Some effects of multiple large meteorite impacts on Mars

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Model setup
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 investigated 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. Our 2D models include a detailed description of mantle mineralogy and chemistry and consider core cooling (cf. Ruesch and Breuer, 2017). These models are combined with a parameterization of the effects of an impact built on the approach of Watters et al. (2009) and the pressure-decay distance from the impact center as given by the “inverse-square” parameterization from Ruesch (2017). In order to relate the spacing and timing of subsequent impacts to their magnitude, we scale the spacing Δt with the diameter of the impact core Dic and the time Δt between impacts by an estimated decay time Δt for the dynamical effects of an impact in some models.

Results: Two-impact models
The sudden input of energy into the planetary interior by the impact produces a jump in several dynamical variables, e.g., the mean flow velocity v rms, the mean mantle temperature Tmean, and the global mean surface heat flow q, followed by an initially steep decline (Fig. 1). 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 in v rms (t) tends to increase with decreasing Δt, because the lingering thermal anomaly from the first impact boosts the upwelling triggered by the second;
- the second v rms (t) and T mean (t) maxima are larger for smaller Δt but the latter grows with Δt, because the total heated volume is larger in models with less overlap of the affected regions;
- the second q (t) peak decreases with both increasing Δt and Δt, whereas the decrease with Δt is due to the deposition of cold material at the surface.

Melt production and extraction in the shock-heated regions reduce their density, thus enhancing their buoyancy and reinforcing convection caused by impacts. This can also result in increased production of crust, but the extreme depletion of the shallower mantle in the impact-affected region counteracts this effect. As the impact-generated anomalies spread and spread out beneath the lid they may collide and merge after initial stage of somewhat independent evolution. In cases with large Δt, a piece of normal mantle can get caught between them and induce a downwelling due to its relatively higher density, especially for smaller impacts with less vigorous dynamics (Fig. 2).

Results: Multiple impacts on a great circle
A succession of various-different large impacts produces a strongly variable depletion pattern in the uppermost mantle (Fig. 3), but the vigorous post-impact dynamics and merging of individual anomalies preserves the distinction of clear boundaries between discrete events. As in the two-impact models, thick crust is formed immediately after the impacts but partly delaminates on timescales on the order of 10-100 Myr. However, the more perturbed dynamics of models with several impacts result in more extensive lithospheric instability in the later evolution, which in turn stills the mantle up and enables prolonged melt and crust production in some places by transporting relatively fresh or re-enriched material into the melting zone. This leads to a second era (limited and localized) crustal production considerable time after the last large impact that generates some sites of permanent thick crust at least five or six basin-forming impacts on a great circle occur.

The lithospheric instability and subsequent transient accumulation of relatively cool material at the CMR also has potential implications for core dynamics. In most of these models, a subduction zone doubles for several hundred Myr after the impacts relative to the impact-free reference model (Fig. 5). The only exception, in which the increase is much less pronounced, is model GC5, which had only four impacts and was also the least productive in terms of post-impact crust formation.

Summary
Impacts are not isolated events but can influence each other through their dynamical effects. Very closely spaced impacts occurring shortly after one another can almost appear like a single large impact, whereas the interaction is less direct and more complex as Δt and/or Δt grow.

The differences between the models in the system’s dynamical variables diminish with time, and the thermal impact signatures have disappeared long before the present. Compositional anomalies are preserved, but they are difficult to discern as sharp boundaries between the region of influence of individual sufficiently closely spaced impacts. Variations in post-impact crust formation are also reflected in the crustal thickness.

Very large impacts can trigger lithospheric instabilities that modify the convection flow field, and beyond some threshold these instabilities can become so extensive that they set the state on a global scale and can reinforce crustal production. The accumulation of lithospheric material at the CMR may also have an effect on core dynamics.

References