Meteorite Hills 01210

Anorthosite-bearing basaltic (polymict) fragmental breccia

22.8 g

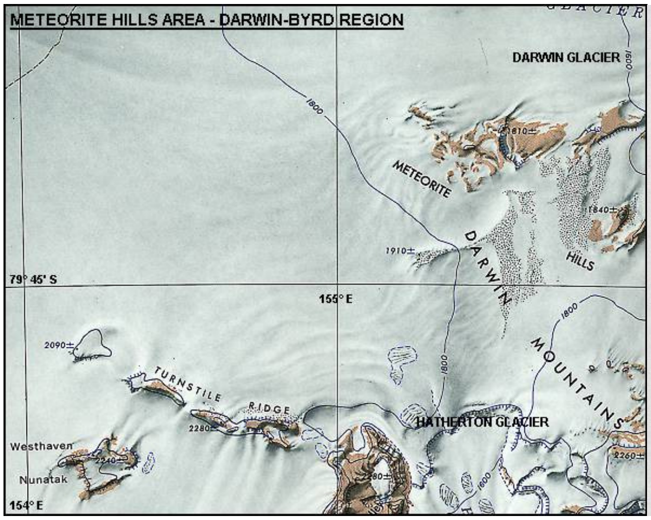
Figure 1: Meteorite Hills (MET) 01210 as found in the bare ice in 2002.

Introduction

Meteorite Hills (MET) 01210 was found in the Meteorite Hills region of Antarctica on December 23, 2001 (Figs. 1-3). It has roughly 30% black shiny fusion crust, and contains many white and brownish mineral and lithic fragments. These two types of clasts are an indicator of its chemical composition – that of a mingled meteorite, despite it original classification as a feldspathic regolith breccia.

Petrography and Mineralogy

MET 01210 is a polymict regolith breccia (Fig. 4 to 6) containing mineral clasts of plagioclase feldspar, pyroxene, olivine, ilmenite, and metal, and lithic clasts of coarse-grained basalt/gabbro, feldspathic clasts, granulites, and symplectites (Figs. 7 to 11; Arai et al., 2005, 2009; Joy et al., 2006; Zeigler et al., 2005; Day et al., 2006). Olivine and plagioclase mineral clasts are more fayalitic and sodic, respectively, suggesting a basalt origin rather than highlands (Joy et al., 2006). The amount of basaltic and highlands materials in MET 01210 has been estimated at 68% basaltic by Arai et al. (2008, 2009) based on mixing calculations. Huber and Warren (2004) argue for the presence of more finely exsolved pyroxene in MET 01210 than other Apollo basaltic rocks (Fig. 8). This may indicate a slower cooling history for some of the materials within this sample. Detailed minor and trace element measurements for individual phases have been reported by Day et al. (2006), but are not tabulated here.



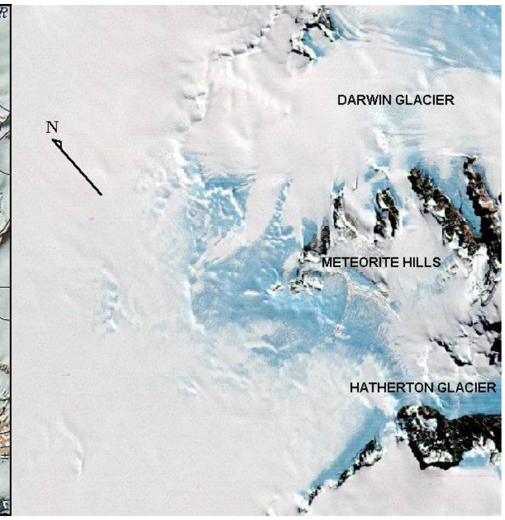


Figure 2: Map of the Meteorite Hills region of Antarctica in the upper right corner of the region. Figure 3: Satellite image of the Meteorite Hills region, at a slightly different orientation than Figure 2 - Turnstile Ridge, oriented horizontally in lower left of Figure 2, is rotated counterclockwise approximately 45 degrees in Figure 3.

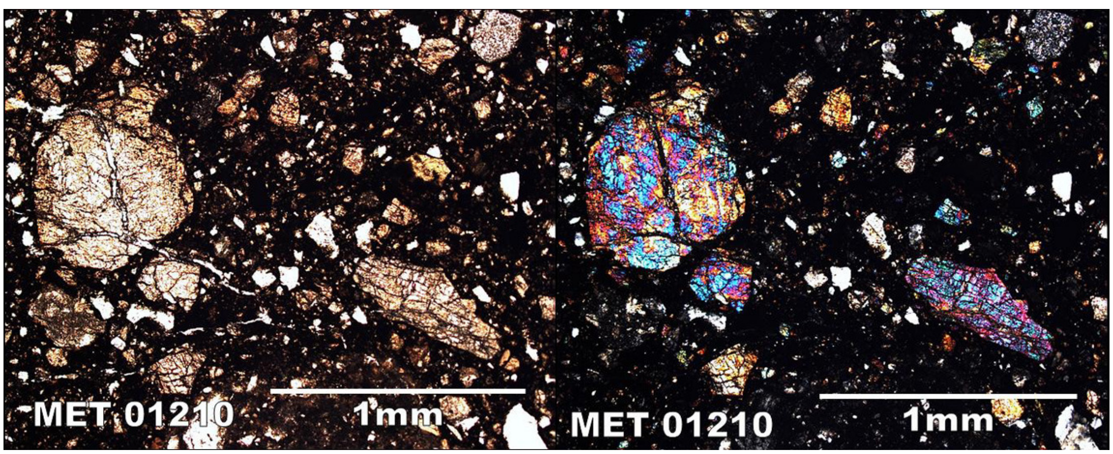


Figure 4: plane polarized (left) and crossed nicols (right) views of section ,4 of MET 01210, showing pyroxene-rich clasts in a dark breccia matrix.

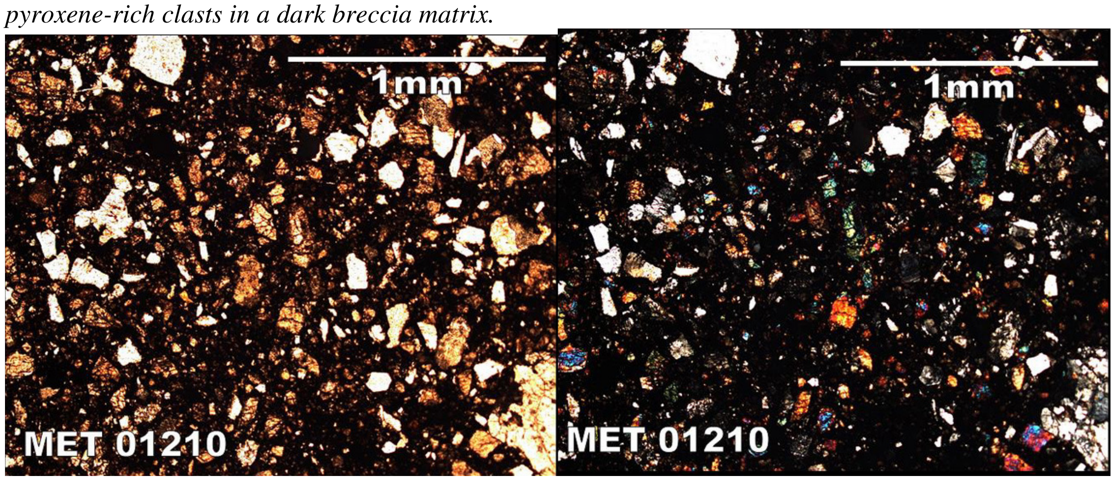


Figure 5: plane polarized (left) and crossed nicols (right) views of a different region of section ,4 of MET 01210, showing a mixture of pyroxene-bearing and feldspathic clasts in a dark breccia matrix.

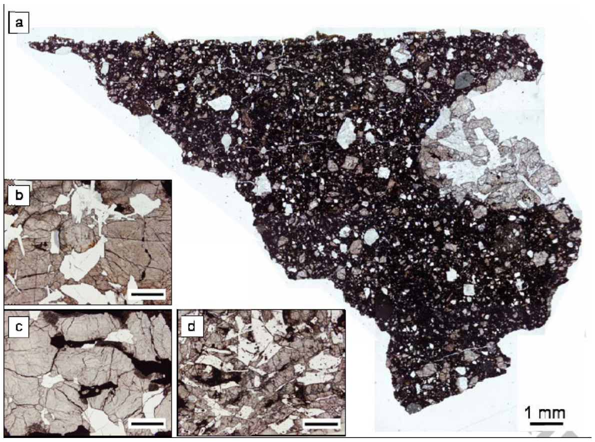


Figure 6a: Optical micrograph of section MET 01210 ,19 (from Arai et al., 2009).

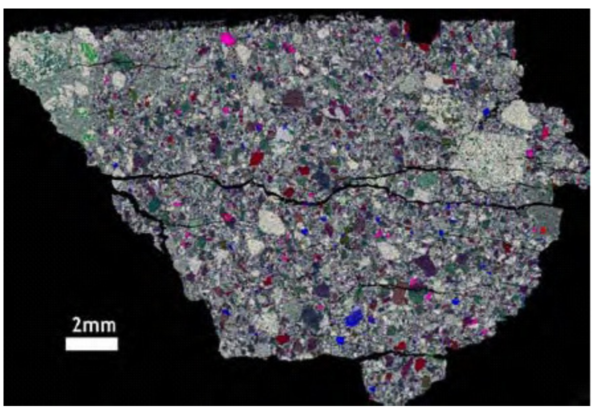


Figure 6b: Elemental map of MET 01210 ,27 (from Joy et al., 2006), showing Si as blue, Al as white, Mg as green, Fe as red, Ca as yellow and Ti as pink. Both aluminous and basaltic clasts can be identified on this basis.

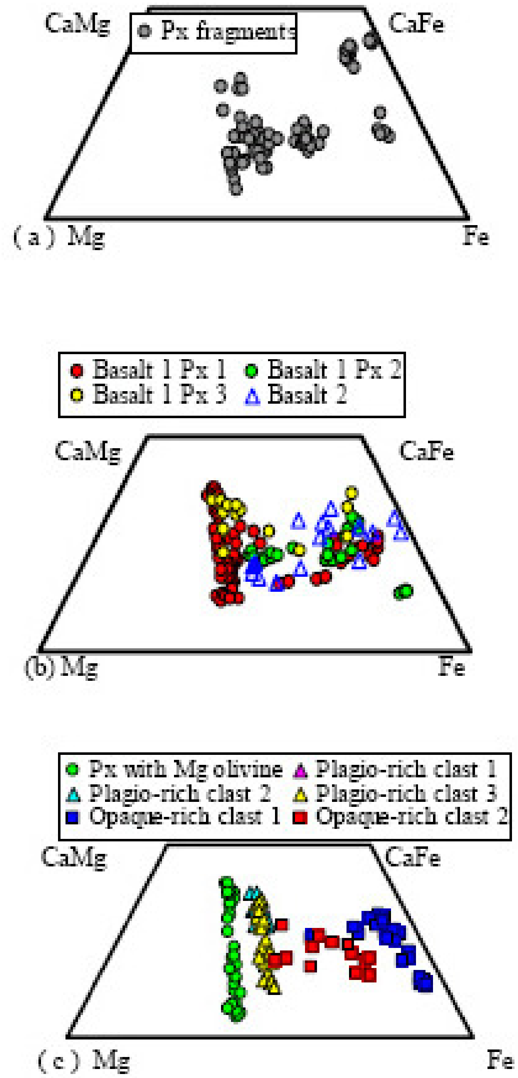


Figure 7: Compositional variation observed in pyroxenes from MET 01210, in basaltic and feldspathic clasts (from Arai et al., 2005).

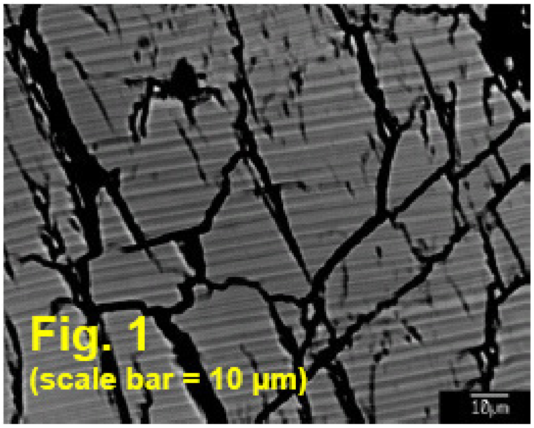
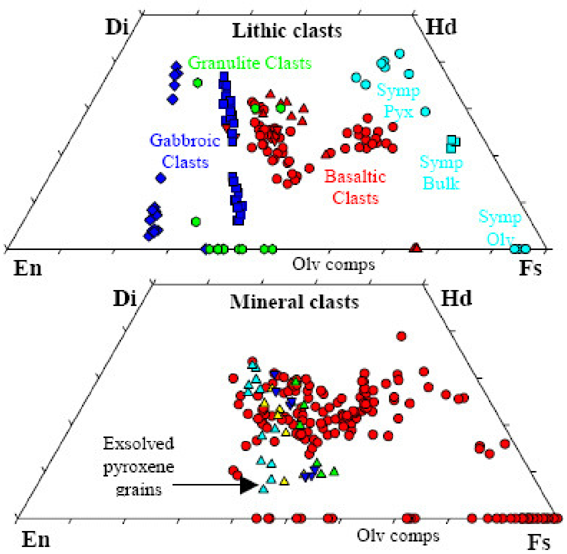


Figure 8: Very fine exsolution lamellae in pyroxene from MET 01210 from the study of Huber and Warren (2004).



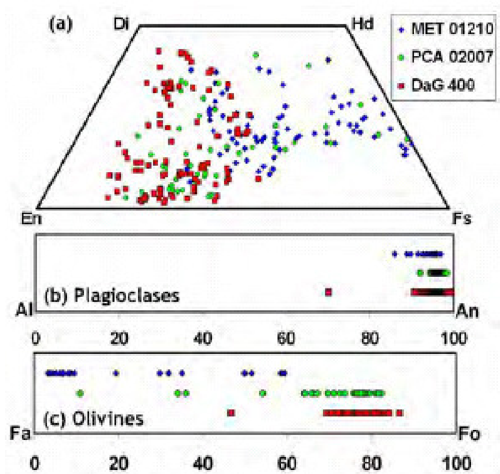


Figure 9: Compositional range of pyroxenes from lithic and mineral clasts MET 01210 ,20 (from Zeigler et al., 2005).
Figure 10: Compositional range of pyroxenes from lithic and mineral clasts MET 01210 ,27 (from Joy et al., 2006).

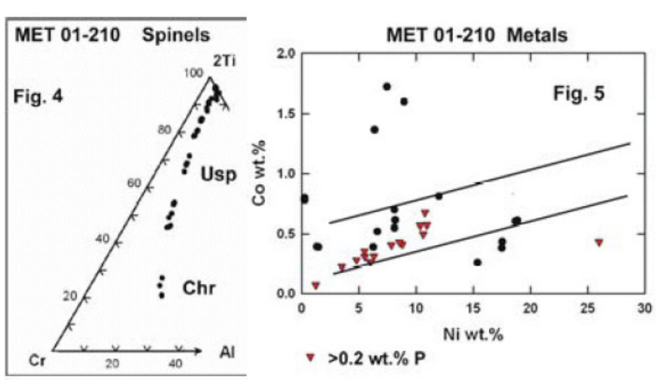


Figure 11: Compositional range of spinel from a gabbroic clast and metals from the matrix in MET 01210 ,18 (from Patchen et al., 2005).

Chemistry

The mingled petrography of MET 01210 is born out by it chemical composition which is intermediate between mare and highlands end members (Fig. 12; Table 1). For example, CaO and FeO are ~ 15 wt% and ~ 16 wt%, respectively. MET 01210 contains more TiO_2 than other basaltic meteorites (1.6 to 2.0 wt%), which is also a reflection of the clasts within – they are of low Ti derivation as opposed to the very low Ti derivation of many of the other basaltic meteorites (e.g., Yamato 793169, QUE 93169, or EET 87521). In addition, the low μ source region calculated for basaltic clasts in MET 01210 defined by U-Pb studies (Terada et al., 2007) is different from the relatively high μ source characterized from Apollo basalts, and puts MET into a small group of basaltic lunar meteorites which have this chemical distinction in common (Terada et al., 2007).

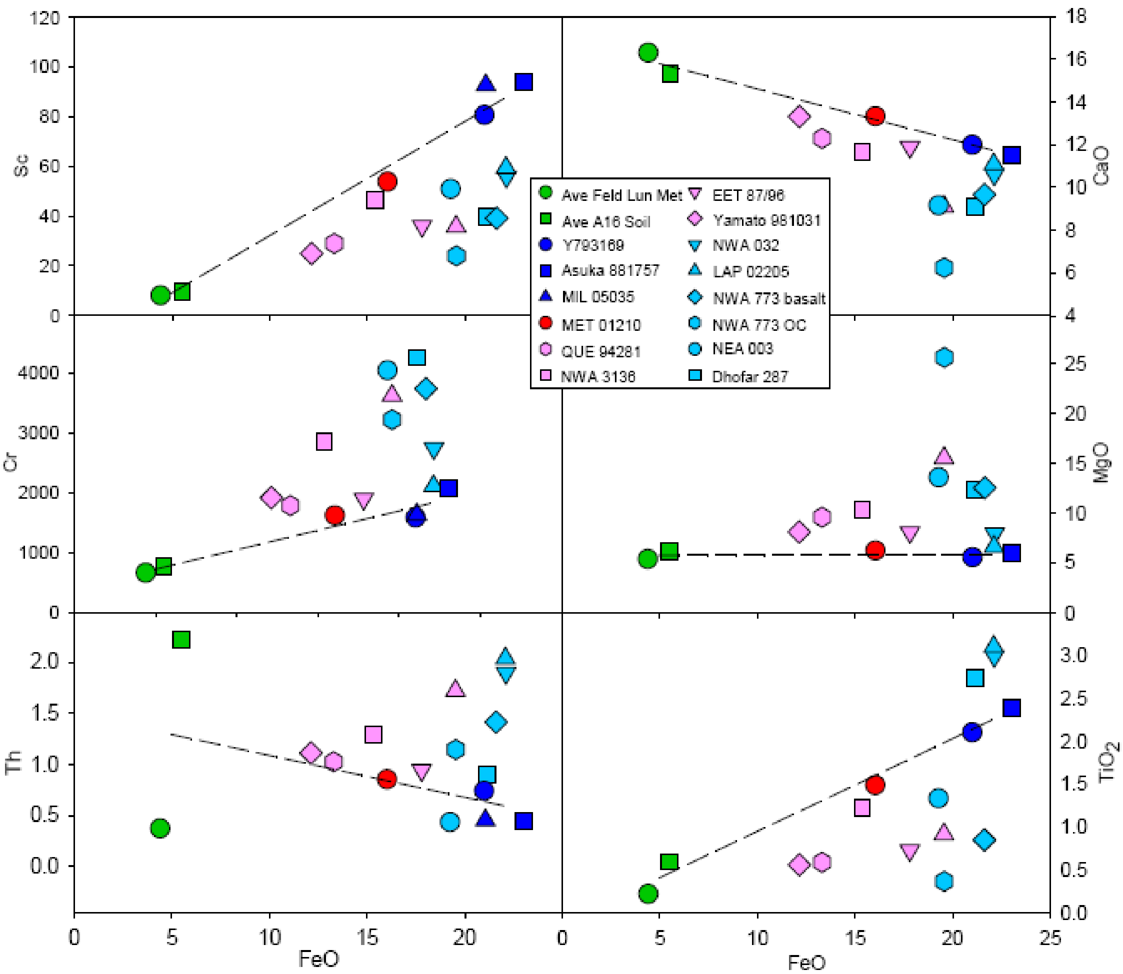


Figure 12: FeO, CaO and Th contents of MET 01210 compared to several other mingled lunar meteorites (pink) as well as mare (blue) and highlands (green) meteorites and soil (from Zeigler et al., 2007). The dashed line is a mixing line between the average composition of A88 and Y79 and an average of Apollo 16 soils and feldspathic lunar meteorites. In every case, MET falls on or very near this mixing line, suggesting that MET is composed primarily of A88/Y79 basalt (~65%), that has been diluted by some moderately ITE-enriched (relative to feldspathic lunar meteorites) feldspathic component.

Table 1a. Chemical composition of MET 01210

reference	1	2	3	3
weight	fc		20-60	240
technique	a,c	b,d	a	c
SiO2 %	44.8	44.03	45	
TiO2	1.58	1.55	1.41	
Al2O3	17	16.6	17	
FeO	16.2	16.46	16.03	16.03
MnO	0.26	0.22	0.21	
MgO	5.97	6.2	6.22	
CaO	13.6	12.96	13.3	14.7
Na2O	0.26	0.32	0.3	0.304
K2O		0.06	0.04	0.03
P2O5		0.05	0.05	
S %				
sum			99.8	
Sc ppm		56		53.7
V		60		
Cr	1300	1881		1620
Co		32		26.6
Ni		212		180
Cu		23		
Zn		37		
Ga		19.1		
Ge				
As				<0.7
Se				n.a.
Rb		1.34		<5
Sr		163		150
Y		37		
Zr		103		90
Nb		1.07		
Mo				
Ru				
Rh				
Pd ppb				
Ag ppb				
Cd ppb				
In ppb				
Sn ppb				
Sb ppb				
Te ppb				
Cs ppm		0.089		<0.3
Ba		81		79
La		6.69		5.39
Ce		13.8		14.6

Pr	2.12	
Nd	10.7	9.8
Sm	3.58	3.6
Eu	1.11	1.03
Gd	4.54	
Tb	0.905	0.85
Dy	5.85	
Ho	1.26	
Er	3.63	
Tm	0.532	
Yb	3.54	3.36
Lu	0.519	0.474
Hf	2.37	2.66
Ta	0.103	0.366
W ppb		
Re ppb		
Os ppb		
Ir ppb		7.1
Pt ppb		
Au ppb		1.9
Th ppm	0.855	0.85
U ppm	0.321	0.23

technique (a) EMPA, (b) ICP-MS, (c) INAA (d) XRF

Table 1b. Light and/or volatile elements for MET 01210

Li ppm	8	
Be	1.72	
C		
S		
F ppm		
Cl		
Br		<0.7
I		
Pb ppm	0.551	
Hg ppb		
Tl	0.009	
Bi		

1) Zeigler et al. (2005); 2) Joy et al. (2006); 3) Korotev et al. (2009b)

Radiometric age dating

The U-Pb ages of phosphates (merrillite and apatite) in basaltic clasts from MET 01210 are 3.8 to 3.9 Ga (Fig. 13), similar to the old ages determined for Asuka 881757, Yamato 793169, and Miller Range 05035 (Terada et al., 2007).

Cosmogenic exposure ages

Studies of MET 01210 so far have determined ^{10}Be and ^{36}Cl ages of 0.95 Ma and 0.90 Ma, respectively (Nishiizumi et al., 2005, 2006), and a terrestrial exposure age of < 20 Ka. The similarity of petrography, composition and exposure ages led Arai et al. (2005) to suggest that Asuka 881757 and Yamato 793169 are launch paired with MET 01210. This has been extended to include MIL 05035, Arai et al., 2008 and 2009, who propose a cryptomare origin for these meteorites (called YAMM) – maybe the Schiller-Schickard region near the SW limb (Fig. 14).

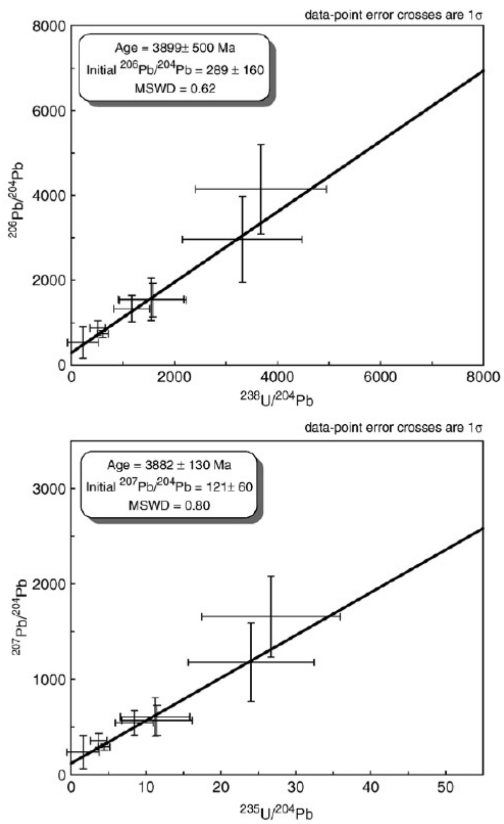


Figure 13: U-Pb ages of phosphates from a basaltic clast in MET 01210 (Terada et al., 2007).

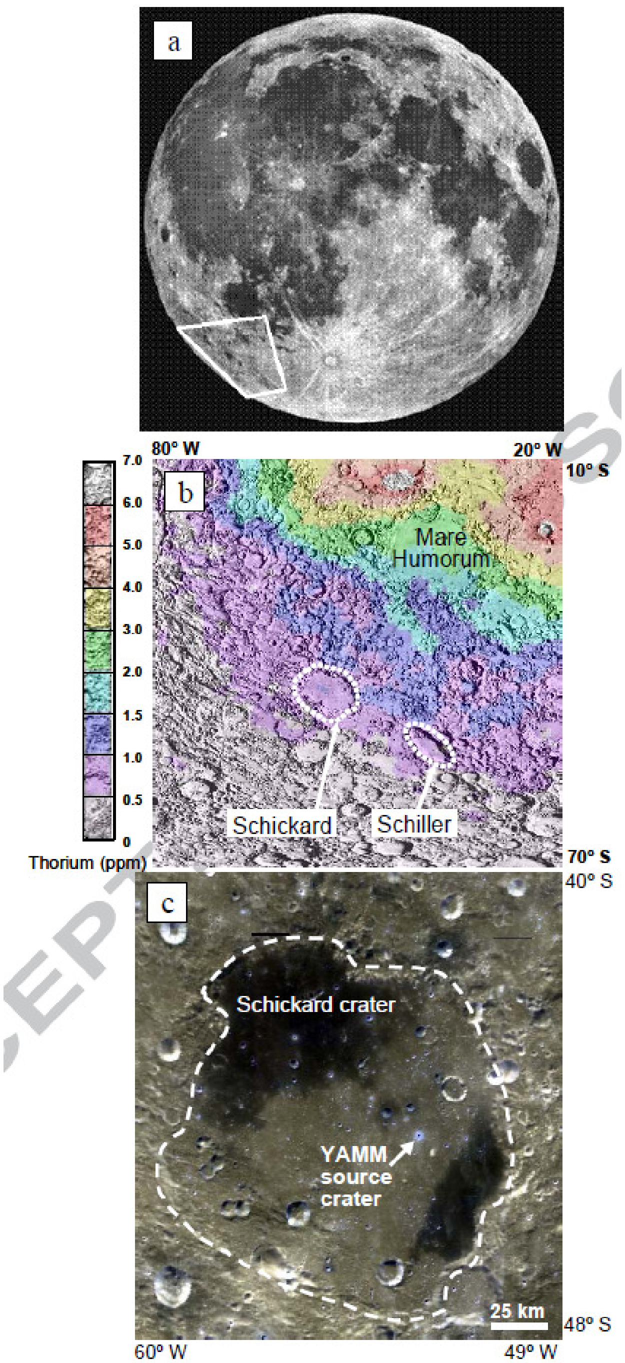
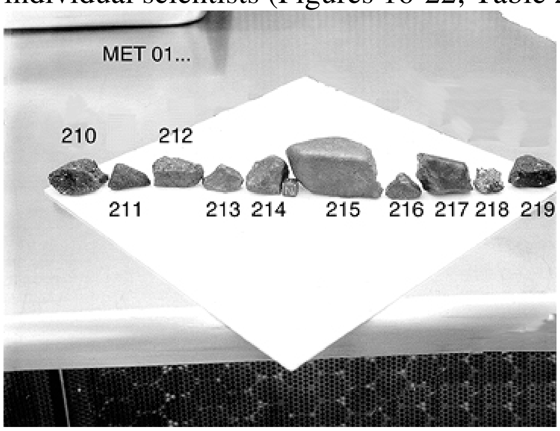


Figure 14: (a) Full moon photograph showing the location of the Schiller-Schickard cryptomare region of the nearside. (b) Th abundance map of the Schiller-Schickard region based on the Lunar Prospector Th data (Lawrence et al., 2003). The Th abundance is mostly 0.5 - 1 ppm in the Schickard crater. (c) Clementine albedo map (http://pdsmaps.wr.usgs.gov) showing the proposed source crater (53°W, 44.5°S) for the YAMM meteorites on the floor of the Schickard crater. The crater is 1.4 km in diameter and extremely young with bright ejecta around it (Figure from Arai et al., 2009).

Processing

MET 01210 was not initially recognized to be lunar, and thus was processed together with many smaller meteorites from the 2001-2002 season (Fig. 15). Later processing has been extensive and close to 20 splits and sections have been sent out to individual scientists (Figures 16-22; Table 2).



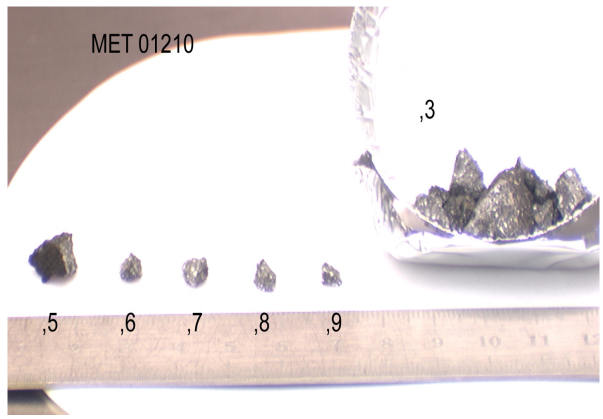
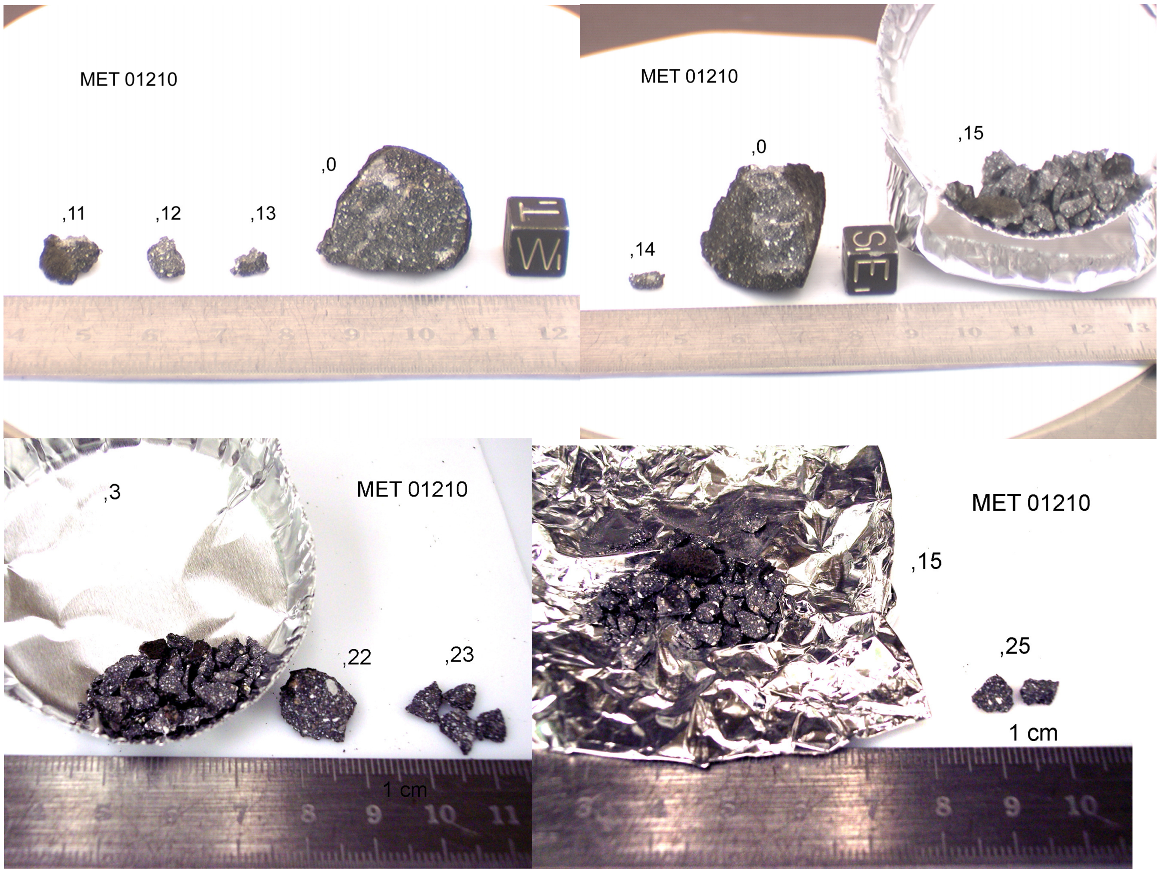


Figure 15: Initial processing photo of MET 01210 in the Meteorite Processing Laboratory of NASA-JSC.
Figure 16: Splits 3 through 9 of MET 01210.



Figures 17 to 22: Main mass (,0) and Splits 11 through 15, 22, 23, and 25 of MET 01210.

Table 2. Allocation history of MET 01210 (March, 2008)

split	TS	parent	mass	PI/location	comment
0		0	11.578	JSC	Documented chip
1		0		Entirely subdivided	Potted butt
	2		0.01	McCoy/SI	Thin section
	17		0.01	Warren	Thin section
	18		0.01	Taylor (LA) / JSC	Thin section
	19		0.01	Arai	Thin section
	21		0.01	Russell	Thin section
	27		0.01	Russell	Thin section
	28		0.01	Warren / JSC	Thin section
3		0	1.974	JSC	Chips and fines
5		3	0.479	JSC	Potted butt
	20		0.01	Korotev	Thin section
6		3	0.111	Busemann	Interior chip
7		3		Arai	Interior chip
8		3		Herzog	Interior chip
9		3		Korotev	Interior chip
11		0		Nishiizumi	Exterior chip
12		0		Nishiizumi	Interior chip
13		0		Korotev	Interior chip (E face)

14		0		Korotev	Interior chip (W face)
15		0		JSC	Chips and fines
22		3	1.447	JSC	Potted butt
	29		0.01	Taylor (GJ) / JSC	Thin section
	31		0.01	Terada	Thin section
	34		0.01	Righter	Thin section
23		3	0.531	Warren	Interior chips
25		15	0.264	Russell	Interior chips
32		3	0.084	Podosek	Interior chip