KEY SCIENCE INVESTIGATIONS OF THE MOON'S POLAR REGOLITH – A NONVOLATILE PERSPECTIVE. Brett W. Denevi[1] and Mark S. Robinson[2], [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA (brett.denevi@jhuapl.edu), [2]Arizona State University, Tempe, AZ, USA.

Introduction: Understanding the Moon requires understanding the lunar regolith. Defined as the layer of fragmental debris above a more coherent substrate [1], all returned lunar samples have come from the regolith (no bedrock has been investigated in situ), and most of our remote data is sensing only the regolith as well. A landing site near the lunar south pole provides important opportunities to acquire new knowledge of the Moon by learning from the polar regolith. Although the polar regolith is rife with the scientific and exploration potential of volatiles, here we focus on the plain and old, yet information-rich, dirt.

Space Weathering: With exposure to the solar wind and micrometeoroids, regolith on the surface of the Moon matures: it becomes darker and develops a steeper (redder) visible–near-infrared spectral slope and weaker absorption bands [e.g., 2,3]. But what is not certain are the relative roles of the solar wind and micrometeoroids in causing these changes. Trends in reflectance that correlate with differences in solar wind flux suggest that the solar wind may play a pivotal role in the ultimate spectral reflectance that a mature soil reaches [4–8], despite conclusions from laboratory studies that suggest micrometeoroid bombardment dominates [9].

Because the curvature of the Moon reduces the effective solar wind flux at high latitudes (flux scales with the cosine of latitude), polar regions are the perfect place to test this hypothesis. Although minimal differences in maturity are seen in the highlands between ±75° latitude, higher reflectance and steeper continuum slopes are observed closer to the poles [4–6]. Thus any returned sample of "typical" mature regolith from a polar region will provide new insight into the nature of space weathering. More information still could be gained from sampling regolith on the equator- and pole-facing slopes of a crater, or any two points that experience a different solar wind flux due to topography.

An additional, exciting test of space weathering would be possible if a landing site was selected on or near a ray of Tycho crater. Fortuitously, a ray of Tycho passes directly across the ridge between de Gerlache and Shackleton craters (Fig. 1), a location previously identified as a potential landing site due to its persistent illumination, proximity to permanently shadowed regions, and relationship to the South Pole–Aitken basin [10–12]. Secondary craters from the Tycho impact event were sampled by Apollo 17 astronauts ~2200 km away from the crater at the Taurus Littrow Valley. Cosmic ray exposure ages from those materials and from the light mantle, a landslide thought to have been triggered by the Tycho event, date the crater's formation to ~100 Ma [13–16]. The opportunity to sample Tycho ray material at the south pole would not only provide a test of that age, but would enable a direct comparison of the

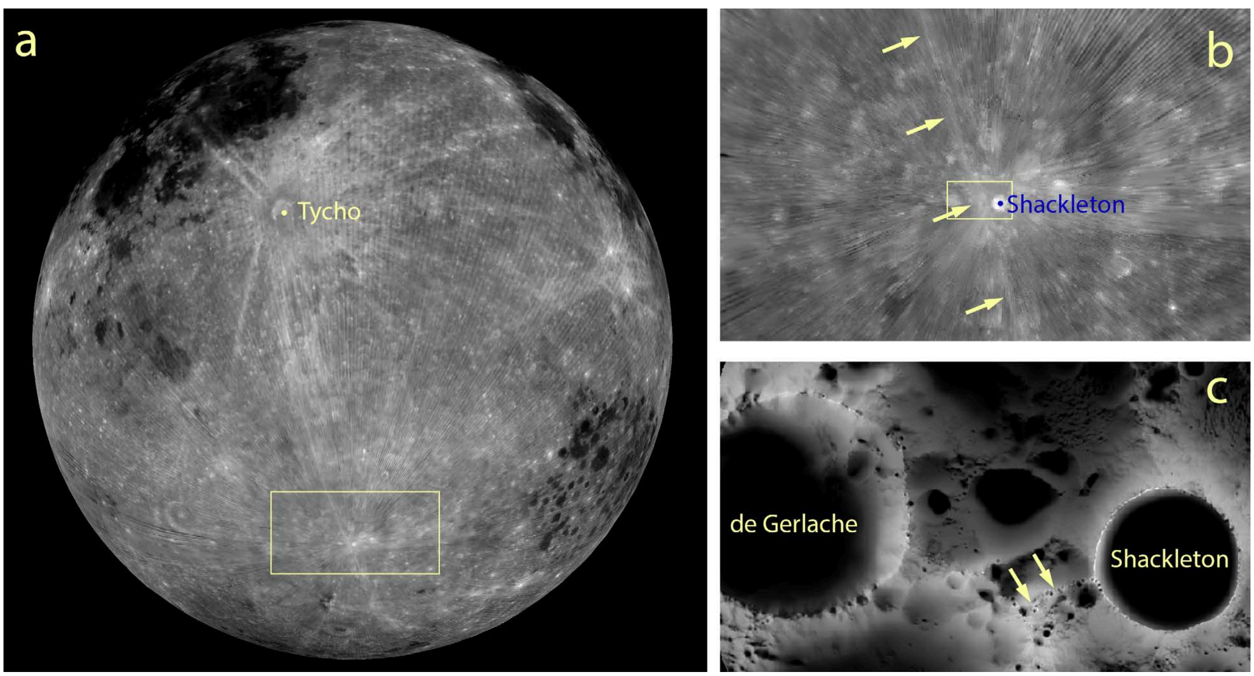

Fig. 1. A ray from Tycho crater crosses the ridge between de Gerlache and Shackleton craters, adding additional scientific interest to this potential landing site. a) Orthograhic view (centered at 60°S, 0°E) of LOLA reflectance data [6]; location of panel b is indicated by yellow box. b) LOLA reflectance data of the south polar region; yellow arrows indicate ray from Tycho crater, yellow box shows the location of panel c. c) Illumination map [12]; arrows indicate the location of the ridge between de Gerlache and Shackleton craters. For scale, Shackleton crater is 21 km in diameter.

maturation of highland material exposed to the surface at the same time, but at the two extremes of the lunar space weathering environments (the ~equatorial light mantle, the polar ray).

Regolith Mixing and Ballistic Sedimentation: Exploration of the south polar region will provide a chance to gather new information about regolith mixing. Every Apollo and Luna sample return site in the highlands was within close proximity to the mare, and vice versa, and the samples returned recorded the transport of material from neighboring terrain. Most sites were within several tens of km of a mare–highland boundary, only Apollo 16 was ~220 km from a mare deposit, but it still contained basaltic fragments [e.g., 17]. A polar landing site will be >500 km from any mare deposit, and will thus provide a chance to better understand the distal transport of material by impact mixing [18].

Recent observations have provided a new understanding of the of great distances over which impact crater ejecta can affect the surface [19–22], but there have been fewer advances in understanding the fraction of primary material deposited at these distances vs. local disturbed material. What will the basaltic component be, hundreds of kilometers from the nearest mare deposit? The component from the South Pole–Aitken Terrane? A sample of mature regolith from essentially anywhere within the polar region will provide a treasure trove of lithic fragments that hold the answers to this history of mixing. If a ray from Tycho is visited, a comparison to the much older Copernicus ray visited at the Apollo 12 landing site will provide rich new information on the process of ballistic sedimentation [23], particularly if material from within and outside of the ray are sampled.

Coring and trenching is an excellent way to learn about the local history of the polar regolith. Layers derived from discrete ejecta emplacement events can be observed within Apollo core samples [24–26], recording the unique impact history of that location. This regolith layering is observed as differences in grain size and maturity, as well as some compositional variation. At the example of the Shackleton–de Gerlache ridge (Fig. 1), sampling the regolith with depth would provide a history of the Tycho, Shackleton, and de Gerlache impact events, and the more recent shallower reworking of these materials. The ancient highlands regolith also contains fossil regoliths (paleoregolith) that could provide a history of changes in the solar wind, or major events such as from solar flares or cosmic rays. A trench dug either from a relatively flat area or by digging into a crater wall would expose layering. Subtle differences in these layers could be discerned with multispectral imaging to document this stratigraphy and aid in selecting samples from each layer to bag and return.

Ground penetrating radar (GPR) also shows promise for revealing the local stratigraphy, as seen at the Change'e 3 and 4 sites [27,28]. Those results suggest that the regolith in the maria is substantially thicker than was interpreted from Apollo seismic data [29,30]. GPR measurements of highlands regolith, produced by a longer and more intense period of bombardment, would reveal new insights into regolith development and provide greater context to results from coring/trenching.

In Situ Spectroscopy of the Regolith: While never observed in situ, photometric and thermal measurements show that the uppermost regolith (upper few mm) is an extremely porous (>80% porosity) "fairy castle structure" where grains are precariously supported by adhesive and electrostatic forces [e.g., 31–33]. This upper structure has profound effects on remote reflectance and emissivity observations. Microscopic images of this microstructure and spectral measurements of the regolith disturbed by the landing and astronaut activities, and undisturbed regolith (away from the landing site), would be a boon to understanding remote sensing data anywhere on the Moon.

Summary of Needed Investigations: An investigation of the Moon's south pole will be largely an investigation of its regolith. Understanding the unique history of that location, as well as larger questions about space weathering, regolith mixing, and sample provenance all benefit from a detailed understanding of the regolith. Local regolith samples from the surface, from portions of a landing site that experience distinct solar wind fluxes, and from coring and trenching would bolster numerous studies. Multispectral imaging of the landing site and microscopic imaging of regolith texture would make those samples all the more valuable by documenting their context and revealing how their undisturbed state is manifest in remote sensing data. Greater regional context and regolith stratigraphy at larger depths could be provided by GPR. A polar landing site within a ray from Tycho crater (Fig. 1) would provide additional tests of key Solar System processes.

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