# MINERALOGICAL, ELEMENTAL, AND TOMOGRAPHIC RECONNAISSANCE INVESTIGATION FOR CLPS (METRIC): A PROPOSED MISSION TO THE LUNAR SOUTH POLE-AITKEN BASIN.

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**Introduction:** The global Lunar Magma Ocean (LMO) hypothesis is based on analyses of ferroan anorthosites (FAN), magnesian plutonic rocks (Mg-suite), and KREEPy (Potassium - K; Rare Earth Elements - REE; Phosphorous - P) material present at the Apollo landing sites and the assumed global distribution of these lithologies. However, orbital spacecraft data over the last two decades have highlighted that the location of the Apollo missions within and near the Procellarum KREEP Terrane (PKT) is compositionally anomalous and not representative of the entire lunar surface and suggests that Apollo samples provide a biased view of the Moon. Further, lunar meteorites, which originate from random areas on the lunar surface, including those not visited by Apollo, Luna, or Chang'E-5, provide complementary datasets that reveal a more complex lunar formation and evolution than the simple LMO onion skin model. While many recent investigations support and refine the LMO model, other recent studies have questioned whether this mechanism alone is responsible for the primordial differentiation of the Moon. Thus, relating the distinct and asymmetrically distributed geochemical terranes on the Moon, especially KREEP which is a predicted global LMO product, to lunar formation and differentiation remains a fundamental goal of lunar science.

The South Pole-Aitken (SPA) impact carved a two-and-a-half thousand-kilometer basin into the Moon's ancient crust, excavating material from as deep as the upper mantle [1]. Orbital remote sensing of the basin indicates compositions with elevated thorium (Th) contents and unique mineralogies [2,3] that provide a window into early lunar structure and LMO processes. We propose to land a powerful characterization laboratory at Birkeland crater (Fig. 1) on the far side of the Moon - where Th-rich SPA ejecta have been re-exposed near the surface - in order to address outstanding questions about the evolution of the Moon.

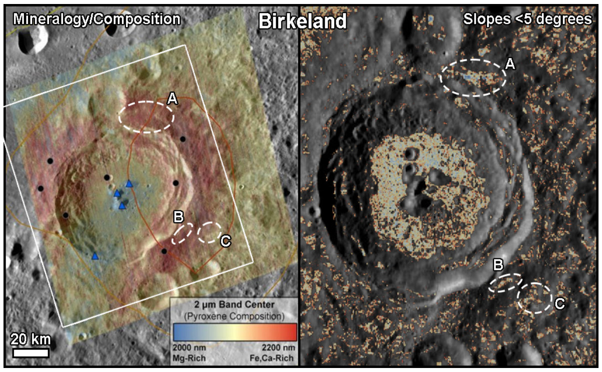

**Fig. 1.** Proposed landing sites at Birkeland crater on the lunar farside.

**Science Objectives:** Our proposed mission has two main objectives that are traceable to specific questions and goals in the Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032, Artemis III Science Definition Team Report (2020), and NAS Scientific Context for Exploration of the Moon: (1) Establish whether the KREEP signature on the nearside represents a global feature on the Moon, and (2) Determine the diversity of material excavated by the SPA impact. Under (1), two science questions relate to the KREEP signature at SPA and its relation to the Apollo sample suite: S1. Do the elevated Th terranes at SPA have a similar chemical signature as the KREEP-rich material distributed in and around the Imbrium impact (i.e., the Procellarum KREEP Terrane)? S2. Does the lower Th content at SPA relative to the PKT result from dilution by impact mixing of feldspathic crustal material?

Additional science questions concern the apparent gabbronoritic compositions identified by remote sensing: S3. What are the lithologies present at the regions with elevated Th? How do these lithologies compare to remote sensing interpretations? S4. What is the source of plagioclase in this material? Did plagioclase crystallize with the coexisting minerals or were the minerals mixed by impact processes? S5. Does the mineralogy of Th-rich terranes at SPA reflect more evolved igneous sources? How does this lithology compare to lunar samples, hypothesized LMO cumulates, and crystallized impact melts?

These science questions can be answered using in-situ measurements of quantitative mineralogy and chemistry of regolith and larger rocks, supplemented with textural analysis of regolith grains.

**Payload:** The Mineralogical, Elemental, and Tomographic Reconnaissance Investigation for CLPS (METRIC) is an instrument suite comprising an X-ray Diffraction/X-ray Fluorescence instrument (XRD, mineral structure analysis; XRF, elemental composition analysis) (Fig. 2) and an X-ray micro Computed Tomography instrument (XCT, 3D internal micromorphological analysis) (Fig. 3) mounted on a CLPS lander, with an imaging infrared spectrometer (IRS, mineralogy and spatial geological context) onboard a small supplemental rover. This suite can quantify the mineralogy, composition, and micromorphology of the regolith and rocks at the Birkeland crater landing site to address key questions about the early evolution of the Moon. Over the course of a lunar day, we would use a Honeybee Robotics (HBR) SPEAR drill on the lander to collect regolith for measurement with the XRD/F and XCT, and we would conduct a rover traverse to image the regolith and boulders within the surrounding area with the IRS.

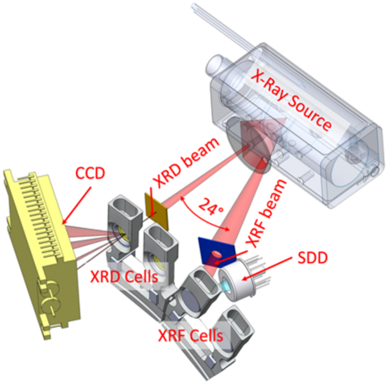

**Fig. 2.** 3D geometry of the METRIC XRD/F.

The XRD/F will provide definitive and quantitative mineralogy and geochemistry, enabling the most diagnostic and complete characterization of regolith possible with landed spacecraft. The XCT instrument will, for the first time, determine the 3D internal micromorphology of a lunar soil sample in situ on the lunar surface. This will serve as a ground-breaking technology demonstration of XCT on another planetary surface.

**Concept of Operations:** The broad concept of operations for METRIC is 1) to perform XRD/F and XCT analyses of regolith collected by the SPEAR drill from a fixed position under the lander and 2) to have the IRS-equipped rover acquire hyperspectral data of the exhausted sample material and the area surrounding the landing site to evaluate the petrologic diversity of the site and provide local and regional geologic context for the sample.

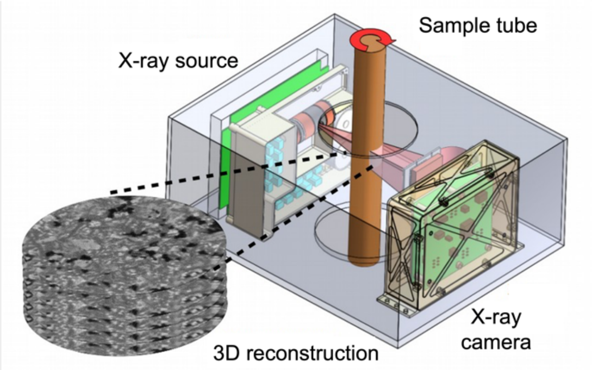

**Fig. 3.** 3D geometry of the METRIC XCT X-ray source, beam, and detector with representation sample tube and reconstructed stack of images.

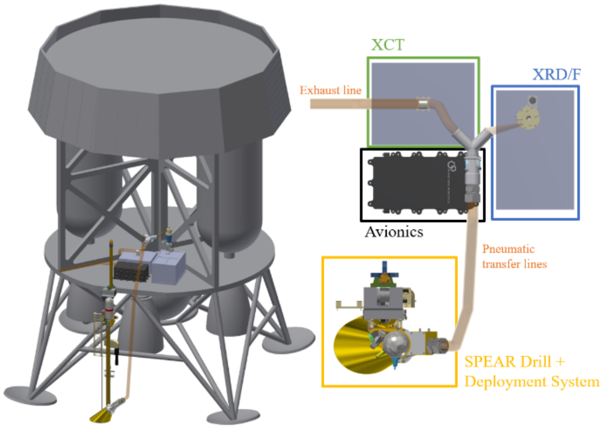

**Fig. 4.** System layout on a nonspecific CLPS lander.

**Conclusions:** METRIC is a highly capable instrument suite that is well suited for quantitative compositional analyses at any location on the Moon including for human Artemis missions. Here, we propose to demonstrate its capabilities by addressing fundamental lunar science questions related to material excavated by the SPA basin.

**References:** [1] Melosh H. J. et al. (2017) *Geology*, 45, 1063. [2] Lawrence D. J. et al. (2000) *JGR: Planets*, 105, 20307. [3] Moriarty III D. P. et al. (2021) *JGR: Planets*, 126.