GLOBAL DISTRIBUTION OF IRON ON THE MOON AND ITS IMPLICATIONS FOR THE MAGMA OCEAN, CRUSTAL STRUCTURE AND LUNAR ORIGIN; Paul G. Lucey and G. Jeffrey Taylor, Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, 2525 Correa Rd. Honolulu HI 96822; Erick Malaret, Applied Coherent Technology Corp. Herndon, VA.

In a companion abstract we presented a method for derivation of the abundance of the element Fe at high precision (1-2 wt%) from visible wavelength multispectral imaging and applied this method to data obtained recently by the Clementine mission. This mission provides 100% coverage of the lunar surface at 100-300 meter resolution(1). Of this coverage we have processed data for 93% of the lunar surface between latitudes of 70°S to 70°N at 35 km resolution(2). These Fe abundance data provide key tests of hypotheses for the early style of differentiation, current compositional structure, and lunar origin.

Despite its acclaim, the magma ocean hypothesis has not been proved rigorously(3). The abundance of anorthosite is a key test of the hypothesis. Models of magma ocean evolution suggest that to be positively buoyant in a magma ocean, mineral assemblages are required to have less than about 4 wt% Fe(4). Ferroan anorthosites range in Fe contents between .2 and 4 wt%, averaging 1 wt%. The Apollo 16 landing site, often considered to be typical of the highlands crust(5), contains about 3.8 wt% Fe (6). Thus, if the Apollo 16 landing site is taken as typical, the average crust is barely rich enough in anorthosite to have been produced via flotation in a magma ocean. Other hypotheses are not excluded.

Our new data show that the Apollo 16 site is not typical, is more iron-rich, and thus less anorthositic than most of the lunar highlands surface. Figure 1 is the histogram of Fe abundance with area for the lunar surface. It is immediately apparent that the lunar surface is very low in iron, lower than estimates based upon the composition of Apollo 16. Indeed, excluding the mare basalt surfaces which are secondary differentiates, 60% of the lunar surface is poorer in Fe than the Apollo 16 site and region. The peak value of Fe content is slightly less than 3 wt%. Substantial portions of the Moon, mostly on the farside, are extremely depleted in iron, some areas having Fe contents indistinguishable from zero. These data clearly show that the lunar highlands are not just enriched in anorthosite, but that large areas are composed exclusively of anorthosite as predicted by the magma ocean hypothesis. We conclude that the ancient lunar highlands must have been formed as the result of plagioclase flotation in global magma system.

Impact craters excavate material from depth and allow the vertical structure of the lunar crust to be investigated by compositional measurements of the ejecta of impact craters(7). Applying this principle to multiringed impact basins, Ryder and Wood (1977)(8) suggested that the composition of the lower crust resembles that of LKFM (Low-K Fra Mauro basalt). Most LKFM rocks contain between 7 and 8.5 wt% Fe, though a group of impact melts at Apollo 16 contains slightly less, about 6 wt%. Extending this method to other basins using Apollo orbital geochemistry data, Spudis et al (1984)(9) showed a correlation between basin size and abundance of LKFM in mixing model results for basin ejecta. They concurred with Ryder and Wood that the lower crust is similar in composition to LKFM.

Our data further support this conclusion. The largest impact structure thus far identified on the Moon (and in the Solar System) is the vast South-Pole Aitken (SPA) basin occurring on the southern lunar farside. The lunar crust within the SPA basin is extremely thin (10) and almost certainly is composed of lower crust uplifted during the impact event which formed the basin. Our Fe data show the basin interior (excluding minor puddles of mare basalt) to have about 8 wt% Fe. Although other suggestions have been made about the nature of the interior of this impact basin (11) the most straightforward interpretation is that, as the derived Fe content of the interior of SPA lies with in the LKFM field and not within the field of any other major lunar rock type in terms of Fe abundance excepting the related KREEP rocks, it is similar in composition to LKFM. So then must be the lower crust in this portion of the Moon. Turning
attention to the nearside of the Moon, mentally stripping away the high-Fe mare basalts, one can observe an Fe-anomaly about the same size as the SPA anomaly of approximately 8wt% Fe centered roughly on the Imbrium basin. This observation is entirely consistent with the detection of LKFM in the samples. Thus, with the addition of SPA and so the farside to the data, an interpretation of an LKFM composition for the lower crust Moonwide is strengthened.

A crucial test of hypotheses of lunar origin is the bulk chemical composition of the Moon. The abundances of refractory elements such as Al, U, and Th are particularly important (12). Mueller et al. (13) estimated the bulk Al2O3 abundance of the Moon to be roughly equal to the primitive earth, 3.6wt% (12), which allows virtually all hypotheses for lunar origin including those that derive the Moon from the early earth. Our new data suggest that Mueller et al. have underestimated the Al2O3 composition of the bulk Moon. The Al2O3 content is estimated by the assumed composition of the lower and upper crust and their relative proportions. As we have shown the upper crust is more anorthositic than previously believed. Earlier estimates were in the range 26-28wt% Al2O3. Our new data suggests that the aluminum abundance of the upper crust (expressed as oxide) is closer to 30wt%. Further, despite the fact that the lunar highlands is saturated with major basins (14,15), apparently only South Pole-Aitken and a few basins in the vicinity of Imbrium tapped lower crustal compositions. This suggests that the estimate of an upper crustal thickness of anorthositic material of 20 km used by Mueller et al. is too low. Our inferred LKFM composition is similar to the lower crustal composition used by Mueller et al. Based on the recognition of a thicker, more anorthositic crust than used by Mueller et al., it is almost certain that the Moon is enriched in refractory elements compared to the earth. This rules out models of lunar origin which require that the Moon and Earth have the same composition.


Figure 1. Histogram of Fe abundance on the Moon with common rock types ranges indicated. Average Apollo 16 composition also indicated.