Contents — A through D

"COLD" OR "WARM" EARLY MARS: NEW ANALYSIS OF WARREGO VALLES FROM THEMIS AND MOLA DATA . V. Ansan and N. Mangold, Orsay-Terre, FRE2566, CNRS et Université Paris-Sud, Bat. 509, 91405 ORSAY Cedex, France, ansan@geol.u-psud.fr.

Introduction: The debate about the Noachian climate is very dependent on the interpretation of geomorphic features like valley networks. Valley networks were first interpreted as surface runoff under warmer climate [1], but surface runoff has been criticized because of the low drainage density [2] and alternative hypothesis have been proposed in cold climate [e.g.3]. Flows sustained by regional hydrothermal activity have been involved especially for the Thaumasia region in which Warrego networks because of the association of runoff sources with old volcanoes and fault zone [4]. In this study we infirm this possibility and we show that fluvial activity due to precipitation is a likely process to form Warrego valleys. Evidences for such processes are taken from new MGS and Odyssey data.

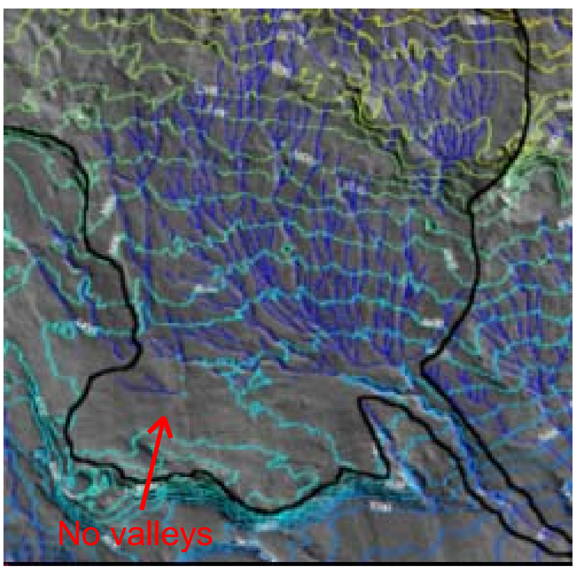


Fig. 1: Viking MDIM with MOLA elevation curves and warrego valles network in blue. Note the apparent absence of valleys on south flank whereas THEMIS data (Fig. 2) permit to identify valleys at this location.

MOC and THEMIS observations: Warrego Vallis is located on the southern part of the Thaumasia region, so the southern part of Tharsis bulge (Fig. 1). Other less developed networks similar in shape also exist on the flank east of Warrego. MOC high resolution images provide local information on the shape of valleys. Valleys are mantled by smooth material, likely dust eolian material. This filling of valleys makes the detection of small tributaries very difficult. New THEMIS IR images can be used to detect valleys that are not visible on Viking imagery. Indeed, THEMIS image south of the networks show several valleys not identified on the Viking images (Fig. 2). Their absence on Viking image (Fig. 1) is likely an effect of the sun incidence. THEMIS image permit to rebuilt a network geometry showing that the flank south of the main valley is involved in the network. The lack of volcanoes or large impact craters at the upper part of this south flank makes the hypothesis of hydrothermally controlled network unlikely. On the contrary, the smaller elevation difference of only 500 m on this flank may explain that valleys are less visible on Viking images.

Topography of the valley network: MOLA data shows that valley heads in the north part of the network occur at height of about 8 km. The average slope is of 0.03 with a total of 6000 m of elevation difference (Fig. 3). A usual criticism to runoff formed by precipitation is that networks are poorly dendritic, this means that intersection between rivers is low and not orthogonal like for dendritic pattern. However, the intersection angle depends strongly on the slope on which runoff forms. Terrestrial studies show that under about 0.026 of slopes (1.5°) the drainage is dendritic with nearly orthogonal intersections and up this value of 0.026 the drainage becomes parallel, with low angle intersections [5]. MOLA data shows that we are in the case of such parallel network, because slopes are of about 0.03 north of the main valley. The observed geometry is consistent with terrestrial parallel drainage due to the slope. On the contrary, the network is dendritic near the main valley where the slope is lower than 1.5°. In addition, we estimate a drainage density of 1.32 km^{-1}. This value is in the range of terrestrial environment by comparison to previous drainage densities usually less than 0.1 km^{-1} found from Viking data [2].

Origin of valley network: Finally, (1) MOC images show that valleys are strongly degraded and that small tributaries are possibly erased, (2) the regional slope measured by MOLA can explain the parallel geometry of the network and (3) THEMIS IR data shows that some valleys exist on the south flank showing that this network is not only controlled by sources on the northern part. Thus, evidences against runoff formed by precipitations are eliminated. On the contrary, it is unlikely that hydrothermal sources explain rivers in the south flank as they have their sources on a structural relief poorly related to any volcanic activity. Sapping is also difficult because it is controlled by layers and the geometry is different than typical sapping valley like Nirgal valleys. Moreover, the sources take place at elevations of up to 8 km which are the highest points in the regions, making unlikely an underground system at such crest line without refilling by run off.

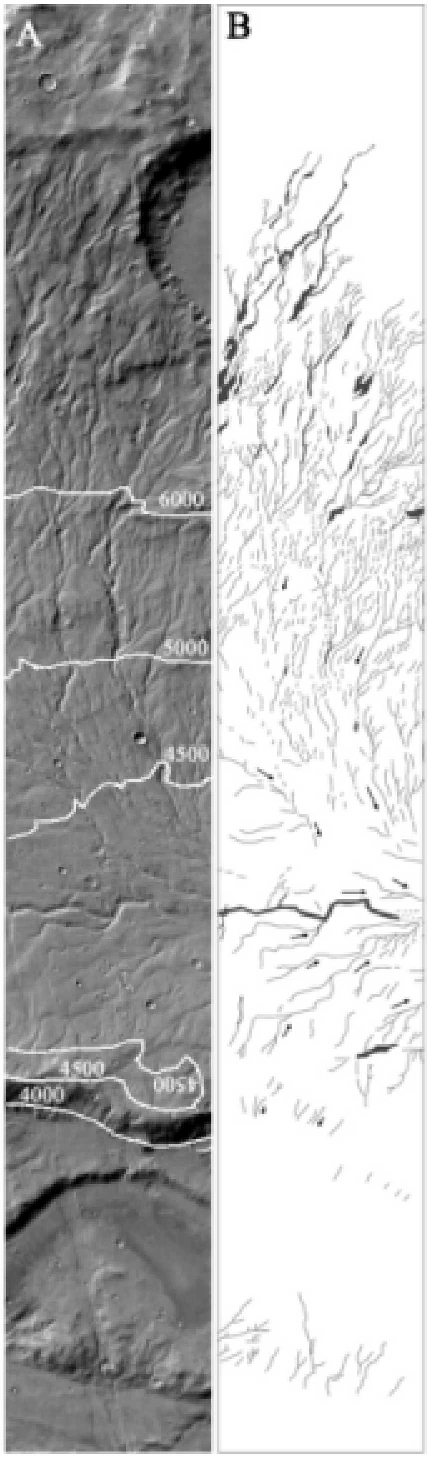


Fig. 2: A. Day-IR themis image I01714004 (100 m/pix) on which the MOLA altimetry is projected with a height interval of 500 m. B. In the lower part of the network, newly observed valleys connect to Warrego main valley with a North downstream. These valleys were not observed on Viking images.

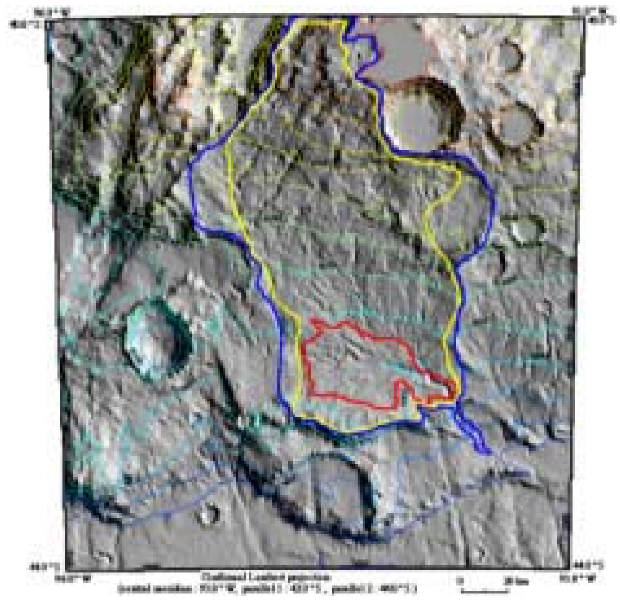


Fig. 3: Warrego Vallis from MOLA shaded relief. The yellow curve shows part of valley network where slopes are over 1.5°. The red curve limits the area where the slope is less than 1.5°. We see from the Themis data (Fig. 2) that the network is parallel in the yellow area and dendritic in the red area.

Conclusion: Using different sets of data, topography, visible and IR images at all possible scale, we show that Warrego valleys have characteristics in favour to surface runoff produced by precipitation. This conclusion favors observation such as those discussed by Craddock and Howard [7]. Warrego is a unique network in terms of density of drainage but the lack of other dense network can be explained because Warrego is one of the rare location with regional slope of more than 2°. Our conclusion, if confirmed by future works, would be useful to constrain climate models of Early Mars which often reject the possibility of warmer climate. It also shows the interest to use THEMIS data to identify valley networks on Mars.

References: [1] Craddock and Maxwell, *J.G.R.*, 102, E6, 13321-13340, 1997 [2] Carr, M. H., *J.G.R.*, 102 (E4), 9145-9152, 1997, [3] Carr, M. H., *Water on Mars*, 1996. [4] Dohm J. M. and K. L. Tanaka et al, *Planet. Spa. Sci.*, 47, 411-431, 1999. [5] Schumm, S.A., M. P. Mosley and W. E. Weaver, *Experimental flows*, WileyInterscience, 1987 [6] Tooth., *Earth Science Reviews*, 51, 67-107, 2000, [7] Craddock and Howard, *J.G.R.*, 107, E11, 5111, 2002.

IDENTIFICATION OF PAST POLAR DEPOSITS AMONG LAYERED TERRAINS ON MARS: PRELIMINARY RESULTS V. Ansan and N. Mangold, Orsay-Terre, FRE2566, CNRS et Université Paris-Sud, Bat. 509, 91405 ORSAY Cedex, France, ansan@geol.u-psud.fr.

Introduction: The origin of layered terrains interpreted to be of sedimentary origin on Mars is debated since their discovery from Viking observations [1,2,3]. Lacustrine, fluvial, volcanic ashes, eolian, ancient polar deposition are the usual hypothesis for their origin. Recently, using MOC images, light-toned deposits have been interpreted as old Noachian deposits formed under water [1]. In this study, we focus on the differences in geologic context, age and geomorphic between deposits on the floor of 4 craters (Fig. 1). We conclude that 2 crater deposits are likely due to past processes involving water at surface, but that the 2 others have more debatable origin.

Location and context of 4 crater interiors analyzed:
Holden crater: 27°S, 35°W. 100 km large crater at the mouth of Uzboi valles. Layered deposits are several hundreds of meters thick.
Terby crater: 28°S, 285°W. 100 km large crater north of Hellas. The crater floor is dissected by canyons where layered deposits are observed over 1 km.
Spallanzani crater: 58°S, 274°W. South-East of Hellas crater. The 50 km large crater is filled by deposits of about 1.5 km thick.
Galle crater (not to confound with Gale crater): 52°S, 30°W. Crater east of Argyre. Deposits are 500 m thick on the south of the crater floor.

Geomorphic characteristics: The erosion of these layered deposits is different from one crater to the other. Holden and Terby crater floors are dissected in canyons and cliffs where layers are observed. These layers are strong and homogeneous with no large debris aprons on the foot of scarps. On the contrary, Spallanzani and Galle layers are not so uniform, with numerous interlayers with strong erosion and low strength as visible by lot of small scarps. They do not show the typical light ton but they could be covered by thin layer of dust. Closed pits and large yardangs due to wind action confirm that the material is not very much consolidated. By comparison, light-toned deposits also display yardangs (Fig. 1B) but at a scale very different which implies a more consolidated material.

Age from stratigraphical relationships and crater counts: Holden deposits are overlain by dark material, both in the interior of valleys and on the top of cliffs. This material is probably a crust of eolian material accumulated after erosion of the deposits. These dark deposits are strongly craterized, sometimes nearly saturation, implying that the age of deposits are at least Hesperian, if not older. In Terby, same dark crust blanket the light-toned deposits which are only visible in some natural cross-section where this blanket was eroded. The large surface which is not dissected by canyons gives an age in the Noachian period from crater counts at MOC and Themis visible image scale. The blanket of dark material was probably removed recently explaining the low proportion of craters on the layered deposits. On the contrary, Galle and Spallanzani crater deposits are completely devoid of craters. They are also devoid of dark blanket, except some young dunes which fills pits and throughs. These deposits seem very young by comparison to Holden or Terby. Nevertheless both deposits are submitted to a strong and recent erosion, so it is not possible to know if the surface was exhumed from much older terrains than it appears.

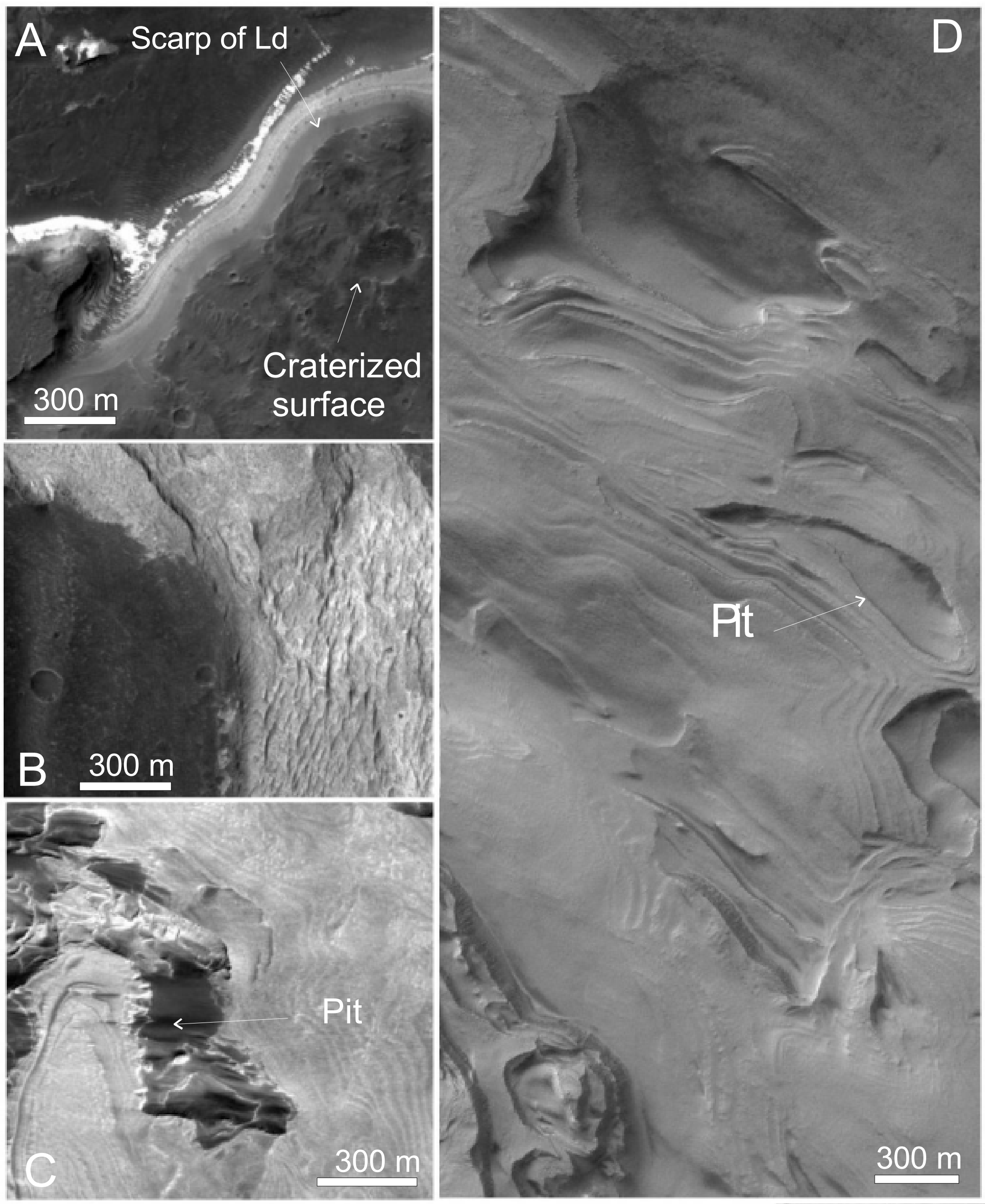
Channels close to deposits: Both Holden and Terby have channels crossing the deposits. Uzboi vallis in the case of Holden, and different small channels going down from crater rims in the case of Terby. Galle is inside the region of Argyre which is supposed to have been dissected by channels in the Hesperian age but we do not see any fresh channels with potential age in agreement with the apparent youth of the layered terrains inside Galle. On the contrary, Spallanzani is apparently not connected with any channels.

Discussion: The 4 craters can be classed in two groups. On one hand, the deposits of Holden and Terby are probably both of Noachian age. They occur in connection with channels and valley networks. They correspond to the same light toned material than the layers of Terra Meridiani or Valles Meridiani analyzed by [1]. Both craters deposits are good candidates for sedimentary deposition under water as already proposed. On the other hand, Spallanzani and Galle deposits are much more desegregated by wind, the material is clearly different than for Holden and Terby. These craters are located at latitudes of 52° and 58° South, thus at latitudes where ice is stable close to the surface, or was stable in a recent past. Recent models show that deposits of ice and dust as polar layered deposits can occur much more equatorward than currently during period of high obliquity [e.g. 4]. They could thus be the result of past period of high obliquity. In such hypothesis, the deposits are quickly eroded by wind action and the closed pits and throughs could correspond to cryokarstic effects of the sublimation of ice which exists currently at these latitude. Alternatively, the deposits could be old and ice could be still present as ice is stable deep in the ground at these latitudes. Then the progressive erosion could have exhumed these terrains progressively and the sublimation would have created the pits and throughs. Finally, if Spallanzani is a potential candidate for past polar deposits, Galle remains more uncertain because of the geological context in a region where water played a strong role in the past.

Conclusion: The identification of polar deposits on the whole planet may permit to give paleoclimatic informations. This study highlights the necessity to determine geomorphic criteria in order to discriminate between the different hypothesis for the origin of layered deposits. Among the 4 craters studied, Holden and Terby confirm past studies assuming that they are crater lakes, but the deposits of Spallanzani crater could correspond to potential polar deposits which are now eroded by wind.

References: [1] Malin and Edgett, Science, [2] Cabrol and Grin Global Planetary Changes 35, 199-219, 2002 [3] Carr, M. H., *Water on Mars*, 1996. [4] Michna et al., 6th Mars int. Conf. , Pasadena, 2003.

Fig. 1: A: MOC image of Holden crater. Note the cratered surface on the plateau. B MOC image of Terby crater. C. MOC close-up of Galle crater. Layers are freshly dissected. D. MOC image of Spallanzani crater. Closed pits and erosion of scarps imply large wind effects in the erosional process.



GRAIN GROWTH OF ICE WHICH CONTAINS MICROPARTICLES. N. Azuma, T. Takeda and K. Funaki, Department of Mechanical Engineering, Nagaoka University of Technology,Nagaoka, Niigata, 940-2188, Japan; azuma@mech.nagaokaut.ac.jp

Martian ice-cap ice contains a large number of microparticles (>1%vol.)[1] To estimate grain size in Martian polar ice caps is of vital importance to understand the deformation mechanisms in the ice caps. However, the estimate greatly depends on the microparticle content in ice because microparticles impede grain growth[2]. The dependence of grain growth rate on the concentration of microparticles have not been well investigated experimentally because of the difficulty in preparation of samples containing uniformly distributed microparticles.

We conducted grain growth experiments using artificial ice samples that have various concentrations (0.1-5%) of silica particles with a uniform size of 0.3 σm. Here we discuss the dependence of grain growth rate on concentration of microparticles (Fig 1 and Fig.2) . We also present the effect of the microparticles on the grain size evolution of ice during deformation.

References:

[1] Thomas P.et al. (1992) In Mars, ed. H.Kieffer et. al., Univ. Ariz.Press, 767-795

[2] Alley R.B. et al. (1986) J.Glaciol.,32 (112), 415-433

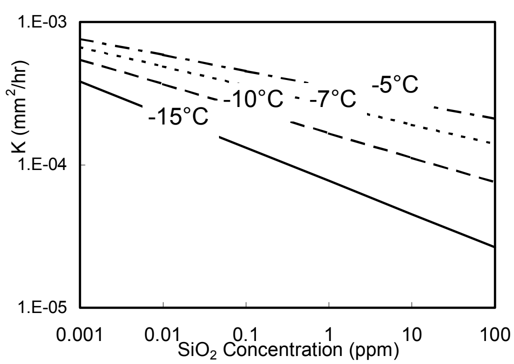


Figure 1 Results of grain growth experiments.
K represents the grain growth rate.

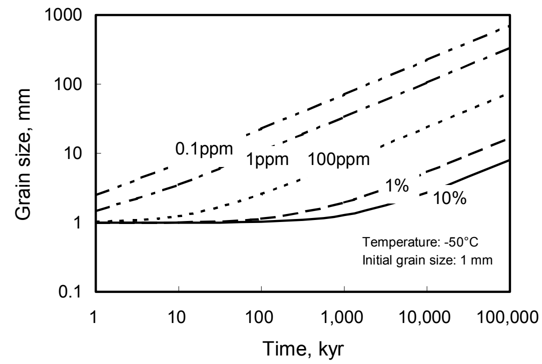


Figure 2 Grain size versus time curves estimated from present results.

AN ASSESSMENT OF THE ISSUES AND CONCERNS ASSOCIATED WITH THE ANALYSIS OF ICE-BEARING SAMPLES BY THE 2009 MARS SCIENCE LABORATORY. D.W. Beaty, (Mars Program Office, Jet Propulsion Laboratory, California Institute of Technology, dwbeaty@jpl.nasa.gov; 818-354-7968), S.L. Miller (JPL/Caltech), J.L. Bada (Univ. of Calif. San Diego), G.H. Bearman (JPL/Caltech), P.B. Black (CRREL, Picatinny Arsenal), R.J. Bruno (JPL/Caltech), F.D. Carsey (JPL/Caltech), P.G. Conrad (JPL/Caltech), M. Daly (MD Robotics), D. Fisher (Geological Survey of Canada), G. Hargreaves (USGS/National Ice Core Laboratory), R.J. Henninger (JPL/Caltech), T.L. Huntsberger (JPL/Caltech), B. Lyons (Byrd Polar Research Center), P.R. Mahaffy (NASA—GSFC), K. McNamara (NASA—JSC), M. Mellon (University of Colorado), D.A. Papanastassiou (JPL/Caltech), W. Pollard (McGill University), K. Righter (NASA—JSC), L. Rothschild (NASA—ARC), J.J. Simmonds (JPL/Caltech), J.G. Spray (University of New Brunswick), A. Steele (Carnegie Institute of Washington), A.P. Zent (NASA—ARC)

Introduction: In early 2003, the Mars Icy Sample Team (MIST) was formed to address several questions related to the acquisition and analysis of ice-bearing samples on the surface of Mars by a robotic mission. These questions were specifically framed in the context of planning for the 2009 Mars Science Laboratory (MSL) lander, but the answers will also also have value in planning other future landed investigations.

Questions:

- Which scientific investigations, in priority order (especially of relevance to an assumed mission theme of habitability), can be addressed using ice-bearing samples and the MSL landed system?
- Which measurements are needed on ice-bearing samples to support these investigations?
- What are the minimum sample collection hardware and processes needed to acquire the necessary ice-bearing samples?
- What are the minimum sample preparation steps required for ice-bearing samples?
- What are the issues associated with preservation of the scientific content of the samples between the time of their collection and the time of their analysis?
- Can common hardware be used to interact with both ice-free and ice-bearing samples? This would allow the decision of where to send the mission (i.e., in terms of a latitude band) to be deferred until very late in the mission development process.

Assumptions: For the purpose of this analysis, we have defined four model sample types: Weakly ice-cemented regolith, ice-saturated regolith, ice-supersaturated samples (up to 100% ice), and ice-bearing rocks. These sample types have different concentrations of ice, different texture, and different resistance to sampling devices.

Ice Science Priorities: The MIST team ranked the scientific objectives of studying an ice-bearing sample (using the potential capabilities of the MSL landed system). The following is a prioritized list, using the impact on astrobiology as the prioritization criterion.

1. Is ice present and in what abundance?
2. Are organic molecules present in the sample, and if so, what is their identity, and what is their relationship to the ice fraction of the sample?
3. Is some fraction of the water present in the sample in the liquid state (e.g., as fluid inclusions, or along grain boundaries)? If so, how much, and what is its composition?
4. How did the ice get into the ground? Was it trapped from the atmosphere? Is it buried surface ice? Did it percolate from surface standing water or from sheetwash?
5. How old is the ground ice?
6. Has the ground ice been processed, melted, or redistributed since deposition? If so, when and how?

In addition, the planetary scientists on the MIST team concluded that several additional high priority investigations (origin of the water, climate at the time the ice formed, exchange rates/processes, planetary modeling, etc.).could be supported by measuring the isotopic properties of the water.

Some assertions regarding ice sample science: Based on the collective experience of the MIST team, we pose the following assertions regarding deriving science value from an ice-bearing sample on the martian surface.

1. For the ice-related investigations described above, well-designed measurements on a small number of ice-bearing samples will be more useful than poorly designed measurements on a large number of samples.

2. None of the high-priority ice-related measurements require that ice-bearing samples be crushed.
3. It is not scientifically necessary to split a sample to make multiple ice-related measurements. Most of the logic for doing this for the refractory portions of geologic samples does not apply to the ice fraction. It is far more important that the samples are fresh than to have statistically equivalent splits.
4. Sample aging is always a problem with ice-bearing samples. An acceptable solution to minimizing these effects is to optimize the operational scenario (e.g., transfer ice samples at night, while it is cold). This will be far simpler than mechanical means of sample preservation (e.g. encapsulation, refrigeration).
5. It is impossible to design a simple sample preparation and distribution system in which dry and wet samples follow the same path. We never do this in Earth labs.
   - If the ice fraction of a sample melts in a system designed for dry samples, there is potential for serious damage (un-removable contaminants, and perhaps worse).
   - Note: It may be possible using thermodynamic arguments to show that the ice will sublimate rather than melt, and if so, an engineering solution is not required.

Discussion:

For the highest-priority astrobiology investigations, non-destructive measurements are essential. Textural relationships between ice crystals, any organic material present, liquid/salt inclusions, and any associated mineral material need to be observed. Microscopy, probably with different kinds of illumination, will be key. For the highest priority planetary science investigations, subliming the ice and running the vapor through a mass spectrometer is essential. Given the priorities of the Mars program, we do not see a good scientific reason to subject an ice-bearing sample to mechanical sample preparation steps such as crushing and splitting. Thus, the mechanical process of interacting with an ice-bearing sample is in some ways simpler than interacting with rocks, which need to be crushed and split for many types of measurements.

The most useful kinds of ice-bearing samples for the scientific objectives described above are ice-saturated regolith and ice-supersatured material. These two sample types cannot be effectively sampled without a drill. We do not have a good way of calculating the depth of penetration necessary to acquire these sample types, but in our judgement a subsurface access capability of 0.3-0.5 m is a minimum.

When a cold ice-bearing sample is moved from its natural state to the warmer environment of the rover, it will progressively degrade, first by addition (freezing of water vapor onto the sample), then by subtraction (sublimation). We were unable to model the rate of this degradation process in the time available to us, but it will be dependent on the integrated exposure to higher temperature over time and air circulation. How much time-temperature is acceptable?--Preliminary calculations suggest that several hours should be acceptable if ΔT is modest.

Recommendations:

1. We recommend including a means of determining whether or not ice is present in the acquired sample either at the site of sample collection, or at the front end of the lab.
2. Minimize the effects of sample degradation by:
   - Placing ice-critical instruments in a cold part of the rover.
   - Collecting and processing samples for ice-related measurements at night.
   - Processing and analyzing ice samples quickly. We recommend that instruments needing to receive raw ice-bearing samples have a “by-pass” port, which would allow raw material to be introduced without passing through the sample preparation systems.
3. To protect the principal (dry) sample prep and analysis systems which are at the heart of MSL’s scientific objectives, we recommend that samples be dried prior to introduction into crushing, splitting, or sieving operations.
   - The combination of time and temperature necessary to achieve the minimum necessary state of dryness needs more analysis and discussion. A part of this analysis needs to include assessment of the temperature at which one starts to lose information on hydrated phases.

Conclusion:

Our summary conclusion is that it is possible to design a single overall surface system that can interact with both ice-bearing and ice-free samples. However, this system will need to have more complexity than a system designed to interact only with ice-free samples. Such a system could be designed now, and we would be able to send it to a location selected years from now in response to future discoveries (possibly either ice-free or ice-bearing).

Detection of Organic Compounds in Polar Ices on Mars Using AP MALDI Luann Becker[1], William Brinckerhoff[2] and Robert J. Cotter[3], [1]Department of Geology, University of California, Santa Barbara, 1140 Girvetz Hall, Santa Barbara, CA 93106 email: lbecker@crustal.ucsb.edu; [2]Applied Physics Laboratory (APL), Laurel MD, 20723; [3]Johns Hopkins School of Medicine (SOM), Baltimore, MD, 21205

Introduction

With the current and planned missions to Mars and to some outer planetary moons such as Europa and Titan, NASA is now entering a new phase of planetary exploration strongly motivated by *Astrobiology*. Our interest in Mars is, in part, a result of recent studies of martian meteorites that suggest that the early history of the red planet was remarkably similar to that of the Earth, where life apparently arose both quickly and early on (possibly as soon as ~3.85 Ga). If this is indeed the case, then Mars was presumably a much warmer, wetter, planet then it is today. This hypothesis is further supported by the images returned by the Viking, Mariner and Mars Global Surveyor (MGS) orbiter spacecrafts that all show compelling evidence that copious liquid water existed on the surface of Mars in the past. In fact, new images provided by MGS suggest that there may be current sources of liquid water and ice at or near the surface of the red planet. Other MGS images show evidence of an early ocean at the North Pole and extensive underwater channels draining into large valleys (Valles Marineris) near the equator. All of these data support the possibility that life may have arisen on Mars in liquid water environments.

The search for organic matter in rocks, sediments and ices from Mars is critical to the assessment of any extinct or extant life. Our missions to Mars have the potential to further address the question of whether life arises spontaneously, given appropriate planetary conditions, as well as possibly learning more about our own prebiotic evolution that has been all but erased from the Earth's crustal record. The search for life beyond our own planet is one of considerable interest to scientists and the general public alike. Yet, as we learned from the Viking missions, the search for life signs in a complex environment is problematic and requires an appropriate strategy that will maximize our opportunities to properly examine these compelling questions. This strategy must encompass both the selection of appropriate measurement techniques and the careful testing and evaluation of those techniques in an environment with challenges similar to those found *in situ*.

One of the highest technical barriers to obtaining sensitive analyses of solid phase materials (e.g. ices) on Mars is the often complex and resource-intensive process of sampling. Powerful instruments, such as mass spectrometers, typically require solid samples to be cleanly manipulated and vacuum processed in order to achieve their advertised capabilities. We are in the process of developing and testing an integrated mass spectrometer system that uses a direct sampling and ionization method operating at ambient atmospheric pressure, yet achieves the very high sensitivity and discriminatory power required for complex *in situ* samples. The atmospheric pressure matrix assisted laser desorption/ionization (AP-MALDI) method uses a pulsed laser to volatilize and ionize organic compounds from the surfaces of solid samples, which are then immediately drawn into a differentially-pumped miniature mass spectrometer inlet for analysis.

The development of a MALDI source that operates at ambient atmospheric pressure was strongly motivated by the drive toward higher throughput screening analyses in proteomics and chemical/biological agent detection. In the case of AP-MALDI, the ions are formed at ambient pressure and then drawn into the system. By eliminating the sample acquisition and vacuum loading steps, AP-MALDI has the potential to be used on large sample arrays or wide-area collection plates within a robotic monitoring system or directly on rocks and ice in the field. Moreover, there are a number of features of AP-MALDI that are especially advantageous for use on geological samples in a harsh, remote environment such as Mars. **First,** ambient laser desorption maintains the pristine nature of samples, and the capillary inlet does not contact the sample. Therefore, AP-MALDI could be implemented at the end of an articulated robot arm. **Second,** laser desorption is able to perform local analyses of undisturbed samples that are heterogeneous at the grain scale; the focal diameter is typically in the range from 100 microns to 1 mm. Thus highly localized mineralogical "niches" that may contain biomarker organics are more likely to be detected than with a bulk sample. **Third,** the Mars ambient pressure of 5-10 Torr is precisely in the range that has been shown to dramatically increase sensitivity and decrease metastable fragmentation. That is, a method that provides increased performance at a complexity and convenience cost in terrestrial AP-MALDI may be available without those costs on Mars. The lower ambient pressure (5–10 vs. 760 Torr) at Mars also reduces the overall complexity of the instrument inlet and the requirements on the pumping system because of the reduced differential pressure gradient to reach the required base pressure of the analyzer.

Earth Analogs – Antarctica
Since the exploration of Mars will necessitate a highly robust and refined instrument technology testing equipment in the appropriate Earth analog, like the environments encountered in Antarctica, would greatly facilitate the development of *in situ* instrumentation. Exploration of the ice cap and the unique preservation of organic material in the Antarctic environment will provide the testing ground for the development of our AP- MALDI instrument. Several studies of Antarctic ice have revealed both extraterrestrial and terrestrial sources of organic compounds that are concentrated in the surface ice by the natural process of sublimation (Becker et al., 1999, 2002). The cold and dry Antarctic conditions are ideal for evaluating the preservation of organic compounds and the effects of seasonal changes that may lead to the decomposition of biologically relevant compounds. The acquisition of this data set, both through *in situ* field measurements and with samples collected and returned to the laboratory, will be invaluable to our strategy for the search of extinct/extant organic compounds on Mars.

The current expectation of the ability of AP-MALDI to perform these analyses is based upon initial laboratory work with a breadboard, which has been used to detect 10–50 femtomole (fmol) of analyte (liquid) deposited on a target surface in a four-component mixture of peptides in the 800-1700 Dalton (Da) molecular weight range. Recent analyses of portions of Vostok ice cores revealed between 2 x 10^2 and 3 x 10^2 bacterial cells per milliliter and low concentrations of potential growth nutrients (Karl et al., 1999; Priscu et al., 1999) suggesting that Lake Vostok may contain viable microorganisms. We have available, samples of accreted ice from Lake Vostok. We will present preliminary results on these ice samples and other materials (minerals, sediments) using our AP-MALDI functional proto-type instrument. Testing of the prototype instrument in Antarctica will begin in 2003. This initial testing program will be used to implement the design of our brassboard instrument that will be tested again in Antarctica in the 2006 field season.

References: Becker, L. Popp, B., Rust, T. and Bada, J. L. (1999) *Adv. Space Res*. 24, 477-488. Becker, L. (2002) *National Research Council, Signs of Life: A report based on the April 2000 Life Detection Workshop on Life Detection Techniques,* National Academies Press, Washington, D.C. Karl, D. M., Bird, D. F., Bjorkman, K., Houlihan, T., Shackelford, R., Tupas, L. (1999) *Science* 286, 2144-47. Priscu, J.C., E.E. Adams, W.B. Lyons, M.A. Voytek, D.W. Mogk, R.L. Brown, C.P. McKay, C.D. Takacs, K.A. Welch, C.F. Wolf, J.D. Kirstein. R. Avci. (1999) *Science* 286, 2141-2144.

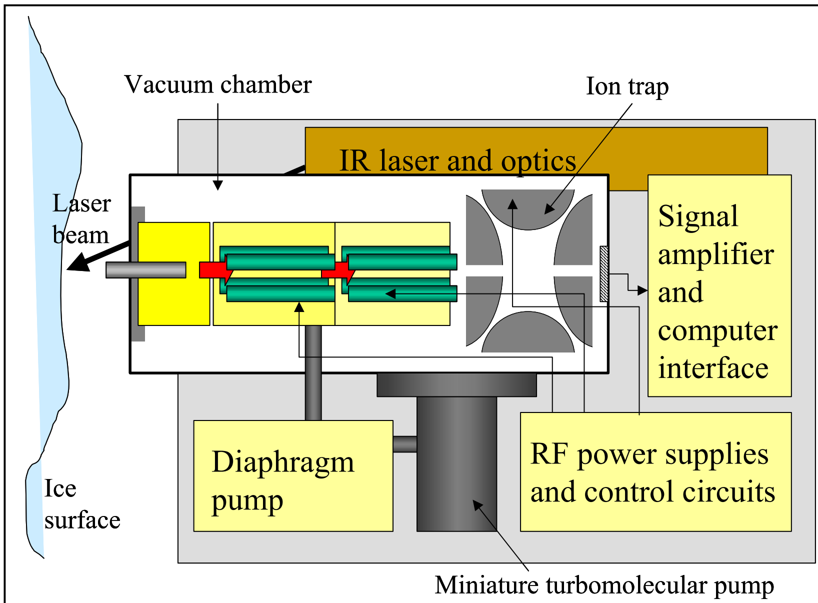


Fig. 1 The envisioned integrated brassboard AP-MALDI-ITMS concept. The instrument analyzes an ice or ice matrix sample deposit in situ, in a non-contact "stand-off" mode. The sample-inlet distance in the mm range depends on a number of factors to be investigated. Laser- sampled ions travel through the inlet stage and focused by a quadrupole/octopole rod assembly to maximize signal. The laser, ion trap, power, and data collection systems are controlled through a user-monitored interface. The asynchronous operation of laser and ion trap permit analyses to be performed in autonomous programmed modes.

YEARLY COMPARISONS OF THE MARS NORTH POLAR CAP: 1999, 2001, AND 2003 MOC OBSERVATIONS. J. L. Benson and P. B. James, Ritter Astrophysical Research Center, Dept. of Physics and Astronomy, Univ. of Toledo, Toledo, OH 43606 (jbenson@physics.utoledo.edu; pbj@physics.utoledo.edu)

Introduction: The seasonal cycle of the martian north polar cap has been studied since the time of William Herschel, who published the first quantitative observations of the seasonal recession of the polar caps in 1784 [1]. Ground-based observations made after Herschel were summarized by Slipher in 1962 [2]. More recent ground-based observations of the north polar cap have been done by Iwasaki et al. [3, 4, 5, 6]. Mariner 9 [7] and Viking [8, 9] also made north polar observations. Cantor et al. used Hubble Space Telescope observations between 1990 and 1997 to determine several north polar recessions and Lambert albedos of the cap [10].

Mars Global Surveyor went into orbit around Mars in September 1997. The wide-angle cameras on the Mars Orbiter Camera (MOC) acquire images of the entire planet every day at a resolution of ~ 7.5 km/pixel in both red (575 nm – 625 nm) and blue (400 nm – 450 nm) bandpasses (WAR and WAB). Some polar cap observations were acquired during the aerobraking (AB) and science phasing (SPO) of MGS before systematic mapping began in March, 1999 at L_S = 110°.

More than two complete Martian years have now been monitored by MGS/MOC, including three summer seasons in the northern hemisphere. Data pertaining to the spring / summer recessions of the north cap during the first year of mapping has been reported previously [11]. The north polar recession in 2000 was very similar to previously observed recessions. The MOC observations confirmed an almost linear cap regression from L_S = 340° until L_S = 60°.

Using WAR images, we have studied the subsequent spring recession of the north seasonal polar cap and also made albedo measurements of the residual cap. We look for interannual variability between this and previous years observed by MOC. This comparison is especially interesting because an extensive planet encircling dust storm occurred in early northern fall of the second Martian year while there was no such large storm in the first year. Therefore, it may be possible to determine the effects of dust on the condensation and sublimation of the carbon dioxide in the cap.

Seasonal North Cap: The late winter and early spring portions of the north cap recession have been phases for which the largest interannual variability has been reported. The extent of the surface cap boundary in late winter has been controversial. Also, a halt in cap regression in early to mid-spring has been reported [3, 8]; that is, the boundary of the cap remains fixed at a latitude of about 65º for several weeks before the recession resumes. A global dust storm during the condensation phase of the north cap is one mechanism suggested to be responsible for this variability. However, it is difficult to separate interannual effects from longitudinal asymmetries in the cap due to the gradual change in the longitudes on Mars seen from a location on Earth.

We have determined the regression curves for the 2000-2001 and 2002-2003 recessions of the north polar cap (Figure 1); a planet encircling dust storm occurred in early fall in the second year. The regression curves from the two years are very similar, however, there are small differences between L_S=10º and L_S=50º. There is no sign of a halt in cap regression in either year.

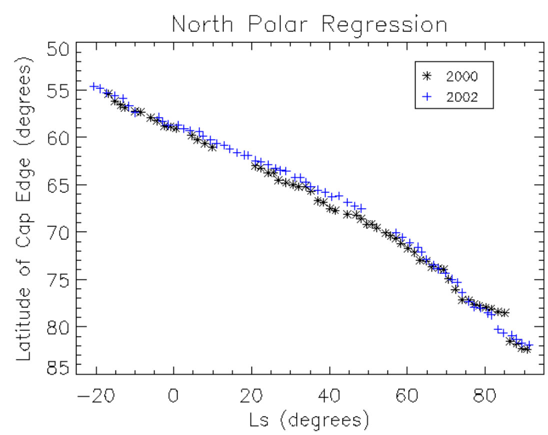


Figure 1: Regression of the north polar cap in 2000 (*) and 2002 (+). The latitude of the cap edge on a sterographic projection is ploted versus areocentric solar longitude. Recessions are similar, however, there are slight variations between L_S=10º and L_S=50º.

Residual North Cap: Mars Global Surveyor mapping began at L_S = 110º in 1999. Detailed comparisons of the caps in different years are complicated by frequent dust storms that may obscure the surface cap; fallout from these storms on the surface cap may also affect the apparent albedo for longer periods.

In Figure 2, the average Lambert albedo of the center (geographic pole) of the RNPC is plotted against L_S

for 1999 (*) and 2003 (Δ). Due to a change in sensitivity of the MOC WA Red Camera during the fall of 2001, those data are not included here, however, James and Cantor have reported these results [12]. The general behaviors of the albedo in this central region of the cap seem to be similar in the two years. The main exceptions are two data points from 1999 near L_S = 135°. There is a gap in the MOC WA red mapping subsequent to these events due to the Geodesy Campaign; so the question of the duration of this suppression is not answered by the red images alone, and additional investigation using the blue filter mapping images, which continued through the period, will be needed. The decrease after $L_S > 160°$ is probably due to the fact that the Lambert approximation fails at the large incidence angles in late summer.

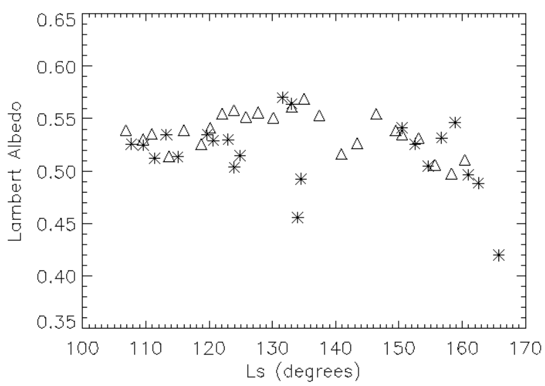


Figure 2: Average Lambert albedo for a 30 × 30 pixel^2 region around the geographic north pole as a function of L_S for 1999 (*) and for 2003 (Δ).

Acknowledgements: The authors were supported by grants from the Mars Data Analysis Program.

References: [1] Herschel, W. (1784) *Phil. Trans.*, 24, 233-273. [2] Slipher, E. C. (1962) *The Photographic Story of Mars*, Northland Press. [3] Iwasaki, K. et al. (1979) *JGR*, 84, 8311-8316. [4] Iwasaki, K. et al. (1982) *JGR*, 87, 10265-10269. [5] Iwasaki, K. et al. (1984) *PASJ*, 36, 347-356. [6] Iwasaki, K. et al. (1999) *Icarus*, 138, 20-24. [7] Soderblom, L. A. (1973) *JGR*, 78, 4197-4210. [8] James, P. B. (1979) *JGR*, 84, 8332-8334. [9] James, P. B. (1982) *Icarus*, 32, 565-569. [10] Cantor, B. A. et al. (1998) *Icarus*, 136, 175-191. [11] James, P. B. and Cantor, B. A. (2001) *Icarus*, 154, 131-144. [12] James, P. B. and Cantor, B. A. (2001) *BAAS XXXIII*, Abstract #19.16.

EFFECTS OF ATMOSPHERIC AND SURFACE DUST ON THE SUBLIMATION RATES OF CO_2 ON MARS. B. P. Bonev[1], P. B. James[1], J.E. Bjorkman[1], G. B. Hansen[2], and M. J. Wolff[3], [1]Ritter Astrophysical Research Center, Dept. of Physics and Astronomy, Univ. of Toledo, Toledo, OH 43606, USA (bbonev@kuiper.gsfc.nasa.gov; pbj@physics.utoledo.edu; jon@physics.utoledo.edu), [2]Planetary Science Institute, Northwest Division, Univ. of Washington, Seattle laboratory, Seattle, WA 98195 (ghansen@rad.geology.washington.edu), [3]Space Science Institute, 3100 Marine Street, Boulder, CO 80303-1058, USA (wolff@colorado.edu).

Introduction: We present an overview of our modeling work dedicated to study the effects of atmospheric dust on the sublimation of CO_2 on Mars. The purpose of this study is to better understand the extent to which dust storm activity can be a root cause for interannual variability in the planetary CO_2 seasonal cycle, through modifying the springtime regression rates of the south polar cap. We obtain calculations of the sublimation fluxes for various types of polar surfaces and different amounts of atmospheric dust. These calculations have been compared qualitatively with the regression patterns observed by Mars Global Surveyor (MGS) in both visible [1, 2] and infrared [3] wavelengths, for two years of very different dust histories (1999, and 2001).

Atmospheric modeling: Our approach is to model the radiative transfer through a dusty atmosphere bounded by a sublimating CO_2 surface. Although we have done some preliminary monochromatic calculations [4], our main focus has been to employ a full spectrum model, which incorporates the main effect of atmospheric dust. This is the redistribution of the radiation incident to the surface from visible frequencies to the IR. We have adapted a monte-carlo radiative equilibrium algorithm, initially developed for modeling circumstellar envelopes [5], to the case of a plane-parallel dusty planetary atmosphere. This model was introduced in a case study [1] applied to the regression of the Mountains of Mitchel, one of the brightest regions in south seasonal polar cap. This work points out that although our model atmosphere is one-dimensional, our radiation transfer code is three-dimensional and includes wavelength-dependent dust opacity, anisotropic scattering and thermal dust emission. We have used the most recently calculated dust single scattering properties for both visible and IR wavelengths [6]. An important modification of the original code, has been the treatment of anisotropic scattering in the visible spectral region, which enabled incorporating the phase function appropriate for Martian dust [7].

Surface modeling: The surface albedo spectrum is a major parameter in this study. Its accurate modeling is of primary importance and without it, the effects of atmospheric dust cannot be assessed correctly. There are a number of parameters influencing the surface albedo spectrum [8], the most important of which is the amount of *surface dust intermixed in the frost*. The amount of surface intermixed dust and water, and the grain size of the CO_2 frost, can be constrained by data from at least three spectral regions: the thermal IR near 25 microns [8], the near-IR [9], and the visible ranges of the Mars Orbiter Camera (MOC) on MGS [10]. We initially conducted a limiting case study [1] of the sublimation of surfaces with zero and very high dust content. In [11] we have examined in depth the albedo changes with surface dust-to-ice mixing ratio and CO_2 frost grain size; the variation of the albedo with photon incident angle and the dependence on the ratio of direct/diffuse incident radiation. In monte carlo calculations the albedo dependence on the direction of the reflected photons is also important. This variable has been held as a free parameter by simulating different laws of surface reflection. A good constraint of the best directional distribution of the photons reflected would enable incorporating this factor accurately into our model.

Sublimation fluxes for different amounts of atmosheric and intermixed surface dust: We have calculated sublimation fluxes (SF) for a number of combinations between the total atmospheric dust optical depth and the type of the CO_2 ice surface. The SF have been normalized to the total flux incident on the atmosphere and calculated as a difference between the spectrally integrated fluxes absorbed and emitted by the surface (set to sublimate at 147 K). An example calculation is presented on Figure 1. It corresponds to a particular grain size, but this parameter has been varied as well [11]. The main model results reproduce qualitatively the observational comparison between 1999 (relatively dust free year) and the 2001 (global dust storm) south polar cap regression patterns, observed by MGS and described in [2, 11]:

1. The absorption of surface frost with a high dust content (1 wt% being the upper limit [8]) is dominated by visual photons. Therefore the attenuation of direct solar radiation by atmospheric dust results in retarded sublimation.

2. Conversely, the absorption of regions with low dust content is dominated by IR photons, owing to the

high visual albedos. In this case the visual-to-IR redistribution of the energy incident to the surface, caused by atmospheric dust, leads to increased sublimation rates.

3. There is a wide range of combinations between surface dust content and frost grain size for which the CO_2 sublimation rates show only subtle variations with the amount of atmospheric dust load. In these cases the surface absorption is distributed equally between visual and IR wavelengths, so the overall atmospheric dust effect is not important. It should be emphasized that the discussed region of the parameter space represents a "typical frost" [8] and consequently explains the apparent insensitivity of the *average decay rate* of the south seasonal cap to dust storm activity [2]. Strong coupling between sublimation and atmospheric dust exists primarily on *local scale* for regions with "deviant" surface albedos such as the Mountains of Mitchel (high visual albedo, faster regression in 2001 [1,3]), and the "Cryptic" region [12] (low visual albedo, slower regression in 2001 [3]).

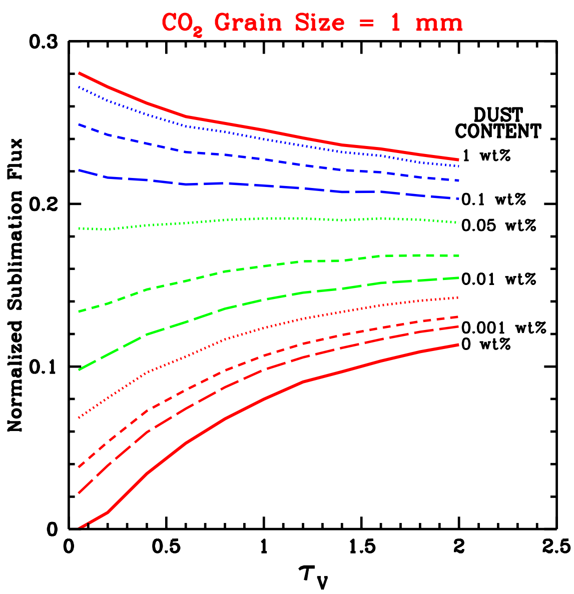


Figure 1. CO_2 Sublimation Flux vs. Total Atmospheric Dust Optical Depth at 550 nm for a frost grain size of 1 mm and various contents of intermixed surface dust.

A note should be made about the possibility that newly deposited surface dust played a role in the faster regression of bright regions (like the Mountains of Mitchel) by lowering the surface albedo and thus increasing the absorbed flux and consequently the sublimation rate. While this scenario cannot be ruled out, it fails to explain the slowing down of the dark regions such as the Cryptic region, which is consistent with the effect of atmospheric dust.

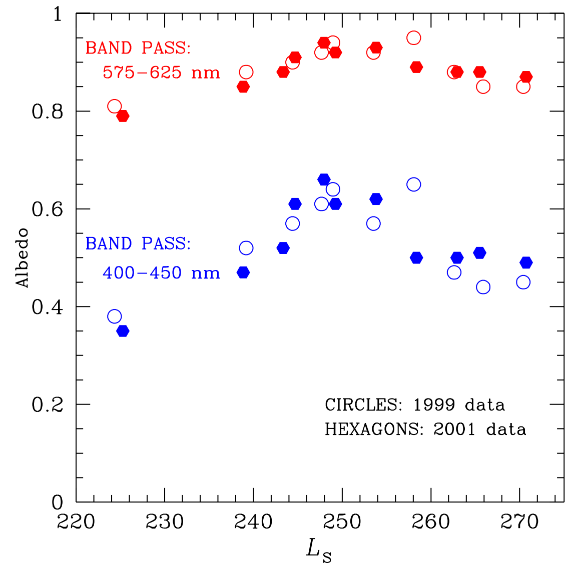


Figure 2. Top-of-the atmosphere Lambert albedos from 1999 and 2001 MOC data, averaged over a region within the perennial residual south polar cap.

In progress: In addition to the presented overview, we will discuss improvements of the atmospheric modeling, and some aspects of the study of the perennial residual south polar cap. The high maximum values of the red visual albedo of the residual cap (Figure 2) suggest small contents of intermixed surface dust and low sublimation rates at dust free conditions. The maximum values of the red and blue albedo measurements (like L_s~148°, 1999) most likely have minimal atmospheric contribution and can be used to constrain the ice properties through models of surface albedo spectra [8]. The likely higher sublimation the cap has undergone in 1972 (Mariner 9 observations) will also be addressed.

Acknowledgement: Four of the authors (BPB, MJW, PBJ, GBH, and JLB) were supported by grants from the Mars Data Analysis Program. JEB was supported by NSF Grant AST-9819928.

References: [1] Bonev, B. P. et al. (2002) *GRL*, *29*, 2017, doi:10.1029/2002GL015458. [2]. James, P. B. et al. (2003), *Intern. Mars Conf. VI,* #3093. [3] Titus, T. N. and Kieffer, H. H. (2002) *LPS XXXIII*, #2071. [4]. James, P. B. et al. (2000) *DPS 32, #51.10.* [5] Bjorkman, J. E. and Wood, K. W. (2001) *ApJ*, *554*, 615-623. [6] Wolff, M J. and Clancy, R. T. (2003) *JGR*, in press. [7] Tomasko et al. (1999) *JGR, 104, 8987-9007*. [8] Hansen, G. B. (1999) *JGR, 104*, 16,471-16,486. [9] Glenar et al. (2002), *DPS 34, #15.23.* [10] James et al. (2001) *JGR, 106, 23,635-23,652*. [11] Bonev, B. P. et al. (2003), *Intern. Mars Conf. VI*, #3111. [12] Kieffer, H. H. et al. (2000) *JGR, 105, 9653-9699.*

ICE IN THE POLAR REGIONS OF MARS: EVIDENCE FOR WET PERIODS IN THE RECENT PAST.

W. V. Boynton[1,2], M. Chamberlain[1], W. C. Feldman[3], T. Prettyman[3], D. Hamara[1], D. Janes[1], K. Kerry[1] and the GRS Team. [1]Lunar and Planetary Lab, Univ. of Arizona, Tucson AZ 85721, [2]Department of Planetary Science, Univ. of Arizona, Tucson AZ 85721, [3]Los Alamos National Laboratory, Los Alamos N.M 87545.

Introduction: In our earlier work [1] we showed that the south polar region of Mars had high contents of subsurface ice. This conclusion was based on a preliminary analysis of data from the Mars Odyssey Gamma-Ray Spectrometer instrument suite. Subject to the assumptions made at the time, the GRS observations in the south-polar region could be fit to a two-layer model consisting of a "dry" upper layer with low hydrogen content and an ice-rich lower layer. The upper layer ranged in H content, expressed as H_2O, from 2% near -45° latitude to 3% near -75°. The thickness of the upper layer, expressed as column density, ranged from >100 g/cm^2 at -55° latitude to 40 g/cm^2 near -75°. The ice content of the lower layer was inferred to be 35 ± 15% with the higher end of the range preferred.

Several necessary assumptions were made in this work, the most significant of which was that we needed to make a normalization for the absolute flux of both gamma rays and neutrons. We now know that both of these assumptions were incorrect, and we have determined better normalization values. For the neutrons, we normalize to the case of the thick CO_2 seasonal frost in the north overlying the water-ice residual cap [3]. For the gamma rays, we normalize to the frost-free northern residual cap [4]. The effect of these re-normalizations is to increase the amount of subsurface ice compared to the earlier work.

Results: The results are shown in the first two maps in fig. 1. In these maps, the gamma-ray flux has been converted to equivalent amount of H_2O assuming that the hydrogen is evenly distributed with depth, *i.e.* there is not an overlying ice-free layer. This assumption is clearly incorrect, but it serves to provide a firm lower limit to the amount of H_2O in the soil. If, as seems clear, the ice-rich regolith is covered by an H_2O-poor layer, the H_2O content in the lower layer must be substantially higher because the overlying layer will attenuate the gamma-ray flux. In both polar regions, away from the residual cap, this lower limit to the H_2O content is around 40%. A similar analysis based on the epithermal neutron flux, again assuming the H_2O is uniformly distributed with depth, shows a minimum limit of around 60% H_2O in the polar regions [5].

Another interesting result is to look at the limit on the thickness of the upper "dry" layer in the case of a two-layer model (fig. 1). These maps have been made by assuming the ice-rich layer is pure ice, and that the gamma-ray signal is attenuated by the overburden of the dry layer (here assumed to be 3% H_2O). Again for both polar regions, we see that the maximum thickness the upper layer could have is about 20 g/cm^2. This result is inconsistent with the results of the data from the GRS Neutron Spectrometer, as the thermal neutron flux clearly shows a minimum in the south around 70 deg latitude [2,1], and this minimum occurs when the H_2O-rich layer is buried by around 50 g/cm^2 of dry material, a result that is nearly independent of the amount of H_2O in the lower layer.

Discussion: We are drawn now to the conclusion that the simple two-layer model does not describe the observations. This result is not surprising considering that the footprint of the GRS is large, about 550 km, and a variety of different H_2O contents and depths could co-exist in our footprint.

Nevertheless, one of the important observations is still the very large quantity of ice found in the polar regions. The minimum amount, about 60% by mass, requires that an emplacement mechanism other than vapor diffusion to fill pore spaces was responsible for depositing the ice in the polar regions. This conclusion follows from consideration of the data in Table 1, which shows the relationship between volume percent and weight percent assuming a bulk grain density of 2.5 g/cm^3. The column "Ice-free density" is the density of the soil without ice assuming the ice was completely filling the pore space. If we allow for some experimental uncertainty on the GRS results, it is still clear that the minimum H_2O content is conservatively between 50% and 65% by mass. When converted to volume %, we require unreasonably low-density soils to have sufficient pore space to accommodate the high concentration of ice found by the GRS.

One mechanism that could emplace with a high ice/dust ratio is the deposition ice in the form of snow or frost directly onto the surface in the polar regions. In this case the deposition rates of ice and dust would determine the bulk ice/dust ratio. Obviously for this mechanism to satisfy the GRS observations, the rate of ice deposition would have to be higher than the rate of dust deposition.

Table 1. *Relationship between ice content and ice-free soil density.*

Weight % ice	Volume % ice	Ice-free density
35%	59%	1.01
50%	73%	0.67
65%	84%	0.41

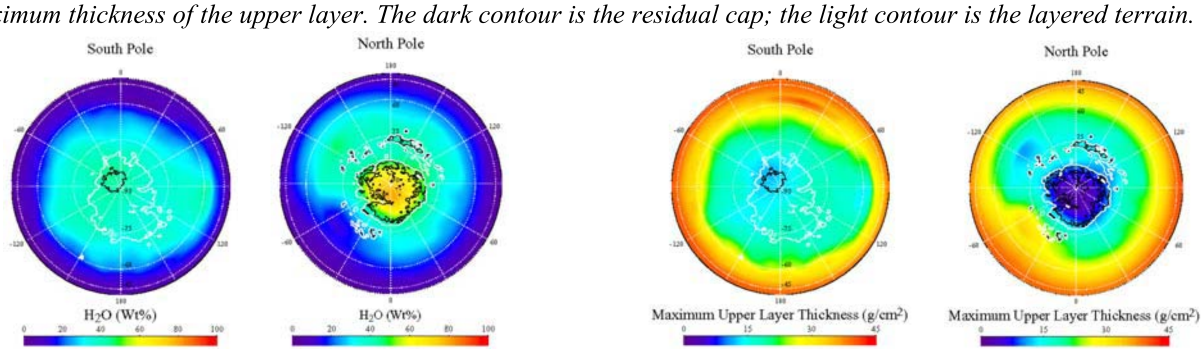
Presumably the dust and ice could be deposited at different times over the course of a Mars year, but the ice would have to be present on the surface year round. Any significant seasonal sublimation of ice would leave behind a lag deposit of dust which would dilute the snow or frost deposited the next year. Clearly in order to build up the regolith with a high ice/dust ratio, the lag deposit cannot be greater than the layer of ice which is deposited in any given season.

The current Mars epoch is clearly not conducive to the deposition of snow or frost on the surface to survive throughout the year, but if this kind of process is responsible for emplacing the ice with a high ice/dust ratio, an important question is how long ago did this happen. Even though the amount of ice seems to be inconsistent with its emplacement by vapor deposition, it seems clear that that the process of vapor deposition and ice sublimation [6,7] is operating on Mars. This conclusion is based on the observation that the line marking the beginning of the ice-rich region in the south [1] precisely matches the predictions for where subsurface ice should be stable under current martian conditions. Even though the high content of ice could not be emplaced by vapor deposition, once emplaced under the appropriate wet conditions, it can subsequently sublime away to its stable depth leaving a lag deposit above it when the climate changes to one more like the present.

Since the deposition/sublimation mechanism appears to be viable now, it must also work under other conditions with different obliquities. Under such conditions, the depth to the frost point will change [7]. Because the high ice content is within about 20 g/cm^2 of the surface and because vapor deposition cannot re-emplace ice in the high concentrations observed, it would appear that the maximum depth to the frost point has never exceeded this value of around 20 g/cm^2 after the ice was emplaced in the form of snow or frost. If, as seems likely, conditions in the past were such that the lag deposit could have gotten much thicker, the observation of the near-surface ice-rich deposit implies that the wet conditions for snow or frost deposition occurred more recently.

References: [1] Boynton *W. V. et al.*, (2002) *Science, 297,* 81. [2] Feldman W. C. *et al.*, (2002) *Science, 297,* 75. [3] Feldman W. C. *et al.*, (2003) *GRL*, submitted [4] Boynton W. V. *et al.*, (2002) 6th Mars Conf. Abstract #3259. [5] Feldman W. C. *et al.*, (2002) 6th Mars Conf. Abstract #3218. [6] Leighton R. B. and Murray B. C. (1966) *Science, 153,* 136. [7] Mellon M. T. and Jakosky B. M. (1993) *JGR, 98,* 3345..

Fig. 1. *Polar stereographic views of the minimum H_2O content inferred from the Mars Odyssey GRS (left) and maximum thickness of the upper layer. The dark contour is the residual cap; the light contour is the layered terrain.*



INTERANNUAL ATMOSPHERIC VARIABILITY SIMULATED BY A MARS GCM: IMPACTS ON THE POLAR REGIONS. Alison F.C. Bridger[1], R. M. Haberle[2] and J. L. Hollingsworth[3]: [1]Department of Meteorology, San Jose State University, San Jose CA 95192-0104, USA (bridger@met.sjsu.edu); [2,3]NASA Ames Research Center, MS 245-3, Moffett Field, CA, 94035-1000, USA (robert.m.haberle@nasa.gov, jeffh@humbabe.arc.nasa.gov).

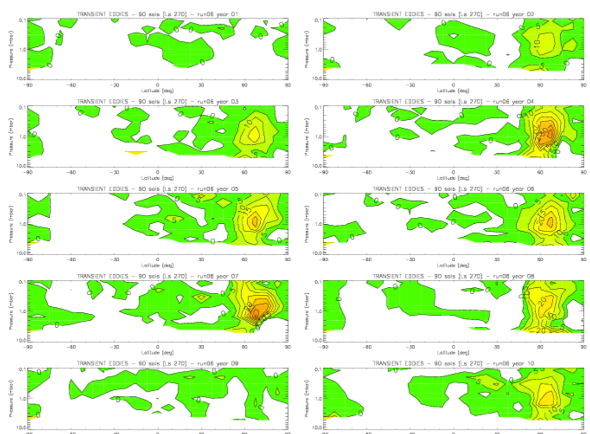
Abstract: It is often assumed that in the absence of year-to-year dust variations, Mars' weather and climate are very repeatable, at least on decadal scales. Recent multi-annual simulations of a Mars GCM reveal however that significant interannual variations may occur with constant dust conditions [1]. In particular, interannual variability (IAV) appears to be associated with the spectrum of atmospheric disturbances that arise due to baroclinic instability. One quantity that shows significant IAV is the poleward heat flux associated with these waves. These variations – and their impacts on the polar heat balance – will be examined here.

Background: The dust loading of the martian atmosphere can vary significantly from location-to-location, from sol-to-sol, and from year-to-year. The surface dust reservoir varies too. However, were the surface and atmospheric dust distributions to remain fixed from one year to the next, it seems likely that the resulting atmospheric circulation at a give season would be repeatable from year-to-year. This follows from the absence of oceans on Mars.

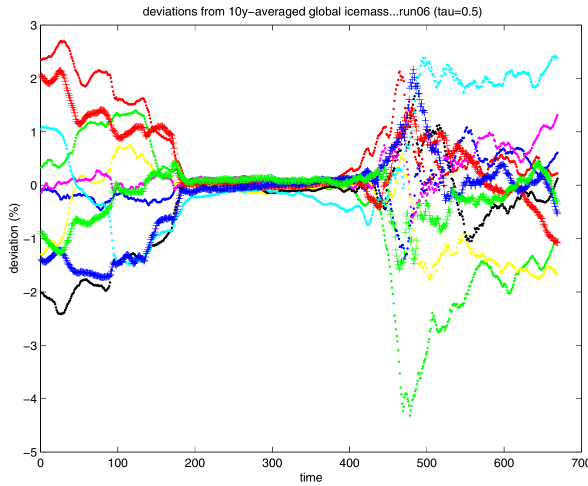
We have recently conducted several multi-annual simulations with the NASA-Ames Mars General Circulation Model (MGCM; [2]). These extend for 10 years beyond a spin-up year (some 40 year simulations have also been performed). Some simulations have fixed dust all year (e.g., with a visible opacity of 0.5), while others have opacities varying through the year (e.g., following Viking observations). In these cases, the dust loading and distribution at a given *Ls* is the same during every year of the simulation. In a new series of simulations, we randomly specify the annual dust variation to fall between a low dust scenario (e.g., 0.3) and a high dust scenario (e.g., Viking)..

Results: In the first set of simulations (opacity fixed at 0.5 for all time), there is significant IAV in a number of parameters. For example, sol-averaged surface pressures at higher latitude sites (e.g., the Viking Lander 2 site) show variations of several tenths of a millibar from the 10-year average during the midwinter season [1]. This is an O(10%) variation from the long-time mean. Likewise, sol-averaged surface temperatures can be as much as 10-20 K above/below the 10-year average at these same sites. Such IAV is typical in the northern winter season at higher northern latitudes; it is far weaker in the corresponding southern winter season.

The region of high IAV is coincident with the location (in space and season) of baroclininc wave activity, suggesting a connection between the baroclinic wave activity and IAV. We have computed the poleward-directed heat flux $\left(\overline{v'T'}\right)$ associated with these eddies (on Earth, this is a substantial fraction of the total poleward atmospheric heat flux). Figure 1 shows the resulting distributions of $\overline{v'T'}$ computed over a 90 sol period centered on Ls 270 for each of the 10 years in the fixed opacity 0.5 simulation (the north pole is to the right on each plot, and the contour interval is 5 Km/s, with larger values shaded). Clearly, there are significant year-to-year variations in heat transport into the winter polar regions; the eddy heat flux in some years is virtually zero (e.g., years 01 and 08), whereas in other years values are O(30-40 Km/s). By comparison, poleward-directed heat fluxes associated with topographically-forced stationary waves have magnitudes O(10 Km/s) and show much less year-to-year variation [1].



In the light of these variations in eddy heat fluxes into to winter polar region, we examine impacts on the polar heat budget. For example, the total accumulated ice mass in the northern polar region, computed as a function of *Ls*, deviates from the 10 year-average by up to ±O(3%) (Figure 2; each color represents a different year, and time is plotted a sol number, where sol 0 is *Ls* 0).



In this talk, we will expand upon the consequences of IAV for the polar region, with attention focussed on those quantities that might be detectable in long-term observations.

References: [1] Bridger,A.F.C., J. L. Hollingsworth, R.M.Haberle and S.R. Rafkin (2003), Granada workshop. [2] Haberle, R.M. *et al* (1999), JGR, 104, p. 8957.

AN AUTOMATED, LOW MASS, LOW POWER DRILL FOR ACQUIRING SUBSURFACE SAMPLES OF GROUND ICE FOR ASTROBIOLOGY STUDIES ON EARTH AND ON MARS.

G. A. Briggs, C. McKay, NASA Ames Research Center, J. George, G. Derkowski, NASA Johnson Space Center, G. Cooper, K. Zacny, University of California, Berkeley, R. Fincher Baker-Hughes International, W. Pollard, McGill University, S. Clifford, Lunar and Planetary Institute

As a project that is part of NASA's Astrobiology Technology & Instrument Development Program (ASTID), we are developing a low mass (~20kg) drill that will be operated without drilling fluids and at very low power levels (~60 watts electrical) to access and retrieve samples from permafrost regions of Earth and Mars. The drill, designed and built as a joint effort by NASA JSC and Baker-Hughes International, takes the form of a down-hole unit attached to a cable so that it can, in principle, be scaled easily to reach significant depths.

A parallel laboratory effort is being carried out at UC Berkeley to characterize the physics of dry drilling under martian conditions of pressure, temperature and atmospheric composition. Data from the UCB and JSC laboratory experiments are being used as input to a drill simulation program which is under development to provide autonomous control of the drill.

The first Arctic field test of the unit is planned for May 2004. A field expedition to Eureka on Ellesmere Island in Spring 2003 provided an introduction for several team members to the practical aspects of drilling under Arctic conditions. The field effort was organized by Wayne Pollard of McGill University and Christopher McKay of NASA ARC. A conventional science drill provided by New Zealand colleagues was used to recover ground ice cores for analysis of their microbial content and also to develop techniques using tracers to track the depth of penetration of contamination from the core surface into the interior of the samples.

VAST ATMOSPHERIC COLD TRAPS WITHIN THE LARGE RINGED TOPOGRAPHIC FEATURES IN NE SIBERIA: IMPLICATION FOR MARS. G. A. Burba, Vernadsky Institute of Geochemistry and Analytical Chemistry, 19 Kosygin St., Moscow 119991, Russia e-mail: burba@online.ru

Introduction: The ridges within the vast mountain country of the NE Siberia have been revealed recently to comprise two giant ring structures (RS), 500 and 400 km in diameter [1] . Such evidence is a new look on the general topographic structure of the area and could be of importance for climatic consequences.The central lower areas of these structures, which are enclosed within a ring wall of mountain ridges, work as giant "cold traps" for the atmospheric air. During the winter seasons the temperature inversion in the near-surface layer of the atmosphere take place there.

Topographic description: The highest area of the North-East Siberia, Russia, consists of the mountain ridges arranged as the two adjacent RS. These RS are located between Lena River Mouth and Magadan Coast of the Sea of Okhotsk. Each of the two rings have circular pattern of mountain ranges, which encircle a plateau area in the central part of the ring. The general topographic shape of each RS is a complex of high mountain rings (altitudes 1000 to 3000 m) with a lower, but still topographically high (400-1200m) plateau inside, and lowland plains outside (50-200 m). The outer diameter of each structure is about 700 km. The rim crest diameters are about 500 km for Yana Ring Structure (YRS), NW in the couple, and 400 km for Oymyakon Ring Structure (ORS), SE one. YRS is located between 63 and 70°N, 125 and 140°E, and ORS – between 61 and 67°N, 136 and 151°E. In general YRS is somewhat lower than ORS, especially with its inner area. The structures are named after the Yana River and Oymyakon settlement, which are located within each of the them.

Air temperature data: The weather observations at Verkhoyansk on Yana River, near the center of YRS, and at Oymyakon on Indigirka River, near the center of ORS, have determined as early as in 1930s that these areas are the coldest places at the Northern hemisphere of the Earth with the minimal records of air temperature as low as – 68° C at Verkhoyansk and – 71° C at Oymyakon. Further long-term meteorological data revealed the areas of Verkhoyansk and Oymyakon as the enclosed regions with very low air temperatures in winter. Both areas have value of the mean monthly air temperature for January defined as "lower than – 48° C" [2]. And over the whole NE Asia such low values are typical ONLY to these two areas, the central parts of YRS and ORS.

Interpretation: Now, after a new look at the topographic structure of the NE Siberia, it could be explained that each of these "cold poles" is located within the lower areas at the central parts of the large ring structures (intermountain basins), which works as a giant cold traps being enclosed within a ring wall of mountain ridges. Such situation could lead to the circumstances of the temperature inversion in the near-surface layer of the atmosphere.

Implication for Mars: Couldn't the similar situation with the air temperature take place during the winter season within the craters and large basins in the polar regions of Mars?

References: [1] Burba G. A. (1995) *LPSC XXVI*, 189-190. [2] Atlas SSSR (1984) Map "Air temperature", 99 (Atlas of the USSR – *In Russian*).

Climactic history from south polar residual cap geomorphology. S. Byrne[1], A.P. Ingersoll[1], A.V. Pathare[1] and F.S. Jiron[1], [1]Division of Geological and Planetary Sciences, California Institute of Technology, Mail-stop 150-21, 1200 East California Blvd., Pasadena, CA 91125, USA. shane@gps.caltech.edu, api@gps.caltech.edu, avp@gps.caltech.edu, franklin@its.caltech.edu

Introduction: The southern residual CO_2 cap is a small (88,000 km^2) high-albedo feature which sits atop the much thicker and more extensive southern layered deposits. It persists throughout the year in contrast to the thinner seasonal CO_2 frost which appears and disappears each year. The solid CO_2 which lasts throughout the year both controls circulation patterns regionally and buffers the atmospheric pressure globally. In turn this residual CO_2 deposit is affected by changes in environmental conditions wrought by external forces such as dust storm activity.

This solid CO_2 reservoir has been theorized and observed for decades [1, 2]. Mars Global Surveyor data have revealed this CO_2 residual deposit to contain a rich variety of geomorphic features [3]. One of the most ubiquitous classes of features on the residual cap are the flat-floored quasi-circular pits with steep walls (see Fig. 1), dubbed Swiss-cheese features.

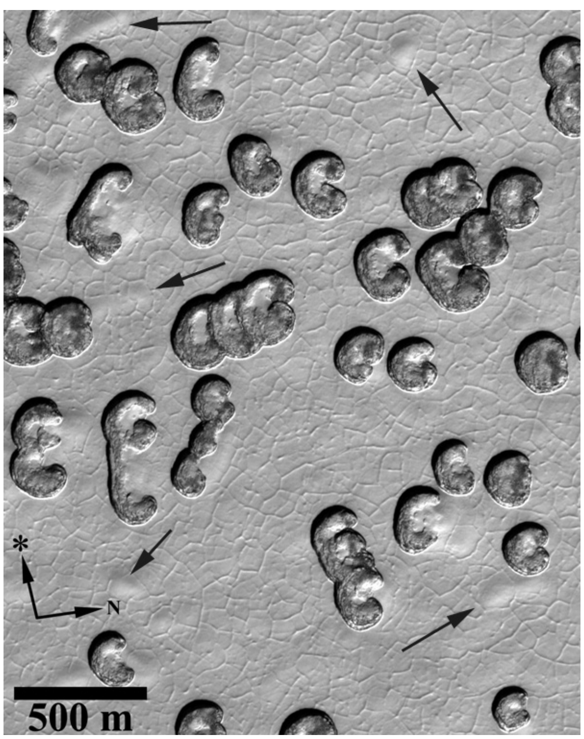


Figure 1. Surface of the Martian residual CO_2 cap showing heart-shaped depressions (Swiss-cheese features). Arrows denote shallow bowls, discussed later. Sub-frame of MOC narrow angle image E13/00663, 87° S, 352° E, L_s 323° (late southern summer), bottom arrows denote direction to sun and north.

Feature description: Swiss-cheese features are characterized by flat floors and steep walls. Features in the region shown in figure 1 and discussed in the next section have a definite symmetry axis found to point in the north-south direction (7). Features in other parts of the cap commonly posses a raised central island in their center surrounded by a moat.

Late in the southern summer when the seasonal covering of CO_2 frost has been removed the walls can be seen to be darker than the surrounding flat upper surfaces.

No changes in shape or size were observed in these features over timescales of a single season (3, 5) but *Malin et al.* (6) observed, using images separated by one Martian year, that the walls of these depressions are expanding laterally at rates of 1-3 m/yr. The rapidity of this expansion is only possible in a medium as volatile as CO_2 ice. *Byrne and Ingersoll* (4) modeled the evolution and growth of these depressions as a hole in a layer of CO_2 ice underlain by water ice and matched their observed expansion rates and morphologic properties, including the flat floors and steep walls.

Swiss-cheese features in local regions all exhibit the same depth, *i.e.,* they all penetrate to the base of the CO_2 deposit, their downward expansion being halted by the involatile nature of the water-ice substrate (4). Different areas on the residual cap exhibit differing thicknesses of the overlying CO_2 slab. The thickest CO_2 deposits appear to be 8-10 meters; however most of the rest of the cap has a much thinner covering. In features which possesses moats and raised central islands it is the moat which penetrates to the underlying water ice layer (7). Modeling results indicate however that the thickness of the overlying CO_2 slab does not affect the retreat rates of the walls.

Environmental history from Swiss-cheese feature populations: The fast rate of wall retreat observed (6) and modeled (4) combined with the small sizes of the depressions indicate that all Swiss-cheese features visible today were created recently (7). Our modeling results indicate that walls should retreat at constant rates once the initial formation phase is over.

In previous work we selected a study region within the residual cap and measured the sizes and orientations of all Swiss-cheese features that it contained (see figure 2). The size distribution is quite narrow indicating that the measured population has initiated over a very short period of time. We estimate this formation period to have occurred 43-217 Martian years ago. The large spread in age is due to the large spread in modeled wall retreat rates. Values ranging from 0.5-2.5 m/yr are possible with different subsurface albedo conditions (4).

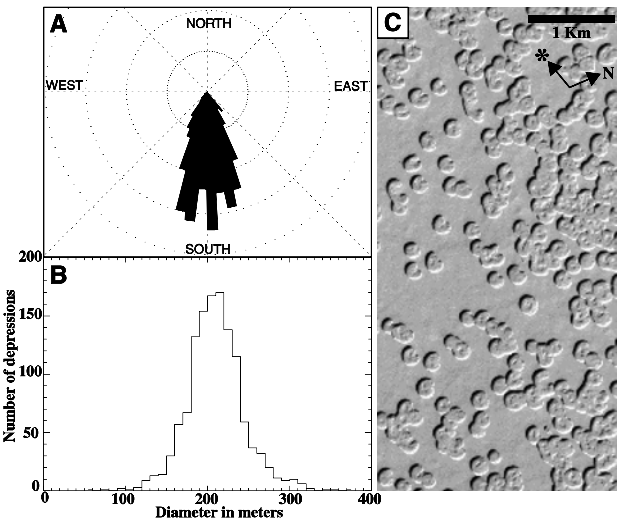


Figure 2. Taken from (7). **A)** Rose diagram of Swiss-cheese feature orientations. Azimuth refers to the direction from the cusp to the opposite wall, through the center of the depression. The total number of features measured was 370, the mean azimuth was within 0.2° of south and the standard deviation was ~17°. Concentric circles indicate number in increments of 10. **B)** Histogram of sizes of identifiable Swiss-cheese features. Diameter here refers to the longest axis for non-circular features. The total number of features measured is 1263, the mean size was 217m and the standard deviation was ~35m. **C)** Many Swiss-cheese features destroying the upper 8m thick layer in a sample view of the study area. Sub-frame of MOC narrow angle image M07/04167, taken at 86.8° S, 355° E, and L_s 211°.

Some change in environmental conditions started this particular population of features growing. Unfortunately we have only begun to observe Mars in detail over the past few decades so understanding what the nature of this event may have been is difficult.

The shallow bowls that are indicated by arrows on figure 1 may be a new generation of Swiss-cheese features. If this is the case we would expect from our modeling that these features would be less than 30 Martian years old. One significant event in Martian history that may have been responsible for their genesis is the 1971 global dust storm. This would lead to increased erosion of the residual cap, but it is unclear why that would initiate the growth of isolated depressions. If the number density of features is an indication of the severity of the event that initiated them, then the event which initiated the main population discussed above and in figure 2 must have been much more severe than this dust storm.

Work to be presented: There are several avenues of research that we are perusing and which will be presented.

- We will report on investigations into the overall mass budget of the CO_2 residual cap. If the Swiss-cheese feature walls are retreating and the mass is not being recondensed elsewhere on the cap then the cap itself will disappear within a few Martian centuries. It seems unlikely that we are observing Mars at such a special time in its history.
- A large range of expansion rates is possible depending on the subsurface albedo profile (4, 7). This is a major obstacle in using our modeling results to date observed Swiss-cheese populations. We will attempt to measure the subsurface albedo profile by examining Mars Orbiter Camera (MOC) images of exposures in the walls of the Swiss-cheese features.
- We have already modeled the initial growth of Swiss-cheese features. However, we always initiated our modeled depressions from pre-existing small surface features. We will report on more detailed investigations into the genesis of Swiss-cheese populations and the possible link to climactic events such as the 1971 dust storm.
- We will continue to catalogue new population statistics for different regions in the residual cap. Each distinct new Swiss-cheese population that we can identify will give us information on previous environmental events that may have occurred.

Investigations into Swiss-cheese features have the potential to describe the last millennia of Martian polar history. It will provide a link from present conditions to longer term variations in Martian climate (due to changing orbital elements) which are perhaps recorded in the layered deposits.

References: [1] Leighton, R. B., and B. C. Murray, *Science* (1966) *153*, 136-144. [2] Kieffer, H. H. (1976) *JGR*, *84*, 8263-8288. [3] Thomas P. C. et al. (2000) *Nature*, *404*, 161-164. [4] Byrne, S., and A. P. Ingersoll (2003) *Science, 299*, 1051-1053. [5] Malin, M. C., and K. S. Edgett (2001) *JGR*, *106*, 23429-23570. [6] Malin, M. C. et al. (2001) *Science*, *294*, 2146-2148. [7] Byrne, S., and A. P. Ingersoll (2003) *GRL, 30(13)*.

The most recent section of the south polar layered deposits. S. Byrne[1] and A.B. Ivanov[2], [1]Division of Geological and Planetary Sciences, California Institute of Technology, Mail-stop 150-21, Pasadena, CA 91125.. [2]Jet Propulsion Laboratory, MS168-416, Pasadena, CA 91106. shane@gps.caltech.edu, anton.ivanov@jpl.nasa.gov

Introduction: The polar layered deposits of both hemispheres contain a record of Martian environmental conditions. In this study we will assemble a fully three dimensional stratigraphic sequence for the topmost section of the southern layered deposits.

A prominent layer sticks out as a bench part-way down the section. We will correlate other layers relative to this one in exposures on opposite ends of the section. In this way we hope to learn how this part of the overall southern layered deposits is organized in three dimensions.

The necessary datasets which will be utilized will be hires topographic grids from the Mars Orbiter Laser Altimeter (MOLA) provided by the MOLA team and high resolution Mars Orbiter Camera (MOC) images with spatial resolutions of 1.4 to 12 m/px. Due to continuous repeat coverage of the polar orbiting Mars Global Surveyor and Mars Odyssey (MGS & MO) spacecraft this area has very high coverage. MOC frames almost totally cover the entire exposure which makes it ideal for this kind of study.

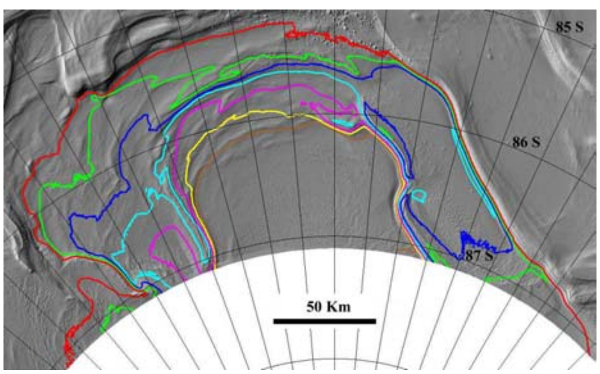


Figure1: MOLA derived shaded relief view of the top of the south polar layered deposits illuminated from the left. The coloured lines represent elevation contours from 4000m to 4600m (red to brown) at 100m intervals.

Regional context and marker bed: The layered sequence in the southern layered deposits can be divided into discrete sections based on elevation (see figure 1). The topmost section is centered on 87° S 5° E and its exposures span elevations of 4300m - 4600m. The highest point of the layered deposits (~4800m) also lies within this area. The top surface is covered with a thin skin of CO_2 ice which comprises part of the southern residual cap.

The layers comprising this section are exposed in scarps to the east and west at 350° E and 20° E as shown in figure 1. The northern edge of this section is not well exposed due to a smooth mantling cover and disruption from the McMurdo secondary crater field. The southern end of this section is well exposed on continuations of the eastern and western scarps however the lack of spacecraft data poleward of 87° S prohibits analysis in this region.

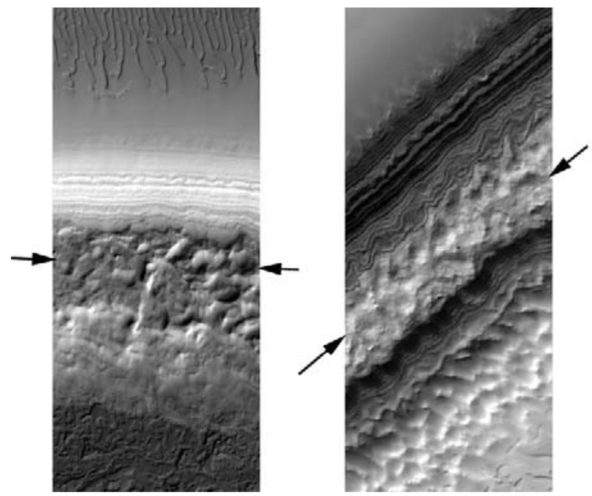


Figure 2: MOC images M08/06301 (left) and M08/02672 (right) from the western and eastern scarps respectively. Scale in both cases is the same (each image 2.8 km wide). Illumination from lower right and upper left respectively. Elevation decreases from top to bottom by 400-500 meters in both cases.

Figure 2 shows an example of two MOC frames separated by ~100 km. The same heavily pitted topographic step is visible part way down the scarp in both cases. This layer will serve as a marker bed by which the position of other layers can be measured.

Work to be presented: We will report on variations in elevations of layers within the topmost section of the south polar layered deposits. We will consider models where the layers are represented as inclined planes and surfaces containing low-order curvature.

We will document changes in strikes and dips as a function of elevation which can be interpreted as erosional unconformities. A lack of erosional unconformities within the section would imply a stable polar environment over the time it took this section to form.

CONSTRAINTS ON THE WITHIN SEASON AND BETWEEN YEAR VARIABILITY OF THE NORTH RESIDUAL CAP FROM MGS-TES. W.M. Calvin[1], T.N. Titus[2], and S.A. Mahoney[1]. [1]Dept. of Geological Sciences, MS172, University of Nevada, Reno, NV 89557, wcalvin@unr.edu, [2]U.S. Geological Survey, Flagstaff, AZ 86001, ttitus@usgs.gov.

INTRODUCTION: There is a long history of telescopic and spacecraft observations of the polar regions of Mars. The finely laminated ice deposits and surrounding layered terrains are commonly thought to contain a record of past climate conditions and change. Understanding the basic nature of the deposits and their mineral and ice constituents is a continued focus of current and future orbited missions. Unresolved issues in Martian polar science include a) the unusual nature of the CO_2 ice deposits (“Swiss Cheese”, “slab ice” etc.) b) the relationship of the ice deposits to underlying layered units (which differs from the north to the south), c) understanding the seasonal variations and their connections to the finely laminated units observed in high-resolution images and d) the relationship of dark materials in the wind-swept lanes and reentrant valleys to the surrounding dark dune and surface materials.

Our work focuses on understanding these issues in relationship to the north residual ice cap. Recent work using Mars Global Surveyor (MGS) data sets have described evolution of the seasonal CO_2 frost deposits [1-5]. In addition, the north polar residual ice cap exhibits albedo variations between Mars years and within the summer season [4-6]. The Thermal Emission Spectrometer (TES) data set can augment these observations providing additional constraints such as temperature evolution and spectral properties associated with ice and rocky materials. Exploration of these properties is the subject of our current study.

MGS-TES DATA SET: Mars Global Surveyor began systematic mapping of the planet in March of 1999. The Mars season was early northern summer, L_s=104. As Kieffer and Titus [2] noted, the seasonal CO_2 frost had disappeared by that time and they observed the growth of higher albedo regions (onset of winter frosting) beginning at L_s ~ 164. James and Cantor [4] monitored the seasonal cap recession of 2000 and found the signature of the residual cap emerging under the seasonal CO_2 frost between L_s 60 and 70. We somewhat arbitrarily mark our timeframe of interest as L_s 65 to 165. This allows study of the albedo, temperature and spectral properties of the residual cap through the seasonal cap and the “bare” residual cap. In this regard we can compare variations within the summer season to properties observed under thin or sparse CO_2 frost coverage. The table below illustrates that there are two full and one partial northern summer seasons of data acquired. The data from the first two summers are available via the PDS and the second full summer’s data are being released over the next several months.

Northern Summer	L_s 65	L_s 165	Mission Phase
1-partial	4-Dec-98 (pre-mapping)	5-Jul-99	Map
2-full	20-Oct-00	22-May-01	Map/Ext
3-full	8-Sept-02	9-Apr-03	Ext-Ext

PREVIOUS OBSERVATIONS: Earlier workers noted the change in albedo in a number of north pole bright outliers and in the overall coverage by bright ice deposits both between Viking summers and between Viking and Mariner 9 [6-8]. This was possibly attributed to the affects of global dust storms [8]; however Bass et al. [6] showed that significant within season variation occurred among Viking imagery. Cantor et al. [5] also explored this variation in MOC images and noted brightening at the edges within a given Mars summer season and changes in the cap appearance at the same L_s between MGS years (1 and 2 as defined in the table above). The early season appearance was possibly attributed to the occurrence of a large dust storm the previous year, and it was noted that late season ice extent recovers to Viking levels but exhibits small-scale inter-year variations that may not be related to globally repeated weather events [5].

These brightness variations are most extensively observed in the quadrant from 0 to 120 east longitude (lower right) on a polar stereographic projection (see Figures 1 and 2). Typically the large “tail” below the Chasma Boreal and its associated plateau (see Zuber et al. [9] for topography) remain bright while highly sloped cap edges and valleys are defrosted in the early season. Malin and Edgett [10, Figure 76] also call out variations on the end of the southern “tail” (-15 to -40 longitude) and in spiral structures above the Chasma Boreal observed at the same L_s in different Mars years. We note there also appears to be substantial frost variation at the “source” of Chasma Boreal (10 to 25E) from Viking to recent years, being darker in the present epoch in MOC and TES albedos than it was during Viking (Figures 1 and 2).

PRELIMINARY RESULTS: We are examining these seasonal and interannual variations of the north cap in the TES data set. This includes comparison of TES albedo with visible appearance in MOC imagery, merging TES, MOC and Viking data with high-resolution topography, and mapping spectral properties associated with seasonally varying and more constant units within the north residual cap. Figure 2 shows initial results for the early season of MGS "Summer 2" acquired from 12/20/00 to 1/03/01 or L_s ~ 92 to 98. Early season "defrosted" units are seen quite similar to the MOC and Viking results [5, 6, and 10] described in the preceding section. We will present the evolution of TES albedos within this MGS northern summer and the ability to use temperature and slope as a proxy for units which are susceptible to summer and annual changes.

TES spectra are notoriously difficult to work with for these cold polar temperatures. Kieffer et al. [1] show representative examples, but typically use large regional averages to improve the signal-to-noise, especially at higher wavenumbers (>1200 cm-1) where the radiance is dropping rapidly. In an effort to examine seasonal trends they developed several multichannel "bands" and used brightness temperatures (T_b) of these broadband averages and their differences to define surface units. Kieffer and Titus [2] presented data either longitudinally averaged or using these broadband temperatures. We are currently developing methods of handling the spectral variations including use of 2-temperature models to fit mixed pixels of warm rock and cold ice as well as cold surfaces under a warmer atmosphere (e.g. [11]). We will report on the status of various methods and their comparison to previous approaches. We will present preliminary spectral characteristics of ice units that are seasonally variable, seasonally stable and of non-ice units both within and surrounding the residual north cap.

REFERENCES: [1]Kieffer et al, *JGR*, **105**(E4), 9653-9699, 2000. [2]Kieffer and Titus, *Icarus*, **154**, 162-180, 2001. [3]Titus et al. *JGR*, **106**(E10), 23181-23196, 2001. [4]James and Cantor, *Icarus*, **154**, 131-144, 2001. [5]Cantor et al. *JGR*, **107**(E3), 10.1029/2001JE001588, 2002. [6] Bass et al. *Icarus*, **144**, 382-396, 2000. [7] Kieffer, *JGR*, **96**, 1481-1493, 1990, [8] Paige et al. *JGR*, **99**, 25959-25991,1994. [9] Zuber et al. *Science*, **282**, 2053-2060, 1998. [10] Malin and Edgett, *JGR*, **106**(E10), 23429-23570, 2001. [11] Hanel et al., *Exploration of the Solar System by Infrared Remote Sensing*, 1992.

ACKNOWLEDGMENTS: This material is based on work currently supported by NASA under the MDAP Program, Grant: NAG5-12223 to the University of Nevada, Reno and through the 2005 Mars Reconnaissance Orbiter MARCI/CTX Science Team. Viking base image of Mare Boreum courtesy of NASA and obtained through the Planetary Photojournal Web Site at the USGS Flagstaff.

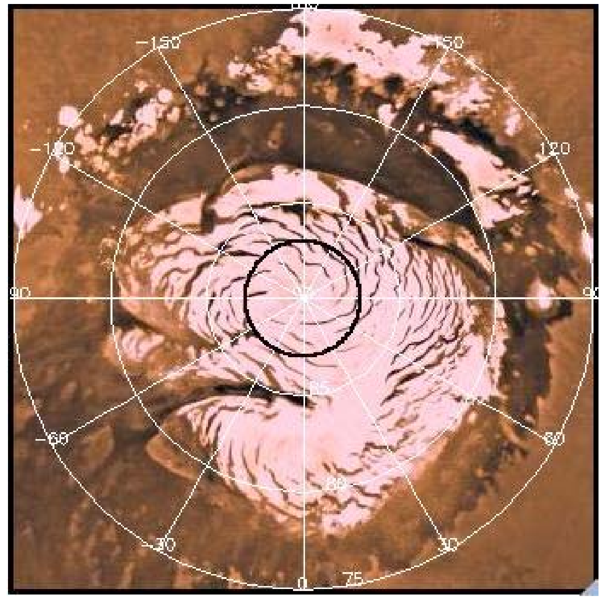


Figure 1: North residual cap as observed by Viking. Black ring denotes area within which TES does not acquire data.

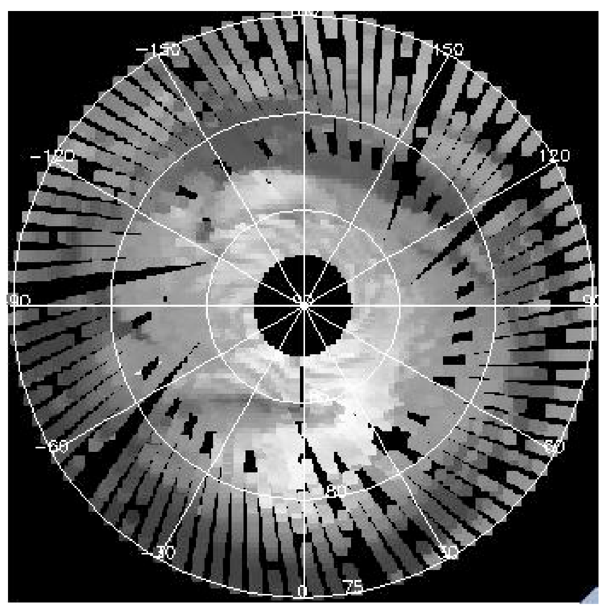


Figure 2: TES albedo map Ls~95 (Dec00/Jan01). Note the lack of bright areas from 30 to 120 E longitude, the extent of Chasma Boreal and the shape of ice surfaces below the Chasma compared with Viking. Squares do not model TES pixel size.

EVOLVING TECHNOLOGIES FOR IN-SITU STUDIES OF MARS ICE F. D. Carsey[1] and M. H. Hecht[2], [1]MS 300-323, Jet Propulsion Laboratory California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA 91109, USA, fcarsey@jpl.nasa.gov, [2]MS 264-255, Jet Propulsion Laboratory California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA 91109, USA, mhecht@jpl.nasa.gov.

Introduction: Icy sites on Mars continue to be of high scientific importance. These sites include the polar caps, the southern mid-latitude subsurface permafrost, and the seasonal frost. These sites have interest due to their roles in climate processes, past climates, surface and near-surface water, astrobiology, geomorphology, and other topics. As is the case for many planetary features, remote sensing, while of great value, cannot answer all questions; in-situ examination is essential, and the motivation for in-situ observations generally leads to the subsurface, which, fortunately, is accessible on Mars. It is clear in fact that a Mars polar cap subsurface mission is both scientifically compelling and practical.

Recent data from orbiting platforms has provided a remarkable level of information about the Mars ice caps; we know, for example, the size, shape and annual cycle of the cap topography as well as we know that of Earth, and we have more information on stratification that we have of, for example, the ice of East Antarctica. To understand the roles that the Mars polar caps play, it is necessary to gather information on the ice cap surface, strata, composition and bed.

In this talk the status of in-situ operations and observations will be summarized, and, since we have conveniently at hand another planet with polar caps, permafrost and ice, the role of testing and validation of experimental procedures on Earth will be addressed.

Exploration Science: The usual Mars scientific topics, life, climate, geophysics and water, are all well connected to Mars ice, and in situ examinations are necessary to obtain the composition, stratification, surface processes, or basal conditions. The primary emphasis for these studies are climate history and processes, on Mars as on Earth. More speculative, but not less interesting, is the prospect that the basal environments of the Mars polar caps, in a climate scenario warmer than the present, would be an excellent habitat, supplied with nutrients and protected from Surficial unpleasantness.

Technologies: In short, Mars polar ice subsurface in-situ missions call for transport to Mars, soft-landing on the polar cap, operations on the surface, power, communication, conduct of surface and near-surface science, access to the subsurface, observing and/or sampling of the subsurface ice cap material, sample management of this material for instrumentation, and planetary protection. It is worth emphasizing that in several of these areas polar science can be accomplished more easily that at other sites. We will proceed here assuming availability of transport to Mars.

Soft landing on a polar cap. The polar caps are characterized by springtime CO_2+H_2O frosts of unknown mechanical properties; we need better information on the response of this frost to landing processes.

Surface operations. The polar caps are benign places in summer with steady temperatures and constant or near-constant sunlight; however, overwintering calls for dedicated development for survival of infrastructure, and this can be accomplished, especially with a nuclear power source. In addition, a mission that lands while the frost is present must accommodate to some decimeters of the landing surface burning off, possibly in nonuniform ways, early in the mission.

Power. A summer mission with low power needs, i.e., one that does not involve deep drilling, has access to ample solar power, although degradation of solar cells in the environment must be examined. Nuclear power from a reactor would solve a host of problems related to high power requirements, as for deep drilling, and to multiyear missions, due to the long life and abundant thermal power produced. This thermal output is also an engineering challenge, since it can both melt away its floor and provide heat that will influence local environmental conditions. Finally, the radiation field of a reactor becomes an engineering issue for electronics. Non-reactor nuclear power occupies a middle ground, with modest power, heat and multiyear capability with fewer difficulties, other than acquiring the radioactive salts.

Communication. Communication from the poles is not challenging. Linkage to orbiters is enhanced by frequent overpasses, and direct communication to Earth is quite simple in the Martian summer.

Surface and near-surface science. Ice cap surface properties and fluxes are likely to be required for any polar cap mission, and the conduct of the measuring programs can be demanding. Key complications are the small variations and fluxes that must be measured accurately, the influence of the spacecraft as an obstacle to windflow and sunlight, operations at the triple point of water, the non-steady surface conditions, and the unknown properties of the surface material.

Access to the subsurface. Drilling even a meter into ice-rich material in the temperature range near –100°C cannot be taken lightly; this material is hard.

Use of thermal methods can be energy intensive and will generate vapor. Thermal methods have received extensive attention and have interesting aspects in their favor at depth, but for shallow penetration with limited power a mechanical approach is favored. Working at depth calls for thermal methods, and both closed-hole (or cryobot) and open-hole strategies have been examined. Power levels become crucial for moderate (10's of meters) and deep (100's of meters) access. It is astonishing to consider that it is within our capability to access essentially any depth of the Mars polar caps.

Scientific observations, sampling and sample management at depth. Once the subsurface has been accessed, sampling must be addressed. Cold ice-rich material is hard and brittle; once a sample is removed and exposed it begins to sublimate if warmed, and if it contains a mix of granular material and salts it may crumble or become mushy or wet; if introduced into instruments, it may adhere to surfaces. Clearly, any observations that can be accomplished non-invasively, e.g., APXS, light scattering, fluorescence, Raman, NMR, etc, are desirable, and some are capable of acquiring data from material within the ice, material not effected by the presence of the drill. On the whole an excellent array of non-invasive scientific instrumentation suitable to subsurface science is in development and requires only adaptation to the specific environment. Sample acquisition and management approaches, of clear value to any in-situ mission, are also in development but have more problems to confront.

Planetary protection. Soon planetary protection requirements for a Mars polar cap mission will be formulated as category IVc, a new (not yet fully documented) category for "special regions" which includes the polar caps. While the specifics of the standards are still in study by the National Research Council, it is clear that rigorous standards of cleanliness will be in force, and these requirements should be integrated into planning early in mission thinking, if possible.

Earth Opportunities for Advancing Mars Polar Exploration Technologies: The high latitudes of Earth contain ice sheets, glaciers, periglacial terrain, permafrost, seasonal snow, rock glaciers and related icy sites in which strong Mars analogs can be developed, as is well known. In the context of climate change, it is of interest to address sites that have changed through cooling, and these are not obvious since Earth seems to be warming now. Some sites worthy of mention:

West Antarctica. The ice streams of West Antarctica (and possibly other locations) are now seen as exhibiting periodic behavior, so called "binge and purge" cycling, in which the bed cools immediately after rapid movement and warms during stagnation.

South Pole "lake". Near South Pole a subglacial flat spot has been observed on airborne radar and identified as a subglacial lake or frozen paleolake or perhaps just a curiously flat spot. Should it be the site where liquid water was present during a previous interglacial, it would today be a fascinating case study in frozen biota, possibly not unlike sites on Mars.

Subglacial volcanoes. At least one active subglacial volcano discovery has been claimed in West Antarctica, and other active volcanoes, with permanent ice and snow covers, can be found in Antarctica and Alaska. Such sites may be highly valuable for comparison with sites in the north polar region of Mars.

Greenland and Antarctica. Substantial regions of both Greenland and Antarctica are at the pressure melting point, and a zone of obvious interest is the transition region between wet and frozen bed areas; these zones can make clear the matter of how this subglacial water alters bed chemistry and biology.

Permafrost. Terrestrial permafrost has long been compared to Mars, and recent Odyssey results certainly encourage this thinking. In the western Arctic, permafrost has been warming, drying, and collapsing, while in Scandinavia there are reports of cooling permafrost. Comparisons of these changes could be useful for Mars thinking. DNA from permafrost has been shown to be well preserved over a few millennia; specific chemical changes to biochemicals over longer time intervals and environments would be interesting for Mars mission planning.

Basal and bed science. For a number of reasons terrestrial glaciology today is strongly interested in bed processes. This is good news for Mars polar science as these projects directly support future Mars polar science in the development of instruments and insights.

Conclusion: Mars polar cap science has received much attention at this, as well as other, scientific meetings, and its high value is well understood among the participants here. An examination of exploration technologies shows us that many of the tools we need to conduct comprehensive scientific studies of the Mars polar caps are available or are in active development. Moreover current work in Earth science is addressing analogous questions in analogous sites; there are effective means to develop, test, validate and assess relevant tools and approaches. In short the scientific questions are mature and the means to address them are maturing quickly. The time is essentially here for significant missions to the polar caps of Mars, and the possibilities are very exciting to contemplate. It is up to us to make these missions happen.

EARTH'S ICY BIOSPHERE. B. C. Christner[1] and J. C. Priscu[1], [1]Montana State University, Department of Land Resources and Environmental Science, Bozeman, MT 59717. mailto: bchristner@montana.edu or jpriscu@montana.edu.

Abstract: Earth's biosphere is cold, with 14% being polar and 90% (by volume) cold ocean <5 ºC. More than 70% of Earth's freshwater occurs as ice (Fig. 1) and a large portion of the soil ecosystem (~20%) exists as permafrost.

Figure 1. Global locations of existing glacial ice sheets and caps (denoted by shading).

Paleoclimate records for the past 500,000 years have shown that the surface temperature on Earth has fluctuated drastically, with strong evidence showing that the Earth was completely ice-covered during the Paleoproterozoic and Neoproterozoic periods [1, 2]. New discoveries of microbial life in cold (-5ºC) and saline lakes, permanent lake ice, cryoconite holes, polar snow, glacial ice, and subglacial environments are extending the known boundaries of the biosphere. Despite the mounting evidence for microbial life in frozen ecosystems, little is know about the psychrophilic or psychrotolerant microorganisms that inhabit them. Molecular-based ecological studies have revealed close phylogenetic relationships between isolates from global locations, with little in common between these environments except that all are permanently cold (Fig. 2), arguing that microorganisms from these genera evolved under cold circumstances and likely possess survival strategies to survive freezing and remain active at low temperature.

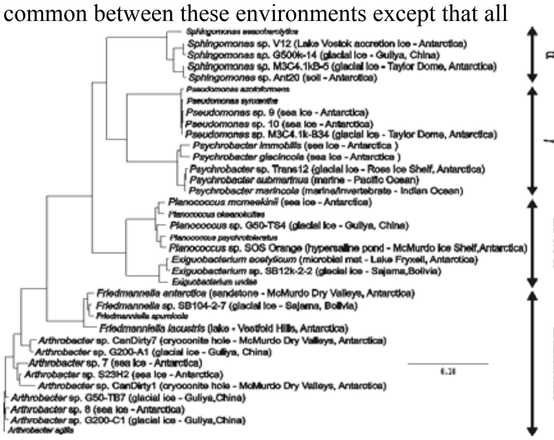


Figure 2. Neighbor-joining tree based on 16S rDNA sequences obtained from isolates (shown in bold) inhabiting permanently cold environments.

Studies of Earthly ice-bound microbes are also relevant to the evolution and persistence of life on extra-terrestrial bodies. During the transition from a clement environment to an inhospitable environment on Mars, liquid water may have progressed from a primarily liquid phase to a solid phase and the Martian surface would have eventually become ice-covered [3]. Habitats in polar ice may serve as a model for life on Mars as it cooled and may assist us in our search for extinct or extant life on Mars today. Biochemical traces of life or even viable microorganisms may well be protected from destruction if deposited within polar perennial ice or frozen below the planet's surface. During high obliquity, increases in the temperature and atmospheric pressure at the northern pole of Mars could result in the discharge of liquid water that might create environments with ecological niches similar to those inhabited by microorganisms in terrestrial polar and glacial regions. Periodic effluxes of hydrothermal heat to the surface could move microorganisms from the martian subterranean, where conditions may be more favorable for extant life. The annual partial melting of the ice caps might then provide conditions compatible with active life or at least provide water in which these microorganisms may be preserved by subsequent freezing [4].

We propose that the Earth's cryosphere and associated sub-ice lakes should be included as biospheric components of our planet. Here, the cryosphere is defined as that portion of the Earth's surface where water is in a solid form as snow or ice, including solid forms such as sea ice, freshwater ice, snow, glaciers, and frozen ground. Examining permanently ice-covered habitats and microorganisms preserved for extended periods within ice is relevant to astrobiological discussions of past or present life on Mars, and the concept that planetary bodies may not be biologically isolated. Such remote and seemingly inconsequential frozen environments may harbor as yet undiscovered microbial ecosystems that could shed light on the natural history and evolution of life on a frozen Earth, as well as other icy planets and moons in the solar system.

References: [1] Kirschvink, J.L., E.J. Gaidos, L.E. Bertani, N.J. Beukes, J. Gutzmer, L.N. Maepa, and R.E. Steinberger. (2000) *PNAS*, 97, 1400-1405. [2] Hoffman, P.F., A.J. Kaufman, G.P. Halverson, and D.P. Schrag. (1998) *Science,* 281, 1342-1346. [3] Wharton, R.A., Jr., R.A. Jamison, M. Crosby, C.P. McKay, J.W. Rice, Jr. (1995) *J. Paleolimnology,* 13, 267-283. [4] Clifford, S.M. et al., (2000) *Icarus,* 144, 210-242.

CHALLENGES AND SOLUTIONS FOR THE HUMAN EXPLORATION OF THE MARTIAN POLES.
Charles Cockell, SETI Institute, NASA Ames Research Center, Moffett Field, CA 94035-1000.

Introduction: The Martian poles present special challenges for human scientific expeditions that bear similarities to operations in terrestrial polar regions. These challenges include mobility on snows and ices, the problem of accommodation in the deep field, methods for the use of local resources and problems of station maintenance. Because the polar regions are dynamic, substantial volatile sinks, the exploration of the polar regions by humans is a potentially high priority exploration goal. Furthermore, the high astrobiological potential of these regions makes them attractive targets for human exploration.

The exploration of the Martian poles might begin in the earliest stages of a human presence on the planet or missions of exploration might be launched from lower-latitude stations that would avoid the 9-month 24 hr darkness of polar winter, which imposes substantial long-term safety problems.

Mobility: I describe a series of concepts in response to these challenges [1-3]. Mobility on Martian snows and ices can be achieved with pressurized tracked rovers or unpressurized skidoos using methane or other fuels readily made from CO_2 and H_20, both abundantly available at the poles. Materials and supplies can be carried by Nansen sledge in an analogous way to Earth. By heating the underside of the sledges, a sublimed vapor layer can be used to assist in mobility and reduce the chances of freezing to the polar substratum ('polar hover').

Field stations: Field stations, depots and deep-field sites can be realized with pressurized 'ball' tents that allow two scientists to rest within a pressurized, heated environment. Larger versions of such easily assembled stations ('ball field stations') can be used for emergencies and the establishment of short-term camps on the polar ice caps. An augmentation of the ball tent is the Migloo - Martian igloo assembled from a pressurized tent surrounded with blocks of ice that can be used as a Solar Particle Event shelter, the ice reduces the radiation flux. These structures may also find use in deploying robust depots across the polar caps.

In-situ resourse use: Liquid water for drinking and for fuel and oxygen production can be gathered from the poles by two means – either 1) subliming the ice and snow by heating it and gathering the vapor for use in various manfacturing processes. This can be achieved with innovations such as 'sublimation netting' (Figure 1), a network of hollow, heated fibres that heat the ice and snow and draw it into a vacuum system or 2) pressurizing blocks of cut snow and ice and then heating directly into a liquid state, thus avoiding the cost of the latent heat of vaporisation.

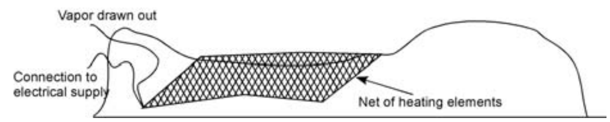


Figure 1. Sublimation netting can be used to gather water for in-situ resource utilization at the Martian poles.

Trans-polar assaults: As well as scientific exploration at specific points on the polar caps, future expeditions might be launched as exploratory trans-polar expeditions across the Martian poles. These expeditions would gather samples across a polar transect and complete traverses that in distance are similar to Trans-polar Antarctic expeditions. I discuss operations at the Martian poles during the 24 hr darkness of polar winter and the challenges presented to overwintering operations.

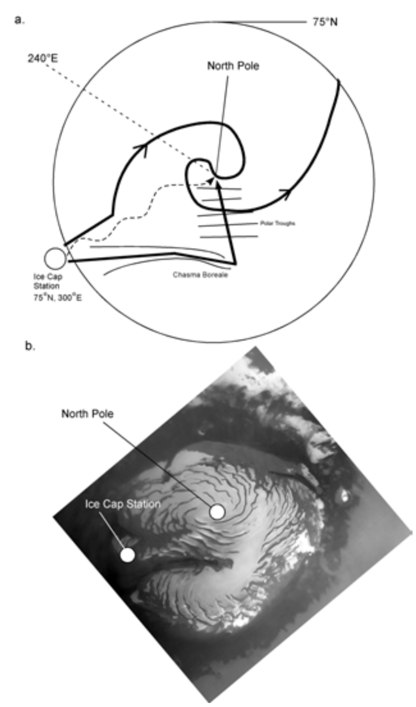


Figure 2. Trans-polar expeditions provide opportunities for polar sampling and purely exploration-driven assaults.

References: [1] C.S. Cockell, (1995) *JBIS*, 48, 359-368. [2] C.S. Cockell, (2001) *Acta Astronautica*, 49, 693-706. [3] C.S. Cockell and A.A. Ellery, (2003) *JBIS*, 56, 33-42.

LIFE IN POLAR IMPACT-SHOCKED ROCKS – AN ANALOG FOR MICRO-HABITATS AT THE MARTIAN POLES.

Charles Cockell[1], Pascal Lee[1], Gordon Osinski[2], David Fike[3]. [1] SETI Institute, NASA Ames Research Center, Moffett Field, CA 94035-1000. [2] Planetary and Space Science Centre, Department of Geology, University of New Brunswick, 2 Bailey Drive, Fredericton, NB E3B 5A3, Canada. [3] David A. Fike, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, England

Introduction: We describe the colonization of shocked gneissic rocks from the Haughton impact structure in the Canadian High Arctic (75°N) [1] as a potential analog for habitats at the Martian poles for speculative indigenous life or contaminants that have already been transferred to Mars by vehicles such as the crashed Mars Polar Lander.

We have used 16s RNA sequencing and SEM to demonstrate the presence of a diverse heterotrophic community of microorganisms throughout the rocks, including spore-forming *Bacillus* spp., which are a known genus of microorganisms to be found on spacecraft surfaces [2]. The low nitrate and phosphate abundances in the polar desert and probably the low leaching rate of organics into the rocks mean that these communities are likely to be nutrient stressed and may spend most of their time in a dormant state. Many of these organisms phylogenetically match psychrophilic species, suggesting adaptation to low growth temperatures.

As well as heterotrophic components, the rocks are also colonized by photosynthetic organisms. Cyanobacteria of the genera *Chroococcidiopsis* and *Dermocapsa* inhabit the rocks as endolithic bands from the surface to a depth of ~5 mm where light levels are sufficient for photosynthesis [1].

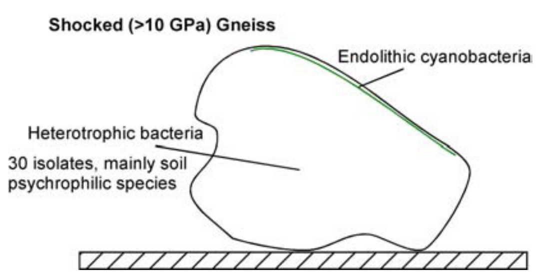


Figure 1. Impact shocked gneiss provides a habitat for a diversity of microorganisms adapted to survival in the terrestrial arctic.

The organisms grow as biofilms on the surfaces of impact fractures and are attached to the rocks in a polysaccharide matrix. The organisms probably enter the rocks after wind deposition onto the surface of the rocks and leach into the subsurface of the rocks with water that penetrates into the inter-connected microfractures. Both phototrophic and heterotrophic components derive their water from snow-melt and rain during the brief ~1.5 month growing season and remain frozen and dormant during the 24 hr darkness of polar winter when temperatures drop to -45°C. We have shown that water can be retained within the rocks for many days after a precipitation event or snow-melt.

During the 24 hr light of polar summer the organisms are protected from UV radiation by the overlying rock and they gain the advantage of thermal heating of the rock [3]. We have shown using sections of rock overlying monolayers of *Bacillus subtilis*, that 0.5mm of rock is sufficient to reduce microbial inactivation by one order of magnitude. The implications of this data are that under 1.5 mm of rock, the damage experienced by micro-organisms entrained into a similar microhabitat on Mars would be similar to that on the exposed surface of present-day Earth under the protection of the ozone column, demonstrating the effectiveness of the endolithic habitat as a refugium from Martian UV radiation.

Using thermisters embedded into the rocks, we found that at a depth of 1 mm the temperatures rose to 10°C higher than the air temperature [3]. Thus, the communities within the rock may experience substantially higher temperatures in the micro-climate than in the external macro-climate, consistent with observations of Antarctic endolithic communities [4].

The similar obliquity of Mars and Earth, and thus the requirement for any potential Martian polar life (indigenous or contaminant microorganisms) to be able to survive the dark Martian polar winter, makes the study of terrestrial polar microorganisms and their modes of survival of special interest as analogs to guide life detection strategies at the Martian poles. Because the Martian surface has a large number of impact craters, which compared to the Earth, are unsubducted and relatively uneroded, understanding the growth and survival of microorganisms within a polar impact structure can yield important insights into the ability of microorganisms to take advantage of impact habitats in the polar regions of Mars.

References: [1] Cockell, C.S., Lee, P., Osinski, G., Horneck, G., Broady, P. (2002). Meteoritics and Planetary Science, 37, 1287-1298. . [2] Fike, D., Cockell, C.S., Pearce, D., Lee, P. (2003). International Journal of Astrobiology, **1**, 311-323. [3] Cockell, C.S., McKay C.P., Omelon, C. (2003). International Journal of Astrobiology, 1, 305-310. [4] McKay, C.P. & Friedmann, E.I. (1985). *Polar Biology* **4**, 19-25.

LIFE IN MARTIAN SNOWS – MEASUREMENTS OF UV PROTECTION UNDER NATURAL ANTARCTIC SNOWS IN THE UVC (254 nm)

Cockell, C.S. British Antarctic Survey, High Cross, Madingley Road, Cambridge. CB1 3AR. UK

Introduction: Ultraviolet radiation down to 195 nm penetrates to the surface of the Martian north polar ice cap during the polar summer on account of the lack of an ozone column, in contrast to the Earth where only radiation above ~290 nm penetrates to the surface (except under ozone depletion, when radiation down to ~280 nm may penetrate). During the winter, spring and fall some ozone production does occur over the Martian poles, but the column abundance is about two orders of magnitude lower than terrestrial stratospheric ozone values. Although this ozone will provide some protection from UVC (200-280 nm) radiation, it is transient. The DNA-damage experienced on the surface of the Martian poles is approximately (under clear, dust-free skies at vernal equinox) three orders of magnitude higher than that experienced by terrestrial polar organisms (under an undepleted ozone column at the same orbital position).

UV in Antarctic and Martian Snows: To investigate the potential of Martian snow to act as a protection mechanism for contaminant microorganisms or organics, the penetration of 254 nm radiation (produced from a field-portable mercury vapor source) into natural snows was measured at Mars Oasis, Antarctica (72°S) during the 2001 austral summer.

Sections of icy snow-pack of approximate dimensions 10 x 10 cm were placed between the cosine-corrected collector of a calibrated Ocean Optics S-2000 spectrometer and the radiation source. A control measurment was taken before each snow-pack measurement and the ratio of the value under the snow-pack to the control was calculated as the attenuation coefficient. The thickness of each snow-pack sample was measured.

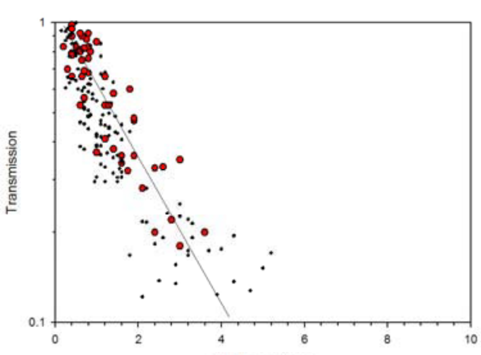


Figure 1. Attenuation of 254 nm radiation (large circles) through snow-pack of different thicknesses. Small dots show attenuation of solar radiation at 310 nm.

The measurements at 254 nm were used as an approximation of the UV-attenuating properties of Martian snows across the whole UVC range. The attenuation of the snow was linearly interpolated between 254 and 310 nm and then linearly extended to 200 nm to make a crude attenuation throughout the Martian UVC range.

For measurements of natural solar radiation between 310 and 400 nm, values were acquired at 1 nm intervals and the collector was held in a clamp directly pointing towards the sun for the control and snow-pack measurement. The penetration of solar radiation from 310 to 400 nm was used for transmission values for the UV ranage common to Earth and Mars [1].

Convolved with a simple Mars radiative transfer model, the data suggests that under ~6 cm of Martian snow, DNA-damage would be reduced by an order of magnitude [2]. Under approximately 30 cm of snow, DNA damage would be no worse than that experienced at the surface of the Earth. Although we do not know the exact characteristics of Martian snows, these first-order data suggest that burial in even modest coverings of Martian snows could allow for the long-term survival (and if water if present, even growth) of contaminant microorgannisms at the Martian polar caps even under the extreme UV fluxes of clear Martian skies. These coverings of snow will also allow for enhanced preservation of organics against UV-degradation.

Intriguingly, at the depth at which DNA damage is reduced to similar levels as those found on the surface of present-day Earth, light levels in the photosynthetically active region (400 to 700 nm) are still two orders of magnitude higher than the minimum required for photosynthesis, showing that within snow-pack on planets lacking an ozone shield, including Mars, UV damage can be mitigated, but light levels are still high enough for organisms that have a requirement for exposure to light for their energy needs. Photosynthetic life is not expected at the Martian poles, but the data reveal the apparently favourable radiation environment for life within the polar caps.

References: [1] Cockell, C.S. and Cordoba-Jabonero, C. Photochem. Photobiol. (in review). [2] Cockell C.S. Abstracts of the 2nd European Exo/Astrobiology Conference, 2002.

Carbon Dioxide Convection in the Martian Polar Night and its Implications for Polar Processes. A. Colaprete[1] and R. M. Haberle[2], [1]SETI (NASA Ames Research Center, Moffett Field, MS 245−3, Mountain View,CA 94035, tonyc@freeze.arc.nasa.gov, [2]NASA Ames Research Center (NASA Ames Research Center, Moffett Field, MS 245−3, Mountain View,CA 94035).

Introduction: Each Martian year nearly 30% of the atmosphere is exchanged with the polar ice caps. This exchange occurs through a combination of direct surface condensation and atmospheric precipitation of carbon dioxide. It has long been thought the amount of condensation within the polar night is maintained by a balance between diabatic processes such as radiative cooling and latent heating from condensing CO_2. This assumption manifests itself in Mars General Circulation Models (GCM) in such a way as to never allow the atmospheric temperature to dip below the saturation temperature of CO_2. However, observations from Mars Global Surveyor (MGS) Radio Science (RS) and the Thermal Emission Spectrometer (TES) have demonstrated this assumption to be, at best, approximate. Both RS and TES observations within the polar nights of both poles indicate substantial supersaturated regions with respect to CO_2. The observed temperature profiles suggest conditionally unstable regions containing planetary significant amounts of potential convective energy. Presented here are estimates of the total planetary inventory of convective available potential energy (CAPE) and the potential convective energy flux (PCEF). The values for CAPE and PCEF are derived from RS temperature profiles and compared to Mars GCM results using a new convective CO2 cloud model that allows for the formation of CAPE.

CO_2 Convection: A rising air parcel will cool along the dry adiabat until saturated (Level of Condensation Lifting) at which time condensation and the release of latent heat force the parcel to cool along the wet adiabat. If the release of latent heat maintains the air parcel temperature above the environment temperature then it can become buoyant and freely convect (Level of Free Convection). Free convection will continue as long as the parcel remains warmer than its surroundings (Level of Neutral Buoyancy). The amount of free convection that can occur depends on the difference in temperature between the ascending air parcel and its environment. One measure of the ability of a parcel to freely convect is the convective available potential energy (CAPE). The CAPE of a parcel can be expressed as

$$CAPE = \int_{z_1}^{z_2} b\,dz \qquad 1.$$

where z_1 and z_2 are the initial and ending altitudes of the rising parcel of air and b is the buoyancy

$$b = g\frac{(T_p - T_e)}{T_e} \qquad 2.$$

with T_p and T_e being the temperature of the parcel and environment respectively. Within the Martian polar night the atmosphere is frequently at or above the CO_2 saturation temperature. If an air parcel near the surface is forced to rise it will very quickly become saturated and cool along the wet adiabat. However, since the surrounding atmosphere is already at the wet adiabat the parcel's buoyancy is nearly zero ($T_p - T_e$? 0). Therefore there is very little CAPE (with respect to CO_2 convection) within the Martian polar night and CO_2 convection would be shallow.

Not all of the Mars polar night atmosphere is at or above the saturation temperature, however. RS measurements indicate regions of CO_2 supersaturation in the lower atmosphere below about 1−2 mbar. Examples of RS observations showing supersaturations are shown in Figure 1. In Figure 1 four RS measurements, two for the South polar region and two for the North polar region, are shown with their corresponding CAPE (J kg^{-1}). These supersaturated regions can form if the air in the region is clear of any previously existing CO_2 cloud particles and new cloud particle nucleation has not yet occurred, or if atmospheric cooling rates are so high that the release of latent heat from growing CO_2 cloud particles is insufficient to compensate for the decrease in temperature. Under these conditions a rising parcel may be buoyant and will rise if condensation occurs. The CAPE for the profiles shown in Figure 1 varies from about 35 −250 J kg^{-1}. For comparison moderate to strong terrestrial convective systems have CAPE in the range from 500−1000 J kg^{-1}. Larger terrestrial thunderstorms can have CAPE greater than 2000 J kg^{-1}. On Earth, for similar amounts of CAPE as that calculated from the RS soundings in Figure 1, low to moderate levels of convection resulting in unorganized microbursts would be expected.

RS Observations: In the 6921 RS profiles analyzed thus far, approximately 25% of them show some amount of CAPE (as defined by Eq. 1). Figure 2 shows the location of the RS profiles which contained CAPE. The highest value of CAPE was in the North and had a value of 421 J kg^{-1}. If all 421 J kg^{-1} of CAPE in this profile was converted to convective motion (neglecting entrainment effects and possibly cloud particle drag) the resulting updraft would have a velocity of almost 30 m s^{-1}. The total integrated CAPE in the profiles shown in Figure 2 is approximately 28 kJ kg^{-1}. Due to the limited spatial and temporal nature of the observations, the temperature profiles studied only constitute a fraction of the total atmospheric volume and time that CAPE is present. An estimate of the total rate of CAPE formation was made by linearly interpolating, in time and space, observed CAPE tendencies between observation points. Assuming all CAPE is converted to heat a total potential convective energy flux (PCEF) was calculated and is shown in Figure 3. The periods of highest PCEF correspond to the mid to late winter periods at both poles. The PCEF magnitude is largest in the North being about twice that of the South. During the late winter period the PCEF constitutes approximately 10% the total latent heating budget, or approximately equal to the total meridional heat transport.

A new CO_2 cloud model recently implemented in the Ames GCM reproduces the observed supersaturated regions. The cloud model includes the microphysical processes of nucleation, condensation, and sedimentation. Proper treatment of ice nuclei (IN) nucleation, assumed here to be dust grains, is critical to reproducing the observed supersaturated regions. The supersaturation at which new CO_2 cloud particles will form was recently measured to be 35%, consistent with the maximum supersaturations observed in the RS temperature profiles. Integrated CAPE and PCEF from simulations utilizing this new CO_2 cloud model are consistent with those estimated from the observations.

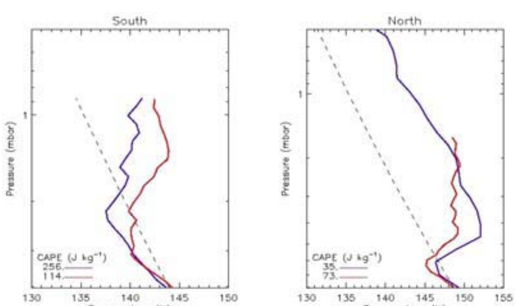


Figure 1. Examples of RS profiles (red and blue curves) showing supersaturated regions and the corresponding CAPE. The dashed curve is the frost temperature for CO2.

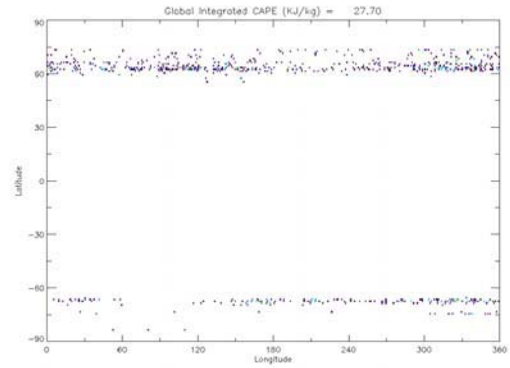


Figure 2: Location of RS profiles having CAPE associated with them.

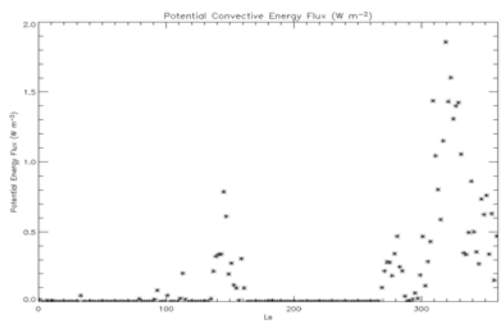


Figure 3. The estimated potential convective energy flux (PCEF) calculated from the total CAPE associated with all RS observations.

BASAL WATER AT THE NORTHGRIP DRILL SITE.

Dorthe Dahl-Jensen[1], Sigfus Johnsen[1], Eske Willerslev[2], Heinz Miller[3], Thorsteinn Thorsteinsonn[4]

[1]Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, DK/2100 Copenhagen OE, Denmark (e-mail: ddj@gfy.ku.dk), [2]Zoological Insitute, University of Copenhagen, [3]Alfred Wegener Istitute, Columbusstrasse, D-27568 Bremerhaven, Germany, [4]University of Iceland.

On July 17 2003, the North GRIP deep ice core drilling program on the Greenland Ice Sheet (75.1 0N, 42.3 0W; 2930 m.a.s.l.), came to a successful end when the drill hit bedrock at 3085 m depth. In the last run the drill was lowered down in the basal water and on surface approximately 10 kg of reddish, bubbly frozen basal water was attached to the drill. A frozen 30 cm long jet of basal water hang from the drill head (www.glaciology.gfy.ku.dk)

The main purpose of the NGRIP project has been to obtain ice dating from the last interglacial period, the Eemian (ca. 115-135 ka BP). A full record of Eemian climate has hitherto not been obtained from a Greenland ice core and the occurrence of rapid climate change during the Eemian, originally inferred from studies of the GRIP ice core, has not been confirmed by other records. Results from airborne radar measurements showed that internal layers, isochrones could be traced from the deep coring sites at Summit in Central Greenland (GRIP and GISP2) to the North GRIP site. However, as the drilling progressed and measurements of ice temperature were made in the borehole, it became clear that the geothermal heat flux was unusually high at NGRIP and that the ice at the bottom was at the melting point.

At present, the bottom ice from the NGRIP core is tentatively estimated to be 127,000 years old. The melt rate at the base is estimated to be 7 mm per year. A study of the internal layers in North Greenland reveal a area of 300 km x 200 km with ice on the melting point. The amount of water produced by the basal melting is enormous and the drainage system must be good as no big lakes are observed under the Greenland Ice Sheet.

The basal water frozen to the NGRIP drill is mainly glacial basal melt water that contains air from the glacial ice. The reddish color however indicates evidence of a content of sediments in the water. Is it possible to find traces of ancient DNA and microbilogical life in the melt water found under the ice which has been closed from the surface for the last 2-5 million years? We hope to return next year and drill cores of the frozen basal water now standing 47 m up in the borehole.

SIMULATIONS OF THE SEASONAL VARIATIONS OF THE MARS SOUTH POLAR CAP: PRELIMINARY RESULTS. K. Dassas , F. Forget , *Laboratoire de Meterologie Dynamique du CNRS, Universite Paris 6, BP99, 75252 Paris Cedex 05, France (dassas@lmd.jussieu.fr)*.

Introduction

Every martian year, as much as 30% of the CO_2 atmosphere of Mars condenses in the polar caps of each hemisphere during their respective polar nights. During the spring and summer seasons in a given hemisphere, the seasonal CO_2 cap sublimates back into the atmosphere. While the north polar cap remains roughly circular and centered on the geographic pole during its recession, the south polar cap becomes assymetric with strong variations with space and time. In particular, the preservation of a permanent CO_2 deposit all year long near the south pole raises important issues such as the potential ability of these deposits to buffer the atmosphere. The TES observations of the south polar region during its recession have also confirmed that two regions have different behavior than the rest of the cap in terms of albedo and CO_2 budget. These are the Mountains of Mitchel, a high albedo area where the frost is left behind after the rest of the polar cap recedes each spring, and the Cryptic region, an extended low albedo area which sublimates earlier than the rest of the cap [1]. As of today , the existence and location of the residual cap, the mountains of Mitchel, and the Cryptic region remain poorly understood. No obvious correlations have been found between these areas of interest and topography, geology, thermal inertia or ground albedo [1-2].

Current situation

In the LMD martian general circulation model [3-5], the condensation and sublimation of carbon dioxide on the ground is primarily controlled by relatively simple physical processes. When the surface temperature falls below the condensation temperature, CO_2 condenses, releasing the latent heat required to keep the solid-gas interface at the condensation temperature. Conversly, when CO_2 ice is heated, it partially sublimes to keep its temperature at the frost point temperature. In the atmosphere, condensation may result from radiative cooling on the one hand (especially when the atmosphere is dust laden) and from adiabatic cooling in upward motions on the other hand. The radiative effect of CO_2 snow fall and fresh snow can be taken into account by lowering the emissivity [3]. Although the LMD GCM represents pretty well the boundaries and the total mass of the polar caps, it doesn't reproduce neither the Cryptic region nor the mountains of Mitchell or the residual polar cap. The modeled south polar cap completely sublimes by the beginning of summer.

Investigation

To better understand and simulate polar cap features like the Cryptic region, the mountains of Mitchel or the perenial CO_2 ice cap, different investigations have been done.

What happen's during the polar night?

Using the LMD GCM, simulations have been performed during the polar night (Ls90-120) in order to highlight possible enhanced or reduced CO_2 condensation rate in regions of interest. No obvious correlations between atmospheric or ground condensation rate and neither the Cryptic region nor the mountains of Mitchel have been found. Such a work could be of interest to compare with the Mars clouds detected by the Mars Orbiter Laser Altimeter (MOLA) [6].

New albedo parametrization.

Previously in GCM, the ice albedo parametrization was not dependent on the incident solar flux. According to the observations the CO_2 ice albedo increases as the CO_2 ice is exposed to increasing insolation [6]. We added this parametrization in the GCM. At the same time, we have simulated the fact that slab CO_2 ice becomes transparent when it becomes thin by defining the albedo as a combination of the ice and underlying ground albedos depending on a chosen thickness of the CO_2 ice layer.

Taking account slope orientation.

The previous parametrization of the incident solar flux surface was not taking account the slope (orientation and absolute value). We have performed simulations with a new slope dependent parametrization. Slopes have been calculated using the MOLA topography data (32 pixels / degree).

Future work

In order to better understand the seasonal variations of the south polar cap, we will continue this project and, in particular, perform very high spatial resolution simulations in order to highlight the slope effect or the spatial variations of atmospheric condensation. We also want to improve CO_2 ice microphysic representation, and some work should be done to determine the role of dust. Once all these processes will be taken into account, the GCM should be able to predict features like the Mountain of Mitchel or the Cryptic region. Otherwise, these features will have to be considered as a major enigma of the martian climate system.

References [1] Kieffer H. et al (2000) JGR, 105, 9653-9699. [2] James P. et al (2001) JGR, 106, NO. E10, 23,635-23,652. [3] Hourdin F. et al (1993) JAS, 50, 3625-3640. [4] Forget F. et al (1998) Icarus, 131, 302-316. [5] Forget F. et al (1999) JGR, 104, 24,155-24,176. [6] Neumann et al (2003) JGR, 108, NO. E4, 5023. [7] Paige D.A (1985) Science, 228, 1160-1168.

EPISODIC ENDOGENETIC-DRIVEN ATMOSPHERIC AND HYDROLOGIC CYCLES AND THEIR INFLUENCE ON THE GEOLOGIC RECORDS OF THE NORTHERN AND SOUTHERN HEMISPHERES, MARS

J. M. Dohm, *Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona (jmd@hwr.arizona.edu)*, **A. G. Fairén**, *CBM, CSIC-Universidad Autónoma de Madrid, 28049-Cantoblanco, Madrid, Spain,* **V. R. Baker,** *Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona,* **J. C. Ferris**, *United States Geological Survey, Denver, Colorado,* **R.C. Anderson**, *Jet Propulsion Laboratory, Pasadena, California,* **E. R. Uceda,** *Servicio de Endocrinología, Hospital Ramón y Cajal, Madrid.*

Diverse evidence shows a direct correlation between episodic endogenetic events of the Tharsis magmatic complex (TMC)/Superplume [1], flood inundations in the northern plains [2], and glacial/lacustrine/ice sheet activity in the south polar region, which includes Hellas and Argyre impact basins (**Fig. 1**) [3-5], corroborating the MEGAOUTFLO hypothesis [6,7]. The TMC encompasses a total surface area of approximately 2×10^7 km^2, which is slightly larger than the estimated size of the Southern Pacific Superplume [8]. These hydrologic events include (1) a Noachian to possibly Early Hesperian oceanic epoch and related atmospheric and environmental change (a water body covering about 1/3 of the planet's surface area [9]) related to the incipient development of Tharsis Superplume and the northwestern sloping valleys (NSVs) [10,11] and possibly early circum-Chryse development [12-14], the northwest and northeast watersheds of Tharsis, respectively, (2) a smaller ocean [6-7; 15-17] inset within the former larger ocean related to extensive Late Hesperian to Early Amazonian effusive volcanism at Tharsis [18] and Elysium [19-20] and incisement of the circum-Chryse outflow system [e.g.,12-13]. During this time, magmatic/plume-driven tectonic activity transitioned into more centralized volcanism [4,21]. This Late Hesperian water body may have simply diminished into smaller seas and/or lakes [22] during the Amazonian Period, or renewed activity at Tharsis [21] and Elysium [20,23] resulted in brief perturbations from the prevailing cold and dry climatic conditions to later form minor seas or lakes [2]. All of the hydrologic phases transitioned into extensive periods of quiescence [1,2].

Dynamic, pulse-like, magmatic activity, especially at Tharsis [10] is partly the result of a stagnant-lid lithospheric regime where the internal heat of the planet builds over time to catastrophically erupt magmas and volatiles at the martian surface [1,6,7]. This is not to be unexpected, as pulses of activity are also documented for the Southern Pacific Superplume on Earth where present plate tectonism is recorded [8]. On Mars, the primary releases of the stored-up internal heat of the planet occur at dominant vent regions such as at Tharsis and Elysium and along pre-existing zones of weaknesses related to earlier magmatism and tectonism. This may include both impact events and plate tectonism during the earlier stages of planetary development [1,24]. Persistent periods of quiescence transpired between these violent outbursts sending the planet back into a dormant deep freeze [1,25], with the exception of areas where elevated geotherms persist and local hydrologic activity occurs.

Following a persistent deep freeze and ever thickening cryosphere, an Ontong Java-sized event on Mars (especially considering it is unvegetated and less than half the size of Earth, allowing a far greater impact to the climatic system) would trigger enhanced atmospheric conditions and hydrologic dynamics. A prime example of this process is observed during the Late Noachian/Early Hesperian; a time when magmatic-driven activity included the emplacement of older wrinkle ridged materials in the Thaumasia Planum region, the formation of the Thaumasia plateau, and major development of the primary centers of activity, Syria and central Valles (Stage 2 of Tharsis Superplume evolution; see [4,10-11,21]).

Though variation in the orbital parameters of Mars must be considered as a contributing influence on environmental change [26], a direct correlation between endogenic activity at Tharsis (and to a lesser extent Elysium) and global aqueous activity on Mars is observed in the geologic and paleohydrologic records of Mars (schematically portrayed in **Fig. 1**), including: (1) inundations in the northern plains and relatively short-lived climatic perturbations [1,2,6-7,25], (2) growth and retreat of the south polar ice sheet [5], (3) glacial and lacustrine activity in and partly surrounding Hellas [27] and Argyre [3-4], (4) outflow channel activity at NSVs [10-11] and circum-Chryse [e.g.,12-13], (5) formation of the Tharsis Montes aureole deposits [28], and development of impact crater lakes [29,30]. As such, any theoretic modelling of martian atmospheric or surface conditions must take into account endogenetic-driven activity as distinctly expressed in the geologic record.

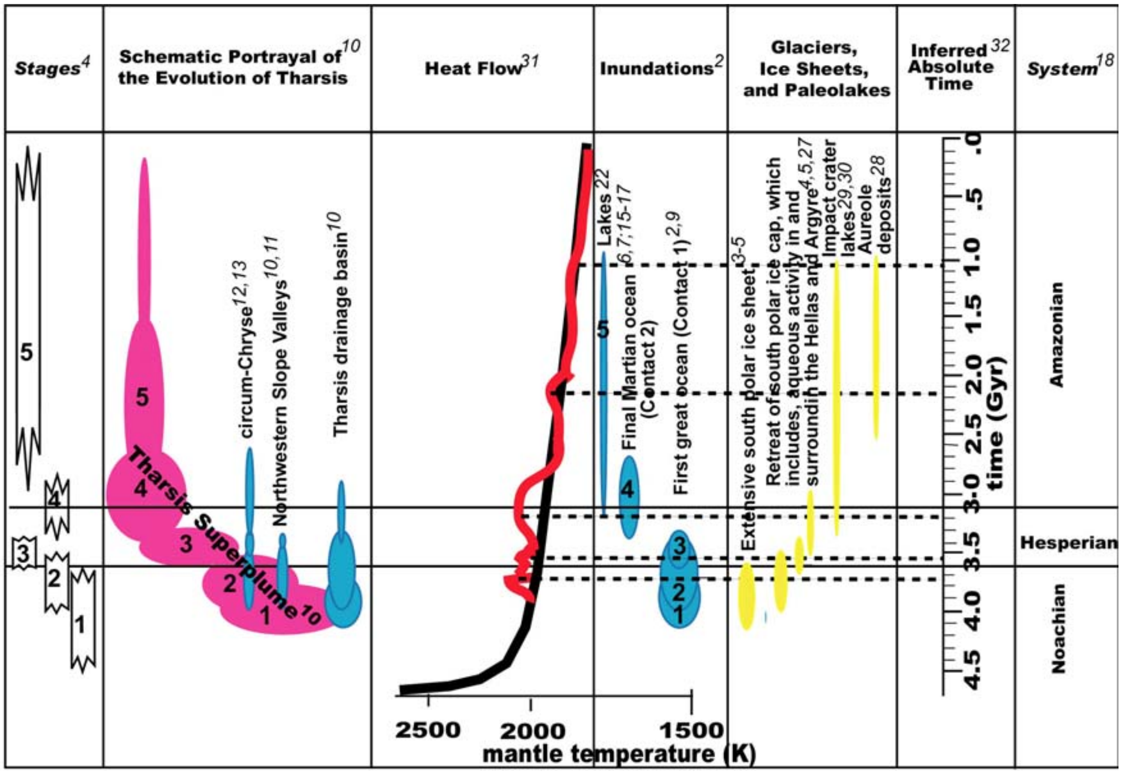


Figure 1. Schematic diagram portraying the spatial and temporal occurrence of major geologic and hydrologic events in martian history.

References. [1] Baker, V.R., *et al*. (2002). A theory for the geological evolution of Mars and related synthesis (GEOMARS). *Lunar Planet. Sci. Conf.*, XXXIII, #1586 (abstract) [CD-ROM]. [2] Fairén, A.G., et al. (2003). Episodic flood inundations of the northern plains of Mars. *Icarus*, in press. [3] Kargel, J.S., and Strom, R.G. (1992). Ancient glaciation on Mars. *Geology*, 20, 3-7. [4] Dohm, J.M., et al., (2001a). Geologic, paleotectonic, and paleoerosional maps of the Thaumasia region of Mars: USGS Misc. Inv. Ser. Map I-2650, scale 1:5,000,000. [5] Milkovich, S.M., et al. (2002). Meltback of Hesperian-aged ice-rich deposits near the south pole of Mars: evidence for drainage channels and lakes. *J. Geophys. Res*., 107, 2001JE001802. [6] Baker, V.R., *et al.* (1991). Ancient oceans, ice sheets and the hydrological cycle on Mars. *Nature*, 352, 589-594. [7] Baker, V.R., *et al.* (2000). Mars' Oceanus Borealis, ancient glaciers, and the MEGAOUTFLO hypothesis. *Lunar Planet. Sci. Conf.*, XXXI, #1863 (abstract) [CD-ROM]. [8] Maruyama, Shigenori, 1994. Plume tectonics, J. Geol. Soc. of Japan, 100, 24-49. [9] Clifford, S. M., and Parker, T. J. (2001). The evolution of the Martian hydrosphere: Implications for the fate of a primordial ocean and the current state of the northern plains. *Icarus*, 154, 40–79. [10] Dohm, J.M., *et al*. (2001b). Ancient drainage basin of the Tharsis region, Mars: Potential source for outflow channel systems and putative oceans or paleolakes. *J. Geophys. Res*., 106, 32,943-32,958. [11] Dohm, J.M., *et al*. (2001c). Latent outflow activity for western Tharsis, Mars: Significant flood record exposed. *J. Geophys. Res*., 106, 12,301-12,314. [12] Rotto, S.L., and Tanaka K.L. (1995). Geologic/geomorphologic map of the Chryse Planitia region of Mars. *U.S. Geol. Surv. Misc. Invest. Ser.* Map I-2441. [13] Nelson, D. M., and Greeley, R. (1999). Geology of Xanthe Terra outflow channels and the Mars Pathfinder landing site. *J. Geophys. Res*., 104, 8653-8669. [14] Zuber, M.T., et al. (2000). Internal structure and early thermal evolution of Mars from Mars Global Surveyor topography and gravity. *Science*, 287, 1788-1793. [15] Parker, T. J., *et al.* (1987). Geomorphic evidence for ancient seas on Mars. In *Symposium on Mars: Evolution of its Climate and Atmosphere, LPI Tech. Rept. 87-01*, 96-98, 1987. [16] Parker, T.J., *et al.* (1993). Coastal geomorphology of the Martian northern plains. *J. Geophys. Res*., 98, 11061-11078. [17] Head, J.W., *et al.* (1999). Possible ancient oceans on Mars: Evidence from Mars Orbiter laser altimeter data. *Science*, 286, 2134-2137. [18] Scott, D.H., and Tanaka, K.L. 1986. Geologic map of the western equatorial region of Mars, *USGS Misc. Inv. Ser. Map I-1802-A (1:15,000,000)*. [19] Greeley, R, and Guest, J. E. 1987. Geologic map of the eastern equatorial region of Mars, *USGS Misc. Inv. Ser. Map I-1802B (1:15,000,000)*. [20] Tanaka, K.L., et al. (2003). Resurfacing history of the northern plains of Mars based on geologic mapping of Mars Global Surveyor data. *J. Geophys. Res*., 108, 8043, doi: 10.1029/2002JE001908. [21] Anderson, R.C., *et al.* (2001). Primary centers and secondary concentrations of tectonic activity through time in western hemisphere of Mars. *J. Geophys. Res.,* **106**, 20,563-20,585. [22] Scott, D.H., *et al.* (1995). Map of Mars showing channels and possible paleolake basins. U.S. Geol. Surv. Misc. Invest. Ser. MAP I-2461. [23] Skinner, J. A., and Tanaka, K. L. (2001). Long-lived hydrovolcanism of Elysium. *Eos. Trans. AGU* ***82***, Fall Meet. Suppl., Abstract P31B-07. [24] Fairén, A.G., et al. (2002). An origin for the linear magnetic anomalies on Mars through accretion of terranes: implications for dynamo timing. *Icarus*, 160, 220-223. [25] Baker, VR. (2001). Water and the Martian landscape. *Nature*, 412, 228-236. [26] Touma, J., and Wisdom, J. 1993. The chaotic obliquity of Mars. *Science*, 259, 1294-1296. [27] Moore, J. M., and Wilhelms, D. E. 2001. Hellas as a possible site of ancient ice-covered lakes on Mars. *Icarus*, 154, 258-276. [28] Scott, D.H., et al. (1998). Geologic map of the Pavonis Mons volcano, Mars: *USGS Misc. Inv. Ser. Map I-2561* (1;2,000,000 scale). [29] Cabrol, N. A., and Grin, E. A. (1999). Distribution, classification and ages of Martian impact crater lakes. *Icarus*, 142, 160-172. [30] Cabrol, N. A., and Grin, E. A. (2001). The evolution of lacustrine environments on Mars: is Mars only hydrologically dormant? *Icarus*, 149, 291-328. [31] Schubert, G., and Spohn, T. 1990. Thermal history of Mars and the sulfur content of its core. *J. Geophys. Res.* 95, 14,095-14,104. [32] Hartmann, W. K., and Neukum, G. 2001. Cratering chronology and the evolution of Mars. *Space Sci. Rew*., 96, 165-194.

LIFE DETECTION AND CHARACTERIZATION OF SUBSURFACE ICE AND BRINE IN THE MCMURDO DRY VALLEYS USING AN ULTRASONIC GOPHER: A NASA ASTEP PROJECT. P. T. Doran[1], Y. Bar-Cohen[2], C. Fritsen[3], F. Kenig[1], C. P. McKay[4] A. Murray[3] and S. Sherrit[2] [1]University of Illinois at Chicago, Earth and Environmental Sciences, 845 West Taylor Street (MC186), Chicago, IL 60607 USA email:pdoran@uic.edu or fkenig@uic.edu, [2]CALTECH, Jet Prop Lab, 4800 Oak Grove Dr, M-S 82-105, Pasadena, CA 91109 USA email: yosi@jpl.nasa.gov or ssherrit@jpl.nasa.gov, [3]Desert Research Instite, 2215 Raggio Parkway, Reno, NV 89512 USA email:cfritsen@dri.edu or alison@dri.edu, [4]NASA Ames Research Center, Divion of Space Science, Moffett Field, CA 94035 USA, email:cmckay@mail.arc.nasa.gov

Introduction: Evidence for the presence of ice and fluids near the surface of Mars in both the distant and recent past is growing with each new mission to the Planet. One explanation for fluids forming spring-like features on Mars is the discharge of subsurface brines. Brines offer potential refugia for extant Martian life, and near surface ice could preserve a record of past life on the planet. Proven techniques to get underground to sample these environments, and get below the disruptive influence of the surface oxidant and radiation regime, will be critical for future astrobiology missions to Mars. Our Astrobiology for Science and Technology for Exploring Planets (ASTEP) project has the goal to develop and test a novel ultrasonic corer in a Mars analog environment, the McMurdo Dry valleys, Antarctica, and to detect and describe life in a previously unstudied extreme ecosystem; Lake Vida (Fig. 1), an ice-sealed lake.

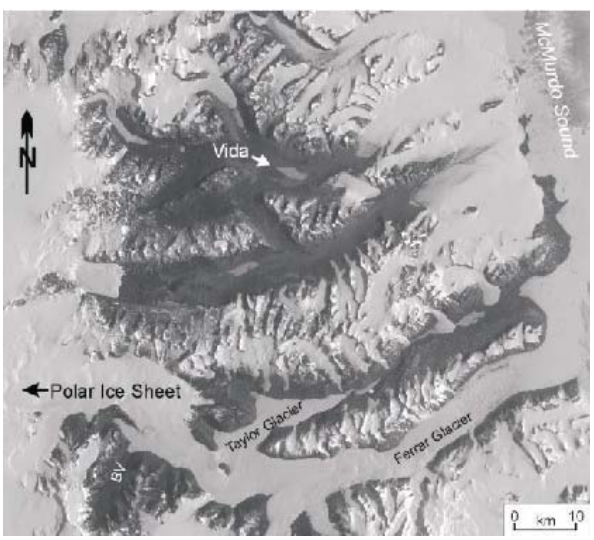


Figure 1: Landsat image of the dry valleys region showing location of Lake Vida. The image is centered at 77.5oS 162oE.

Ice-Sealed Lakes: Lakes in the McMurdo Dry Valleys of East Antarctica have long been studied as extreme environments and potential analogs of purported Martian lakes of the past [e.g. 1, 2]. Commonly studied dry valley lakes have a 2 to 6 m perennial ice cover and 20 to 60 m water column beneath. These lakes also have a range a salinities from fresh to hypersaline, and all allow suffienct sunlight to pass through the ice for photosynthesis to occur in the water column and benthos.

A few lakes in the dry valleys have been largely unstudied until recently because they were believed to be frozen to their beds. One of these lakes (Lake Vida) is also one of the two largest lakes in the dry valleys. Using a combination of ground-pentrating radar and ice coring techniques we have established that Lake Vida comprises a NaCl brine with a salinity seven times sea water and temperature constantly below -10^{o}C lies beneath ~20 m of ice that is at least 2,800 radiocarbon years old [3]. Microbial mats occur throughout the ice column and are viable upon thawing. Sediment layers in the ice effectively block incoming solar radiation (Fig. 2).

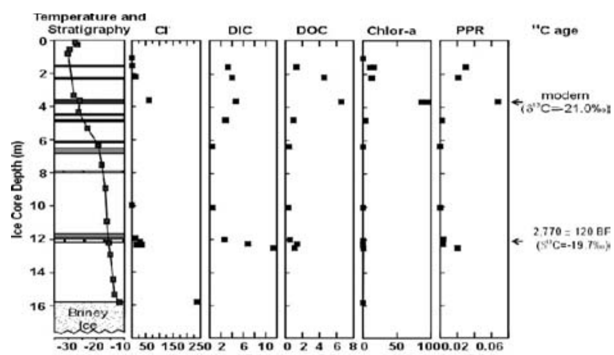


Figure 2: Physical and chemical properties of Lake Vida ice core taken in October 1996. Black horizons on the stratigraphy plot represent sediment layers, gray horizons are sandy ice, and vertically banded horizons contain microbial mat. The temperature profile shown was taken at the time of ice extraction.

Ultrasonic Gopher: Planetary sampling using conventional drilling and coring techniques is limited by the need for high axial force necessitating the use of heavy rovers or anchoring mechanisms. A novel ultrasonic/sonic driller/corer (USDC) mechanism [4] was developed that overcomes these and other limitations of conventional techniques. The novel element of the USDC is the free-mass that operates as a frequency transformer converting 20 KHz ultrasonic waves to a 60-1000 Hz sonic hammering action (percussion) that is applied onto the drilling/coring bit. The USDC actuator consists of a stack of piezoelectric ceramics with a backing material that focuses the emission of the acoustic energy forward, and a horn that amplifies the displacements generated by the stack. The tip of the ultrasonic horn impacts the free-mass creating a sonic resonance between the horn and the bit.

The USDC has been demonstrated to drill rocks that range in hardness from hard granite and basalt to soft sandstone and tuff. This novel drill is capable of high-speed drilling (2 to 20 mm/Watt·hr for a 2.85mm diameter bit) in basalt and Bishop Tuff using low axial preload (<10 N) and low average power (<5 W). The USDC mechanism has also demonstrated feasibility for deep drilling. The Ultrasonic-Gopher (Fig. 3a) can potentially be used to reach great depths and large diameters (3 and 4.5 cm have been demonstrated) using a low mass rover. Generally, the bit creates a borehole that is larger than the drill bit outer diameter and it also creates a core that is smaller in diameter than the inner diameter of the coring bit. This reduces the chances of bit jamming where hole integrity is maintained, and it eases in the extraction of the core from the bit. Current models suggest that the USDC performance does not change significantly with changes in ambient gravity.

Figure 3: a) Ultrasonic-Gopher and extracted limestone core, b) Recent prototype of ice gopher. Ice chisel bit on the left and actuator on the right.

"Ice Gopher": Ice below 16 m depth in Lake Vida and the brine body have never been sampled directly due to logistical constraints. We are building an ultrasonic "ice gopher" (Fig. 3b) to make in situ ecosystem measurements, and acquire samples to be further analyzed. Early versions of the "ice gopher" suggest that coring through ice may prove a bigger challenge than coring through rock. A large part of our efforts in the early stages of development are focused on the problems of chip handling and ice melt during drilling, both of which can create significant potential for getting the instrument stuck during the mission.

Our field plan is to use the gopher to core through the Lake Vida ice cover, cycling in and out of the hole to retrieve ice cores along the way. The gopher will sample brine as it goes and the brine will be collected at the ice surface under clean and sterile conditions. Using the gopher we will address two main hypotheses

H1. Microbial communities within the brine (include brine pockets in the deep ice) and benthic sediments are currently viable, active and affect the present-day geochemistry of the lake.

H2. The ice, water column and benthos of deeply frozen lakes contain geochemical signatures of past microbiological activity.

Conclusions: Lake Vida provides the unique opportunity to investigate lake ecosystems on the edge of existence to determine what conditions may lead to the eventually complete freezing of a lake and the subsequent development/evolution of microbial communities and geochemical signatures. The combined hypersaline, aphotic, atmospherically isolated and cold conditions in Lake Vida make it potentially among the most extreme aquatic environments on Earth. These conditions were likely to have been present during the last stages of purported lakes on Mars near the end of its water-rich past. Our drilling program will provide useful insight into the challenges of drilling though cold dirt and ice with a low power and light weight instrument to retrieve samples for life detection.

References: [1] McKay C. P. et al. (1985) *Nature, 313,* 561-562. [2] Doran P. T. et al. (1998) *JGR, 103(E3),* 28481-28493. [3] Doran P. T. et al. (2003) *PNAS 100,* 26-31. and Author C. D. (1997) *JGR, 90,* 1151–1154. [4] Bar-Cohen Y. et al. (2001) "Ultrasonic/Sonic Driller/Corer (USDC) With Integrated Sensors," U.S. Patent filed.

THE RHEOLOGY CO_2 CLATHRATE HYDRATE AND OTHER CANDIDATE ICES IN THE MARTIAN POLAR CAPS. W. B. Durham[1], S. H. Kirby[2], L. A. Stern[2], and S. C. Circone, [1]UCLLNL (P.O. Box 808, Livermore, CA 94550; durham1@llnl.gov), [2]USGS (Menlo Park, CA 94025).

Introduction: Modeling the evolution of the Martian polar ice caps requires, among other things, knowledge of the rheologies of their component phases. We review here the known flow laws for water ice and solid CO_2, which are, respectively, the major icy phase, and major CO_2-bearing phase, if conventional wisdom is to be believed. We also present first measurements on the flow of CO_2 clathrate hydrate, whose presence in the south polar cap has been suggested. Earlier measurements of methane clathrate, which is structurally analogous to CO_2 hydrate and which is dramatically harder than water ice suggested that the presence of important volumes of clathrates in the south polar cap were unlikely, owing to the exceedingly high strength of the material. The new measurements show that CO_2 hydrate is significantly weaker than CH_4 clathrate, but still much stronger than water ice. Thus, the rheological basis for dismissing CO_2 hydrate is somewhat weakened, but relaxation models for the south polar cap are still inconsistent with the strength of CO_2 clathrate. Concerning the water ice phase in the polar caps, it is important to consider the balance between grain-size-sensitive (GSS) and grain-size independent (GSI) mechanisms of creep.

Background: Laboratory experimentation on ices is aimed at providing a constitutive rheological law, typically of the form

$$\dot{e} = As^n \exp(-Q/RT) \qquad (1)$$

where $\dot{e}$ is the ductile (permanent, volume conservative) strain rate, s is differential stress, T is temperature, R is the gas constant, and the three parameters A, n, and Q are material-specific constants. It is possible to duplicate Martian temperatures and Martian differential stresses in the laboratory, but it is not possible to duplicate them simultaneously because the resulting Martian strain rates will be too low to measure on the laboratory time scale. While we endeavor to reach ever finer levels of resolution, the current limit on laboratory strain rates, about 2 ¥ 10^{-8} s^{-1}, is still several orders of magnitude faster than strain rates in the spreading Martian polar caps.

Experimental measurements: The pure phase rheological properties have now been measured in the laboratory for most of the candidate Mars polar cap materials [1-4], and in the case of water ice, a distinction has also been discerned between a GSS and GSI rheology. Conveniently, there are some rather extreme rheological contrasts between some of the phases. In particular, the effective viscosity (proportional to $s/\dot{e}$ in Eq. 1) of pure CO_2 ice is several orders of magnitude lower than that of water ice, and the strength of gas hydrates is several orders of magnitude higher than that of water ice. The Mars polar caps are therefore unlikely to hold large reservoirs of CO_2 either as solid CO_2, because the caps would have relaxed far below their current profiles, or as hydrate, because they would not have flowed at all, contrary to what observational evidence suggests.

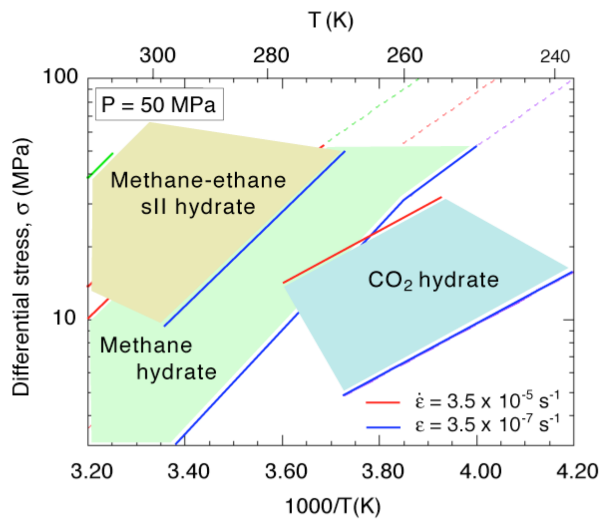


Figure 1. Laboratory measured rheologies of three different gas clathrate hydrates. Methane and CO_2 clathrate are both so-called structure I clathrates, while the methane-ethane clathrate as tested is a structure II material. Fields are bounded by lines of constant $\dot{e}$, following Eq. (1)

The latter conclusion was based on the measured strength of methane clathrate, a common earth material with a structure identical to that of CO_2 clathrate. We have now measured the flow of CO_2 clathrate itself (Fig. 1), and found it to be considerably weaker—by about two orders of magnitude in viscosity—than methane clathrate. Although the CO_2 clathrate is still two orders of magnitude more viscous than water ice at similar conditions, the conclusion is now less robust, at least on rheological grounds, that important volumes of CO_2 clathrate cannot exist in the Mars polar caps. We may have to wait until Mars geology is better understood before we can make additional conclusions.

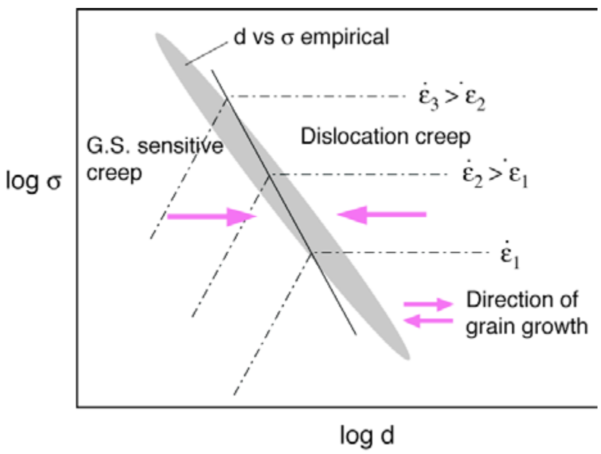


Figure 2. Theoretical evolution of grain size during GSS and GSI (here: dislocation creep) creep, and its effect on steady-state. Grain size tends to increase during GSS creep, but decrease during GSI creep, thus working at cross purposes with respect to the host mechanism. (from [5]).

There is one point we wish to emphasize regarding the rheology of polycrystalline water ice, which is likely to be the major phase in the Mars polar caps. Goldsby and Kohlstedt [1] were able to activate and quantify a GSS rheology in ice, one of the few materials where this has been possible in the laboratory. The finding is quite important to geology and planetary geology because GSS mechanisms are ordinarily less stress sensitive than GSI mechanisms ($n \approx 2$ vs $n \approx 4$ in Eq. 1) and therefore would tend to be favored over GSI mechanisms at the very low stresses and strain rates typical of geological settings.

However, caution should be applied when modeling glacier flow with GSS creep. As pointed out by de Bresser and colleagues [5], one finds many instances in natural settings on Earth (in calcite- and olivine-bearing rocks in particular) where the observed grain size and inferred strain rate imply conditions, following Eq. (1), such that the strain rates contributed by GSS and GSI creep are roughly comparable. Figure 2 offers an explanation for such a phenomenon. Since GSI creep usually involves the movement and growth of dislocations, internal energy of individual grains tends to increase with strain. Since internal energy tends to drive recrystallization, which in turn often results in finer grain sizes, grain size can decrease during GSS creep (the left-pointing red arrow in Fig. 2). GSS creep depends on the presence of grain boundaries in the material, so this action of GSI creep to decrease grain size can have the effect of increasing the proportion of strain rate contributed by GSS creep. On the other hand, deformation by GSI creep takes place by the rigid slip of grain boundaries or by the transport of material along grain boundaries, neither of which changes the internal defect structure or therefore the internal energy of grains. The grains may therefore grow under the motivation of ordinary surface energies (right-pointing arrow in Fig. 2).

The combined result of GSS and GSI creep working at cross purposes with respect to grain growth is that we might expect a balance to eventually be struck, with both mechanisms contributing to flow. In modeling the flow of ice in the Martian polar caps, both flow laws (Eq. 1) for GSS and GSI should be considered.

References: [1] Goldsby D.L. and Kohlstedt, D.L. (1997) *Scripta Mater.*, *37*, 1399-1406. [2] Durham W. B., Stern L. A., and Kirby S. H (1999) *Geophys. Res. Lett.*, *26*, 3493-3496. [3] Durham W. B. and Stern L. A. (2001) *Annu. Rev. Earth Planet. Sci.*, *29*, 295-330. [4] Durham W. B., Kirby S. H., Stern L. A., and Zhang W. (2003) *JGR*, *108*(B4), 2182, doi:10.1029/2002JB001872. [5] de Bresser J. H. P., ter Heege J. H., Spiers C. J. (2001). Grain size reduction by dynamic recrystallization: Can it result in major rheological weakening? *Int. J. Earth Sci., 90,* 28. doi 10.1007/s005310000149