Observations on Tectonic Evolution and Prospectivity of Madagascar Offshore Basins Based on Interpretation of New Seismic Data*

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Abstract

TGS has completed a geophysical and geological evaluation of the hydrocarbon prospectivity of the entire western offshore margin of Madagascar from the Cap St. Marie Basin in the south to the Ambilobe Basin in the north. The study was based on 49,000 km of multiclient 2D seismic acquired in partnership with OMNIS, with 20,000 km of this acquired in partnership with BGP. The seismic and potential field data were acquired between 2001 and 2013 and were integrated in the study along with existing well data. A revised tectono-stratigraphic framework will be presented for the offshore Madagascar basins. This study has identified new exploration targets and plays, e.g. the Jurassic tilted fault block play in the frontier Ambilobe Basin. The TGS Clari-Fi™ broadband solution enabled sharper definition of previously poorly understood and imaged plays in the Morondava Basin and outboard of the Davie Fracture Zone (DFZ). Three major events have influenced the formation of the offshore basins of Madagascar in its present form: Early Jurassic rifting of Madagascar-India from Africa, Middle Jurassic to Aptian movement south along the DFZ transform and Aptian to Late Cretaceous rifting that resulted in the break-up of India and Seychelles from Madagascar. Results from this study indicate that the Late Cretaceous tectonic events had a much greater influence on the western offshore Madagascar basins than previously known. The seismic data show the DFZ was re-activated during India-Madagascar separation and resulted in large inverted structures in the Morondava Basin. This permits creation of trap structures and migration of hydrocarbons from older source rocks. The potential for drape traps over volcanic structures (and pinchout traps against them) will also be discussed. The new, denser seismic coverage better defines the geometry and extent of large fan complexes (e.g. Morondava and Majunga) associated with the tilting of Madagascar to the west during the India-Seychelles separation.

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April 2016

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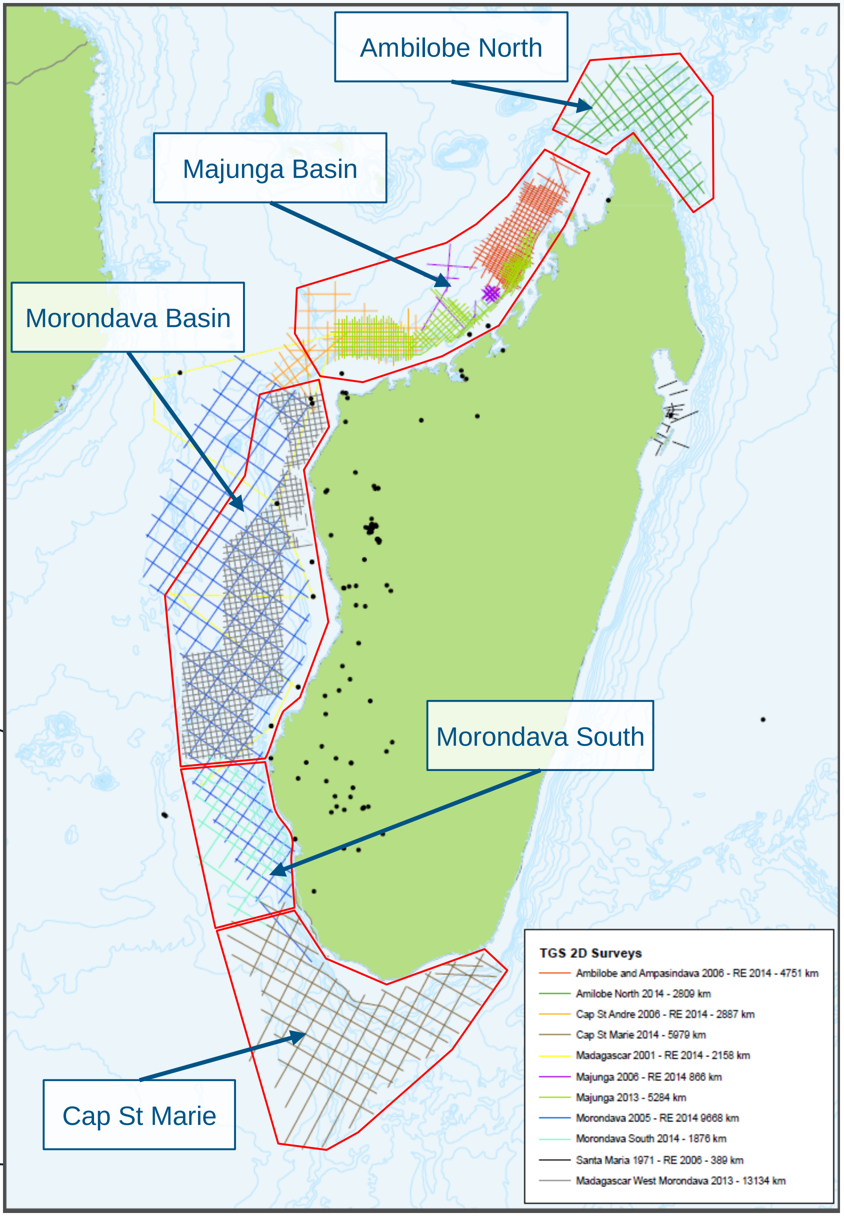
Introduction | Database

- c. 50,000 km 2D seismic and marine gravity/magnetic data available in Madagascar
- Total of 98 wells of which eight are offshore and all are in shallow water
- Integrated interpretation studies for all offshore basins are completed

TGS 2D Surveys

- Ambilobe and Ampasindava 2006 - RE 2014 - 4751 km
- Amilobe North 2014 - 2809 km
- Cap St Andre 2006 - RE 2014 - 2887 km
- Cap St Marie 2014 - 5979 km
- Madagascar 2001 - RE 2014 - 2158 km
- Majunga 2006 - RE 2014 866 km
- Majunga 2013* - 5284 km
- Morondava 2005 - RE 2014 9668 km
- Morondava South 2014* - 1876 km
- Santa Maria 1971 - RE 2006 - 389 km
- Madagascar West Morondava 2013* - 13134 km

* in partnership with BGP



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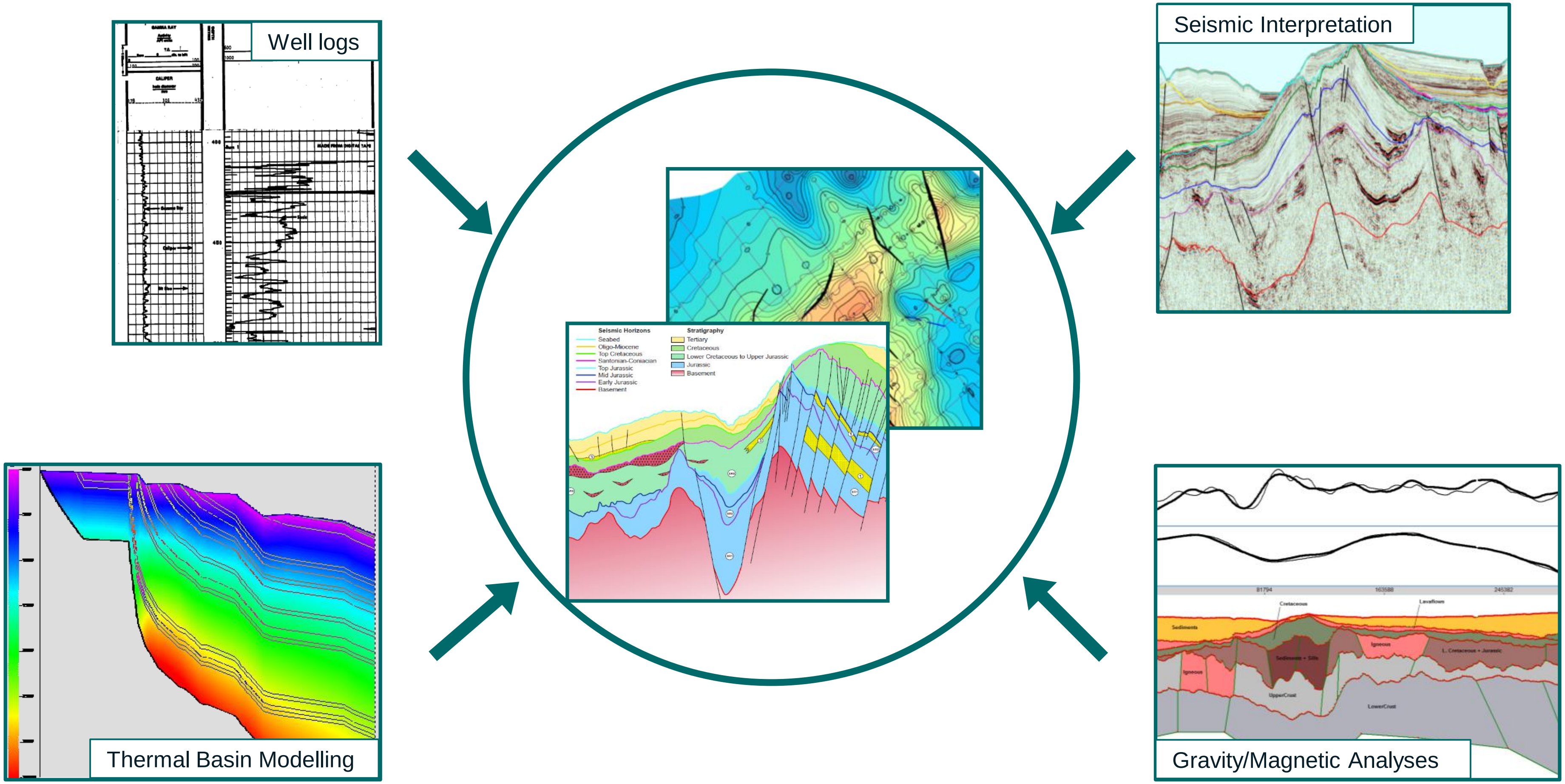
Integrated Regional Interpretation Study

Provides a comprehensive understanding of the tectonic history and the geologic domains of basin margins in order to better identify plays within a petroleum system



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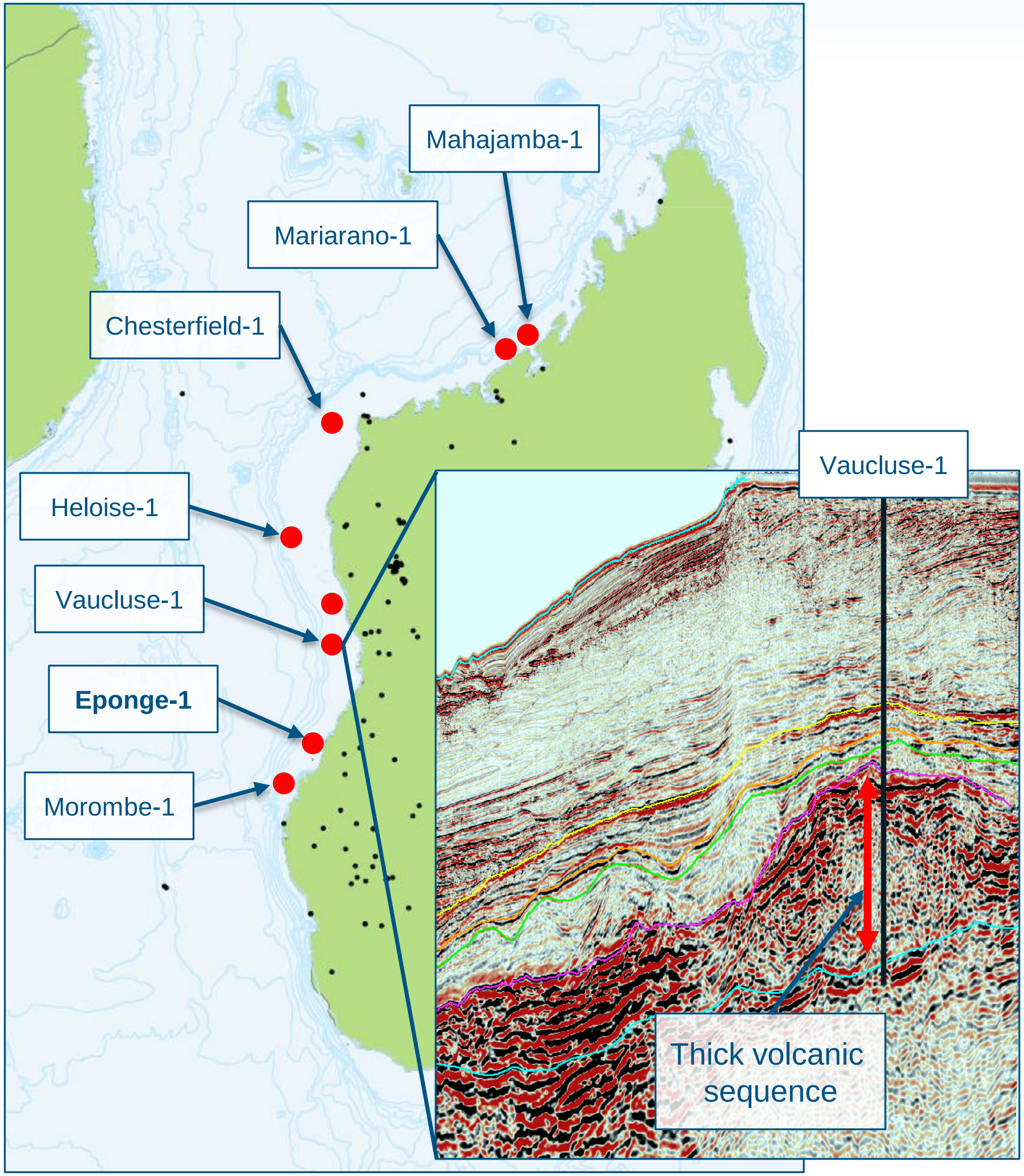
Exploration History

- Only eight wells have been drilled in offshore Madagascar, all in shallow water
  - Eponge-1 – non commercial gas discovery in Cretaceous sandstones
  - Gas shows in all other offshore wells

- Chesterfield-1, Heloise-1, Vaucluse-1 and Morombe-1 all drilled volcanic structures

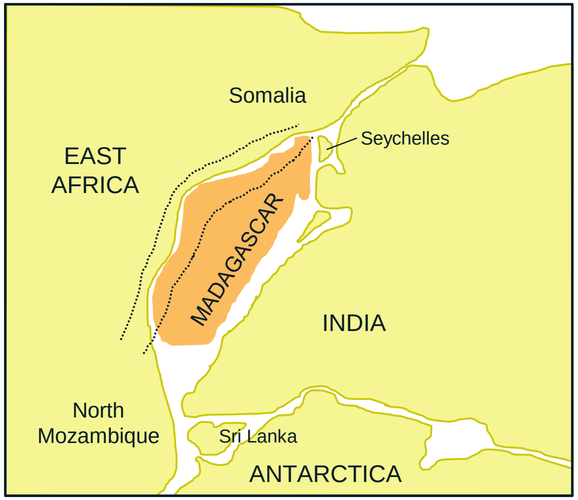
- Valid structures have not yet been tested, so there is still a lot of potential for future discoveries



Tectonic History

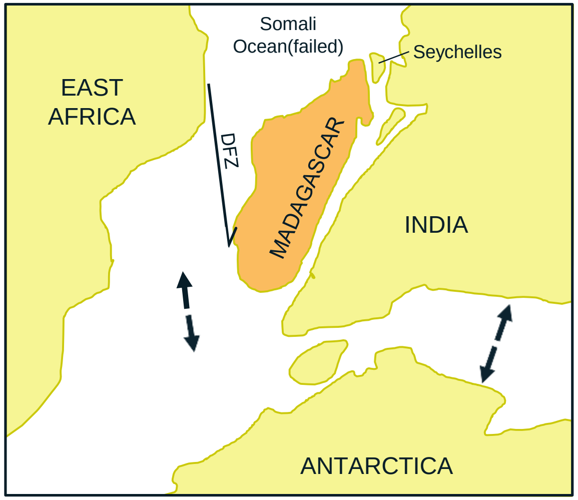
Modified after Reeves, 2014

182 Ma



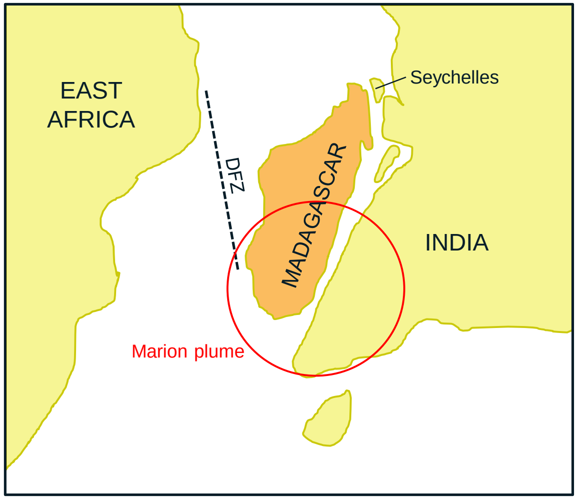
- Permo-Triassic Karoo failed rift
- Jurassic rifting event started in the Toarcian
- Breakup in the Bajocian between East Africa and Madagascar

120 Ma



- Madagascar drifted southward along DFZ (dextral transform fault)
- Spreading failed in the Somali Ocean in the Aptian and relocated south
- Extension between Madagascar and India started

88 Ma



- Marion plume became active between 92 – 84 Ma
- Breakup of India and Madagascar
- Uplift of eastern margin Madagascar
- Increased erosion and focused deposition of sediments along western margin

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Petroleum Systems

The following proven or potential petroleum system elements have been identified in the offshore basins of Madagascar from literature, seismic or well reports:

Source rocks:

- Proven Lower Triassic Sakamena lacustrine shales (charged the Tsimiroro and Bemolanga fields onshore Madagascar),
- Toarcian-Aalenian (Mid-Juassic) restricted / shallow marine shales (proven source in East Africa),
- Upper Jurassic and Cretaceous marine shales (Saronanala-1 and Serinam-1 wells onshore Madagascar).

Reservoir rocks:

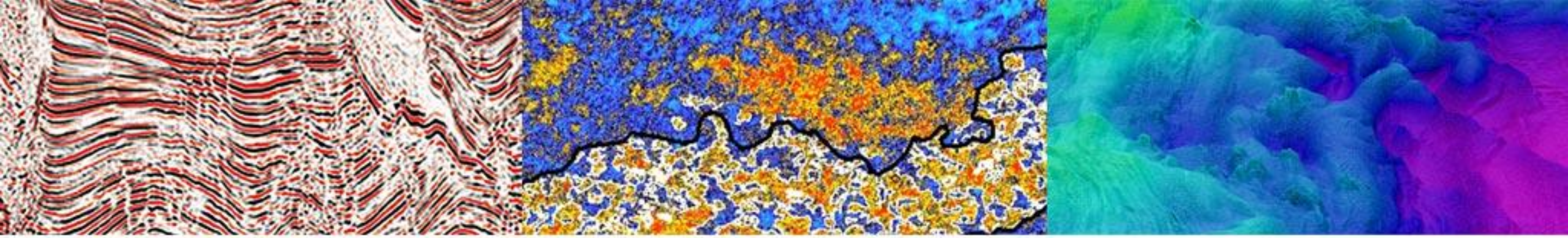
- Permo-Triassic Sakamena Group and Lower Jurassic Isalo Formation sandstones (reservoirs for the Tsimiroro and Bemolanga fields and Manandaza light oil shows onshore Madagascar),
- Middle Jurassic shallow marine carbonates and sandstones,
- Cretaceous and Tertiary basin slope and basin floor turbidite fans and channel sandstones (as identified from seismic interpretation).

Traps:

- Jurassic and Cretaceous rotated fault blocks,
- Transpressional anticlines (toe thrusts) and fault controlled three or four-way dip closures,
- Salt related three- and four-way dip closures and salt flank pinchouts,
- Intrusion related closures, drapes, ponds, and pinchouts,
- Cretaceous stratigraphic pinch-outs and toe-thrust/roll-over anticlines,
- Tertiary stratigraphic pinch-outs.

Seal:

- Thick marine shales in Cretaceous and Tertiary sequences (as identified from seismic facies).



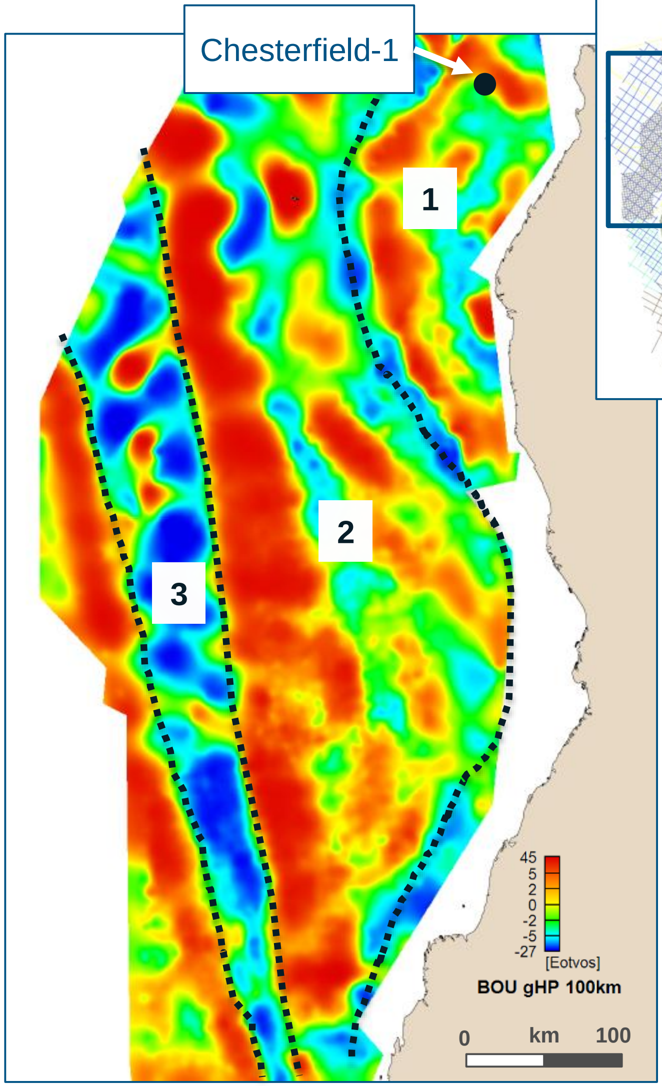
Morondava Basin

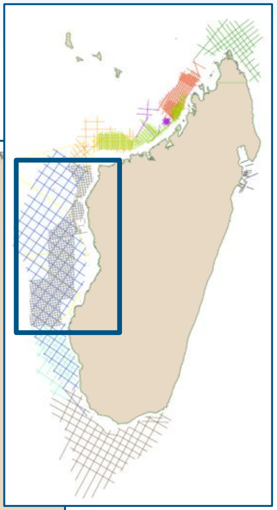
Morondava Basin | Structural Elements

1. Morondava Shelf
   - Karoo and Jurassic rifting
   - Well imaged rifted fault blocks
   - Reef structures

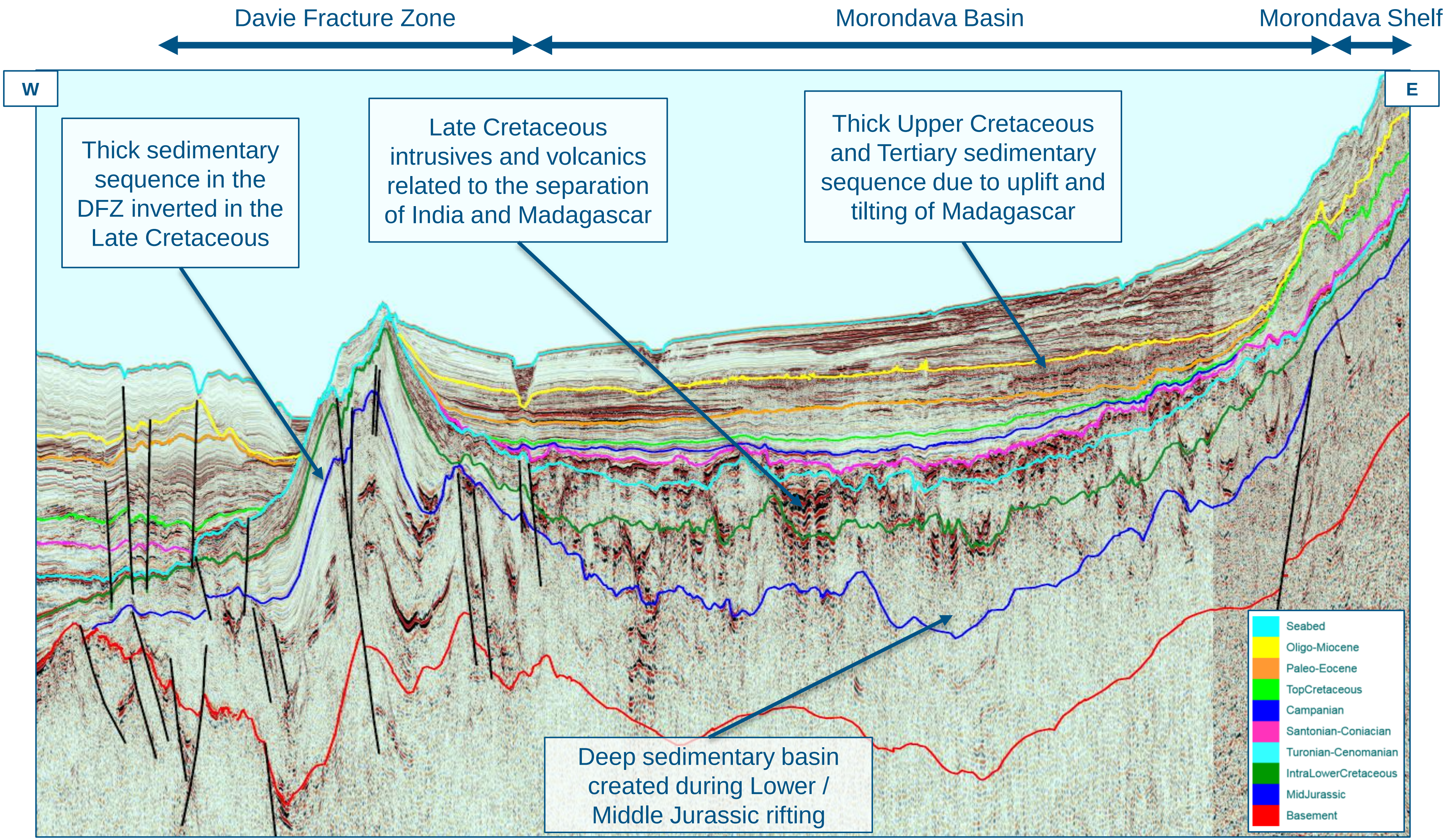
2. Morondava Basin
   - Jurassic rift basin
   - Thick sedimentary infill

3. Davie Fracture Zone (DFZ)
   - Pronounced gravity low
   - Thick crustal root
   - Large inverted basins within DFZ
   - Seamounts within DFZ





Morondava Basin | Structural Elements



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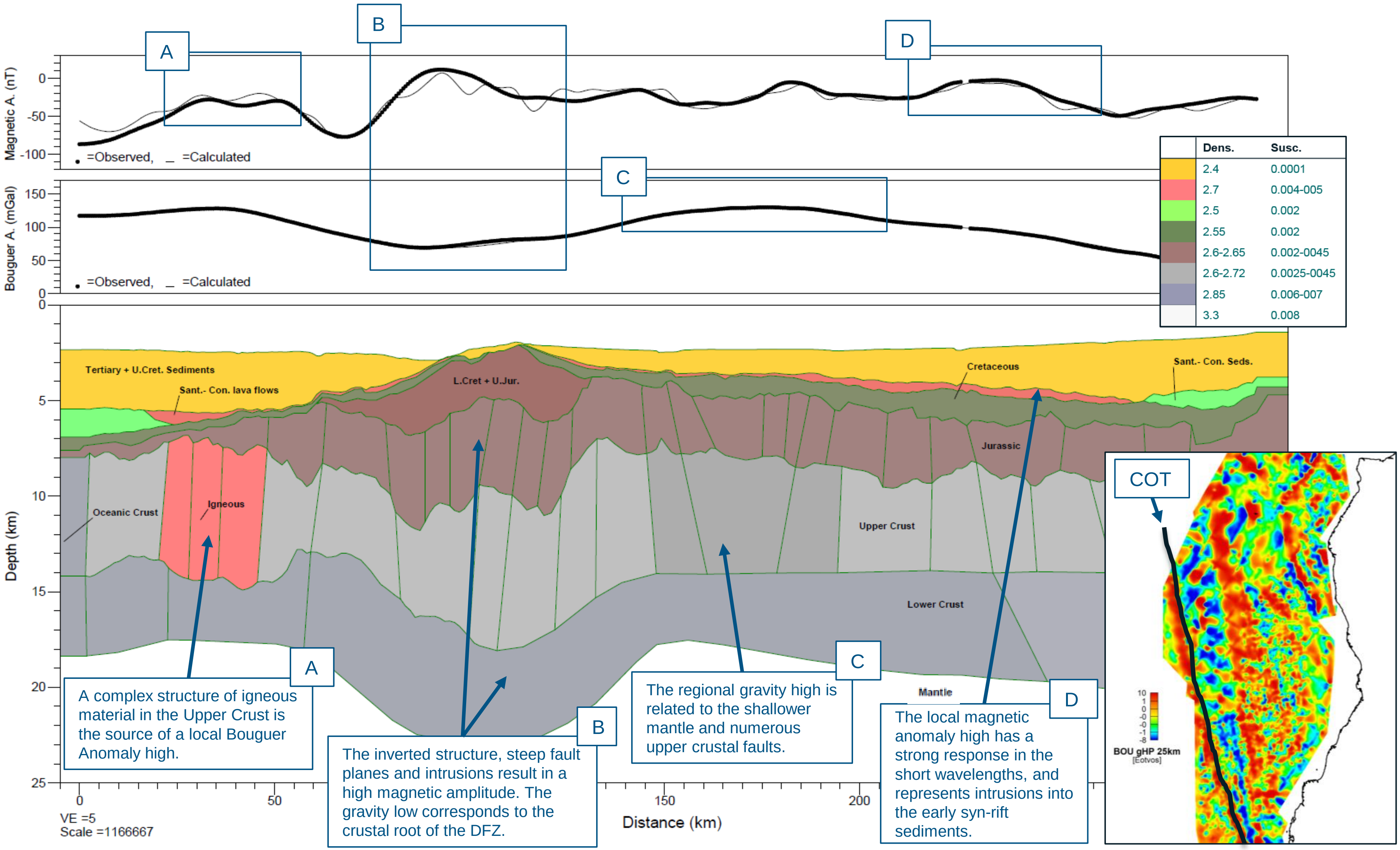
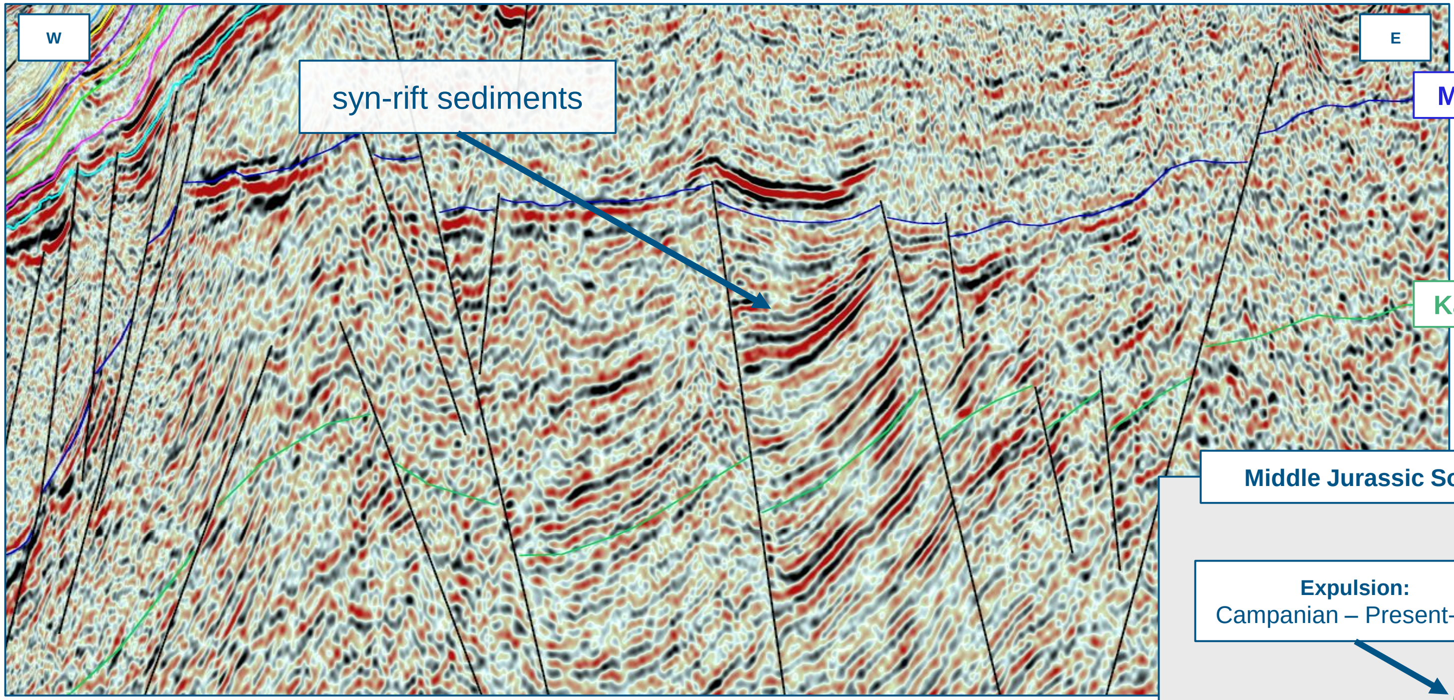
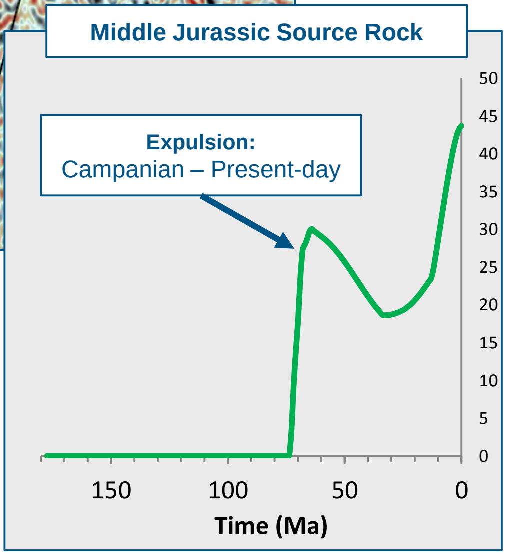
Morondava Basin | Gravity & Magnetic Model



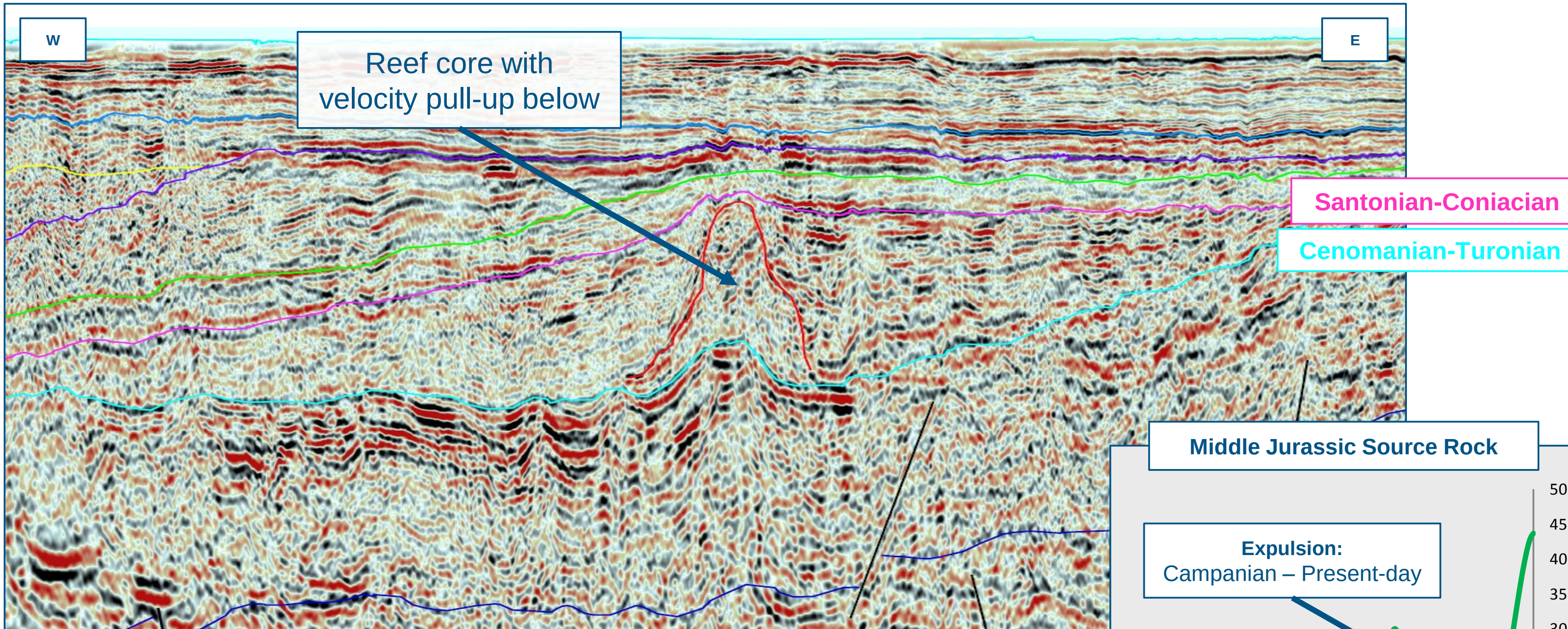
Morondava Shelf

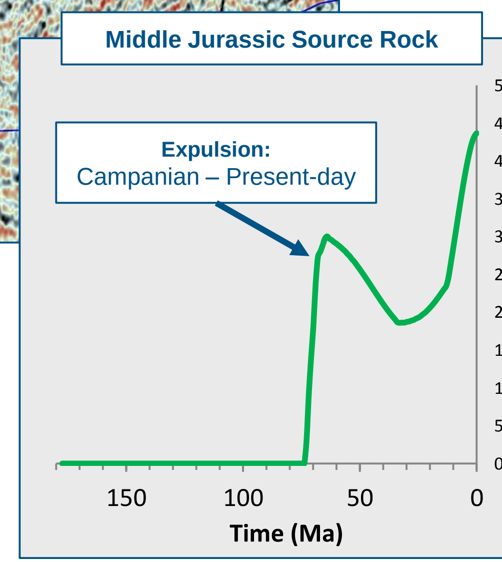




- Permo-Triassic sediments rotated during Jurassic rifting
- Proven Permo-Triassic Karoo source rocks expelled oil during Middle and Late Jurassic
- Middle Jurassic syn-rift source rocks expelled oil from the Late Cretaceous to Present-day
- **Jurassic source and possibly Karoo source work on the shelf**

Morondava Shelf





- Reef structures identified in Upper Cretaceous and Tertiary
- Middle Jurassic syn-rift source rocks expelled oil from the Late Cretaceous to Present-day
- Modelling showed Jurassic source rock works, but valid structures not yet explored
- Towards the south the Middle Jurassic source rock is push into the gas expulsion window

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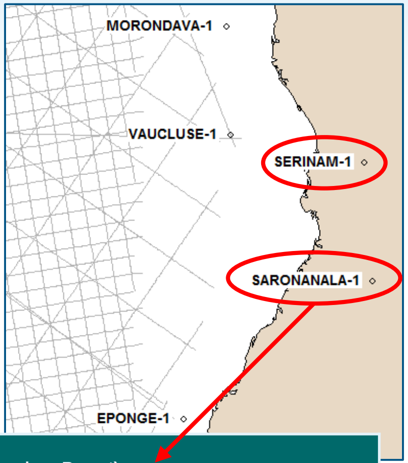
Morondava Basin

- Potential for organic-rich shales in Morondava Basin
- Saronanala-1 and Serinam-1 wells encountered Cenomanian to Valanginian interval with TOCs up to 7.7% (average ~4%)
- Upper Jurassic source rock with TOCs of >2%
- Deposited in restricted marine environment between the paleo-shelf (before uplift of Madagascar) and DFZ providing anoxic conditions

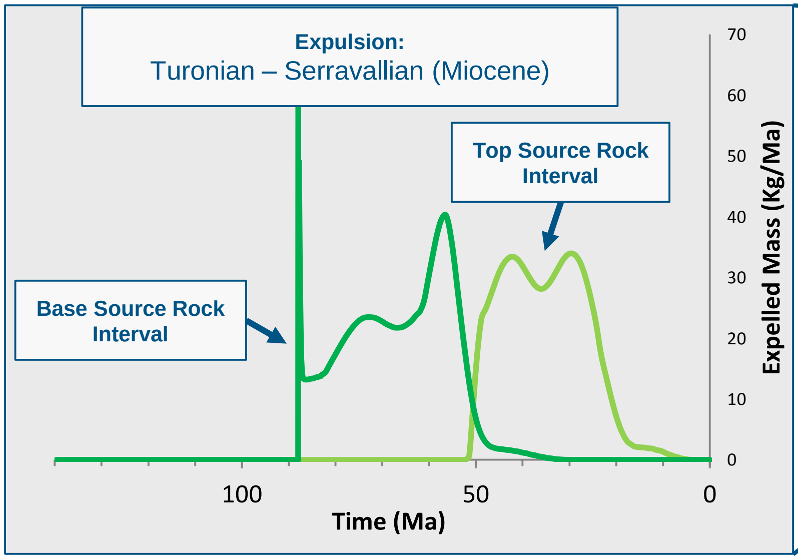


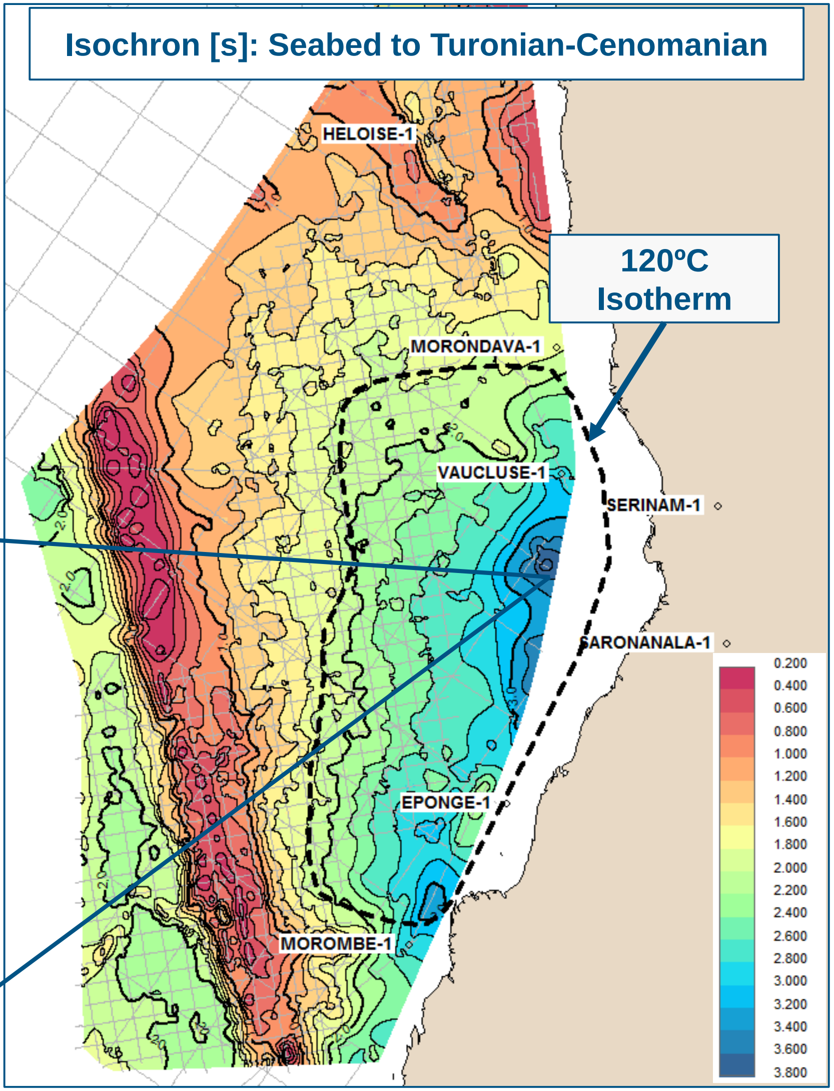
Saronanala-1 (from Petra-Chem Geochem Report)

Depth (m)	Stratigraphy	TOC (%wt)
579-594	Cenomanian / Albian	7.76
683-692	Albian	4.71
1073-1088	Aptian	5.9
1103-1116	Barremian	5.45
1140-1161	Barremian	2.25
1241-1271	Hauterivian	4.91
1277-1308	Hauterivian	2.69
1311-1341	Hauterivian	3.67
1366-1396	Hauterivian/Valanginian	3.57
1417-1445	Valanginian	2.80
1466-1494	Valanginian	1.87
1497-1524	Valanginian	2.78
1783-1814	Tithonian/Kimmeridgian	2.22

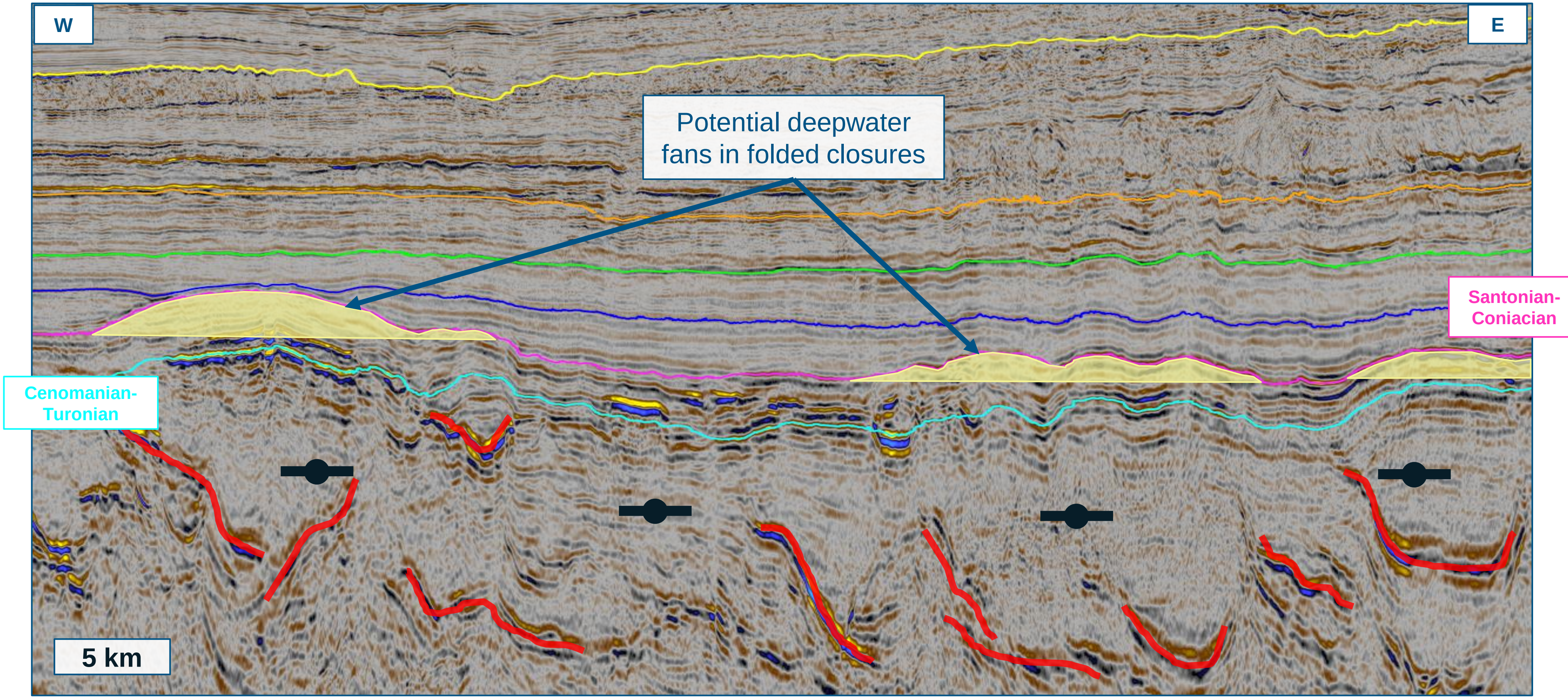
Morondava Basin

- Large part of Morondava basin conditions are very favourable for expulsion of hydrocarbons from Late Cretaceous to Present-day
- Supported by numerous oil seeps from piston cores and satellite oil seeps



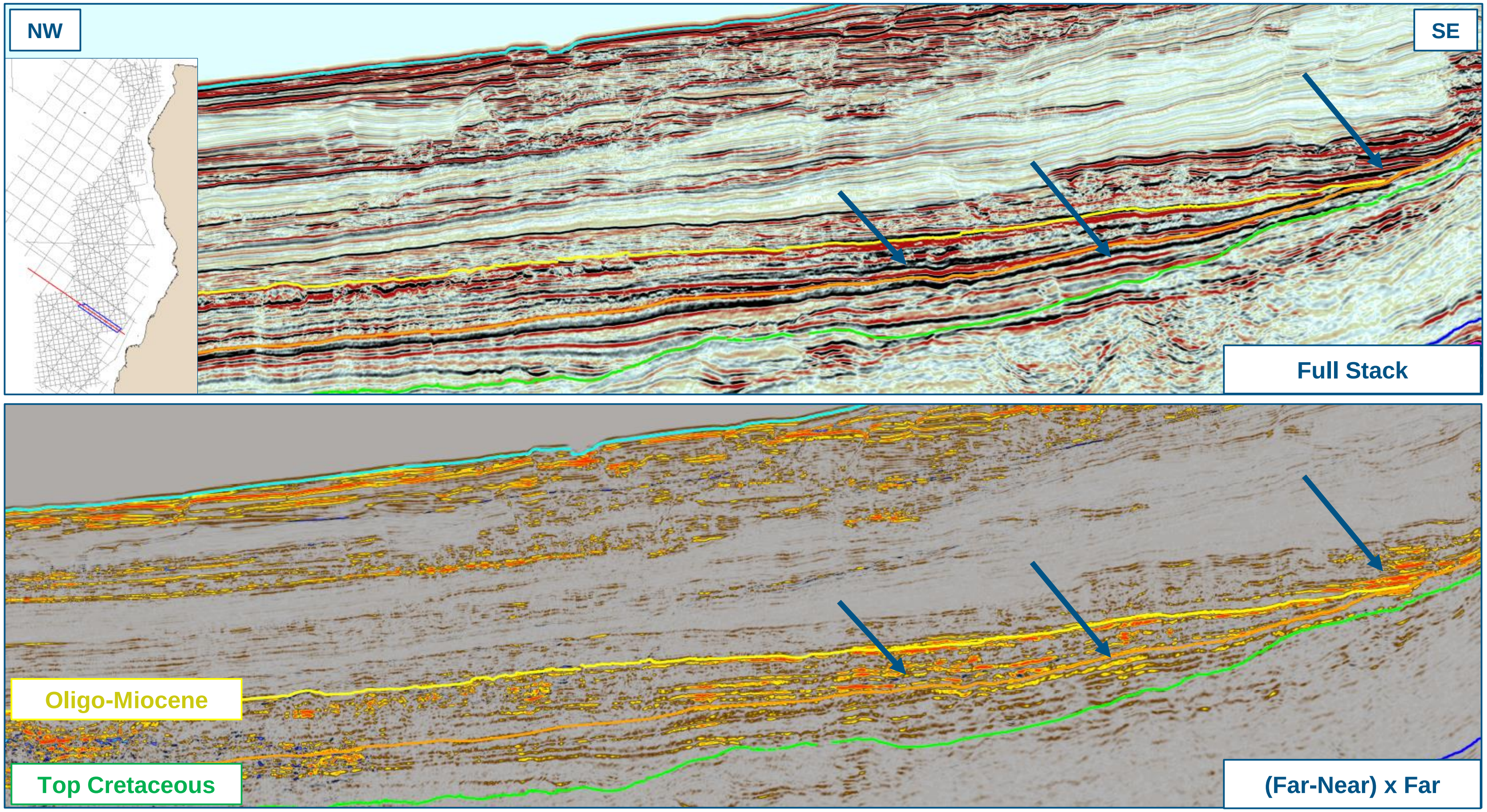


Morondava Basin



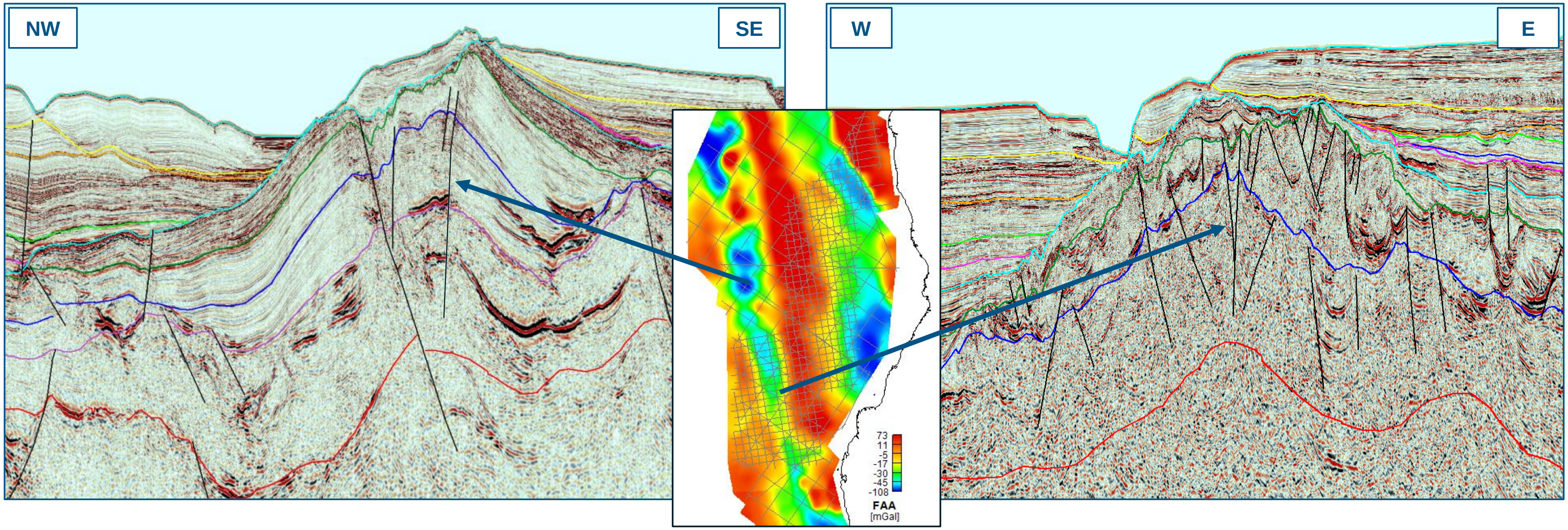
Upper Cretaceous deepwater fans in folded closures as a result of underlying intrusions. These structures are directly overlying Lower Cretaceous source rocks which have been expelling hydrocarbons throughout the Tertiary.

Morondava Basin



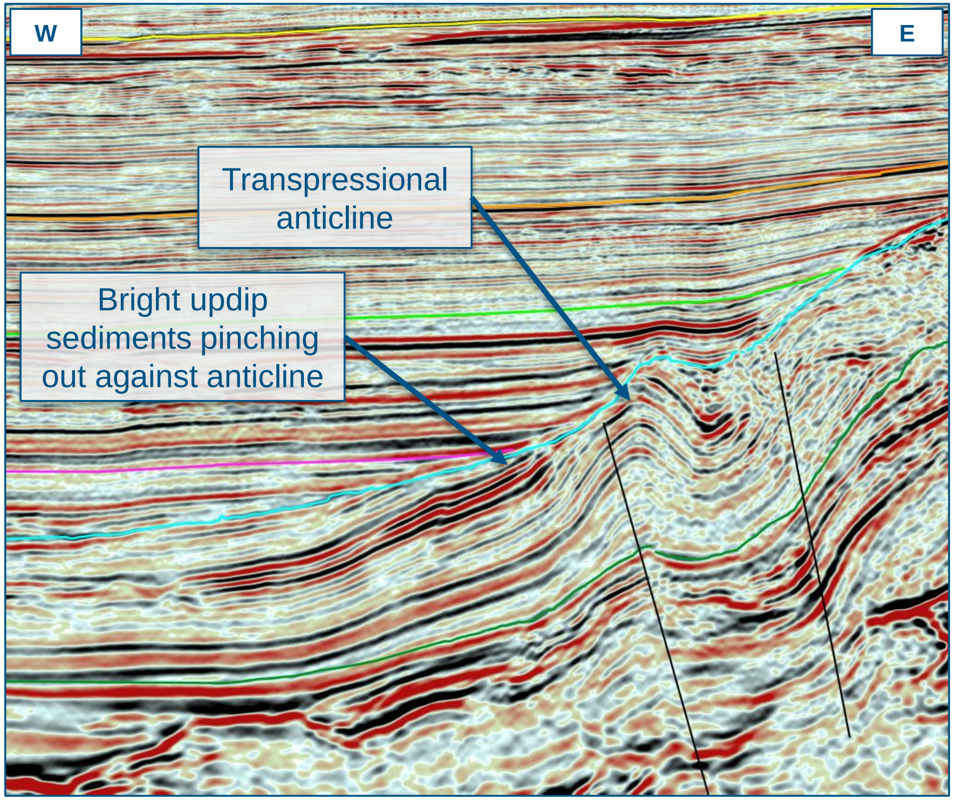
Tertiary deepwater fan systems are overlying the Lower to Upper Cretaceous “kitchen area” in the Morondava Basin. These fans systems are encased in deep marine shales and potential traps depend on lateral pinchouts and/or facies change.

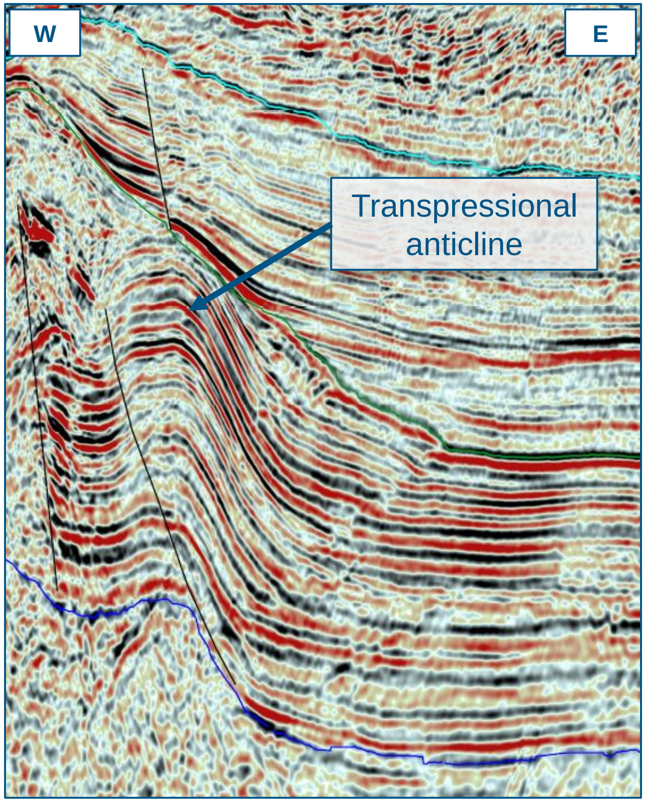
Davie Fracture Zone



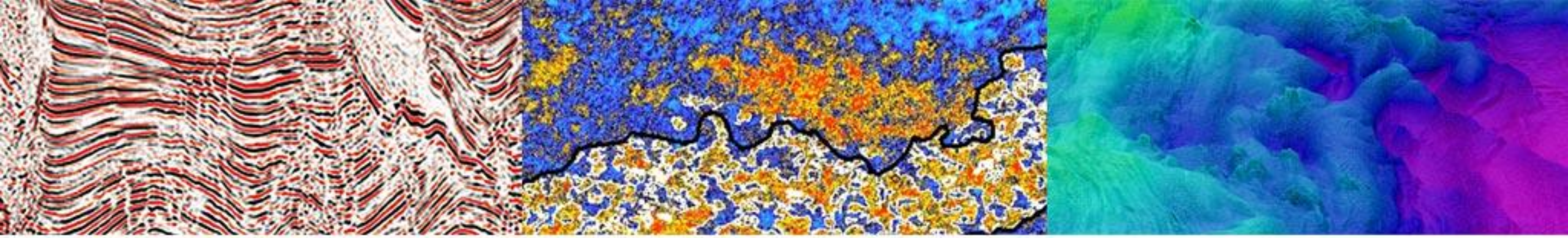
- DFZ is a highly variable complex structure along the Morondava Basin
- It contains Cretaceous and Jurassic sediments and possibly even older rocks
- Well imaged, inverted, thick sedimentary basin in the north
- Highly faulted and compressed sediments in the south
- Inversion due to transpression related to breakup India and Madagascar
- Indications of erosion at the crest of the DFZ

Davie Fracture Zone





- Deepwater fan systems trapped in transpressional structures on the flanks of the DFZ
- Potentially charged by Jurassic syn-rift source rocks
- Source rocks have expelled hydrocarbons since the Aptian to Present-day
- Supported by oil samples from piston cores and satellite oils seeps



Majunga Basin

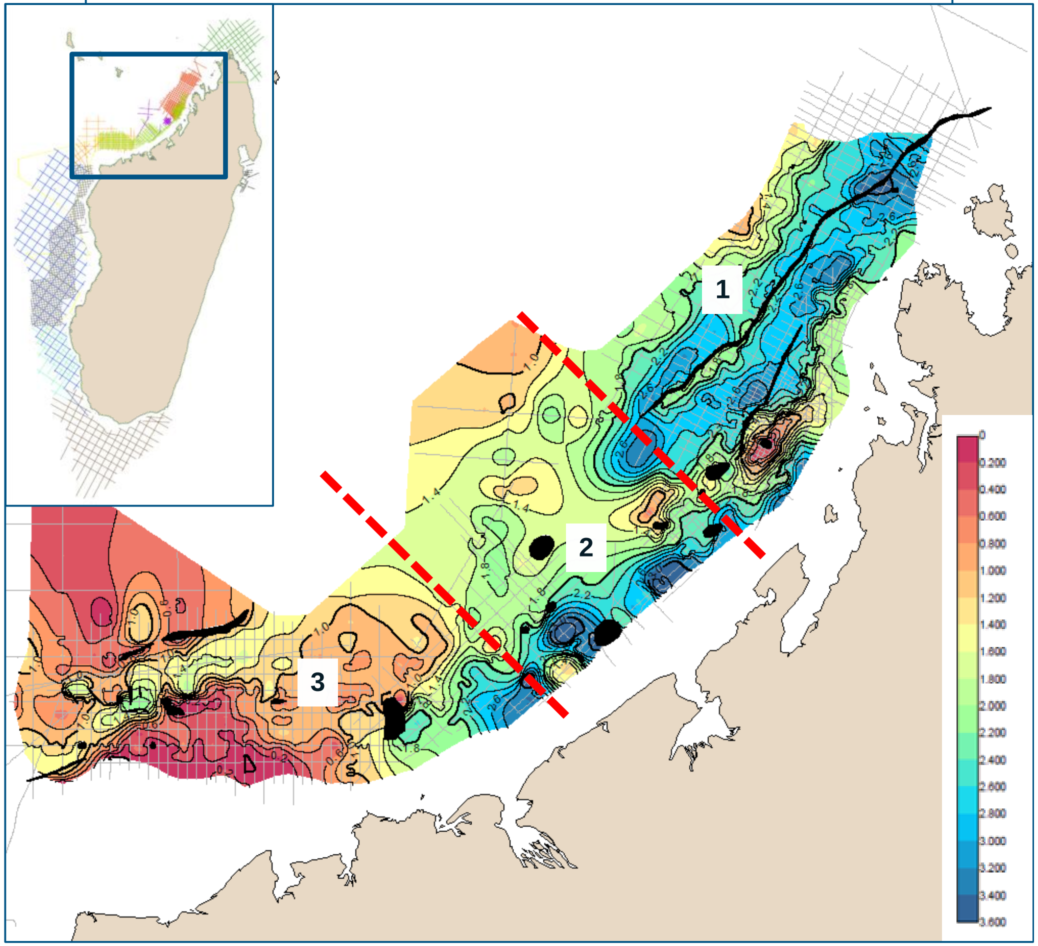
Majunga Basin

1. Deep rift basin with well imaged horst and graben structures. Karoo aged structures are reactivated during the Jurassic rifting episode.

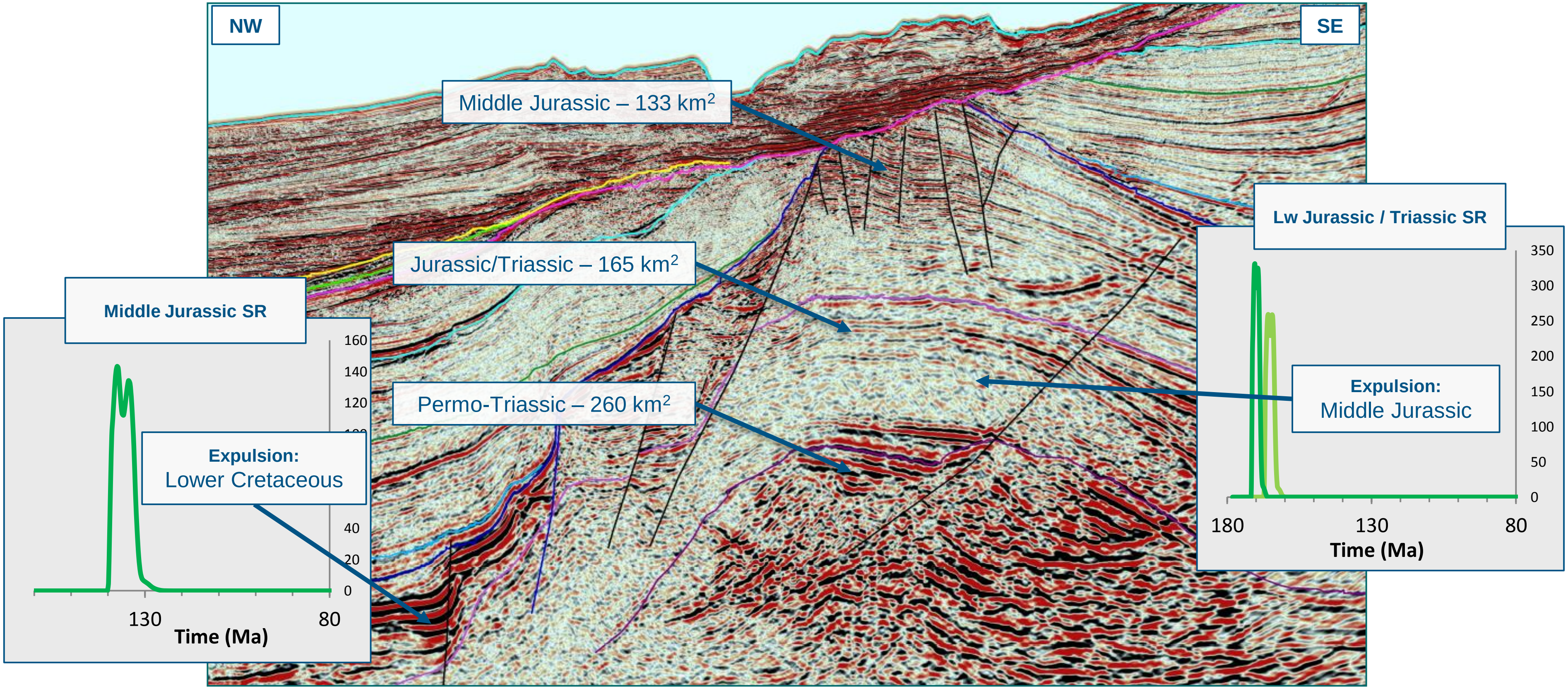
2. Jurassic salt basin. Characterized by allochthonous salt diapirs and canopies. Numerous toe-thrusts are present.

3. Broad shelf with steep slope down to the basin. Less post rift overburden. Volcanics more apparent than in other parts of Majunga Basin.

Isochron [s]: Santonian-Coniacian to Middle Jurassic

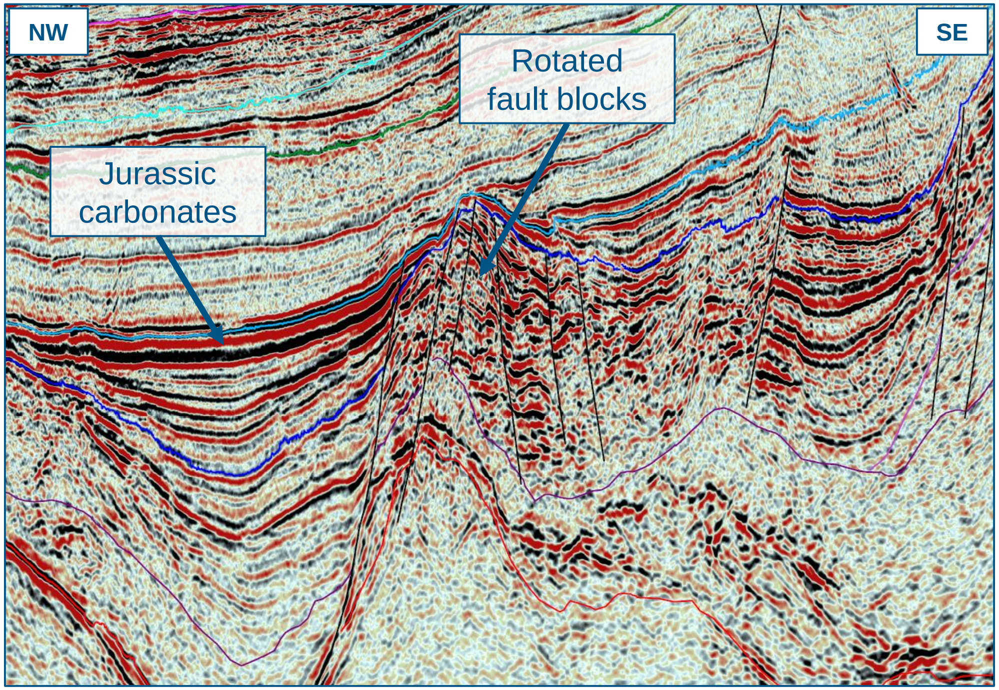


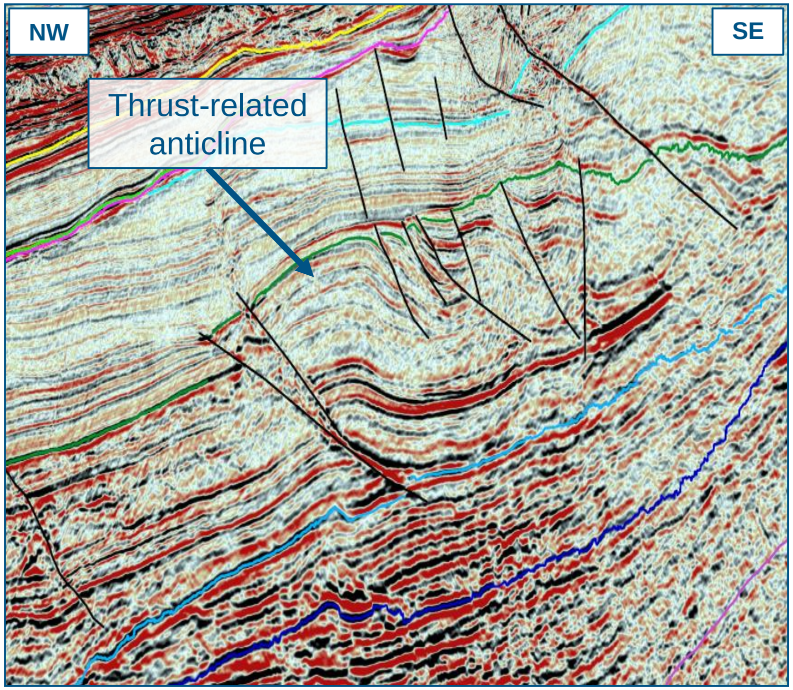
Majunga Basin



Large inverted structure with 4WD consisting of Middle Jurassic and Karoo aged sediments. Favourable location for charging by multiple source rock levels. A working petroleum system is supported by multiple large slicks reported near this structure.

Majunga Basin





- Tilted fault blocks potentially containing Karoo and Jurassic syn-rift sandstones with possible overlying shallow marine carbonates
- Cretaceous deep-water fan systems in toe thrust/rollover anticlines
- Expulsion of Jurassic syn-rift source rocks in the Upper Jurassic and Lower Cretaceous

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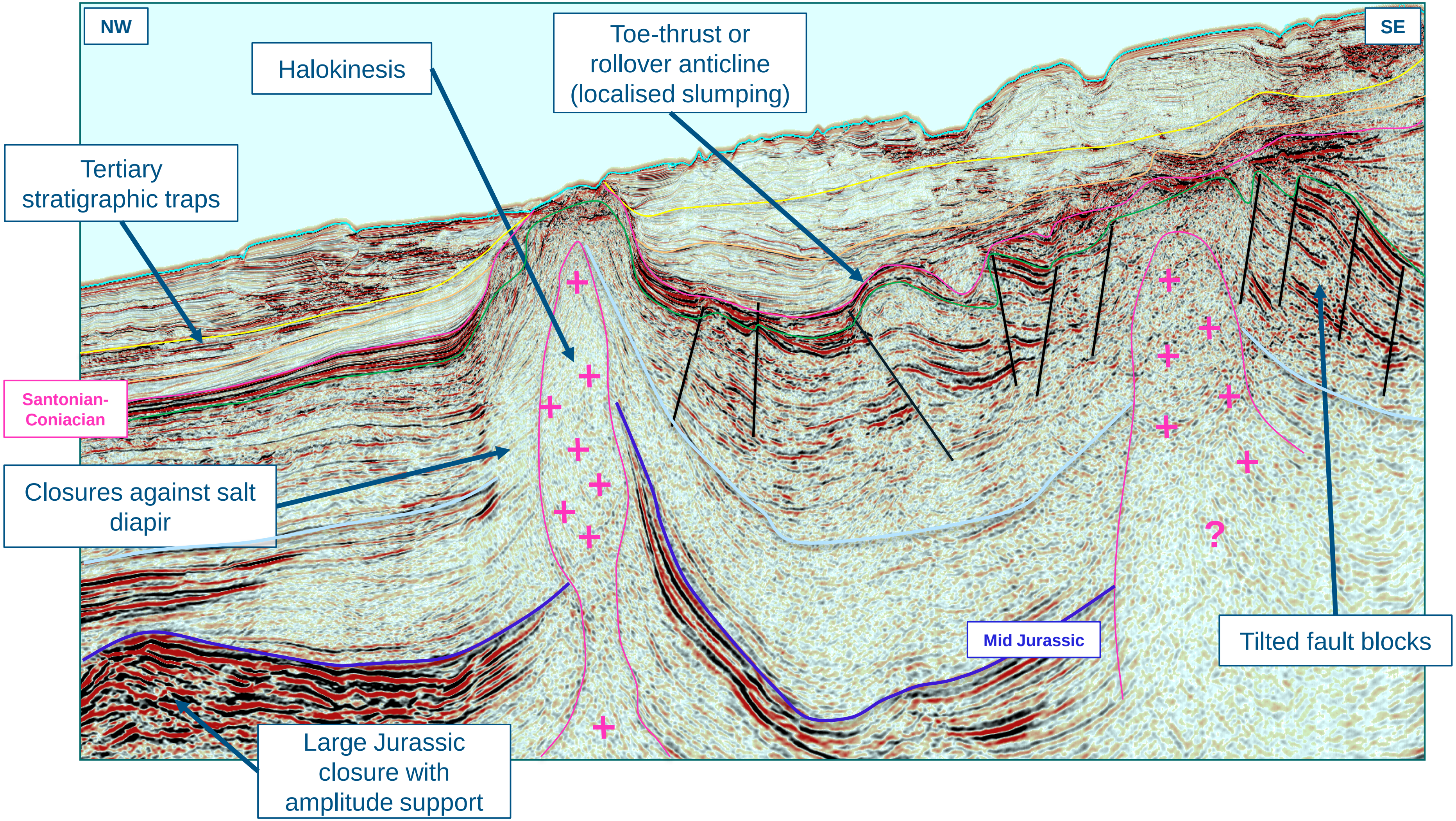
Majunga Basin



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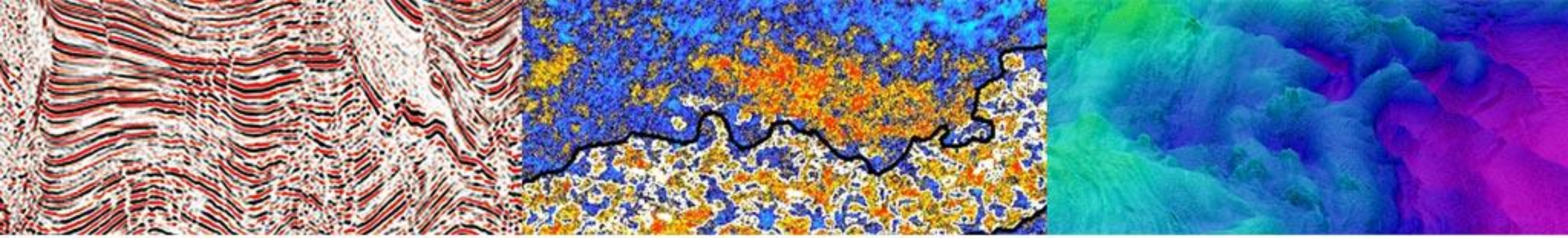


Ambilobe North Basin

Ambilobe North Basin

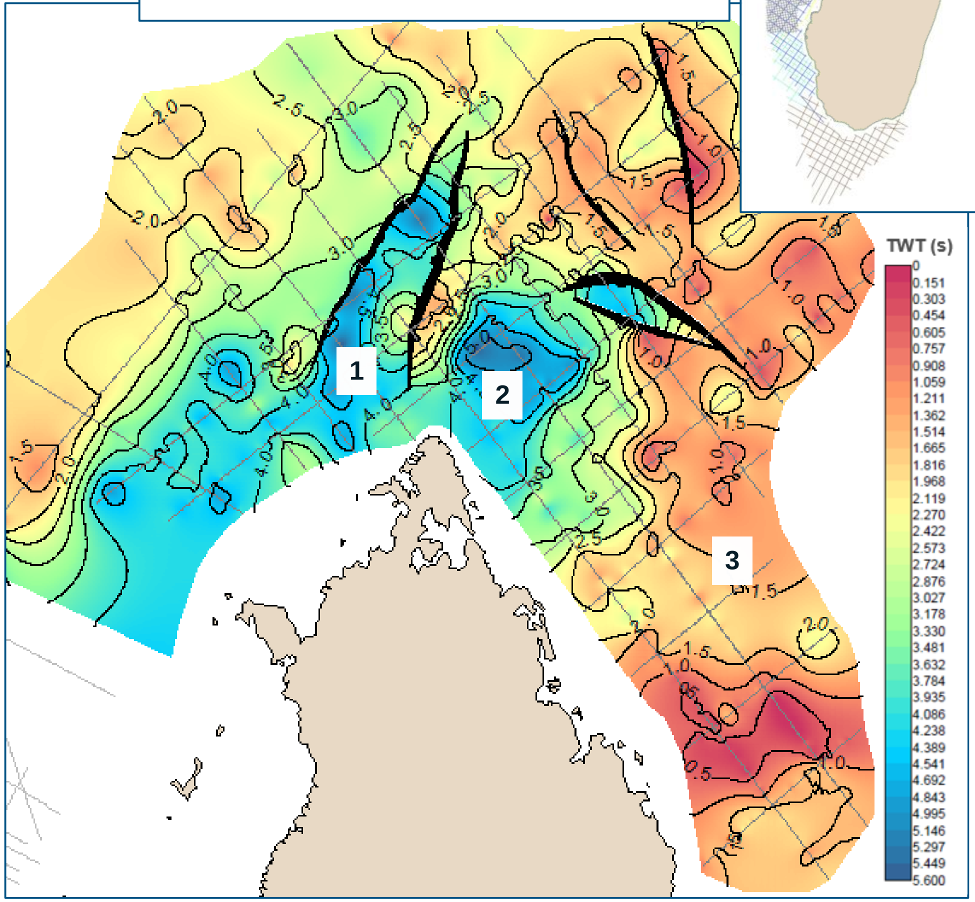
Untested frontier area, first MC data shot over this basin

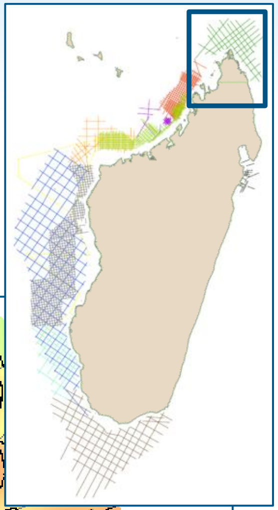
1. Deep sedimentary basin bounded by large regional faults active since Karoo times

2. Structural high affected by Jurassic rifting which created many rotated fault blocks

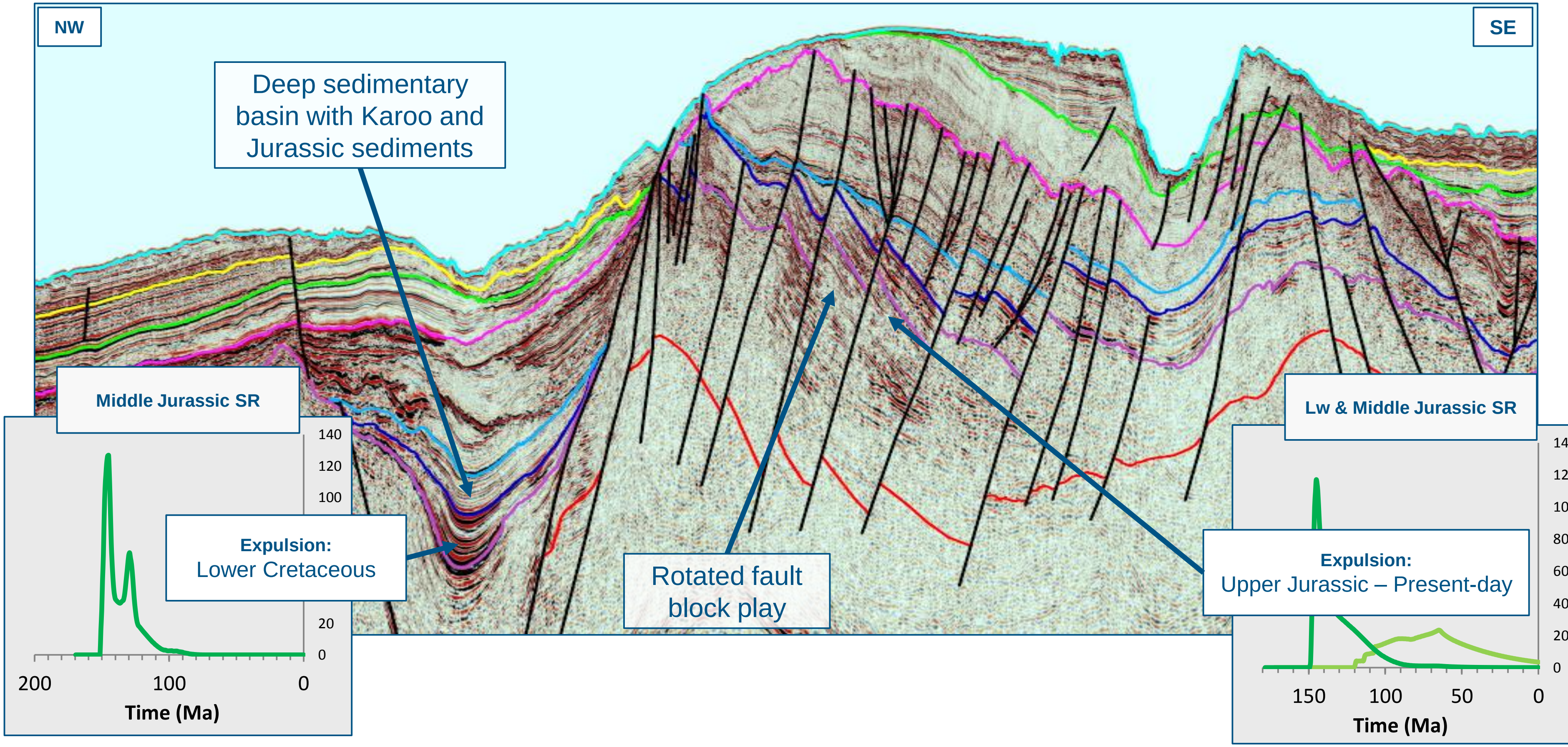
3. Basin related to breakup of Madagascar and India. Less post-breakup sedimentary cover compared to basins to the west

Isochron: Seabed to Basement





Ambilobe North Basin



Deep sedimentary basin with potential for Karoo and Jurassic syn-rift source rocks. The rotated fault blocks form fault bounded traps and likely contain Karoo and Jurassic syn-rift sandstones with overlying Jurassic shallow marine carbonates.

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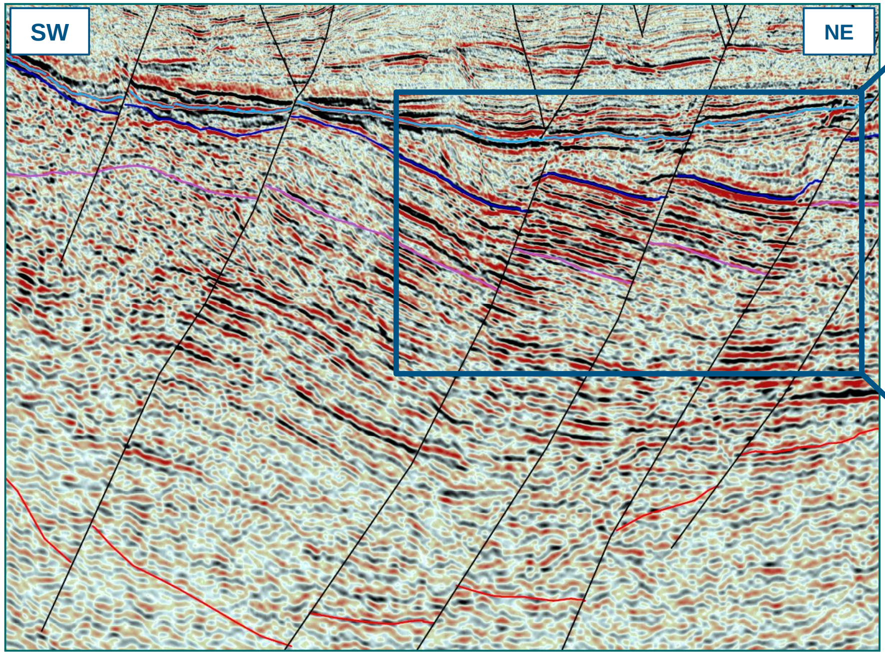
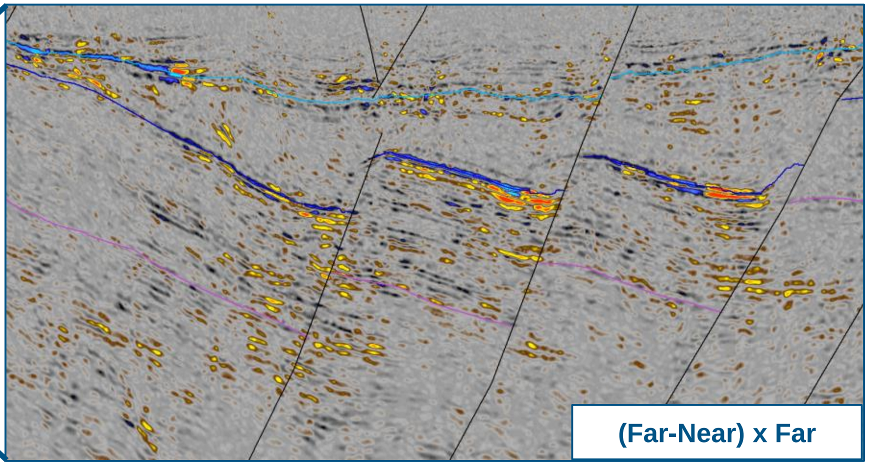
Ambilobe North Basin





- Promising area with structural traps
- Presence of proven Karoo and Jurassic syn-rift source rocks and reservoirs
- Expelling source rocks since Upper Jurassic
- DHIs
- Shallow water depths

Summary

- All the offshore basins are undrilled or sparsely drilled and their potential is untested
- Jurassic syn-rift source rocks are thought to have expelled oil after trap formation
- Lower Cretaceous source rocks in onshore wells are likely to be present in the Morondava Basin and within the Present-day oil expulsion window
- Many attractive structural and stratigraphic plays have been interpreted and are within drillable depths in all offshore basins
- Licensing round anticipated end 2017

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BGP:

Xu Wenshuai and Xing HongKai

OMNIS:

Lalanirina Ranoroarisoa and Bonaventure Rasoanaivo

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Thank you

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