Sergipe Basin Undrilled Potential Surpasses Giant Offshore Discoveries

PSDM dip line showing syn- and post-rift targets as well as candidate Moho deep reflectors.

Evaluation of up to 16,000 km of modern, high quality, long-offset 2D seismic data, acquired by Spectrum in 2014 over the Sergipe Alagoas Basin (Figure 1), has confirmed the extension of a turbidite channel system into open acreage offered in the ongoing licensing Round 14. This channel system has been proven to contain several billion barrels of reserves from recent exploration programmes, including the Barra, Muriu and Farfan discoveries. Integration of derived seismic attributes and potential field data has resulted in a better understanding of the main elements of the petroleum system, allowing for the identification of multiple untested play types. This evaluation demonstrates that the undrilled potential offshore Sergipe may surpass the discovered resources to date.

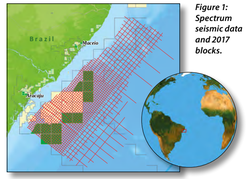

Figure 1: Spectrum seismic data and 2017 blocks.

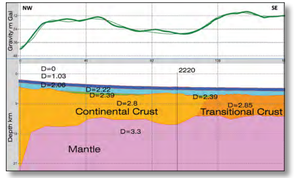

Figure 2: Constrained gravity model.

The long-offset 2D seismic data was processed through pre-stack time migration using conventional techniques, and through pre-stack depth migration using both conventional and broadband processing techniques. The application of these two technologies resulted in seismic data with a vertical resolution as fine as 5–10m (Saunders et al., *First Break*, 2015), allowing identification of additional levels of interest which are mostly beyond seismic resolution in the conventionally processed seismic data.

Additionally, AVO stacks and attributes have been generated over an area encompassing the Sergipe Sub-basin. A targeted pre-processing flow was used to produce conditioned-angle gathers, calibrated with existing well data, indicating numerous potential AVO anomalies (Saunders et al., *GEO ExPro*, Vol. 11, No. 5).

Ship-borne gravity data has also been integrated with the seismic interpretation of a relatively clear Moho reflection on the PSDM sections, to produce a series of density models (see Figure 2). This modelling exercise has resulted in a very clear interpretation of the crustal architecture. The outcome of the exercise will be a higher confidence in crustal architecture, leading to improved heat flow prediction and thermal maturity profiles.

Detailed evaluation of available seismic data indicates that the Sergipe deepwater plays extend further outboard to the east and south-east, where they have an added opportunity in a basin floor fan setting. To the north-east, primarily in Alagoas, channel fill sediment play, rifted basin fill, and faulted Palaeozoic sediments are all exploration targets. As part of the current licensing Round 14 and with strong indications of huge untapped potential, exploration activity, inclusive of drilling in this highly prospective area, is expected to yield continued success, with undrilled potential surpassing discovered resources.

Spectrum

Sergipe Basin Potential Revealed

Integration of seismic attributes and potential field data has resulted in a better understanding of the main elements of the petroleum system, allowing for the identification of multiple untested play types.

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	Type	Reservoir	Primary Source	Seal
1	3-way with fault seal and 4-way dip closed structures	Early Cretaceous syn-rift fluvio deltaic and fluvial/aeolian sands	Early Cretaceous syn-rift lacustrine shales and juxtaposed Aptian marine shales	Intra formational shales
2	Unconformity truncation play	Early Cretaceous syn-rift fluvio deltaic and fluvial/aeolian sands	Early Cretaceous syn-rift lacustrine shales (and juxtaposed Aptian marine shales?)	Aptian shales, Intra formational shales
3	Still assisted closure?	Early Cretaceous syn-rift fluvio deltaic and fluvial/aeolian sands	Early Cretaceous syn-rift lacustrine shales	Sills and shales
4	Stratigraphic unconformity lag trap	Aptian/Barremian transgressive sands	Early Cretaceous syn-rift lacustrine shales and juxtaposed Aptian marine shales	Aptian shales
5	Stratigraphic seaward dipping	Aptian sands and lmsts	Aptian marine shales and lmst	Aptian shales
6	3 way dip closing against Seamount	Aptian sands and lmsts	Aptian marine shales and lmst	Aptian shales
7	Intrusive induced anticline	Aptian sands and lmsts	Aptian marine shales and lmst	Aptian shales
8	Fault controlled 3 way dip closure	Aptian lmst and clastics	Aptian/Albian marine shales and lmst	Albian and late Cretaceous shales
9	Intrusive induced anticline	Aptian lmst and clastics	Aptian/Albian marine shales and lmst	Late Cretaceous shales
10	Stratigraphic seaward dipping	Late Cretaceous Calumbi fm Slope apron and base of slope deep water turbidite sands	Aptian/Albian marine shales and lmst	Late Cretaceous shales
11	Fault controlled 3 way dip closure	Late Cretaceous Calumbi fm Slope apron and base of slope deep water turbidite sands	Aptian/Albian marine shales and lmst	Late Cretaceous shales
12	Intrusive induced anticline	Late Cretaceous Calumbi fm Slope apron and base of slope deep water turbidite sands	Aptian/Albian marine shales and lmst	Late Cretaceous shales
13	Stratigraphic landward dipping	Late Cretaceous Calumbi fm base of slope fan sands deep water turbidites	Aptian/Albian marine shales and lmst	Late Cretaceous shales
14	3 way dip closing against Seamount	Late Cretaceous Calumbi fm base of slope fan sands deep water turbidites	Aptian/Albian marine shales and lmst	Late Cretaceous shales

Related Closures: Structural, Intrusive, Stratigraphic, Unconformity

Geological period: Early Cretaceous Syn Rift, Aptian/Albian, Late Cretaceous and later

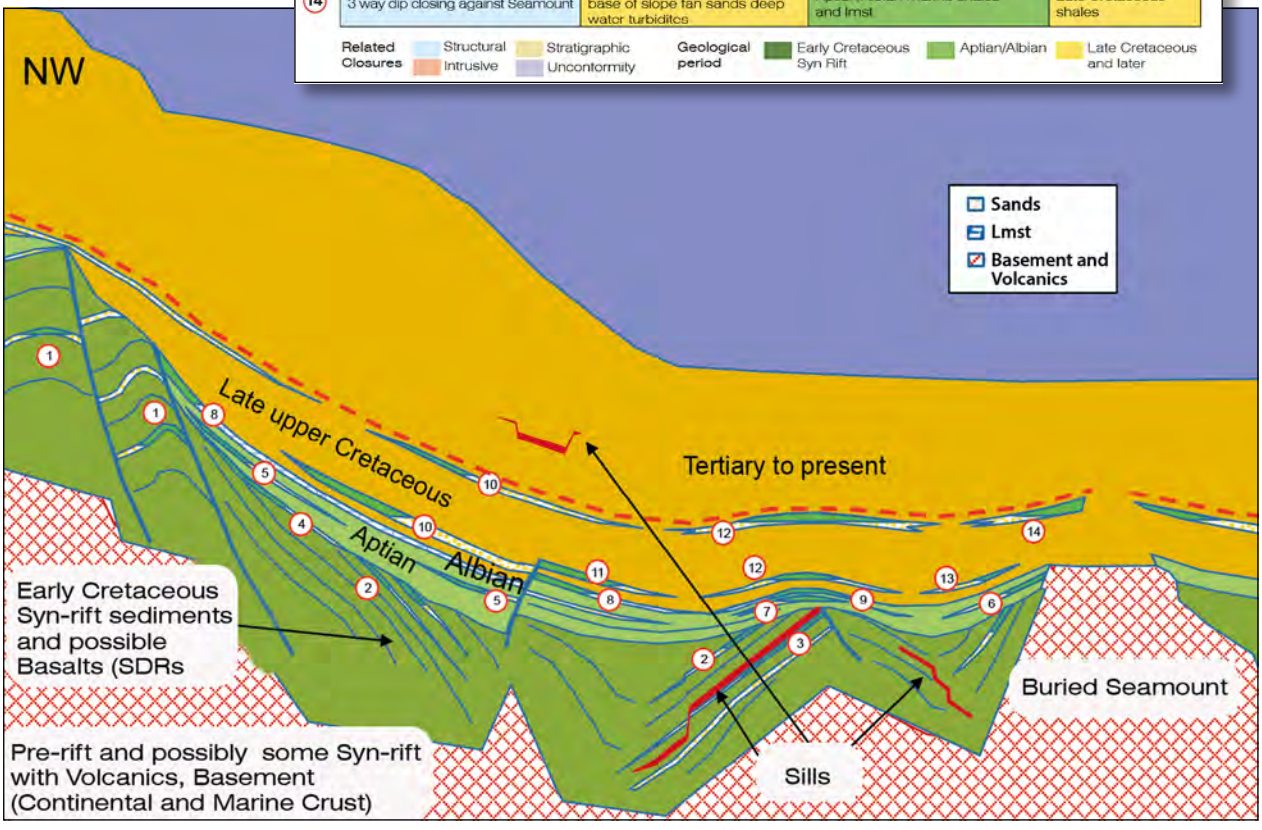

Figure 3: Play types offshore Sergipe Basin (see text page 42 for explanation).

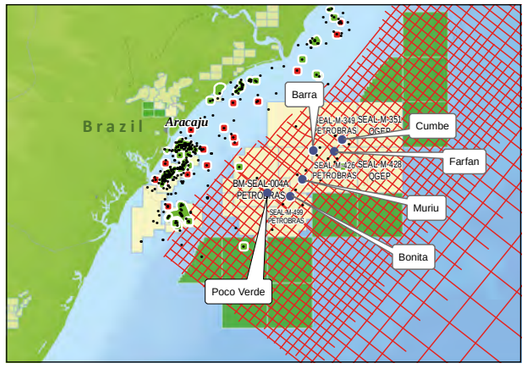

Figure 4: Sergipe deepwater discoveries.

The Sergipe Basin is located offshore north-east Brazil. It is divided into two sub-basins, Sergipe in the south and Alagoas in the north. With an offshore area of 35,000 km^2 and water depths up to 3,500m, it is classified as a passive margin / pull-apart basin with initial Early to Mid-Cretaceous rift basin development, followed by a passive margin drift phase from the Mid-Cretaceous to present, resulting from the separation of South America from Africa. The Alagoas Basin is dominated by a thick syn-rift succession and an abbreviated post-rift/drift sedimentary section. The Sergipe Basin is characterised by a major extensional rift phase and the presence of a fully developed post-rift sequence.

The onshore basin is mature, having experienced exploration activity for almost 100 years, although prior to the 1950s it was sporadic. In the '60s there was heightened drilling activity and the largest onshore field, Carmopolis, was discovered at this time. Offshore, significant seismic and drilling commenced in the 1970s and the 110 MMboe Caioba field was discovered. Exploration on the shelf continued through the '80s to late 2000s with moderate to small discoveries. In 2010 Petrobras made several significant Upper Cretaceous to Lower Tertiary, turbidite channel system discoveries in the deeper water of the Sergipe Basin. The company submitted eight appraisal evaluation plans to the ANP (National Agency of Petroleum) and drilling on the recent discoveries is continuing in order to commercially confirm some 3+ Bboe of reserves.

Undrilled Discovery Analogues

The Barra discovery well was drilled in September 2010, reaching a depth of 6,510m in 2,341m of water. Permeability and porosity conditions in the reservoir are excellent at well depths of approximately 4,650–4,750m, where drill stem tests indicate gas and condensate present in commercial quantities. The gross thickness of the zone of sandstones encountered in the Barra well is approximately 80m and well tests indicate a high porosity/low density, gas-charged reservoir.

Two other discoveries in the deepwater area of this basin include the Muriu and Farfan finds, with estimates indicating 3 Bboip and rising due to other exploration successes, including the latest Poço Verde discovery (Figure 4). These discoveries are in turbidite channel systems of Mid to Late Cretaceous and Early Tertiary age. They are associated with clear amplitude anomalies as illustrated in both dip and strike seismic sections over the Barra discovery (Figure 5).

Using the angle stack attribute (Far-Near*Far) it was possible to identify multiple undrilled amplitude and AVA anomalies, with similar character to the Barra trend of discoveries and of similar and larger size. These can be seen extending into open acreage and blocks in the current licensing round.

Basin Floor Fan Play Fairway

An extensive dataset of modern long-streamer 2D seismic along both sides of the South Atlantic margin has been used to identify a regional basin floor fan play fairway with a regional distribution of source rock and kitchen areas. At the same time, depth domain seismic profiles have revealed the true geometries of these basin floor fans. A deepwater basin floor fan play model (Figure 6) indicates a huge trapping geometry on seismic displays corrected for water depth, where it becomes apparent that the basin floor fans directly overlying mature Aptian source rock are in fact dipping landward or pinching out towards the mid-oceanic ridge, thereby eliminating the most dreaded up-dip seal trapping risk for this type of play.

This geometrical relationship is observed offshore Sergipe, outboard of the turbidite channel discoveries in the basin floor fan setting. Amplitude and AVA anomalies indicate that there could be significant hydrocarbon accumulations associated with extensive basin floor fans to the east of the channel discoveries and with a separate trap provided by 3-way dip closure and up-dip pinch-out to the east.

Proven and New Play Types

Integrating all available seismic tools, a schematic section has been put together to illustrate the various play types identified in the Sergipe Basin (see Figure 3, beginning of article). Source rock, reservoir, seal and trap evaluation has been combined with amplitude and AVA anomaly analysis, resulting in up to 14 different potential targets in pre- to syn-rift and post-rift sequences which have been mapped and are potentially associated with hydrocarbon indicators. These play types include the proven stratigraphic seaward dipping Late Cretaceous Calumbi Formation slope apron and base of slope deepwater turbidites.

Many new untested play types include Early Cretaceous syn-rift 3-way dip closures with fault seal and 4-way dip closed structures with either fluvio-deltaic or aeolian sandstone reservoirs, Aptian source rock and intra formational shale seals. Also in the Early Cretaceous, syn-rift unconformity truncation plays similar to those associated with the successful Dentale play fairway in Gabon have been identified.

Aptian/Albian plays could be sourced by either Aptian or Albian source rock and include Aptian/Barremian transgressive sands, sandstones and limestones in stratigraphic unconformity lag or seaward dipping traps, as well as 3-way dip closures against sea mounts or intrusive induced anticlines and fault controlled 3-way dip closures.

Late Cretaceous and younger rocks have similar traps to those mentioned above, with the Calumbi formation as the reservoir and either Aptian or Albian source rocks. The combined structural-stratigraphic landward-dipping basin floor fans are a significant untested play type with excellent amplitude and AVA seismic indicators. Figure 7 shows a dip seismic line in time, displaying the (Far-Near*Far) angle stack attribute. Yellow indicates a soft kick which brightens in the far angle stack (AVA anomaly). A zoomed-in panel of the dashed box shows a strong AVA anomaly with an associated basin floor fan geometry. The conventional seismic PSDM zoomed-in display, with water depth corrected, shows the true geometry of this basin floor fan.

Gravity Modelling

An accurate interpretation of the crystalline basement and the Moho discontinuity was made possible by the high quality PSDM imaging (see foldout). The interpreted horizons and interval velocity models were used to constrain modelled gravity profiles, from which were derived gridded maps of the base of sediment (top crystalline basement) and the Moho discontinuity.

These modelled gravity inversions have led to an improved interpretation of the crustal geometry by augmenting the seismic imaging, resulting in a clearer picture of crustal architecture including the amount of stretching associated with rifting across the basin (Figure 2). The beta factors that are implied by this stretching help to constrain the modelling of heat flow and thermal maturation.

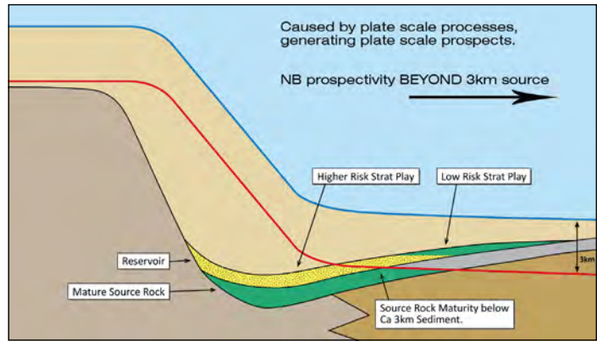

Figure 6: Atlantic margin basin floor fan play fairway model – note up-dip closure of apron fan.

Sergipe Past, Present and Future

Evaluation of modern, high quality seismic data has led to the confirmation of the extension into open acreage of proven turbidite channel systems of Mid to Late Cretaceous and Early Tertiary age. Using an extensive long-offset seismic dataset spanning both sides of the Atlantic, a model has been put together showing basin floor fans dipping landward and pinching out towards the mid-oceanic ridge. In Sergipe these basin floor fans are associated with AVA anomalies similar to those of the discoveries. This play type is being tested by the Yakaar well offshore Senegal and is set to become the exploration target of the future due to its huge potential.

Integration of available seismic and potential field data has resulted in a greater understanding of the main elements of the petroleum system and, therefore, in the identification of multiple as yet untested play types in this basin. Again, with calibrated amplitude support and with pre- to syn-rift analogies in the successful targets in the conjugate Gabon margin, modern tools are available which confirm that the undrilled potential offshore Sergipe easily surpasses the discovered resources to date. ■

Figure 5: Dip line (a) and strike line (b) through the Barra well.

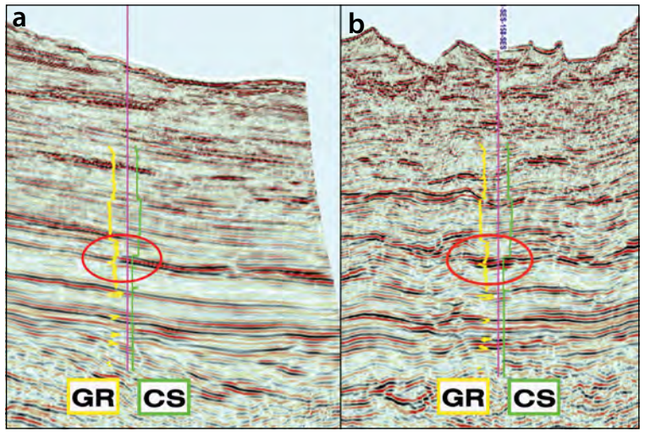

*Figure 7: Basin floor fan play with AVA anomaly on Far-Near*Far display.*