MINERALOGY, PETROLOGY AND OXYGEN ISOTOPIC COMPOSITION OF NORTHWEST AFRICA (NWA) 12379, A NEW METAL-RICH CHONDRITE WITH AFFINITY TO ORDINARY CHONDRITES.

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Introduction: Northwest Africa (NWA) 12379 is a new metal-rich chondrite with unique characteristics which distinguish it from meteorites of any previously described chondrite groups. Chondrule sizes, textures, mineral chemistry, and O-isotope composition suggest affinity to metamorphosed (type 3 range) ordinary chondrites (OCs). However, high metal content (~70 vol%) and complete lack of matrix are inconsistent with OC classification; these characteristics are typical for metal-rich carbonaceous (CH and CB) and G chondrites. In contrast to the metal-rich chondrites, but similar to OCs, the meteorite experienced fluid-assisted thermal metamorphism that resulted in nearly complete chemical equilibration of chondrule olivines, and formation of Cl-apatite, merrillite, chromite, tetrataenite, and ferroan olivine that replaces low-Ca pyroxene.

Mineralogy and Petrography: NWA 12379 consists of ~70 vol% Fe,Ni-metal, ~25–30 vol% silicates, <5 vol% troilite, <1 vol% chromite and phosphates (Cl-apatite and merrillite); fine-grained matrix is absent. The meteorite experienced a minor degree of terrestrial weathering and no shock features were observed in thick section studied. The silicate portion is dominated by virtually metal-free chondrules, chondrule fragments, and abundant silicate inclusions in Fe,Ni-metal. Neither refractory inclusions nor Al-rich chondrules have been found within the x-ray mapped regions of ~50 mm^2. Apparent chondrule sizes range from 60 to 1200 µm (mean ~400 µm, N=22). Porphyritic olivine (PO), olivine-pyroxene (POP) and pyroxene (PP) are the most common types (Fig. 1). Barred olivine (BO), cryptocrystalline (CC) and skeletal olivine (SO) chondrules are rare. Metal phases are mainly kamacite; taenite and tetrataenite are rarer. Accessory troilite occurs as coarse isolated grains (up to 200 µm), occasionally associated with tetrataenite. Merrillite, Cl-apatite, and Ti-bearing chromite are found inside metal grains and in peripheral parts of some chondrules (Figs. 1, 3).

Electron microprobe analyses show a large spread of silicate compositions in porphyritic chondrules: olivine $Fa_{25.3\pm3}$ ($Fa_{18.1-28.5}$, median $Fa_{26.5}$, PMD=11.9, Cr_2O_3 = 0.03±0.02 wt%, FeO/MnO = 53.6±5.9, N=36), low-Ca pyroxene $Fs_{14.7\pm3.7}Wo_{1.4\pm1.3}$ ($Fs_{3.2-18.7}Wo_{0.2-4.5}$, median $Fs_{15.8}Wo_{0.8}$, N=19) (Fig. 2). Chondrule mesostasis contains abundant high-Ca pyroxene crystallites. Isolated low-Ca pyroxene grains enclosed by metal and low-Ca pyroxene phenocrysts in some chondrules are replaced to various degrees by ferroan olivine (Figs. 3a,b) with fairly uniform composition ($Fa_{27.3\pm0.6}$, FeO/MnO = 53.8±4.1, N=13). Chromite: mean Cr/(Cr+Al) = 0.88, mean TiO_2 = 1.85 wt% (N=2). One fragmented bleached CC chondrule was found and some chondrules show enrichment in P (i.e. presence of phosphates) in their peripheral parts (Fig. 4a). Most metal grains are unzoned kamacite, some grains show weak chemical zoning with M-shaped Ni profiles (Fig. 4b).

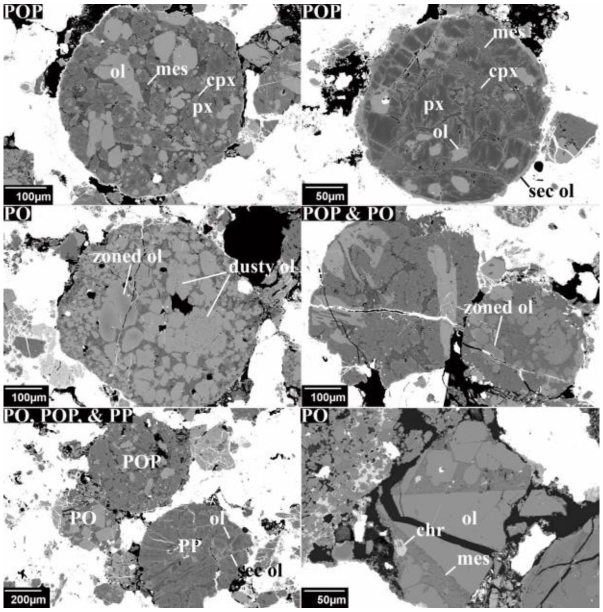

Fig. 1. BSE images of some representative porphyritic chondrules surrounded by Fe,Ni metal (white), labeled by type. While most olivine crystals are uniform in composition, some chondrules contain zoned olivine crystals with increasing Fa content from core to rim and dusty olivine crystals with (sub)-µm-sized inclusions. Interchondrule fine-grained matrix and fine-grained matrix-like rims are absent. Abbreviations: ol = olivine, px = low-Ca pyroxene, cpx = high-Ca pyroxene, chr = chromite, mes = mesostasis, sec = secondary.

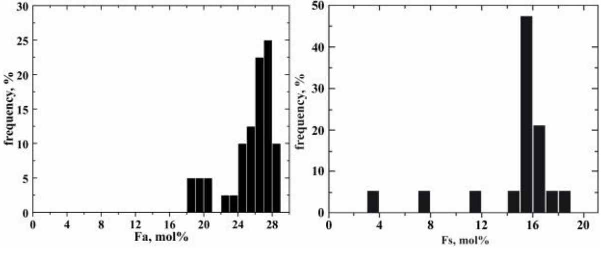

Fig. 2. Histograms of Fa and Fs contents in olivine and low-Ca pyroxene ($Wo_{<5}$) in porphyritic chondrules.

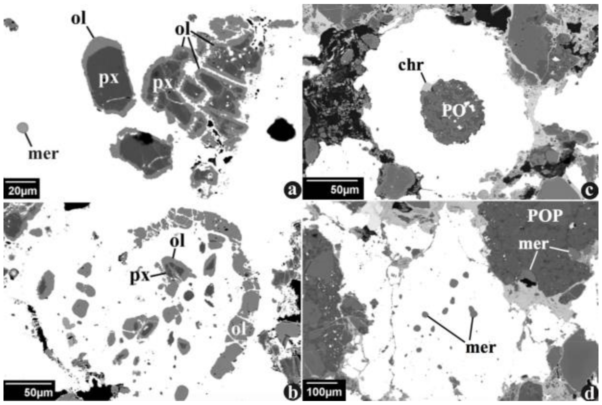

Fig. 3. BSE images of (a, b) silicate inclusions in Fe,Ni-metal; low-Ca pyroxenes (px) are replaced to a various degree by ferroan olivine (ol); (c) PO chondrule and chromite (chr) enclosed by Fe,Ni-metal; (d) merrillite (mer) inclusions in Fe,Ni-metal and peripheral part of a POP chondrule.

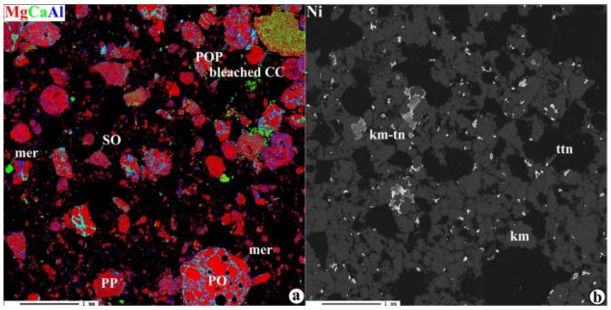

Fig. 4. (a) Combined x-ray elemental map in Mg (red), Ca (green) and Al (blue) and (b) x-ray elemental map in Ni of the NWA 12379 meteorite. Abbreviations: mer = merrillite, km = kamacite, tn = taenite, ttn = tetrataenite.

Oxygen isotopes: Bulk O-isotope analysis of a 1.98 mg chondrule revealed $\delta^{17}O$ = 3.69‰, $\delta^{18}O$ = 5.14‰, $\Delta^{17}O$ = 0.96‰. Additional work is in progress.

Comparison with other chondrite groups and classification: Typical OC features include a high abundance of FeO-rich (type II) porphyritic and non-porphyritic chondrules, rarity of Al-rich chondrules and refractory inclusions [1]. Bleached chondrules are common in OCs of all petrological types, but most abundant in type 3 OCs [2]. Whole-rock O-isotope compositions of OCs plot above the terrestrial fractionation line with $\Delta^{17}O$ of ~ 1‰ [1]. Merrillite, Cl-apatite, and chromite are typical minerals in metamorphosed OCs [3]. NWA 12379 shows all of these characteristics. For type 4–6 OCs the major element compositions of olivine are generally equilibrated (e.g., [4]) with the standard deviation on the mean fayalite content being <1 mol% [5]. The larger spread of olivine compositions in NWA 12379 is within the range of type 3 OCs and clearly shows the unequilibrated nature of this meteorite.

Although NWA 12379 has some textural similarities to metal-rich carbonaceous (CH, CB) and non-carbonaceous (G) chondrites, such as high metal abundance and lack of fine-grained matrix, the dominance of porphyritic FeO-rich chondrules and OC-like O-isotope composition of a single chondrule measured so far clearly distinguish it from these meteorites.

According to the discussed petrographic, mineralogical and $\Delta^{17}O$ similarities to OCs, the silicate portion of NWA 12379 appears to be related to mildly metamorphosed L3 chondrites. However, the high metal content and lack of fine-grained matrix, are inconsistent with OC classification. Therefore we classify NWA 12379 as "ungrouped metal-rich chondrite" with affinities to OCs.

Discussion: At this stage it remains unclear whether the major components of this meteorite, chondrules and metal, originate from the same cosmochemical reservoir in the early solar system or formed separately and were mixed together afterwards. Whole-rock Cr, Ti, Fe, and Mo isotopic measurements of the silicate and metal fractions of the meteorite are required to answer this question [6–10]. Note that preliminary mass-independent Fe-isotope data suggest an outer solar system origin for the metal fraction of NWA 12379.

The unique overall composition of NWA 12379 may represent a remnant of an atypical chondrite formation scenario, possibly a low-velocity collision of an OC-like parent body with a metal-rich body such as core material of a differentiated planetesimal or inhomogeneous mixing and re-accretion (regolith formation) of unmelted non-matrix material from different regions (depths) of the colliding bodies.

After the final accretion, oxidation and fluid-assisted mild thermal metamorphism took place on the NWA 12379 parent body, which explain the formation of phosphates, chromite, and secondary ferroan olivine. Currently though, both the source of the fluids and whether oxidation and metamorphism took place simultaneously or consecutively, do also remain open issues.

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