Northwest Africa 4472 and 4485

Anorthosite-bearing basaltic (polymict) breccia

64.3, 188 g

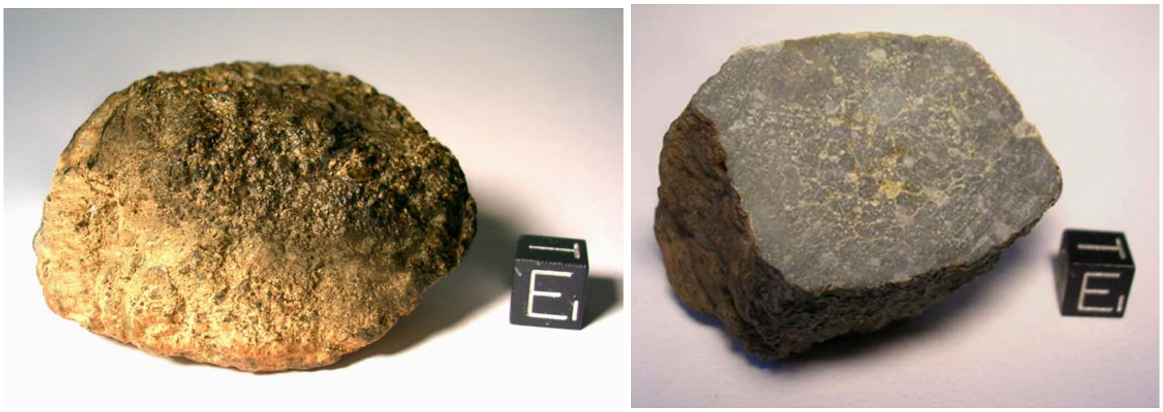


Figure 1: Northwest Africa (NWA) 4485: entire stone (left) and cut mass (right). Cubes are 1 cm. Photos by S. Ralew and M. Altmann.

Introduction

Northwest Africa (NWA) 4472 and 4485 were found in Algeria, and purchased in Morocco in July and September (respectively) of 2006. NWA 4472 is a single 64.3 g stone (without fusion crust) with visible pale gray to whitish clasts in a dark gray matrix. The exterior has fractures and thin coatings of desert varnish on exposed surfaces. NWA 4485 is a single 188 g spheroidal stone with a brown weathered exterior (Fig. 1). The interior consists of pale gray to whitish clasts in a dark gray matrix, and has visible thin veins of terrestrial carbonate (Connolly et al., 2007).

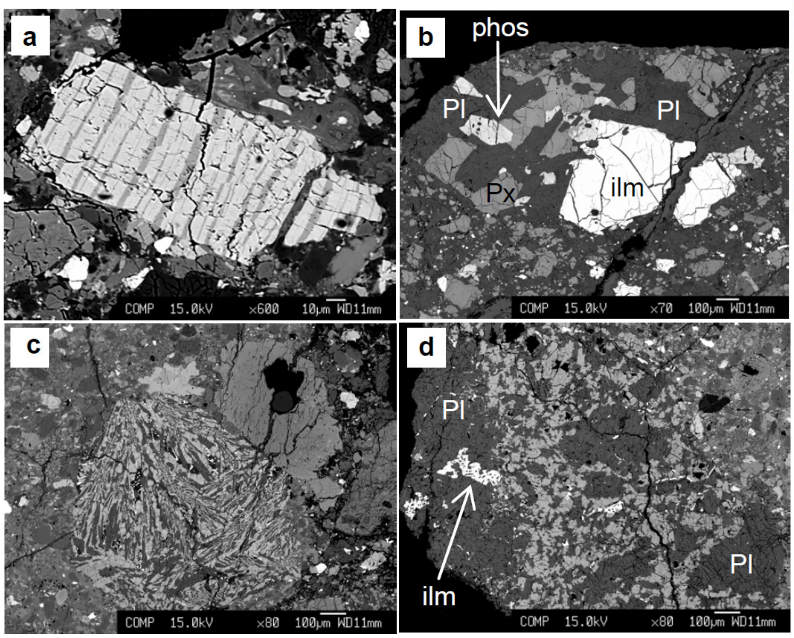
Figure 2: Cut slab of NWA 4472 illustrating dark glassy matrix and light colored feldspathic clast. Cube is 1 cm. (from Kuehner et al., 2007).

Figure 3: Cut slab face of NWA 4472 illustrating dark glassy matrix and light colored feldspathic clast. Cube is 1 cm. (from Kuehner et al., 2007).

Petrography and mineralogy

In both NWA 4472 and 4485, lithic clasts (up to 0.65 cm) are predominantly various types of ophitic to quench-textured basalts (composed of pyroxene(s), plagioclase, olivine, ilmenite, and rare baddeleyite; Figs. 2 and 3). Granophyre clasts (consisting of "ribbon-like" subparallel intergrowths of silica and K-feldspar with accessory baddeleyite and rare tranquillityite) are present as a minor component, as well as clasts composed mainly of fayalite (with associated glass, silica, K-feldspar, and merrillite) and spherical to ellipsoidal glass objects (up to 60 µm across) (Kuehner et al., 2007). In addition there are KREEP basalt, feldspathic, and exsolved lithologies present among the clasts (Fig. 4; Arai et al., 2009). Mineral clasts include pyroxenes, olivine, plagioclase, silica, zircon, baddeleyite, merrillite, Ti-chromite, fayalite, ilmenite (with baddeleyite inclusions), metal (both kamacite and taenite), troilite, and schreibersite (Connolly et al., 2007; Kuehner et al. 2007; Joy et al., 2007; 2008). Some unusual exsolution features have been noted in both samples, and they involve silica and potassium feldspar intergrowths (Fig. 5).

Mineral compositions are: Olivine ($Fa_{26.3–64.6}$), plagioclase ($An_{86.9–95.5}Or_{0.2–0.6}$), orthopyroxene ($Fs_{18.9–29.3}Wo_{3.8–4.6}$), subcalcic augite ($Fs_{48.9–52.6}Wo_{26.7–39}$), Al-Cr-rich pigeonite ($Fs_{27.0}Wo_{17.1}$; Al = 3.10 wt%, Cr = 1.01 wt%), fayalite ($Fa_{90.3}$), barian K-feldspar intergrown with silica ($Or_{80.9–55.6}Ab_{15.3–30.2}$ $Cn_{0.6–6.3}$) (from Connolly et al., 2007).



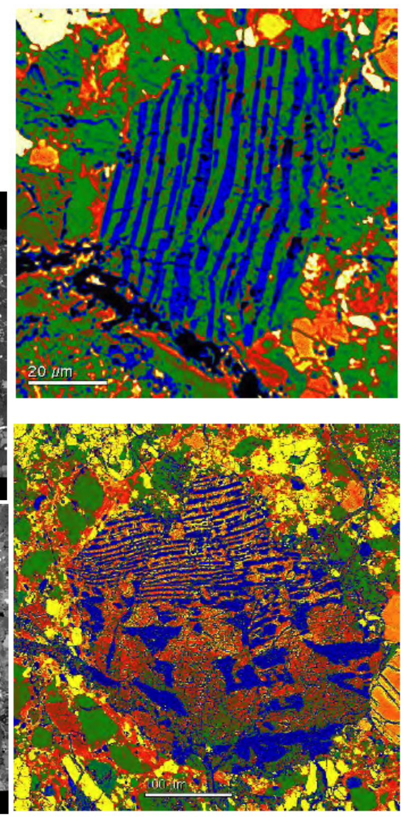
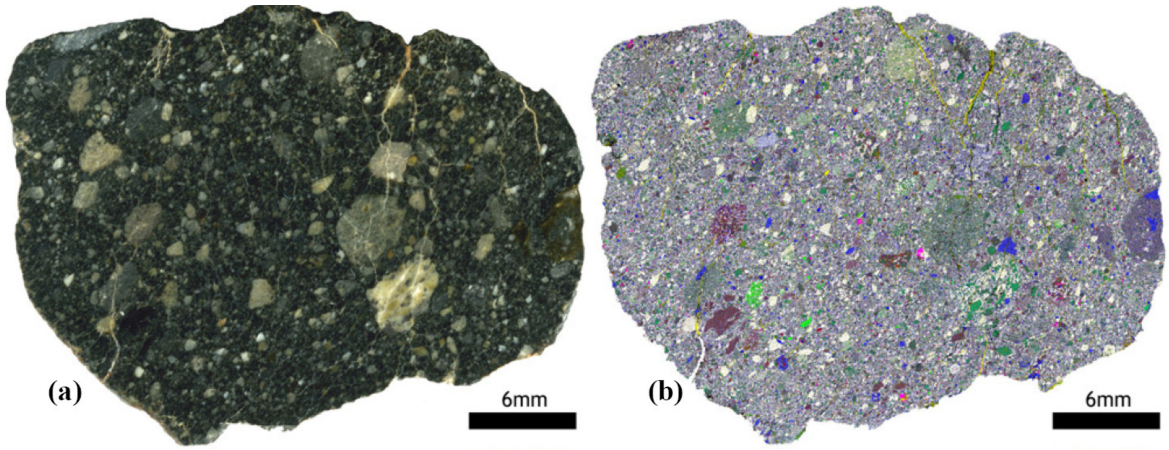
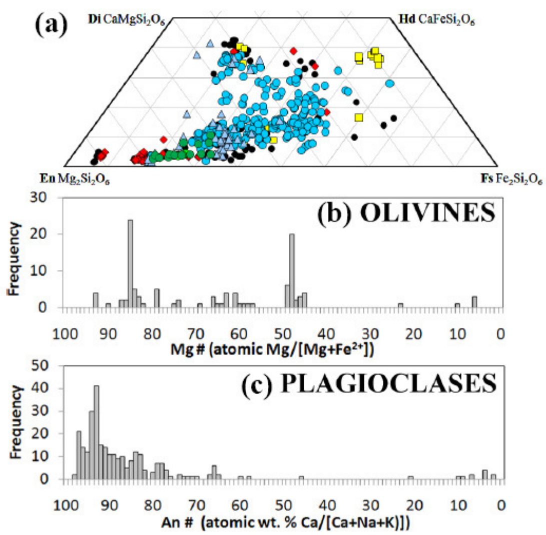


Figure 4: Back-scattered electron images. (a) Pyroxene fragment with coarse exsolution lamellae: augite lamellae in host pigeonite, (b) Intersertal KREEP basalt clast, (c) Intergranular clast, and (d) Feldspathic breccia clast. Pl: plagioclase, Px: pyroxene, ilm: ilmenite, and phos: phosphate (from Arai et al., 2009).

Figure 5: Exsolution features in clasts from NWA 4472 (above) and NWA 4485 (below) – silica (blue), K-feldspar (green to red) (from Kuehner et al., 2007).

In depth studies of clasts in NWA 4472 have revealed clasts of basalt, FeO-rich glass, Mg suite lithologies, granophyric silica + K-spar intergrowths, impact melt and granulitic breccia (Joy et al., 2008; Figs. 6, 7 and 8).





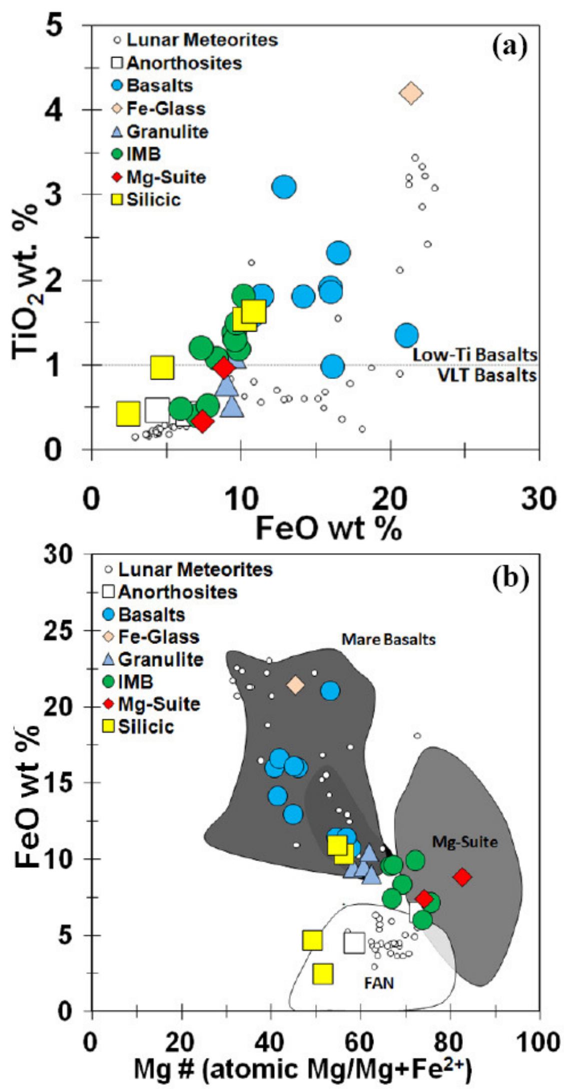


Figure 6: scanned image of NWA 4472 slab (top left) along with x-ray montage of same slab where blue clasts are silicic KREEP-like, green clasts are Mg-suite, and red clasts are FeO-rich mare basalt.

Figure 7: Pyroxene, olivine and plagioclase compositions from Joy et al. (2008).

Figure 8: Major element compositions of various clasts in NWA 4472 studied by Joy et al. (2008).

Chemistry

INAA analyses of nine ~30 mg subsamples gave a mean composition of: Na = 0.448, Fe = 7.14 (both wt%), Sc = 20.9, La = 44.7, Sm = 19.51, Eu = 1.50, Yb = 13.4, Zr = 438, Hf = 11.1, Ba = 601, Th = 7.49 (all ppm). and is very similar in bulk composition and petrologic characteristics to Northwest Africa 4485. INAA on eight ~30 mg subsamples of NWA 4485 gave a mean composition of: Na = 0.441, Fe = 7.27 (both wt%), Sc = 21.7, La = 31.6, Sm = 14.12, Eu = 1.46, Yb = 11.0, Zr = 443, Hf = 11.4, Ba = 375, Th = 6.37 (all ppm). The bulk composition of NWA 4485 is essentially identical to that of Northwest Africa 4472 (Fig. 9). The presence a minor mare basalt component cannot be ruled out in either sample, but these specimens are dominated by materials with KREEP-like composition. Furthermore the REE contents of these samples is higher than most other lunar materials, and similar to SaU 169 in this respect (Fig. 9,10). This compositional characteristic suggests an origin in the Procellarum KREEP terrane on the nearside of the Moon (Joy et al., 2008).

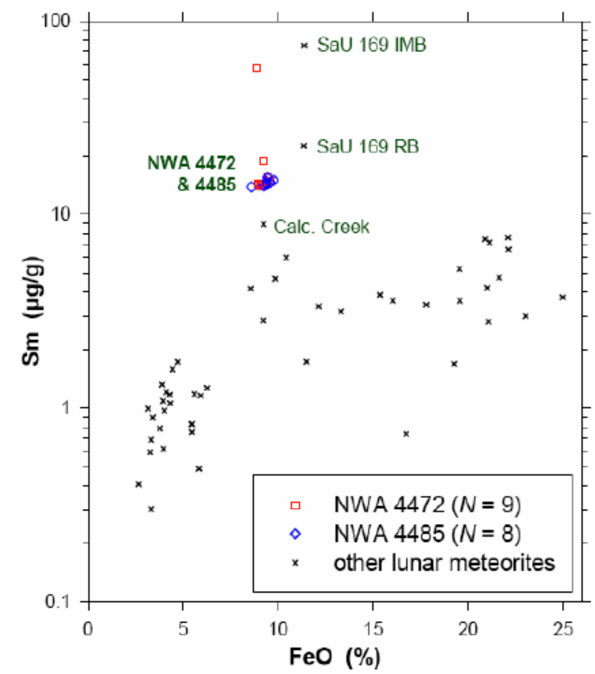


Figure 9: Sm vs. FeO for NWA 4472 and 4485 compared to other lunar meteorites, illustrating their unusually high concentrations of SM (and other REE), in a similar range to those measured for SaU 169.

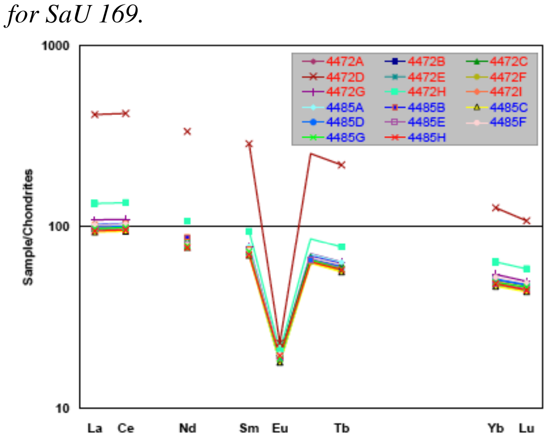


Figure 10: Chondrite-normalized REE abundances of NWA 4472 and NWA 4485 subsamples (very enriched subsample probably contains abundant phosphate).

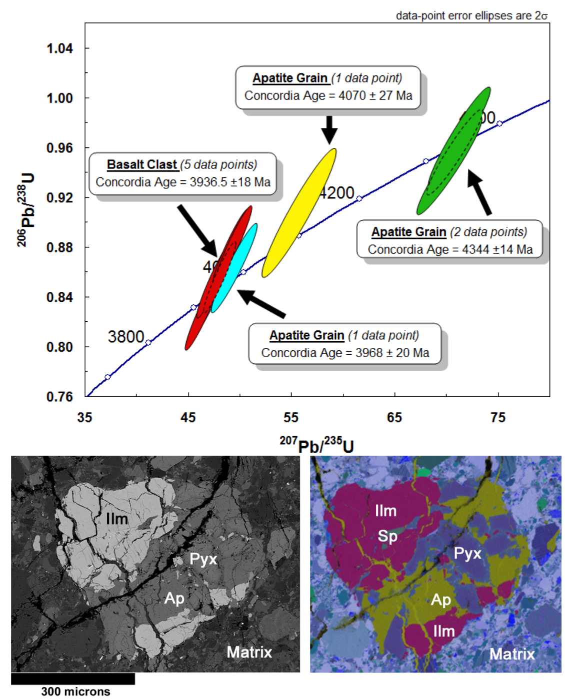


Figure 11: U-Pb isochron diagram for a basalt clast from NWA 4472, as well as BSE and x-ray maps of the clast illustrating the apatite-rich fragment (from Joy et al., 2009a).

Radiometric age dating

Determination of the age of clasts within NWA 4472 and 4485 have been carried out by Joy et al. (2009, 2009b) using U-Pb and Ar-Ar approaches. Ion probe U-Pb and Pb-Pb isotopic study of phosphates show that NWA 4472 has sampled a range of Pre-Nectarian (>3.92 Ga) lunar volcanic and plutonic lithologies. An evolved basalt fragment (3.93- 3.94 Ga), and matrix apatite and merrillite grains (3.94-4.07 Ga) are consistent with the ages of Apollo and Luna KREEP basalts (Figure 11; Joy et al., 2009a,b). An older apatite grain dated to be ~4.34 Ga may represent the crystallization age of the HAS clast component (Joy et al., 2009b).

Cosmogenic exposure ages

Cosmogenic exposure irradiation (calculated from the $^{38}Ar/^{36}Ar$ ratio of the high temp. release steps) suggest a near surface regolith residence time of ~300 Ma; consistent with NWA 4472 being a sample of the ancient lunar regolith (Joy et al., 2009b).

Table 1a:Chemical composition of NWA 4472/4485

reference	1	1
weight	20-60	323/262
technique	a	c
SiO_2 %	48	
TiO_2	1.28	
Al_2O_3	17.8	
FeO	9.26	9.26
MnO	0.14	
MgO	9.38	
CaO	12.1	12.5
Na_2O	0.59	0.6
K_2O	0.42	0.49
P_2O_5	0.27	
S %		
sum	99.5	
Sc ppm		21.2
V		
Cr		1565
Co		23.1
Ni		131
Cu		
Zn		
Ga		
Ge		
As		<1
Se		0.08
Rb		11
Sr		205
Y		
Zr		440
Nb		
Mo		
Ru		
Rh		
Pd ppb		
Ag ppb		
Cd ppb		
In ppb		
Sn ppb		
Sb ppb		
Te ppb		
Cs ppm		0.48
Ba		500
La		38.8
Ce		100.8
Pr		
Nd		60
Sm		17.09
Eu		1.48
Gd		
Tb		3.54
Dy		
Ho		
Er		
Tm		
Yb		12.35
Lu		1.697
Hf		11.21
Ta		1.55
W ppb		
Re ppb		
Os ppb		
Ir ppb		3.7
Pt ppb		
Au ppb		<8
Th ppm		6.99
U ppm		1.89

technique (a) EMPA, (b) ICP-MS, (c) INAA (d) XRF

Table 1b. Light and/or volatile elements for NWA 4472/4485

Li ppm	
Be	
C	
S	
F ppm	
Cl	
Br	4.4
I	
Pb ppm	
Hg ppb	
Tl	
Bi	

References: 1) Korotev et al. (2009b)