Correlation between homologous basins in the Southern Atlantic indicates great potential for the Southern Pelotas Basin in Brazil

Pedro V. Zalan[1*], Randall Etherington[2] and Milos Cvetovic[2] demonstrates how the same source rocks from the African side of the South Atlantic show the potential for petroleum systems in the South American side of the southern South Atlantic.

Introduction

Following the discovery of two vast fields of gas/condensate in South Africa (Brulpadda with 2.1 TCF/112 MMbc, Luiperd 1.3 TCF/80 MMbc) and, more recently, of oil/gas in Namibia (Graff, 700 MMbor, and Venus, with rumoured recoverable resources ~13.4 billion boe) a new proven petroleum system was established in the southern South Atlantic. These discoveries share the same source rock of Aptian anoxic marine shales and reservoirs in Cretaceous turbidites deposited as channels and lobes (Hedley et al, 2022; Winter et al, 2022). The trapping mechanism is purely stratigraphic (lateral and updip pinch outs) and the tectono-stratigraphic environment of their occurrence is the basal portions of mostly undisturbed siliciclastic Drift Sequences resting upon Seaward-Dipping Reflectors (SDRs) or oceanic crust. This petroleum system was already known to be highly productive in the Equatorial Atlantic Ocean (Guyana/Suriname and Ghana/Ivory Coast) and in the northern parts of the South Atlantic Ocean (Sergipe-Alagoas, Equatorial Guinea, Angola, Espirito Santo/Campos/Santos). Its occurrence in more austral latitudes with such effectiveness and richness was a surprise to the petroleum industry. Therefore, it was a natural next step for the oil companies to look across the ocean and focus their attention on the homologous margins of southern Brazil, Uruguay, and Argentina.

This successful petroleum system is named the **Cretaceous Marine Anoxic Shales-Late Cretaceous Turbidites (!)**. The source rocks are marine anoxic shales of Aptian/Turonian ages, of which the Aptian shale seems to be the richest and most effective contributor. The reservoirs are Late Cretaceous turbidites deposited in large basin floor submarine fans fed by channelized systems. The traps are primarily of stratigraphic nature, being the superposition of the reservoir upon the source rock the optimum geometric relationship. In three of the four discoveries cited above, the reservoirs are of Aptian age and rest upon the Aptian organic-rich shale. This system is ubiquitous in the continental margins of the South Atlantic Ocean. The only variation among

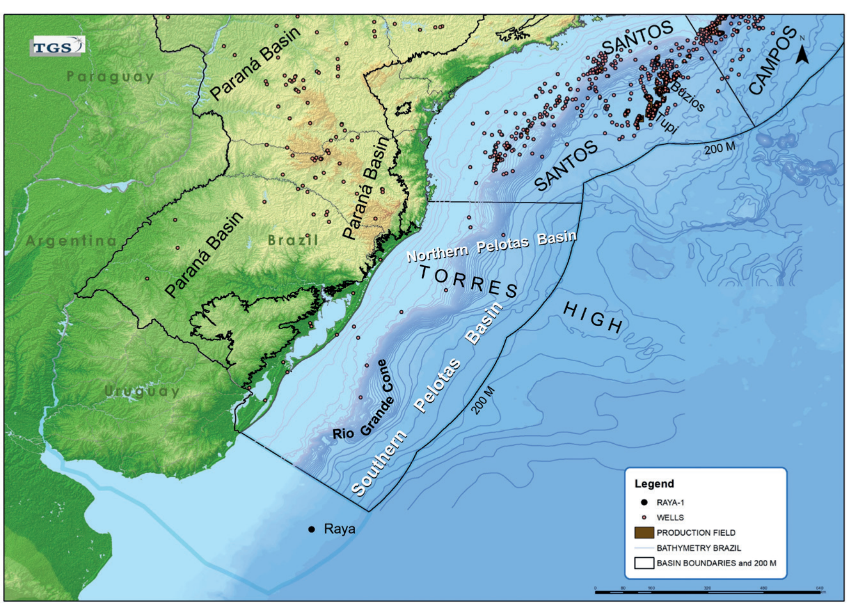

Figure 1 Situation map for Pelotas Basin in southern Brazil. The Torres High divides the basin into two sub-basins: Northern Pelotas and Southern Pelotas. Nine wells were drilled in the basin. The Raya well in Uruguay is also displayed for further referencing. The Rio Grande Cone is an important depositional feature in the Southern Pelotas Basin.

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DOI: xxx

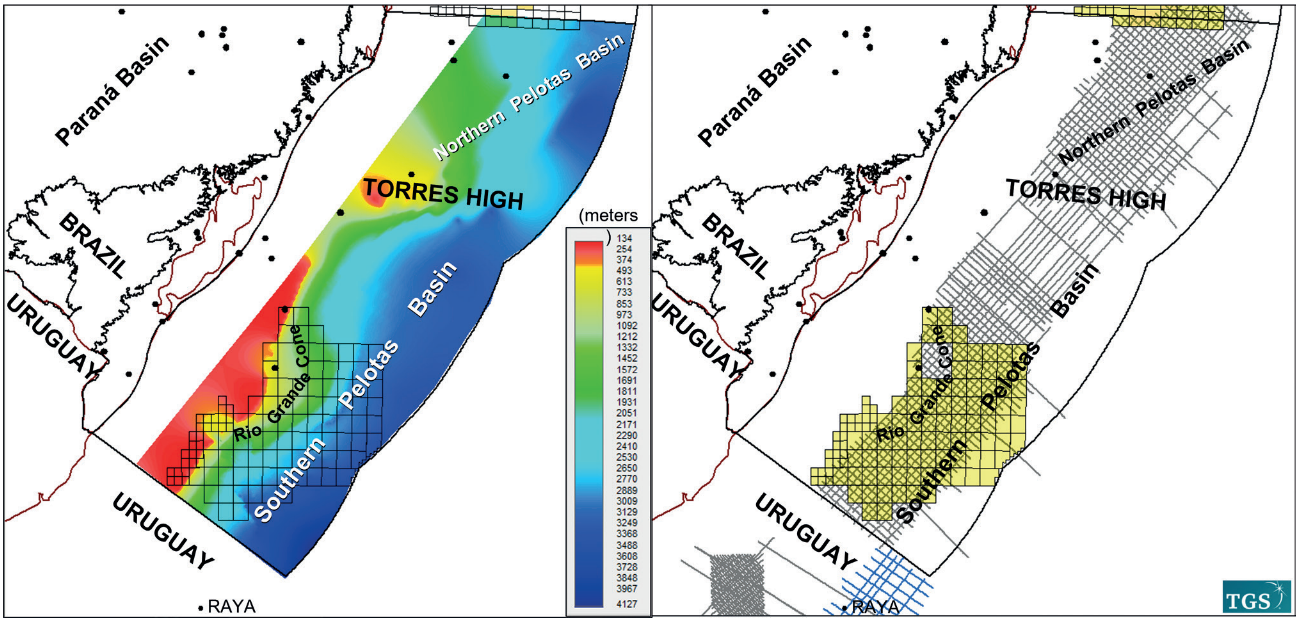

Figure 2 Left: Bathymetry of the Pelotas Basin and blocks offered in the Permanent Offer mode in the Southern Pelotas Basin. The influence of the Rio Grande Cone is exerted upon 1/3 of the blocks offered. Only three wells were drilled in water depths greater than 400 m. Right: Seismic data available from TGS. Most of the blocks are covered by a regular 10 km X 10 km grid.

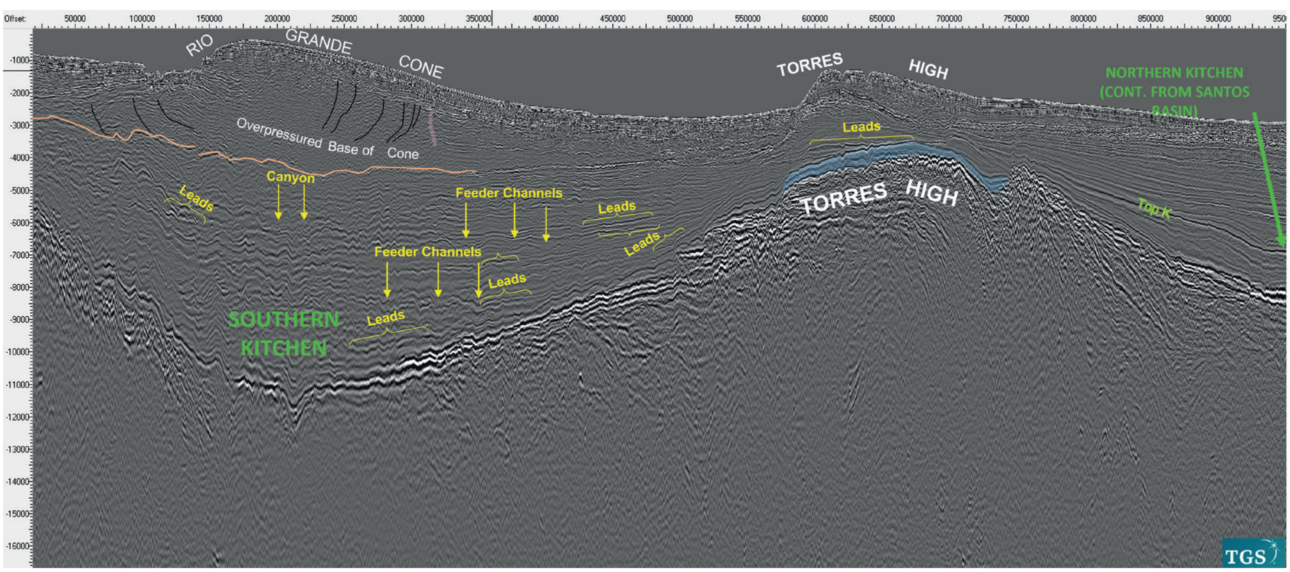

Figure 3 Regional strike-oriented section displaying the Torres High, Rio Grande Cone, the northern and southern hydrocarbon kitchens, canyons, and feeder channels for turbidites, leads, and an Albian carbonate platform developed on top of the Torres High (blue). The Torres High is a strong positive feature at both the basement and sea bottom levels. The Rio Grande Cone is a depositional feature that warped the basement downward and created a bathymetric high.

these different basins is the age of the primary contributing source rock, sometimes Turonian/Cenomanian (Equatorial Atlantic), sometimes Albian (northern South Atlantic), and sometimes Aptian (southern South Atlantic).

The time has now come to prove the presence and effectiveness of these source rocks in the South American side of the southern South Atlantic. The **Greater Pelotas Basin** is comprised of a single, uninterrupted, enormous offshore sag basin, extending from Southern Brazil, through Uruguay, to northern Argentina. It contains large thicknesses of Lower and Upper Cretaceous to Cenozoic Drift Sequences, resting upon volcanic substratum (either Seaward Dipping Reflectors (SDRs) or Oceanic Crust). It is the quintessence of a Volcanic Passive Margin. Ten wells (nine in Brazil and one in Uruguay) have been drilled in this frontier area, and only three of them are in deep/ultra-deep water (Figures 1 and 2). In this article, we will be dealing only with the Brazilian portion of the **Greater Pelotas Basin** because of the more considerable extension, greater thicknesses, better seismic coverage, and greater similarity with the Namibian discoveries.

Petroleum potential

The Pelotas Basin in Brazil is comprised of two sub-basins: Northern Pelotas and Southern Pelotas. The division happens at the Torres High (Figures 1 and 2), which is a huge structural high at the level of the economic basement (top of SDRs) with strong reflection upon the sea bottom as well (Figure 3). The

Torres High is considered to be a promontory of continental crust impinging upon oceanic crust; thus, the high elevation of its top is due to the buoyancy effect of the lighter continental crust (Jeck et al., 2019). Its importance to petroleum geology should lie in the focusing effect of its shoulders dipping into the depths of the surrounding basins, creating various situations for stratigraphic trapping of hydrocarbons (Figure 3). The Northern Pelotas is the simple continuation of the Santos Basin to the south, with its official northern boundary having no geological meaning at all. The Southern Pelotas, on the contrary, is an entirely different basin, much deeper and presenting a much thicker Drift Sequence. The significant number of canyons and feeder channels that can be seen in its shallow waters is indicative of the large amount of sandy turbidites in deep and ultra-deep waters (Figure 3). A third of its area is influenced by the large Rio Grande Cone, a Neogene deltaic feature whose load has down-warped the underlying sedimentary and volcanic strata. This created a huge depocentre, which most probably constitutes the main hydrocarbon kitchen of this basin (Figure 3). The Southern Pelotas Basin is the main focus of this article.

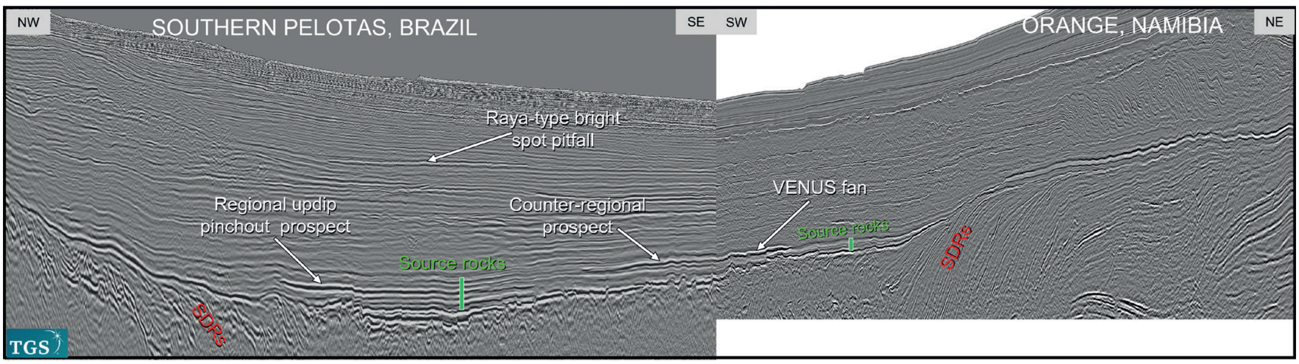

Figure 4 Tentative seismic correlation between the homologous Orange and Southern Pelotas Basins. The geological fit and the geophysical similarity is impressive. The super-giant Venus discovery is clearly illustrated by a bright spot pinching updip. The Brazilian side also shows a bright spot, pinching updip and forming a counter-regional prospect at the same level. Towards the coast, another bright spot pinch-out, this time towards the regional dip, constitutes another potential prospect. The source rock seismic facies are identical. A strong, shallow bright spot is also indicated in Southern Pelotas, and it is very similar to the target aimed by the Raya well, and that came out as excellent water-saturated sandstones.

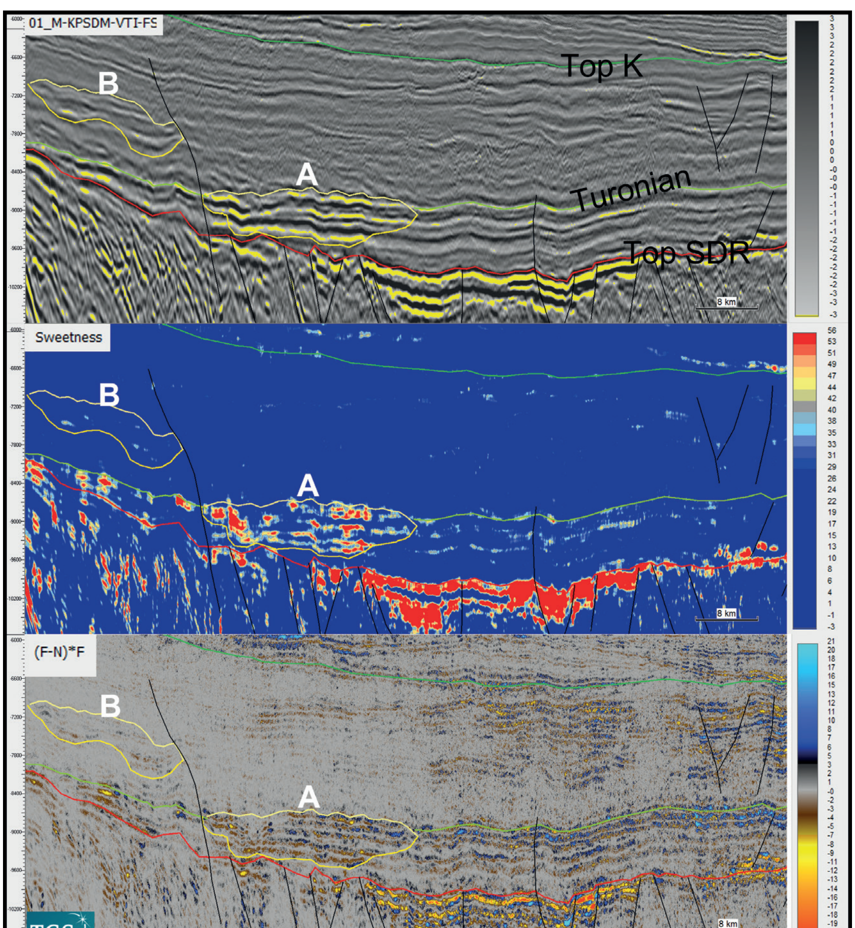

Figure 5 Dip-oriented section displaying the source rock seismic facies (Turonian to Top SDR) and a channel incised into it. Cretaceous Prospect A shows the typical geometry of channels, bright spots, positive sweetness anomalies, and a predominantly Type IV AVO response in the (F-N)*F attribute. Prospect B has a clear channel geometry, but none of the DHI responses of Prospect A.

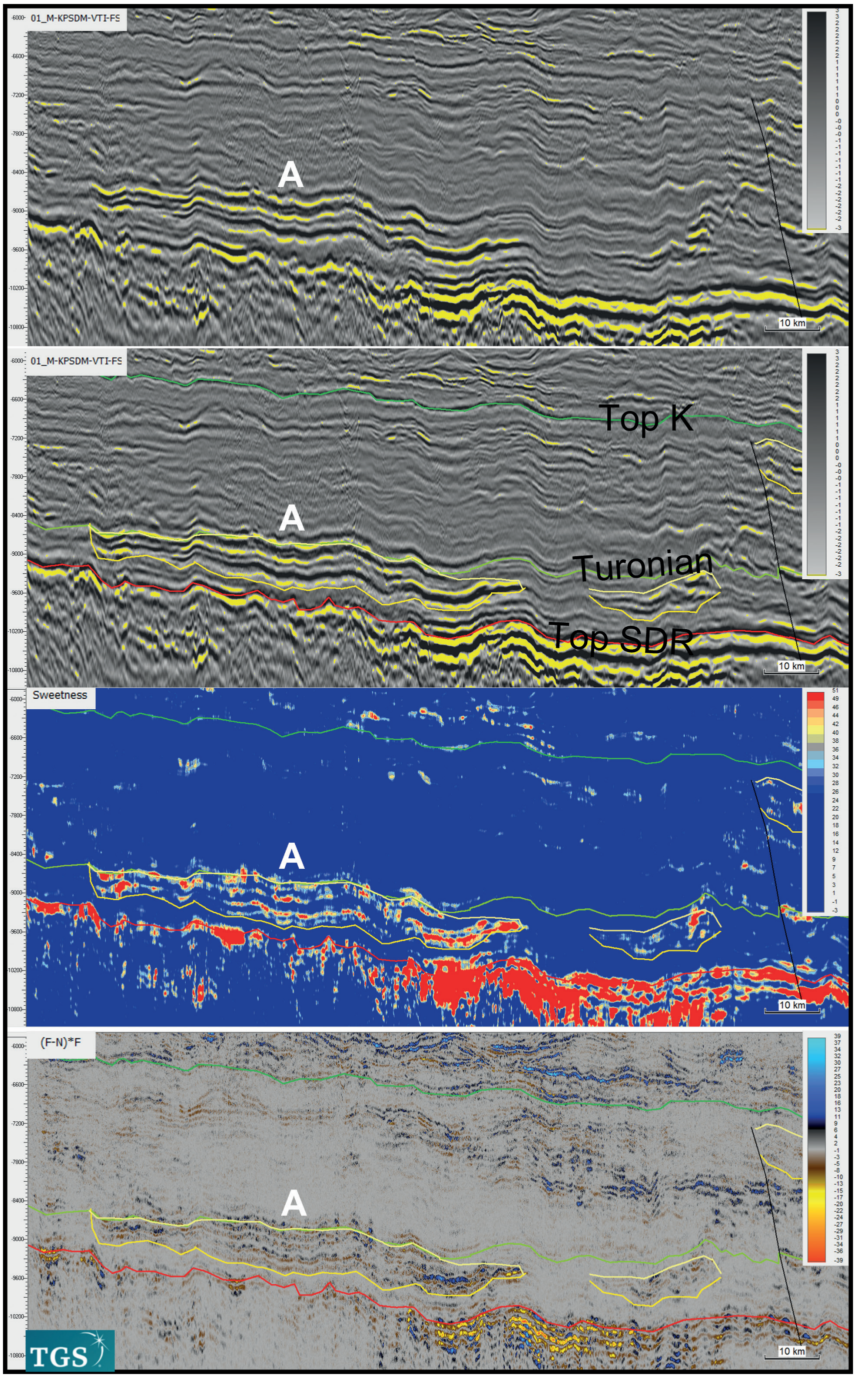

Figure 6 Composite seismic section crossing cretaceous Prospect A (displayed in Figure 5) in several directions. The channel geometry, the bright spots, the positive sweetness anomaly and the Types IV/III AVO response in the (F-N)*F attribute are persistent. This enormous prospect has an approximate area of 3000 km^2.

Figure 4 shows two seismic sections, the first is in Namibia, containing the super-giant Venus discovery and the underlying Aptian sourcing rocks. The second is in Brazil, in the Southern Pelotas Basin, displaying great similitude to the Namibian geology and geophysics and the presence of several potential prospects. The two sections are fitted one against the other as if they were a continuum, which they are not. The natural flow of the geology through the sections, across their limits, is impressive. The Venus submarine fan seems to continue in Pelotas through a bright spot that looks like the mirror image of the super-giant accumulation. This bright spot dips towards the continent, pinching out towards the ocean, constituting a highly potential counter-regional prospect. The package of source rocks appears the same, the Pelotas package being thicker than in the Orange Basin. On the western end of the Pelotas Basin a strong bright spot, interlayered with the source rocks, pinches out updip towards the continent, forming a classical stratigraphic trap, similar to the Venus discovery.

The drift strata is largely unfaulted and undisturbed nature (except for the Rio Grande Cone) and their upward thinning towards the continent and to the ocean, point to essentially stratigraphic traps as the targets of future exploratory wells. Furthermore, the absence of visible migration routes of tectonic nature clearly indicates that the submarine fans and channels to be tested by ultra-deep wells should be the ones in direct contact with the source rocks, that is, preferably the Aptian-Albian-Turonian fans, Campanian-Maastrichtian at most (Zalan, 2017). This exploratory model is analogous to the successful model applied in Ghana/Ivory Coast and Guyana/Suriname.

With this model in mind, a thorough mapping of the available seismic data was carried out, especially in the area covered by blocks that are in the Permanent Offer mode by ANP (Figure 2). Tens of potential stratigraphic prospects were identified and mapped, each with areas in excess of 100 km^2, some in excess of 1000 km^2. Only examples contained within the Permanent Offer blocks will here be presented. All the seismic sections displayed are depth-migrated (Kirchoff PSDM).

Figure 5 shows a zoomed view of the basal portion of a dip-oriented section illustrating the source rock package (situated between the Turonian shale and the Top of SDRs) and two prospects mapped. One of them is a channel incised within the source rocks, and the other is a channel situated above the source rocks. The deeper prospect presents several characteristics of DHIs, such as bright spots, positive anomalies in the Sweetness attribute, and Types IV/III AVO response in the (F-N)*F attribute. The shallower prospect has a clear channel geometry, but none of the DHI responses of the Prospect A were found within it. These two examples clearly demonstrate the importance of being in close contact with the organic-rich shales. Figure 6 shows the same prospect highlighted in Figure 5 as seen in a composite line crossing the turbidite body in several areas and directions. The same DHI characteristics seen in the last figure are confirmed in this section.

Figure 7 is a regional dip-oriented view of the area covered by the Rio Grande Cone. The Cone is a huge gravitational cell displaying both the extensional zone updip and the contractional fold belt downdip. The basal detachment fault is clearly visible soling out at around 4800 m deep. The upper part of the Cone is brilliant due to the presence of free gas underneath a BSR (base of hydrates). The deeper part, however, is a blind zone probably obscured due to overpressure. Beneath the basal detachment fault, the geology becomes clear again, and three prospects displaying submarine fan and channel geometries, highlighted by strong bright spots, can be mapped. Although their nature is confirmed by the positive anomalies of the Sweetness attribute (sandstones with anomalous low velocities), the presence of hydrocarbons is not confirmed by the (F-N)*F attribute. This lack of AVO response seems to be directly linked to the blind overpressured zone right above them. It is possible that the overpressured shales at the base of the Cone absorbed most of the energy of the downgoing seismic waves leaving little energy to pound these prospects.

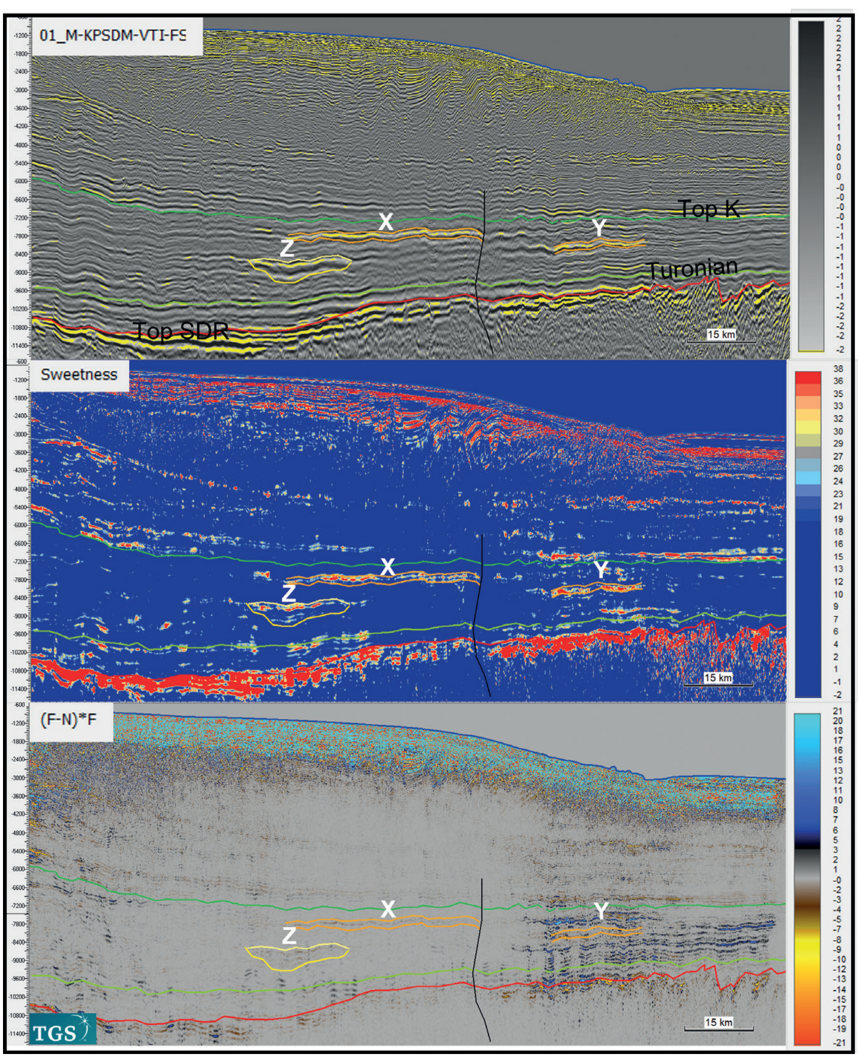

Figure 7 Dip-oriented seismic section showing with great clarity the geology underneath the Rio Grande Cone. Source rock package and turbidite features are clearly seen. Cretaceous Prospects X, Y and Z display strong bright spots and positive sweetness anomalies. The (F-N)*F attribute shows a very faint Type IV AVO in Prospects X and Z and its response is probably weakened by the high-pressure blind zone at the base of the Rio Grande Cone.

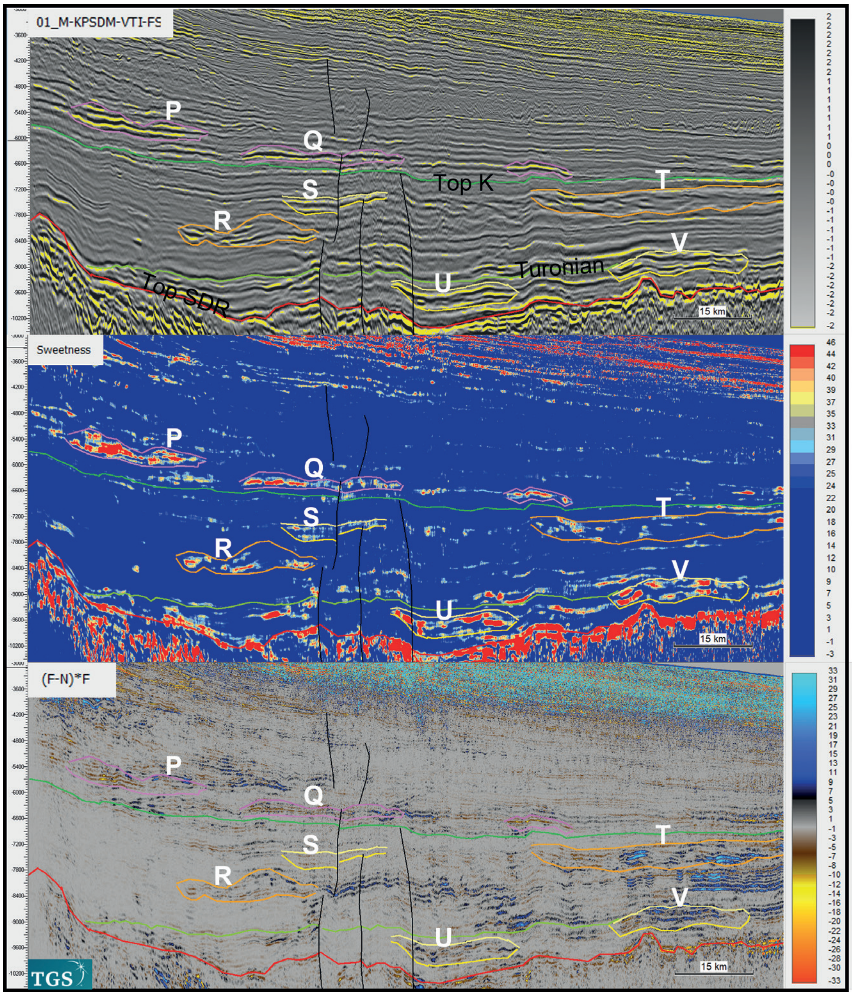

Figure 8 Dip-oriented seismic section displaying several Cenozoic and Cretaceous prospects. Cenozoic Prospects P and Q display strong bright spots, positive sweetness anomalies, and Type IV AVO response. Faults link the source rock package to Prospect Q. Interestingly, deeper Cretaceous Prospects R, T U, and V present strong Type III AVO responses, besides all other hydrocarbon indicators. Prospect S, although presenting a channel geometry and bright spot, its responses in the sweetness and (F-N)*F attributes are not encouraging.

Figure 8 is a dip-oriented seismic section displaying several Cenozoic and Cretaceous prospects. The Cenozoic Prospects present strong bright spots, positive sweetness anomalies, and Type IV AVO response. Faults link the source rock package to one of the prospects, providing a rare view of a possible migration route from the basal source rocks to a far-located prospect. Four of the five prospects mapped in the Cretaceous section present strong Type III AVO responses, besides all other hydrocarbon indicators. Only one Cretaceous prospect, although presenting a channel geometry and bright spot, has unencouraging responses in the Sweetness and (F-N)*F attributes.

Conclusions

The dense grid of 2D seismic data in the Southern Pelotas Basin allowed the identification and mapping of several potential prospects of mostly Late Cretaceous age (Figures 4-8). The most important ones are those interlayered with the source rocks, as demonstrated by the Brulpadda, Luiperd, and Venus discoveries. All of them were first identified by their turbidite-like geometries with associated bright spots. The confirmation of the anomalously low-velocity character of the bright spots was obtained by the sweetness attribute. DHIs were then obtained by the (F-N)*F attribute, unfolding Types III and IV AVOs. The correlation with the Orange Basin in Namibia and the occurrence of so many stratigraphic prospects of great dimensions indicate that the Southern Pelotas Basin is a potential petroleum-rich frontier that deserves the immediate attention of the petroleum industry and the drilling of deep wells in its deep and ultra-deep waters.

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