ALHA 81005: PETROGRAPHIC COMPONENTS OF THE TARGET.

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Introduction: Our petrographic and microprobe study of ALHA 81005 had the intention of determining the provenance of the component material e.g. plutonic or extrusive, and to compare them with other, known lunar rock types. Unfortunately we had less than one month to carry out the work, thus it is incomplete and some intersting observations and analysis could not be followed up and checked. We concentrated on single mineral analysis for mafic mineral fragments (major and minor elements), and in lithic clasts (granulites, anorthosites, and others, but not including crystalline impact melts), and on analysis of glasses - beads, blebs, and shards, nearly all clear and colorless, but also some brown matrix glass. Routine, 10-element analysis were the rule, but for Ca and Ni in olivines, and N, K, P, and Ti in some glasses, more precise analysis were made using manually-determined peaks and backgrounds and 100-second counts. Some of the latter analysis were performed at the Naturhistorisches Museum in Vienna.

Mafic mineral grains were studied optically and with the microprobe. Of those analyzed (about 50 larger than 100 μ. about 60 % were olivines.

Pyroxene fragments: Under the microscope pyroxenes are a diverse group, ranging from colorless to brown; from clear to inclusion-rich; and from unexsolved to finely-exsolved (less than 1 u. to 5 μ.) to less common, coarsely-exsolved varieties. Major element analyses (Fig. 1) show a corresponding diversity. Attemps were made to resolve lamellae, but inadequate time produced inadequate results. Almost invariably the browner pyroxenes, and nearly all those which contain inclusions (Ti-oxide, sulfides) are Fe-rich. Some are more Fe-rich than known lunar ferroan anorthosites, and some are too Ti, Cr, and/or Al-rich to be from such samples. Several have compositions similar to pyroxenes from very-low Ti and low Ti mare basalts - these are Ca-rich and either unexsolved or finely-exsolved. The pigeonite at $En_{68}Wo_{8}$ is unexsolved, and has minor elements consistent with a low-Ti mare basalt source. Other pyroxenes are similar to those in ferroan anorthosites, with low Ti, Cr and Al abundances and either no or coarse (>10 μ) exsolution. Mg-rich pyroxenes (Mg'~80) are colorless, and either unexsolved or coarsely exsolved, and similar to lunar front-side plutonic norites. They are much coarser than pyroxenes in the granulites in the sample. Several grains, both Mg and Fe-rich, are dominantly high-Ca pyroxenes; all show some exsolution. Pyroxenes appear to come from three major sources: Mg-rich plutonic norites. ferroan anorthosites, and extrusive or shallow-intrusive Fe-rich rocks, probably mare basalts.

Olivine fragments: Olivines are generally inclusion-free, and colorless to pale green. They are dominantly Mg-rich (Mg'>77), and although they cluster strongly around the compositions of olivines in the granulites (Fig. 1), many of them are coarser (>200 u.) than olivines in the granulites (rarely 100 u.), suggesting a different source. A few are iron-rich. Routine analysis showed no olivines with CaO above our detectability limit of ~0.15%, and more precise analysis (detectability better than 0.01 %) for 9 grains confirms the very low CaO (Fig. 2) far below the 0.2 to 0.5 % for olivines in mare basalts and highland impact melts. Most are similar to known plutonic rock samples. Ni in the 9 olivines ranged from 100 (±30) ppm in the Fo_{94} grain to less than the usual detectability limit of ~50 ppm. These Ni abundances are typical of lunar pristine rocks, and are lower than phenocryst olivines in low-Ti mare basalts.

Lithic fragments. We analyzed mafic minerals and plagioclases in clasts which were dominantly plagioclase (cataclastic anorthosites), in feldspathic granulite impactites similar to front-side granulites, and in 3 small " cumulate"-looking samples, as well as some other minor types (Fig. 3 and Fig. 1 of accompanying abstract). The anorthosites are all ferroan, and have pyroxenes with low minor element contents; a few contain iron-rich olivine. In general the compositions are clearly distinct from the granulites, but some granulites are also ferroan. The granulites are all olivine-rich, and are almost exclusively granulite rather than poikiloblastic. One of the "cumulates" is magnesian (Mg'84), similar to granulites except that it is coarser-grained (px >200 μ., rather than a few tens of microns), and lacks olivine. The other two "cumulates" are ferroan; both have pyroxenes and plagioclase 500 μ. across, and one is poikilitic with exsolved pyroxene. All plagioclases are calcic (Ab<5).
One lithic fragment consists of angular, coarse, very calcic plagioclase fragments embedded in a mafic glass (M in Table) whose dominant component appears to be a mafic troctolite. Several small clasts contain the assemblage Fo_{80} - En_{80} - An_{97}, unknown among lunar frontside plutonic rocks. Although this assemblage is similar to granulites, their grain size is coarser, and they may represent a plutonic igneous rock suite. One fragment consisting mainly of pyroxene may be a mare basalt (dots in Fig. 3) The pyroxene, mainly one grain is about 500 μ. across, and is not, under the microscope, visibly exsolved. Within the clast are two blebs of silica (~ 50 μ.) and minor plagioclase and troilite. The pyroxene is iron-rich and is analyses form two clusters, one high-Ca and one low-Ca, but these are not separate grains. Instead they represent either zoning or a tendency toward exsolution. Ti, Cr, and Al are inconclusive as to provenance, but are compatible with a slowly-cooled, very low-Ti mare basalt.

Glasses: Ou glass analyses were concentrated on clear, near-colorless impact glass, the fusion crust, some brown matrix glass, and the glassy matrix of a plagioclase-rich breccia. A range of analyses is shown in the Table, and all glass averages are plotted on Fig. 4 and Fig. 5. We believe that the fusion crust provides the best estimate of the bulk rock composition, and analyzed 6 points in the vesicular, clear-glass portion at the edge, far removed from interferences from partly digested clasts. This analysis (F in Table 1) is close to being an average of all the other clear glasses, except for the extreme compositions (Fig. 4). One of the beads is nearly identical in composition to the fusion crust except for even lower Na (B3). Three analyses of brown matrix glass are more dispersed. Phosphorous is extremely low, consistent with a lack of KREEP. Some of the more extreme glasses show some evidence of a mare component in their elevated Ti/K and Ti/P ratios: among known lunar rock types mare basalts have Ti/K of 30-50, all others less than 6; mare basalts have Ti/P 60, all others less than 20, mainly less than 10. The high Ti-glass (22) may have Ti contributed dominantly by a mare component, and certainly not from a KREEP component, the other known major source of Ti in lunar samples.

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Components of ALHA 81005: The fusion crust and main cluster of glass compositions are less aluminous than A 16 soils and have a higher Mg/Fe ratio, and lower TiO_2 and Na_2O (both $<.3$ %) than any other lunar soils, consistent with the dominance of troctolitic and granulitic components and the absence of KREEP. The "troctolitic" component is not well defined, except that, according to glass norms and the mafic mineral fragments in the rock, it is plutonic, magnesian, low in Ni, has a high al/px ratio, and, if it contains plagioclase, the plagioclase is very calcic. It could be similar to lunar front-side, Mg-suite troctolitic and/ or similar to the olivine-rich component in L 20 soils. Several lines of evidence suggest the presence of a small mare basalt component.

TABLE: Glass analyses for ALHA 81005

	F	B3	B1	B7	◆5	◆22	M
SiO_2	45	45	37	41	46	46	45
TiO_2	0.27	0.271	0.240	0.259	0.223	1.62	0.567
Al_2O_3	25.1	25.1	30.4	23.9	20.3	21.2	16.7
Cr_2O_3	-	0.17	0.10	0.22	0.28	0.21	0.20
FeO	5.6	5.6	4.9	9.5	9.2	7.8	10.7
MgO	8.9	8.5	9.2	10.6	14.0	9.9	15.1
CaO	14.6	14.5	17.4	13.6	11.4	12.7	10.3
Na_2O	0.24	0.116	0.069	0.06	0.237	0.151	0.248
K_2O	-	0.047	<0.02	0.05	0.045	0.104	0.07
P_2O_5	-	<0.019	<0.012	-	0.032	0.058	-
Ni	-	170 ppm	-	84 ppm	-	-	-
Mg'	73.9	72.9	76.9	66.3	73.1	69.3	71.6
Ti/K	-	4.1	>10	>15	3.6	11.2	~5.8
Ti/P	-	>20	>24	-	9.6	40	-

Key: F = Fusion crust. B = beads. ◆ = blobs. M = matrix of glass breccia.

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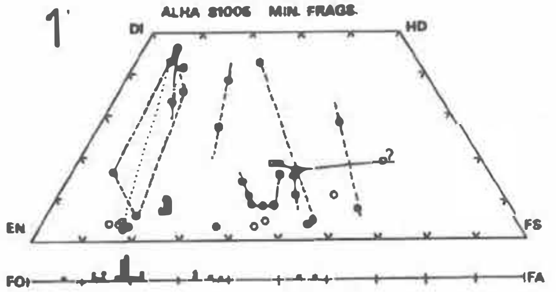

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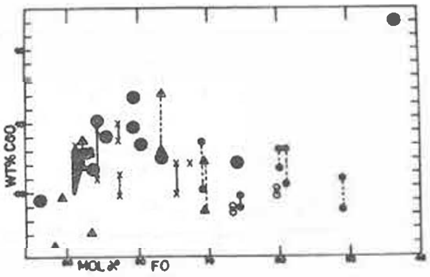

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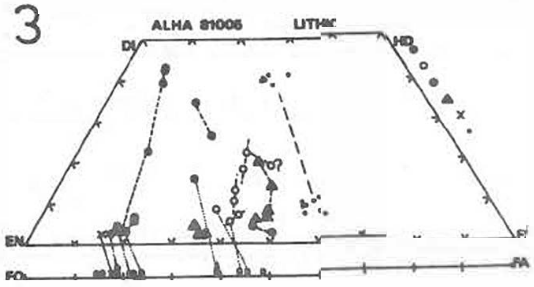

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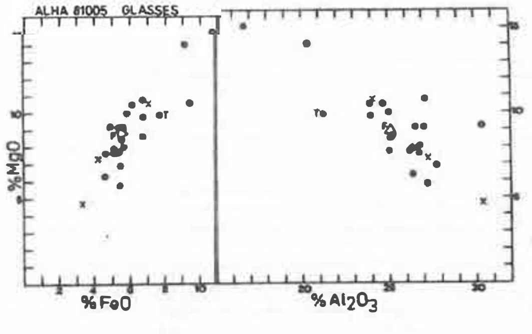

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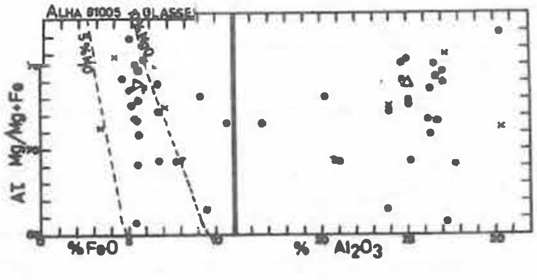

Fig. 1: Pyroxene and olivine compositions for single mineral fragments. Open circles, unexsolved, closed circles, exsolved. Dashed lines connect analyses on exsolved grains, solid lines connect analyses on unexsolved grains. Olivine analyses, each dot is the average for a single grain. Fig. 2: CaO in olivines, black dots = ALHA 81005, triangles = lunar Mg-suite, hexagons = anorthosites, x granulites. Dotted symbols = Chicago data, open symbols = our own unpublished work. Hatched area = our own numerous analyses of dunite 72415. For our own analyses, precision is better than ± 0.01 %. Fig. 3: Pyroxenes and olivines in lithic clasts. Figs. 4, 5: Glass compositions. Black dots = clear glass, x = brown glass, triangle = fusion crust, T = Ti-rich glass, open circle with dots = glass matrix of breccia.