THE SPATIAL AND TEMPORAL DISTRIBUTION OF LUNAR MARE BASALTS AS DEDUCED FROM ANALYSIS OF DATA FOR LUNAR METEORITES. A. T. Basilevsky [1,2], G. Neukum[2] and L. Nyquist[3]. 1-Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow, Russia atbas@geokhi.ru ; 2-Freie Universitaet Berlin, Berlin, Germany, 3-KR/NASA Johnson Space Center, Houston, Texas 77058, USA.

Introduction: In this work we analyze chronological data for 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 thereafter as Compendium) compiled by Kevin Righter and from the associated literature.

The data: The Lunar Meteorite Compendium currently lists 54 meteorites represented by 108 specimens (Figure 1). This collection is large enough that taking in mind the stochastic nature of impacts delivering pieces of lunar rocks to Earth one may consider these 54 meteorites to be a rather representative random sampling of the lunar near-surface crust.

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 - brecciated mixtures of these two end-members. The latter type has also been referred to as "mingled". 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. The abundances of these groups and their varieties are a subject of the following analysis.

Another subject of our analysis is the data for 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 only in 6. The results of these datings acquired mostly from the literature cited in Compendium and partly from recent publications are given in Table 1.

Analysis of the data: We analyze the available data along the following lines:

1) Relative abundance of the groups B, F and M: If the analyzed collection is a representative sample of the near-surface part of the lunar crust, one should expect that the relative abundances of basalts/gabbros and feldspatic (anorthositic) breccias in this sample are proportional to the relative areal abundances of the lunar maria and highlands. The latter is known to be ~1:5, while the B vs. F abundance is 1:3 differing somewhat from the mare to highland area ratio. But, if we combine the abundances of groups F and M, then B vs. F+M is 1:4.4, i.e., close enough to the mare to highland area ratio.

2) Significance of regolith breccias: Regolith breccias were formed within the regolith layer [e.g, 1], the thickness of which as estimated by different techniques varies from 3-5 m in maria to 15-35 m in highlands [e.g., 1,2]. 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 breccias but with the components of bedrock. Regolith breccias compose 35% (19 of 54) of the considered collection. This means that ~1/3 of the craters from which ejecta are present in the considered collection, were not significantly deeper than 3-5 to 15-35 m. Taking in mind that depth of ejection from impact craters is ~1/10 of the crater diameter [3] one can conclude that these craters had diameters not significantly larger than several hundreds of meters. This agrees with the conclusion of [4] that typical lunar meteorite source craters are << 3.6 km in diameter and smaller source craters are easily possible and with model estimates by [5] which support the "small impact" scenario with maximum parent crater of about 0.6-1 km. As an option one may suggest that lunar regolith breccias have been ejected from the Moon by mechanism of spallation of the surface layer suggested by [6]. However this mechanism could be effective only in the case of large craters (in the case of small craters the spallation zone is too small), but consequence of this should be large amount of launch-paired meteorites. The latter are present in the collection , but not ftrequent [Compendium].

3) Significance of mingled breccias: These breccias contain clasts of both mare and highland rocks. This implies that each of the craters from which ejecta provided meteorites of group M had to be formed in targets composed of both mare and highland materials. It is also necessary to keep in mind that 8 of 14 breccias of group M are regolith breccias. The mingled breccias could be delivered from three geologic situations: 1) a mare-highland boundary, 2) the mare areas where the highland material basement is at small enough depth, and 3) cryptomare areas, where the highland material mantles overlie ancient maria. The group M breccias compose 26% of the considered collection so the mare-highland boundary (which is narrow) looks 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 meters to a few tens of meters thick, which would lead to very peculiar mare/highland embayments not typical for the Moon. Cryptomaria [7,8] 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) =~1/3), and that about half of them are covered with very thin highland material mantles. The meteorite launch-pairing may decrease this eatimate. These suggestions can be tested with analysis of images of Lunar Reconnaissance Orbiter Camera.

4) Ages of meteoritic mare basalts. As is seen in Table 1 and Figure 2, most of the meteoritic mare basalts have been dated by several techniques. As a rule, for a given meteorite the age values determined by Sm-Nd, U-Pb and Rb-Sr techniques are close, but those determined by K-Ar technique are often lower probably due to subsequent thermal episode(s). So, for our consideration we used values determined by the Sm-Nd, U-Pb and Rb-Sr techniques [9-15], and only in one case the K-Ar value [16] because no other techniques were applied to this meteorite.

Fig 1 shows what has been noted already by other reserarchers [e.g., 10,13,17]: the meteorite mare basalts show a time span broader than basalts sampled by Apollo and Luna missons. It is interesting that the meteorite basalts ages fill the gaps in the Apollo/Luna basalt age distribution and generally are in a good agreement with the mare basalt age distribution determined by the crater count technique [16] that was mentioned earlier by [10].

Conclusions: The above analysis shows that the distribution of lunar meteorites in broad petrologic groups seems to be proportional to the areal distribution of latter, that a significant part of the lunar meteorite source craters are smaller than hundreds of meters in diameter, that cryptomaria seem to be rather abundant, and that the meteorite mare basalt ages fill the gaps in the Apollo/Luna basalt age distribution.

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Yamato 793169, 6,09 g | Asuka 881757, 442 g | Nortwest Africa 479, 156 g | La Paz IF 02205, 1226 g | Dhofar 287, 154 g

Figure 1. Photos of selected lunar meteorite basalts from Lunar Meteorite Compendium (http://www-curator.jsc.nasa.gov/antmet/lmc/contents.cfm)

Table 1. Isotope age determinations of the lunar meteorite basalts

Group	Meteorite name	Short description	Absolute age, Ga
B1	Yamato 793169	Unbrecciated basalt	3.8-3.9 U-Th-Pb, 3.43 Sm-Nd, 1.64 K-Ar
B2	Asuka 881757	Gabbro	3.94 U-Th-Pb, 3.84 Rb-Sr, 3.87 Sm-Nd,, 3.75 K-Ar
B3	NWA 032, 479	Unbrecciated basalt	2.85 Rb-Sr, 2.69 Sm-Nd, 2.75-2.73 Ar-Ar
B4	NEA 003	Unbrecciated basalt (with basaltic breccia)	3.09 Sm-Nd, 2.38 Ar-Ar
B5	NWA 773, 2700, 2727, 2977, 3160	Gabbro (with basalt and breccia)	3.10 Sm-Nd, 2.67-2.94 Ar-Ar
B6	Dhofar 287	Unbrecciated basalt (with basaltic breccia)	3.35 U-Pb, 3.46 Sm-Nd
B7	La Paz IF 02205, 02224, 02226, 02436	Unbrecciated basalt	2.93 U-Pb, 2.99 Rb-Sr, 3.15 Sm-Nd, 2.94 Ar-Ar
B8	Miller Range 05035	Unbrecciated basalt	3.90 Rb-Sr, 3.80 Sm-Nd
B9	NWA 4898	Unbrecciated basalt	3.58 Rb-Sr
M1	Yamato 793274, 981031	Anorthosite-bearing basaltic regolith breccia	3.5 U-Pb IM mare, 4-4.1 U-Pb anorthosite
M2	Elephant Moraine 87521, 96008	Basaltic or gabbroic fragmental breccia	3.53-3.69 U-Pb (accept 3.6), 3.23-3.30 Ar-Ar
M4	Queen Alexandra Range 94281	Anorthosite-bearing basaltic regolith breccia	3.77 K-Ar
M5	Kalahari 008, 009	Anorthositic regolith / basaltic fragmental breccias	4.35 U-Pb IM, 4.3 Sm-Nd, 4.29 Lu-Hf, 2.67 Ar-Ar
M7	Meteorite Hills 01210	Anorthosite-bearing basaltic fragmental breccia	3.8-3.9 U-Pb accept 3.85
M8	Sayh al Uhaymir 169	Basalt-bearing anorthositic regolith breccia	3.91 U-Pb, 3.8 Ar-Ar

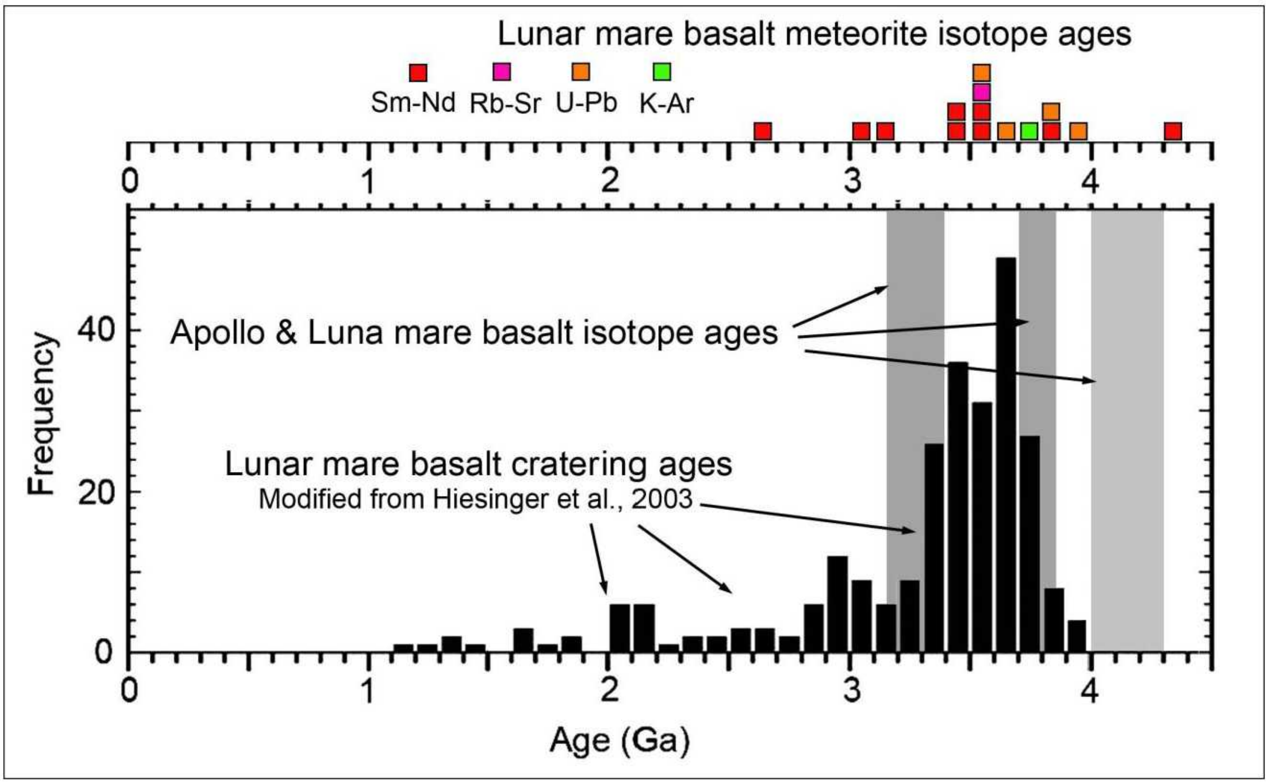

Figure 2. Lunar meteorite mare basalt ages of crystallization in comparison with Apollo/Luna mare basalt ages and ages determined by crater count technique [16].