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**The Rima Bode Region – Absolute Model Ages of a Candidate Future Lunar Landing Site** H. Hiesinger<sup>1</sup>, C. H. van der Bogert<sup>1</sup>, A. Wedler<sup>2</sup>, R. Jaumann<sup>3</sup>, U. Mall<sup>4</sup>, J.W. Head<sup>5</sup>, M. Anand<sup>6</sup>, B. Jolliff<sup>7</sup>, P. Pinet<sup>8</sup>, L. Xiao<sup>9</sup>, M. Ivanov<sup>10</sup>, B. Gundlach<sup>11</sup>, N. Schmitz<sup>12</sup>, M. Schweitzer<sup>13</sup>, C. Bergemann-Mecucci<sup>13</sup>, A. Jaime<sup>13</sup>, M.C. DeSanctis<sup>14</sup>, S. Besse<sup>15</sup>, M. Massironi<sup>16</sup>, I. Crawford<sup>17</sup>, E. Hauber<sup>12</sup>, A. Frigeri<sup>14</sup>, R. Tartese<sup>18</sup>, F. Rull<sup>19</sup>, F. McDonald<sup>20</sup>, J. Carpenter<sup>20</sup>.  
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**Introduction:** The Rima Bode region offers unique opportunities to study lunar volcanism as it hosts several compositionally different mare units, as well as pyroclastic deposits [e.g., 1, 2]. In addition, the area is affected by ray material from Copernicus crater, ejecta from Eratosthenes crater, and exhibits highland material and ejecta from the Imbrium basin [e.g., 1, 2]. In short, the Rima Bode site is extremely geologically complex and permits the study of several key science questions concerning early crustal differentiation, volcanic history and evolution, impact history, and the potential for utilizing pyroclastic deposits for the extraction of volatiles and other potential lunar resources (i.e., ISRU).

Last year, we presented a first evaluation of the Rima Bode region as a potential landing site for a future lander mission [2]. Since then, ESA has formed a topical team of lunar scientists to investigate the scientific potential of several candidate landing sites, including Ina D, Copernicus and Tsiolkovsky craters, and a long traverse across Mare Imbrium, to name only a few. Among the discussed landing sites, Rima Bode ranked very high, because of its broad scientific potential and the relatively low technical risks. All geologically diverse units can be accessed with a rover traverse less than ~150-200 km long and slopes less than ~7°. ESA is currently developing plans to utilize the European Large Lunar Lander (EL3) for science-driven missions. EL3 will allow us to bring at least 1.5 tons of payload to the lunar surface and a first mission without a rover to a polar landing site is scheduled for 2029. This mission will be followed by more complex and comprehensive missions that will include a rover in the 2030's. Thus, we envision a rover that will be able to travel 10s -100s of kilometers, have night survival capabilities, and carry a comprehensive suite of instruments (e.g., LIBS, Raman, IR-spectrometer, multispectral stereo cameras) to characterize and pre-select interesting samples. A continuously operating ground-penetrating radar would yield information on the sub-surface regolith structure along rover paths [3].

The lander will also carry instruments, including a geophysical package (e.g., seismometer, heat flow probe, laser retroreflector, etc.) that acquires long term

stable measurements and could perform geochemical analyses of samples (e.g., in situ radiometric age determination with a laser ablation resonance ionization mass spectrometer [4]). ISRU technology demonstrations are also planned for the lander. With our mission concept, we aim to comprehensively study lunar volcanism with respect to timing, spatial distribution, composition, mineralogy, eruption style, volumes, and ISRU potential.

In a companion abstract [5], we present a preliminary geologic map of the area, which was created in order to further investigate the local geology for the selection of the “best” landing site to accomplish the mission goals. One major question concerns the detailed stratigraphy of the mapped geologic units and their absolute model ages (AMA). Ages of volcanic deposits, determined via crater size-frequency distributions (CSFD) and/or radiometric and exposure ages, allow the reconstruction of the thermal evolution of the Moon [e.g., 6,7].

**Data and Method:** We used Kaguya and LROC images to map count areas and perform CSFD measurements. The Kaguya images have a pixel scale of about 10 m on the surface and large incidence angles favorable for CSFD measurements. The images were imported into ArcGIS. Within ArcGIS, we used CraterTools [8] to perform our CSFD measurements. The CSFDs were then plotted with CraterStats [9], using the lunar production and chronology functions of [10]. The technique of CSFD measurements has been described extensively [e.g., 10-14]. For our crater counts, we tried to map homogeneous areas on several geologic units and particularly paid attention to avoid obvious secondary craters.

**Results:** With our CSFD measurements we determined AMAs for several geologic units around the Rima Bode landing site south of Bode C crater (11.6°N / 4.7°W) (Fig. 1). In particular, we dated three dark presumably pyroclastic deposits, three mare units, the ejecta blanket of crater Bode E, and also selected a count area on the ray of Copernicus crater, which crosses the landing area (Fig. 1).

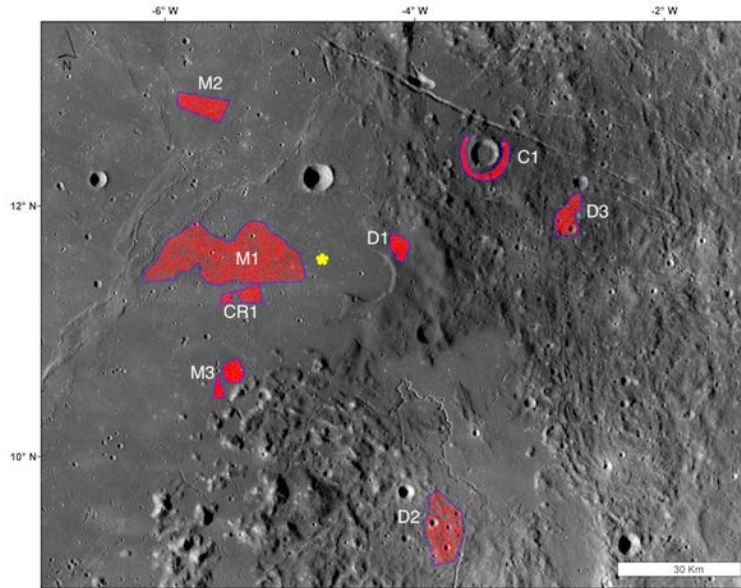


Fig. 1 Rima Bode landing site (yellow star) and count areas  
(CR1: Copernicus ray; M1-3: Mare units; D1-3: Dark mantle deposits; C1: Bode E ejecta)

Our CSFD of this ray material (CR1 in Fig. 1) yields an AMA of  $\sim 3.45$  Ga, which is much older than the canonical age of Copernicus crater of  $\sim 800$  Ma [e.g., 15 and references therein]. We interpret this old age to reflect the age of the underlying mare basalt, which is covered by only a thin veneer of ray material that did not reset the crater statistics. The mare unit M1 immediately north of the ray shows an age of  $\sim 3.70$  Ga with a resurfacing at  $\sim 2.54$  Ga. The second mare unit M2 farther north is topographically lower, is younger, and has an AMA of  $\sim 2.96$  Ga. Our CSFDs for the third and southernmost mare unit M3 yield an AMA of  $\sim 3.27$  Ga. This mare unit was dated by combining two adjacent count areas. The counted craters on the ejecta blanket of Bode E (C1) are in equilibrium up to diameters of  $\sim 800$  m. Although we were unable to accurately date the crater, we can infer an age of at least  $\sim 3.8$  Ga. Because Bode E is superposed on the ejecta material of the Imbrium basin (i.e., Fra Mauro Formation) it is plausible that Bode E is younger than  $\sim 3.92$  Ga, which we assume as the age of Imbrium. The dark mantle deposit D1 of unit *Idp2* in the geologic map of [5] shows an AMA of  $\sim 3.71$  Ga and, thus, is older than the adjacent mare basalts. This stratigraphic sequence is supported by the sharp contact between the pyroclastic deposits and the mare basalts, which is consistent with a superposition of the mare basalts on top of the pyroclastic deposits. The pyroclastic deposits D2 of unit *Ir* [5] exhibit a wide range of AMAs with evidence for at least one resurfacing event. In particular,

our CSFD measurement indicates an old AMA of  $\sim 4.07$  Ga and a resurfacing at  $\sim 3.52$  Ga. We interpret the old age to represent the age of underlying highlands or potential cryptomare and the younger age to be related to the deposition of the pyroclastic material. Finally, for the dark mantle deposits D3 of unit *Idp1* [5], we find an extremely young AMA ( $\sim 510$  Ma), which we consider unrealistic in relation to the relative stratigraphy and absolute model ages of the other units. This CSFD measurement will need to be re-investigated.

**Conclusions:** On the basis of our landing site assessment, we consider the region south of crater Bode C to be safe and to be scientifically very interesting particularly for a better understanding of volcanism on the Moon. With a capable lander/rover combination delivered to the lunar surface by EL3, major scientific advances could be achieved and various techniques of ISRU could be tested in preparation for a human lunar outpost. The new preliminary results provide first order information on the stratigraphy of some of the major geologic units in the vicinity of the landing site that can be used to develop a more detailed mission scenario, to guide a rover, and to design a sampling strategy.

**References:** [1] Spudis and Richards (2018) LLW2018-21; [2] Hiesinger et al. (2021) LPSC 52, 1485; [3] Head and Wilson (2020) Geophys. Res. Lett. 47; [4] Anderson et al. (2015), Rapid Comm. Mass Spectrom. 29; [5] Mikołajewski et al. LPSC 53; [6] Wieczorek et al. (2006) Rev. Min. Geochem. 60; [7] Ziethe et al. (2009), Planet. Space Sci. 57; [8] Kneissl et al. (2012) Planet. Space Sci. 59; [9] Michael and Neukum, (2010) Earth Planet. Sci. Lett. 294; [10] Neukum (1983) Habil. thesis, U. of Munich; [11] Neukum et al. (2001) Space Sci. Rev. 96; [12] Hiesinger et al. (2000) J. Geophys. Res. 105; [13] Hartmann (1966) Icarus 5; [14] Crater Analysis Working Group (1979) Icarus 37; [15] Barra et al. (2006) Geochim. Cosmochim. Acta 70.