Reference List

LAR 06319 - 78.6 grams
Enriched Olivine-phyric Shergottite

Figure 1a: *Processing photo of Larkman Nunatak 06319. Scale and cube are 1 cm.*

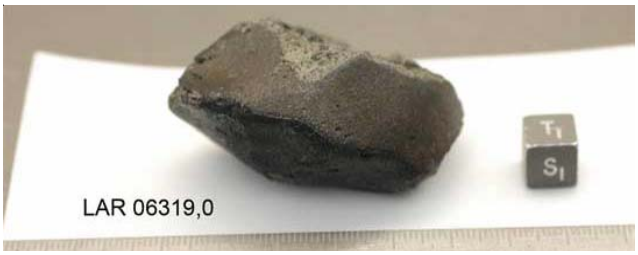

Figure 1b: *Photo showing fusion crust on LAR 06319 (from Antarctic Newsletter 30 #2).*

Figure 2: *Photo of LAR06319 on ice.*

Introduction

An olivine-phyric shergottite from Mars, found near Larkman Nunatak in 2006, was reported in the Antarctic Newsletter 30, #2, 2007 (figure 2). According to McBride et al. the exterior has 60% dark brown to black fusion crust with a very fine grained wrinkled texture (figures 1 a, b). The fusion crust exhibits a slight sheen. The interior has a gray and black matrix that is fine grained and very hard.

The crystallization age of LAR0639 is ~190 m.y. and it has been exposed to cosmic rays for 3.3 m.y. It is somewhat akin to NWA1068 *"Louise Michel"*.

Petrography

Thin section descriptions have been published by McCoy et al. (Newsletter), Mittlefehldt and Herrin (2008), Basu Sarbadhikari et al. (2009) and Peslier et al. (2010). Shafer et al. (2009) describe LAR06319 as "an olivine-phyric shergottite consisting of olivine phenocrysts (up to 3 mm) set in a matrix of pyroxene and maskelynite interspersed with minor oxide phases, phosphate phases and shock melt veins" (figure 3). The olivine and pyroxene are highly zoned (figure 5).

Modal mineralogy for LAR06319

Basu Sarbadhikari 2009

Olivine	24.4 vol. %
Pyroxene	
Opx	4.1
Pigeonite	27.7
Augite	22.2
Plagioclase	17.8
Phosphate	2.1
Oxides	1.3
Sulfides	0.3

Olivine has an unusual brownish color. Chromite, Ti-chromite, apatite, merrillite, troilite, pyrrhotite, pyrite are reported (Basu Sarbadhikari et al. 2009; Peslier et al. 2010).

Basu Sarbadhikari et al. (2009) determined the modal mineralogy. There are both high-Ca and low-Ca

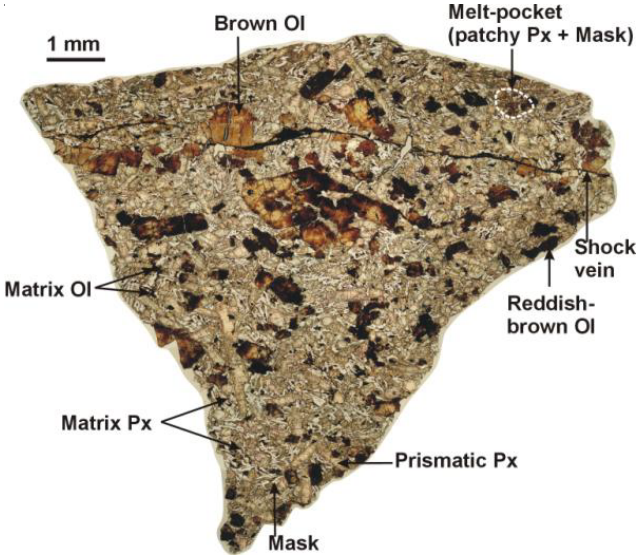

Figure 3: *Photomicrograph of thin section LAR06318, 37. Section about 1 cm across (from Basu Sarbadhikari et al. 2009).*

pyroxenes similar to "lherzolitic shergottites" and there are abundant "melt inclusions" in the olivine and pyroxene cores. Peslier et al. (2010) and Basu Sarbadhikari et al. (2011) studied the "melt inclusions" in detail.

Peslier et al. (2010) carefully studied the oxidation state of LAR06319 during the full range of crystallization. They conclude it was initially relatively reduced (QMD -2), but that somehow it became more oxidized as it crystallized (figure 12).

LAR06319 has also been shocked. The original plagioclase is now maskelynite. Olivine and pyroxene exhibit mosaicism, and pockets and veins of shock melt are found throughout the sample (Peslier et al. 2010).

Mineralogy

Olivine: The olivine phenocrysts in LAR06319 have very pronounced zonation of phosphorous (Peslier et al.2010).

Pyroxene: LAR06319 has three kinds of pyroxene and they are chemically zoned (figure 5). Orthopyroxene and pigenonite cores are mantled with sub-calcic augite. Pyroxene in the matrix is Fe-rich (Peslier et al. 2010).

Plagioclase: Plagioclase (An_{52}) is shocked to maskelynite.

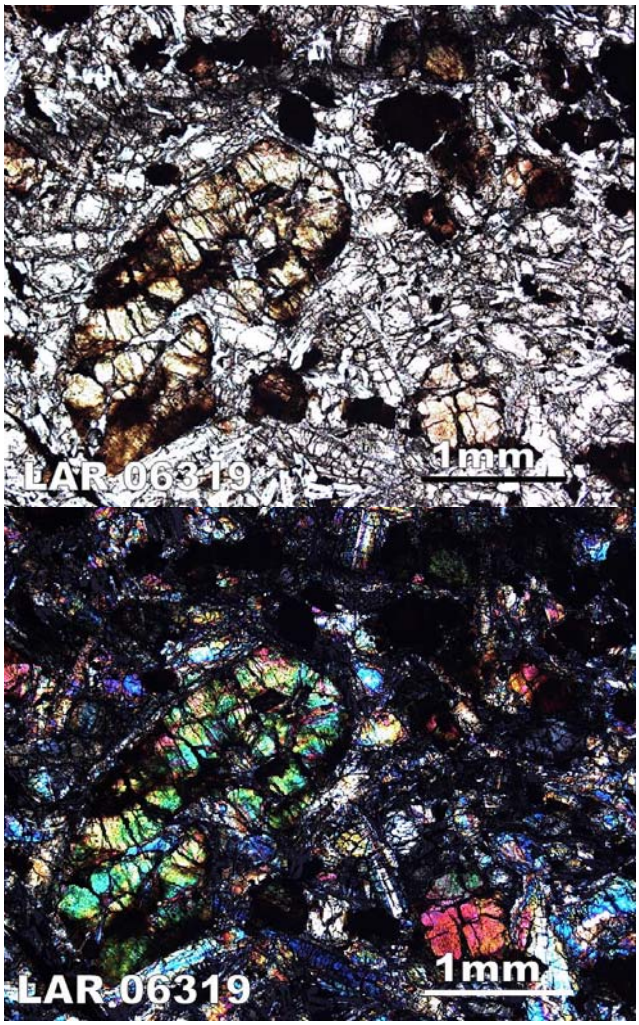

Figure 4: *Thin section photos for LAR06319 from Antarctic Newsletter. Top is plane polarized light; bottom is crossed-polarized.*

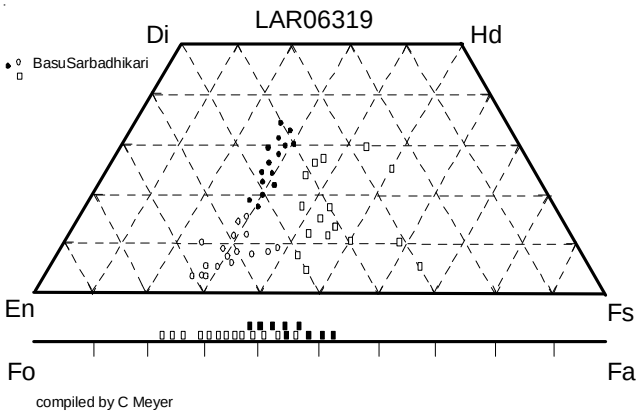

Figure 5: *Pyroxene and olivine in LAR 06319 is highly zoned (Basu Sarbadhikari et al. 2009).*

Opaques: LAR06319 has four types of spinel and two types of ilmenite (Peslier et al. 2010).

Table 1. Chemical composition of LAR 06319.

reference	Basu S 09	
weight		
SiO2 %	46.7	(a)
TiO2	0.68	(a)
Al2O3	6	(a)
FeO	20.4	(a)
MnO	0.48	(a)
MgO	15.8	(a)
CaO	6.46	(a)
Na2O	1.14	(a)
K2O	0.14	(a)
P2O5	0.61	(a)
S %		
sum		
Sc ppm	30.2	(a)
V	202	(a)
Cr	3677	(a)
Co	54.9	(a)
Ni	182	(a)
Cu	7.21	(a)
Zn	41.3	(a)
Ga	13.5	(a)
Ge ppb	1020	(a)
As		
Se		
Rb	5.49	(a)
Sr	44.9	(a)
Y	11.3	(a)
Zr	48.4	(a)
Nb	3.41	(a)
Mo	Brandon2012	
Ru	1.51	(b)
Rh		
Pd ppb	7.4	(b)
Ag ppb		
Cd ppb		
In ppb		
Sn ppb		
Sb ppb		
Te ppb		
Cs ppm	0.3	(a)
Ba	24.5	(a)
La	1.73	(a)
Ce	4.25	(a)
Pr	0.57	(a)
Nd	2.94	(a)
Sm	1.1	(a)
Eu	0.47	(a)
Gd	1.55	(a)
Tb	0.3	(a)
Dy	2.01	(a)
Ho	0.42	(a)
Er	1.14	(a)
Tm	0.16	(a)
Yb	1.15	(a)
Lu	0.15	(a)
Hf	1.28	(a)
Ta	0.12	(a)
W ppb	930	(a)
Re ppb	0.076	(b)
Os ppb	0.76	(c)
Ir ppb	0.54	(b)
Pt ppb	4.18	(b)
Au ppb		
Th ppm	0.26	(a)
U ppm	0.07	(a)
technique	*(a) ICP-MS*	

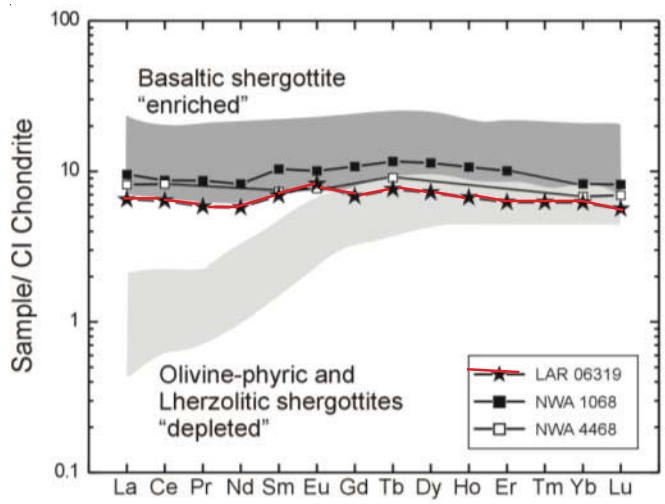

Figure 6: *Normalized rare-earth-element diagram with LAR compared with other shergottites (from Basu Sarbadhikari et al. 2009).*

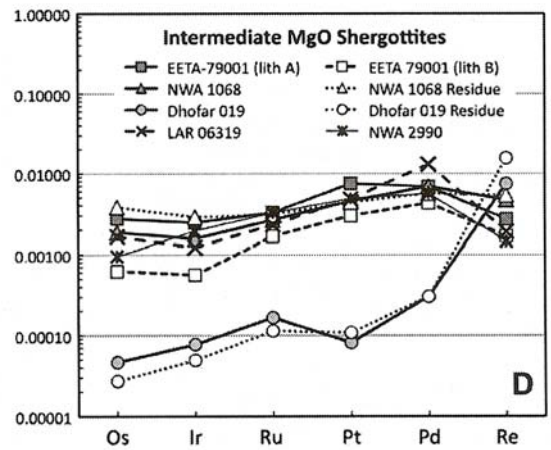

Figure 7: *PGE and Re (from Brandon et al. 2012)*

Chemistry

Basu Sarbadhikari et al. (2009) determined the bulk chemical composition and REE pattern for LAR06319 (table 1, figure 6). LAR06319 has a composition similar to the "enriched" shergottites. Walker et al. (2009) and Brandon et al. (2012) also reported data on the highly siderophile element contents (figure 7).

Radiogenic age dating

Shih et al. (2009) have dated LAR06319 by internal Rb-Sr isochron at 207 ± 14 m.y. with I_{Sr} = 0.722509 ± 69 (figure 8) and by Sm-Nd isochron at 190 ± 29 m.y. (figure 9). Shafer et al. (2009, 2010) also dated LAR06319 by Sm-Nd (183 ± 12 m.y.) and by Lu-Hf internal isochrons 197 ± 29 m.y. (figures 10 and11).

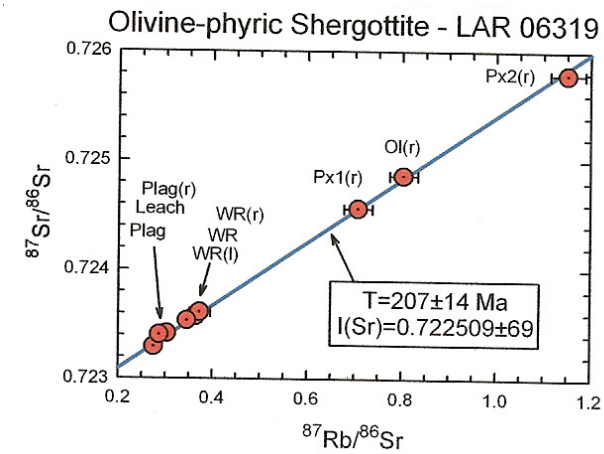

Figure 8: *Rb-Sr isochron for LAR 06319 (from Shih et al. 2009).*

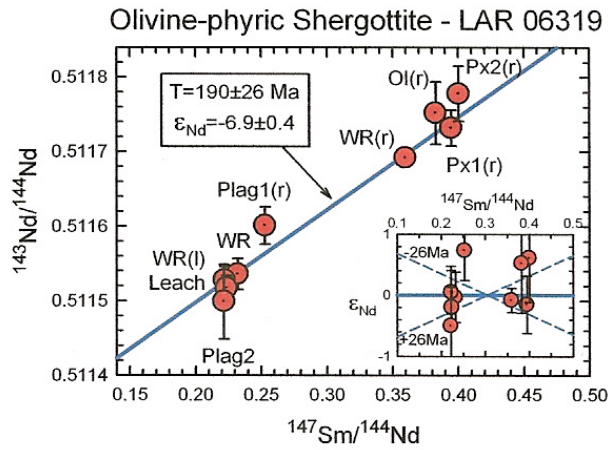

Figure 9: *Sm-Nd isochron for LAR 06319 (from Shih et al. 2009).*

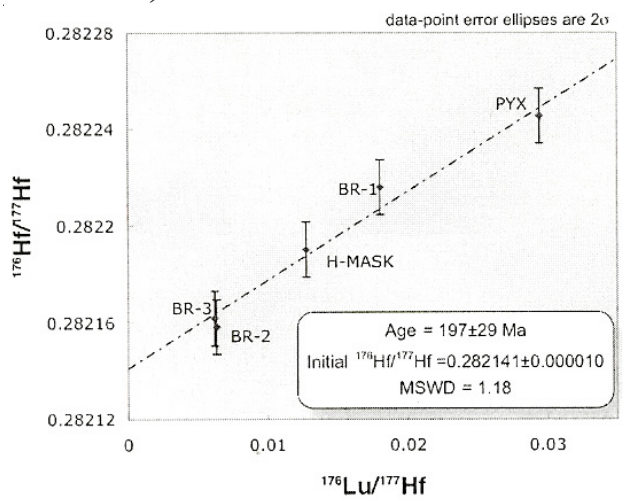

Figure 10: *Lu-Hf isochron for LAR 06319 (from Shafer et al. 2009).*

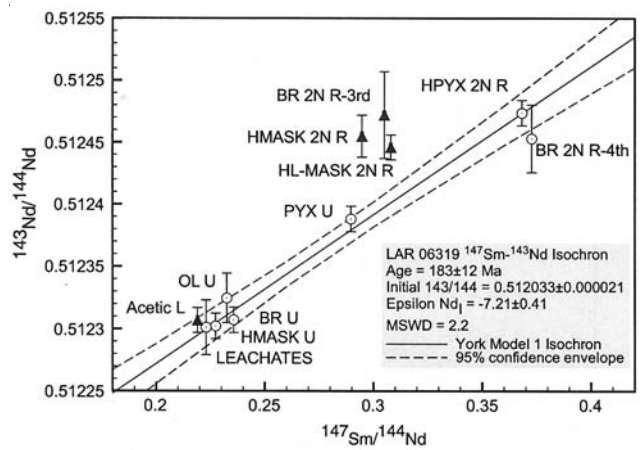

Figure 11: *Sm-Nd isochron for LAR 06319 (from Shafer et al. 2010).*

Summary of Age Data for LAR06319

	Rb-Sr	Sm-Nd	Lu-Hf
Shih et al. 2009	207 ± 14 m.y.	190 ± 26	
Shafer et al. 2009		183 ± 12	197 ± 29

Cosmogenic isotopes and exposure age

Nagao and Park (2008) reported an "exposure age" of 3.3 m.y.

Other Studies

Oxygen isotopes, determined by Z. Sharp were reported in Antarctic Newsletter 30 #2 and confirmed by Basu Sarbadhikari et al. (2009). Boctor et al. (2009) reported H isotopes and Franz et al. (2008) studied S isotopes.

References for LAR06319

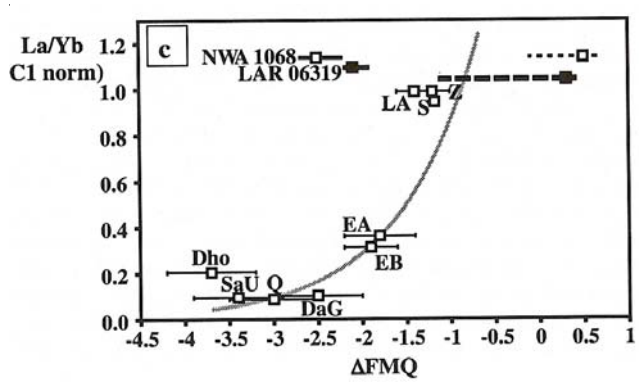

Figure 12: *Oxygen fugacity plotted against La/Yb ratio. LAR06319 and NWA1068 are reported to record a range of oxygen fugacity (Peslier et al. 2010).*