NWA 2737

DRAFT

Shocked Dunite

611 grams

Figure 1: Photograph of NWA 2737 (Diderot) kindly submitted by Carine Bidaut and Bruno Fectay. Is that a centimeter scale? Where's this rock now?

Introduction

NWA 2737 (field name "Diderot") is a dark black rock, found as several pieces in the Moroccan Sahara, August 2000, but not recognized as a meteorite until 2004 (figure 1). With 90% modal olivine, it is akin to a dunite, as is Chassigny (Beck et al. 2005; Mikouchi et al. 2005). However, NWA 2737 has a somewhat higher Mg/Fe ratio than that of Chassigny and is highly shocked (Van de Mooretele et al. 2007). Oxygen isotopes, Fe/Mn = 55, and Ga/Al = 3 x 10^{-4} prove it is Martian in origin (Beck et al. 2006; Connolly et al. 2006).

NWA 2737 is not highly altered by weathering. It has low U, Sr and Ba, which are the usual indicators for desert weathering (Barrat et al. 2003). However, the isotopic composition of Sr indicates at least some

Mineralogical Mode of NWA2737

	Beck et al. 2005	Mikouchi et al. 2005	Treiman et al. 2007
Olivine	89.6 vol. %	89	85.1
Augite	3.1	3	5
Pigeonite	1.0	4	4
Chromite	4.6	3	2.9
Sanadine	1.6		
Glass		1	2.2
Phosphate	0.2		
Carbonate			0.9
Nanophase iron			tr.

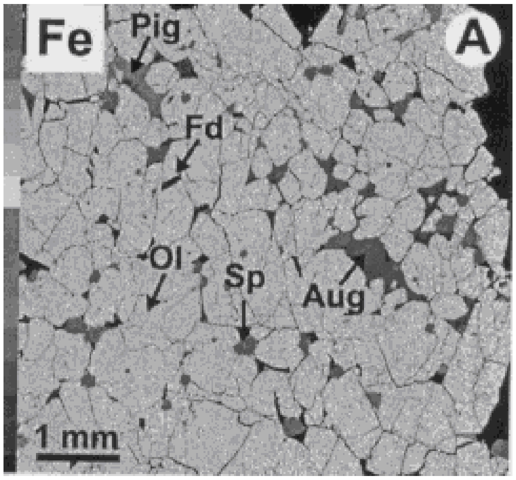

Figure 2 : X-ray map for Fe of polished thin section of NWA2737 showing cumulate texture (figure 2a from Beck et al. 2006).

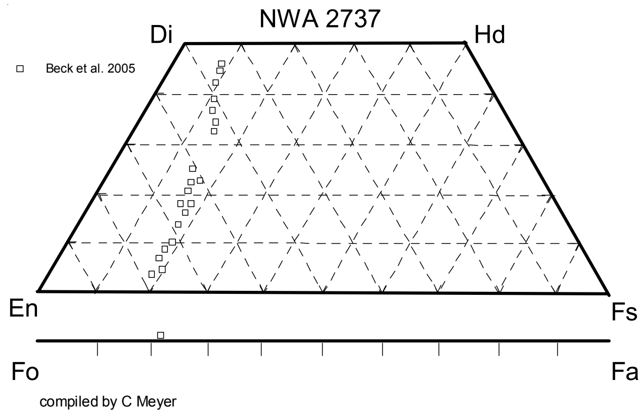

Figure 3: Pyroxene and olivine composition of NWA 2737 (lifted gently from Beck et al. 2005, Mikouchi et al. 2005).

alteration (Misawa et al. 2005). Carbonate has been reported in veins.

NWA2737 orginally crystallized ~ 1.3 b.y., but was severely shocked ~ 170 m.y. ago.

It is a shame this rock can't officially be named after Denis Diderot, who was the editor-in-chief of "Encylopedia" and a famous 18th century enlightenment thinker, as was originally proposed.

Petrography

The texture of NWA 2737 is that of a cumulate (Beck et al. 2005, 2006), with olivine and minor pyroxene the main phases (figure 2). Plagioclase is absent, but minor sanidine and/or K-rich glass is present. The most distintive feature is that the olivine is a dark brown color (also seen in olivine in some other Martian samples).

Beck et al. (2006) and Nekvasil et al. (2006) have studied the melt inclusions found in olivine. These are crystallized products of magmatic melt trapped in the olivine as the olivine originally crystallized. Kaersutite is found in these inclusions.

Treiman et al. (2007) find that two post-crystallization shock events are required to explain detailed petrographic observations. One event, reaching extreme pressure ~55 GPa , produced diffuse X-ray reflections (Mikouchi et al. 2005) and the dark brown color of olivine. Van de Moortele et al. (2007) have discovered a new high-pressure polymorph of olivine in NWA 2737, along with nanophase metalic iron due to this exteme shock. In addition, Treiman et al. (2007), noticed that "ribbons" of visually colorless olivine are cut or displaced by planar features due to a second low-pressure shock event.

The boundary of some calcite-pyroxene grains in NWA 2737 are found to be offset by shock features (Beck et al. 2005, 2006); evidence that some of the carbonates in NWA 2737 may be from Mars.

Mineralogy

Olivine: Olivine in NWA 2737 is up to 2 mm and is black due to shock (Beck et al. 2005)(see figure 7). It is rather homogeneous and mafic (Fo_{79}). Treiman et al. (2006) find the olivine is "brown" in thin section (as is also the case in some other Martian meteorites), because of the presence of Fe^{+3}. They speculate that shock heating may have released H^+ from the lattice?! Pieters et al. (2006) have determined the spectra of olivine and list several possible cause for "brown" olivine – all involving shock. McCanta et al. (2006) also reported substantial Fe^{+3} in the olivine. On the other hand, Reynard et al. (2006) found that "black" olivine contained nanophase metallic iron.

Pyroxene: Pyroxenes fall along a tie-line ($En_{80}Wo_2$ - $En_{45}Wo_{46}$)(figure 3). Pyroxenes have fine exsolution lamellae (1 micron). Trieman et al. (2006) and Reynard et al. (2006) calculate an equilibrium temperature of ~1150 deg C from the end member pyroxenes.

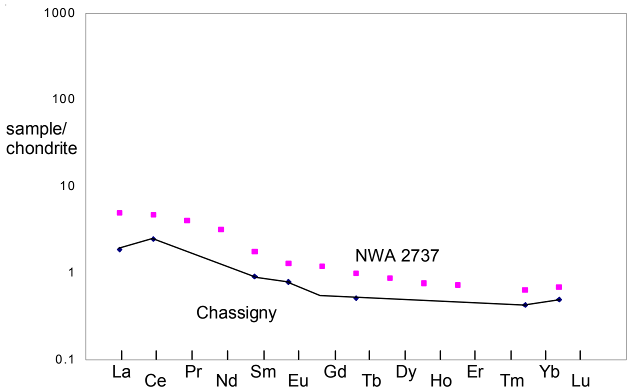

Figure 4: Normalized rare-earth-element diagram of NWA 2737 (data from Beck et al. 2005) compared with that of Chassigny (from Mittlefehldt 1996).

Chromite: Chromite shows chemical zoning (Beck et al. 2005; Mikouchi et al. 2005).

Kaersutite: Ca-poor kaersutitic amphibole has been reported as a minor phase by both Beck et al. (2005) and Mikouchi et al. (2005).

K-spar: Sanidine is $An_{1-13}Ab_{68-79}Or_{15-23}$ (Beck et al. 2006).

Phosphates: Apatite has up to 2.7 wt. % Cl (Beck et al. 2006).

Carbonates: Carbonates are found in cracks in NWA 2737 and in intersticies between minerals. It is mostly calcite, but some aragonite (Beck et al. 2006).

High-density phases: Olivine in NWA2737 has been severely shocked. Laihunite (olivine with Fe^{+3}) and a new, metastable, high-density, polymorph of Mg_2SiO_4 have been reported by Van de Moortele et al. (2007).

Chemistry

The composition of NWA2737 was determined by Beck et al. (2005b) (table 1). The rare-earth-element pattern (figure 4) had been previously reported by Beck et al. (2005a).

Radiogenic age dating

Misawa et al. (2005) determined a crystallization age of 1.42 ± 0.06 b.y. by Sm-Nd (figure 5). Marty et al. (2005) reported a K-Ar age of 1.29 b.y. (assuming no trapped ^{40}Ar). Bogard and Garrison (2006) reported an age of 169 ± 4 m.y. from an intermediate temperature plateau in Ar/Ar (figure 6). Bogard and Garrison interpret this young age as due to an "outgassing" event. Treiman et al. (2007) interpret the ~170 m.y. event as the extreme shock event that produced the dark color of the rock.

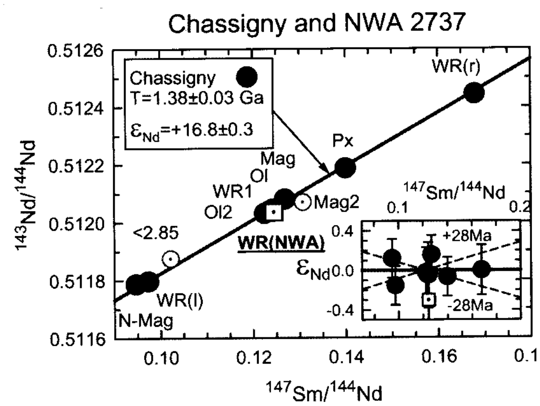

Figure 5: Crystallization age of Chassigny by Sm/Nd with preliminary data for NWA2737 (from Misawa et al. 2005).

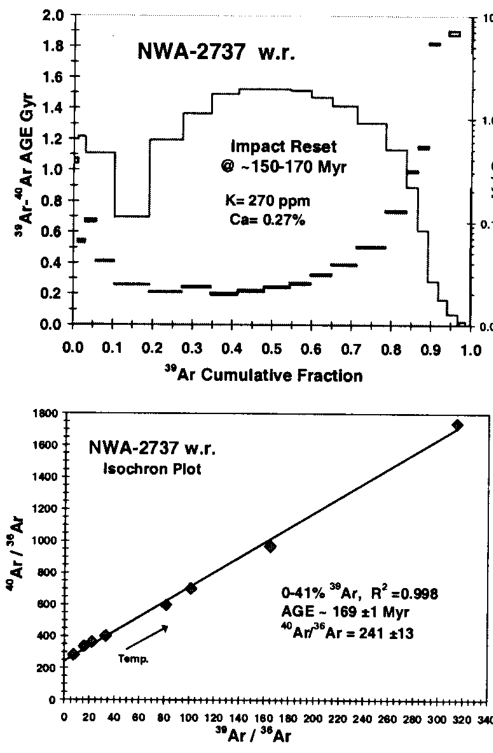

Figure 6: Ar/Ar plateau age for NWA2737 (from Bogard and Garrison 2006).

Cosmogenic isotopes and exposure ages

Tim Jull (private communication) reports that ^{14}C is 16.9 ± 0.7 dpm/kg and ^{10}Be is 19.3 ± 0.4 dpm/kg (close to saturation and typical of nakhlites and Chassigny). From these measurements he calculates

Table 1. Chemical composition of NWA 2737.

reference	Beck 2006	
weight		
SiO2 %	37	(a)
TiO2	0.13	(a)
Al2O3	0.86	(a)
Fe2O3	21.79	(a)
MnO	0.4	(a)
MgO	37.1	(a)
CaO	0.84	(a)
Na2O	0.17	(a)
K2O	0.05	(a)
P2O5	0.1	(a)
S %		
sum		
Sc ppm	4.6	(b)
V	*70*	(a)
Cr	11700	(a)
Co	78	(b)
Ni	875	(a)
Cu	4.3	(b)
Zn	45	(b)
Ga	1.43	(b)
Ge ppb		
As		
Se		
Rb	1.28	(b)
Sr	27.2	(b)
Y	1.21	(b)
Zr	5.01	(b)
Nb	1.19	(b)
Mo	0.15	(b)
Ru		
Rh		
Pd ppb		
Ag ppb		
Cd ppb		
In ppb		
Sn ppb		
Sb ppb		
Te ppb		
Cs ppm	0.063	(b)
Ba	37.5	(b)
La	1.17	(b)
Ce	2.87	(b)
Pr	0.363	(b)
Nd	1.43	(b)
Sm	0.266	(b)
Eu	0.0721	(b)
Gd	0.237	(b)
Tb	0.0367	(b)
Dy	0.213	(b)
Ho	0.0427	(b)
Er	0.117	(b)
Tm		
Yb	0.105	(b)
Lu	0.017	(b)
Hf	0.14	(b)
Ta	0.07	(b)
W ppb	100	(b)
Re ppb		
Os ppb		
Ir ppb		
Pt ppb		
Au ppb		
Th ppm	0.13	(b)
U ppm	0.056	(b)
technique	*(a) ICP-AES, (b) ICP-MS*	

Figure 7: Photo illustrating "black" olivine.

a ^{14}C terrestrial age of 9.5 ± 1.3 k.y. and $^{14}C/^{10}Be$ terrestrial age of 9.6 ± 0.4 k.y.

Marty et al. (2005) apparently determined ~10 m.y. for the cosmic ray exposure (referenced in Mohaptra et al. 2006).

Other Studies

Oxygen isotopes are reported as Delta ^{17}O = +0.305 (Beck et al. 2005, 2006), proving its Martian status.

The optical properties (spectra) of NWA2737 have been studied by Pieters et al. (2006). Raman spectra of minerals are reported by Beck et al. (2006) and Reynard et al. (2006). Mossbauer spectra are reported by Treiman et al. (2007).

Xenon isotopes have been studied by Mohapatra et al. (2006).

Figure 8: North West Africa where NWA2737 was found (where's the nearest post office?).

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