Calcalong Creek

Basalt-bearing anorthositic (polymict) regolith breccia

19 g

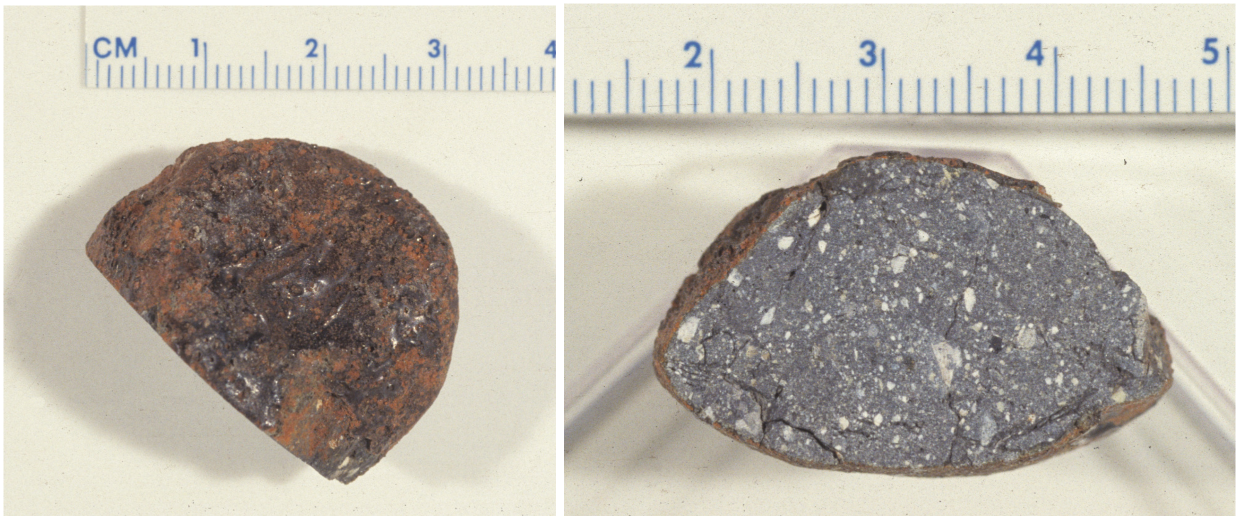

Figure 1: Left: Exterior photo of Calcalong Creek showing the shiny fusion crust as well as some rusty regions from terrestrial weathering. Right: Interior photo of Calcalong Creek showing many clasts and mineral fragments. In both images is shown a 4 cm scale bar. Photos courtesy of D. Hill.

Introduction

Calcalong Creek (Fig. 1) was found in 1990 in the Nullarbor Plain of South Australia (Fig. 2). This ~ 3 cm, 19 g single stone was 100% fusion crusted, and was the first recognized lunar meteorite from a desert locality. In hand sample it is clearly a polymict breccia with sub mm clasts welded by a glassy vesicular matrix (Fig. 3).

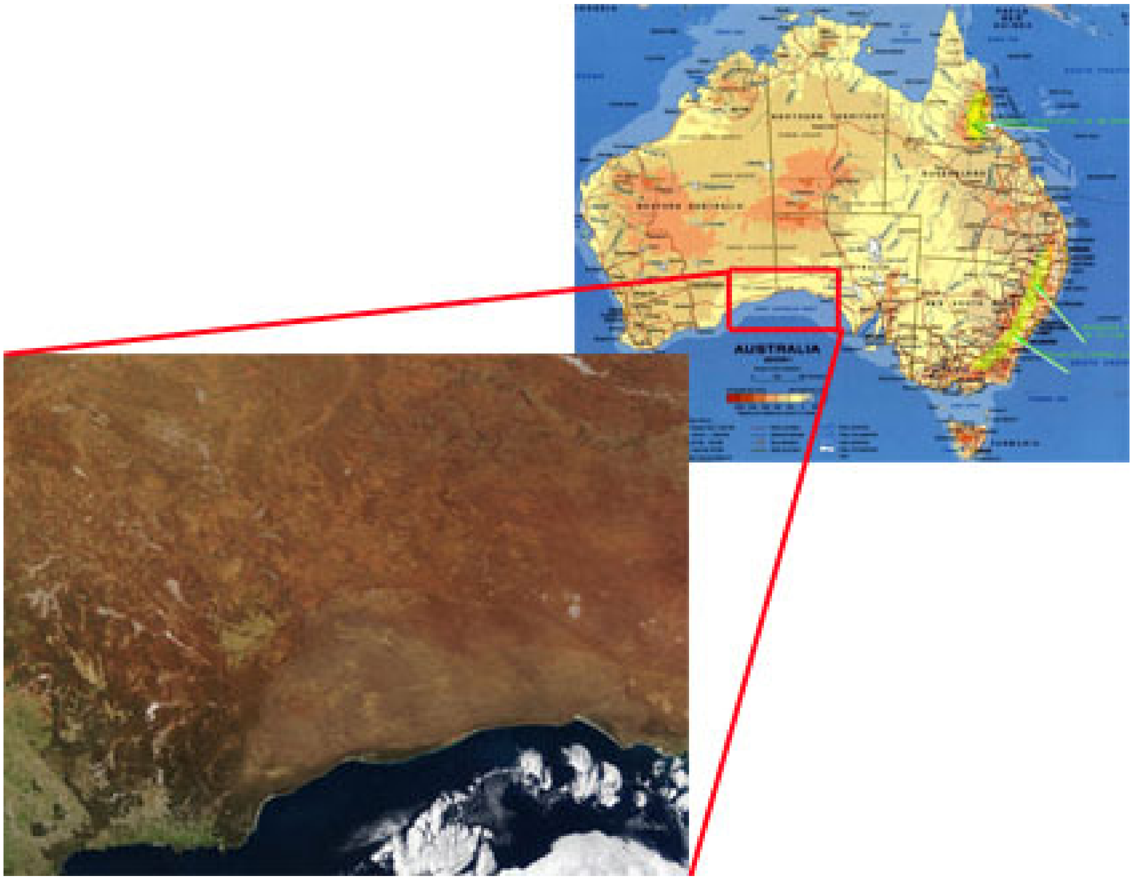

Figure 2: Location of the Nullarbor Plain in South Australia, where Calcalong Creek and many other meteorites have been found in the desert (Bevan et al., 2002).

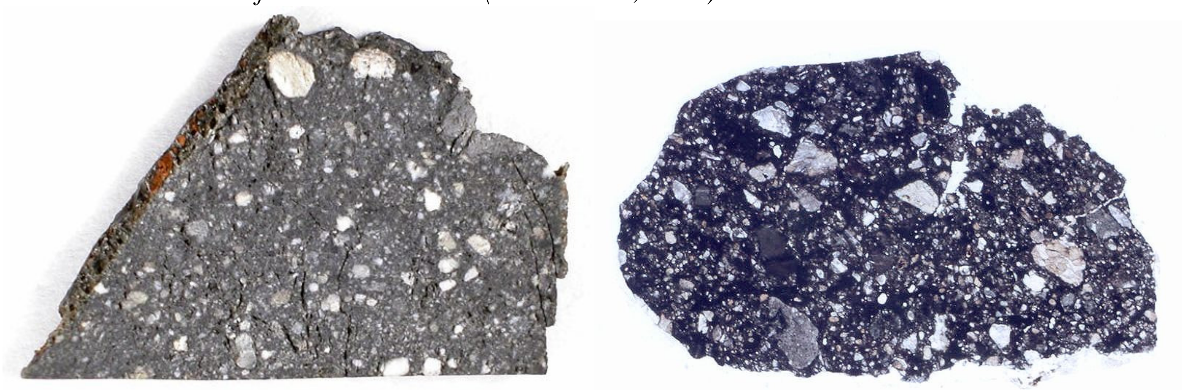

Figure 3: A small slab (left) and thin section (right) of Calcalong Creek illustrating the sizes of the small clasts and the preponderance of matrix.

Petrography and mineralogy

Calcalong Creek is comprised mainly of dark glassy matrix (Fig. 3), but contains a variety of clast types and mineral fragments, dominated by highlands lithologies, such as anorthosites, gabbroic anorthosite, spinel troctolite, and KREEP basalt (Marvin and Holmberg, 1992; Hill and Boynton, 2003). In addition, many of the mineral fragments are similar in composition to Fe-rich basalt material (fayalite, pyroxferrite, ferro-hedenbergite, ferro-augite, silica and troilite). X-ray maps show the modal mineralogy to be 26% plagioclase, 60% pyroxene, 2% olivine, < 1% of k-spar, ilmenite, whitlockite, troilite, and chromite, and 11% vesicles (Hill and Boynton, 2003).

Chemistry

Four small bulk splits and several individual clasts of Calcalong Creek have been analyzed (Table 1; Hill and Boynton, 2003). Major element compositional characteristics of Calcalong Creek are similar to other mingled breccias in that it has intermediate values of FeO and TiO_2 (Fig. 4). Other major and trace element characteristics also point toward a mixed or mingled origin for Calcalong Creek. For example, Sm, Th and Al_2O_3 characteristics of the bulk and clast samples show it is intermediate between mare, highlands, and KREEP end members (Fig. 5). Similarly, Eu, Ga, Al, Na, Ca, and Mg# diagrams show that many of the clasts are of highlands nature, but that the bulk composition is more intermediate (Fig. 6). Clast F of the Hill and Boynton (2003) study is clearly KREEP-like (Fig. 6). Rare earth elements and incompatible elements are high in the bulk sample analyses, and it also exhibits a negative Eu anomaly (Figs 7 and 8). On the other hand, Calcalong Creek REE concentrations are not as high as SaU169 or KREEP samples. Finally, siderophile element concentrations are high in Calcalong Creek, with Re and Os close to chondritic levels, and Ir, Ni, Co and Au between 0.01 and 0.1 chondritic values consistent with mature regolith (Fig. 9).

Comparison of lunar meteorite bulk compositions to the Lunar Prospector Gamma Ray Spectrometer data have enabled Corrigan et al. (2009) to propose that Calcalong Creek (as well as Dhofar 961 and Yamato 983885) could be from the South Pole Aitken (SPA) basin region of the Moon. In particular the high Si and low Mg of Calcalong Creek and SPA are good matches.

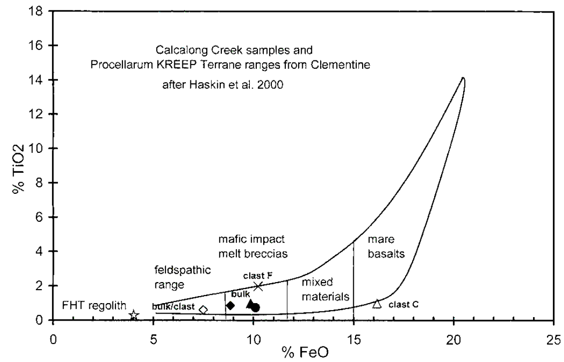

Figure 4: FeO vs. TiO_2 for bulk and clast analyses from the study of Hill and Boynton (2003).

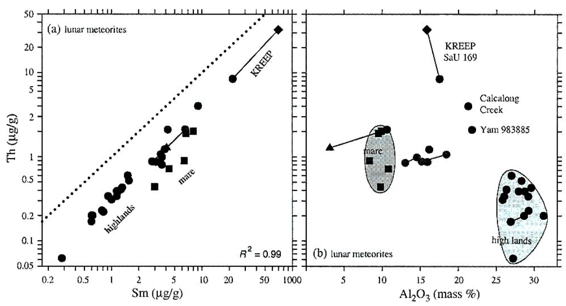

Figure 5: Th-Sm-Al_2O_3 systematics of Calcalong Creek compared to mare, highlands, and KREEP samples (from Korotev, 2005).

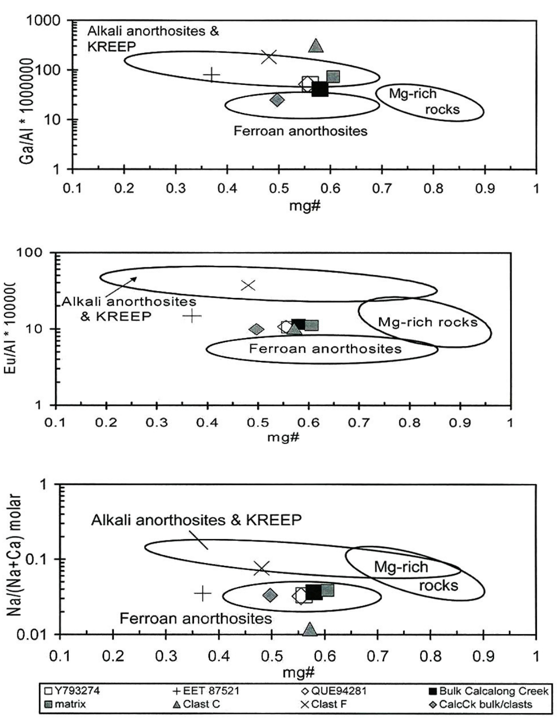

Figure 6: Eu, Ga, Al, Na, Ca and Mg# characteristics of Calcalong Creek bulk and clasts compared to mare, highlands, and KREEP samples (from Hill and Boynton, 2003).

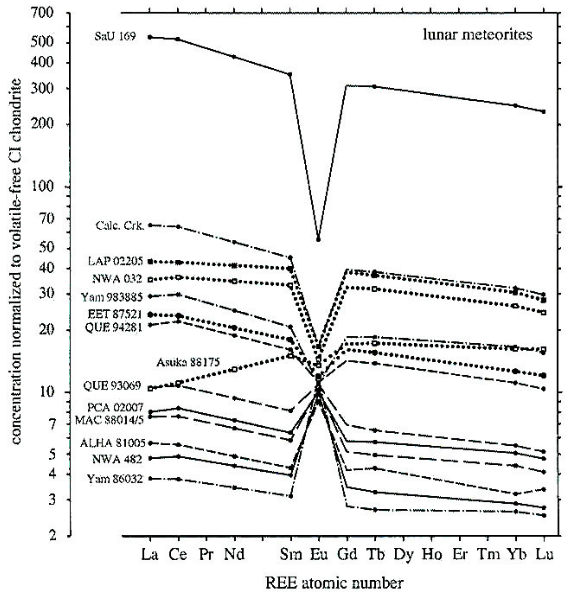

Figure 7: Rare earth element characteristics of Calcalong Creek compared to other feldspathic lunar meteorites (from Korotev, 2005).

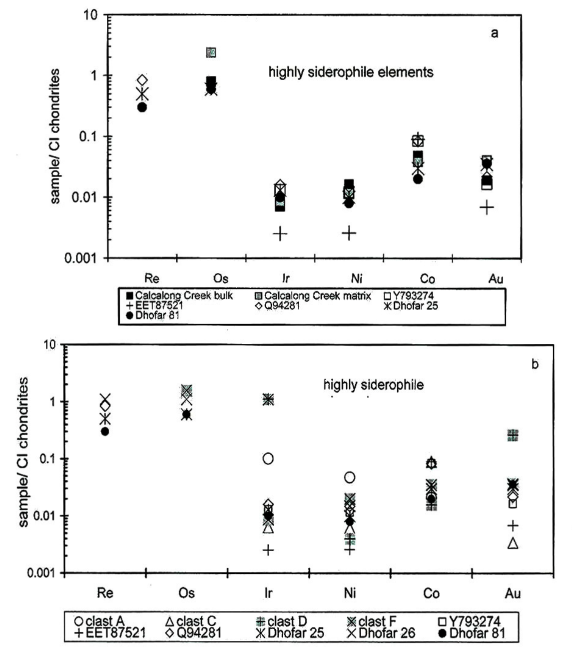

Figure 9: Siderophile elements of Calcalong Creek bulk and clasts compared to several other lunar meteorites (from Hill and Boynton, 2003).

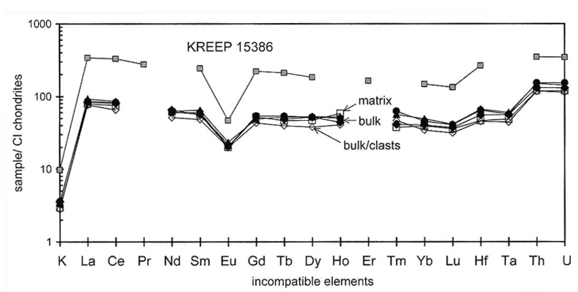

Figure 8: Incompatible lithophile elements of Calcalong Creek bulk and clasts compared to KREEP sample 15386 (from Hill and Boynton, 2003).

Radiometric age dating

No studies are known yet.

Cosmogenic isotope studies

Calcalong Creek has a relatively old lunar exposure age of ~ 3.0 Ma (Nishiizumi et al., 1992, 1995; Swindle et al., 1995). As for other lunar meteorites it has a short transit time (200 Ka), and a young terrestrial age (< 30 Ka; Nishiizumi et al., 1992, 1995; Swindle et al., 1995).

Table 1a. Chemical composition of Calcalong Creek

reference	1	1	1	1	1	1	2	2
weight	18.9	6.1	38.8	avg	3	0.3	208	208
technique	c	c	c	c	c	c	c	e
SiO2 %								47.3
TiO2	0.719	0.964	0.833	0.817	0.605			0.77
Al2O3	21.17	20.26	21.55	20.83	21.94	19.77		20.5
FeO	10.1	9.86	8.84	9.69	7.49	10.98		9.66
MnO	0.15	0.14	0.12	0.14	0.11	0.16		0.14
MgO		6.47	8.12	7.11	4.15	9.45		7.51
CaO	13.73	13.1	13.57	13.31	14.07	13.05		12.9
Na2O	0.48	0.49	0.49	0.49	0.46	0.51		0.44
K2O	0.25	0.23	0.24	0.24	0.19	0.2		0.24
P2O5								0.16
S %								
sum								99.9
Sc ppm	22.49	21.6	17.68	21.24	15.66	24.88	22.3	
V	54	65	48	55.3	47	85		
Cr	1301	1146	1099	1170	835	1752	1260	
Co	25.11	23.97	26.9	24.82	19.55	28.3	25.9	
Ni	273	159	202	180	129	151	113	
Cu								
Zn		5.68	7.2		4.4	5.7		
Ga			4.7	4.7	2.9	7.7		
Ge								
As		0.22	0.12			0.192	0.37	
Se							<1	
Rb	10.1	9	7.7	9.37	6.1	7.29	6	
Sr	141	150.4	153	149.2	160	129	121	
Y								
Zr	250	375	187	354	212	236	253	
Nb								
Mo	1.83	1.72		1.79	1.7	0.94		
Ru								
Rh								
Pd ppb								
Ag ppb								
Cd ppb								
In ppb								
Sn ppb								

Sb ppb							
Te ppb							
Cs ppm	0.37	0.37	0.44	0.367	0.281	0.33	0.29
Ba	224	271	241	257	153	215	208
La	21.09	22.63	20.23	21.83	18.7	19.3	19
Ce	53	54.6	51.6	54.1	41.7	48.3	49.4
Pr							
Nd	28.3	29.7	30.7	29.5	24.27	29.3	29
Sm	9.3	10.02	8.71	9.55	7.41	8.71	8.59
Eu	1.199	1.356	1.282	1.303	1.146	1.162	1.06
Gd	11	10		10.5	8.8	10.7	
Tb	2.01	1.946	1.83	1.941	1.483	1.735	1.76
Dy	13.23	13.4	13.2	13.28	9.64	11.9	
Ho	2.83	2.96	2.49	2.67	2.31	3.3	
Er							
Tm	1.6	1.45	1.06	1.407	1.19	0.96	
Yb	7.52	8.1	6.69	7.5	5.69	6.5	6.71
Lu	1.036	1.05	0.945	1.024	0.796	0.911	0.92
Hf	7.69	7.93	6.58	7.15	5.39	5.5	6.77
Ta	0.966	1.015	0.95	0.991	0.752	0.824	0.9
W ppb	550	800	460	554	660	720	
Re ppb							
Os ppb		400	160	200	1200		
Ir ppb	3	3	6	3	4	3	3.4
Pt ppb							
Au ppb	3	2	6	3	5.9	2	3
Th ppm	4.4	4.303	3.76	4.28	3.36	3.39	3.95
U ppm	1.24	1.15	1.06	1.18	0.92	0.966	1.1

technique (a) ICP-AES, (b) ICP-MS, (c) INAA, (d) Ar, (e) EMPA

Table 1b. Light and/or volatile elements for Calcalong Creek

Li ppm							
Be							
C							
S							
F ppm							
Cl							
Br	0.566	1.67		0.829	0.42	0.22	0.27
I							
Pb ppm							
Hg ppb							
Tl							
Bi							

1) Hill and Boynton (2003); 2) Korotev et al. (2009b)