NEW HIGH-RESOLUTION MELT DISTRIBUTION MAP AND TOPOGRAPIC ANALYSIS OF TYCHO CRATER.

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Introduction: The 83 km diameter lunar crater Tycho was proposed by [1] to be an oblique impact. Subsequent studies support this interpretation through investigation of the Optical Maturity Parameter (OMAT) [2], the asymmetrical distribution of the continuous ejecta blanket [3], and the distribution of Tycho's bright rays [4]. Here, we present a new topographical analysis and a high-resolution melt pool distribution map, that both show strong evidence for an oblique impact from the southwest with an impact angle between 35°-45°. The map documents over 3000 melt pools, and provides a detailed look at their spatial distribution, as influenced by the obliquity of the impact and the pre-existing topography.

Data: For identifying and mapping the melt pools, we used Lunar Reconnaissance Orbiter Narrow Angle Camera (LROC-NAC) and Wide Angle Camera (LROC-WAC) images [5], as well as Selenological and Engineering Explorer (SELENE) Terrain Camera (TC)-ortho images [6]. The topography was investigated with the Lunar Orbiter Laser Altimeter (LOLA) instrument onboard the LRO mission [7].

Methods: Mapped melt pools were identified by their morphological features, including, albedo, surface smoothness, morphologic onlap and superposition on underlying topography, emplacement in topographic lows, flow features, and cooling fractures. The remote sensing datasets were processed using ISIS [8] and investigated and mapped with ESRI ArcGIS 9.3.

Results: The high-resolution melt pool map ***(Fig. 1)*** shows that melt pools are more abundant in the NE and SE of the Tycho impact. Except for the impact melt sheet within the crater itself, the largest melt pools occur on the eastern continuous ejecta blanket, outside of the crater. In the SW a significantly smaller number of melt pools occur and large melt pools are absent.

The melt pool map shows a total of 3010 melt pools, with a combined surface area of 690.83 km². The melt pools were sorted by their surface area ***(Fig. 2)***, showing that most melt pools have a surface area under 1 km². Melt pools tend to get smaller in size with increasing distance from the crater.

The NE crater wall of Tycho has the highest elevation of over 5000 m and the steepest slopes (~40°) of the entire crater wall. The SW crater wall has an elevation that is ~500 m lower, and is less steep (~25°) ***(Fig. 3)***.

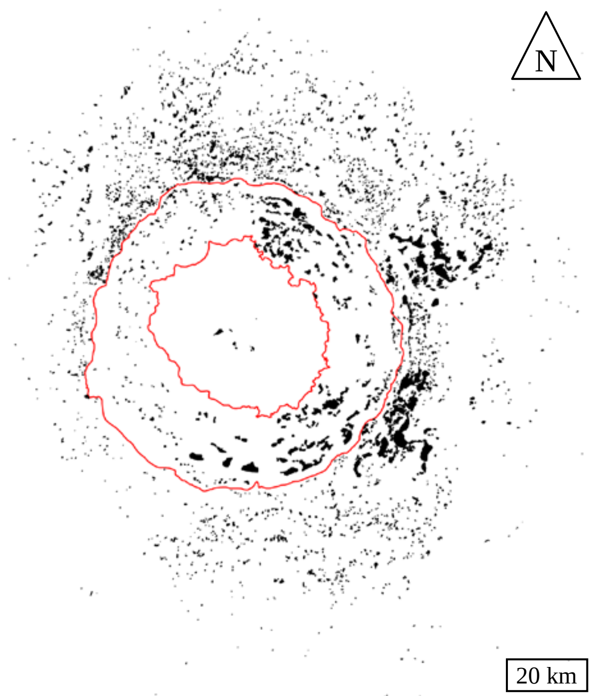

Figure 1. *Melt pool distribution at Tycho crater. The boundaries of the melt floor and the crater rim are shown in red.*

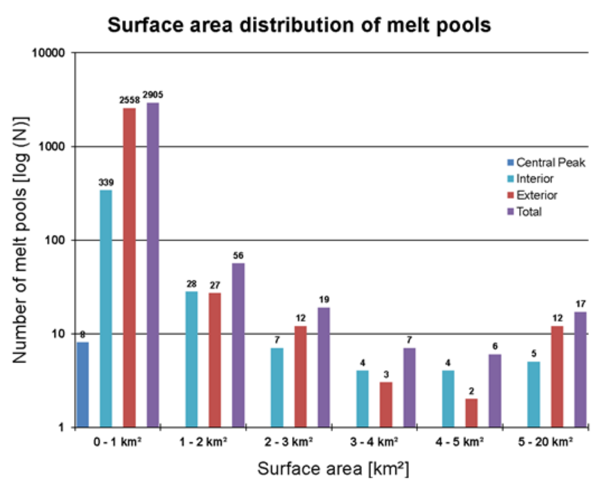

Figure 2. *Melt pool surface area distribution at Tycho crater. Most melt pools have a surface area under 1 km² and occur outside the crater rim.*

Discussion: The investigation of melt pools at Tycho crater reveals an asymmetric distribution of melt pools, consistent with the proposed impact of the Tycho impactor from the SW [1,11]. Similar results were derived by [11] with their investigation of melt distribution at Tycho crater. However, our new map allows a higher-resolution analysis of the distribution of small melt deposits. The largest melt pools occur on the eastern crater wall. The distribution of the melt pools is consistent with the asymmetric distribution of the continuous ejecta blanket of Tycho [3,9] and the distribution of the bright rays of Tycho [4].

The topography of Tycho crater also provides insight into the impact direction. An oblique impact generally displays the strongest wall failure in the uprange direction and the steepest slopes in the downrange direction [9,10]. The LOLA data are thus also consistent with an impact direction from the SW.

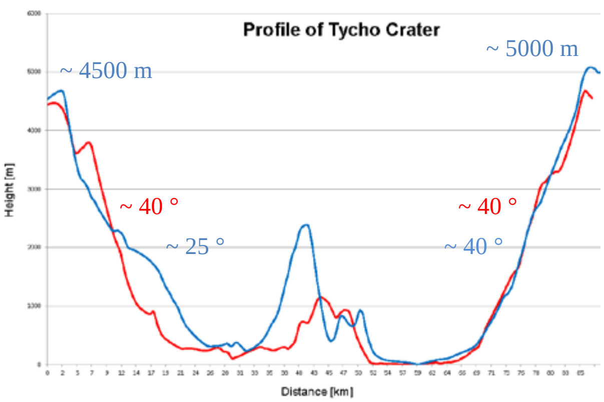

Figure 3. *Profiles across Tycho crater from NW to SE (red, perpendicular to the impact trajectory) and SW to NE (blue, along the impact trajectory). The SW exhibits shallow slopes and a collapsed crater wall, whereas the NE shows the steepest slopes and highest elevation.*

Interpretation: In the process of the formation of an oblique crater, the crater wall in downrange direction will exhibit a higher elevation and steeper walls than the wall in the uprange direction. The crater wall in the uprange direction collapses and the slopes of this part of the wall will show a much shallower slope [e.g., 10, 12]. The distribution of the ejecta blanket is a far better indicator for an oblique impact, getting modified at angles up to 60°. The radial pattern is lost at angles below 45°-35°, and even lower obliquities produce forbidden zones and butterfly patterns. Early in the excavation stage, the impactor excavates material to the sides. Hardly any material is ejected uprange, resulting in a wedge-shaped forbidden zone. At very low angles, lower than 20°, this forbidden zone is located downrange as well, resulting in a butterfly shaped deposition of the ejecta [10]. Studies suggest that the momentum of the impactor is preserved in form of uprange initiation of crater collapse and the migration of the uplifting crater floor downrange [e.g., 12,13]. For Tycho crater this suggests an oblique impact from the southwest, with an degree of 35°-45°. The map of melt pools ***(Fig. 2)*** shows the highest number of melt pools NE of Tycho. The provinces with the largest melt pools are in the NE and E. The emplacement of melt during an oblique impact produces a distribution with the largest amount of melt being emplaced in the downrange direction [9,10]. The least amount of melt is emplaced in the forbidden zone in the uprange direction of the impact, i.e., for Tycho in the SW [9,10]. To the N of Tycho, a high volume of melt is also deposited in melt flows [14]. The largest volume of deposited melt for Tycho is located in the NE, hence supporting an oblique impact from the SW ***(Fig. 4)***.

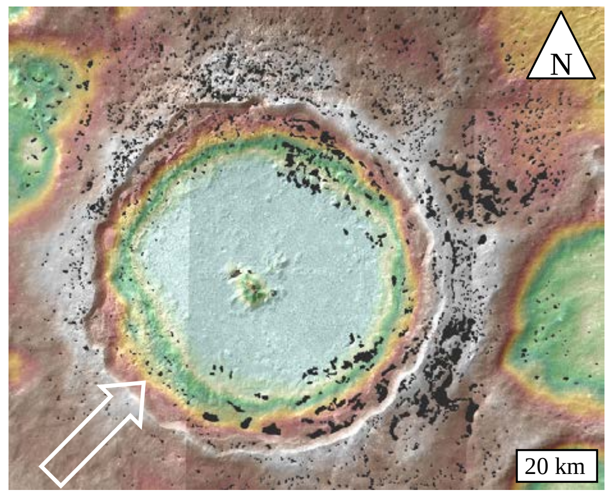

Figure 4. *Melt pool (black) distribution at Tycho crater shown on the LOLA DTM superposed on the SELENE TC ortho-mosaic. The white arrow indicates the impact direction. The highest abundance of melt pools is in the NE/downrange part of Tycho and the smallest number of melt pools occur in the SW/uprange.*

References: [1] Schultz, P.H. (1976) Moon Morphology, 641 pp. [2] Hirata et al. (2004), *LPSC* XXXV, # 1615. [3] Grier et al. (2001) *JGR* 106, DOI: 10.1029/1999JE001160. [4] Dundas and McEwen (2007) *Icarus* 186, DOI: 10.1016/j.icarus.2006.08.011. [5] Robinson et al. (2009) *Space Sci. Rev.* 150, DOI: 10.1007/s11214-010-9634-2. [6] Haruyama et al. (2008) *Adv. Space Res.* 42, DOI: 10.1016/j.asr.2007.04.062. [7] Smith et al. (2010) *Space Sci. Rev.* 150, DOI: 10.1007/s11214-009-9512-y. [8] Anderson et al. (2004) *LPS* 35, #2039. [9] Osinski et al. (2011) *EPSL*, 310, DOI: 10.1016/j.epsl.2011.08.012. [10] Melosh, H. J. (1989) Impact cratering; a geologic process, Oxford Monographs on Geology and Geophysics 11. [11] Morris et al. (2000) *LPSC* XXXI, #1828. [12] Scherler et al. (2006), *EPSL* 248, DOI: 10.1016/j.epsl.2006.05.002. [13] Ivanov and Artemieva (2002) *GSA Special Paper* 356, 610-630., [14] Krüger et al. (2012) *EPSC*, 7, #842-1.