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Davie Ridge: Cretaceous Incipient Subduction Zone in the Mozambique Channel

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Summary

The main objective of this study is to understand the origin of crustal features and geodynamic of the David Ridge and Angoche Basin in the Mozambique Channel as it is a crucial step in plate reconstruction as well as enabling an assessment of petroleum potential. This study is based on interpretation of 2D seismic and potential field data integrating with oil slick dataset.

The Davie Ridge is characterized by a zone of N-S trending Bouguer gravity low and high anomaly, and composed of more than one ridge on seismic data. The ridge comprises a compressed Jurassic and Cretaceous sedimentary unit interpreted to be an accretionary wedge, and some volcanic intrusion interpreted to be an incipient volcanic arc. Based on our findings, the Davie Ridge is an ocean-continent convergent plate boundary, representing an incipient subduction zone where the Angoche's oceanic crust converges with the Madagascar continental microplate from possibly Early Cretaceous to Turonian.

Numerous sea surface oil slicks and DHIs found within the study area point to a presence of source rock and new prospective oil province in the Angoche Basin and DSZ, along with play prospects within the subduction zone concept which remain to be proven in the study area.

Introduction

The Davie Ridge has been observed as a prominent morphological feature in the Mozambique Channel. It is characterized by a zone of N-S trending gravity low anomaly bounded to the east by gravity high anomaly striking across the continental margin of Mozambique and Madagascar. The ridge was discovered by Heirtzler and Burroughs (1971) who, upon noticing a bathymetric elevation in the Mozambique Channel, proposed that the Davie Ridge represents the expression of a transform fault resulting from the relative southward motion of Madagascar with respect to Africa. The entire feature was subsequently termed the Davie Fracture Zone by Scrutton (1978).

It has long been considered that Madagascar was first disconnected from the Kenya-Somalia part of the African continent during the Middle Late Jurassic, by dextral transform movement along the Davie Ridge (e.g. Coffin and Rabinowicz, 1987; Kusky et al., 2007), after the Gondwana breakup in the Late Liassic (Geiger et al., 2004) creating the West Somali Basin (WSB). Most of plate tectonic reconstructions have assumed an inactive transform fault of the Davie Ridge since 125 Ma based on the extinction of the spreading centre in the WSB (e.g. Coffin and Rabinowicz, 1987; Gaina et al., 2013; Reeves, 2014). The Davie Ridge was interpreted to represent either the western transform fault of the WSB (Coffin and Rabinowicz, 1987), continent-ocean transform margin (e.g. Gaina et al., 2013), or ocean-ocean transform margin (Phethean et al., 2016), in respect to the southward movement of the Madagascar-India continent in relation to Kenya-Somali.

The Davie Ridge is also commonly interpreted as a fracture zone accommodating the southward movement of Antarctica in relation to Africa following the break-up of the Gondwana super-continent (Senkans et al., 2019; Leinweber and Jokat, 2012; Mueller and Jokat, 2017). The break-up of the African and Antarctic continents resulted in the formation of the Angoche/Mozambique Basin in the central Mozambique passive margin in the Middle Jurassic (Senkans et al., 2019), and this is based on an identification of magnetic anomaly chron M38n indicating that the first oceanic crust formed in the Angoche Basin at 164 Ma (late Collovian) (Mueller and Jokat, 2017). The break-up also resulted in the fragmentation of the Gondwana super-continent Beira High, showing a remaining pre-rift sedimentary unit on seismic sections (Senkans et al., 2019).

Understanding the origin of crustal features and geodynamic of the David Ridge and Angoche Basin is a crucial step in plate reconstruction, as well as enabling an assessment of petroleum potential, including potential source rocks and geothermal gradient estimation and its implication on source rock maturity.

Data and mythology

This study was based on an integration of reprocessed 2D seismic data offshore Madagascar and recently acquired 2D seismic data covering offshore central Mozambique, south of the Rovuma Basin and in the Angoche Basin, across the Davie Ridge with potential field data and sea surface oil slicks identified from satellite imagery. The objectives of this study included:

- To understand geodynamic and crustal feature of the Davie Ridge
- To identify crustal features and basin architectures of the Angoche Basin
- To assess potential hydrocarbon source rock maturity and prospective plays

Result and key observation

A) Incipient Davie Subduction Zone (DSZ)

The Davie Ridge appears to be a neotectonic feature with seamount morphology, but it in fact is an old structure. The ridge is composed of more than one ridge making ‘the Davie Zone’ a better term, based on its display on Bouguer gravity anomaly and seismic data. This zone comprises compressed sedimentary ridges and troughs, and is made up of thick sedimentary layers, younger well stratified and older compressed sediments (Figure 1). A compressed sedimentary unit was also observed by Klimke et al. (2018) along the minimum gravity of the Davie Zone, and we have interpreted this to be a shortening of continental crust representing an accretionary wedge of a subduction zone, which stratigraphically continues in to the offshore Morondava Basin of Madagascar (Figures 1). We believe that these structural features were created during an incipient stage of the Davie Subduction Zone (DSZ), where the thinner and more dense Angoche's oceanic crust of the African plate was overridden by the thicker and less dense continental crust of the Madagascar microplate (Figure 1). The accretionary wedge is composed of the Jurassic and Cretaceous sediments, with potential Permo-Triassic Karoo sediments in the deep section.

The edge of shortening tectonics of the DSZ can be correlated to the Turonian Unconformity marker in the offshore Morondava Basin in Madagascar, and it represents the last tectonic event of the DSZ. The top part of the compressed sedimentary unit has a very robust erosional surface which has been explored on land, and some part of this unit was eroded off for some time before the deposition of the younger Turonian sedimentary unit above the Turonian Unconformity. We also observe some volcanic intrusion as part of the ridge morphology along the subduction zone, and it is interpreted to be an incipient volcanic arc of the DSZ. This coincides with a Turonian tholeiitic volcanism suggesting mid oceanic ridge basalt origin in the onshore Morondava Basin (Bardintzeff et al., 2010).

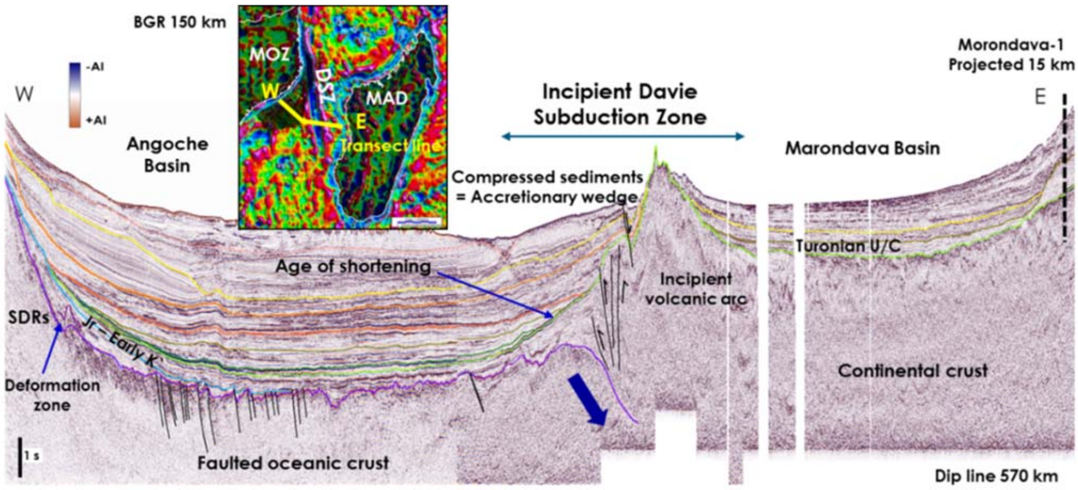

Figure 1 *2D seismic transect from the Angoche to Morondava Basins across the incipient DSZ demonstrating structural contexts within the DSZ. Courtesy of INP, Spectrum and WesternGeco.*

B) Crustal features and basin architectures of the Angoche Basin

The Angoche basin shows a continental magma-rich passive margin style with deformation of Seaward Dipping Reflectors (SDRs) identified between the inboard continental crust and outboard oceanic crust (Figure 2). The margin shows a narrow area of SDRs compared to other volcanic rifted margins, for instance the South Atlantic margin of Namibia and South Africa. We identify two types of oceanic crust within the Angoche Basin; Type 1: disrupted to discontinuous and strong amplitude seismic reflectors, representing semi-stratified volcanic layers, and faulted Type 2: homogenous and low amplitude seismic reflectors, and mostly un-faulted (Figure 2). These types of oceanic crust are recognised along the passive margin of the Angoche Basin until they meet the DSZ where we observe a shortening of continental crust with thick sedimentary overburden (Figure 2).

Two trends of small-scale intensely deformed structures are identified within the SDRs zone in the centre and north of the Angoche margin, and these trends are almost parallel to the Mozambique coast line (Figure 2). Based on our observation, the intensely deformed structures are associated with reverse faults or reactivated normal fault, and also accompanied by a deformed early post-rift sedimentary unit especially in the centre of the Angoche Basin. These intensely deformed structures are probably the result of a combination of a compressional force from the DSZ and movement of evaporitic or under-compacted shale layer underneath the early post-rift sedimentary unit.

The Angoche Basin is a narrow elongate basin as seen on the post-rift sedimentary TWT (s) thickness map (Figure 2). The basin depocentre is situated along the basin axis, with an indication of thick post-rift sedimentary overburden of up to 5.5 TWT (s) in the south of the 2D dataset towards the Zambesi Delta. The basin depocentre becomes narrower towards the DSZ (Figure 2).

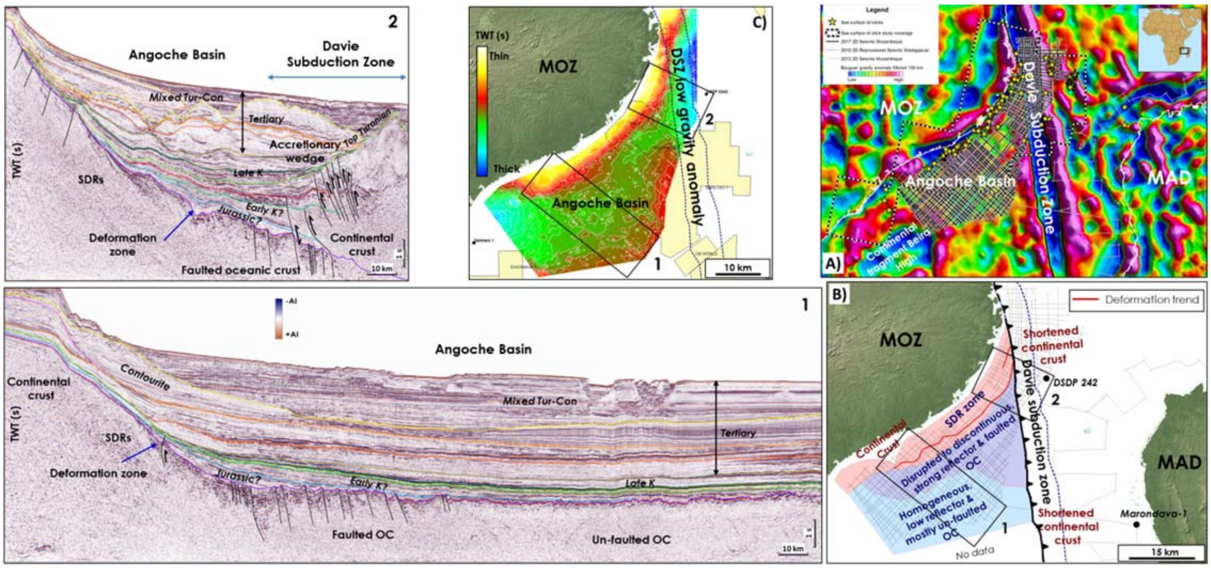

Figure 2 *Regional 2D seismic sections representing the Angoche Basin (1) and DSZ (2). Line location is within the black polygon in the inset figures B) and C). A) Study area and dataset used in this study B) Mapping of crustal features identified within the study area C) Sedimentary overburden thickness in TWT (s) above the acoustic basement of the Angoche Basin. OC= Oceanic crust, MOZ = Mozambique and MAD = Madagascar. Courtesy of INP, Spectrum and WesternGeco.*

C) Potential source rocks and play prospects

Several high confidence naturally occurring sea surface oil slicks have been identified from optical satellite imagery along the shelf break of the Angoche Basin and within the DSZ, some comprising clusters re-occurring over time (Figure 2). These oil slicks provide direct indication of source rock presence. Potential source rocks within the continental crust of the DSZ could be Permo-Triassic (Karoo) lacustrine shales, Jurassic and possibly Early Cretaceous marine shales. While in the Angoche Basin the Jurassic and Early Cretaceous marine shales are major potential.

Other direct hydrocarbon indicators (DHIs) have been identified within the modern 2D seismic data such as Bottom Simulating Reflectors (BSRs), pock marks, fluid escape features and shallow high amplitude reflectors. Estimation of the geothermal gradient from BSRs thickness found within the oceanic crust, west of the DSZ, indicates 18º C/km geothermal gradients. This would enable oil maturity window for the deeply buried post-rift Late Jurassic to early Cretaceous source rocks of the Angoche Basin.

We identify play prospects associated to the DSZ in the Angoche Basin, such as anticlinal structural closure of up to 500 km^2 and stratigraphic pinch out onto the accretionary wedge of the DSZ.

Conclusion

The Davie Ridge is an ocean-continent convergent plate boundary in the Mozambique Channel, representing an incipient subduction zone where the Angoche's oceanic crust converges with the continental crust of the Madagascar microplate from possibly Early Cretaceous to Turonian.

Numerous sea surface oil slicks and DHIs found within the study area point to a presence of source rock and new prospective oil province in the Angoche Basin and DSZ, along with encouraging play prospects within the subduction zone concept which remain to be proven in the study area.

References

Bardintzeff, J-M., Liégeois, J-P, Bonin, B, Bellon, H. and Rasamimanana, G. [2019] Madagascar volcanic provinces linked to the Gondwana break-up: Geochemical and isotopic evidences for contrasting mantle source. *Gondwana Research*, **18**, 295-314.

Coffin, M.F. and Rabinowicz, P.D. [1987] Reconstruction of Madagascar and Africa: evidence from the Davie fracture zone and western Somali basin. *Journal of Geophysical Research,* **92** (B), 9385-9406.

Gaina, C., Torsvik, T.H., van Hinsbergen, D.J.J., Medvedev, S., Werner, S.C. and Labails, C. [2013] The African Plate: A history of oceanic crust accretion and subduction since the Jurassic. *Tectonophysics*, **604**, 4-25.

Geiger, M, Clark, D.N. and Mette, W. [2004] Reappraisal of the timing of the breakup of Gondwana based on sedimentological and seismic evidence from the Morondava Basin, Madagascar. *Journal of Afircan Earth Sciences*, **38** (4), 363-381.

Heirtzler, J.R. and Burroughs, R.H. [1971] Madagascar's Paleoposition: New Data from the Mozambique Channel. *Science,* **174**, 488-490.

Klimke, J., and Franke, D., Mahanjane, E. S. and Leitchenkov, G. [2018] Tie points for Gondwana reconstructions from a structural interpretation of the Mozambique Basin, East Africa and the Riiser-Larsen Sea, Antarctica. *Solid Earth*, **9** (1), 25-37.

Kusky, T.M, Toraman, E. and Raharimahefa, T. [2007] The Great Rift Valley of Madagascar: an extension of the Africa - Somali diffuse plate boundary?. *Gondwana Research*, **11**, 577-579.

Leinweber, V.T. and Jokat, W [2012] The Jurassic history of the Africa-Antarctica corridor - New constraints from magnetic data on the conjugate continental margins, *Tectonophysics*, **530-531**, 87-101.

Mueller, C.O. and Jokat, W [2017] Geophysical evidence for the crustal variation and distribution of magmatism along the central coast of Mozambique. *Tectonophysics*, **712-713**, 684-703.

Phethean, J.J.J., Kalnins, L. M., van Hunen, J., Biffi, P.G., Davies, R. J., McCaffrey, K.J.W. [2016] Madagascar's escape from Africa: A high resolution plate reconstruction for the Western Somali Basin and implications for supercontinent dispersal. *Geochemistry, Geophysics, Geosystems*, **17** (12): 5036-5055.

Rabinowitz, P.D. [1971] Gravity anomalies across the East African Continental Margin. *Journal of Geophysical Research,* **76**, 7107-7117.

Reeves, C. [2014] The position of Madagascar within Gondwana and its movements during Gondwana dispersal. *Journal of African Earth Science,* **94**, 45-57.

Scrutton, R.A. [1978] Davie fracture zone and the movement of Madagascar. *Earth and Planetary Science Letters,* **39**, 84-88.

Senkansa, A., Leroya, S., d'Acremonta, E., Castillab, R., and Despinoisb, F. [2019] Polyphase rifting and break-up of the central Mozambique margin. *Marine and Petroleum Geology*, **100**, 412-433.