A GEOMORPHIC STUDY WITH GEOLOGICAL EMPHASIS USING REMOTE SENSING DATA OF THE SÃO MIGUEL DO TAPUIO CIRCULAR STRUCTURE, EASTERN PARNAÍBA BASIN, PIAUÍ

Jackson Alves Martins[1], Raimundo Mariano Gomes Castelo Branco[1], Neivaldo Araújo de Castro[3], Jean-Pierre Peulvast, Sergio Bezerra Lima Junior[1,2] [1]Laboratório de Geofísica – Universidade Federal do Ceará, [2]Instituto de Ciências do Mar – LABOMAR/UFC, [3]Universidade Federal de Santa Catarina

Abstract

The São Miguel do Tapuio circular structure (SMTCS) is one of the largest ones recognized in the Phanerozoic sedimentary rocks of the Parnaiba Basin, Piauí State, Brazil. Research works about the genesis of the SMTCS consider either an endogenetic origin or a formation by a meteoritic impact. The present study is based on bibliographic survey, field work and laboratory analyses (remote sensing). Remote sensing is used to characterize the superficial morphological features, their organization and total diameter, as well as the multi-directional pattern and the high density of lineaments inside the structure. It allowed the definition of morphostructural units such as the outer margin, an intermediate ring, an annular depression and a central topographic high. From field work was identified a variable thermal metamorphism in the sandstones in which the SMTCS is formed. An increase of the metamorphism grade was clearly observed from the margin to the center, with the presence of highly recrystallized and consolidated metasandstones around the center of the structure. Finally, the geomorphic characterization and the geometric signature obtained for the SMTCS seem to correspond to those of complex impact structures (presence of a central uplift). Moreover, the identification of macroscopic deformation structures in the sandstones (yet not typical of shock origin) may be more conclusive for a meteoritic origin, as well as the lack of evidence of igneous activity which might explain the observed thermal metamorphism.

Keywords: Parnaíba Basin, astroblemes, orbital sensors.

Introduction

In the last decades, various structures of circular or semi-circular shapes were identified and studied. The principal objective is to define the origin of these structures, either formed by endogenetic processes (structural highs, igneous intrusions and dome structures) or by meteoritic impacts.

A few circular structures recognized in Brazil are interpreted as impact-generated: Araguainha (MT-GO), Vargeão (SC), Vista Alegre (PR), Cerro do Jarau (RS), Serra da Cangalha (TO) Santa Marta (PI) and Riachão (MA). However, other circular or semi-circular structures were formed by endogenetic processes, either by reactivation of faults or other structures of the basement, or by intrusion of alkaline magma: Poços de Caldas alkaline massif (MG), Complexo Catalão (GO) Caldas Novas dome (GO). A few of them correspond to dome structures in Phanerozoic sedimentary basins: Structural High of Quatiguá (PR), Pitanga dome (SP).

Besides, a few other structures are informally considered as astroblemes, such as those of Colônia (SP), Inajah (PA) and São Miguel do Tapuio (PI). Although they present morphological and structural similarities with impact structures, more conclusive evidence of direct impact generation are still missing (Crosta *et al*. 2010).

The object of the present study is the São Miguel do Tapuio circular structure, located in the easternmost part of the Piauí State, northeast Brazil (Fig. 1).

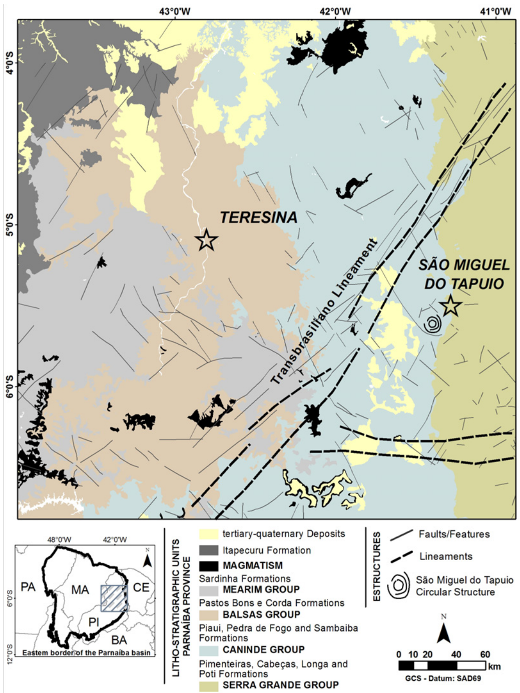

Figure 1: Location and geological map of the SMTCS and surroundings, with linear features and magmatism.

Reaching a diameter of ~20 km, it is inset in the Phanerozoic sediments of the Parnaíba basin. It displays a complex morphology, including a margin, an intermediate ring, a central topographic high (suggesting similarities with the central uplift of complex impact structures), and annular depressions. According to Siqueira Filho (1970), Nunes *et al*. (1973) and Lima (1978), this structure would have been produced by endogenetic processes associated with a non-outcropping igneous intrusion (laccolith) or by reactivation of lineaments in the underlying crystalline basement. However, Torquato (1981), Crósta (1982), Castelo Branco (1994) and Martins (2011) suggested a possible meteoritic origin (astrobleme).
In order to address this issue, we propose a detailed characterization of the superficial morphology and of the geometry of the SMTCS. The origin of this structure is discussed through a description of the state of the art, of geological data obtained from field work, and from remote sensing.

Method
The methods used here correspond to the following stages: i) acquisition of the data and cartographic material available for the study area; a) 1:100,000 plani-altimetric sheets and b) 1:1,000,000 Geological Map of the Piauí State (Correia Filho, 2004); ii) bibliographic review (circular and semi-circular structures, SMTCS); iii) remote sensing from satellite images: data acquisition and processing, and production of thematic maps. Source material: a) Landsat scene TM-5 sensor; b) SRTM (*Shuttle Radar Topographic Mission*) c) altimetric data from the *ASTER GDEM (Global Digital Elevation Map)*; iv) Geographic information system (GIS); and v) field work in the SMTCS region in January 2010, in order to precise the petrological characteristics of the lithotypes.

Results
The products obtained by digital processing of LANDSAT, SRTM e ASTER/GDEM) data helped defining the geomorphic configuration of the SMTCS. The main results are (Fig. 2 e 3):

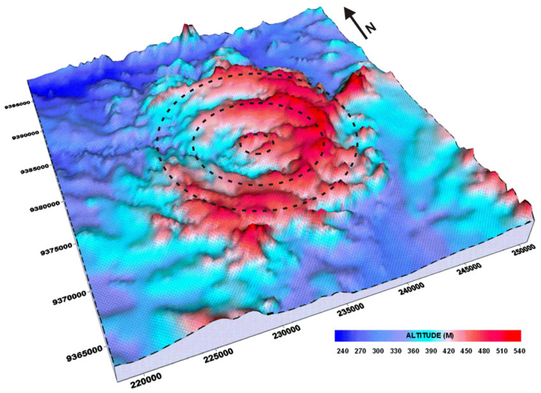

Figure 2: 3D visualization of a Digital Elevation Model of the SMTCS.

i) identification of morphostructural units in correlation with the geological features; ii) an almost perfect symmetry of the concentric rings and the multiring character of the structure, which is well distinct from the surroundings; iii) the presence of discontinuities (lowering) in the elevated rings, mainly in the western part of the structure; iv) the preferential lineament directions, extracted and analyzed by the means of rose diagrams and density maps; and v) a slight tendency of the drainage pattern to an annular/radial pattern in the inner part of the SMTCS.

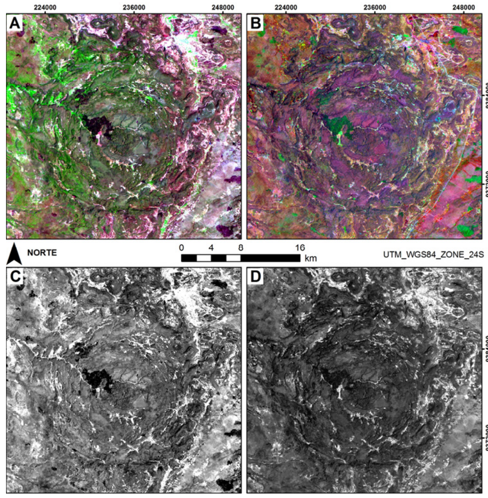

Figure 3: SMTCS: Products obtained by processing Landsat-5/TM images. a) Colored composition R(5), G(4), B(3); b) Band subtraction R(5-7), G(5-1),B(3-1); c) Band 4; and d) Principal Component (PC1).

The morphostructural units (compartments) identified in our study are (Fig. 4): i) an elevated outer margin (500 m a.s.l.) representing the total diameter of the structure (20.5 km); ii) an elevated intermediate ring (530 m a.s.l.), with an approximate diameter of 15.6 km; iii) annular rings with lower altitudes (360 m), mainly between the intermediate ring and the central high; and iv) a central high (520 m a.s.l.), slightly elliptic, with an approximate diameter of 3,8 km (major axis).

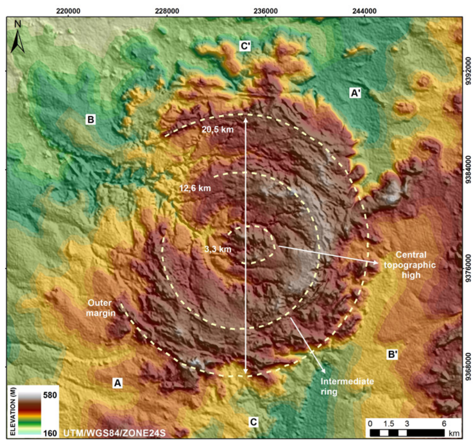

Figure 4: Digital Elevation Model of the SMTCS (ASTER GDEM). Subdivision in outer margin (20.5 km), intermediate ring (12.6 km) central high (3,3 km) and annular depressions.

The intensity of the thermal metamorphism observed in the SMTCS sandstones is variable. The metamorphism grade increases form the margin to the center, with the presence of intensely recrystallized and consolidated metasandstones in the central parts of the SMTCS (Fig 5). These sandstones bear atypical deformation structures and textures, sometimes similar to those observed in less deformed and recrystallized sandstones. However, these structures are strongly obliterated by the intense recrystallization. In a petrographic analysis of these sandstones from the margin to the center, Martins (2011) indicates a complete elimination of the former matrix, a diminution and comminution of the quartz grains, and the occurrence of fracture planes in these grains.

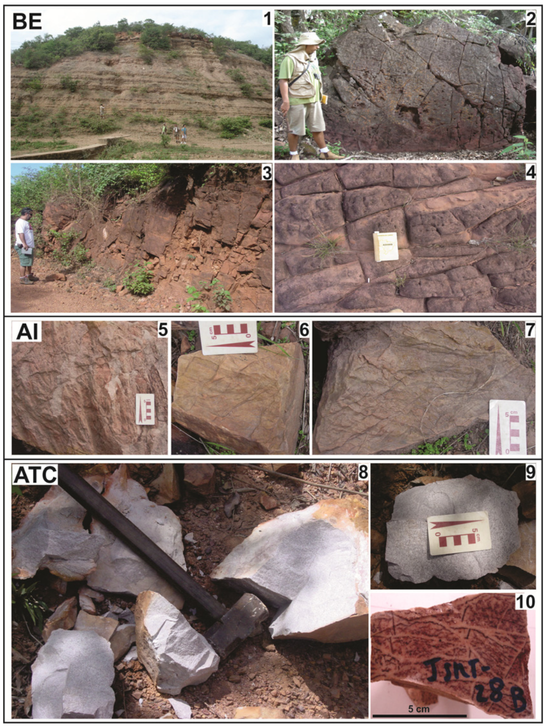

Figure 5: Details of the sandstones outcropping in the SMTCS with particularities corresponding to distribution in the structure: i) sandstones in horizontal layers, at the outer margin (BE1) and in thicker, tilted and fractured layers, inside the structure (BE2,3,4); ii) fine-grained, well consolidated and highly fractured, sandstones, with typical deformation structures, close to the intermediate ring (AI5,6,7); iii) metamorphic sandstones, intensely recrystallized and consolidated, close to the central high (ATC8,9,10).

The rocks observed in the silicification zone of the west of the structure will deserve more attention in future research works, since they do not present deformations compatible with those of the circular structure: they must have been formed by a later recrystallization process. The use of thermochronological methods such as apatite fission track analysis (AFTA) might give an idea of the minimal age of this circular structure and of the depth of burying and exhumation of the presently exposed levels.

The topographic profiles indicate the almost perfect symmetry of the concentric rings forming the structure. Assuming an exogenetic origin of the SMTCS, discontinuities in the western portion might be explained by oblique impact. In studies of lunar impact structures with different diameters, Forsberg et al. (1998) stated that those formed by impacts with angles between 15° and 45° exhibit a discontinuous rim portion on the opposite side to the direction of impact.

From the analysis of lineament distribution, two distinct areas are evidenced (Fig 6): i) the SMTCS itself, with a high density of lineaments; and ii) outside the structure, with much minor densities. In both areas, the main directions are NW-SE, followed by the ENE-WSW direction.

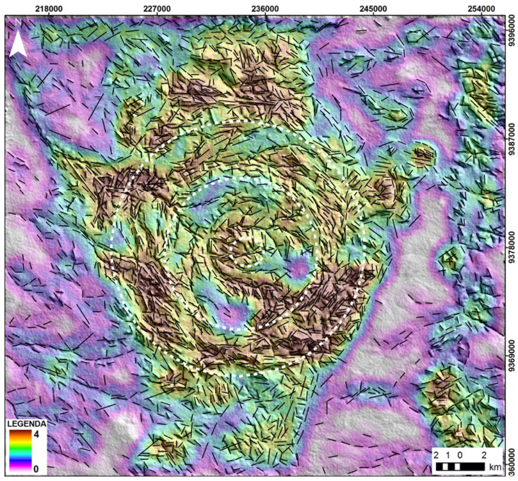

Figure 6: Lineament density map (lineament length in km/km²) extracted in the study area and superposed upon the DEM. The white discontinuous lines correspond to the limits of the outer margin, intermediate ring and central high.

The analysis of aeromagnetic data (Martins 2011) showed the total absence of any subjacent anomaly indicative of basic and/or alcaline igneous intrusion which might be associated with a circular structure of this size. The lack of superficial or sub-superficial igneous rocks, confirmed by field work as well as by airborne geophysical investigations, also indicates that an endogenetic origin may be discarded for the SMTCS.

Conclusions

Finally, various geomorphic and geometric characteristics of the SMTCS are similar to those of various complex impact structures (rings, presence of a central high). Moreover, the fact that macro and micro-deformation structures (even non-conclusive) were identified in the sandstones affected by the SMTCS, together with the lack of evidence of any igneous intrusion that might explain the observed thermal metamorphism, strongly suggests an impact-related origin. However, uncertainties reported in the literature about the origin of the SMTCS, such as the lack of conclusive evidence of shock deformation (MacDonald et al., 2006; Vasconcellos et al., 2010), suggest that a more superficial explosion, such as the airblast of a big impactor (ice?) close to the surface, sending a shock- and heat- wave without direct impact, such as proposed for the origin of "splotches" or halos on

Venus (Schaber et al., 1992), should also be considered. Although not entirely comparable because of the difference in atmospheric densities which control the maximal size of such impactors, the diameter and the structural features of the SMTCS (rings, fractured surface of the radar-bright splotches…) ranges in those observed on Venus. A confirmation of one of these interpretations, also taking into account the role of erosion in the blast- or impact-modified rocks and structures, might be obtained by more detailed morphostructural (e.g. identification – or not - of a former transient cavity and of a central uplift: Degeai and Peulvast, 2006) and geophysical investigations, possibly including electromagnetic methods of deep investigation, as well as by detailed geological work, mainly on the central high.

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