**APPLYING THE USGS RESOURCE ASSESSMENT METHODOLOGY TO THE MOON: THREE VERY DIFFERENT CASES.** L. Keszthelyi[1], J. Hagerty[1], L.D. Meinert[2], W.I. Ridley[3], [1]USGS Astrogeology Science Center, Flagstaff, AZ 86001, [2]USGS Minerals Program, Reston, VA, 20192, [3]USGS Central Mineral and Environmental Resources Center, Denver, CO, 80225.

**Introduction and Rationale:** We have successfully demonstrated that the 3-part USGS quantitative resource assessment methodology can be used to estimate natural resources in asteroids [1]. We expect that the same methodology will be useful in assessing natural resources on the Moon, including ice, bulk regolith, and solar energy. However, the approach will have to take into account our current understanding of the nature of each of these types of resources, leading to different steps that can be taken in the near future.

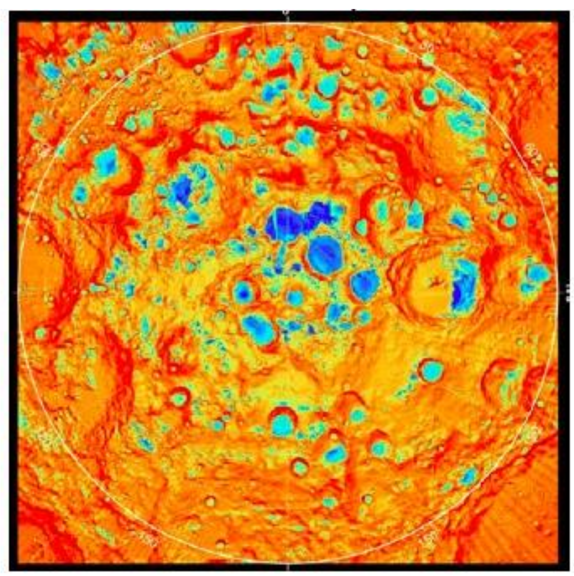
In-Situ Resource Utilization (ISRU) is not essential for short missions to the Moon that follow the Apollo model. However, it is likely that ISRU would greatly benefit any long-term human activity on the lunar surface. ISRU activity on the Moon could plausibly also support exploration activity in cislunar and deep space.

Before ISRU can be prudently incorporated into the exploration architecture, the resources need to be assessed. These assessments need to be unbiased, quantitative, and reliable. Creating such assessments is the Congressionally mandated responsibility of the United States Geological Survey.

**Assessing Lunar Ice:** Water, which on the Moon would be in the form of ice in polar cold traps, is the most desired of lunar resources. It is useful for human sustenance, rocket fuel, radiation shielding, and more. However, a quantitative assessment of lunar ice is extremely difficult. While basic physics and a whole host of measurements are strongly suggestive of ice deposits, definitive proof of such deposits is still elusive. As such, there are many fundamental science questions to answer before all aspects of the USGS resource assessment methodology can be effectively brought to bear on this problem.

Still, the framework of a formal resource assessment can be useful in guiding the research. For example, the first step in the assessment process is to develop separate "descriptive" models for deposits formed by different geologic process. The mixture of ice and rock in the deposits could be quite different if the water is delivered from local impacts of water-rich comets and asteroids versus migrating solar wind protons versus gas released by a handful of large volcanic eruptions. The next step is to identify "tracts" where the deposits could plausibly exist. This would be driven by thermal models that rely on accurate topography and verification against orbital temperature data (Fig. 1). Then the range of plausible water contents would need to be estimated, with heavy reliance on constraints from the various neutron spectrometers and radar observations. While the one direct sampling point provided by LCROSS is important, the lack of statistically significant numbers of ground-truth observations will be a major challenge for a reliable quantitative assessment. All this is before any consideration of the technical challenges of extracting the ice. When those engineering issues are added to the equation, it is almost certain that an assessment done today (i.e., relying on current data and technologies) will report very large uncertainties – and a high probability of little to no useful ice. It is debatable if such a report would be actually useful for decision makers. However, it would provide an interesting benchmark as new data and ISRU technologies are developed, reducing uncertainties and raising the expected amount of useful ice.

Figure 1. Maximum temperature around the lunar south pole as measured by DIVINER. Areas in blue are cold enough for surface ice to be geologically stable. From Paige et al. [2].



**Assessing Lunar Regolith:** Our state of knowledge of regolith is much higher than for ice. Impacts are the only basic process by with regolith is formed on the Moon. We have extensive relevant global data sets, especially maps of temperature (Fig. 4), topographic roughness, optical maturity, and radar properties, that delineate different types of regolith. We have excellent in-situ data from the Apollo missions (Fig. 2) and useful additional data from robotic landers. Furthermore, we have sufficient quantities of high quality analog materials for industrial scale experiments. While there are some uncertainties, our current state of knowledge is ready to support a quantitative assessment.

Figure 2. Jack Schmitt sampling regolith on Apollo 17.

The biggest challenge for a formal USGS resource assessment is related to extraction technologies. There are a variety of proposed techniques for utilizing bulk regolith, ranging from simply bulldozing regolith over a habitat for shielding to forming lunar concrete to build complex structures. The chemical composition and the nature of the particle size distribution can affect the suitability of the regolith for different utilization processes. However, the urgency of regolith utilization is modest at the moment, so it may not be best target for the first USGS lunar resource assessment.

**Assessing Lunar Solar Power:** Our understanding of the nature of solar power and the technology to extract it are mature. The uncertainties in the availability of solar energy is tied to our knowledge of the ephemerides of the Moon, Sun, and Earth and lunar topography – all of which are known with great accuracy and precision. This knowledge is verified via insolation maps from LROC images (Fig. 3). Similarly, the technology to extract energy from sunlight is at TRL10 with no significant technical uncertainties. The only questions are related to the specific design choices for the landers and solar arrays. This makes a resource assessment for solar power very similar to a landing site assessment. Key variables are the precision of the landing system, and the slopes the landing system can tolerate. In fact, this assessment provides the opportunity to invert the normal landing site selection process and define the requirement for the lander from the power requirements.

Figure 3. Multi-temporal illumination map of the lunar south pole. Shackleton crater (19 km diameter) is in the center. Mapped area extends from 88°S to 90°S [NASA/GSFC/Arizona State University].

**References:** [1] Keszthelyi L. et al (2017) *USGS Open-File Report* 2017-1041. [2] Paige, D. A., (2010) *Science, 330*, 479-482. [3] Williams, J.-P., et al. (2017) *Icarus, 283*, 300-325.

Figure 4. DIVINER surface maps based on minimum and maximum temperature anomalies from Williams et al. [3].