Geologic Studies in Support of Manned Martian Exploration

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Abstract

With the advent of the space exploration of the middle part of this century, Mars has become a tangible target for manned space flight missions in the upcoming decades. The goals of Mars exploration focus mainly on the presence of water and the geologic features associated with it. To explore the feasibility of a manned mission, a field analog project was conducted. The project began by examining a series of aerial photographs representing "descent" space craft images. From the photographs, local and regional geology of the two "landing" sites was determined and several "targets of interest" were chosen. The targets were prioritized based on relevance to achieving the goals of the project and Mars exploration. Traverses to each target, as well as measurements and sample collections were planned, and a timeline for the exercise was created. From this it was found that for any mission to be successful, a balance must be discovered between keeping to the planned timeline schedule, and impromptu revision of the mission to allow for conflicts, problems and other adjustments necessary due to greater information gathered upon arrival at the landing site. At the conclusion of the field exercise, it was determined that a valuable resource for mission planning is high resolution remote sensing of the landing area. This led us to conduct a study to determine what ranges of resolution are necessary to observe geology features important to achieving the goals of Mars exploration. The procedure used involved degrading a set of images to differing resolutions, which were then examined to determine what features could be seen and interpreted. The features were rated for recognizability, the results were tabulated, and a minimum necessary resolution was determined. Our study found that for the streams, boulders, bedrock, and volcanic features that we observed, a resolution of at least 1 meter/pixel is necessary. We note though that this resolution depends on the size of the feature being observed, and thus for Mars the resolution may be lower due to the larger size of some features. With this new information, we then examined the highest resolution images taken to date by the Mars Orbital Camera on board the Mars Global Surveyor, and planned a manned mission. We chose our site keeping in mind the goals for Mars exploration, then determined the local and regional geology of the "landing" area. Prioritization was then done on the geologic features seen and traverses were planned to various "targets of interest". A schedule for each traverse stop, including what measurements and samples were to be taken, and a timeline for the mission was then created with ample time allowed for revisions of plans, new discoveries, and possible complications.

1. Introduction

The intensive study of Mars through exploration by humans is a long-term goal of the United States space program, although a definite schedule has not been established for this to take place. The cost of a human mission to Mars will be very high – certainly billions of dollars. The mission must therefore be very efficient in achieving the goals for Martian exploration. The primary goals, as prescribed by NASA (McCleese 1998), encompass many issues from scientific to human exploration, and are summarized as follows; the search for water (when, where, form, and amount), the search for life (extinct or extant), the examination of climate (weather processes and history), and the exploration of resources (environment and its possible usefulness to future missions). The question of the availability of water on the surface of Mars is relevant to all the objectives. The possibility of the development of life, whether past or present, and how water has shaped the geologic and climatologic histories of the planet are both dependent on the presence of liquid water. The history of Mars and the corresponding implications of the potential for life could be useful in the study of how life evolved on Earth and interacted with its primeval surroundings. The latter goal is concerned with the availability and feasibility of exploiting in situ resources for future missions. In situ resources would greatly diminish the cost of exploration by providing the raw materials for fuel synthesis, construction of settlements, and the ability to initiate and maintain closed, self-sustaining life support systems.

In order to ensure the success and efficiency of a human mission to Mars, it is essential that the mission be planned and practiced in detail with simulations on Earth. This approach will provide astronauts rigorous training that will make routine activities time effective. At the same time, the simulation should help identify potential unexpected conditions and hazards, as well as assist astronauts in responding effectively to these conditions. Simulations on Earth also permit testing of equipment and procedures, and enable subsequent modifications at a small relative cost. Earth can provide an excellent analog environment, because its geology approximates some of that expected to be found on Mars.

In this report, we discuss our involvement in a Mars Field Analog Project conducted in October and November of 1998. We briefly explain our methods used in this exercise, as well as our results and conclusions derived from the information gathered in the field. We also discuss the procedure and results collected from a resolution study, which stemmed from our findings in the Field Analog Project. The third section of this report summarizes our planning of a manned mission to Mars using the information gained from the field exercise and the resolution study. We explain the procedures used as well as our reasoning behind our methods.

2. Field Analog Project

2.1 *Project Objectives*

The Field Analog Project was created to allow students to experience all aspects involved in sending humans to Mars, including planning, executing and examining the data gathered from a manned mission. The project not only explores what goes into planning and executing a mission, but also what problems can occur and what steps are necessary to plan, correct and/or adjust for those problems. The objectives of this project were to become more familiarized with Mars and its geology, to be able to use and interpret remote sensing data, to plan and run a field exercise, and to analyze the results from that exercise.

2.2 *Approach*

By taking into consideration the goals stated for Mars exploration, a simulated manned mission was conducted using two teams of geologists at two locations in northern Arizona, to study the feasibility of such a mission to Mars. One stipulation of the exercise was to have no prior knowledge of the site other than aerial photographs, taken at different scales, which simulated a sequence of space craft descent pictures. These pictures were used to plan and execute a manned mission as if on Mars. The local and regional geology of the two areas were determined and several “targets of interest” were chosen and prioritized based on their relevance to achieving the goals of the mission. Traverses were planned to each site and a timeline for the intire mission was created. The benefits of a manned mission over robotic missions were addressed including the problem-solving abilities of humans versus the programmability, expendability, and environmental tolerances of robots. Robotic missions, although expendable, are inherently less efficient due to the communications lag times between Earth and Mars that are involved. The use of experienced humans allows split-second, on site decision-making. The ability of communicating rapidly is useful in coping with potential uncertainties or problems encountered by a robotic mission.

2.3 *Procedure*

The first step in planning for the field exercise was the analysis of four or five photos of each respective landing area. These photographs simulated the increase in image resolutions that would be collected during the descent of a vehicle landing on Mars, in addition to the orbital images that are typically utilized in actual mission planning. Geologic features were identified according to the Mars exploration goals (McCleese 1998). Topography was estimated from the shadow lengths of features and the time of day of the photography.

After key geologic targets were identified, preliminary geologic maps and histories of each site were developed. Given the perspective that precise landing sites are rarely known until it occurs, prioritization of features was based on perceived accessibility and scientific value. Possible traverse routes and schedules for the six-hour exercise were devised. Prioritization was based on relevance to the Mars exploration goals, as stated above, accessibility to the features based on calculated topography and traverse length, and mission length or how much total time was available. Therefore, features that encompassed more than one objective were given a higher priority over other features. Alternate and contingency traverses for time or environmentally restricted mission profiles were also planned according to the prioritization used above. Time was also added into the schedule for the possible “collection” of rock and soil samples, as well as atmospheric content samples and temperature readings.

Upon arrival at the simulated landing site, one member of each team was chosen as the "geologist", another as the "backup geologist", and the third as CAPCOM. The geologist was required to wear a heavy frame backpack, large heavy-duty outdoor gloves, and a plexiglass visor to simulate the life support system (space suit) that the astronauts would be required to wear during their traverses. Once in the field, the first problem addressed was orientation to the surroundings. Although the true landing points were only off by tens of meters, no one 'landed' precisely where their traverses were planned to begin, and revisions were hastily devised according to the alternate prioritizations. Additionally, actually surveying the terrain predicated some traverse alterations solely for safety concerns. Initial observations in the field also prompted radical reworking of target prioritization in most cases. Over the course of the exercise innumerable 'targets of opportunity' that had not been foreseen in the preliminary remote sensing arose as well as emergency situations, which placed time constraints on the project. Final analysis invariably resulted in revised site geologic histories and maps, and the formulation of laboratory analyses of proposed returned field samples. The actual collecting of samples was precluded by the property owners, the Navajo Nation.

2.4 *Geology of the Landing Sites*

2.4.1 Site A Sedimentology and Structures

The geology of Site A based on the remote sensing showed some specific dominant features. The lowest resolution image showed that the general geologic context of the area as predominantly flat-lying terrain with little or no change in relief. Wind streaks, soil variations, and some larger channels were the dominant features at this scale, but many of the more detailed features were not identifiable. Channel structures could be traced through the field area on the higher resolution photos, and the shading and texture of the surface suggested relatively recent debris from running water. Most of the area between the channels seemed to be flat but strewn with cobbles of various sizes. A few of these cobbles seemed to have a wood-like texture. Near the western edge of the area, a large hill or possibly a butte dominated the terrain. Its summit showed signs of weathering in the broken nature of the boulders, which were interpreted to be volcanic. The areas between the hill and the channels seemed have a substantial, fine soil cover indicated by half-buried clasts and mud cracks. The shading of the main surface material changed over the entire area from the channels to the hill, which could indicate differences in composition or differences in weathering and/or soil formation.

4.2.1 Site A Igneous Petrology

If indeed the hill was volcanic in nature, then most of the rocks in the area should have compositions that fit with this hypothesis. The soils were thus assumed to be clays and muds directly associated with the weathering of volcanics. The specific types of weathering products from different types of extrusive igneous rocks are well defined based on starting composition of the source rock (Blatt & Tracy, 1996). By determining the types of volcanics that the hill is comprised of, the nature and composition of the soils, clays and muds could then be inferred and tested. The change in color of the soil material may reflect the compositional differences from the weather of the hill material as uposed to other sources. The fractures observed in the photos should have also been consistent with known jointing patterns of the appropriate volcanic rocks, such as columnar jointing in basalts. Together with these attributes, the albedo or coloring of the rocks at the site should have also been appropriate for the type of rocks.

2.4.3 Planning the Site A Traverses

Prioritization of features to examine in the area was completed after the preliminary photogeologic analyses. The main goal for Site A was to visit the channels that were probable locales for the preservation of water related structures. Adhering once again to the main mission goals for Martian exploration, the presence of water-sculpted landforms was the first step to detecting the possible existence of liquid water at the surface. This in turn could indicate that paleoclimatic conditions were once warm enough to support life. The traverse from the landing site to the main channel would be the most important for these reasons. The second most important goal involved determining the composition of the hill. Was it indeed volcanic or was it something else? The final area of interest was the soil and its formation. Could the weathering be traced through the differences in the soil types? Many locales across the field area were chosen as alternates for the various priorities since accessibility to these sites would be limited by time and landing location.

2.4.4 Actual Site A Geology in the Field

The geology of the site provided some unexpected surprises when compared to the photogeologic study. The first observations were of the actual landing site, where the clasts that were observed on the photos were identified. The soil had a hard, reddish covering and was strewn by pieces of petrified wood, sandstone, and jasper. There was no real distinction between particles of different sizes, indicating the sorting was poor. Mud cracks were nearly ubiquitous. The channels provided a look at the sediment being carried downstream. The middle of the channels was coated in a fine-grained gray sediment that seemed to match the layers seen in the distance near the hill (Figures 2.3, 2.4). The size of these sediments was a fine grained to silty sand. There were areas in or near the channels that seemed to be where water had pooled and then evaporated leaving the behind evaporate residue. In the largest channel there was a cut bank where the stratigraphy could easily be seen (Figure 2.5). At this locale the red surface soil was measured to be 13.5 cm thick. It appeared to be an oxidized zone with a slight fining upward sequence in the distribution of the coarser grained particles, although the sorting was still poor. Below this layer was a predominately greenish-gray layer approximately 30-35 cm thick. The sorting in this layer was better developed and also contained possible root casts that were filled with red sediment from the above layer (Figure 2.3). The hill in the field area that appeared to be volcanic rock was actually a sandstone layer lying on top of softer shale or mudstone layers. The less resistant layers were eroding causing the upper, more resistant sandstone layers to fracture. The result was the creation of fairly large sandstone boulders, some of which could be found on the plain where the channels were located. In general, the topography and geologic features found at the site were visible and identifiable on the "descent" images. The one main difficulty discovered was determining the compositional nature of the hill and surrounding areas. Other discrepancies mainly occurred with the size of the features seen. Smaller features, such as the stratigraphy within the large channel were not as visible in the images due to the resolution used. Another discrepancy we found dealt with estimating the topography of the area from the "descent" sequences. In many cases, the steepness of the landscape was greater than originally perceived from the images.

Table 2.1 Site A geologic predictions and observations.

Predictions from photogeology	Observations from field work	Rating of Accuracy
Boulders and hill were volcanic	Boulders and hill were sedimentary	1
Small clasts in photos looked like wood	Petrified wood, jasper, sandstone	7
Channels - braided	Braided streams	10
Fine grained sediment at bottom of channel	Fining upward sequence and evaporites	8
Channel walls have some stratigraphy	Two main layers, red and gray with root cas	5
Soil differences with changes in shading	Two main soil types, red and gray	8
Mottled surface of soil - mudcracks	Mudcracks and uneven soil surface	9
Some vegitation and animal tracks	More extensive vegitation and animal tracks	7

Rating of 1 is lowest accuracy and 10 is the highest.

2.4.5 Site B Sedimentology and Structures

The reconnaissance photographs of the landing site showed that the general geologic context of the area as predominantly flat-lying terrain with little or no change in relief. Wind streaks, soil variations, and some larger channels were the dominant features at this scale, but many of the more detailed features were not identifiable. The high resolution photographs showed that the region consisted mostly of thin bedded, light colored sedimentary rocks with several dry streambeds that cut into the sedimentary layers at the southern end of the study area, possibly as much as one to two meters, creating ledges and small overhangs. It seemed possible that the dry beds were once braided streams due to their winding channels and uneven floors. The region appeared to dip SSW to SW at a low angle, and displayed evidence of aeolian erosion from a SE direction based on wind shadows present behind outcrops and other obstructions. One region to the north of the proposed landing site had several large boulders of possible granitic composition on a small plateau. It was hoped that these were transported features that would offer insight into regions well beyond the travel constraints of the mission. Numerous small, shallow tributaries crossed the relatively flat surface to "feed" into the larger streambeds. These tributary paths were faint, but branched several times, possibly indicating that whatever amount of water present at the site was drained out of the region. The large number of tributaries seemed to indicate that the transport volume of each stream was very low. These features led to the hypothesis that the region was the modern remnant of an ancient floodplain.

2.4.6 Igneous Petrology

If the boulders located to the north edge of the site location were granitic in composition, it would explain their greater resistance to weathering than the surrounding sedimentary units. The boulders also have a very rounded appearance, consistent with the spheroidal exfoliation weathering pattern of granite. Quartz and feldspars would then be assumed to be present, due to the extent of weathering of the boulders, and soil samples were planned to be collected at and near that location (Blatt & Tracy, 1996). Also, the sandstones seemed to be darker in color (possibly red) which may indicate a more arkosic composition. This would agree with the granitic composition of the boulders since they could then become the source of the feldspars necessary for the arkose sandstones.

2.4.7 Planning the Site B Traverses

Prioritization of features to examine in the field was completed after the preliminary photogeologic analyses. It was decided that the main points of interest were the large channel to the south of the photos as well as the boulder region to the north. The large channel, being the most likely source of liquid water, was chosen as a high priority to look for evidence of life, as well as give clues to the climatological history of the area. The boulder region was chosen as a priority in order to determine if they were the same composition as the flat sediments, if they were an intrusive igneous body, thus creating the possibility of hydrothermal environments for life, or if they were transported from another location. With these areas in mind, several traverses were planned according to possible landing locations and differing time constraints.

2.4.8 Actual Site B Geology in the Field

Upon the preliminary observations from the landing site the original traverses were altered. It was determined that the boulders to the north were not transported from another location, and were of sedimentary origin. The large streambed to the south would thus be the most likely source of finding a diversity of samples. Roughly clockwise traverse plans starting in the eastern region of the study area were adopted, and the researchers extensively studied the large southeastern outflow channel, the upper end of the flow system in the south west and offered cursory observations of the boulder-filled northern region.

Most of the rocks at Site B were red to tan, fine-grained sandstones. The sandstones contained cross beds of various sizes indicating more than one possible depositional environment. Larger cross beds may have represented ancient sand dunes and would indicate a desert environment, while more recent fine mica-bearing cross beds seemed to be deltaic deposits indicating an aqueous environment. The intermixing of the two cross bed features meant that the amount of water entering the area fluctuated several times during the emplacement of the sediments. Some of the sandstones contained carbonate material weathered from the rocks in the form of weathered out holes (Figure 2.7), and solution pits on the exposed surfaces. The general reddish color of all of the rocks of the region indicated an oxidizing environment typical of a deltaic system. Samples documented at the site included extensive transported chert from the southeastern outflow channel, and small pieces of coal and petrified wood from the southwestern channel system. Evidence of recent fluvial activity in the region included ripple marks (Figure 2.6), puddles of water in the bases of some streambeds (Figure 2.8), and mud cracks in other streambeds where water has seeped into the ground or evaporated. Vegetation and signs of animal life were observed at the site, and vegetation growth patterns were found to coincide with a regional vertical joint set oriented towards the NW. Again, the topography and geologic features found at the site were visible and identifiable on the “descent” images. The main difficulty discovered was determining the compositional nature of the boulders and surrounding areas. Other discrepancies mainly occurred with the sizes of features that were detectable. Smaller features, such as the stratigraphy within the large channels were not as visible in the images due to the resolution used. Another discrepancy we found dealt with estimating the topography of the area from the “descent” sequences. In many cases, the steepness of the landscape was greater than originally perceived from the images.

Table 2.2 Site B geologic predictions and observations.

Predictions from photogeology	Observations from field work	Rating of Accuracy
Thinly bedded sedimentary rocks	Thinly bedded sandstones with cross-beddir	10
Streams braided	Not very braided, only in places	6
Large boulders igneous or sedimentary	Sedimentary boulders (sandstones)	5
White spots on photos: weathering rinds	Caliche, evaporites	8
Oxidation not really apparent	Red, oxidized coating widespread	4
Small clasts, volcanic or sedimentary	Chert, coal, petrified wood	3
Sedimentary structures not identifiable	Ripple marks, puddles, mudcracks	2
Some vegetation and animal tracks	More extensive vegetation and animal track	7
Vegetation lineations mirror joints	Vegetation followed vertical jointing of rock	6

Rating of 1 is lowest accuracy and 10 is the highest.

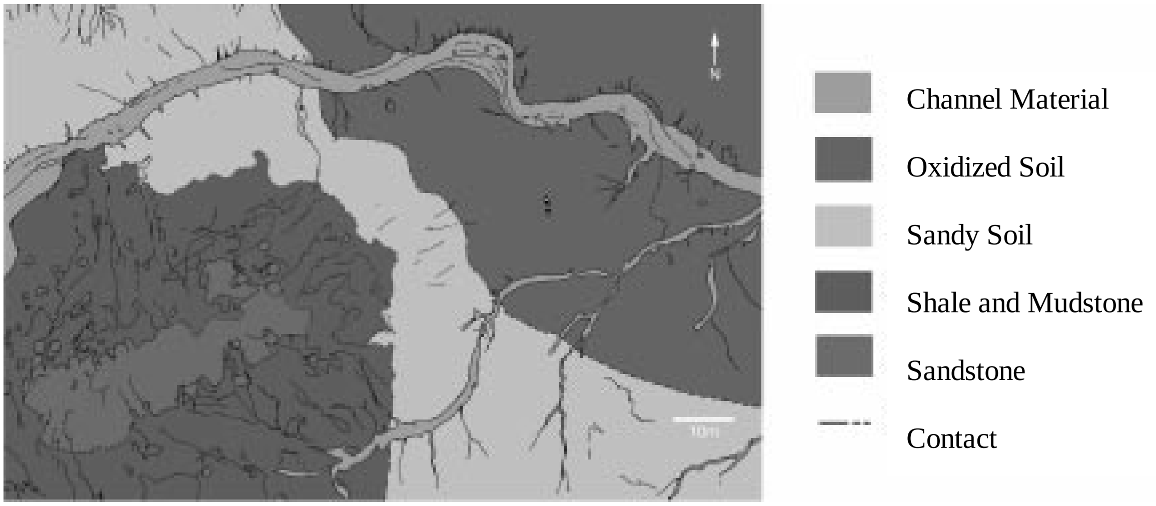

Figure 2.1 *Post-field geologic map of Site A*

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Figure 2.2 *Post-field geologic map of Site B*

Channel Material

Sedimentary Boulders

Youngest Sedimentary Layer

Fifth Sedimentary Layer

Fourth Sedimentary Layer

Third Sedimentary Layer

Second Sedimentary Layer

Oldest Sedimentary Layer

Contact
Road
Tributary Paths

Figure 2.3 *Soil stratigraphy from Site A channel showing root casts.*

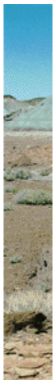

Figure *orizons.*

Figure 2.5 *Evaporite deposite from Site A channel.*

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Figure 2.6 *Ripple marks in sediment at Site B.*

Figure 2.7 *Weathered sandstone with carbonate at Site B.*

Figure 2.8 *Standing liquid water and ripple marks at Site B.*

2.5 *Discussion and Implications for Manned Missions*

2.5.1 Results of the Mars Analog Field Exercise

Given the resolution of the remote sensing and the cursory field survey parameters of the exercise, it was shown that a degree of successful ‘mission’ planning can be accomplished using the techniques mentioned above. A major success was the ability to identify large scale geologic structures such as fluvial systems or sedimentary strata in their study areas with only minor difficulties. Also, relatively precise planning of preliminary transit routes and traverse timing resulted from accurately mapped horizontal distances in each of the study areas. One discovery made during the exercise was the necessary balance between keeping to the planned timeline schedule, and impromptu revision of the planned mission to allow for conflicts and problems. A good deal of planning needed to be done before arrival in the field, not only of the traverses, but also of what experiments we wanted to conduct, and samples we wanted to take. Once in the field however, many of these plans needed to be corrected, due to the greater amount of information gathered about the area from field observations. Many areas of interest that were discovered upon landing at the site were not visible in the ‘descent’ photos due to the resolution of the images, and thus could not be planned for, causing minor alterations to the planned traverses. (It should be noted that the photographic resolution is only limited by grain size or the emoltion of the film used.) Also, some areas turned out to be of more scientific value than originally thought and thus, due to time constraints, other areas had to be cut from the schedule. These decisions could only be made upon arrival, and thus any planned mission must allow for these types of changes in its schedule. The people involved should be qualified and able to make the decisions necessary to compensate for these unforeseen discoveries.

2.5.2 Complications Experienced During Field Exercise

Numerous problems occurred during the exercise, many of which remained completely unforeseen during planning. Most notable amongst the failures was the unreliable estimation of topography based on shadows in the reconnaissance photos. In most cases distinction of shadow from equally dark features was very difficult, making accurate measurement of shadow lengths very nearly impossible. In some instances, solar geometry in the photos completely concealed topography that at other times would have been clearly visible. These two factors combined to produce gross underestimates of vertical transit possibilities at both study areas.

Field documentation proved cumbersome throughout the exercise. Maintaining the analog environment of the project, the actual field geologist on Mars would be in an environmental suit with bulky gloves and a visor; precise, delicate movements would be severely limited. Two different methods of taking field notes were utilized; the use of strictly audio-recorded notes compared to that of traditional written field notes. The use of written field documentation, such as those methods acceptable in traditional field geology prove to be far too time consuming in the restricted EVA environment. One way around this shortcoming was to include photo documented samples that would have been collected and returned to a laboratory environment. By voice annotating the samples and photos, a very clear picture of the collection environment could be maintained without the use of notes. Rock and soil samples were not allowed to be taken from the study areas as required by the landowners.

Proper spatial orientation at any given time also proved to be an onerous issue. Orientation for site documentation purposes was done using the descent photographs, and was an experience that consumed the attention of all present. The final accuracy of these impromptu map reading sessions was usually highly questionable; at a minimum, teams became slightly disoriented, but perhaps most problematic was the inference of local geology to regional geology. By not knowing exact locations, the field observations allowed only cautious conclusions concerning the macro-geology on a regional scale of tens to hundreds of kilometers.

2.5.3 Proposed Field Mission Revisions

Mission planners should make extensive accommodations for time management in field operations. From a technological standpoint this should include mission specific implements such as specialized geologic tools. During the field exercise, the geologists' simulated life support system rendered most standard geologic tools worthless. Simple items such as hammers, sample containers, hand lenses, and cameras must be carefully designed in conjunction with EVA equipment. Inclusion of some sort of absolute location system analogous to terrestrial GPS would be beneficial to efficient field operations. The researchers in the field exercise also discovered that at least minimal geochemical analysis, such as detecting carbonates with hydrochloric acid, would have been highly beneficial in sample selection.

Secondly, simulated astronaut injuries indicated that several of the team members should be trained in multiple disciplines in order to compensate for unforeseen accidents or problems experienced during the course of the mission. During the field exercise, the "astronaut geologist" was injured, thus making field operations difficult. The other team participants had to then try and assume a major portion of the role of "geologist" that could not be performed by the injured person. Having the astronauts trained in a variety of disciplines insures that under such conditions, mission activities would continue with little to no loss of time or resources.

Currently in manned space exploration, the only information available to the astronauts for mission planning is the images taken by remote spacecraft. Thus, the remote sensing should be of the highest resolution possible in order to obtain the greatest amount of information about the landing site. Due to weight, size and cost limitations in spacecraft designs, the equipment used to produce the highest resolution imagery is not always chosen. With this in mind, it is necessary to determine the lowest resolution needed to view the regional and local geologic features that pertain to the objectives of Mars exploration with enough accuracy to adequately plan a manned mission. Therefore an in-depth study was done to quantify the resolution limitations of a variety of specific geologic features important to this type of mission.

3. Image Resolution Study

3.1 *Objective*

From our experiences during the Field Analog Project, we discovered that the one piece of information most useful to us were the 'descent images' of the proposed landing sites. However, the resolution of these images (3mm/pixel), though much higher than those used in current space exploration (not including the most recent Mars Orbital Camera (MOC) images), were not as adequate as we would have liked for determining the local geology of the site. The main reason for this section of research was to determine what resolution was necessary to view geologic features of differing size scales, which are important to achieving the main goals for Mars exploration.

3.2 *Approach*

For this study, we took a set of images and degraded each of them to differing resolutions, creating a resolution sequence. The sequences were then examined to try and determine what geologic features could be detected or interpreted at each resolution within the sequence. Each geologic feature was rated, from 1 to 10, as to its visibility or recognizibility at each resolution stage. The results were then tabulated with the hopes that a minimum necessary resolution could be determined.

3.3 *Procedure*

The method implemented in this research involved taking the highest resolution images of each "decent" set from the Field Analog Study and images from other analog sites elsewhere. These images were digitized on a HP DeskJet III flatbed scanner with HP's DeskScan II software and were stored as TIFFs for processing with Adobe Photoshop 5.0.1. Due to the size of the original photographs, they were scanned in sections and then hand mosaicked together using Photoshop, and some corrections were made to even out the contrast and brightness variation that occurred during the scanning process. The composite images were cropped to remove interfering overlays or objects along the edges of the images. Raw image resolutions were computed using scale references (the 3 meter cloth and 10.1meter width of road in a few of the images), and appropriate scale bars were produced. The images were then saved as Photoshop PSD files. Image dimensions were then calculated for new image sizes that would represent scaled degradations of the raw image.

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(note: the width was auto-scaled to height in Photoshop so the other dimension was accounted for).

This was done to produce sets of degraded images with resolutions ranging from 3 centimeters/pixel to 25 meters/pixel, depending on the original starting resolution of the image used. A resizing command was executed, scaling the images to greatly reduced pixel scales using Photoshop's Bicubic interpolation algorithm, which is "for the slowest, but most precise, method resulting in the smoothest tonal gradations" (Adobe Tech Document #315461, 1999). By this operation, pixel information was averaged, removing pixels from the overall image to simulate a lower resolution. The degraded images were next rescaled, again with the Bicubic algorithm, to the exact printable dimensions of their original images, which removed most of the pixellation and ensured that all the images were at uniform scales for analysis. This operation used the reduced image to interpolate the now missing pixels back into the image. Appropriate scale bars were added to the new images and then saved as Photoshop documents. Each degradation stage image was then viewed to try and determine what geologic features could be seen and interpreted, and the features were rated on a scale of 1 to 10 for visibility/recognizibility. The results were then tabled and a necessary resolution threshold was determined. This was done using a general gradient from the lowest resolution to the highest, which was based on an increasing assurance of feature recognition.

3.6 *Results*

From examining the degraded images and tabulating our results, it was determined that a fundamental resolution of approximately 1 meter/pixel was necessary to observe the general topography. By grouping the geologic features seen into fluvial, bedrock, and volcanic categories, the necessary minimum resolution can be narrowed down for each group. It is important to note, however, that this minimum resolution depends strongly on the size of the feature observed. For fluvial features, large streams and tributaries could be identified with a resolution of 3 meters/pixel while smaller features such as small streams, braided floors and smaller tributaries were identifiable at higher resolutions of approximately 70 to 50 centimeters/pixel. The volcanic features included fissures and fractures, which could be seen at 3 to 1 meter/pixel, flows and polygonal cracks, which could be seen at 70 to 50 centimeters/pixel, and small folds and bombs, which could be seen at 30 to 10 centimeters/pixel resolution. Boulders generally ranged in resolution from 3 meters/pixel to 50 centimeters/pixel, again depending on the size of the boulders (see Figure 3.1).

3.7 *Discussion & Implications*

Water is the key to finding life on Mars, and water related landforms can be divided into three main categories that are specific to different aspects of the search for life. The first of these categories involves looking for areas that are known to have had liquid water at some point in time. Locations of this nature would be useful in determining the time frame on the development of life and possibly some of the most recent occurrences. Sites of liquid water would include valleys with incised channels, where some stratigraphy could be observed in the walls, lacustrine or lake settings, with fine-grained sediment, and flood plains were intermittent finer- and coarser-grained materials could be good for preserving fossil evidence of early life.

The second category of locales involves a type of environment that is just recently becoming better understood on Earth. Hydrothermal settings would be good places to look for life on Mars because they are local areas of specialized temperature, pressure, and chemical composition. Locations on Earth that fit this description include places like the hot springs in Yellowstone National Park or black smokers at vents at the bottom of the ocean. These locales have the unique property that their extreme compositions and temperature and pressure regimes actually serve to protect organisms from surrounding hostile conditions. In the case of the black smokers, the heat and gases provide a region around the vent that is habitable for certain types of organisms that normally could not survive at the extreme high pressures and low temperatures of the sea floor. Regions such as the hot springs in Yellowstone could easily exist on Mars around thermal vents or volcanic settings. Geothermal heat and sulfides would be perfect for anaerobic microorganisms to thrive, much like they do on Earth (Farmer 1996). The mineral concretions formed in these settings have the ability to entomb any organisms providing a potential good fossil record (Cady and Farmer 1996).

The third potential area of interest would be anywhere where there is substantial amounts of ice. Places that would include this are presently limited to the polar ice caps. However, there are a couple of other areas that are possible locations of ice. Some of the water that once was on the surface has been hypothesized to have migrated to subterranean reservoirs. Here under the surface, reaping the benefits of some lithostatic pressure from the rocks above, ice could theoretically exist. Ice of this nature could potentially provide protection for the remains of organisms that were carried there by liquid water originally and then frozen in the subsurface. Another possibility for finding evidence of life is that of glacial landforms. Places where ice moving in the form of glaciers could have carried life with it and then deposited it in the fine-grained till material left after the glacier had vanished (Kargel and Strom 1992).

Geologic features that are found in these settings would most likely be important indicators of the presence of water and/or other potentially important resources. Some places that are indicative of water can then be possible locales for preservation of extinct life. By using the results of the Image Resolution Study, limitations can be placed on the types of imaging systems needed for the detection of these geologic features. Minimal resolutions for the positive identification of most moderately sized features have been determined to be around 1 meter/pixel. This estimate is dependent on the magnitude of the features being examined and is therefore biased against moderate and smaller features.

It is likely that MOC or MOC variants will be the standard of manned-mission planning data, because the highest resolution of the instrument corresponds well to the experimentally determined resolution limitations of the important geologic features, although, better resolution is still needed to adequately view features on the surface. Transporting significantly more robust imaging systems to Mars that are larger and thus capable of higher, multispectral resolutions, however, is not a realistic option given the cost and payload constraints of Discovery-class missions and the marginal benefits such an instrument would provide. Constraints on landing site selection can be better accomplished because the mapping resolution of MOC is higher than that necessary to identify geologic features. This increased resolution makes observation of higher order features possible, which allows for better prioritization of possible landing sites and traverses.

4. Planning a Mars Mission

4.1 *Introduction*

The goals for Mars exploration, as stated earlier, include the search for water, the search for extant and extinct life, and the exploration of resources for use in future missions. In achieving these goals, it is believed that manned missions would be more useful and more successful than robotic missions for several reasons. One benefit of sending humans over robots is the problem solving ability and reasoning skills versus the programmability and autonomy. Robotic missions, although more expendable, are less efficient when dealing with time constraints due to communication lag times between Earth and Mars. The ability of rapid communication is extremely useful in coping with potential uncertainties or problems and split-second and on site decision making could reduce damages to both the people and equipment involved.

4.2 *Approach*

This section of research was conducted to simulate the planning and initial exploration phase of a Mars Manned Mission using actual Mars data and images taken by the Mars Global Surveyor (MGS) and the Mars Orbital Camera (MOC). In this exercise, we attempted to perform all the steps involved in planning, preparing for and executing a human mission, including examining images for possible landing locations, determining local geology from MOC images of landing area, prioritizing possible sample collecting sites and geologic features, planning traverses, and creating plausible timelines for planned activities.

4.3 *Procedure*

The first step of this exercise was to look through the images of the surface of Mars taken by the Mars Orbital Camera (MOC) which were located on the JPL Photojournal website. These images were taken at 1.5 meters/pixel. We chose our site, a small crater within the larger Alexey Tolstoy crater, keeping in mind the goals for Mars exploration. We wanted an area that a spacecraft would be capable of landing at, that showed some evidence of liquid water in the area, and that had local geology that could potentially harbor life. Once the site was chosen, MOC photos of the site, as well as regional photos taken by *Viking 1* were examined for local and regional geology of the area, and preliminary climatological and geological histories were constructed. For Alexey Tolstoy crater, there are breaks in the crater wall which resemble places where channels might have eroded through the wall, allowing water to flow into the crater itself. This main crater is large, about 94 kilometers, which implies that it should be very deep. The observed floor of the crater is not much deeper than the rim, suggesting significant amounts of fill material. With evidence of possible channels and significant deposition of material in the crater, Alexey Tolstoy could be a good place for the preservation of fossil life forms. Looking at the smaller crater contained with in the walls of Alexey Tolstoy, this gives a natural window into the stratigraphy of the crater fill material.

Once the local geology was determined, the next step was to prioritize the geologic features seen in terms of meeting the goals and objectives of the mission. Features that would possibly give information about the sedimentary and aeolian materials within the crater floor were chosen for sample collection and other measurements to be conducted. Traverses were then planned to the various features discovered and locations for measurement and sample collections were determined. A schedule for each traverse stop and a timeline for the mission were constructed, with ample time allowed for revisions of plans, new discoveries and possible problems or complications.

4.4 *Results and Discussion*

4.4.1 Regional Geology

Alexey Tolstoy crater is located at approximately 47°S latitude, 235°W longitude, is 94 kilometers in diameter, and is situated in Promethei Terra on the boundary between the southern highlands and the northern lowlands. Looking at the crater area in the *Viking 1* orbiter image, the region consists mostly of cratered terrains believed to be volcanic in origin. There is a gradation from young to old craters, but the classification is based more on morphology than superposition/chronology. The oldest craters are very irregular in shape, subdued, have very eroded and degraded rims, and lack visible ejecta blankets, while the younger craters are more circular in shape, have good rims and small ejecta blankets. Many of the larger craters have slump material from the crater walls into the interior floor, possibly covering up any evidence of a central peak structure. In several places along the rim of Alexey Tolstoy, there appears to be areas where the rim has been down cut by some process, possibly by water. These small channels could have supplied water and sediment into the crater, filling it in and evening out the topography on the crater floor. A majority of these craters have accumulated aeolian material on their floors, creating a flatter appearance. There are several large scarps and wrinkle ridges trending northeast and a few edges of large ejecta blankets can be traced out along the landscape. In the west and southwest there are numerous knobs that rise approximately 5-10 kilometers above the local topography, and possess debris aprons around their bases. These knobs may be either remnants of basement material, emplaced by fracturing or faulting, which is currently being eroded and covered by aeolian material.

4.4.2 Local Geology

The image taken by the MOC, is a close up of the interior of Alexey Tolstoy crater. The area seems to have two material units: a darker, rougher, more knobby material located in the upper region of the image, and a lighter, smoother material located in the lower region. It appears that the lighter material has been eroded back, exposing both the darker underlying material and a small crater, approximately 850 meters in diameter, within the floor of

Alexey Tolstoy. A majority of the ejecta blanket from this small, unnamed crater is visible, except the lower right portion, and the center of the crater is completely filled in with the lighter material. The rim is partially exposed, and it seems to be slightly eroded, having some breaks across it, possibly indicating cut channels into the floor of the small crater. There are a few smaller, possibly secondary impact craters in the area, but they are not as visible due to the smooth nature of the lighter material. There is a smaller section in the lower left corner of the image that is light in color but slightly rougher in texture than the rest of the light colored material.

4.4.3 Mapping Units

In the *Viking 1* Orbiter image, the slightly rough material from which the majority of the knobs penetrate was mapped as Old Knobby Terrain, whereas areas that were smoother and were devoid of knobs were mapped as Smooth Old Terrain. These two areas contain many scarps and extremely eroded craters. The younger craters were mapped according to relative age based on superposition of units. Crater floor material, slump material and ejecta blankets were assigned to each crater when possible (see Figure 4.1). For the MOC image, the three main materials were mapped into separate units based on surface roughness and albedo (dark rough unit, light rough unit, and light smooth unit). The main crater materials were also mapped into rim material, floor material and ejecta material, which were separated based on observed topography and surface roughness. (see Figure 4.2)

4.4.4 Feature prioritization, traverse locations and timeline

When examining the small crater of the MOC image, we determined that two traverses were necessary to cover the areas of interest found. First, we want to take samples of the material filling in the small crater as well as the excavated material from below. This material is thought to be comprised of sedimentary and aeolian deposits emplaced by the small channels that cut the rim of Alexey Tolstoy and flood the floor of the large crater. To sample some of the excavated material, we chose a sample collection site along the ejecta blanket for the crater (see figure 4.3 for traverse map). A stop along the rim of the crater was also planned to sample and to examine any possible stratigraphy of the underlying layers. We also want to take samples of the dark, rougher material exposed to the north, the light, rougher material in the lower left corner of the image, and the light, smooth material burying the crater. In examining these samples we will try to determine their compositions and see if the albedo differences seen are due to compositional or textural differences, or some combination of both. We also hope to find some evidence of extant or extinct life preserved within the sedimentary deposits. By estimating the amount of time necessary to travel to each site, to collect each sample and take other measurements, a rough timeline was devised for the two traverses and this portion of the mission. From these samples, we hope to be able to construct a more detailed geologic and climatic history of Alexey Tolstoy Crater and the surrounding area.

Timeline for Small Crater Traverse

Day 1 Central Traverse to Crater

00:00	Egress
00:00-00:30	**Landing Site**: Photography Contingency *Collections*
00:30-01:30	Assembly of Automated Meteorological Systems Assembly of Geophysical Systems
01:30-02:00	Transit to Site 4
02:00-02:45	**Site 4**: Photography Sample Collection of Ejecta Material
02:45-03:15	Transit to Site 5
03:15-04:00	**Site 5**: Photography Sample Collection of Rim Material Floor Material
04:00-04:45	Transit to Base Camp
04:45	Ingress

5. Conclusions

Currently, Mars exploration has four main goals that focus primarily on the presence of water, the geologic features associated with it, and their relationships to the possibilities of life. It is believed that manned missions would be more useful and more successful than robotic missions for several reasons that were discussed in this paper. To explore the feasibility of a manned mission, a Field Analog Project was conducted. The project began by examining a series of aerial photographs representing "descent" space craft images from which the local and regional geology of the two "landing" sites was determined and several "targets of interest" were chosen. The targets were prioritized based on their relevance to achieving the goals of the project and Mars exploration in general. Traverses to each target, as well as measurements and sample collections were planned, and a timeline for the exercise was created. From this it was found that for any mission to be successful, a balance must be discovered between adherence to the planned timeline schedule, and impromptu revision of the mission to allow for conflicts, problems and other adjustments necessary due to greater information gathered upon arrival at the landing site. At the conclusion of the field exercise, it was determined that a valuable resource for mission planning is high resolution remote sensing of the landing area.

This led us to conduct a study to determine what ranges of resolution are necessary to observe geology features important to achieving the goals of Mars exploration. The procedure implemented involved degrading a set of images to differing resolutions, which were then examined to determine what features could be seen and interpreted at each degradation stage. The features were rated for recognizability, the results were tabulated, and a minimum necessary resolution was determined**.** Our study found that for the streams, boulders, bedrock, and volcanic features that we observed, a resolution of at least 1 meter/pixel is necessary. We note however that this resolution depends on the size of the feature being observed, and thus for Mars the necessary resolution may be lower due to the larger size of some features.

With this new information, we then examined the highest resolution images taken to date by the Mars Orbital Camera (at 1.5 meters/pixel) on board the Mars Global Surveyor, and planned a manned mission. We chose our site, keeping in mind the goals for Mars exploration, then determined the local and regional geology of the "landing" area. Prioritization was then done on the geologic features seen and traverses were planned to various "targets of interest". A schedule for each traverse stop, including what measurements and samples were to be taken, and a timeline for the mission was then created with ample time allowed for revisions of plans, new discoveries, and possible complications. One point to note with this exercise is that with the increased resolution given by the MOC, you are seeing the features in greater detail, however, the size of the area you are viewing is much smaller than with lower resolution images, such as the *Viking 1* orbiter.

This exercise has given us an opportunity to experience what is necessary to plan and execute a manned mission. It also exposed us to the problems and complications that are associated with these types of operations, as well as the mechanical, technological, and design constraints for accomplishing the scientific goals of a mission of this type. Improvements in these areas, however, are allowing more scientific work to be done in greater quantities and at finer detail than previously accomplished. Perhaps these advancements will give a better understanding of the Martian geologic history that might, in turn, further the understanding of the beginnings of life on Earth.

6.0 *Acknowledgements*

We would like to thank several people for their help and input during this study. First, thank you to the members of last semester's Fundamentals of Planetary Geology class for allowing us to use some of their data for the Field Analog Project (Laural Cherednik, Violet Taylor, Charles Leidig, Bob Mickelson, Frank Chuang, Thomas McGrath, and Aaron Kader). Secondly, we would like to thank Ramón Arrowsmith for his input on the degraded images and insight on the resolution study, Jack Farmer for his knowledge on what specific geologic features to look for when exploring for life, and Phil Christensen for his help on how best to conduct and interpret the resolution data. We would also like to thank Patricio Figueredo for his help on the poster version of this paper. Lastly, we would like to thank our advisor Ronald Greeley for all his help and input, and Stephanie Holaday for scheduling and in general putting up with us.

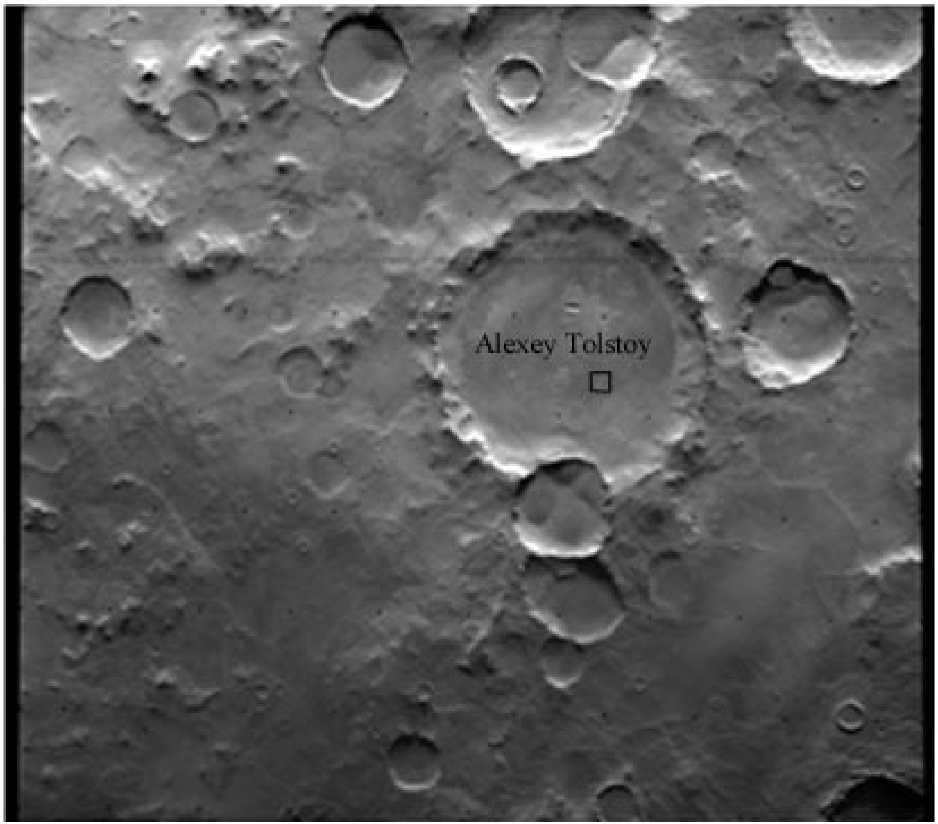
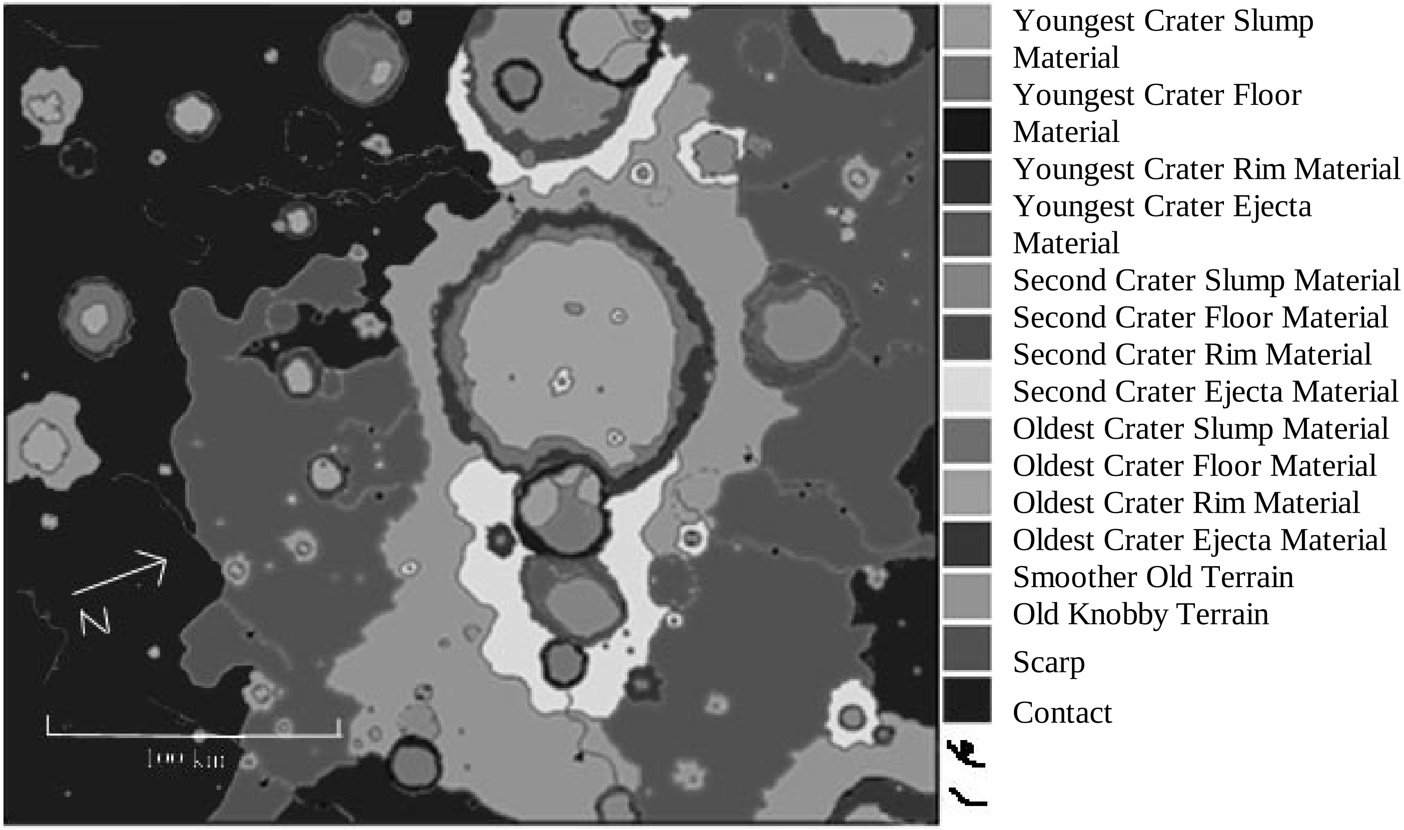


Figure 4.1 The upper image is of Alexey Tolstoy Crater and surrounding area taken by the *Viking 1* Orbiter. The lower image is a geologic mape created from the *Viking 1* image. The units were determined by



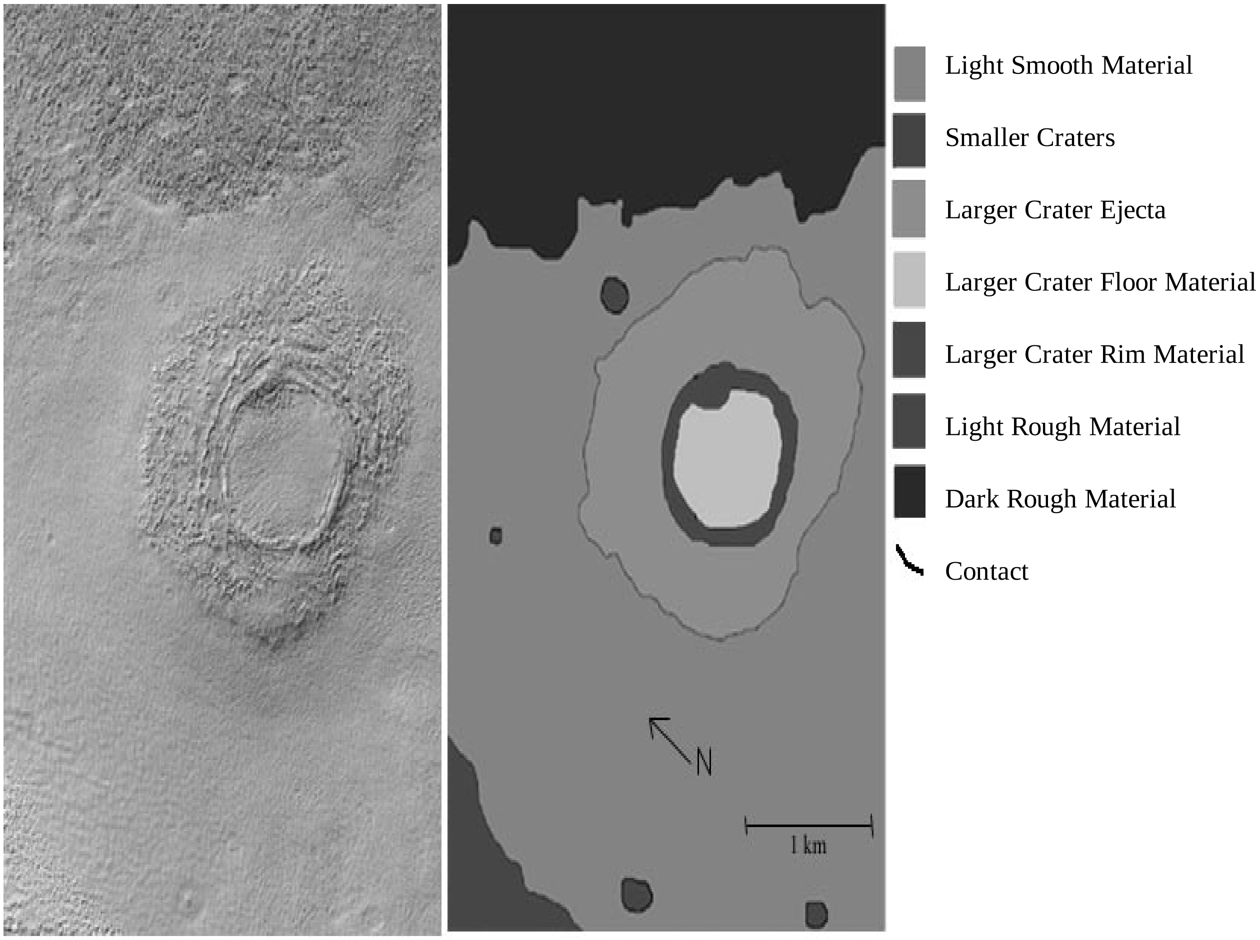


Figure 4.2 The image on the left is of the proposed landing area within Alexey Tolstoy crater taken by MOC. The image on the right is a geologic map created from the MOC image. The units were determined by superposition of materials as well as textural and albedo differences.

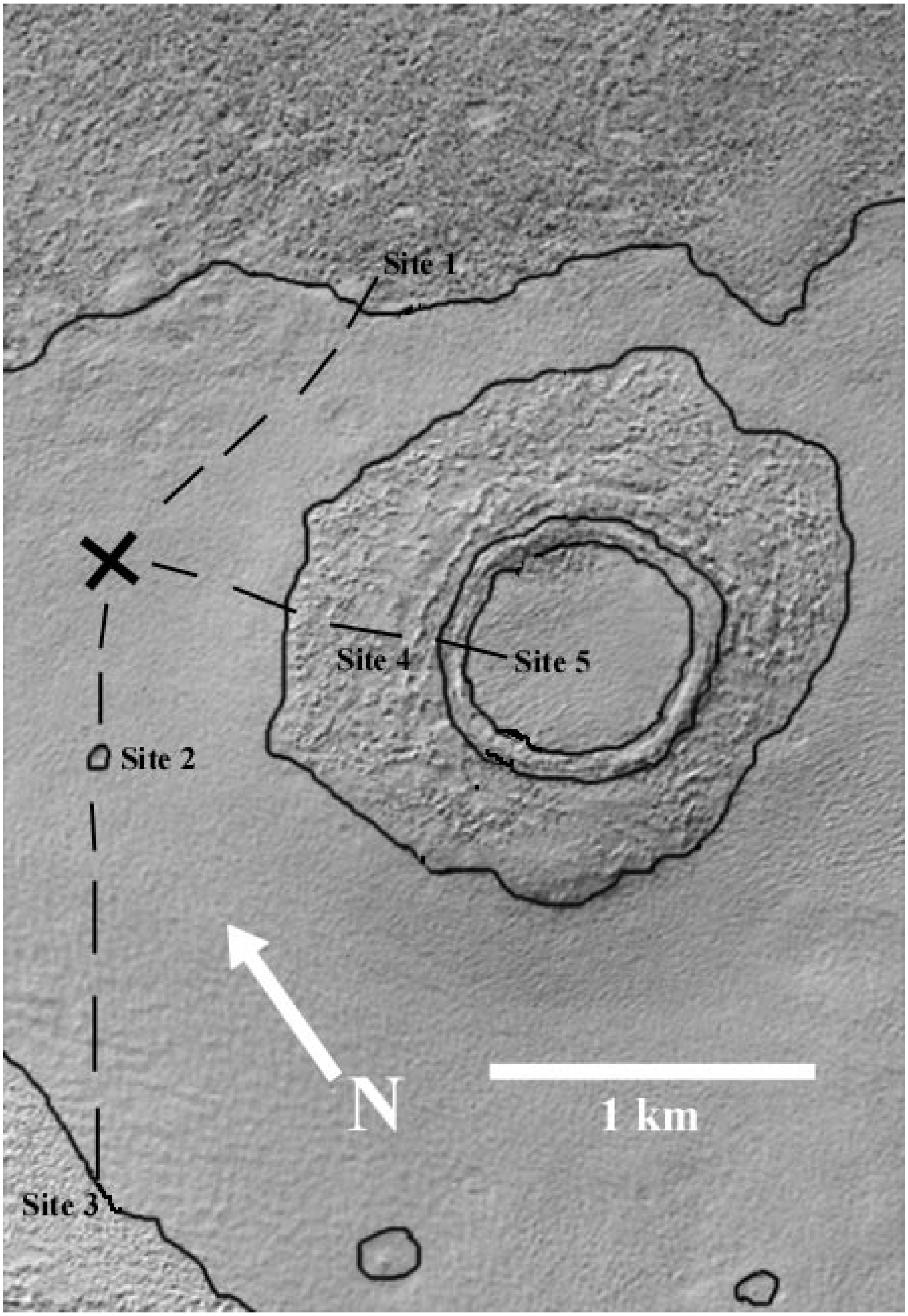


Figure 4.3 Planned traverses of the proposed landing site within Alexey Tolstoy Crater. The sites labeled are locations where samples of the materials and measurements will be taken to examine the local sedimentary and aeolian units of the area.

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