TOTAL SULFUR ABUNDANCES AND DISTRIBUTIONS IN THE VALLEY OF TAURUS-LITTROW: EVIDENCE OF MIXING, Everett K. Gibson, Jr. and Gary W. Moore, TN7, Geochemistry, NASA Johnson Space Center, Houston, Texas 77058.

Total sulfur abundances have been measured in 31 Apollo 17 soils, basalts and breccias using the procedures of Gibson and Moore (1). Results are given in Table 1. Calibration standards were NBS steel 55e (S = 110±10 μgS/g) and USGS reference rock BCR-1 (S = 464±10 μgS/g). Sulfur values obtained in this study are similar to the x-ray fluorescence values reported in the Apollo 17 LSPET report (2). Powders used for 17 of the samples analyzed were the same splits used for the Apollo 17 LSPET studies.

Apollo 17 basalts have unusually high sulfur contents (1580 to 2770 μgS/g) as compared to Apollo 12 and 15 basalts and terrestrial basalts (3). However, sulfur concentrations are almost identical with those reported for the Apollo 11 basalts (mean value = 2200 μgS/g (4)). Apollo 17 basalts have sulfur contents 10 to 100 times greater than some fresh Hawaiian basalts which contain 20 to 200 μgS/g (5). Enrichment in sulfur for Apollo 17 and 11 titanium-rich basalts as compared to those from other mare sites indicates a higher sulfur content in the lunar magma(s) which generated these basalts. Enrichment in sulfur required p_{S_2} values greater than that normally found for terrestrial magmas. Sulfur is usually found as FeS, an accessory phase, in lunar basalts. A negative correlation between % metallic iron (6) and sulfur content for Apollo 17 basalts occurs (Fig. 1). This correlation suggests that a portion of the metallic iron in lunar basalts may result from desulfuration of the melt prior to crystallization from the lunar magma.

Sulfur contents for the three major rock types found at the Apollo 17 site vary with their major element chemistry (2). Basalts with FeO contents between 18 and 20% have sulfur concentrations between 1580 and 2770 μgS/g (Fig. 1). Two anorthositic rocks have S contents of 270 and 368 μgS/g while their FeO content varies between 5.14 and 6.19%. Anorthositic gabbro 77017 which has been severely shocked resulting in glass injection throughout the fractures has a sulfur content of 955 μgS/g. Higher S suggests addition of S to the sample during the cataclastic event which introduced the melt into the fractures of the sample.

Noritic breccias which have FeO values between 8.70 and 11.58% have S contents between 720 and 950 μgS/g. These abundances are intermediate to those of the Apollo 17 anorthositic and basaltic rocks (Fig. 1). Three separate samples from the noritic breccia 76315 produced S values of 755, 950 and 785 μgS/g for (1) composite sample, (2) dark gray phase and (3) blue-gray phase respectively. The narrow concentration range indicates that for the 3 separate samples analyzed, sulfur distribution is similar throughout the sample. Dunite clast 72415 contained the lowest sulfur content (44±10 μgS/g) of any Apollo 17 sample examined. The low sulfur content was similar to those measured for the white portion of the black and white breccias from Apollo 16. However, these two samples differ widely in their chemical compositions. Both the anorthositic materials and the dunite clast are low in the sulfur content. Soil breccia 79315 contains a sulfur value (1020 μgS/g) intermediate between the massif samples and subfloor basalts. The differences in S content between massif samples (275 to 950 μgS/g) and mare basalts (1580 to 2770 μgS/g)

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indicates either that highland materials were initially low in sulfur or they have been efficiently outgassed and depleted in sulfur relative to mare basalts.

Orange soil 74220 has a chemical composition similar to the Apollo 17 titanium-rich basalts (2). However, its sulfur content is only 550 and 750 μgS/g (2 separate sample allocations) The low sulfur content, in light of the basaltic composition (Fig. 1), shows that whatever mode or origin chosen for the orange soil (fire fountaining or impact derived (7)), the process was extremely efficient in removing sulfur from the sample, or we are looking at material from a different source with the same major element chemistry. Low sulfur content along with associated surface correlated volatile elements and compounds is consistent with the fire fountaining hypothesis because terrestrial pyroclastic materials with similar morphologies are also extremely depleted in sulfur relative to the source materials. The depletion in sulfur indicates severe outgassing of the material during the pyroclastic event and associated elevated temperatures. The extremely low vesicularity of the orange glass supports the hypothesis that the samples were nearly completely "degassed".

Twelve Apollo 17 soils have sulfur concentrations ranging from 550 to 1300 μgS/g. Those soils collected at both the North and South Massifs have sulfur concentrations below 1000 μgS/g with the exception of soil 78501 (1125 μgS/g) collected at the Sculptured Hills Station. Soils collected on the Taurus-Littrow valley floor, which were associated with the subfloor basalts, have sulfur concentrations greater than 1000 μgS/g with the exception of the orange soil, which apparently is a special case.

Total sulfur contents of Apollo 17 soils can be accounted for by a simple mixing model between the mare basalts which are enriched in sulfur and massif materials which are depleted in sulfur. A direct correlation between the percent basaltic component in the soils with total sulfur content of the soils can be seen in Fig. 2. The percent basaltic component is obtained from the petrographic study of Apollo 17 soils by Heiken and McKay (8) and the Apollo 17 Sample Catalog (9). Additional mixing models constructed by Schonfeld (10) for Apollo 17 soils indicates that around 1 to 2% meteoritic component (based upon the Ni content) is present in the Apollo 17 soils. Moore et al. (11) have shown that sulfur addition to the lunar fines from meteorite infall (based upon C-1 composition of S = 6.0%) is not significant in contributing to the observed sulfur abundances for lunar fines. Their mixing model does not take into account sulfur from the solar wind (only a minor contributor) or recycled meteoritic sulfur, but it does indicate that large amounts of sulfur cannot have been added to the lunar surface from meteorites unless some major loss mechanism has operated. Gibson and Moore (1) have shown that sulfur can be volatilized slowly from lunar soils at temperatures as low as 750°C and such surface processes as microcratering, vapor transport and lunar outgassing may move small amounts of sulfur around on the lunar surface. However, the major process which accounts for sulfur abundances in lunar fines is mixing of sulfur-rich components such as mare basalts with sulfur-poor materials like anorthosite and noritic breccias.

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Table 1

APOLLO 17 TOTAL SULFUR ABUNDANCES

	Description	Mean μgS/g
Basalts		
70035,1	Basalt	1580 ± 40
70215,2	Basalt	2210 ± 30
70215,54	Basalt	2210 ± 20
74275,56	Basalt	1650 ± 20
75035,37	Basalt	2770 ± 40
75055,6	Basalt	2210 ± 20
Massif Samples, Breccias and Miscellaneous		
722715,2	Noritic breccia	890 ± 20
72415,2	Dunite clast	44 ± 10
72435,1	Noritic breccia	945 ± 20
73275,24	Green-gray breccia	927 ± 10
76055,5	Noritic breccia	720 ± 40
76230,4	Anorthosite	270 ± 20
76315,2	Noritic breccia	755 ± 40
76315,33	Dark-gray phase of noritic breccia	950 ± 30
76315,65	Blue-gray phase of noritic breccia	785 ± 20
77017,2	Anorthositic gabbro with glass	955 ± 20
77135,2	Noritic breccia	800 ± 30
78155,2	Anorthosite-cataclasite	368 ± 15
79135,1	Dark matrix breccia	1020 ± 20
Soils		
70011,19	S.E.S.C. soil	1300 ± 30
73141,8	LRV stop between ST 2-3	630 ± 30
74220,5	Orange soil	560 ± 20
74220,84	Orange soil	750 ± 20
74260,5	Gray soil	1080 ± 20
75111,5	LRV stop between ST 5-6	1260 ± 30
75121,6	LRV stop between ST 5-6	1140 ± 20
76240,9	Soil beside Station 6 boulder	650 ± 10
76260,3	Soil beside Station 6 boulder	795 ± 20
76280,6	Soil beside Station 6 boulder	822 ± 10
76501,18	Rake reference soil	665 ± 40
78501,20	Rake reference soil	1125 ± 20

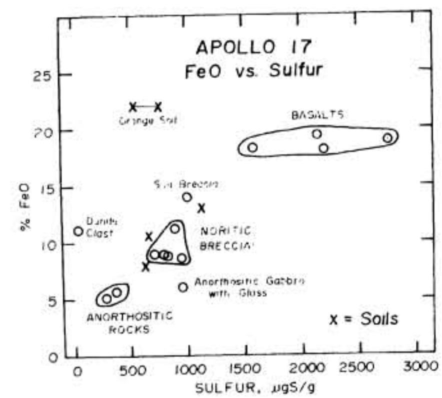

Figure 2. FeO content and total sulfur correlations. FeO data taken from (2).

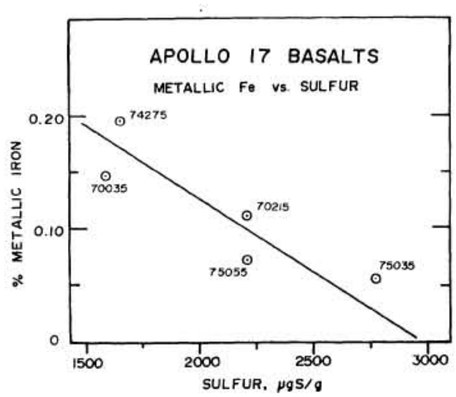

Figure 1. Metallic iron content vs. total sulfur for Apollo 17 basalts. Fe^0 data taken from (6).

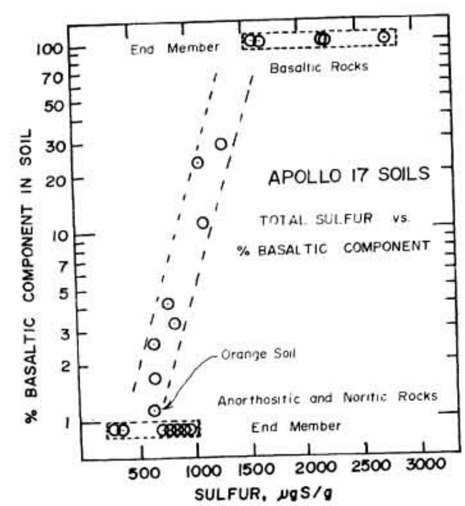

Figure 3. Total sulfur vs. percent basaltic component in soils. Percent basaltic component taken from (8).