10060
Regolith Breccia
722 grams

Figure 1. Photo of 10060. NASA S86-38114. Sample is 11 cm high.

Introduction

Lunar sample 10060 is one of the largest and best studied Apollo 11 breccias. One side (the top?) of 10060 is smooth-rounded with a high percentage of glass-lined micrometeorite pits (Schmitt et al. 1970). McGee et al. (1979) and Fruland (1983) describes 10060 as a "typical soil breccia". Thiemens and

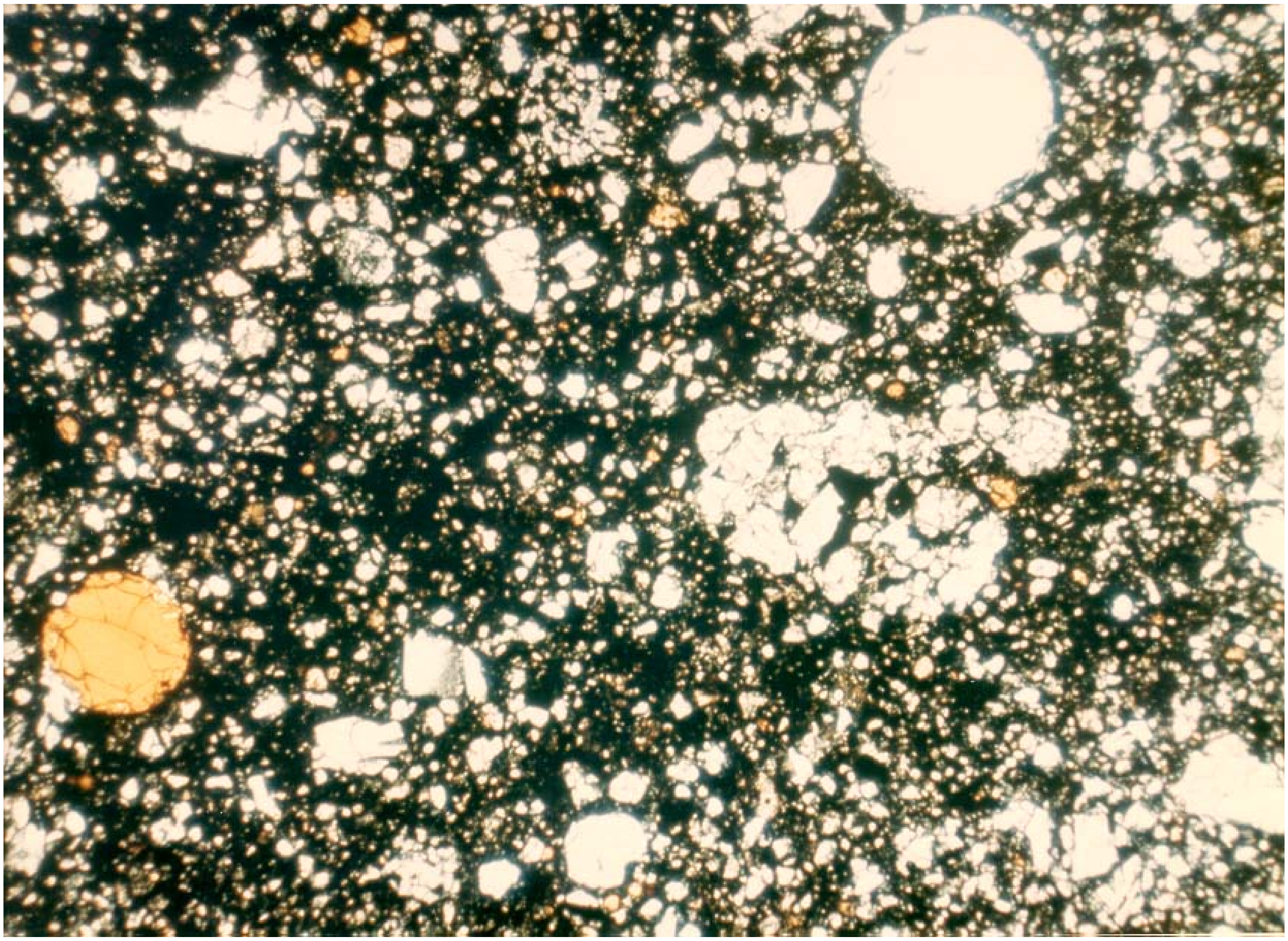


Figure 2: Photomicrograph of thin section of 10060. NASA S70-49013. Scale is 2.5 mm.

Clayton (1980) discuss the very long exposure age (~2.3 b.y.) of Apollo 11 soil breccias.

Petrography

10060 is a large, gas-rich, regolith breccia made up of ancient soil from the Apollo 11 site (Fruland 1983). The grain size distribution is seriate with a majority of grains less than 39 microns (McGee et al. 1979). It is porous with micron-sized intergranular voids that can best be seen in reflected light or by SEM (Phinney et al. 1976). It has an abundance of glass of various types and stages of devitrification (Lofgren 1971).

Mineralogical Mode for basaltic clast "delta" in 10060

Olivine	3 %
Pyroxene	41
Plagioclase	
Armalcolite	1
Ilmenite	14
Glass	41

Basaltic fragments are the predominant lithic clast type in 10060. Beaty and Albee (1978) studied one of the largest basaltic clasts (,17 delta) in 10060. Basaltic clast "delta" is a vitrophyre which contains subhedral to euhedral pyroxene phenocrysts (41%), subhedral olivine (3%), bladed armalcolite (1%) and bladed ilmenite (14%) set in a groundmass of basaltic glass with incipient feathery pyroxene. The large armalcolite grains have a reaction relation with the melt, forming ilmenite at the rims. Grove and Beaty (1980) were

Mineralogical Mode for 10060

	McGee et al. 1979
Matrix < 39 microns	55
Plagioclase	1.2
Mafic	2.3
Opaque	0.4
Glass, hetero	2.6
Glass, homo	0.5
Glass, devitrified	4.4
Breccia, frags	3.7
Mare Basalt	29.8

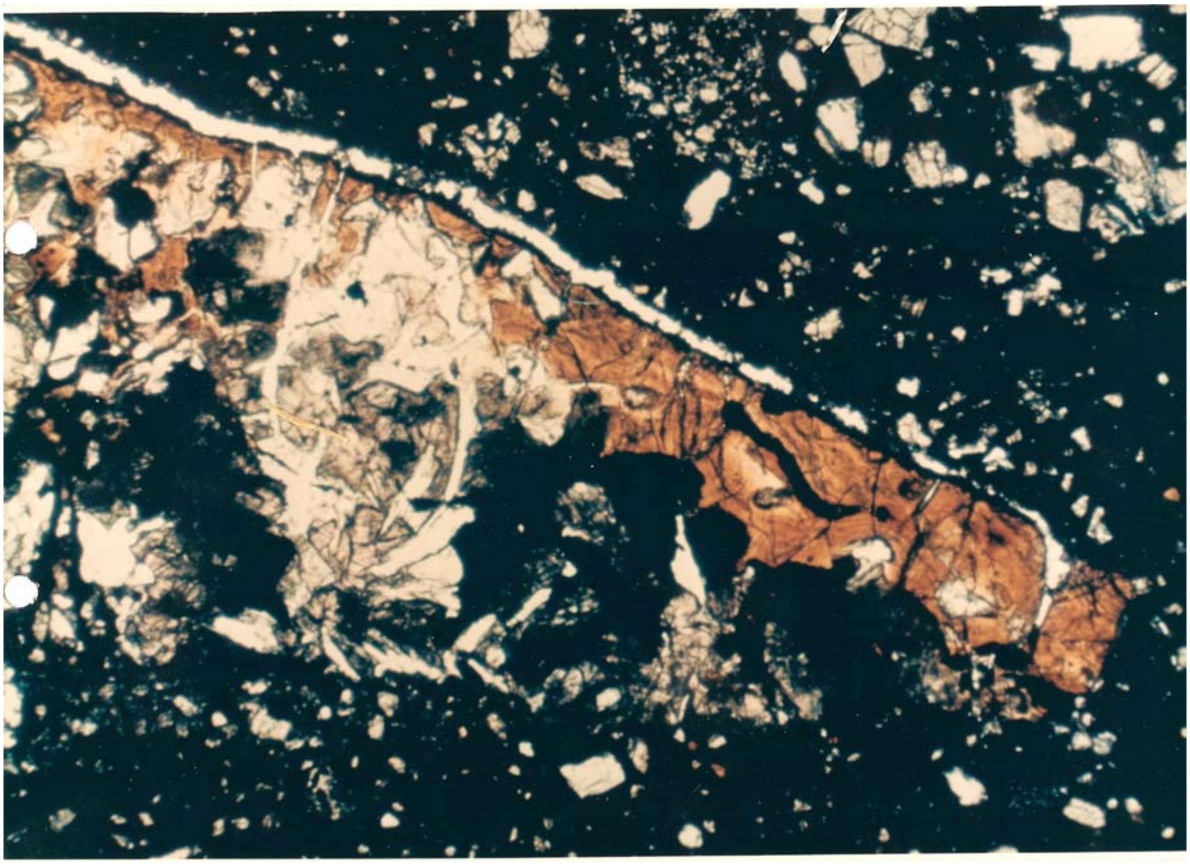


Figure 3: Photomicrograph if thin section of 10060 showing glass coating on basalt clast. Scale unknown. S70-19538.

able to reproduce this texture experimentally and discuss the cooling rate and crystallization history.

Phinney et al. (1976) used SEM petrography to determine the sintering of the glass in the matrix. They report a porosity of ~ 35% with filaments and thin glass films between very fine grains in the matrix. Uhlmann et al. (1981) calculate the cooling rate for 10060 from observation of the devitrification of glass in 10060 and their studies of nucleation barriers to crystallization of glass.

Chemistry

A large number of analyses were done on 10060 (table 1 and figure 4). Kaplan et al. (1970) determined the carbon (135 ppm C) and sulfur contents (1120 ppm S) and isotopic rations. Thiemens and Clayton (1980) determined 93 ppm nitrogen (with a very negative delta ^{15}N).

Schonfeld and Meyer (1972) calculated that 10060 was a mix of mare basalt with ~17 % gabboic anorthosite and ~1 % KREEP, while Rhodes and Blanchard (1981) found it was a mix of soil and high-K basalt. However,

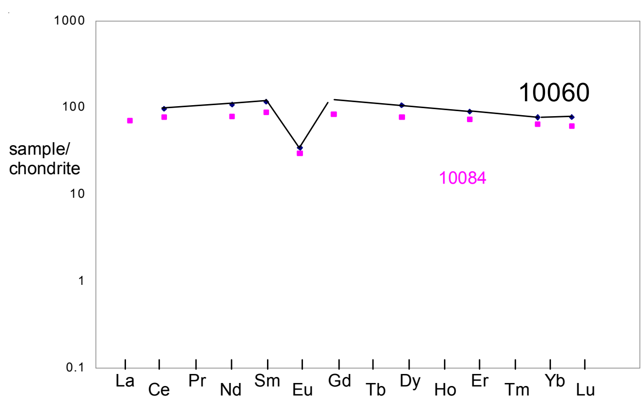


Figure 4: Normalized rare earth element diagram for breccia 10060 compared with soil 10084 (data from Wiesmann et al. 1975).

Simon et al. (1984) could not identify such a high percentage of highland component.

Radiogenic age dating

Silver (1970) determined the U, Th and Pb isotopes for 10060, finding them more like the soil (10084) than the rocks.

Table 1. Chemical composition of 10060.

reference	Rhodes81	Wanke70	Philpotts70	Haskin70	Goles70	Smales70	Morrison70	Agrell 70	Wasson70
weight			218 mg						
SiO2 %	41.5 (a)	42.36 (b)			42.8	41.8	40 (d)	41.96	
TiO2	9.15 (a)	7.7 (b)			8.5	8.7	8.5 (d)	9.02	
Al2O3	11.8 (a)	11.7 (b)			11.5	11.5	11.3 (d)	11.85	
FeO	17 (a)	17.7 (b)			16.8	16.7	17.7 (d)	16.89	
MnO	0.23 (a)	0.17 (b)			0.21 (b)		0.2 (d)	0.23	
MgO	7.52 (a)	7.6 (b)			8.1	7.6	7.63 (d)	7.63	
CaO	11.6 (a)	11.6 (b)				11.2	14.5 (d)	11.38	
Na2O	0.78 (a)	0.48 (b)			0.49 (b)	0.51	0.55 (d)	0.49	
K2O	0.18 (a)		0.19 (c)			0.2	0.19 (d)	0.2	
P2O5	(a)						0.14 (d)	0.07	
S %								0.15	
sum									
Sc ppm		70 (b)			64 (b)		70 (d)		
V					58 (b)		62 (d)		
Cr	2258 (a)	1820 (b)			1880 (b)		2200 (d)	2121	
Co		30.1 (b)			31.6 (b)		32 (d)		
Ni									
Cu							11 (d)		
Zn							25 (d)		
Ga							5.1 (d)		
Ge ppb							1400 (d)		240 (e)
As							90 (d)		
Se							900 (d)		
Rb			4.13 (c)			4.2	4 (d)		
Sr			167 (c)				180 (d)		
Y							210 (d)		
Zr					770 (b)		580 (d)		
Nb							45 (d)		
Mo							0.7 (d)		
Ru									
Rh									
Pd ppb									
Ag ppb							10 (d)		
Cd ppb							300 (d)		
In ppb									*1030* (e)
Sn ppb									
Sb ppb							5 (d)		
Te ppb									
Cs ppm						0.17	0.2 (d)		
Ba			224 (c)				250 (d)		
La		18 (b)		20.8 (b)	17.7 (b)		24 (d)		
Ce		60 (b)	59 (c)	58 (b)	61 (b)		62 (d)		
Pr							13 (d)		
Nd			50 (c)	46 (b)			82 (d)		
Sm		13.8 (b)	17.5 (c)	15.4 (b)	15.4 (b)		24 (d)		
Eu		1.61 (b)	1.98 (c)	2.06 (b)	1.84 (b)		2 (d)		
Gd				24 (b)			28 (d)		
Tb		4.2 (b)		3.6 (b)	3.7 (b)		5 (d)		
Dy			26.2 (c)	26.3 (b)			41 (d)		
Ho					5.3 (b)		10 (d)		
Er			14.5 (c)	16 (b)			30 (d)		
Tm							1.8 (d)		
Yb		10.9 (b)	12.7 (c)	13.2 (b)	13.2 (b)		22 (d)		
Lu		1.57 (b)	1.92 (c)	2 (b)	2.3 (b)		2 (d)		
Hf		14 (b)			12.1 (b)		13 (d)		
Ta		1.9 (b)			2.1 (b)		1.7 (d)		
W ppb							350 (d)		
Re ppb									
Os ppb									
Ir ppb									5.4 (e)
Pt ppb									
Au ppb									1.4 (e)
Th ppm							3 (d)		
U ppm					0.51 (b)		0.6 (d)		

technique: (a) XRF, (b) INAA, (c) IDMS, (d) various, (e) RNAA

Figure 5: Reflect light photo of polished surface of 10060. Scale unknown

Cosmic ray exposure

Thiemens and Clayton (1980) discuss the very long exposure age (~2.3 b.y.) of gas-rich Apollo 11 soil breccias.

Other Studies

Hintenberger and Weber (1973) and Hintenberger et al. (1975) determined the rare gas abundance (figure 6) and reported the isotopic ratios. Friedman et al. (1970) determined the gas content evolved from heating 10060 is vacuum and in O_2. They found 83 ppm hydrogen with low D/H ratio and ~100 ppm C.

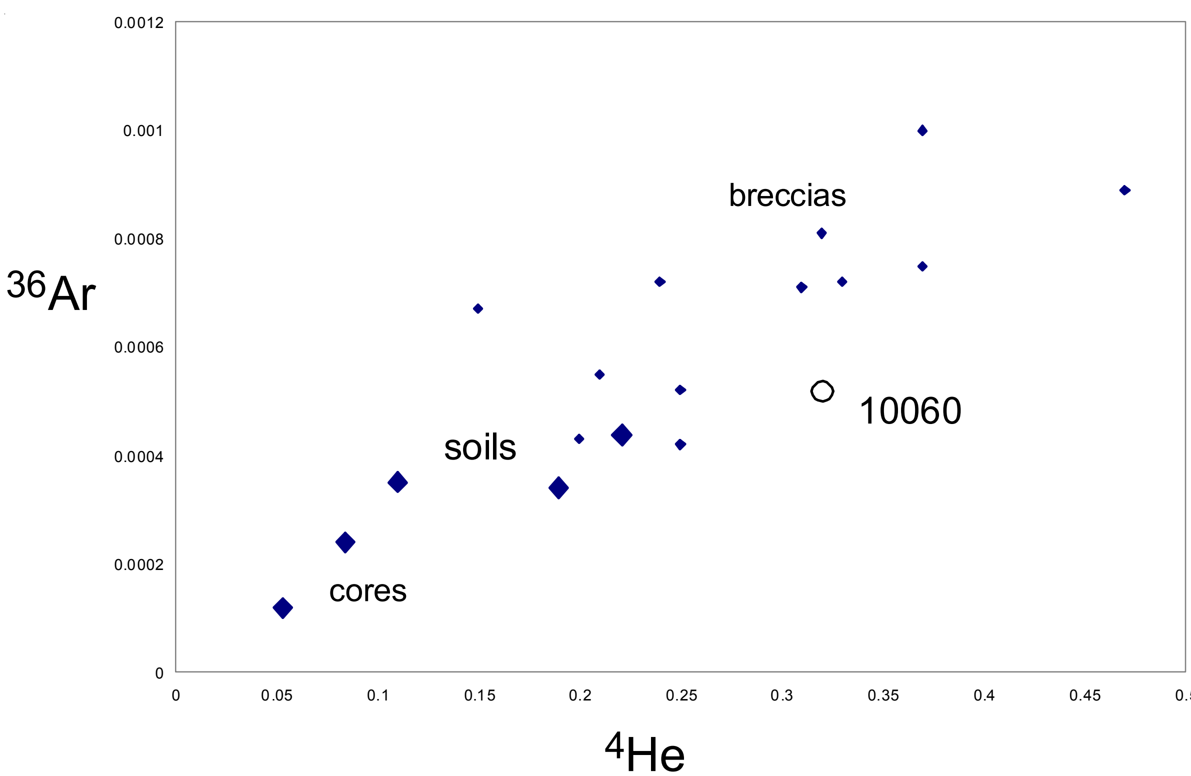
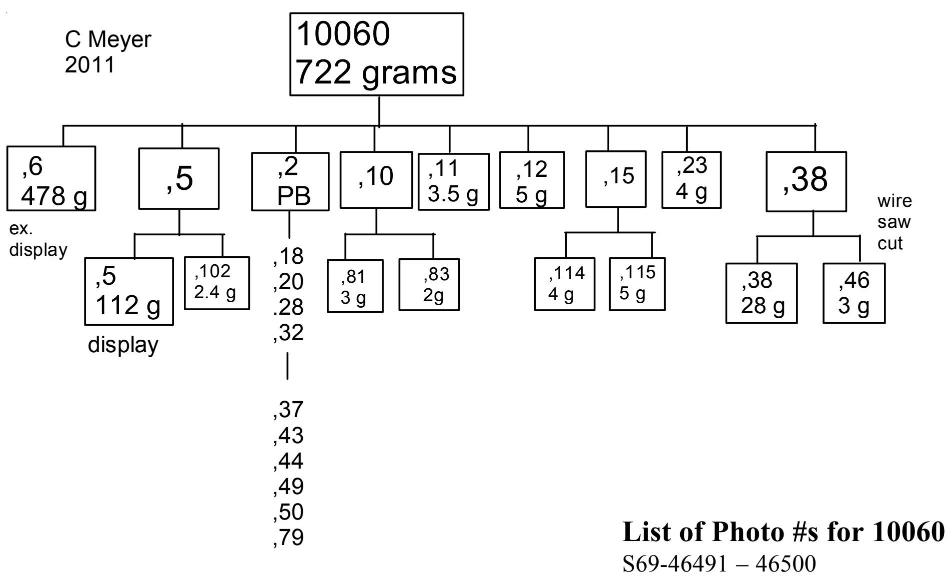


Figure 6: Implanted solar wind in 10060 compared with Apollo 11 soils and breccias (Funkhouser et al. 1070 and Hintenberger et al. 1976). Units STP cc/g.

Figure 7: Initial breaking of 10060. S69-48458.



List of Photo #s for 10060

S69-46491 – 46500	
S69-48450 – 48459	
S69-53976	TS
S69-59239 – 59241	TS
S76-25884 – 25891	

Processing

Apollo 11 samples were originally described and cataloged in 1969 and "re-cataloged" by Kramer et al. (1977). There are 16 thin ections.

Figure 8: Photo of 10060,5. Cube is 1 cm. S76-25888.

Figure 9: Photo of 10060,38 showing saw cut. Cube is 1 cm. S76-25549.

References for 10060

Agrell S.O., Scoon J.H., Muir I.D., Long J.V.P., McConnell J.D.C. and Peckett A. (1970) Observations on the chemistry, mineralogy and petrology of some Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 93-128.

Beaty D.W. and Albee A.L. (1978) Comparative petrology and possible genetic relations among the Apollo 11 basalts. *Proc. 9th Lunar Planet. Sci. Conf.* 359-463.

Clayton R.N. and Thiemens M.H. (1980) Lunar nitrogen: Evidence for secular change in the solar wind. *In* **The Ancient Sun**. 463-473. (eds Pepin, Eddy, Merrill)

Friedman I., Gleason J.D. and Hardcastle K.G. (1970) Water, hydrogen, deuterium, carbon and C13 content of selected lunar material. *Proc. Apollo 11 Lunar Sci. Conf.* 1103-1109.

Fruland R.M. (1983) Regolith Breccia Workbook. Curatorial Branch Publication # 66. JSC 19045.

Goles G.G., Randle K., Osawa M., Lindstrom D.J., Jerome D.Y., Steinborn T.L., Beyer R.L., Martin M.R. and McKay S.M. (1970) Interpretations and speculations on elemental abundances in lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1177-1194.

Grove T.L. and Beaty D.W. (1980) Classification, experimental petrology and possible volcanic histories of the Apollo 11 high-K basalts. *Proc. 11th Lunar Planet. Sci. Conf.* 149-177.

Hintenberger H., Weber H.W. and Takaoka N. (1971) Concentrations and isotopic abundances of the rare gases in lunar matter. *Proc. 2nd Lunar Sci. Conf.* 1607-1625.

Hintenberger H., Schultz L. and Weber H.W. (1975a) A comparison of noble gases in lunar fines and soil breccias: Implications for the origin of soil breccias. *Proc. 6th Lunar Sci. Conf.* 2261-2270.

Hintenberger H., Schultz L. and Weber H.W. (1975b) Differences of the rare gas abundance pattern between lunar soils and breccias (abs). *Lunar Sci.* **VI**, 367-369. Lunar Planetary Institute, Houston.

Kaplan I.R., Smith J.W. and Ruth E. (1970) Carbon and sulfur concentration and isotopic composition in Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1317-1329.

Kramer F.E., Twedell D.B. and Walton W.J.A. (1977) **Apollo 11 Lunar Sample Information Catalogue** (revised). Curator's Office, JSC 12522

LSPET (1969) Preliminary examination of lunar samples from Apollo 11. *Science* **165**, 1211-1227.

McGee P.E., Warner J.L., Simonds C.E. and Phinney W.C. (1979) Introduction to the Apollo collections. Part II: Lunar Breccias. Curator's Office. JSC

Morrison G.H., Gerard J.T., Kashuba A.T., Gangadharam E.V., Rothenberg A.M., Potter N.M. and Miller G.B. (1970) Elemental abundances of lunar soil and rocks. *Proc. Apollo 11 Lunar Sci. Conf.* 1383-1392.

Philpotts J.A. and Schnetzler C.C. (1970a) Potassium, rubidium, strontium, barium and rare-earth concentrations in lunar rocks and separated phases. *Science* **167**, 493-495.

Philpotts J.A. and Schnetzler C.C. (1970b) Apollo 11 lunar samples: K, Rb, Sr, Ba and rare-earth concentrations in some rocks and separated phases. *Proc. Apollo 11 Lunar Science Conf.* 1471-1486.

Phinney W.C., McKay D.S., Simonds C.H. and Warner J.L. (1976a) Lithification of vitric- and clastic-matrix breccias: SEM photography. *Proc. 7th Lunar Sci. Conf.* 2469-2492.

Schonfeld E. and Meyer C. (1972) The abundances of components of the lunar soils by a least-squares mixing model and the formation age of KREEP. *Proc. 3rd Lunar Sci. Conf.* 1397-1420.

Schmitt H.H., Lofgren G., Swann G.A. and Simmons G. (1970) The Apollo 11 samples: Introduction. *Proc. Apollo 11 Lunar Science Conf.* 1-54.

Silver L.T. (1970) Uranium-thorium-lead isotopes in some Tranquillity Base samples and their implications for lunar history. *Proc. Apollo 11 Lunar Sci. Conf.* 1533-1574.

Simon S.B., Papike J.J. and Shearer C.K. (1984) Petrology of Apollo 11 regolith breccias. *Proc. 15th Lunar Planet. Sci. Conf.* in *J. Geophys. Res.* **89**, C109-132.

Smales A.A., Mapper D., Webb M.S.W., Webster R.K., Wilson J.D., and Hislop J.S. (1971) Elemental composition of lunar surface material (part 2). *Proc. Seond Lunar Sci. Conf.* 1253-1258.

Sutton R.L. and Schaber G.G. (1971) Lunar locations and orientations of rock samples from Apollo missions 11 and 12. *Proc. 2nd Lunar Sci. Conf.* 17-26.

Thiemens M.H. and Clayton R.N. (1980) Ancient solar wind in lunar microbreccias. *Earth Planet. Sci. Lett.* **47**, 34-42.

Wänke H., Rieder R., Baddenhausen H., Spettler B., Teschke F., Quijano-Rico M. and Balacescu A. (1970) Major and trace elements in lunar material. *Proc. Apollo 11 Lunar Sci. Conf.* 1719-1727.

Wasson J.T. and Baedecker P.A. (1970) Ga, Ge, In, Ir, and Au in lunar terrestrial and meteoritic basalts. *Proc. Apollo 11 Lunar Sci. Conf.* 1741-1750.