Reference List

NWA 480 - 28 grams
NWA1460 - 70 grams
NWA5029 - 17.7 grams
Intermediate Basaltic Shergottite

***Figure 1**: Photograph of NWA 480 kindly provided by Bruno Fectay and Carine Bidaut.*

Introduction

NWA 480 was found in November 2000 in Morocco (Barrat *et al.* 2001, 2002; Grossman and Zipfel 2001). It was almost completely covered with fusion crust (figure 1) and appeared to be rather fresh with only a few spots of weathering products on the surface. Apparently, NWA 480, was sold to the National Centre for Space Studies (CNES), where it is "*being put to use to prepare for analysis of samples returned by planned missions to Mars" (according to Philippe Gillet*) and is being studied by *Consortium Théodore Monod*.

In December 2001, **NWA 1460** (70.2 grams) was acquired in Agadir, Morocco (Irving and Kuehner 2003). This sample is also covered with a complete fusion crust and appears to be paired with NWA 480 (*preliminary assessment based on comparison of figure 1 with figure 3*).

An additional stone (**NWA5029**) was purchased in 2003 in M'hamid, Morocco by Fectay and Bidaut (Meteoritical Bulletin). It also has a similar texture, but it is not quite the same (see below).

The age of NWA1460 has been determined to be 346 m.y. with exposure to cosmic rays for 2.6 m.y.

Petrography

NWA480 has a coarse-grained basaltic texture consisting predominately of subhedral to euhedral pyroxene (up to 5 mm) and interstitial, lath-shaped maskelynite (Grossman and Zipfel 2001). NWA1460 is illustrated in figures 2 and 3 and NWA5029 in figure 5. These samples have predominate zoned pyroxene surrounded by lath-shaped plagioclase (now maskelynite)(figure 4). Zoning continues to extreme iron enrichment and fine-grained fayalite-hedenbergite-silica intergrowths at the outer rim of the pyroxene. Accessory phases include merrillite, apatite,

Figure 2: *Copyrighted photograph of NWA 1460 taken by Nelson Oakes showing nearly complete fusion crust.*

Figure 3: *Photograph of sawn surface of NWA 1460 showing basaltic texture similar to that of NWA 480. Photo by Nelson Oakes.*

titanomagnetite, ilmenite, chromite, pyrrhotite, silica, baddeleyite and K-rich glass (Irving and Kuehner 2003).

Beck et al. (2004) have performed a detailed study of Li concentration and isotopic composition in minerals from NWA480.

NWA480 contains "melt pockets", as well as maskelynite and stishovite (Barrat *et al*. 2002; Beck et al. 2006), indicating that it has been shock-melted. Chennaoui Aoudjehane (2006) has examined the cathodoluminescence spectra.

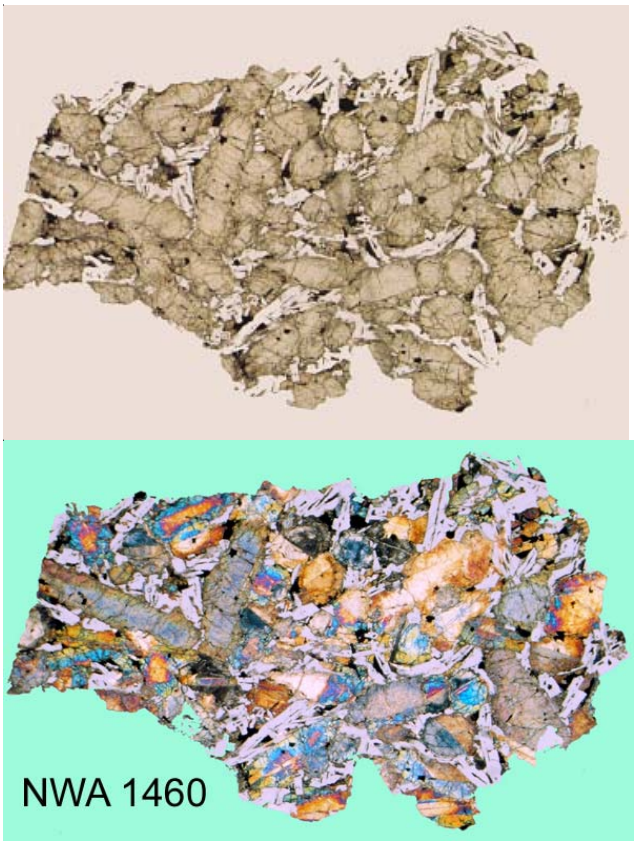

Figure 4: *Thin section photo of NWA1640 (from Ted Bunch).*

Mineralogical Mode

	Barrat *et al.* (2002)
Pyroxene	72 vol. %
Plagioclase	25
Phosphate	1
Opaques	1

Mineral Chemistry

Pyroxenes: Pyroxenes in NWA 480 (figure 6) are complexly zoned with Mg-rich cores ($En_{77}Fs_{20}Wo_{3}$-$En_{65}Fs_{29}Wo_{6}$), surrounded by Mg-rich augite ($En_{41}Fs_{29}Wo_{30}$) and finally zoned to Fe-rich pigeonite ($En_{5}Fs_{84}Wo_{11}$). The zoning in NWA1460 is exactly the same (Irving and Kuehner 2003). There is no exsolution in the pyroxene except for the most Fe-rich rim.

Maskelynite: All of the plagioclase has been shocked to form maskelynite ($An_{46\text{-}50}Ab_{52\text{-}48}Or_{2)}$.

Phosphates: Both merrillite and chlor-apatite are present in NWA 480. Fayalite-silica symplectite intergrowth is illustrated surrounding merrillite in figure 7 of Barret *et al.* (2002).

Figure 5: *Photo of 2.7 gram slab of NWA5029 (photo by Fectay and Bidaut).*

Oxides: Analyses of ilmenite and chromite are given in Barret *et al.* (2002).

Sulfide: Lorand et al. (2006) determined that the sulfide in NWA480 was pyrrhotite and give an analysis.

Silica: Silica grains found included in maskelynite have been found to be a mixture of high-pressure silica glass and stishovite by Raman spectroscopy and cathololuminescence (Barrat *et al.* 2002, Chennaoui Aoudjehane et al. 2005).

Note: Crozaz et al. (2001) have determined the REE pattern of pyroxenes, apatite and merrillite in NWA 480. The low-Ca pyroxenes are found to have 'elevated La' – presumably due to terrestrial contamination, despite the fresh appearance of this meteorite.

Whole-rock Composition

The chemical composition of NWA 480 is reported by Barrat *et al*. (2001, 2002) (Table 1). The REE pattern (figure 7) was found to be "similar" to ALH77005.

NWA 480 has normal Th/U, Ba/La and Sr/Nd ratios similar to Antarctic Martian meteorites, indicating that it is a fresh meteorite, free of the effects of terrestrial weathering (Barrat *et al*. 2002).

Radiogenic Isotopes

Nyquist et al. (2006, 2009) have dated NWA1460 by Rb-Sr and Sm-Nd (336 ± 15 b.y. and 350 ± 16 b.y.)(figures 7 and 8). The ^{40}Ar plateau diagram is in agreement (figure 9).

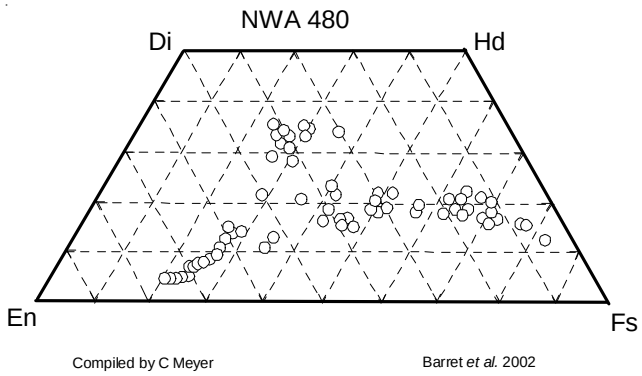

Figure 6*: Pyroxene quadrilateral for NWA 480 (data replotted from Barrat et al. 2002).*

Cosmogenic Isotopes and Exposure Ages

Marty *et al.* (2001) and Mathew et al. (2003) report an "average exposure age" of 2.4 ± 0.2 m.y. Nishiizumi et al. (2004) reported a ^{10}Be exposure age of 2.2 - 3 m.y. for pieces of NWA1460.

Other Isotopes

Barrat *et al*. (2001, 2002) determined the isotopic composition of oxygen as ä^{17}O = 2.91‰, ä^{18}O = 4.78‰, with $\Delta^{17}O$ = +0.42 ‰.

Nishiizumi et al. (2004) determined ^{10}Be and ^{41}Ca on NWA1460.

Hoffmann et al. (2011) has compared the magnetic properties of these three samples.

Processing

Photos of NWA480 and NWA1460 show that they were both first sliced by a saw cut across one end (figure 1 and 3). NWA1460 was processed at JSC. Figure 10 compares two of these rocks.

References for NWA48, 1460 and 5029.

Barrat J-A., Gillet Ph., Jambon A., Sautter V., Jovoy M., Petit E. and Lesourd M. (2001a) New from the Moon and Mars: preliminary examinations of two new Saharan finds (abs#1317). *Lunar Planet. Sci.* **XXXII** Lunar Planetary Institute, Houston.

Barrat J-A., Gillet Ph., Sautter V., Jambon A., Javoy M., Göpel C., Keller F. and Petit E. (2001b) The basaltic Shergottite North West Africa 480: Petrology and geochemistry (abs). *Meteorit. & Planet. Sci.* **36**, A14.

Table 1: Composition of NWA 480 and 1460.

			1460	
reference	Barret 02		Nyquist 09	
weight	182 mg.			
SiO2 %				
TiO2	1.16	(a)		
Al2O3	6.46	(a)		
FeO	19.44	(a)		
MnO	0.51	(a)		
CaO	9.32	(a)		
MgO	10.06	(a)		
Na2O	1.26	(a)		
K2O	0.1	(a)		
P2O5				
sum				
Li ppm	2.93	(b)		
Be	0.21	(b)		
S				
Cl				
Sc	28	(b)		
V	202	(b)		
Cr	2121	(a)		
Co	37.6	(b)		
Ni	63	(b)		
Cu	17.6	(b)		
Zn	64	(b)		
Ga	16.27	(b)		
Ge				
As				
Se				
Br				
Rb	2.67	(b)	2.36	(c)
Sr	49.3	(b)	52.1	(c)
Y	16.46	(b)		
Zr	58.74	(b)		
Nb	1.99	(b)		
Mo				
Pd ppb				
Ag ppb				
Cd ppb				
I ppm				
Cs ppm	0.19	(b)		
Ba	28.4	(b)		
La	1.48	(b)		
Ce	3.77	(b)		
Pr	0.619	(b)		
Nd	3.7	(b)	2.8	(c)
Sm	1.73	(b)	1.36	(c)
Eu	0.76	(b)		
Gd	2.67	(b)		
Tb	0.477	(b)		
Dy	3.05	(b)		
Ho	0.62	(b)		
Er	1.57	(b)		
Tm				
Yb	1.33	(b)		
Lu	0.19	(b)		
Hf	1.64	(b)		
Ta	0.1	(b)		
W ppb	340	(b)		
Re ppb				
Os ppb				
Ir ppb				
Au ppb				
Tl ppb				
Bi ppb				
Th ppm	0.22	(b)		
U ppm	0.064	(b)		

technique (a) ICP-AES, (b) ICP-MS , (c) TIMS

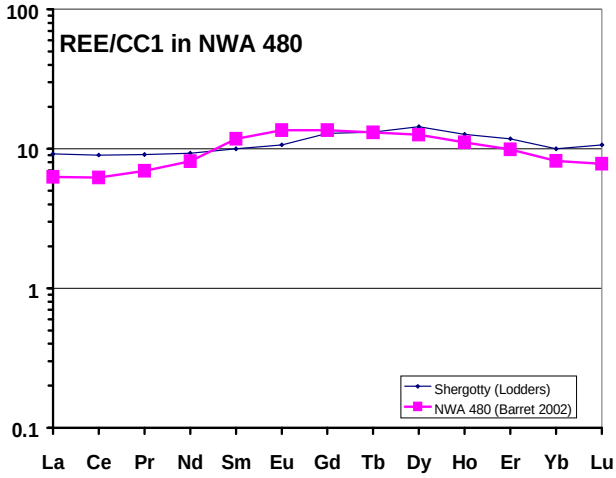

***Figure 6**: Normalized rare earth element diagram for NWA 480 and Shergotty (data from Barrat et al. 2002 and Lodders 1998).*

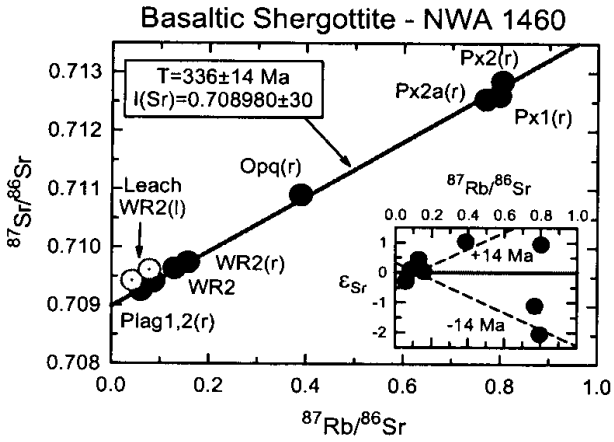

***Figure 7:** Rb-Sr isochron for NWA 1460 (Nyquist et al. 2006).*

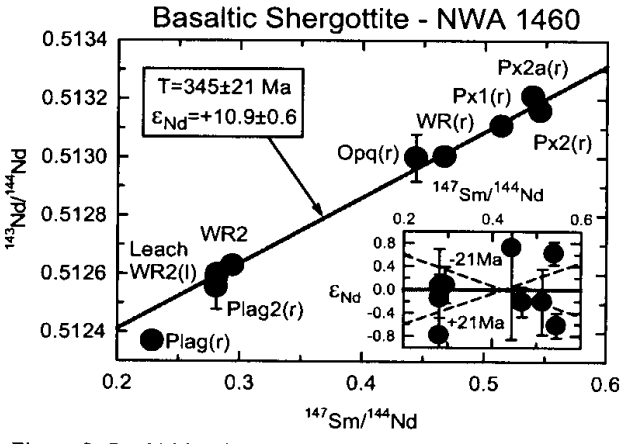

***Figure 8:** Sm-Nd isochron for NWA 1460 (Nyquist et al. 2006).*

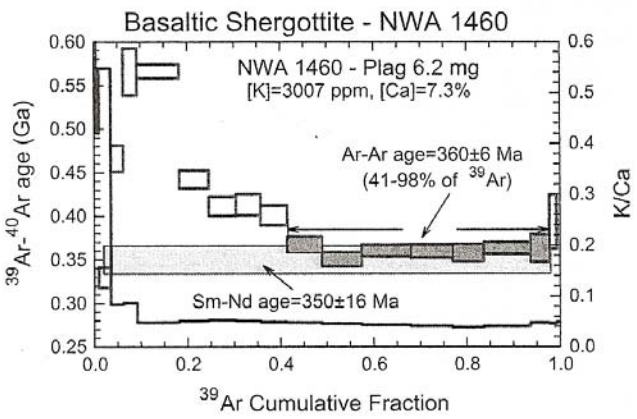

Figure 9: *40Ar plateau age for NWA1460 (from Nyquist et al. 2006).*

Barrat JA., Gillet Ph., Sautter V., Jambon A., Javoy M., Göpel C., Lesourd M., Keller F. and Petit E. (2002a) Petrology and geochemistry of the basaltic Shergottite Northwest Africa 480. *Meteorit. & Planet. Sci.* **37**, 487-499.

Beck P., Barrat J-A., Chaussidon M., Gillet Ph. and Bohn M. (2004a) Li isotopic variations in single pyroxenes from the Northwest Africa 480 Shergottite (NWA 480): A record of degassing of Martian magma? *Geochim. Cosmochim. Acta* **68**, 2925-2933.

Beck P., Barrat J-A., Chaussidon M., Gillet Ph. and Bohn M. (2004b) Li isotopic composition of the NWA 480 Shergottite (abs). *Lunar Planet. Sci*. **XXXV**, Lunar Planetary Institute, Houston.

Beck P., Ferroir T., Gillet Ph., Montagnac G., Bohn M. and Lesourd M. (2006) Shock melting of Martian basalts and the entrapment of atmospheric gases

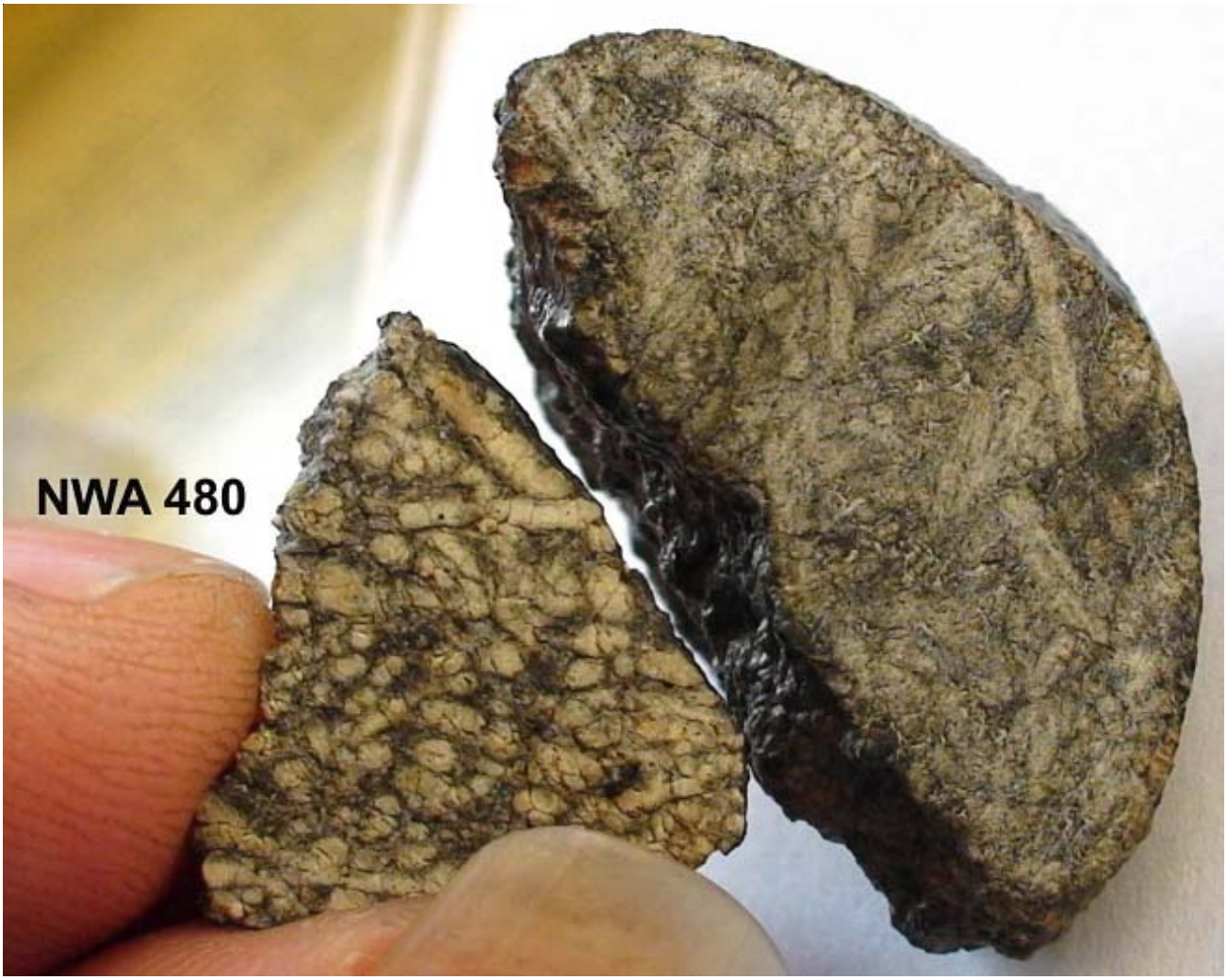

Figure 10: *Comparison of NWA5029 with NWA480 (when looked at this way, not the same).*

(abs#1939). *Lunar Planet. Sci*. **XXXVII** Lunar Planet. Institute, Houston.

Bogard D.D. and Park J. (2007b) Ar-Ar age of NWA-1460 and evidence for young formation ages of Shergottites (abs). *Lunar Planet. Sci. Conf.* Lunar Planetary Institute, Houston.

Chennaoui H., Jambon A., Reynard B. and Blanc P. (2002) High pressure silica phases in Shergottites: A cathodoluminescence spectroscopic study (abs). *Meteorit. & Planet. Sci.* **37**, A32.

Chennaoui Aoudjehane H., Jambon A., Reynard B. and Blanc P. (2005) Silica as a shock index in Shergottites: A catholuminescence study. *Meteorit. & Planet. Sci*. **40**, 1-14.

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

Connolly H.C. and 7 authors (2008) The Meteoritical Bulletin, No. 93, 2008 March. *Meteorit. & Planet. Sci*. **43**, 571-637.

Crozaz G., Wadhwa M. and Barrat J.A. (2001) Trace elements in NWA480: Still more diversity in the basaltic Shergottite group (abs). *Meteori. & Planet. Sci.* **36**, A45.

Deloule E. (2002) D/H ratio ion probe measurements on magmatic minerals from Martian meteorites: Implications for degassing of the Martian mantle (abs#1607). *Lunar Planet. Sci.* **XXXIII** Lunar Planetary Institute, Houston.

Filiberto J., Chin E., Day J.M.D., Franchi I.A., Greenwod R.C., Gross J., Penniston-Dorland S.C.,, Schwenzer S.P. and Treiman A.H. (2012) Geochemistry of intermediate olivine-phyric Shergottite Northwest Africa 6234, with similarities to basaltic Shergottite Northwest Africa 480 and olivine-phyric Shergottite Northwest Africa 2990. *Meteorit. & Planet. Sci*. **47**, 1256-1273.

Grossman J.N. and Zipfel J. (2001) The Meteoritical Bulletin, No. 85, 2001 September. *Meteorit. & Planet. Sci.* **36**, A293-A322.

Hoffmann V., Mikouchi T., Torii M., Funaki M. and Hochleitner R. (2011) Magnetic signature of NWA5029: A basaltic Shergottite related to NWA 480/1460 (abs#5427). *Meteorit. & Planet. Sci.* **46**, A98.

Irving A.J. and Kuehner S.M. (2003) Petrology of NWA1460: A baddelyite-bearing Shergottite paired with NWA480 (abs#1503). *Lunar Planet. Sci.* **XXXIV** Lunar Planetary Institute, Houston.

Lorand J-P., Chevrier V. and Viola Sautter (2005) Sulfide mineralogy and redox conditions in some Shergottites. *Meteorit. & Planet. Sci.* **40**, 1257-1272.

Marty B., Marti K. and Th. Monod Consortium (2001) Noble gases in new SNC meteorites NWA817 and NWA 480. *Meteorit. & Planet. Sci.* **36**, A122-123.

Marty B., Mathew K.J. and Marti K. (2003) Noble gases in newly discovered SNC: Insights into the evolution of Mars and comparison with Earth (abs). International Symposium. *Evolution of Solar System: A New Perspective from Antarctic Meteorites*, 71-72. Nat. Inst. Polar Res., Tokyo.

Mathew K.J., Marty B., Marti K. and Zimmermann L. (2003) Volatiles (nitrogen, Noble gases) in recently discovered SNC meteorites, extinct radioactivities and evolution. *Earth Planet. Sci. Lett.* **214**, 27-42.

Mikouchi T. and Barret J-A. (2009) NWA 5029 basaltic Shergottite: A clone of NWA 480/1460? (abs#5344) *Meteorit. & Planet. Sci*. **44**, A143.

Nagao K. and Mikouchi T. (2010) Noble gases of the basaltic Shergottite NWA 5029: Comparison with NWA 480 (abs#5196). *Meteorit. & Planet. Sci*. **45**, A145.

Nishiizumi K., Hillegonds D.J., McHargue L.R. and Jull A.J.T. (2004) Exposure and terrestrial histories of lunar and Martian meteorities (abs#1130). *Lunar Planet. Sci*. **XXXV** Lunar Planetary Institute, Houston.

Nyquist L.E., Shih C-Y., Reese Y.D. and Irving A.J. (2004) Crystallization age of NWA 1460 Shergottite: paradox revisted.

Nyquist L.E., Shih C-Y., Reese Y.D. and Irving A.J. (2006a) Concordant Rb-Sr and Sm-Nd ages for NWA1460: A 340 Ma old basaltic shergotite related to Lherzolitic Shergottites (abs#1723). *Lunar Planet. Sci. Conf.* **XXXVII** Lunar Planetary Institute, Houston.

Nyquist L.E., Bogard D.D., Shih C-Y., Park J., Reese Y.D. and Irving A.J. (2009) Concordant Rb-Sr, Sm-Nd, and Ar-Ar ages for Northwest Africa 1460: A 346 Ma old basaltic Shergottite related to "Lherzolitic" Shergottites. *Geochim. Cosmochim. Acta* **73**, 4288-4309.

Rumble D. and Irving A.J. (2009) Dispersion of oxygen isotopic compositions among 42 Martian meteorites determined by laser fluorination: Evidence for assimilation of (ancient) altered crust (abs#2293). *Lunar Planet. Sci*. **XL**, Lunar Planetary Institute @ The Woodlands.