A PETROLOGIC PROVINCE MAP OF THE LUNAR HIGHLANDS FROM ORBITAL GEOCHEMICAL DATA.

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Introduction. The lunar highlands consist of rocks and soils that are complex mixtures of pristine rocks (ferroan anorthosite, some KREEP basalts, and the Mg suite that includes troctolite, norite, dunite, and lherzolite) and of mare basalts. Most geochemical studies of the highlands [1-7] have concentrated on lunar sample data because they provide the basis for the determination of the existence, exact chemistries, and origins of pristine rock types. However, the global coverage provided by the Apollo 15 and 16 orbital geochemical data allows geologic inferences to be made for a large portion of the lunar equatorial region, despite the artificial mixing of mare and highland rock types that results from the poor resolution of these data (15 km for the X-ray data; 100 km for the gamma-ray data). Consequently, the orbital data have been used to infer the regional distribution of highland rock types, the relative proportions of pristine rocks in highland soils, and the role of pristine rocks in the origin of the lunar highlands [8-12]. Our efforts in the present study go beyond that of any previous orbital geochemical study: we have used all existing orbital geochemical data simultaneously to define more accurately and completely the distribution of distinct petrologic provinces in the lunar highlands. Our methods are similar to those used on sample geochemical data.

Method. Longhi and Boudreau [3] and Norman and Ryder [6] showed that a plot of Sm/Ti and Mg^* (=100 Mg/Mg+Fe) for pristine lunar rocks separates most of these rock types into distinct fields. In our study, we examined two possibilities: (1) the attaining of a similar degree of separation between rock types by replacing Sm with Th in the Sm/Ti ratio, because of similar geochemical incompatibility of these two large-ion-lithophile elements in minerals that have commonly been involved in lunar igneous processes; and (2) the application of the observed rock-sample relations to the orbital geochemical data. We generated a digital image of both the Th/Ti and Mg^* ratios, using the Fe and Ti [13], Th [14], and Mg [9] orbital data. The resultant Th/Ti values were plotted against the Mg^* values for each pixel (picture element) in the databases; this plot was also generated from lunar sample data, from both pristine rocks [15-17] and mixed rock and soil [18, 19]. The Th/Ti ratio used in this study is normalized to C1 chondritic Th and Ti values [20, 21], so that a ratio value of 1.0 signifies chondrite abundances. In addition, plots of pixel and sample Th/Ti versus Fe (wt %) values and Mg^*/(Th/Ti) versus Al (wt %) were constructed to determine the usefulness of these plots in unambiguously defining known petrologic regions within the highlands. The former plot was constructed because the lesser coverage of the X-ray data limits the applicability of the Th/Ti-Mg^* relation to the lunar eastern hemisphere; the latter plot provides better discrimination between the Mg-suite rock types than does the Th/Ti-Mg^* ratio plot. Each pair of sample and orbital data plots was examined to determine their degree of similarity. In addition, within each of the three orbital-data plots, petrologic fields were defined based on their respective sample-data plot and on obvious mixing trends of the rock types. The spatial distribution of each plot's petrologic provinces on the Moon was determined by assigning a distinct color to representative pixels in Lunar Consortium image format. The three resulting classification maps were then examined to determine the distribution of predefined petrologic units or regions in the highlands and the geologic significance of the observed distributions of petrologic units in terms of highland crustal genesis.

Results. The distributions of sample and orbital data on the three different plots are very similar (e.g., Figure 1). However, the majority of orbital points fall between rock-sample fields. This distribution is related both to a real component (mechanical mixing of rock types) and to an artificial component (the geochemical detectors' rather large field of view). Overall, the Mg^*/(Th/Ti)-Al plot best discriminates between KREEP and the Mg suite, and among the Mg-suite rocks. Both this plot and the Th/Ti-Fe plot easily discriminate ferroan anorthosites from other rock types, whereas the Th/Ti-Mg^* plot shows considerable overlap between ferroan anorthosites and mare basalts. Even though it is difficult to discriminate between norites and KREEP on the Th/Ti-Fe plot (Fig. 1a), this plot has an advantage over the

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other two in that it provides circumequatorial coverage. Unit 1 (Fig. 1b) probably represents regional deposits of virtually pure anorthosite. This unit appears on the classification map north (10° N., 90° W.) and northwest (5° N. - 10°S., 110°-120° W.) of the Orientale Basin, north of Korolev Basin (10° N., 170° W.), west of Mendeleev Basin (10° N., 135° E.) and south of Mare Smythii (10° S., 85° E.). Unit 3 (Fig. 1b) is another extreme compositional type whose chemistry corresponds to that of troctolites. This unit occurs in isolated patches on the floor of Hertzsprung Basin (3° S., 127° W.), north of Ingenii Basin (35° S., 165° E.), southwest of crater Gagarin (20°-30° S., 140°-150° E.) and in the central highlands east of crater Ptolemaeus (10° S., 5°-10° E.). Other petrologic units may generally be explained as mixtures of the major rock types. For example, unit 8 (Fig. 1b) corresponds to mixtures of anorthosite and mare basalt in proportions ranging from 3:1 to 3:2; admixture of less than 5% Mg-suite rocks is also permitted. This unit is widespread on the eastern lunar farside and also occurs as scattered patches on the western farside, suggesting that significant quantities of mare basalt are incorporated into the local highlands material. Its widespread occurrence is additional evidence for extensive early mare volcanism [22].

The technique described herein is very useful for petrologic interpretation of orbital geochemical data. Simultaneous use of all the existing orbital databases and comparison with similar data for lunar rock types enables the construction of a petrologic province map that gives insight into the distribution of rock types on the Moon. This technique will be of immense value when the higher resolution, global data of the Lunar Geochemical Orbiter are in hand.

References. [1] Duncan, A.R., et al. (1976) PLSC 7, 1659; [2] McKay, G.A., et al. (1978) PLPSC 9, 661; [3] Longhi, J., and Boudreau, A.E. (1979) PLPSC 10, 2085; [4] Norman, M.D., and Ryder, G. (1979) PLPSC 10, 531; [5] Ryder, G. (1979) PLPSC 10, 561; [6] Norman, M.D., and Ryder, G. (1980) PLPSC 11, 317; [7] Walker, D. (1983) JGR 88, B17; [8] Hawke, B.R., and Spudis, P.D., (1980) Proc. Conf. Lunar Highlands Crust, 467; [9] Clark, P.E., and Hawke, B.R. (1981) PLPS 12B, 727; [10] Haskin, L.A., and Korotev, R.L. (1981) PLPS 12B, 791; [11] Spudis, P.D., and Hawke, B.R. (1981) PLPS 12B, 781; [12] Spudis, P.D., and Davis, P.A. (1983) Workshop Pristine Rocks, LPI Tech. Rpt. 83-02, 69; [13] Davis, P.A. (1980) JGR 85, 3209; [14] Metzger, A.E., et al. (1977) PLSC 8, 949; [15] Ryder, G., and Norman, M. (1978) Catalog Pristine Rocks, NASA JSC-14565 and -14603; [16] Warren, P. and Wasson, J. (1979) PLPSC 11, 431; [17] Warren, P., et al. (1981) PLPSC 12B, 21; (1983) JGR 88, A615; (1983) JGR 88, B151; [18] Taylor, S.R. (1982) Planetary Science, LPI Press, 481p; [19] Papike, J.J., et al., (1982) RGSP 20, 761; [20] Morgan, J.W. (1971) Handbook of Elemental Abundances in Meteorites, 517; [21] Mason, B. (1971) Handbook of Elemental Abundances in Meteorites, 181; [22] Spudis, P., and Schultz, P. (1983) LPS XIV, 737.

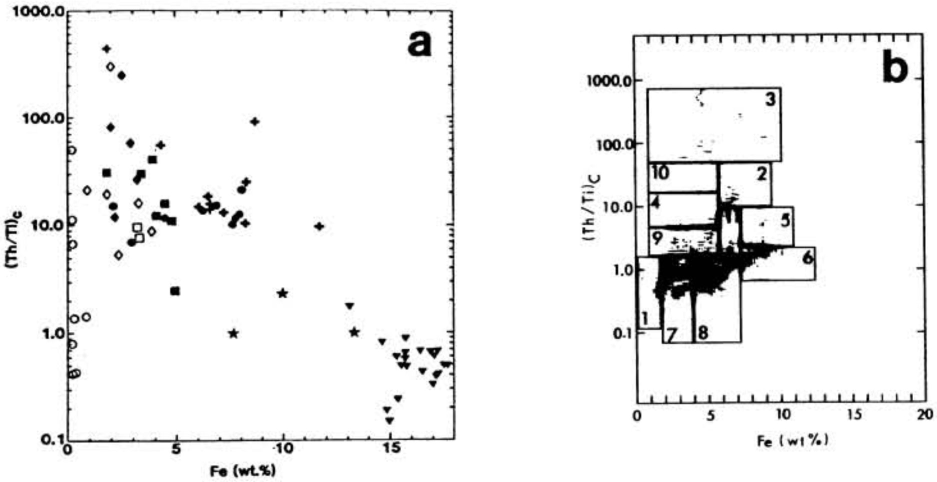

Figure 1. Plots of $(Th/Ti)_c$ v Fe data from lunar rocks and orbital geochemical data. (a) Sample data from pristine rocks [15-17]. Symbols: open circles - anorthosites; open diamonds - alkalic and troctolitic anorthosites; open squares - anorthositic norites; closed circles - Mg norites; closed diamonds - anorthositic troctolites; closed squares - troctolites; stars - gabbros; crosses - KREEP basalts, QMD and granites; triangles - mare basalts. (b) Orbital data [13,14]. Numbered boxes represent petrologic units; some (e.g., 1 and 3) correspond to pure pristine rock types, but most represent mixtures of pristine rocks and mare basalts.