LUNAR POLES ROVER (LPR) WHITE PAPER: A SEARCH FOR HYDRATED MINERALS, ORGANICS, METALS AND LIGHT AGGREGATES IN PREPARATION FOR *ISRU*

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Introduction: The Moon is a necessary step ahead for the conquest of space, and the development of realistic In Situ Resource Utilization (ISRU) techniques. The exploration of the lunar poles can provide a key opportunity to measure the degree of implantation of hydrous minerals, metals and organics from the impact of carbonaceous chondrite projectiles. Given the surface extension of Permanently Shadowed Regions (PSRs) an experiment could be addressed to identify impacts by organic-rich projectiles in a different range of sizes. The two-member crew planned for the Artemis III mission could be accompanied by a rover with capacity for chemical analysis, focusing on the exploration of extensive regolith-rich region. The rover capacities could also allow identifying key rocks for sample return and relevant ISRU materials. In the previously selected impact craters, the rover could study the bulk chemistry, mineralogy of the terrains and surroundings to quantify the properties of foreign materials associated with the projectiles. Recent studies have pointed out that the lunar flux in the poles is dominated by projectiles from long-period comets in high inclination orbits [1], while it is less likely to have impacts from the zodiacal cloud, main belt and JFC sources because the inclination range is much lower. Meter-sized projectiles from these fragile cometary reservoirs are efficiently disrupted penetrating at hypervelocity in the Earth's atmosphere but colliding and implanting their rock-forming materials in the lunar surface. The recent discovery of hematite by Chandrayaan-1 orbiter has given the evidence of the Moon having rust at its poles [2], and our hypothesis could be tested.

Basic mission description, and main goals: For simplicity, we envision a mission focused in a lander, deploying a last-generation rover with stereoscopic cameras, robotic arm and instrumentation to study the bulk chemical composition and mineralogy of the rover's explored surroundings. The region of interest could be selected among the currently available imagery of recent missions, emphasizing an area with a significant abundance of impact craters, and exhibiting fine-grained regolith, water-ice, and organics. The regolith is particularly a key target as it might contain water and natural light aggregates from rocks of volcanic origin, both with important ISRU implications.

We propose to focus part of the study in impact craters because one of the goals of future exploration is finding water. Certainly, this has been found as ice inside permanently shadowed craters of the polar regions, but it could be also present as hydrous minerals. For example, phyllosilicates are composed of sheets of FeO/OH, MgO/OH or AlO/OH connected to SiO_4 and in-between this metal bearing sheets water is found absorbed by the sheet or bound to it. If heated at temperatures ~100-150 ºC absorbed water can be released and bound water collected if heated at ~300 ºC [3]. Then, it should be implemented a temperature-controlled oven experiment in in-situ collected samples could help to quantify the rock water content. The extraction of oxygen is especially interesting from a biological point of view: future missions may utilize it for the production of water and other life support processes.

Under the level of isolation provided by the low thermal inertia of Lunar regolith, the action of water in moderate depth could have produced aqueous alteration processes transforming native metal in oxides, or silicates into clay minerals with plausible production of organic compounds [4]. By identifying impact craters excavated by carbonaceous chondritic projectiles, probably also containing these hydrous minerals and organics we could test such a scenario. In addition, by completing the study, we could study the local oxidation conditions in the poles and infer properties of the impactors.

Main studies to carry on concerning *ISRU*: Future Artemis sample return missions will provide new samples to continue learning from our satellite. After many robotic and manned missions, the utilization of lunar resources has been proposed for a long time, but it is time to make ISRU proofs of concept. In fact, given its proximity to our planet, our satellite is an ideal planetary body to use it as a space camp to test new technology, to establish space bases, and launch platforms for longer and challenging missions. The continuous depletion of Earth resources put special importance on the exploration of extraterrestrial natural resources potential and the feasibility of its exploitation.

Having into account our current knowledge of the Lunar rock-forming minerals which can be realistically used for ISRU, the following resources are envisioned:

• Metals hosted in the lunar regolith are the consequence of the continuous impact with chondritic and metallic projectiles reaching the Lunar surface. As a consequence, the regolith is rich in a wide amount of minerals such as pyroxene, olivine, ilmenite and native metals such as Fe and Ni. In addition, it can be found hydrated minerals and rare-Earth elements. The fact that most metals are found in the form of oxides (as well as some pure iron particles) makes their extraction costly energy-wise as these components tend to be very chemically stable [5], but their potential use for producing spacecraft parts and in-situ repairs make them more attractive given the typical mass constraints for space cargo.

• Water, probably to be found as ice inside permanently shadowed craters of the polar regions, could be used as rocket fuel and to support life in a Moon base. On the other hand, some regions of the Moon have been hit by carbonaceous chondritic asteroids, rich in clay minerals as we exposed previously.

• Natural light aggregates in Earth usually come from rocks of volcanic origin in which during the process of solidification of the magma from which they come there has been an escape of the gases that carried dissolved and these gases have become trapped inside the rock-forming vesicles, which confers them a very low density. Some Lunar impactites could also share similar properties. In general, to manufacture light concrete the rock has to be strong enough to be used. Such rocks are generally vitreous in nature and have a large number of vesicles inside. Concretes made of these materials have good thermal and acoustic insulation properties, of direct application in future Moon settlements. Obviously, other regions near Lunar domes could be also excellent places to search for such light aggregates.

• Carbon and organic compounds are also present in regolith-rich regions of the Moon. Many projectiles impacting the Moon are CM chondrites [6] that due to the heat of the impact the meteorites dehydrate and probably end up as "graphitized" clasts observed in meteorites [7]. Furthermore, it has been theorized of an uncertain amount of hydrocarbons which are the primary molecules for the production of much complex polymers, resins and plastics.

• Finally, solar wind volatiles can become also implanted in the Lunar regolith: H, N, C and in particular He-3 isotope, rare to find on Earth and key for future developments in nuclear fusion.

Conclusions: Exploration of the Lunar poles using a last-generation rover can provide an opportunity to understand the challenging properties of a Lunar environment affected by low and changing temperatures (120-180 K), but also to study the materials that have reached the surface of the Moon over the eons. The rover could reach the Moon at the same time than the Artemis III crew, but it could also arrive in advance to identify scientific and technologic interest. Specific instruments could quantify the amount of organics and water present in these regions, but also identify the presence of natural light aggregates and metals. These findings could have relevant implications in identifying key raw materials in future ISRU applications [8].

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