DOES THE PUZZLING 'ECLOGITIC' CLAST FROM THE CR2 CHONDRITE, NORTHWEST AFRICA 801, RECORD A HIT-AND-RUN RETURN COLLISION?

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Introduction: Hit-and-run collisions, where the projectile mostly escapes the target, have been invoked to explain features of many meteorite groups [1]. Here we explore how the hit-and-run process might be invoked in the survival of a remarkable and enigmatic clast of 'eclogitic' garnet peridotite in the CR2 chondrite Northwest Africa (NWA) 801 that was described by [2,3].

Though only a few millimetres in size, the clast was reported in three thin sections cut from a single chip of the meteorite. It is made of olivine with minor Mg-Fe garnet, Na-Al-rich clinopyroxene (omphacite), orthopyroxene, phlogopite, graphite, metal, sulphides and phosphate. Its bulk chemistry is chondritic with a flat unfractionated REE profile. The grains are mostly 5 to 30 microns across with equilibrated polygonal outlines. The clast is composite, made of two distinct lithologies, one with and one without graphite. Mineral compositions are uniform throughout (apart from Mg-rich cores of large orthopyroxene grains) and [2] used standard geothermobarometers to infer equilibration at a temperature of about 1000°C and a pressure of about 3 GPa (30 kilobars) corresponding to the deep interior of a Moon-sized body. Based on diffusion rates in minerals, [3] argued that these conditions probably lasted for a period of 100 to 1000 years, consistent with their reasoning that the pressure was 'static' (due to deep burial) and was not due to shock.

To explain the clast's remarkable history [3] appealed to a scenario with two giant impacts. In the first impact, two 1000 km-radius bodies merged into a 1500 km-radius body. Chondritic rock from near the surface of one of the bodies, ended up deep inside the new combined body where it was metamorphosed and changed into garnet peridotite. In the second impact, only a few hundred years later, the 1500 km-radius body was burst assunder and fragments of the garnet peridotite were released into space.

This extraordinary story remains virtually uncited and it clearly awaits further elucidation. Mechanisms for the two postulated impacts were not discussed by [3], and the very short period between them was taken by [3] as perhaps reflecting a period in disk evolution when big impacts were frequent. We ask here whether a particular kind of hit-and-run collision might hold the key to this clast's origin, and might also offer an appealing solution to the puzzlingly brief time interval between the inferred impacts.

Interpretation: Hit-and-run collisions are common during planet-forming accretion. The result can often be a collision chain, that is, two or more giant impacts in a row [4] in which the 'runner' – the shuffled remains of the original projectile – returns to the same target body and suffers another impact. A large mass fraction of remnants ultimately escapes the final accretion. Many varieties of such 'hit-and-run-return' (HRR) collisions, are possible, depending on diameters, impact angles, velocities, accretion efficiencies and return-timescales, leading to diverse scenarios and novel planet-formation hypotheses [e.g., 5]. In the case of the NWA 801 clast, the HRR model opens up the possibility that the garnet peridotite was formed following a first collision when a chondritic protolith became deeply buried inside a scrambled and rapidly reassembled Moon-sized remnant of the projectile. This huge 'runner' may then have returned and been dismembered in a second grazing collision with the target protoplanet, excavating and dispersing pieces of the newly metamorphosed and still fine-grained garnet peridotite. Decompressed fragments would fall onto the accreting CR parent body, itself perhaps debris from the collision. The time between events in a collision chain can range from days (in the case of graze-and-merge) to many thousands of years [4] so might be seen as instantaneous, in terms of isotopic dating, but be well-separated processes petrologically.

Conclusion: If the assumption of metamorphism under static ultra-high pressure conditions is valid, the garnet peridotite clast might plausibly be explained by a collision chain among protoplanetary bodies. In this case the tiny fragment have far-reaching implications for the timing, mechanism, size-scale, and location of protoplanetary mergers, and even perhaps of chondrule formation, during the early planet-building epoch.

References: [1] Scott E. R. D., Asphaug E. et al. (2015) *46th Lunar and Planetary Science Conference*, abstract 2741. [2] Kimura M. et al. (2013) *American Mineralogist* 98:387–393. [3] Hiyagon H. et al. (2016) *Geochimica et Cosmochimica Acta* 186:32–48. [4] Emsenhuber A. and Asphaug E. (2019) *The Astrophysical Journal* 875:95 (18pp). [5] Asphaug E. et al. (2021) *Planetary Science Journal* 2:200 (20pp).

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