3D Seismic Interpretation of the Praia Grande Impact Structure – Upper Cretaceous of Santos Basin, Offshore Brazil

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Abstract

This work presents the Praia Grande impact structure, located in the Santos Basin, approximately 200 km southeast from the coastline of São Paulo State, Brazil. The identification of this structure is based on the interpretation of three-dimensional seismic data, acquired and processed in 2004 for petroleum exploration in a Petrobras concession block in the Santos Basin. The principal morphological elements, imposed on Upper Cretaceous rocks, are a structural high in the center of the crater, an adjacent ring syncline, and, externally, several concentric circular listric normal faults. The structure is apparently well preserved from erosion, measures around 20 km in diameter, and is buried by 4 km of rocks deposited after the impact time, which occurred in the Santonian (85,8–83,5 Ma).

Introduction

Recent three-dimensional marine seismic data from the southern Santos Basin, offshore Brazil, acquired and processed for petroleum exploration in Petrobras BM-S-3 block, show a nearly circular area of anomalously deformed Upper Cretaceous rocks, ranging 20 km in diameter, and covered with 4000 m of sediment below the seabed. Based on morphological seismic interpretation, we propose a meteorite impact in the Santonian (85,8–83,5 Ma) as the origin for these geologic features, which we name as the Praia Grande impact structure, after its location 200 km southeast from Praia Grande, São Paulo State. The geographical coordinates of the center of the structure are 25º38'50''S and 45°37'30''W (Fig. 1).

There are several examples of 2D seismic images of impact structures in the literature (*e.g*. Mazur *et al*, 2000). In Brazil, the first seismically identified impact structure is the Tefé River impact structure, in the Solimões Basin, which coincidently also affected Upper Cretaceous rocks (Menezes *et al*., 1999). However, Praia Grande structure is the second example of full 3D seismic imaging in the world of an impact structure (Figs. 2 and 3), following Silverpit crater in the North Sea (Stewart & Allen, 2005).

The identification of impact structures include geometrical, geophysical, geochemical and shock-metamorphic criteria. The latter are considered conclusive proof of impact origin, since they occur under an extremely high pressure field exclusive to hypervelocity (20 to 70 km per second) body impacts (Grieve & Pilkington, 1996). In this paper, only seismic morphology is presented. Even tough the seismic signature of the studied structure fitted the expected geometry for an impact structure, the shock origin is assumed as the most probable hypothesis, and awaits future identification of shock metamorphic features (for example, planar deformation in quartz and shatter cones).

Other possible hypotheses for the origin of the Praia Grande structure are volcanism and mud or salt diapirism. Available gravimetric data modeling doesn't show compatible responses with the presence of any large body of volcanic rock in the center of the structure. With respect to the presence of salt or mud, whose density contrasts to the host rocks are relatively weaker, the gravimetric modeling is inconclusive due to the thick overburden over the structure. Anyway, stratigraphic criteria also weaken the diapiric alternatives because occurrences of mud movement and autochthonous or allochthonous salt bodies are not observed elsewhere in the Santos Basin in the Santonian-Cenomanian interval. Moreover, seismic interpretation criteria do not support the delineation of mud or salt bodies that could explain the observed deformation pattern.

Seismic signature of Praia Grande impact structure

Morphologically, Praia Grande impact structure is of the complex type, which is typical of craters greater than 2-4 km and is characterized by a structurally complex rim, a downfaulted annular trough, and a structurally uplifted central area (Grieve & Pilkington, 1996). This geometry results from the gravitational collapse of the transient crater produced by the shock. Immediately after the impact, a centripetal flow of collapsed rocks is installed in the direction of the cavity opened in the crust, resulting in the uplift of a nearly cylindrical structural high the center of the crater, which is surrounded by a ring syncline, and, externally, by concentric circular listric normal faults (Fig. 4).

At the end of the gravitational collapse process, that takes only a few seconds, the final crater is wider and shallower than the original one. By seismic interpretation, we estimate that the rocks of the central uplifted area of the Praia Grande structure suffered a stratigraphic uplift (SU) of 2 km, at least , which is an amount compatible with a 20-km in diameter (D) impact structure, according to the equation SU= 0.1D (Grieve & Pilkington, 1996) (Fig. 5).

The Praia Grande structure is partially eroded by an unconformity near the top of Santonian interval. The quality of seismic images is affected by high frequency reflection multiples right below this interface, obscuring the visualization of the annular syncline fill and the precise upward termination of the concentric extensional faults. In the center of the impact, the deformation affects a 4-km thick package of Itajaí-Açu, Itanhaém and Guarujá formations rocks (Turonian to Albian). The inner circular normal fault planes, whose shapes are conical in three dimensions, show detachment on the top of Itanhaém Formation carbonates. On the other hand, toward the external rings of the structure, the circular normal faults are detached at progressively shallower stratigraphic interfaces, sometimes showing preference by shaly beds, like the Turonian anoxic shale. The central uplift is probably composed of Cenomanian to Santonian rocks, with up to 30 degrees in dip. Post-impact Cenozoic strata are folded by differential compaction around the central high, corroborating the hypothesis of older uplifted rocks at that place. The relatively greater rigidity of the central uplift, which is not observed in the Silverpit structure, might also indicate the presence of partial melt rocks (suevites) associated to strong positive reflections in a small area at the summit of the central high (Fig. 2).

Conclusions

Based on the interpretation of three-dimensional seismic data, this work presents the Praia Grande impact structure, located in the Santos Basin, approximately 200 km southeast from the coastline of São Paulo State, Brazil, inside a Petrobras concession block.

The structure is apparently well preserved from erosion, measures around 20 km in diameter, and is buried by 4 km of rocks deposited after the impact time, which occurred in the Santonian (85,8–83,5 Ma). The principal morphological elements, imposed on Upper Cretaceous rocks, are a nearly cylindrical structural high in the center of the crater, an adjacent ring syncline, and, externally, several concentric circular listric normal faults.

The shock origin is assumed as the most probable hypothesis, and awaits future identification of shock metamorphic features in well cores (for example, planar deformation in quartz and shatter cones).

Acknowledgments

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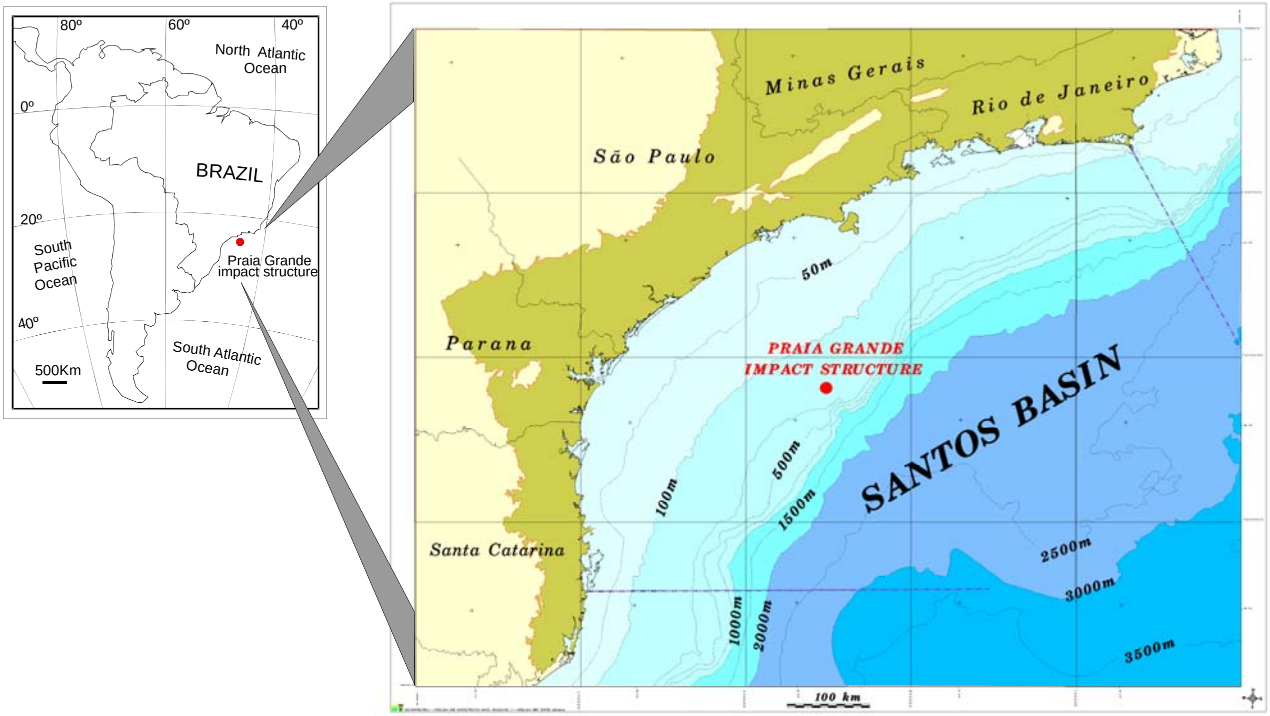

Figure 1 - Location map of the Praia Grande impact structure (25º38’50’’S, 45°37’30’’W).

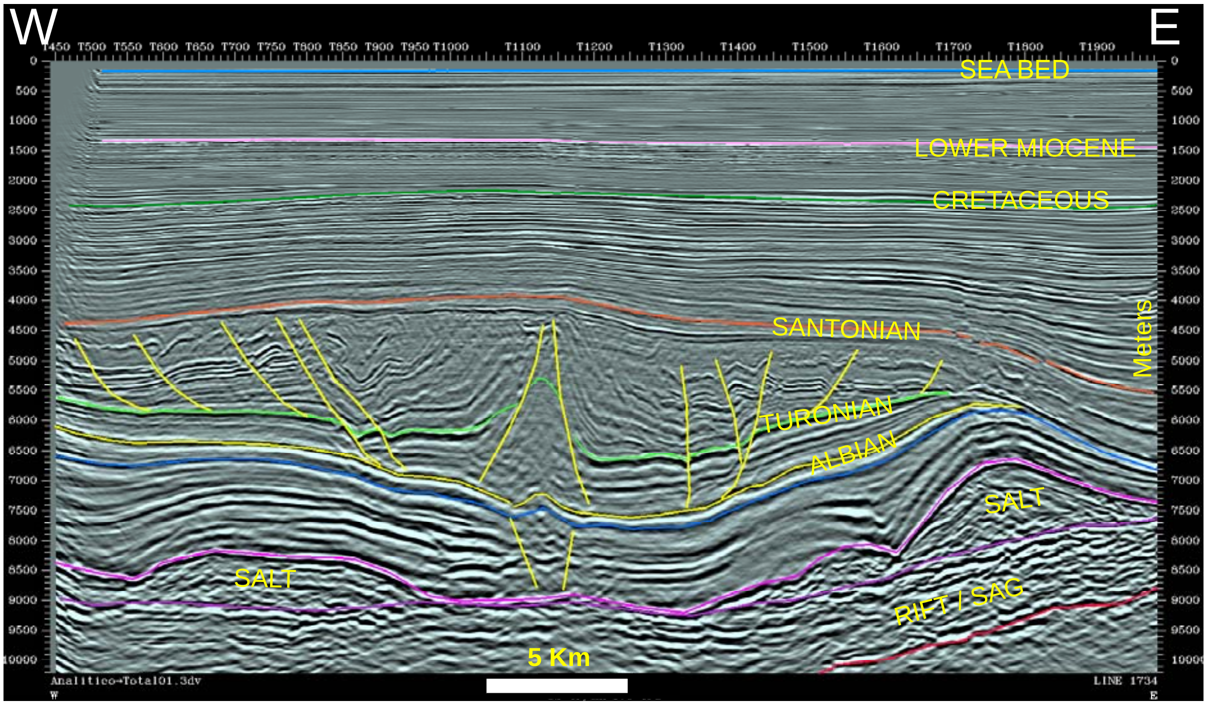

Figure 2 - Depth-converted seismic line 1734, crossing the center of the structure and showing a structural high in the center of the crater. This high is surrounded by a ring syncline, and, externally, by listric normal faults. Seismic line location in Fig. 4.

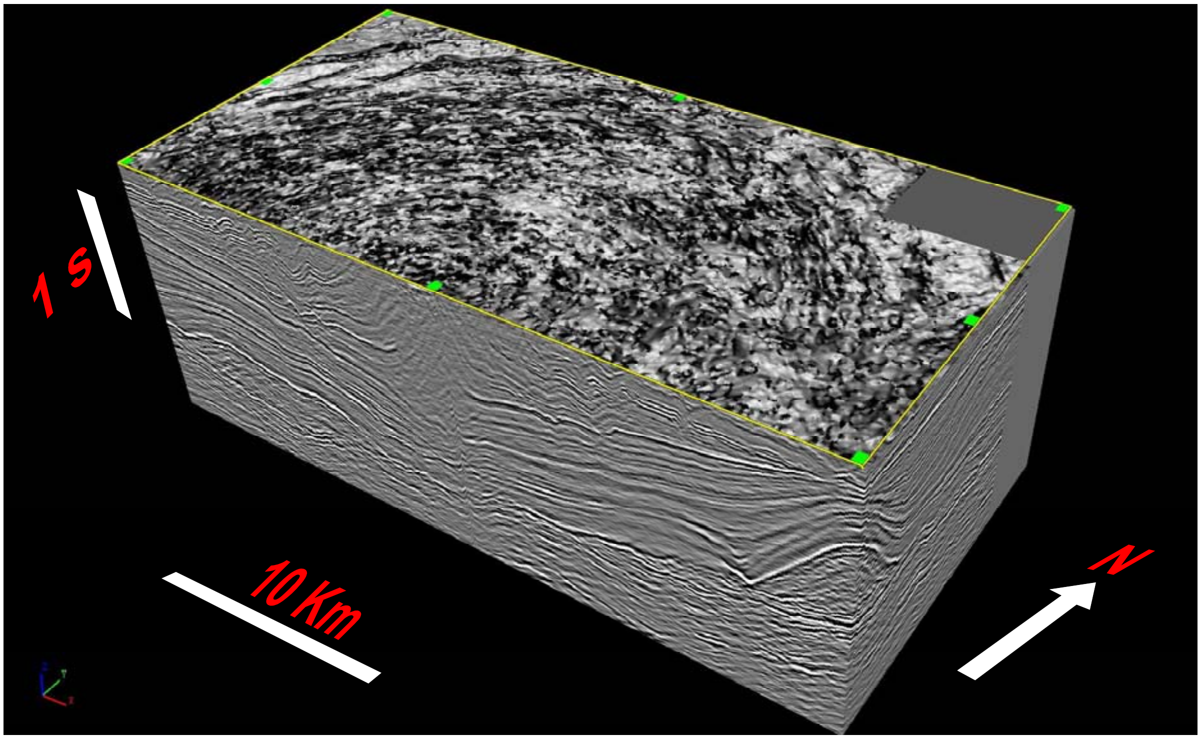

Figure 3 - Seismic data cube in time, flattened for approximate reconstruction of the geometry at the impact time. Notice the concentric distribution of faults around the central high in the horizontal section of the top of the cube, where the dip seismic attribute of the reflectors is shown.

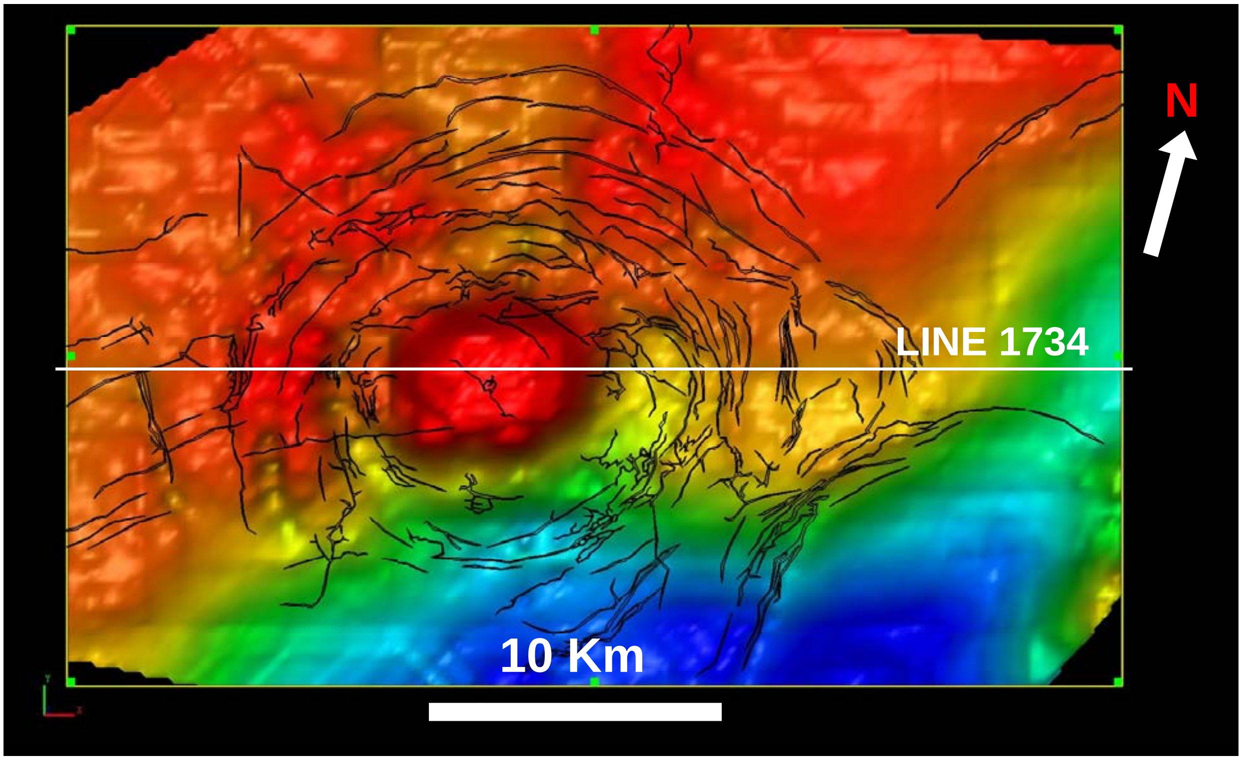

Figure 4 - Map of impact-process associated faults, superposed upon the structural contour in time of a horizon interpreted in the Santonian interval.

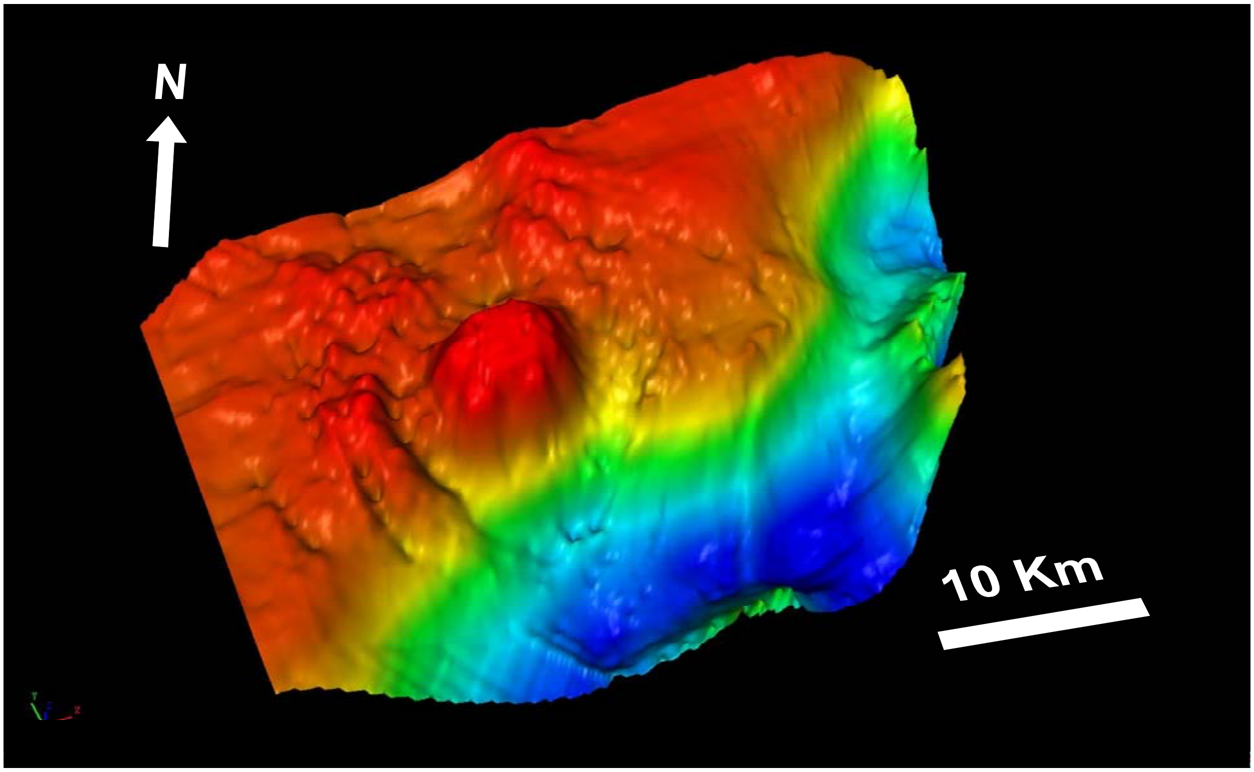

Figure 5 - Oblique view of a seismic horizon in time, interpreted in the deformed Santonian interval, showing the nearly cylindrical central high, the ring syncline and the concentric circular faults produced by the impact.