ANALYSIS AND NUMERICAL MODELLING OF PIT CRATERS ON MERCURY

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INTRODUCTION

We present an analysis of an unusual feature present in two different impact structures: a steep-sided cone within an impact crater, surrounded by a trough. The aim of this work is to establish if this cone corresponds to the central peak of the crater and if this unusual morphology is due to pyroclastic volcanism, or if this structure is caused by constructive volcanic processes. To achieve this goal we have studied two impact craters, 41 km and 72 km in diameter, through numerical modelling.

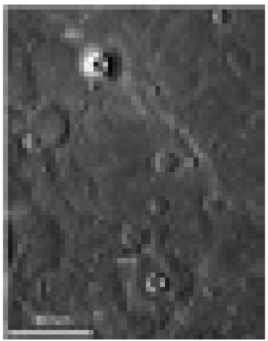
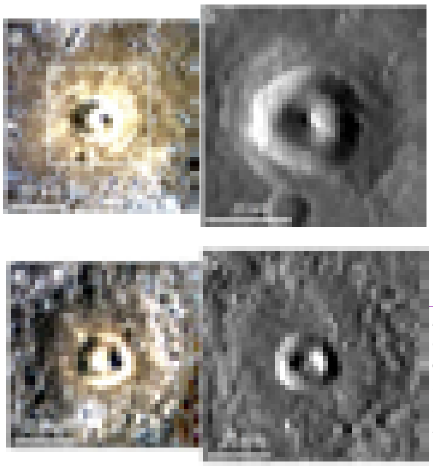


Fig. 1 *Image of the two craters studied in this work.*



GEOLOGICAL CONTEXT

High-resolution images obtained by the MESSENGER spacecraft reveal cone-like features in two different craters located in the region of -136° E, -6° N (Fig. 1).

The cones have basal radii of 6 km and 10 km (steep sides up to 23.5° and up to 26) and lie at the center a 40 and 70 km diameter crater respectively. An extensive area of relatively bright and red material with diffuse outer edges surround them (Fig. 2). Such deposits have been suggested to be pyroclastic in origin [1], so their presence at this location may suggest that these cones have a volcanic genesis. If this hypothesis is correct, these features represent the only examples of steep-sided volcanic edifices recognized thus far on Mercury.

We have observed that putative pyroclastic pits in other impact craters are often located circumferential to central structures. This observation leads us to the alternative hypothesis that the cone is in fact the central peak of an impact crater, and its unusual morphology is due to the formation of a moat-like pit around it caused by pyroclastic volcanism. This would be consistent with the hypothesis [2] that faults and fractures associated with impact craters play a controlling role on the location of pyroclastic vents on Mercury.

Fig. 2 *Steep-sided cones with proposed volcanic or pyroclastic genesis at the center of a 40 km (-136.7° E, -3.5° N) and 70 km diameter crater (-136.3° E, -7° N), above and below respectively.*
a. *Colour composite showing surrounding relatively bright and 'red' deposits (MDIS images EW0262430050I, EW0262430054F and EW0262430070G and MDIS images EW0262430050I, EW0262430054F and EW0262430070G for 40 km and 70 km diameter crater respectively);* ***b.*** *monochrome images of the cone (MDIS image EN0212282968M and MDIS image EN0242378054M for 40 km and 70 km diameter crater respectively) (Credit: NASA/JHUAPL/ Carnegie Washington)*

DTM GENERATION

DTM generation was performed following a photogrammetric workflow with many steps and several tools. The files were fed into ISIS3, radiometrically calibrated, and ortho-rectified with the *cam2map* program (i.e. projected onto the reference surface of the Mercury spheroid). They were then correlated using the Area Based image matching software "Dense Matcher" [3]. The Ames Stereo Pipeline (ASP) routine was used for triangulation, modifying the Dense Matcher disparity map to produce input data in the format accepted by ASP. After any necessary Bundle Block Adjustment, a GeoTiff raster DTM was produced at the resolution of the images processed and was imported in a GIS software package in order to extract the profiles shown in Fig. 4.

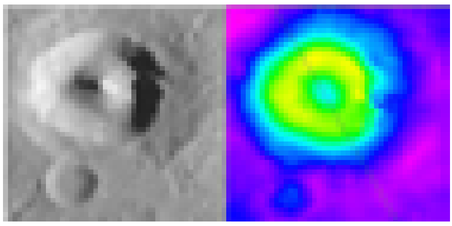


Fig. 3 *On the left the orthophoto produced from the DTM; on the right the elevation-color-map with the profile section for the 40 km diameter impact crater. The same procedure was also followed for the 70 km diameter impact crater.*

NUMERICAL MODELLING

We use the **iSALE shock physics code** ([4], [5], [6], [7], [8]), a multi-material, multi-rheology code, to model the formation of both diameter impact structures discussed above considering a similar model setup since they are located in the same region.

- We based our simulation on a spherical basalt projectile, with an impact velocity of 30 km/s [9] and an impact angle of 90°.
- The Hermean surface was modeled as a double layer made up of a brecciated 5 km basalt layer overlying an intact basalt layer.
- The thermodynamic behavior of both the projectile and the target materials is described by tables generated using the basalt ANalytic Equation Of State (ANEOS) adopting different values of material strength for the two different layers forming the target .
- We used a density for the target equal to 2900 kg/m^3, ignoring the porosity of the target; while we fixed a projectile porosity at 10%.
- The ordinary constitutive model accounting for changes in material shear strength [5] must be supplemented by a transient target weakening mechanism, called acoustic fluidization model, which is controlled mainly by the viscosity and the decay time [10].

RESULTS AND DISCUSSION

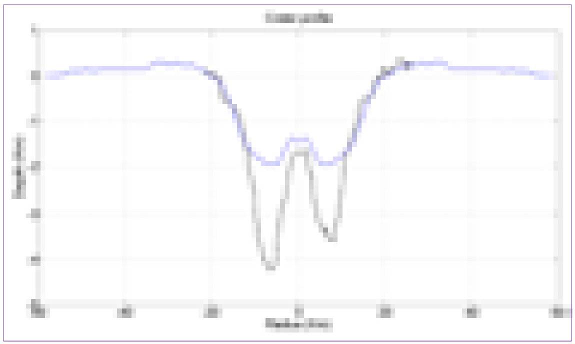


Fig. 4a *DTM profile obtained with DM software (black line) and iSALE (blue line) profile of the 40 km pit crater corresponding to a decay time of 48s and a viscosity value of 60000 m/s^2*

40 km pit crater

In Fig. 4a we compare the DTM profile with the iSALE output observing a good match in terms of dimension, but the morphology appears slightly different with the observed crater. We propose that this is due to the pyroclastic event(s) that affected it, generating an asymmetric drop of several hundred meters in the level of the crater floor around the central.

The projectile, with a diameter of 2.4 km, generates a crater diameter in agreement with the DTM profile considering that the final output of iSALE has a 4% radius uncertainty. Results from the simulation reproduce the predicted depth of the crater, which would be expected to be 1 km to 2 km on the basis of a depth-to-diameter ratio of 0.034 ± 0.010 [11] for complex craters with a diameter higher than 50 km. This depth is an approximate result because we have extrapolated the statistical data presented in [11] to a lower diameter range in order to apply the relationship above to our case. Following this approach we have also found that the expected height of the central peak would be in the range of 0.3-0.9 km and the simulated central peak obtained from the best-fit simulation is in agreement with this estimation.

Combining the results from simulations with the morphological considerations of [11] allows us to understand the pyroclastic event that affected this crater. For example, the volume of material missing in the pit below the predicted original floor depth of -1750 m is ~ 400 km^3

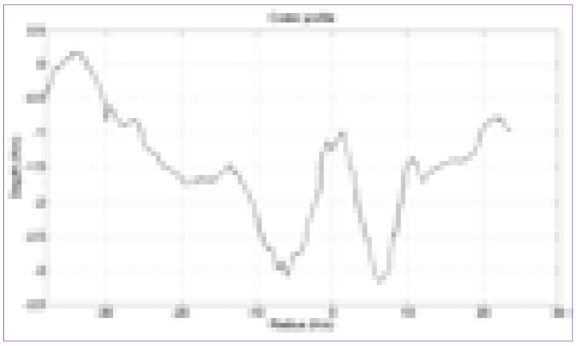


Fig. 4b *DTM profile obtained with DM software (black line) of the 70 km pit crater.*

70 km pit crater

The DTM profile obtained with DM software is shown in Fig. 4b: the left side of the crater profile is well known, while part of the right side profile lacks due to the images used.

Preliminary results from the simulations show that the projectile diameter that generates the 70 km diameter impact crater is 3.6 km, but we are carrying out a series of simulation over a broad range of AF parameters in order to find the best solution.

We are also investigating the possibility that this crater could be a protobasin. The 1.8 km crater depth indicated by our DTM gives it a depth-diameter ratio close to the protobasin value proposed by [11], 0.027 ± 0.007.

From the analysis of the 40 km impact crater and the preliminary considerations of the 70 km impact crater we support the hypothesis that the 'cone' is the crater's intrinsic central peak structure, surrounded by pyroclastic deposits originating from a pit that encircles the peak.

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