SBGf22099

Geophysical evidence of a possible impact structure at the K-T boundary of the Solimões basin, Brazil

Jorge Rui C. de Menezes, Cleomar F. de Souza, Fernando P. Fortes* and Coaracy Barbosa Filho

PETROBRAS S/A, Brazil (* retired)

Abstract

The Tefé River possible impact structure (4º57''44''S, 66º03'17''W) was formed in the Late Cretaceous of Solimões Basin, Brazil. The target rocks are Cretaceous continental sandstones underlain by Paleozoic siliciclastic, carbonate and evaporitic rocks, which were intruded by thick diabase sills in the Mesozoic. The overburden is a 350 m-thick Tertiary (Miocene to Pliocene) sequence. A 2D reflection seismic lines dataset allowed the identification of a complex-type impact structure with a 2 km in diameter central uplift which consists of a chaotic arrangement of thrust faults, moderate- to steep-dipping beds and with slump-slided borders. A 5 km in diameter ring depression forms a syncline or graben around the central high, which was probably produced by normal listric faulting and by rotational block movement associated to the uplift of the central high. The outer rim is eroded by the Tertiary lower sequence boundary and its original diameter could reach more than 15 km. The infill of the crater is probably composed of slumped and fluidized Cretaceous sandstones, suggesting the presence of high water level and unconsolidated sediments, thus showing a very contrasting mechanical behavior in relation to Paleozoic rocks and diabase sills, which collapsed at steeper fault angles. Modelling of ground gravimetry and magnetometry measurements supports the presented structural interpretation, both leading to the hypothesis of a low-angle northeast-to-southwest bolide trajectory. As the structure remains undrilled, impact origin confirmation by means of shock-metamorphic features identification is to be done, as well accurate dating. Available dating based mostly on palinomorphs indicate a tens-of-million-years hiatus between Cretaceous and Tertiary sequences.

INTRODUCTION

In the early 80's a unique, circular, buried structure was unveiled by PETROBRAS seismic survey near the left margin of upper Tefé River, Solimões basin, Amazon State, Brazil (Figure 1). Explorationists first suspected it could be an igneous intrusion cutting Paleozoic and Cretaceous strata. Later in 1996 a new reflection seismic line was shot passing across the center of the structure in order to achieve better quality imaging and ground magnetometry and gravimetry. The intrusion hypothesis was not supported by the new potential field data because both density and magnetic susceptibility are weaker than expected for most igneous intrusion rocks. Thus, a new work hypothesis came up from the detailed study of available geophysical data: the unusual but increasingly well known terrestrial impact structure.

Impact structure is a generic term for the morphological impact craters *s.s.* as well for all geologically and geophysically recognizable cosmic object impact site. The number of known terrestrial impact structures is only around 150 partly because most of them were eroded or recycled by the intense endogenic activity of our planet (Grieve and Pilkington, 1996). But the more is known about these geologic features the more increases the list. Barringer crater in Arizona was the first proven impact structure. Fragments of the impactor body were found inside the crater in the 20's and became the only acceptable proof for an impact origin. But fragments of the impactor were no longer found in most impacts, specially in the larger ones. In the 60's, many researchs revealed another physical marker of impact structures, the shock metamorphism features, which comprehends shatter cones, microscopic planar deformation features in quartz and feldspar grains, diapletic quartz e high pressure mineral phases like stishovite. Includind volcanism, no Earth process can reach the extremely high pressures created during an impact, so shock metamorphism features is now the accepted proof of impact origin.

The morphology of impact structures is divided into simple and complex structures (Dence *apud* Grieve and Pilkington, 1996). Simple structures have a form of a bowl-shaped depression with a structurally uplifted rim, wich includes an overturned flap overlain by ejecta. At diameters larger than 2-4 km, collapse features in the rim area become more prominent, and the structure evolves into the so-called complex structure, which consists of a structurally complex rim, a downfaulted annular trough, and a structurally uplifted central area.

In this paper, we propose the Tefé River impact structure as a possible one based on geophysical data (seismic, magnetometric and gravimetric). Rock samples for shock metamorphism identification are not available because the structure is covered by 350m-thick post–impact Tertiary strata (Solimões formation) and it remains an undrilled structure.

SEISMIC STRUCTURAL INTERPRETATION

The Tefé River impact structure is classified as a complex structure. The target rocks are 300m-thick Cretaceous continental sandstones underlain by 1400 m-thick Paleozoic siliciclastic, carbonate and evaporitic rocks, which were intruded by 900 m-thick diabase sills during Mesozoic. The overburden is a 350 m-thick Tertiary (Miocene to Pliocene) sequence.The 120-fold, time-migrated, reflection seismic section across the structure (Figure 2) shows a central uplift with about 2 km in diameter which consists of chaotic arrangement of thrust faults, moderate- to steep-dipping beds and slump-slided borders which is slightly truncated at the top. Surrounding the central high, there's a ring depression like a syncline or graben, which is produced by normal faulting coupled with radial rotational block movement associated to the uplift of the central high. The so-called outer rim is apparently not preserved from erosion at the lower Tertiary sequence boundary and its original diameter could reach more than 15 km. The Cretaceous sequence seismic facies changes laterally from parallel to chaotic/mounded around the central high. These two Tertiary seismic facies show equivalent seismic velocities (2600m/s), and are not clearly separated by an acoustic interface but show a low-dip step-like boundary between the two. This disturbed material may be the infill of the crater composed of slumped and fluidized Cretaceous rocks. Despite the fluvial depositional environment attributed to these Cretaceous rocks, the presence of high water level and unconsolidated sediments is probable, thus showing a very contrasting mechanical behavior with relation to Paleozoic rocks and diabase sills, which collapsed at steeper fault angles. The Permian-Carboniferous sequence seismic facies also changes dramatically from paralell to intensely disrupted and chaotic under the central high. The disturbance of coherent subsurface reflectors is most prominent in the central uplift and decreases outward and downward from this zone, as postulated by Grieve and Pilkington (1996) for complex impact structures. A small graben is present under the central high and as a whole the Tefé River impact structure resembles Red Wing Creek structure, as presented by Donofrio (1981), also regarding to the the present erosional level.
The seismic structural map of the Cretaceous sequence lower boundary shows the uplift of this horizon around the outer faulted borders of the ring depression, except in its southwestern segment. This feature might be associated with angle and direction of impact of the bolide. If this is true, the impactor trajectory is from northeast to southwest, with some oblique angle (Figure 3).

POTENTIAL FIELD INTERPRETATION

Solimões basin shows a remarkable feature which is the intrusion of Mesozoic diabase sills in the Paleozoic strata. Measurements performed by PETROBRAS Research Center and PUC-SP show that these rocks are around 2.8 g/cm^3 in density, with magnetic susceptibility ranging from 3 x 10^{-6} to 4.5 x 10^{-6} emu units. The Paleozoic sedimentary rocks present very low magnetic susceptibility and densities in the 2.0 to 2.7 g/cm^3 range. As in the rest of the Solimões basin, the most of the magnetic anomalies are produced by variations in the diabase bodies like thickness variation, stratigraphic intrusion level changes, folds and edge effects. The airborne magnetometric data was produced by LASA/ENCAL in 1981 for PETROBRAS, with N-S flight lines, spacing 2.5 km at 800 m flight altitude. In 1996, ground gravimetry and magnetometry was accomplished during the seismic acquisition of reflection seismic line 06 by crew 254. Geomagnetic field in the study site presents 28,000nT, 10º inclination and 10º declination, which means a near magnetic equator location. The airborne residual magnetometric map (Figure 4) shows a high-frequency anomaly (a magnetic high, as we are near magnetic Equator) which coincides with the central high of the structure. According to Grieve and Pilkington (1996) impact structures show a magnetic low (magnetic high in the equatorial case) caused by susceptibility reduction. The causes of magnetic lows at impact structures are not clear. However, the impact process undoubtely results in a reduction in the magnetisation intensity of the target material. As the fractured rocks well below the floor of several Canadian structures also show diminished magnetisation, the cited authors suggested that the propagating shock wave is the likely cause.
The modelling of ground gravimetry and magnetometry was done using the GM-SYS, which is licensed by Northwest Geophysical Associate, Inc. Residual gravimetry shows a central high with two lateral assimetric lows (Figure 5). Gravimetric modelling indicates that most of the response is due to density contrast between the structural central high and the surrounding lower density crater. The structural central high composition is assumed as shock-altered diabase and Paleozoic rocks and the crater infill is probably formed by slumped or brecciated Cretaceous rocks. Magnetic responses simulation, on the other hand, need a more complex arrange of diabase blocks, in which the upper diabase sill is completly absent or non-magnetic on the structural central high, and slightly less magnetic in part of the adjacent northern block. The downward second diabase sill is divided into small blocks bearing reduced but variable magnetic susceptibilities, which are smaller in the southward direction. If this behavior is linked to shock wave propagation, then it supports the previous structural seismic map trajectory.

CONCLUSIONS

Tefé River structure is a possible complex-type impact structure, formed in the Late Cretaceous of Solimões Basin, Brazil. Except for the erosional outer rim absence, all other structural elements are present. Particular remarks can be made on the infill of the crater by probably slumped and fluidized Cretaceous sandstones, suggesting the presence of high water level and unconsolidated sediments. The creation of the ring depression and the central high are presumably coupled, by means of central high rebound, radial block rotation and normal listric faulting. The potential field modeling indicates that most of the gravimetric response is due to density contrast between the structural central high and the surrounding lower density crater infill. Magnetic responses show a more complex arrangement of diabase blocks, which might be linked to shock wave propagation produced by a low-angle impact coming from northeast to southwest, a hypothesis also supported by seismic structural mapping. As the structure remains undrilled, impact origin confirmation by means of shock-metamorphic features identification is to be done, as well accurate dating. Available dating based mostly on palinomorphs indicate a tens-of-million-years hiatus between Cretaceous and Tertiary sequences .

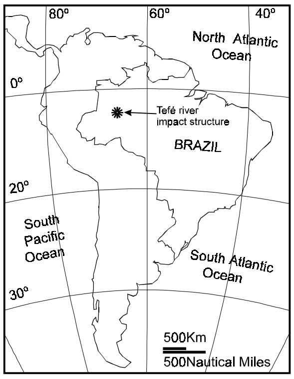
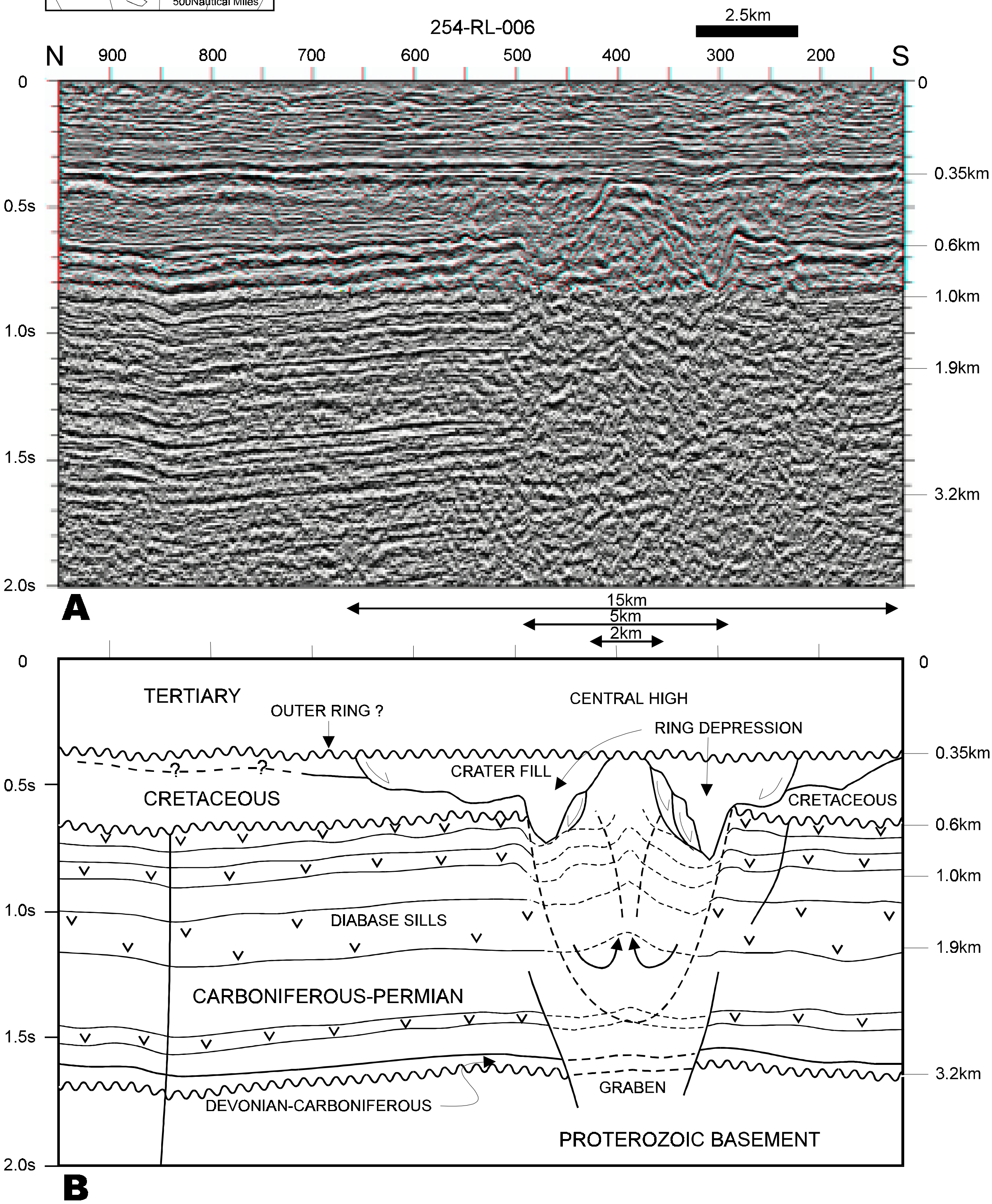


Figure 1 - Location map of Tefé River impact structure.

Figure 2 - A) Uninterpreted, 120-fold, time-migrated, PETROBRAS reflection line 254-RL-006 across Tefé River impact structure; B) seismic interpretation of principal structural features. For orientation see figure 3.



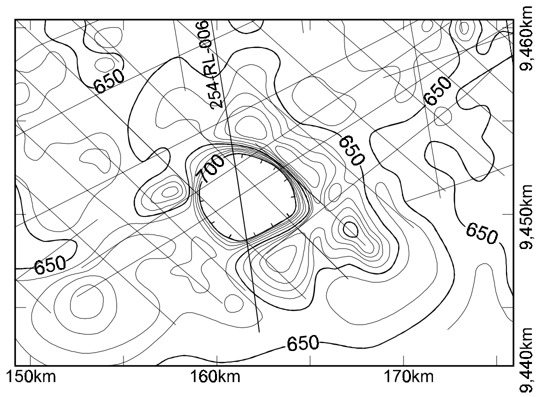


Figure 3 – Seismic structural map of Cretaceous lower sequence boundary, showing the uplift of the horizon around ring depression. Southwest segment is collapsed suggesting low angle northeast-to-southwest trajectory. Contour interval is 10m, seismic lines are indicated. UTM coordinates C.M. 63º

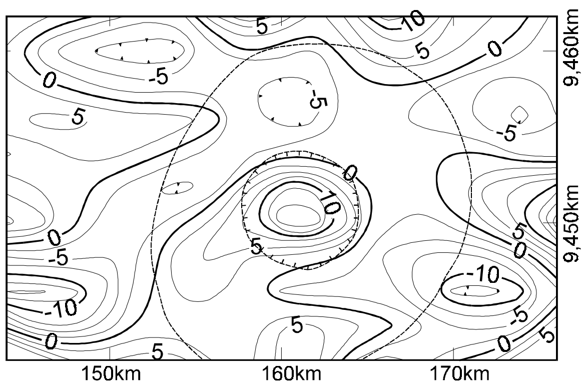


Figure 4 – Residual airborne magnetometric map. Eroded outer rim and ring depression indicated. Contour interval is 2.5 mGal. UTM coordinates, C.M. 63º

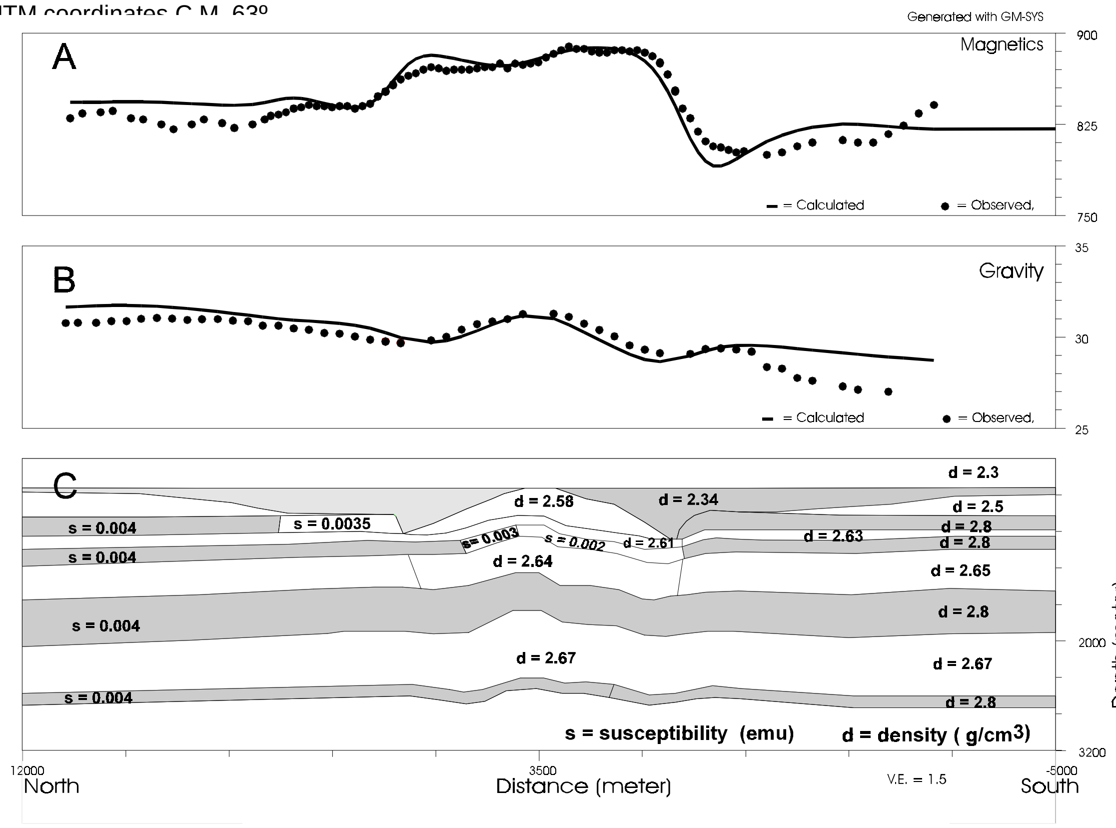


Figure 5 – Ground gravimetric and magnetometric response modelling along seismic line 254-RL-006. A) Magnetics; B) gravity; C) geological model.

REFERENCES

Donofrio, R.R., 1981, Impact craters: implications for basement hydrocarbon production: Journal of Petroleum Geology, 3, 3, p.279-302.

Grieve, R.A.F. and Pilkington, M., 1996, The signature of terrestrial impacts. AGSO Journal of Australian Geology & Geophysics. 16(4), p.399-420.

ACKNOWLEDGEMENTS

We would like to thank PETROBRAS for permission to publish this work.