PROPOSED LUNAR SAMPLE RETURN MISSION AT TSIOLKOVSKIY CRATER. É. A. Laflèche*[1,4], K. P. J. Kells*[2,4], S. J. Lambier*[3,4], C. D. Neish[2,4], G. R. Osinski[2,4], M. Cross[5,4], L. Tornabene[2,4]. *These authors contributed equally to the work. [1]Department of Earth and Planetary Sciences, McGill University, Montreal, QC, Canada. [2]Department of Earth Sciences, University of Western Ontario, London, ON, Canada. [3]Department of Physics and Astronomy, University of Western Ontario, London, ON, Canada. [4]Institute for Earth and Space Exploration, University of Western Ontario, London, ON, Canada. [5]Department of Electrical and Computer Engineering, University of Western Ontario, London, ON, Canada. (emilie.lafleche2@mail.mcgill.ca).

Introduction: Tsiolkovskiy crater (20.1°S, 128.6°E) is a ~3.55 ± 0.1 Ga, 185-km diameter, complex lunar crater with a well-preserved central peak and crater floor infilled by mare [1]. This site was previously the subject of consideration for the Apollo program's final mission, Apollo 17 [2]. Ultimately, it was not selected due to technical requirements (e.g., the need for a communications relay satellite) and a limited budget. However, several studies have since revealed the crater's unique scientific value, especially as it pertains to its location on the lunar farside [2,3]. We advocate for the reconsideration of a crewed sample return mission to Tsiolkovskiy during the Artemis era. We provide a summary of key science objectives, a proposed new potential landing site, and a suggested traverse plan that would address these objectives.

Science Objectives: This proposed sample return mission has three scientific themes, outlined below. Its primary goal, common to all themes, is to ground-truth remote sensing data, which would serve to improve future orbital instrumentation design and provide further insight into lunar farside processes.

Lunar Geochronology. Traditionally, lunar geochronology is assessed remotely with crater counting. While a robust lower limit (>3.2 Ga) has been established for Tsiolkovskiy's age using this method, age estimates vary widely [1,3,4]. Additionally, Tsiolkovskiy has high rock abundance and low regolith thickness, which is more consistent with a younger crater age than that predicted by other dating methods [4]. The crater's age could be further constrained by using ^{40}Ar–^{39}Ar dating on returned samples as the crater fill region (see *Crater Fill* section below) is composed primarily of plagioclase. Other applicable methods for determining ages of sampled crater materials include Rb-Sr (for mare basalts), U-Pb, and Th-Pb dating [3,5,6]. As such, this proposed mission aims to return samples of crater material, including impact melt, to Earth for laboratory dating.

Impact Cratering Processes. Impact cratering dynamics can be studied by investigating shock metamorphic effects. Such effects include planar deformation features (PDFs) and diaplectic glasses, along with shatter cones and high-pressure polymorphs [7]. Impactites such as impact melt rocks and breccias also provide critical information on cratering processes. This proposed mission aims to acquire samples and in-situ measurements of impactites within the crater, such as shocked anorthosite, with the goal of providing insight into the impact cratering process. Currently, it is difficult to study shock metamorphic features either remotely or in-situ, although technological advancements in Raman spectroscopy show it to be a promising tool for the in-situ study of shock metamorphism on Earth and other planetary bodies [8].

Volcanism. Tsiolkovskiy's prominent mare unit is a rare display of extrusive volcanism on the lunar farside, making it a key target for studying farside volcanic processes. Previous work has relied predominantly on remote sensing instruments, such as Clementine's UVVIS and LRO's LOLA, to analyze various components of this feature, namely its age, mineralogy, thickness, volume, and formation history [3,4,9]. The volcanism objective for this mission would aim to ground-truth what is known about these properties by means of sample return and in-situ measurements of the mare and related volcanic materials.

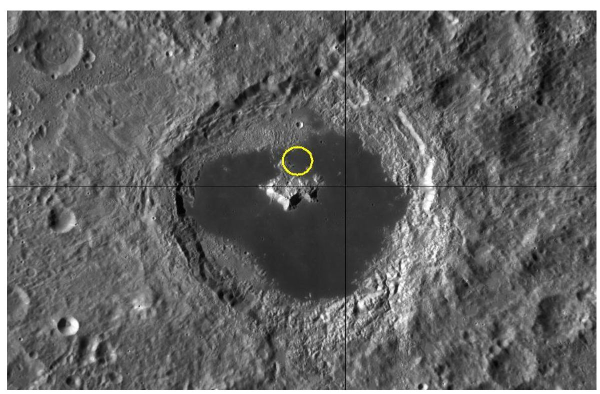

Figure 1: Tsiolkovskiy crater. Proposed landing site enclosed by the yellow circle 20 km in diameter. Image made in JMARS with LRO WAC basemap.

Proposed Traverse: The proposed mission's traverse (Fig. 2) aims to provide multiple opportunities at each stop for sample collection and in-situ measurements. The target region was chosen through a process of overlaying a circle with a 10-km radius over the crater and searching for a region which satisfied all three science objectives. The 10-km radius was chosen to represent the maximum distance away from the lander the research team could travel in a day. This was framed around a 7-day mission itinerary, with arrival and sampling of the landing site, four EVAs, and departure allotted a day each. An extra day was added to our estimate to account for any potential setbacks. (Note: travel time from and to Earth is not included in this itinerary). Key target locations are listed below.

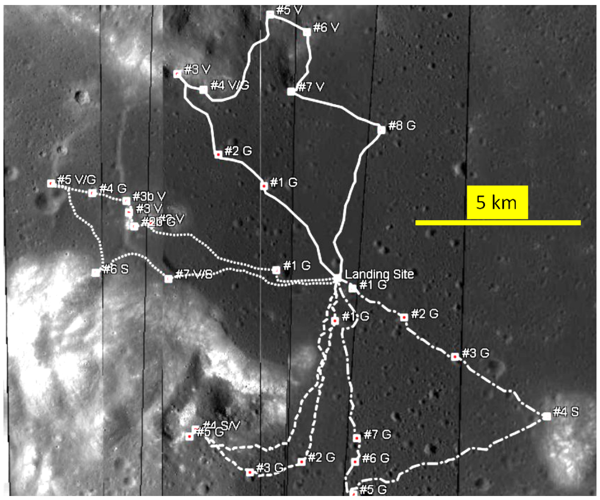

Figure 2: Proposed traverse. Traverse Alpha (top left) is represented by dots, traverse Bravo (top right) by a solid line, traverse Charlie (bottom left) by dashes, and traverse Delta (bottom right) by dots and dashes. Image made in JMARS with LRO NAC basemap.

Landing Site. This site was chosen due to its central location to all desired traverse stops, as well as its average values of slope from LOLA data (0.947°), Mini-RF circular polarization ratio (0.435), and Diviner rock abundance (1.07%), which collectively characterize a smooth, flat surface ideal for landing. Moreover, samples and measurements may be taken of the mare material on-site for later analysis.

Craters. Small impacts act as natural excavators for the lunar subsurface. By stopping at craters along the traverse, samples can be retrieved from deeper in the mare and possible underlying impactites, useful for the creation of a stratigraphic column. Specifically, traverse Delta stop #5 is a crater 635 m in diameter (~1.3×10^1 m deep) close to the central peak, where the mare is thinner and there presents the possibility to sample layers below the mare.

Central Peak Samples. Shock features are most likely to be found in the central peak. Multiple sampling sites enable cross-comparison of mineralogy, composition, and shock effects, as well as the verification of ages determined by chronological analyses. Traverse Alpha's stops #6 and #7 access boulder trails from the exterior face of the peak, which allows for the observation of peak material in contact with the surrounding mare and investigates the relationship between the central peak and an adjacent rille in the mare. Stop #4 on traverse Charlie, located more centrally to the peaks, investigates shock metamorphism. Traverse Delta's fourth stop is to sample a light-coloured mound, which is thought to be another outcrop of central peak material.

Crater Fill. Crater fill primarily consists of impact melt material emplaced during crater formation. It is thus of utmost value in determining the age of Tsiolkovskiy due to this impact melt. Traverse Delta's stops #3-7 access this material, though there is some debate about whether this location is actually crater fill rather than a landslide [10].

Mare Rille. Mare rilles contain well-preserved evidence of past lunar farside volcanic activity, and possibly represent collapsed lava tubes [11]. Moreover, a smooth regolith cover has been observed in this region, implying either very fine-grained and ponded regolith or the lack thereof [12]. In the latter case, the regolith would not interfere with the identification and sampling of rille features, thereby facilitating the process. At this location, analysis of the rille's composition, morphology, etc. can be done on-site. Traverse Alpha's stops #2-3b, and #5 are all located at mare rilles.

Mare. Tsiolkovskiy's mare is thought to have formed soon after the initial crater-forming impact, but its emplacement is still poorly understood [3,13]. Previous studies have reported its basaltic, low-Ti mineralogy to be similar to nearside maria [3]. However, it is unclear if local compositional variation exists within the mare material, since the mare near the central peaks seems lighter in colour than the surrounding mare. Several sites allow for sampling of mare to date and identify its bulk mineralogy, though traverse Charlie's stop #4 is of particular interest to classify the sample as mare or peak material.

Conclusions: In this work, we established that a lunar farside mission to Tsiolkovskiy crater is a timely and worthy endeavour. The crater has been shown repeatedly to host a wealth of scientific value and should thus be considered for an Artemis-era mission.

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