MIL03346 (1st update)

Clinopyroxenite

715 grams

Figure 1: *Initial processing photo of MIL 03346. Cube is 1 cm. for scale. Photo is from newsletter.*

Introduction

The Mars Exploration Program supplemented the 2003-2004 ANSMET expedition in the hope of improving the chance of finding additional samples of Mars, and, as luck would have it, a large nakhlite was recovered from the blue ice on Dec 15, 2003 in the Miller Range, among the other 1358 new specimens discovered during this field season.
http://geology.cwru.edu/~ansmet/

The initial (PET) petrographic description is available at:
http://www-curator.jsc.nasa.gov/antmet/amn/amnaug04/petdes2.htm#MIL03346
About 60 % of the surface of MIL 03346 was covered with a black, wrinkled fusion crust (figure 1). The initial description showed that MIL 03346 is a nakhlite with abundant clinopyroxene and rare olivine set in a fine-grained mesostasis with some alteration (figure 2).

MIL03346 is 1.3 to 1.4 b.y. old, with an exposure to cosmic rays of ~ 10 m.y.

Petrography

MIL 03346 is a cumulate of abundant elongate clinopyroxene (0.5 to 1 mm) and minor olivine crystals (up to 1.7 mm) set in a dark-colored, fine-grained intercumulate mesostasis (Stopar et al. 2005, McKay and Schwandt 2005, Mikouchi et al. 2005 and Rutherford et al. 2005). Stopar et al. compared the grain size distribution of MIL with that of the other

Mineralogical Mode for MIL 03346

	Stopar et al. 2005	Rutherford et al. 2005	McKay and Schwandt 05	Anand et al. 2005	Mikouchi et al. 2005
Olivine	2 vol. %	tr.	4.6		4
Pyroxene	78	65	79.8	75	74
Plagioclase					
Mesostasis	19	35	15.7	25	22
Opaques			0.9		
"alteration"	0.9				

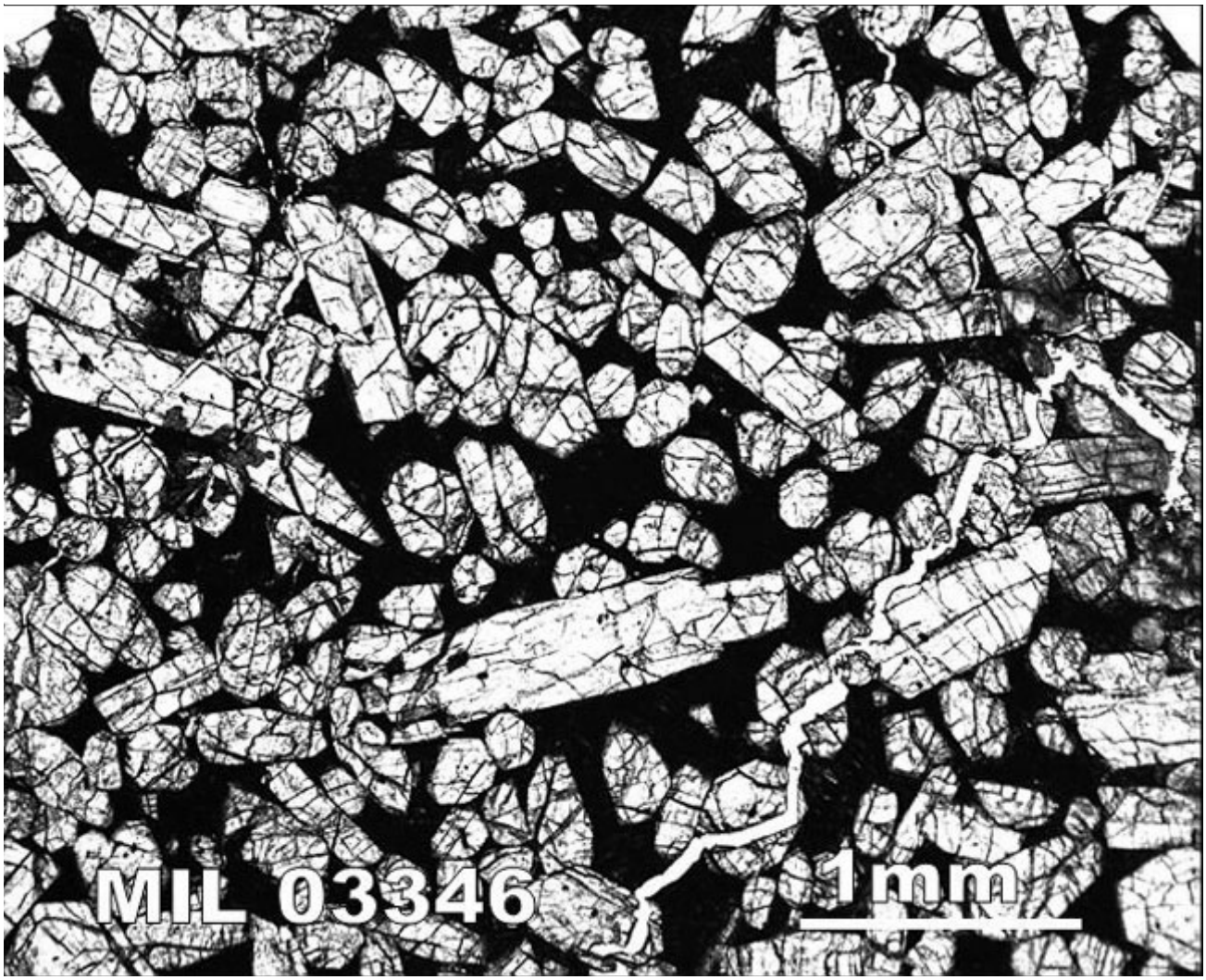

Figure 2: *Thin section photomicrograph of MIL03346. Scale bar is 1 mm. Euhedral clinopyroxene is set in fine-grained mesostasis (opaque). Areas of apparent alteration are present. Photo is from newsletter.*

clinopyroxenites. Melt inclusions are reported in the olivine (Rutherford et al. 2005).

The mesostasis consists of a dendritic intergrowth of fayalite, ferro-heddenbergite, Ti-magnetite, cristobalite, apatite and feldspar glass (similar to that of NWA 817). Day et al. (2005) conclude that MIL03346 is part of the same cumulate-rich lava flow as the other nakhlites, but that it experienced less equilibration and faster cooling than the other Nakhlites.

Olivine has "iddingsite-smectite"(?) alteration in cracks, similar to that found in the other nakhlites (Arnand et al. 2005, Stopar et al. 2005). Mikouchi et al. (2005) note that the alteration in MIL 03346 (Antarctica) is similar to that in NWA 817 (Sahara Desert) and that this might indicate the alteration is pre-terrestrial. Stopar et al. (2005) report that "gypsum is found in cracks, voids and veins throughout the thin sections." Sautter et al. (2005) report Cl-rich amphibole, chlorite, phosphaste and a "mixed sulfate of Fe and S" which they interpret as derived from a soil component on Mars.

Mineral Chemistry

Olivine: McKay and Schwandt (2005) found that large olivine grains (up to 1.7 mm) have uniform cores Fo_{44-43}, but zone to Fo_5 at their outer rims (figure 3). Tiny skeletal fayalite is found in the mesostasis.

Pyroxenes: Cores of clinopyroxene cluster around $Wo_{39}En_{27}$. The rims zone increase in Fe and decrease in Ca to ~$Wo_{34}En_{14}$. Mikouchi et al. (2005), Anand et al. (2005) and McKay and Schwandt found that the

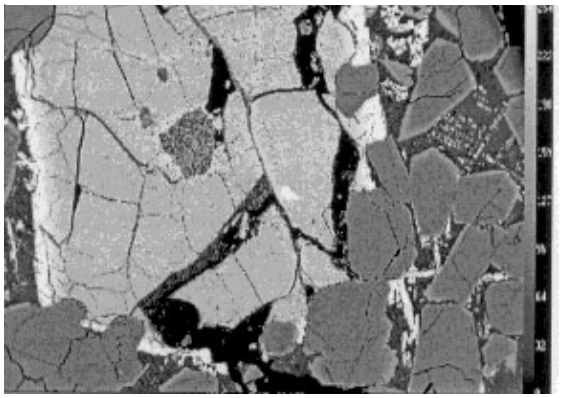

Figure 3: BSE image of large olivine (500 microns) with Fe-rich rim (from Rutherford et al. 2005).

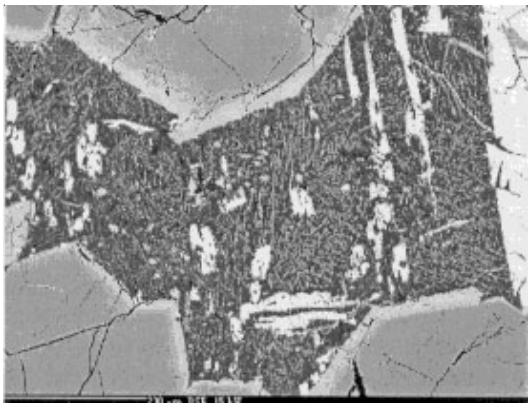

Figure 4: BSE image of matrix of MIL 03346 showing skelytal magnetite and also Fe-rich rim on euhedral clinopyroxene (Rutherford et al. 2005).

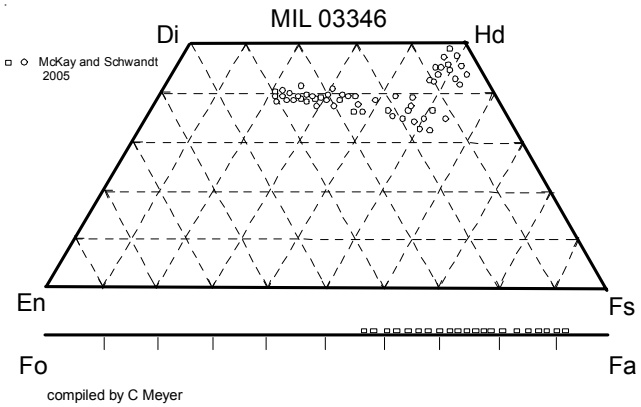

Figure 5: Pyroxene and olivien compositions of MIL 03346 (from McKay and Schwandt 2005).

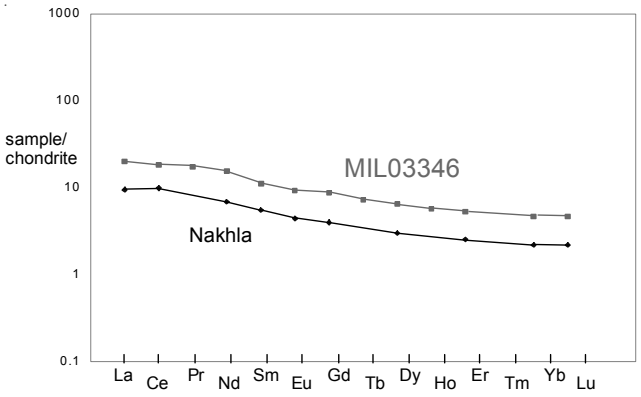

Figure 6: Normalized rare-earth-element pattern for MIL03346 compared with that of Nakhla. Data from Barrat et al. 2006 and Nakamura et al. 1973.

outer rims, adjacent to the mesostasis, zone to ferro-heddenbergite (figure 5). Domeneghetti et al. (2006) found the iron was oxidized (Fe^{+3}).

Ti-magnetite: Dendritic chains of Ti-magnetite are prevalent in the mesostasis (similar to NWA 817). Magnetite has very fine ilmenite exsolution lamellae. Both Dyar et al. (2006) and Morris et al. (2006) reported magnetite in their Mossbauer spectra.

Glass: Feldspathic-glass compositions in the mesostasis are $An_{29-38}Or_{7-14}$ (Anand et al. 2005).

Silica: Anand et al. (2005) and Mikouchi et al. (2005) report small (5 micron) blebs of silica in the mesostasis. Chennaoui Aoudjehane et al. (2006) used cathodoluminescence to study shock effects.

Amphibole: Sautter et al. (2006) reported the presence of Cl-rich amphibole (1.5 to 7% Cl) in melt inclusions in augite and in olivine.

Phosphates: Fries et al. (2006) studied phosphates in MIL03346 by confocal Raman imaging techniques and found that they were "hydrated".

Whole-rock Composition

The whole rock composition was initially determined by Anand et al. (2005). A new analysis including trace elements has been obtained by Barret et al. (2006) (table 1). Barret et al. found that Co, Ni, Cu and Zn were similar to other nakhlites. The large ion lihophile elements are similar to but elevated compared with Nakhla (figure 6). Note the lack of any Eu anomaly. Dreibus et al. (2006) reported 147 ppm F, 248 ppm Cl, 0,45 ppm Br, 610 ppm S and 315 ppm carbon.

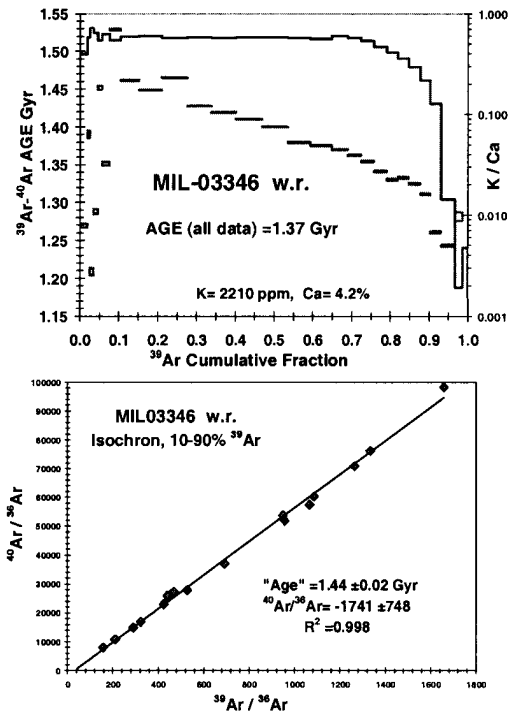

Figure 7: Ar/Ar age dating of MIL03346 by Bogard and Garrison 2006.

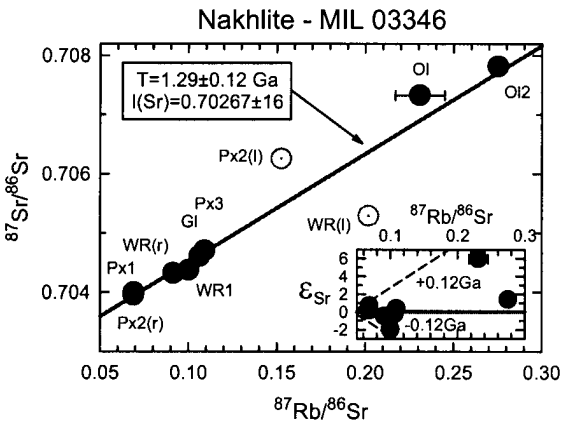

Figure 8: Rb-Sr isochron diagram for MIL03346 by Shih et al. 2006.

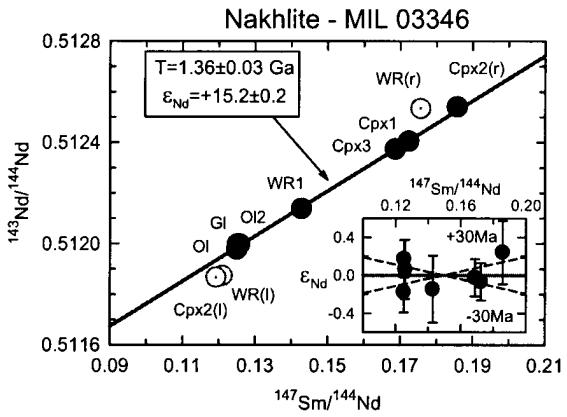

Figure 9: Sm-Nd isochron diagram for MIL03346 by Shih et al. 2006.

Radiogenic Isotopes

Murty et al. (2005) determined a U,Th-^{4}He age of 1.02 ± 0.15 b.y. and K-Ar age of 1.75 ± 0.26 b.y. (based on U,Th,K contents of Nakhla!). Bogard and Garrison (2006) determined an Ar plateau age of 1.44 ± 0.02 m.y. (figure 7). Shih et al. (2006) determined a Rb-Sr isochron of 1.29 ± 0.12 and a Sm-Nd isochron of 1.36 ± 0.03 b.y. (figures 8 and 9).

Cosmogenic Isotopes

Murty et al. (2005) determined an average exposure age of 9.5 ± 1.0 m.y. for MIL 03346.

Other Isotopes

Oxygen isotopes are not reported.

Murty et al. (2005) reported the isotopic ratios of rare gases extracted at different temperatures from MIL 03346.

Dyar et al. (2005) determined the Mossbauer, reflectance and thermal emission spectra of MIL03346 (figures 10, 11 and 12), claiming that this rock is highly oxidized with abundant Fe^{3+}. Roechette et al. (2005) reported the magnetization.

Processing

During initial processing, a 1 cm thick slab was cut through the center of MIL 03346 (McBride et al. 2005). About 45 thin sections were prepared and allocated (see diagram).

Age data for MIL03346

	Ar/Ar	Rb/Sr	Nd/Sm
Bogard and Garrison 2006	1.44 ± 0.02 b.y.		
Shih et al. 2006		1.29 ± 0.12	
			1.36 ± 0.03

Table 1. Chemical composition of MIL 03346.

reference	Anand 2005	Barret 2006	
weight			
SiO2 %	49.2		
TiO2	0.07	0.69	(a)
Al2O3	3.59	3.66	(a)
FeO	19.23	19.12	(a)
MnO	0.45	0.46	(a)
MgO	9.33	9.99	(a)
CaO	15	15.75	(a)
Na2O	1.01	1	(a)
K2O	0.29	0.27	(a)
P2O5	0.22	0.25	(a)
S %			
sum			
Sc ppm	46	54.5	(a)
V	184	208	(a)
Cr	1300	1192	(a)
Co	25	35.7	(a)
Ni	60	49	(a)
Cu	13	8.2	(a)
Zn	65	61.3	(a)
Ga		6.51	(a)
Ge ppb			
As			
Se			
Rb		4.14	(a)
Sr	106	131.7	(a)
Y	7	8.44	(a)
Zr		23.29	(a)
Nb		3.98	(a)
Mo			
Ru			
Rh			
Pd ppb			
Ag ppb			
Cd ppb			
In ppb			
Sn ppb			
Sb ppb			
Te ppb			
Cs ppm		0.29	(a)
Ba	53	59.58	(a)
La		4.7	(a)
Ce		11.01	(a)
Pr		1.56	(a)
Nd		7.07	(a)
Sm		1.64	(a)
Eu		0.522	(a)
Gd		1.73	(a)
Tb		0.266	(a)
Dy		1.57	(a)
Ho		0.317	(a)
Er		0.851	(a)
Tm			
Yb		0.766	(a)
Lu		0.114	(a)
Hf		0.69	(a)
Ta		0.23	(a)
W ppb		0.4	(a)
Re ppb			
Os ppb			
Ir ppb			
Pt ppb			
Au ppb			
Th ppm		0.42	(a)
U ppm		0.09	(a)

technique: (a) ICP

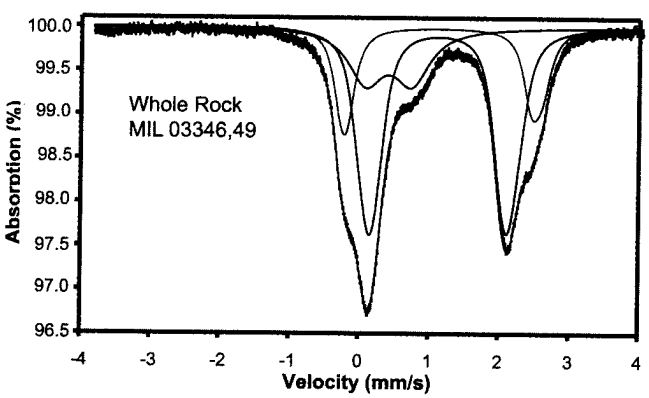

Figure 10: Mossbauer spectra of MIL03346 from Dyar et al. 2006.

MIL 03346 was examined and split in dry-nitrogen glove boxes at JSC which have been thoroughly cleaned and dried immediately before processing of this sample. The sample was only exposed to stainless steel, aluminum and Teflon, although the gloves, gaskets and band saw wheels are made of Neoprene and/or Viton. However, the sample itself is only handled with Teflon overgloves.

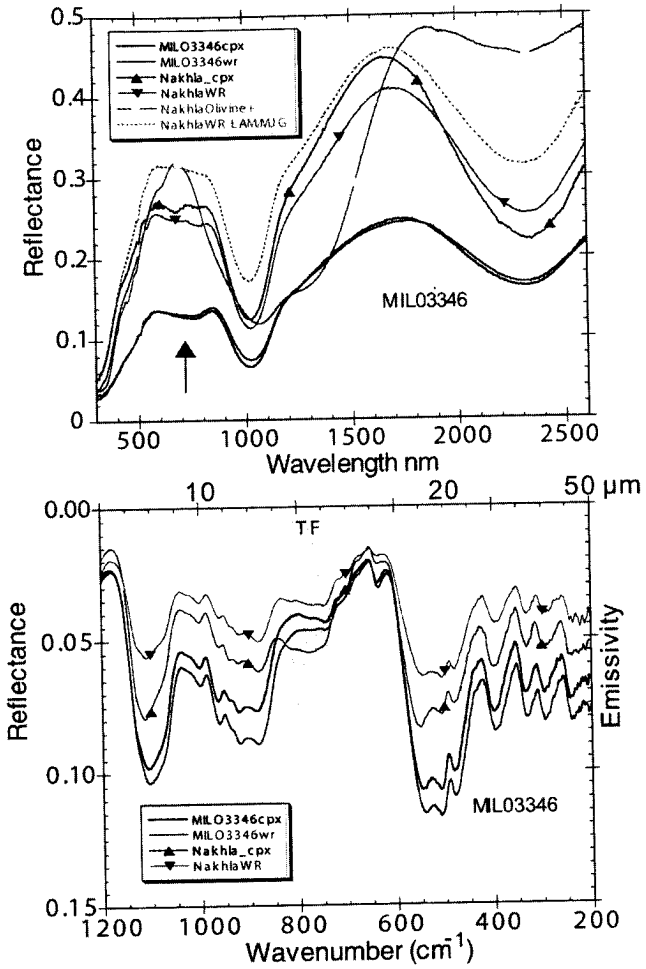

Figure 11: IR-visible-UV reflectance specta for MIL03346 (dominated by clinopyroxene) from Dyar et al. 2006.

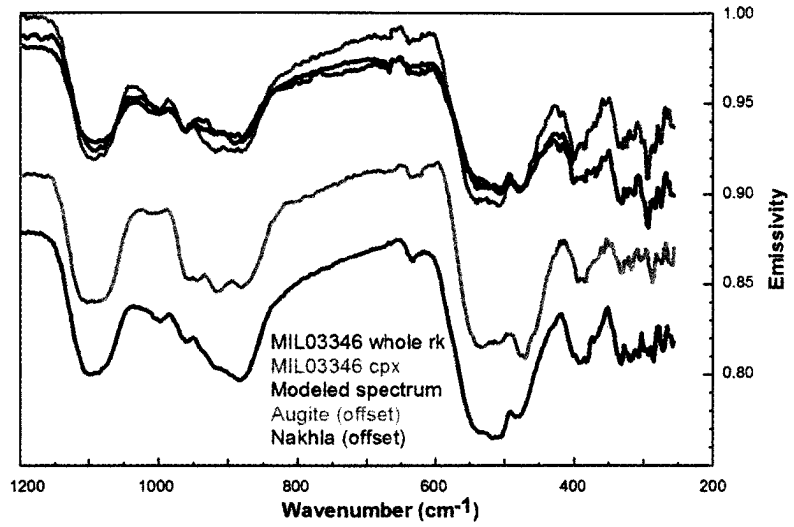

Figure 12: Thermal emission spectra of MIL03346, Augite and Nakhla from Darby et al. 2006.

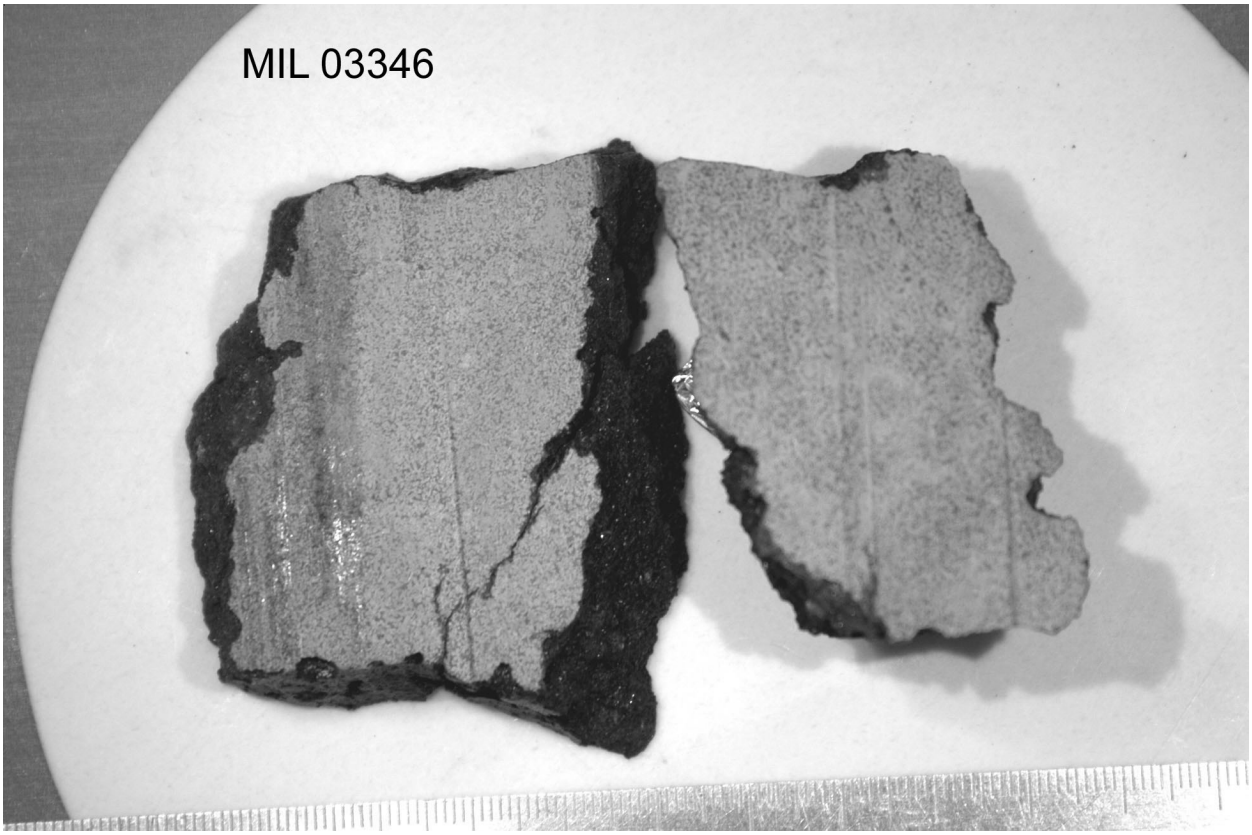

Figure 6: Sawn surfaces of MIL03346,66 and slab ,61. Sacle is in cm. (photo courtesy of Kathleen McBride).