NUMERICAL MODELLING OF SERRA DA CANGALHA IMPACT STRUCTURE: PRELIMINARY ANALYSIS.

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Introduction: The Serra da Cangalha (SdC) impact structure, centered at 8°04'S/46°51'W, is a complex impact structure that is ~13-km in diameter and has a 5.8 km diameter central uplift. It is located in Tocantins state, northeastern Brazil and is formed in Phanerozoic sedimentary rocks of the Parnaíba Basin. The basin was developed over a Cambro-Ordovician rift system, and its sedimentary record comprises Silurian, Devonian and Carboniferous-Triassic sequences. The central uplift at SdC consists of a pronounced collar that rises up to 350 meters above the surrounding terrain and a depression at the innermost 1.5 km that is interpreted as an erosion feature [1]. The periphery of the central uplift has been affected by erosional processes that make it appear more subdued than the collar of the central uplift, although still morphologically prominent as shown by satellite imagery (Fig. 1,2). 2D numerical modeling of a vertical impact has been employed to attempt to quantify under what conditions the observed surface expression and crater morphometry (e.g. depth-diameter relationship, stratrigraphic uplift) may have been formed. In order to obtain a model that reproduces the geological information available for the SdC impact structure best, we carried out a series of 160 cratering simulations using the iSALE code [e.g. 2,3] and varied impact energy, the mechanical properties of the different lithological units, and the amount of erosion.

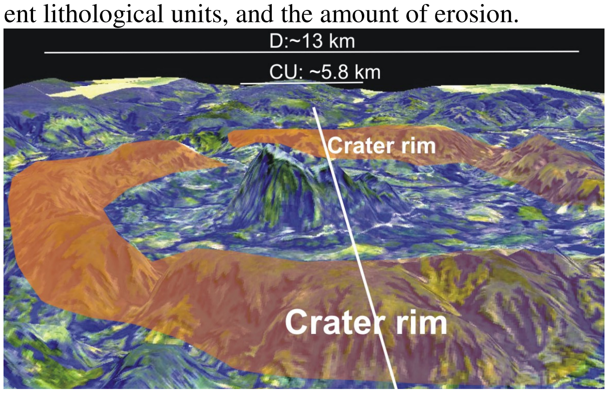

Figure 1- 3D image of the SdC impact structure of ~13 km diameter (D) showing the central uplift (CU) with higher elevation than the crater rim elevation.

Geological setting: Serra da Cangalha comprises a sedimentary sequence of four stratigraphic units that occur inside the crater, namely the Longá, Piauí, Poti and Pedra de Fogo formations, from the lowermost to the uppermost unit. Dark shales of the Devonian/Lower Carboniferous Longá Formation constitute the oldest rocks at Serra da Cangalha, and they are exposed in the inner basin within the central uplift. Due to the structural complexity of this innermost part and the poor outcrop conditions it is well possible that blocks with even older strata may occur. The Poti Formation comprises sandstones and claystones of Lower Carboniferous age that form the collar of the central uplift. The Piauí Formation forms the periphery of the central uplift and also most of the synclinal part of the structure around it; the Piaui Formation, in turn, is covered by the Pedra do Fogo Formation that comprises sandstones and chert layers of Permian age, which form the rim of the structure, as flat-topped plateaus, and the mesas and buttes in the wider environs. The depth of the crystalline basement underneath the crater was estimated at 2.4 km, based on regional aeromagnetic investigations [1]. This estimate is corroborated by data from an oil exploration borehole located 70 km north of SdC.

Modeling constraints: Whilst model parameters such as the mass of the impactor, petrophysical properties of the target rocks, and the amount of erosion were varied during our study to find the best possible match between model and observations. As the sedimentary strata of the SdC comprise mainly sandstones from different depositional environments, we use for this general analysis only two different layers in the model (Fig. 2).The first layer comprises a sedimentary package about 2.8 km thick, considering 2.4 km for the current thickness of the strata below the crater and 0.4 km for the amount of erosion [4]. We assumed the same rheological properties for the whole sedimentary package and used the ANEOS [5] equation-of-state for quartzite [6] to calculate the thermodynamic behavior of the material upon impact. The second layer in our model resembles the basement and was modeled with ANEOS for granite [7]. We account for 10% of porosity in the sediments by using the $\varepsilon-\alpha$–model [2]. The relative ease of rocks to succumb to plastic deformation was modeled by the strength model according to [8]. We assumed also a temporary weakening of the target rocks during crater formation by using the acoustic fluidization model [9,10,11] in order to explain the pronounced stratigraphic uplift at SdC.

Results: The model that best matches the final morphology of the crater, comparing it with the characteristics observed in remote sensing and field data, is shown in Fig. 2. The projectile in this model is 1400 m in diameter which corresponds to a kinetic energy of 2.74×10^{20} J (assuming an impact velocity of 12 km/s and a density of 2650 kg/m^3). The chosen constitutive properties of the impacted rocks correspond to typical mechanical behavior of rocks for the given lithology; however, a relatively high cohesion of several KPa (sediments) and MPa (basement) in the damaged state had to be assumed to prevent collapse of the pronounced central uplift subsequent to uplift. Moreover the model is constrained by the observation that the available geophysical data (gravity) do not indicate structural uplift in the basement, which turned out to be difficult to bring into accordance with the large amount of structural uplift in the sedimentary units. The transient crater in our model reaches ~2.8 km depth and is ~10 km in diameter. The model is in agreement with the observed crater diameter of ~13 km, considering 0.4 km of erosion. The central uplift in the model has a diameter of ~6 km and a relatively gentle relief . The model shows that the degree and the complexity of the deformation increase significantly from the rim towards the central uplift (Fig. 2), corroborated by field observations [12].

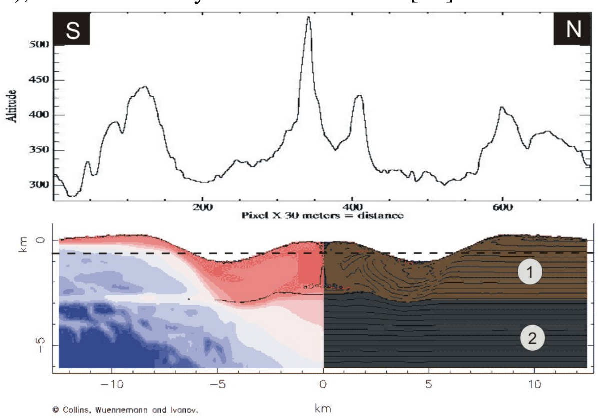

Figure 2- The upper figure shows the topographic profile based on SRTM dat measured along the white line in the figure 1. The lower figure is the final morphology for SdC (projectile:1.4 km diameter). The left side shows the deformation degree, with hotter colors indicating more intense deformation/fracturing, and colder colors less intense deformation. The right side shows that the deformation of the strata (straight lines) increasing from the rim towards the central uplift. Dashed line corresponds to the present erosion level.

The higher elevation of the collar in comparison with the elevation of the rim could not be reproduced in the model. Therefore, we consider a higher erosion degree along the rim than for the collar, which may be justified due to the higher resistance of the silicified sandstones of the collar and the high degree of fracturing at the very centre. It is assumed that erosion also carved out the central depression.

The left side of Fig. 2 shows the deformation degree, with hotter colors indicating more intense deformation. This result may be interpreted that the material has undergone a higher degree of brecciation and thus is less resistant against erosion. Currently, the model enables only a qualitative description of fragmentation. The highest deformation takes place in the central uplift region and the rim exhibits intermediate deformation. This is in agreement with observations in the field, with more deformed strata at the central uplift and undeformed strata, showing well preserved sedimentary structures, along the rim.

Finally the model allows for a quantification of the distribution of peak shock pressures (Fig.3) in the sedimentary and basement rocks. In the model the innermost region of the central uplift contains areas that are shocked to 10-15 GPa, which is in accordance with observations of shock features in samples obtained during fieldwork. The left panel in Fig. 3 shows the temperature distribution after impact. The hot spot at the sedimentary-basement interface is due to the strong impedance contrast of both materials.

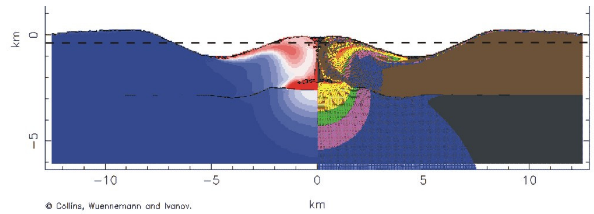

Figure 3- Final crater morphology for SdC, caklculated for an impact with a projectile of 1.4 km diameter. The right side shows peak shock pressures. The pressure range is (in GPa): red: 50; orange: 25; yellow: 15; green: 10; magenta: 5; blue: 1. The left side shows the temperature range (in K) Miminum(blue):273 K;Maximim(red):1000 K. Dashed line corresponds to erosion level.

Conclusions: In general our iSALE-model is in good agreement with the general characteristics of SdC, such as final crater diameter at an assumed level of erosion of 0.4 km and central uplift diameter. Pressure ranges between 10-15 GPa derived from the model can be related to shock pressures estimated based on the observed occurrence of shock indicators. The higher elevation of the collar in comparison with the rim is probably related to deeper erosion levels at the rim. For the future we plan to separate the different lithological units in the sedimentary sequence according to realistic rheological properties and porosities and to take the angle of impact into account by using iSALE-3D.

References:

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