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Crystallization experiment of alpha-Fe, gamma-Fe and iron compounds found in the Almahata Sitta and Antarctic ureilites

AOYAGI, Yuya[1*] ; MIKOUCHI, Takashi[1] ; SUGIYAMA, Kazumasa[2] ; YOKOYAMA, Yoshihiko[2] ; GOODRICH, Cyrena A.[3] ; ZOLENSKY, Michael E.[4]

[1]Dept. of Earth & Planet. Sci., Univ. of Tokyo, [2]Inst. for Materials Research, Tohoku Univ., [3]Planet. Sci. Inst., [4]NASA-JSC

Ureilites are ultramafic achondrites whose origin and petrogenesis are still controversial. The cooling rate of ureilites estimated from silicates is approximately a few degrees per hour, and it was considered to reflect catastrophic disruption of the ureilite parent body. Ureilites were broken into meter-sized fragments and then formed daughter body(ies) by re-accumulation.

Fe-Ni metal is one of the major components of all types of ureilites. Almahata Sitta, having fallen on the earth in October 2008, was classified as a polymict ureilite and ureilitic fragments from the Almahata Sitta contain abundant Fe-Ni metal. In previous studies, some grain boundary metals in Almahata Sitta ureilites show unique textures, not found in main group ureilites. These textures show characteristic assemblages with various combinations of α-iron (bcc), γ-iron (fcc), cohenite ($[Fe,Ni]_3C$) and schreibersite ($[Fe,Ni]_3P$).

Those metal textures resemble the product by steelmaking process in the earth, for example martensite (α-iron and γ-iron). Generally, these textures require rapid cooling equivalent to quenching by water (>100 ℃/s). However, the cooling rate estimated from silicates (ca. several ℃/h) is much slower than that in producing the martensite. Thus, these metal textures may record the event separated from the event that recorded in the silicates, that is, disruption of parent body. Therefore, studying these complicated metal textures will contribute to a better understanding of the formation and origin of metal in ureilites with the information about their thermal histories.

Those metal textures were only found in Almahata Sitta fragment #44, in previous studies, but we found similar assemblages composed of iron metal and its compounds in other fragments of Almahata Sitta and Antarctic ureilites. Forms and abundances are variable depending on samples, but it is suggested that those mineral assemblages in Fe-Ni metal are commonly found in ureilites.

To estimate the cooling rate which can form these iron and iron compounds textures, we performed cooling experiments by the electric furnace to heat and quench metal whose compositions correspond to metals showing complex metal phase assemblages in Almahata Sitta ureilite. The results suggest that those metal textures can be achieved in the cooling rate faster than the lowest limit between 10 ℃/s and 0.83 ℃/s, whose chemical composition is $Fe_{79.2}Ni_{3.4}P_{2.5}Si_{2.7}C_{12.2}$. At lower cooling rate (0.83 or 0.04 ℃/s) and 10 ℃/s of other starting material ($Fe_{86.4}Ni_{2.8}P_{0.7}Si_{4.1}C_{6.0}$), interstitial schreibersite among rounded iron was detected and neither cohenite nor γ-iron has been formed. In the carbon-free composition ($Fe_{91.2}Ni_{3.9}P_{0.5}Si_{4.4}$), similar textures were not generated at all cooling rates. This cooling rate, forming metal textures, is much faster than that estimated from silicates, and thus it is concluded that the event recorded by the silicates and the event formed the metal textures were truly separated.

Before disruption of ureilite parent body, primary metals probably melted and mixed with surrounding materials (graphite, phosphide and other iron compounds) to various extents at high temperature. The iron phase was considered to be uniformly γ-iron. Then, the ureilite parent body was destroyed and silicate minerals obtained cooling rate by quenching. Later, daughter body(ies) formed by accumulation of meter-size fragments. If daughter body(ies) was either shocked while still hot or heated by shock and then disrupted into smaller fragments (cm-size), the formation of iron textures may be achieved by super rapid cooling exceeding 1 ℃/s. The metal grains without γ-iron would experience relatively slow cooling due to larger fragment size. Consequently, it is considered that the complex coexistences of iron and iron compounds found in ureilites have recorded temperature change and fragmentation process due to the impacts on the parent body and daughter body(ies).