SCULPTURED HILLS: IMPLICATIONS FOR THE RELATIVE AGE OF SERENITATIS, BASIN CHRONOLOGIES AND THE CRATERING HISTORY OF THE MOON Paul D. Spudis, Lunar and Planetary Institute, Houston TX 77058; Don. E. Wilhelms, U. S. Geological Survey (retired), Mark S. Robinson, Ariz. State Univ. Tempe AZ 85287 spudis@lpi.usra.edu

New LROC WAC images show the distribution and geological relations of the Sculptured Hills, a knobby unit found in the highlands between the Serenitatis and Crisium basins. Understanding the stratigraphic position of this unit has significant implications for delineating the formation sequence of impact basins and the lunar cataclysm.

The age of the Serenitatis basin has been of concern to lunar students for many years. Initial studies, noting its old and degraded appearance, proposed that it was one of the very oldest basins on the Moon; relative chronologies placed it well back in pre-Imbrian time [e.g., 1-4]. Study of the Apollo 17 highland samples and the assumption that such rocks are fragments of ejecta from the Serenitatis basin forced a reconsideration of this relative age assignment [e.g., 5,6]. The revision held that Serenitatis is relatively young, only slightly older than the Imbrium basin; its degraded appearance resulting from blanketing and eroding by Imbrium ejecta. This re-interpretation never sat well among some lunar students [e.g., 6, p. 173].

A key piece of evidence for the relative age of the Serenitatis basin may lie in the distribution and relations of units near its rim. Sculptured Hills is an informal name given to a knobby highlands unit found near the massifs of the Apollo 17 landing site [5,7]. It is widespread though out the Taurus Mountains, occurring with light plains throughout the intermountain terrae [5]. Sculptured Hills are found near the Apollo 17 site, and Station 8 was chosen to investigate and sample this key unit during the last EVA [5].

Orientale basin displays a unit of similar surface morphology, the Montes Rook Formation [8-10]. This knobby unit occurs primarily between the main-rim Cordillera scarp and the Outer Rook ring. It is interpreted as a facies of basin ejecta, emplaced nearer the rim at higher angles than the apparently low-angle, radially textured Hevelius Fm. Several investigators note the similarity in appearance between the Montes Rook Fm and the Sculptured Hills and argue that they have similar origins [5,7,11]. This interpretation means that the Sculptured Hills is a facies of Serenitatis basin ejecta. It occurs between the outer basin rim and an inner ring [e.g., 11] and would be the deepest, nearest rim ejecta deposits from the Serenitatis basin.

This interpretation was widely accepted. It appears congruent with the interpretation that the Apollo 17 highland melt breccias are fragments of the Serenitatis basin "melt sheet." In such a reconstruction, the North and South Massifs at Apollo 17 are parts of an inner Serenitatis basin ring (analogous to the Outer Rook Mts. of Orientale) and the Sculptured Hills are Serenitatis basin ejecta (analogous to the Montes Rook Fm. ejecta of Orientale) [5,11].

Spudis and Ryder [12] noted that Sculptured Hills knobs overlie large crater rims (e.g., Littrow, Le Monnier) that are superposed on the Serenitatis basin rim (Fig. 1). This observation creates a stratigraphic problem: Sculptured Hills material cannot be a facies of Serenitatis basin ejecta if it postdates large craters that postdate the basin. Moreover, it was noted that north of the Apollo 17 site, Sculptured Hills knobs are gradational with radially lineated terrain (Fig. 1), whose orientation and morphologic prominence suggest a relation to the Imbrium basin. On the basis of these observations, it was suggested that the Sculptured Hills might be a facies of Imbrium basin ejecta [12] and that outcrop of this unit near the Apollo 17 site calls into question the exclusive Serenitatis basin provenance of rocks collected there.

New LROC WAC images show the geology of the highlands between Serenitatis and Crisium (which were poorly photographed by Lunar Orbiter) in superb detail. We now see clearly that Sculptured Hills are not localized around the Apollo 17 site, but are widespread throughout the Taurus Mountains. The unit shows several morphological facies, including knobby, undulate, radially lineated and rolling, plains-like terra (Fig. 1). The Alpes Formation, a knobby type of ejecta from the Imbrium basin resembling the Montes Rook Fm. of Orientale, is widespread north of Mare Serenitatis [4,13]. North of Posidonius, the Alpes Fm. transitions into Sculptured Hills material near the crater G. Bond (Fig. 1). Lineations in Sculptured Hills terrain point to Imbrium, not to Crisium or Serenitatis (except where the radials to basin centers of the two coincide, south of Römer). In addition, the Sculptured Hills material everywhere lies on top of a multitude of large, post-Serenitatis impact craters [12]. The distribution, inter-relation with other terra units and relative age of the Sculptured Hills unit all suggest that it is a facies of ejecta from the Imbrium basin.

Sculptured Hills occur adjacent to the North Massif at the Apollo 17 site and on the backslopes of both North and South Massifs [5,12]. If the Sculptured Hills are not ejecta from Serenitatis, then the Serenitatis provenance of Apollo 17 impact melt breccias is suspect. As long as the highland units around Apollo 17 were assigned only Serenitatis basin origins, it was hard to imagine that ejecta from that event did not dominate the Apollo 17 samples [5]. Spudis and Ryder [12] suggested that while a Serenitatis origin for

the poikilitic "melt sheet" is likely, the aphanites show chemical, petrological and physical features that suggest origin in multiple, different event(s). Now we must also re-examine the Serenitatis origin of the poikilitic rocks.

If the Apollo 17 impact melts do not come from Serenitatis, what might they represent? Haskin *et al.* [14] suggested that all melt rocks containing KREEP are ultimately derived from the Procellarum region and dispersed over the Moon by the Imbrium impact. This suggestion took the sample community aback; such an origin is at variance with our understanding of the process of impact melt homogenization with regard to the wide diversity observed in lunar impact melts. The Haskin *et al.* [14] model for producing melt heterogeneity in a basin-forming impact is implausible, yet we do not know how the composition of melt from such a large-scale event varies.

A large number of old, degraded craters are superposed on the Serenitatis basin, yet underlie the Sculptured Hills (Fig. 1; [6]). If the Sculptured Hills are a facies of Imbrium basin ejecta, then Serenitatis may be relatively old, as originally thought. We propose that the new image data confirm the senior age status of Serenitatis. The original basin-forming chronologies [1-3] made Serenitatis one of the oldest lunar basins, older than Nectaris, Crisium and Imbrium. Our preliminary geological mapping and crater counts point to a pre-Nectarian age for Serenitatis; Crisium basin is confirmed as Nectarian.

Geological consequences for the interpretation of Apollo 17 impact melts in this scenario are profound. If the Apollo 17 melts are samples of the Serenitatis basin melt sheet, then Serenitatis formed around 3.87 Ga ago [6]. As the formation of Imbrium basin is constrained to earlier than 3.84 Ga (the age of the younger, infilling Apennine Bench Fm. KREEP basalts; [15]), such a scenario would mean that not only Serenitatis and Imbrium, but virtually all other large basins and craters on the Moon formed within a narrow 30 Ma interval – truly a "cataclysm" in its most extreme form [16]. On the other hand, if the Apollo 17 melts are not from Serenitatis, they must be from other major impact(s) (e.g., deep-seated clasts, no surficial component). Given the proximity of Imbrium-related Sculptured Hills near the site, the Apollo 17 rocks might be Imbrium basin impact melt [14]. If that is indeed the case, differences in composition and age between these rocks and presumed Imbrium melts from elsewhere on the Moon indicate that we possess little systematic understanding of the effects of large-body impacts – the conventional wisdom of impact melt homogenization, distinct siderophile signatures, and precision Ar-dating are wrong at worst or incomplete at best. Either scenario necessitates a complete revision of our understanding of the history and evolution of the Moon.

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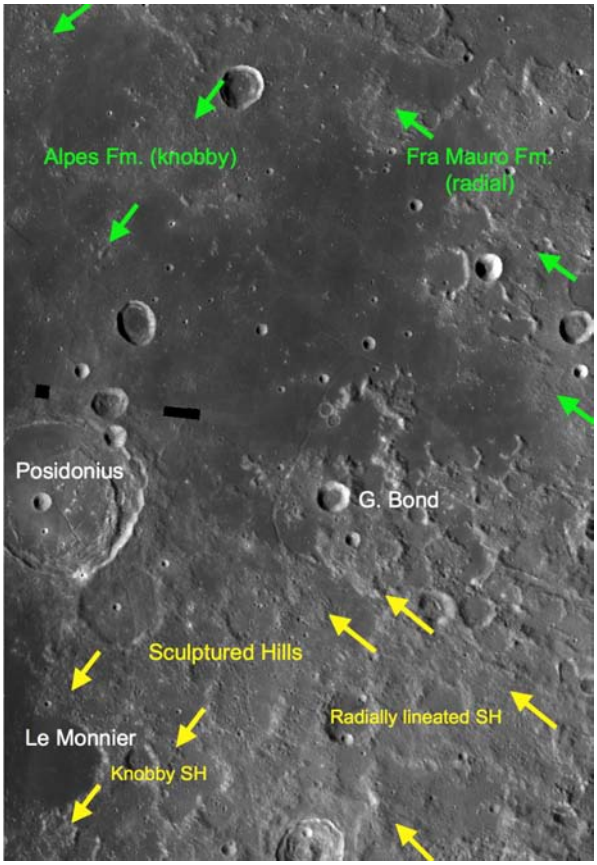

Figure 1. Knobby and radially textured units in the Taurus highlands. Imbrium-basin Alpes and Fra Mauro Fm. are both displayed in highlands north of G. Bond. Sculptured Hills show both knobby and radial texture; lineated SH is radial to Imbrium, not Serenitatis. These observations suggest that Sculptured Hills are actually Imbrium deposits and overlie both the Serenitatis rim and many post-Serenitatis craters (e.g., Le Monnier). LROC WAC mosaic.