Amazing Ametista Prospect – Albian Atoll on Top of Exhumed Mantle, Santos Basin

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Introduction

The Santos Basin in southern Brazil is known to host 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 circa 4 million boepd. There are also oil and gas fields in the so-called "Post-Salt Plays". Numerous turbidite-hosted and carbonate-hosted fields/discoveries present much modest figures of reserves and production. The objective of this work is to present one quite amazing prospect in the Post-Salt Play.

The Ametista Prospect was identified due to the acquisition of a new high-quality 3400 km² 3D multi-client (MC) marine survey shot by TGS, that completely covered the Ametista Block (Figure 1). The seismic data was treated with the latest processing techniques. The prospect consists of a large buildup composed of stratified seismic facies exhibiting basin-edge offlaps/clinoforms, locally capped by a massive structureless construction, developed upon a protrusion of exhumed mantle (Figure 2). 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 (Figure 2). Considering the nearby geology, this buildup is interpreted as an Albian carbonate platform capped by a reef (rudists?). 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.

Seismic Data Acquisition and Processing

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 regularizing algorithms. Since several 3D surveys have been acquired in this area over the years, we also tried to match the data as close as possible 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).

Interpretation and Exploration Model for Ametista Prospect

With new and improved imaging, it is inferred that the basement of the prominent high shown in Figure 2 was a protrusion of exhumed mantle. This exhumed mantle was part of a V-shaped strong positive gravity anomaly, informally known as the Propagator (Figure 1). Ultra-deep seismic sections shot by ION in the late 2000's already showed this possibility (BrasilSPAN 2D survey). The Propagator was considered the end zone of a propagating crustal rupture, that evolved from South to North and ended up aborted sometime at the end of the rifting stage of the Santos Basin (Early Albian). The sub-cropping mantle arch is 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. Salt bodies onlap the flanks of the exhumed arch. Not only is salt absent, but also any graben typical of the Pre-Salt section (Figures 2, 4, 5, 6). The exhumation of the mantle seems to have occurred during the rift phase and continued into the thermal subsidence phase during the salt deposition. It seems that it always constituted a positive structural feature, impeding the deposition of any sediments on it. This backbone high (Central High) is divided into two structural closures (A and B, Figures 2, 3). In Closure B there are sharp conical constructions that are characteristic of volcanoes (Figures 2, 5). In Closure A, the lithological cover of the exhumed mantle is remarkable. A thick package (hundred meters) of strong, stratified, sub-parallel layered reflectors drape the exhumed mantle completely, and constitute a large four-way closure (Figures 4, 5, 6). They strongly resemble carbonate beds, displaying clinoforms on the edges of the closure and several V-shaped collapse features (Figures 4, 5). Massive, irregular structureless bodies occur at localized areas at the base and, especially, at the top of these stratified facies (Figures 2, 5 and 6). The deduced Albian age of these strata is favorable 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. One close example of such carbonates constituting producing oil fields lies in the nearby "String of Pearls" (Figure 1). A series of aligned small oil fields that produced oil and gas for decades and are a living proof that the Albian play is working in the area surrounding Ametista. In the area of Ametista Block, this protrusion of exhumed mantle, reminiscent of the rift phase, provided a shallow water environment in the invading sea, allowing the development of a carbonate platform.

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 kilometers along the edge of carbonate platforms. They formed buildups that were hundreds of meters 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 meters 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 Albian-Cenomanian-Turonian source rocks (ACT) 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 of the Santos Basin.

Modern and Ancient Analogs

Considering that the Ametista play described here is a novelty in Brazilian petroleum geology, it is advisable to search for analogs worldwide and to show similarities between them. Regarding modern structural/environmental analogs we turned our focus to atolls where large shallow seamounts allowed the coexistence of volcanoes and carbonate platforms/reefs. Figure 7 displays the 3D view of the Central High structure (with Closures A and B) compared to a modern atoll in the Pacific Ocean (with indicated elevations A and B). The coexistence of volcanoes in Closure B of the Central High and carbonate packages in Closure A can be compared to the Raiatea Atoll in French Polynesia, which is very similar in shape, size and composition to the Ametista paleo-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 some patch reefs. Just for the sake of correctness, elevations A in Figure 7 are also composed of volcanoes, different from what is suggested by us to Closure A (elevations of exhumed mantle without volcanism). Regarding the hypothesis of having a prominent protrusion of exhumed mantle in the middle of a nascent sea functioning as a shoal to receive carbonate deposition, a modern analog can also be pointed out. The island of St. John's (or Zabargad) in the Red Sea (Figure 7) 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.

There are also good analogs to Ametista Prospect in the geologic record, in successful similar exploratory targets that became significant discoveries of oil and gas. Figure 8 presents three such analogs. The Zohr field offshore Egypt is a super-giant gas field, discovered by drilling an obscure buildup mapped in vintage 2D seismic data. The field consists of stacked carbonate buildups developed upon an important regional structural high during the Cretaceous and the Miocene. Interestingly enough, the best Cretaceous reservoirs are Albian rudist reefs (Cozzi et al., 2028), just as proposed for the reef facies of the Ametista Prospect. The Malampaya field offshore Phillippines is a giant gas/condensate/oil field, composed of an Eocene/Miocene carbonate platform/coral reef buildup, developed on the crest of a tilted normal fault block. The overall shape and internal facies of the Malampaya buildup are strikingly like those of Ametista. In Guyana, ExxonMobil discovered a large oil field in the Ranger carbonate buildup, an Albian construction developed upon a volcano. As in Zohr, the Ametista Prospect is seismically much better defined than in Ranger.

Conclusions

Ametista Prospect is fully covered by modern 3D NAZ dataset. Its overall seismic definition (shape, extent, internal seismic facies, source rocks, seal, regional context) is crystal clear and amazingly challenging in terms of petroleum geology novelty, as here proposed. The hypotheses outlined regarding its composition and reservoir properties can be matched against several recent and past analogs. It can be stated that Ametista presents all the items pertaining to the successful Cretaceous Marine Anoxic Shales-Albian carbonates (!) petroleum system of the Santos Basin, and thus, a great probability of becoming a significant petroleum discovery in the near future.

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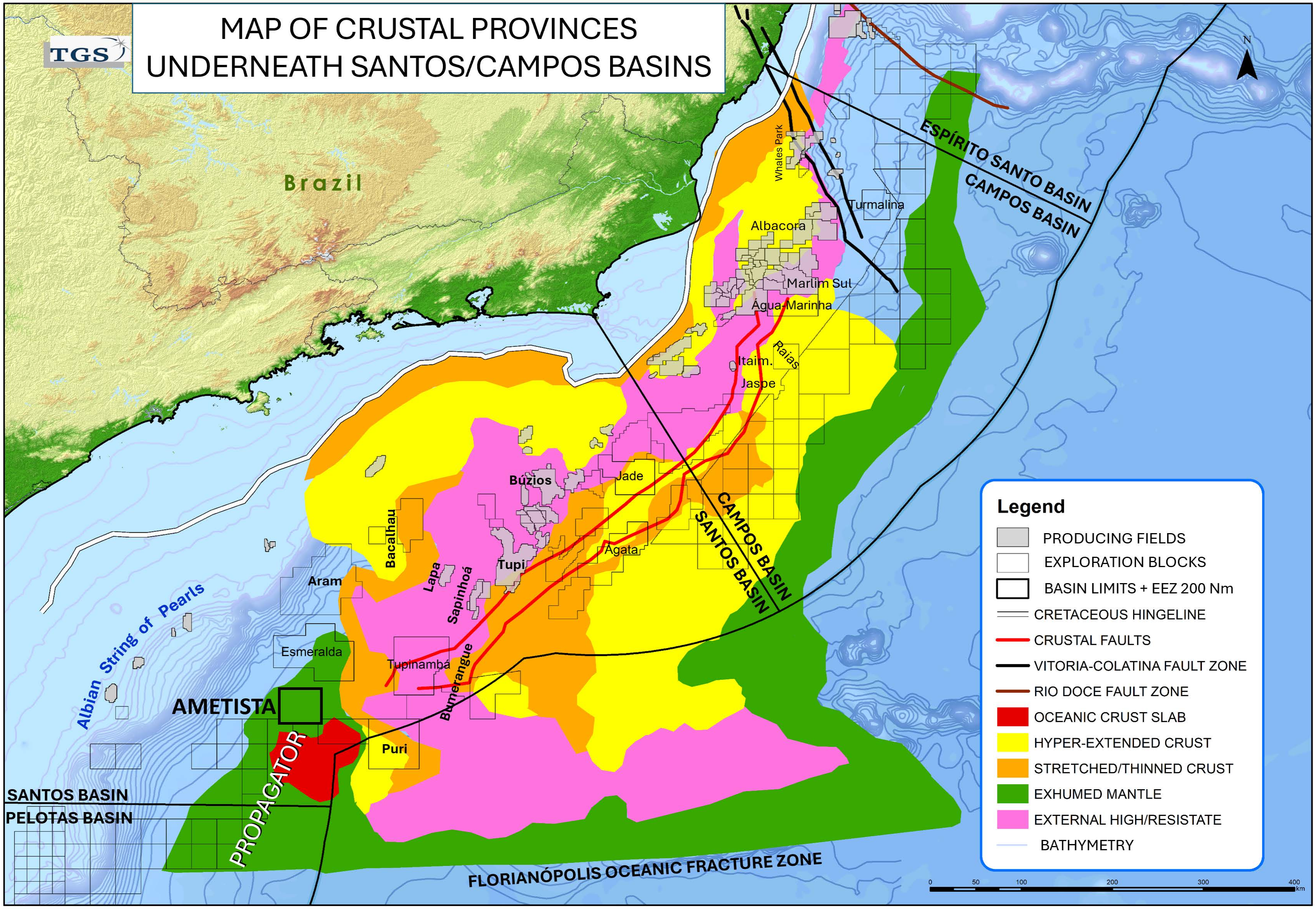

Figure 1. Location of Ametista Block on the map of the crustal provinces of the Santos and Campos Basins (modified from Zalán, 2024). Notice its special location upon the V-shaped tip of exhumed mantle (*Propagator*). *Albian String of Pearls* refers to several producing Albian age carbonate-hosted oil and gas fields. Major Pre-Salt fields and exploration blocks highlighted.

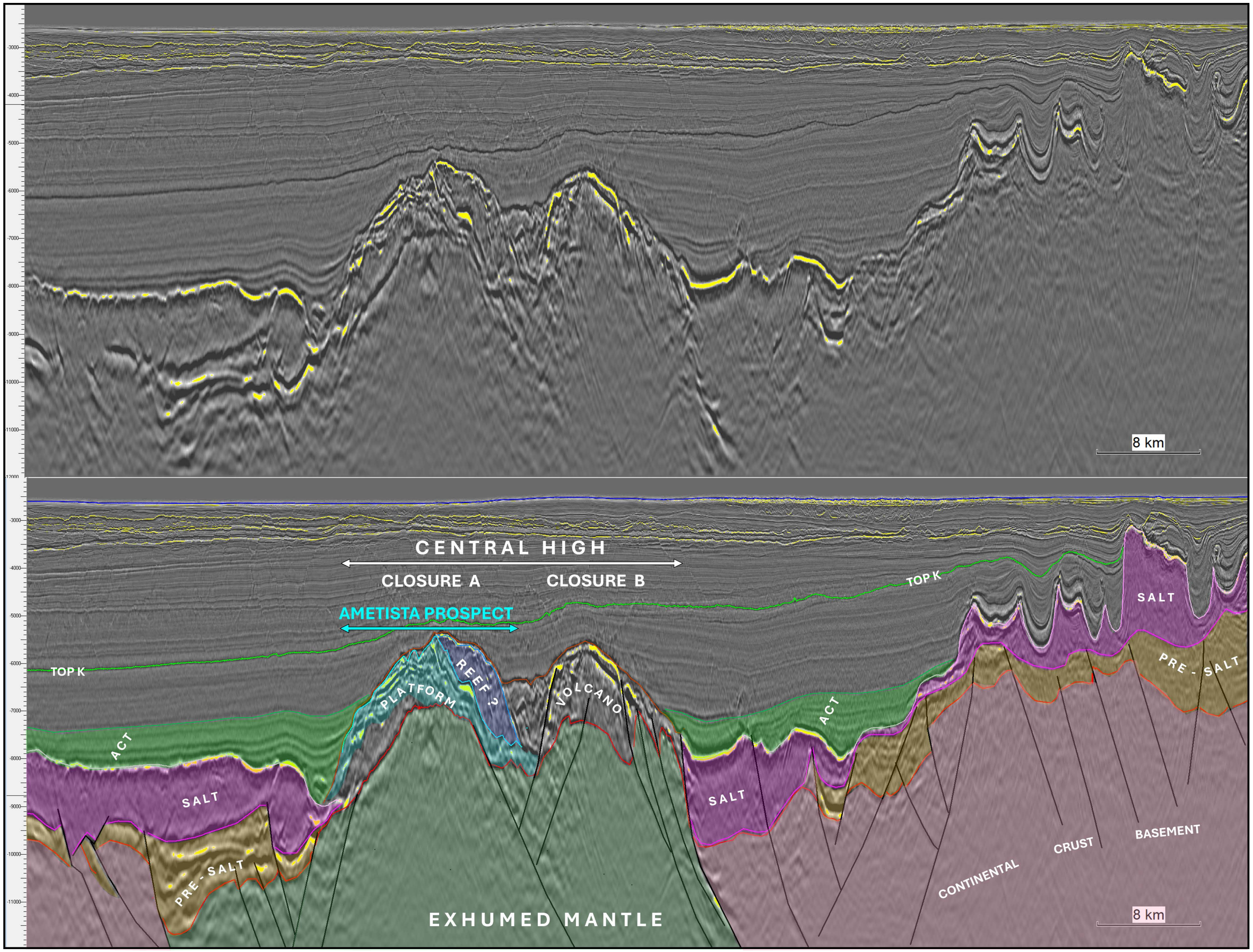

Figure 2. 3D KPSDM (m) section crossing Ametista Block displaying the Central High developed upon a protrusion of exhumed mantle. Two structural closures (A and B) define this high. Closure A presents a large buildup constituted by stratified seismic facies (platform) capped by a massive structureless 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 as the ACT source rocks (from Zalán et al., 2025).

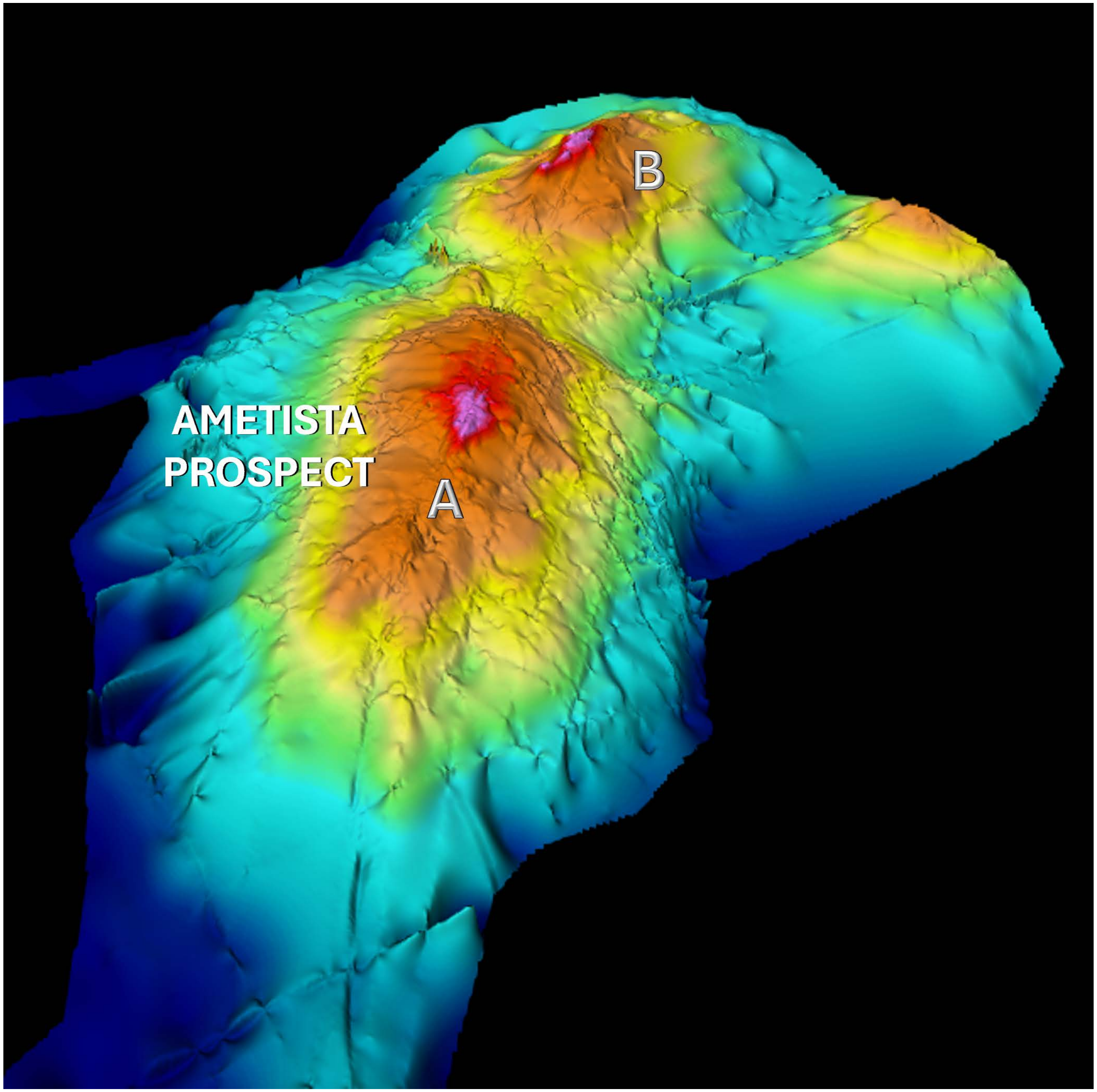

Figure 3. 3D visualization of Ametista Central High and of Closures A and B. Closure A constitutes Ametista Prospect.

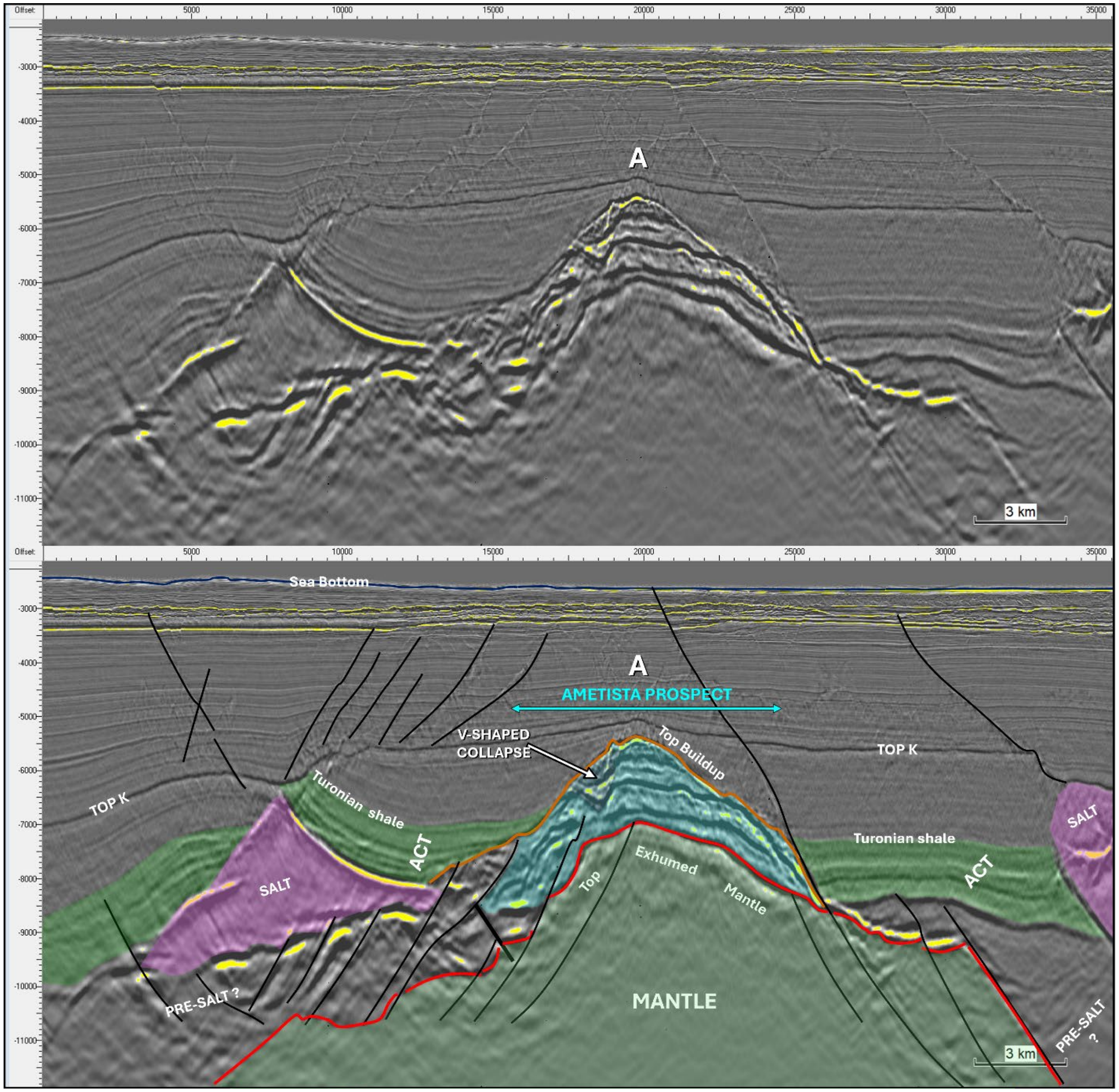

Figure 4. 3D KPSDM (m) section crossing Ametista Prospect displaying the stratified nature of the buildup facies (in blue), as well as a V-shaped collapse feature characteristic of carbonate terrains. Notice the direct lateral contact between the buildup and the ACT source rocks (green), highly favorable for hydrocarbon migration into the prospect.

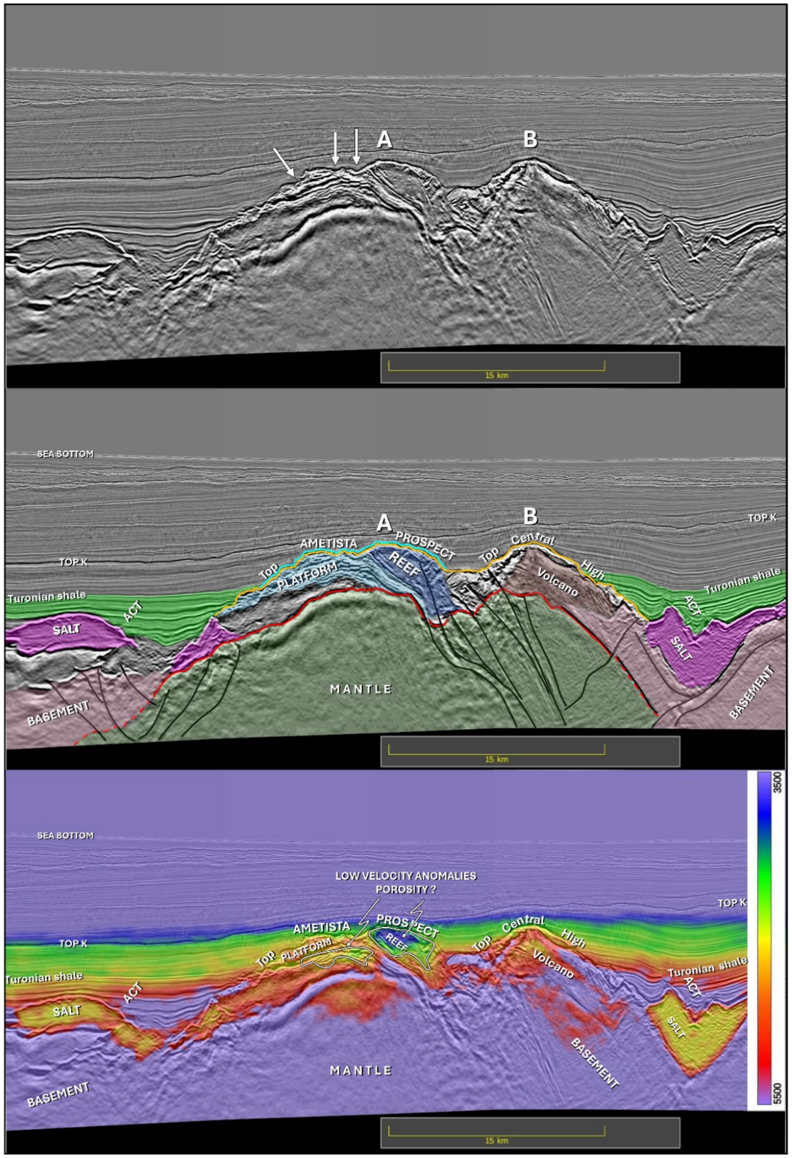

Figure 5. 3D KPSDM (m) longitudinal section crossing Closures A and B at Ametista Central High. Non-interpreted, Interpreted, Velocity Overlay. Closure A displays stratified seismic facies (sub-parallel layered reflectors) (carbonate platform); capped by a massive, structureless facies, here interpreted as a possible 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 (from Zalán et al., 2025).

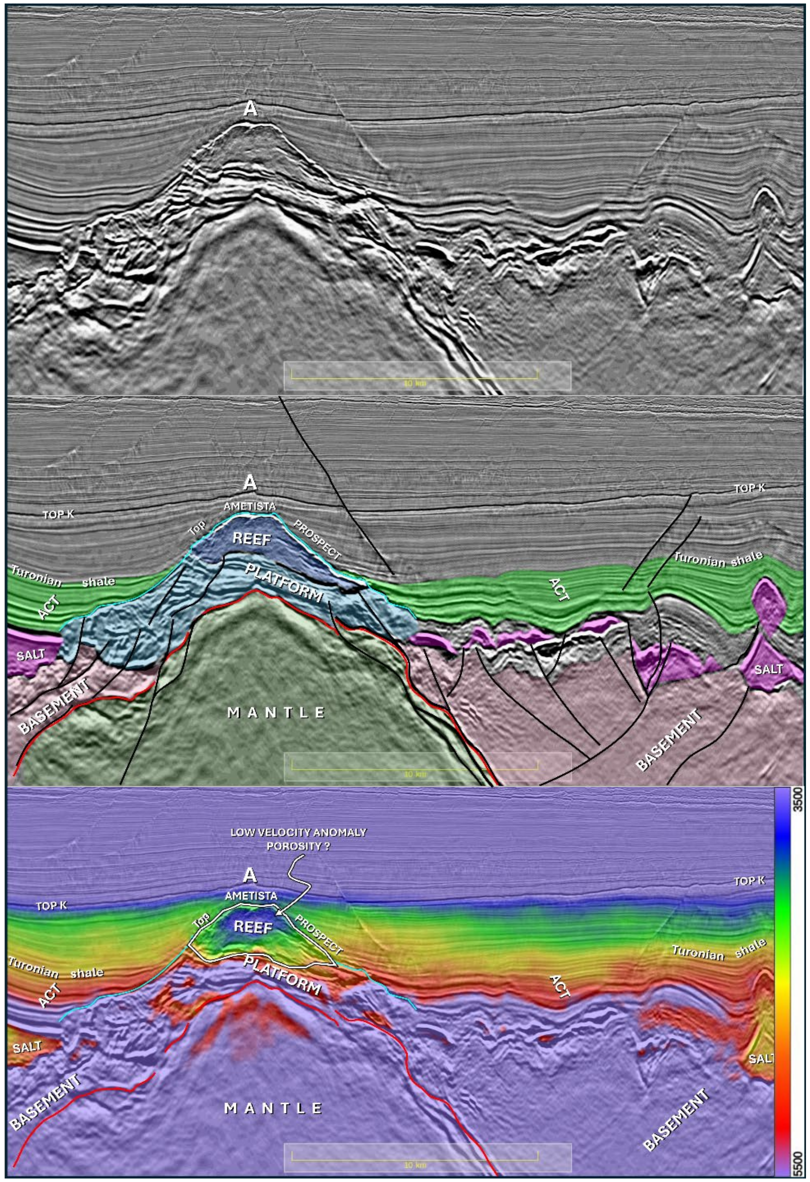

Figure 6. 3D KPSDM (m) transversal section crossing Closure A at Ametista Central High. Non-interpreted, Interpreted, Velocity Overlay. Closure A displays a stratified seismic facies (sub-parallel layered reflectors) (carbonate platform); capped by a massive, structureless facies (reef) of several hundred meters thick. Striking low velocity anomaly within the reef facies may indicate porous lithologies, corroborating the presence of reservoirs (from Zalán et al., 2025).

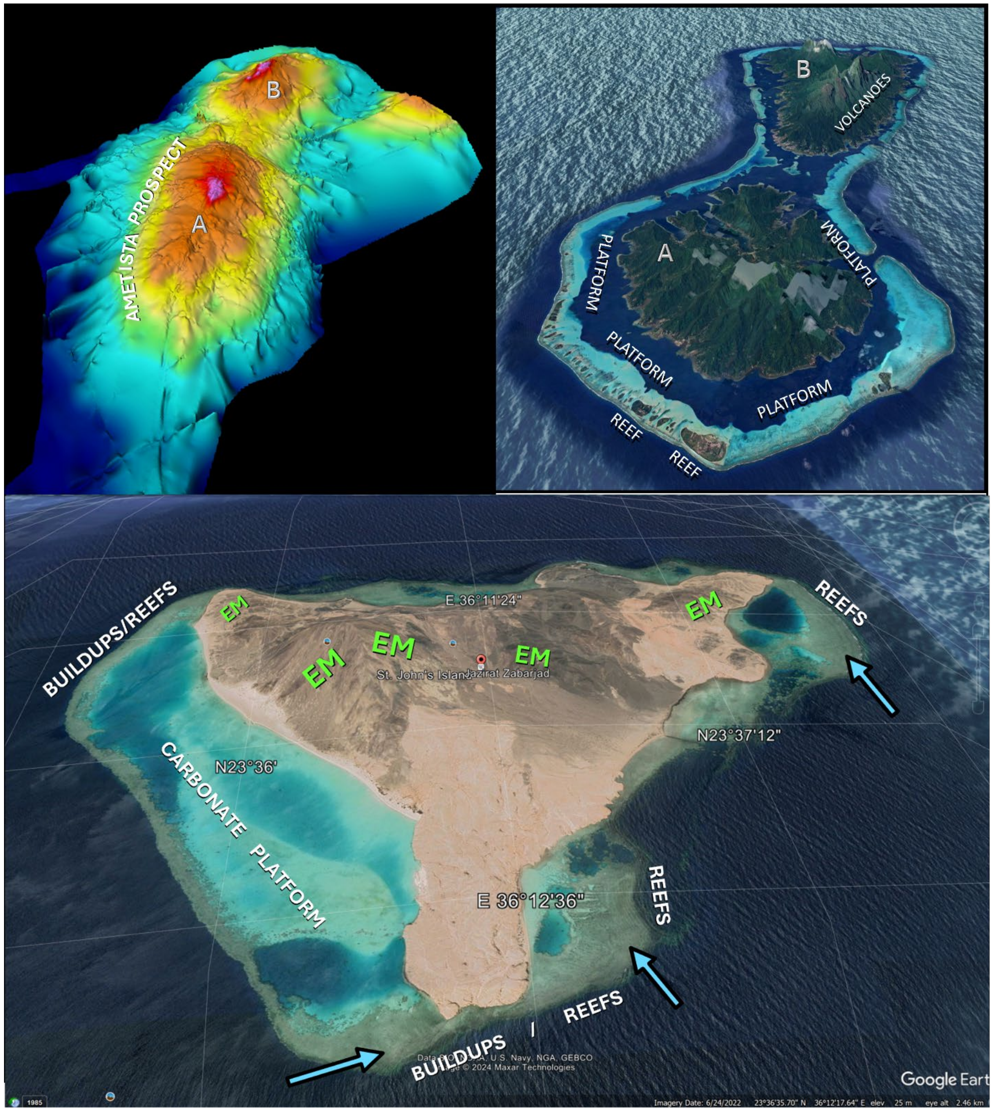

Figure 7. Comparison of Ametista Prospect (top left) to possible analog Atoll Raiatea (Leeward Islands, French Polynesia) (Google Earth Pro image) (top right). The analogy with the present-day atoll with elevations A and B is remarkable. The large carbonate platform surrounding elevation A in the atoll would correspond to our layered seismic facies in Closure A (Ametista Prospect). Google Earth Pro image of St. John's (Zabargard) Island in the Red Sea (bottom). 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.

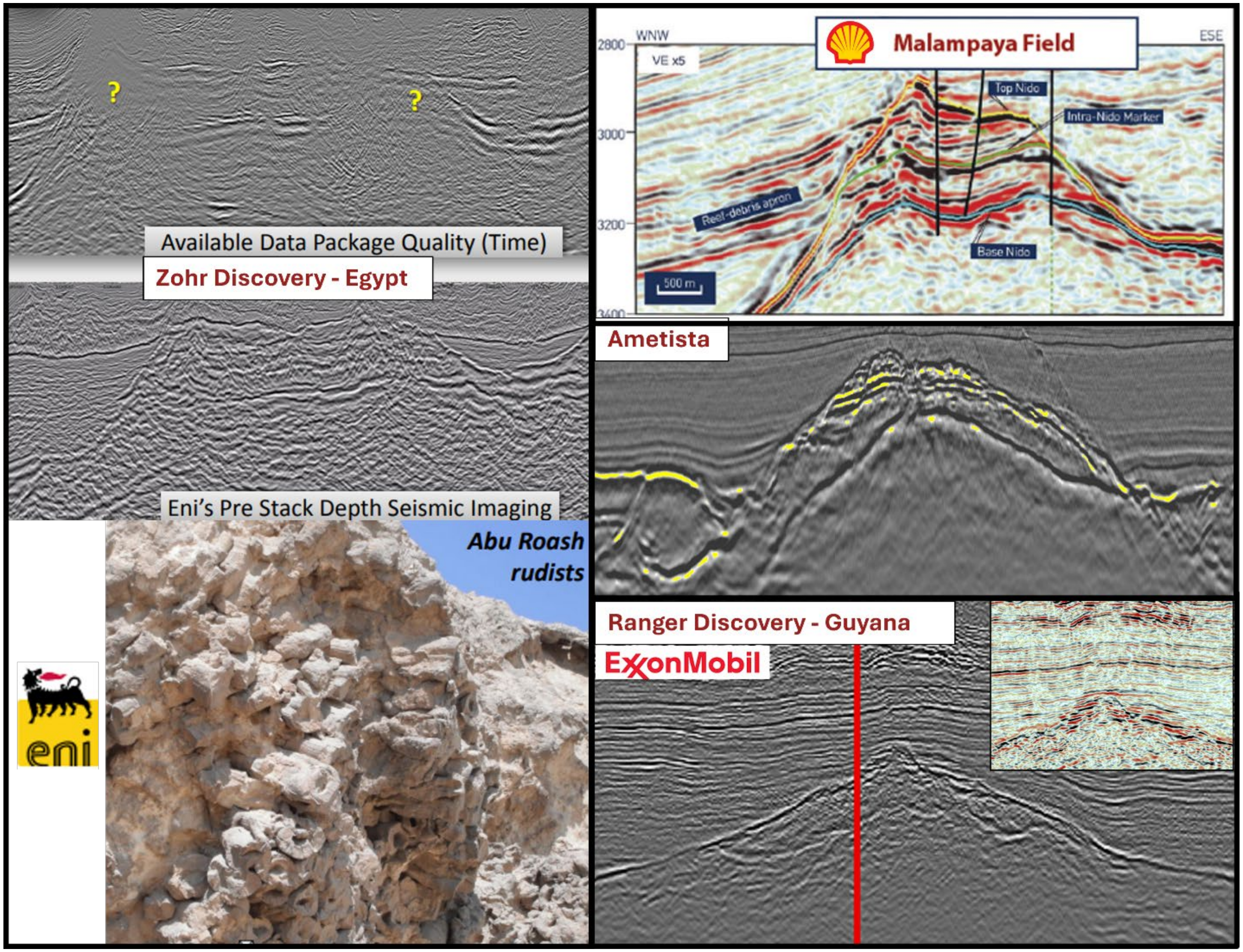

Figure 8. Comparison of Ametista Prospect buildup to well-known significant discoveries of oil and gas in carbonate buildups, developed on top of bathymetric highs amidst paleo-oceans, that served as shoals for the carbonate environment. The Zohr field was discovered with the use of 2D data, such as shown, displaying an ill-defined composite buildup developed upon a trend of structural highs. Rudist reefs compose some of the reservoirs in the Albian section of the buildup (adapted from Cozzi et al. 2028). Malampaya field, in the Philippines, is a clear Eocene/Miocene carbonate buildup developed upon a distinct structural high (from Hedley, 2020). Ranger oil discovery in Guyana is an Albian carbonate buildup developed upon a volcanic edifice.