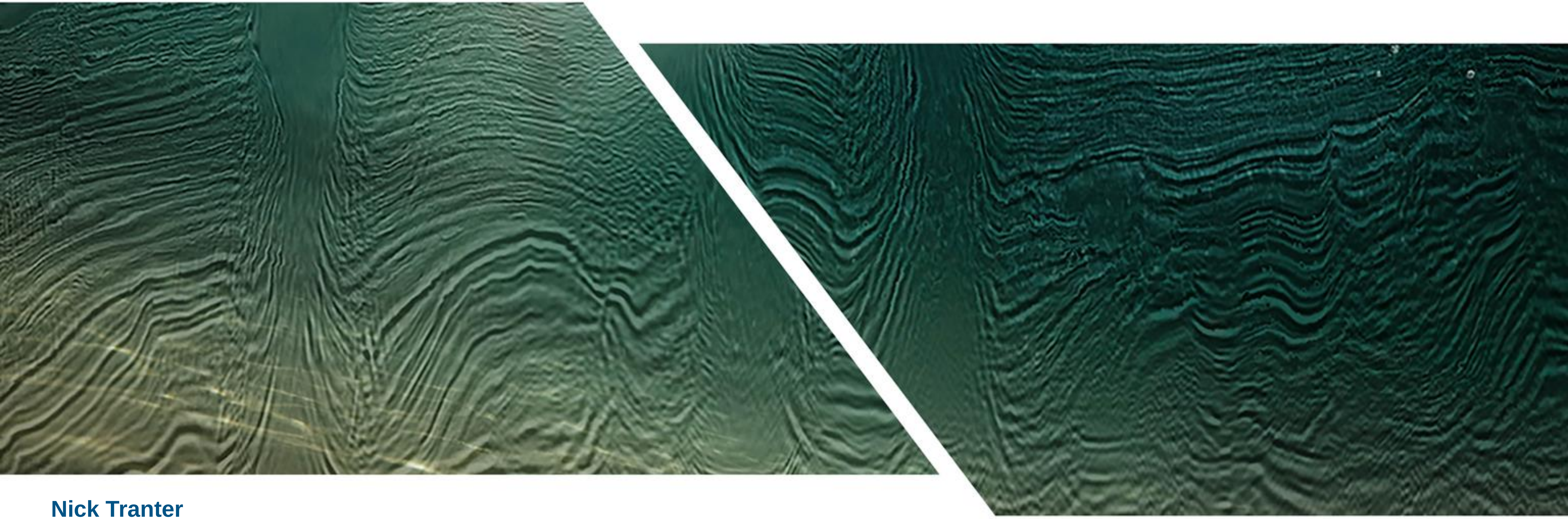
Offshore Madagascar: hydrocarbon potential in frontier basins



Nick Tranter
TGS – Africa and Middle East

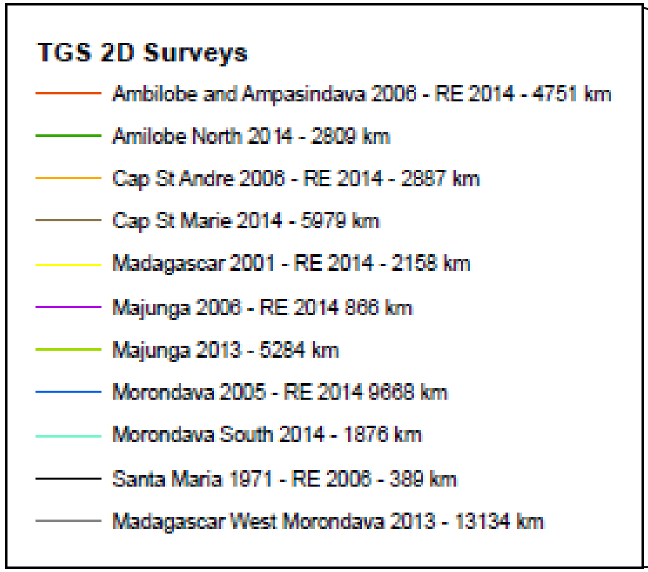
February 2017

LEGAL NOTICE

Contents

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 are completed



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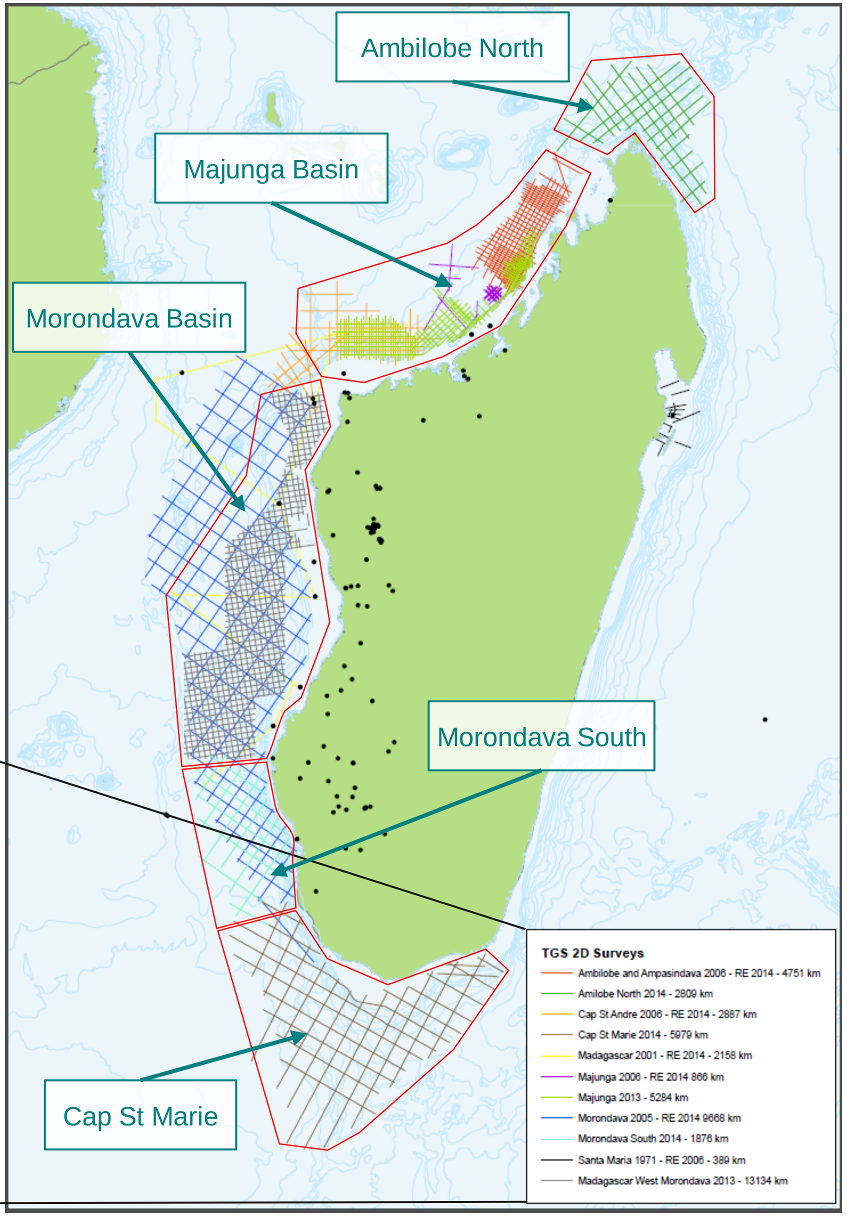

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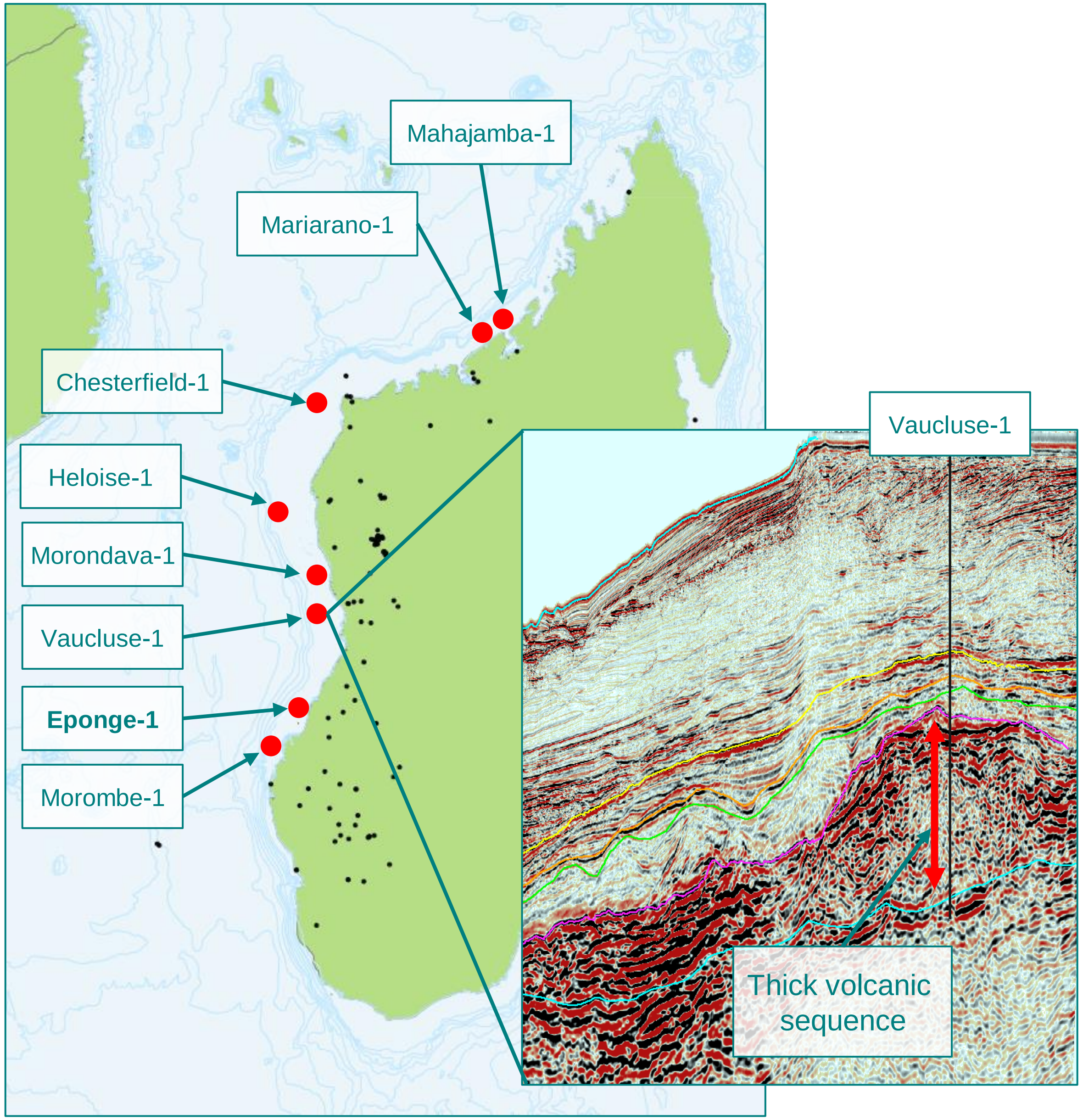
Exploration History

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

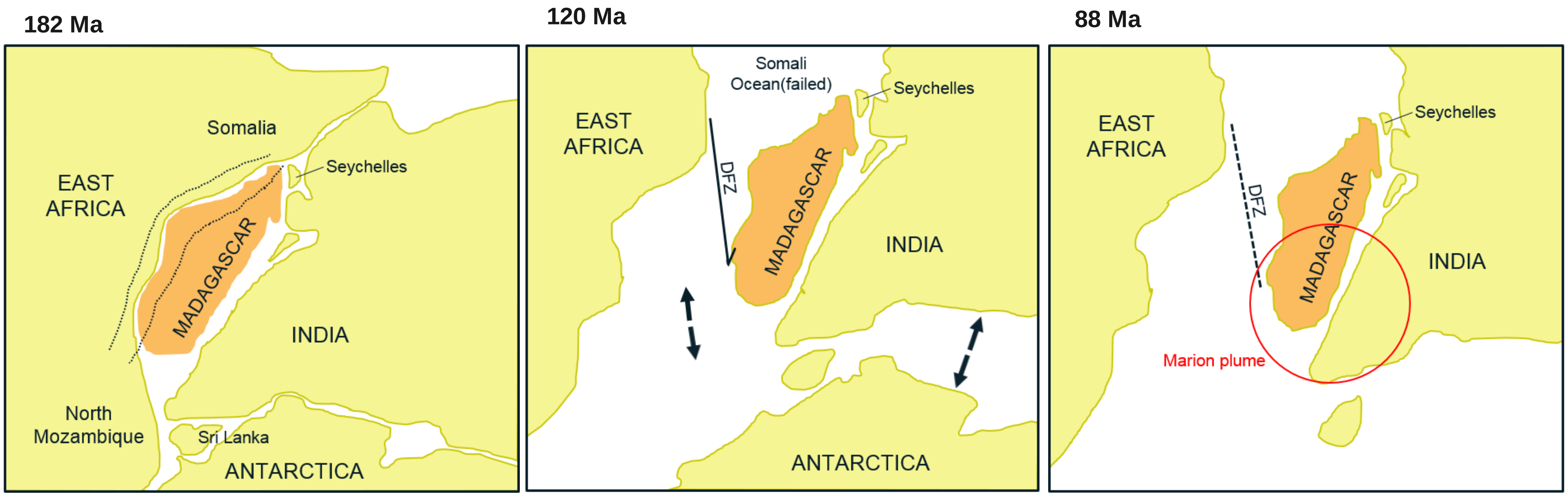
- 4 offshore wells penetrated thick volcanic sequences:
  - Heloise-1, Morondava-1, Vaucluse-1 and Morombe-1
  - Thought to be structural closures or reefs
  - Thus half of all offshore wells did not target valid structures

- The varying results of the few wells drilled offshore Madagascar suggest there is still a lot of potential for future discoveries.



Tectonic History

Modified after Reeves, 2014



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

- 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

- 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

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:

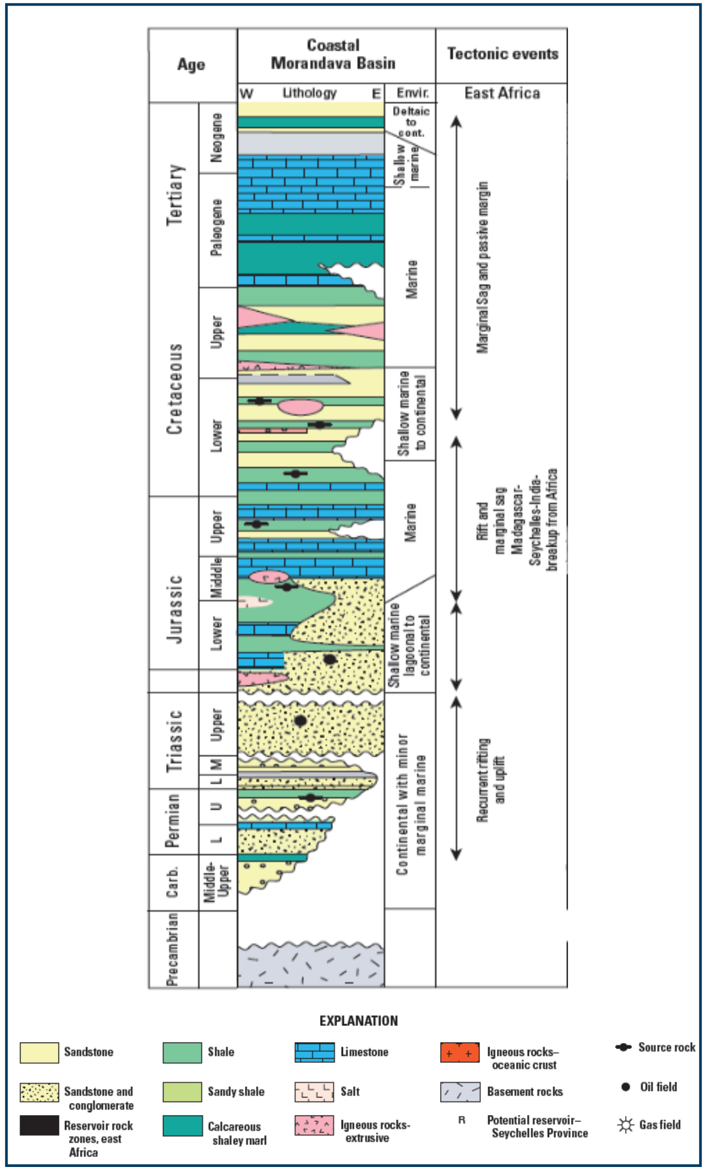
- Permo-Triassic Sakamena Group and Lower Jurassic Isalo Formation sandstones (reservoirs for the Tsimiroro and Bemolanga fields and Manandaza light oil shows onshore Madagascar),
- Middle Jurassic shallow marine carbonates and sandstones,
- Cretaceous and Tertiary basin slope and basin floor turbidite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

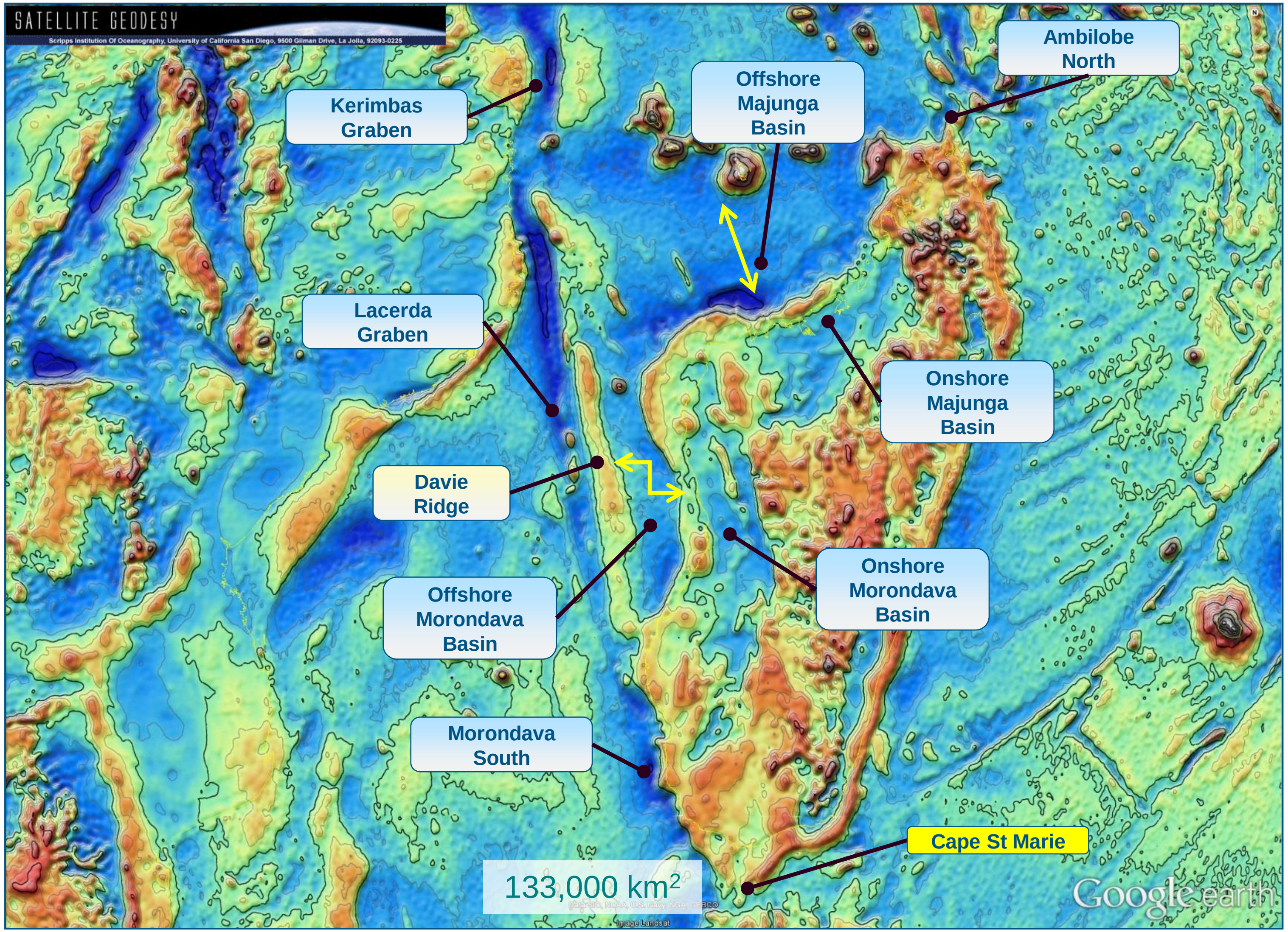
Seal:

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



Cap St. Marie

Cap St. Marie



SATELLITE GEODESY
Scripps Institution Of Oceanography, University of California San Diego, 9500 Gilman Drive, La Jolla, 92093-0225
Kerimbas Graben
Offshore Majunga Basin
Ambilobe North
Lacerda Graben
Onshore Majunga Basin
Davie Ridge
Onshore Morondava Basin
Offshore Morondava Basin
Morondava South
Cape St Marie
133,000 km^2
Google earth

Cap St. Marie

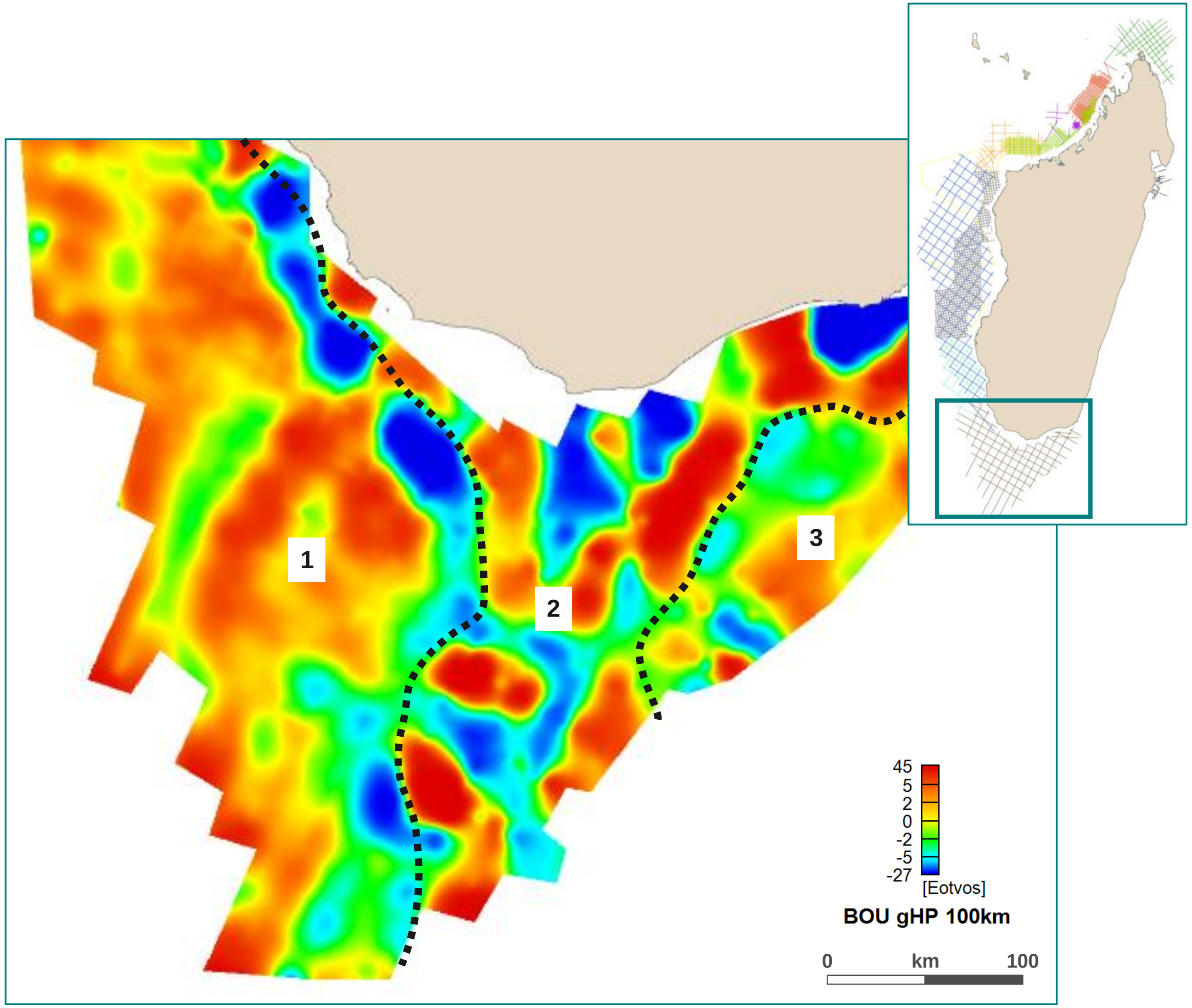
Potentially affected by four rift phases, the basin can be split into three:

1. Passive margin sedimentation with potential for deepwater fan systems in stratigraphic pinchouts

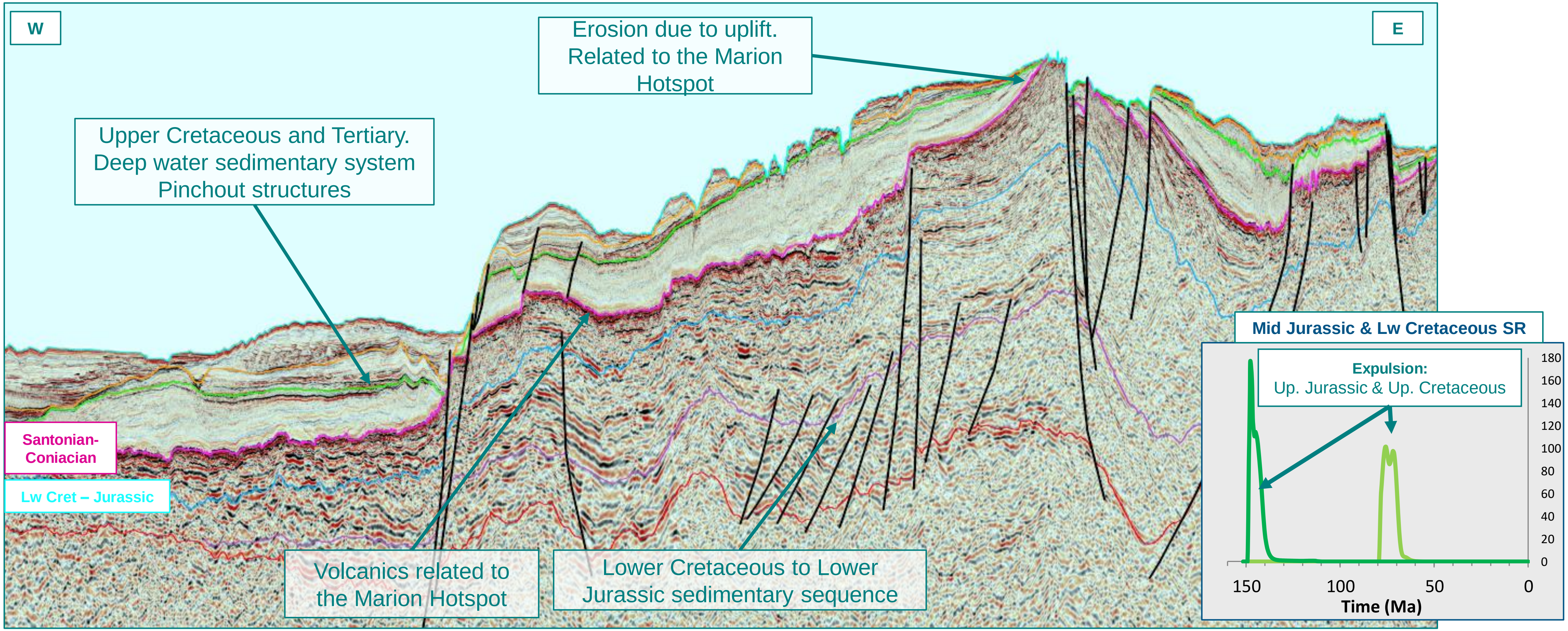
2. Uplifted zone with an interpreted thick Lower Cretaceous to Lower Jurassic interval

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

Marion hotspot (c. 92 Ma to 84 Ma) had a regional effect



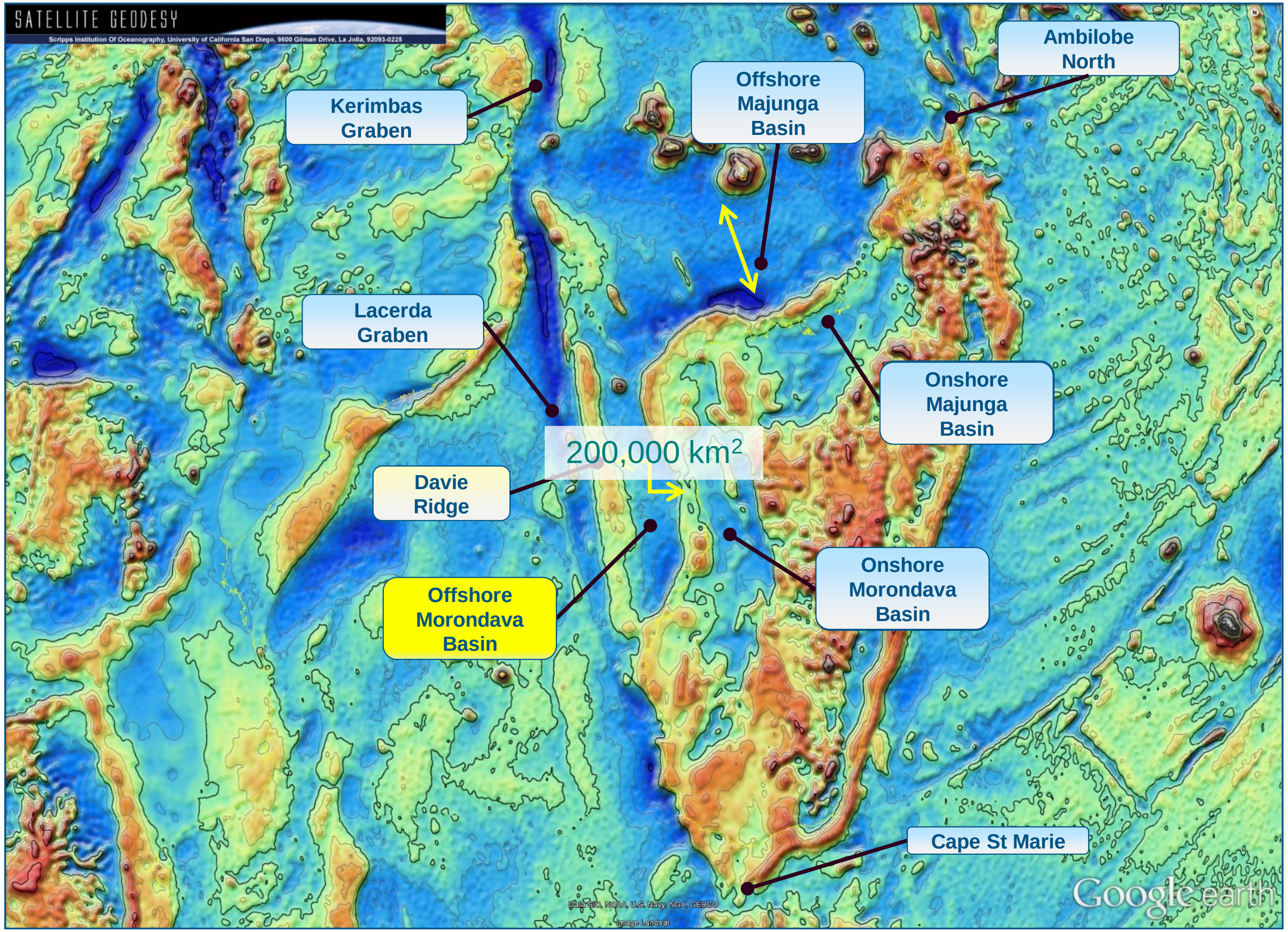
Cap St. Marie



The central Cap St. Marie area is characterized by a thick Lower Cretaceous to Lower Jurassic sedimentary sequence with fault blocks and potential structural closures.

Morondava Basin

Morondava Basin

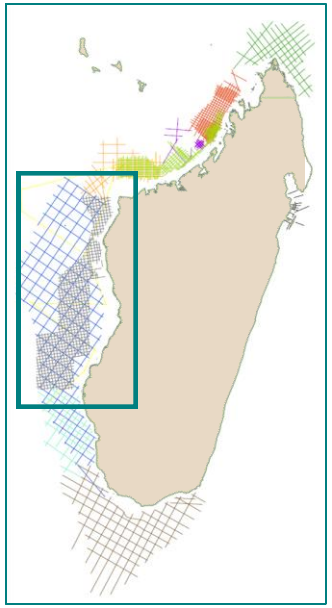


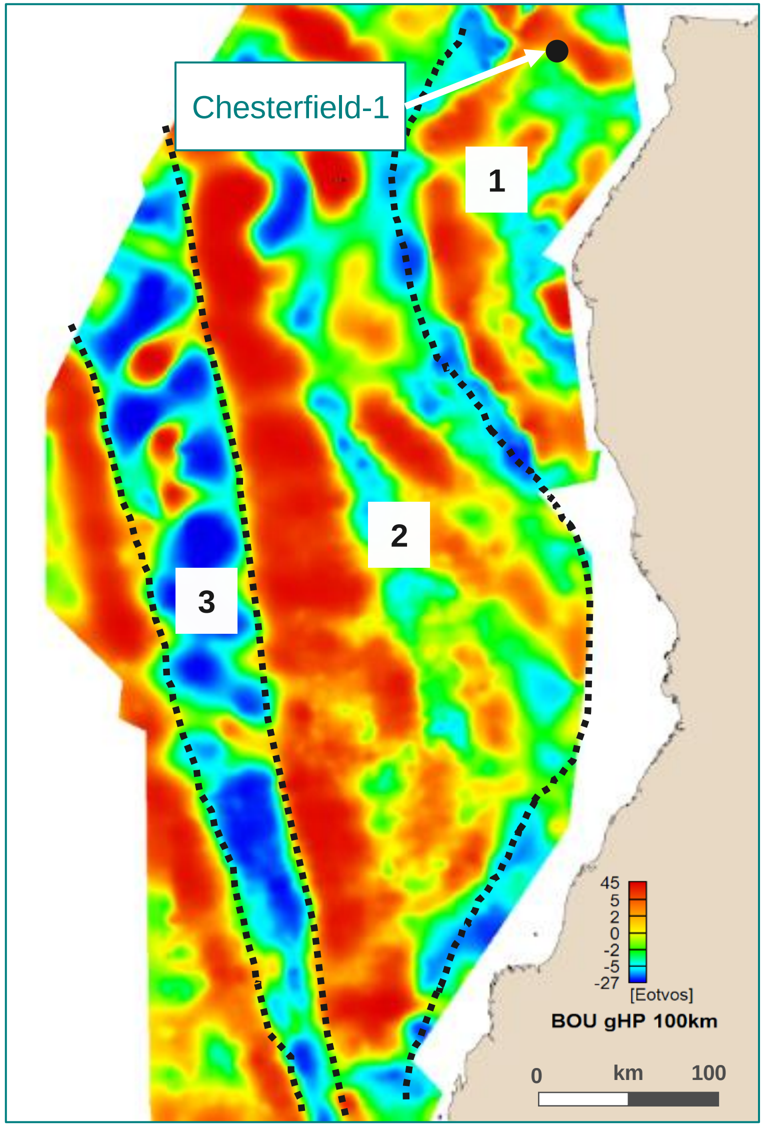
Morondava Basin | Structural Elements

1. Morondava Shelf
   - Karoo (Chesterfield-1)
   - Well imaged rifted fault blocks
   - Reef structures

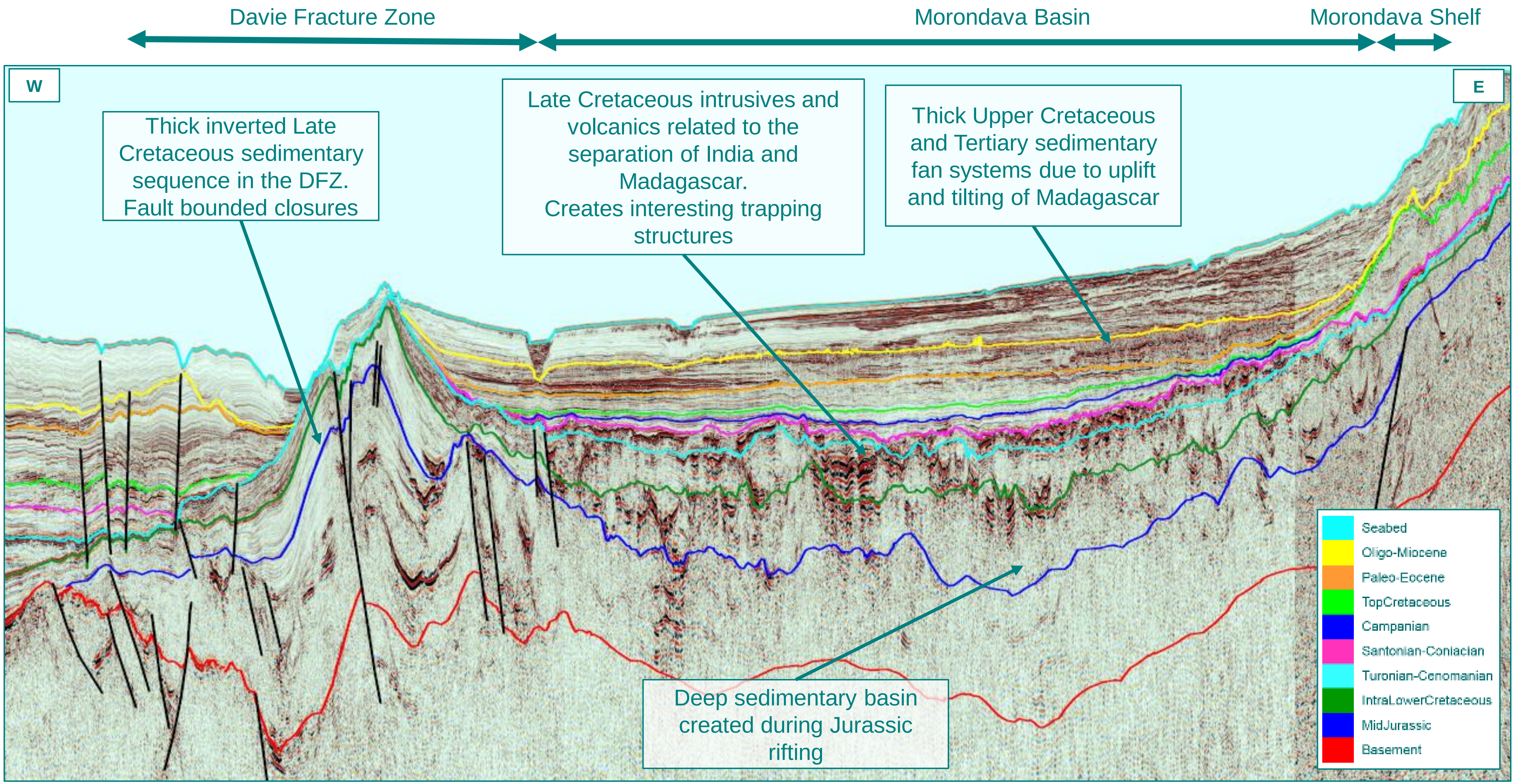
2. Morondava Basin
   - Jurassic rift basin
   - Thick sedimentary infill

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

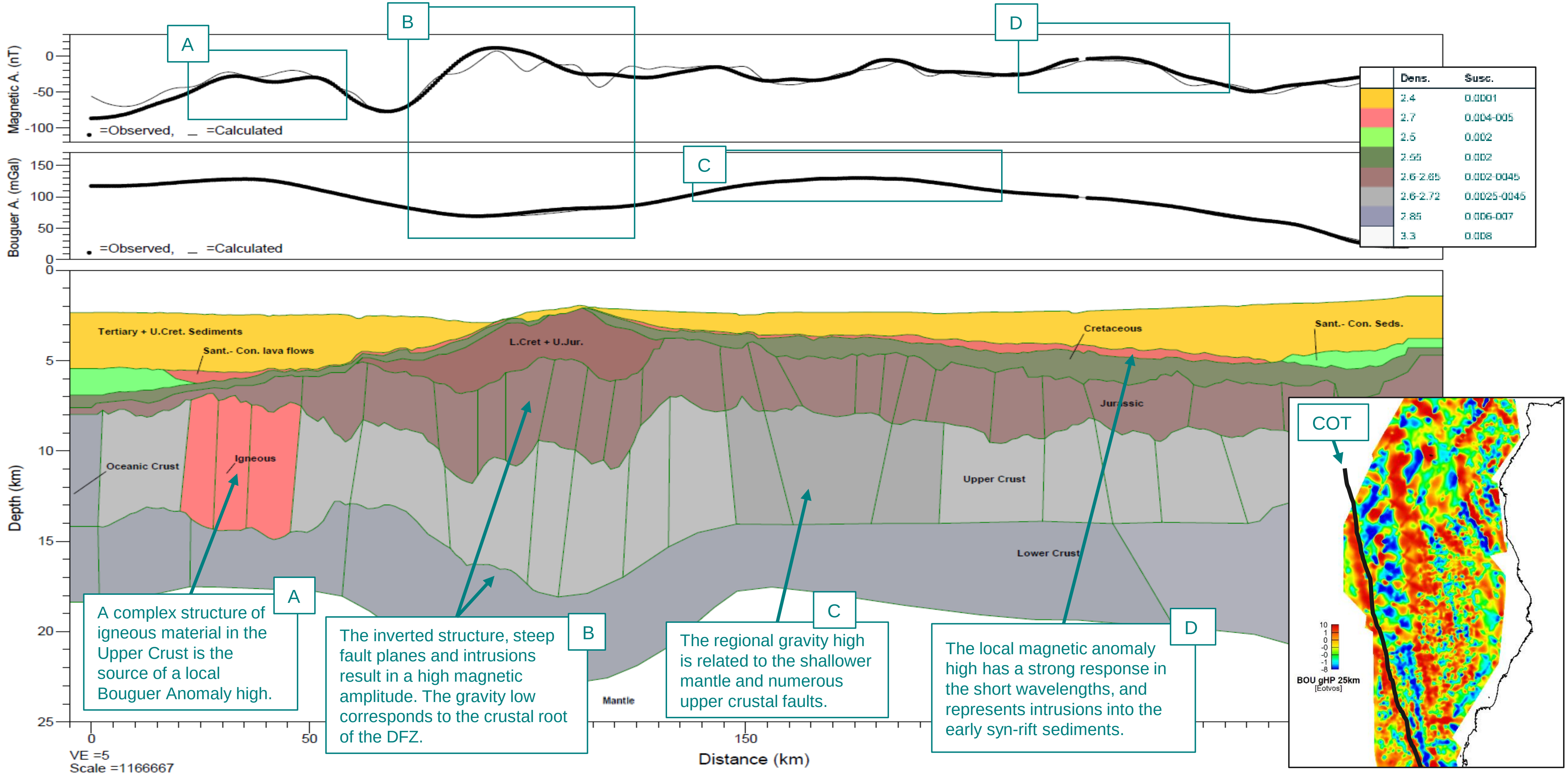




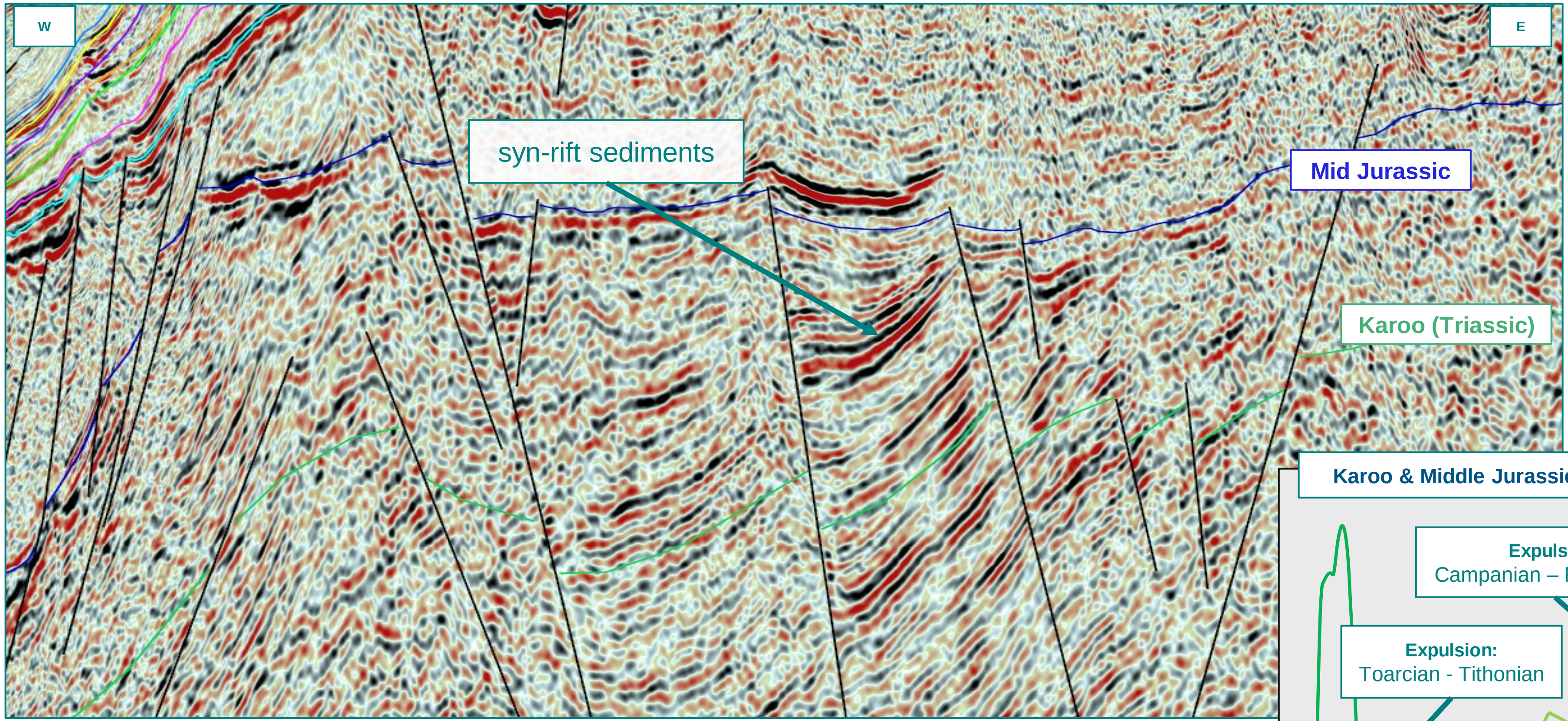
Morondava Basin | Structural Elements

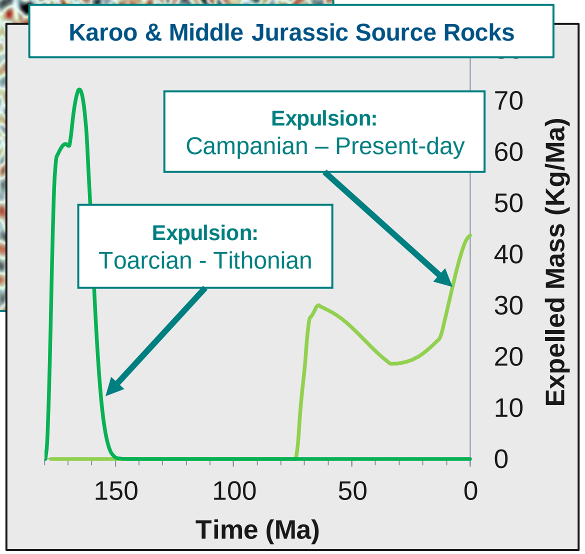


Morondava Basin | Gravity & Magnetic Model



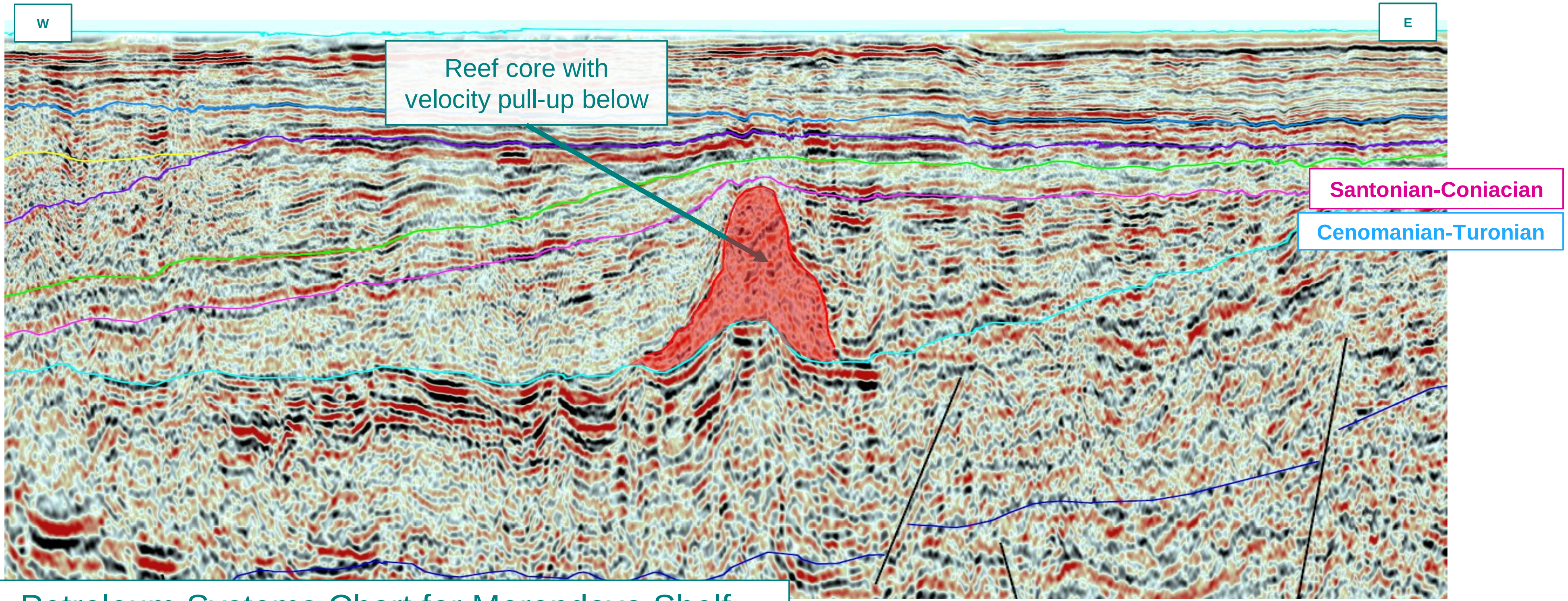
Morondava Shelf



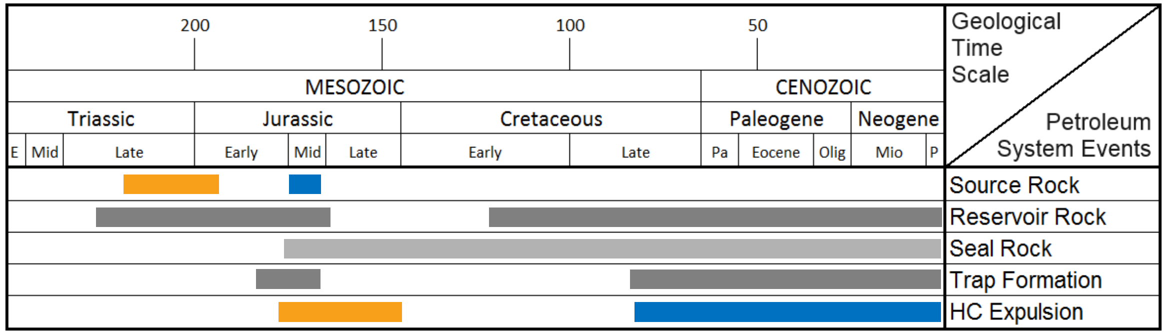


- Permo-Triassic and Lower Jurassic sediments rotated during Jurassic rifting
- Charged by Permo-Triassic Karoo source rocks, proven onshore
  - Charging two onshore fields (heavy oil)
  - Light oils in the Manandaza well

Morondava Shelf



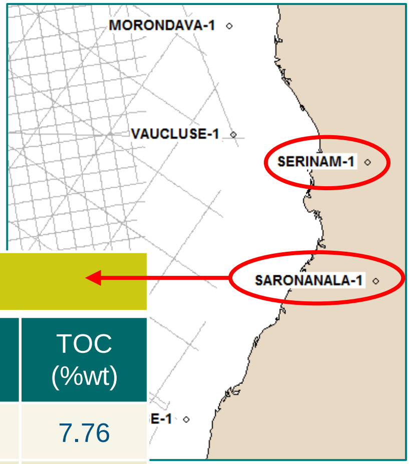
Petroleum Systems Chart for Morondava Shelf



- Jurassic syn-rift source rocks could have charged syn-rift and younger structures
- Eponge-1 well thicker overburden in the south, compared to the north

Morondava Basin

- Jurassic and Karoo source may be over-mature
- Need to rely on another source
- 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

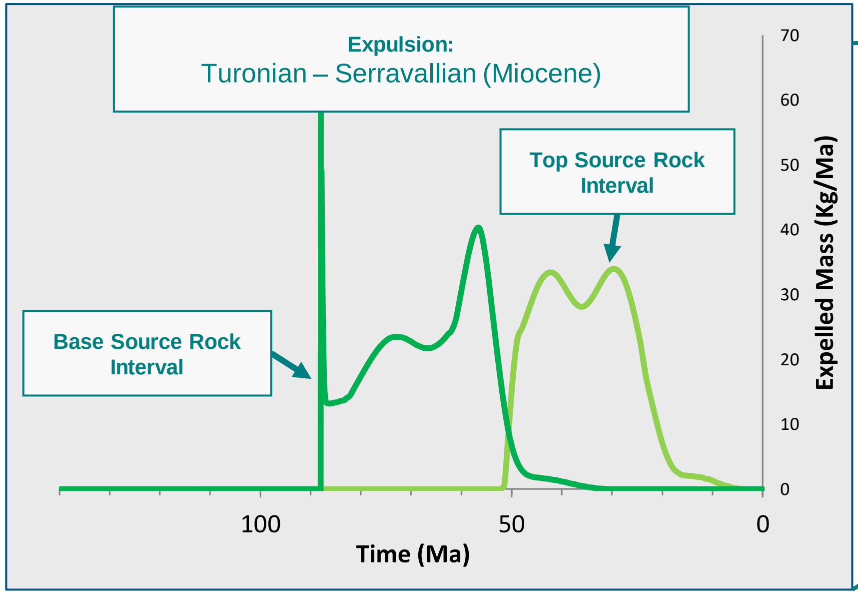


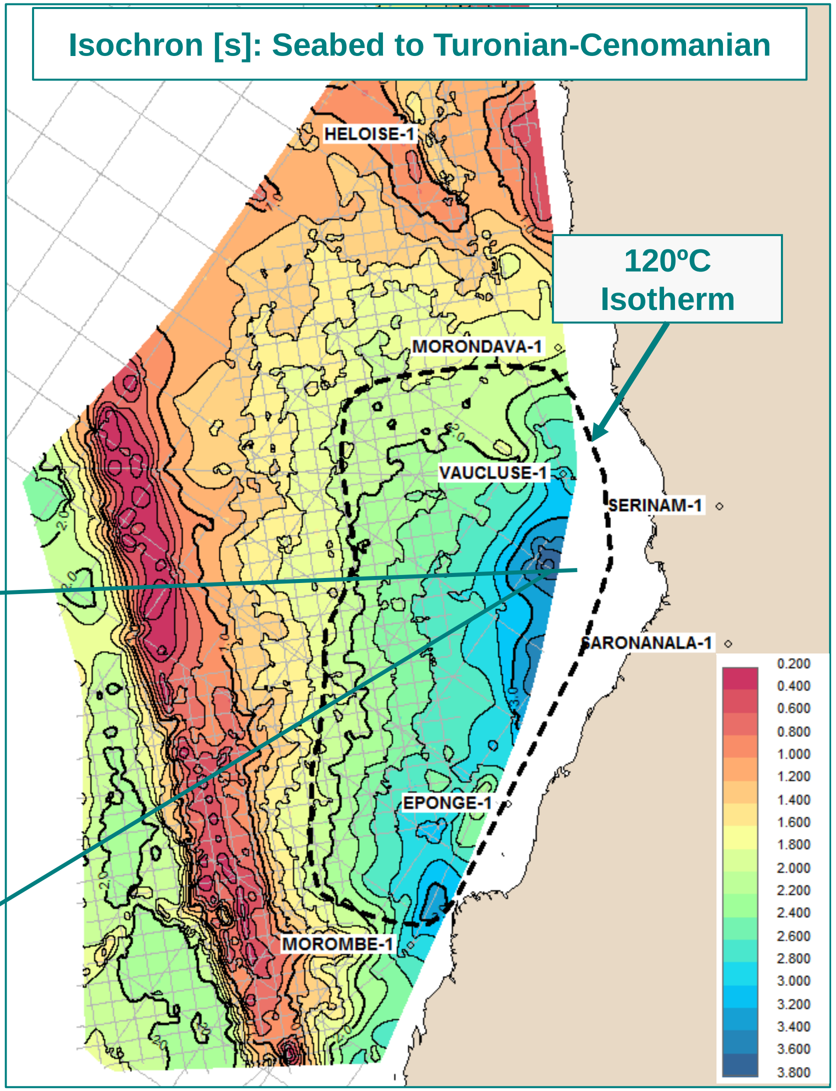
Saronanala-1 (from Petra-Chem Geochem Report)

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

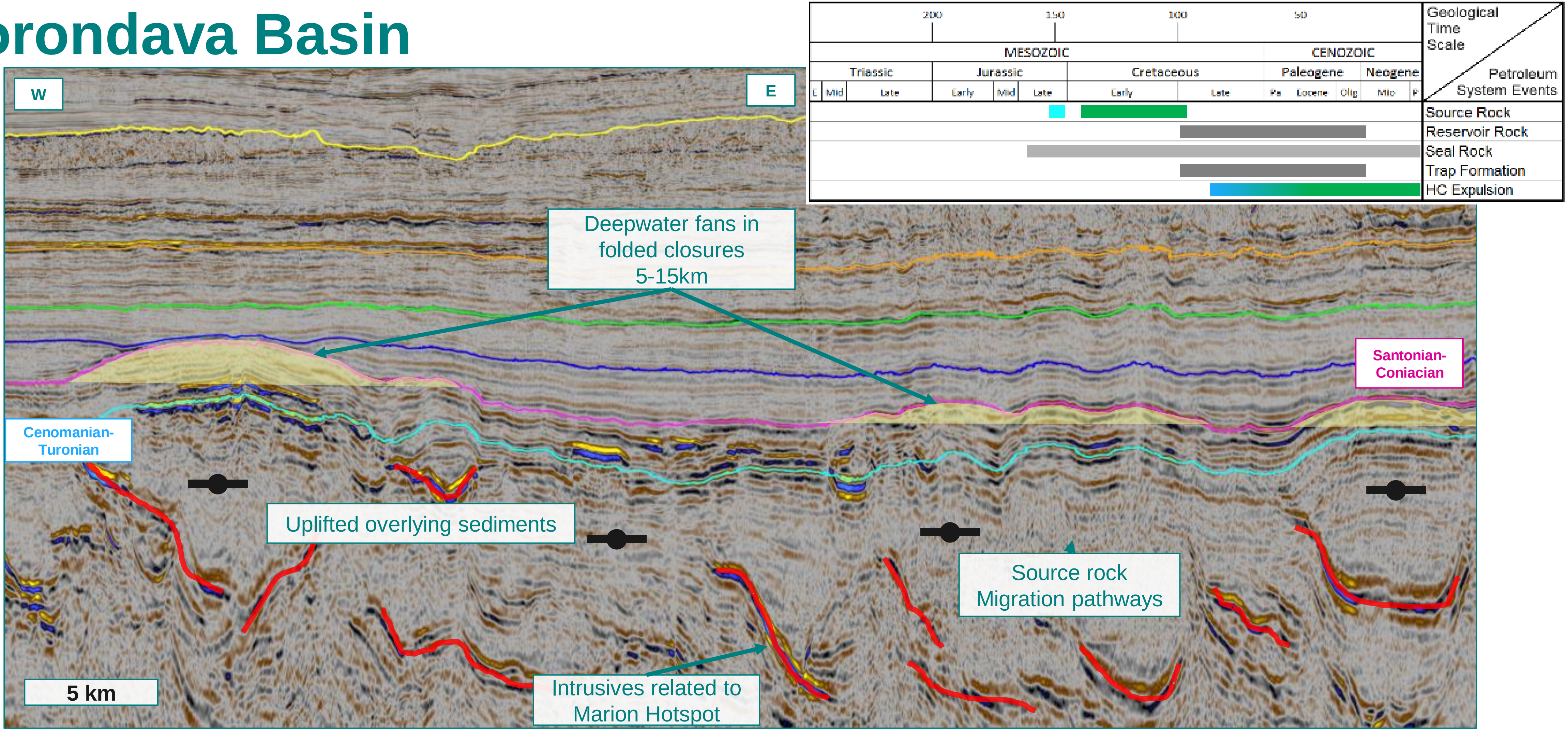
Morondava Basin

- Modelled Cretaceous/Upper Jurassic source at thickest overburden location
- Overburden gets thinner, oil window moves closer to present day
- Numerous oil seeps from piston cores and satellite oil seeps
- Overlying source are structures related to the intrusives





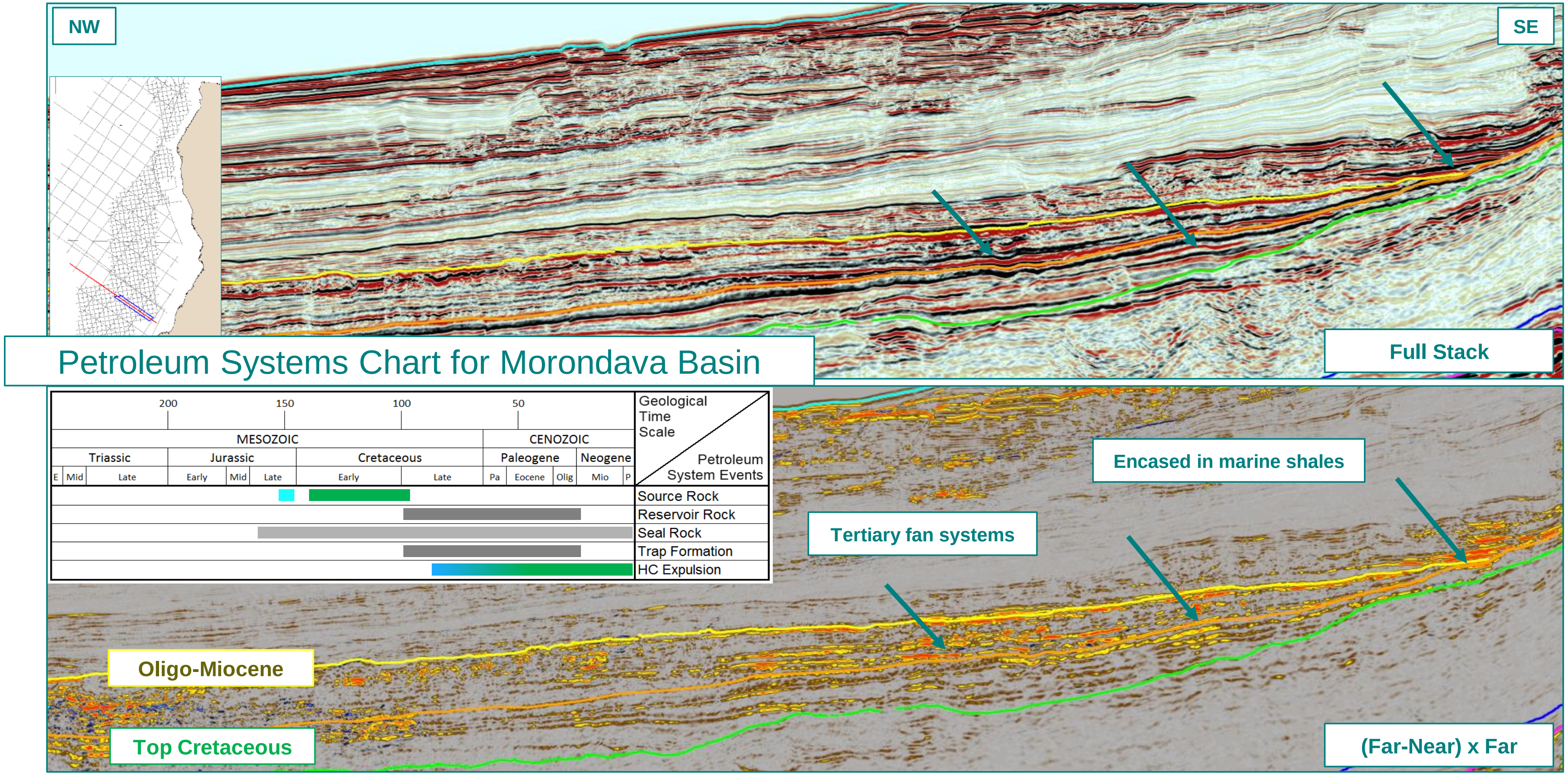
Morondava Basin



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.

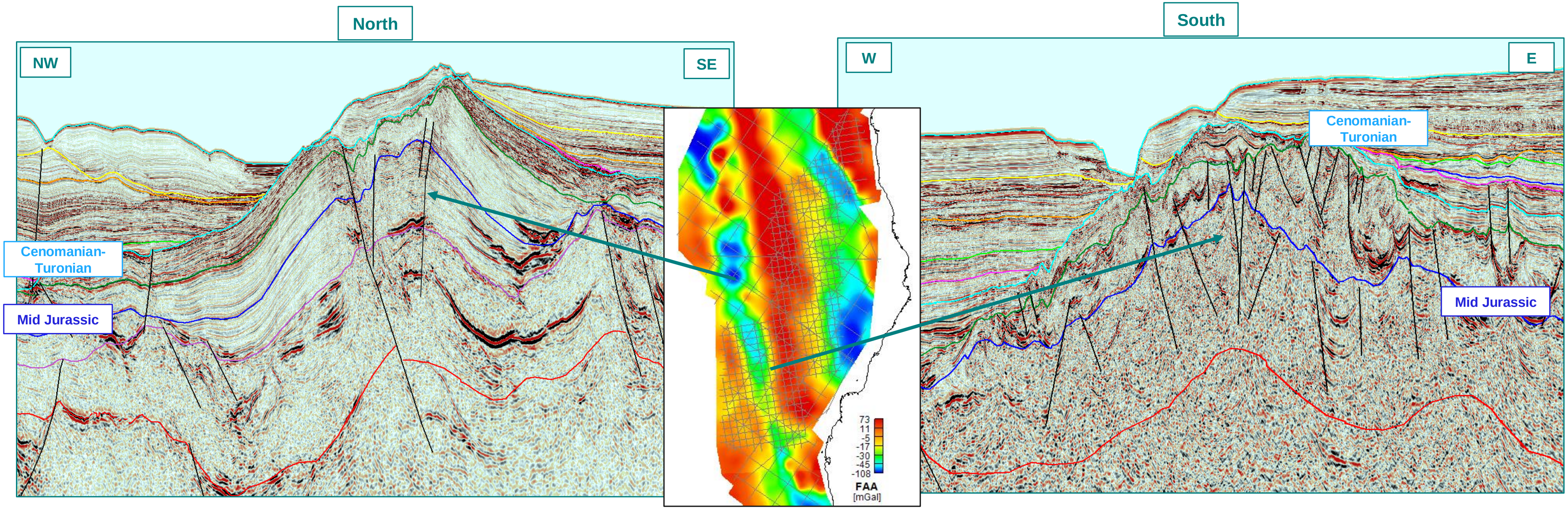
TGS

Morondava Basin



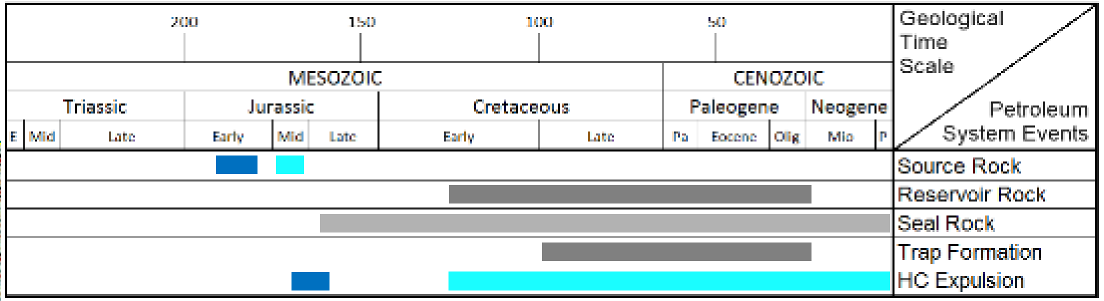
Tertiary deepwater fan systems are overlying the Lower to Upper Cretaceous "kitchen area" in the Morondava Basin. These fans systems are encased in deep marine shales and potential traps depend on lateral pinchouts and/or facies change.

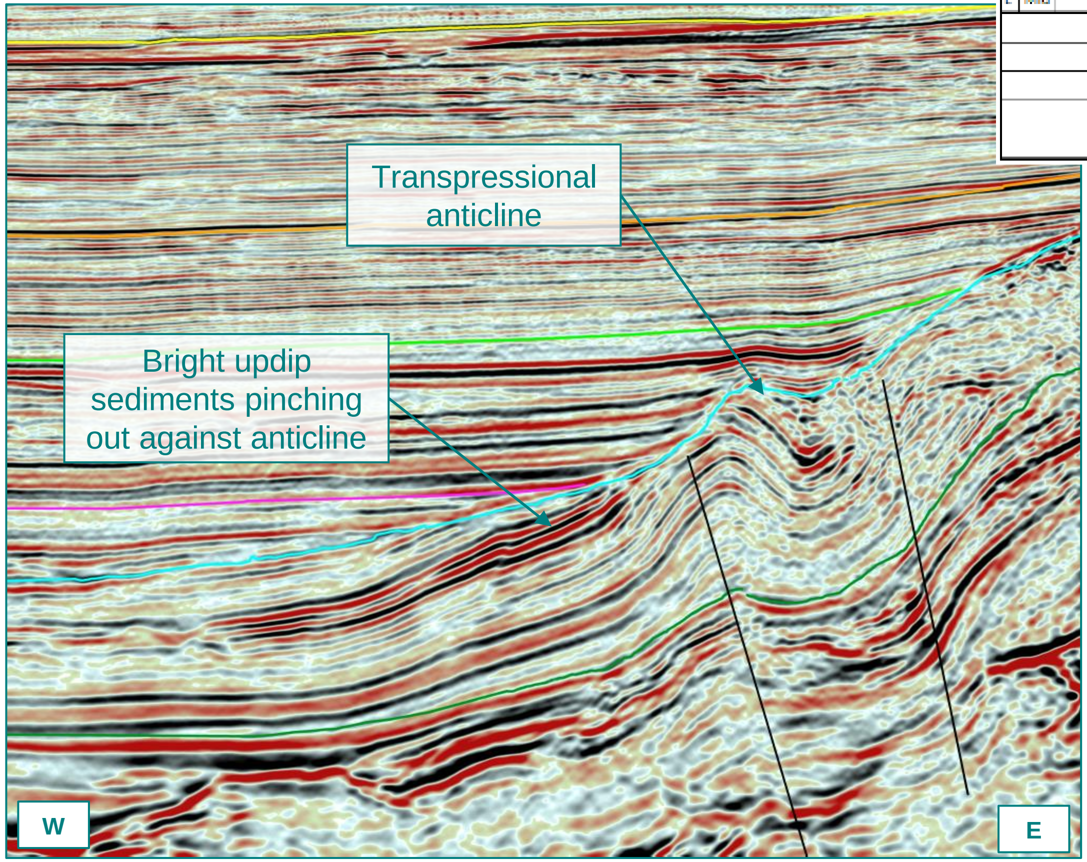
Davie Fracture Zone

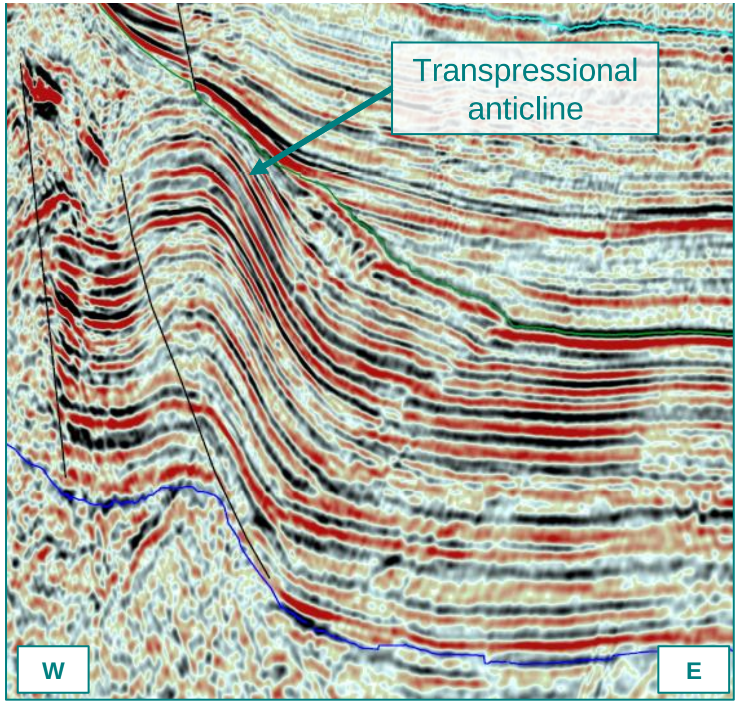


- DFZ is a highly variable complex structure
- Well imaged, inverted, thick sedimentary basin in the north
- Highly faulted and compressed sediments in the south
- It contains Cretaceous and Jurassic sediments and possibly even older rocks
- Interesting structures on flanks

Davie Fracture Zone



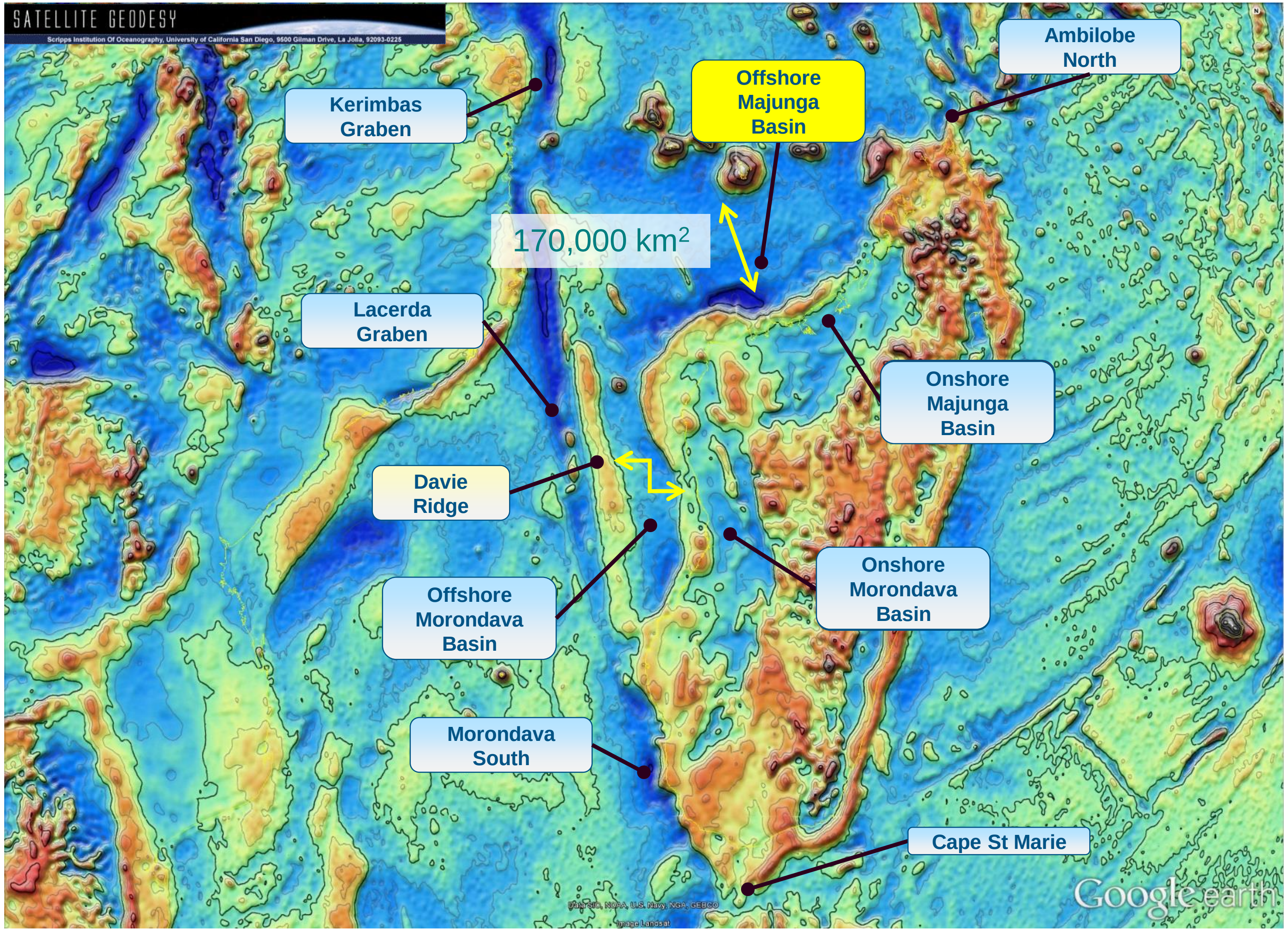




- Deepwater fan systems trapped in transpressional structures on the flanks of the DFZ
- Potentially charged by Jurassic syn-rift source rocks
- Source rocks have expelled hydrocarbons since the Aptian to Present-day
- Supported by oil samples from piston cores and satellite oils seeps


Majunga Basin

Majunga Basin



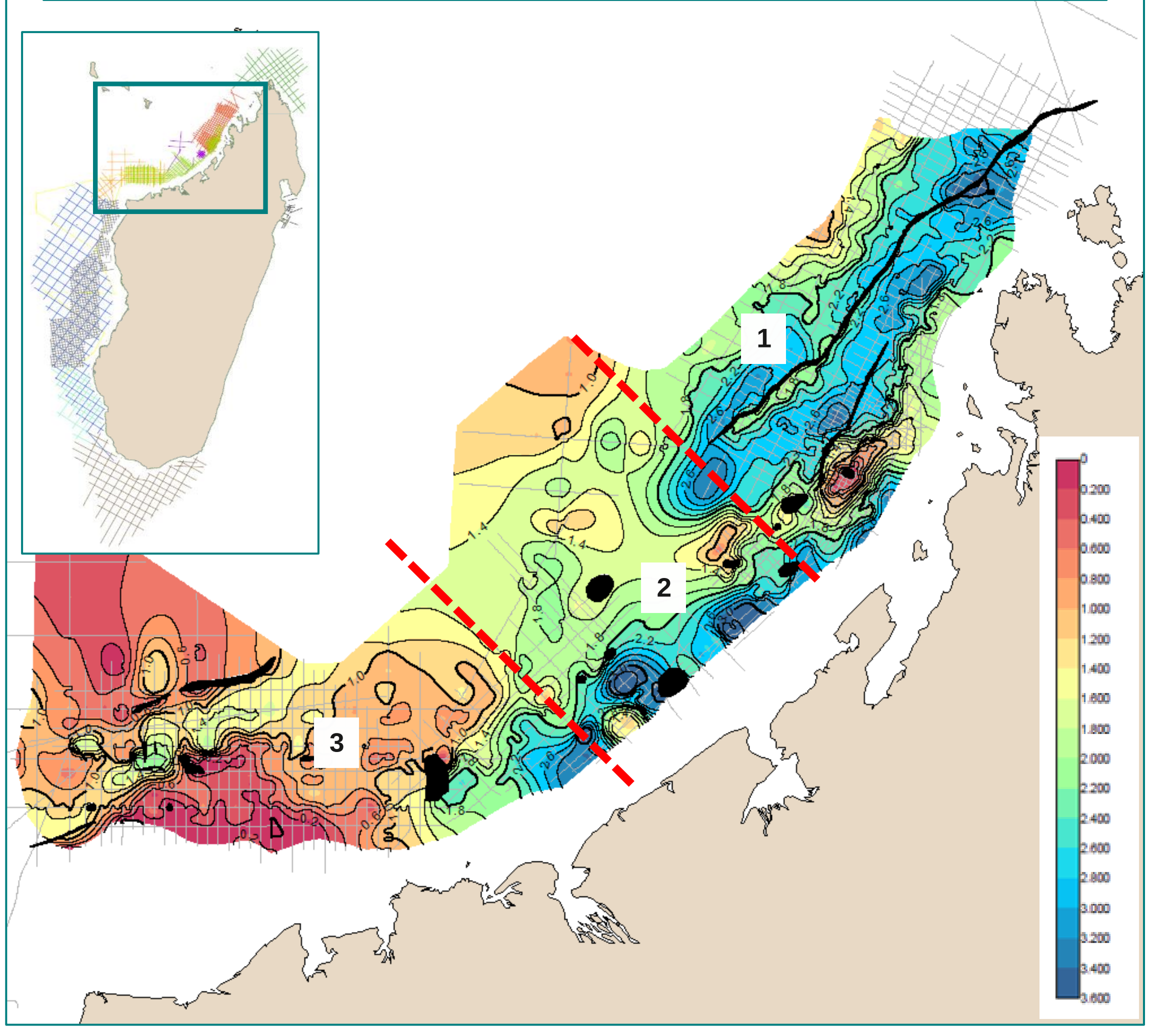
Majunga Basin

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

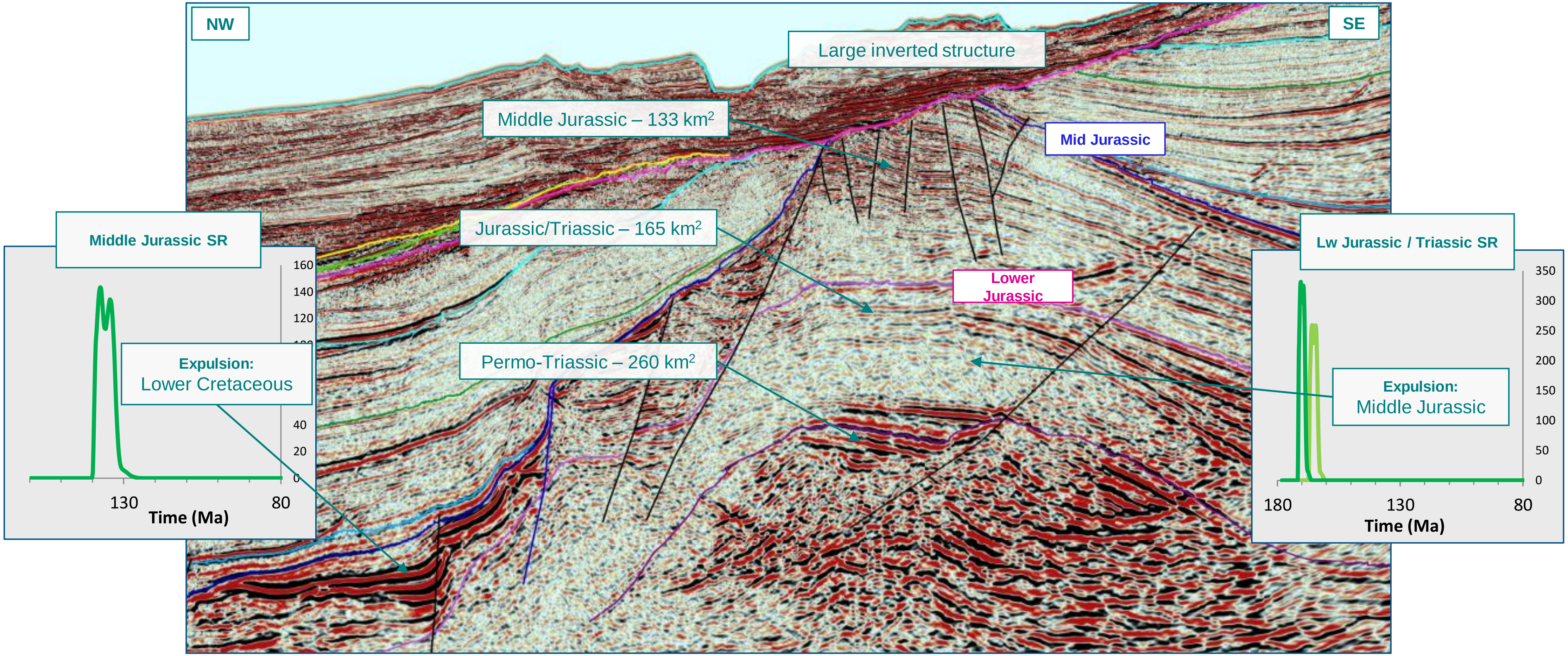
2. Jurassic salt basin. Characterized by allochthonous salt diapirs and canopies. Numerous toe-thrusts are present.

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 (top syn-rift) to Middle Jurassic

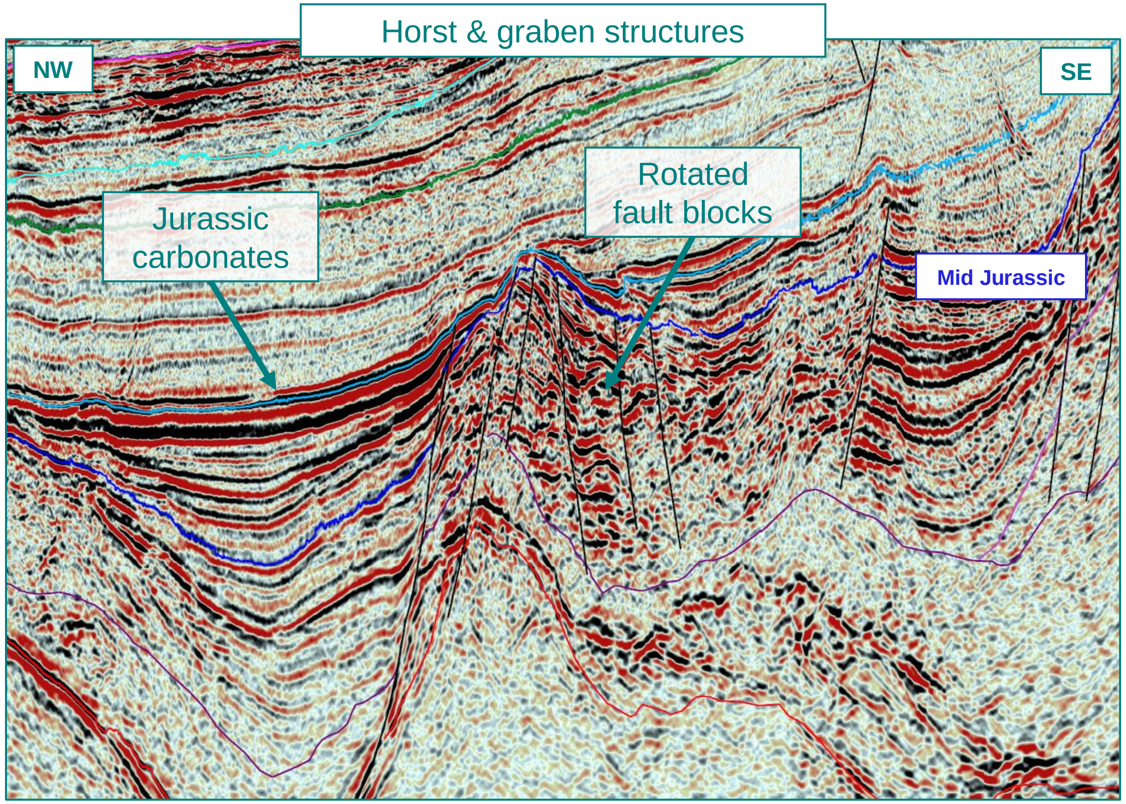


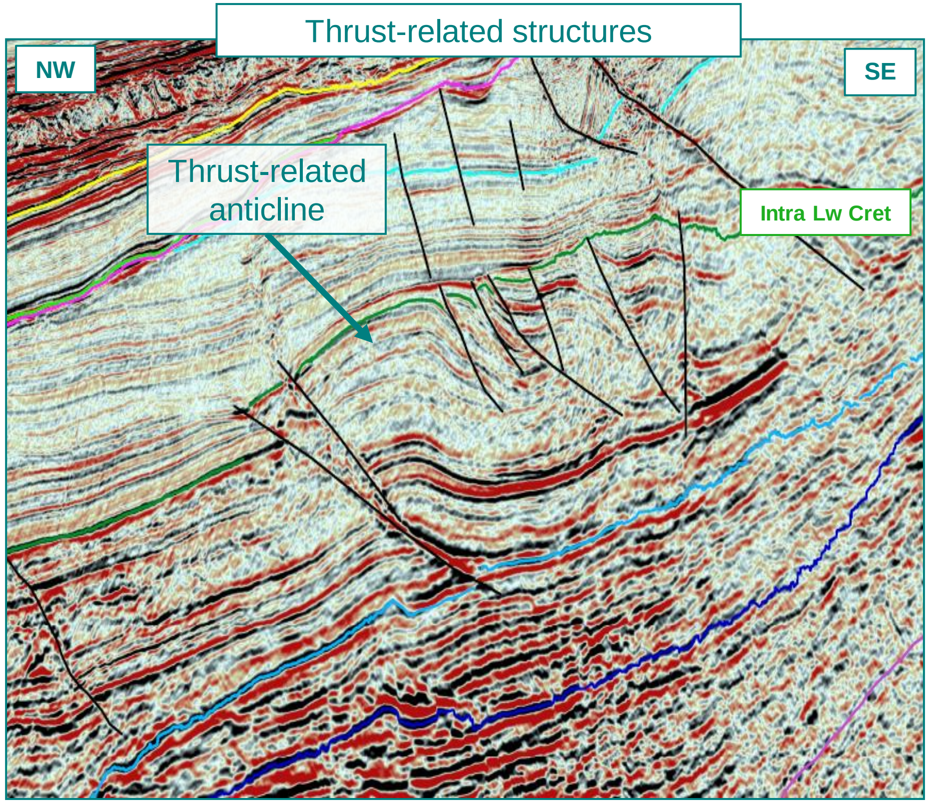
Majunga Basin



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.

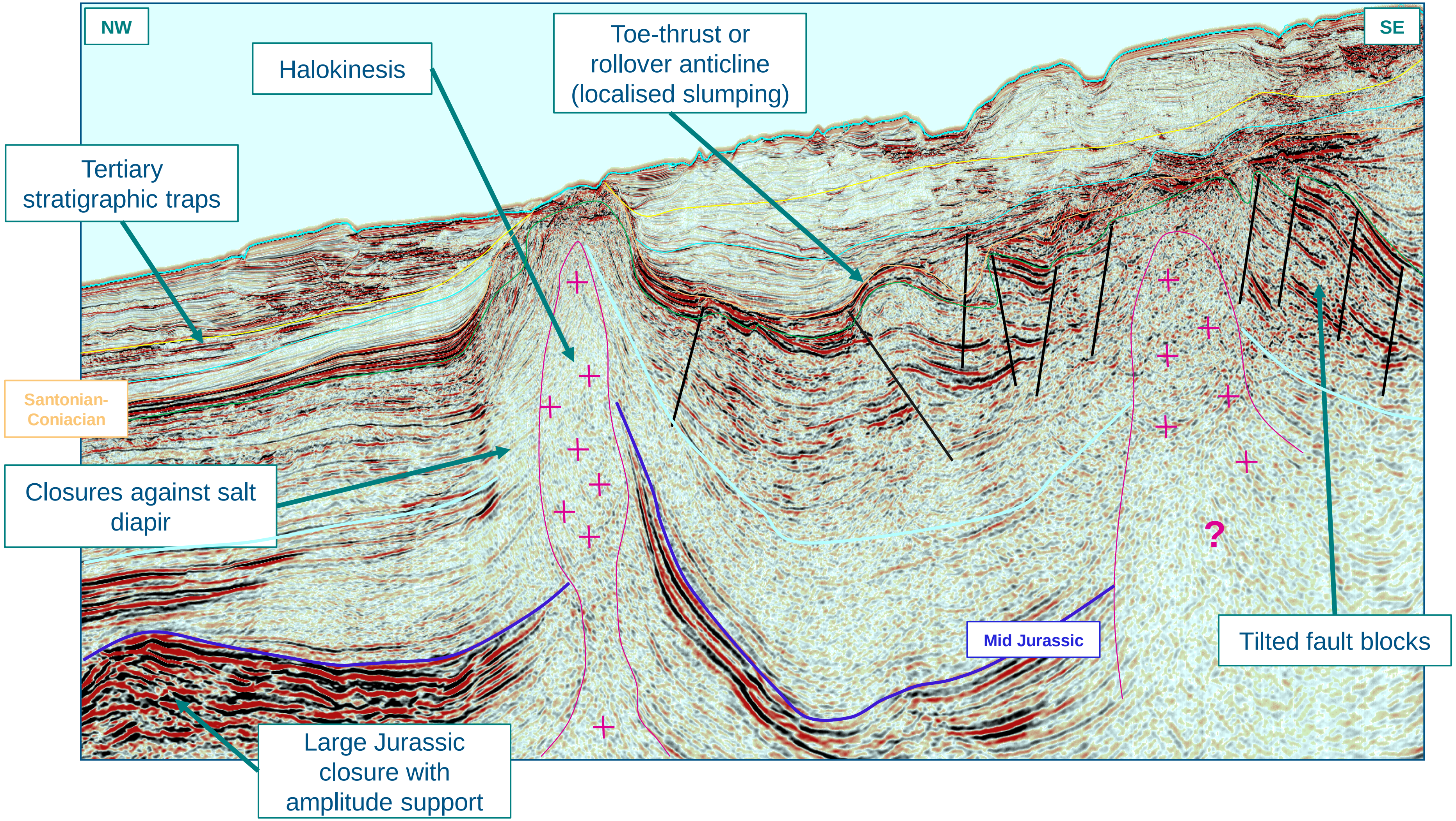
Majunga Basin

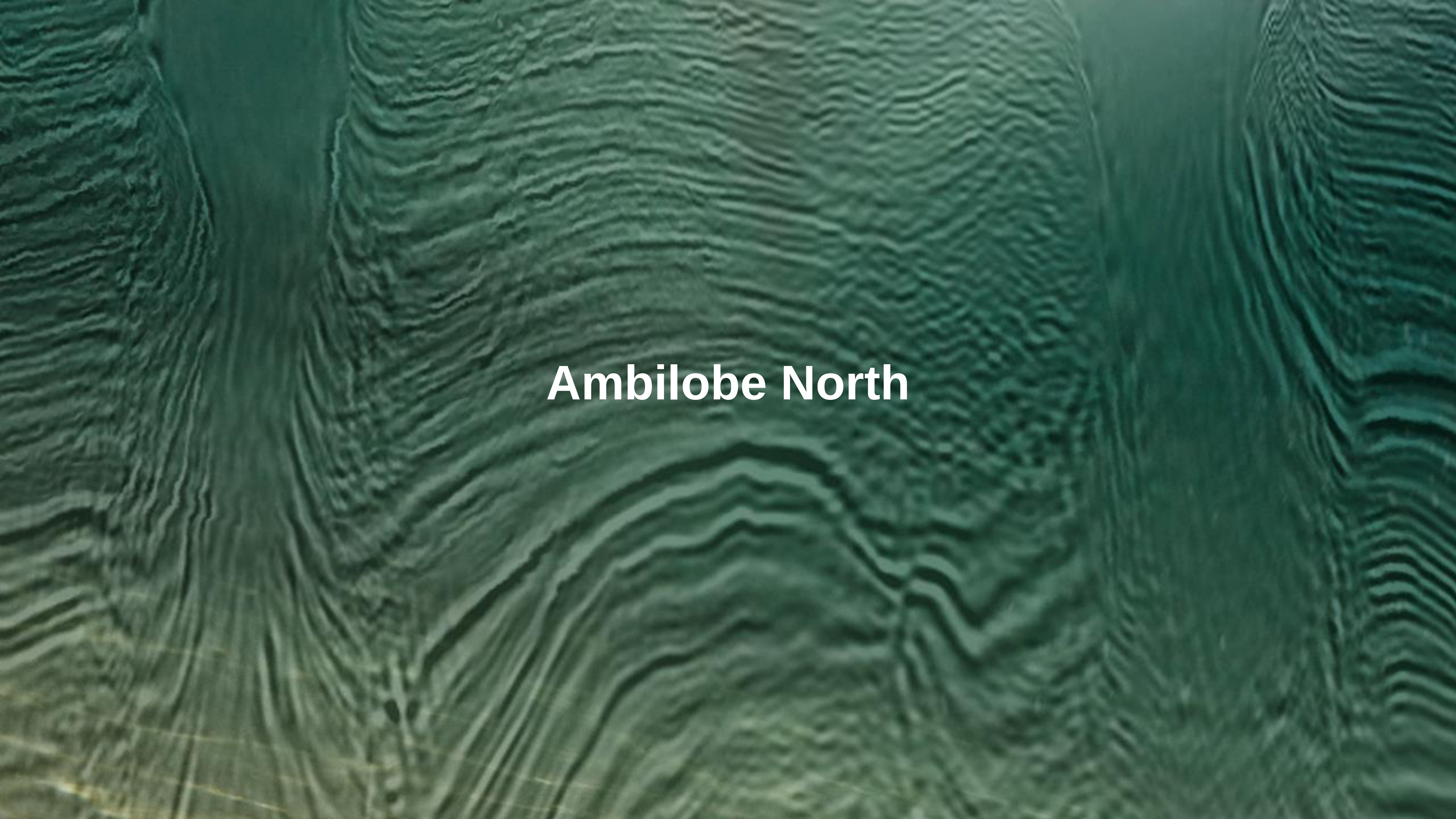




- Tilted fault blocks potentially containing Karoo and Jurassic syn-rift sandstones with possible overlying shallow marine carbonates
- Cretaceous deep-water fan systems in toe thrust/rollover anticlines
- Expulsion of Jurassic syn-rift source rocks in the Upper Jurassic and Lower Cretaceous

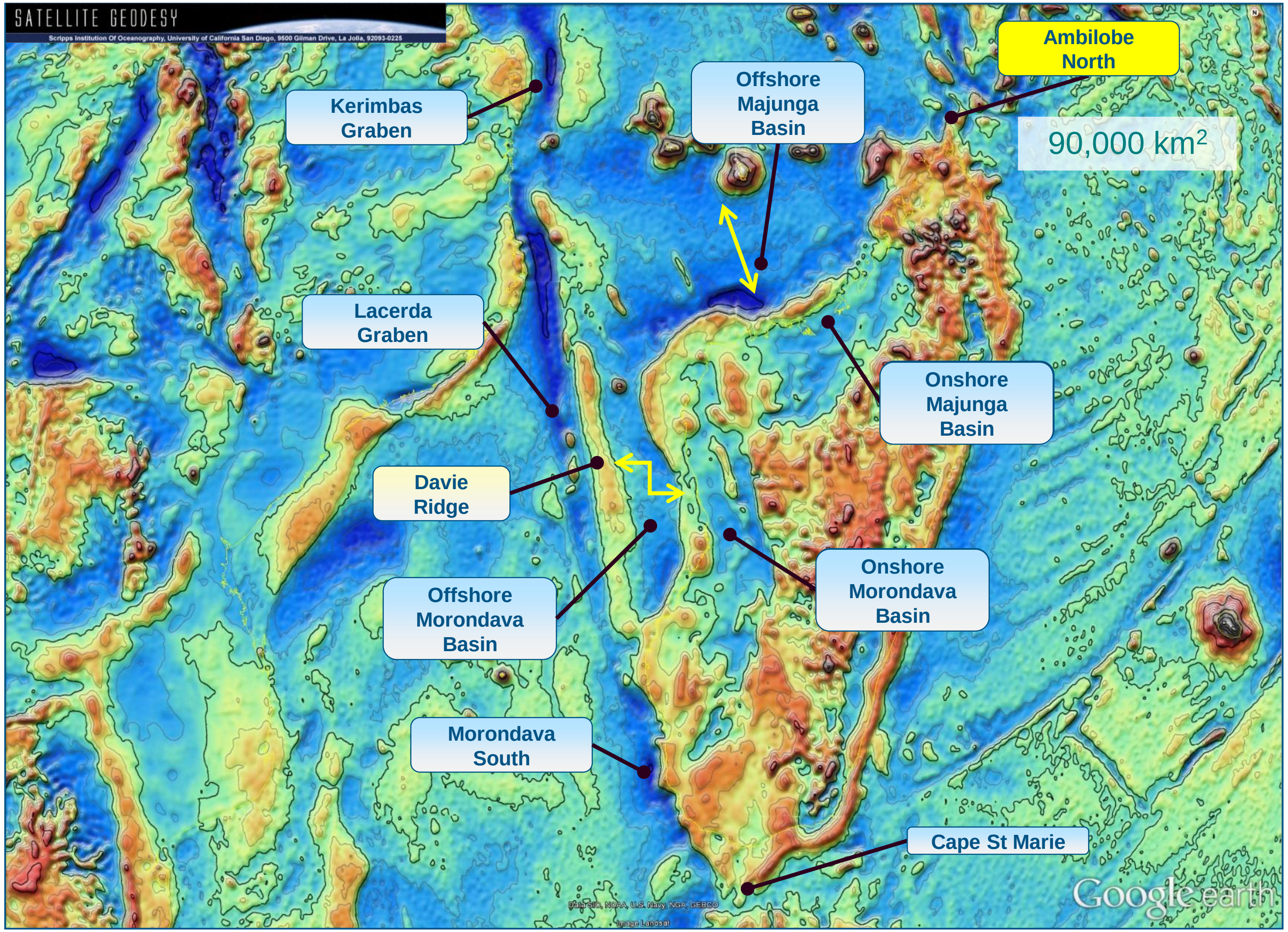
Majunga Basin





Ambilobe North

Ambilobe North

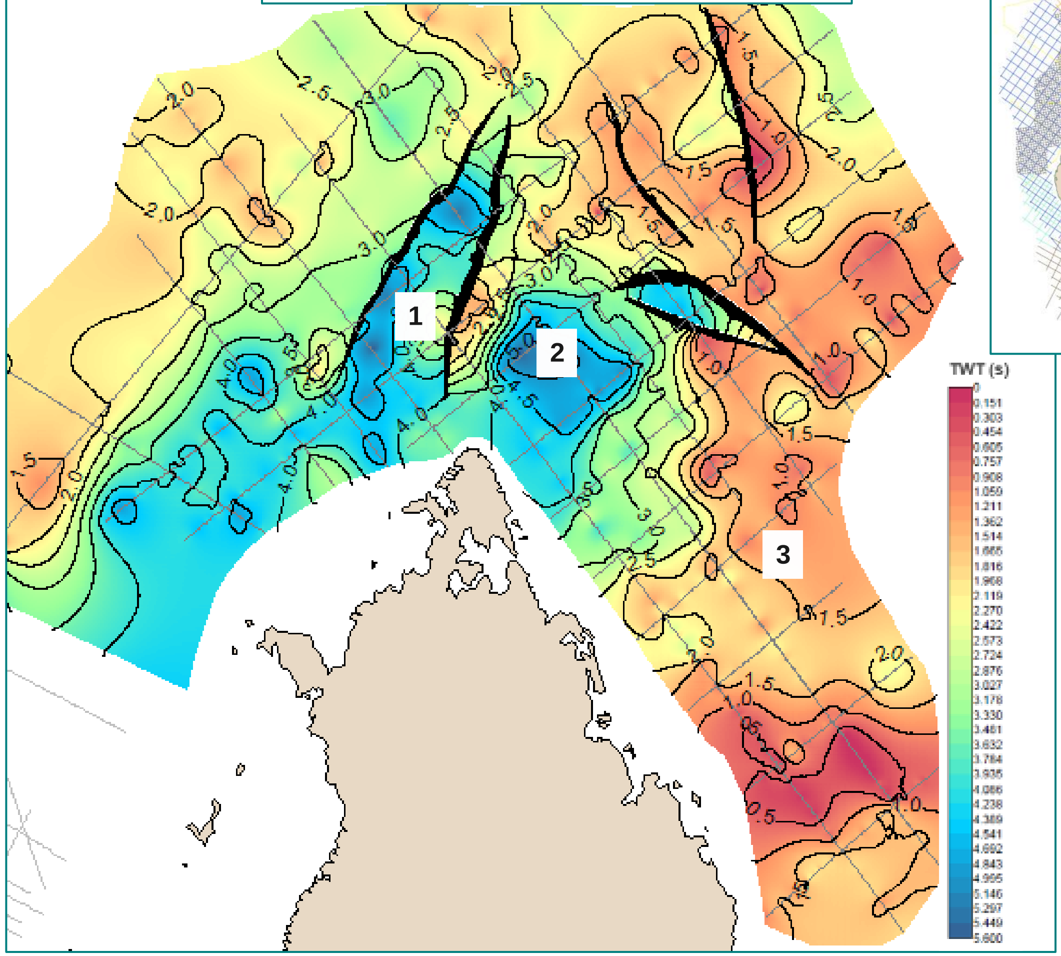


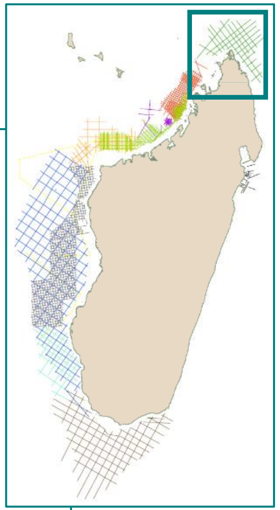
Ambilobe North

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 [s]: Seabed to Basement





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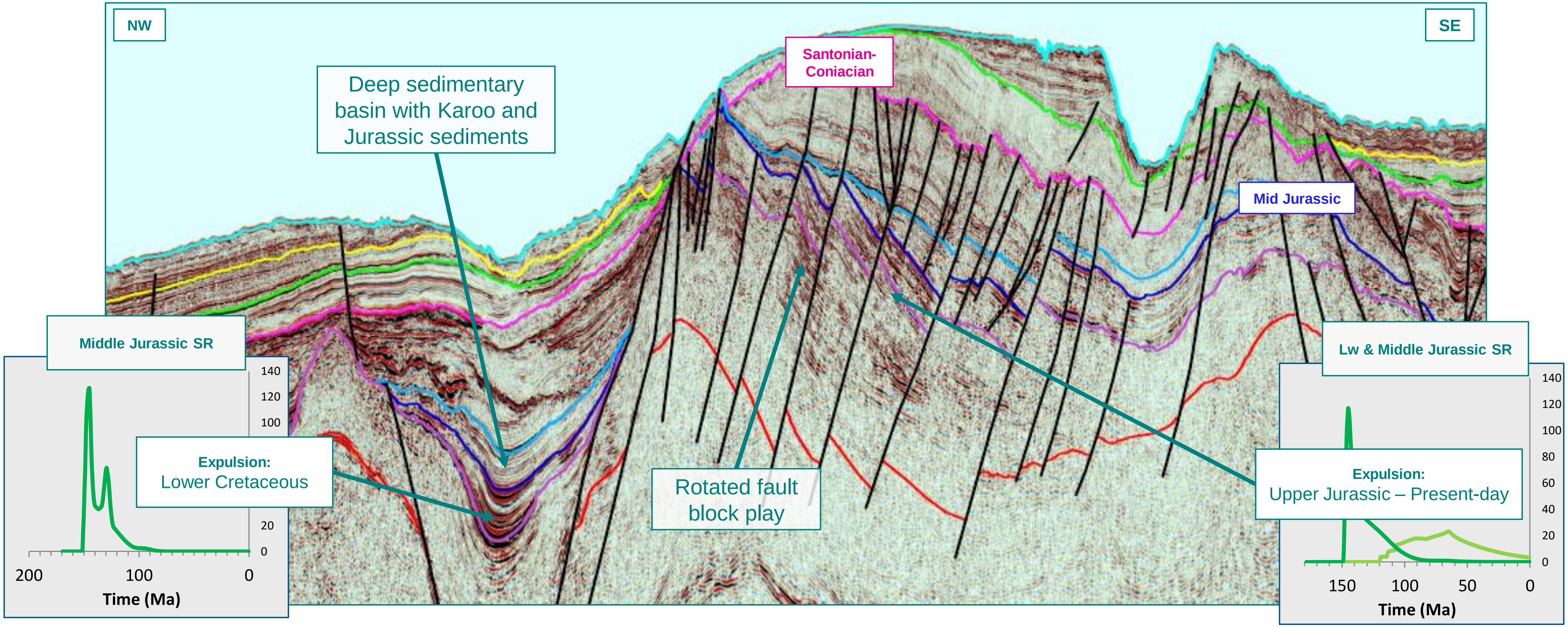
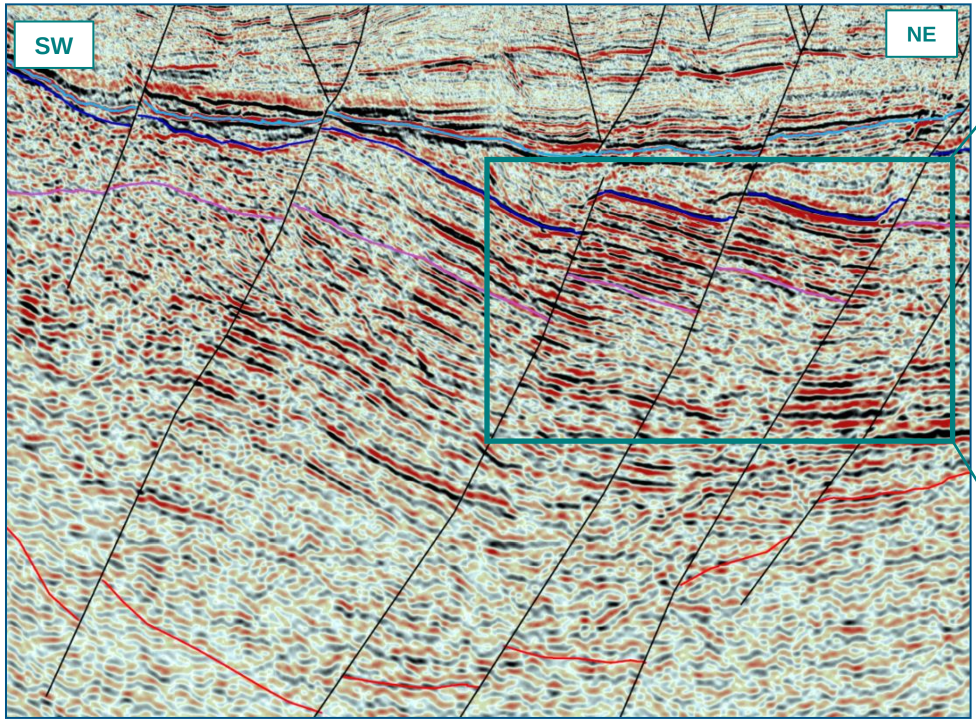
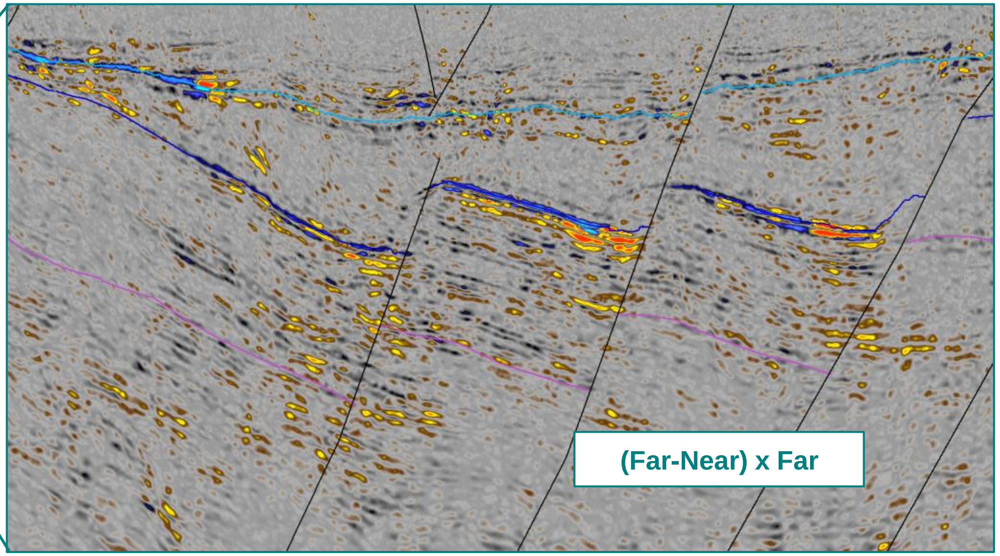


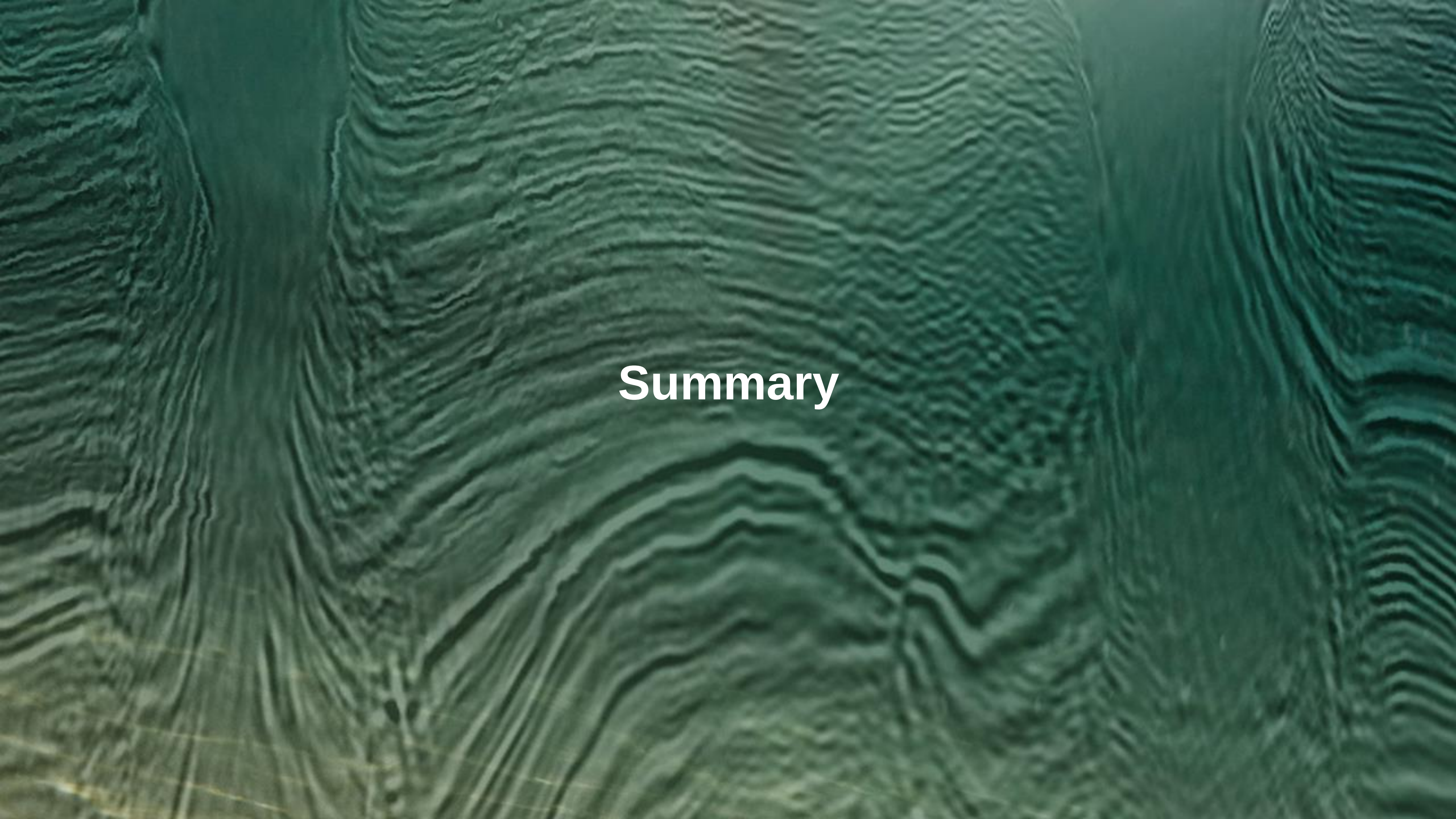
Deep sedimentary basin with potential for Karoo and Jurassic syn-rift source rocks. The rotated fault blocks form fault bounded traps and likely contain Karoo and Jurassic syn-rift sandstones with overlying Jurassic shallow marine carbonates.

Ambilobe North





- 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

Summary

- All the offshore basins are undrilled or sparsely drilled and their potential is untested
- Jurassic 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

Acknowledgements

TGS colleagues:

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Thank you

Nick Tranter

+44 (0) 208 339 4285

Nick.Tranter@tgs.com