DOES IT PUNCH THROUGH OR NOT? THE SURVIVAL OF IMPACTOR CORES UPON COLLISION EVENTS DURING THE LATE ACCRETION PHASE.

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Introduction: The reason for the relatively high concentrations of highly siderophile elements in Earth's mantle [1] is still debated. The addition of metal-rich cores during the late accretion phase might be one possible explanation [2]. Since giant impacts like the Moon forming impact most likely resulted in magma oceans covering the planet at this time period [3], a better understanding of impacts of differentiated bodies into such molten targets is essential. To what extent iron cores break apart during impact is of great importance to understand how much mixing with surrounding mantle material may have occurred [4]. A better quantitative understanding of this process has been addressed in previous experimental and numerical studies [5,6,7]. To expand on the numerical work, we implemented a new method that enables more realistic treatment of fragmentation of impactor material during simulations. This method allows to obtain detailed size frequency distribution data for differentiated bodies as a function of varying impact parameters (size, velocity, etc.). In a second step our results can be used to study the ultimate fate of the impactor material in mantle convection simulations [8].

Methods: We use the iSALE-2D shock physics code [9,10] with an Euler grid to perform simulations of asteroid impacts. Lagrangian tracers, moving along the surrounding velocity field without interactions, are used to track the behavior of the material. From these tracers, the fate of the material and its fragmentation can be reconstructed in a post processing step, like a stretching ratio model [7]. However, this reconstruction cannot solve existing problems in the simulation due to under-resolved fragments or numerical clumping effects.

To improve the treatment of fragmentation in our model, we implemented a new method to reduce the effect of artifacts and improve the tracking of small fragments. During each time step, we first identify individual impactor core fragments in the grid, then we search for very small pieces and areas in larger ones where resolution problems might occur. If such cases are found, we take the closest tracer to the relevant area and look at the distance between it and its initial tracer neighbors. If the closest of these distances still exceeds a specific cutoff value, we remove the material from the grid, replacing it with target material, and save the removed mass and volume in a nearby target material tracer. This represents the material fragment from then on.

The setup of our simulations consists of a differentiated impactor composed of a dunitice mantle and iron core. Different impactor velocities and sizes are used. The target consists of dunite as well and is assumed to have no internal strength, approximating the hydrodynamic behavior of a magma ocean. The resolution is varied between 20 and 100 cells per projectile radius (cppr).

Results: Figure 1 shows simulations with a 200 km diameter impactor at an impact velocity of 11.5 km/s at a resolution of 80 cppr both with (left) and without (right) the new method at different time steps. The impactor core material is shown in yellow and the tracers used for the method as red dots. It is clearly visible that the core penetrates deep into the magma ocean, breaking apart during the process. The position of the fragments after 500s is similar in both cases.

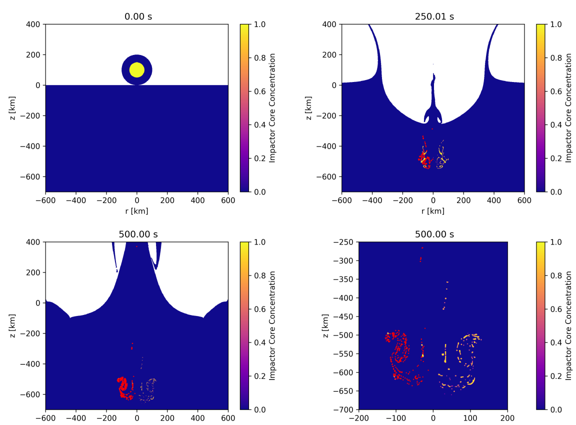

Figure 1: Impact of a differentiated projectile into a magma ocean at different time steps with (negative x) and without (positive x) the new method. The impactor core material is yellow, the dunite blue and the tracers in the method red.

While the position of the fragments is not significantly affected, the resulting size frequency distribution is quite different. This can be seen in figure 2. Here, cumulative size frequency distributions for the setup above, with and without the method are shown. The cutoff for the method is varied as well. It is obvious that the method creates more small fragments, with even more fragmentation for a smaller cutoff value.

The effect of a change in impact velocity can be seen in figure 3, showing that higher velocities will lead to stronger fragmentation.

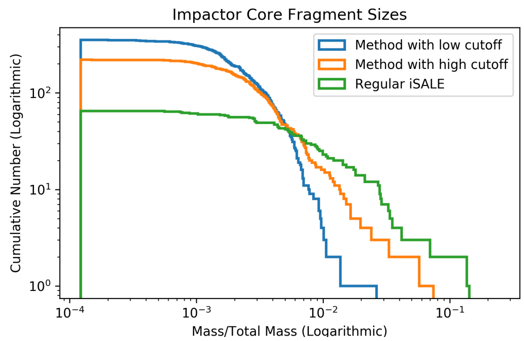

Figure 2: Double logarithmic cumulative size frequency distribution of impactor core fragments with and without the new method. The setup is the same as used for the snapshots in figure 1. In the runs with the method, the cutoff value for it is varied.

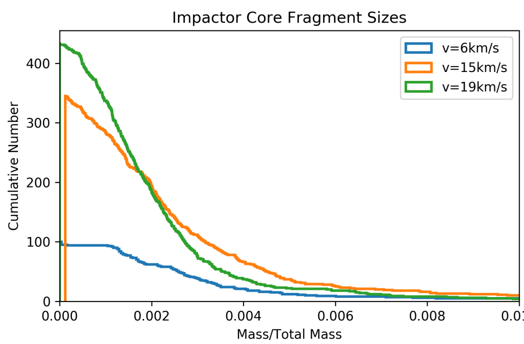

Figure 3: Cumulative size frequency distribution of impactor core fragments with the new method for different impact velocities. Apart from the impact velocity, the setup is the same as for figure 1.

The effect of further parameters like the size of the impactor is of great interest as well and is currently investigated.

Discussion and Conclusion: The new method used here allows for more realistic fragmentation behavior in the simulation, since the effect of numerical artifacts that cause unphysical breakup and clumping of material are reduced. As a result, the iron core of the impactor breaks apart even more significantly than in regular model runs. The resulting fragmentation is roughly in line with the findings using a stretching ratio model [7], but allows for a more quantitative analysis of the fragment size frequency distributions. The effect of different setup parameters like velocities and sizes can be analysed in detail as well.

While the current criterion used for the new method contains a simple approximation of strain in form of the tracer displacement, more realistic incorporation of physical parameters is certainly possible in the future. Replacing the fixed cutoff with one based in fragment size, representing the lower strength in larger bodies, would also be an improvement. Further advancements could be to allow additional fragmentation after the material is turned into tracers. In addition the interaction of these particles with the surrounding material shall be taken into consideration in the future.

The preliminary results show that the cores of impactors tend to break up into pieces with the biggest in the range of a few percent of the initial mass of the impactor. However, this maximum size, as well as the size distribution of the remaining material, depends on parameters like impact velocity and others, possibly also on the impact angle, that need to be further explored. Nevertheless the survival of the entire core seems to be unlikely unless the depth of the magma ocean is comparable to the size of the impactor or a certain percentage of it.

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