ON THE ORIGIN OF NONMARE MATERIALS AT THE APOLLO 12 LANDING SITE.

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The Apollo 12 soils and rock samples contain KREEP-bearing, nonmare materials as well as several Th-poor types of mare basalt (see [1]). High-resolution Th data from the Lunar Prospector gamma-ray spectrometer (LP-GRS) [2] and FeO derived from Clementine UVVIS data [3] permit a re-examination of possible sources of the KREEPy, nonmare materials.

The average Th concentration of typical Apollo 12 soils is 5.8 ppm [1] and the LP-GRS datum for a 1° square containing the landing site is ~5.6 ppm [4]. These values are considerably greater than the Apollo 12 basalts (~1 ppm), indicating that the regolith contains a significant proportion of nonmare component(s). For example, if the KREEP-bearing component has a Th concentration similar to the Apollo 14 soils, some 46% of the soil would be of nonmare origin [1].

Potential sources of nonmare materials at the Apollo 12 site include (1) ejecta from large craters such as Copernicus, Reinhold, and other Eratosthenian and Copernican craters (Fig. 1); (2) laterally mixed material from smaller impacts into nearby exposures of the Alpes and Fra Mauro Formations (Fig. 1, 2a); and (3) vertical mixing from local penetration of small impacts through basalt and into underlying nonmare rock and regolith units.

A prominent Ray from Copernicus crosses the landing site, and nonmare material having an exposure age of ~ 0.8 Ga has been linked to Copernicus [5]. However, as we discuss below and in [1], primary ejecta from Copernicus may not be the sole source of nonmare material in the Apollo 12 soils; ejecta from Reinhold may also be a significant source. Exposures of Alpes and Fra Mauro Formations, both Imbrium ejecta deposits, occur within 100 km in almost all directions from the landing site (Fig.1, 2a), thus it is tempting to infer that material has been delivered laterally due to small impacts into that material. However, on close inspection, there are no young, local craters large enough to deliver a significant amount of nonmare material to the site. Lastly, nearby excavation and vertical mixing of underlying nonmare rock units might have occurred if the basalt flows in the vicinity of the landing site are thin. These possibilities are addressed in more detail below.

Copernicus, Reinhold, and other large craters. The Apollo 12 site lies about 400 km from the rim of Copernicus (93 km), about 200 km from Reinhold (~48 km), and within several hundred km of other large Copernican and Eratosthenian craters (Fig. 1). For these craters, the amount of primary material delivered to the site (using the mass-balanced average crater-ejecta model of [6]) is greatest for Copernicus ejecta, followed closely by Reinhold ejecta. Copernicus ejecta should on average produce a deeper regolith deposit, but the two craters should contribute about the same mass of primary material, and <<10% each. Copernicus, because of the concentration of material along a site-crossing ray, may have delivered a factor of 2–3 more material than the average. No other Eratosthenian or Copernican craters contribute significantly compared to these two. Copernicus on the whole is not a Th hotspot [2,4], but the southern part of its target may have been buried Fra Mauro Formation [5]. Reinhold, on the other hand, lies within a Th hotspot [2,4].

We use the variation of FeO across the Copernicus ray to constrain the proportions of nonmare material added to the soil (A-A', Fig. 2, 3). Within the ray, FeO drops from 17.6% to 16%, indicating addition of only ~14 % ejecta having 6% FeO, or 21% if the Copernicus ejecta in this region had as much as 10% FeO. To dilute the landing-site soils from the ~20 wt.% average FeO of Apollo 12 basalts to the “background” level of 17.6% would require an initial addition of primary, nonmare ejecta of ~17 to 24% (for 6% and 10% FeO ejecta, respectively). According to the ejecta mass-balance model of [6], however, this amount of material is unlikely, even considering all of the craters noted on Fig. 1.

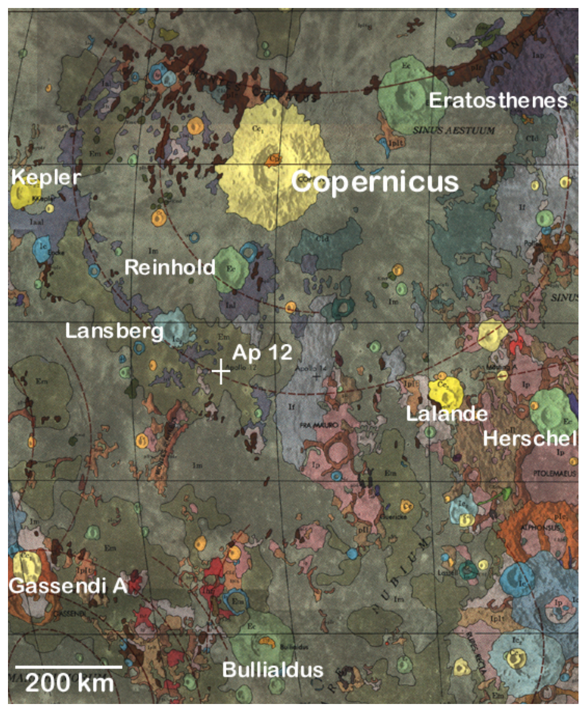

Figure 1. Extract from geologic map of the near side of the Moon [7] showing locations of large Copernican (yellow) and Eratosthenian (green) craters and major rock formations relative to the Apollo 12 landing site. Lansberg is Upper Imbrian. Alpes Fm. is colored purple and Fra Mauro Fm., lavender.

Local lateral mixing. Numerous exposures of the Alpes Fm. occur within 50 km of the landing site (Fig. 2). Horizontal mixing occurs as a result of continuous small impacting into these exposures. However, the profile asso-

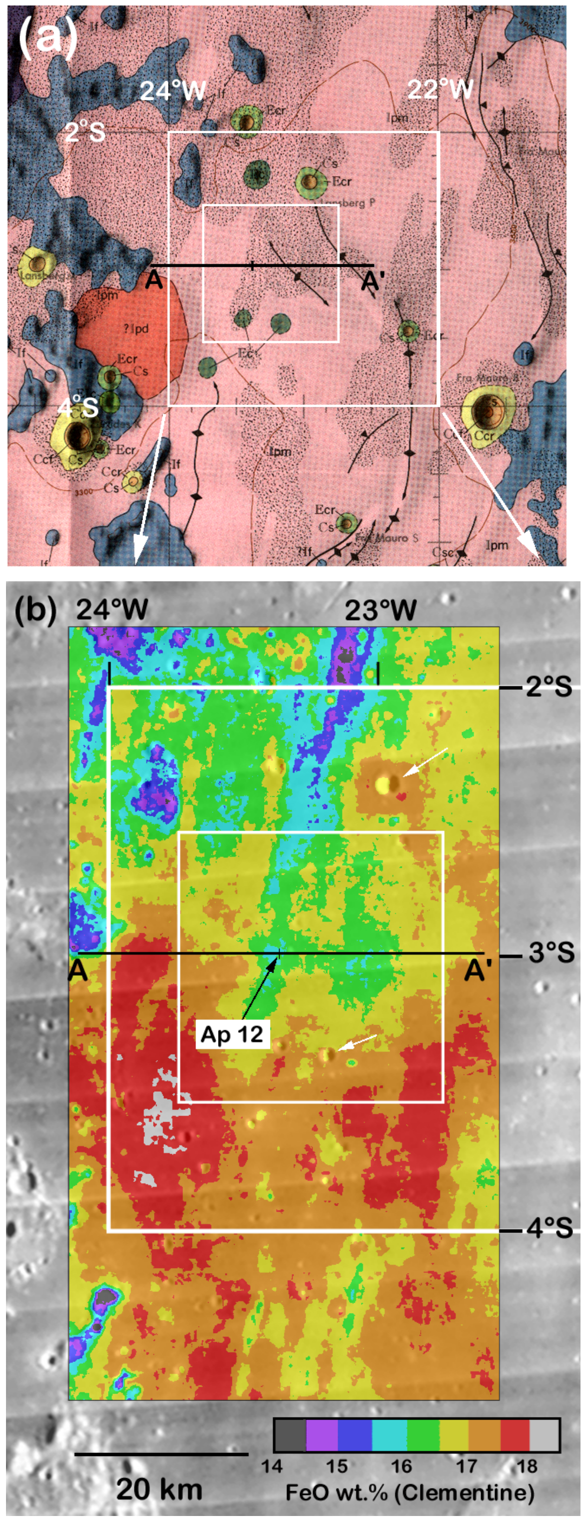

Figure 2. (a) Extract of geologic map [8] showing location of FeO traverse and 1° pixel for LPGRS Th determination [4]; and (b) Clementine UVVIS-derived FeO map overlain on Lunar Orbiter image IV-125H3. Inner white box is the 1° pixel in which Th=5.6 ppm (calibration of [4]). Arrows show examples of craters that do not penetrate through basalt.

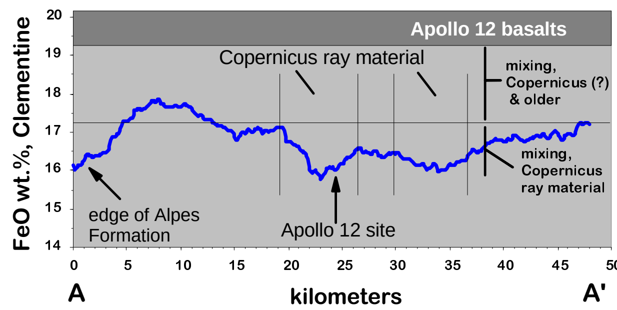

Figure 3. FeO Traverse through Apollo 12 site: conceptual mixing relationships based on UVVIS-derived FeO.

ciated with mixing basalt and adjacent Alpes material (Fig. 3) shows that mixing effects are significant only ~10 km into the basaltic plains (left side of A-A'). Thus it appears that local lateral mixing of Alpes Fm. by small impacts is not a significant source of nonmare material at the site.

Local vertical mixing. The composition of ejecta of craters in the 1 to several km range using Clementine UVVIS-derived FeO (Fig. 2b), as well as thickness estimates by [9], indicate that in the Apollo 12 region, basalt thickness exceeds 300 m. Using a 1/10 depth to diameter relationship, the basalt thickness is constrained by the diameter of the largest craters that have FeO-rich ejecta. All of the craters located near the Apollo 12 site, including the ~3 km diameter Lansberg P (~23°W, 2.4°S), have FeO-rich ejecta. Thus, in areas of basalt away from Alpes exposures, basalt thicknesses preclude significant vertical mixing unless such mixing occurred during the interval of basalt emplacement. Basalt ages from Apollo 12 samples are in the range 3.1 to 3.3 Ga [5], suggesting that emplacement of the upper flows occurred over a relatively short time. Perhaps the 39 km Upper Imbrian crater Lansberg mixed nonmare ejecta with Imbrian basalts beneath the present-day Apollo 12 site.

Conclusion. From their size and distance from the Apollo 12 site, Copernicus and Reinhold should have contributed roughly similar masses of nonmare material to the Apollo 12 soil. However, even though a Copernicus ray crosses the site, the nonmare material in the soil exceeds the amount that can be explained by addition of ejecta from these two and other Copernican and Eratosthenian craters. We suggest that Lansberg also contributed ejecta to the site that, although covered by the latest basalt flows, were mixed and gardened into the present surface soils by small impacts. Reinhold and Lansberg impacted KREEP-rich targets and should be considered as well as Copernicus as potential sources of KREEPy nonmare materials.

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References: [1] Korotev et al. (this vol.) [2] Lawrence et al. (1999) *GRL* **26**; [3] Blewett et al. (2000) *JGR*, in press; [4] Gillis et al. (this vol.) [5] Wilhelms (1987) *USGS Prof. Pap. 1348*; [6] Moss and Haskin (1994) *LPS XXV*, 943–944; [7] Wilhelms & McCauley (1971) *Geologic Map of the Near Side of the Moon*; [8] Eggleton (1965) USGS Map I-458. [9] DeHon (1979) *PLPSC 10th*.