LUNAR METEORITES: WHAT THEY TELL US ABOUT THE SPATIAL AND TEMPORAL DISTRIBUTION OF MARE BASALTS.

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1. Introduction: Here we analyze the chronology and statistical distribution of lunar meteorites with emphasis on the spatial and temporal distribution of lunar mare basalts. The data are mostly from the Lunar Meteorite Compendium (http://www-curator.jsc.nasa.gov/ antmet/lmc/contents.cfm cited hereafter as Compendium) compiled by Kevin Righter, NASA Johnson Space Center, and from the associated literature. The Compendium was last modified on May 12, 2008.

2. The data: The Lunar Meteorite Compendium currently lists 108 "stones" representing 54 meteorites. Among the latter are identified several so-called "launch-paired" meteorites, which are considered to be ejected together by the same impact event but landed on Earth in different areas. They may represent either different or similar rock types.

In the Compendium, lunar meteorites are subdivided into three groups: group B – mare basalts and gabbros, group F - feldspatic (anorthositic) highland breccias, and group M - "mingled", brecciated mixtures of these two end-members. Of the 54 meteorites, 10 belong to group B, 30 to group F, and 14 to group M. Breccias of groups F and M (44 meteorites in total) are presented by 4 varieties: regolith breccias – 19, fragmental breccias – 12, impact-melt breccias – 10, and granulitic breccias – 3.

Among the launch-paired meteorites are Yamato 793169 (B), Asuka 881757 (B), Miller Range 05035 (B), and Meteorite Hills 01210 (M), which based on their similarity of composition, exposure histories, and crystallization ages are considered to be launched-paired [1, 2, 3, 4]. It was also suggested that meteorite NWA 032 (B) is paired with the La Paz Ice Field basalts (B) [*2*]. And the mingled meteorites, Yamato 793274/981031 (M), Elephant Moraine 87521/96008 (M) and Queen Alexandra Range 94281 (M), are also launch-paired [1, 2].

The launch-paired meteorites should be taken into account if one considers the petrological aspect of the meteorite source craters. The first launch-paired group consisting of three group B meteorites and one group M meteorite represents a mixture of mare and highland materials so the source crater is "mingled". The second group consisting of two group B meteorites represents one "basaltic" source crater. And the third group consisting of three group M meteorites represents a "mingled" source crater. So, 6 craters supplied group B meteorites, 30 craters, group F ones, and 13 craters, group M ones. The total number of source craters is 49.

Another subject of our analysis is the data for the absolute ages of crystallization of the meteorite basalts. Among the 10 basalts and gabbros of group B, 9 have been isotopically dated, and among 14 mingled breccias, basaltic clasts have been isotopically dated in 6. The results of these datings acquired mostly from the literature cited in Compendium and partly from more recent publications, not mentioned in Compendium, are given in Table 1 of [5] and shown here in Fig. 1.

3. Analysis of the data: We analyze the available data along the four following lines:

3.1. Significance of regolith breccias: Regolith breccias were formed within the regolith layer [e.g.,6], the thickness of which as estimated by different techniques varies from 3-5 m in maria to 15-35 m in highlands [6, 7]. Craters ejecting fragments of regolith breccias should not be significantly deeper than the regolith thickness. If the crater was significantly deeper, then its ejecta should be dominated not with the regolith materials (including regolith breccias), but with the components of bedrock. Regolith breccias came from 18 of 49 source craters. This means that more than 1/3 of the source craters were not significantly deeper than 3-5 to 15-35 m. Keeping in mind that depth of ejection from impact craters is ~1/10 of the crater diameter one can conclude that these craters had diameters not much larger than several hundreds of meters. This agrees with the conclusion of [8], based on evidence different from ours, and with model estimates by [9].

3.2. Significance of mingled breccias: Source craters of the mingled breccias had to be formed in targets composed of both mare and highland materials. It is important that 8 of 14 group M breccias are regolith breccias. The mingled breccias could be delivered from the four geologic situations: 1) a mare-highland boundary, 2) small mare basalt ponds within highlands like those observed in the vicinity of Orientale basin [10], 3) mare areas where the highland material basement is at small depths, and 4) cryptomare areas, where the highland materials overlie ancient maria. The group M breccias derived from 13 of 49 source craters. So the mare-highland boundary (which is narrow) and small mare ponds within highlands (which total area is small) both look unfavorable for providing such a large fraction of the collection. The mare areas with shallow highland-material basement also do not look promising, especially for the cases of regolith breccias. In the latter cases, the mare layer should be only meters to a few tens of meters thick, which would lead to numerous highland islands not typical for the Moon. Cryptomaria [11, 12] look most promising in this respect. But, if they are the major supplier of the group M breccias this may mean that cryptomaria are rather abundant in the lunar highlands ($14/(14+30) \approx 1/3$ if to count meteorites, or $13/(13+30) \approx 1/3$ if to count source craters), that about half of them are covered with very thin highland material mantles (8 of 14 mingled breccias are regolith ones), and that the source craters of the group M breccias are mostly within the highland domain.

3.3. Relative abundances of the meteorite source craters: If the analyzed lunar meteorite collection is a representative sample of the near-surface part of the lunar crust, one should expect that in this sample the relative abundances of major petrologic types of meteorites are proportional to the areas of these types on the lunar surface. Working on this approach, one should consider not only meteorites, but the source craters as well. We know that the lunar maria occupy ~16% of the lunar surface and the rest is highlands [e.g., 6, 7]. So the maria vs. highlands areas proportion is ~1:5. To calculate this proportion for lunar meteorites we should take in account the amounts of mare basalt/gabbro meteorites (B = 10), the highland feldspatic breccias (F = 30) and mingled breccias (M = 14). The latter as it was concluded above probably derived mostly from cryptomaria, which are part of the highlands. So, the mare- to highland-derived meteorites ratio is B:(F+M) = 10:(30+14) = 1:4.4, rather close to ~1:5. The abundances of source craters representing different petrologic types are: B = 6, F = 30, and M = 13. So B:(F+M) = 6:(30+13) ≈ 1:7. This is not as close to the known proportion of mare to highland areas (~1/5), but keeping in mind that the numbers of the source craters, and especially those craters that are sources for mare basalt meteorites (only six) are small, the 1:7 ratio looks reasonably close to 1:5 and one may conclude that the lunar meteorites are a rather representative and random sample of the upper part of lunar crust.

3.4. Ages of meteoritic mare basalts: Most of the meteoritic mare basalts have been dated by several techniques. As a rule, for a given meteorite the age values determined by the Sm-Nd, U-Pb and Rb-Sr techniques are close, but those determined by the K-Ar technique are often lower, probably due to loss of argon in subsequent thermal episode(s). So, for our consideration we used values determined by the Sm-Nd, U-Pb and Rb-Sr techniques (see Fig. 1), and only in one case the K-Ar value [13] because no other techniques were applied to this meteorite. Fig. 1 shows what has been noted already by other researchers [e.g., 13, 14, 15]: the meteorite mare basalts show a time span broader than basalts sampled by the Apollo and Luna missions. It is interesting that the meteorite basalt ages fill the gaps in the Apollo/Luna basalt age distribution (see recent summary in [16]) and generally are in a good agreement with the mare basalt age distribution determined by the crater count technique [17] as was mentioned earlier by [14].

4. Conclusions: The above analysis shows:

- A significant part of the lunar meteorite source craters are smaller than hundreds of meters in diameter;
- Cryptomaria seem to be rather abundant in lunar highlands;
- The proportions of lunar meteorites belonging to three broad petrologic groups (mare basalt/gabbro, feldspatic highland breccias, mingled breccias which are a mixture of mare and highland components) seems to be proportional to the areal distribution of these rocks on the lunar surface,
- The meteorite mare basalt ages show a range from ~2.5 to 4.35 Ga and fill the gaps in the Apollo/Luna basalt age distribution.

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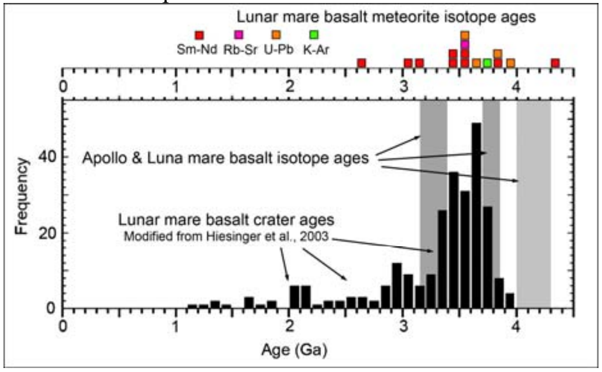

Figure 1. Lunar meteorite mare basalt ages of crystallization in comparison with the Apollo/Luna mare basalt ages and ages of lunar mare units determined by the crater count technique [Hiesinger et al., 2003].

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