LUNAR MARE BASALTS: SCIENTIFICALLY IMPORTANT TARGETS FOR LROC. H. Hiesinger1, K. Klemm1, C. H. van der Bogert1, D. Reiss1, J. W. Head2. Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany. 2Dept. of Geological Sciences, Brown University, Box 1846, Providence, RI 02912. Hiesinger@uni-muenster.de

Introduction: The majority of lunar mare basalts are exposed on the lunar nearside within large impact structures, but also occur on the lunar farside, although over a reduced spatial extent [1]. Even after the Apollo and Luna sampling programs, absolute radiometric age data are still absent for most of lunar basalts. Remote sensing techniques allow us to derive relative and absolute model ages for unsampled regions. For example, inspection and interpretation of the superposition of geologic units, including embayment and crosscutting relationships as seen with 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 for the derivation of relative and absolute model ages [e.g., 3-14]. In previous papers, we presented age data based on remote sensing techniques, that is, crater counts [e.g., 11-14]. Our age data represent the most comprehensive data set on lunar mare basalt ages and can help 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 some cases, distinctive kinks in the cumulative crater size frequency distribution can also be used to estimate the thickness of lava flows [14,15]. These thicknesses can be used to estimate the flux of lunar mare basalts over time in order to constrain the thermal evolution of the Moon.

Scientific Questions: (1) Mare volcanism in space and time: Despite the undisputed 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 samples alone, the onset and extent of mare volcanism are not well understood (summarized by [16]). The returned samples indicate 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 cryptomare basalts might be among the oldest basalts on the Moon, implying that volcanism was active prior to ~3.9 b.y. ago. Early volcanism is also supported by radiometric age dating of the lunar meteorite Kalahari 009, which revealed that volcanism was already active at least 4.35 b.y. ago [25]. On the basis of crater degradation stages, Boyce [6] and Boyce and Johnson [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]. Indications of late mare volcanism are discussed by Schultz and Spudis [8], who 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. Our crater counts indicate that lunar volcanism in the large nearside maria 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. Crater counts of a few basalts on the lunar farside revealed similar results [28].

(2) Mineralogical evolution of the Moon: The presence of basaltic deposits on planetary surfaces is indicative of the thermal activity and volcanic evolution of the body [29-31]. In order to understand the geologic evolution of a planetary body, it is crucial to know when basaltic volcanism was active and how the mineralogy varied with time. Lunar basalts show a large range in TiO2 content; this broad variation in Ti abundances allows the separation of different basalt types using both laboratory and remote sensing techniques. In the sample collection, three major groups of basalts can be identified: high-Ti (9-14 wt% TiO2), low-Ti (1-5 wt% TiO2), and very-low-Ti (< 1 wt% TiO2) basalts. Laboratory data show a distinctive bimodal distribution of titanium concentrations of basalts in the sample collection with peaks at ~2.5-3 and 12-13 wt% TiO2, but remote sensing data suggest that there is a continuous distribution of very-low-Ti to high-Ti mare basalts [32]. Early Ti-rich basalts flooded large regions in the eastern lunar hemisphere (Ap11, Ap17) in the early Imbrian Period (3.3-3.8 b.y.) [1]. These basalts were followed by widespread eruptions of less Ti-rich basalts of middle to late Imbrian age (Ap12, Ap15). Finally Ti-rich basalts, which have not been sampled so far, flooded parts of Mare Imbrium and Oceanus Procellarum in the early Eratosthenian Period (2.5-3.0 b.y.). Combining our absolute model ages with mineralogical data from spacecraft (e.g., Clementine, Lunar Prospector), we can study the relationship between the mineralogy and the age of a basalt. Our investigation showed that there is no systematic relationship between the age and the Ti abundance of a lunar basalt, contrary to the results from sample analysis. Based on our investigation of ~220 basalt units in 9 different mare regions we see that Ti-rich basalts can erupt simultaneously with Ti-poor basalts. We do not find any evidence that older basalts are systematically more Ti-rich.

(3) Flux and thermal evolution of the Moon: In order to investigate the volumes and the flux of lunar mare basalt volcanism, it is crucial to know the thicknesses of mare flow units. Previous work on basalt flow thicknesses was based on (1) shadow measurements in high-resolution images that were taken under low-sun conditions in order to enhance subtle surface morphologies of flow units [e.g., 33-35]; (2) in situ observations of Hadley Rille at the Apollo 15 landing site [36], and (3) studies of the chemical kinetic aspects of lava emplacement and cooling [37]. Nukum and Horn [38] showed that endogenic lava flow proc-
esses could be identified by their characteristic effects on crater size-frequency distributions without identifying individual flows directly in the images. For example, emplacement of a young lava flow on top of an old flow results in a preferential destruction of small craters and hence a characteristic deflection in the cumulative crater curve. The crater diameters at which these deflections occur are indicative of the thickness of the flow. Once these diameters are derived, the flow unit height is estimated using the rim height/diameter relationship of [39]. Our measurements of the flow heights of ~70 mare units exposed within the nearside mare revealed an average thickness of ~30-60 m with a variation between 20 and 220 m. Combined with the size of our units, this yields flow volumes in the range of 30 to 7700 km$^3$, averaging 590-940 km$^3$.

**Targeting Strategy:** In June 2009, the Lunar Reconnaissance Orbiter will be launched to investigate the lunar surface in unprecedented detail [40]. 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 was chosen in order to emphasize subtle morphologic details. Hence, the global WAC and the local/regional NAC data sets will be extremely valuable for crater counts, particularly on the farside. We have specified and entered into the data base more than 1800 targets that cover more basaltic. Our targets were selected based on the count areas of our previous papers [11-14], which in turn were selected to represent spectrally homogeneous areas. Within each of those old larger units, we have now specified several subunits that can realistically be covered with LROC NAC images. We particularly endeavor to avoid secondary craters, wrinkle ridges, ejecta blankets, etc., that could influence our crater counts. Because mare basalts are flat-lying and exhibit rather few morphologic features, we rarely request the acquisition of geometric or photometric stereo images. In order to make full use of the high-resolution capabilities of the NAC to measure small craters, binning of the data should only be applied if necessary.

**References**