Dhofar 081, 280, 910, 1224

Anorthositic fragmental breccia

174, 251.2, 142, 4.57 g

Figure 1: Photo of Dhofar 081 with a 1 cm cube for scale (photo from R. Korotev).

Introduction

Dhofar 081 (Fig. 1) was found in the Dhofar region of Oman (Figs. 2 and 3) in November, 2001 (Grossman et al., 2000). The 751 g brownish gray stone lacks fusion crust, and has terrestrial weathering in cracks such as akaganeite (FeOOH), calcite, celestite, barite, and gypsum. Smaller additional stones Dhofar 280, 910 and 1224 were found in 2001 and 2003, and are paired on the basis of their location of find, textures and chemical compositions.

Petrography and mineralogy

Dhofar 081 is a regolith breccia consisting of many mineral fragments and lithic clasts in a glassy matrix (Fig. 4). Clasts include anorthositic troctolite (Fig. 5) and troctolite, as well as granulites. Plagioclase feldspar has a narrow compositional range between An_{94} and An_{98}. Pyroxenes are largely magnesian, consistent with a highlands origin, and olivines vary in composition from Fo_{40} to Fo_{82} (Fig. 6). As with other Dhofar feldspathic and feldspathic lunar meteorites in general, the olivine, pyroxene and plagioclase feldspars on Dhofar 081 span the gap between the high Mg suite (HMS) and ferroan anorthosites (FAN) from the Apollo samples (Fig. 7). An unusual discovery in Dhofar 280 (paired with Dho 081) are the reduced minerals FeSi, $FeSi_2$ and a new mineral hapkeite (Fe_2Si; Anand et al., 2002, 2005), that have been proposed to form by impact induced vapor phase deposition in the lunar soil (Fig. 8).

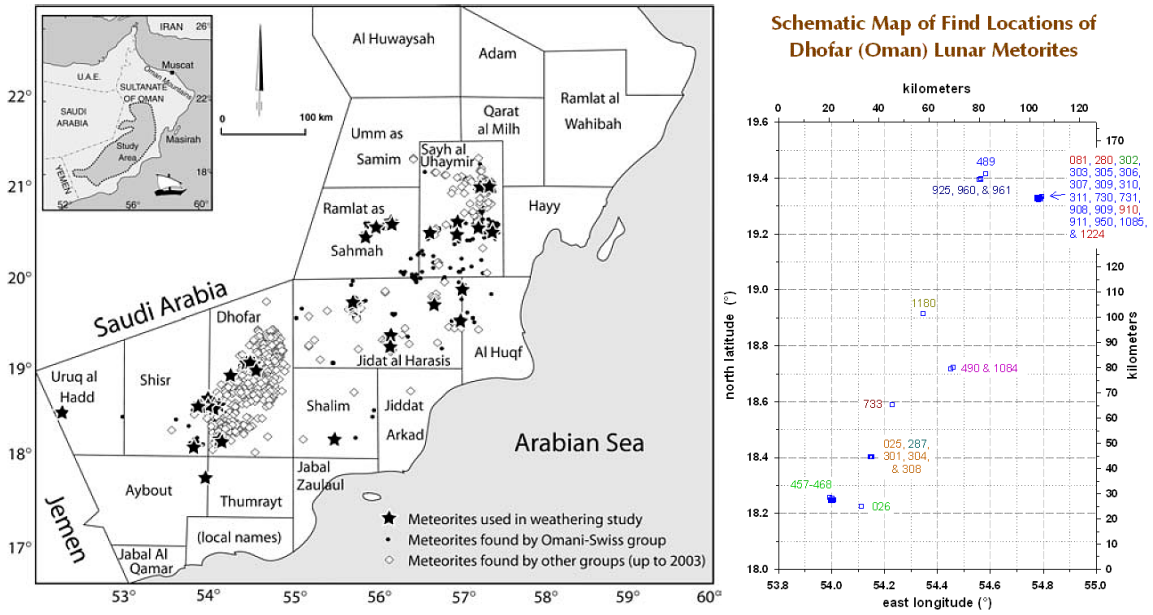


Figure 2: Map showing location of regions within Oman where meteorites have been recovered, such as Dhofar.

Figure 3: More detailed locations of the Dhofar meteorites, including Dho 081, 280, 910, and 1224 (shown in red in upper right).

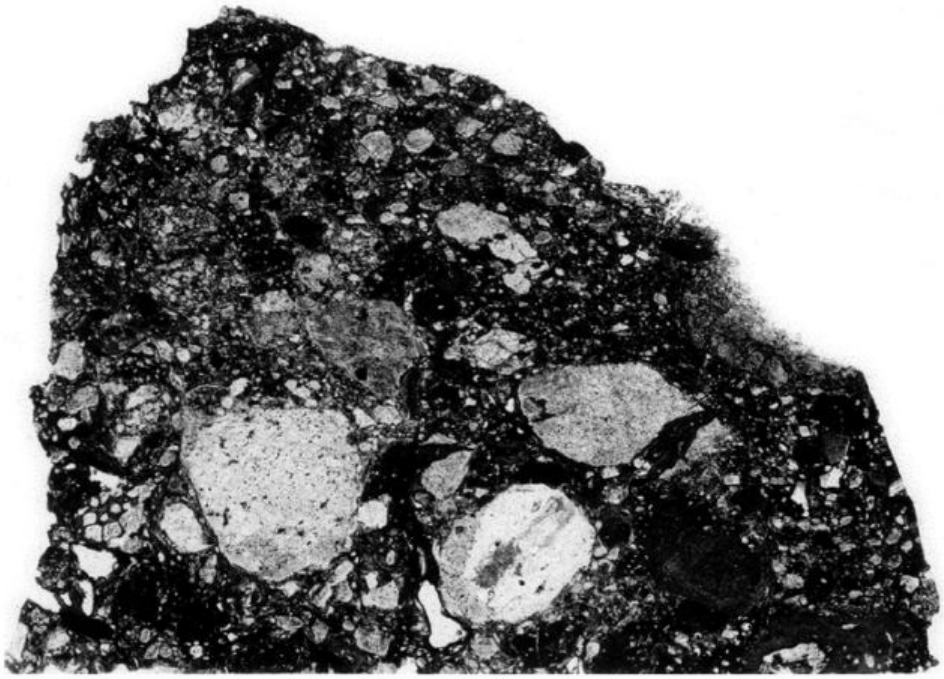


Figure 4: Photo of a slab of Dhofar 081, illustrating the nature of the anorthositic clasts (from Bischoff, 2001).

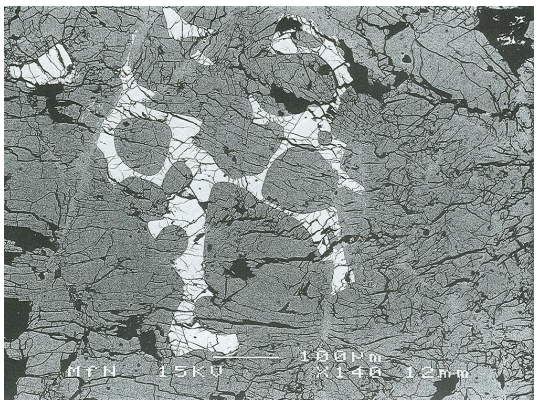
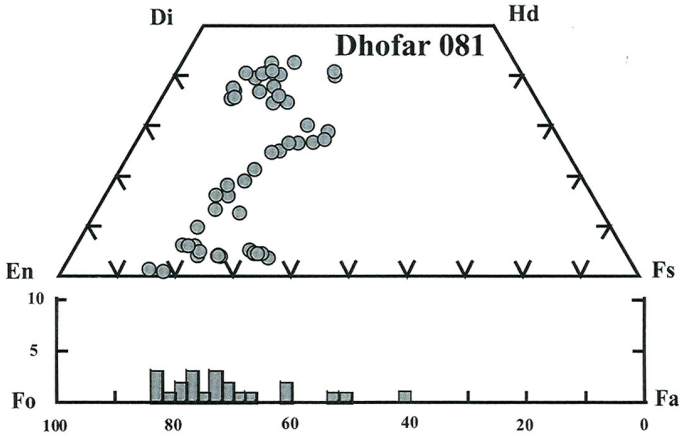


Figure 5: Back scattered electron image of an anorthosite clast from study of Greshake et al. (2001).



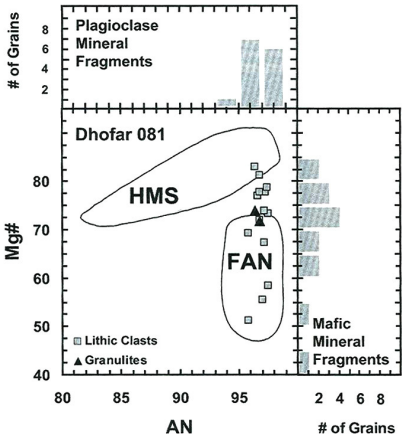


Figure 6: Dhofar 081 pyroxene quadrilateral (from Cahill et al., 2004).
Figure 7: Mg# - An content diagram (from Cahill et al., 2004).

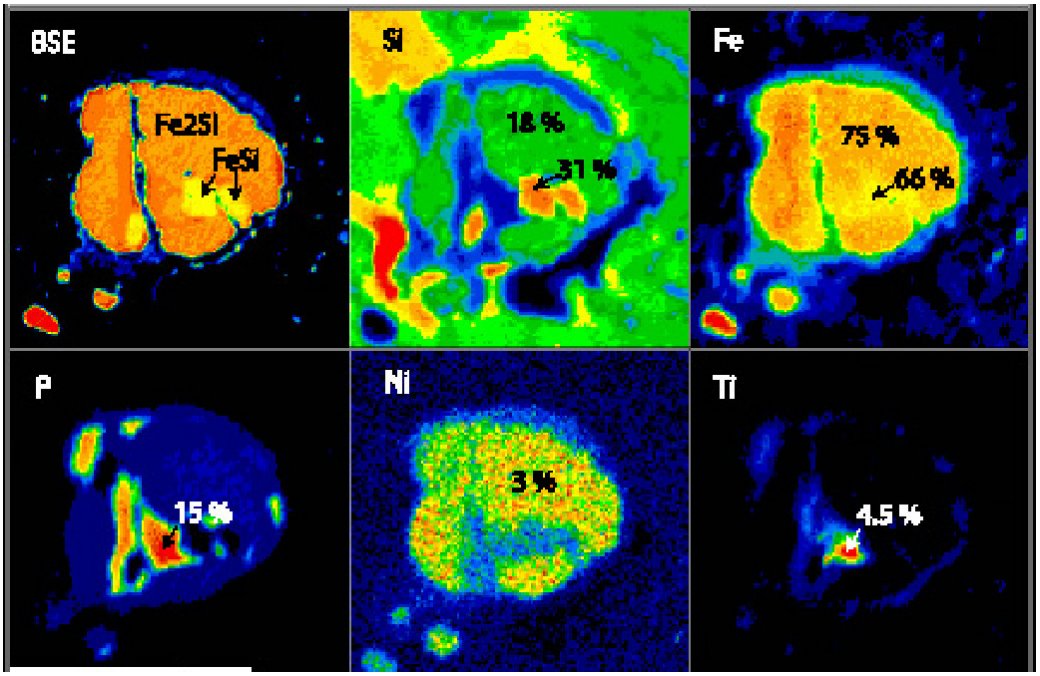


Figure 8: False color x-ray maps of Hapkeite(Fe2Si) and FeSi in Dhofar 280 (from Anand et al., 2002, 2004).

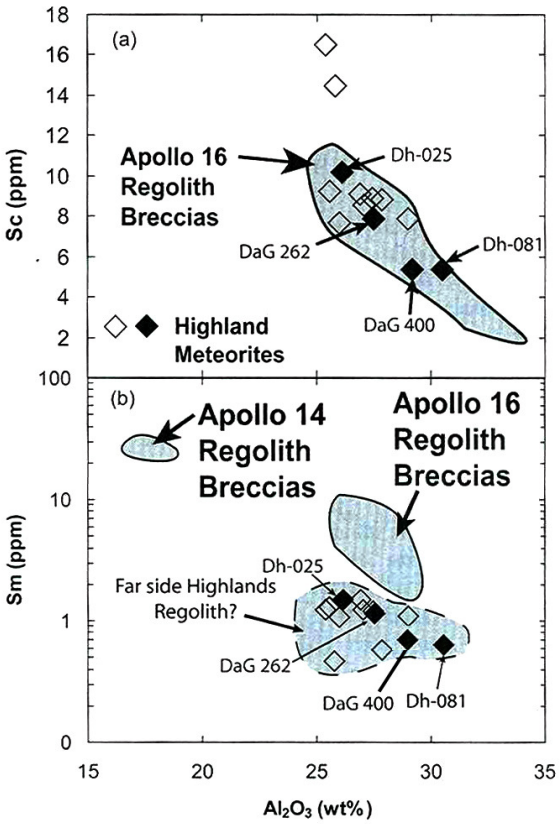


Figure 9: Sc and Sm vs. Al_2O_3 for Dhofar 081 compared to other lunar highlands meteorites, Apollo 15 and 14 regolith breccias (modified from Cahill et al., 2004).

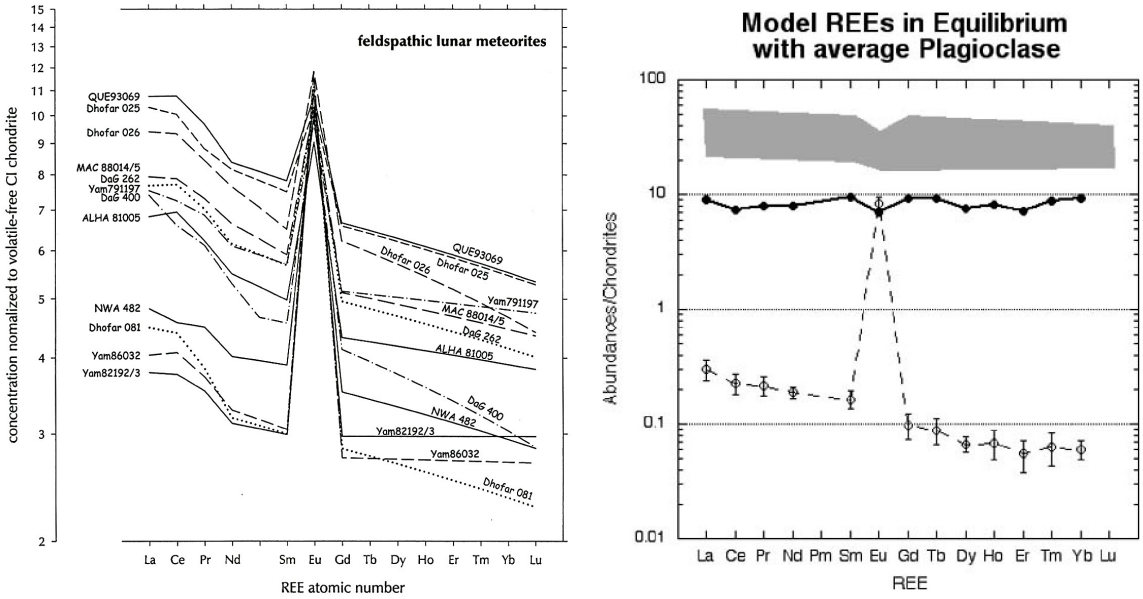


Figure 10: Rare earth element pattern for Dhofar 081 compared to other lunar feldspathic meteorites (from Korotev et al., 2003).

Figure 11: parental melts to Dho 081 feldspars are much lower in REE than Apollo samples (Consolmagno et al., 2004).

Chemistry

Dhofar 081 and its pairs have compositional features that make lunar feldspathic meteorites distinct from Apollo samples - they have high Al_2O_3 (~ 30 wt%; Fig. 9) and low FeO (~3.2 wt%). They have similar Sc and siderophile elements such as Ir, compared to Apollo 14 and 16 breccias, but lower Sm, Th, and Na (Figs. 9 and 10; Warren et al., 2005; Cahill et al., 2004; Korotev et al., 2003). Rare earth elements (REE) are as lower than many lunar feldspathic meteorites (Fig. 10). And calculated parental melts to some of the feldspar clasts also yield low REE parents (Fig. 11). Also, elements such as Ba and Sr are elevated above values for other Antarctic feldspathic meteorites, most likely from terrestrial alteration (Nazarov et al., 2004; Floss and Crozaz, 2001; Korotev et al., 2003). Low noble gas concentrations (Greshake et al., 2001; Shukolyukov et al., 2001).

Radiogenic age dating

Fernandes et al. (2004) studied Dhofar 280, and obtained a range of ages from 2.33 to 3.70 from plagioclase grains in the matrix.

Cosmogenic isotopes and exposure ages

Studies of noble gases and cosmic ray exposure ages have yielded a residence time of 680 +/- 140 Ka (Lorenzetti et al., 2005). The very short Earth-Moon transit time (<0.01 Ka), together with a short terrestrial age (0.04 +/- 0.02 Ka) results in a ejection age of 0.04 +/- 0.02 Ka (Nishiizumi et al. (2001, 2004).

Table 1: Chemical composition of Dho 081

			Dho 280
reference	1	2	3
weight	408		
method	e	d	a,e,g
SiO_2 %	44.71	45	44.4
TiO_2	0.15	0.1	0.19
Al_2O_3	31.17	32	30.7
FeO	3.04	3.2	3.4
MnO	0.05	0.05	0.05
MgO	2.80	2.4	2.53
CaO	17.63	16	18.2
Na_2O	0.31	0.7	0.39
K_2O	0.02	0.06	0.02
P_2O_5		0.1	0.06
S %			
sum			
Sc ppm	5.8		5.6
V	19		
Cr	380	520	287
Co	10.4		9.1
Ni	94	90	170
Cu			

Zn		
Ga	2.4	
Ge		
As	<0.06	
Se		
Rb		
Sr	280	220
Y		
Zr	<20	25
Nb		
Mo		
Ru		
Rh		
Pd ppb		
Ag ppb		
Cd ppb		
In ppb		
Sn ppb		
Sb ppb	<7	
Te ppb		
Cs ppm	0.038	
Ba	20	25
La	1.43	1.6
Ce	3.6	3.3
Pr		
Nd	1.96	2
Sm	0.6	0.6
Eu	0.85	0.8
Gd		
Tb	0.139	0.14
Dy	<0.89	
Ho	0.18	
Er		
Tm		
Yb	0.53	0.47
Lu	0.074	0.08
Hf	0.49	0.49
Ta	0.067	0.35
W ppb		
Re ppb		
Os ppb		
Ir ppb	4.8	9.9
Pt ppb		
Au ppb	5.5	5
Th ppm	0.2	0.33
U ppm	0.075	

technique (a) ICP-AES, (b) ICP-MS, (c) IDMS, (d) FB-EMPA, (e) INAA, (f) RNAA, (g) XRF

Table 1b. Light and/or volatile elements for Dho 081

Li ppm	
Be	
C	
S	
F ppm	
Cl	
Br	0.35
I	
Pb ppm	
Hg ppb	
Tl	
Bi	

References: 1) Warren et al. (2005); 2) Greshake et al. (2001); 3) Demidova et al. (2007)

Lunar Meteorite Compendium by K Righter 2010