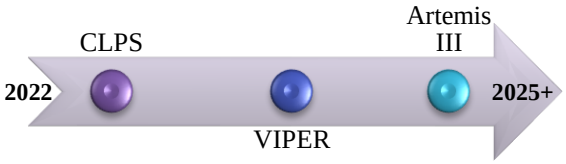
TOWARDS MINING RESOURCES ON THE MOON: PROSPECTING WITH ARTEMIS. G. Hedrick[1], [1]The MITRE Corporation, Center for Advanced Aviation System Development (CAASD), 7515 Colshire Drive, MS N560, McLean, VA 22102

Introduction: Extraterrestrial resources, especially lunar, have been of interest for a long time. In 1960, Dr. Ernst Steinhoff published a study, as part of a working group on extraterrestrial resources, establishing the inevitability of a manned lunar base, should the Apollo missions be successful, and the necessity of mining resources in-situ rather than relying on shipments from Earth [1]. 8 years later, the same working group (which counted NASA and the Air Force as participants) published documents that highlighted the importance of In-Situ Resource Utilization (ISRU) for processing fuel on the Moon and the associated infrastructure, manufacturing and construction needed to achieve it [2]. Beyond ISRU, Astronaut Harrison "Jack" Schmitt has long advocated for mining Helium 3 (He3) [3], and NASA's planned return to the Moon includes longer-term goals comprised of exploration and potential processing of metals [4].

A Return to the Moon: NASA and its partners (international, national, industry, academia and government) are going back to the Moon with the launch of the Artemis Accords [4]. There will be a phase I, mostly technology demonstrations in addition to a couple of short, crewed missions to the Moon (see Figure 1), and a phase II, that will focus on establishing a sustained presence on the Lunar surface [5].



MISSION	ROLE
CLPS: Commercial Lunar Payload Services	16 instruments delivered to the Moon.
VIPER: Volatiles Investigating Polar Exploration Rover	Rover to characterize the distribution and concentration of volatiles.
Artemis III	Crewed mission to the Lunar surface.

Figure 1. Artemis timeline of missions that can carry prospecting capabilities.

In-Situ Resource Utilization (ISRU). One of the major steps to achieving human settlement on the Moon is to produce fuel and life support constituents in-situ, at industrial-scale, starting with the extraction of water from the ice and icy regolith [4]. Water was found in Permanently Shadowed Regions at the South Pole, at the surface and subsurface [6][7], which is the main reason behind selecting this area for a lunar base [4].

Manufacturing and Construction. Sustained presence involves habitats and mining capabilities on the Moon, and research is ongoing regarding possibility of in-situ manufacturing and construction, such as regolith-based habitat or use of lava tubes for living quarters [8][9].

Leveraging the Artemis Plan to prepare for mining other resources: NASA is implementing the first missions to the Lunar surface (see Figure 1), including the Commercial Lunar Payload System (CLPS) to various sites on the Moon [10]. This is a great opportunity to begin prospecting for resources at different locations, among which Ocean Procellarum and South Pole Aitken Basin (see Figure 2).

Rare Earth Elements. One such example is Rare Earth Elements (REEs), considered vital to the economy [13] (i.e., they are listed as critical minerals), particularly to defense technology. Coupled with a supply risk on Earth, this led the U.S. government to declare the lack of REE supply of U.S. origin a national emergency [14]. Therefore, it is important to investigate long-term options for REE mining, such as the Moon. Ocean Procellarum and South Pole Aitken Basin are the richest regions in REEs [11], which makes CLPS a suitable option to begin survey work in order to better understand and characterize REE distribution at the surface and at depth (currently unknown [12]).

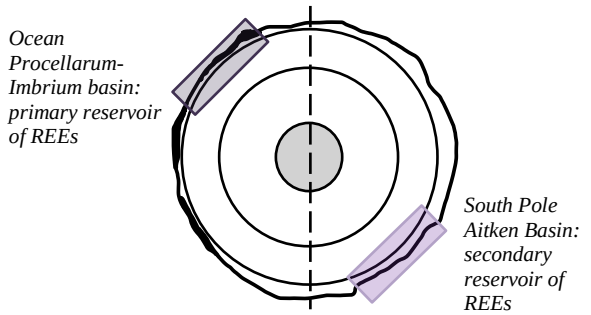


Figure 2. High-level picture of the Moon showing the core, mantle and crust, and the main reservoirs of REEs.

Helium 3. He3, another resource of interest, has also been detected at the South Pole [15]. There are many current applications (Magnetic Resonance Imaging (MRI), rocket propulsion systems [16]) as well as potential applications, such as magnetic levitation [16] and electricity [3]. CLPS offers the opportunity to

further understand the distribution of He3 to prepare for potential mining of the element.

The Importance of Prospecting: While NASA's efforts are directed towards ISRU (mostly water mining) on the Moon, it is important to tackle technical and non-technical hurdles to prepare for mining resources, such as He3 and REEs. Gaps include the lack of ground survey to characterize the distribution of resources at depth in complement to orbital data. Prospecting is the foundation step to mining (see Figure 3) that should be taken as soon as possible to ensure a successful outcome.

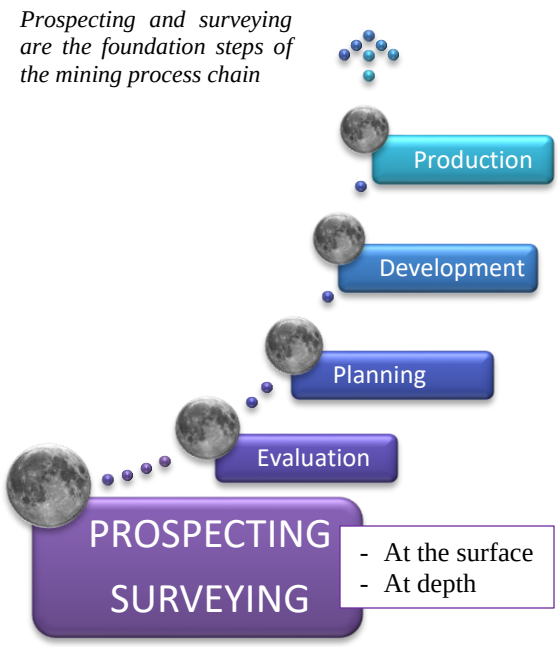


Figure 1. High-level overview of the mining process.

This endeavor would be of interest to many agencies within the government, other than NASA, such as Department of Defense (REEs are essential to national security), Department of Commerce, or U.S. Geological Survey (tasked with the assessment of critical minerals on Earth).

Conclusion: Prospecting for lunar resources is a challenge that can be tackled in the next few years by leveraging NASA's upcoming missions to the Moon, CLPS and Artemis III (see Figure 1). This will give the government immediate insight into potential sources of elements and help move forwards with the possibility of mining. By acting early, mining capabilities developed for ISRU can be built with a multi-purpose goal, so they can be more easily leveraged for other resources once the lunar base is established.

Acknowledgments: The author would like to thank Andy Anderegg and Joseph Kolly for their support on this project.

References: [1] E.A.Steinhoff (1960) *Lect. In Aero. Medicine,* 270. [2] R.S. Novosad (1968) *Proc. Of 6th annual meeting of WG on Extrater. Resources*. [3] H.H. Schmitt, (2006) *Return to the Moon*. [4] NASA (2020) *Artemis Plan*. [5] R. Clinton (2021) *ASCEND*. [6] A. Colaprete (2010), *Science*. [7] S. Li et al. (2010) *Proc. of Nat. Academy of Sc. of the USA*. [8] Y. Akisheva et al. (2021) Applied Sc. [9] M. Naito et al. (2020) *J. of Radiological Protection*, 40, 947-961 [10] Commercial Lunar Payload Services Overview | NASA [11] P. Hess (2001) JGR, 106, E11, 28,028-28,032. [12] M. Wieczorek et al. (2006) *Rev. in Mineralogy & Geochem*., 60, 221-364. [13] Critical Minerals of the United States | U.S. Geological Survey (usgs.gov). [14] FACT SHEET: Securing America's Critical Supply Chains | The White House [15] R. Miguel (2021) *ASCEND*. [16] N.R.C. (2000) *The Impact of Selling the Federal Helium*.