A mineralogical and chemical study of primitive achondrite NWA 6704 and its potential use for calibration of extinct radionuclide chronometers.

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Introduction:

The study of several daughter isotopes of now-extinct radionuclides in meteorites provides chronological constraints on events in the early solar system. Due to their short half-lives, the extinct radionuclide chronometers have high time resolutions, but they provide only relative ages. To map the relative ages onto the absolute timescale, we need to calibrate these extinct radionuclide chronometers with an absolute precise long-lived chronometer, namely, U-Pb chronometer. Therefore, it is essential to establish a "time anchor", i.e., a meteorite to which high precision U-Pb chronometer can be applied and in which the initial abundances of various short-lived radionuclides can also be determined. While the D'Orbigny angrite (4564.42 ± 0.12 Ma; [1]) is now most widely used as a "time anchor", a new time anchor from a different group of meteorite is essential to evaluate the homogeneous distribution of the now-extinct radionuclides in the early solar system.

NWA 6704, found in Algeria in 2010, is an ungrouped primitive achondrite. The U-Pb dating for this meteorite shows the crystallization age of 4563.75 ± 0.41 Ma [2]. The meteorite is composed predominantly of low-Ca pyroxene, less abundant olivine, plagioclase, chromite, metal, and phosphates (e.g., [3-5]). In addition, the texture displays no diagnostic shock deformation effects [6], implying the potential of NWA 6704 as a new time anchor for extinct radionuclide chronometers.

In this study, we have further investigated the suitability of NWA 6704 as a time anchor based on the mineralogy and mineral chemistry using SEM-EDS, EPMA and LA-ICP-MS.

Results:

The SEM images of the sample showed that some low-Ca-pyroxene ($Fs_{40-42}En_{53-57}Wo_{3-4}$) grains contain sub-micrometer-size exsolution lamellae, and others contain augite ($Fs_{17}En_{45}Wo_{39}$) blob, and a few plagioclases ($Ab_{91-93}An_{5-6}Or_{2-3}$) associated with whitlokites. The Fe-Ni metals are highly enriched in Ni (78-81 wt% Ni). In addition, cation ratio is estimated as Fa_{50-53} for olivine, and Cr /(Cr+Al) = 90 -96 for chromite, respectively. The low-Ca-pyroxene often occurs as inclusions in olivine and chromite grains, indicating that low-Ca-pyroxene crystallized earlier than the latters. We found, however, that olivine rarely occurs as inclusions in low-Ca pyroxene (Fig.1) and these olivine inclusions have Fe-rich compositions (Fa_{54-55}) relative to "normal" olivine grains (Fig.2). Considering that earlier crystallization of such Fe-rich olivine cannot be explained by simple igneous differentiation processes, the Fe-rich olivine may represent inherited components from igneous precursor materials.

The incompatible trace element composition in various low-Ca-pyroxene grains showed positive correlation between Sr and Y as well as Y and Yb. Each of these grains was characterized by the homogeneous major element composition.

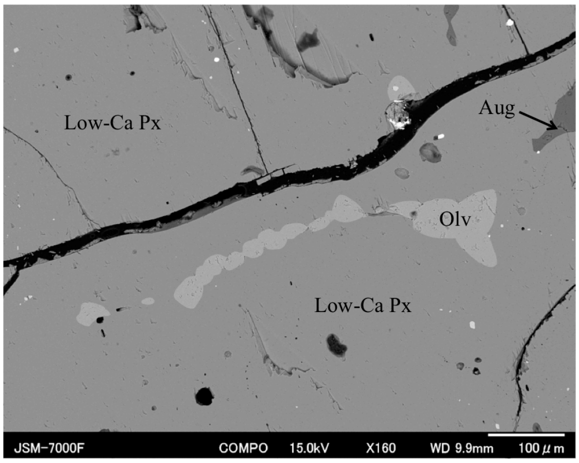

Fig. 1. SEM image of NWA6704. Note the presence of Fe-rich olivine inclusions (Fa_{54-55}) in low-Ca-px with a typical length scale of a few hundred microns.

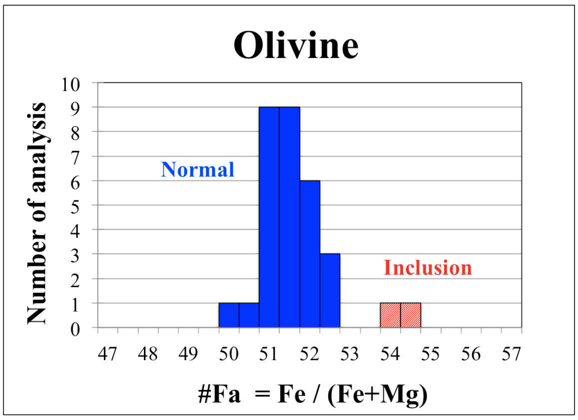

Fig. 2. #Fa variations of olivine grains in NWA6704. Note the slightly higher #Fa in olivine "Inclusion" than in "Normal" olivines.

Discussion:

Based on the mineral assemblage and chemistry, we found that several short-lived as well as long-lived isotopic chronometers are applicable to NWA 6704 as summarized in Table 1.

Table 1. Several short- and long- lived chronometers which are applicable to NWA 6704.

Parent - Daughter	**Half-life**	**Minerals dated**
$^{26}Al \rightarrow ^{26}Mg$	717 Kyr	Pl – Olv,Px
$^{60}Fe \rightarrow ^{60}Ni$	2.6 Myr	Chr – metal
$^{53}Mn \rightarrow ^{53}Cr$	3.74 Myr	Olv – Chr
$^{182}Hf \rightarrow ^{182}W$	8.9 Myr	Px – metal
$^{92}Nb \rightarrow ^{92}Zr$	36 Myr	Px – Chr
$^{146}Sm \rightarrow ^{142}Nd$	68 Myr	Chr,Px – Pl
$^{176}Lu \rightarrow ^{176}Hf$	3.54 Byr	Px – Chr
$^{87}Rb \rightarrow ^{87}Sr$	4.88 Byr	metal – Pl
$^{147}Sm \rightarrow ^{143}Nd$	106 Byr	Chr,Px – Pl

Despite the relatively homogeneous composition of major elements, we found the positive correlation between incompatible trace elements (Sr-Y and Y-Yb). This indicates that the degree of chemical re-equilibration was low probably because this meteorite has not been influenced by secondary reheating events.

Our finding of Fe-rich olivine inclusions within low-Ca-pyroxene grains suggests the presence of exotic components within this meteorite. Such exotic olivine grains (xenocrysts with sizes up to 3 mm) are also observed in several quenched angrites including D'Orbigny [7]. Considering that these exotic olivine grains would not be isotopic equilibrium with the other components, isotopic age data defined by olivine such as Al-Mg and Mn-Cr should be interpreted with great caution.

References:

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