

Crystallization and subsolidus processes of the NWA 6704 ungrouped achondrite

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Introduction: NWA 6704 is an unique ungrouped achondrite. It consists of low-Ca pyroxene, less abundant olivine and plagioclase, minor chromite and merrillite, and trace awaruite, heazlewoodite, and pentlandite (1, 2). Although its bulk oxygen isotopic ratio is within the ranges of the acapulcoite-lodranite and CR chondrites, its petrography and mineralogy are evidently different from both of them (1). The U-Pb dating of this meteorite gives a ²⁰⁷Pb/²⁰⁶Pb date of 4563.75 +/- 0.41 Ma (3). To deduce its formation processes is important to understand formation of its parent body that may have predated the formation of chondrite parent bodies.

Methods: Polished thin sections were investigated by optical microscopes, electron microprobe analyzer (EPMA), field-emission scanning electron microscope (FE-SEM), Raman spectroscopy, and electron backscattered diffraction (EBSD).

Results: The most abundant mineral in NWA 6704 is orthopyroxene containing blobs of augite. Both Raman spectroscopy and EBSD data indicate that this pyroxene is orthopyroxene. The texture of the blob-bearing orthopyroxene is very similar to Kintokisan-type orthopyroxene (inverted pigeonite) (4). We call it early formed (ef-) pigeonite. There are another less abundant low-Ca pyroxenes: augite blob-free orthopyroxene, and pigeonite containing sub-micrometer-size augite exsolution lamellae. Here we call them primary orthopyroxene and later formed (lf-) pigeonite. Lf-pigeonite occurs as coherent overgrowth of the primary orthopyroxene and discrete grains in the interstices of large ef-pigeonite. Lf-pigeonite also occur as inclusions in olivine. Based on the EBSD data, modal abundances of ef-pigeonite, olivine, lf-pigeonite, primary orthopyroxene, feldspar, chromite, awaruite are 67.2, 16.8, 3.4, 0.6, 10.9, 0.4, and 0.4 vol.%, respectively. Crystallization sequence estimated based on the petrography is following: primary orthopyroxene =>awaruite =>ef-pigeonite =>chromite =>lf-pigeonite =>olivine =>augite (quite rare crystallized from melt) =>heazlewoodite =>pentlandite =>merrillite =>feldspar. Early formed pigeonite (blob-bearing orthopyroxene) shows a LPO of the [010] axis. Lf-pigeonite contains complex exsolution lamellae of augite. The thickest lamellae have ~0.2 micrometer in width and 1-2 micrometer wavelength. Finest lamellae have <0.1 micrometer thick and ~0.2 micrometer wavelength.

Discussion: Because [010] lattice preferred orientation of pyroxene in terrestrial rocks has been interpreted as settling of tabular pyroxene crystals in a stagnant magma chamber (5), ef-pigeonite could have settled in a stagnant magma chamber. Presence of Fe³⁺ in chromite and high NiO concentration in olivine (0.89 wt.% on average) suggest that this meteorite crystallized under an oxidized condition. About 1100 °C equilibrium temperature was estimated by using two pyroxene geothermometry and ~950 °C by using olivine-spinel geothermometry. These high temperatures suggest that the meteorite cooled rapidly in this range of temperature. Multiple exsolution lamellae with thickness and wavelength similar to this meteorite were observed in Zagami martian meteorite. Its cooling rate between 1100 °C to 950 °C was estimated to be ~0.02 °C/hr (6). This meteorite could be cooled as slow as Zagami did. Further studies are needed to clarify if a monotonous cooling can accomplish both high equilibrium temperatures estimated by geothermometers and sub-micrometer-size exsolution lamellae in lf-pigeonite. NWA 6704 has petrography similar to that of NWA 6693. However, there is a stark difference between these two meteorites. Blob-bearing orthopyroxene is the most abundant pyroxene in the former. On the other hand, low-Ca pigeonite is the most abundant in the latter. Therefore, it is possible that NWA 6704 is not mere a pair of NWA 6693.

References: (1) Irvine et al. (2011), (2) Warren et al. (2012), (3) Iizuka et al. (2013), (4) Ishii and Takeda (1974), (5) Jackson (1961), (6) Brearley (1991).

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