

NWA 2737
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 = 3×10^{-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.

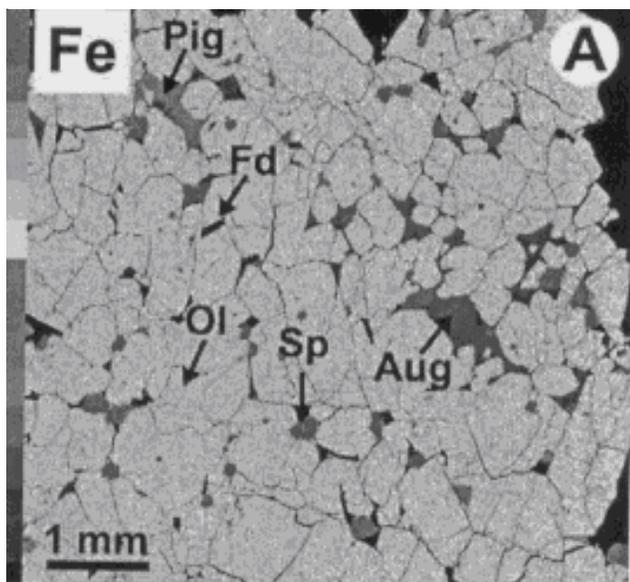


Figure 2: X-ray map for Fe of polished thin section of NWA2737 showing cumulate texture (figure 2a from Beck et al. 2006).

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

NWA2737 originally crystallized ~ 1.4 b.y., but was severely shocked ~ 170 m.y. ago. It has a cosmic ray exposure age of about 10 m.y. and a terrestrial exposure age of about 10 thousand years.

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

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 distinctive 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. (2007) 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

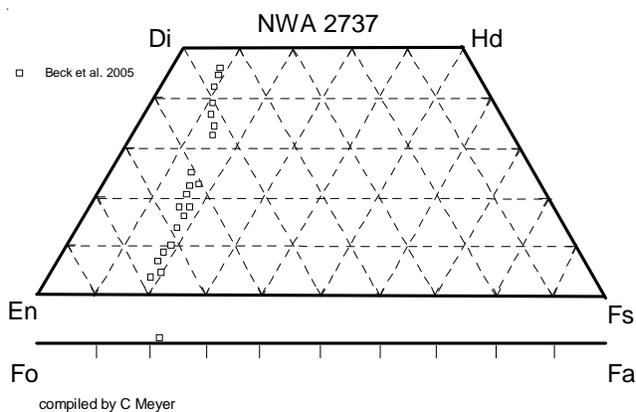


Figure 3: Pyroxene and olivine composition of NWA 2737 (lifted gently from Beck et al. 2005, Mikouchi et al. 2005).

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 metallic iron due to this extreme shock (see also Blaess et al.). 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; Blaess et al. 2010)(see figure 7). It is rather homogeneous and mafic (Fo₇₉). 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) and Blass et al. (2010) found that “black” olivine contained nanophase metallic iron particles, causing the black color.

Pyroxene: Pyroxenes fall along a tie-line (En₈₀Wo₂ - En₄₅Wo₄₆)(figure 3). Pyroxenes have fine exsolution lamellae (1 micron). Trieman et al. (2006) and Reynard

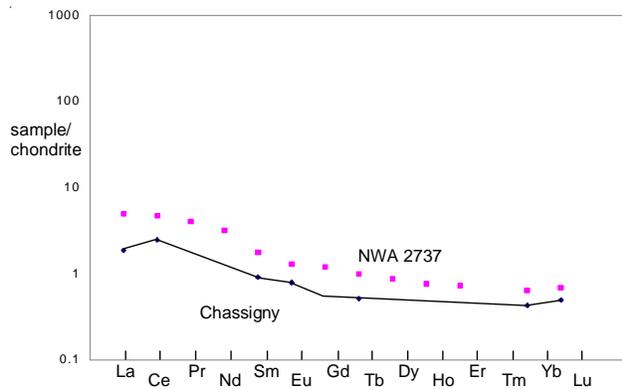


Figure 4: Normalized rare-earth-element diagram of NWA 2737 (data from Beck et al. 2005) compared with that of Chassigny (from Mittlefehldt 1996).

et al. (2006) calculate an equilibrium temperature of ~1150 deg C from the end member pyroxenes.

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 Beck et al. (2005), Mikouchi et al. (2005) and Nekvasil et al. (2007).

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 interstices 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

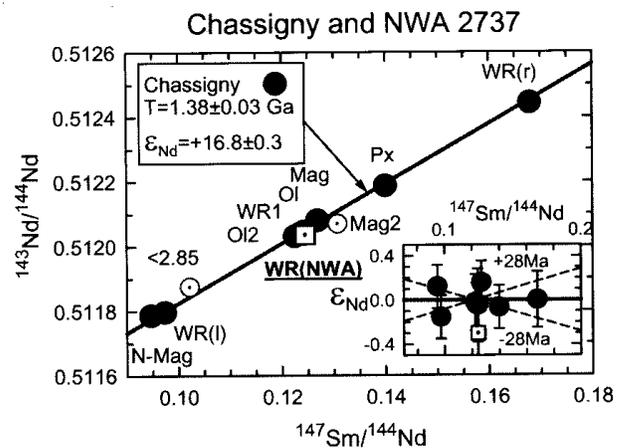


Figure 5: Crystallization age of Chassigny by Sm/Nd with preliminary data for NWA2737 (from Misawa et al. 2005).

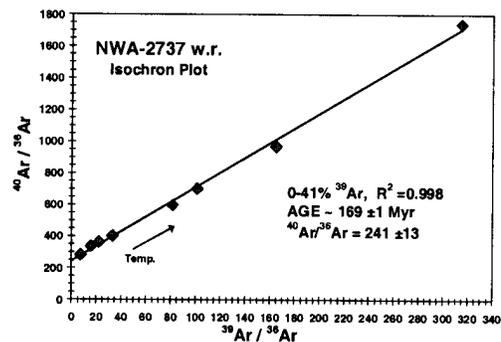
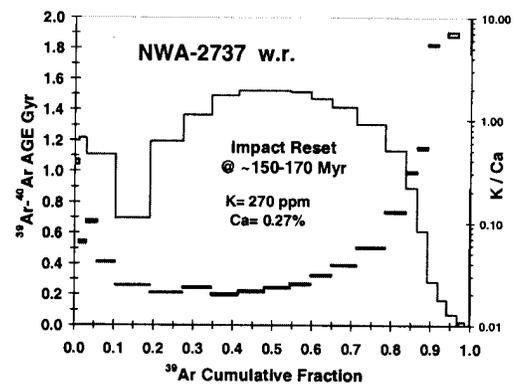


Figure 6: Ar/Ar plateau age for NWA2737 (from Bogard and Garrison 2006).

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.

Table 1. Chemical composition of NWA 2737.

reference	Beck 2006	
<i>weight</i>		
SiO ₂ %	37	(a)
TiO ₂	0.13	(a)
Al ₂ O ₃	0.86	(a)
Fe ₂ O ₃	21.79	(a)
MnO	0.4	(a)
MgO	37.1	(a)
CaO	0.84	(a)
Na ₂ O	0.17	(a)
K ₂ O	0.05	(a)
P ₂ O ₅	0.1	(a)
S %		
<i>sum</i>		
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)
<i>technique</i>	(a) ICP-AES, (b) ICP-MS	



Figure 7: Photo illustrating “black” olivine.

Cosmogenic isotopes and exposure ages

Tim Jull (private communication) reports that ¹⁴C is 16.9 ± 0.7 dpm/kg and ¹⁰Be is 19.3 ± 0.4 dpm/kg (close to saturation and typical of nakhlites and Chassigny). From these measurements he calculates a ¹⁴C terrestrial age of 9.5 ± 1.3 k.y. and ¹⁴C/¹⁰Be 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 Mohapatra et al. 2006).

Other Studies

Oxygen isotopes are reported as $\Delta^{17}\text{O} = +0.305$ (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) and Blaess et al. (2010).

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

Processing

There are pictures of several small slices, so it has been sawn.

References for NWA 2737.

Beck P., Barret J-A., Gillet Ph., Franchi I.A., Greenwood R.C., Van de Moortele B., Reynard B., Bohn M. and Cotton J. (2005b) The Diderot meteorite: the second Chassignite (abs#1639). *Lunar Planet. Sci.* **XXXVI** Lunar Planetary Institute, Houston.



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

Beck P., Barrat J.-A., Gillet Ph., Wadhwa Mini, Franchi I., Greenwood R.C., Bohn M., Cotton J., Van de Moortele B. and Reynard B. (2006) Petrology and geochemistry of the Chassignite Northwest Africa 2737 (NAW2737). *Geochim. Cosmochim. Acta* **70**, 2127-2139.

Bläss U., Langenhorst F., Frosch T., Schmitt M. and Popp J. (2006) Shock metamorphic state of the Chassignite NWA 2737 (abs#5311). *Meteorit. & Planet. Sci.* **41**, A23.

Bläss U.W., Langenhorst F. and McCammon C. (2010) Microstructural investigations on strongly stained olivines of the Chassignite NWA2737 and implications for its shock history. *Earth Planet. Sci. Lett.* **300**, 255-263.

Bogard Don D. and Garrison D.H. (2006) Ar-Ar dating of Martian Chassignites, NWA2737 and Chassigny, and Nakhilite MIL03346 (abs#1108). *Lunar Planet. Sci.* **XXXVII**, Lunar Planetary Institute, Houston.

Bogard D.D. and Garrison D.H. (2008) ^{39}Ar - ^{40}Ar age and thermal history of Martian dunite NWA 2737. *Earth Planet. Sci. Lett.* **273**, 386-392.

Connolly H.C. and 11 authors (2006) The Meteoritical Bulletin, No. 90. *Meteorit. & Planet. Sci.* **41**, 1383-1418.



Figure 9: Photo of small slice of NWA2737 (N. Classen).



Figure 10: Photo of NWA2737 slice by Jim Strope.

Kurihara T., Mikouchi T., Saruwatari K., Kameda J., Ari T., Hoffmann V. and Miyamoto M. (2008a) Transmission electron microscopy of "brown" color olivines in Martian and lunar meteorites (abs#2478). *Lunar Planet. Sci.* **XXXIX** Lunar Planetary Institute, Houston.

Kurihara T., Mikouchi T., Saruwatari K., Kameda J. and Miyamoto M. (2008b) Transmission electron microscopy of olivine in the LAR06319 olivine-phyric Shergottite (abs#5177). *Meteorit. & Planet. Sci.* **43**, A83.

Kurihara T., Mikouchi T., Saruwatari K., Kameda J. and Miyamoto M. (2009) Fe-Ni metal and magnetite nanoparticles in "brown" color olivines from Martian meteorites (abs#1049). *Lunar Planet. Sci.* **XL**, Lunar Planetary Institute @ The Woodlands.

- Marty B., Grimberg A., Heber V.S. and Wieler R. (2005) Noble gases in the newly found NWA2737 Chassignite (abs#5175). *Meteorit. & Planet. Sci.* **40**, A98.
- Marty B., Heber V.S., Grimberg A., Weiler R. and Barrat J-A. (2006) Noble gases in the Martina meteorite Northwest Africa 2737: A new Chassignite signature. *Meteorit. & Planet. Sci.* **41**, 739-748.
- McCanta M.C., Dyar M.D., Treiman A.H., Pieters C.M., Hiroi T., Lane M.D. and Bishop J.L. (2006) Mossbauer and synchrotron microxanes analysis of NWA2737 (abs#1751). *Lunar Planet. Sci.* **XXXVII** Lunar Planetary Institute, Houston.
- Mikouchi T. (2005a) Comparative mineralogy of Chassigny and NWA2737: Implications for the formation of Chassignite igneous body(s) (abs#5240). *Meteorit. & Planet. Sci.* **40**, A102.
- Mikouchi T., Monkawa A., Koizumi E., Chokai J. and Miyamoto M. (2005) MIL03346 Nakhilite and NWA2737 (Diderot) Chassignite: Two new Martian cumulate rocks from hot and cold deserts (abs#1944). *Lunar Planet. Sci.* **XXXVI** Lunar Planetary Institute, Houston.
- Misawa K., Shih C-Y., Reese Y., Nyquist L.E. and Barrat J-A. (2005c) Rb-Sr and Sm-Nd isotopic systematics of NWA 2737 Chassignite (abs#5200). *Meteorit. & Planet. Sci.* **40**, A104.
- Mohapatra R.K., Crowther S.A., Gilmour J.D. and Marty B. (2006) Xenon isotopic components in NWA2737 – A Chassignite from the hot desert (abs#1840). *Lunar Planet. Sci. Conf.* **XXXVII** Lunar Planetary Institute, Houston.
- Nagao K. and Park J. (2009) Heterogeneous Noble gas distributions in the NWA 2737 Chassignite (abs#5198). *Meteorit. & Planet. Sci.* **44**, A152.
- Nekvasil H., Filiberto J., McCubbin F. and Lindsley D.H. (2005) Combining Chassigny and NWA2737: New constraints on possible parental magmas and crystallization histories (abs#5259). *Meteorit. & Planet. Sci.* **40**, A112.
- Nekvasil Hanna, Filiberto J., McCubbin F. and Lindsley D.H. (2007) Alkalic parental magmas for Chassignites? *Meteorit. & Planet. Sci.* **42**, 979-992.
- Pieters C.M., Dyar M.D., Hiroi T., Lane M.D., Treiman A., McCanta M., Bishop J.L. and Sunshine J. (2006) Optical properties of Martian dunite NWA2737: A record of Martian processes (abs#1634). *Lunar Planet. Sci. Conf.* **XXXVII** Lunar Planetary Institute, Houston.
- Pieters C.M., Klima R.L., Hiroi T., Lane M.D., Treiman A., Noble S.K., Sunshine J. and Bishop J.L. (2007) The origin of brown olivine in Martian dunite NWA 2737 (abs#5062). *Meteorit. & Planet. Sci.* **42**, A125.
- Pieters C.M., Klima R.L., Hiroi T., Lane M.D., Treiman A., Noble S.K., McCanta M., Sunshine J. and Bishop J.L. (2008) Martian dunite NWA 2737: Integrated spectroscopic analyses of brown olivine. *J. Geophys. Res.*
- Reynard B., Beck P., Barret J-A. and Bohn M. (2006) Pyroxene crystal chemistry and the late cooling history of NWA2737 (abs#1963). *Lunar Planet. Sci. Conf.* **XXXVII** Lunar Planetary Institute, Houston.
- Reynard B., Van de Moortele B., Beck P. and P. Gillet (2006) Shock-induced transformations in olivine of the Chassignite NWA2737 (abs#1837). *Lunar Planet. Sci. Conf.* **XXXVII** Lunar Planetary Institute, Houston.
- Treiman A.H., McCanta M., Dyar M.D., Pieters C.M., Hiroi T., Lane M.D. and Bishop J.L. (2006) Brown and clear olivine in Chassignite NWA2737: Water and deformation (abs#1314). *Lunar Planet. Sci. Conf.* **XXXVII** Lunar Planetary Institute, Houston.
- Treiman A.H., Dyar M.D., McCanta M., Noble S.K. and Pieters C.M. (2007) Martian dunite NWA2737: Petrographic constraints on geological history, shock events and olivine color. *J. Geophys. Res.* **112**, E04002
- van de Moortele B., Reynard B., McMillan P.F., Wilson M., Beck P., Gillet Ph. and Jahn S. (2007) Shock-induced transformation of olivine to a new metastable (Mg,Fe)₂SiO₄ polymorph in Martian meteorites. *Earth Planet Sci. Lett.* **261**, 469-475.
- van de Moortele B., Reynard B., Rochette P., Jackson M., Beck P., Gillet P., McMillan P.F. and McCammon C.A. (2007) Shock-induced metallic iron nanoparticles in olivine-rich Martian meteorites. *Earth Planet Sci. Lett.* **262**, 37-49.