**COPERNICUS CRATER: COMPELLING SCIENCE EXPLORATION TARGET WAITING FOR FUTURE MISSIONS.** Deepak Dhingra, Carle M. Pieters and James W. Head, Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02906 (deepdpes@gmail.com)

**Introduction:** Copernicus crater (9.62° 339.92°; 96 km), located on the lunar near side, is a geologically young crater [1,2] with a cluster of towering peaks on the floor, an array of melt ponds and flow features, and an extensive ray system [3]. It was the proposed Apollo 18 landing site as well as the alternative site for Apollo 20 mission [4] before the cancellation of the lunar program after Apollo 17. Significant findings at Copernicus crater have been made since that time, starting with the discovery of olivine in the central peaks [5] and later in the northern crater wall [e.g. 6]. We highlight several new insights resulting from recent missions and suggest science/technology exploration targets that merit consideration by future lunar landers and rovers, including those being developed for Google Lunar X-prize.

**New Discoveries with Modern Sensors at Copernicus**: Modern imaging sensors onboard recent remote sensing missions [e.g.7,8,9,10] have provided high spatial imaging (1-10 m) and high spectral resolution near-IR data enabling a much closer look at the Moon than was previously possible. There have been at least 5 new findings made at Copernicus crater alone:

*i) Impact melt origin of olivine exposed on the northern wall:* The occurrence of olivine in the northern wall has been assumed to be of the same origin as olivine exposures in the central peaks [e.g. 6]. However, our high resolution integrated mineralogical and morphological analysis indicates that the northern wall exposure is associated with impact melt [11]. It is important to note the secondary nature of this material which may not be directly associated with olivine in the peaks. Similar secondary vs primary relationships for olivine may be common elsewhere on the Moon.

*ii) Olivine exposures on the crater floor:* Apart from previously known olivine exposures in the central peaks and the wall, several additional exposures have been identified on the crater floor (and some on the walls) [11]. These olivine occurrences represent a new geologic setting and have implications for the source region and formation mechanism of olivine since the sampling depths of the various crater units (viz. floor, wall and the peaks) are different.

*iii) Mg-spinel exposure:* Copernicus crater hosts a small exposure of the recently discovered Mg-Spinel lithology on the Moon [12,13,14]. The exposure is associated with a small mound on the crater floor and is in close proximity with a mafic lithology that may or may not be directly associated [15]. If true, the Copernicus Mg-spinel exposure would be unique in being associated with a mafic mineralogy.

*iv) Heterogeneous mineralogy of impact melt ponds:* Detailed analysis of morphologically identifiable impact melt ponds (few kilometers across) located at Copernicus crater on the walls and the rim region indicate an azimuthal variation in the mineralogy of impact melt [16]. Impact melt ponds in the NW part of the crater are mafic-poor in contrast to the mafic-rich nature of the ponds in the SE part of the crater. This mineralogical heterogeneity at small spatial scales indicates that melt could be locally derived and undergo minimal lateral mixing.

*v) Mineralogically distinct impact melt feature:* Apart from the pond mineralogy, Copernicus hosts a ~30 km long sinuous impact melt deposit which has a distinctly different mineralogy than impact melt in the immediate vicinity [17]. The sinuous feature is dominated by low calcium-pyroxene mineralogy while two fresh craters in nearby impact melt have a high calcium-pyroxene mineralogy. In addition, the sinuous melt-feature does not have any distinct morphological or topographic signature associated with it. As a consequence, it cannot be easily detected on imaging data unless accompanied by mineralogical information. This is so far the only documented feature of its kind on the Moon (or elsewhere) and has implications for our understanding of the large scale melt mixing and emplacement during the cratering process.

Such an impressive diversity in mineralogy and the corresponding geological context together with the young age of Copernicus makes it an extremely interesting target for further exploration in the near future.

**Achievable Science/Technological Objectives**: The detailed studies carried out at this crater have helped in outlining the scientific and technological objectives that could be achieved should a mission be planned to Copernicus crater:

i) *Characterizing olivine diversity at Copernicus*: The suggested primary and secondary origin of olivine lithology at Copernicus would benefit immensely from a ground-level close examination in terms of composition, surface texture (grain size, porosity), geological association and spatial distribution.

ii) *Obtaining ground truth for Mg-Spinel lithology*: Mg-Spinel lithology has so far only been detected remotely and no direct sample from any of the identified locations is yet available. Ground truth measurements in terms of Mg-spinel abundance, associated mineralogy and local geological context would be crucial in refining the character and possible origin of this new rock type on the Moon.

iii) *Characterizing the mineralogical heterogeneity of impact melt at various spatial scales*: The mineralogical character of the large sinuous melt feature on the floor and the small impact melt ponds needs to be assessed on the ground in terms of surface expression, local variability, extent and geological association.

Testing of technological capabilities on scientifically relevant targets would provide practical experience on the challenges and scope for improvements. We provide two examples of technological objectives that could be fulfilled with exploration at Copernicus:

iv) *Rover mobility on the olivine-bearing central peaks and Mg-Spinel bearing mound*: Certain parts on the easternmost peaks on Copernicus crater floor would likely provide slopes amenable for a rover traverse. The slopes on the Mg-Spinel bearing mound would especially be favorable for a rover traverse. Apart from demonstrating capabilities related to traverses on variable slopes and navigation enabled by hazard avoidance, such an exercise would give an opportunity for mapping the local geological context of olivine/Mg-spinel and the characterization of any impact melt cover.

v) *3D reconstruction of small-scale and large scale scientific features of interest:* Numerous small-scale structures on the floor of Copernicus are at the limit of resolution for the currently available remote sensing datasets. Technology enabling 3D reconstruction of these features could be very useful and be demonstrated at Copernicus. Some of these features include collapse pits and fractures which could potentially support human habitats in the future.

We have utilized the available information to identify potential target locations which would be scientifically productive and time efficient from an exploration standpoint. We describe here our most preferred location which is the c*rater center, in the vicinity of the central peaks*. This region has probably the maximum scientific return in view of the rich diversity of targets (Figure 1). It includes several high quality exposures of olivine lithology in the peak representing material that originated from the greatest depth. There is also a likely pseudo-tachylite exposure on the centre-most peak which could help in dating the Copernicus event. The exposure of Mg-spinel could be sampled along with the low Ca-pyroxene bearing sinuous melt feature. Several collapse pits in the area could be explored for human habitation potential, for obtaining a vertical profile of impact melt pile at that location as well as studying possible subsurface drainage pathways of impact melt. The region has a megablock, comparable in size to the central peaks that could be a morphologically subdued part of the central peak cluster. Its analysis could shed light about its provenance. All the exploration targets are situated in close proximity.

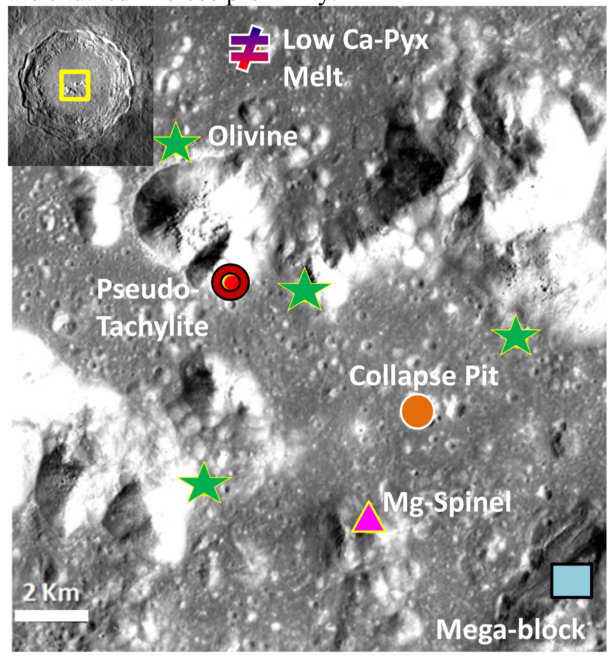


**Figure 1** Exploration target diversity at the crater center.

The floor topography is relatively flat. However, the close proximity to the central peaks may provide some challenges for spacecraft landing around this location owing to the small landing ellipse requirement.

We recognize that selection of landing sites involves critical assessment of numerous engineering and scientific aspects. In this study, we are not strictly suggesting a landing site but wish to provide relevant scientific target information along with their relative proximity that could feed into landing site selection process. Copernicus crater remains a compelling target as we plan to return to the Moon.

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