NORTHWEST AFRICA 4480 REVISITED: PETROLOGIC, ISOTOPIC AND NOBLE GAS STUDIES OF AN UNSHOCKED, MASKELYNITE-FREE MAFIC SHERGOTTITE WITH A LONG COSMIC RAY EXPOSURE AGE.

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Introduction: Northwest Africa 4480 is a very unusual, small (13 gram) unpaired shergottite stone recovered in 2007. We previously [1] described most of its petrologic features, but because a thin section had not yet been prepared we did not realize its unusually low levels of shock. Bulk analyses of fusion crust [1, 2] suggested that NWA 4480 has an intermediate lithophile element signature. Despite its unique petrologic features among shergottites (some 65 unpaired specimens now recognized), NWA 4480 has an oxygen isotopic composition ($\Delta^{17}O$ +0.27 per mil) within the established field for Martian meteorites [3].

Figure 1. *Cut NWA 4480 stone with dark brown fusion crust. © G. Hupé.*

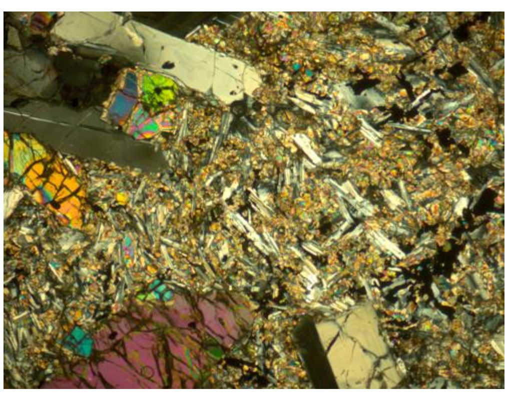


Figure 2. *Cross-polarized light microscope image showing the birefringent, twinned plagioclase. Other phases are olivine (lower left) and zoned clinopyroxene (mostly finer grained and associated with plagioclase laths). Width of field = 2.37 mm.*

Petrography: This specimen is mostly relatively fine grained (mean grainsize 0.15 mm), but it contains some coarser glomerocrystic regions. The major minerals are zoned clinopyroxene, olivine ($Fa_{67.9-79.2}$, FeO/MnO = 49-52) and birefringent plagioclase ($An_{58.4-61.0}Or_{1.6}$), accompanied by accessory Ti-chromite, ilmenite, merrillite, baddeleyite and rare Si-rich glass. Pyroxenes have subcalcic augite cores ($Fs_{24.9-31.2}Wo_{35.3-31.1}$, FeO/MnO = 30-32) and pigeonite rims ($Fs_{55.4-56.4}Wo_{17.5-15.4}$, FeO/MnO = 36).

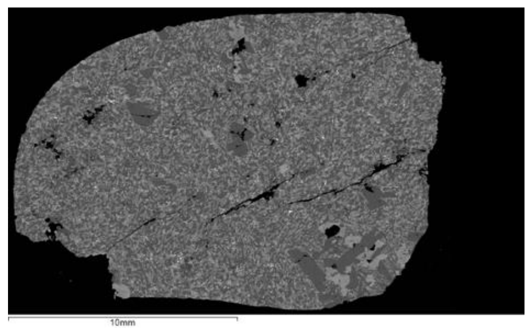
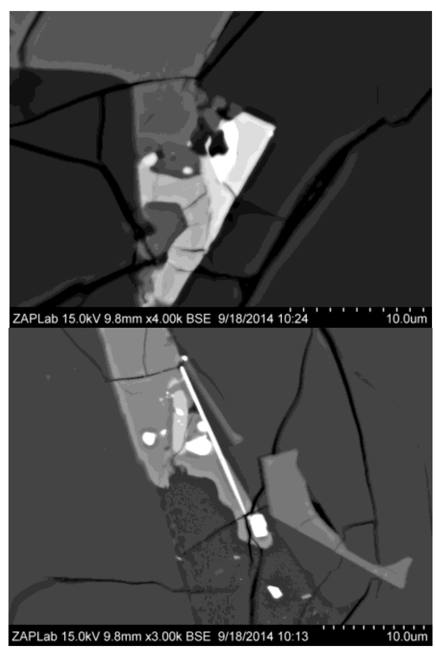


Figure 3. *BSE images.* ***Above.*** *Entire thin section.* ***Below.*** *Detail of baddeleyite grains (brightest) coexisting with ilmenite, pyroxene and plagioclase.*



Radiogenic Isotopic Compositions of NWA 4480 and Four Intermediate Shergottites: We determined Hf and Nd isotopic compositions of NWA 4480 and four intermediate shergottites. NWA 1460 is a unique mafic diabasic shergottite with concordant Nd, Sr and Ar-Ar crystallization ages of 346 Ma [4]. NWA 2646 is a permafic poikilitic shergottite [5], as is NWA 7721 (which is likely paired with NWA 1950 [6]). NWA 4797 is a highly shocked ultramafic poikilitic shergottite [7]. Clean interior fragments (~100 mg) of each specimen were bomb-digested and multiply-spiked prior to measurement by multicollector ICPMS. Although the analyzed material for each of these specimens may not be truly representative of their bulk compositions, the simultaneous analysis of parent-daughter elemental abundances ensures that the measured isotopic ratios mirror those of their sources.

Isotopic Ratios and Element Abundances (in ppm)

	NWA 4480	NWA 1460	NWA 2646	NWA 4797	NWA 7721
εHf	+37.2	+15.7	+27.2	+27.8	+27.7
Lu	0.572	0.179		0.008	
Hf	3.010	1.98	1.092	0.697	0.29
εNd	+35.0	+11.9		+3.5	
Sm	0.572	1.651		0.636	
Nd	5.157	3.371		1.463	

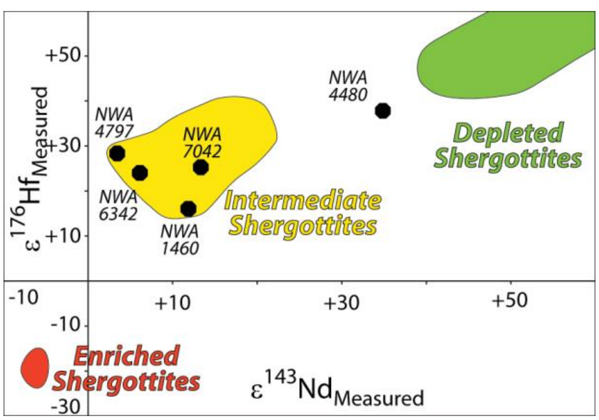


Figure 4. *Correlation of Nd and Hf isotopic compositions for shergottites (data from this work, [8] and unpublished University of Houston results).*

Noble Gas Composition and CRE Age: A ~90 mg fragment of NWA 4480 was analyzed at ETH using techniques described in [9]. The yield of cosmogenic noble gases was remarkably high, but Ar/Xe, Kr/Xe and $^{129}Xe/^{132}Xe$ plot in the field for shergottites [10]. Average CR production rates were calculated [11] from elemental data [1, 2] assuming a small meteoroid.

	^{3}He	^{3}He	^{20}Ne	$^{21}Ne/^{22}Ne$	^{38}Ar
($\times10^{-8}$ cm^3/g)	16.26	487	2.384	= 0.7995	2.55
CRE Age (Myr)	~11			~16	~21

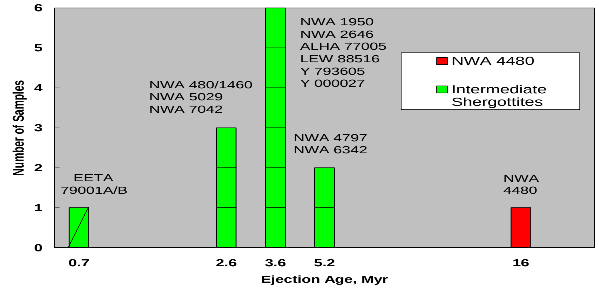


Figure 5. *Distribution of cosmic ray exposure ages for NWA 4480 and intermediate shergottites [8, 12].*

Discussion: In many respects NWA 4480 is a unique Martian specimen. [*Note:* We use the term "shergottite" to describe this rock despite the lack of maskelynite, for which the "type locality" [13] is the Shergotty meteorite]. It appears to have experienced no more shock than a terrestrial basaltic lava flow, so its impact ejection from Mars must have involved significant shielding and spallation mechanics. Although its trace element abundances (especially of REE) place it with the intermediate shergottites, isotopically it has sampled a unique mantle source reservoir.

Whereas the εHf value of +37 would place NWA 4480 among the most depleted intermediate shergottites (IS), the εNd value of +35 would make it the most enriched depleted shergottite (DS). In fact NWA 4480 is the first shergottite with isotopic characteristics *between* the more populated DS and IS fields (see Figure 4). That plus its high and likely unique CRE age (~16 Myr) suggest that this specimen derives from a previously unsampled region on Mars. It will be important to determine a precise crystallization age, and the mineralogy of NWA 4480 makes it very amenable to Sm-Nd and Lu-Hf isochron dating. The freshness and lack of shock also make this specimen an ideal candidate for Pb-Pb isotopic dating.

References: [1] Irving A. et al. 2007 *70th Meteorit. Soc. Mtg.*, #5127 [2] Irving A. et al. 2010 *Lunar Planet. Sci.* **XLI**, #1833 [3] Rumble D. and Irving A. 2009 *Lunar Planet. Sci.* **XL**, #2293 [4] Nyquist L. et al. 2009 *GCA* **73**, 4288-4309 [5] Bunch T. et al. 2005 *68th Meteorit. Soc. Mtg.*, #5209 [6] Gillet P. et al. 2005 *MaPS* 40, 1175-1184 [7] Walton E. et al. 2012 *MaPS* 47, 1449-1474 [8] Irving A. et al. 2015 *Lunar Planet. Sci.* **XLVI**, #2290 [9] Wieler R. et al. 2016 *MaPS* (in press) [10] Cartwright J. et al. 2014 *EPSL* 400, 77-87 [11] Leya I. and Masarik J. 2009 *MaPS* 44, 1061-1086 [12] Herzog G. and Caffee M. 2014 in *Treatise in Geochemistry*, 2nd Ed., p. 419-454 [13] Tschermak G. 1872 *Sitzber. Akad. Wiss. Wien, Math.-Naturwiss. Kl. Abt. I* **65**, 122-146.