The metallographic cooling rate of the Tafassasset primitive achondrite

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Tafassasset (Tafa) is a primitive achondrite with carbonaceous chondrite-like (CC) isotopic (Cr etc.) signatures. Cooling rates and chronological information give valuable insight on the evolution of achondrite parent bodies. Brent et al. [1] constructed an evolutionary model (the parent body with a radius ~17 km, accreted at ~1 Ma after CAI; Tafa is located in the middle of the mantle). It is mainly based on the chronology, but is considered to be supported by the metallographic cooling rate (100~200 C/Ma). But it is said to require refinement. Here we report observations of the metal texture and compositions, based on which a cooling history is derived.

Observation

Fe-Ni grains (average composition ~10 mol.% Ni) in Tafa show various textures. Many grains show kamacite that nucleated on the metal-silicate boundary and expanded inward during cooling. The central part is zoneless plessite which must be martensite at higher temperatures but now is made of kamacite and taenite. An interesting feature is that the boundary of kamacite and interior plessite is made of thin (~a few mm wide) taenite wall, suggesting rapid coolig. The compositions range from 17 to 31 % Ni and the average is ~26% Ni. Considering the difficulties in measuring compositions of thin taenite rim, the real value could be ~31% Ni. The zoneless plessite interior (average composition ~10 mol% Ni) is made of taenite islands in kamacite matrix. The taenite island sizes are usually only a few mm or less and the compositions range, if measurable, from 28 to 39% Ni, and the average is ~34% Ni. Again, the real value is considered to be close to ~39% Ni. A typical distance between taenite islands is ~10 mm. There are isolated zoned taenite grains, the central compositions of which are correlated with the size. There are zoned taenite grains which are surrounded by kamacite. Their compositions at the center mostly do not depend on the size, and is ~10 mol.% Ni. We note that cloudy taenite is not observed in any taenite grains. It is also to be noted that the phosphorous content in metal is nearly zero because phosphide is not observed.

Cooling rates

Estimates of the cooling rates can be made based on the above observations. Plotting on Fig.1 of [2], the isolated taenite data suggest a cooling rate slightly faster than 10^4 C/Ma. The data from zoned taenite surrounded by kamacite, when plotted on the same diagram, suggests a much faster cooling rate, but this may be artifact due to late nucleation of kamacite. Using the concept of closure, the thin taenite wall with ~31% Ni suggests a cooling rate ~10^4 C/Ma. Similarly, taenite islands with ~39% Ni in zoneless plessite suggest a cooling rate ~10^3 C/Ma. Distance between taenite islands could also be used for the cooling rate estimate. Assuming that diffusion in kamacite controls the island separation, a cooling rate of ~10^4 C/Ma is obtained. Absence of cloudy taenite is also consistent with rapid cooling.

Discussion

Although there are variations in the cooling rates depending on the features used for the calculation, it is clear that the cooling rate of Tafa (~10^4 C/Ma) is much faster than previously considered [2]. In order to cool at this rate, Tafa has to be located at a shallow depth (~1km from the surface). Because of this, the parent body size cannot be constrained well, except that it is much larger than 10 km in order to be kept warm at ~3.5 Ma (Mn-Cr age [3]). The rapid cooling is consistent with the chronological data. All (Hf-W, Pb-Pb, Mn-Cr and Al-Mg) ages may be identical. Or, the Hf-W age may be older than the rest because of the higher closure temperature.

[1] Brent et al., 2015, EPSL, 45, 193.

[2] Taylor et al., 1987, Icarus, 69, 1.

[3] Gopel et al., 2015, GCA,156,1.

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