COMPARING GEOLOGIC DATA SETS COLLECTED BY PLANETARY ANALOG TRAVERSES AND BY STANDARD GEOLOGIC FIELD MAPPING: IMPLICATIONS FOR PLANETARY EXPLORATION PLANNING.

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Introduction: Human planetary exploration has always been at the horns of a unique dilemma – human intelligence, imagination, and abilities for correlation of diverse information is superior to robotic assets, but the difficulties of keeping humans safe and productive in a hostile environment means that human missions are more expensive than robotic missions. The cost of placing humans on the surface of a planet dictates that one must efficiently employ the unique skills they bring to exploration, which includes optimizing use of crew time. Exploration with *both* human and robotic assets can never assume unlimited time on the surface regardless of the scope and scale of the mission, so a critical part of exploration planning is how to best utilize human explorers' time on a planetary body.

The Apollo crewmembers conducted a program of documented sampling based on detailed pre-mission science and science operations planning [1]. This planning integrated pre-mission geologic mapping of landing sites with mission constraints based on hardware limitations, crew fatigue considerations and overall mission safety. Apollo surface operations did not conduct conventional geologic mapping – rather, specific sampling stations were chosen to provide the most diverse sample suite based on pre-mission mappers' interpretation of the landing site geology, and crews were extensively trained in basic geologic principles so they could recognize and sample the suite of rock types at each site they visited on the surface.

In the 40+ years since Apollo, there have been a number of analog missions that have applied this operational approach to testing new exploration hardware and operational approaches. Most notable of these has been the Desert RATS series of tests in the San Francisco Volcanic Field [2,3]. However, there has never been a study that compared scientific results of a site investigation based on "Apollo-style" investigations with the same site investigated with conventional geologic mapping approaches. This study was conducted to perform a double-blind test to compare the geologic interpretation of an area that had been extensively traversed and sampled by the 2010 Desert RATS crews with the surface-based geologic map and interpretation prepared by experienced field geologists.

Study Design: An area of ≈25 km^2 of the San Francisco Volcanic Field was chosen for the study, based on previous developed RATS 2010 pre-mission planning data and the availability of an extensive data set of samples, photographs, videos and crew geologic notes derived from the Desert RATS 2010 mission. The field area was specifically chosen because the terrain did not allow full traversing and sampling by the Desert RATS crews. Moreoever, the geologic diversity appeared, on the basis of topography and outcrop pattern, to be significantly more complicated than could be elucidated by the Desert RATS traverses. The terrain limitations, in particular, meant that there were substantial portions of the area that were neither sampled nor described geologically; hence, it could be expected that there were potential differences in geologic interpretation between the limited investigation on Desert RATS and a more detailed investigation conducted by a team of field geologists.

In order to develop data sets that could be compared, one team (Feng, Evans and Gruener) prepared a geologic map based on both the pre-mission, geologic interpretation from remotely-sensed data, and the syn-mission samples, photos, videos and Crew Field Notes collected by the Desert RATS 2010 crews. The second team (Eppler, Skinner, Bleacher, Janoiko, Hurwitz and Whitson) prepared a geologic map using traditional field mapping methods in June, 2013. Both teams worked independently for the first half of the study, and compared data sets only after each team felt they had developed the best geologic maps and interpretations with the data available to them. Once each team reached those limits, the individual data sets were then compared and integrated.

Study Results: Here, we consider the science operations implications that arose from our results. In particular, our results may be applied to architecture considerations that drive significant differences for future planetary surface mission planning and execution. Additional abstracts [4-6] discuss the specific scientific results of this study.

One question that has been debated continuously in both lunar and Mars surface exploration planning has been the relative merits of 1) executing multiple, Apollo-style sortie missions; 2) immediately committing significant surface assets to a single fixed outpost location with no pre-cursor sortie missions; or 3) providing limited fixed permanent surface assets while delivering robust surface exploration capability in the form of pressurized rovers with significant that significantly extend mission duration and range of travel. The first approach respresents a continuation of the Apollo approach. The second approach has the benefit of providing progressively-increasing surface infrastructure at the expense of extensive access to a whole planet's surface. Finally, the third approach allows for extensive, detailed surface exploration, but does not allow the buildup of a significant base infrastructure that will be a necessary element of permanent surface habitation. One critical question in this debate has been which approach provides supports the most efficient and highest quality science return. Although there has been much discussion, pro and con, there has been limited practical experience brought to the discussion.

This study found that the limited data set derived from a sortie-type mission is sufficient to develop a general idea of geologic history, but misses key detail in areas not traversed. In particular, the 2010 RATS traverses missed data that would have allowed for full discrimination of all surface rock units, data that is necessary to develop a complete and accurate interpretation of the area's geologic history. If the goal of a particular exploration program is to develop a detailed and comprehensive geological history for large areas of the target planet, simple sortie missions that are of necessity bounded by operational constraints will not be sufficient. The second approach allows for more extensive exploration around the chosen base area, but depending on the mobility assets delivered to the surface, this approach could rapidly reach "science saturation", where the amount of new information derived from the area accessible is diminished. This is particularly relevant with respect to the time required to access the edge of an increasingly distant circle of exploration. It is not inconceivable that crews could reach a point where attaining access to unexplored terrain could take up the majority of a given day, limiting the time spent actually exploring and conducting science to a small fraction of the time spent in the field. A long transit time reduces the efficiency of crew time in the field, limiting the science return from a mission of this design. In contrast, the third approach enhances mobility and increases the range that crew can explore, though at the expense of permanent infrastructure. The key to selecting the appropriate approach is to clearly define the goals of each mission and to then identify the infrastructure that will best meet the goals of that mission.

A further consideration raised by this work is how quickly a particular field project reaches a point of diminishing returns. Compared to early studies [7] and the RATS 2010 activity, this work generated a greater level of detail and a better understanding of a complex eruptive history at a single vent site. However, both teams agreed that given the degree of erosion and post-eruptive modification of the field area, it seems unlikely that more detailed follow-on field work would result in a signficantly improved interpretation of the geologic history of this vent site.

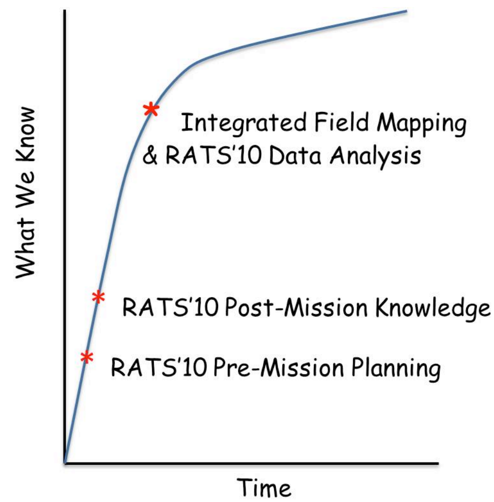

Figure 1. Notional representational knowledge of geological history of the field area based on Desert RATS planning, post-mission assessment of data and traditional field mapping of area

One possible visualization of this idea is a schematic "knowledge capture curve" (**Fig.1**). As a study progresses, the slope of the knowledge capture curve for a given area begins to flatten out. We believe that the answer to assessing a particular exploration architecture approach with respect to science return should be based on a similar evaluation of science knowledge capture as a function of time. In particular, the mission set that appears to provide the best science return, based on this work, is the one that allows human and robotic crewmembers the freedom to investigate a particular area until such time that the knowledge curve begins to flatten out. At that point, additional efforts will result in a lower rate of science return, indicating that exploration assets should move to a new venue.

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References: [1] Eppler, et al. (2013) Act. Astronaut., *90*, 224-241. [2] Skinner, et al., (2013), Act. Astronaut., *90*, 242-253. [3] Hörz et al., (2013), Act. Astronaut., *90*, 54-267. [4] Bleacher, et al. (2014) LPSC. [5] Feng et al. (2014) LPSC. [6] Skinner et al., (2014) LPSC). [7] Ulrich, G. and Bailey, N., 1987, USGS Misc. Field Studies Map MF-1956.