# ANORTHOSITE ON THE LUNAR FARSIDE AND ITS RELATIONSHIP TO SOUTH POLE-AITKEN BASIN.

C. A. Peterson[1], B. R. Hawke[1], P.G. Lucey[1], G. J. Taylor[1], D.T. Blewett[1], P.D. Spudis[2], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822 [2]Lunar and Planetary Institute, Houston, TX 77058.

**Introduction:** There is much evidence to support the hypothesis that a giant impact on the early Earth created the Moon and that a magma ocean was present on the young Moon [e.g., 1,2]. As the magma cooled and crystallized, plagioclase flotation could have produced the upper part of the Moon's original crust. But how much of this original crust has survived to the present? Has it been entirely disrupted, or do portions remain relatively unchanged? Remote sensing studies of the lunar highlands, combined with analysis of lunar materials returned from known locations on the surface of the Moon, have allowed the determination of the lithologies present in many locations on the Moon. Our study of the distribution of the various lunar highland rock types has revealed large-scale patterns that suggest the broad outlines of the evolution of portions of the lunar crust.

Our previous efforts have used Earth-based spectra and Galileo SSI data to study the lunar nearside. We have used Clementine UV-VIS data to extend our studies of the lunar highlands to the farside. Calibration of the Clementine UV-VIS data is essentially complete, and FeO and $TiO_2$ values derived from the Clementine data have been derived from this well-calibrated data. In addition, Lunar Prospector data is now available in preliminary form and can add to our understanding of the composition of highlands units on the farside. We can use this combined data set to: 1) study the composition of farside highlands units; 2) identify and determine the distribution of anorthosite on the lunar farside; and 3) investigate the stratigraphy of the farside crust.

**Method:** The great majority of the Moon's highlands surface is composed of only a few minerals, and these are easily distinguishable using reflection spectroscopy at wavelengths from the UV through visible light and into the near infrared [e.g., 3]. The mafic minerals pyroxene and olivine contain iron which causes the minerals to absorb light with a wavelength near 1 µm. In contrast, plagioclase feldspar does not absorb light near 1 µm, although plagioclase can show absorption of light near 1.25 µm if it has not been highly shocked by impacts.

Through the analysis of Earth-based telescopic reflectance spectra, it is possible to determine the lithologies present in the area observed, typically from 2 to 6 kilometers in diameter. The Galileo and Clementine spacecraft returned multispectral images of the Moon that, while of lower spectral resolution than Earth-based spot spectra, covered large areas of the Moon and used filters at wavelengths useful for determining the lithologies present. These spacecraft data have also been used to determine the abundance of FeO and $TiO_2$ present in lunar surface materials. Other products, such as band ratio maps, have been produced, and spectra have been extracted from co-registered image cubes.

Lunar Prospector has collected a large quantity of gamma ray and neutron spectrometer data. While much of the data will require further processing before reliable quantitative interpretations can be made, some data from that mission have already been made available. In particular, gamma ray spectrometer counting data for Th, K, and Fe [4] can be used to confirm and extend our knowledge of the composition of the lunar farside crust. In addition, a map of Th absolute abundances at 2° resolution has recently been produced from the data [5].

**Results:** Noritic anorthosite and anorthositic norite are the predominant rock types at the surface of the nearside lunar highlands. Lesser amounts of anorthosite, norite, troctolite, and gabbroic rocks are also present [2]. Studies of Earth-based reflectance spectra initially revealed the presence of anorthosite in isolated outcrops extending in a narrow band from the Inner Rook mountains in the west to the crater Petavius in the east [e.g., 6]. More recently, additional outcrops of anorthosite have been identified in the central peaks of some craters, such as Aristarchus, and in the northern and northeastern nearside [7,8]. In most cases, these anorthosite deposits have been exposed by impacts that removed a more mafic overburden and raised them to the surface from deeper in the crust, for example in the peak rings of the Orientale, Humorum, and Grimaldi basins [9,10,11]. Much of the nearside lunar highlands likely shares this stratigraphic sequence: a layer of pure anorthosite overlies a more mafic lower crust and is in turn overlain by a somewhat more mafic layer. Much anorthosite likely remains hidden by this surface layer on the nearside today.

On the lunar farside, the giant South Pole-Aitken (SPA) basin shows a mafic anomaly that is the dominant compositional feature on the farside. At 2500 km in diameter, SPA (centered at 55°S, 180°E) is the largest unambiguously identified impact basin on the Moon. It is also the oldest identified lunar basin except, possibly, for the proposed Procellarum basin. There is a 13-km difference in elevation from the interior of the SPA basin to the surrounding highlands[12]. The FeO content of material exposed in the interior of the basin is 7-10 wt.% higher than for material in the surrounding highlands, and portions of the interior exhibit enhanced $TiO_2$ values [13]. Portions of the interior also display elevated Th and K abundances.

The high FeO values found inside SPA drop off with increasing distance to the north of the basin. The region between 100° E and 100° W and between 40° N and 70° N exhibits very low values of FeO and $TiO_2$. The new Lunar Prospector data show very low Th and K abundances there as well. FeO maps produced from high spatial resolution Clementine data reveal extremely low FeO values, many indistinguishable from zero within the limits of the technique, near the crater Fowler (43° N, 145° W) in the vicinity of the Coulomb-Sarton basin. We interpret these data as indicating a region in which pure anorthosite is dominant. Many areas in this region appear to contain nothing but anorthosite.

Between SPA and the far north, the data generally indicate intermediate FeO values and low Th values. However, some lower FeO values can be found in this intermediate region. Very low FeO values (<2 wt.%) are exhibited in the inner rings of the Hertzsprung and Korolev basins. This parallels the situation at nearside basins where anorthosite was exposed from beneath more mafic material.

In the Freundlich-Sharanov basin, material very low in FeO is excavated by the 44-km crater Virtanen (15.5°N, 176.7°E) which is on or very near the inner ring of the basin as mapped by Wilhelms[14]. Low-FeO material is also exposed in the northern interior and adjacent exterior portions of the basin in the vicinity of the craters Dante and Larmor.

At Mendeleev basin, the crater Benedict (4.4°N, 141.5°E), also on or very near the inner ring as mapped by Wilhelms[14], exposes low-FeO material. In the Keeler-Heaviside basin, the rims of the craters Keeler and Heaviside intersect and expose low-FeO material near where one might expect to find the inner ring of the basin if those impacts had not obscured its location. In addition, there are a number of small outcrops of low FeO material in a region that straddles the SPA basin rim near the crater McKellar (15.7°S, 170.8°W).

**Discussion:** The striking difference between the distribution of lithologic types on the lunar nearside and that on the farside appears to be attributable in part to the enormous SPA impact event. Huge quantities of ejecta would have been deposited outside the basin, thickest near the basin rim and tapering off with increasing distance from the basin. This ejecta, especially that deposited nearest the basin rim, must have contained much material from the lower crust and possibly even some mantle material. If the original plagioclase flotation crust was largely intact at the time of the SPA impact event, the great thickness of more mafic ejecta deposited near the basin could have insulated that original upper crustal material (anorthosite) from all but the largest subsequent cratering events. Large impacts, such as those that produced the Orientale, Hertzsprung, and Korolev basins could have penetrated through the SPA ejecta deeply enough to expose anorthosite in their peak rings. Farther to the north, where the thickness of ejecta from SPA was much less, small basins such as Birkhoff and Coulomb-Sarton could have removed most of the overburden of SPA ejecta to reveal the underlying anorthosite crust. Also, an annulus of anorthosite should have been exposed in the inner wall of the SPA basin by the basin-forming impact. It could have been reburied by slumping such as during megaterrace formation and/or by ejecta from subsequent nearby impacts. The low-FeO material exposed near the SPA rim might have derived from this annulus.

If this scenario is accurate it has great implications for the geologic history of the Moon. It is conceivable that large numbers of very large impacts preceded the SPA event and are not seen today simply because evidence of them has been erased by subsequent impacts. However, that possibility is argued against if most of the original plagioclase flotation crust was still present on the lunar farside at the time of the SPA impact event. This has important bearing on the question of the flux of large impactors during the early history of the inner solar system.

The Lunar Prospector data must be further calibrated and reduced, but the preliminary results have already added greatly to our understanding of the Moon. It is encouraging that ground-based data, Clementine, and Lunar Prospector data are providing a consistent picture of the composition of the lunar surface. The complementary nature of the data sets enhances the value of each set. We eagerly await the additional insight that may be provided by the full set of Lunar Prospector data

**References:** [1] Hartmann, W.K. *et al.* eds. (1986), *Origin of the Moon*, LPI; [2] Heiken, G.H. *et al.* eds. (1991), *Lunar Sourcebook*, Cambridge Univ. Press; [3] Pieters, C.M. and Englert, P.A.J. eds. (1993), *Remote Geochemical Analysis*, Cambridge Univ. Press; [4] Lawrence, D.J. *et al.* (1998), *Science.*, **281**, 1484; [5] Lawrence, D.J. *et al.* (1998), *Geophys. Res. Lett.*, **26**, 2681; [6] Hawke, B.R., *et al.*, (1992), *LPSC XXIII*, 505; [7] Tompkins, S. and and C.M. Pieters, *Met. Planet. Sci*, (1999), in press; [8] Spudis, P.D. *et al.*, (1997), *LPSC XXVII*, 1361; [9] Hawke, B.R. *et al.* (1991) *GRL*, **18**, 2141; [10] Hawke, B.R. *et al.* (1993) *GRL*, **20**, 419; [11] Peterson, C.A. *et al.* (1995) *GRL*, **22**, 3055; [12] Spudis, P.D. *et al.*, *Science*, **266**, 1848; [13] Blewett, D.T. *et al.* (1999), *LPSC XXX*; Abstract #1438; [14] Wilhelms, D.E. (1987) *U.S.G.S. Prof. Paper 1348*.