Dar al Gani 400

Anorthositic regolith breccia
1425 g

Figure 1: Dar al Gani 400 as found in the Libyan desert in 1998. Width of sample is approximately 20 cm.

Introduction

Dar al Gani (DaG) 400 was found in the Libyan desert on March 10, 1998 (Fig. 1 and 2). It is partially covered with brown fusion crust but fresh surfaces are gray to dark gray and reveal light colored anorthositic clasts and mineral fragments (Fig. 3). Terrestrial weathering of this sample is evident in calcite veins that criss-cross the sample; some elemental concentrations have also been affected by weathering (see below).

Petrography and Mineralogy

Detailed petrographic studies of DaG 400 have revealed the presence of many impact melt breccia clasts (Zipfel et al., 1998; Korotev et al., 2003; Cahill et al., 2004; Warren et al., 2005; Bukanovska et al., 1999). Many of the clasts are impact melt breccias, and a small percentage are glassy spherules (with quench textures) (Warren et al., 2005). Modes estimated for one section resulted in 80% lithic clasts, 10% mineral fragments, and 10% glassy matrix (Semanova eet al., 2000). Among the lithic clasts, 95% are anorthositic, range up to 2.5 mm, and have feldspar compositions of nearly pure anorthite (Fig. 4). The other 5% lithic clasts are anorthositic norites and troctolites, again with a narrow compositional range and anorthite-rich feldspar. Olivine and pyroxene in the anorthositic clasts are slightly more Fe-rich than that in the norites and troctolites (Fig. 5 and 6), and olivine and pyroxene fragments in the matrix overlap both rock types. However, pyroxene compositions in matrix mineral fragments extend out to more FeO-rich ferroaugite compositions, suggesting the presence of a minor mare basalt component

(Fig. 5 and 6). Spinel in the troctolite is Mg- and Al-rich and similar in composition to other lunar troctolites (Semenova et al., 2000). The matrix also contains ilmenite, troilite, chromite, silica, and metal (Semenova et al., 2000; Bukanovska et al., 1999). Glassy fragments are largely feldspathic in composition, but there are a minor amount of more FeO-rich glasses, again suggesting a mare basaltic component (Fig. 7).

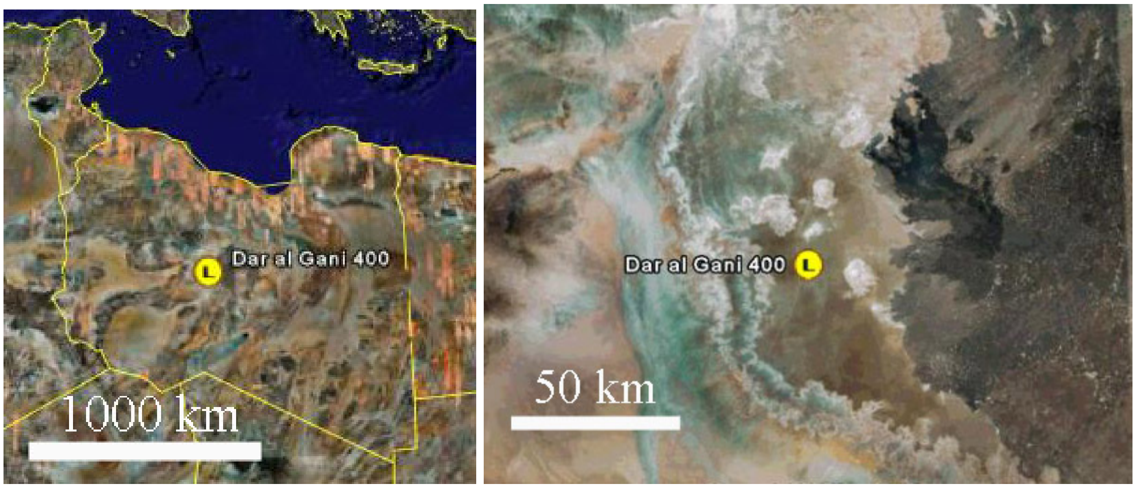

Figure 2: Map of Libya (left) and the Dar al Gani region (right) showing the location of DaG 400. Satellite images are from Google Earth.

Figure 3: Cut slab of DaG 400 showing the many feldspathic clasts and mineral fragments. Maximum dimension of slab is 9 cm

Photo courtesy of Steve Arnold.

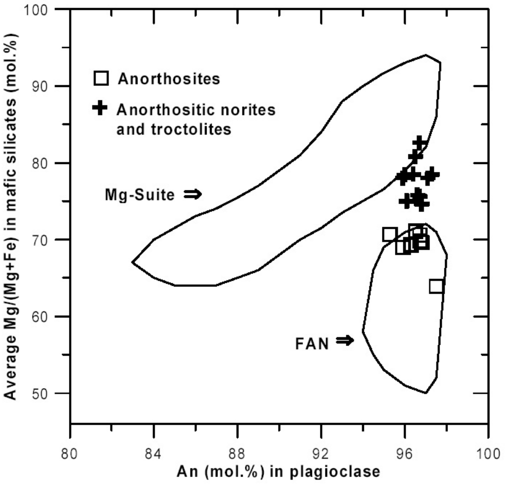

Figure 4: Feldspar compositions and Mg# in the anorthositic, noritic and troctolitic clasts and matrix of DaG 400 (from Semenova et al., 2000).

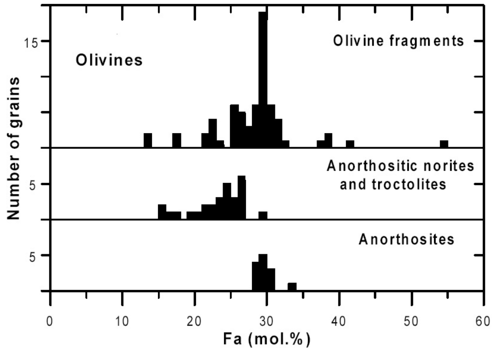

Figure 5: Olivine compositions in the anorthositic, noritic and troctolitic clasts and matrix of DaG 400 (from Semenova et al., 2000).

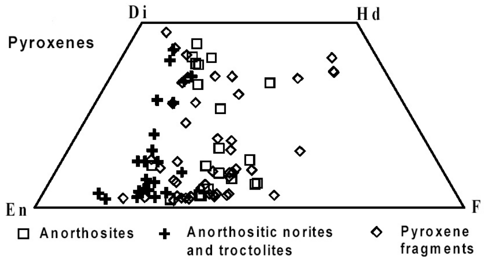

Figure 6: Pyroxene compositions in the anorthositic, noritic and troctolitic clasts and matrix of DaG 400 (from Semenova et al., 2000).

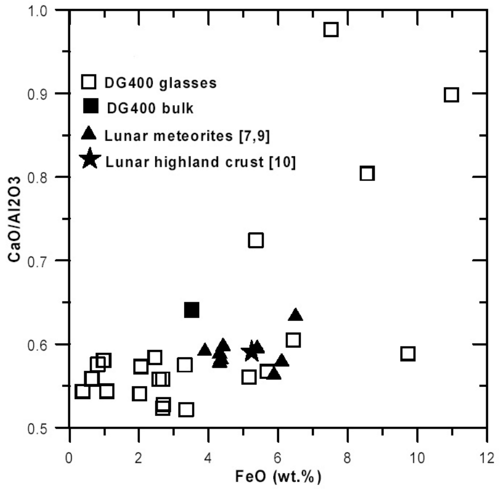

Figure 7: FeO and CaO/Al_2O_3 for glasses in matrix and clasts from DaG 400 (from Semenova et al., 2000).

Chemistry

DaG 400 has low FeO and high Al_2O_3, as expected for a feldspathic highlands breccia (Fig. 8 and Table 1). Whereas DaG 400 has Fe and Sc contents very similar to highlands breccias (Fig. 9), it has lower Sm/Al_2O_3 ratios, as observed in many other highlands meteorites, indicating a different composition of the far-side highlands regolith from that of the Apollo 16 and 14 regolith breccias (Fig. 10; Korotev et al., 2003; Cahill et al., 2004). Ba and Sr contents are variable presumably due to non-uniform distribution of terrestrial weathering products (Korotev et al., 2003; Zipfel et al., 1998). Rare earth element compositions of DaG 400 show a typical positive Eu anomaly (Fig. 11). Noble gases measured in 5 subsamples from DaG 400 show that this meteorite has very small amounts of solar noble gases, comparable to those measured in MAC88104/5 (Fig. 12).

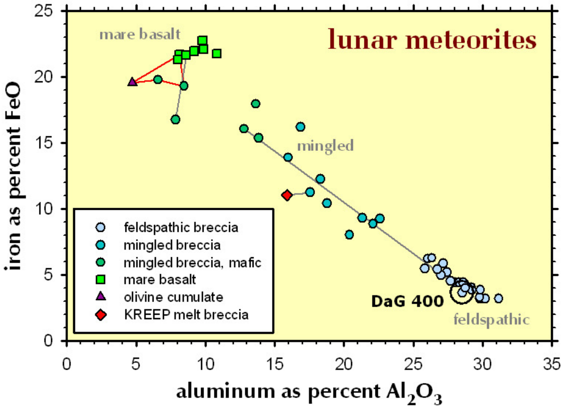

Figure 8: FeO vs. Al_2O_3 for DaG 400 compared to all other lunar meteorites (from Korotev et al., 2003).

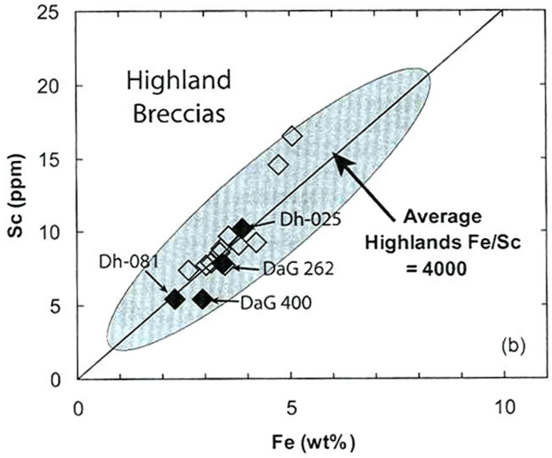

Fig. 9: Sc vs. Fe for DaG 400 compared to other highland breccias and the average highlands Fe/Sc ratio of 4000 (from Cahill et al., 2004).

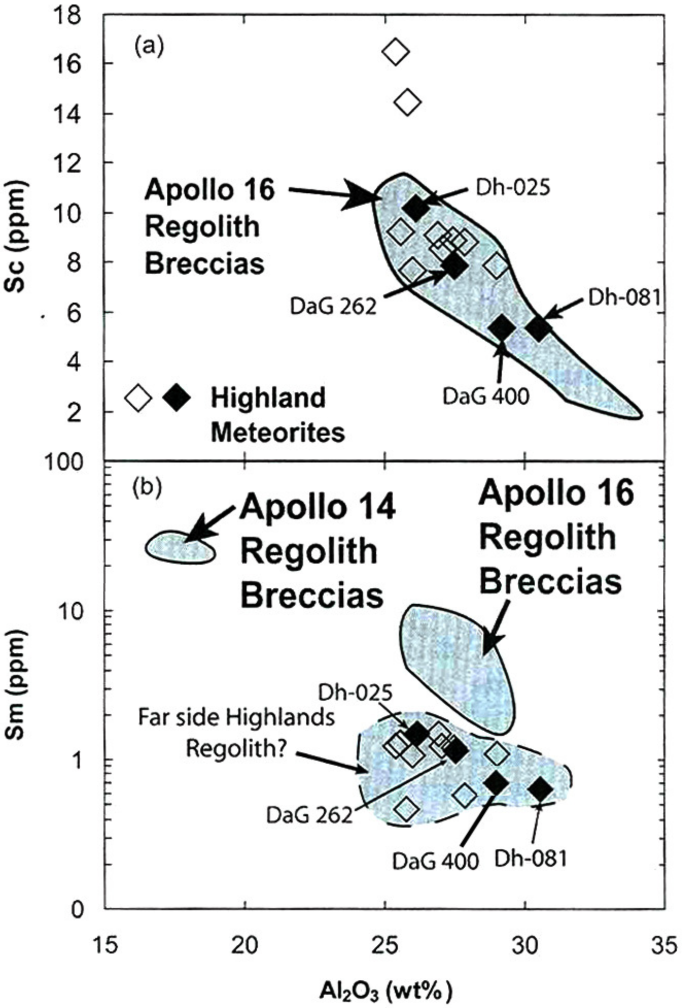

Fig. 10: Sc and Sm vs. Al_2O_3 for DaG 400 compared to other lunar highlands meteorites, Apollo 1`5 and 14 regolith breccias (modified from Cahill et al., 2004).

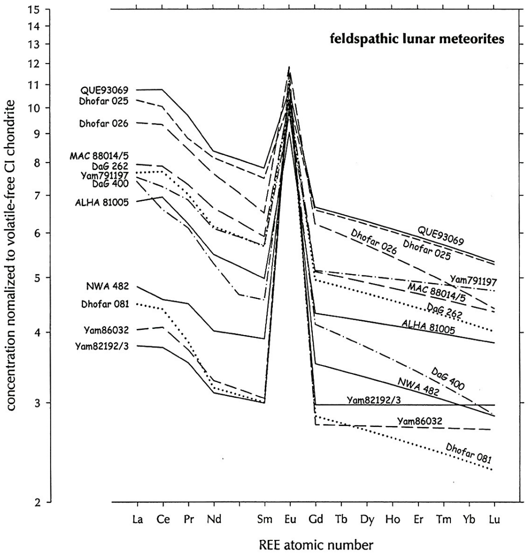

Fig. 11: Rare earth element pattern for DaG 400 compared to other lunar feldspathic meteorites (from Korotev et al., 2003).

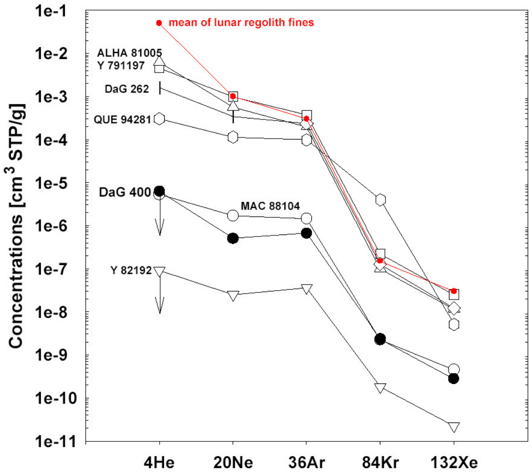

Figure 12: Noble gas isotopes for DaG 400 showing low concentrations relative to many other feldspathic lunar meteorites (from Scherer et al., 1998).

Table 1: Chemical composition of DaG 400

reference	1	2	3	3	4	5
weight	146		92.7	20		
method	e	e	e	d	e	a,b
SiO_2 %	43.00			43.5	43.4	41.42
TiO_2	0.14	0.18		0.18	0.23	0.17
Al_2O_3	27.01	29.2		28.8	28.6	27.76
FeO	3.72	3.78	3.4	3.62	3.52	3.61
MnO	0.07	0.05		0.07	0.06	0.07
MgO	4.81	5.14		4.62	3.8	4.84
CaO	19.87	17.4	17	18.44	18.7	17.24
Na_2O	0.32	0.32	0.33	0.34	0.33	0.39
K_2O	0.08	0.07	0.06	0.09	0.1	0.08
P_2O_5		0.11		0.22		0.42
S %						
sum	99.01			99.66	98.74	95.58
Sc ppm	6.4	5.4	5.99			7
V	23					18
Cr	500	550	520	547		527
Co	15.1	14	13.84			15
Ni	160	113	132			143
Cu						16
Zn						5

Ga	2.9			3.66
Ge				
As	1.02		0.79	
Se				
Rb			<2	0.882
Sr	300	190	268	451
Y				10
Zr	<24		28	40
Nb				2.26
Mo				0.945
Ru				
Rh				
Pd ppb				
Ag ppb				
Cd ppb				
In ppb				
Sn ppb				
Sb ppb	72		151	
Te ppb				
Cs ppm	0.066		0.043	0.022
Ba	820	140	257	1203
La	2.5		2.22	3.52
Ce	5.3		5.52	7.62
Pr				1.07
Nd	2.6		3.3	4.85
Sm	0.93		0.894	1.33
Eu	0.78		0.717	1.02
Gd				1.48
Tb	0.21		0.18	0.266
Dy	1.36			1.62
Ho	0.25			0.342
Er				1
Tm				0.141
Yb	0.73		0.689	0.903
Lu	0.078		0.096	0.129
Hf	0.65		0.628	0.691
Ta	0.107		0.12	0.195
W ppb			2000	
Re ppb				
Os ppb				
Ir ppb	5.3	4	4.2	
Pt ppb				
Au ppb	2.3		26	
Th ppm	0.37		0.302	
U ppm	0.58		0.29	

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 DaG 400

Li ppm	6

Be			0.294
C			
S			
F ppm			
Cl			
Br	3.6	1	
I			
Pb ppm			1.35
Hg ppb			
Tl			0.105
Bi			

References: 1) Warren et al. (2005); 2) Zipfel et al. (1998); 3) Korotev et al. (2003); 4) Semanova et al. (2000); 5) Joy et al. (2006)

Radiometric age dating

Bogard and Garrison (2000) studied bulk DaG 400 material and found that the ages derived depend upon the assumed ^{40}Ar/^{36}Ar of trapped Ar. Ages no higher than 3.8 Ga are derived assuming a range of reasonable ^{40}Ar/^{36}Ar trapped (Fig. 13). This is suggestive of a resetting age due to the spike in flux thought by many to be a lunar cataclysm. In additional studies of DaG 400, Cohen et al. (2005) using laser heating of micro-cored and extracted individual clasts, resulted in three distinct groupings of ages for 16 samples. These groupings at approximately 2.6, 3.0 and 3.4 Ga may represent evidence for three different impact events on the Moon, all post-dating the late heavy bombardment at 3.85 Ga.

Cosmogenic exposure ages

There are very few constraints on the regolith residence time, Moon-Earth transfer time and terrestrial age of DaG 400, but the measurements of Scherer et al. (1998) have allowed an upper limit estimate of 3 Ma and 1 Ma for the residence age and transfer time, respectively.

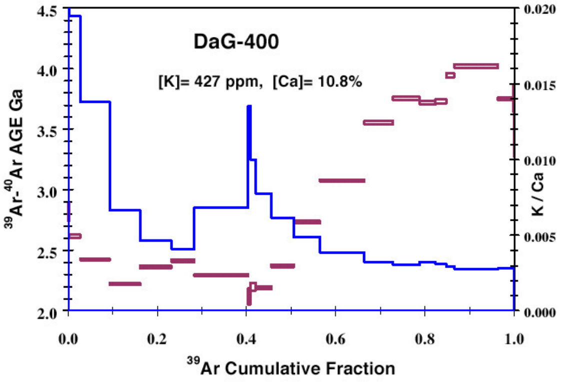

Figure 13: ^{39}Ar-^{40}Ar age (Ga) and K/Ca vs. ^{39}Ar cumulative fraction for a bulk sample of DaG 400, from the study of Bogard and Garrison (2000).