WHY ARTEMIS WILL FOCUS ON THE LUNAR SOUTH POLAR REGION

INTRODUCTION

This paper will highlight the unique value to exploring the south polar region of the Moon. In 2019 NASA was directed to land astronauts in the lunar south polar region. The lunar polar regions are of unique value in part due to the lighting conditions, which include locations with nearly continuous sunlight throughout a year, ranging to continuous darkness. Long duration lighting provides thermal stability for human exploration hardware and solar power generation, while permanent shadow protects the surface from the solar wind and creates environments where volatiles could be trapped as ices. Access to these ices will yield scientific knowledge about the role of volatile processes across the inner solar system throughout Earth's history that cannot be gained elsewhere, which is critical knowledge for understanding life in general. Furthermore, these ices might yield resources that enable future astronauts to live off the land and put NASA on a path towards sustainable exploration. Ices that are trapped in the south polar region are located within some of the oldest terranes on the Moon, which provides opportunity to collect samples to help understand the history of the Moon, the Sun, and our home planet of Earth, where samples and knowledge from this era of Solar System development have largely been lost through plate tectonics, or greatly altered by the very environment that supports the existence of life here. The south polar region is located near the South Pole Aitken Basin, the largest impact basin in the Solar System. Studying samples from the south polar region will help us understand when this basin formed, which is a high science priority to help us understand how and when collisions between large objects occurred during the birth and evolution of the Solar System.

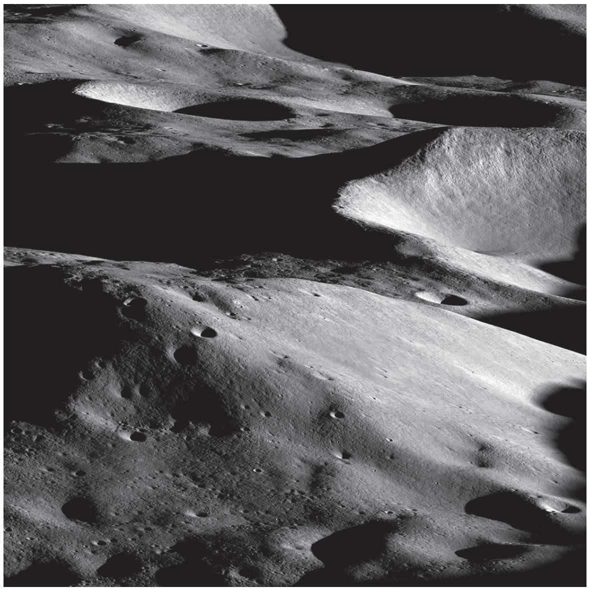

Figure 1. Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera image M1432398306LR showing the Malapert Massif in the south polar region of the Moon. Malapert is a high elevation feature that is Sunlit, but surrounded by areas of darkness cast by shadows from other high elevation features such as impact crater rims.Credit: NASA/GSFC/Arizona State University

LUNAR LIGHTING

Our view of the Moon, as seen from Earth and during the Apollo surface missions, is of an object whose appearance changes regularly and reliably over time. Humans have long defined these lunar cycles or phases and how they relate to life here on Earth. However, the lunar poles are different from what we see of the Earth-facing side of the Moon (Fig. 1), and as a result they are scientifically unique and compelling locations to explore [1]. Like the Earth, the Moon experiences seasons. These seasons are less dramatic than what we experience on Earth because the lunar polar axis has less of a tilt than the Earth relative to its orbit around the Sun. This difference has critical implications for the lunar polar environment, its impact on human exploration systems, and the science that we will be able to conduct when we go there. In addition, we know that the south pole of the Moon is geologically distinct from areas explored by Apollo, presenting an opportunity to unravel the earliest history of the Earth-Moon system.

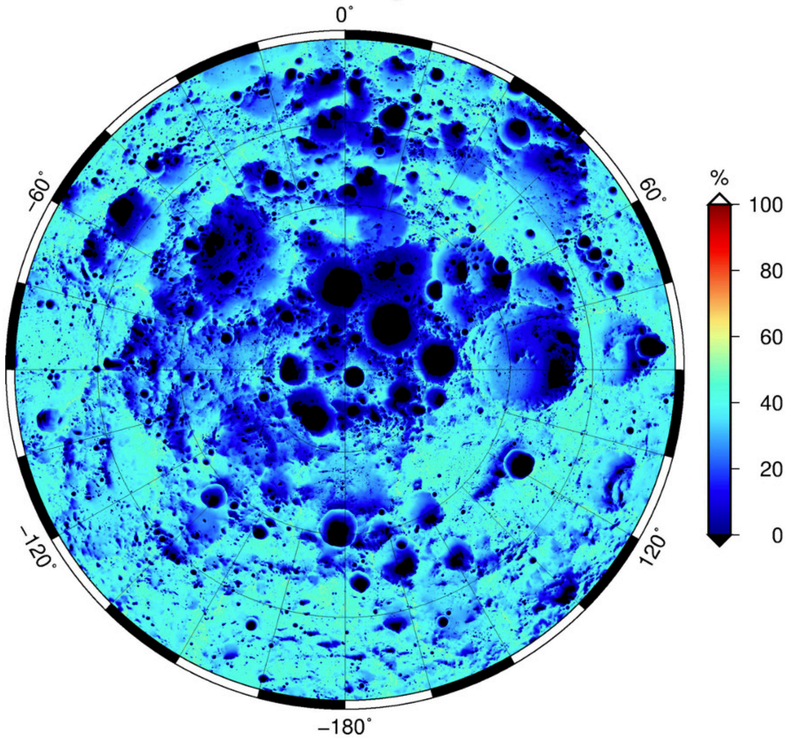

Figure 2. Map of the lunar south polar solar illumination, averaged over hourly timesteps spanning 18.6 years, for the south polar region. Shown over 85S-90S (60m/px). Black shows locations that never see sunlight in depressions and impact craters whereas lighter toned colors can see > 50% sunlight especially along crater rims and high topographic ridges.

The lighting conditions in the lunar south pole enable unique opportunities. Unlike equatorial locations, such as the Apollo sites, the polar day-night cycle is irregular and heavily influenced by the lunar seasons. At Apollo sites there are ~14.5 Earth days of light, followed by ~14.5 Earth days of night. At polar locations, this rhythm is distinct, due to both the inclination to the lunar equator to the ecliptic plane (1.54°) as well as the topography of the surface. These factors create one of the most unique aspects of the poles: that there are regions that never receive direct sunlight, as well as areas that are illuminated for longer than the 14.5 days experienced at equatorial locations, and are in darkness for much shorter times than those equatorial areas (Fig. 2). Lunar landings during Apollo took advantage of the equatorial lighting conditions, landing early in the day/night cycle in order to experience many Earth days of exposure to continuous light. Furthermore, at these more equatorial locations, the entire region is exposed to sunlight as the sun slowly tracks overhead from one horizon to the next. Near the poles, a person would observe the sun circle their location, never rising more than a few degrees above the horizon, and sometimes sinking below the horizon, completely out of sight. At the poles, the sun never rises overhead of an observer. The result is a breathtaking scene of contrasting light and darkness, creating oases of light surrounded by extensive stretches of shadow (Fig. 1).

These lighting conditions provide operational benefits. The oases of light offer locations where hardware will experience more constant thermal conditions and can generate solar power for longer periods of time than at the equator, while requiring less battery power to survive stretches of shadow and darkness. Taking into consideration the timing of astronaut or robotic activities, travel between oases of light is possible along sunlit ridges. An additional benefit from the south pole is the connection with the Earth. Like Apollo sites, there are areas on the Earth-facing hemisphere that have constant and nearly constant view of the Earth (Fig. 3), obviating the need for additional communication assets for short duration missions early in Artemis. The corollary to this is that there are areas that don’t see the Earth, which enable opportunities for lunar-based radio astronomy assets that can observe the universe in a radio-quiet environment [1] all within fairly short distances of single to 10s of kilometers.

LUNAR VOLATILES

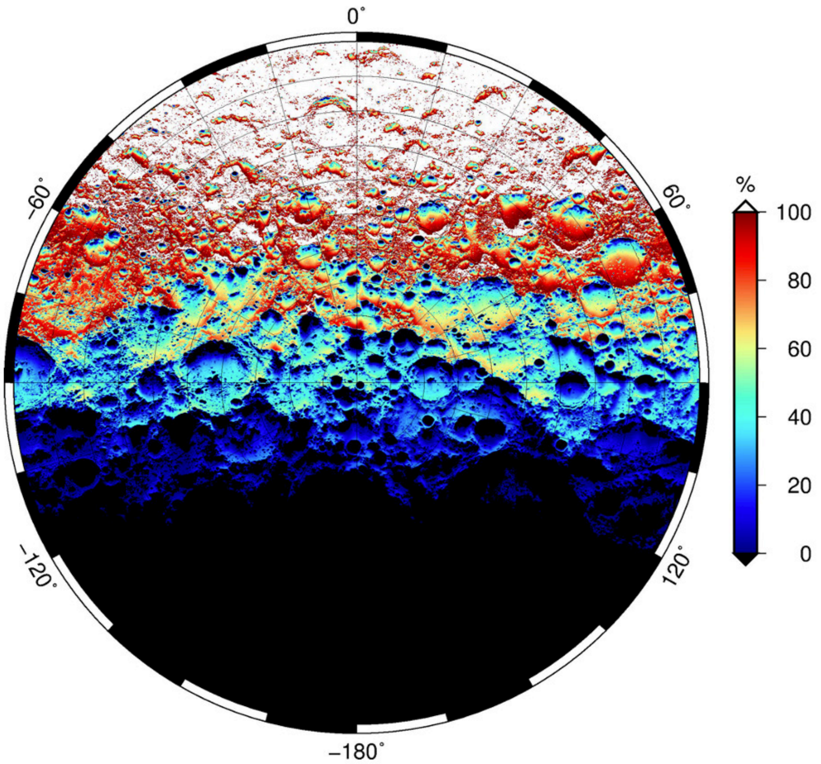

Figure 3: Map of average Earth-visibility over 18.6 years, centered on the south pole with the Earth-facing hemisphere at top. Figure from [3]

These unusual environments result in perhaps the most compelling science we can accomplish at the Moon with Artemis. After Apollo, the science community believed that the lunar surface was dry; that the temperature extremes on the Moon would not support stable volatiles (specifically H2O and OH) at the lunar surface. It was hypothesized that the poles could harbor surface volatiles due to the cold surface environment, specifically areas that are in permanent shadow. We now know that large areas of permanent darkness in the polar regions preserve volatiles collected throughout the Moon’s past. Recent remote sensing data paint a complex picture of volatile distribution in the lunar poles-- not all areas of permanent shadow contain volatiles, and there are areas that are partially illuminated and still appear to retain volatiles at or near the surface. Crewed and robotic exploration of these regions will constrain the controls on volatile distribution, transport, and retention. With careful sampling and return to Earth of these volatiles, we will learn about their origin and age, gaining insight into the processes that distribute water throughout the Solar System. There are competing theories for the origin of lunar water; some water may have originated from the lunar interior, reflecting water remnant during the formation of the Moon over 4.5 billion years ago; water may originate from comets and asteroids that have impacted the Moon over its entire history; some water may be forming today because of solar wind interacting with the surface. Ultimately these processes may have each contributed to what is observed at the surface today, but only once we have samples in labs on the Earth, will we be able to fully interpret the lunar volatile history.

The sampling and analyses of volatiles will not only reveal the rich history of the Solar System, but also may provide the very material to sustain a presence on the Moon and enable exploration deeper into space. Identifying the abundance, form, and small-scale distribution of volatiles at and near the surface directly feeds into how we will utilize resources available at the south pole. Artemis missions will directly contribute to our understanding of volatiles and their resource utility, starting with the collection of samples in early missions to understand the presence of volatiles, leading to more complex samples and sampling methods as Artemis missions mature. It will be the early Artemis missions that establish the necessary guidelines for sampling, collecting, and eventually utilizing those resources.

ANCIENT SURFACES

Those very volatiles are imprinted on some of the oldest surfaces on the Moon. Mapping of the south pole (Fig. 4) suggests that regions in the Artemis exploration zone will have surfaces older than ~3.85 billion years (and in some places older than that), older than any of the Apollo sites. The south polar region includes the margins of the South Pole-Aitken Basin (SPA), the largest and oldest impact basin in the solar system, which formed as a result of a collision between the Moon and another large solar system object. Determining when the SPA event occurred is a high priority for the science community as it could mark the beginning of collisions between solar system debris of such large sizes, after which life could begin to gain a foothold on planets. The proximity of the south pole to the SPA basin increases the chances of collecting samples from that event relative to landing in the north polar region. Much of the region within the Artemis exploration zone is dominated by materials from the formation of SPA and materials that have been modified by subsequent impacts. Well-documented samples collected by Artemis from this region will record these multiple impact events, determining their ages unambiguously via laboratory analysis will vastly improve our knowledge of the dynamics of the early history of the Solar System, most importantly the Earth-Moon system.

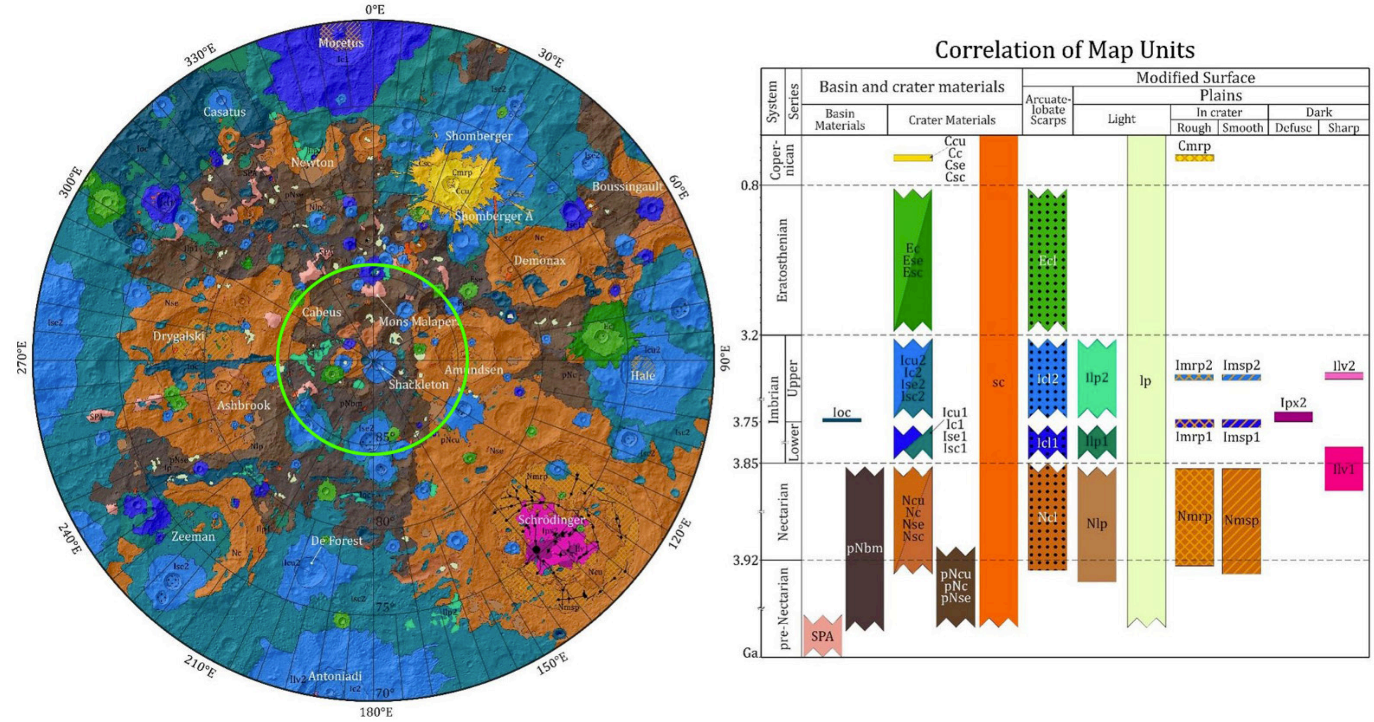

Figure 4. Geologic map [3] of the lunar south pole, illustrating the distribution of ancient surfaces (brown colors) around the pole. These ancient units are associated with the South Pole-Aitken basin, the oldest recognized crater in the Earth-Moon system. The green circle marks the Artemis exploration zone.

The ancient material at the South Pole not only records the bombardment history of the Moon, it also is a witness plate to billions of years of interactions with the Sun and galactic cosmic rays. Apollo samples are used to identify changes in the Sun's output over hundreds of millions of years as well as contributions from outside our Solar System, but are limited to the ages of those units. The ancient surfaces explored during Artemis will allow us vastly improved insight into the history of the Sun and interactions with the galaxy over several billion years. This history is directly relevant to interpreting the history of the Earth and its interactions with the Sun and the space environment, a record that is largely absent or erased from the Earth.

REFERENCES AND ADDITIONAL BACKGROUND

[1] NASA, (2020) Artemis III Science Definition Team Report, SP-20205009602.
[2] Mazarico, E., et al. (2011), Icarus, Vol. 211, pp. 1066-1081
[3] Krasilnikov, S. S., et al., (2023) Icarus, 394, 115422.

KEY TAKE-AWAYS

The lighting conditions in the south polar region contribute to unique scientific and operational opportunities. Sites of permanent darkness in the polar regions provide locations that are not exposed to the solar wind and could preserve volatiles collected throughout the Moon's past. Conversely, long exposure to sunlight creates environments that are suitable to long duration survivability of hardware and for solar power generation. The south polar region is also among the oldest parts of the Moon. Sample collection in the south polar region will help identify the age of the largest impact basin in the solar system, helping identify when life might have been able to survive on Earth. Volatiles, likely trapped as ice in areas of permanent shadow, could reveal valuable knowledge about the history of the inner solar system, including when life gained a foothold on the Earth after the significant impacts that formed the large basins. Just as ancient ices hold scientific value, lunar samples from this area will increase our knowledge of the history of the Moon itself and of the solar processes that have impacted the Earth and Moon. Additionally, these ices could serve as valuable resources for use during future exploration.

This white paper was developed as part of NASA's 2022 strategic analysis cycle to address topics of frequent discussion. For the latest white papers or other architectural documents related to human missions to the Moon and Mars, please visit: **www.nasa.gov/MoonToMarsArchitecture**.