SCALING RELATIONSHIPS FOR IMPACT BASINS ON MARS.

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Introduction: Impact cratering is a common geological process in the Solar System, having played an important role in the formation and evolution of most planetary objects with solid surfaces [1,2]. It results in the formation of impact craters with varying morphology depending mainly on impact momentum and energy, and geological properties of the target [2,3]. Through comparison of numerical impact cratering simulations with available space exploration data, remote observations, and geophysical modelling, it is possible to establish constrains on some properties of the target body at the time of crater formation, similarly to what has been made for the Moon in recent years [4,5]. A planet's crustal structure, internal structure, and thermal regime effect large crater morphology and can be further investigated using simulations.

In this work, we performed numerical simulations of the formation of large impact craters (or impact basins) on Mars. We used the latest discoveries by the NASA InSight mission about the crust and mantle structure of the planet [6,7], and recent geophysical thermal models [8,9] to determine the most suitable target conditions at the time of impact. Here, we propose a preliminary set of impact scaling relationships for Mars' basins, i.e., the relationships between impact conditions and formed impact basins, for a range of crustal thicknesses and geological epochs.

Method: Our simulations were performed using iSALE-2D, a multi-material, multi-rheology shock physics code that can simulate impacts in geological materials [www.isale-code.de]. Our current investigation is focused on the effects of crustal thickness and temperature profile variations, as they were deemed the most important factors in the formation of lunar impact basins [4,5].

We implemented the latest interpretation of the interior structure of Mars derived from the NASA InSight mission in our numerical impact modelling. The average global crustal thickness (ct) is estimated to be between 30 and 72 km, ranging from less than 5 km at the center of basins such as Hellas and Isidis to more than 120 km in regions of the southern highlands [7]. The estimates from InSight were used to calculate thermal models at 4.4 Ga, when the crust was relatively hotter, and 3.5 Ga, when the crust was comparatively colder [9]. We considered two crustal thickness values, 47 and 91 km, corresponding to the average crustal thicknesses below and above the global average respectively, which is roughly equivalent to the lowlands and highlands regions on Mars.

We considered vertical impacts at 10 km/s at 3.5 (young) and 4.4 Ga (old), for a thin (47 km) and thick (91 km) crust. The target was considered flat, composed of a basalt crust and a dunite mantle. For the time being, six projectile sizes were tested, namely 5, 20, 40, 60, 80 and 100 km in diameter, producing impact basins ranging from ~50 to ~1000 km in main rim diameter.

Results and Discussion: Based on our numerical impact modelling, we derived a preliminary set of scaling relationships for Mars' impact basins (Fig. 1).

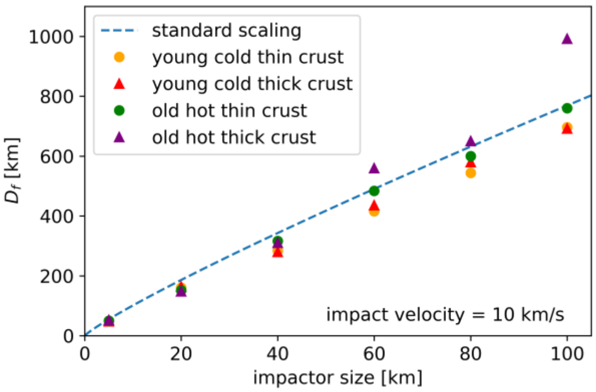

Fig. 1 - Preliminary scaling relationships for impact basins on Mars, calculated for four scenarios: young cold thin crust (3.5 Ga, ct = 47 km) in yellow, young cold thick crust (3.5 Ga, ct = 91 km) in red, old hot thin crust (4.4 Ga, ct = 47 km) in green and old hot thick crust (4.4 Ga, ct = 91 km) in purple. Impactor size is shown on the x-axis and final crater rim diameter (D_f) on the y-axis, both in km. Gravity-dominated standard scaling [1,2] is shown in blue.

Gravity-dominated standard scaling [1,2] seems to slightly overestimate final crater rim diameter for the entire size range in all cases, except for craters in old and hot thick crust at larger diameters, for which standard scaling underestimates crater size (Fig. 1). For impacts in a young and cold crust, there seems to be little variation in final crater diameter due to crustal thickness, as both thin and thick crust cases resulted in similar final crater diameter estimates. Impacts in an old and hot thin crust are the most similar to standard scaling for the investigated size range. For impacts in an old and hot thick crust, the crater size is comparable with craters forming in an old and hot thin crust for diameters up to ~400 km. For larger sizes, simulations suggest noticeable larger final crater rim diameters when compared to the standard scaling law.

Our impact simulations suggest that crater morphology is affected by crustal age and thickness before impact, especially for larger craters. The crustal thinning and mantle uplift at the crater center forms during the crater modification stage, when crustal overturn flows back towards the crater center [4]. Significant differences in the resulting crater morphology can be seen when examining cross sections of impact simulations over different ages and thicknesses (Fig. 2). For the same impact conditions, craters formed in younger and colder crust (Fig. 2a, b) show a lesser mantle uplift in comparison to craters formed in older and hotter crust (Fig. 2c, d). Crustal overturn and inflow forms a crustal cap within the crater center. Its average thickness varies, being larger in craters formed in younger and colder crust (Fig. 2a, b) in comparison to craters formed in old and hotter crust (Fig. 2c, d).

The differences in crater morphology could be explained by differences in target strength. A hotter target would have lower shear strength compared to the colder crust [4], therefore mechanically weaker and subject to flow during crater collapse compared to a colder target. Hence, impacts taking place at 4.4 Ga, very early in Mars' evolution, when the planet was hotter and the crust respectively weaker, could be expected to form craters with larger crustal thinning and main rim diameters. Relatively, impacts at 3.5 Ga, when the planet was colder and the crust stronger, could result in craters with smaller crustal thinning and main rim diameters.

Conclusions: We simulated the formation of impact basins on Mars for a range of impactor sizes and target conditions. Based on our simulations, we aim to derive a new set of impact scaling relationships for Mars' large craters/basins (Fig. 1). Age and crustal thickness before impact affect crater morphology. Craters forming in older and hotter crust have larger final rim diameters, larger crustal thinning diameters and more pervasive mantle uplift, while craters formed on younger and colder crust have smaller final rim diameters, smaller crustal thinning diameters and less pervasive mantle uplift. This agrees with similar effects observed on the Moon [4,5] and will be expanded upon in future works.

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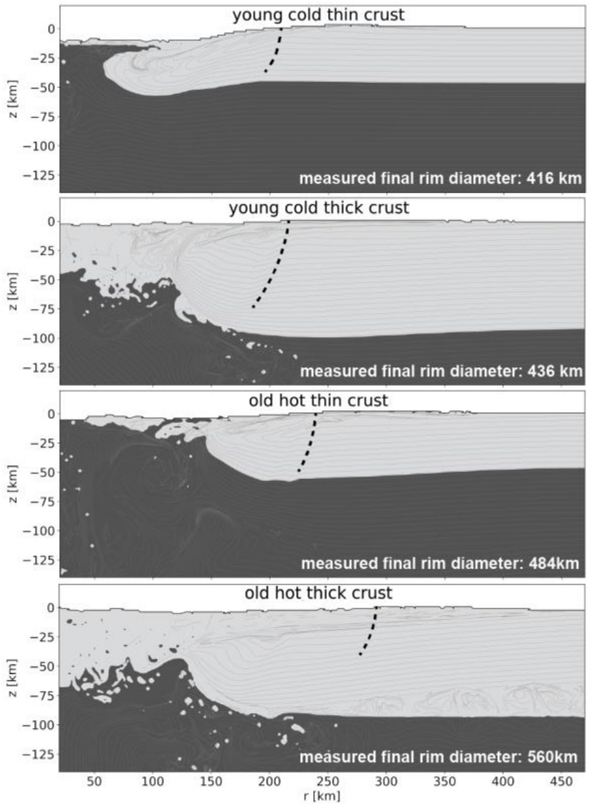

Fig. 2 - Numerical impact cratering simulation results made with iSALE-2D shown as vertical cross-sections of half-craters. All impacts were made by a dunite projectile 60 km in diameter hitting a target composed of basalt crust (light grey) and dunite mantle (dark grey) vertically at 10 km/s. Panels show different target conditions, in combination of old and hot/young and cold, thin/thick crust bracketing the range of possible ages and crustal thickness for basin formation conditions on Mars. The black dashed lines indicate interpreted faults used for diameter measurements. Measured final rim diameters are written in each panel. Standard scaling predicts a final diameter of 491 km.

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