PROVENANCE OF IMPACT-MELT BRECCIAS COLLECTED AT THE APOLLO LANDING SITES: WHAT DID WE LEARN AND WHAT ARE THE IMPLICATIONS FOR FUTURE EXPLORATION? B. L. Jolliff, R. L. Korotev, and R. A. Zeigler. Department of Earth and Planetary Sciences and the McDonnell Center for the Space Sciences, Washington University, St. Louis, MO, 63130, USA (blj@wustl.edu).

In the past four decades, much has been learned about samples returned from the Moon by Apollo and Luna, and more recently, from the study of lunar meteorites. One of the legacies of the lunar samples is the correlation between ages of rocks that were created in or affected by impact events and the locations where they were sampled. From such correlations, precise ages have been assigned to events that seemed most logical according to geologic relationships. Moreover, with a few accurately determined ages, an entire relative chronology was developed according to stratigraphic relationships and impact crater size-frequency distributions [reviewed by 1].

Still, after 40+ years of study, the provenance of samples and ages of key events continue to be a focus of research and a topic of debate. Central to the argument are the formation ages of the impact basins and the implications of those ages. From geologic relationships, we infer that (1) noritic impact-melt breccias and crystalline melt rocks from Apollo 14 and 15 record the formation age of the Imbrium Basin, (2) those from the boulders of the highland massifs at Apollo 17 record the age of Serenitatis, (3) those from the KREEP-poor impact-melt-breccia groups at Apollo 16 record the age of Nectaris, and (4) similar materials from Luna 24 record the age of Crisium. Ejecta from such prominent craters as Copernicus and Tycho were sampled at Apollo 12 and 17, respectively, and local craters such as Cone at Apollo 14, and North Ray and South Ray at Apollo 16 were also sampled and ages determined for those events. Much of what we understand about the impact flux is based on these ages.

One fundamental conclusions from the data is that impact basin ages point to a late, heavy bombardment or "cataclysm," with a pronounced spike in large impact events ~4.0–3.8 Ga. The paucity of impact melt rocks older than 4.0 Ga has been interpreted to mean that either (1) most impact basins formed at this time, or (2) the large, near-side, relatively late basins whose ejecta deposits dominate the Apollo samples simply obscured or reset impact rocks formed earlier [2].

To complicate matters, different age-dating methods can yield different ages of formation. In some cases, the information is complementary, for example, Sm-Nd or Rb-Sr isotopes might give a crystallization age whereas an Ar-Ar age from the same rock might record an event that reset the isotopes but did not completely melt the rock. Recent data from the sensitive, high-resolution ion microprobe (SHRIMP) date zircons in impact-melt rocks has given a precise age determination of a Th-rich lunar meteorite, SaU-169 [3], and a group of very similar Apollo 12 impact-melt breccias [4] of 3.91 Ga. The simplest interpretation is that these samples were produced by Imbrium. What does this mean for the more commonly cited age of Imbrium of 3.86 Ga [5]?

Although the origin of the impact-melt breccias from Apollo 17 has been called into question [2], samples from boulders that have clear origins in the massif deposits were most likely formed by the Serenitatis event. Their ages, determined mainly by Ar geochronology, point to 3.89 Ga.

Impact-melt rocks from Apollo 16 span a range of geochemical characteristics and ages. The Cayley Plains and most of the mafic impact-melt groups likely have an Imbrium origin. KREEP-poor melt rocks may come from Nectaris; and still others may even come from Serenitatis. Ages, mostly by ^{40}Ar-^{39}Ar, have proven difficult to interpret [6].

What is needed is to sample directly impact melt rocks from within a basin, i.e., its melt sheet. The deposition of basin ejecta deposits is largely ballistic, so distal deposits have mixed provenance. Direct sampling of a basin such as Orientale or Schrodinger, where basin melt deposits are unambiguous, or sampling the ejecta of a young crater that penetrates mare to excavate underlying impact deposits is needed.

A high-priority goal of impact basin chronology on the Moon is to test the Cataclysm hypothesis. Perhaps the best approach is to determine the chronology of the South Pole-Aitken Basin, the oldest and largest recognized basin on the Moon. Its location far from the large and late, nearside basins coupled with impact ejecta modeling indicating that rocks of the original impact-melt sheet should still be the dominant component of the regolith in the Basin interior makes it a prime exploration target for sample return. Confirming or refuting the Cataclysm hypothesis will have implications for the early bombardment history of the Solar System at a critical time for surface evolution of the Earth and other planets of the inner Solar System.

Acknowledgements: Support is from the NASA Cosmochemistry program, # NNX07AI44G.

References: [1] Stöffler et al. (2006) *RIM-G,* **60***,* 519-596; [2] Haskin et al. (2003) *Meteorit. Planet. Sci.*, **38**, 13-33; [3] Gnos et al. (2004) *Science*, **305**, 657-659; [4] Liu et al. (2002) *LPS 41,* Abstract #2477; [5] Dalrymple and G. Ryder (1993) *JGR*, **98**, 13,085-13,095; [6] Norman (2009) *Elements*, **5**, 23-28.