Hunting for Africa's new transform play trends

Karyna Rodriguez[1*] and Neil Hodgson[1] demonstrate how the Brulpadda-1 discovery in the Southern Outeniqua Basin, offshore South Africa, will lead to exploration for similar passive margines with obliquely cutting fault-ridge systems on the fragmented Gondwanna margins.

Introduction

The abyssal plains of Africa's passive margins have been inaccessible to drilling until recently, and traps for true basin floor fans little explored. Turbidite flows reaching the basin floor through confined slope channels can begin to lose energy and deposit coarser clastic components, although if the basin floor continues to gently slope down in an offshore or lateral direction then turbidite flows can continue for long distances. However, younger, hotter and more buoyant oceanic crust generally lies offshore from older, colder oceanic crust riding deeper on the mantle. This creates an up-dip-to-offshore (UDTO) geometry to the basin floor. UDTO basins, can therefore present opportunities for basin floor turbidite flows to onlap and form stratigraphic trapping geometries towards the offshore on oceanic crust. Yet such plays are often in water deeper than 3 km (i.e. the Early Cretaceous basin floor play under the Raya-1 well offshore Uruguay), unless the crust is supported by mantle convection (Yakaar-1 offshore Senegal).

However, another UDTO trapping geometry is created when transform faults cut obliquely across passive margins. An example of this is the Agulhas-Falklands Ridge running perpendicular to the South African coast. This is the strike-slip or transform fault that allowed the Malvinas/Falklands Plateau to separate from Africa during the break-up of Gondwana. Here, the north side of the ridge comprises the wrenched Jurassic syn-rift graben that separated, accommodating the opening of the Atlantic, while the south side of the ridge is formed from oceanic crust that formed at a spreading centre to the NE.

This transform fault zone has provided a positive basin floor ridge since the Jurassic period against which turbidites supplied from the north have been directly onlapping, creating huge, laterally continuous stratigraphic traps (Figure 1). Located at the basin floor, yet still on continental crust, these plays can be accessed in 1-2 km of water providing a new class of drilling target.

The oblique transform ridge ponded stratigraphic play

Sediment supply down slope from the exposed and eroding sand factory provided by mature quartzite sandstones of South Africa's Cape fold belt occurred throughout the Cretaceous period in turbidite systems, running downslope in constrained channels controlled by the underlying NW-SE oriented pull-apart sub-basins of South Africa's southern syn-rift. These sub-basins are arranged en-echelon from the easternmost and oldest Southern Gamtoos sub-basin to the westernmost and youngest Bredasdorp sub-basin (Figure 2) and represent the long-lived effect of movement along the transform fault. Most of the exploration activity on the shelf

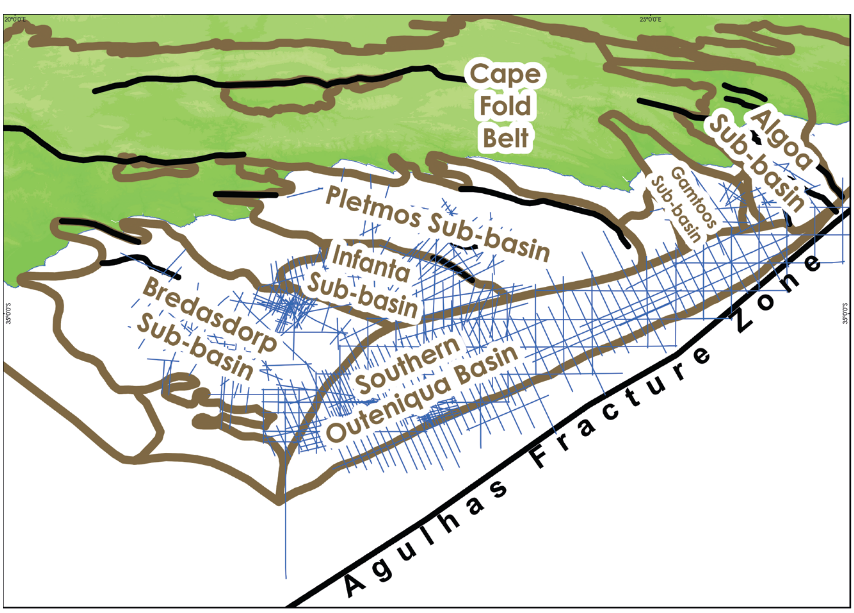

Figure 1 200 km-long NW-SE sea water compensated composite 2D seismic section close to the Brulpadda discovery. Reprocessed 2016 PSTM 2D seismic section in the southern Outeniqua Basin. Far-Near-Far angle stack displays highlight, amplitude anomalies brightening in the far angle stack (equivalent to AVO Type III) analogous to the Brulpadda discovery. Note the ponding of Cretaceous to Tertiary deposits against the prominent marginal ridge to the right of the section.

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and upper slope has focused here dating back to the 1960s and delivered key oil and gas exploration discoveries.

Yet down dip of the pull-apart basins lies the Agulhas-Falkland ridge at the southern end of the Southern Outeniqua Basin. This is observed on bathymetry as a continuous high ridge running NE-SW across the basin, comprised of structurally complex, inverted and deformed syn- and pre-rift blocks, that are represented as a positive gravity anomaly. This ridge is the manifestation of the Agulhas Falklands Fracture Zone (AFFZ) (Figure 3).

Previous exploration efforts in the southern Outeniqua Basin were complicated by extremely strong NE-SW ocean currents from the Agulhas Current. This has presented huge challenges to seismic acquisition and drilling such that the first well attempting to drill Brulpadda had to be abandoned. Using the lessons learnt from the first well and based just on strong geophysical indications on available 2D seismic data (no 3D seismic data had been acquired), Total drilled and successfully completed the second Brulpadda well in 2019 as a gas and condensate discovery stating that '…the well encountered 57 m gas and condensate net pay in the Lower Cretaceous reservoirs from two sand intervals'. The well was drilled in approximately 1400 m of water in the Southern Outeniqua Basin with a TD of 3633 m. It is estimated to contain significant resources of at least 1 TCF of gas equivalent.

The main Brulpadda reservoir interval is interpreted as a coarse clastic basin floor turbidite fan of Aptian-Albian age. This fan pinches out up-dip (UDTO) towards the NE-SW trending structurally high Agulhas Fracture Zone deformation. On Figure 1 the Early Cretaceous sequences are thinner towards the North West (toward the shelf), thicker in the basin centre (the 'gutter') and then thin and pinch out to the SE against the Agulhas-Falklands Ridge. The Late Cretaceous above this is dominated by a huge contourite drift, suggesting an initiation of the main Agulhas contourite current at the end of the Early Cretaceous period. Prior to this contourite currents could have been affecting turbidite deposition. As has been reported in Rovuma and elsewhere, the coarse clastic deposits of such mixed systems are often very high quartz content, as fine sediments are winnowed by the orthogonal contourite currents and redeposited as drifts elsewhere.

The transform ridge ponded clastic play is characterized by an extremely well-defined high amplitude soft kick anomaly with a distinctive flat spot and AVA response clearly recognized and mapped on several strike lines on Spectrum's extensive Outeniqua basin reprocessed 2D data (Figure 1). The Brulpadda discovery is mappable – arguably as a number of risk-segments, over a very large area suggesting that this is a very important discovery for the future energy resource supply of South Africa, and a new and important play for deepwater exploration globally.

Several high amplitude reflectors with similar AVA response in similar intervals to the Brulpadda reservoir have also been identified on the Spectrum 2D dataset to the north west, at the ends of the en-echelon syn-rift pull-apart grabens. However, the basin floor fan play is generally restricted in a narrow and elongated Cretaceous 'gutter' bounded to the south by the NW-SE trending AFFZ (Figure 1). Anywhere in this Cretaceous gutter that turbidite sandstones have poured will express the same UDTO trapping geometry, and indeed these can be traced

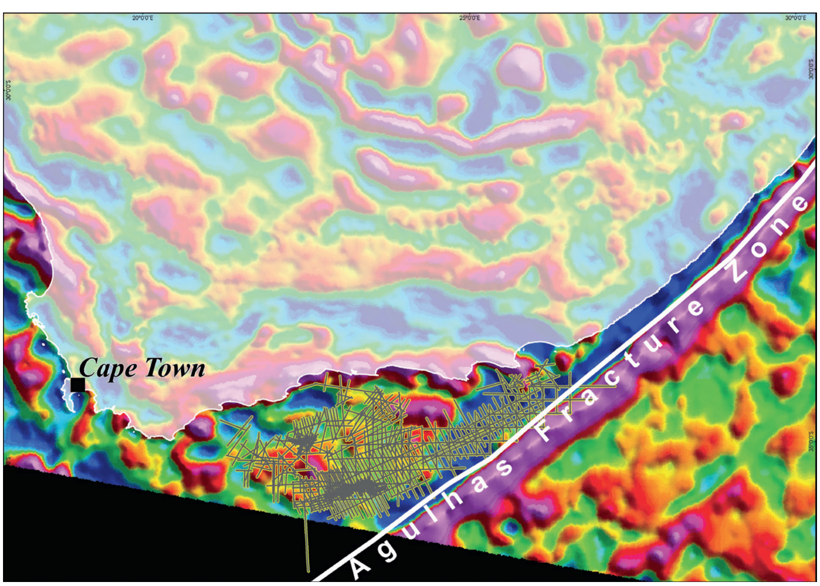

Figure 2 Southern Outeniqua and pull apart sub-basins offshore East South Africa and available 2016-2018 reprocessed seismic dataset.

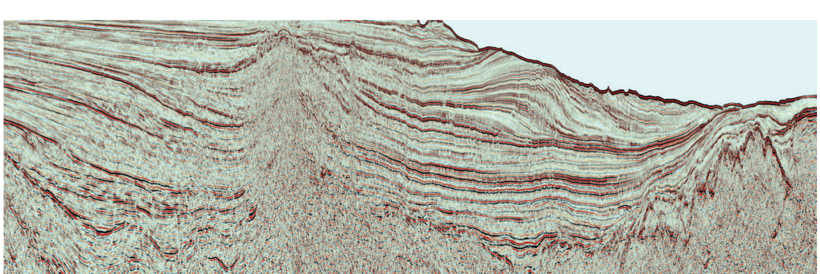

Figure 3 Gravity anomaly map showing the AFFZ associated with a positive gravity anomaly. The marginal ridge is strongly related with this lineament. The ridge is present all along this trend, but from the available 2D seismic dataset its character can be observed to vary. These variations are important when mapping the extent of the play fairway.

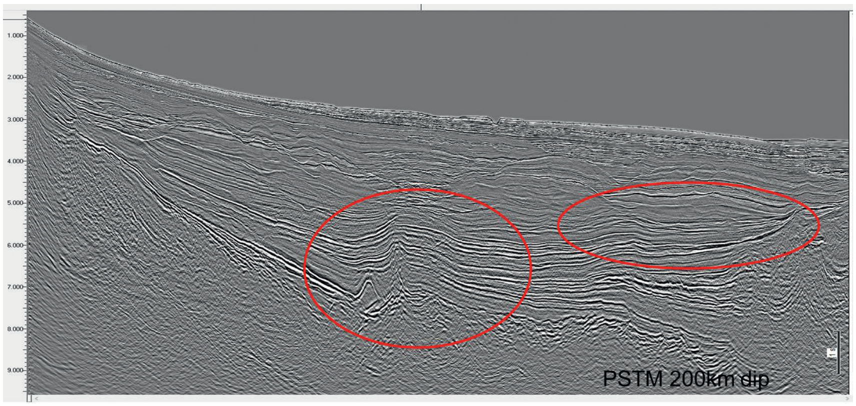

Figure 4 2017 PSTM 2D seismic section offshore Mozambique. The red polygons outline large trap with soft kick amplitude anomalies. To the left is a large four-way dip closed structural trap with turbidites draped over it. To the right of the section a very extensive UDTO trapping geometry can be mapped against the accretionary wedge of the Davie Ridge.

along the East Coast margin from the Southern Outeniqua Basin to the Tugela Cone. Charge from the underlying syn-rift, or in places the Early Cretaceous, may be more oil prone where it is less deeply buried by overburden.

The Agulhas-Falklands Fracture Zone extends north east from South Outeniqua into the Durban Basin. Detailed seismic interpretation and gravity modelling studies carried out in collaboration with Leeds University indicate the presence of continental crust linked to a prominent marginal ridge. This ridge again provides a deposition barrier to turbidite flows pouring off the shelf into the Durban Basin. Confined channel systems on the slope are mapped leading into basin floor fans, which eventually dip upwards to offshore (UDTO). As we discussed in South Outeniqua, in the Durban basin sedimentation is mixed turbidite and contourite. Above many of the UDTO fan pinchouts that have been mapped, large Cretaceous contourite drifts comprising mostly mudstones and some siltstones have been interpreted. These provide excellent top-seals to the underling coarse clastic fan plays which also display AVO Type III soft kick amplitude anomalies in a very similar setting to the Brulpadda discovery on Spectrum's 2D seismic data.

Far from providing a single opportunity for a new and hitherto unique exploration play, we are now finding more examples of the play style both on Africa margins and its conjugates.

Chasing the up-dip-to-offshore (UDTO) transform ponded play fairway trend

Similar cross-cutting transform fault ridge plays formed during Gondwanan break-up can be found on the West African transform margin (though often in very deep water) and its conjugate margin in Suriname to North Brazil. To date, however, these plays remain undrilled despite their recognition in basins such as the Para-Maranhao basin of Brazil as representing huge UDTO prospects, where stratigraphic trapping has an extremely high chance of being effective for trap risk. In basins such as the Para-Maranhao, strike slip or transform faults offsetting ocean crust segments, may also bring the 'carbonate build-up on volcanic guyot' play (recently proven by Exxon in Guyana) into water-depths accessible by modern drilling technology.

Farther to the north and east of South Africa's transform margin the early break-up of Gondwana allowed the Madagascar – Antarctica – India continental fragment to migrate SE from Gondwana during the early Jurassic period along a right-lateral strike slip, transform fault. In the Angoche Basin between Mozambique and Madagascar this transform fault is recognizable as the Davie 'Fracture Zone' or Davie Ridge, and has again presented a basin floor topographic high throughout the basin's history.

Here though, the west side of the transform comprises Jurassic Oceanic Crust while the east side represents fragments of extended Madagascan crust. The buoyancy of this crustal component on the mantle keeps this part of the ridge relatively shallow, providing targets accessible with current drilling technology. Of course the effect of the transform ridge as a depositional barrier during the Cretaceous period is the same as in South Outeniqua and Durban basins as this creates an UDTO geometry for ponding of turbidites, shed from the Mozambique mainland. While it is possible that the transform fault of the Davie Ridge also represents a 'failed' early-mid Cretaceous subduction zone (Intawong et al., 2018) the formation of this ridge, and its potential accretionary wedge, provides a natural barrier, and ponding site to sediments coming from the west. This is not the only play that can work in the Angoche Basin, as compressional inversion structures containing basin floor fans are clearly visible in the basin centre of Figure 4. The outboard transform ridge ponded play is aerially elongated within the 'gutter' inboard of the Davie ridge and is likely to receive charge from underlying syn/pre-rift, or the Early Cretaceous (Albian) global ocean anoxia event source.

The new transform ridge ponded play trend

The chase for places to explore basin floor fans on Africa's prolific margins has taken a huge leap forward. Previously the basin floor fan plays with up dip to offshore closure could only be tested in ultra deepwater, or where mantle convection induced dynamic topography had created relatively shallow water over Cretaceous basin floor fans. However, with strikingly similar characteristics to the Brulpadda discovery, in relatively shallow water settings, leads and prospects comprising basin floor fans ponded against major transform fault ridges have been identified from South Africa up to Mozambique setting off the chase for acreage in this new exploration trend. Identification of transform faulting, with depositional topology running obliquely to orthogonally to the shelf is key to locating the next swarm of plays of this style around Africa's margins.

References

Intawong, A., Hodgson, N., Rodriguez, K. and Hargreaves, P. [2019]. Oil prospects in the Mozambique Channel: where incipient subduction meets passive margin. *First Break*, **37** (3), 75 – 81.