Experiments on the consolidation of chondrites and the formation of dense rims around chondrules

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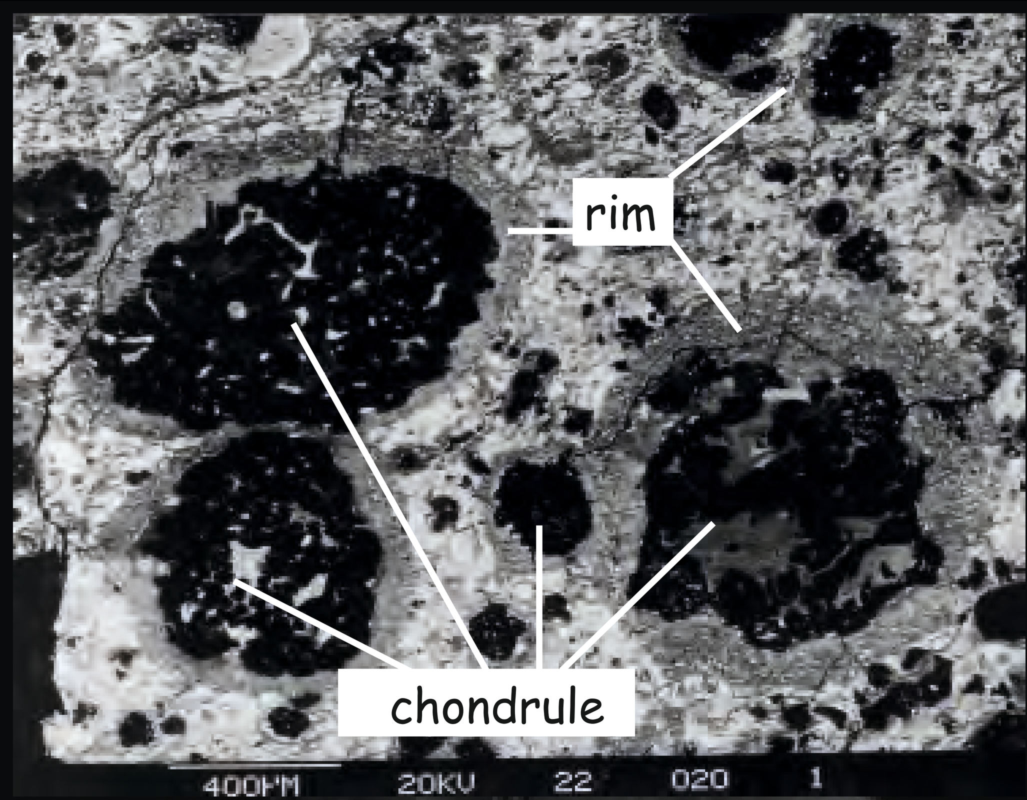
Introduction

The physical processes driving the formation of planetesimals are still under debate. Current studies can explain the accumulation of dust particles to aggregates on the order of millimeters. These are the typical sizes of chondrules of which we know that they were frequently formed early in the solar system. They are accounting for up to 80 percent of the chondrites' volume and were thus ubiquitious [1]. Chondrites have a typical porosity of 10-20 percent [2], which is significantly lower than the porosity that is predicted for the coagulation of pre-chondrites in low- velocity collsisions [3]. Collisions between those pre-chodnrites are discussed to be responsible for the consolidation of the initially porous structures to their present stage. The typical approach velocity between such pre-chondrites depends on their orbital parameters. Collisions among the pre-chondrites are also discussed as the causes of the fine-grained chondrule rims [4].

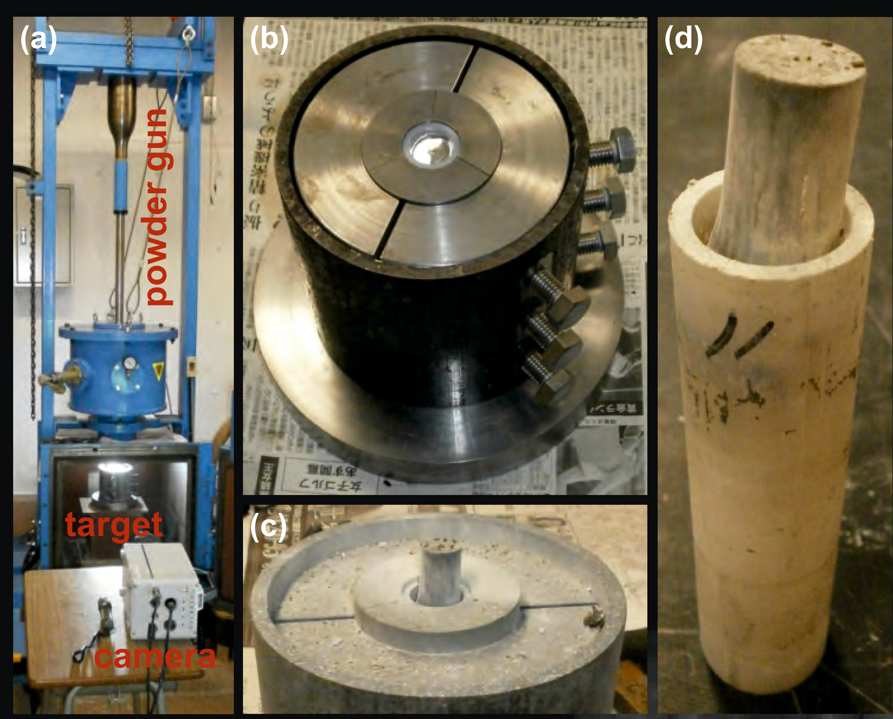
In this study, we performed impact experiments into pre-chondrite analogs to determine the velocity and pressure ranges in which the different chondrite classes were typically compacted, and to test whether or not chondrule dust rims formed by compaction [5].



SEM image of the CM chondrite Pollen [image credit: Knut Metzler]

Experiments

In our experiments, aluminum cylinders were used as projectiles to compact the pre-chondrite analogs in a velocity range between 165 and 1200 m/s. The resulting impact pressures in the samples fall between 90 and 2400 MPa. To measure the achieved porosities of our samples, 25 samples were analyzed using computer-aided tomography. From these images, the volume filling factor was determined. We found volume filling factors (porosities) between φ = 0.70 (30%) and φ = 0.99 (1%), which covers the observed range for carbonaceous chondrites (CC) and ordinary chondrites (OC).



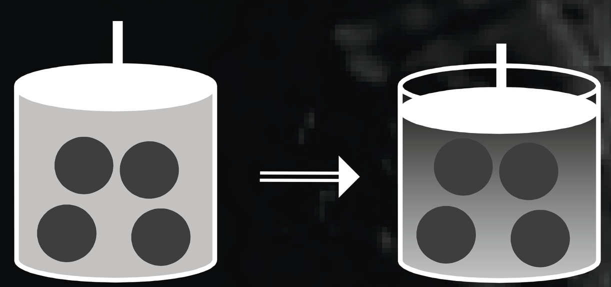
The experimental setup (a) consists of a vertically mounted powder gun, located at the University of Kobe, that is capable of shooting aluminum cylinders with a diameter of 1.5 cm at velocities of up to 1500 m/s into a vacuum chamber. Here, the impact velocity is measured by a high-speed camera in back-light illumination.

The target consists of porous intermixtures of dust and chondrule analogs that are filled into a nylon tube. To prevent the nylon from breaking apart, the tube was covered by a massive steel housing (b).

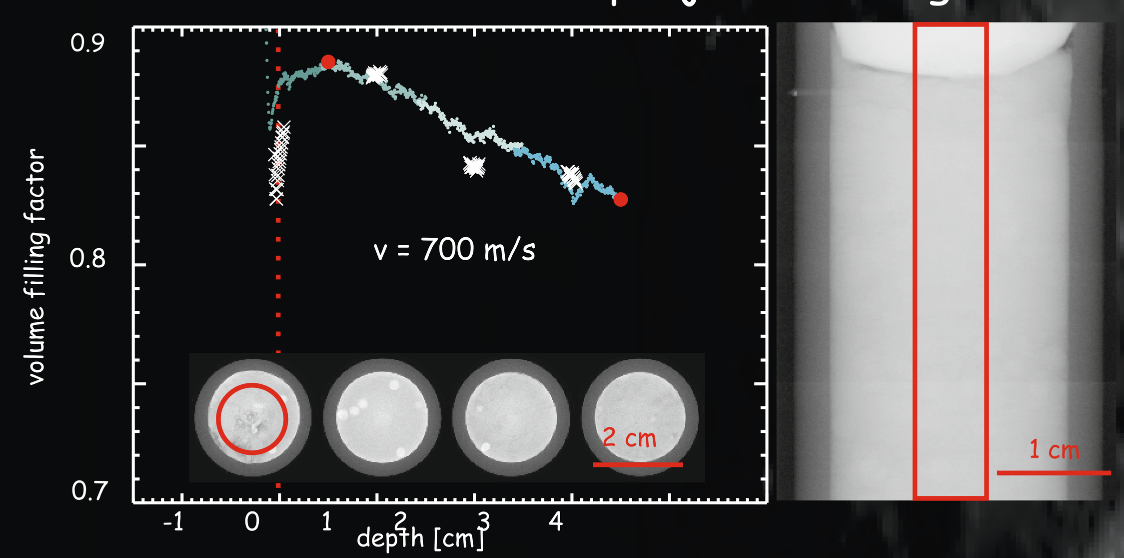
Figure c) depicts the post-impact situation in which the projectile still sticks on the compressed target.

In Figure d) a recovered nylon tube is shown.

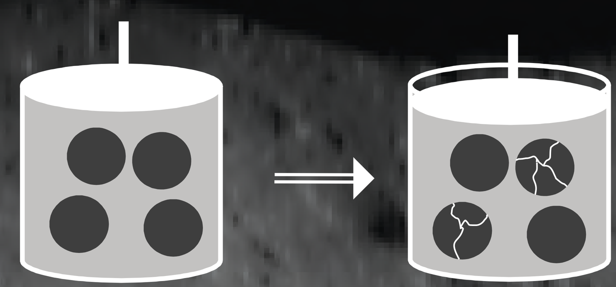
Compaction



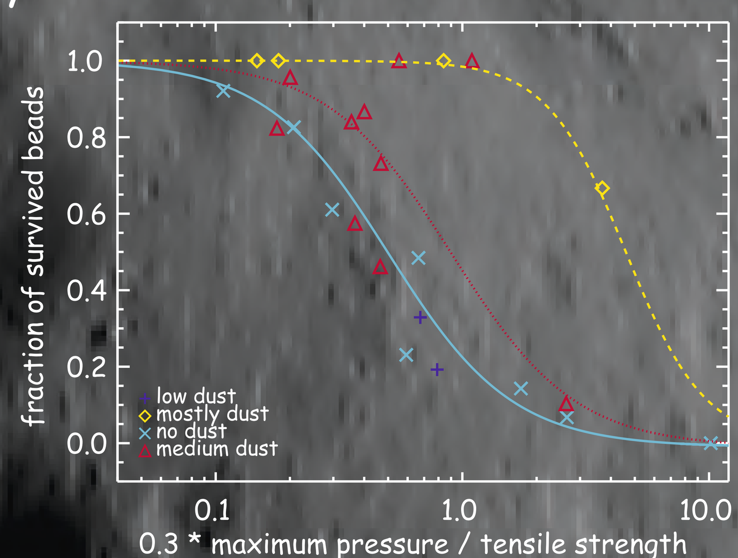
The samples were maximally compacted at the impact point, at which also the maximal pressure occurs. With increasing depth, the pressure and the volume filling factor decrease, following $p \sim h^{-1.8}$ where h is normalized to one projectile's length.



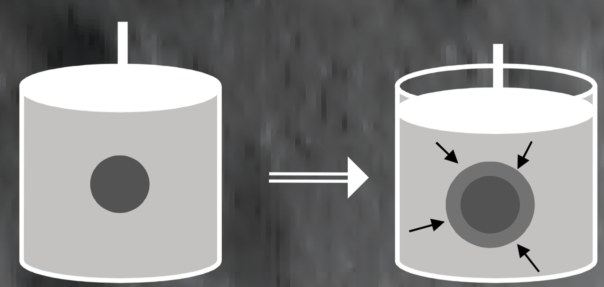
Break-up probability



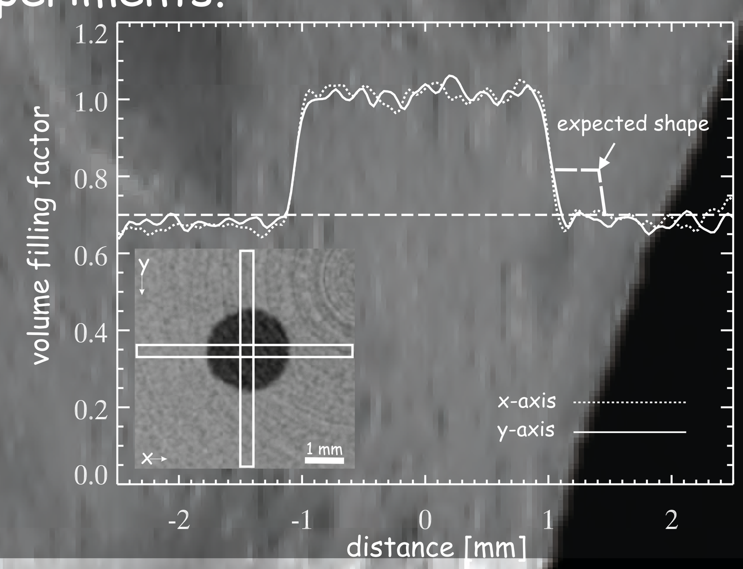
Chondrules start to fragment when the pressure exceeds their respective tensile strength. When the chondrules are in contact to each other, their fragmentation starts at lower pressure, an effect caused by the formation of force chains.



Rim formation



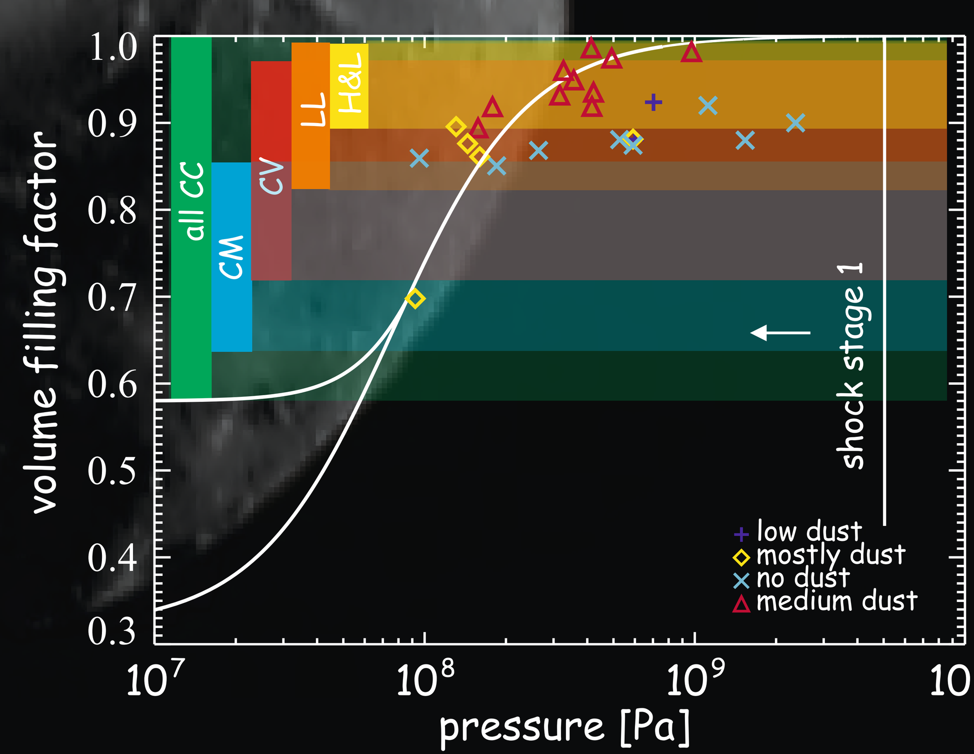
Fine-grained chondrule rims show a significantly higher volume filling factor compared to the matrix [3] and have a thickness of about 20 percent of the chondrule diameter [6]. Such rims were not formed in our experiments.



Conclusion

From our experiments, we expect CM chondrites likely to be compacted in a pressure range between 60 and 150 MPa, CV chondrites appear to be compacted with pressures between 100 and 500 MPa, and for OCs we only determined a lower limit of the compaction pressure of 150 MPa. These dynamic compaction pressures are in good agreement with the typical shock stages of the chondrites and, thus, we can confirm that CM chondrites are less shocked than CV chondrites and significantly less shocked than OCs. Finally, we found a factor of 10 difference in the dynamic-pressure compaction range of CCs and OCs, corresponding to impact velocities of 200 and 2000 m/s, respectively .

For CCs and OCs, formation distances of 2.75 ± 0.25 and 2.25 ± 0.25 are predicted [7]. This orbital difference leads to a difference in collision velocity of only 50 m/s. This is not sufficient to explain the difference in the required dynamic pressure or velocity range. To explain the porosity of CCs or OCs, eccentricities of 0.01 or 0.1 are required at the given formation distances. This allows us to infer either a larger distance between the formation location of the two chondrite families than current models predict or a strong difference in orbital eccentricities for the two groups.



For questions, please contact me via e-mail (e.beitz@tu-braunschweig.de).

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References: [1] Scott and Krot 2003; [2] Macke et al.2011; [3] Beitz et al. 2013 (GCA in press) [4] Trigo-Rodriguez et al. 2006; [5] Beitz et al. 2013 (Icarus); [6] Metzler et al. 1992; [7] Morbidelli et al. 2012.