ULTRAMAFIC ACHONDRITE NORTHWEST AFRICA 5400: A UNIQUE BRACHINITE-LIKE METEORITE WITH TERRESTRIAL OXYGEN ISOTOPIC COMPOSITION.

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A metal-bearing ultramafic achondrite with petrological similarities to brachinites has been found to have an oxygen isotopic composition on the Terrestrial Fractionation Line (TFL). The only other types of meteorites with this characteristic are the majority of lunar meteorites and the various enstatite-rich meteorites (both chondrites and achondrites). Angrites, one pallasite (Zinder) and one ungrouped carbonaceous metachondrite (NWA 2788) have oxygen isotopic compositions relatively close to, but resolvably removed from, the TFL [1]. Alternative possibilities are that the new specimen is (a) a terrene meteorite, (b) a Theian meteorite, or (c) a meteorite related to another former differentiated body accreted near Earth.

Petrography: Northwest Africa 5400 is a single dense, dark brown, rounded stone (4818 grams) about half covered with weathered fusion crust and exhibiting several narrow fractures (see Figure 1). Dimensions are 19.5 cm x 16.0 cm x 9.7 cm.

Figure 1. *Whole Northwest Africa 5400 stone*

This coarse-grained rock (grainsize mostly 0.2-0.8 mm) has a protogranular texture, and is composed predominantly of olivine (79 vol.%; $Fa_{30.1-30.4}$, FeO/MnO = 56.1-70.8, CaO = 0.11 wt.%) with subordinate orthopyroxene (10.5 vol.%; $Fs_{24.4}Wo_{2.1}$, FeO/MnO = 34.2), clinopyroxene (8.9 vol.%; $Fs_{9.4}Wo_{45.1}$, FeO/MnO = 25.5, Cr_2O_3 = 0.74 wt.%, Al_2O_3 = 0.74 wt.%), chromite (1.4 vol.%; Cr/(Cr+Al) = 0.821, Mg/(Mg+Fe) = 0.236, TiO_2 = 1.4 wt.%, ZnO = 0.30 wt.%), Cl-rich apatite, troilite, altered kamacite and minor taenite. No plagioclase was observed. This specimen has experienced minor terrestrial weathering, resulting in partial alteration of primary metal (to inhomogenous, fine grained mixtures of iron hydroxides and indeterminate Si-bearing phases), and minor veining by calcite, clay minerals and iron hydroxides.

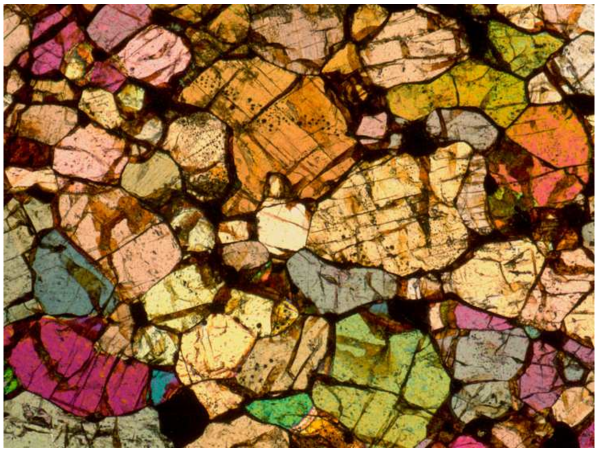
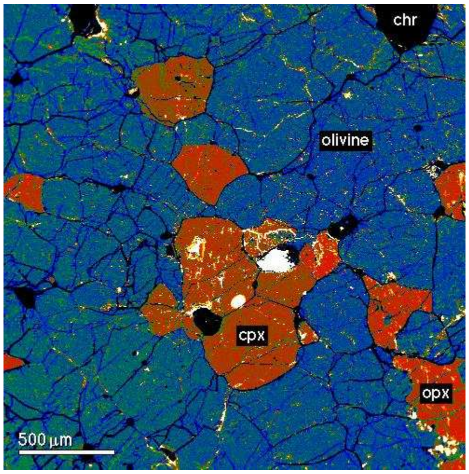


Figure 2. *Cross-polarized light optical thin section image (above, width of field = 1.2 mm) and inverted false-color back-scattered electron image (below).*



Oxygen Isotopes: Clean, acid-washed silicate material was obtained from two separate crushed portions of the type specimen after removal of metal and associated phases with a clean hand magnet. Replicate analyses by laser fluorination at different times gave consistent results: respectively, $\delta^{18}O$ = 5.061, 5.223, 4.486, 4.880; $\delta^{17}O$ = 2.681, 2.741, 2.367, 2.525; $\Delta^{17}O$ = 0.019, -0.006, 0.008, -0.042 per mil. Given the terrestrial alteration in this specimen (which is less than in other meteorites we have analyzed), we paid special attention to obtaining clean material for analysis, and we are confident that the results pertain to the primary meteoritic mineral assemblage.

Bulk Composition: Powder from a representative 1.9 gram slice was analyzed by XRF at the University of Cologne (in wt.%): SiO_2 37.2, TiO_2 0.05, Cr_2O_3 0.95 Al_2O_3 0.98, FeO_T 28.3, MnO 0.38, MgO 29.6, CaO 1.44, P_2O_5 0.18, SUM = 99.0; Mg/(Mg+Fe) = 0.651.

Formation Age and Radiogenic Isotopic Studies: We have no specific data constraining the formation age of NWA 5400, but its strong textural and mineralogical similarities to brachinites suggest that it may be very ancient. A ^{53}Mn-^{53}Cr age of 4.564 Ga has been determined for Brachina [2]. ^{53}Mn-^{53}Cr studies on NWA 5400 are in progress, and measurements of ^{142}Nd and ^{182}Hf-^{182}W on separated mineral phases are planned, as well as PGE abundance measurements.

Discussion: The provenance of NWA 5400 is difficult to establish with certainty. We exclude the possibility of any relationship to aubrites and other enstatite achondrites based upon the very different mineralogy, and the inference that NWA 5400 formed under more oxidizing conditions than aubrites. The very different Fe/Mn ratios in olivine and pyroxenes set NWA 5400 apart from any known lunar rock, as well as any modern terrestrial rock from Earth's crust or shallow mantle (especially given the presence of accessory FeNi metal). In texture, mineralogy and mineral compositions, NWA 5400 resembles some brachinites, but those ancient achondrites have very different oxygen isotope compositions [3].

Thus we are left with the possibility that NWA 5400 could be an ancient terrene meteorite, or else a sample from a different, differentiated Earth-like body. The well-known overlap in oxygen isotopic compositions for lunar and terrestrial samples provides strong support for the giant impact hypothesis for the origin of the Moon [4]. According to this theory, a large differentiated planet of approximately the size of Mars collided with the early (but already differentiated) proto-Earth about 4.52 Ga ago, and some of the more refractory material from both bodies re-accreted in near-Earth orbit to form the Moon. The observed excess angular momentum in the Earth+Moon system provides further strong support for this model [e.g., 5].

The composition of the impactor planet (Theia) is difficult to constrain with any certainty. If Theia accreted originally in the vicinity of Earth, it may have possessed a similar bulk oxygen isotopic composition. Even though extensive mixing of material from both the proto-Earth and Theia may have occurred rapidly [e.g., 6], it seems unlikely that their oxygen isotopic compositions could have been drastically different – otherwise mass balance arguments make it more difficult to explain the virtually identical isotopic compositions of terrestrial and lunar rocks. Actually there are a few lunar meteorites with oxygen isotopic compositions measurably below the TFL [7], but these are all breccias and could contain a very minor amount of impact-admixed carbonaceous chondrite component(s).

The giant collision of Theia with proto-Earth (or collisions involving other Earth-like bodies) may have resulted in the ejection of some asteroid-sized fragments of one or both colliding bodies into orbits that precluded their reaccretion to Earth or Moon. Some such spalled fragments could have been (1) accreted to or captured as satellites by other extant planets, (2) captured by the Sun, or (3) trapped within the main asteroid belt. In the last case, such bodies could be targets for very recent impacts and collisions, and delivery of material as meteorites to Earth.

Some of the expected characteristics of such meteorites would be:

[1] very ancient formation ages
[2] isotopic compositions compatible with Earth
[3] ultramafic silicate or silicate+metal assemblages
[4] probably non-brecciated textures
[5] magnetic properties consistent with core formation
[6] siderophile element abundances consistent with prior core separation

Further Work: Analyses of cosmogenic radionuclides are in progress, but such data may inform us more about the space transport history of this meteorite rather than its provenance. Measurement of the magnetic properties of an interior sample of this specimen is planned, and as was found for angrites [8] may inform us whether an ancient dynamo was present on the parent body for NWA 5400. Siderophile element analyses also are in progress, and may shed light on the same issue (cf., [9]).

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