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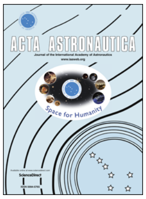

Designing remote operations strategies to optimize science mission goals: Lessons learned from the Moon Mars Analog Mission Activities Mauna Kea 2012 field test

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ABSTRACT

The Moon Mars Analog Mission Activities Mauna Kea 2012 (MMAMA 2012) field campaign aimed to assess how effectively an integrated science and engineering rover team operating on a 24-h planning cycle facilitates high-fidelity science products. The science driver of this field campaign was to determine the origin of a glacially-derived deposit: was the deposit the result of (1) glacial outwash from meltwater; or (2) the result of an ice dam breach at the head of the valley?

Lessons learned from MMAMA 2012 science operations include: (1) current rover science operations scenarios tested in this environment provide adequate data to yield accurate derivative products such as geologic maps; (2) instrumentation should be selected based on both engineering and science goals; and chosen during, rather than after, mission definition; and (3) paralleling the tactical and strategic science processes provides significant efficiencies that impact science return. The MER-model concept of operations utilized, in which rover operators were sufficiently facile with science intent to alter traverse and sampling plans during plan execution, increased science efficiency, gave the Science Backroom time to develop mature hypotheses and science rationales, and partially alleviated the problem of data flow being greater than the processing speed of the scientists.

1. Introduction

In reconnoitering remote regions, geologists utilize robotic landers and vehicles to perform data acquisition and analysis. Operations scenarios are designed, tested and refined for the unique problems associated with conducting geology remotely, for the abilities of the vehicles and landers in their specific environments, and for the science goals of the mission. This allows scientists to use these tools to efficiently maximize science return. For example, Mars Exploration Rovers (MER) science operations strategies were designed

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Abbreviations: MMAMA, Moon Mars Analog Mission Activities; MER, Mars Exploration Rovers; MSL, Mars Science Laboratory; GPR, Ground-Penetrating Radar; MIMOS, MIniaturized MÖssbauer Spectrometer; VAPoR, Volatile Analysis by Pyrolysis of Regolith; RESOLVE, Regolith and Environment Science and Oxygen and Lunar Volatile Extraction; PDL, Payload Downlink Lead; SOWG, Science Operations Working Group; FOSIL, Field Operations, Science and Integration Lead

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to accommodate the latency in communications between Earth and Mars, a delay that required separating science-driven decisions based on analysis of the surroundings, from the actual execution of remote field activities [1–5]. A science support team (the "science backroom") determined science priorities and observations to be executed by the rover the following Martian day, or "sol"; these observations, along with other necessary activities, were planned and executed by the rover engineers. The science operations strategies for Phoenix were developed from the MER operations blueprint, but were initially planned to meet the dual constraints of a landed (immobile) spacecraft and a known, finite lifetime for mission activities [4]. In addition to the science team that planned each sol's activities (the tactical team), the Phoenix mission was to use a strategic science team to evaluate the returned data and develop a plan for the next sols. The timing of these two processes, tactical and strategic, was to be planned so that the strategic team's input would be the basis for the upcoming sol's plan.

Likewise, the strategies currently in use for the Mars Science Laboratory (MSL) rover mission were created in part by adopting salient parts of the MER and Phoenix lander science operations architectures to meet the unique constraints of MSL. These included the significantly larger data stream acquired by the MSL rover compared to the MER and Phoenix missions, the greater complexity in operations due in part to the number and type of instruments on-board, and the resultant additional tactical (short-term) and strategic (longer-term) planning made necessary by these factors. The MSL model requires a complex interplay of strategic, tactical and supratactical science and engineering processes to manage the demand on resources, each of which must feed into and inform the others. Ultimately, however, the 24-h latency between planning and execution, and the integration and close communication between the backroom scientists and the spacecraft engineers regardless of their role in the tactical or strategic process [6], remain key uniting factors in the science operations of all three missions.

The science-driven operational strategies from these missions have been used to acquire data from which products such as geologic maps, compositional rock classifications, thermal inertia maps, and stratigraphic cross-sections have been produced [7–9]. But the fidelity of these products cannot be fully assessed without comparison to a known standard, which is impossible for a truly remote location such as Mars or the Moon. In lieu of comparing remotely-derived products such as maps to a known standard, products derived from analog activities conducted on Earth can be compared to those derived from standard terrestrial techniques at the same location, to determine the efficacy of those remote methods in acquiring the necessary data to produce high-fidelity products. Mauna Kea, Hawai'i, is a key site to carry out Moon and Mars analog activities [10–13]. For the Moon Mars Analog Mission Activities Mauna Kea 2012 (MMAMA 2012) field test, we compared products and science results derived from field test rover activities at a Mars analog site, with those produced by geologists on the ground using traditional field techniques. Our goal was to assess how effectively the science operations strategy for an integrated team operating on a 24-h planning cycle facilitates data acquisition that yields accurate, high-fidelity science products. The science objective of this field campaign was to geologically map and determine the origin of a glacially-derived deposit, with two potential hypotheses to be tested: the deposit was the result of (1) glacial outwash from meltwater; or (2) the breach of an ice dam at the head of the valley. This objective provided the parameters by which success was measured (outlined in Section 4).

2. Geologic setting of field site

The field campaign was conducted in a valley on the southeast flank of the Mauna Kea volcano at an elevation of 11,500 ft, in an area known locally and informally as "Apollo Valley;" our study area lies across the access road from the Mauna Kea Ice Age Natural Area Reserve [14] (Fig. 1). Mauna Kea is composed of tholeiitic basalts from an active shield stage, capped by relatively low silicate alkali and transitional hawaiite basalts erupted relatively slowly during a stage of postshield volcanism (e.g., [15,16]). The valley itself has been mapped as an unconsolidated gravel outwash deposit of subrounded to rounded hawaiite and mugearite cobbles and boulders that is part of the Pleistocene-aged Makanaka Glacial Member of the Laupahoehoe Volcanics [16,17], a glaciation episode coinciding with the late Wisconsin glaciation of North America [18,19]. Bounding the valley on the upslope side is till of that same glacial member. This broad ridge of till largely plugs the relatively narrow span between the valley walls here, with the exception of a ravine incised between it and the western wall. At the end of the valley to the southeast, and predating the glacial deposits, are several Pleistocene-aged hawaiite/mugearite cinder cones. An extensive Pleistocene hawaiite/mugearite flow unit forms the bedrock of the valley sides and outcrops from below outwash deposits at the valley's southern end.

Attempts to date the advance and retreat of the Pleistocene glaciers [20–22] have led to various interpretations of the glacially-derived valley deposit. Pigati et al. [21] interpreted the valley deposit as a "boulder fan" and suggested, based on boulder composition, that boulders were excavated from the Younger Makanaka moraine currently plugging the northern valley entrance, and transported a few 100 m downslope. They interpreted the valley deposit as having formed over ~3–4000 years as glacial meltwater cut through and washed out portions of the moraines, redepositing clastic material downstream in channels and fans. However, Anslow et al. [22] calculated a bimodal distribution of ages for boulders in the deposit, and explained this discordance with the dates of Pigati et al. [21] by observing that the fan is composed of unsorted sediment with well-defined edges lying in a V-shaped gully that eroded through the distal moraine to the east of Pu'u Keonehinoe. They interpreted the deposit as having formed by catastrophic drainage of a moraine-dammed lake, a one-time event occurring around 12,000 years ago. Differences in ages of the deposit calculated by the two works would then be attributable to the temporal separation between the glacial retreat and the ice-dam breach. Our focus in this field campaign was to acquire data using a MER-type model of science operations, and to use this data to determine whether the valley deposit formed over time through