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Lunar chronology from lunar meteorites

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There are approximately 36 different lunar meteorites collected on Earth some of which represent regions of the Moon that were not sampled by the Apollo and Luna missions [1]. These meteorites therefore provide the first global sample-set of lunar samples and provide a context for interpreting the age and chemical results of Apollo samples, particularly as the latter were strongly influenced by Imbrium ejecta and development of the Procellarum KREEP terraine [2]. Since our lunar work is laboratory-based and concentrates on chronology and geochemistry of lunar meteorites we are most interested in attempting to tie the lunar meteorites to ground truth on the Moon - specifically where are their sources. Thus, an important next step will be to integrate results obtained from the meteorites with geochemical data obtained by orbiting (and in the future lander) spacecraft (e.g. [3])

Most lunar meteorites are feldspathic breccias that have experienced only mild shock during the ejection event, insufficient to disturb their isotopic ages. Some of these breccias contain clasts of impact melts, having chemical compositions distinct from those found in Apollo and Luna samples, indicating their formation in relatively large impacts where substantial amounts of melt were produced. The Ar-Ar ages obtained from melt clasts in different lunar meteorites record multiple major impact events occurring between $<$1.0-3.9 Ga ([3-6]. These ages do not cluster at 3.8-3.9 Ga, the dominant impact event recorded by Apollo impact melts, but there is a notable lack of impact ages older than 3.9 Ga, representing the period before most of the major lunar basins were formed.

Basaltic lunar meteorites (and polymict breccias containing mare material) are predominantly low-Ti basalts, some having a KREEP-rich composition (e.g. NWA 773). Determination of their crystallisation ages is an area of active research with those determined so far being as follows: NWA 032 - 2.779 $\pm$ 0.014 Ga [7]; LAP 02205 - 2.957 $\pm$ 0.02 Ga [8], for NWA 773 - 2.9 Ga [7,9]; EETA 96008 – 3.52 $\pm$ 0.01 Ga [10]; Yamato 793169 - 3.93 $\pm$ 0.05 Ga [11]; and Asuka 881757 - 3.94 $\pm$ 0.03 [12]. The overall range of 2.8-3.9 Ga is similar to the age range from Apollo and Lunar basalts and probably reflects the prevalence of mare volcanism in the Procellarum KREEP terraine.

An important distinction between Apollo samples and lunar meteorites is that the former were picked up from the surface of the Moon while the latter were excavated from (as yet unknown) depths by impacts. An important aim is to investigate to what extent a comparison of the solar wind, cosmic ray proton, and lunar neutron exposures of lunar meteorites and Apollo samples can tell us about the excavation depths of lunar meteorites and the size of the impacts necessary to have launched them into space. Since they have short cosmic ray exposure ages reflecting capture times by the Earth following ejection they must come from very young cratering events smallish (?) ray craters similar to South Ray at Apollo 16. 1. Pin-pointing the source of lunar meteorites involves orbital geochemical surveys combined with a view to matching chemical compositions near young craters to lunar meteorites. Ultimately, this approach can be extended to surface landers to obtain compositional measurements near to candidate craters. In this respect, He analyses can be used to identify fresh material which will have very low solar wind Ne and He concentrations, and exposure ages based on ^{21}Ne contents of fresh ray material can be directly related to those obtained from meteorites.

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