Ametista Block – An unusual prospect in Santos Basin – Albian atoll upon exhumed mantle

Pedro V. Zalan[1]*, Milos Cvetkovic[2], Henri Houllevigue[2], Kyle Reuber[2] and Andrew Hartwig[2] present a new, distinctive prospect in the southern Santos Basin, constituted a possible Albian atoll developed upon exhumed mantle.

Abstract

The authors present a new, distinctive prospect in the southern Santos Basin, constituted of a possible Albian atoll developed upon exhumed mantle. The prospect was identified due to the acquisition of new high-quality 3D with the latest processing techniques. The prospect shows great petroleum potential and has excellent analogs in the present Pacific atolls and on an island in the Red Sea. A large buildup composed of stratified seismic facies exhibiting basin-edge offlaps/clinoforms, and capped by a massive structureless construction, is developed upon a protrusion of exhumed mantle. This four-way closed structure is surrounded by Aptian salt bodies that onlap its flanks and by the lowermost strata of the Drift Sequence of the Santos Basin, known to be the ACT source rocks. Considering the nearby geology, this buildup is interpreted as an Albian carbonate platform capped by a reef (rudist?). An adjacent on-trend structure is constituted by volcanos developed upon the exhumed mantle. The overall structure resembles the well-known atolls of the Pacific Ocean.

Introduction

The Santos Basin in southern Brazil became famous for the fabulous reserves of oil and gas in the Aptian microbialite reservoirs of the so-called ‘Pre-Salt Play’. Super-giant fields such as Tupi and Búzios, and giant fields such as Sapinhoá and Mero, among others, produce close to 2 million boepd. These fields and numbers blur the modest existence of different, but still effectively producing, oil and gas fields in the so-called ‘Post-Salt Plays’. Numerous turbidite-hosted and carbonate-hosted oil and gas fields are also noteworthy in terms of reserves and production. The objective of this work is to present one quite unusual prospect in the Post-Salt Play.

The Ametista Block in southern Santos Basin is one of a kind; half of its area is inside the Pre-Salt Polygon, regulated by Production Sharing directives, and the other half is situated outside the polygon, regulated by Concession regime (Figure 1). Until recently, all the interpretation and basin evolution assessment have been done on gravity and magnetics data, aided by 2D seismic data, some of it acquired and processed 10-15 years ago.

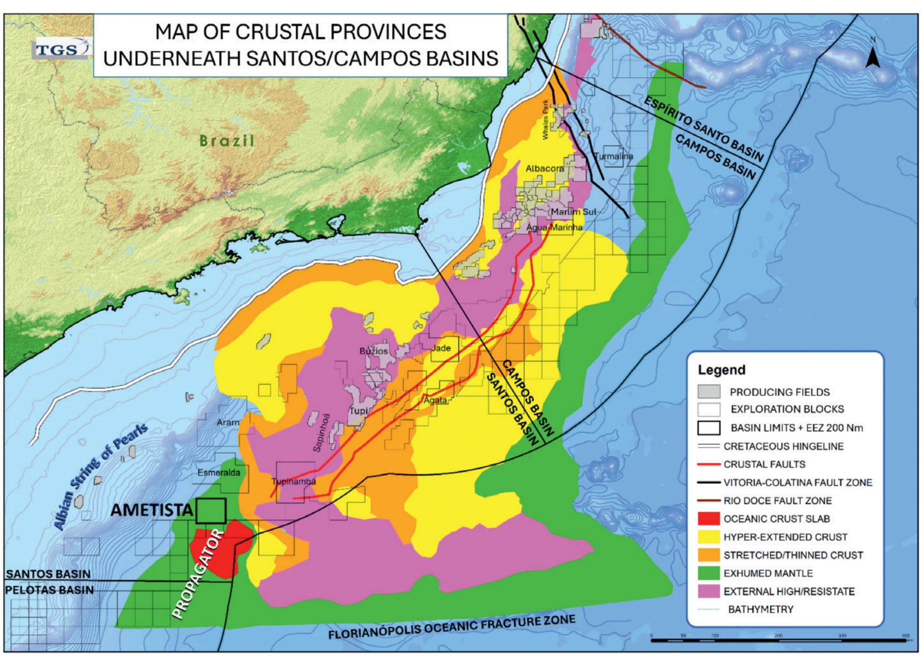

Figure 1 Location of Ametista Block on the map of the crustal provinces of the Santos and Campos Basins (modified from Zalan, 2024). Notice its special location upon the V-shaped tip of exhumed mantle. Albian string of pearls refers to several producing Albian age carbonate-hosted oil and gas fields.

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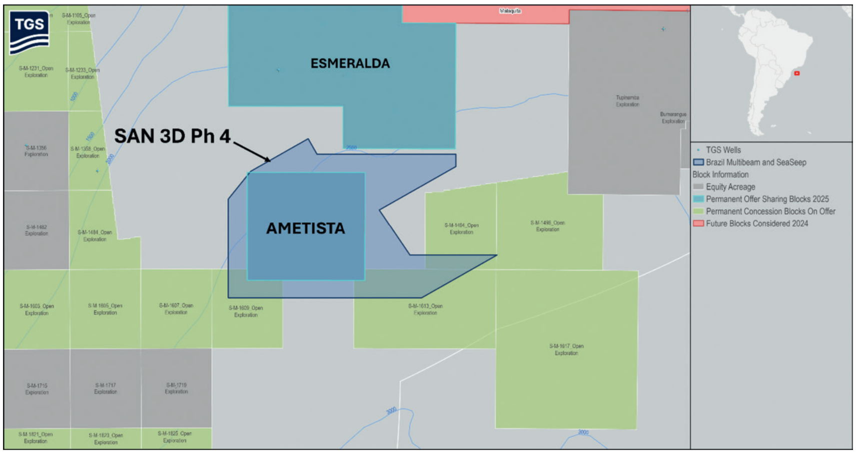

Figure 2 Outline of new 3D survey shot over Ametista Block, termed by TGS SAN 3D Ph4. See regional context of block in Figure 1.

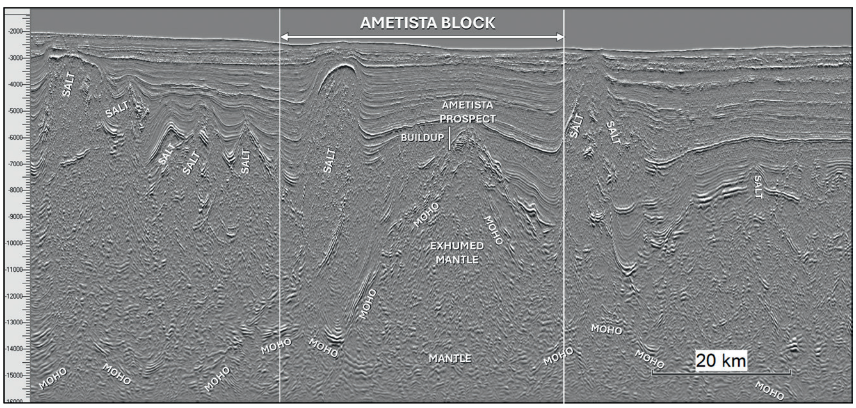

Figure 3 NW-SE regional 2D seismic section (depth) (Pseudo-Relief/TecVa attribute) depicting the uniqueness of the Ametista Block among surrounding terrains. Central High is the expression of exhumed mantle, it is devoid of salt and displays a stratified buildup (Ametista prospect) developed upon it.

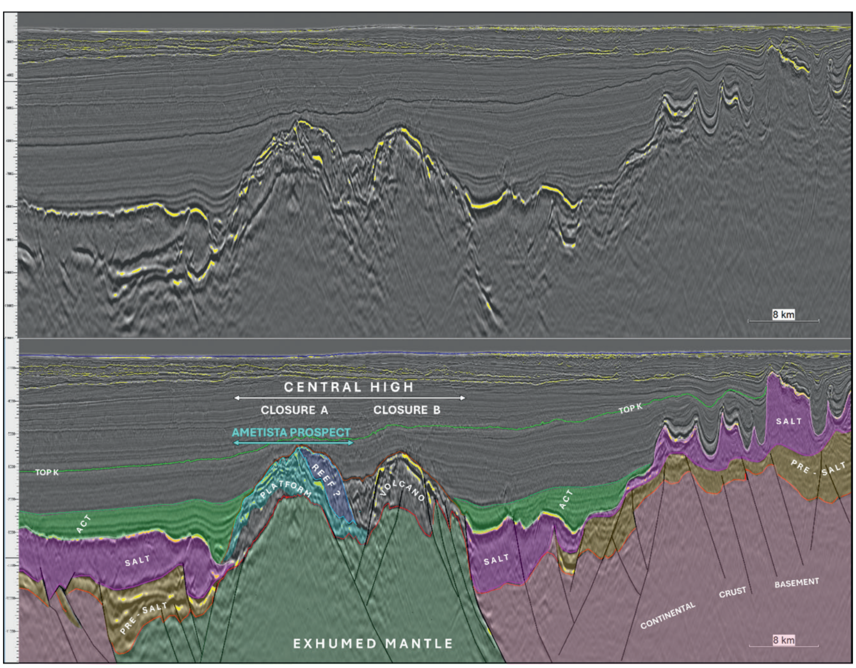

Figure 4 3D KPSDM section inside Ametista Block displaying the Central High developed upon a protrusion of exhumed mantle. It is constituted by two structural closures (A and B). Closure A presents a large buildup constituted by stratified seismic facies (platform) capped by a massive structureless construction (reef?). Closure A constitutes Ametista Prospect. Closure B is devoid of stratified facies, and it is interpreted as volcanoes. The Central High is surrounded by Aptian salt bodies that onlap its flanks and by the lowermost strata of the Drift Sequence of the Santos Basin, known to be the ACT source rocks.

Recently acquired 3D data shot specifically to unravel the potential of Ametista Block (Figure 2) displayed a rather unusual, but highly prospective, petroleum system. Geologically, it is the only exploratory block in Brazil situated entirely over exhumed mantle (Figure 1, Zalan 2024). This unique economic basement is the tip of a V-shaped crustal feature termed ‘Propagator’ (Figure 1), considered to be a failed crustal zipper-like rupture, from south to north, formed during the breakup stage (syn-rift) of Western Gondwana. A strong V-shaped positive Bouguer gravity anomaly and direct visualisation in seismic sections set the foundation for this interpretation (Figure 3 and 4). The exhumed mantle forms an outstanding structural high along the centre of the block (Central High). Over this high, no salt is visible, although it is plentiful around it. On top of it, along its crest, lies the other unusual aspect of this block: a possible Albian atoll constituting a possible prospect with all the characteristics that can be found in Pacific atolls of French Polynesia.

The Ametista Block has an area of 1587 km² and is slated to be offered to the industry in the 3rd Round of Production Sharing in 2025. The block was originally outlined by ANP because of the existence of a prominent high, that in the poor quality 2D seismic data appeared to be capped by either salt diapirs or volcanic constructions. In 2021, TGS acquired a 3400 km² 3D multi-client (MC) marine survey that completely covered the Ametista Block (Figure 2). The modern acquisition and processing build confidence in exploration geologists' interpretation and correlation to other post-salt and pre-salt fields in proximal parts of Santos Basin – for an updated perspective of this unique opportunity.

In the southern Santos Basin, close to the Ametista Block, there are several discoveries and producing oil fields distributed as a string of pearls (Tubarão-Estrela do Mar-Coral-Caravela-Cavalo Marinho) (few tens of million boer each) (Figure 1) hosted in oncolite grainstones of Albian age. The producing petroleum system is the Cretaceous Marine Anoxic Shales-Albian carbonates (!). The reservoirs are Albian carbonates that are bountiful producers in Campos and Santos Basins; the source rocks are marine anoxic shales of Albian-Cenomanian-Turonian ages (ACT); and the traps consist of classic rollover structures developed upon mobile salt.

The same successful petroleum system is expected to be working in the Ametista Block. Inside the block, a prospect also termed Ametista, was mapped and an unusual hypothesis for its composition and formation is here presented.

Acquisition, processing, and model building

The new 3D Narrow Azimuth (NAZ) hydrophone data was acquired with 10 streamer setups, each 10,500 m long, 100 m apart and 13 m below sea surface. A dual source, 25 m flip-flop configuration with sources at 8 m below sea level was used. Outboard parts of Santos Basin often experience challenges such as rough weather, strong currents, and rapid barnacle growth on the cables throughout the year. The configuration used allowed for the best combination of data quality and most efficient data acquisition, which is both operationally and environmentally friendly.

The pre-processing workflow is modern broadband with rigorous QCs at every step to ensure the highest quality, AVO-compliant data. We use inversion-based de-blending, 3D de-ghosting and a robust set of de-multiple, de-noise and 4D regularising algorithms. Since several 3D surveys have been acquired in this area over the years, we also tried to match the data as close as possibly in phase and amplitude between different vintages.

Model building and imaging also reflect advanced workflows tailored for Brazil salt basins, where we are using a top-down approach with a combination of Tilted Transversely Isotropic Kirchhoff Pre-Stack Depth Migration (TTI KPSDM) and Reverse Time Migration (RTM) algorithms as well as reflection tomography and Dynamic Matching Full Waveform Inversion (DM FWI) (Cvetkovic et al. 2023).

We began with an initial 3D model created from a grid of underlying 2D data. By integrating all available regional data, the starting Vertical Transversely Isotropic (VTI) model was tied and calibrated with major regional horizons. The Vp model is updated with reflection-based tomography using non-parametric moveout picker and inversion for a global tomography solution with dip structural smoothing. We apply three to four passes of tomography to achieve overall flat gathers that allow for good structural imaging and salt interpretation.

Salt model building is performed in typical interpretation workflow where top of salt is interpreted, a constant salt interval velocity is 'flooded', followed by interpretation of salt flanks and regional base of salt. Overhangs and pre-salt section are updated by Common Offset RTM gather tomography and then later refined by DM FW'. DM FWI uses both refraction and reflection and with 10 km of offsets we have available here, we are getting good reliable updates up to the base of the Central High lithology.

Figure 5 shows models before and after DM FWI and respective KPSDM stacks. Here we see that the left part of the Central High (Closure A), with an opaque appearance, is updated with slower velocities, varying from 3600m/s up to 3900m/s. On the other side of the Central High (Closure B), a combination of speedup and slowdowns can be seen, and this is supported by the number of QCs we run in both the data and image domain. KPSDM gathers are flatter and the stacking response also improves. Other data domain QCs such as forward

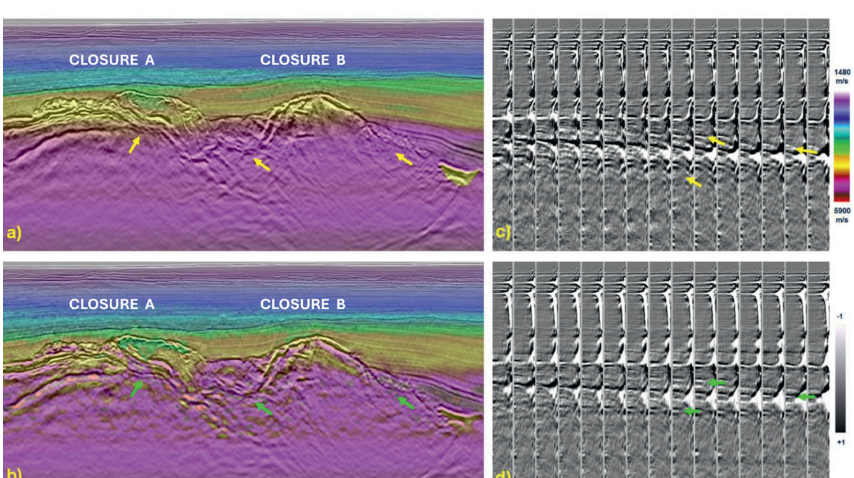

Figure 5 3D KPSDM stack overlay with velocity model, before and after DM FWI (and b), respective KPSDM gathers (c and d). Arrows point to imaging improvements mentioned in text above.

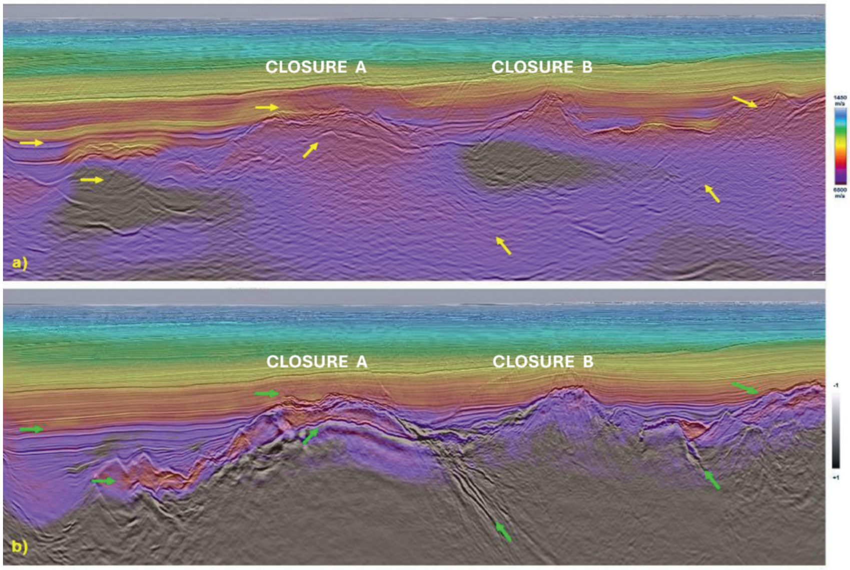

Figure 6 Improvements in 3D imaging, leading to more certain interpretation. 2D vs 3D arbitrary line PSDM stacks overlay with velocity model over Ametista Central High. Arrows point to clear imaging improvement across the section.

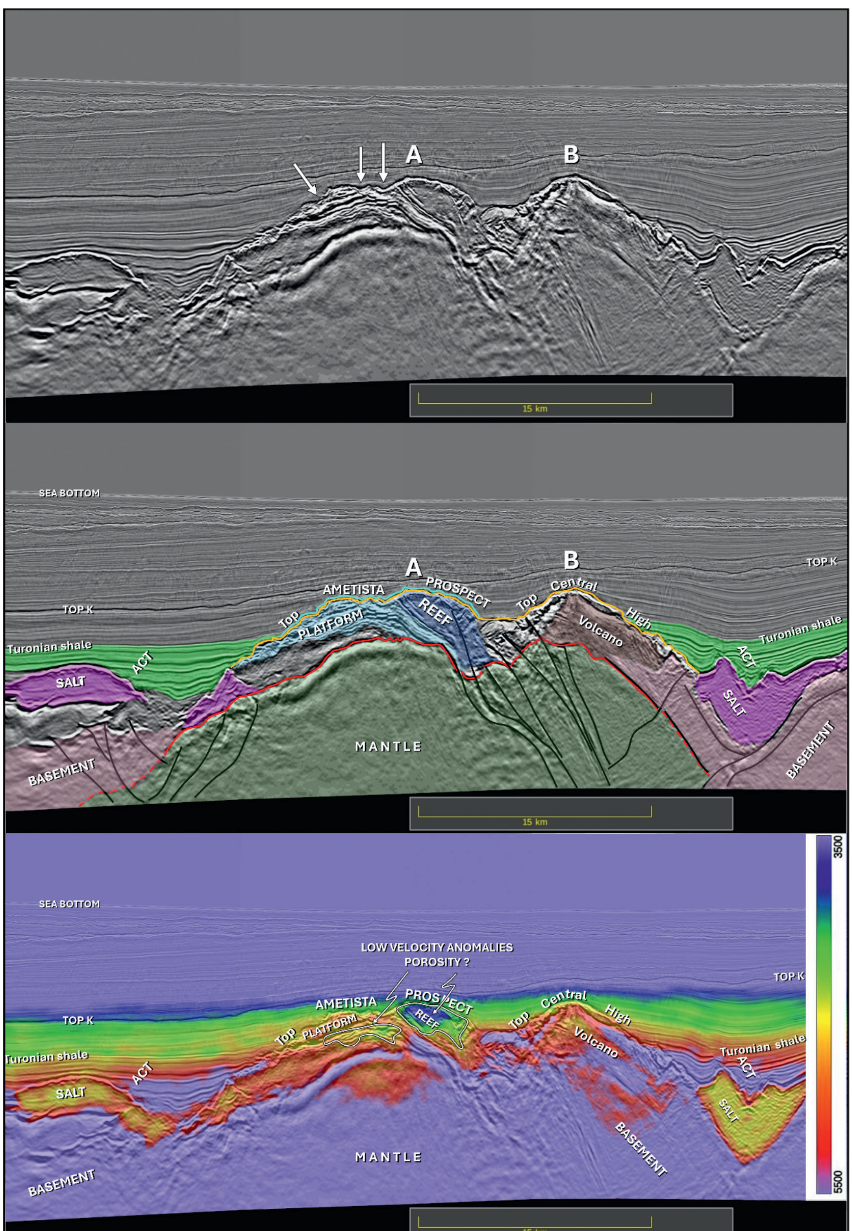

Figure 7 3D KPSDM longitudinal section crossing Closures A and B in Ametista Central High. Non-interpreted, Interpreted, Velocity Overlay. Closure A displays a stratified seismic facies (sub-parallel layered reflectors) (platform); capped by a massive, structureless facies (reef). Arrows point to V-shaped collapse features, typical of karstic topography of carbonate terrains. Closure B presents the typical shape and facies of a cone volcano. Low velocity anomalies within the platform and reef facies may indicate porous lithologies, corroborating the presence of reservoirs.

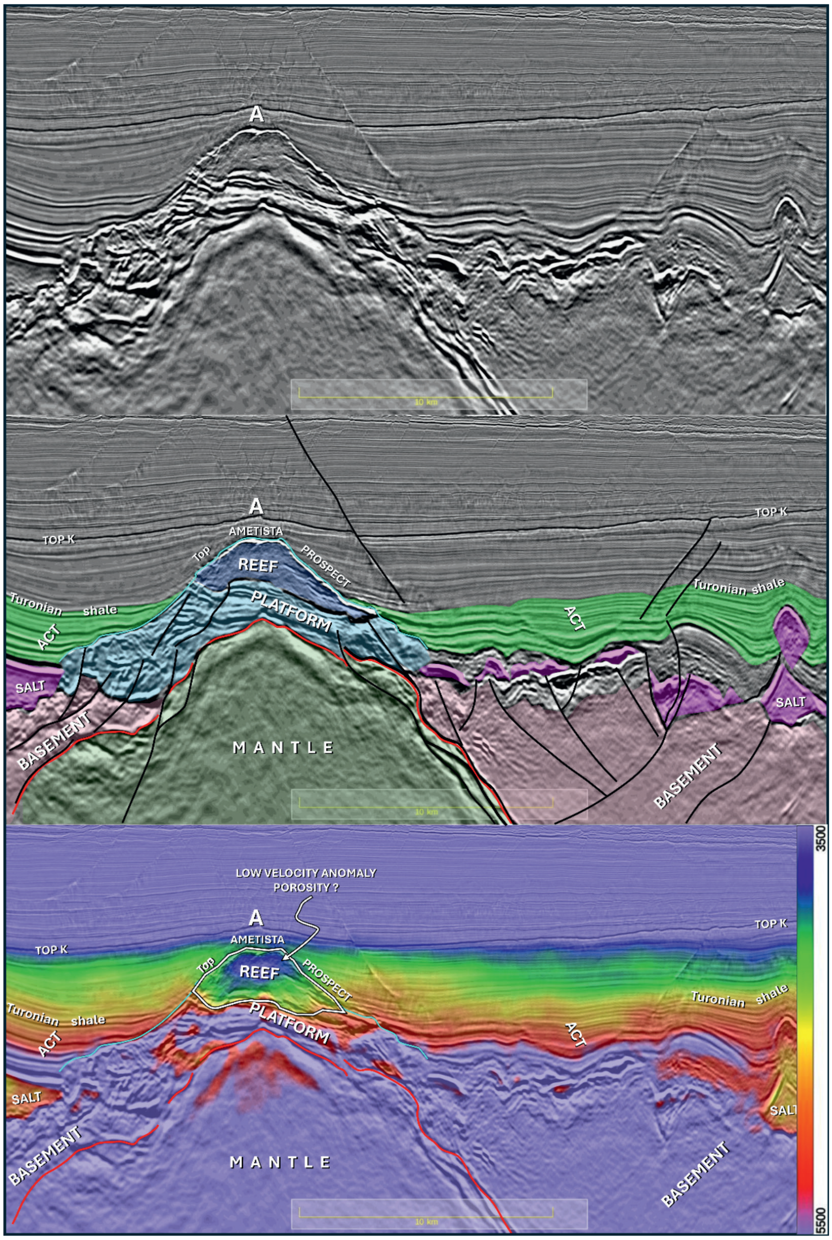

Figure 8 3D KPSDM transversal section crossing Closure A in Ametista Central High. Non-interpreted, Interpreted, Velocity Overlay. Closure A displays a stratified seismic facies (sub-parallel layered reflectors) (platform); capped by a massive, structureless facies (reef) of several hundred meters thick. Striking low velocity anomaly within the reef facies may indicate porous lithologies, corroborating the presence of reservoirs.

model shots and correlation coefficients across different bands support the DM FWI models.

Figure 6 shows improvements in imaging compared to 2D data that most exploration geologists have been using historically. When comparing 2D and 3D data, we often see that incremental improvement in 3D pre-processing, model building and imaging leads to significant uplift in final data quality and interpretability. Besides much better signal to noise ratio, clearer and continuous seismic events are imaged across entire sections, and we can start interpreting different geologic facies and structural details that on 2D data cannot be distinguished. Deep crustal faulting and rift structures are better imaged as well. This new 3D data is now imaged at the same high-quality standard as most of the 3D datasets covering inboard parts of the basin.

New interpretation

With new and improved imaging, we can strongly infer that the basement of the prominent high was a protrusion of exhumed mantle (Figure 3, 4, 7 and 8). Second, the sub-cropping mantle arch was completely devoid of salt cover. Salt was undoubtedly never deposited on top of it, although its flanks and surroundings are rich in salt domes and diapirs (confirmed during the model-building process). Not only is salt absent, but also any graben typical of the Pre-Salt section (Figure 4, 7 and 8). The exhumation of the mantle seems to have occurred during the rift phase and continued into the thermal subsidence phase during the salt deposition. This backbone high (Central High) is divided into two structural closures (A and B, Figures 4-7). In Closure B there are sharp conical constructions that are characteristic of volcanoes (Figure 4-7). In Closure A (Figure 4-8), the lithological cover of the exhumed mantle is startling.

A thick package (a few hundred metres) of strong, stratified, sub-parallel layered reflectors cover the exhumed mantle completely, in a large four-way closure. They strongly resemble carbonate beds, displaying clinoforms on the edges of the closure and several V-shaped collapse features (Figure 7). Massive, irregular structureless bodies occur at localised areas at the base and, especially, at the top of these stratified facies (Figure 4, 7 and 8). The deduced Albian age of these strata is favourable to the carbonate hypothesis, because of the well-known Albian carbonate platforms that are common throughout the eastern Brazilian offshore basins. Thermal subsidence that ensued after the cessation of rifting allowed the incursion of sea waters and provided increasing accommodation space in these basins. The encroaching seas are reflected under the form of a typical transgressive cycle, deposited during Early Albian to Coniacian. Albian carbonates developed during the first marine invasions into the Brazilian marginal basins. They started as shallow water oncolite grainstones, changing gradually into peloidal packstones/boundstones and carbonate mudstones, as the seas deepened.

Given the interpreted carbonate depositional environment and its Albian age, this upper massive structureless construction could tentatively be interpreted as a reef. A well-known reef-builder organism that thrived during the Albian were rudists. Rudists were bivalve mollusks, benthic marine organisms, constructors of very extensive and large reefs, that lived in tropical shallow seas during the Late Jurassic and Cretaceous (Neo-Tethys and Paleo-Pacific Oceans realms). They climaxed during the Albian and are famous for the numerous and voluminous reefs hosting large reserves of oil and gas in the Middle East and the Gulf of Mexico regions. Some reefs ran for hundreds of kilometres along the edge of carbonate platforms. They formed buildups that were hundreds of metres tall (Johnson, 2002). Their porosities and permeabilities are phenomenal.

In the past, these organisms were distributed along warm low paleo-latitudes, somewhat concentrated in boreal domains. Their presently known geographic distribution is somewhat confined to 40^0 North and 30^0 South latitudes. The southernmost reported occurrence of rudists is in Madagascar (30^0 South, Sha et al., 2020). The Ametista Prospect is situated at 27^0 South; thus, although unknown in the South Atlantic, the possibility of their occurrence in the Ametista Prospect is viable and cannot be eliminated. According to Johnson (2002) rudists larvae were dispersible and were carried along with plankton in surface currents, allowing them a cosmopolitan distribution.

The entire structural high is completely encased in thousands of metres of argillaceous Upper Cretaceous seismic facies providing an efficient seal to this unusual prospect. At the base of this Upper Cretaceous package, continuous, parallel and moderately strong reflectors denounce the presence of the ACT source rocks completely surrounding the entire structural high. As a result, the Ametista prospect presents all the items of the successful Cretaceous Marine Anoxic Shales-Albian carbonates (!) petroleum system.

Modern analogs

Figure 9 displays the 3D view of the Central High structure (with Closures A and B) compared to a modern atoll in the Pacific Ocean (with elevations A and B). The coexistence of volcanoes in Closure B of the Central High and carbonate packages in Closure A reminds us of the famous atolls of the Pacific Ocean. In particular, the Raiatea Atoll in Frech Polynesia is very similar in shape, size and composition to the Ametista atoll. While in Closure B and elevation B volcanism was active and carbonate deposition scant, Closure A and elevation A received shallow water organisms that created a wide carbonate platform and, later, a possible rudist reef. Just for the sake of correctness, elevations A in Figure 9 are also composed of volcanoes, different from what is suggested by us to Closure A (elevations of exhumed mantle without volcanism).

The prominent protrusion of exhumed mantle in the middle of a nascent sea functioning as a shoal to receive carbonate deposition also has a modern analog, in the island of St. John`s (or Zabargad) in the Red Sea (Figure 10). The island is composed of exhumed mantle rocks (Bonatti et al. 1981 and 1983, Abu El Rus 2007), surfacing in the middle of the young Red Sea, in a purely extensional environment. These mantle rocks are rimmed by carbonate platforms and reefs. This is exactly the environment envisaged for the Ametista Prospect (Closure A) in the Early Albian transgressive sea in the young Santos Basin. The protrusion of exhumed mantle must have functioned just as a guyot in the present Pacific Ocean; as a shallow water paradise for carbonate deposition.

The petroleum potential of the Ametista Prospect (Closure A) is very high given its size, the notable four-way closure, the presence of carbonates as reservoirs, the presence of a thick package of the ACT organic-rich shales surrounding and onlapping the structure and the very thick seal of Late Cretaceous argillaceous strata enveloping the entire four-way closure.

An alternative hypothesis

We also have an alternative hypothesis to the Albian atoll interpretation, still based on another carbonate lithology. These could be pre-salt carbonates, microbialites, travertines and

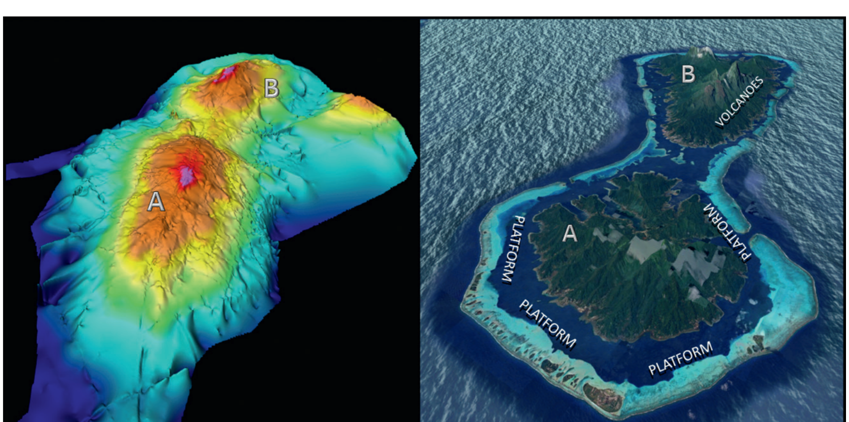

Figure 9 Left — 3D visualisation of Ametista Central High and of Closures A and B. Right — The analogy with the present-day Atoll Raiatea (Leeward Islands, French Polynesia) with elevations A and B (image from Google Earth Pro) is remarkable. The large carbonate platform surrounding elevation A in the atoll would correspond to our layered seismic facies in Closure A (Ametista Prospect).

Figure 10 Google Earth Pro images of St. John`s (Zabargard) Island in the Red Sea. The island is composed of exhumed mantle rocks (EM, outcrops indications based on Abu Le Rus, 2007). Carbonate platforms surround the mantle rocks and are rimmed by reef constructions/buildups, some of them displaying large proportions (arrows). This modern analog to Closure A demonstrates the plausibility of our hypothesis.

coquinas. Since there are no visible sedimentary grabens on top of the exhumed mantle and salt was never deposited on it, a syn-tectonic microbial platform could have developed during the continued exhumation of mantle during the late rifting phase/starting of thermal subsidence phase of basin development. The massive structureless facies could then be interpreted as travertines or coquina pile ups, like those found at the giant Mero and Búzios Pre-Salt fields. Different from a classic Pre-Salt prospect, the hydrocarbon charge would be from the ACT source rocks instead of from Barremian/Early Aptian lacustrine organic-rich shales.

Conclusions

The newly acquired and processed 3D NAZ dataset over Ametista block provides a step change in imaging of this part of Santos Basin. Whether the Ametista Prospect is a Post-Salt Albian atoll capped by a rudist reef (preferred interpretation) or a Late Aptian Pre-Salt microbialite platform, this promising prospect and associated petroleum system deserves a more detailed subsurface investigation and a drilling campaign to unlock the southern Santos Basin frontier.

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References

Abu El-Rus, M.M.A. [2007]. Plagioclase lherzolites from Zabargad Island, Red Sea, and their bearing on the evolution of lithospheric mantle beneath an embryonic ocean. *Proceedings of the Fifth International Conference on the Geology of Africa*, V-181–V-213.

Bonatti, E., Clocchiatti, R., Colantoni, P., Gelmini, R., Marinell, G., Ottonello, G., Santacroce, R., Taviani, M., Abdel-Meguid, A.A., Assaf, H.S. and El Tahir, M.A. [1983]. Zabargad (St. John's) Island: an uplifted fragment of sub-sea Red Sea lithosphere. *Journal of the Geological Society*, **140**(4), 677-690. https://doi.org/10.1144/gsjgs.140.40677.

Bonatti, E., Hamlyn, P. and Ottonello, G. [1981]. Upper mantle beneath a young oceanic rift: Peridotites from the island of Zabargad (Red Sea). *Geology*, **9**(10), 474-479. https://doi.org/10.1130/0091-7613.

Cvetkovic, M., Yong, S.L., Johnson, T., Armentrout, D., Brookes, D., Pralica, N., Ge, L, Soelistijo, B. and Baldock, S. [2023]. The value of uplift processing in frontier exploration basins – Offshore Brazil case studies. 84th EAGE Annual Conference and Exhibition, *Extended Abstracts*.

Deckelman, J.A., Chi, S., Hartwig, A.K., Reuber, K.R. and Fruehn, J. [2021]. The role of megaregional seismic data in Santos Basin pre-salt exploration and development. *AAPG Memoir*, **124**, 487–516.

Johnson, C.C. [2002]. The rise and fall of Rudist reefs. *American Scientist*, **90**(2), 148-153. DOI 10.1511/2002.2.148.

Sha, J., Cestari, R. and Fabbi, F. [2020]. Paleobiogeographic distribution of rudist bivalves (Hippuritida) in the Oxfordian-early Aptian (Late Jurassic-Early Cretaceous). *Cretaceous Research*, **108**, 104289. https://doi.org/10.1016/j.cretres.2019.104289

Zalán, P.V. [2024]. Remaining petroleum potential of Brazil – State of the art 2023. *Derbyana*, **45**. htpps://doi.org/10.14295/derb.v45.826