CONSEQUENCES OF IMPACTS SEQUENCES ON THE MANTLE OF TERRESTRIAL PLANETS AND UPPER MANTLE DEPLETION. C. Gillmann\textsuperscript{1} \textsuperscript{1}Rice University, Earth Environmental and Planetary Sciences, MS-126, 6100 Main Street, Houston, TX 77005, USA (cg62@rice.edu).

Introduction: Collisions of meteorites with terrestrial planets have probably been ubiquitous in the solar system and beyond and are even part of the formation of solid planets (Accretion). Primitive impacts are indeed responsible for the initial composition and conditions of terrestrial planets, as they govern metal, silicate and volatile species delivery, as well as, Magma Ocean or core formation or surface conditions. Later impacts on planets with a solid surface are important too, and may also affect the evolutionary path of the body, as evidenced by the debate about the composition of Late Accretion \cite{1}, for example (dry or wet), and studies about atmospheric erosion by impacts \cite{2}. They are complex events that can deeply change the course of the surface evolution of a planet but also affect its interior, possibly as deep as the core in extreme cases. Here we do not try to improve models for direct thermal consequences \cite{3}. Instead, we investigate the consequences of impacts on evolution, from how they affect convection patterns to their effects on mantle depletion to melting or heat fluxes specificities.

Model: We use a simplified method to account for the thermal effects of large impacts \cite{4}, adding a thermal anomaly to the temperature field of the mantle. The model is adapted to take into account variations in impact velocities. The thermal anomaly represents the heating from shock pressure and the following adiabatic decompression in the mantle and lithosphere, under the impact location. Here, we neglect effects that are not linked to thermal evolution such as ejecta, crater formation or accretion of material to the solid planet. The temperature anomaly depends on the radius of the target body, impactor velocity, efficiency of kinetic energy transfer, and physical parameters of the target body (size, composition). Near impact location, temperature increase is nearly uniform in an isobaric core, then it decreases with distance to the impact site following a law $\sim (1/r)^{4.4}$ \cite{5}. After the impact occurs and the thermal anomaly is included into the mantle temperature field in the mantle dynamics code, StagYY \cite{6}, no further modification is needed and the convection calculation proceeds using the modified temperature field.

Impact sequences and mass-radius distributions are calculated using N-body simulations \cite{7}. These simulations provide plausible evolutionary histories that match our current interpretation of the constraints. Various scenarios involve impactors of different minimum sizes, from 50 km to 250 km radius, thus testing top-heavy (more stochastic) distributions, as well as sequences with smaller bodies.

Results: Due to the high temperature inside the isobaric core, the anomaly is thermally buoyant. Temperatures reached in the isobaric core are not dependent on the size of the impactor but on the size of the planet and on the collision velocity. However, the size of the isobaric core depends on impactor size. After the emplacement of the buoyant anomaly, a stage of thermal relaxation occurs, where the hot zone flattens under the surface of the planet and widens.

Long term effects on the mantle are only seen if the impactor is large enough to penetrate the lithosphere and deposits enough energy to keep the thermal anomaly alive to drive motion in the upper mantle. Typically, this requires either fast collisions or a large target body (Earth- or Venus-like rather than Mars-like). With the largest, most energetic impacts, this can lead to global events mobilizing the whole upper mantle. In those cases downwelling/melting can be observed in the antipodal position due to conservation of mass, as the upper mantle is pushed away from the impact by the thermal anomaly.

Melting is likely to occur in most cases, leading to the emplacement of fresh crust. This is especially the case near the impact location, where it becomes the thickest. As a consequence, it can insulate the mantle below this area, leading to a lower local heat flux, and hotter mantle (and increased surface heat flux near the edges of the insulated region). Additionally, the thicker, cool crust, associated with a warmer mantle can become unstable and produce subduction events.

Figure 1: Temperature anomaly in the mantle temperature field caused by impacts of different sizes. Short term evolution of said anomalies is shown \cite{6}.

![Figure 1: Temperature anomaly in the mantle temperature field caused by impacts of different sizes. Short term evolution of said anomalies is shown](image.png)
during later evolution. Therefore, large impacts can be responsible for subduction initiation, either directly, or indirectly, or even “prim” the mantle for later downwellings [8]. This process depends greatly from the thermal history of the planet during and before the impacts.

Melting during impacts also depletes the mantle of terrestrial planets, with possibly further consequences for long term evolution (the mantle becomes more difficult to melt, for example). It also affects volatile repartition, as they are usually incompatible elements.

While single large impact can deplete the mantle very efficiently near the impact location, even at large depth, for sufficiently large impactors, a series of smaller impacts can be much more efficient at depleting the upper mantle of a planet, for a given similar total impacted mass. It also leads to a more symmetrical pattern in mantle composition and temperatures, as the effects of impacts all over the planet average out. However, the last large impact of the sequence still has a special importance for further evolution as the pattern it imposes and the crust generation and mantle temperature field is not disturbed by further events.

![Figure 2: Mantle composition field showing impact depletion 8 Myr after the end of the impact sequence for a single giant 800 km radius impact (top) and a series of 9 smaller impacts (a few 100s of km radius) amounting to the same total mass (bottom). Depleted material is material that has melted and is shown in light blue/off-white.](image1)

![Figure 3: consequences of 300 km diameter impactor on heat fluxes at the surface (black line) and CMB (dashed line) of a Mars-like planet. Dotted line is for reference surface heat flux evolution. [9]](image2)

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