Identifying the Sweet Spot for an Impact-Induced Martian Dichotomy. Harry Ballantyne[1], Martin Jutzi[1] and Gregor Golabek[2], [1]Universität Bern, Space Research & Planetary Sciences (WP), Bern, Switzerland, [2]Bayerisches Geoinstitut, Germany.

Introduction: Almost 50 years ago, NASA's Mariner 9 space probe performed the first complete orbit of a planet other than Earth. This was around our smaller celestial neighbour – Mars. Along the way, this spacecraft obtained images of approximately 85% of the planet's surface in unprecedented detail, revealing a stark contrast between the northern and southern hemispheres now known as the martian crustal dichotomy. This moniker predominantly refers to the 4-8 km difference in elevation between the southern hemisphere and an apparent basin covering roughly 42% of the north. Other associated features include a higher density of volcanoes and visible impact craters in the south relative to the north.

Some studies have attempted to explain these properties through endogenic means; namely via degree-1 mantle convection studied using large-scale thermochemical models [1]. Others have taken the exogenic route, proposing that a giant impact early in Mars' history caused the excavation of a large mass of material from the northern hemisphere, thus giving rise to the observed dichotomy [2]. Given that such collisions are expected to be very common in the final stages of terrestrial planetary accretion, this approach is highly feasible. The latter studies have, however, generally ignored any long-term geodynamical consequences on the martian interior that such an event may cause.

Recent work has proved the importance of coupling these methods, introducing a hybrid exogenic-endogenic scenario whereby a giant impact triggered a localized magma ocean and subsequent superplume in the southern hemisphere [3]. This hypothesis has, however, only been investigated using a very limited range of initial parameters, all of which lead to significant heating deep into the mantle. This therefore motivates an interesting area of study – could there be a parameter space that leads to a hemispherically-thickened crust without significantly heating the mantle? We aim to answer this question using a suite of smoothed-particle hydrodynamics (SPH) simulations, using the SPHLATCH code [5], that explore a large parameter-space chosen with the intention of limited internal heating. For the analysis of the simulation outcomes we apply a newly developed scheme to estimate the thickness and distribution of (newly formed or re-distributed) post-impact crust.

Method: The chosen initial parameters for the main suite of SPH simulations are as follows: impact angles of 0-90° in steps of 15°; impact velocities of 1.0, 1.2 and 1.4 times the mutual escape speed; impactor radii of 1000km, 1500km and 2000km; and relative core masses of 25% and 50%. All of these simulations use a resolution of 200,000 SPH particles, with near head-on collisions (0-30°) being modelled for 50 hours after impact and oblique collisions (45-90°) for 200 hours to allow for any secondary (or even tertiary) impacts. In addition, a smaller set of high resolution (1,000,000 SPH particle) simulations are being used to investigate extremely low-velocity (less than mutual escape speed) collisions in a bid to quantitively identify the transition from impacts of large-scale mantle heating to those of relatively cool accretionary piles similar to those described in [4]. This then allows for discussion of the potential mechanisms that could lead to such events and their feasibility.

Each model includes the effects of shear strength and plasticity (via a Drucker-Prager-like yield criterion) as such effects have been shown to be significant on the scales concerned in this study [5]. Moreover, the sophisticated equation of state ANEOS is being used along with a Mars-specific solidus [6] to accurately calculate the physical environment in which such solid characteristics must be considered.

In all of these studies, both Mars and the impactor are treated as differentiated bodies composed of an iron core and a silicate mantle. An example result of one of these simulations can be seen in Figure 1.

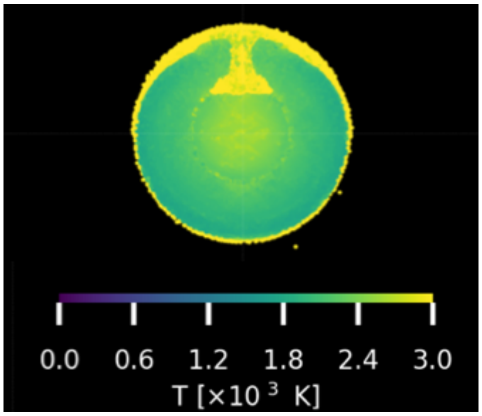

Figure 1: The resulting temperature field of a Mars-like body from a 10^6 particle SPH simulation, 12hr after an impact with a ≈1000km radius impactor at a 0° impact angle and a velocity of 80% of the mutual escape speed. A slice has been taken through the centre of the body to show the interior, with each circle representing an SPH particle.

Preliminary Results: The SPH kernel interpolation is used to convert the data of the simulations into high resolution, uniformly-spaced spherical grids. For each grid cell point we calculate a melt fraction using a simple linear relation involving the temperature, solidus temperature and liquidus temperature for the given pressure [7]. The Mars-specific solidus mentioned earlier is used for this purpose, along with a pressure-dependent peridotite liquidus [3,8] that has been modified to include the latent heat of melting. This then gives us a distribution of melt fraction throughout the entire mantle of our Mars-like body, as can be seen in Figure 2.

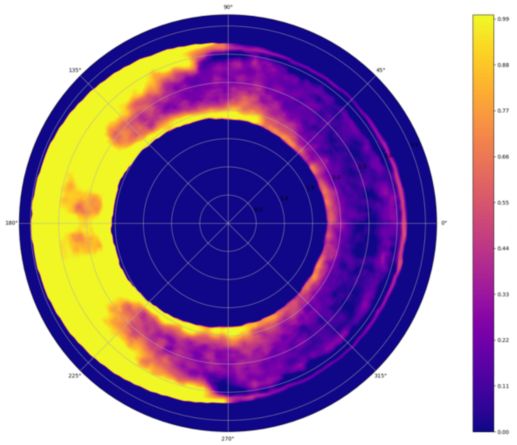

Figure 2: The melt fraction distribution of a Mars-like body 50hr after an impact with a ≈1500km radius impactor at the mutual escape speed and a 30° impact angle. A slice has been taken through the centre of the body to show the interior, with any volume above the body's surface being ignored and thus represented by a melt fraction of zero.

In order to estimate what fraction of this melt crystallises into basaltic to andesitic crust we use the pyroxene fraction of a fertile mantle: roughly 20% by mass [9]. In addition, any melt at pressures greater than approximately 7.4 GPa (equivalent to a neutral buoyancy depth of around 600km) [10] should become negatively buoyant and is therefore ignored in our crustal calculations. For each latitude and longitude coordinate on the grid, we can now find a total crustal mass and convert this to a thickness using a current estimate on the density of the martian crust [11]. This allows us to create maps of crustal thickness for each of our SPH simulations, an example of which can be seen in Figure 3.

The initial results of this study have revealed promising hemispherical features in certain cases, with further analysis being made in an attempt to compare the results to those of the observational data in a quantitative manner (e.g. through bimodal fitting of crustal thickness histograms or k-means clustering). In addition, the effects of a uniform, primordial crust being present on Mars before the dichotomy-forming event are being studied, as well as an investigation into the final distribution of the impactor material as this could be chemically distinct from the primordial martian composition.

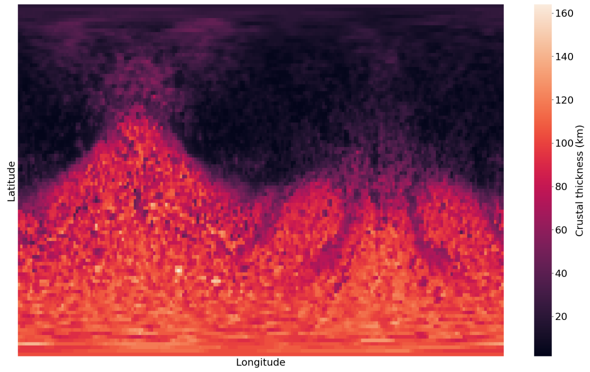

Figure 3: A global map of crustal thickness for the same case as Figure 2.

Of notable interest are the results of the grazing impact angles, as some of the initial kinetic energy of the impactor is converted to rotational energy of Mars, allowing for subsequent merging events of decreased impact velocity. In addition, the effects of material strength have been found to be non-negligible, in contrast to previous beliefs that such aspects can be ignored on the length-scales involved in planetary collisions.

Acknowledgements: This project is supported by the Swiss National Science Foundation under grant 200021_175630. We gratefully acknowledge the developers of the SPHLATCH code, including A. Reufer and A. Emsenhuber.

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