INVESTIGATING THE MARTIAN DICHOTOMY MEGA IMPACT FORMATION HYPOTHESIS.

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Introduction: The most clearly visible feature on Mars is the hemispheric dichotomy: the difference in elevation (~4 km), crustal thickness (~30 km), roughness, and impact crater density between the Northern and Southern hemispheres [1,2]. The depression in the northern hemisphere encompasses ~35% of the planet's surface, equivalent to an average diameter of 7700 km [2]. The dichotomy formed early in Mars' history, likely in the first 50 Myr [1]. The dichotomy boundary is expressed both as steep scarps in places and gentle slopes in others [2].

Despite the crustal dichotomy's prominent nature, its formation mechanism remains unknown. The possible formation mechanisms fall in the categories of endogenic and exogenic. For endogenic processes, degree-1 mantle convection is often invoked [e.g. 3]. Exogenic scenarios call for a single mega impact [2] or multiple smaller impacts [4]. If the crustal dichotomy is formed by a mega impact, the impact must not shatter the planet or produce sufficient melt to obliterate all surface and crustal evidence of the impact.

We investigate whether the Mars crustal dichotomy could have formed by a single mega impact. This first requires characterizing planetary-scale impacts, which have not been extensively studied; these impacts differ from the thoroughly studied smaller impacts due to, in part, the importance of surface curvature in planetary-scale impacts. We focus on the effect of a planetary-scale impact on early Mars, especially on the martian crust and surface. We compare the results of these simulations to observations to evaluate whether a single mega impact may have formed the dichotomy. Particularly, we investigate the depth of penetration of the projectile, the amount of melt produced, and the redistribution of excavated material.

Modeling: We use a fully 3 dimensional Smoothed Particle Hydrodynamics (SPH) model to simulate the impacts. SPH is a Langrangian method in which an object is represented by particles, where each particle's mass remains constant, but its size, pressure, internal energy, and density change in response to external forces. SPH has been extensively used for simulating the Moon-forming impact [5]. In our simulations we use 20,000 to 200,000 particles, nominally using 50,000 particles. The semi-empirical Tillotson Equation of State (EOS) is employed [6]. Figure 1 shows a snapshot of a simulation.

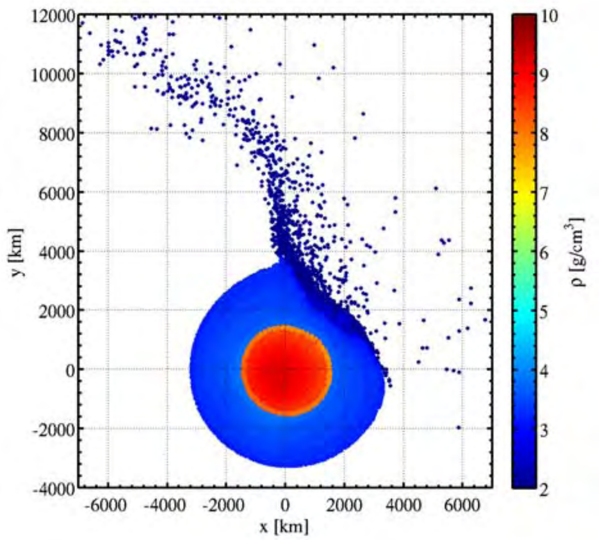

Figure 1. Snapshot of an impact simulation: t = 25 min after impact. Half-space shown. Impact parameters v = 6 km/s, $D_{impactor}$ = 860 km, 1.45x10^{29} J, D_{crater} ~ 8000 km, impact angle = 30 deg.

Initial Conditions and Melt Production. We calculate melt production using two criteria: a pressure threshold and an energy threshold. In the pressure melting criterion, material shocked above its threshold pressure melts. Pressures are assumed to be hydrostatic. For the energy melting criterion, the results depend on material properties and internal energy initial conditions. Thus we assume the surface and core-mantle boundary temperatures from parameterized convection models [7], and impose an adiabatic compression heating profile in the planet to obtain the mantle and core internal energies. Early Mars is likely to have had a convecting mantle and core, resulting in an adiabatic profile.

Equation of State: In order to properly implement the initial conditions, appropriate material properties must be chosen for the mantle and core. We assume an iron core. The Tillotson EOS library does not include an olivine-like material, so to match mantle density we create our own olivine EOS. We used the same parameterization and formulation as the Tillotson EOS. Density [8], bulk modulus [9], and heat capacity [10] values were obtained from the literature; all other values were set to the average of available representative materials (basalt, granite, anorthosite lpp & hpp, andesite). Our model of Mars matches the known planetary radius and mass, and the pressure profile [11] and core size [12] are within expected ranges.

Impacts parameter space: We simulate impacts with velocities of 6 to 50 km/s (where 5 km/s is Mars' escape velocity and 50 km/s is twice Mars' orbital velocity), impact angles of 0 (vertical impact), 15, 30, 45, 60, and 75 degrees, and impact energies sufficient to create 4000 to 10,000 km craters (following the gravity regime scaling in [2]).

Results: Figures 2 & 3 show results on the depth of penetration of the impactor and mass of melt produced.

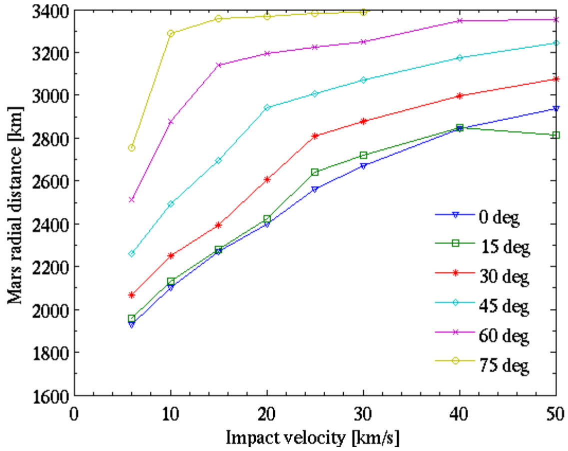

Figure 2. Penetration of deepest 10% of impactor. Colours represent impact angle; R_{core} = 1600 km, R_{Mars} = 3400 km; impact energy = 1.45×10^{29} J.

Preliminary results indicate that, keeping impact energy constant, large (therefore slow) and low angle impacts penetrate the deepest. In constant energy impacts, as the impact velocity decreases, the impactor size and momentum increase. The smaller depth of penetration of oblique impacts is expected due to the grazing nature of high angle impacts. Thus, faster (therefore smaller) and higher angle impacts result in less disruption of the planet.

We also find that a head-on impact produces the equivalent of 30-40 km deep global equivalent layer (GEL) of melt. This depth of melt is significant and may erase all signs of the impact. For more oblique impacts, specifically 60-75 degree impacts, the produced melt is reduced to 5-10 km GEL, which could allow for the retention of the crater. However, the resulting size and shape of the crater for different impact angles still needs to be investigated.

An interesting feature we observe is that for vertical impacts the maximum melt is produced at about 15 km/s impacts, and the amount of produced melt decreases for both lower and higher impact speeds. For the very oblique impacts this trend is not present and the melt produced decreases with impact velocity. The increase in melt produced at intermediate velocities is attributed to the pressure melting criterion. Pressure melting is more important at low impact angles. In the energy melting regime, the maximum melt is produced at low impact velocities. This trend is due to larger, slower impactors depositing energy over a larger volume of the planet. Since the material is already close to its melting point, this increase in internal energy results in larger melt production.

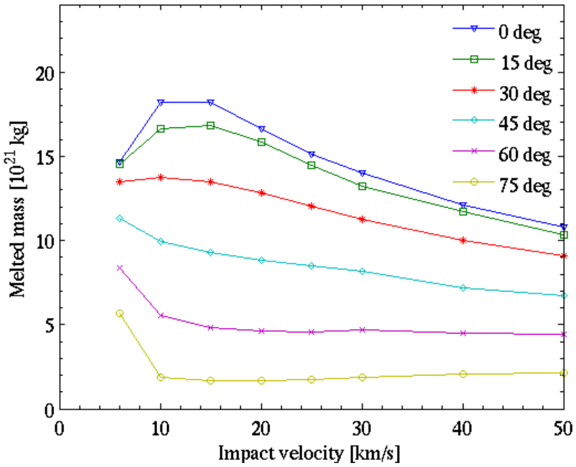

Figure 3. Produced melt that is retained, in terms of glabal equivalent layer over Mars; 10 km depth = 5.1×10^{21} kg. Impact energy = 1.45×10^{29} J.

References:

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