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Geophysical characterization of the Jacutinga Fault Zone in the Paraná Basin: evaluation for fluid percolation in the Serra Geral Basalts.

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Abstract

The study focuses on the geophysical characterization of the Jacutinga Fault Zone (JFZ) in the central Paraná Basin using magnetic and structural data. The integrated analyses of aeromagnetic maps and 2D seismic data revealed the existence of a wide ENE-striking positive magnetic lineament, which represents the JFZ. The association between the magnetic lineament, indicative of magmatic sources at various depths, and the JFZ suggests that it acted as a conduit for the magmatism of the Serra Geral Group. The structural depth maps shows two distinct compartments: a deeper north-western block and a shallower south-eastern block, separated by the magnetic lineament and its related JFZ. Therefore the seismic and magnetic evidence the tectonic compartmentation of the study area, probably caused by reactivations of the JFZ.

Introduction

The emission of greenhouse gases such as carbon dioxide (CO_2) into the atmosphere is a major contributing factor to climate change. The reduction of CO_2 in the atmosphere can be achieved through the process of geological storage involving *in situ* mineralization of basalts leading to the formation of stable carbonates (Raza et al., 2022). The aquifers can also contribute to mitigating the climate change by using geothermal energy to reduce CO_2 emissions, as well as the capture and storage of emitted CO_2 (Epting et al., 2023). It is well known that structures on aquifers have a significant impact on fluid percolation routes, which study is useful to ascertain the carbon capture and storage capacity of an area. The first step for its evaluation is the geophysical characterization of deep structures and their relationship with permeability pathways for fluid migration.

The Paraná Basin is a Paleozoic intracratonic basin filled with volcanic and sedimentary rocks in southern Brazil (Figure 1). The basin has undergone a complex tectono-stratigraphic evolution, resulting in NE-SW- and NW-SE-striking structures, as well as secondary E-W structures (Zalán et al., 1991; Besser et al., 2021). The study area (Figure 1) encompasses the Neoproterozoic NE-SW-trending Jacutinga Fault Zone (JFZ), first reactivated as a sinistral transpression and later as a dextral extensional transcurrent system in the Serra Geral magmatism (Rostirolla et al., 2000). The Serra Geral Group (SGG) is characterized by a high volume of mafic rocks with different porosity and permeability and is located close to important industrial centers, demonstrating a potential for future carbon capture and storage (Pelissari, 2022; Rosenqvist et al., 2024).

This study is a preliminary geophysical characterization of a target area for carbon storage in the central Paraná Basin (Figure 1). We applied a seismic interpretation and magnetic mapping to investigate basement faults and the structural compartmentation of the Paleozoic basalts of SGG and sandstones of Taciba Fm., as well as exploring its implications for the geological storage of CO_2.

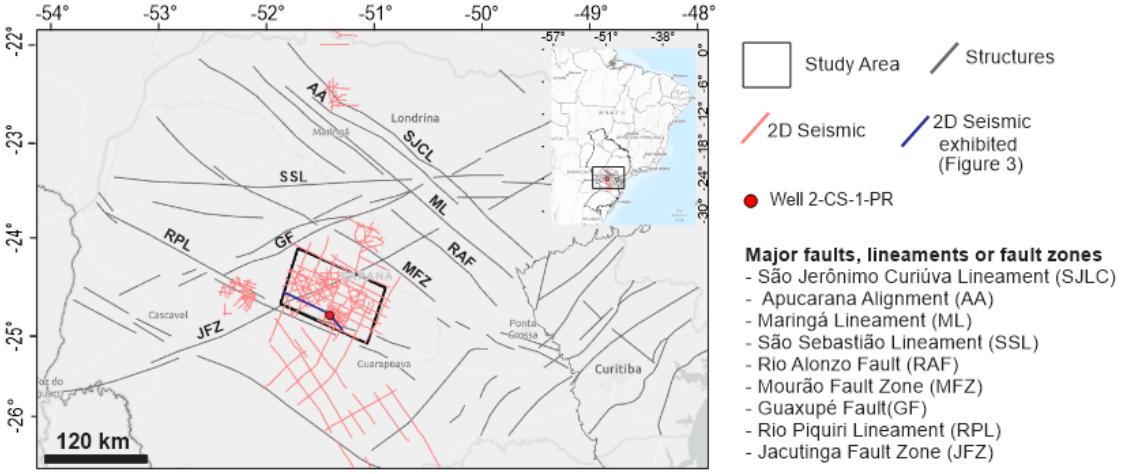

Figure 1: Regional structural sketch of the Paraná basin (modified from Besser et al., 2021).

Methods

This study developed an integrated analysis in the central Paraná Basin, using aeromagnetic maps associated with 2D seismic reflection data as the primary analytical tool. The public database is from CPRM (Geological Survey of Brazil) and the National Agency for Petroleum, Natural Gas and Biofuels (ANP). We knitted together several magnetic surveys and performed the first vertical derivative and the upward continuation filters using Geosoft® software.

We interpreted time-migrated 2D seismic reflection data using Petrel® tied to the well 2-CS-1-PR tied (Figure 2). The structural depth maps were integrated with magnetic maps for constraining the regional trends.

Results and discussions

The total magnetic anomaly map (Figure 2) upward continued at 5 km (A), the total magnetic anomaly map (B); and its first vertical derivative (c) display an ENE-striking positive magnetic lineament in its central portion. Its signature in all maps indicates that it is associated with sources (probably magmatic) at both deep and shallow depths (Fig. 2A and C respectively) and encircled by regions of positive magnetic anomalies. This magnetic lineament coincides with the tectonic contour corresponding to the JFZ.

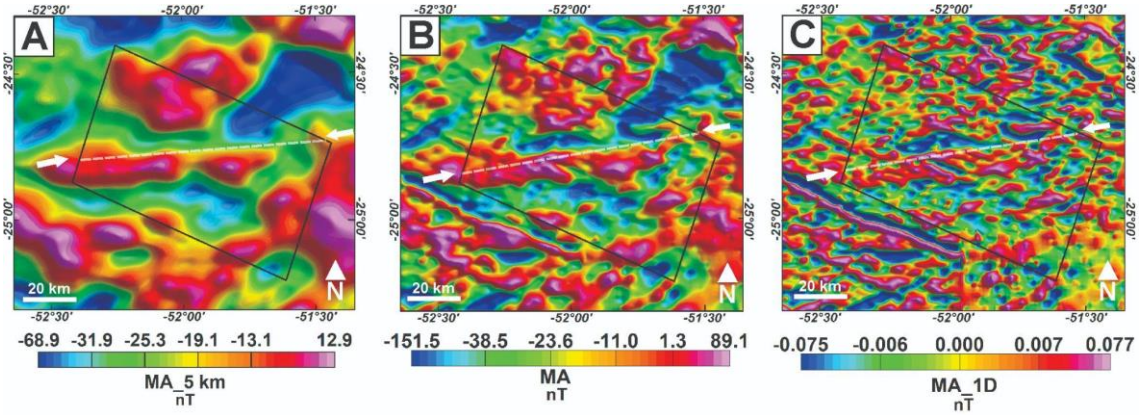

Figure 2: Magnetic maps of the central Paraná Basin, (black rectangle shows the study area). A) Total magnetic anomaly map upward continued at 5 km; B) Total magnetic anomaly map; C) First vertical derivative of the total magnetic anomaly. The white arrows and white line indicate the position of the JFZ.

As illustrated in Figure 3, the structural contour maps of the top basement (A), top Taciba Formation (B), and base of the Serra Geral Group (C) reveal the presence of at least two compartments distinguished by different depths. The seismic section (Figure 3D and 3E) displays normal faults of the JFZ with different throws that affect all the mapped horizons in the area. The northwest compartment is characterized by a greater depths while southeast is distinguished by comparatively shallower depths. The compartments limit corresponds to the positive magnetic lineament associated with the interpreted JFZ.

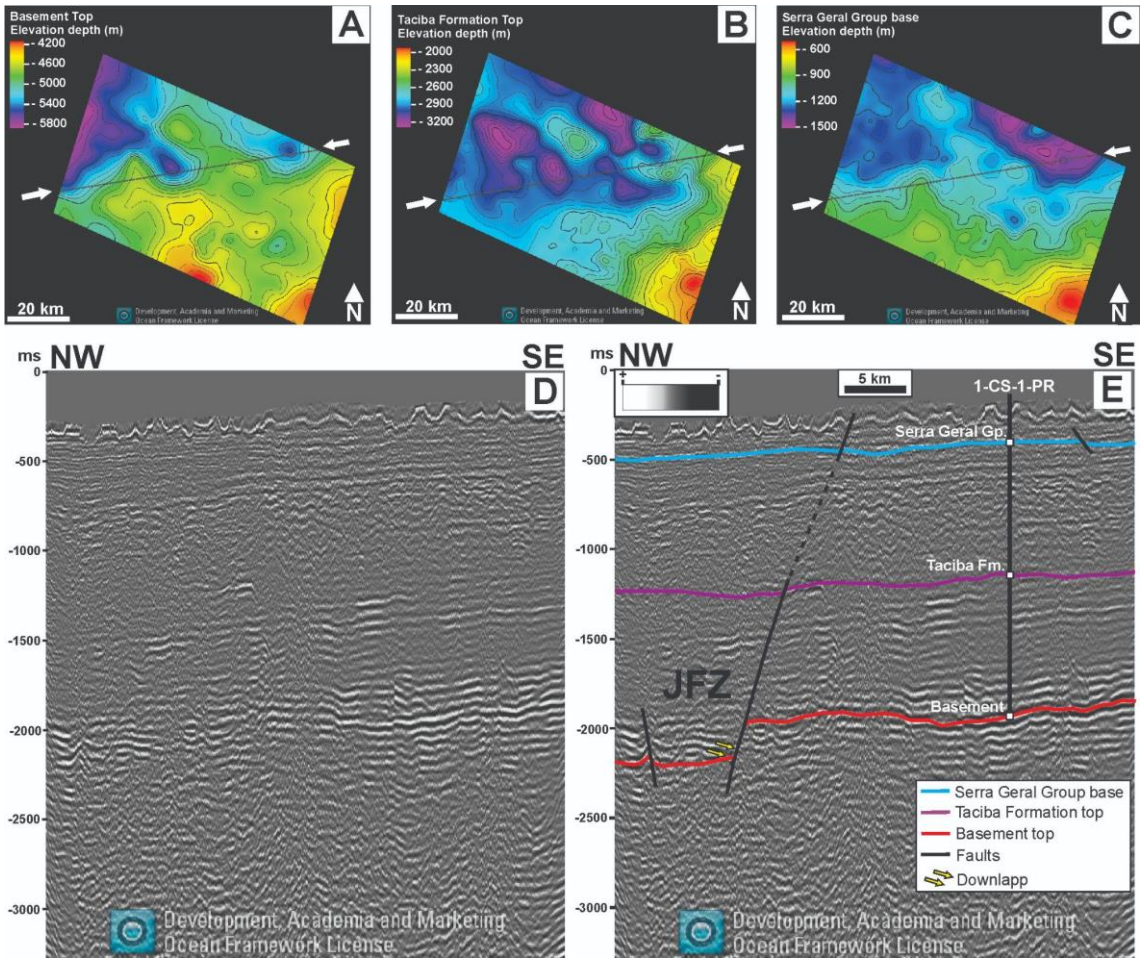

Figure 3: Structural contour maps and the seismic section. A) Top Basement contour map; B) Top Taciba Formation contour map; C) Base Serra Geral Group contour map. It is important to note the structural high to the southeast, as well as the structural low to the northwest.. D) 2D seismic reflection line uninterpreted and E) interpreted. The white arrows and black line indicate the position of the JFZ. See Fig. 1 for seismic profile location.

The association of the interpreted JFZ (Fig. 2A) with the positive magnetic lineament suggests that this fault system acted as a conduit for the magmatism of the SGG. The contour maps and the seismic section (Fig. 3) evidence an apparent vertical movement between the northwest and southeastern blocks, and that JFZ was active until the top of Serra Geral. Previous works show that the northeastern prolongation of the JFZ displays open fissures and fluid percolation creating an aquifer (Rostirolla et al., 2000). Thus there are evidences of multiple reactivation of the Jacutinga Fault Zone, which resulted in the collapse of the northwestern compartment leading to the subsequent relative uplift of the southeastern compartment.

Preliminary conclusions

The integrated analysis of magnetic and seismic data allows us to recognize the JFZ as an active and fundamental tectonic structure in the geological evolution of the studied area. The coincidence between the positive magnetic lineament and the JFZ indicates that this fault zone acted as a route for ascending magma during the events associated with the Serra Geral Group.

The structural maps and seismic section reveal the existence of two compartments with different depth levels, separated by this important fault zone, suggesting multiple phases of fault reactivation.

The JFZ played a key role in the structural compartmentalization of the region, exerting control on the magmatism and the formation of hydrogeological systems, related to its tectonic dynamics.

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