MAJOR LUNAR CRUSTAL TERRANES: SURFACE EXPRESSIONS AND CRUST-MANTLE ORIGINS. B. L. Jolliff, J. J. Gillis, L. A. Haskin, R. L. Korotev, and M. A. Wieczorek, Dept. of Earth and Planet. Sciences & the McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130. (blj@levee.wustl.edu)

Results from the 1998 Lunar Prospector mission [1] and the 1994 Clementine Mission [2] are leading to significant new views of the structure and distribution of materials in the crust and upper mantle of the Moon. Multispectral imaging (MSI), geochemical imaging, and geophysical constraints indicate that instead of having a grossly layered stratigraphy, the Moon's crust can better be characterized in terms of at least 3 major geologic terranes, each of which we propose to represent the surface expression of a geologic province having distinctive character at depth, and each of which has a significant and distinctive geologic history.

The compositional asymmetry of the Moon has been recognized for many years. However, the high resolution and compositional definition afforded by the Clementine mission (altimetry, UV-VIS MSI, gravity) have highlighted broad regions such as the South Pole-Aitken basin and the Imbrium-Procellarum resurfaced area as being distinctive in both their compositions and their topographic expressions. Apollo remote sensing provided hints of the unusual character (Th-rich) of the Imbrium-Procellarum region, but it was the Prospector global coverage data that showed the region to have the form of an extensive oval [3], and to be the only major area of concentrated Th on the Moon [4]. Models of lunar crustal structure based on Clementine Doppler radar tracking and refined by Lunar Prospector are leading to an improved understanding of how the crust responded in different regions to deep basin impacts [e.g., 5, 6]. Such models complement the geochemical evidence for crustal asymmetry and, coupled with results of Apollo geophysical experiments, provide important constraints on the nature of the crust and mantle at depth beneath major lunar surface provinces.

Traditionally, lunar terrains and their materials have been classified as "highland" or "mare" principally on the basis of relief relative to local grade and albedo. The new geochemical information from Prospector and Clementine as well as consideration of sample data emphasize the shortcomings of this approach, as is evident from the following discussion. A feldspathic crust developed over most of the Moon's surface, but the concentration of Th and associated KREEPy elements into the 'Great Lunar Hot Spot' [7] led to development of a more mafic geochemical province. The modes of evolution and the materials present in the 'Great Lunar Hot Spot' as it solidified produced materials and a terrane significantly different from those of the feldspathic crust. Thus, in this abstract, we advocate dividing the *lunar crust* into three major geologic terranes, the Feldspathic Highlands Terrane (FHT), the Procellarum KREEP Terrane (PKT), and the South Pole-Aitken (SPA) Terrane. We use the term 'terrane' to mean a group of rock formations that has some specific aspect of geologic history in common and that differs from adjacent groups of rock units. In our use, this term connotes a province that has a depth dimension to it. Thus, the terranes represent provinces that extend downward to the base of the crust and possibly into the underlying upper mantle. These terranes thus reflect major early lunar differentiation as well as later modification events, including mare volcanism. Although in this abstract, we focus on three crustal terranes, mare basalts could be considered separately, and we do list in Table 1 the mare basalts that occur outside of the PKT and the FHT separately. However, within those terranes, volcanic flows are probably coupled in petrogenetically important ways (e.g., timing, compositions, assimilation, vertical mixing, and heat production) to the nature and origins of terranes [e.g., 8]. To define the boundaries of each terrane as reflected by its surface exposure, we use the FeO map derived from Clementine UV-VIS data by Lucey et al. [9] and the Th data from Lawrence et al. [4] calibrated to the Apollo gamma-ray data as described by Gillis et al. [10].

Feldspathic Highlands Terrane. The most common lunar terrane is the Feldspathic Highlands Terrane, constituting roughly 70% of the Moon's surface. This terrane is characterized at the surface by high albedo, heavy cratering, elevated topography, high local relief, and highly feldspathic compositions. This terrane is readily delineated on the global FeO map [9]. Concentrations of FeO at the surface and presumably through a substantial thickness of megaregolith are low, averaging ~4.2 wt.% away from areas that have been mixed at the surface with ejecta from nearby basins (Table 1, cf. independent estimate by [11]). Based upon Fe-Al correlations among Apollo samples, concentrations of Al_2O_3 in this terrane would be correspondingly high, averaging ~29 wt.% away from basin ejecta [cf. 11]. This terrane covers the bulk of the lunar farside, excluding the SPA basin and ejecta, Mare Moscoviense, and a few other isolated areas of mare basalt, and is centered around 40N, 180E. The expansive region of the farside that is dominated by highly feldspathic surface exposure is possibly the surface expression of an ancient ferroan "super continent" that is anorthositic at the surface and more mafic with depth, as evidenced by the haloes of more FeO-rich ejecta surrounding basins (average FeO of ~6 wt.% - BE in Table 1, such as can be seen in the FeO map around the Crisium and South Pole-Aitken basins). The mafic materials, however, are probably ferroan noritic or gabbroic rocks as opposed to 'LKFM.'

Table 1. FeO and Th concentrations in lunar crustal terranes.

	FeO (wt.%)		Th (ppm)		% of Area (60S-60N)
	mean	stdev	mean	stdev	
FHT-An	4.2	0.5	0.8	0.3	24.8
FHT-BE	5.8	1.6	1.5	0.8	44.2
PKT-mare	17.3	1.7	5.6	1.1	8.1
PKT-nonm	10.7	2.0	5.4	1.3	6.2
SPAT-inner	10.1	2.1	1.9	0.4	5.3
SPAT-outer	5.7	1.1	1.0	0.3	5.7
Other Mare	13.6	4.2	2.1	0.8	6.0

FHT – Feldspathic Highlands Terrane (An – anorthositic, BE – basin-ejecta covered); PKT – Procellarum KREEP Terrane (nonm – nonmare); SPA – South Pole-Aitken Terrane. The % of area is for 60 S to 60 N latitudes.

Procellarum KREEP Terrane. This terrane corresponds to the Th-rich regions of the crust (e.g., 'high-Th Oval Region' of [3]; 'Great Lunar Hot Spot' of [7]; also 4, 10]. The surface expression of this terrane coincides roughly with the resurfaced area extending to the outer boundaries of Oceanus Procellarum and including parts of Maria Imbrium, Frigoris, Cognitum, Insularum, Vaporum, Nubium, and Humorum (~20E–80W, 30S–70N). Depending on the Th concentration used to define its boundaries, it occupies about 14 % of the Moon's surface (using 4 ppm). This terrane contains materials of both light and dark albedo, i.e., nonmare 'highlands' and volcanic flows that, in addition to conventional mare basalts, appear to include Th-rich lavas in areas that are mainly resurfaced and that have average Th concentration as high as some regions dominated by nonmare formations (Table 1). We speculate that this terrane, which derived by solidification of the 'Great Lunar Hot Spot,' is and always has been fundamentally different from the Feldspathic Highlands Terrane and that it may have never had a thick layer of feldspathic rock. We suggest that it is mafic near the lunar surface, mafic with high fertility to a depth of tens of km, contains much of the lunar budget of Th and other trace elements, is the source of essentially all materials with KREEP chemical signature, and is possibly the main source of the magnesian-suite intrusive rocks [e.g., 7]. In this scenario, both the FHT and the PKT are products of the Moon's early chemical differentiation. We suggest that the darker and smoother nature of much of the PKT relative to the FHT results from the absence of a thick feldspathic crust and, as a consequence of internal heat from the high concentrations of Th and other radioactive elements, non-mare volcanism continued as well as mare volcanism within the boundaries of the terrane beyond the period of the late heavy bombardment of the Moon. Perhaps the lower crust and upper mantle that developed during evolution of the 'Great Lunar Hot Spot' were coupled through an exchange of high-density mafic residua and lower density, magnesian, olivine-rich mantle cumulates, resulting in the generation of magnesian-suite magmas and possibly their eruptive equivalents.

South Pole-Aitken Terrane. We regard the South Pole-Aitken Terrane as a separate terrane for the following reasons: (1) With a diameter of 2600 km [12], it is the largest impact basins in the Solar System. (2) It occurred early in the Moon's history and undoubtedly had an enormous effect on the Moon's thermal evolution, especially in the crustal/upper mantle section where it struck. (3) It occupies a broad region of extreme topographic depression [12]. (4) It has a high average FeO concentration relative to typical nonmare lunar crust. Within the topographic basin, the average FeO concentration is ~10 wt.% (Table 1, [cf. 13]). Extensive ejecta deposits can be seen clearly on the global Clementine FeO map, with a rough butterfly-wing pattern and an average FeO concentration of ~6 wt.%. Despite its mafic character, which may reflect a lower crust-upper mantle component [13], it has only slightly elevated Th concentrations (average ~2 ppm [10]) relative to Feldspathic Highlands Terrane, and significantly less than the PKT terrane (average 5–6 ppm Th), reinforcing the notion that a KREEP component was not present in the lower crust in this region. The SPA Terrane may in part represent exposed, more mafic crust belonging to the FHT, but the lithology of the mafic floor material remains unknown.

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