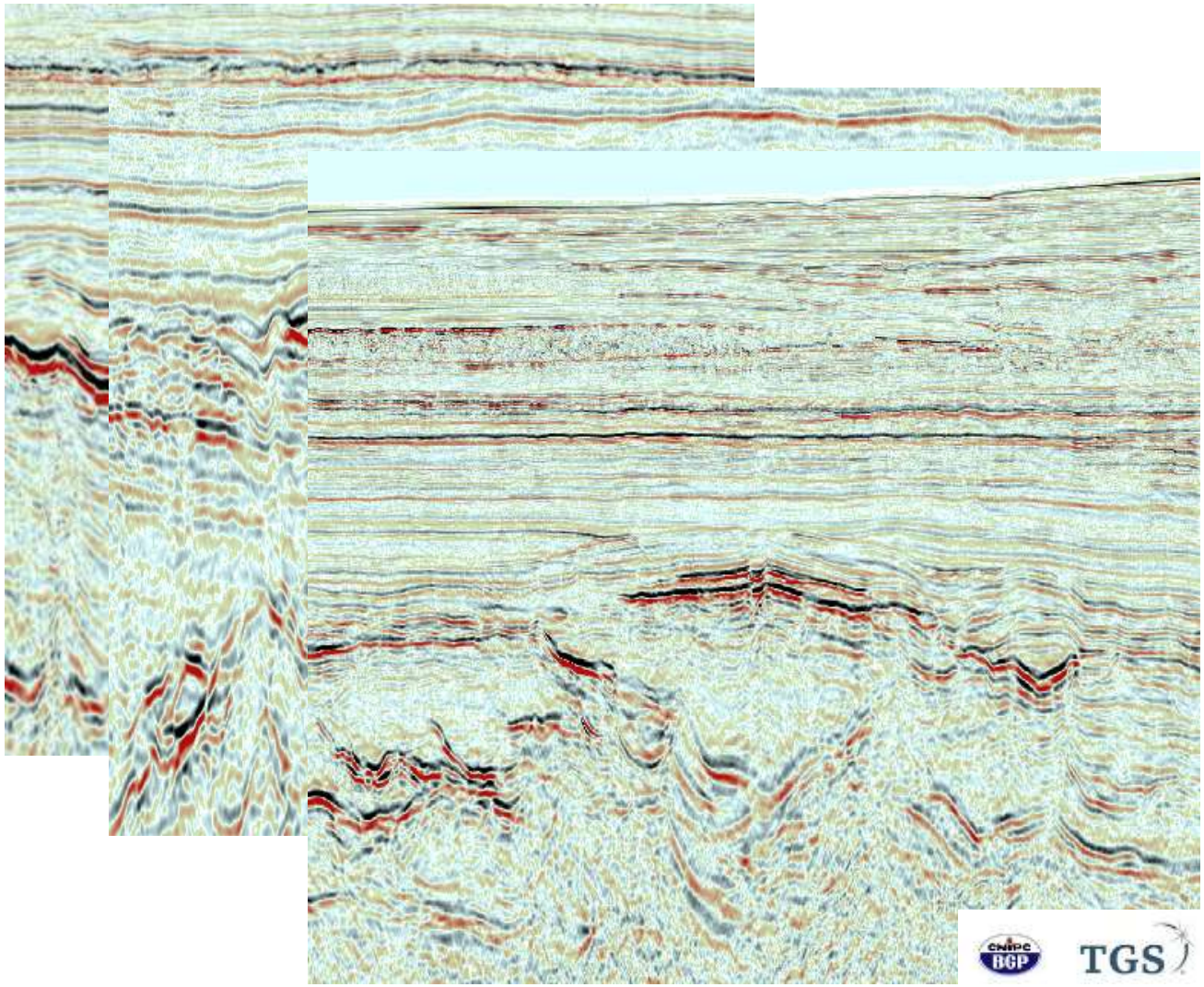
Clear imaging inside the DFZ

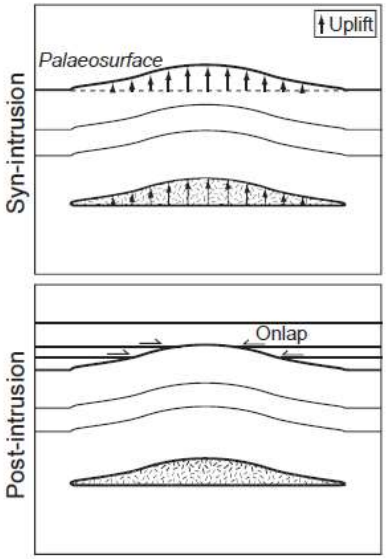
Intrusion-induced Anticlines



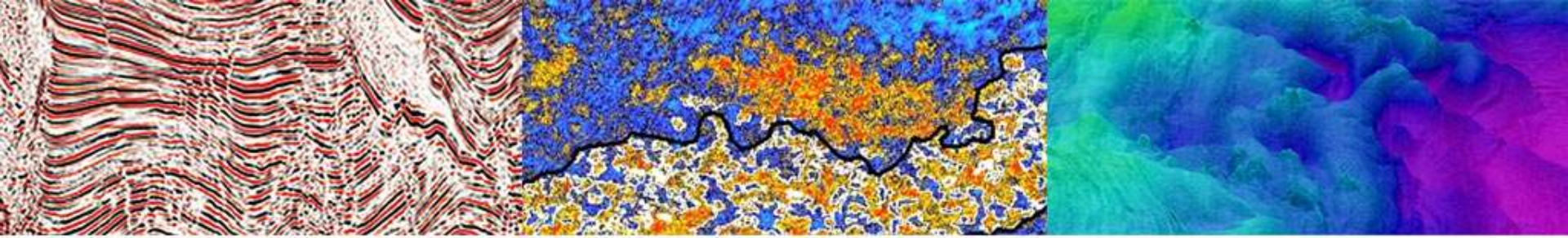
(Magee et al 2014)

Intrusion-induced Anticlines



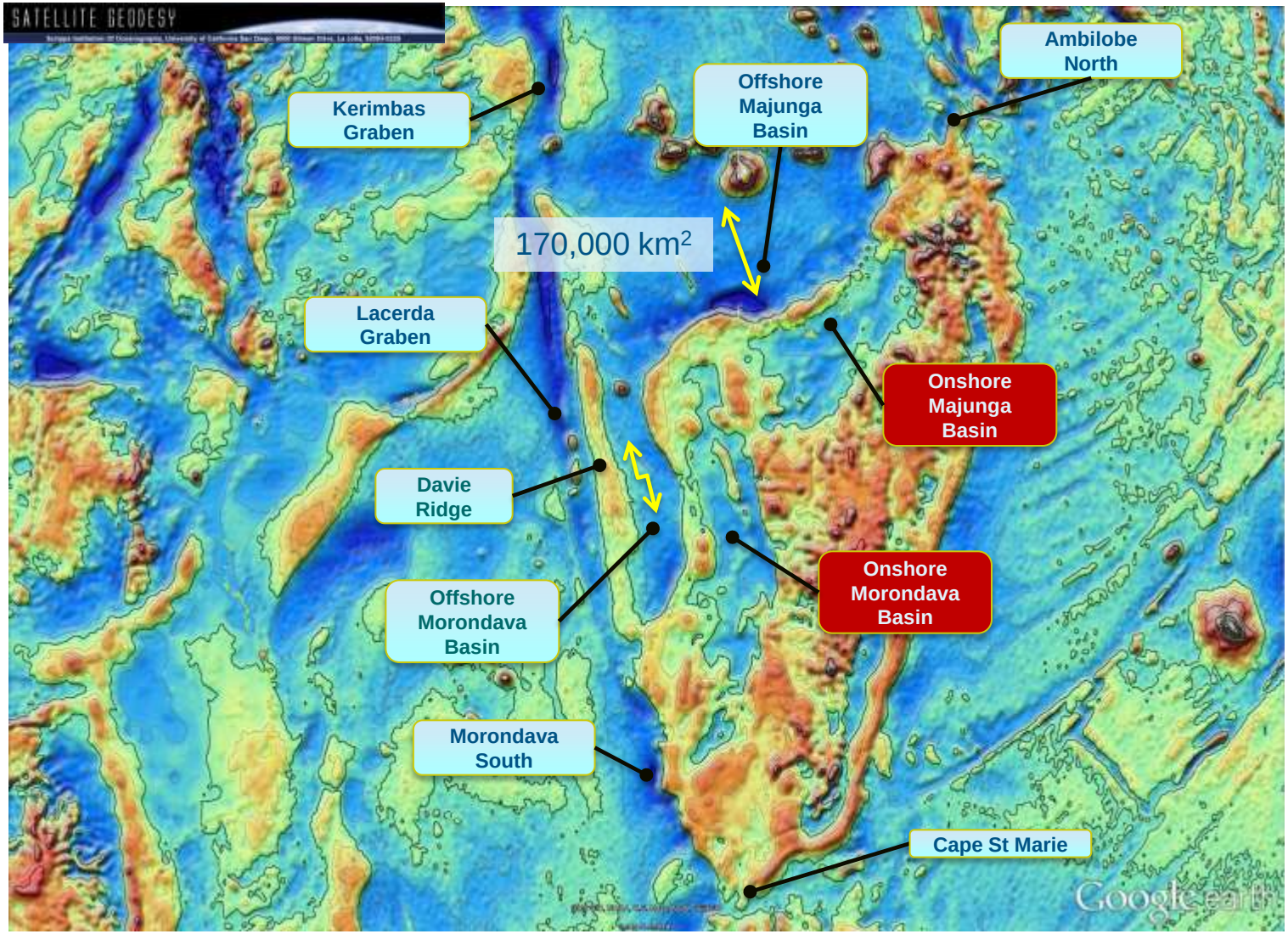


Natural closures in the positive structures as well as the potential for stratigraphic traps in the onlaps.



Basin Tour: Majunga

Location Map and Free Air Anomaly



Majunga Basin Petroleum System

Source rocks:

- Lower Triassic Middle Sakamena formation;
- Upper Jurassic Shales;
- Toarcian-Aalenian Beronono shallow marine shales and marls;
- Hypothesised Cretaceous source.

Reservoir rocks:

- Triassic-Lower Jurassic Isalo group sandstones,
- Middle Jurassic shallow marine biogenic limestones,
- Lower Cretaceous Sitampiky sandstone formation;
- Upper Cretaceous Cenomanian to Campanian deltaic sandstones, deep water fan and channel sandstones
- Eocene neritic limestones and dolomites.

Seal:

- Thick marine shales in Cretaceous and Tertiary sequences and Jurassic salt.

Petroleum Potential

Traps type:

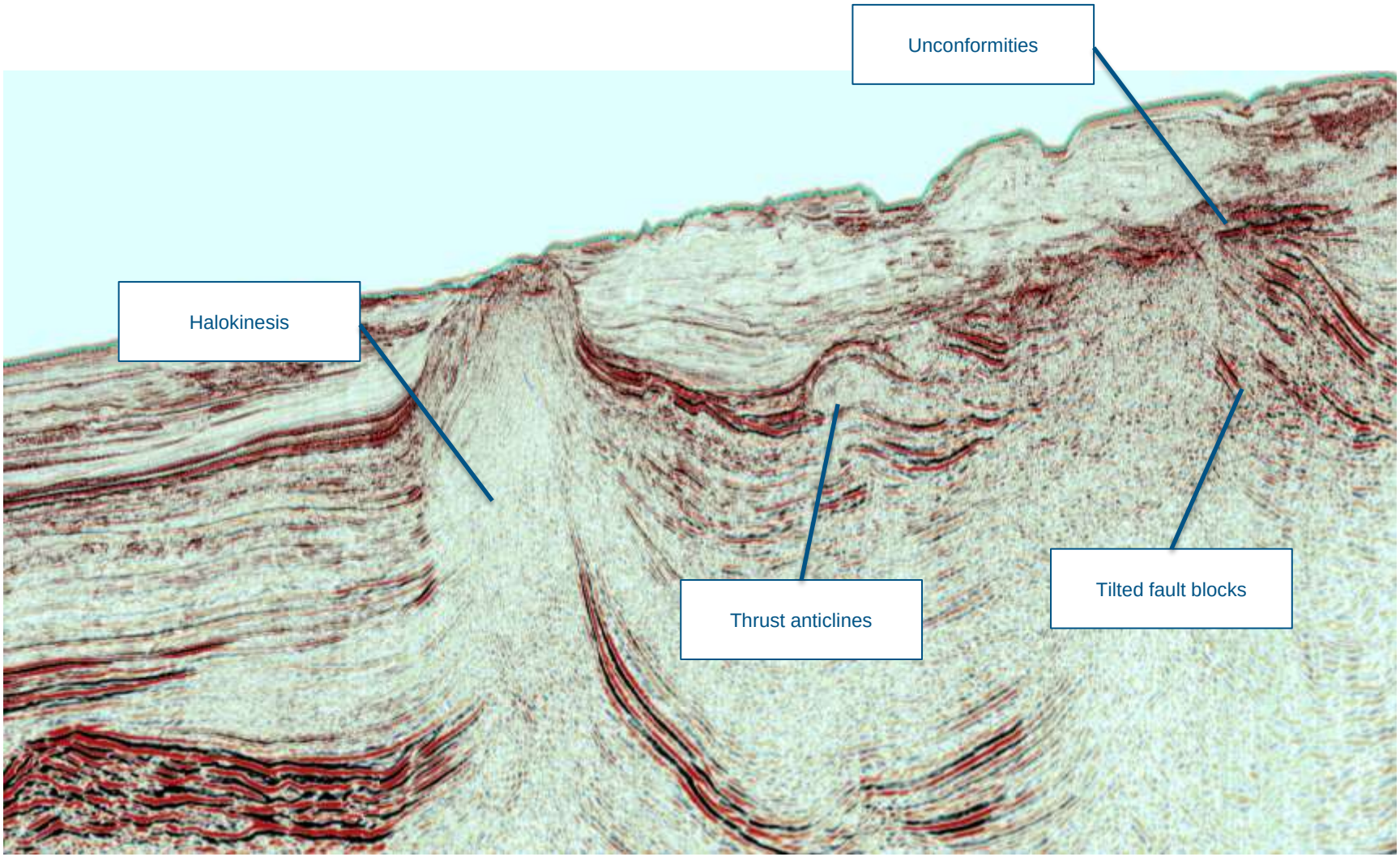
- Tilted fault blocks, drape anticlines, rollover anticlines in the failed rift province;
- Tilted fault blocks, and localised compressional anticlines in passive margin;
- Multiple types of salt-related traps and features such as thrusts;
- Stratigraphic traps: facies change, depositional pinch-out, submarine fan, unconformity in passive margin.

Migration:

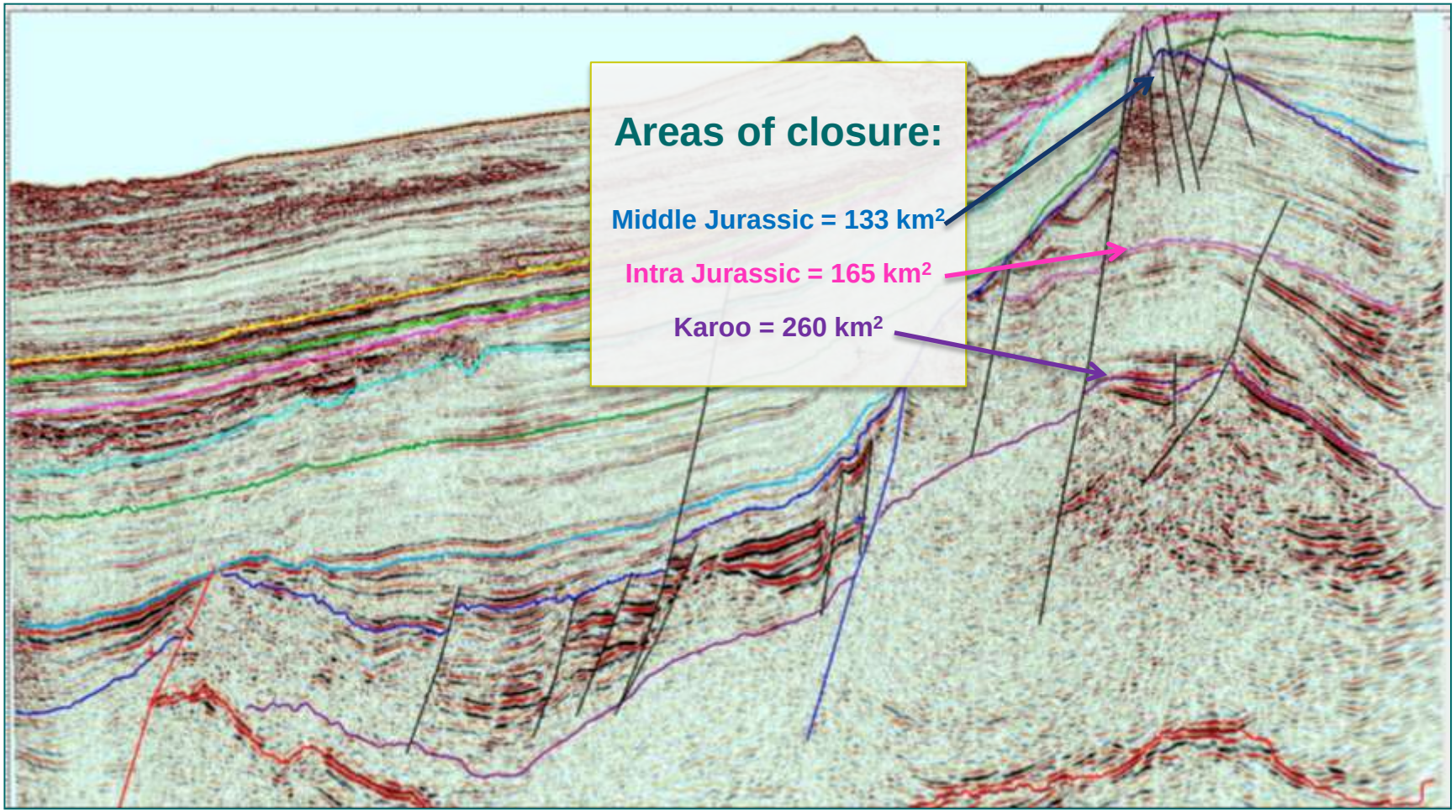
- Mainly vertical charge
- Minor lateral charges

Slick features indicate a working hydrocarbon system within the Majunga Basin.

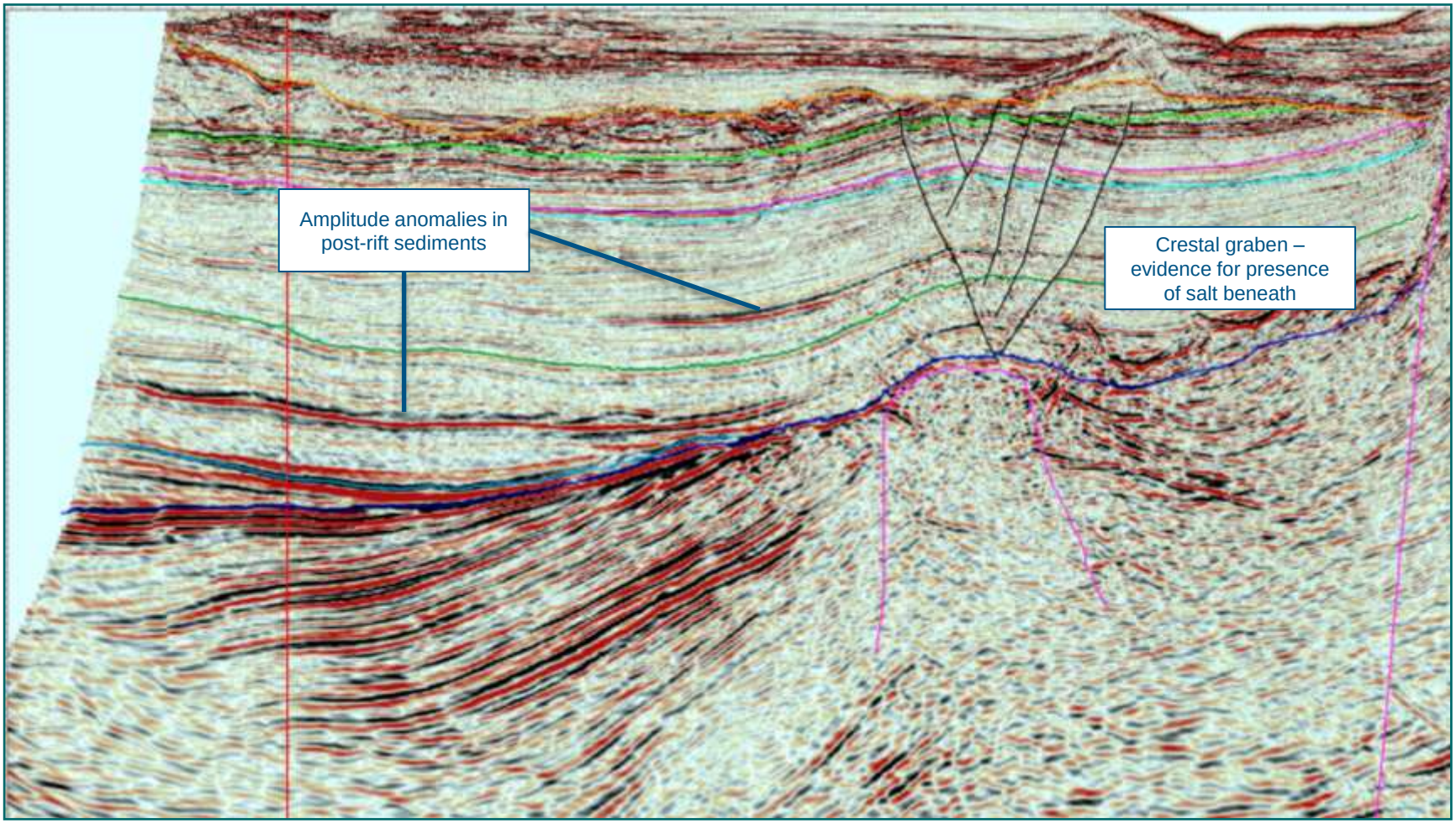
Majunga Type Section



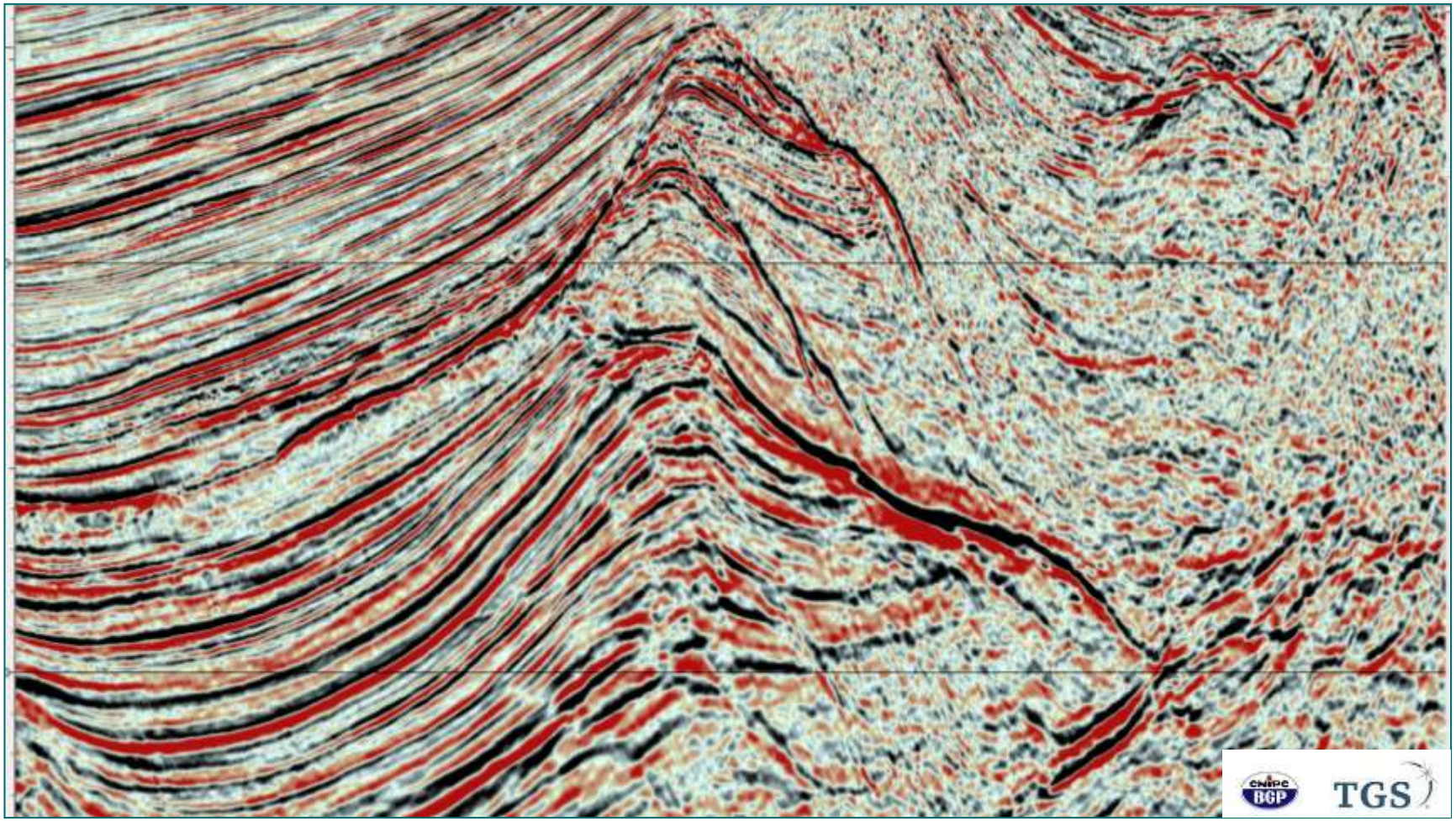
Transpressional Induced Inversion Structure



3-Way Closures Against Salt

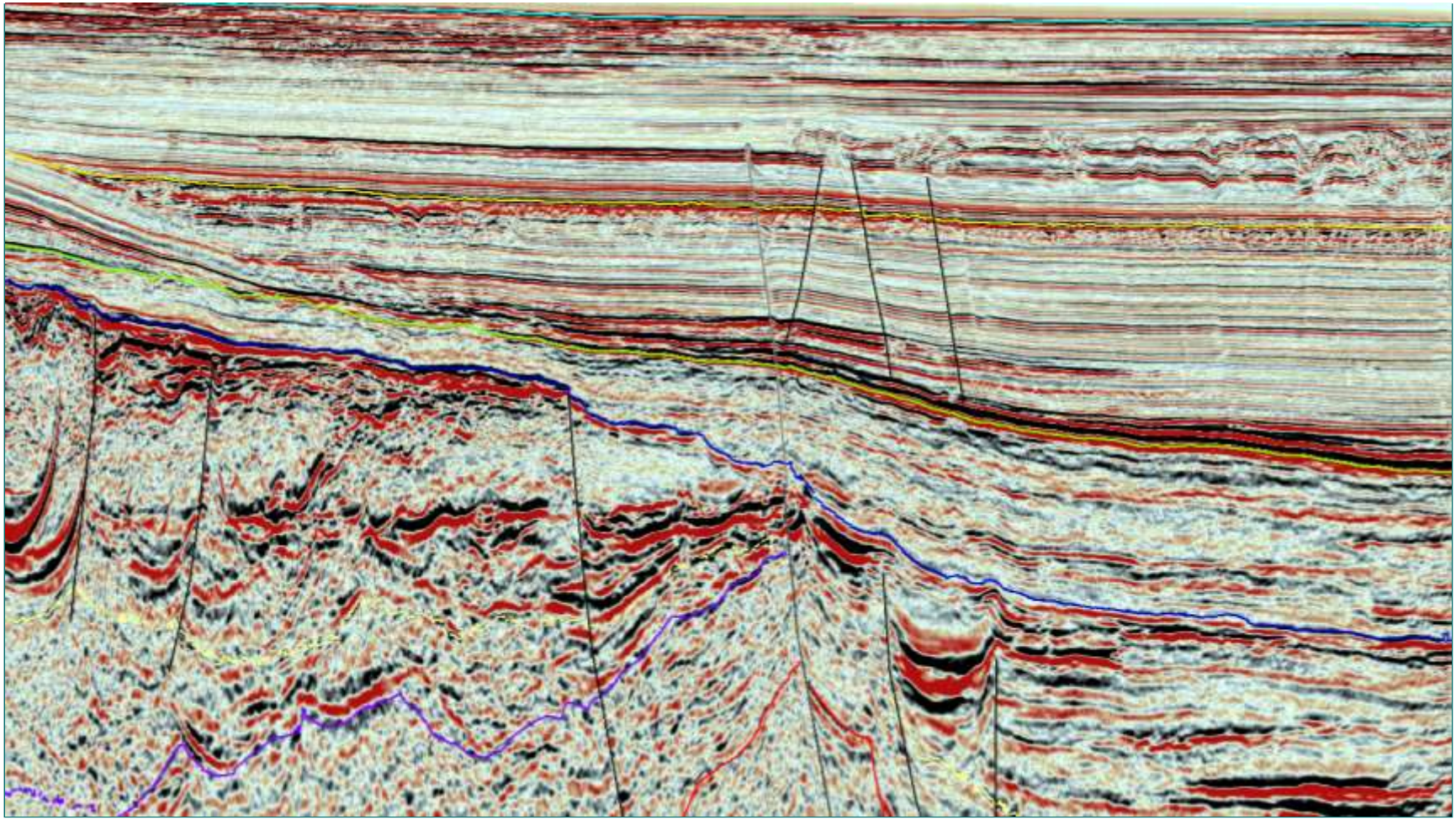


Post-Rift Cretaceous 4-way Dip Structures

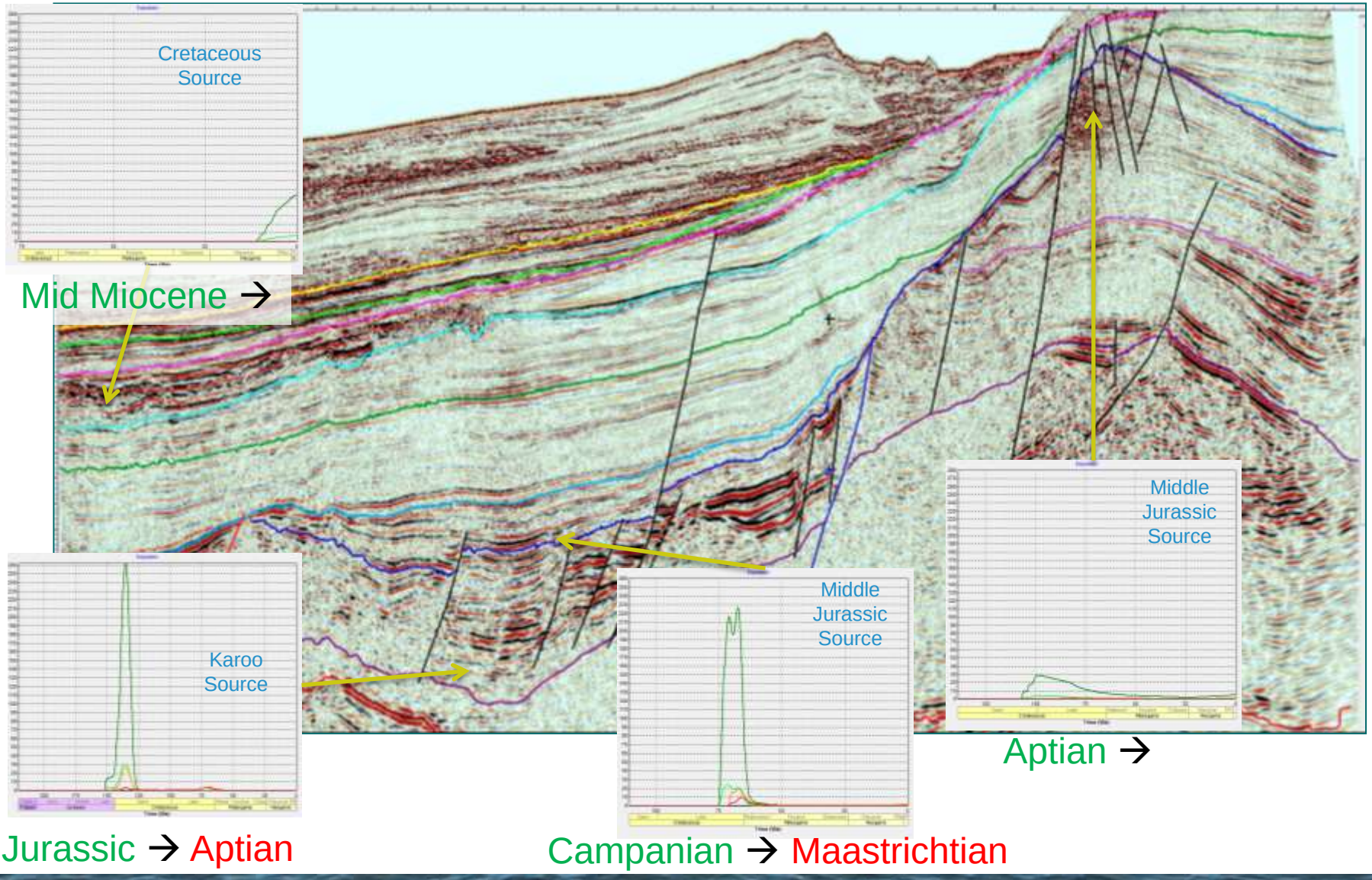


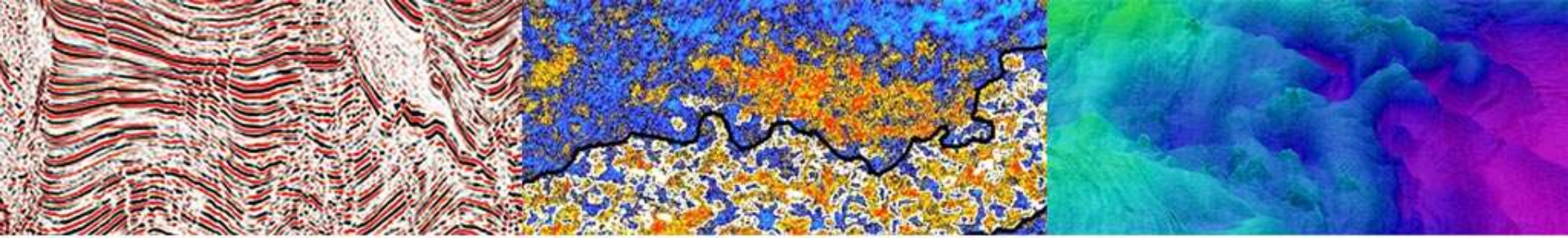
Stratigraphic Trap

S N



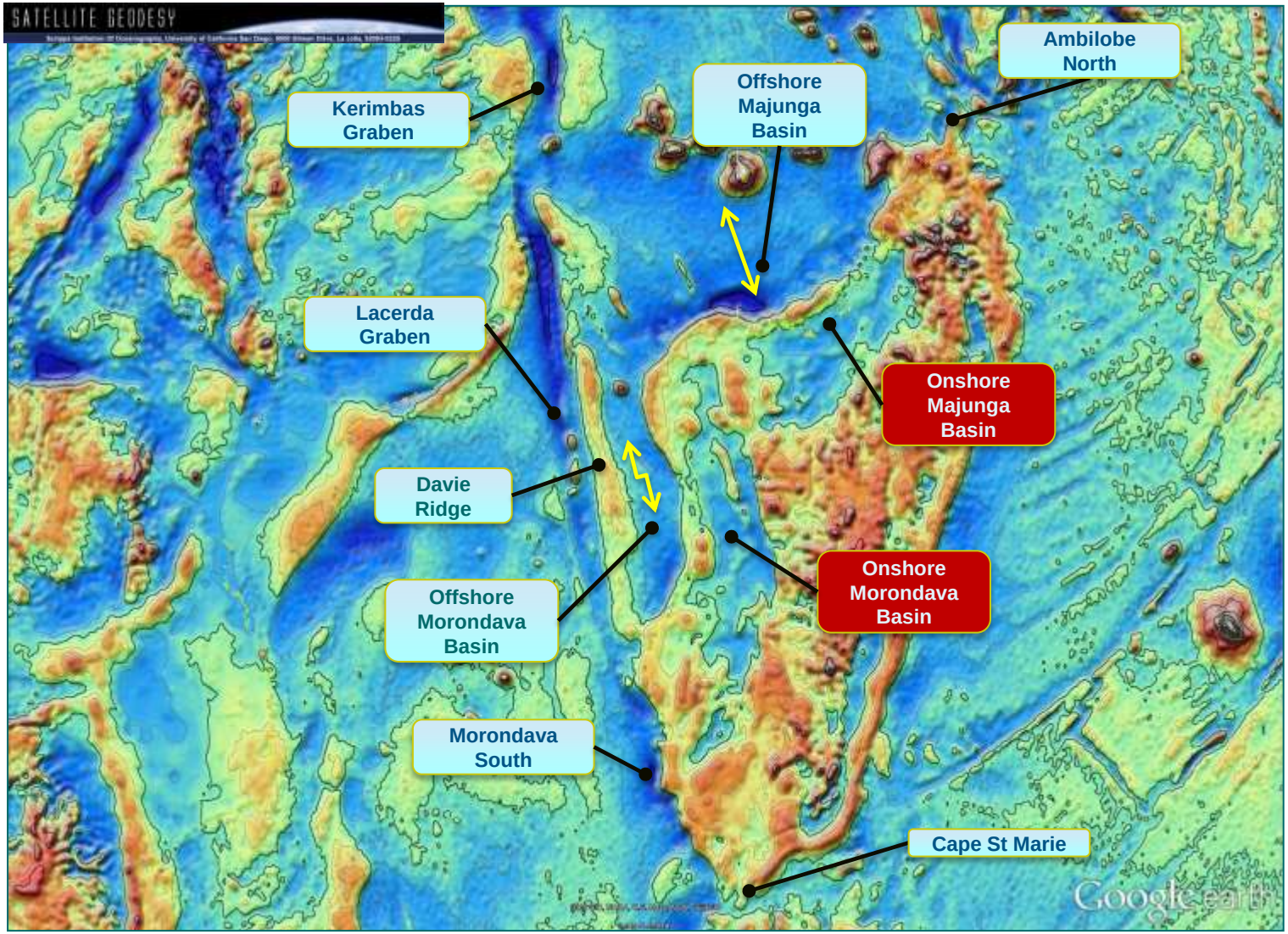
Source Rock Expulsion





Basin Tour: Ambilobe North

Location Map and Free Air Anomaly



Petroleum Potential

- Thick Jurassic / Cretaceous section;
- Large potential closures;
- Well defined rotated fault block plays;
- Untested frontier area, with TGS data being the first MC data ever shot in this basin.

Ambilobe Basin Petroleum System Elements

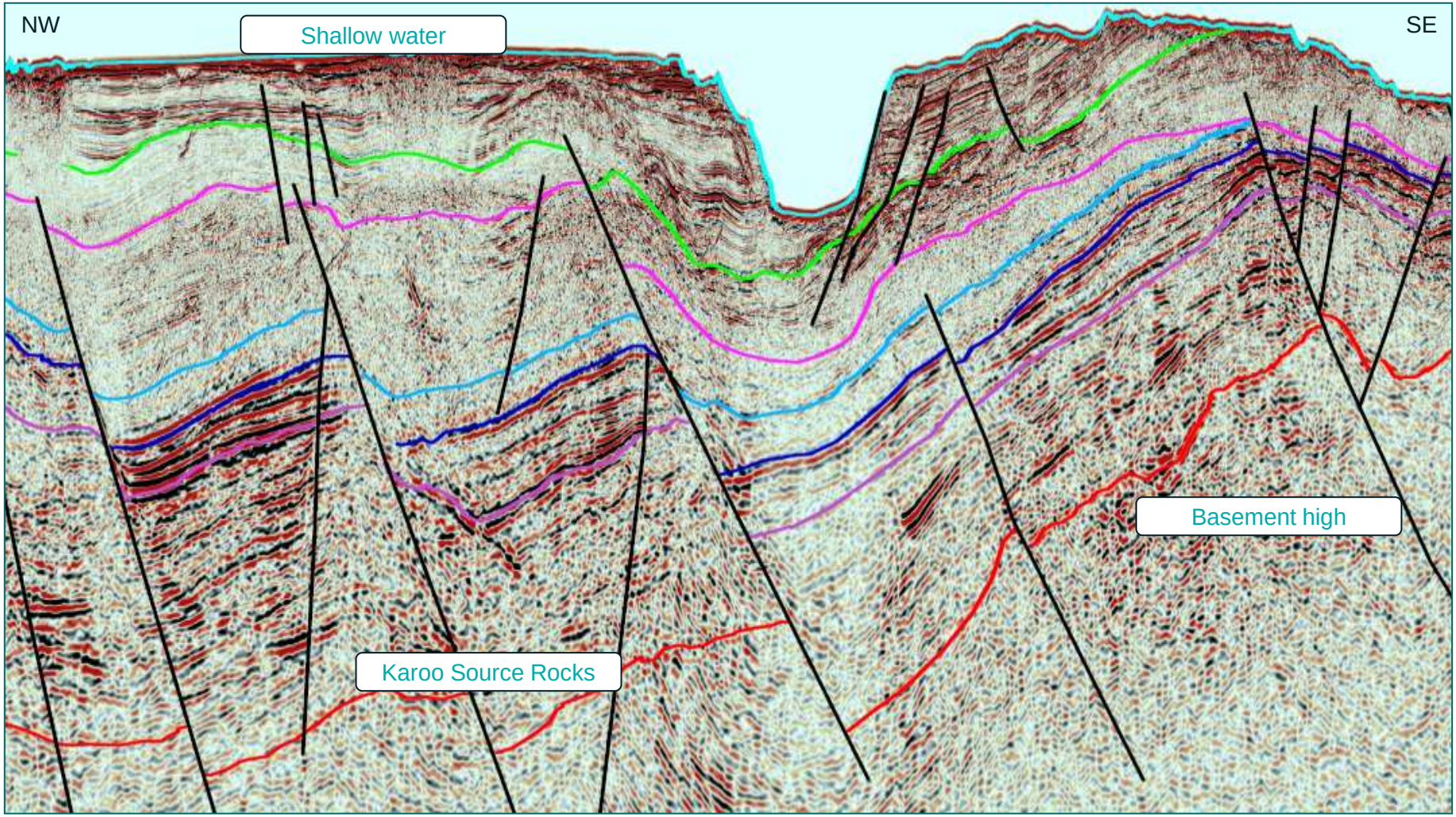
Source rocks:

- Triassic Karoo formation,
- Lower to Middle Jurassic shallow marine shales and marls,
- Lower Cretaceous marine source.

Reservoir rocks:

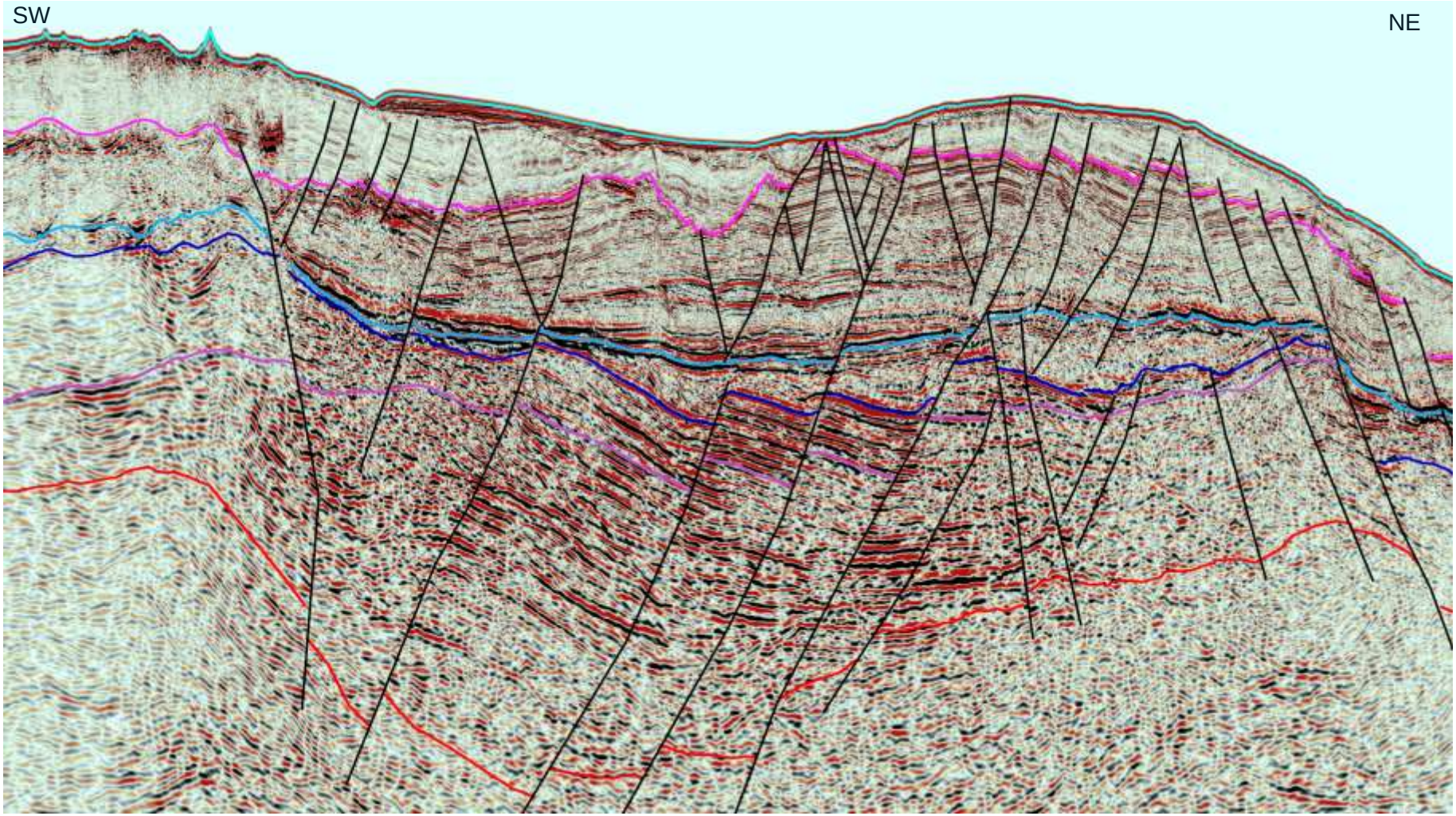
- Triassic-Lower Jurassic Isalo group sandstones,
- Middle Jurassic shallow marine biogenic limestones,
- Lower to Upper Cretaceous sandstones and clastics.

Tilted Fault Block Play



Tilted Fault Block Play

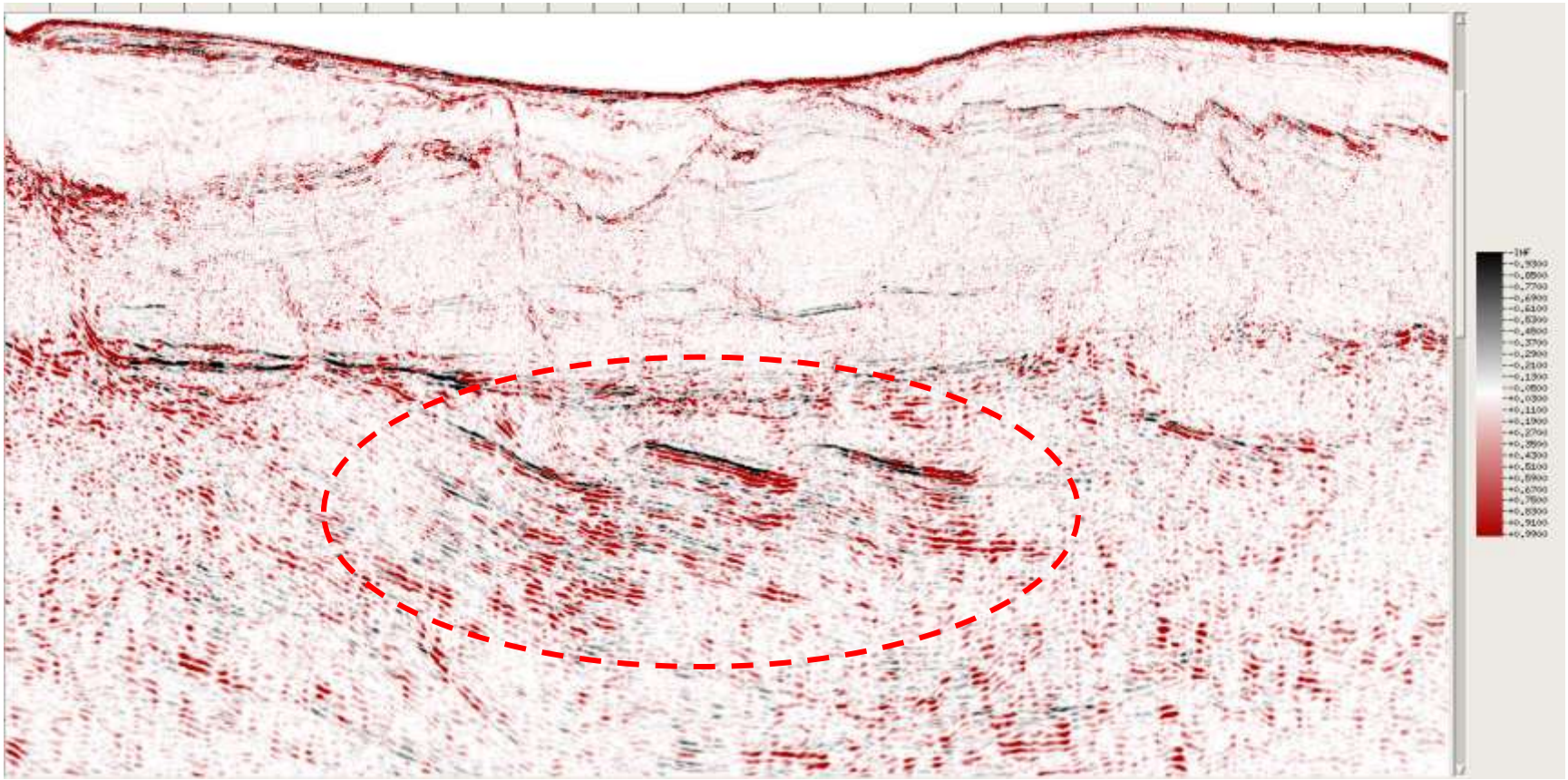
Perpendicular line



FNF - Possible Class II / III AVO anomalies

SW

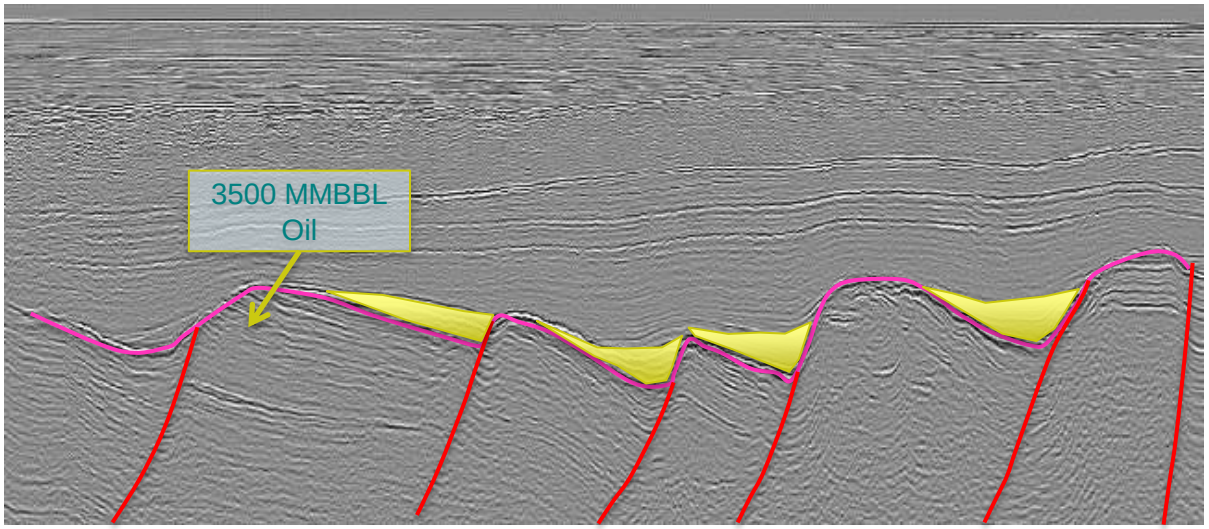
NE



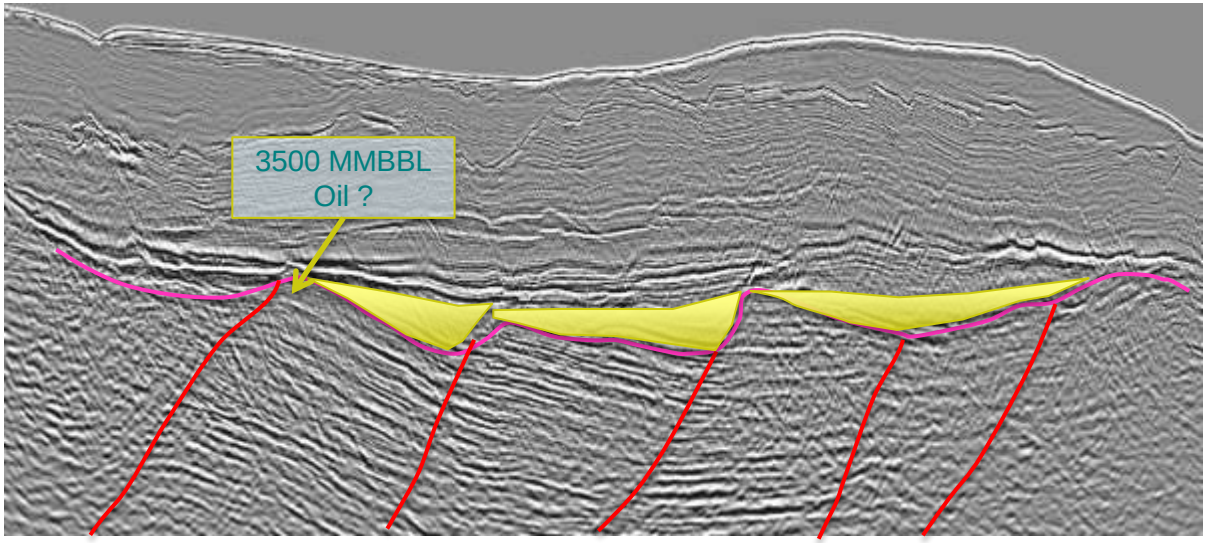
Red on FNF stack = positive value;
Positive value = Class II to Class III AVO anomaly

Ambilobe vs Brent

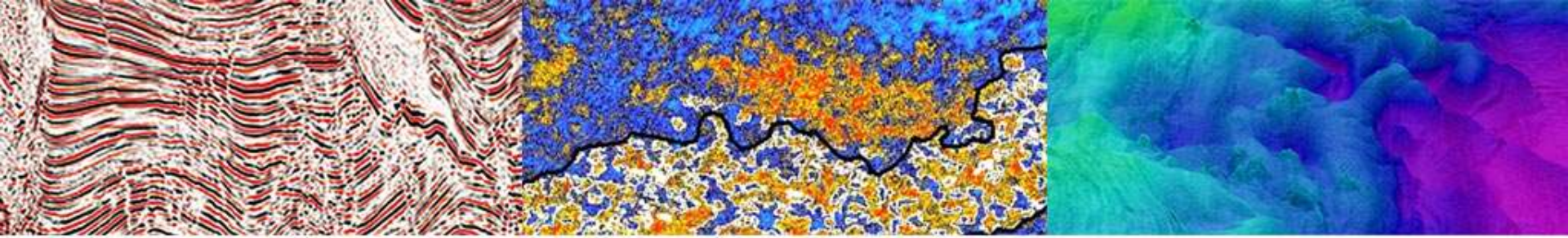
SAME HORIZONTAL SCALE



BRENT



AMBILOBE



Concluding Points

Concluding Points

- All the offshore basins are undrilled or sparsely drilled and their potential is untested;
- Oil mature source rocks with reservoirs at drillable depths are considered to be present in all basins;
- There are many attractive structural and stratigraphic play types present;
- TGS together with our partners OMNIS and BGP have the seismic, potential fields data and interpretation studies to allow screening, evaluation and high grading of areas in these basins.

Acknowledgements

TGS Geophysicists: Roel Dirkx, Katie Hernon, Felicia Winter, Sadiqah Musa, Alex Birch-Hawkins, Dario Chisari, Jennifer Halliday and Richard Cooke

Other TGS colleagues: Paul Chandler, Honorata Rutkowska, Robert Mansfield and Erika Tibocha

References

- Magee, C., Jackson, C.A-L. & Schofield, N. (2014). Diachronous sub-volcanic intrusion along deepwater margins insights from the Irish Rockall Basin. Basin Research, 26: 85-103.
- Pomar, L., Brandano, M. and Westphal, H. (2004), Environmental factors influencing skeletal grain sediment associations: a critical review of Miocene examples from the western Mediterranean. Sedimentology, 51: 627–651.
- Reeves, C., (2015). Gondwana Reconstruction Animation of Indian Ocean. Accessed at: http://www.reeves.nl/gondwana. January 2016.
- USGS, (2012): Assessment of Undiscovered Oil and Gas Resources of Four East African Geologic Provinces. World Petroleum Resources Project. Fact Sheet 2012-3039.

Thank you

Ben Sayers
+44 208 339 4239
ben.sayers@tgs.com

All images in this presentation have had the quality reduced. For a higher resolution data room, please contact TGS.