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Revisiting martensite formation and its consequences in iron meteorites

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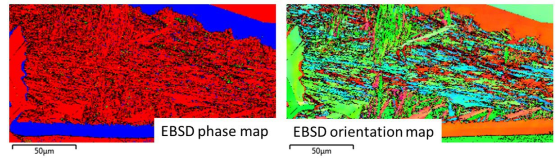
Most iron meteorites are remnants of planetesimal cores formed during the first millions of years of the solar system's history. They represent the only natural samples of planetary core forming materials. Their microstructures and compositions are interpreted using classical metallurgical concepts, profoundly shaping our description of the formation conditions and cooling rates of planetary cores, even on larger bodies. Here we will refute the common interpretation of martensite formation and decomposition in iron meteorites based on a correlative electron backscatter diffraction (EBSD) and atom probe tomography (APT) investigations of the IIIAB Cape York iconic meteorite (a medium octahedrite), coupled with thermodynamic arguments.

Martensite, as one of the constituents of iron meteorites, is mostly observed in octahedrites. Following the common view in steel metallurgy, it is widely accepted that a high cooling rate is necessary for martensitic transformation to occur at temperatures as high as 300°C. This view was transmitted to the field of cosmochemistry, illustrated by the addition of a line representing the martensite start (Ms) temperature in the FeNi phase diagram [1]. But this view is biased for iron meteorites, primarily because of their recognized extremely low cooling rates, and because they do not contain significant amounts of carbon. We will demonstrate that martensitic transformation in iron meteorites may only occur at sub-zero celcius (or even lower, i.e. cryogenic) temperatures. The actual Ms temperature will be shown to be exclusively dependent on the local Ni content of the parent taenite (inherited from the taenite to kamacite phase transformation), ruling out the necessity of rapid cooling.

Consequently, this result questions the various models of microstructural evolution which assume that martensite is a transitory phase, further decomposing into kamacite and/or taenite, in, for example, the formation of plessite [1,2]. Indeed, if martensite forms at sub-zero celcius temperatures, there is clearly no atomic mobility left to accompany the reconstructive formation of taenite, a process that would be contradictory to the existence of the previous martensitic transformation.

[1] Wood J.A., Icarus 3 429-459 (1964)

[2] Goldstein J.I., Michael J.R., Meteoritics & Planetary Science 41, Nr 4, 553–570 (2006)



EBSD maps of a residual taenite island in the Cape York (IIIAB) meteorite showing the martensitic structure of its core (phase map: blue: fcc; red: bcc).