Sayh al Uhaymir 169

Basalt-bearing anorthositic (polymict) regolith breccia

206.45 g

Figure 1: Sayh al Uhaymir 169 as found in the Oman desert January 16, 2002.

Introduction

SaU169 is a complete, light grey-greenish rounded stone (7.0 × 4.3 × 4.0 cm) weighing 206.45 g, and found in the Sayh al Uhaymir region of Oman (Figs 1 and 2). Dark brown fusion crust is only locally preserved. Impact melt breccia comprises 87 vol% of the stone, and contains 25–40 vol% of strongly shocked noritic and granulitic clasts (up to 17 mm) and fragments, set in a fine-grained (<0.1 mm) crystalline matrix (Fig. 3). Most crystal fragments are shocked plagioclases, locally associated with enstatite. Minor amounts of metallic iron, spinel, olivine, and orthopyroxene clasts are also present. The K/U = 553, Fe/Mn of 75.1, and oxygen isotope composition of $\Delta^{17}O = 0.001 \pm 0.032‰$, all indicate a lunar origin.

Petrography and mineralogy

The fine-grained impact melt matrix consists mainly of short prismatic low-Ca pyroxene ($En_{61–64}$, $Wo_{2–4}$), interstitial plagioclase ($An_{75–81}$) intergrown with potassium feldspar. The remaining minerals are poikilitic ilmenite, whitlockite, olivine ($Fo_{58–59}$), zircon, and traces of troilite, kamacite and tridymite. The regolith (13 vol%) present on one side of the meteorite comprises crystalline and glassy volcanic rocks, igneous lithic fragments, breccia fragments, fragments of mafic granulites, and crystal fragments.

Figure 2: Complete stone of SaU169 showing the fusion crust and also a large clast.

Figure 3: Cut slab of SaU169 illustrating the impact melt breccia (light tan, below) and the regolith breccia (dark brown, above).

Chemistry

SaU169 is very similar in composition to Apollo KREEP impact melt breccias, but has slightly lower Al and Si, and higher Na, Ti and P (Gnos et al., 2003, 2004; Table 1). The impact melt breccia contains 32.7 ppm Th and 8.6 ppm U, 0.47% K, and 1332 ppm total REE, indicating it is more enriched in KREEP elements than any other known lunar rock (Fig. 4, 5 and 6). Th and Sm are higher than all mare and highlands lunar meteorites, and similar to KREEP (Fig. 4). And SaU169 stands alone as an unusual composition of mingled breccia, having intermediate Al_2O_3 like others such as Calcalong Creek, and Yamato 983885, but much higher Th (Fig. 4). Mafic impact melt breccias from Apollo 12 and 14 are close compositionally to the SaU169 impact melt breccia (Fig. 5; Zeigler et al., 2006), and more detailed studies and comparisons of these samples will undoubtedly led to a better understanding of this unusual meteorite. In comparison, the average regolith (Table 1) is similar in composition to Apollo 12, 14 and 15 regoliths, but is not depleted in Na and K. The regolith clast is also KREEP related, but not directly related to the impact melt because it has a higher K/U ratio (1253).

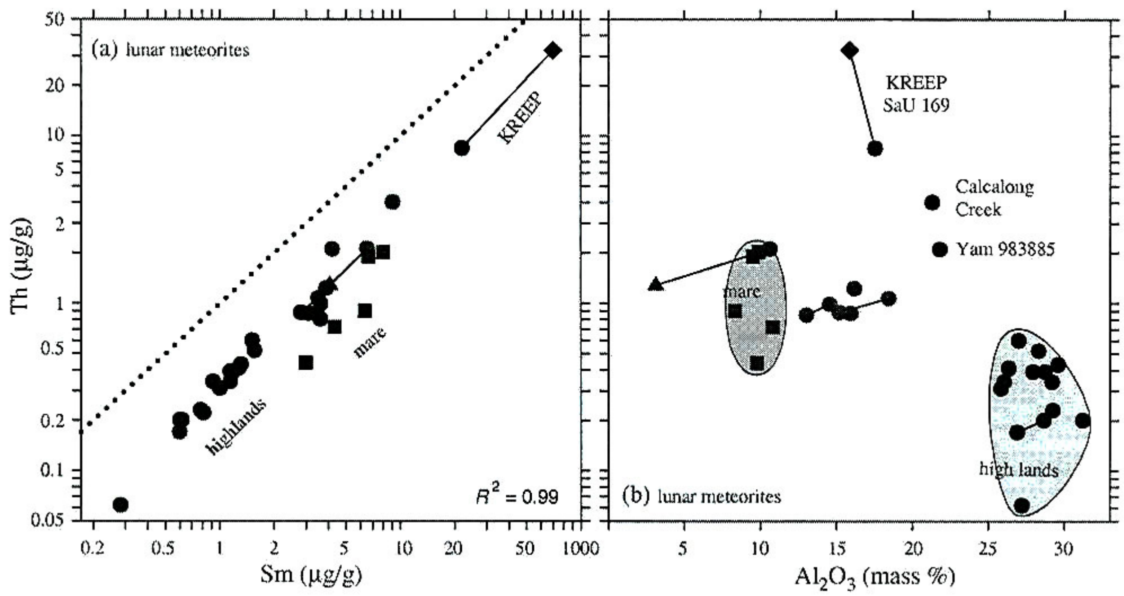
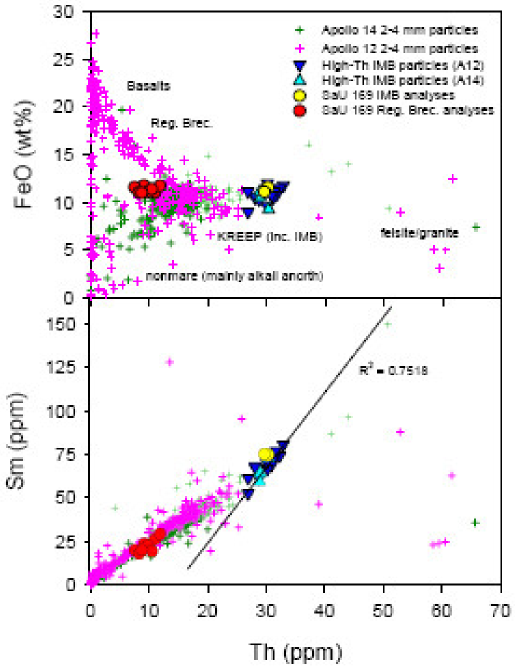


Figure 4: Th-Sm-Al_2O_3 systematics of SaU169 compared to mare, highlands, Calcalong Creek and KREEP samples (from Korotev, 2005).



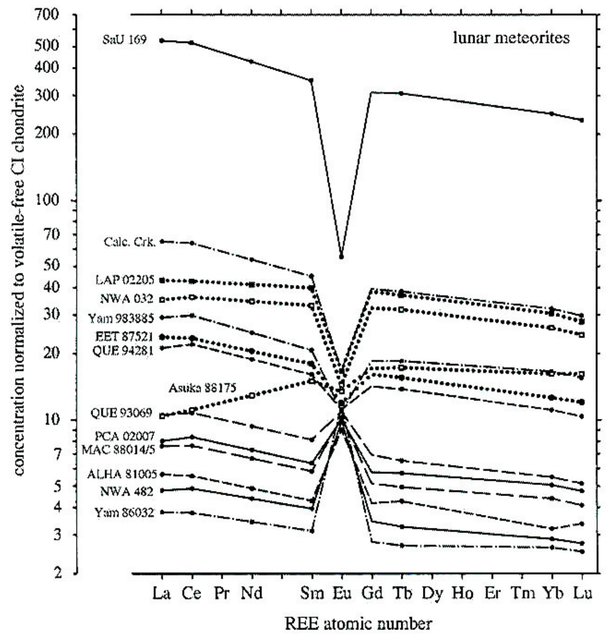


Figure 5 (left): Comparison of SaU169 analyses with those from impact melt breccias from the Apollo 12 and 14 collections (from Zeigler et al., 2006).

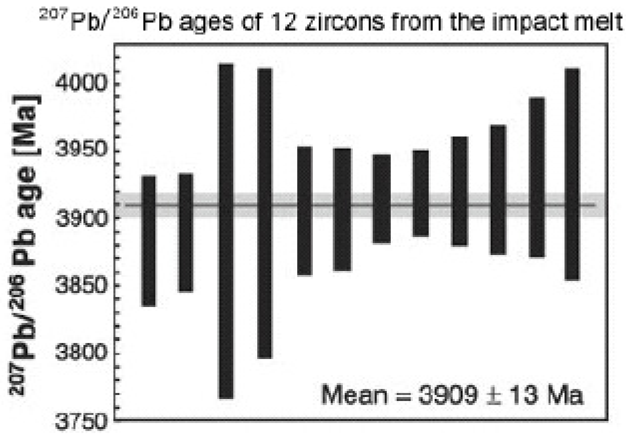
Figure 6 (right): REE pattern for SaU169 illustrating its high concentrations of REE compared to all other lunar meteorites (from Korotev, 2005).

Radiometric age dating

^{39}Ar-^{40}Ar dating of feldspar concentrates from SaU169 yielded a 2800 Ma age, suggesting a resetting event at this time. ^{207}Pb-^{206}Pb isotope ratios were measured on 12 different impact melt zircons and yielded a weighted average age of 3909 Ma (Fig. 7). This age is similar to the age proposed for the Imbrium impact event, and together with the KREEP-rich nature of SaU169 has led Gnos et al. (2004) to propose an origin near the Procellarum KREEP Terrane. Follow up U-Pb ion probe zircon dating studies (Fig. 8) by D. Liu et al. (2009) confirm this age, and these authors go on the propose that the slightly older age for SaU and some Apollo 12 impact melts suggest that there is a distinct impact cratering event from those that formed the Imbrium basin at 3.85 Ga (Liu et al., 2009).

Cosmogenic isotopes

Cosmogenic isotope studies of SaU169 have yielded ^{21}Ne and ^{38}Ar lunar surface exposure ages of 150 to 200 Ma (Gnos et al., 2004). ^{10}Be measurements indicate a short transfer time of < 0.234 Ma, and a terrestrial age of < 9700 yrs. was found using ^{14}C and ^{10}Be (Gnos et al., 2004).



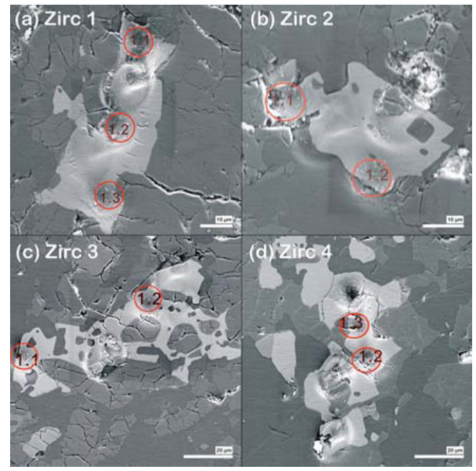


Figure 7 (left): results of $^{207}Pb/^{206}Pb$ dating of 12 zircon grains from the impact melt (from Gnos et al., 2004).

Figure 8 (right): BSE images of zircons analyzed using a SHRIMP II ion microprobe in the study of D. Liu et al. (2009).

Table 1a. Chemical composition of SaU169

				IMB	IMB	reg Br	reg Br
reference	1	1	1	2	2	2	2
weight	827	185	117	20-60	98	20-60	296
technique	c	c	c	e	c	e	c
SiO2 %	45.15	46.9		45.5		47.2	
TiO2	2.21	2.49	1.47	2.3		2.52	
Al2O3	15.88	17.54	16.34	15.2		16.8	
FeO	10.67	11.09	8.8	11.38	11.38	11.35	11.44
MnO	0.14	0.14	0.12	0.15		0.16	
MgO	11.09	7.94	6.92	10.84		8.15	
CaO	10.16	11.72	10.6	11.1	12.3	11.3	12.7
Na2O	0.98	0.78	1.18	0.87	0.865	0.76	0.739
K2O	0.54	0.46	0.88	0.41	0.61	0.52	0.52
P2O5	1.14	0.42	0.76	1.32		0.35	
S %	0.33						
sum				99.2		99.4	
Sc ppm	25	28	18		25.8		28.5
V	36	61	36				
Cr	992	1310	811		918		1590
Co	31	19	12		30.2		24.3
Ni	204	82	58		252		49
Cu	9	<20	<20				
Zn	31	<60	<60				
Ga							
Ge							

As				<1	<1
Se				n.a.	<2
Rb	13.7	10	20	9	11
Sr	359	214	230	310	233
Y	532	162.5	338		
Zr	2835	596	1397	2260	700
Nb	124	18	112		
Mo					
Ru					
Rh					
Pd ppb					
Ag ppb					
Cd ppb					
In ppb					
Sn ppb					
Sb ppb					
Te ppb					
Cs ppm	0.8	0.4	0.9	0.52	0.57
Ba	1520	593	1351	1285	627
La	170	52	113	172	47.5
Ce	427	139	297	436	124
Pr	57.45	17.1	35.6		
Nd	256.5	76.9	162	258	72
Sm	70.15	21.9	44.9	74.8	21.7
Eu	4.2	2.43	2.45	3.95	2.23
Gd	86.4	25.3	50.4		
Tb	15.1	5.08	10.5	15.2	4.53
Dy	94.15	30.7	63.9		
Ho	21.3	6.36	13		
Er	58.05	18.6	39.3		
Tm	9.13	2.72	5.96		
Yb	54.65	16.9	36	54.8	16.7
Lu	7.64	2.53	5.24	7.5	2.31
Hf	64.3	14.8	34.7	52.4	17.8
Ta	7.1	2.14	4.16	6.45	2.27
W ppb	3450	1300	2500		
Re ppb					
Os ppb					
Ir ppb	4.2			<20	<4
Pt ppb					
Au ppb	6			<30	<8
Th ppm	32.7	8.44	21.7	30	9.05
U ppm	8.6	2.27	5.83	7.9	2.62

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

Table 1b. Light and/or volatile elements for SaU169

Li ppm	
Be	

C							
S							
F ppm							
Cl							
Br					0.83		0.43
I							
Pb ppm	13.8	<10	<10				
Hg ppb							
Tl							
Bi							

1) Gnos et al. (2004) three columns are impact melt breccia, average regolith and KREEP clast, respectively

2) Korotev et al. (2009b)