AGES OF MARE BASALTS ON THE LUNAR NEARSIDE: A SYNTHESIS. H. Hiesinger[1], J. W. Head[2], U. Wolf[3], G. Neukum[3], R. Jaumann[4]. [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany. [2]Dept. of Geological. Sciences, Brown University, Box 1846, Providence, RI 02912. [3]Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin. [4]DLR-Inst. für Planetenforschung, Rutherfordstr. 2, 12489 Berlin. Hiesinger@uni-muenster.de

Introduction: Lunar mare basalts cover about 17% of the lunar surface [1]. The majority of lunar mare basalts are exposed on the lunar nearside mostly within large impact structures but also occur, although spatially less extensively, on the lunar farside. Even after the Apollo and Luna programs absolute radiometric age data are still lacking for most of the lunar basalts. By making use of remote sensing techniques we can derive relative and absolute model ages for unsampled regions. For example, inspection and interpretation of superposition of geologic units onto each other, embayment and crosscutting relationships within high-resolution Apollo and Lunar Orbiter images were used to obtain relative ages for lunar surface units [e.g., 2]. In addition it has been shown that crater degradation stages and crater size-frequency distribution measurements, calibrated to the landing sites, are useful to derive relative and absolute model ages [e.g., *3-14*]. Here we present age data that are based on remote sensing techniques, that is, crater counts. Our age data represent the most comprehensive data set on lunar mare basalt ages and can help to constrain boundary conditions for the thermal and petrologic evolution of the Moon. In particular, our ages can be correlated with Lunar Prospector and Clementine data in order to study the mineralogical evolution of mare basalts with time. In addition, in some cases distinctive kinks in the cumulative crater size frequency distribution can be used to estimate the thickness of lava flows [14,15]. Together with the areal extent of a basalt unit and its age, these thicknesses can be used to estimate the flux of lunar mare basalts over time [12].

Method: Our ages are derived from crater size-frequency distribution measurements for spectrally homogeneous basalt units on the lunar nearside. We used a high-resolution Clementine color ratio composite (e.g., 750-400/750+400 ratio as red, 750/990 ratio as green, and 400/750 ratio as blue) to map the distribution of distinctive and spectrally homogeneous basalts units. We assume that these units were formed within a short period of time with homogeneous mineralogy to a first order, such as a single eruptive phase. After having defined such units with Clementine images, we transferred the unit boundaries to high-resolution Lunar Orbiter IV images in order to measure the crater size-frequency distribution. This was necessary because due to their high sun angles, Clementine images are not well suited for crater counts. The technique of crater size-frequency distribution measurements on spectrally homogeneous regions has been described in detail [11,13].

Results: Despite the enormous scientific value of the returned samples from six Apollo and three Luna landing sites, these data are insufficient to completely explain the thermal evolution of the Moon. For example, based on the samples alone, the onset and extent of mare volcanism are not very well understood (summarized by [16]). The returned samples revealed that mare volcanism was active at least between ~3.9 and 3.1 b.y. [17,18]. Ages of some basaltic clasts in older breccias point to an onset of mare volcanism prior to 3.9 b.y. [19], perhaps as early as 4.2–4.3 b.y. in the Apollo 14 region [16,20,21]. Early volcanism is also supported by remote-sensing data. For example, dark halo craters have been interpreted as impacts into basaltic deposits that are now buried underneath a veneer of basin or crater ejecta [e.g., 22-24]. These underlying basalts might be among the oldest basalts on the Moon, implying that volcanism was active prior to ~3.9 b.y. ago. Such early volcanism has been supported by radiometric age dating of the lunar meteorite Kalahari 009, which revealed that volcanism was already active 4.35 b.y. ago [25]. On the basis of crater degradation stages, [6] and [26] derived absolute model ages that indicate volcanism might have lasted from 3.85±0.05 b.y. until 2.5±0.5 b.y. ago. Support for such young basalt ages comes from a recently collected lunar meteorite, Northwest Africa 032, which shows a Ar-Ar whole rock age of ~2.8 b.y. [27]. *Schultz and Spudis* [8] made crater size-frequency distribution measurements for basalts embaying the Copernican crater Lichtenberg and concluded that these basalts might be less than 1 b.y. old.

Figure 1 shows the distribution of ages of our ~352 basalt units that are exposed in the investigated basins. For this plot we combined results from our age determinations for basalts in Mare Imbrium, Serenitatis, Tranquillitatis, Humorum, Humboldtianum, Australe, Oceanus Procellarum, Cognitum, Nubium, Frigoris, and several basalts exposed within impact craters and small isolated patches.

Our data indicate that lunar volcanism in the large nearside mare started at ~4 b.y. and ended at ~1.1 b.y. ago. Most of the investigated basalts on the lunar nearside erupted during the late Imbrian Period between ~3.3-3.8 b.y. and there is possibly a second period of enhanced volcanic activity at ~2-2.2 b.y. ago. Our ages, which are based on a much larger database, are consistent with previously obtained remote-sensing ages. However, compared to the basalt ages derived from crater degradation [6,26] and ages of the geologic maps that were based mainly on brightness differences, morphology and qualitative crater densities on telescopic and Lunar Orbiter images [e.g., 28], our data fit spectral and lithological units and represent a major improvement in accuracy.

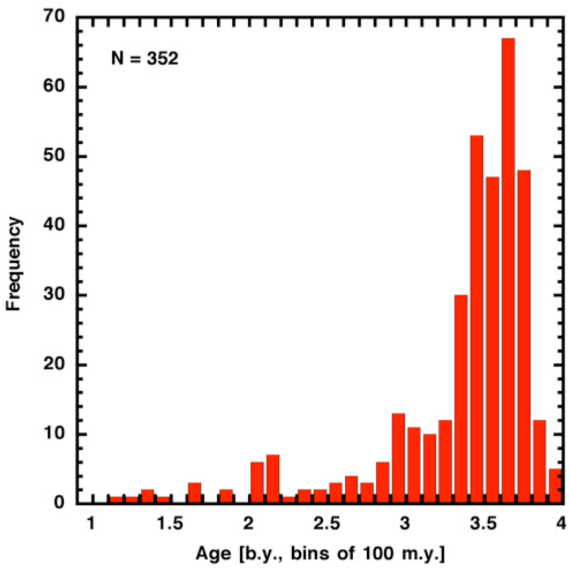

Fig. 1: Frequency distribution of all 352 measured mare basalt model ages. Data are binned into bins of 100 m.y.

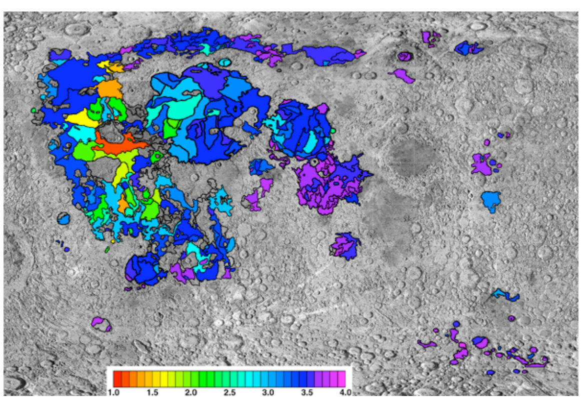

Fig. 2: Color-coded spatial distribution of measured mare basalt model ages. Simple cylindrical map projection. Warm colors indicate young ages; purple colors represent old basalt ages.

Plotting the age data on a global shaded relief map shows that the measured model ages are not equally distributed across the lunar surface (Fig. 2). Rather, we find older basalts exposed within Mare Tranquillitatis, Mare Australe, Mare Humboldtianum, and Mare Marginis, hence mostly in the eastern nearside regions. The youngest mare basalts are exposed within Oceanus Procellarum, in the vicinity of the Aristarchus Plateau and this correlates generally well with the distribution of radiogenic thorium as derived from Lunar Prospector data [29].

Outlook: In October 2008, the Lunar Reconnaissance Orbiter will be launched in order to investigate the lunar surface in unprecedented detail [30]. On board the spacecraft are two narrow angle cameras (NAC) and a wide-angle camera (WAC) providing global coverage at about 100 m/pixel and coverage of large areas at spatial resolutions of less than 1 m/pixel. The illumination geometry has been chosen in order to emphasize subtle morphologic details. Hence, this global data set will be extremely valuable for crater counts, particularly on the farside.

Conclusions: Based on our age determinations for basalts that are exposed on the lunar nearside we conclude that (1) volcanism was active over a long period of time, starting at ~4 b.y. and ending at ~1.1 b.y.; (2) the largest number of basalt units were formed in the late Imbrian Period at ~3.3-3.8 b.y.; (3) there may be a second peak in volcanic activity at ~2-2.2 b.y.; (4) the number of erupted basalt units is significantly smaller during the Eratosthenian Period; (5) basalt ages are not equally distributed over the lunar nearside; (6) older basalts appear to be exposed in the eastern lunar nearside basins; (7) the youngest basalts are located in Oceanus Procellarum, in the vicinity of the Aristarchus Plateau; (8) new data, for example from the Lunar Reconnaissance Orbiter cameras will expand our capabilities to date basalts in areas for which this has been previously not possible.

References

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