THE DISTRIBUTION AND MODES OF OCCURRENCE OF LUNAR ANORTHOSITE;
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INTRODUCTION. A critical question is whether there is an enrichment in plagioclase in the lunar crust. If the Moon once had a magma ocean, an anorthositic crust should have been produced by plagioclase floatation. Hence, it is important to determine the distribution and modes of occurrence of anorthosite on the lunar surface. In recent years, we have been conducting a variety of remote sensing studies of lunar basin and crater deposits in order to determine the composition of surface units and to investigate the stratigraphy of the lunar crust.[1,2,3,4] We have combined both visible and near-IR spectral observations with multispectral imaging in order to determine the lithology of relatively small areas (2-10 km) of the lunar surface. Numerous deposits of pure anorthosite (plagioclase >90%) have been identified, and an interesting pattern has emerged. The purposes of this report are 1) to summarize the results of our previous studies of the distribution of anorthosite, 2) to present new findings concerning the modes of occurrence of lunar anorthosite, and 3) to assess the implications for the composition and stratigraphy of the lunar crust as well as the magma ocean hypothesis.

DISTRIBUTION AND MODES OF OCCURRENCE. Orientale Basin Region: With the exception of the Inner Rook massifs, all the highlands units inside the Orientale basin appear to be composed of either noritic anorthosite or anorthositic norite.[1,2] Our previous data[1] indicated that two of the Inner Rook Mts. are composed of pure anorthosite. Multispectral imaging data confirm this view; the entire eastern Inner Rook Mts. contain only minute amounts of low-Ca pyroxene. Thus, it appears that the Inner Rook ring of the Orientale basin is a mountain range composed of anorthosite. The plagioclase absorption band (~1.25 μm) occurs in some spectra, but not in all, suggesting either different shock histories or different plagioclase compositions for various portions of the Inner Rook ring.

Humorum Basin Region: The most complete Humorum basin ring is 440 km in diameter and bounds Mare Humorum.[5] A rimlike scarp almost twice as large (820 km in diameter) and resembling the Cordillera ring of the Orientale basin lies outside this mare-bounding ring. At least a portion of the mare-bounding ring of Humorum is composed of pure anorthosite. Spectra were collected for Mersenius C (diameter = 14km) and the Gassendi E and K complex. These small impact craters expose fresh material from beneath the surface of massifs in the mare-bounding ring. The "1μm" absorption features in these spectra are extremely shallow. Only very minor amounts of low-Ca pyroxene are present in the areas for which these spectra were obtained; an anorthosite lithology is indicated. Anorthosite also appears to have been exposed by Liebig A, a 12-km impact crater on the western portion of the mare-bounding ring. However, this entire ring is not composed of anorthosite, and to date no anorthosites have been identified on the outer Humorum ring.

Grimaldi Basin Region: We have obtained one spectrum of an anorthosite from a portion of the inner ring of Grimaldi basin. Other spectra for the inner ring exhibit a very shallow pyroxene absorption feature, which indicates the presence of very minor amounts of orthopyroxene. These areas may also prove to be composed of anorthosite.[2] Another anorthosite deposit has been identified just inside the outer Grimaldi ring. Apparently, this anorthosite was excavated from beneath the Grimaldi floor material by subsequent impacts. Other highlands deposits emplaced in the Grimaldi region as a result of the Orientale impact event appear to be composed of noritic anorthosite.[2]

Nectaris Basin Region: While noritic anorthosites and anorthositic norites are the dominant rock types in the region, anorthosite deposits have been identified.[3,4] Bohnenberger F is a small (10km) impact crater on an elongated highland massif inside the Montes Pyrenaeus ring of the Nectaris basin. Neither of the two spectra obtained for Bohnenberger F exhibits the well-defined "1μm" absorption feature seen in spectra for typical fresh highland craters that expose pyroxene-bearing rock types.[3,4] Bohnenberger F exposed a deposit of nearly pure anorthosite.

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Anorthosite also occurs in two areas on the east wall of Kant crater (33 km) which is located on a platform massif of the main Nectaris basin ring.[3] We have also found anorthosite deposits in two areas within Cyrillus A crater (17 km). Moreover, Pieters[6] found additional anorthosite deposits in the central peaks of Piccolomini and Theophilus craters. Anorthosites have now been identified on, or very near, the four innermost rings of Nectaris.

Other Occurrences: Anorthosites have also been identified in the central peaks of Alphonsus and Petavius craters.[6,7] Both of these craters are very near major rings of ancient impact basins.[8]

DISCUSSION. The distribution of anorthosite on the lunar nearside exhibits a very interesting pattern. To date, anorthosites have only been identified in a relatively narrow zone extending from Petavius in the east to the Inner Rook Mts. on the western limb. Extensive spectral studies of many nearside regions (e.g., Imbrium, northern central highlands) have failed to reveal additional deposits of pure anorthosite.[1,2,3,6,7] However, few spectra have been obtained for some nearside regions (e.g., east limb, northern highlands, southern and southeastern portions of the central highlands), and analyses of the Apollo orbital geochemistry data sets suggest that anorthosites may be located in selected areas (e.g., Smythii basin). Future telescopic observations will focus on these candidate areas.

The results of this study indicate that lunar anorthosite deposits are almost always found on or very near basin rings. An important objective of this effort has been to obtain an understanding of the significance of this correlation. We have concluded that this association is important only for the inner rings of basins such as Grimaldi and Orientale. The Inner Rook ring and the inner ring of Grimaldi appear to be composed, at least in part, of pure anorthosite that was derived from beneath a more mafic-rich layer in the pre-impact target sites. It is important to note that at Orientale and Grimaldi, the inner ring massifs are composed of anorthosite. These anorthosites are exposed by small, fresh impact craters on the rings or simply on the steep, relatively young slopes of the massifs. In contrast, the anorthosites associated with the outer rings of Nectaris and other basins are commonly found in the central peaks and walls of large impact craters. These anorthosites were derived from layers many kilometers beneath the crater target sites. It does not appear that surfaces of these outer rings are composed of anorthosite although such material must exist at depth.

Finally, the results of our spectral studies have important implications for the stratigraphy of the lunar crust in those areas that exhibit anorthosites. In every instance, the anorthosites were exposed from beneath a shallower near-surface layer of more pyroxene-rich material. This is usually noritic anorthosite (plagioclase 80-90%) or, less commonly, anorthositic norite (plagioclase 70-80%). While this unit is more mafic than the anorthosite layer (commonly >90% plagioclase), it still contains abundant feldspar. The thickness of this more pyroxene-rich layer ranges from a few kilometers to tens of kilometers. A major challenge for future studies is to develop and test hypotheses for the formation of this stratigraphic sequence.

References: 1) P. Spudis et al. (1984) *PLPSC, 15*, C197; 2) B. Hawke et al. (1991) *GRL, 18*, 2141; 3) P. Spudis et al. (1989) *PLPSC, 19*, 51; 4) B. Hawke et al. (1986) *NASA TM-88383*, 526; 5) D. Wilhelms (1987) *USGS Prof. Paper 1348*; 6) C. Pieters (1986) *Rev. Geophys., 24*, 557; 7) C. Coombs et al. (1990) *PLPSC, 20*, 161; 8) D. Wilhelms and J. McCauley (1971) *USGS Map I-703*.