WHY ARE APOLLO 17 IMPACT-MELT BRECCIAS ASSIGNED A SERENITATIS ORIGIN: A BRIEF CRITICAL REVIEW; Kaylynn M. Rockow and Larry A. Haskin , Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, One Brookings Drive, St. Louis, MO 63130

"One of the few aspects of Apollo-landing-site geology on which there is virtual unanimity of opinion is the origin of the terra melt rocks collected at the Apollo 17 Taurus-Littrow landing site. These rocks ... representative of an ejecta sequence from a single large impact which formed the Serenitatis basin [1]" What are the main arguments that have led to this apparent consensus, which was stated by [2]? We are seriously considering that Apollo 17 melt breccias may represent Imbrium ejecta [3], but should we be? Is their Serenitatis origin as well established as [2] indicate? And does it matter?

The principal arguments that led to this conclusion are: a) The Apollo 17 site is at the edge of the Serenitatis basin, so ejecta from that basin should be abundant (used, e.g., by [4, 5] to argue the provenance of melt breccias). b) Early ejecta modeling indicated that Serenitatis ejecta would dominate the geology of the site [6] (used, e.g., by [7] to argue provenance of Boulder 1, Sta. 2). c) Initial photogeologic assessment of the Apollo 17 site did not find evidence for Imbrium ejecta, and the North and South Massifs were interpreted to be Serenitatis analogs to roughly similar Orientale ejecta [8] (used as an argument by [9] to argue provenance of 73215). d) Compositions of melt breccias cluster by landing site (e.g., [10, 11]). e) Ancient meteorite group 2 is concentrated at the Apollo 17 site and was assigned to the Serenitatis bolide [12] (used by [13]). f) Early data suggested that the age distribution at the Apollo 17 site differed from that of the other sites (e.g., [14]).

The 73215 Consortium [9] *tentatively* suggested that melt breccia 73215 was formed by the Serenitatis impact, mainly from field evidence that the boulder came from the upper part of South Massif and the photogeologic argument of [15] that the massifs were of Serenitatis origin. This tentative conclusion was cited the following year [16] as "[Apollo 17 light gray breccias are] most probably ejecta from the Serenitatis Basin [9]." The conclusion by [16] was then used by the author of [9] as partial evidence of wide support for a Serenitatis origin [17]. [13] stated, in reference to the impact that formed the Apollo 17 melt breccias, "Whether or not this event corresponds to one of the large basin-forming events cannot be conclusively proved, although meteorite trace elements suggest that the Serenitatis event produced this melt [12]." The meteorite trace-element investigators [18] turned this around, using [13], among others [19, 20]: "Moreover, petrographic studies suggest that the Apollo 17 boulders containing the group 2 component are impact melt sheets from the Serenitatis event." Thus, we add to the list argument g): Investigators from other fields say so.

Argument a) (proximity) is irrefutable but does not identify Serenitatis ejecta or exclude substantial amounts of material from a subsequent source, such as Imbrium. Argument b) has often been used to support a Serenitatis origin for Apollo 17 melt breccias (e.g. [7]) but was regarded by some investigators as leaving their origin ambiguous (e.g., [21]). Our recent modeling [22] suggests that the average Imbrium-produced deposit should be much thicker (~900 m) than that estimated by [6] (26 m to 102 m), so the probability of an Imbrium origin for some of the sampled material is greater than initially estimated. The deposit thicknesses of [6], based on photogeologically estimated ejecta deposit thicknesses, fall substantially short of mass balance for depth/diameter of 0.1 and do not adjust for spherical geometry.

Argument c), failure to identify any specific *structures* of Imbrium origin [8] became evidence against an Imbrium origin for *material* at the Apollo 17 site. The Apollo 17 site appears on a regional geologic map as an anomalous Imbrium-sculpture-free "window" surrounded by Imbrium sculpted terrain [23]. In fact, [23] questions the proposed absence of Imbrium material at that location, and [24] proposes that the Sculptured Hills are partially of Imbrium origin.

Although the compositions of melt breccias do vary by landing site, melt breccias have many shared compositional characteristics. Most have mafic composition and relatively high incompatible trace-element concentrations with characteristic KREEPy relative abundances [25, 26]. Some investigators emphasized compositional similarities over differences and suggested or acknowledged that melt breccias might have a common origin (e.g., [27]), but most favor the idea that each compositional group represents a separate impact (argument d). Melt breccias believed on petrographic grounds to have formed in basin-sized impacts, have generally been assigned to the nearest basin, i.e. Apollo 17 melt breccias to Serenitatis, Apollos 14 and 15 to Imbrium and Apollo 16 to Nectaris [9, 10, 11, 26, 28]. An underlying assumption, that an impact homogenizes target material to produce melt with a uniform compositions, originated with the study of terrestrial intracrater

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melt sheets on Earth which are surprisingly homogeneous [19]. It is not clear, however, that a much larger basin-forming impact into heterogeneous terrain would develop such a homogeneous melt sheet, or that melt ejected well beyond a crater rim would have the same composition as the melt sheet or even a single composition. The strength of argument d) is diminished somewhat by recognition of multiple compositional clusters (e.g., [26, 29]) and age differences [30] for melt breccias from a single Apollo site. If melt ejected by a basin-forming event produces clusters of compositions at a single Apollo site, it might produce even greater inter-Apollo-site heterogeneity.

Relative abundances of siderophile elements in lunar breccias were interpreted as fingerprints of the bolides that produced major lunar basins, (e.g., [12]), who regarded ancient meteorite group 2 fingerprints as typical of Apollo 17 and assigned the group to the Serenitatis bolide on the basis of the proposed distribution of ejecta units [6]. Both groups 2 and 3 were found in Apollo 17 melt-breccia boulders, however, and some Apollos 11, 12, and 16 breccias contain group 2 [31, 32]. No simple assignment of most meteorite groups to basin-forming impacts could be made by [32]. The value of meteorite signatures have previously been questioned by [2]. Would a single basin-forming bolide produce a single siderophile-element fingerprint? Whether the fingerprints represent extinct meteorite groups rather than currently found ones is being reexamined [33, 34].

Ages of melt breccias from different Apollo sites and Luna 20 are very similar [35]. It was acknowledged that all dated melt rocks might be from one event (an Imbrium only "cataclysm," [27, 36]), but a popular conclusion is that major nearside basins formed within a small time interval (e.g., the cataclysm; [37, 38]). Few melt breccias yield concordant ages from different methods, and interpretation of reported ages is not straightforward. It is necessary to argue away some breccias and some ages (e.g., no Ar plateau, too large an age uncertainty) to find differences among the rest that support (slightly) different times of origin for different basins. Meticulous recent $^{40}Ar/^{39}Ar$ work on twelve Apollo 15 melt breccias [30] yielded well defined and similar ages (3852 ±14 to 3870 ±12 Ma; weighted mean 3865 ±5) for five melt breccias belonging to three distinct compositional groups, a different age (3836 ±11 Ma) for one belonging to the same compositional group as one of those five, no datable plateaus for five, and low-T-high-T age differences for one. $^{40}Ar/^{39}Ar$ measurements on two Apollo 17 "Serenitatis" melt breccias [39] yielded ages of 3893 ±16 and 3900 ±16 Ma which, given individual uncertainties, is in the range of the five Apollo 15 melt breccias with well defined ages. Nonetheless, [30] conclude that the Imbrium basin is no older than 3870 Ma (and probably no older than 3836 Ma, based on one sample?) and [39] that the age of the Serenitatis impact is 3896 ±11 Ma.

We conclude that the argument that Apollo 17 melt breccias originated in the Serenitatis event, while plausible, could be stronger. Does it matter? We say yes, because it affects our ideas about the following: a cataclysm; the composition of the early central highland crust; the perceived age of the Serenitatis basin; interior lunar structure and heterogeneity; differentiation modeling and the magma ocean; KREEP distribution.

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