COORDINATED GEOLOGIC AND GEO-THEMATIC MAPS: THE UNIFYING PLATFORM FOR MAXIMIZING SUCCESS OF LUNAR SURFACE SCIENCE. J. A. Skinner, Jr., J. J. Hagerty, C. M. Fortezzo, A. E. Huff, T. M. Hare, and M. A. Hunter, U. S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Drive, Flagstaff, AZ 86001 (jskinner@usgs.gov).

Introduction: In the most basic sense, geologic maps provide spatial and temporal *context* for the rock, sediment, and soil at and near the land surface, and place geologic phenomena into relationships with each other and their immediate and distal environments. Beyond providing geologic information, scientists and decision-makers alike use geologic maps to help identify and prepare for natural hazards; site and build civic infrastructure; locate and develop natural resources; and promote informed decisions for land-use and planning [1-2]. The essentiality of geologic maps to support exploration does not stop at national or even planetary boundaries; the same principles prove geologic maps are equally applicable to basic and applied science questions beyond Earth. In this abstract, we do not argue for specific sites or propose instrumentation for exploration by the Artemis missions to the lunar south pole. Rather, we assert that such efforts cannot evolve in the absence of coordinated, standardized geologic maps. Well-constructed, consistent, and theme-diverse geological maps are essential, not optional, infrastructure to plan for and maximize the scientific return of the Artemis missions. Considerations of the unifying aspects of geologic mapping fall squarely into the "*concepts, options, capabilities, and innovations*" intent that guides this workshop.

Lunar Mapping Strategy: For the NASA Artemis Program, geologic and geo-thematic maps will be required for (1) characterization of geology and identification of resources when selecting landing sites, (2) classification of selected site terrains and constraint of mission-specific exploration objectives, and (3) documentation and contextualization of field investigation and instrument results. This continuous need for geologic maps before, during, and after surface operations demands products be standardized, accurate, and scientifically robust. Furthermore, these products must be constructed in a way that places map-specific information within the broader geologic framework of the Moon (that is, the assimilated context of regional- and global-scale geologic knowledge). The targeted development of geologic and geo-thematic map products will accelerate mission progress and amplify Artemis program success.

Need. The geology and stratigraphy of the Moon has been resolved body-wide only at regional scales (**Fig. 1**) [2]. Very local scale geologic maps are uncommon, areally dispersed, and, though locally informative, rarely enable extrapolation to the broader geologic framework of the Moon. For the lunar south pole, pre-Nectarian massifs, Nectarian terra, Imbrian plains, and Eratosthenian crater units are all resolved at regional scale (**Fig. 1**), but the existence and geometry of these units within 6° of the south pole is ill-constrained. We identify a pre-mission need for a mapping campaign that locally extends regionally-identified units to support selection of a safe, scientifically relevant landing site and to maximize science within the exploration zone. <u>Recommendation</u>: Immediate commencement of an expedited geologic mapping campaign framed by a common set of purpose, process, product, and scale to guide lunar surface science operations and promote comparability of basic and applied research afforded by the Artemis missions. Effort would ideally be team-based, guided by a community review panel of subject matter experts, and released for community use at regular intervals.

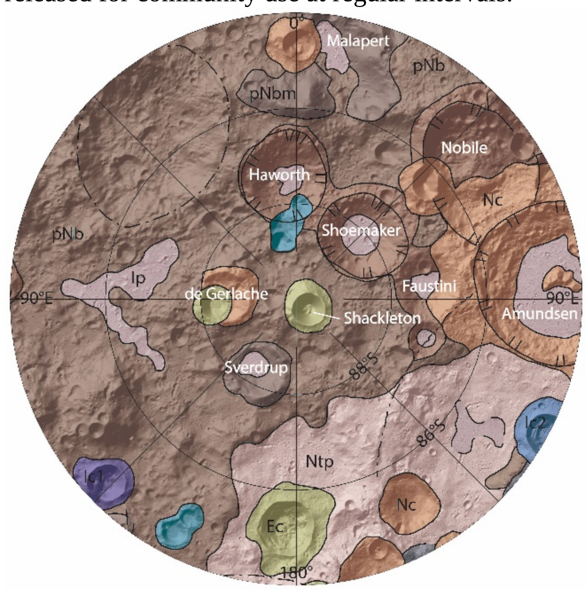

Figure 1. 1:5M-scale Unified Geologic Map of the Moon [3] of the lunar south pole (84 to 90°S). Units include pre-Nectarian basin (pNb), pre-Nectarian basin massif (pNbm), Nectarian terra-mantling and plains (Ntp), Nectarian crater (Nc), Imbrian plains (Ip), Imbrian crater 1 and 2 (Ic1 & Ic2), and Eratosthenian crater (Ec). LOLA shaded relief base.

Process. Geologic mapping, particularly wherein operational considerations are at the forefront, should follow well-vetted rules, principles, and processes. This broadens understanding of the operational environment or, perhaps more importantly, limits misunderstanding. It is increasingly clear to data producers and users that certain widely-accepted standards are essential to creating, managing, and disseminating geoscience information [4-6]. Standardization allows all participants of the exploratory mission to operate on the same plane of knowledge, regardless of expertise. Artemis mission participants should recognize that adherence to a common suite of cartographic representations enables seamless cross-comparison of geologic maps and thematic geoscience data to establish context and afford successful operations. The absence of broadly-applied standards impedes development of a common knowledge database and severely limits co-location of planetary geologic map information. Recommendation: Early discussion and adoption of cartographic and data standards in the preparation and conveyance of geologic maps to ensure such products are used and understood by all stakeholders (*e.g.*, astronaut crew, engineers, mission scientists, program managers, and policy makers).

Product. Like many scientific disciplines, the geosciences are becoming a collection of specialized fields that result in more and more specialized types of maps. Though the conventional geological map continues to provide a common link [7], modern software enables a robust level of data collation and interaction that was not available during the Apollo era. Technological advances have altered geologic mapping production over the past few decades, most specifically the availability of geospatial data and use of geographic information systems (GIS). These permit geologic map information to be electronically stored, displayed, queried, and analyzed in conjunction with a variety of other data types. However, contrary to terrestrial geologic mapping, planetary geologic mapping has experienced no impetus to migrate fully into applied research products that specifically co-locate basic and applied results to enable decisions that impact national assets throughout the mission timeline. Artemis is that impetus, as surface material types, boundaries, and thicknesses derived from dedicated geologic mapping will necessarily be corroborated and compared with hazard, solar illumination, line-of-sight, slope, and other maps. Recommendation: Ensure capture of mapping results from various geoscience disciplines, making products publicly available.

Scale. Map scale conveys an accurate sense of size and space on any derived cartographic map product. Map scale for geologic maps is not equivalent to data resolution but, rather, leverages a range of data types and resolutions to make and convey scale-appropriate observations of the characteristics and distribution of rock and sediment masses. Awareness of map scale for the Artemis missions will help guarantee that pre-cursor local and land-based observations can be applied well beyond the exploratory envelope and not be scientifically isolated. We identify three specific scales upon which Artemis-supportive maps should be devised. These scales are selected in order to "nest" themselves with each other, the broader lunar geologic framework, and available data types and resolutions. 1:500,000 to 1:100,000 scale (1 mm map = 500 to 100 m ground) provides geologic context and enables cross-comparison to global data sets and past investigations. 1:100,000 to 1:20,000 scale (1 mm = 100 to 20 m) enables site specific exploration beyond the landing site. 1:20,000 to 1:4000 scale (1 mm = 20 to 4 m) provides details for landing hazards, site development, resource planning, and traversing. Further larger scale (smaller area) mapping will require improved data resolutions or field mapping by mission crew. Recommendation: Create geologic and geo-thematic maps based on an established set of "nested" map scale to ensure geologic maps are prepared to promote cross-correlation.

Conclusions: The efficacy of lunar surface operations will be driven – before, during, and after landing – by the preparatory context afforded by scientists and engineers. Without an understanding of the operational environment, there will be a strong tendency to miss key steps in the logical thought process, which increases the probability of miscommunication and error. Therefore, the question is not whether geologic maps and associated products will be made to support the Artemis missions (they will) but rather how useful, timely, and consistent these products will be. We call for a direct, non-duplicative effort to prepare, standardize, coordinate, corroborate, and distribute geologic and geo-thematic mapping efforts. This will result in predictable and comparable products across the most relevant scales for science, engineering, and decision-making. We underscore that successfully planning for and execution of an exploratory mission to the lunar south pole will not occur effectively without the context afforded by coordinated geologic maps and thematic geoscience data and reiterate that planetary geologic mapping efforts need to commence immediately and be cognizant of the applied research purposes of these maps. This will ensure that NASA's Artemis-based observations and investigations merge seamlessly with pre-mission mapping efforts and provide stake-holders with a landscape-level understanding of the landing site as well as the potential for resources, hazards, and siting assessments.

References: [1] GSA (2017) Position Statement: *The Value of Geologic Mapping*. [2] National Geologic Mapping Act (1992) *2 USC Sec. 31a*. [3] Fortezzo, C. M. (2020), *51st Lunar Plan. Sci. Conf.* #2760. [4] OMB (2002) *Circular No. A-16, revised*. [5] OMB (2010). *Circular No. A-16, Supp. Guidance*. [6] FGDC (2013) *NSDI Strategic Plan 2014-2016*. [7] Maltman, A. (1990) *Geological Maps*, Open Uni. Press, 184 p.