Mapping sills and dikes integrating magnetometric and seismic data on the Amazonas Basin.

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This paper was prepared for presentation during the 18th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 October 2023.

Abstract (Font: Arial Bold, 9)

The Brazilian Paleozoic basins have been challenging for onshore hydrocarbon exploration for many years. Recently, the Gas Production on the Parnaíba and on the Amazonas basins have triggered new exploratoty campaigns and increased interest on them once again. Their size and the occurrence of igneous intrusions and lava flows that overlies the sedimentary succession damage seismic imaging. To overcome these challenges, this study proposes an integrated use of airborne magnetometric data and 2D seismic lines to map sills occurrence domains and dikes on a regional scale. In the Amazonas Basin, Pre-Albian unconformity intercepts different sills levels on seismic lines. The intersection of the PA unconformity and tip of sill levels can be clearly seen on the 2D seismic data. On a map view, the ASA data shows that low- and high- frequency domains on a regional scale. Integrating seismic lines and the ASA data on a map view, four domains were mapped. The domains were divided based on the number of sills that occur and the relative ASA frequency.

Introduction

The Brazilian Paleozoic basins have been challenging for the seismic data acquisition to interpretation, and consequently, to subsurface geology understanding and hydrocarbon exploration. One of the main challenges is the occurrence of igneous intrusions and lava flows that overlies the sedimentary succession and damage its imaging on seismic data. In addition to that, lateral variation of igneous rocks thickness generates complex time to depth conversion of seismic lines that may cause pull-ups or push-downs of potential hydrocarbon accumulation structures. To shed light on this topic, this study proposes an integrated use of 2D seismic line with airbourne magnetic data to regionally map igneous intrusions domains and features.

2D Seismic data are mostly used to map horizontal features along a section. On the other hand, airbourne magnetometric data are better used to map horizontal variations on a map view. Gathering the best use of these two geophysical methods, this study integrated them to map sills and dikes on the Amazonas basin. In areas of sparce 2D seismic lines, the proposed integration in this work is a tool of great use to extrapolate 2D seismic line data using the magnetometric data in a map view. The area of study is focused on the central part of the basin where the current bided exploratory blocks and the only producing gas field of the basin is located (Azulão Gas Field) (**Figure 1)**. The Amazonas basin petroleum exploration have been frozen for many years and is now alive once again with a producing gas field and new gas and oil discoveries. The aim of this work is to apply integrated geophysical methods on a regional scale to better understand the subsurface geology of the hydrocarbon prolific central part of the Amazonas Basin.

Geological Setting

The Amazonas Basin is an elongated paleozoic cratonic basin located on the northern region of Brazil. The igneous-sedimentary succession reaches up to 5km and range from the Ordovician to the Tertiary and can be divided into two main Megasequences, the Paleozoic-Mesozoic and Mesozoic-Cenozoic Megassequences. The youngest Megasequence comprises the Monte Alegre, Itaituba, Nova Olinda and Andirá formations (Cunha *et al.* 2007). In the area of study, these formations are associated with most hydrocarbon shows and accumulations on the central part of the basin. After the Andirá Formation deposition, a major erosive and non-depositional event occurred, and the next preserved sediment is only of cretaceous age. Within this time interval, from ca. 242 Ma to 120Ma, the CAMP event ca. 201Ma and Mesozoic Tectonic events occurred (Cunha *et al.* 2007; Davies *et al.* 2017). The igneous rocks occur as sills and dikes. The last occur mainly in N-S direction with some inflections to NNW and NNE directions and the first as concordantly intrusions along stratigraphic levels. The current knowledge of the basin suggests that there was no sedimentary record in the basin for 122 Ma and it has generated the Pre-Albian (PA) unconformity that mostly erodes the Andirá and Nova Olinda formation and its hosted igneous intrusions. This major unconformity is overlain by Mesozoic-Cenozoic Megassequence which is composed of the Alter do Chão, Solimões and Marajó formations. Significant Cenozoic tectonic events occurred in different structural domains (Costa, 2002).

The area of study is in the north flank of the basin, between the central trough and the basement, where the paleozoic formations dips in low angles. Regarding the structural framework, Cenozoic structures may occur in different settings and intensities. The PA unconformity is a guide horizon to observe Cenozoic structures. From W to E, it may be absent where the pre-Albian unconformity is not deformed; reactivate NE-SW Mesozoic structures where faults deforms the PA unconformity; and occur as positive flower structures associated with NE-SW faults close to the Urucará transpressive fault system (Costa, 2002).

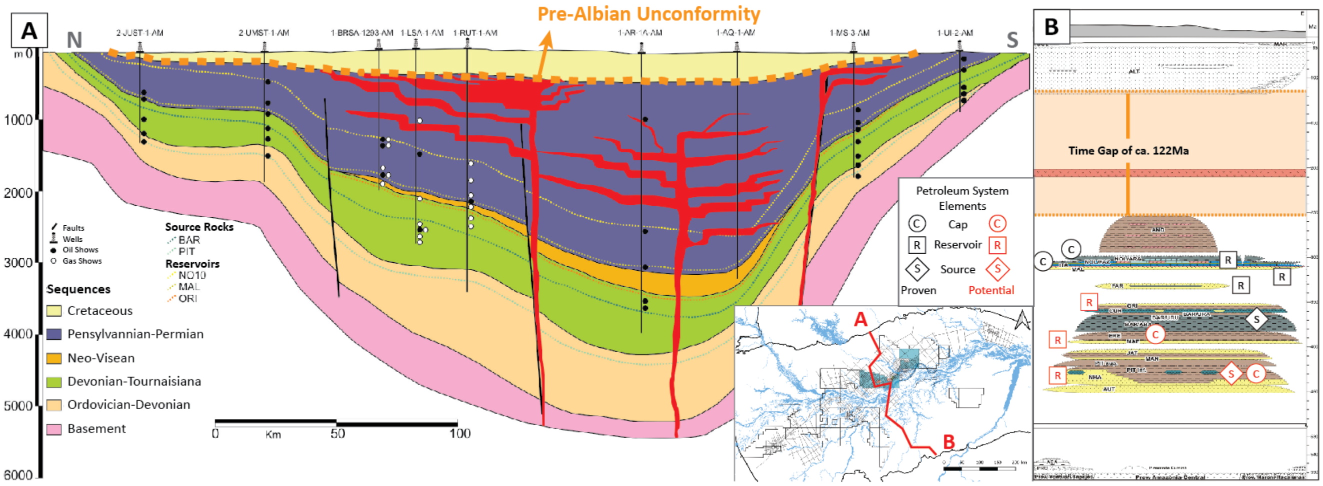


Figure 1. A) North-South Geological Schematic Section highlighting the Pre-Albian Unconformity (Orange dashed-line). **B)** Geological Chart with the main petroleum system elements and the time interval associated with the PA Unconformity.

Method

The airbourne magnetometric data used in this work (0401_MAG_apr111_Amazonas) were made available by ANP (Brazilian National Agency of Petroleum, Natural Gas and Biofuels) and was acquired by ENCAL SA in 1985 hired by Pecten Brazil Amazon Exploration as part of the Médio Amazonas – Block 1 (Project Number 4038). The flight and tie lines spacing were 2km in N-S direction and 6km in E-W direction, respectively. The data were gridded using a Bidirectional grid, a cell size of 500m. Than a Cosine Direction correction of 0° azimute and function of 2 was performed to remove oversampling effect along the flight lines. A quality control was done to make sure that N-S geological features were not removed. A differential reduction to pole was applied using an amplitude correction of 45º to avoid deformations on the borders of the survey. To enhance the features of interest, first and second order vertical derivatives, tilt derivative and analytical signal amplitude maps were generated using Oasis Montaj from Geosoft. The seismic line interpretation was done using 2D lines that were made available by ANP and that was internally reprocessed by Eneva SA. All products were compared to the seismic data to empirically see which presents the best match of vertically centralizing the magnetometric data. A schematic workflow is presented on Figure 2 highlighting the products used for interpretation. The analytical signal amplitude was the best to map magnetic domains and the tilt derivative to map lineaments.

Results

The sills can be classified based on the host stratigraphic level they are emplaced. From the shallowest to the deepest, they are sequentially named 0, 1, 2 and 3. The last two concordantly intrudes stratigraphic levels and present a homogeneous thickness. The first two represent a group of thin discontinuous sills that are intercalated with sediments and that are hard to be distinguished on a regional scale.

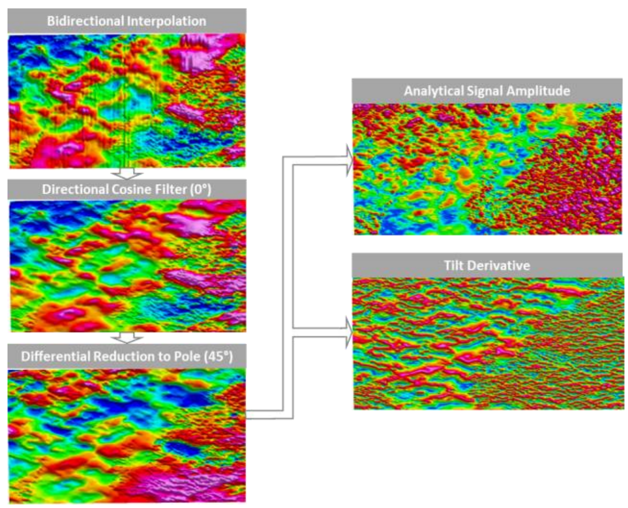


Figure 2. Simplified Worflow of Airbourne Magnetic Survey Data Processing.

All sills are intruded into the Nova Olinda and Andirá formations which are overlain by the Pre-Albian angular unconformity. The Nova Olinda and Andira formation stratas dips in very low angles to SE. As the PA unconformity is marked by a horizontal discontinuity, the Nova Olinda and Andirá formation sediments and sills hosted along stratigraphic levels are eroded toward the NW. The intersection of the PA unconformity and tip of all above mentioned sill levels can be clearly seen on the 2D seismic data. On a map view, the ASA data shows that low- and high- frequency domains on a regional scale. Integrating unconformity-sill tip points over a few seismic lines and the ASA data on a map view, four domains were mapped (A, B, C and D – Figures 3 and 4). The domains were divided based on the number of sills that occur and the relative ASA frequency. They are limited where the PA unconformity intercepts a sill tip.

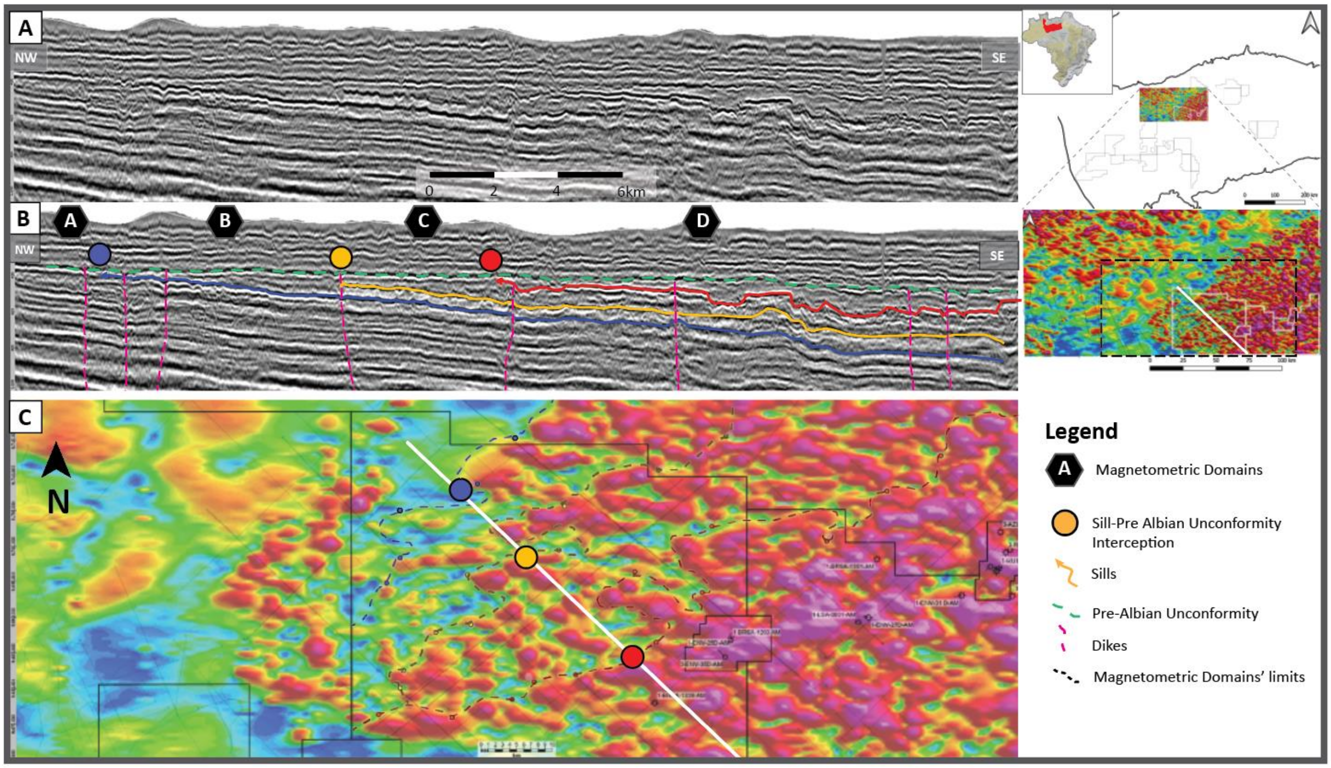
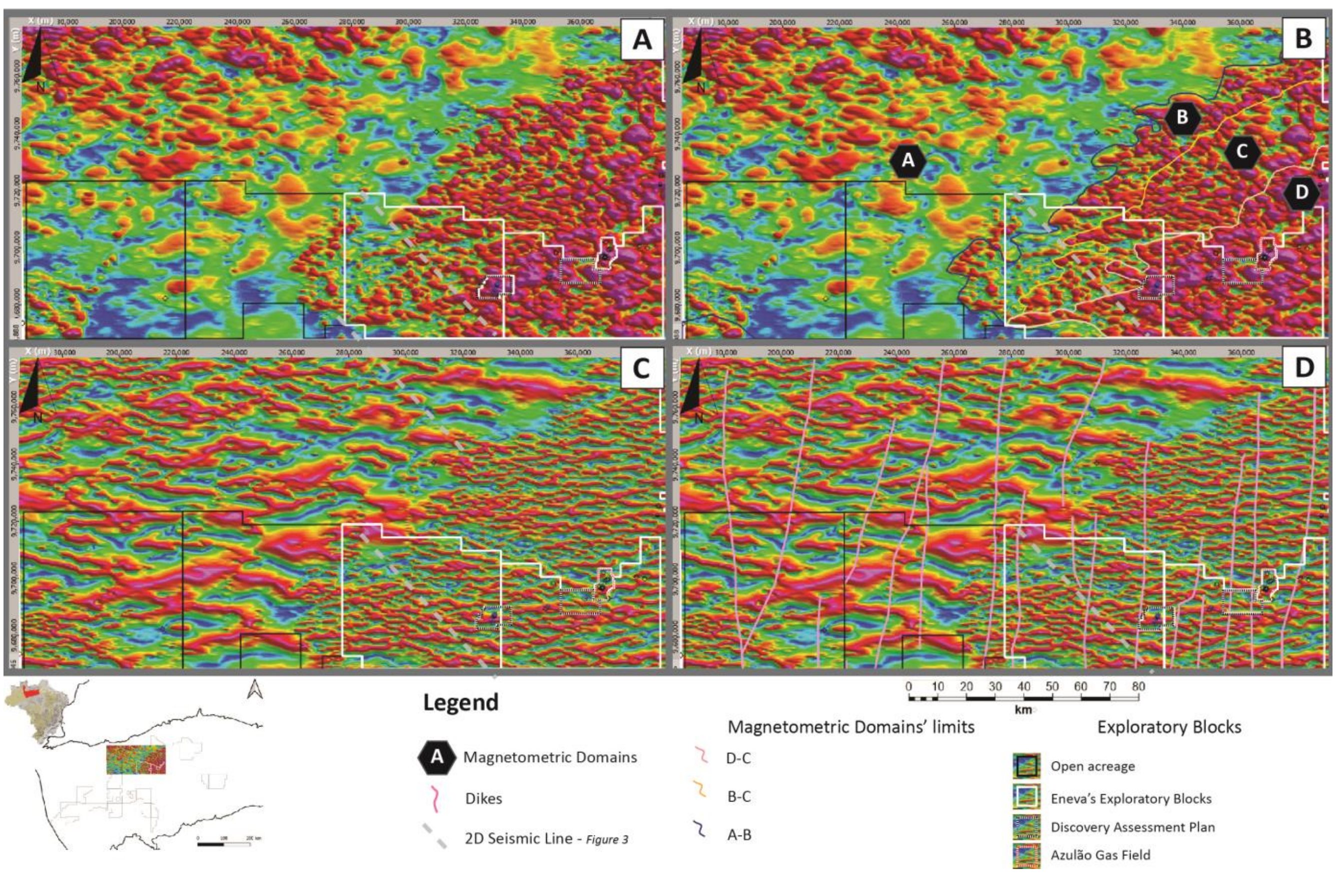


Figura 3. A) Seismic line in time. **B)** Seismic line with interpretation **C)** ASA map with interpretation.



Domain A is marked by a very low frequency on the ASA data and no sills on seismic and well data. Domain B is marked by a relative medium frequency and only the sill 3 occurs. Domain C comprises the area where sills 2 and 3 occur and present a relative high frequency on the ASA data. Domain D is where all sill levels occur and present the highest frequency domain.

The dikes are harder to be seen on both seismic and airborne magnetometric data due to its vertical geometry. However, dikes can be recognized by their lack of reflection along a vertical zone on 2D seismic lines. On the magnetometric data, very high frequency N-S features cuts low frequency highs on the Tilt-Derivative data. The greater number of sills, higher is the background frequency. Therefore, it is harder to map N-S features where many sills occur using Tilt-Derivative data (e.g. Domains C and D area)—. However, major N-S lineament zones can be mapped over the Tilt-Derivative data.

Conclusions

Every method has its positive side and its limitation. When it comes to geophysical or any indirect measurement methods, using and integrating the best of each method is the best way to decrease each method uncertainty and limitation. The 2D seismic lines allowed us to pick unconformities and sill tips interceptions and dike features on cross-section view. However, the sparse and open irregular grid make it hard to connect seismic line data. On the other way, airborne magnetic survey is a great tool to map the different igneous rocks domains and lineaments directions on a map view. However, almost no vertical interpretation can be directly done using it. When both methods are integrated, the sparse 2D seismic data can be extrapolated on a map view using the magnetometric data and the later can be better interpreted by using the vertical information provided by the first. On a regional scale, the integration of both proved to be useful to map domains and lineaments on the Amazonas Basin. On future studies, this methodology can be used on greater and finer scale and be complemented by gravimetric and potential methods inversions models to better understand the igneous rocks complex geometry and thickness variation.

Acknowledgments

The authors would like to thank Eneva SA to allow the present study to be public.

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