The origin of primitive achondrites inferred from a mineralogical and isotope cosmochemical study of NWA 6704

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Introduction: NWA 6704 is an ungrouped primitive achondrite found in 2010. It's composed predominantly of low-Ca pyroxene, with less abundant olivine, feldspar, chromite, awaruite, sulfides and whitlockite. The U-Pb dating shows the crystallization age of 4563.75±0.41Ma (Iizuka et al., 2013). This ancient primitive achondrite provides unique insights into the differentiation of asteroids in the very early stage of solar system evolution. To better understand the formation processes of NWA 6704, we've conducted textural and mineral-chemical study of thin sections using SEM-EDS-EBSD and EPMA. Furthermore, we've determined Cr and Ti isotope compositions using MC-ICP-MS to clarify genetic relationships of this unique meteorite and other grouped meteorites.
Results & Discussion: SEM images show that the texture is represented by aggregates of orthopyroxene (opx) megacrysts up to 1.56 cm in length ($Fs_{40-42}En_{53-57}Wo_{3-4}$) with finer interstices including olivine (Fa_{50-53}), chromite (Cr/(Cr+Al)~0.93), awaruite (~80wt% Ni), feldspar ($Ab_{91-93}An_{5-6}Or_{2-3}$) and whitlockite. Feldspars separated with each other share the same optical extinction position over up to 1 cm irrespective of its occurrence either as complete inclusions of or interstitial to opx megacrysts. Feldspars isolated in the megacrysts have apparently euhedral rectangular morphology, but the facets are controlled by crystallographic orientation of opx megacrysts. These observations suggest that opx crystals are actually “hollow” megacrysts so that many interstices are connected with one another. Although most olivines are subrounded and found in the interstices, Fe-rich olivine occurs as inclusions showing vermicular morphology in one place of each opx megacryst. Such vermicular olivine is considered to be the relict decomposition product of the precursor pyroxene through abrupt heating to cause incongruent melting (ca.>1300℃; Tsuchiyama et al., 1986) followed by rapid cooling, which is most plausibly realized by impact-induced heating. This is consistent with the abnormally large size of opx and its hollow morphology and we argue that the initial crystallization occurred under rapid cooling (ca.1-10^2 ℃/hr; Lofgren et al., 1980). On the other hand, later slow cooling is suggested by the existence of pigeonite containing thin augite exsolution lamellae and the relatively homogeneous mineral compositions. Using the geospeedometry based on Mg-Fe exchange between chromite and silicate phases (Fabriès, 1979; Ozawa, 1984), we estimate the cooling rate at 950-850 ℃ to be 10^{-4}-10^{-2} ℃/hr. The olv-spl oxygen geobarometer (Ballhaus et al., 1991) gives fO_2 of FMQ-2.6.
Cr and Ti are successfully extracted with a new five-stage column chromatographic procedure. The Ti isotope analyses yielded ε^{50}Ti = 2.28±0.23, which is distinct from differentiated meteorites and ordinary and enstatite chondrites but within the range of carbonaceous chondrites (Warren et al., 2011). Given that the oxygen isotope composition of NWA 6704 is plotted near the fractionation line of CR chondrite (Irving et al., 2011), its carbonaceous chondritic ε^{54}Cr (Sanborn et al., 2013) and ε^{50}Ti even more likely support its genetic link with carbonaceous chondites. Our results have indicated that the presence of carbonaceous chondrite-like asteroid at about ≤3.55Ma (after CAI formation; U-Pb age). This is consistent with preservation of ^{26}Al in the undifferentiated parent asteroid at about T=2-3.5Ma (Sahijpal et al., 2007). This and the inferred thermal history suggest high internal temperature of the parent body owing to ^{26}Al decay was augmented by impact to have achieved abrupt heating up to above liquidus, followed by rapid cooling and later slower cooling owing to blanketing effect of impact ejectas pilled up on the parental body.

Keywords: Primitive achondrite, NWA 6704, impact-induced heating, Cr, Ti, stable isotope

