

PETROLOGY AND OXYGEN ISOTOPIC COMPOSITIONS OF ANOMALOUS ACHONDRITE NWA

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Introduction: Northwest Africa (NWA) 011 is a single stone of 40 g and has been discovered in the Moroccan Sahara desert in 1999 [1]. This pyroxene-plagioclase meteorite was classified as noncumulate eucrite, on the basis of petrography and geochemistry [1]. However, certain characteristics of this meteorite such as the high Fe/Mn values in pyroxene (~65) and particularly the bulk-rock oxygen isotopic compositions ($\delta^{18}\text{O} = +2.54$, $\delta^{17}\text{O} = -0.48$) are not of typical eucrites and may suggest a new type of basaltic meteorite [2]. In an attempt to resolve this issue, we have investigated mineral chemistry and oxygen isotopic compositions on portions of NWA 011. Trace-element chemistry and Ar-Ar age is presented in a companion paper [3].

Petrographic Description: Petrographic study of 2 polished thin-sections reveals that the sample is fine-grained monolithic, unbrecciated achondrite [1]. The absence of primary breccia texture (i.e., relic plagioclase and augite grains [2]), even in our larger section (3 cm²), suggests that NWA 011 may not be a recrystallized breccia. Modally, the sample consists mainly of pigeonite (58.50%) and plagioclase (39.56%), with minor amounts of opaque (0.71%), silica (0.67), and phosphate (0.54) minerals. Pigeonite (0.2-0.8 mm) is commonly subhedral and often has curved boundaries at the contacts with plagioclase (Fig. 1). All pigeonite grains contain exsolution lamellae of augite, usually a few microns wide but sometimes reach ~10 μm . Plagioclase (up to 0.1 mm) is anhedral and usually forms crystal aggregates (up to 2 mm) or straddles along grain boundaries or fractures of pigeonite grains. This texture may indicate recrystallization, possibly as a result of thermal metamorphism. Opaque minerals, occurring as small clusters, include ulvöspinel, ilmenite, and small Fe metal-sulfide intergrowths (2-5 μm). Baddeleyite inclusions have also been found in some ilmenites. Olivine usually occurs in the same aggregates as oxides (Fig. 1). Ca-phosphates (whitlockite and Cl-apatite) are common but not evenly distributed.

Mineral Chemistry: Compositions of pigeonite ($\text{W}_{05.7-6.5}\text{Fs}_{63.2-65.1}$; $\text{Mg}\# = 32-33$) and its lamella augite ($\text{W}_{036.1-39.2}\text{Fs}_{35.2-38.3}$; $\text{Mg}\# = 38-43$) are similar to those of Nuevo Laredo Trend eucrites (Fig. 2) [4] and some lunar metabasalts [5]. However, the Fe/Mn ratios (Pig = 67, Aug = 65) are significantly higher than those of

typical eucrites (Fig. 3). Plagioclase is bytownite and low in K_2O contents ($\text{An}_{80.2-87.7}\text{Or}_{0.7-0.2}$). Olivine is Fe-rich and its composition varies in a restricted range ($\text{Fa}_{79.5-81.4}$). In ulvöspinel, FeO and TiO_2 contents are 55.3 and 24.2 wt%, resp.; ilmenite contains 45.1 and 52.7 wt%, resp.

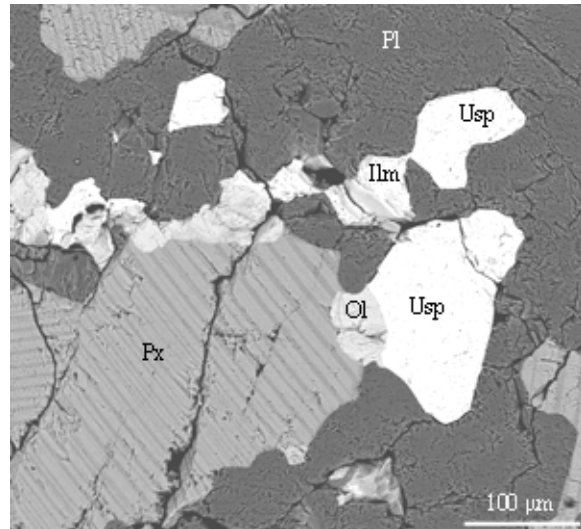


Figure 1. BSE image of meteorite NWA 011.

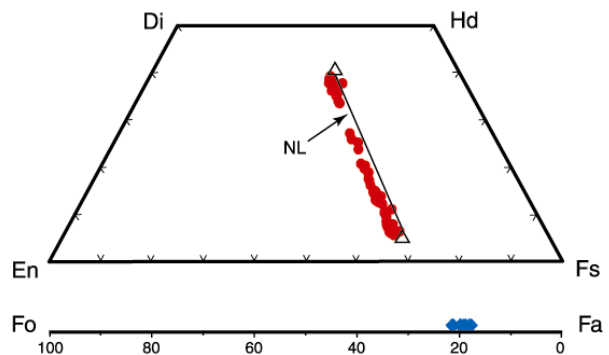


Figure 2. Pyroxene and olivine compositions of NWA 011. The pyroxene compositions are comparable to those of Nuevo Laredo Trend (NL) eucrites [4].

Oxygen Isotopes: Oxygen isotope analyses have been performed on two separate portions (2 aliquots for each) of NWA 011, using a high-precision laser-fluorination technique [6]. Results are shown in Table 1. The newly obtained oxygen data (Fig. 4) is far removed from the known eucrite region (within HED shaded field), with $\Delta^{17}\text{O} = -1.58$ vs. -0.25 of eucrites

[7]. The results confirm the unusual oxygen isotope compositions of NWA 011 observed previously [2].

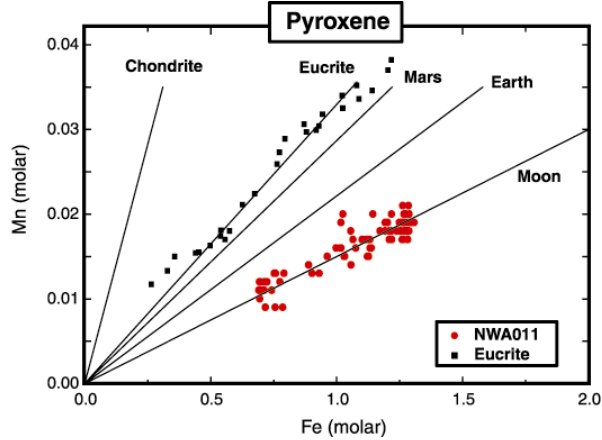


Figure 3. Plot of Fe vs. Mn in pyroxenes of NWA 011 illustrating the unusually high Fe/Mn values in NWA 011 when compared with other euclites.

Table 1. Oxygen isotopic data of NWA 011

Aliquots	$\delta^{18}\text{O}$	$\delta^{17}\text{O}$
A1	3.23	0.10
A2	2.84	-0.10
B1	2.88	-0.08
B2	2.71	-0.17
Average	2.92	-0.06
Std. Dev.	0.22	0.12

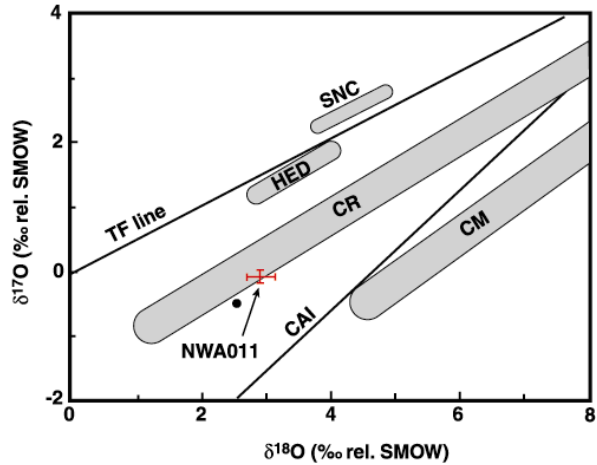


Figure 4. Oxygen isotopic compositions of meteorite NWA 011 shown with error bars. The data confirm the anomalous O-isotope values (filled circle) observed previously [2].

Crystallization Relationship: Bulk compositions from this study and [2] (Table 2) have been used for crystallization modeling, using the MELTS program at an $f\text{O}_2$ of IW. Figure 5 shows the following order of equilibrium crystallization resulted from our bulk composition: Pig + Pl \rightarrow Sp \rightarrow Ol \rightarrow Aug \rightarrow Whit \rightarrow Ilm \rightarrow Silica. The model closely reproduces phases and their compositions as observed in the sample,

suggesting that post-crystallization processes did not significantly alter the original composition of NWA 011. Composition of [2] yields slightly different order of crystallization, with the absence of Ilm and silica mineral, and the olivine with Fo_{62} , which is significantly higher than that obtained from our composition. These differences may indicate the inhomogeneity of the sample.

Table 2. Bulk compositions of NWA 011

	This Study	[2]
SiO ₂	48.22	45.63
TiO ₂	0.85	0.92
Al ₂ O ₃	12.86	13.12
Cr ₂ O ₃	0.19	0.24
FeO	19.95	21.13
MnO	0.29	0.40
MgO	6.05	6.66
CaO	10.76	11.11
Na ₂ O	0.54	0.45
K ₂ O	0.03	0.03
P ₂ O ₅	0.22	<0.02

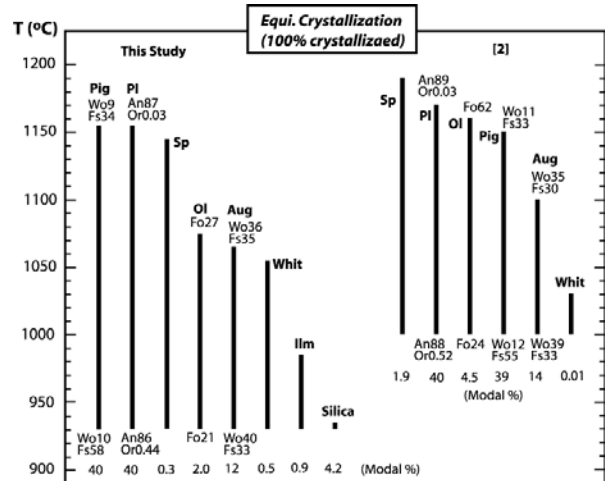


Figure 5. Crystallization modeling of NWA 011.

Discussion: NWA 011 resembles noncumulate euclites on the basis of texture, mineralogy, and certain chemistry. However, there are 2 major differences: NWA 011 has anomalous O-isotopic compositions and higher Fe/Mn values (Figs. 3&4, resp.). Therefore, the sample possibly represents a new type of achondritic basaltic meteorite, with no apparent genetic relationship with euclites. Its parent body could have formed in a different region of solar nebula than that of the HED parent body.

References: [1] Afanasiev S. V. et al. (2000) *MetSoc* 63rd, A19. [2] Yamaguchi A. et al. (2002) *Science* 296, 334–336. [3] Korochantseva E. V. (2003) this volume. [4] Warren P. H. and Jerde E. A. (1987) *GCA* 51, 713-725. [5] McSween H., Jr. et al. (1977) *LSI* 304, 118-120. [6] Wiechert U. et al. (2001) *Science* 294, 345-348. [7] Clayton R. N. and Mayeda T. K. (1996) *GCA* 60, 1999-2017.