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SITE SELECTION FOR MARS EXOBIOLOGY

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ABSTRACT

The selection of sites on Mars that have a high priority for exobiological research is fundamental for planning future exploration. The most immediate need is to identify targets for high resolution orbital imaging during the Mars Observer and Mars '94/'96 missions that can be used to refine site priorities for surface exploration. We present an objective approach to site selection whereby individual sites are selected and scored, based on the presence of key geological features which indicate high priority environments. Prime sites are those that show evidence for the prolonged activity of liquid water and which have sedimentary deposits that are likely to have accumulated in environments favorable for life. High priority areas include fluvio-lacustrine (stream-fed lake systems), springs, and periglacial environments. Sites where mineralization may have occurred in the presence of organisms (e.g. springs) are given high priority in the search for a fossil record on Mars.

A systematic review of Viking data for 83 sites in the Mars Landing Site Catalog /1/ resulted in the selection of 13 as being of exobiological interest. The descriptions of these sites were expanded to address exobiological concerns. An additional five sites were identified for inclusion in the second edition of the MLSC. We plan to broaden our site selection activities to include a systematic global reconnaissance of Mars using Viking data, and will continue to refine site priorities for exobiological research based on data from future missions in order to define strategies for surface exploration.

INTRODUCTION

Major exobiological goals in Mars exploration include: 1) defining the nature of early martian environments, especially those regarded as favorable for the origin and subsequent development of life, 2) understanding the geochemistry of the biogenic elements (C, N, O, S, P) and organic compounds and 3) determining whether a biosphere presently exists on Mars or has existed in the past. In approaching these objectives, future missions must systematically explore the planet for organic compounds, water and/or biologically-important minerals, a fossil record and evidence of extant life.

At this stage of exploration, site selection for Exobiology relies primarily on the identification of water-associated landforms and sedimentary deposits using remote sensing data. Modem and ancient environments on Mars that are presently of most interest to exobiologists include: fluvio-lacustrine (stream-fed lake) systems, springs, and penglacial (permafrost) terranes. Each of these environments differs in its potential for meeting the basic science objectives of Exobiology (e.g. the search for biologically-important minerals, organic molecules, fossils, and extant life). We regard geological environments in which mineralization is likely to have occurred in the presence of organisms (e.g. subaerial springs, playa lakes) as having high priority in the exploration for organic molecules and a fossil record. We place a greater emphasis on periglacial environments (e.g. permanent ground ice) and subsurface hydrothermal systems in the search for extant (or recently extant) life.

In this report we outline an objective approach to site selection for Mars Exobiology and present preliminary results of our evaluation of sites listed in the Mars Landing Site Catalog (MLSC) /1/. In addition, we further elucidate our site selection methodology by reviewing, in some detail, one high priority stream-fed lake (fluvio-lacustrine) site located at Margaritifer Sinus, which serves to illustrate a range of exobiological objectives.

METHODOLOGY

In selecting sites from the MLSC for future exobiological investigations, we followed a stepwise procedure, beginning with broadly-based regional reconnaissance. At this stage we relied on Viking Mars Charts (scale 1:2 million) and Mars Transverse Mercator photomosaics (scale 1:500,000) to identify terranes that show evidence for the past activity of water. Sites having water-related features were evaluated further using Viking Orbiter images, referenced in the MLSC /1/. These sites were subsequently described in detail using Mosaicked Digital Image Models (resolution 231 m/pixel) and the highest resolution Viking Orbiter images (~30-250 m/pixel) identified in the Image Retrieval and Processing System.

Based on our study of high resolution images, sites were individually scored based on the presence/absence of key geological criteria (erosional features and/or sedimentary deposits). The geological features at each site were assigned a subjectively weighted score based on: 1) a "Visibility" factor, ranging from 0 to 3 (0=not visible, 3=highly visible), which indicated the relative clarity of geological features at the highest resolution avaialable for each site, 2) a "Value to Exobiology" factor ranging from 1 to 3 (1=low significance; 3=high significance), which estimated the importance of a particular feature for meeting the basic exobiological objectives (defined above) and 3) a "Process Uniqueness" score ranging from 1 to 3 (1=not unique; 3=unique), which evaluated the specificity of the feature-process relationship, important for assessing potential errors in interpretation resulting from inadequate image scale and resolution, and needed to address the problem of superficially similar features that originate by different geological processes. For a detailed discussion of the scoring procedure. see Fanner et al. /2/.

Within each facies type, the initial prioritization of sites was based on a comparison of total scores. Next, site priorities were refined by evaluating the significance of more broadly-based subjective criteria not considered in the initial scoring. For example, the relative duration of hydrologic systems is regarded as important for evaluating the potential for sites to accumulate and preserve a record of past life. Duration was assessed by comparing geomorphic features and relative age relationships of sites within the same facies category. Other things being equal, sites having features indicative of more sustained hydrological activity were given a higher priority than sites exhibiting features believed to have been formed by rapid, catastrophic releases of water.

RESULTS

Of the 83 sites evaluated from the first edition of the **MLSC** /1/, 13 were identified as having exobiological priority (Table 1). In addition, five sites selected from the published literature /3, 4, 5, 6, 7/ were also evaluated by the same methods. The latter sites (137-141, Table 1) have been described in detail and will be added to the second edition of the MLSC /2/.

TABLE 1. **Preliminary List** of Mars **Exobiology Sites by Facies**

SITE TYPE & #(MLSC)	REGION (SITE NAME)	TARGET LOCATION &AT.-LONG.)	PRIORITY (WITHIN FACIES)
FLUVIO-LACUSTRINE			
1	Eridania NW	37.0^{0}S, 230.0^{0}W	High
2	Margaritifer Sinus SE	22.0^{0}S, 11.0^{0}W	High
8	Mare Tyrrhenum SE	22.8^{0}S, 230.6^{0}W	High
10	Mare Tyrrhenum SW	24.8^{0}S, 265.8^{0}W	High
79	Aeolis SE	15.5^{0}S, 188.5^{0}W	High
137	Mangala Valles	6.3^{0}S, 149.5^{0}W	High
138	Aeolis NE (Gusev)	15.5^{0}S, 184.5^{0}W	High
140	Iapygia NW	7.3^{0}S, 305.0^{0}W	High
5	Iapygia NE	11.0^{0}S, 279.5^{0}W	Moderate
7	Eridania NE	43.2^{0}S, 208.1^{0}W	Moderate
22	Candor Mensa	6.1^{0}S, 73.8^{0}W	Moderate
4	Eridania SE	57.0^{0}S, 197.0^{0}W	LOW
21	Chryse Planitia	18.9^{0}N, 53.5^{0}W	LOW
26	Maja Valles	18.1^{0}N, 55.7^{0}W	LOW
77	Ares Vallis	2.0^{0}N, 16.0^{0}W	Low
141	Hebes Chasma	1.5^{0}S, 76.5^{0}W	LOW
V-1*	Chryse Planitia	22.5%. 47.9^{0}W	LOW
V-2*	Utopia Planitia	47.9^{0}N, 225.7^{0}W	LOW
SPRING			
32	Dao Vallis	33.2^{0}S, 266.4^{0}W	High
77	*Ares* Vallis	2.5^{0}N, 19.0^{0}W	Moderate
PERIGLACIAL			
139	Oxia Palus	22.1^{0}N, 37.6^{0}W	LOW

*Viking Lander Site

Within each facies category (fluvio-lacustrine, spring and periglacial), sites were assigned a priority ranging from high to low. For comparison, the two Viking lander sites were also evaluated. These sites (V-1 and V-2, Table 1) were assigned a low priority relative to other fluvio-lacutrine sites because of the probable catastrophic origin of the outflow channels in that region, along with evidence for extensive aeolian reworking. Three of the sixteen "strawman" sites selected for the MESUR mission /8/, were covered by our MLSC survey (Sites 32.138, and V-1, Table 1) and the results were used by the Science Definition Team to refine proposed landing targets for the MESUR mission.

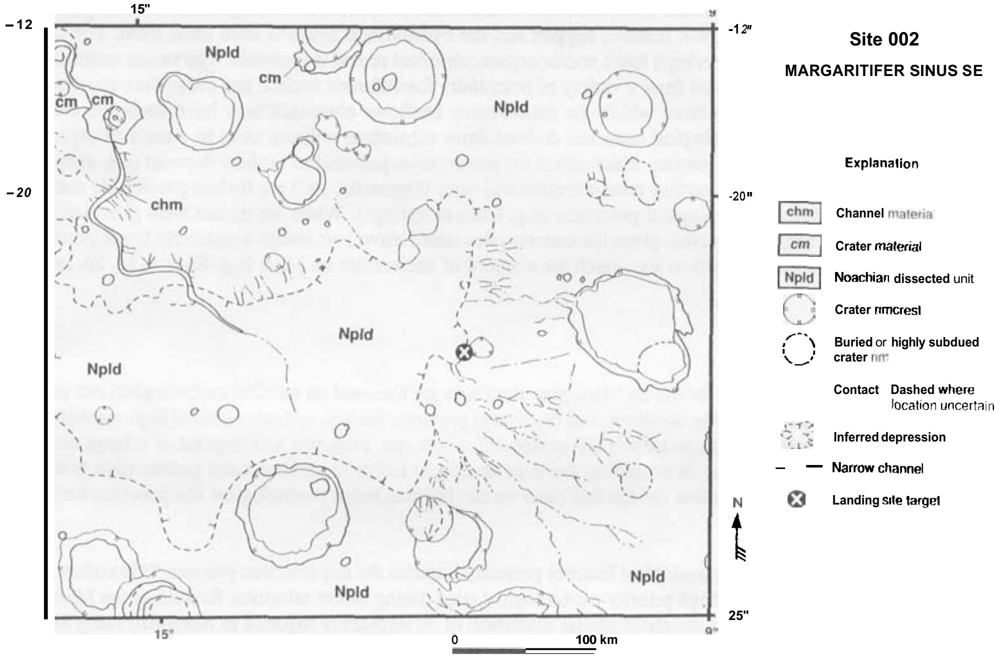
The following example (Margaritifer Sinus, **MLSC**, Site 2, Table 1) serves to illustrate the features of a high priority. fluvio-lacustrine (stream-fed lake) system. This site type presently dominates the list given in Table 1. The small number of spring and periglacial sites is to some extent an artifact of the scientific emphasis of the first edition of the MLSC but is also a consequence of poor Viking image quality €or some sites. The fluvio-lacustrine example chosen serves to illustrate the general approach to site selection and clarifies some important exobiological science objectives within such environments. For an interim review of other exobiological site types the reader is referred to Fanner et al. /2/.

Margaritifer Sinus SE (Viking Orbiter Images 615A45, 47, 66; Mars Chart 19SE Latitude: 22°S, Longitude: 11°W) exhibits geological criteria potentially favorable for the preservation of organic molecules and a fossil record. The site is located within ancient cratered terrane /9/ that has been heavily dissected by numerous dendritic valley networks (Figure 1). Channel networks surround a central basin suggested to have been a depocenter for fluvio-lacustrine sedimentation /4, 10/. Most of the valleys terminate along the southeast margin of the basin. The basin apparently drained through a single channel of simple morphology that originates near the middle of the depression and extends for a few hundred kilometers to the northwest. Basin-filling sediments appear be at or near the surface at this location, although in places the basin floor exhibits an unusal hummocky surface that may include an aeolian mantle.

Formation of the valley networks surrounding the basin was apparently preceded by an early period of mostly larger impacts, evidenced by the dissection of the rims of many of the older craters by headward erosion of the valleys. The period of hydrologic activity that produced the valleys was followed more recently by a period of smaller impacts, some of which were superimposed on the older craters and valleys. The intervening period of hydrologic activity that created the valleys may have been of relatively long duration, as indicated by the presence of two or more levels of tributaries in several of the longer channel systems, and varying degrees of erosional degradation exhibited by the older craters.

The primary target is near the basin margin, where several major valleys terminate, and may include coarser-grained. water-lain sediments deposited where the streams entered the basin. At this location, deposits are probably of mixed parentage, including both materials excavated from local subsurface sources by impact, as well as those derived primarily from older upland sources.

Fig. 1. Geological map of the Margaritifer Sinus region of Mars /9/.



Under appropriate geohydrological conditions on Earth, coarser-grained, nearshore lacustrine facies are 'often a locus for carbonate mineralization. This process is of special interest to exobiologists because mineralization typically enhances the preservation of microbial fossils and organic matter. For example, in many alkaline lakes in the Great Basin (western United States), microorganisms living on the surfaces of submerged tufa mounds associated with sublacustrine springs, or interstitially within coarser sediments associated with lake margin facies (e.g. fan delta deposits), are commonly entombed by precipitating carbonate minerals /11/. Evidence of microbial activity is preserved within ancient tufas and carbonate cements as cellular microfossils and stromatolites. as well as disseminated organic matter. Such deposits are regarded as excellent targets in the search for a fossil record on Mars /12/.

Assuming a lake once existed at the Margaritifer site, the proposed target may provide access to potentially fossiliferous deltaic and/or shoreline deposits such as those described above. Although crater ejecta may offer the best opportunity to sample subsurface units at this basin margin site, it is also possible that any organic matter present may have been destroyed by shock metamorphism.

The Viking life detection experiments suggest that shallow surface sediments on Mars have been extensively oxidized /13, 14/. Therefore, coring may be necessary to penetrate below a zone of surface weathering and oxidation, in order to sample for organic materials.

In developing an exploration strategy, priority should be given to sedimentary deposits that have the highest potential for preserving a closed chemical system after burial. Sediments of low permeability that have neither been buried deeply, nor subjected to high geothermal gradients, are favored for the retention of organic compounds. On Earth, the sediments deposited in the deeper areas of lacustrine basins are typically fine-grained, organic-rich mudstones and shales, sometimes interbedded with evaporites. Such lithologies are generally more favorable for preserving organic compounds than the more porous and permeable lithologies associated with marginal basin facies.

At Margaritifer Sinus, the basin floor is dissected by a northwest-trending channel that apparently postdates the major period of basin filling (Figure 1). The walls and floor of the upper reaches of this channel may provide access to fine-grained, deeper basin facies, such as shales or evaporites. However, it may be necessary to excavate into the subsurface to get beyond a zone of surface oxidation and weathering.

Duration of Fluvio-Lacustrine Systems on Mars

Evaluating the relative duration of hydrological activity is an important aspect of site prioritization for Exobiology. For fluvio-lacustrine terrains, associations of geomorphic features can be evaluated for relative duration by applying classical theories for landscape evolution on Earth /2/. Given our limited understanding of hydrological processes on Mars and the limitations of terrestrial analogs, we have tried to exercise caution in addressing the problem of duration in establishing site priorities. We do feel justified, however, in distinguishing two broad categories of fluvio-lacustrine sites: those dominated by landforms produced by catastrophic outflows versus those created by long-term hydrological activity.

Catastrophic floods, such as those that created the channeled scablands of eastern Washington, U.S.A., significantly modify older features of the landscape and can completely obliterate the preexisting geomorphic record of primary depositional processes. Catastrophic flooding has been invoked to explain many of the large outflow channels on Mars /15, 16/, although the source and release mechanism of subsurface water are more controversial /17, 18, 19/. Although such terranes provide evidence for the past activity of water, geomorphic features suggest that the hydrological systems were short-lived. The favorability of catastrophic outflow deposits for preserving a fossil and/or organic chemical record is uncertain. The parent materials comprising outflow deposits may have been derived from a variety of potentially fossiliferous surface and subsurface sources. In addition, the subsurface hydrological systems from which the catastrophic outflows emanated may have harbored chemosynthetic ecosystems /20/. It is possible that biological materials derived from subsurface sources exist in a state of cryopreservation. However, important lithofacies characteristics which affect the preservation potential of outflow deposits (e.g. average grain size and sedimentation rate, patterns of secondary mineralization and early diagenesis, etc.) are far less predictable than for deposits formed through more sustained hydrological processes (e.g. lakes or springs). While we do not wish to entirely dismiss the exobiological potential of outflow deposits, given the uncertainties stated above, we assign a relatively lower priority to chaotic terrains and associated outflow deposits in the search for a record of ancient life on Mars (e.g. Sites 4, 21, 26, and the Viking Lander sites, Table 2).

DISCUSSION

In developing an exploration strategy for life on Mars, present efforts are focussed on refining exobiological site priorities using Viking data. This is a subjective process, however, and one that is presently limited by both a lack of high resolution images for many areas and an inadequate knowledge of surface composition and age. Progress will depend to a large extent upon the success of upcoming orbital missions in providing the data needed to interpret smaller scale geomorphic features, surface composition and the distribution of ground ice. On that basis we can begin to refine exobiological site priorities for future surface missions.

The inability to identify many smaller geological features presently impedes the site selection process. This underscores the need to obtain high resolution images for high priority exobiological sites during future missions. Results of the Mars Analog Site Study /21/ suggested that a minimum threshold spatial resolution of 30 m/pixel is required to recognize many key geological features in arid environments using visible range imaging. A similar threshold is indicated for the unambiguous identification of similar features on Mars, although even better spatial resolution may be required for the recognition of selected high priority features, such as spring deposits.

In planning exobiological science objectives for future surface missions, emphasis is presently focussed on the targeting of high priority sites for high resolution visible imaging and infrared spectral data (see Table 1). Of fundamental importance for developing a strategy to explore for fossiliferous deposits on Mars is the identification of areas of surface or near surface mineralization within geological settings believed to have been favorable for past life. Ultimately. we may be able to obtain *in situ* compositional data by using rover-based technologies such as X-ray diffraction/fluorescence /22/, differential thermal analysis /23, 24/, gas chromatography /25/, or infrared spectroscopy /26/. Such data should prove to be invaluable in refining exploration strategies for exobiological research and for planning sample return missions.

Much remains to be accomplished. Future objectives include refining the criteria for site selection, while broadening the focus to a systematic global reconnaissance of Mars. It is vital for the success of the Mars Exobiology program that we continue to re-evaluate site priorities as each new phase of exploration is completed, and to use this information to plan future missions. The targeting of sites for high resolution visible and infrared orbital imaging by Mars Observer and the Mars '94/'96 missions constitutes an important first step in an ongoing process ultimately aimed at the refinement of site priorities for robotic surface exploration and eventually, sample return and the human exploration of Mars.

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