**IMPLICATIONS OF HIT-AND-RUN COLLISIONS BETWEEN DIFFERENTIATED PROTOPLANETS: EVIDENCE FROM IRON METEORITES** Joseph I. Goldstein[1], Jijin Yang[1], Edward R. D. Scott[2], G. Jeffrey Taylor[2] and Erik Asphaug[3]. [1]Department of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, MA 01003, USA (jig0@ecs.umass.edu). [2]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, HI 96822, USA. [3]Center for the Origin, Dynamics and Evolution of Planets, University of California, Santa Cruz, CA 95064, USA.

**Introduction:** Modeling by Asphaug et al. [1] suggested that colliding Moon-to-Mars sized protoplanets do not simply merge as commonly assumed—in a grazing impact, the smaller planet may escape as a greatly modified body or chain of diverse objects. We present evidence from IVA and other iron meteorites that many irons may come from impactors that experienced such collisions as they had lost most or all of their silicate mantles when they cooled below 1000 K. If the iron meteorites come from bodies that accreted within 1 Myr of CAIs [2] at 1-2 AU as Bottke et al. suggest [3], we infer that protoplanets in the terrestrial planet region were melted by $^{26}$Al heating, like the parent bodies of the irons, and that the geological history and chemical composition of the protoplanets may have been modified as a result of hit-and-run collisions that they or precursor bodies experienced when they were partly or largely molten.

**Effects of hit-and-run collisions on planetary differentiation and bulk composition:** Hit-and-run collisions between protoplanets might drastically disrupt the course of crystallization of their magma oceans (or other substantially melt-rich system). Consider, for example, the Martian magma ocean. Elkins-Tanton et al. [4] constructed geochemically and geophysically reasonable models of the crystallization of the Martian magma ocean, including its overturn caused by an unstable density gradient resulting from initial crystallization. A hit-and-run collision during magma ocean crystallization would scramble any cumulate pile formed up to that time, perhaps resulting in a temporarily stable configuration of the cumulates. Continued crystallization would produce a density gradient atop that rearranged pile. Subsequent overturn would be substantially more complicated than the simpler models predict, perhaps leading to a mantle even more heterogeneous than predicted and a petrologically complex primary crust. In addition, pressure-release melting of either the cumulate pile or originally unmelted regions in the proto-Mars or in the projectile might cause formation of partial melt that can be added to the partially differentiated (and disturbed) magma ocean.

This process could also affect the bulk composition of a protoplanet. There might be loss of the outer portion of a magma ocean or of the initial crust. These areas would consist of differentiated materials, leaving behind a planet depleted and fractionated in incompatible elements, lower in FeO and Fe/Mg, and possibly fractionated in Mg/Si and Al/Si, depending on depth of magma ocean and initial composition. An energetic collision might also deplete a protoplanet in volatile elements. This might not be as severe as for the case of formation of the Moon during a giant accretionary impact, but it could affect the total volatile inventory of the asteroids and terrestrial planets, and perhaps explain the difference in K/Th in the bulk silicate Earth and Mars. $H_2O$ added during accretion could be lost and, thus, need to be added after or during the late stages of accretion.

**Evidence for hit-and-run collisions from IVA and other iron meteorites:** Most iron meteorites are thought to come from the cores of over 50 asteroids 5-100 km in size, which cooled slowly inside insulating silicate mantles and were then fragmented by impacts [5]. However, this origin is incompatible with the metallographic cooling rates of many irons that vary by factors of 5-100 in each group, as irons from a single well-insulated core should have indistinguishable cooling rates [6, 7]. To help solve this problem, we studied the composition and structure of taenite in group IVA irons, as this group has the largest range of cooling rates [5]. We find that cooling rates for IVA irons at 1000-700 K range from 100 to 6000 K/Myr and increase with decreasing bulk Ni (Fig. 1a). In addition, cooling rates at 600-500 K inferred from the dimensions of the cloudy taenite intergrowths [8] in seven IVA irons vary by a factor of ~10 and are also inversely correlated with bulk Ni (Fig. 1b). These constraints require that the IVA irons crystallized inwards in a 300 km diameter core and were subsequently cooled below 1000 K without any insulating silicate mantle (Fig. 2).

If the core was largely molten at the time of the catastrophic impact, as was inferred to explain the silicates in five IVA irons [9, 10], collisional loss of volatiles may have occurred, as proposed for the Moon and Vesta [11] to account for the extremely low levels of moderately volatile siderophiles in the IVA irons. Ge/Ni values are 0.01-0.001 times chondritic values.

Metallographic cooling rates inferred for groups IIAB, IIIAB, and IVB show ranges of factors of 6-12 (refs. 5-8) suggesting that early partial loss of mantle prior to slow cooling was widespread.

Because catastrophic impacts between asteroid-sized bodies are very inefficient at removing mantle material from cores [13], separation of mantle and core material probably resulted from grazing impacts between Moon-to-Mars sized protoplanets or from tidal stripping of a Vesta-sized or larger body [1].

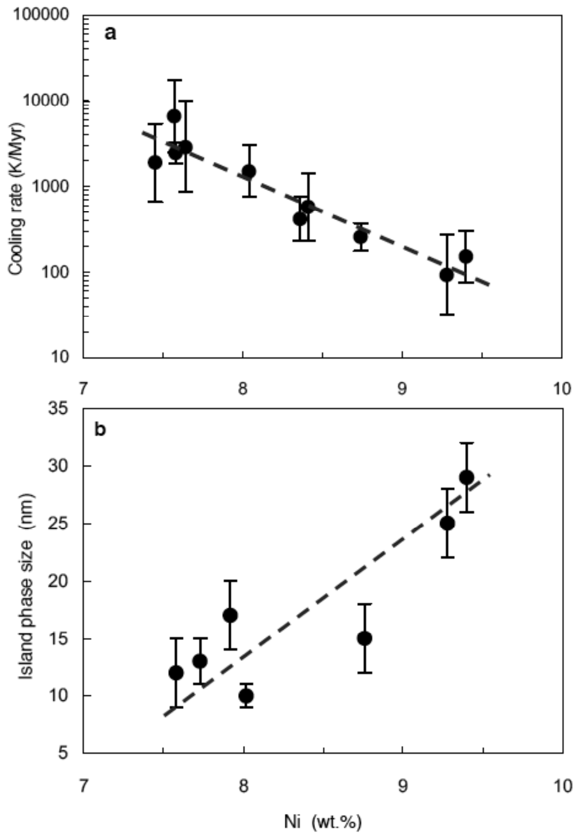


Fig. 1. Estimated cooling rate at 1000-700 K inferred from kamacite growth modelling (a) and the dimensions of the cloudy taenite intergrowth of low-shock irons (b) as a function of bulk Ni concentration for IVA iron meteorites. These data show that the cooling rate of IVA irons decreased with increasing bulk Ni concentration by a factor of ~50 at 1000-700 K, and ~10 at 600-500 K, the temperature range in which cloudy taenite formed.

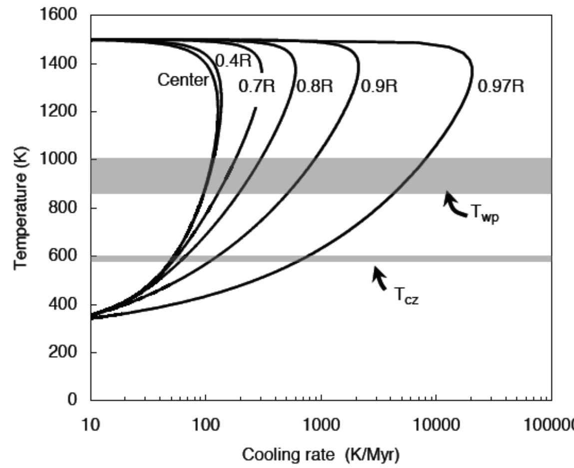


Fig. 2. Cooling rates at different radial locations as a function of temperature for a spherical metallic body exposed to space with a radius R=150 km and an initial temperature of 1500 K. $T_{wp}$ indicates the nucleation temperature for the the Widmanstatten pattern and $T_{cz}$ indicates the start temperature for the cloudy zone microstructure.

**References:**

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