XIV. Dar al Gani 476/489

Basalt, 8 fragments, 6 + kg

Apparent strewn field *(with more likely to be found!)*

Figure XIV-1. *Field photo of Dar al Gani 476. Sample size is ~ 15 by 10 cm. Note the desert varnish, olivine phenocrysts and general "luster". Photo kindly supplied by Jutta Zipfel.*

Introduction

DaG 476 was found on May 1, 1998 in the Dar al Gani region of the Libyan Sahara (Zipfel *et al*. 2000) and weighs 2015 grams (figure XIV-1). A second large fragment, **DaG 489** (2146 g) was also found in 1997 or 1998 (Folco *et al.* 2000)(figure XIV-9). The region is located 27°N - 16°E, between the cities of Zillah, Sabha and Tmassah (Schluter *et al.* 2002). A third fragment, **DaG 670** (1619 g) was found in 1999 (Folco and Franchi 2000). It was found broken in three pieces (688 g, 610 g and 321 g). Two smaller fragments **DaG 735** and **DaG 876** were reported from the same region by Bartoschewitz and Ackermand (2001). **DaG 975** (27 g) is also likely paired with DaG 476 (Russell *et al.* 2003). Thus, this region appears to be a 'strewn field', where more fragments of the same fall might be recovered. The surfaces of these fragments have no fusion crust, and some sides have brown desert varnish. Some fractures contain calcite due to desert weathering.

Petrography

Dar al Gani 476 (and its paired companions) is a basaltic shergottite composed of olivine phenocrysts/megacrysts (up to 5 mm) set in a fine-grained groundmass of pyroxene, maskelynitized plagioclase and mesostasis (figure XIV-2). Goodrich (2003) termed this rock type Olivine-phyric Shergottite (see table I-1). The modal mineralogy of DaG 476 is about 60% pyroxene, 15% olivine, 15% feldspathic glass, 3% opaques, 5% 'impact melt pockets', and with 1-2% carbonate. Minor phases reported include chromite, ilmenite, whitlockite, Cl-apatite, pyrrhotite with Ni-rich exsolutions and perhaps "iddingsite".

Brief descriptions of the bulk hand specimens can be found in Zipfel *et al.* (2000), Folco *et al.* (2000) and Mikouchi *et al.* (2001).

Figure XIV-2. Photomicrograph of thin section of Dar al Gani 476 showing olivine phenocrysts in basaltic texture. Photo kindly provided by Jutta Zipfel.

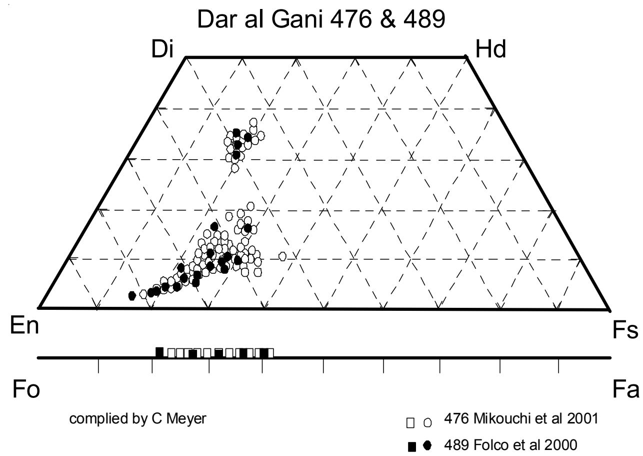

***Figure XIV-3**: Pyroxene and olivine composition diagram for Dar al Gani 476 and 489 (data replotted from Mikouchi et al. 2001 and Folco et al. 2000). See also Zipfel et al. (2000)*

The eight fragments of DaG are similar to one another as well as to SaU and to EETA79001, lithology A (Wadhwa *et al*. 2001). The olivine/pyroxene 'megacrysts' within these melts are also similar. Wadhwa *et al*. (2001) and others make the case that the megacrysts may not be true xenocrysts.

Large pockets of brownish-colored recrystallized impact glass are found associated with pyroxene and olivine (Zipfel *et al.* 2000).

Mineral Chemistry

Olivine: Olivine is typically present as large subhedral crystals, sometimes embayed by the groundmass minerals, suggesting reaction with the groundmass magma (Mikouchi *et al*. 2001). The composition is zoned from Fo_{76} (core) to Fo_{58} (rim). MnO is correlated with FeO and zoned from 0.4 to 0.8% (FeO/MnO = 50). The most mafic olivine is Fo_{74} for DaG 476 (Zipfel *et al.* 2000) and/or Fo_{80} for DaG 489 (Folco *et al.* 2000). Mikouchi *et al.* (2001) have also studied Ca, Cr and Ni contents of olivines in DaG and Herd *et al.* (2000, 2001) have analyzed for Ni, Co, Mn, Sc, V, Cr and Ti by ion microprobe.

Pyroxene: Low-Ca pyroxene is zoned from $En_{76}Fs_{21}Wo_3$ to $En_{58}Fs_{30}Wo_{12}$. Augite is $En_{50}Fs_{18}Wo_{32}$ (see figure XIV-3). Some low-Ca pyroxene (othropyroxene?) is relatively Mg-rich (Zipfel *et al.* 2000, Folco *et al.* 2000; Mikouchi *et al.* 2001). REE abundances of orthopyroxene megacrysts are consistent with their origin as xenocrysts rather than as phenocrysts (Wadhwa *et al*. 2001).

Feldspar: Plagioclase glass (maskelynite) is An_{70-50} (most An_{60+}).

Phosphate: Merrillite is homogeneous $Ca_{8.85}(Mg,Fe)_{1.05}Na_{0.27}(PO_4)_7$ (trace F = 0.6%). Merrillite has been analyzed for REE by Wadhwa *et al*. (2001).

Opaques: Euhedral chromite, Ti-chromite and rare ilmenite are found and have been analyzed by Zipfel *et*

Mineralogical Mode (vol. %)

	Zipfel *et al.* (2000)		**Mikouchi *et al.* (2001)**	**Folco *et al.* (2000)**	**Wadhwa *et al.* (2001)**	
Olivine	14	17	24	20	10.4	17.8
Pyroxene	58	60	59	54	64.6	55.3
Plagioclase glass	17	14	12	17	14.4	15.7
Opaques	3.8	2.6	2	3	1	0.9
Phosphate	tr		1	1	1	1.5
Impact melt glass	4.5	4.0		4	7.2	5.7
Carbonate	2.7	2.2		1	1	3.1

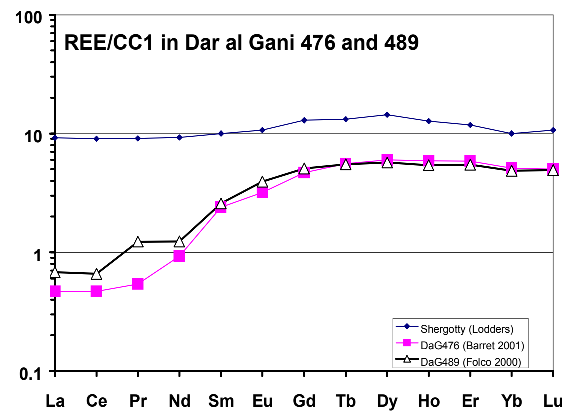

Figure XIV-4: Normalized rare earth element diagram for Dar al Gani 476, 489 and Shergotty (data replotted from Folco et al. 2000, Barrat et al. 2001 and Lodders 1998).

al. (2000), Wadhwa *et al.* (2001) and Herd *et al.* (2002). The chromites and ilmenite in DaG are high in MgO ~ 4.3 % (Zipfel *et al.* 2000).

Carbonates: Zipfel *et al.* (2000) found that the veins in DaG 476 contained "carbonates". Nearly pure calcite is reported by Mikouchi *et al.* (2001).

Iddingsite: Greshake and Stoeffler (1999) and Mikouchi *et al.* (2001) report trace "iddingsite" on the rims of some of the olivine grains.

Barite: Rare grains of $BaSO_4$, typically associated with carbonate, were reported by Zipfel *et al.* (2000).

Whole-rock Composition

Zipfel *et al*. (2000), Folco *et al*. (2000) and Barrat *et al.* (2001) have determined the chemical composition (table XIV-1). DaG 476 is ultramafic (high mg*) and light-rare-earth-element depleted (figure XIV-4). DaG 476 is also depleted in Rb, Nb, Cs, Ta and Th (figure XIV-5). Chemically, DaG 476 is more like lherzolitic shergottites than basaltic shergottites.

The relatively high C and S in the analyses of DaG 476 indicate weathering products (calichi). Barrat *et al.* (2002) use Ba/La and Sr/Nd ratios to show that DaG 476 and 489 have been chemically altered by terrestrial weathering. These samples also have very high U compared to Th, which is another characteristic of terrestrial weathering (figure XIV-6).

Radiogenic Isotopes

Borg *et al*. (2000), determined the age of DaG by Sm-Nd to be 474 ± 11 Ma (figure XIV-7), which is

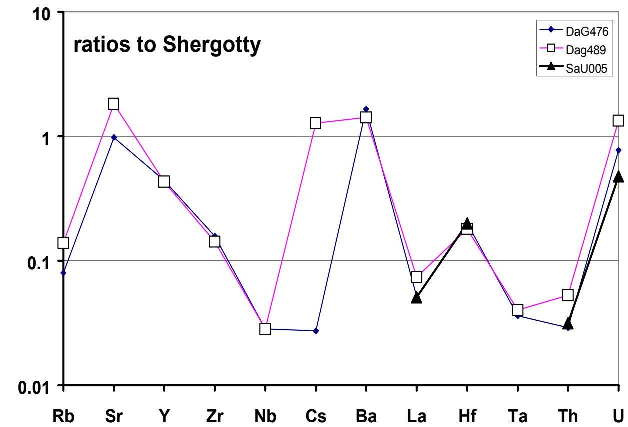

Figure XIV-5: Trace element composition of DaG and SaU samples divided by that of Shergotty (data from dependable sources). Note the depletion in Rb, Nb, Cs, Ta, Th - as well as in LREE.

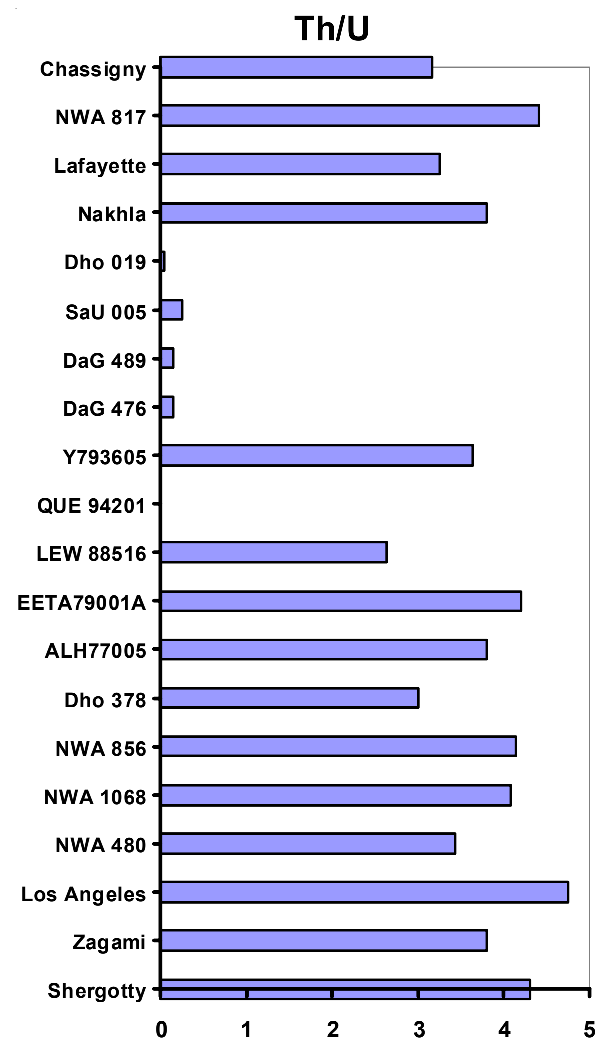

Figure XIV-6: Th/U ratios of Martian meteorites (data from dependable sources). Note that desert meteorites have reativley low Th/U due to adsorbtion of U from ground water.

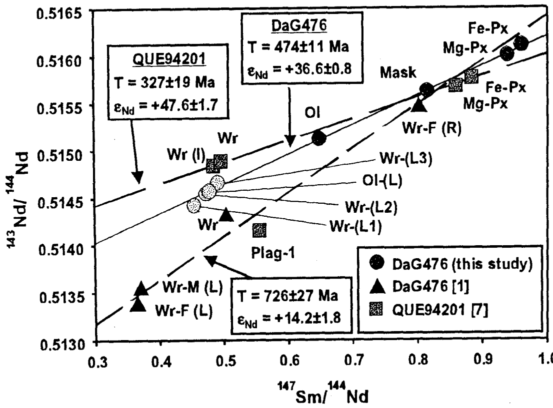

*Figure XIV-7: Sm-Nd internal mineral isochron for Dar al Gani 476 (from Borg et al. 2000; **LPSC XXXI**).*

significantly younger than the age determined by Jagoutz *et al*. (1999) (703 ± 24 Ma). Borg *et al.* (2000) found that the Rb-Sr systematics could not be used to determine an age, because of the extensive terrestrial weathering effects. Crozaz and Wadhwa (2001) urge caution when using whole rock, or even mineral separates, for isotopic studies, because of the 'extreme weathering effects' they observe in samples of DaG.

Cosmogenic Isotopes and Exposure Ages

Zipfel *et al*. (2000) gave ^{21}Ne exposure age of 1.26 ± 0.09 Ma. Nishiizumi *et al*. (2001) determined the exposure age from ^{21}Ne to be 1.05 ± 0.10 Ma and the terrestrial age is 60 ± 20 Ka. Park *et al*. (2001) determined a ^{21}Ne exposure age of 0.75 Ma for DaG 489. Park *et al.* (2003) determined T_3, T_{21}, and T_{38} and calculate ejection age 1.08 Ma.

Other Isotopes

Nishizumi *et al.* (2001) determined the activity of ^{10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca and ^{14}C for four different fragments of DaG. Garrison and Bogard *et al*. (2001) report measurements of Ar isotopes.

Franchi *et al.* (1999) and Folco *et al*. (2001) report Δ^{17}O of +0.316‰ and +0.305‰ for DaG 476 and 489 respectively (*see* Appendix VI).

Weathering

Zipfel *et al.* (2000) noted that the part of DaG 476 that was in contact with the soil was partially covered by calichi (terrestrial weathering) and that the slices were cross cut by a 2 mm thick carbonate vein. "At the contact with this vein, the meteorite is discolored" (Zipfel *et al.* 2000).

A study of terrestrial weathering and 'caliche' has been done by Dreibus *et al*. (2001). Crozaz and Wadhwa (2001) find that the olivine and pyroxenes in DaG are enriched in light REE, Ba, Sr and Cs due to terrestrial weathering, and 'urge caution' when using whole rock, or mineral separates for isotopic data. Indeed, since these samples were extremely low in trace elements (when they left Mars), they are very sensitive to contamination by terrestrial U and Ba (figures XIV-6 and XIV-8)!!

Processing

The main masses of these meteorites are owned by the 'anonymous finders' (Grossman 1999, 2000). Pictures of DaG 489, and how it was sampled, are shown in Folco *et al*. (2000).

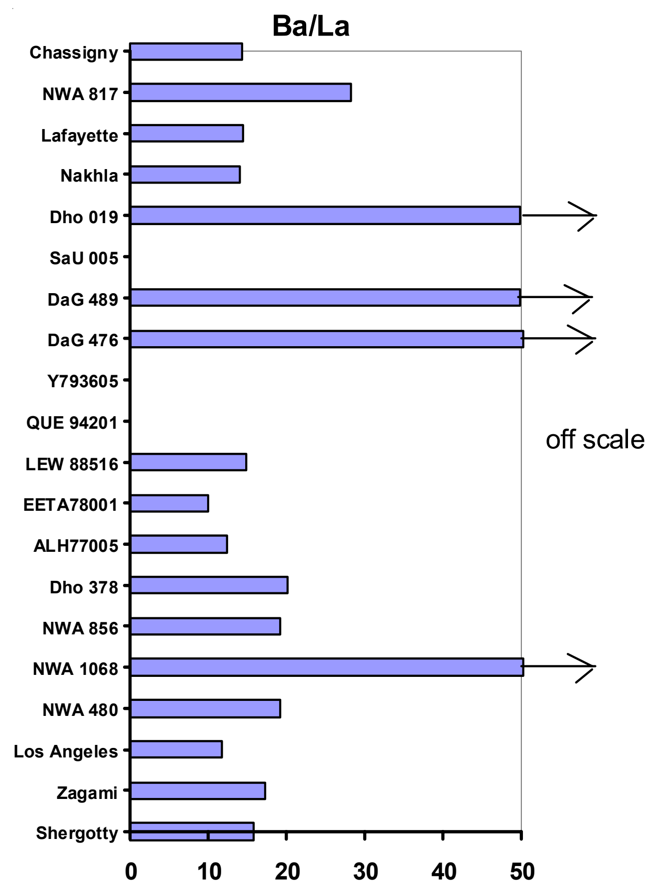

Figure XIV-8: Ba/La ratios for various Martian meteorites. Meteorites found in desert regions often have Ba/La ratios that are off-scale! (data plotted from dependable sources).

Table XIV-1. Chemical composition of Dar al Gani 476.

reference	Zipfel (abs)	Zipfel 2000		Zipfel 2000		Zipfel 2000		Barrat 2001		Barrat 2001		Barrat 2001		Folco 2000	
weight		*66.1 mg.*		*191.5 mg.*		*232 mg.*		*93.7 mg.*		*62.2 mg.*		*138.2 mg.*		*1.5 grams*	
SiO2	48.91					45.76	(b)							47.72	(b)
TiO2		0.38	(a)	0.42	(a)	0.39	(b)	0.33	(e)	0.41	(e)	0.38	(e)	0.35	(b)
Al2O3		4.42	(a)	4.35	(a)	4.37	(b)	4.53	(e)	4.96	(e)	4.17	(e)	4.19	(b)
FeO	17.17	16.1	(a)	16.1	(a)	16.06	(b)	16.12	(e)	15.39	(e)	16.43	(e)	16.52	(b)
MnO		0.43	(a)	0.42	(a)	0.45	(b)	0.47	(e)	0.47	(e)	0.48	(e)	0.394	(b)
CaO	5.84	8.68	(a)	7.25	(a)	7.66	(b)	7.28	(e)	7.48	(e)	7.57	(e)	7.83	(b)
MgO	20.75	18.6	(a)	19	(a)	19.41	(b)	19.18	(e)	18.12	(e)	19.24	(e)	19.36	(b)
Na2O		0.5	(a)	0.51	(a)			0.71	(e)	0.7	(e)	0.66	(e)	0.55	(c)
K2O		0.05	(a)	0.04	(a)	0.038	(b)							0.033	(c)
P2O5						0.32	(b)							0.49	(b)
sum						**94.458**								**97.437**	
Li ppm														2.6	(d)
C	4700			4700	(f)										
S	2700			2700	(f)										
Cl		<840	(a)												
Sc	29.9	30.6	(a)	29.9	(a)			32	(d)	34	(d)	29	(d)	28	(d)
V		182	(a)	186	(a)									171	(d)
Cr	5704													4603	(d)
Co	51.1	52.1	(a)	51.1	(a)			49	(d)	46.5	(d)	51.3	(d)	50	(d)
Ni	300	220	(a)	300	(a)			225	(d)	211	(d)	230	(d)	214	(d)
Cu		<80	(a)	<90	(a)			8.5	(d)	8.4	(d)	8.3	(d)	6.7	(d)
Zn	66	51	(a)	66	(a)			44	(d)	61	(d)	49	(d)	49	(d)
Ga	8.7	8.5	(a)	8.7	(a)			8.56	(d)	9.08	(d)	7.97	(d)		
Ge															
As		0.51	(a)	0.24	(a)										
Se		<0.9	(a)	0.4	(a)										
Br		0.72	(a)	1.29	(a)	**Borg et al.**									
Rb		<4	(a)	<3	(a)			1.19	(d)	0.66	(d)	0.51	(d)	0.89	(d)
Sr								70	(d)	47	(d)	47	(d)	87	(d)
Y								7.99	(d)	9.2	(d)	8.37	(d)	8.2	(d)
Zr								9.19	(d)	10.1	(d)	9.02	(d)	8.1	(d)
Nb								0.18	(d)	0.16	(d)	0.13	(d)	0.13	(d)
Mo														0.18	(d)
Sb ppb		<30	(a)	<30	(a)										
Cs ppm								0.02	(d)	0.013	(d)	0.012	(d)	0.56	(d)
Ba		84	(a)	73	(a)			36.4	(d)	74.3	(d)	55.7	(d)	48	(d)
La		0.09	(a)	0.12	(a)			0.157	(d)	0.121	(d)	0.111	(d)	0.16	(d)
Ce								0.372	(d)	0.327	(d)	0.286	(d)	0.4	(d)
Pr								0.06	(d)	0.062	(d)	0.049	(d)	0.11	(d)
Nd				<0.5	(a)			0.42	(d)	0.494	(d)	0.422	(d)	0.56	(d)
Sm		0.31	(a)	0.39	(a)			0.304	(d)	0.391	(d)	0.352	(d)	0.38	(d)
Eu		0.17	(a)	0.17	(a)			0.186	(d)	0.201	(d)	0.179	(d)	0.22	(d)
Gd								0.751	(d)	0.967	(d)	0.922	(d)	1	(d)
Tb		0.16	(a)	0.2	(a)			0.163	(d)	0.227	(d)	0.204	(d)	0.2	(d)
Dy		1.6	(a)	1.3	(a)			1.23	(d)	1.59	(d)	1.46	(d)	1.38	(d)
Ho		0.2	(a)	0.3	(a)			0.282	(d)	0.352	(d)	0.328	(d)	0.3	(d)
Er								0.798	(d)	1	(d)	0.932	(d)	0.87	(d)
Tm														0.13	(d)
Yb		0.73	(a)	0.81	(a)			0.746	(d)	0.942	(d)	0.83	(d)	0.79	(d)
Lu		0.12	(a)	0.13	(a)			0.115	(d)	0.142	(d)	0.122	(d)	0.12	(d)
Hf		0.32	(a)	0.39	(a)			0.34	(d)	0.42	(d)	0.4	(d)	0.36	(d)
Ta		<0.03	(a)	<0.02	(a)			0.011	(d)	0.012	(d)	0.009	(d)	0.01	(d)
W ppb		<200	(a)	<300	(a)	**Brandon 2000**		40	(d)	20	(d)	20	(d)	240	(d)
Re ppb						0.505		0.633							
Os ppb						1.546		2.008							
Ir ppb		<6	(a)	<2.5	(a)										
Au ppb		<1	(a)	2.1	(a)										
Tl ppb														0.02	(d)
Th ppm		<0.1	(a)	<0.08	(a)			0.025	(d)	0.016	(d)	0.011	(d)	0.02	(d)
U ppm		0.12	(a)	0.09	(a)			0.107	(d)	0.063	(d)	0.081	(d)	0.14	(d)

technique (a) INAA, (b) XRF, (c) AA, (d) ICP-MS, (e) ICP-AES, (f) C, S analysers

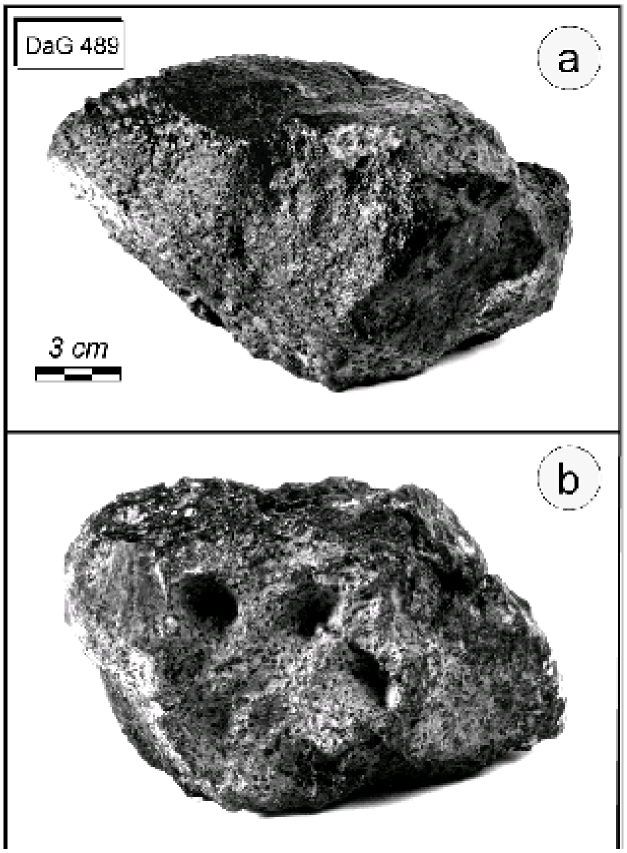

Figure XIV-9: *Photographs of Dar al Gani 489 kindly provided by Luigi Folco (see Folco et al. 2000). (a) DaG 489 is devoid of fusion crust, but has a dark brown film of desert varnish. (b) surface once buried in sand showing porphyritic texture. The cm-sized hollows are wind-carved remnants of regmaglypts.*

Figure XIV-10. *Photograph of DaG670 kindly provided by Matteo Chinellato. Cube is 1 cm.*

Figure XIV-11. *Dar al Gani in Sahara desert. Dark-colored meteorites can apparently be found in abundance in this region, due to preservation in dry conditions, extreme deflation, and contrast with light-colored local rocks (Schultz 1998 and Schultz et al. 1999).*