LUNAR INVESTIGATION USING SELENOPHYSICS (LINUS) TO ASSESS THE AGE OF THE INA IRREGULAR MARE PATCH. N. E. Putzig[1,a], G. A. Morgan[1], M. R. Perry[1], S. W. Courville[1], A. T. Russell[1], M. B. Russell[1], L. M. Liberty[2], K. W. Lewis[3], J. D. Stopar[4], A. Mittelholz[5], T. D. Mikesell[6], A. A. Seshia[7], D. Bergman[8], B. Yen[8], G. Paulsen[8], S. O'Brien[8], I. King[8], and K. Zacny[8], [1]Planetary Science Institute, Lakewood, CO, USA and Tucson, AZ, USA, [2]Boise State University, Boise, ID, USA, [3]Johns Hopkins University, Baltimore, MD, USA, [4]Lunar and Planetary Institute, Houston, TX, USA, [5]Harvard University, Cambridge, MA, USA, [6]NGI, Inc., Houston, TX, USA, [7]University of Cambridge, Cambridge, UK, [8]Honeybee Robotics, Altadena, CA, USA. [a]Contact: nathaniel@putzig.com

Introduction: Volcanism has played a significant role in the evolution of the lunar crust, having resurfaced a fifth of the Moon's exterior in mare flood basalts. Volcanic eruptions peaked around 3.5 Ga, with the final phase believed to have occurred at ~1.2 Ga [1] While the majority of basaltic flows and structures are subdued due to billions of years of impact gardening, Irregular Mare Patches (IMPs)—small regions of apparently pristine basaltic deposits—represent a striking exception.

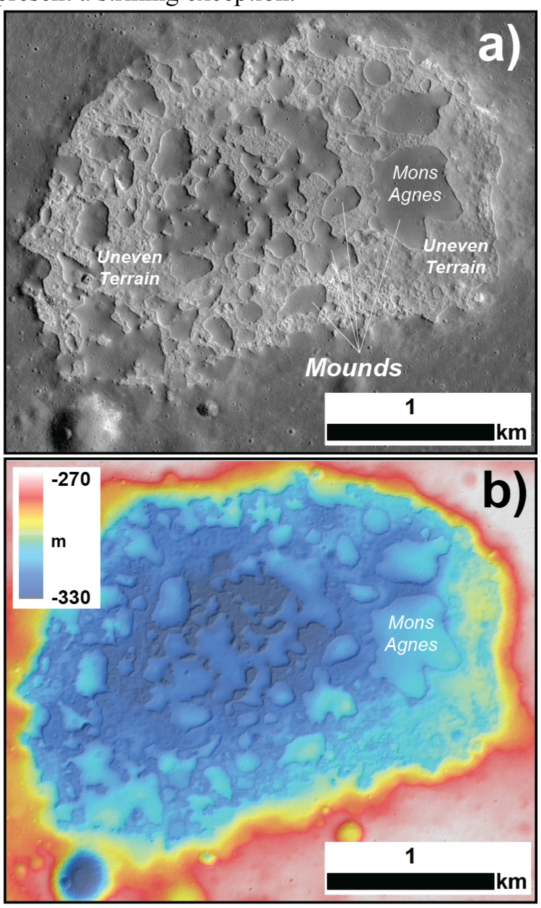

Figure 1. *Ina Irregular Mare Patch. a) LROC NAC mosaic of Ina depression with its two main unit types annotated. b) LROC NAC stereo DTM of Ina.*

Consisting of smooth mounds only tens of meters high and hundreds of meters across that exhibit crisp boundaries and are surrounded by uneven terrain (**Fig. 1**), IMPs are found in multiple locations across the Moon [2-6]. Age estimates based on the crater size-frequency distributions at the surface indicate that IMPs are only tens of millions years old [5] and thus orders of magnitude younger than the rest of the mare. If these age estimates are accurate, then melt generation must have continued until the recent past. Such late-stage magma production and ascent challenges models of how a Moon-size body should cool [e.g. 7,8] and forces us to reconsider the assumptions of such models.

Alternatively, the apparent youthfulness of IMPs may be an artifact of their structure. Hypotheses put forward include the eruption of extremely vesicular magma that would result in atypical crater formation and retention [9,10]. If this scenario is correct, IMPs could be as old as the surrounding mare, which range from ~1.2 to 3.7 Ga [6]. Regardless of their age, IMPs represent a unique volcanic deposit, which may not have an equivalent on other terrestrial bodies, and they need to be understood.

Reconciling the Origin and Age of IMPs: The young and old hypotheses represent end-member scenarios that offer compelling, yet extremely divergent and testable explanations for the presence of IMPs [e.g. 11]. While much progress has been made in examining IMPs from orbit, reconciling the conflicting material properties dictated by each hypothesis requires measurements through the full vertical extent of the mound deposits. We propose the Lunar Investigation Using Selenophysics (LINUS) concept to undertake density and structure measurements critical to differentiate between the IMP formation models.

LINUS Concept: LINUS is a landed geophysical and imaging suite designed to be integrated into a CLPS lander and rover pair (**Fig. 2**). The LINUS instrument suite includes an active-source seismic system (consisting of impulsive and vibrational ground impactors and MEMS ground-motion sensors), gravimeters, magnetometers, and context cameras. The interpretation of data from individual geophysical methods is inherently non-unique. **Integrating** the results of multiple selenophysical measurements will provide robust subsurface models of density, magnetization, porosity and structure (in both 2D and 3D) that can be compared with the surface images to constrain IMP geology and distinguish between the formation models.

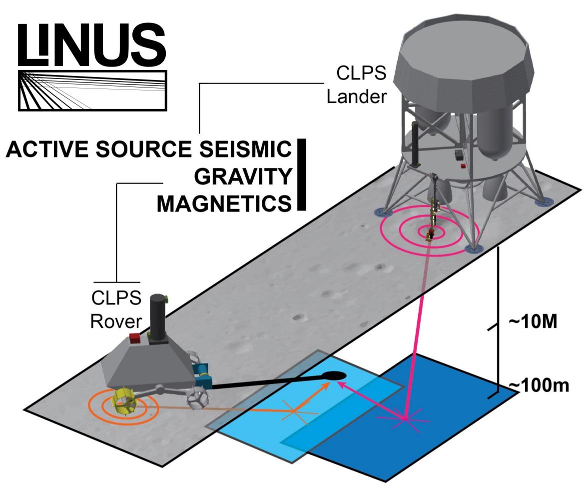

Figure 2. *The LINUS suite of selenophysical instruments enabled by a lander–rover pairing will allow us to probe the subsurface of Ina over a range of depths to directly measure the physical properties and structure of Ina to constrain the age of the deposit.*

Landing Site: We propose the Mons Agnes mound of Ina (**Fig. 1**), the largest and most studied IMP, including new radar results to be presented at this LPSC [12,13]. The new observations reveal potentially unique deposits of fine grained materials at least 1 m thick inside Ina that coincide with anomalous Diviner thermal inertia and H-parameter [14]. Ina might host pyroclastic deposits, nascent regolith, or an "auto-generated" regolith-like surficial deposit [15] that is **ready to be explored by in situ investigations**. The majority of the Mons Agnes surface is safe for landing and roving in terms of slope and absence of rocks and other obstacles, and it affords adequate line of sight to enable roving transects extending 100s of meters away from the lander. Undertaking a series of "flower petal" shaped measurement transects, with the lander in the center, either over a single lunar day or multiple days (with survive-the-night capability), will provide a dense cloud of measurements amenable to 2D and 3D analysis. Leveraging a wealth of terrestrial geophysical processing techniques will permit the geology of the mound and underlying strata to be explored in detail.

Instrument Placement: Distributing the seismic sources and sensors between the lander and rover will permit a maximum depth of penetration defined by the offset between the two. We anticipate probing down to 100 m depth or more, exceeding the anticipated 30 m thickness of the Ina mound units. Seismic sensors on the rover will be fixed to a 3 m streamer that will be dragged along the surface behind the rover. This will ensure that the upper 10 m of the mound (including any regolith layers) is seismically visualized wherever we rove. Data from the rover-borne gravimeter and magnetometer will complement the seismic survey. Placing an equivalent set of instruments on the lander will offer long-baseline gravity and magnetic measurements to allow calibration of the rover data.

LINUS Science: If Ina is host to young, dense lava flows (young hypothesis), we expect to measure high seismic velocities, an elevated local gravity field, and a substrate that lacks a magnetic signature. Alternatively, if Ina is an ancient but highly porous and friable deposit (ancient hypothesis), we expect to measure low seismic velocities, a reduced local gravity field, a thick regolith and possible remanent magnetism. Ground imaging of the landing-site geology, including impact craters and their ejecta, will provide geomorphic constraints in support of our geophysical data. For example, we would address whether the local crater morphology is consistent with impacts into a coherent substrate or is instead indicative of a substantial (and thus older) regolith layer.

If neither endmember hypothesis is consistent with the LINUS measurements, we can use the data collected to explore additional formation models. For example, if we return signatures consistent with the mounds representing typical, thick, yet variable mare regolith, such results would support the recent degassing model presented by [3]. Alternatively, Ina and IMPs in general might host pyroclastics and/or consist of materials/structures not yet considered in the literature. Overall, the comprehensive selenophysical investigation offered by LINUS will address the uncertainties raised from orbital data and will enable us to constrain the true longevity of lunar volcanism.

LINUS Beyond Ina: While LINUS has been optimized to investigate the origin of Ina, the concept offers a range of valuable science applications to other regions of the Moon, including Artemis landing sites and the search for volatiles within permanently shadowed regions. LINUS instruments could be configured on astronaut-operated rovers and landers to provide a window into the subsurface geology.

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