REPORT IN BRIEF

Space Studies Board

September 2015

DIVISION ON ENGINEERING AND PHYSICAL SCIENCES

Review of the MEPAG Report on Mars Special Regions

Planetary protection refers to the practice of both protecting solar system bodies such as planets, moons, and asteroids from contamination by terrestrial life and protecting Earth from possibly harmful life forms that may be returned from other solar system bodies. Planetary protection policies are not static but evolve over time based on the increasing knowledge and understanding of both planetary environments and the physical and chemical limits of terrestrial life. The Committee on Space Research (COSPAR) of the International Council for Science formulates and maintains international consensus planetary protection policies using technical recommendations from its member scientific organizations, including the National Academies of Sciences, Engineering, and Medicine in the United States.

One aspect of these international planetary protection policies is that specific constraints are placed on the development and operation of spacecraft with the potential to enter so-called Special Regions on Mars where conditions conducive to microbial growth might exist. At NASA's request, the community-based Mars Exploration Program Analysis Group (MEPAG) established the Special Regions Science Analysis Group (SR-SAG2) in October 2013 to re-examine the quantitative definition of a Special Region and propose modifications based upon the latest scientific results. Immediately before the formal publication of SR-SAG2's report in the November 2014 issue of the journal *Astrobiology*, NASA's Science Mission Directorate asked the Academies' Space Studies Board (SSB) to review the SR-SAG2 report. At about the same time, the European Space Agency (ESA) issued a parallel request to the European Science Foundation (ESF). To avoid duplication of effort, the SSB and ESF established a joint committee to review the SR-SAG2 report's conclusions and develop recommendations for how the planetary protection requirements for Mars Special Regions should be updated. The resulting report, which will provide input to COSPAR as it revises and updates its planetary protection policies, agrees with many of SR-SAG2's findings including retaining the currently specified environmental parameter limits for life. However, there are some cases where more detailed consideration is warranted. The report provides a list of suggestions for future research and puts forward an expanded definition of Special Regions. This new definition treats geological features that have a probable but unquantified association with liquid water, including potential sources of methane, as Uncertain Regions, to be treated as Special Regions until proven otherwise.

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IDENTIFYING MARS SPECIAL REGIONS

Mars Special Regions refer to places where conditions might be warm and wet enough to support microbes carried by a spacecraft from Earth or where there is a high potential for the existence of extant martian life. Current COSPAR planetary protection policy sets the parameters for Special Regions to include areas that maintain temperatures greater than -25°C and a water activity (the fraction of usable water content in a system) between 0.5 and 1.0 over a 500 year timescale. The review committee agrees that these environmental parameters are still appropriate; however, the identification of these regions remains problematic. First, there is a lack of detailed knowledge of the physical and chemical conditions of the surface and subsurface of Mars at various scales, particularly the microscale. Second, current understanding of the ability of life to propagate is limited. It is not known if one, ten, or a million cells from a single species are required for propagation in an extraterrestrial environment. Alternatively, propagation may only be possible for microbial communities that are collections of many different species. As current and future space missions send back new information about the martian environment and new techniques in biology are developed to address these questions, the current practice of reassessing the concept of a Special Region every 2 years is both appropriate and essential.

POTENTIAL FOR TERRESTRIAL LIFEFORMS TO SURVIVE ON MARS

While SR-SAG2's assessment of the potential for terrestrial life to survive and proliferate on Mars is comprehensive, there are several remaining issues that merit further study in order to better identify Special Regions.

Limits of Terrestrial Life

To date, there have been no experimental attempts to determine whether the number and type of cells that remain on a spacecraft after sterilization and launch are sufficient to establish a population of microorganisms within a Mars Special Region. There is a need for scientific investigations that deepen our knowledge about the limits of life with a focus on survivability, adaptation, and evolution under martian conditions.

Small-Scale Microbial Habitats

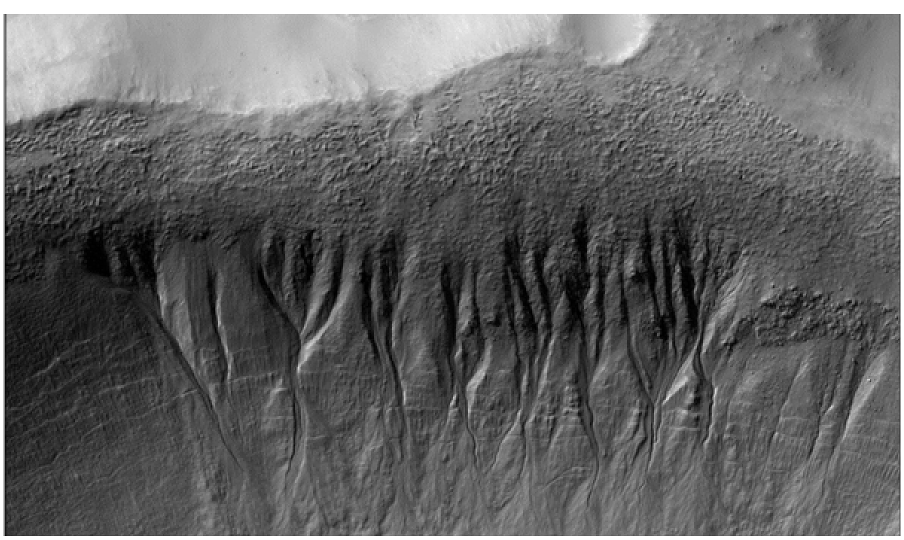
The definition of Mars Special Regions is based on temperature and humidity conditions that are measured on spatial scales of many tens of kilometers that do not necessarily reflect the conditions within microscale niches (millimeters and smaller) that can be potential habitats for microbial communities. Microenvironments underneath rocks, for example, could provide favorable conditions for establishing life on Mars, potentially leading to the recognition of Special Regions where landscape-scale temperature and humidity conditions do not meet the standard definition. To identify Special Regions across the full range of spatial scales relevant to microorganisms, a better understanding of the temperature and water activity of possible microenvironments on Mars is necessary.

Translocation of Terrestrial Contamination

A potential problem with designating Special Regions on Mars is that viable microorganisms that survive the trip to Mars could be transported into distant Special Regions by atmospheric processes, landslides, avalanches, meteorite impact ejecta, or lander impact ejecta. The issue of translocation is especially worthy of consideration because if survival is possible during atmospheric transport, the designation of Special Regions may become difficult or even irrelevant. The viability of translocating microbes could be confirmed or rejected in terrestrial Mars simulation chambers where transport processes such as dust storms can be studied.

MARTIAN GEOLOGICAL FEATURES POTENTIALLY RELATED TO SPECIAL REGIONS

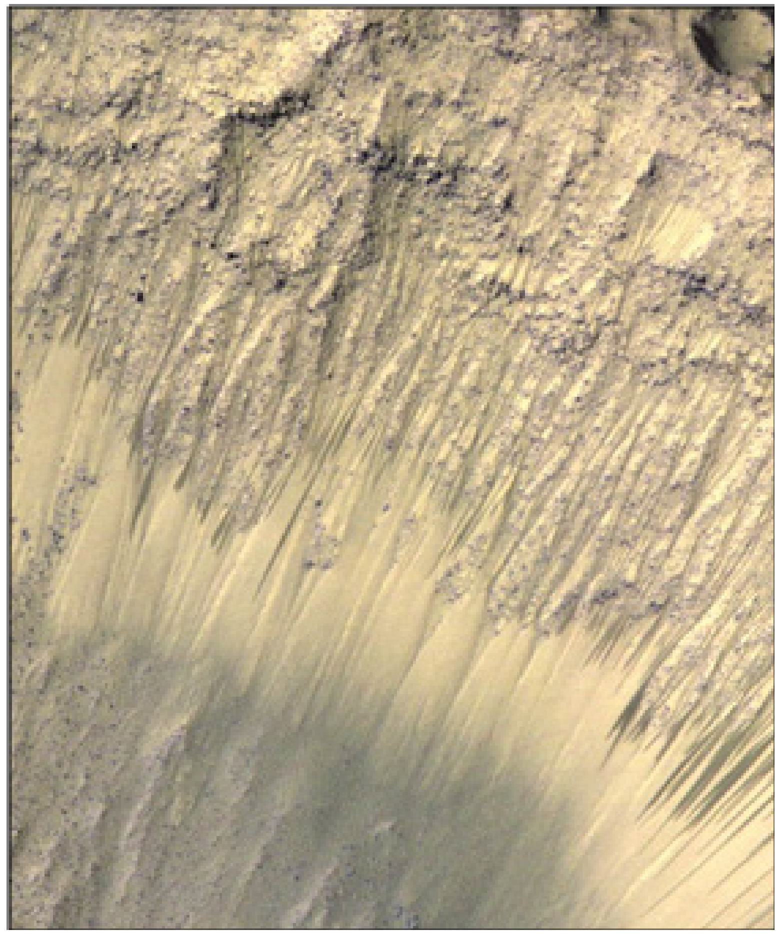
There are several types of geological phenomena observed on Mars that may indicate the presence of liquid water and



Mid-latitude martian gullies at 37.46˚S, 222.95˚E exhibiting erosional alcoves, channels, and depositional aprons, all geological features that appear to be actively evolving and resemble landforms that on the Earth are formed by water. Observations of gullies over the last decade reveal occasional mass wasting and show that they are currently active. However, present-day activity occurs when it is too cold for liquid water and is likely driven by dry granular processes involving CO_2 frost. Scale of photo is approximately 1.5 km from top to bottom. Image credit: NASA/JPL/University of Arizona.

could be considered as possible Special Regions. For example, Recurring Slope Lineae (RSLs) are narrow dark markings on steep, rocky slopes that appear to lengthen during warm seasons and fade in cold seasons. The growth and retreat of RSLs suggests that seasonal water seepage may be involved, but this has not yet been demonstrated. Other notable features include slope streaks, gullies, craters, and caves. While these specific terrains are identified as Special Regions in both the COSPAR policy and in the SR-SAG2 report, they are best regarded as Uncertain Regions. These Uncertain Regions should be treated as Special Regions until proven otherwise, with the final classification depending on the latest scientific knowledge about the environmental parameters of a specific site.

The SR-SAG2 report concludes that the detection of indigenous organic compounds on Mars at very low concentrations should not be used to distinguish Special Regions. However, it is appropriate that special consideration be given to methane, recently detected in episodic plumes near the surface of Mars. Methane could indicate the presence of living organisms on Mars, but it could also result from non-biological processes involving liquid water. In either case, it may be appropriate to designate the regions where methane is being produced, once identified, as Uncertain Regions.



Recurring slope lineae (RSL) in a crater on the floor of central Valles Marineris. RSL are narrow, dark markings on steep, rocky slopes in the equatorial and southern mid-latitude regions of Mars. They appear to incrementally lengthen during warm seasons and fade in cold seasons, best explained as a result of seasonal water seepage by terrestrial analogy, although the origin of water is unknown. Photo is 193 m wide. Image credit: NASA/JPL/University of Arizona.

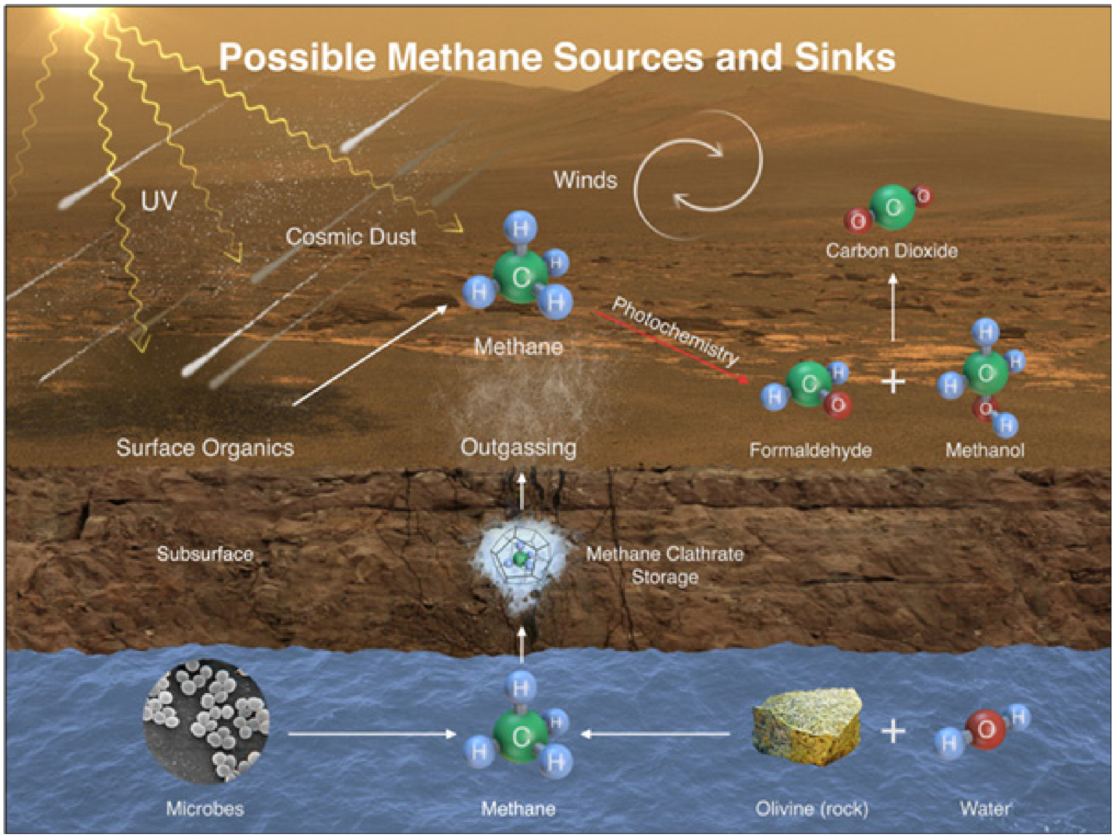
HUMAN SPACEFLIGHT

Even though planning for human missions to Mars is in its infancy, the planetary protection implications of sending astronauts to Mars raises profound questions at the intersection of science, engineering, technology, project management, and public policy. Understanding the implications of humans on Mars and the ability of human systems to meet COPSPAR requirements is essential to ensuring that nations can continue to conduct science investigations without worrying about contaminants introduced by human missions. It is important to make it clear that human missions to Mars will not be exempt from COSPAR planetary protection requirements and that these policies may prevent humans from landing in or entering areas that may be Special Regions.

DISTINGUISHING BETWEEN UNCERTAIN AND SPECIAL REGIONS

While maps are helpful to illustrate the distribution of relevant landforms or other surface features, they only represent a snapshot in time and are of limited use in identifying Uncertain or Special Regions. The knowledge presented in maps is often incomplete, available only at a fixed scale, and subject to change as new information is obtained. Therefore, maps are most useful if accompanied by cautionary remarks on their limitations. Because both small-scale microbial habitats and larger geological features could host conditions favorable for terrestrial life, a multiscale approach is necessary when classifying Special Regions and choosing landing sites for future missions. All available data should be utilized when certifying landing sites on Mars and determining whether Uncertain or Special Regions exist within the proposed landing ellipse.

Uncertain Regions in planned landing ellipses should be evaluated on a case-by-case basis as part of the site selection process. The goal of such an evaluation is to determine whether or not the landing ellipse contains water, ice, or subsurface discontinuities with a potential to contain hydrated minerals that could be accessed via a landing malfunction or by the operation of subsurface-penetrating devices (e.g., drills). As an example, landing site analysis will likely include a geological analysis, drawing on the Mars geologic literature (covering a broad range of relevant topics, including ground truth at previous lander locations) as well as orbital imaging, infrared spectroscopy, gamma-ray spectroscopy, and ground-penetrating radar sounding of the specific region.



This diagram illustrates the known ways that methane (CH_4) could be added to or removed from the atmosphere, processes known respectively as methane sources and sinks. NASA's Curiosity Mars rover is searching for methane traces as a potential sign of life (a biomarker), as well as to gain an understanding of modern surface and subsurface organic processes on Mars. Curiosity has indeed detected fluctuations in methane concentration in the atmosphere, suggesting that both methane sources and sinks are currently at work in the martian environment. Detecting methane does not necessarily mean the presence of life. Methane can be generated by microbes as well as by non-biological processes, such as geochemical reactions, sunlight-induced reactions (photochemistry), or delayed release from subsurface methane stores. Reactions between water and olivine (or pyroxene) and rock can generate methane. Ultraviolet (UV) radiation can induce reactions in a process called photochemistry to produce methane from other organic compounds that are themselves formed by biological or non-biological means, such as comet dust falling on Mars. Recent or ancient subsurface methane may be stored within lattice-structured methane hydrates called clathrates and released over time, a source of modern atmospheric methane that may have formed in the past. Concentrations of atmospheric methane can drop due to redistribution or photochemical sinks. Wind on Mars can quickly reduce localize methane concentrations from an individual source. Just as methane can be generated through photochemistry, it can be broken down in the same way, sunlight-induced reactions oxidizing the methane through intermediary chemicals like formaldehyde and methanol into carbon dioxide, the predominant component of the martian atmosphere. Image credit: NASA/JPL-Caltech/SAM-GSFC/University of Michigan

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