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## Geology and Absolute Model Ages of the Rima Bode Region – a Candidate Future Lunar Landing Site

H. Hiesinger<sup>1</sup>, C. H. van der Bogert<sup>1</sup>, S. Mikolajewski<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>. <sup>1</sup>Inst. für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (hiesinger@uni-muenster.de); <sup>2</sup>DLR-Inst. of Robotics and Mechatronics; <sup>3</sup>Freie Univ. Berlin; <sup>4</sup>Max-Planck Inst. für Sonnensystemforschung; <sup>5</sup>Dept. Earth, Env. & Planet. Sci., Brown Univ.; <sup>6</sup>The Open Univ., UK; <sup>7</sup>Washington Univ. St. Louis; <sup>8</sup>IRAP, CNRS/CNES/Toulouse Univ.; <sup>9</sup>CUG-Wuhan Univ.; <sup>10</sup>Vernadsky Institute; <sup>11</sup>Univ. Braunschweig; <sup>12</sup>DLR-Inst. für Planetenforschung; <sup>13</sup>OHB System AG; <sup>14</sup>INAF-IAPS; <sup>15</sup>Aurora Technology; <sup>16</sup>Univ. di Padova; <sup>17</sup>Univ. London Birbeck, <sup>18</sup>Univ. Manchester, <sup>19</sup>Univ. de Valladolid, <sup>20</sup>ESA-ESTEC

**Introduction:** ESA is currently exploring plans to utilize the European Large Lunar Lander (EL3) for science-driven missions that will allow us to bring about 1.5 tons of payload to the lunar surface. A first mission to a polar landing site is scheduled for 2029. This mission will not carry a rover but subsequent missions in the 2030's will be more complex and comprehensive and will include a rover. Considering the large payload mass, we explore the scientific potential of 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 novelty of our concept is that we propose to continuously operate certain instruments while roving. For example, a continuously operated ground-penetrating radar would yield information on the sub-surface regolith structure and an IR-spectrometer would produce mineralogical/compositional profiles along rover paths [1].

We propose to equip the lander with several instruments, including a geophysical package (e.g., seismometer, heat flow probe, laser retroreflector, etc.). These instruments would benefit from a stable platform and could acquire long-term stable measurements. In addition, geochemical analyses of samples (e.g., in situ radiometric age determination with a laser ablation resonance ionization mass spectrometer [2]) could be performed on the lander. ISRU technology demonstrations are also planned for the lander. Our major science goal with the proposed lander/rover mission concept, is to comprehensively study lunar volcanism with respect to timing, spatial distribution, composition, mineralogy, eruption style, volumes, and ISRU potential.

After a thorough global search of particularly interesting volcanic regions/features, we selected the Rima Bode region as a candidate landing site for the EL3 lander. With several compositionally different mare units, as well as pyroclastic deposits [e.g., 3, 4] and a cone-like structure, this region offers unique opportunities to study lunar volcanism. The area is also affected by ray material from Copernicus crater, ejecta from Eratosthenes crater, and exhibits highland material and ejecta from the Imbrium basin

[e.g., 3, 4]. Hence, the proposed landing region is geologically extremely complex and permits studying 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). All geologically diverse units can be accessed with a rover traverse less than ~150-200 km long, slopes less than ~7°, and low rock abundances.

Recently, ESA has formed a topical team of lunar scientists to investigate the scientific potential of several candidate landing sites. The team discussed and evaluated several candidates on the basis of scientific merits, technological aspects, novelty, and feasibility. Among those candidates were, for example, Ina D, Copernicus and Tsiolkovsky craters, and a long traverse across Mare Imbrium [e.g., 5-7]. Among the discussed landing sites, Rima Bode ranked very high, because of its broad scientific potential and the relatively low technical risks.

We created a preliminary geologic map of the area [8] in order to further investigate the local geology for the selection of the “best” landing site to accomplish the mission goals. This map will also aid us in the detailed traverse planning and is an improvement over the existing LAC map of Mare Vaporum quadrangle [9] in that it distinguishes among several mare basalt units. One major question concerns the detailed stratigraphy of the mapped geologic units and their absolute model ages (AMA). Hence, we performed new crater size-frequency distributions (CSFD) for some of our map units in order to derive their absolute model ages (AMAs). Although this is still work in progress, the ages of volcanic deposits, determined via crater size-frequency distributions (CSFD) and/or radiometric and exposure ages, will help us to, for example, reconstruct the thermal evolution of the Moon [e.g., 10, 11]. As we also attempted to date several key craters in the Rima Bode region as well as the emplacement of material from Copernicus, we are beginning to decipher the local stratigraphy that can then be explored in greater detail by a lander/rover mission.

**Data and Method:** For our study, we used Kaguya and LROC images to geologically map the region and to identify homogeneous count areas for

performing CSFD measurements. The Kaguya images have a pixel scale of about 10 m on the surface and large incidence angles, which are particularly favorable for CSFD measurements. All images were imported into ArcGIS for mapping and CSFD measurements. Within ArcGIS, we followed the PLANMAP mapping standards and used CraterTools [12] to perform our CSFD measurements. The CSFDs were then plotted with CraterStats [13], using the lunar production and chronology functions of [14]. The technique of CSFD measurements has been described extensively [e.g., 14-18] and we particularly paid attention to avoiding obvious secondary craters.

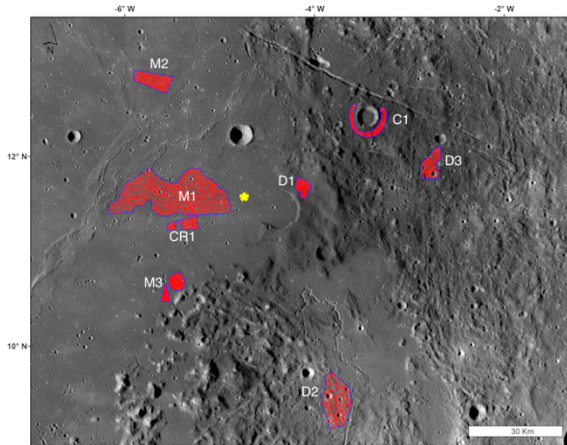


Fig. 1 Rima Bode landing site (yellow star) and count areas (CR1: Copernicus ray; M1-3: Mare units; D1-3: Dark mantle deposits; C1: Bode E ejecta)

**Results:** On the basis of our mapping effort and a preliminary landing site safety assessment, we propose a landing site south of Bode C crater (11.6°N / 4.7°W) (Fig. 1). Utilizing our new geologic map, we determined preliminary AMAs for several geologic units in the Rima Bode region. In particular, we dated three low-albedo mantling 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). Our CSFD indicates an AMA of  $\sim 3.45$  Ga for the Copernican ray material (CR1 in Fig. 1). This is much older than the canonical age of Copernicus crater of  $\sim 800$  Ma [e.g., 19 and references therein]. Hence, this old age likely reflects 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 exhibits an AMA of  $\sim 3.70$  Ga and a resurfacing age of  $\sim 2.54$  Ga. 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 indicate an AMA of  $\sim 3.27$  Ga. This mare unit was dated by combining two adjacent count areas. Although the counted craters on the ejecta blanket of Bode E (C1) are in equilibrium up

to diameters of  $\sim 800$  m, we can infer an AMA of at least  $\sim 3.8$  Ga. However, because Bode E is superposed on the ejecta material of the Imbrium basin (i.e., Fra Mauro Formation) it should be younger than  $\sim 3.92$  Ga, which we assume as the age of Imbrium. The dark mantle deposit D1 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 indicates a superposition of the mare basalts on top of the pyroclastic deposits. The pyroclastic deposits D2 exhibit a wide range of AMAs with evidence for at least one resurfacing event. In particular, our CSFD measurement yielded an old AMA of  $\sim 4.07$  Ga and a resurfacing at  $\sim 3.52$  Ga. We propose that the old AMA represents the age of underlying highlands or potential cryptomare and the younger AMA is related to the deposition of the pyroclastic material. Finally, for the dark mantle deposits D3, we find an extremely young AMA ( $\sim 510$  Ma), which we deem unrealistic in respect to the relative stratigraphy and absolute model ages of the other units. Hence, we are in the process of re-investigating the AMA of this unit.

**Conclusions:** On the basis of our study, we find the Rima Bode region not only to be safe for landing but also scientifically very interesting. In particular, it might hold key information to better understand volcanism and impact crater processes on the Moon. An innovative lander/rover mission delivered to the lunar surface by EL3, could achieve major scientific advances with only small risks. In addition, the pyroclastic material is particularly suitable for testing various ISRU techniques 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.

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