

Fig. 2. Sample 76503, highlands.

Kremser D. T. (1992) *Proc. LPS, Vol. 22*, 275–301. [7] Rhodes J. M. et al. (1974) *Proc. LSC 5th*, 1097–1117. [8] Dymek R. F. et al. (1975) *Proc. LSC 7th*, 301–341. [9] Haskin L. A. et al. (1974) *Proc. LSC 5th*, 1213–1225. [10] Warren P. H. and Wasson J. T. (1978) *Proc. LPSC 9th*, 185–217. [11] Warner R. D. et al. (1976) *Proc. LSC 7th*, 2233–2250. [12] Heiken G. and McKay D. S. (1974) *LSC V*, 319–321. [13] James O. B. and McGee J. J. (1979) *Proc. LPSC 10th*, 713–743.

N 93-9287/94303
THE APOLLO 17 REGOLITH. Randy L. Korotev, Department of Earth and Planetary Sciences, Washington University, St. Louis MO 63130, USA.

Among Apollo landing sites, Apollo 17 provides the best opportunity to study the efficiency of formation and evolution of regolith by impacts, both large and small. The mare-highlands interface is crucial to this endeavor, but the Light Mantle avalanche and presence of fine-grained pyroclastics offer additional constraints. Compositional variation among soils from different locations and depths provides a means to quantify the extent of mixing by larger impacts. Because of their variety and complex history, Apollo 17 soils have been important in establishing agglutinate abundance, mean grain size, and abundance of fine-grained iron metal (as measured by I_p/FeO) as simple index of maturity (relative extent of reworking by micrometeorite impact at the surface) [7,9].

Surface Soils: Both the composition and modal petrography of the surface soils vary significantly across the site, and these variations are related in a reasonable way to the site geology. Soils from the valley floor are dominated by mare basalt, but even the most Fe-rich soils (stations 1, 5, LRV 12) contain ~15% highland material, and this proportion is greater in soils closer to the massifs (Fig. 1). Soil from the South Massif (stations 2, 2A, 3) contains only a small amount of

mare basalt (<4%) and one regolith breccia from station 3 (73131) appears to consist entirely of highland material. Soils from the North Massif/Sculptured Hills area contain a larger proportion of mare material than those from the South Massif, and that proportion increases to the east from stations 6 to 7 to 8 [16,4,5].

Mass-balance models have been successful at quantifying the compositional variation in terms of differences in proportions of components representing major lithologies at the site. Early models used four components, two of mare affinity and two of highlands affinity: high-Ti mare basalt (HT), orange/black pyroclastic glass (OG), noritic impact-melt breccia (NB), and anorthositic norite (gabbro) (AN) [16,6]. An important observation of this early work was that the greater concentrations of incompatible trace elements (ITEs, e.g., Sm; Fig. 1) at the South Massif indicate that the NB:AN ratio (~1:1) is greater there than that at the North Massif (~1:2) [16]. This suggested that the massifs, which were assumed to be structurally similar, had a high proportion of noritic melt (NB, deposited by the Serenitatis impact) at the top, and that the lower slopes were dominated by "anorthositic norite" (AN, actually a potpourri of prebasin crustal lithologies such as granulitic breccias and anorthositic troctolites and norites) [16,5] (Fig. 2). The high NB:AN ratio of the Light Mantle soils reflects their derivation from the upper slope

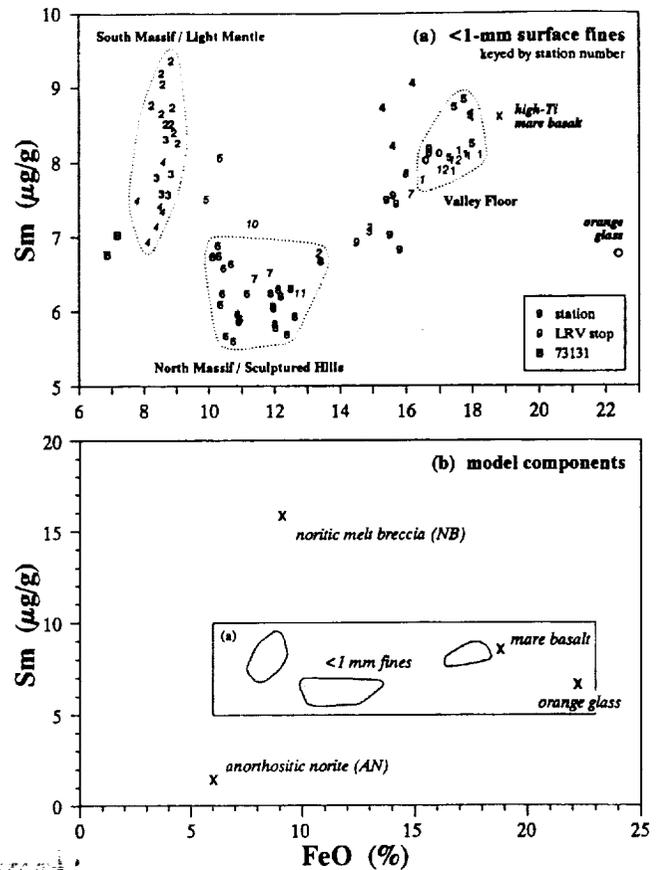


Fig. 1. (a) Compositional variation in Apollo 17 surface soils, from [5]. Sample 73131 is a regolith breccia from station 3. (b) Comparison of compositions of soils with the four major components of mass balance models [5]; inset box shows range of (a). No valley floor soil is devoid of highland material. The South Massif soils contain the least mare basalt and have a greater abundance of noritic melt breccia than the North Massif soil.

of the South Massif, and the low abundance of mare basalt indicates insignificant mixing with underlying or adjacent mare material since the avalanche. The North Massif soils derive primarily from mass wasting from the lower slopes, with mixing of basalt at their interface, hence the greater abundance of mare material [16,4].

Recent refinement of the model, based on a complete set of major- and trace-element data for all surface soils, indicates that more than four components are required to account for the compositional variation [5]. The basalt component of the valley floor soils consistently has a lower average TiO_2 concentration than typical high-Ti mare basalt (HT), suggesting the presence of a low-Ti basalt component in the <1-mm fines [5]. When modeled as VLT (very-low-Ti) basalt, ~7% of the total basalt component (HT+VLT) of soils from the valley floor is VLT basalt on average. This proportion is surprisingly high considering that the only VLT basalts found at Apollo 17 are small soil fragments [e.g., 23]. Perhaps VLT basalt is an old basalt that existed primarily as regolith at the time of eruption of the high-Ti basalts. Modeling also indicates that soils from the North Massif (but not South Massif) contain high-Mg/Fe lithologies not represented by any of the model components [16,5]. The inclusion of an additional component to represent troctolites and norites such as those found at stations 6 and 7 significantly improves model fits for soils from the North Massif area [5]. An improvement in fit for soils from station 2 is achieved by inclusion of a small amount (~4%) of a component of KREEP basalt [5,18]. With these refinements, the new model requires a smaller proportion of orange glass component to achieve mass balance in most soils than is indicated by previous models, and model results [5] now agree well with results of modal petrography for proportions of orange glass in the <1-mm fines [4]. Some orange glass occurs in most soils; away from station 4, the highest abundances are found at LRV stops 3 and 7 (~26%) [5].

Cores: Of the six cores taken on the mission, two are unopened (70012 at LM and 73001/2 at station 3, Lara Crater) and one has not been well studied (76001); the three well-studied cores are all from the valley floor. The deep drill core (DDC: 70001-9; 2.9 m) exhibits substantial variations in composition, lithology, and maturity with depth [6,22,13]. Three to five petrographically distinct units occur in the DDC although all were probably deposited in one event or two closely spaced events during the formation of the Central Cluster of craters [13,21,22]. Between 22 and 71 cm is a unit of coarse-grained,

immature soil dominated by basalt fragments [4,22]. An unusual concentration of siliceous, high-ITE glass occurs between 224 and 256 cm depth [6,22].

The core at Van Serg Crater (79001/2; 0.47 m) is unusual in that the top 8.5 cm is very mature and rich in both total N and cosmogenic ^{15}N . This soil is interpreted as an old soil that received extensive (~2 Ga) near-surface exposure, was buried, and then excavated by the Van Serg impact ~1.6 Ma ago [20]. The bottom of the core is enriched in a high-ITE component that may be noritic melt breccia (Fig. 3) [12]. An unusual variant of high-Ti basalt was encountered at ~42 cm depth [17].

The Shorty Crater core (74001/2; 0.67 m depth) is unique in being composed mainly of orange and black glass droplets having a mean grain size of ~40 μm . There is little variation in modal petrography and composition with depth [1,8], except that the top ~5 cm of soil has undergone *in situ* reworking by micrometeorite impact and addition of basalt and highland material, most of which is probably of local origin [8,11]. The material below 5 cm depth has received practically no surface exposure [2,8,11]. A five-stage model has been proposed [11]: accumulation as a volcanic ash deposit ~3.6 Ga ago, shallow burial for a short time, deep burial for most of the last 3.6 Ga, excavation by Shorty Crater impact 10–15 Ma ago, and *in situ* reworking of surface material since then.

The North Massif core (76001; 0.31 m) appears to be the best example in the lunar collection of continuous accumulation through downslope mass wasting. The core material is mature throughout, but the surface exposure was probably received upslope. Soil at the top (0–20 cm depth) has a larger proportion of noritic melt breccia as well as mare basalt than soil at the bottom (20–31 cm). This is taken as support of the model [16] that the massifs are capped with material rich in noritic melt [14,10,15].

Gray Soil from Station 4: The gray soil (74240, 74260) associated with the orange soils (74220) at station 4 is unusual in being rich in volatiles, containing abundant ropy glass particles, and being highly immature. Petrographic data and the mass-balance model indicate that it has a high NB/AN ratio and a low proportion of orange glass (~5%) [4,5]. The gray soil may contain a large component of old regolith, one that developed by mixing of basalt and underlying highland material prior to the pyroclastic eruptions. It appears to have been in close proximity to, but undergone negligible mixing with, a

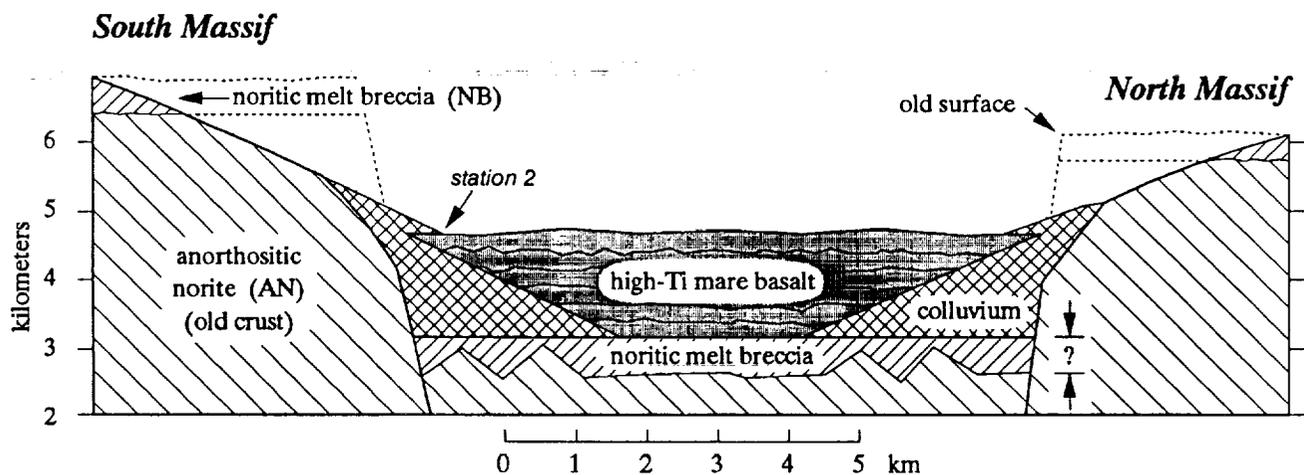


Fig. 2. Cross section of the Taurus-Littrow valley, after [24], with modifications of [16] (no vertical exaggeration). If a unit of noritic melt breccia underlies the basalt, it is probably not as discrete as pictured here, but occurs largely as a regolith mixed with the underlying anorthositic-norite-rich older crustal material.

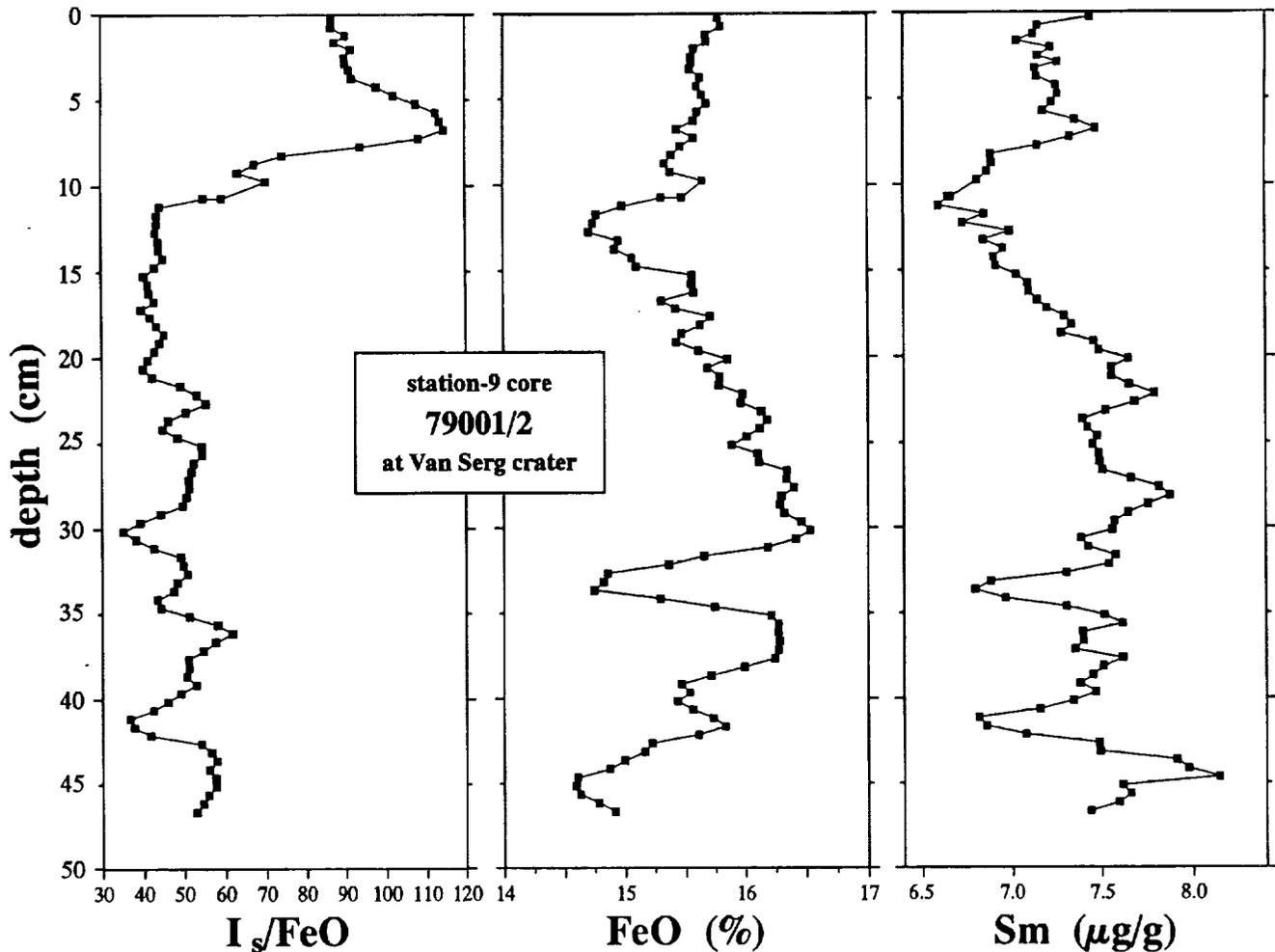


Fig. 3. Variation in maturity (I_s/FeO) and FeO and Sm concentration with depth in double drive tube 79001/2 [12]. For clarity, the data have been subjected to a three-point smooth (running average).

warm deposit of pyroclastics [5]. This soil has had little surface exposure prior to excavation by the Shorty Crater event.

4. Components with Unknown Sources: The regolith contains several rare components, the source of which is not known. Ropy glass particles are common in the gray soil of station 4 [3]. The composition of the ropy glasses is entirely consistent with local derivation as the interior glass is similar in composition to mare-free regolith breccia 73131 (above) [5]. However, a local source crater as large as that believed necessary to produce ropy glasses has not been identified. The high-silica, high-ITE glasses from the DDC (above) have been suggested as a possible Tycho component as the glasses do not resemble any lithic component found at the site or elsewhere [22]. The source of the volcanic glasses with 14% TiO_2 in regolith breccia 74246 is not known [19]. Likewise, VLT basalt is a regolith component with no known local source.

Important Points: Although the evidence of lateral transport of material is undeniable in the Light Mantle deposit, Tycho rays, and station 6 boulders, vertical mixing has also been important in bringing highland regolith to the valley floor [5,15,16,19]. The highland component of the soils from the center of the valley floor has a high NB/AN ratio. This component probably derives not from the tops of the massifs, but from a unit of similar composition underneath the basalt flows, as the valley was formed by block faulting [5,24]

(Fig. 2). The lateral and vertical variations in composition and petrography of the Apollo 17 regolith indicate that impact mixing, even over a time span of >3.5 Ga, is not overwhelmingly efficient. Thus, we are still able to correlate the major components of specific soils with the geologic formations from which they derive.

Future Work: Information about the early history of the site probably lies undiscovered in the gray soil at station 4. Systematic characterization of coarse fines from the massifs should reveal important differences between these bodies and provide data complementary to boulder studies. Mass balance models for soils from stations 1 and 5 suggest the presence of unidentified (mare?) components [5].

Acknowledgment: This work was funded by NASA grant NAG 9-56 to L. A. Haskin.

References: [1] Blanchard D. P. and Budahn J. R. (1978) *Proc. LPSC 9th*, 1969-1980. [2] Bogard D. D. and Hirsch W. C. (1978) *Proc. LPSC 9th*, 1981-2000. [3] Fruland R. M. et al. (1977) *Proc. LSC 8th*, 3095-3111. [4] Heiken G. and McKay D. S. (1974) *Proc. LSC 5th*, 843-860. [5] Korotev R. L. and Kremser D. T. (1992) *Proc. LPS, Vol. 22*, 275-301. [6] Laul J. C. and Papike J. J. (1980) *Proc. LPSC 11th*, 1395-1413. [7] McKay D. S. et al. (1978) *Proc. LSC 5th*, 887-906. [8] McKay D. S. et al. (1978) *Proc. LPSC 9th*, 1913-1932. [9] Morris R. V. (1978) *Proc. LPSC 9th*, 2287-2297. [10] Morris

R. V. and Lauer H. V. Jr. (1979) *LPSC XX*, 861-863. [11] Morris R. V. et al. (1978) *Proc. LPSC 9th*, 2033-2048. [12] Morris R. V. (1989) *Proc. LPSC 19th*, 269-284. [13] Morris R. V. (1979) *Proc. LPSC 10th*, 1141-1157. [14] Nagle J. S. (1979) *Proc. LPSC 10th*, 1385-1399. [15] Papike J. J. and Wyszynski J. (1980) *Proc. LPSC 11th*, 1609-1621. [16] Rhodes J. M. et al. (1974) *Proc. LSC 5th*, 1097-1117. [17] Ryder G. (1990) *Meteoritics*, 25, 249-258. [18] Salpas P. A. (1987) *Proc. LPSC 17th*, in *JGR*, 92, E340-E348. [19] Simon S. B. et al. (1990) *Proc. LPSC 20th*, 219-230. [20] Stone J. and Clayton R. N. (1989) *Proc. LPSC 19th*, 285-295. [21] Taylor G. J. et al. (1979) *Proc. LPSC 10th*, 1159-1184. [22] Vaniman D. T. et al. (1979) *Proc. LPSC 10th*, 1185-1228. [23] Wentworth S. et al. (1979) *Proc. LPSC 10th*, 207-223. [24] Wolfe E. W. et al. (1981) *U.S. Geol. Surv. Prof. Paper 1080*

NO 89/188004 P-3

GEOCHEMISTRY OF HASP, VLT, AND OTHER GLASSES FROM DOUBLE DRIVE TUBE 79001/2. D. J. Lindstrom¹, S. J. Wentworth², R. R. Martinez², and D. S. McKay¹, ¹NASA Johnson Space Center, Houston TX 77058, USA, ²Lockheed Engineering and Sciences Co., 2400 NASA Road 1, Houston TX 77058, USA.

Background: The Apollo 17 double drive tube 79001/2 (station 9, Van Serg Crater) is distinctive because of its extreme maturity and abundance and variety of glass clasts. It contains mare glasses of both high Ti and very low Ti (VLT) compositions, and highland glasses of all compositions common in lunar regolith samples: highland basalt (feldspathic; Al₂O₃ > 23 wt%), KREEP (Al₂O₃ < 23 wt%, K₂O > 0.25 wt%), and low-K Fra Mauro (LKFM; Al₂O₃ < 23 wt%, K₂O < 0.25 wt%). It also contains rare specimens of high-alumina, silica-poor (HASP) and ultra Mg' glasses. HASP glasses [I] contain insufficient SiO₂ to permit the calculation of a standard norm, and are thought to

TABLE 1. Average compositions of common glass types in 79002.

(Wt%)	n=	H B 5	LKFM 23	VLT5 7	VLT6 21	High Ti 16
SiO ₂		44.65	46.76	46.80	46.39	38.73
TiO ₂		0.24	1.15	0.86	0.87	8.87
Al ₂ O ₃		26.31	19.00	10.83	12.25	6.00
Cr ₂ O ₃		0.11	0.24	0.62	0.52	0.66
FeO		4.25	9.27	17.13	17.65	22.37
MnO		0.06	0.13	0.25	0.27	0.27
MgO		8.43	10.35	12.05	10.54	13.90
CaO		15.37	12.15	9.85	10.67	7.50
Na ₂ O		0.12	0.41	0.19	0.16	0.43
K ₂ O		0.03	0.11	0.06	0.02	0.10
P ₂ O ₅		0.02	0.05	0.05	0.03	0.06
Total		99.62	99.67	98.71	99.39	98.98
CaO/Al ₂ O ₃		0.58	0.64	0.92	0.87	1.27
Mg/Mg + Fe		0.77	0.67	0.56	0.52	0.52
(µg/g)	n=	4	7	4	7	2
Sc		8	21	55	55	49
Cr		740	1650	5050	3430	4450
Co		10	25	46	21	62
La		4	4-45	1.1	2.5	6.0
Sm		1.7	2-20	0.9	1.6	6.4
Yb		1.6	1.8-16	1.4	2	4.3

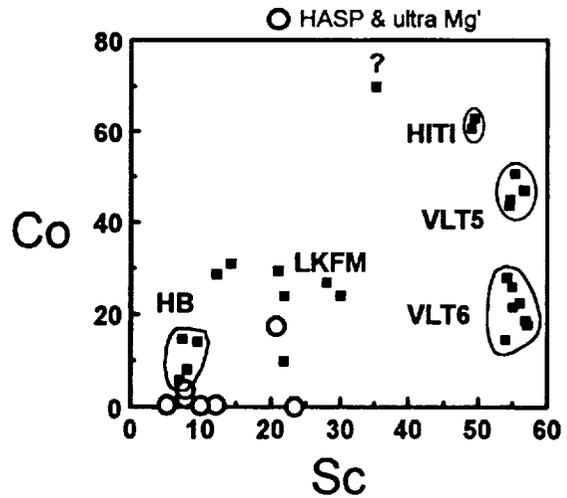


Fig. 1.

be the product of volatilization during impact melting. They have been studied by electron microprobe major-element analysis techniques but have not previously been analyzed for trace elements.

Samples and Methods: The samples analyzed for this study were polished grain mounts of the 90-150-µm fraction of four sieved samples from the 79001/2 core (depth range 2.3-11.5 cm). 80 glasses were analyzed by SEM/EDS and electron microprobe, and a subset of 33 of the glasses, representing a wide range of compositional types, was chosen for high-sensitivity INAA [2]. A microdrilling device removed disks (mostly 50-100 µm diameter, weighing ~0.1-0.5 µg) for INAA. Preliminary data reported here are based only on short counts done within two weeks of irradiation.

Results: Almost half the 80 glasses analyzed by electron microprobe are highland compositions, mostly with compositions ranging from LKFM to KREEP. Seven LKFM glasses were shown by INAA to have typically moderate Sc, Cr, and Co contents and a considerable range in REE (Table 1), and are not discussed further here. Of the more interesting 13 highland samples, five samples are classed as highland basalts. Six samples have HASP compositions (Table 2),

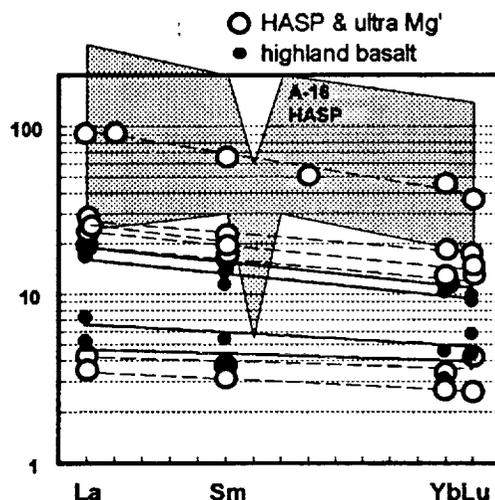


Fig. 2.