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A Simplified Approach to Structural and Velocity Modeling in Serra Geral Group, Paraná Basin

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Summary

This study presents methodologies for building structural and velocity models along a 2D seismic line in the Paraná Basin, Brazil, aiming the improvement of subsurface imaging sub-basalt events. The models integrate seismic data, well logs, and field observations, ensuring geological consistency in regions affected by large-scale magmatism. There are explicitly included key features such as sills, dykes, and intra-basalt low-velocity (LV) vesicular zones, which have significant effects on seismic wave propagation. Three wells supported the seismic interpretation and provided data to a proper assignment of layer properties. Homogeneous velocities were assigned by layer, and it was adopted specific values for LV zones, magmatic intrusions as well as weathering zones. The final models reflect geophysical and geological observations and provide a solid input for computational simulations and improve acquisition strategies in the basin.

Introduction

This study presents methodologies and results for subsurface modelling along a 2D seismic line located in Paraná Basin, Brazil. Aiming the improvement of sub-basalt events imaging, structural and velocity models were developed to support numerical simulations. These models integrate seismic, well logs, and field trips, aiming enhancing the fidelity of geologic models in regions marked by large scale magmatic activity, such as the Serra Geral Gr at Parana-Etendeka igneous province.

Structural model

The structural model position is over the 2D seismic line 236-0062 (ANP/REATE, 2021), acquired with explosives in 1992. Seismic interpretation was performed to define main geological interfaces, intra-basalt low velocity (LV) layers and magmatic intrusive bodies (dykes and sills) that compose the model. The interpretation was supported by well data and seismic attributes. The decision of including LV layers and intrusive bodies on the model relies on their significant impact on seismic wave propagation.

Data from three wells were considered to support seismic interpretation and perform petrophysical analysis. Wells 1-CS-2 and 2-CS-1, located on the seismic line 236-0062 and approximately 3 km apart. They intersect reservoirs in Campo Mourão Fm that presented sub-commercial production. Well 1-GB-1, located 420 meters southeast of the seismic line end, was also used to contribute on the interpretation.

To define which geological formations should be included to the model, an analysis of acoustic impedance contrasts on adjoining layers was performed using average velocities from sonic logs. Only layers that presented significant velocity contrast were selected to compose the model. The deepest layer (Ponta Grossa Fm.) was defined based on its interest as source and low interest of possible reservoirs below it. All layers have been crossed by the three wells, ensuring petrophysical information is available for the whole model. Figure 1 shows position of seismic line and wells, and seismic data interpreted in time.

The intra-basalt LV layers were identified on gamma ray and sonic logs, showing multiple low velocity intervals (Figure 2). These LV layers are vesicular rich zones, usually occurring at top and bottom of lava flows, being formed by the exsolution of gases during the lava cooling, creating bubbles, trapped as vesicles in the solidified rock. In general, a reasonable correlation between seismic reflections and LV interfaces was possible, allowing a reliable lateral extension of these zones. For the shallowest zones without seismic data, a stratigraphic conformity was assumed, with layer continuity based on stratigraphic and geological consistency according to field trips observations. Due to their strong impedance contrast, sills can be clearly identified in seismic, displaying well-defined events with good lateral continuity. Dikes, however, are significantly more challenging to map, due to their sub-vertical orientation and their interpretation involves several uncertainties. Their presence was inferred from seismic data, on regions with abrupt interruptions of reflections and/or complete lack of seismic events.

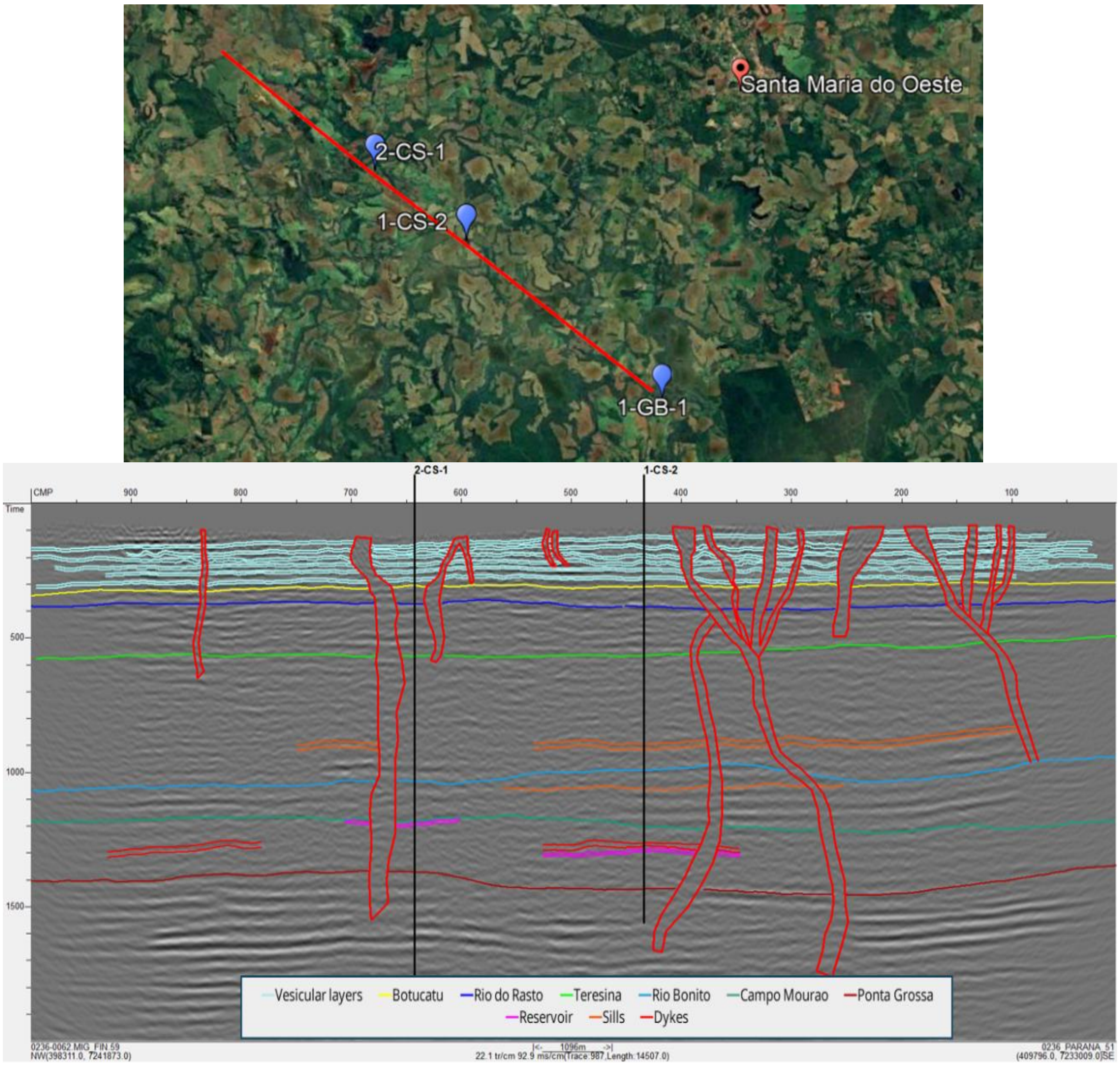

Figure 1: Top: map view of seismic line 236-0062 (~15 km length) and three wells used in the modelling. Bottom: interpretation of key geological interfaces, including sills (orange), dykes (red), vesicular zones (light blue), and reservoirs crossed by wells (purple).

All seismic events were interpreted on time domain. In order to_build the subsurface model, a time-to-depth conversion was performed using an edited time-table from well 1-CS-2 (ANP/REATE, 2021). Additionally, it was included an interface corresponding to the surface topography, based on elevation data extracted from SRTM along the seismic line. To enhance structural model reliability, the depth-converted horizons were adjusted to match geological markers identified on wells.

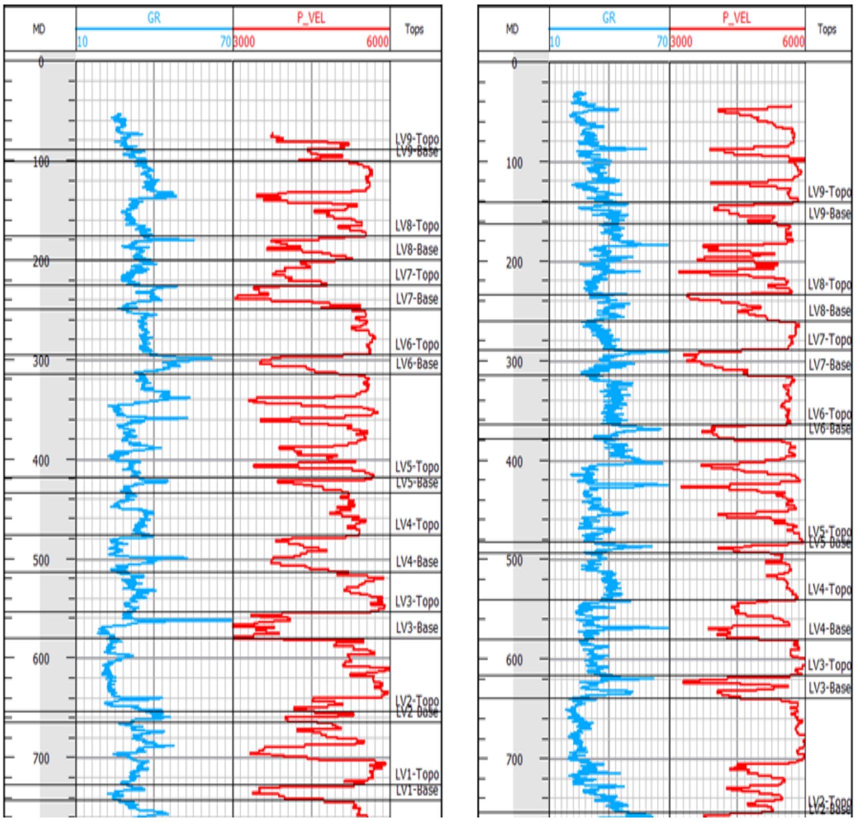

Figure 2: Gamma ray (blue) and sonic (red) logs inside basalt layer (Serra Geral Gr) at wells 2-CS-1 (left) and 1-CS-2 (right). Geological markers for top and base of low velocity (vesicular) zones were defined, correlated, and (except for the shallowest zones) mapped in seismic. Depths (MD) in meters.

Velocity model

The velocity model must capture the variation of the velocity on multiple geological layers as well as relevant structures, such as dikes, sills and vesicular zones inside Serra Geral Gr. Due to spatial heterogeneity of rock properties, defining accurate velocities represent a significant challenge. A proper structural model helps mitigate some of these uncertainties, as rock properties tend to have similar values within the same geological layer. Based on this assumption, homogeneous velocities were assigned to each layer. Diffraction/scattering and noise patterns are expected to be generated from features explicitly represented on the structural model and assigned with constant velocity values.

Velocity values were obtained from seismic log data by computing average velocities for each formation. For magmatic intrusions it was adopted the same velocity of 5600 m/s applied at massive basalt layer. The intra-basalt LV vesicular layers were assigned with 3800 m/s, based on well data and laboratory analysis of field samples.

A weathering zone was algo included in the velocity model. Thickness and velocity for this layer were obtained by tomography, on static corrections step of seismic processing. This zone is located near surface and was included in the model to improve shallow velocity representation. It was subdivided in three constant velocity sublayers, with values of 2200 m/s, 2750 m/s and 3750 m/s.

Results

The obtained structural model has dimensions of 15x4 km, and is discretized into regular and uniform cells of 15x1m. It includes interfaces representing key geological features identified in seismic data and correlated with markers from wells 1-CS-2, 2-CS-1 and 1-GB-1. These features represent geologic formations, intra-basalt low velocity layers, sills and dykes. The velocity model was constructed by assigning homogeneous velocity values to each layer in the structural model framework, these values were obtained from well sonic logs. Additionally, a weathering zone was incorporated, with both extension and velocity values defined from seismic processing.

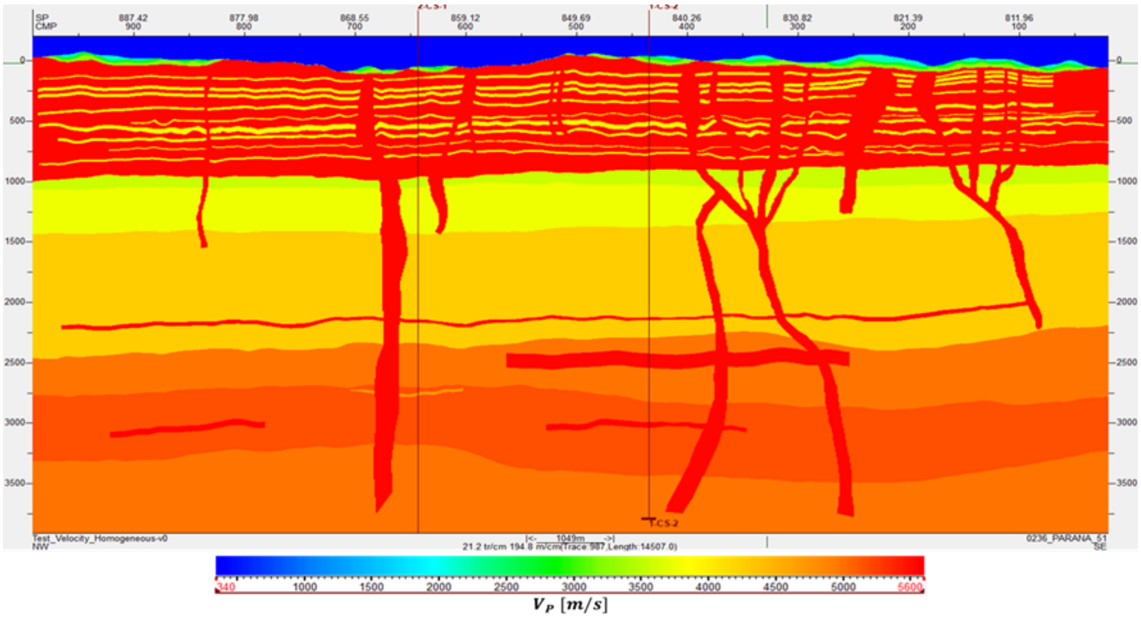

Figure 3: Velocity model in depth, integrating seismic interpretation and processing results, and well log data. This model is being on numerical seismic modeling, to analyze seismic noise at Paraná Basin and collection parameters of new seismic data.

Conclusions

The construction of the structural and velocity models integrates multiple data sources and ensure geological consistency. The inclusion of structures as dykes, sills, and low velocity layers represents a significant improvement over traditional simplified models in large igneous provinces like Parana-Etendeka. This approach enhances the ability to evaluate wave propagation interference patterns at numerical simulations. Future work will incorporate lateral and vertical velocity heterogeneities, and 3D geometries.

Acknowledgments

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