ANTARCTIC METEORITE ALHA 81005, A PIECE OF THE ANCIENT LUNAR HIGHLAND CRUST.

H. Palme, B. Spettel, G. Weckwerth and H. Wänke, Max-Planck-Institut für Chemie, 6500 Mainz, F. R. Germany.

"Der Mond ist ein unartiger Nachbar, weil er mit Steinen nach uns wirft." (The Moon is a naughty neighbor because he throws stones at us). Georg Christoph Lichtenberg 1797

In 1660, an Italian physicist, P. M. Terzago maintained that meteorites are of lunar origin (1). Since then the idea has been repeatedly taken up by scientists, until lunar samples were found to be different from all known types of meteorites. However, it now appears that the old hypothesis was justified, at least with respect to the dynamical problem of transferring material from the Moon to the Earth. The results of our chemical analysis (instrumental neutron activation techniques, Table 1) of Antarctic meteorite ALHA 81005 undoubtedly show that it is a lunar highland breccia, confirming the original suspicion by Mason (2).

1.) Contents of Mn and Fe are in the range of lunar highland rocks (Fig. 1), Fe/Sc, Mg/Cr and Sc/V ratios are identical to the ratios in highland rocks. The latter three ratios are characteristic for highland rocks with a meteoritic component. "Pristine" rocks have different ratios.
2.) The chemical composition of ALHA 81005 fits into the multi-element lunar highland mixing diagram of Wänke et al. (3) (Fig. 2).
3.) The major element composition of ALHA 81005 is very similar to that of a group of lunar highland rocks, called feldspathic granulitic impactites (FGI) by Warner et al. (4). The composition of these FGI-rocks (e.g. 78155) and chemically related materials with about 25% Al_2O_3 (e. g. anorthositic gabbros (5)) comes very close to the proposed composition of the average lunar highlands (Table 2, (6)).
4.) Like FGI-rocks, ALHA 81005 has no KREEP-type pattern of incompatible elements. It has e. g. a flat heavy REE pattern (Fig. 3). Incompatible elements are in general less fractionated than those in KREEP (Table 4). The absolute content of incompatible elements is lower than in FGI-rocks.
5.) ALHA 81005 has, similar to FGI-rocks, a significant meteoritic component with an essentially chondritic pattern of siderophiles (1.5% C1-equivalent) (Fig. 4, Table 3).
6.) The abundances of "plagioclase trace elements" Sr, Eu, Na, Ga are similar to those of the most primitive cataclastic anorthosites, early crystallisation products of the lunar magma ocean. The composition of the mafic component of ALHA 81005 (assuming it is representative for a major crustal unit) may also be relatively primitive. Its mg-number (0.73) is similar to that for Ringwood's parental lunar crust magma (0.70), which represents the composition of the magma ocean, when plagioclase saturation is reached (6).

Conclusions: ALHA 81005 has the average lunar highland composition, far away from the KREEP--rich (high U) areas of the front sider around the great basins. The K and Th content of ALHA - 81005 is even below the estimates for the farside, deduced from the γ-ray experiments (7). This could indicate that a significant fraction of the farside may be lower in K and other incompatible elements than previously thought. Because of the absence of KREEP, ALHA 81005 was formed from a KREEP-free soil. Since the soils at the Apollo landing sites are inevitably contaminated with KREEP, ALHA 81005 may originate from the far side of the Moon, far away from the great basins, or it may have formed before the ejection of KREEP, 3.8 to 4 by ago, or more likely both, since soil breccias on the front side do not appear to have survived the great bombardment of the great basin forming bodies.

Highland rocks on the front side have in most cases ages between 3.85 - 4 by. Only some KREEP-free highland rocks have higher ages. The FGI-rock 78155 has a crystallization age of 4.22 ± 0.04 by (8). Other granulitic impactite clasts are also older than 4 by. This may indicate an age of more than 4 by for ALHA 81005.

Highland rocks formed around 3.9-4 by have almost without exception lower than chondritic Ir/Au ratios. Older rocks or clasts in rocks have higher Ir/Au ratios (9). Since ALHA 81005 has a chondritic Ir/Au ratio, it may be older than 4 by.This is an independent piece of evidence pointing to a high age for ALHA 81005.

Because of the brecciated nature of ALHA 81005 the age estimates are valid for its essential ingredients such as for example granulitic and anorthositic clasts. The compaction age could be much younger.

(1) Cited in E.F.F.Chladni: Über Feuer-Meteore und über die mit denselben herabgefallenen Massen. J.G. Heubner, Wien (1819), p. 418. (2) Mason, B. (1982) Antarct. Meteor. Newslett. 5, No. 4. (3) Wänke, H. et al. (1977) PLSC 8th, 2191. (4) Warner, J.L. et al. (1977) PLSC 8th, 2051. (5) Blanchard D.P. et al. (1977) PLSC 8th, 2507. (6) Ringwood, A.E.: Origin of the Moon, Springer (1979), p. 173. (7) Bielefeld M.J. et al. (1976) PLSC 7th, 2661. (8) Turner G. and Cadogan P.H. (1975) PLSC 6th, 1509. (9) Hertogen J. et al. (1977) PLSC 8th, 17. (10) Wänke H. et al. (1976) PLSC 8th, 3479. (11) Taylor, S.R. (1982) Planetary Science: A lunar perspective, Lunar and Planetary Science Institute, Houston, p. 230.

Sources of data for Figs.: Figs. 1 and 2: all data this laboratory; Fig. 3: modified from Palme, H. et al. (1978) PLSC 9th. Fig. 4: data for 77017 from Laul, J.C. et al. (1974) PLSC 5th, 1047, other data this laboratory; Fig. 5: all data this laboratory. 67035 is a 9.12 g cataclastic anorthosite from North-Ray rake samples. Data unpublished.

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Table 1: Major, minor, and trace elements in ALHA 81005 (128 mg).

	%	est. prec. in %		ppm	est. prec in %
Mg	4.78	5	Zr	30	15
Al	13.40	3	Sb	< 0.05	
Si	21.72	3	Cs	< 0.05	
Ca	10.80	3	Ba	34	15
Ti	0.14	10	La	2.44	3
Fe	4.20	3	Ce	6.9	5
			Nd	3.9	10
	ppm		Sm	1.18	3
			Eu	0.704	3
Na	2250	3	Gd	1.4	20
P	90	30	Tb	0.27	5
K	230	5	Dy	1.7	10
Sc	9.24	3	Ho	0.37	15
V	26	8	Tm	0.18	20
Cr	862	3	Yb	1.06	5
Mn	587	3	Lu	0.15	3
Co	20.2	3	Hf	0.92	3
Ni	186	5	Ta	0.12	8
Zn	18	20	W	< 0.13	
Ga	2.8	5	Ir	0.0073	10
Se	< 0.6		Au	0.0021	7
Rb	< 1.5		Th	0.35	8
Sr	128	10	U	0.103	15

Table 2:

	ALHA 81005	78155* (granulite)	highland** crustal compos.
SiO_2	46.46	45.33	45
TiO_2	0.23	0.28	0.56
Al_2O_3	25.32	25.34	24.6
FeO	5.40	5.63	6.6
MgO	7.92	6.42	6.8
CaO	15.11	15.18	15.8
Na_2O	0.31	0.39	0.45
K_2O	0.029	0.073	0.075
Cr_2O_3	0.12	0.14	0.10
total	100.9	98.8	100
mg'	0.73	0.68	0.66
ppm			
Ba	34	64	66
Sr	128	141	120
Yb	1.06	1.83	1.4
U	0.10	0.24	0.24
Sc	9.24	13.3	10
V	26	39	24
Ni	186	80	100
Co	20.2	14.3	15

* (10); ** (11)

Table 3: Ratios of meteoritic elements in ALHA 81005, assuming an indigeneous Co content of 10.5 ppm.

	C1	ALHA 81005
Ni/Co	21.5	19.2
Ni/Ir	22700	25500
Ir/Au	3.35	3.48

Table 4: Ratios of incompatible refractory elements in ALHA 81005 and in KREEP.

	cosmic ratios (C1-chondrites)	ALHA 81005	KREEP
La/Sm	1.7	2.07	2.2
Sm/Yb	0.93	1.11	1.3
U/Ta	0.58	0.86	1.2
Zr/Hf	31.8	32	44

Fig. 4

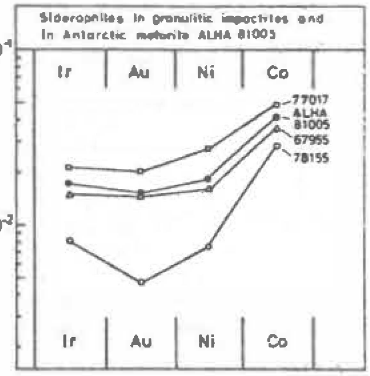

Fig. 5

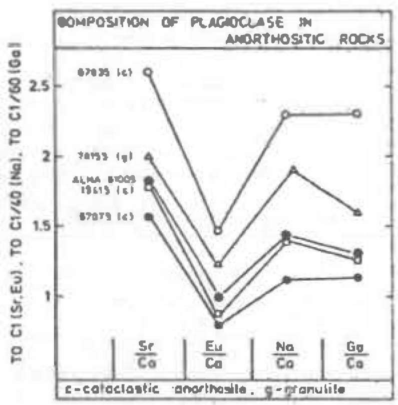

Fig. 1

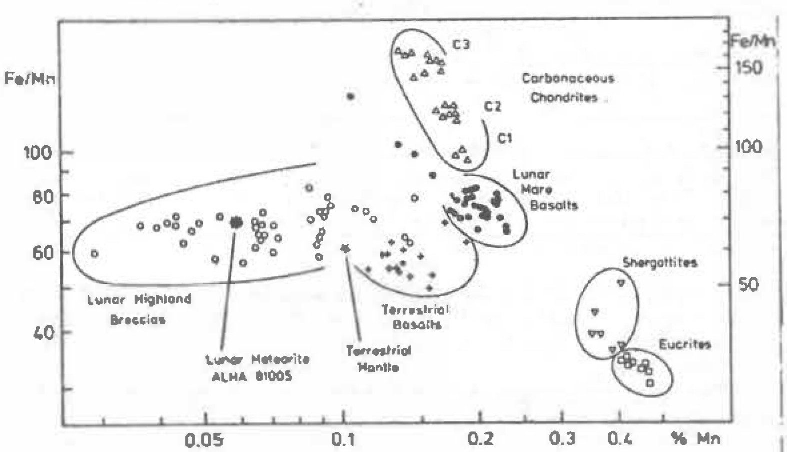

Fig. 2

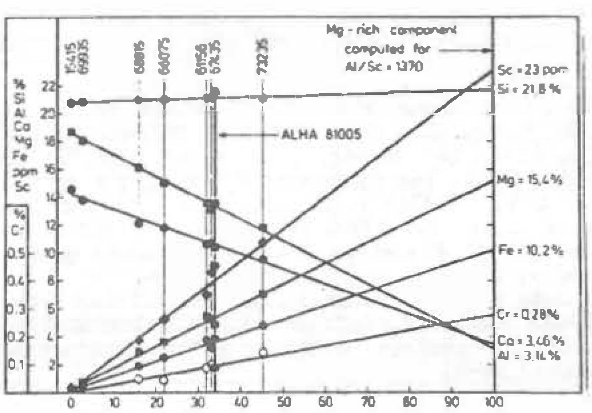

Fig. 3