

NON-MARE AND HIGHLAND ROCK TYPES: CHEMICAL GROUPS AND THEIR INTERNAL VARIATIONS. N. J. Hubbard, NASA Johnson Space Center, Houston, TX 77058; J. M. Rhodes, Lockheed Electronics Corp., Houston, TX 77058; L. E. Nyquist, NASA Johnson Space Center, Houston, TX 77058; C-Y Shih, NRC, NASA Johnson Space Center, Houston, TX 77058; B. M. Bansal, Lockheed Electronics Corp., Houston, TX 77058; H. Wiesmann, Lockheed Electronics Corp., Houston, TX 77058.

Chemical data for non-mare and highland rocks exhibit a high degree of internal structure, i.e., consistent groupings are observed for major elements and lithophile trace elements. These consistent groupings suggest that homogenizing impact processes have not obliterated all traces of the chemical differentiation processes involved in lunar petrogenesis. These groups commonly have large and often parallel internal chemical variations, suggesting that original chemical compositions and internal variations have been basically preserved except for incorporation of a few percent of xenolithic material and an overlay of metamorphic effects.

A plot of MgO vs Al_2O_3 (Fig 1) illustrates the major chemical groups, the major internal variations, and the major immediate causes of the internal variations. Each of these groups is characterized by typical lithophile and minor element abundances. Fig 2 shows REE, Ba, and U data for three of the groups shown in Fig 1. Data for the other groups have been presented in earlier publications (3). Also shown in Figure 1 are some examples of possible olivine, orthopyroxene and spinel control lines, the plagioclase control line for 14310 type KREEP, and a postulated plagioclase control line for the more aluminous VHA basalts. The dominant variant in the proposed low-K anorthositic series (LKAS) is plagioclase. A two component mixing line for 61016 is also shown. Some samples fall outside their seemingly proper groups in Figure 1. For example, 72275 differs most obviously from Apollo 17 KREEP by a much higher Fe content (1). Sample 61016,143 falls to the left of the VHA group and has a REE pattern that is different in detail from VHA samples. Also, samples 67075,53 and 15418 have flat patterns for trivalent REE that distinguish them from members of the LKAS.

Because of ubiquitous brecciation and metamorphic features, one must consider two possible hypotheses to account for the observed compositional groupings and their internal variation; 1) crystal-liquid fractionation of discrete magma types prior to brecciation and metamorphism and 2) mixing in conjunction with brecciation and metamorphism, and perhaps also impact generated partial fusion. Simple crystal-liquid fractionation will produce internal variations consistent with mineral control lines. Mixing, if extensive, will tend to eradicate inherent chemical variations. Local mixing may produce a new chemical group with internal variations caused by mixing two or more local rock types to varying degrees. Local mixing is detectable if the end members have chemical compositions which are impossible or difficult to relate by crystal-liquid fractionation, for example the 61016 mixing series.

Returning to Figure 1, the Apollo 12 and 15 mare basalts have been included to demonstrate that the olivine controlled fractionation trends for these rocks (2), closely parallel the major internal chemical variations of three other groups -- Apollo 14 common KREEP, Apollo 16/Apollo 17 KREEP, VHA

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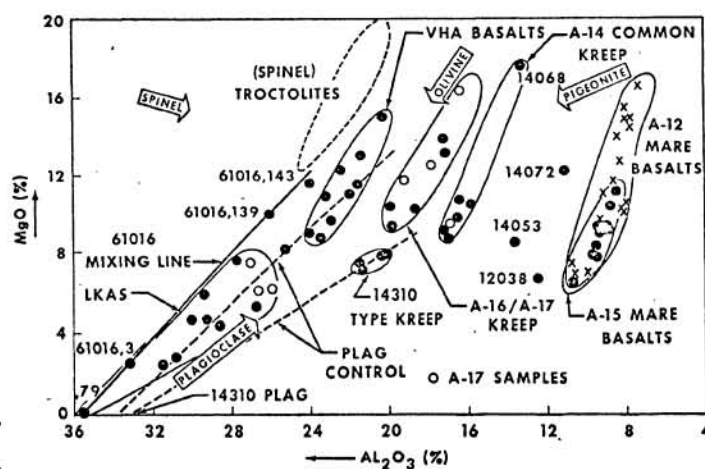


Fig. 1

Fig. 1. Al_2O_3 - MgO relationships for a wide range of chemical groups found among lunar rocks. Apollo 17 data plotted as open circles, previous missions as closed circles. Also shown are several mineral control lines (large arrows), plagioclase control lines for 14310 type samples and VHA basalts (dashed lines) and a mixing line for 61016 (solid line). Field for (spinel) troctolites from Prinz et al. (8).

Fig. 2. REE, Ba and U data for the newest groups shown in Fig. 1.

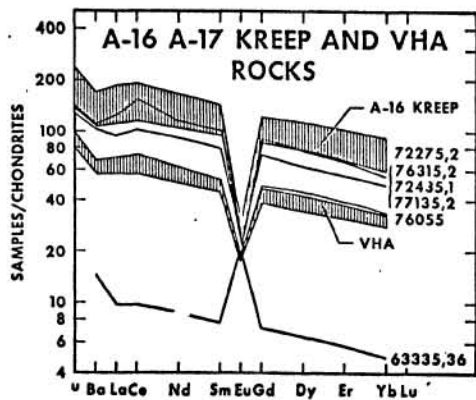


Fig. 2a

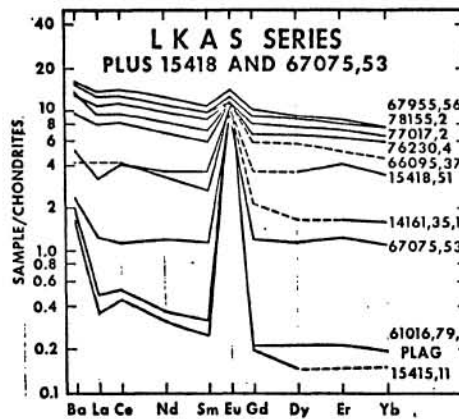


Fig. 2b

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basalts, and possibly also spinel troctolite. This point is strengthened by the olivine control lines which also parallel these groups. Orthopyroxene, spinel and plagioclase control plays a subordinate role in the internal variation of these groups. Crystal-liquid fractionation is obvious for the mare basalts (2) and strongly suggested by Figure 1 for the other chemical groups. One could mix the VHA basalts, Apollo 16/Apollo 17 KREEP, and common Apollo 14 KREEP with dunite in order to produce the observed variation along the olivine control lines. However, such a scheme also demands the prior existence of these independent chemical groups. Extensive intergroup mixing is not supported by the data in Figure 1. However, 14310 type KREEP may be a shock melted mixture of common Apollo 14 KREEP and "anorthosite". Alternatively it may be a plagioclase rich member of the Apollo 16/Apollo 17 KREEP group. VHA basalts appear to owe their major internal chemical variation to olivine rather than to plagioclase, as suggested earlier (3). However 63335 and 60335 may represent VHA samples enriched in cumulate plagioclase.

The LKAS may represent the most widespread lunar crustal material and is perhaps the most ancient chemical composition widely accessible on the lunar surface. The samples returned by Apollo 16 and 17 and the orbital XRF data (4,5) from Apollo 15 and 16 demonstrate that the dominant highland rock types have more than 24% Al_2O_3 , perhaps rocks like 77017, 78155, 76230, 67955, and 66095,37 are typical. Other data (6) are suggestive of an extensive regolith developed on material of approximately the average composition of these rocks. If the LKAS is a true regional rock series that owes its major internal chemical variations to the existence of a plagioclase-liquid system and if the samples 61016,79 plagioclase and 15415 are representative of the plagioclase and, further, samples like 77017 are representative of the equilibrium liquid, then one can use the low Sr 87/86 ratios of 61016,79 and 15415 (7) as a basis for suggesting that this is the oldest chemical group shown in Figure 1. If the LKAS is valid and once was an equilibrium crustal-liquid system, then the total system must have had less REE, etc. and a somewhat larger positive Eu anomaly than samples like 77017. This positive Eu anomaly is evidence that these rocks did not directly originate by partial melting and suggests that they did not have a totally liquid precursor and that they never lost large amounts of plagioclase. In contrast the VHA and KREEP compositions are readily explained by partial melting of plagioclase rich source rocks.

No data tables are included because of space limitations. Such tables will be provided on request.

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