SOME EFFECTS OF MULTIPLE LARGE METEORITE IMPACTS ON MARS Thomas Ruedas[1,2], Doris Breuer[1], [1]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany; [2]Institute for Planetology, University of Münster, Germany (Thomas.Ruedas@dlr.de)

Introduction: Most studies of the effect of basin-forming impacts on mantle convection include only a single impact. The actual evolution of planets, however, is shaped by a multitude of impacts, many of which occur in relatively close succession and proximity to each other, and so interactions between them are expected. We follow up on some earlier studies that considered the potential cumulative effects of successive impacts [1, 2] and investigate the extent of mutual interaction between two or more impacts as a function of spatial and temporal separation with a series of numerical mantle convection models.

Method: The convection code is a modified version of STAGYY [3] and solves the conservation equations of mass, momentum, and energy in the compressible, anelastic approximation with melting on a two-dimensional spherical annulus grid [4] as described by [5]. The impacts are represented as instantaneous thermal anomalies, with shock-heating derived from the peak shock pressure based on the impedance-match model (cf. [6]) and the pressure decay with distance from the impact center as given by the "inverse-r" parameterization from [7]. Supersolidus temperatures from shock heating are cut just above the solidus. As we model the impacts after existing martian craters, we use their observed final diameters D_f as input and deduce impact parameters such as the impactor size via scaling laws [8].

In order to relate the spacing and timing of subsequent impacts to their magnitude, we scale the spacing Δx with the diameter of the isobaric core D_ic and estimate a decay time Δt_d for the dynamical effects of an impact.

Models: The general model parameters used in all models are listed in Table 1. In the first model set, two successive impacts of identical rocky asteroids hitting at 45° with sizes corresponding to either the Isidis ($D_\mathrm{f} = 1352$ km) or the Utopia ($D_\mathrm{f} = 3380$ km) impact basins, respectively, are considered. In all models, the first impact of a pair is assumed to occur at 4 Ga, i.e., 500 My after the model run begins, followed by the second impact $0.5\Delta t_\mathrm{d}$, Δt_d, or $2\Delta t_\mathrm{d}$ later at a distance of D_ic, $2D_\mathrm{ic}$, $5D_\mathrm{ic}$, or $10D_\mathrm{ic}$. For the Isidis-size impacts, $D_\mathrm{ic} = 135.4$ km and $\Delta t_\mathrm{d} = 6$ Myr, and for the Utopia-size impacts, $D_\mathrm{ic} = 385.6$ km and $\Delta t_\mathrm{d} = 12$ Myr. In the second set of models, subsets of the different impacts from [9] that lie on different great circles were used. These impacts strike at variable distances from each other and in variable time intervals.

Results: The quasi-instantaneous input of energy into the planetary interior by the impact produces an almost instantaneous jump in several dynamical variables, e.g., the mean flow velocity v_rms, the mean mantle temperature T_mean, and the global mean surface heat flow, which is followed by an initially steep but lessening decline over the next few millions of years. The signal of the second impact is added to the decaying signature of the first in different ways for different variables. The models show that the second impact peak in $v_\mathrm{rms}(t)$ tends to increase with decreasing Δx of the impact sites (Fig. 1), because the lingering thermal anomaly from the first impact boosts the upwelling triggered by the second. Likewise, the second $v_\mathrm{rms}(t)$ maxima are larger for smaller time intervals between the impacts, especially for the Isidis-sized impacts. The maximum change in $T_\mathrm{mean}(t)$, by contrast, grows with spatial separation, because the total shock-heated volume is larger in models with less overlap between the affected regions, but it decreases with temporal separation. The surface heat flow anomalies for all pairs are all very similar, and no clear effect of spatial and succession interval is identified.

The shock-heated volumes are also depleted in fusible components and are thus compositionally distinct and less dense than pristine mantle material, which contributes to their buoyancy and the reinforcement of convection caused by impacts. Heat and enhanced convection can also result in increased production of melt and crust, but the extreme depletion of the shallower mantle in the impact-affected region counteracts this effect. Whether the resulting post-impact crust is thicker or thinner in the crossover region depends on spacing, timing, and impact size. As the impact-generated anomalies ascend and spread out beneath the lid, they may not only influence each other dynamically, as seen in the $v_\mathrm{rms}(t)$ curves, but may also collide and merge, especially if they are closely spaced. In models with widely spaced impacts in close succession, both anomalies develop somewhat independently for a certain time until they have spread far enough below the lid to run into each other. In such cases a piece of normal mantle can

Table 1: Important model parameters

Mantle thickness	1659.5 km
Surface temperature	218 K
Initial potential temperature	1700 K
Initial core superheating	150 K
Simple/complex transition	5.6 km
Bulk silicate Mars Mg#	0.75
Present-day K, Th, U contents	305 ppm/56 ppb/16 ppb
Initial bulk water content	36 ppm
Impactor density, ϱ_imp	2720 kg/m^3
Impactor velocity, v_imp	9.6 km/s

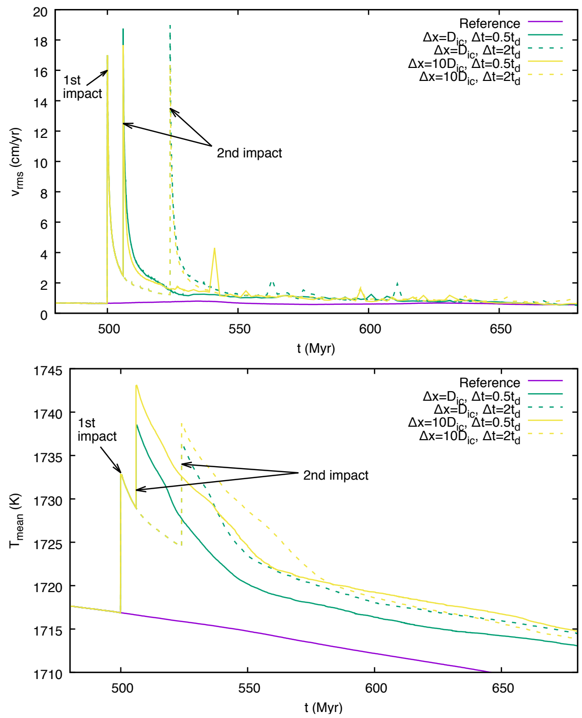

Figure 1: Global rms flow velocity (top) and mean mantle temperature (bottom) for some models with two subsequent Utopia-sized impacts.

get caught between them and induce a downwelling due to its relatively higher density, especially for smaller impacts with less vigorous dynamics; in larger ones, it will simply be swept up by the flow (Fig. 2).

In all cases investigated, the differences between the models diminish with time, and the impact signature in the temporal evolution of the system's dynamical variables fades and has disappeared long before the present. In particular, thermal anomalies fade with time and leave no signal in the present-day heat flux. Compositional anomalies, however, are preserved, as pointed out by [5], but it would be difficult to draw a sharp boundary between the region of influence of one impact or the other if the impacts are close enough to overlap. Variations in post-impact crust formation are also reflected in the crustal thickness and may thus preserve a long-term record of impact-induced mantle dynamics.

As the models with multiple impacts on a great circle show, a succession of various different large impacts produces a strongly variable depletion pattern in the uppermost mantle (Fig. 3). This pattern still reflects the diversity of the impacts that produces it, but the vigorous post-impact dynamics and merging of the individual anomalies precludes the distinction of clear boundaries between the traces of the discrete events.

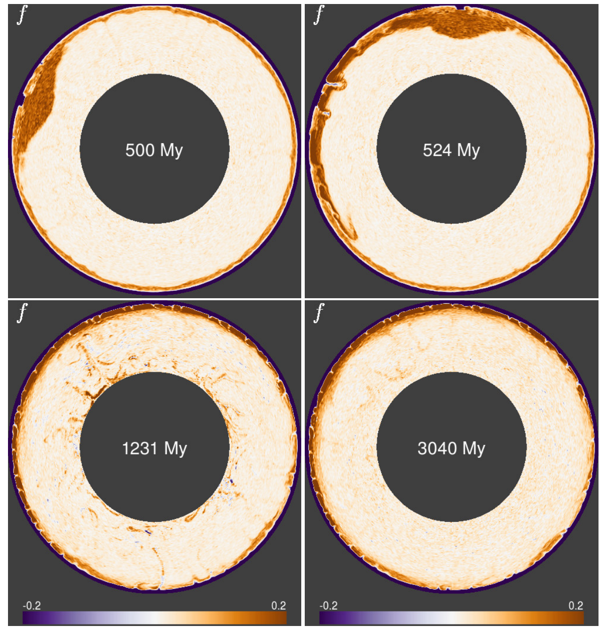

Figure 2: Composition field snapshots at the times of impact and two later stages of evolution for the model with two subsequent Utopia-sized impacts with $\Delta x = 10D_{\mathrm{ic}}$ and $\Delta t = 2t_{\mathrm{d}}$.

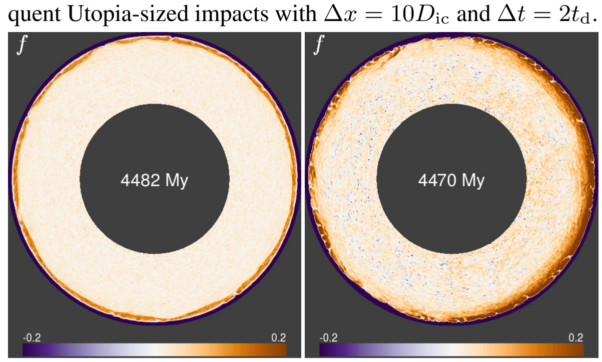

Figure 3: Present-day composition field snapshots of the impact-free reference model and a model with seven different impacts from [9].

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References: [1] J. H. Roberts, et al. (2012) *Icarus* 218(1):278. [2] T. Rolf, et al. (2017) *Icarus* 286:138. [3] P. J. Tackley (2008) *Phys Earth Planet Inter* 171(1–4):7. [4] J. W. Hernlund, et al. (2008) *Phys Earth Planet Inter* 171(1–4):48. [5] T. Ruedas, et al. (2017) *J Geophys Res* 122(7):1554. [6] W. A. Watters, et al. (2009) *J Geophys Res* 114:E02001. [7] T. Ruedas (2017) *Icarus* 289:22. [8] H. J. Melosh (1989) *Impact cratering: a geologic process*, Oxford University Press. [9] H. Frey (2008) *Geophys Res Lett* 35:L13203.