MICROMETEORITE SP-F88: LUNAR OR ANGRITE? S. Taylor[1], F.N. Lindsay[2], J.S. Delaney[2] and G.F. Herzog[2]. [1]CRREL, 72 Lyme Road, Hanover, NH 03755, [2]Rutgers University, Piscataway, NJ 08854.

Introduction: Most MMs resemble known types of meteorites. Over 80% have compositions similar to those of CI and CM meteorites [1]; less than 10% have compositions similar to those of ordinary chondrites [2] the most common meteorite type; and less than 1% have compositions like those of achondrite meteorites [3]. Here we describe a highly unusual micrometeorite with a composition that differs from those of all other MMs with which we are familiar. It is neither terrestrial, nor chondritic, nor like the HED or the Martian meteorites.

Methods: MM SP-F88 was collected from the South Pole water well in 2000 [4] and imaged as part of an ongoing project to build a MM database. We used an FEI XL-30 field scanning electron microscope and energy dispersive X-ray system at Dartmouth College for preliminary characterization and the JEOL 8200 electron microprobe at Rutgers University for quantitative analyses.

Results: SP-F88 is a round, mostly melted micrometeorite, 275µm in diameter (Figure 1). It has 15 vesicles, two partly open to the surface. SP-F88 contains relict (i.e., unmelted during atmospheric entry) feldspar, olivine, and Ti-rich oxides as well as magnetite grains in a glass matrix; these grains are thought to have formed during atmospheric entry. The feldspar is anorthite and in reflected light has well defined but rounded boundaries. The olivine has poorly defined boundaries. Both minerals were probably interacting with surrounding melt prior to quenching. The composition of the glass can be modeled as a mixture of olivine, pyroxene and plagioclase. The small (<5 µm) oxides present in SP-F88 have a characteristic skeletal-quench texture suggesting they precipitated from a high temperature melt. The two largest contained Ti (probably ulvöspinels) and they are relict as their Fe-rich rims indicate they reacted with the melt. Analytical results are listed in Table 1.

Table 1. Compositional analyses of phases in SP-F88.

	Glass	Olivine	Plag.	Ti-phase
	n=16	n=13	n=21	n=1
Na_2O	0.05±0.02	bd	0.07±0.03	bd
MgO	8.19±0.53	23.12±0.8	0.2±0.14	4.07
Al_2O_3	11.63±0.69	bd	34.26±1.40	2.89
SiO_2	41.8±1.6	36.9±1.5	43.1±1.0	0.30
P_2O_5	0.19±0.02	bd		bd
K_2O	bd	bd	0.02	bd
CaO	13.75±0.72	1.02±0.22	19.86±0.27	0.36
TiO_2	0.80±0.08	bd	0.05±0.03	18.91
MnO	0.37±0.03	0.49±0.06	bd	0.39
FeO	23.7±2.3	39.6±1.2	0.93±0.38	72.68
Total	100.4±1.1	101.0±1.3	98.5±1.2	99.73

SP-F88 is a quenched droplet and in this respect resembles microtektites and some volcanic glasses. The volcanic glasses found at South Pole, however, are morphologically and compositionally unlike SP-F88 [5] as are volcanic glasses found at other locations in Antarctica. All have about 5 wt% Na_2O and K_2O, while SP-F88 contains trace amounts of these elements. Neither does SP-F88 match the compositions of microtektites, all of which have higher SiO_2 and Al_2O_3 contents than SP-F88 and otherMMs [6].

SP-F88 is different from virtually all other MMs. The Ti-rich phase in SP-F88 has 19 wt % TiO_2 the highest found in MMs. The glass has a TiO_2 content of 0.80 ± 0.08 wt%, about five times higher than the average TiO_2 concentrations in 789 previously analyzed MMs (0.16 ± 0.11). SP-F88 also contains anorthite, which we have found in only two other MMs [2].

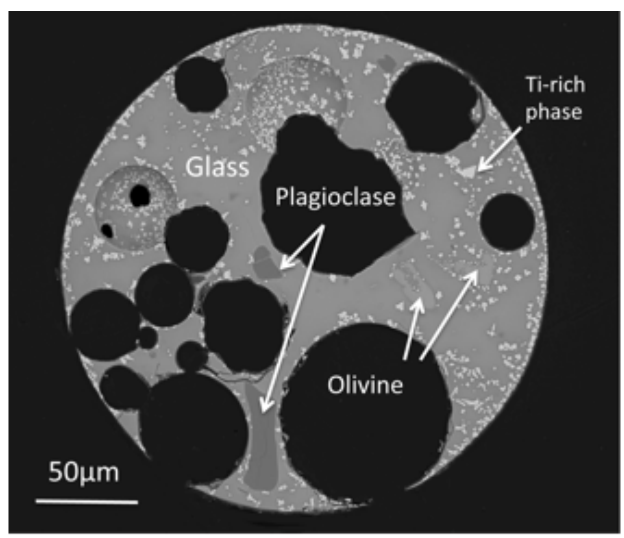

Fig. 1. Backscatter electron image of SP-F88.

Lunar, Martian and other types of meteorites have distinct Fe/Mn and Fe/Mg ratios [7, 8]. Figure 2 shows that the Fe/Mg and Fe/Mn ratios of the glass in SP-F88 are distinctive and similar to lunar Fe/Mn ratios, which are ~70 for bulk lunar rocks. The ratios for SP-F88 are quite different from those of chondrites and most cosmic spherules [9,10,11], which lie within a triangular region defined by two straight lines passing through the origin, and from the HEDs or the Martian meteorites (Fig.2). Fe/Mn ratios in olivines and pyroxenes are also good indicators of origin. The ratio in SP-F88 olivines is 79.7±0.1. Analyses made on four angrites show variable Fe/Mn ratios some close to the lunar band [12].

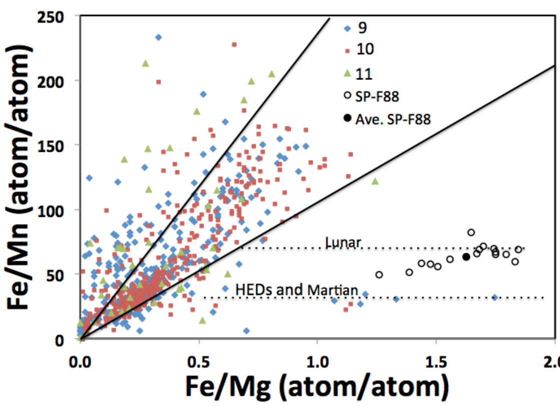

Fig. 2 Fe/Mg - Fe/Mn plot showing where the glass in SP-F88 plots relative to glass cosmic spherules analyzed by various researchers [9, 10, 11], including eight thought to be HEDs.

The compositions of minerals in SP-F88 also provide clues to its origin (Table 1,2). Its relict anorthite grains are very calcic (An$_{98.8-99.8}$) most similar in composition to anorthites in angrites (Table 2). The anorthites found in lunar ferroan anorthosites (An$_{94-98}$, Fo$_{40-62}$), Martian (An$_{57-66}$)[14] and HED meteorites (An$_{72-95}$)[12] and in terrestrial rocks, including those from Antarctica, are less calcic Although common in HED achondrites, anorthite is rare in ordinary chondrites, in many carbonaceous chondrites and in MMs. The olivine in SP-F88 (Fo$_{50-54}$) is also most similar to those in angrites (Fo$_{40-62}$) as it is Fe rich (Mg/(Mg+Fe))=Mg# = 31) compared to olivines in ferroan anorthosites, rocks that would contain calcic anorthites (Table 2).

Discussion: To date nine HED-like but no lunar and no Martian MMs have been found in the SPWW collection. The low Mg# of SP-F88 olivines and the very calcic anorthite are most similar, but not identical, to lunar or angrite materials. Our goal is to make oxygen isotope measurements on the olivine relict grains in SP-F88. If lunar the olivines should have $\delta^{18}O$ values between 5 and 6‰ and these should lie on the terrestrial fractionation line. If SP-F88 comes from an angrite the $\delta^{18}O$ values would be lower, 3.8 to 4.3‰, and below the TFL, $\Delta^{17}O$ of -0.1‰.

A practical scheme to screen for lunar and Martian MMs is to note unusual mineral assemblages and mineral compositions, to follow up by Fe-Mn-Mg ratio plots, and then to make oxygen isotope analyses.

Table 2. Average compositions of anorthite and olivine in SP-F88, angrites (Ang) and lunar ferroan anorthosites (FAN).

	Plagioclase			Olivine		
	F-88	Ang[12]	FAN[13]	F-88	Ang[12]	FAN[13]
	N=21	N=2	N=8	N=13	N=4	N=2
Na_2O	0.07	0.035	0.33	bd	na	
MgO	0.2	0.11	0.05	23.12	27.8	30.5
Al_2O_3	34.26	36.05	35.79	bd	0.05	
SiO_2	43.1	43.55	43.83	36.9	36.0	36.0
CaO	19.86	20.35	19.48	1.02	1.02	0.05
TiO_2	0.05	na	na	bd	na	
Cr_2O_3	bd	na		bd	0.16	0.05
MnO	bd	na		0.49	0.41	0.42
FeO	0.93	0.3	0.14	39.6	34.05	33.3
Total	98.5	98.5	99.6	101.0	101.1	100.4
Mg#				31	39	42

n.a.= not analyzed, b.d. =below detection

References: [1] Kurat G. et al. (1994) *GCA, 58,* 3879-3904. [2] Taylor S et al (2012) *MAPS* **47** 550-564 (2012). [3] Taylor S. et al (2007) *MAPS,* 42, 223-233 (2007). [4] Taylor S. et al. (1998) *Nature*, *392*, 899-903. [5] Palais J.M., et al. (1990) *Annals of Glaciology*, **14**, 216-220. [6] Glass B.P (2004), GCA, **68**, 3971-4006. [7] Goodrich, C.A. et al (2000) GCA **64** 149-160. [8] Papike J.J et al. (2003) American Mineralogist, 88, 469-472. [9] Taylor et al. (2000) MAPS. [10] Cordier C. et al. (2011) *GCA,* 75, 1199-1215. [11] Yada T. et al. (2005) *GCA*, 69: 5789-5804.[12] Mittlefehldt D.W. et al. (1998) *Reviews of Mineralogy* 36, pp. 4-1 to 4-195. [13] Papike J.J., et al. (1991) Lunar Sourcebook, A user's Guide to the Moon. Ed. [14] McSwean and Treiman (1998) *Reviews of Mineralogy* 36, pp. 6-1 to 6-53.