Reference List

NWA 856 – 320 grams
Enriched Basaltic Shergottite

***Figure 1**: Photograph of NWA 856 (Djel Ibone) kindly provided by Bruno Fectay and Carine Bidaut illustrating thin fusion crust and interior basaltic texture (scale is 1 cm).*

Introduction

Jambon *et al*. (2001, 2002) describe the discovery in March 2001 of another shergottite from Morocco. This sample was originally referred to as "Djel Ibone" and is officially known as NWA 856 (Russell *et al*. 2002). The original piece (~ 5 cm) had a thin black fusion crust that was well preserved – see figure 1 in Jambon *et al*. (2002).

This rock is 186 m.y. old and has been in space about 2 m.y.

Petrography

This meteorite is a fine-grained basalt (figure 1) with gray acicular pyroxene phenocrysts up to 12 mm long (Jambon *et al*. 2002). Augite and pigeonite form as separate crystals. Plagioclase (maskelynite) laths are interstitial as is trace merrillite, apatite, pyrrhotite, chromite, Fe-Ti oxides, silica and baddeleyite.

Shock melt pockets are more abundant than in Shergotty or Zagami and this meteorite is highly fractured at all scales. Chennaoui Aoudjehane et al. (2005, 2006) studied the high pressure silica phases.

Mineralogical Mode of NWA856

	Jambon *et al*. 2002
Pyroxene	68 vol. %
Plagioclase	23
Phosphates	1
Oxides	2
Silica	1
Melt Pockets	2

Terrestrial calcite veins cross-cut this meteorite, but terrestrial weathering appears to be at a minimum because Cs, Ba, Sr and U are not elevated (Jambon *et al*. 2002).

Figure 2 shows a large slab of NWA856 with a thin vein of glass and long needles of pyroxene. Photos can also be seen at http://www.jpl.nasa.gov/snc/nwa856.html

Mineral Chemistry

Pyroxenes: As in the Shergotty meteorite, augite and pigeonite are present in NWA856 as separate phases, with no pyroxenes of intermediate composition (figure 3). Pyroxenes are zoned; pigeonite ranges from

Figure 2: *Close-up photo of slab of NWA856 showing long needles and glass vein..*

$En_{59}Fs_{29}Wo_{12}$ to $En_{26}Fs_{59}Wo_{15}$ and augite from $En_{36}Fs_{32}Wo_{32}$ to $En_{48}Fs_{39}Wo_{13}$.

Maskelynite: Plagioclase has been shocked to maskelynite $Ab_{48}Or_{2}An_{50}$.

Phosphates: Both merrillite and Cl-apatite are present. Channon et al. (2011) reported on the abundances of H, F, Cl and S in apatitie.

Stishovite: Relative abundant and large euhedral crystals or thin square needles of stishovite have been observed by Raman spectroscopy (Jambon *et al.* 2002) in melt pockets of NWA 856.

Baddeleyite: Two minute baddeleyite crystals are reported.

Amphibole: Minute amphibole is reported by Jambon *et al.* (2002) located in melt inclusions in pyroxene cores.

Whole-rock Composition

Table 1 gives the composition of NWA 856 as reported by Jambon *et al.* (2001, 2002). The REE pattern of

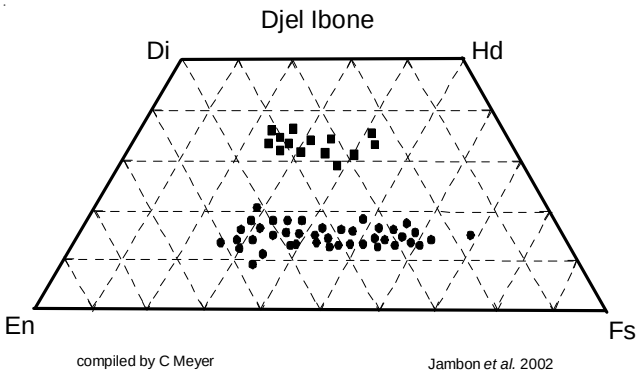

Figure 3*: Pyroxene composition diagram for NWA 856 (data replotted from Jambon et al. 2002).*

NWA 856 is similar to those of Shergotty and Zagami (figure 4). This is what we call "enriched". The Ga/Al ratio (4.1×10^{-4}) indicates that this rock is Martian. Weathering does not appear to have left a significant chemical signature in this desert meteorite (Jambon *et al*. 2002).

Shirai and Ebihara (2008) have also apparently analyzed NWA856 (and other important shergottites).

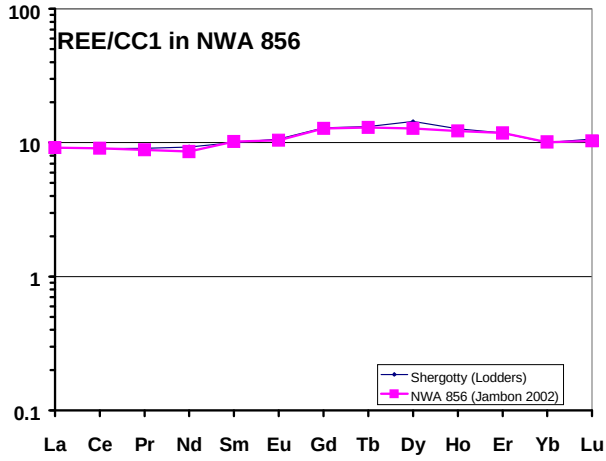

***Figure 4**: Normalized rare earth element diagram for NWA 856 compared with that of Shergotty (data from Jambon et al. 2002 and Lodders 2000).*

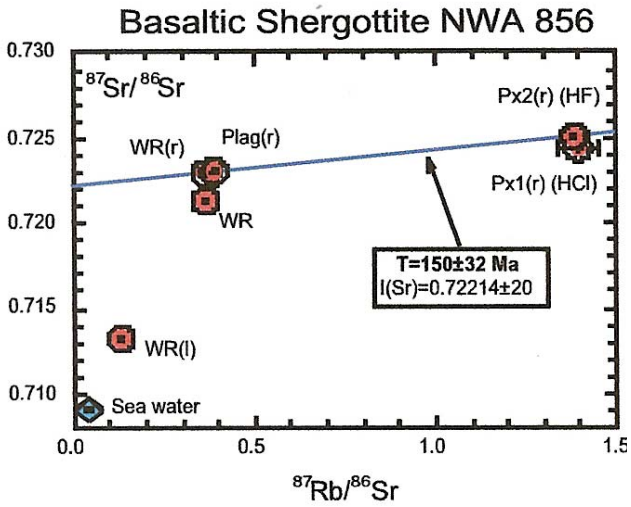

***Figure 5:** Preliminary Rb-Sr mineral isochron for NWA856 (Brandon et al. 2004).*

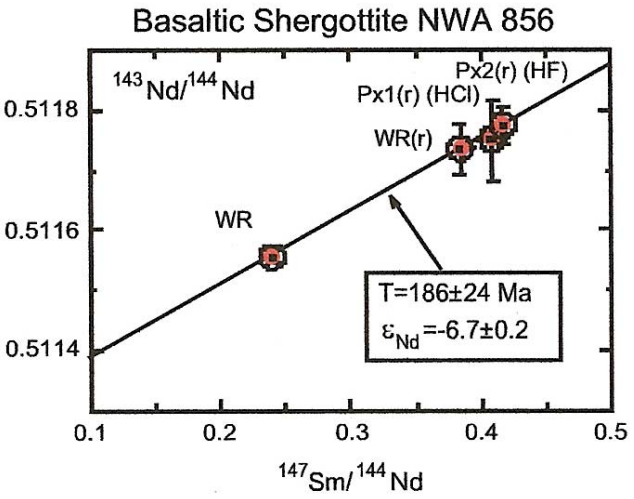

***Figure 6:** Preliminary Sm-Nd mineral isochron for NWA856 (Brandon et al. 2004).*

Radiometric Isotopes

Brandon et al. (2004) presented preliminary data for the Rb-Sr and Sm-Nd isotope systems. They obtained crystallization ages of 150 ± 32 m.y. and 186 ± 24 m.y. respectively (figure 5 and 6). I'm not sure they obtained precise initial Sr and Nd isotope ratios, and I'm not sure why not, but they seem worried about terrestrial contamination.

Misawa and Yamagouchi (2007) obtained an age of 186 ± 12 m.y. by ion microprobe U/Pb dating baddeleyite grains. Again, they emphasize the age determined is "preliminary".

Cosmogenic Isotopes

Berezhnoy et al. (2008) reported on ^{10}Be, ^{26}Al and ^{53}Mn activity and calculate an exposure age of 1.5 m.y. They also quote a 2.6 m.y. age by Mathew et al. (2003).

Other Isotopes

Jambon *et al.* (2002) reported oxygen isotopes with $\Delta^{17}O = \sim 0.47$ ‰ . Rumble and Irving (2009) obtained Delta $^{17}O = 0.23$ ‰.

Processing

Figures 7 and 8 shows the detail of the initial sawing of NWA 856.

***Figure 7:** End cut of main mass NWA856 (from internet). That black coating is the fusion crust!*

References for NWA856

Table 1: Chemical composition of NWA 856.

reference	Jambon 2001	Jambon 2002		Jambon 2002	
weight		500 mg.			
SiO2					
TiO2	0.81	0.81	(a)		
Al2O3	6.83	6.83	(a)		
FeO	17.8	17.81	(a)	19.97	(c)
MnO	0.49	0.49	(a)	0.54	(c)
CaO	10.2	10.24	(a)		
MgO	9.51	9.51	(a)		
Na2O	1.28	1.28	(a)		
K2O	0.13	0.13	(a)		
P2O5					
sum					
Li ppm		4.06	(b)		
Be		0.355	(b)		
F					
S					
Cl					
Sc		55.7	(b)	54.1	(c)
V		295	(b)		
Cr		3361	(b)	3942	(c)
Co		36.3	(b)	43	(c)
Ni	77	77	(b)	85	(c)
Cu		14	(b)		
Zn		59.1	(b)	66	(c)
Ga		14.66	(b)		
Ge					
As				0.18	(c)
Se					
Br				2.64	(c)
Rb		6.24	(b)	8.2	(c)
Sr		48.7	(b)	56	(c)
Y		18.81	(b)		
Zr		62.8	(b)	69	(c)
Nb		3.37	(b)		
Pd ppb					
Ag ppb				< 50	(c)
Sb ppb				14	(c)
Cs ppm		0.43	(b)	0.41	(c)
Ba		41.3	(b)	46	(c)
La	2.16	2.16	(b)	2.34	(c)
Ce		5.49	(b)	6.1	(c)
Pr		0.786	(b)		
Nd		3.88	(b)	3.9	(c)
Sm	3.88	1.5	(b)	1.68	(c)
Eu	1.5	0.582	(b)	0.62	(c)
Gd	0.58	2.51	(b)		
Tb		0.474	(b)	0.48	(c)
Dy		3.12	(b)		
Ho		0.677	(b)		
Er		1.87	(b)		
Tm					
Yb	1.64	1.64	(b)	1.76	(c)
Lu		0.251	(b)		
Hf		1.55	(b)	2.01	(c)
Ta		0.16	(b)	0.23	(c)
W ppb		430	(b)	520	(c)
Au ppb				4	(c)
Th ppm	0.4	0.398	(b)	0.442	(c)
U ppm		0.096	(b)	0.092	(c)

technique: a) ICP/AES, b) ICP/MS, c) INAA

***Figure 8**: Close up of slab of Djel Ibone illustrating basaltic texture (whose fingers?).*