GEOLOGIC MAPPING IN SUPPORT OF SIMULATED ARTEMIS LUNAR SURFACE OPERATIONS: FINDINGS AND RECOMMENDATIONS.

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Introduction: Geologic maps enable successful planetary exploration, as demonstrated first and foremost by the Apollo Program [1-2], when multi-scale geologic maps helped select scientific targets and plan human exploration of the lunar surface [3-4]. The Joint EVA Test Team 3 (JETT3) mission conducted the first field-based Artemis simulation involving a full science team and generation of mission-supportive science products, including geologic maps, to a level required for surface operations [5-6]. Fundamental limitations exist for constructing geologic maps based exclusively on satellite images and photogeologic mapping techniques [3], arising largely from uncertainties in identifying, describing, and correlating terrains that have not been physically contacted. Here, we describe how the JETT3 science team prepared and used geologic maps and offer insights into how products could be improved to support both future simulations and landed missions.

Regional Setting: The SP Mountain region, located ~65 km north of Flagstaff, AZ, has long been used as a training ground for human and robotic planetary exploration [7] due to its geologic diversity, environments analogous to planetary surfaces, and ease of access on private, state, and federal land. The JETT3 study region, located adjacent to and east of SP Mountain, contains lava flows, point-source and fissure vents, alluvial surfaces, and erosional valleys. Despite numerous past field activities, association between volcanic vents and flows and the timing and intensity of surface erosion is unknown at scales appropriate for *in situ* observation. These unknowns provide context to examine the value of mission-supportive geologic maps in surface operations.

Mapping Approach: JETT3 geologic maps were based on expected lunar equivalent data. We used a GeoEye grayscale orthoimage (0.5 m/px) and associated digital elevation model (DEM; 1.5 m/px), which simulated Lunar Reconnaissance Orbiter Camera Narrow Angle Camera images and DEMs. We augmented these with National Agricultural Imaging Program contrast stretched color aerial images (1 m/px). We used topographic inflections and tonal changes to define geologic units, their marginal contacts, and cross-cutting relationships for a 1:20,000 scale map using a 4-m vertex spacing. We subdivided labor by assigning mappers high-, intermediate, or low-standing terrains and reviewed evolving mapping weekly with the full science team. The final map included 15 discrete geologic units within the broader JETT3 region, including 9 pyroclastic units, 4 volcanic flow units, 1 alluvium unit, and 1 strata unit (**Fig. 1**). Of these mapped units, 9 are located within the JETT3 traversable ellipse (4 pyroclastic, 4 flow, and 1 alluvial units). We applied a naming approach that used state names, which were randomly assigned to local landforms (*e.g.*, Colorado massif) and extended to geologic units (*e.g.*, Colorado pyroclasts, unit pco).

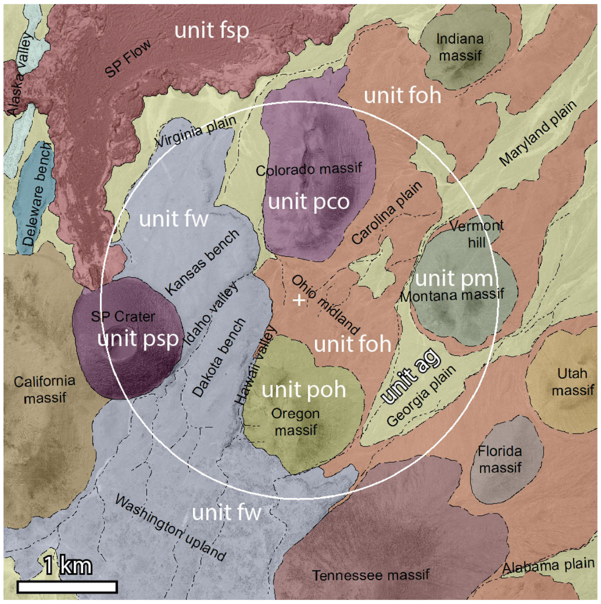

Figure1. Geologic map of the JETT3 region and the 2-km radius traversable ellipse (white circle). Local features informally identified with state names. All traverses began and ended at the simulated base camp (white cross).

Local Geology: When preparing remote-based geologic maps, we cannot state with certainty the geologic character of rocks and sediments exposed on or near the land surface, whether that be on the Earth, on the Moon. We must leverage geologic knowledge, make reasonable inferences, and extrapolate observations at one location to the entire region of study. This results in high and low certainty inferences.

Knowns / High Certainty – We interpreted the local units and landforms as resulting from mafic volcanic eruption and the subsequent erosion and redeposition of those units. The JETT3 base camp was located equidistant between four separate and (presumably) compositionally and temporally discrete cinder cones, the youngest of which was the SP flow (unit fsp). We did not temporally subdivide the other three cones (units pco, pm, and por) due to lack of contact, though topographic prominence implies unit pco is second youngest and unit pm is oldest. We interpreted a single lava flow (unit foh) as dominating the intermediate elevations of the central and eastern part of the ellipse and suggested topographic subdual resulted from erosional deflation, regolith development, and burial by alluvial sediments to an unknown thickness. We leveraged a paucity of topographic inflections to imply the unit was laterally pervasive, though eruptive relationship to adjacent pyroclastic vents remained undetermined. Based on the elevated surface and marginal lobes, we interpreted the surfaces located in the west and southwest as a discrete lava flow (unit fw) that originated from the southwest. We asserted that a single, undifferentiable alluvial unit (unit ag) superposed all volcanic units in the region with unlithified sediments eroded and transported by intermittent sheet-wash and channelized flow. Surficial unit thickness was inferred to be several cm on elevated lava flows and high-slope cones and up to greater than several meters in drainages and flat plains.

Unknowns / Low Certainty – We captured low certainty details by cautioning unit descriptions and employing approximate contacts (*i.e.*, existence certain, location approximate) to convey locational confidence. Major unknowns included: (1) mineralogical character and, thus, uniqueness of each eruptive event, represented in all lava volcanic vent and flow units, (2) clear age associations between three volcanic vents, (3) thickness and particle character of mapped alluvium, (4) occurrence, thickness, and particle character of unmapped alluvium (*i.e.*, regolith) throughout the region, and (5) potential mineralogical association and genetic association between unit foh and units pco, pm, and por. These unknowns are not shortcomings of product but, rather, expected outcome of mapping in the absence of physical contact. These unknowns help identify routes and stations wherein observations can and should be made to refine our understanding of the geologic environment in real time and provide long-lived context for collected samples.

Lessons Learned: We identify findings and offer recommendations (REC) to help guide future efforts.

FINDING: The 1:20,000 scale geologic map often lacked sufficient detail to be highly impactful for mission planners and crew at the scale of JETT3 traverses. REC: Ensure geologic maps are prepared at scales that both enable a holistic understanding of geologic context and prepare all participants (crew and mission support personnel) for field-based observations (*e.g.*, 1:20,000 and 1:5,000, respectively, based on a 2-km radius traversable ellipse), with appropriate consideration given to the resolution limitations of base data.

FINDING: The state-based naming convention we employed resulted in landforms and geologic units being frequently equated. Use of state names inadvertently implied geographic location in the field area. REC: Naming conventions should use names that are geographically benign and non-genetic.

FINDING: Due to compressed timelines, the mission-supportive geologic map was prepared partly in tandem with the science traceability matrix (STM) [8], which diminished the map's potential use in identifying relevant observational stations, potential samples, and traverse pathways. REC: Ensure geologic mapping is completed well in advance of station identification and development of the STM so all map components (*e.g.*, map, unit descriptions, unit correlations) are reviewed by team members.

FINDING: The geologic map did not sufficiently account for the occurrence, distribution, or thickness of rocky outcrop versus surficial sediments. Both are important for resolving the geologic setting and history and significantly impact the type of information inferred from crew images, descriptions, and samples. REC: Geologic maps should identify the occurrence of rocky outcrop versus surficial sediment in the field.

FINDING: A lack of compositional information meant that the geologic map relied exclusively on the shape of the landscape. REC: Mission-supportive geologic maps should integrate more diverse datasets, including visible-near infrared, thermal infrared, and radar data to help establish the most robust set of geologic content and unit descriptions possible. Compressed timelines are obvious limiters for constructing multi-dataset, multi-scale geologic maps.

Conclusions: Though traditional planetary geologic maps have not been crafted to fulfil practical science applications, this effort highlights that basic and applied geoscience maps in highly usable formats are not only possible but critical tools for lunar exploration. We encourage sufficient time be allotted for science backroom, crew, and flight controllers to review mission-supportive geologic maps, including unit descriptions, naming conventions, and expected rock and sediment character in the field.

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References: [1] Wilhelms, D.E. (1972), USGS Astrogeology 55. [2] Schmitt *et al.* (2017), *Icarus* 298. [3] Grolier, M.J. (1970), USGS I-619, 1:25,000 scale. [4] Mission Eval. Team (1972), NASA MSC-07230. [5] Young, K.E. *et al.*, this volume. [6] Caswell, T.E. *et al.*, this volume. [7] Schaber, G.G. (2005) USGS OFR 2005-1190. [8] Fagan, A.L. *et al.*, this volume.