Session Summaries, 7th International Conference on Mars, July 9-13, 2007

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INTRODUCTION

The 7th International Conference on Mars, held July 9-13, 2007 at Caltech, was organized into nine theme-oriented oral sessions (listed below). Each of the oral sessions was configured with a set of papers of relevance to the theme of the session, along with some introductory comments by the session chairs to frame the session, and a concluding discussion session that was moderated by the session chairs. The following master discussion prompts were used for each of the concluding discussion sessions:

- **What do we know?**
- **What do we need to learn next?**
- **Are we doing the right things to find the answers?**

For each of the nine discussion sessions, the comments from the audience were documented, and a primary purpose of this report is to present those exchanges. In addition, because of the role played by the session chairs in both framing these discussions and in moderating their flow, they were given an opportunity to prepare a few paragraphs summarizing their perspective on these questions.

Technical Sessions and Session Chairs

The distribution and context of water-related minerals on Mars
Jack Mustard and Ray Arvidson

Geology of the martian surface: Lithologic variation, composition, and structure
Hap McSween and Janice Bishop

Water through Mars's geologic history
Michael H. Carr and Ben Clark

Volatiles and interior evolution
Roger Phillips and Linda T. Elkins-Tanton

The martian climate and atmosphere: variations in time and space
S. W. Bougher & F. Forget

Modern Mars: Weather, atmospheric chemistry, geologic processes, and water cycle
Rich Zurek and Leslie Tamppari

The north and south polar layered deposits, circumpolar regions, and changes with time
Stephen Clifford and Wendy Calvin

Mars astrobiology and upcoming Missions
David Des Marais and Phil Christensen

Martian stratigraphy and sedimentology: Reading the sedimentary record
Oded Aharonson and Scott McLennan

SESSION SUMMARIES

1. THE DISTRIBUTION AND CONTEXT OF WATER-RELATED MINERALS ON MARS

Session Chairs' Summary (Jack Mustard and Ray Arvidson)
This session consisted of 10 talks covering a diverse range of topics. The first talk framed the session with the timeline of water-related minerals on Mars derived from OMEGA data and integrated with the geologic record derived from other mission data. Subsequent talks focused on the new perspectives on phyllosilicate minerals made possible with CRISM's high resolution views, details of sulfate and hematite deposits in Valles Marineris, and the identification of phyllosilicate minerals in the fluvio-deltaic deposits in Holden crater. Many of these themes were carried forward in the poster session, with additional perspectives offered from theoretical and experimental results.

The key hypothesis framing the session was that phyllosilicates were dominantly formed during Mars' earliest period (Noachian), followed by sulfates in the late Noachian to Hesperian. Since then, there has been little evidence for formation of water-related minerals. This is despite the abundance of morphologic features thought to be water related (e.g. young valley networks and outflow channels, gullies, volcano-ice interactions, and ice-related features).

For the phyllosilicate deposits, it is critical to determine if, and how the composition of the deposits vary in space and time. This is central to inferring the environmental conditions that existed at the time of the formation of these minerals. Were they formed at the surface in concert with an active hydrologic cycle or were they formed at depth in a hydrothermal or warm, wet crust environment? Could they be the result of magmatic water released from the cooling and crystallization of the magma ocean? In order to understand these questions we need to have carefully characterized deposits for which detailed stratigraphic and superpositional relationships can be determined. Many of the phyllosilicate deposits in the southern highlands are found in association with impact craters (e.g. ejecta, walls, and central peaks). A key question here is to what extent does the impact process stimulate the formation of the phyllosilicates and to what extent are the observed minerals passive tracers of the impact process? Impact melts may actually be a source of the phyllosilicates, as opposed to exposing them from lower, preexisting geologic units where water-rich impact melts devitrify. Yet some of the largest phyllosilicate deposits are found outside the obvious influence of impact craters (e.g. Mawrth Valles), indicating that multiple formation processes are likely and need to be understood.

The distinction between the phyllosilicate-rich Noachian and the sulfate-rich late Noachian to Hesperian is an important observation. It is imperative to identify regions where phyllosilicates and sulfates co-occur. The environment of formation for the sulfates has benefited from the success of MER, but the deposits found elsewhere need to evaluated more carefully to understand if they are variations of the MER models or due to other processes. For example, sulfate deposits do not necessarily require surface water to form.

The issue of mineral abundance is a key technical question for the community to consider. Development of approaches that combine the visible-infrared-and thermal infrared wavelengths to determine modal and lithologic mineralogy is important.

Notes from moderated discussion

- How do compositional variations occur, both in space and time?
- Resolution of observations may be an issue…
- We need to look for contacts between sulfates/phyllosilicates to determine the relationships, and for sampling both terrains – analogy to Apollo landing sites at geologic contacts
- What's in the rest of the rocks within (and outside of) sulfate/phyllosilicate units?
- Work needs to be done to understand the geologic context/stratigraphic relationships of sulfates and phyllosilicates
    - Why are these materials exposed in rims/central peaks of craters? Are they exposed, or formed, by these craters?
- Earth analogues are useful for exploration of sulfate terrains, where we have abundant experience with similar deposits
- There is a difference between observations of rock/water interaction, and evidence for the presence of water at the surface of Mars
- Gamma Ray data is telling us about varying chemistry of the crust
- Largest exposure of phyllosilicates is in Mawrth Vallis – and this is not in association with crater walls/peaks
- Mineralogical changes record important, global changes within the Martian environment
    - Sulfate terrains do not demand stable water at the surface
    - Phyllosilicate terrains are the most likely to record the presence of surface hydrology – look for the presence of carbonate grains here, to investigate atmospheric history
- Impact melts may actually be the source of the phyllosilicates, as opposed to exposing them from lower, preexisting geologic units
    - Contemporaneous divitrification, no subsequent alteration
- Magmatic water/hydrothemal alteration may have played a significant role
- Were phyllosilicates formed in the subsurface by alteration, or at the surface by deposition, and how do we resolve this?

2. GEOLOGY OF THE MARTIAN SURFACE: LITHOLOGIC VARIATION, COMPOSITION, AND STRUCTURE

Session Chairs' Summary (Hap McSween and Janice Bishop)

This session covered surface composition at a range of scales including analysis of orbital data and rover data. Two talks described what the Spirit rover has revealed. When viewed at this scale, the crust in Gusev crater is seen as a complex assortment of alkaline volcanic rocks (all related through fractional crystallization) and partially to completely altered materials sometimes showing extreme chemical fractionations. Four presentations then dealt with thermal emission spectra of the Martian surface. New interpretations of TES and THEMIS data reinforce the conclusion that the basaltic crust is mineralogically heterogeneous, although there is still considerable debate about whether TES surface type 2 material represents differentiated igneous rock (andesite) or altered rock surface compositions (probably dominated by silica). One paper then described models for impact melt generation and global dispersal that suggest that glasses should be a significant component of the surface materials. Finally, four presentations described the geologic and stratigraphic context for phyllosilicates in ancient Martian terrains, using hyperspectral VNIR data from OMEGA and CRISM images and high-resolution surface views from HiRISE and HRSC. The session ended with a lively moderated discussion.

What do we know:

We now know that the crust of Mars is dominated by basaltic volcanism, and that aqueous alteration (chemical weathering) occurred early in Mars history but weathering in more recent times has been mostly physical.

What do we need to learn next:

We need to understand the degree to which igneous fractionation has occurred, i.e. is TES surface type 2 material andesitic or altered. The concensus may be growing that it is altered and that Mars is a basalt-covered world, but discussion continues on this. TES and THEMIS analyses are using expanded wavelength coverage for modeling and comparison with lab data that is enabling mapping of four surface types with more precise spectral character. Additional work is needed in comparing the OMEGA and CRISM results with the TES and THEMIS results in order to gain a more complete picture of the global surface composition.

We need to understand how the phyllosilicates seen by OMEGA and CRISM formed. Were they really formed during a warmer, wetter period of less acidic alteration in the Noachian, or could they have formed and been exposed by large cratering events that set up hydrothermal systems? This requires more detailed mapping of phyllosilicates, including variations in the types of phyllosilicates present, the kinds of minerals they are associated with (e.g. mafic minerals such as olivine and pyroxene, or others such as iron oxides/oxyhydroxides, sulfates, carbonates…), and the kinds of structural features they are associated with (e.g. craters, flow features, ridges, etc.).

We need to quantify the amounts and distributions of glasses (igneous and impact-melted) on the Martian surface, and understand what may have modified their spectral characteristics. Coordinated VNIR and thermal spectral analyses may be able to contribute towards improved mapping of glass and altered glass on the surface.

We have a broad geochronological outline, but we need appropriate tools for absolute and relative dating of surfaces on Mars.

Are we doing the right things:

Yes, but more attention must be paid to understanding the geologic context of alteration and magmatism, now that we have spectral information that is nearly on the same scale as imaging.

We need structural information on the crust, which is mostly an untapped area of concern.

We need to resolve the chronological questions associated with crater counting on Mars, and we need absolute calibration points for crater counts.

Notes from moderated discussion

- How can we tell primary basalt from altered basalt? What are the limits of TES in doing so? (Note: our ability to do this may vary from place to place)

- Finding basalt and phyllosilicate or other alteration minerals adjacent to one another is critical
- Do metamorphic rocks exist on Mars and are they being excavated by impact craters?
- Critical to consider the information that different instruments give us from different depths, e.g. latitude dependency in upper hundred microns to 10s cm (TES vs. GRS info)
- What happens in a big impact on Mars? Difficult because we have no Earth analogs and hard to separate from volcanic processes. How do we unravel? Look at young impact craters in volatile-rich regions. Looking at old and young impact craters
- How confident can we be of mapping the silicon value derived from GRS?
- Can we look for additional clays by combining information from OMEGA and GRS? Something hydrated beneath the dust or hydrated dust?
- "Holy grail" may be a location with both sulfate and clay allowing a traverse across both – how well could MSL do this? ChemCam can remotely remove weathering layers and assess underlying composition
- Measurements made by the instruments are probably not wrong. We need to be more creative with combining the data sources (along with laboratory work) in order to interpret them. More MFR funding, perhaps?

3. WATER THROUGH MARS'S GEOLOGIC HISTORY

Session Chairs' Summary (Michael H. Carr and Ben Clark)

The session on "Water Through Mars' Geologic History" included a variety of approaches for attacking this multi-faceted question. Ten papers covered approaches ranging from field analogs of geomorphological features and chemical analogs of acid sulfate lakes, to laboratory analyses of martian meteorites and in situ analyses of chemistry and mineralogical constituents on Mars. This kaleidoscope of diverse methodologies provided an excellent sampling of the tools which may be brought to bear upon the complex history of water on Mars.

The perception that water has played a prominent role in the evolution of Mars stems largely from interpretation of the morphology of the surface. Extensive areas of dissected terrain suggested that, at times in the past, conditions at the surface were such as to permit liquid water to flow across the surface and erode the observed valleys. Until recently this interpretation appeared at odds with the absence of hydrated minerals, the abundance of easily weathered minerals, such as olivine, and climate models. The big question still remains: Was there was ever a global hydrologic system in which precipitation, infiltration, runoff and groundwater flow were in quasi equilibrium with evaporation and sublimation from large bodies of water and ice. Two papers directly address this issue. Howard et al examine the pattern of dissection by valley networks for clues as to the hydrological conditions under which they form, and Benison et al emphasize the role of very acid water in formation of the valleys which has implications for the source of the water.

Another morphological puzzle is the role of water in surface processes on present day mars. Gullies and other slope features appear to be forming at the present day, and liquid water may be playing a role, although this is difficult to reconcile with present-day conditions. The paper by Head et al. suggests that dark slope streaks have close analogs in Antarctica where similar streaks form by the melting of ground ice and flow of the meltwater downslope beneath a dry surface layer. Darkening is caused by wicking of moisture up to the surface.

The paper by McCubbin and Nekvasil sought to constrain the history of magmatic volatiles in the Chassigny maritan dunite, tracing both H2O and halides. Greenwood et al. proposed new constraints on martian H2O reservoirs by examining D/H isotope ratios in apatite grains of martian meteorites to infer major fractionation very early in Mars history, attributable to hydrodynamic escape, followed by low loss rates over the majority of geologic time with H2O trapped as ice.

Through a study of acid lakes in Chile and Australia, coupled with laboratory experiments, Benison et al. are conducting wide-ranging tests of chemical environments and mineralogical consequences. The uptake of H2O from the atmosphere by Mg-sulfates is under laboratory investigation by Vaniman et al, who describe known as well as newly discovered phases and uptake-desorption phenomena. As reported by Goetz et al., Clark et al., and Yen et al., elemental and mineralogical data from the Mars rover missions have revealed both low and high water-rock ratio alterations on Mars.

What do we know?

The history of water on Mars appears to span, literally, the whole of geologic history. It pervades the magmas, has formed evaporitic sandstones as well as nearly pure salt and silica concentrations, yet has only slightly reacted with the wide-spread contemporaneous fine-grained soils. Under today's conditions, it reacts with salts and possibly some silicates.

What do we need to learn next?

Further information on the diversity of salt compositions is welcome. Exploration by in situ measurements at Columbia Hills implicates not only ferric and Mg sulfates, but also Ca sulfate, Ca phosphate, and Al sulfate. The stratigraphic sequence of these deposits and their source materials is currently unknown.

What do we need to do?

Continued exploration by MER rovers, at both sites, could further elucidate the H2O history of these modified terrains. Laboratory studies of H2O interactions with igneous source material (including acidic conditions) as well as appropriate field studies will help reveal the amounts of H2O and environmental influences in past martian surface history. Further study and monitoring of the enigmatic gullies and slope streaks on Mars are needed to understand the driving forces for their formation and evolution. Sample return from areas which clearly contain alteration products of H2O exposure can afford the opportunity for laboratory investigation of materials not now, and unlikely to ever be, in the martian meteorite record.

<u>Notes from moderated discussion</u>

- We have an awful lot of geochemical and geomorphologic data. How can we put it all together?
- We need to better understand the geologic context of observations from small areas

- Several processes have been proposed to explain the different geochemical evidence (volcanism, hydrothermal dissolution and deposition, weathering, groundwater circulation, evaporation). How do we determine what is going on where
- What is causing the large chemical gradients in the top meter or so? What are the roles of fumarolic activity, acid fogs, liquid water?
- On earth, you can get tremendous diversity geochemically from volcanic processes
- When you consider where/when Gusev is, you must consider impact processes as well as volcanism.
- Aqueous activity at a wide range of fluid composition ? high pH mixing with low pH
- See similar heterogeneities in acid lake deposits in Australia
- Distribution of Pasa Robles lighter material is very spotty which may be indicative of impact or fumarole origin
- Low water/rock ratios at Gusev ? details of the elemental ratios can have a dramatic impact on the final evaporitic product
- Meridiani may not have as low water/rock ratios
- pH conditions in hydrothermal vents in 60 impact craters – were all very high pH.
    - Could help distinguish between impact/volcanic origins
- Much of chemical diversity at Gusev is just beneath the surface
- Silica deposits and sulfate deposits are hydrated and appear to be found in local lows.
- Working model: dissolution and reprecipitation of aqueous systems. Volcanic and volcanoclastic because it seems too intricate to be an impact process
- If slope streaks are indicative of liquid water, might they be classified as special regions?
- HiRISE sees some topography associated with slope streaks supporting the dry avalanching theory
    - DEM model of one of the deposits and the slope is very steep so you can have dry flow
- History of water on Mars from D/H ratio
- If water was lost at 4.5Ga, there would have been an influx of more water to explain geomorphology
- Is it possible to explain the extreme D/H ratios by invoking very little communication between atmosphere/water reservoir?
- Current state of what we know/don't know about ancient martian oceans/seas/standing water
    - Period(s) of formation of valley networks may have been short. Landscape is not totally dominated by water erosion features
    - When we talk about water, what do we imply by the composition of the water? Is it dilute or was it very salty/acidic?
    - Debate on whether or not we need rainwater or if groundwater is sufficient
    - Drainage patterns show that in many places it could not have been groundwater
- Some basic geomorphic features are still ambiguous
- Obliquity changes and consequences of snowfall and erosion at the equator
- True polar wander paper ? what do we think about the recent paper?
    - What shoreline feature? Are we tying together different features into a single shoreline?
    - look at the duration of some of the features to see if conditions were a small episode or represented hundreds of millions of years.

4. VOLATILES AND INTERIOR EVOLUTION

Session Chairs' Summary (Roger Phillips and Linda T. Elkins-Tanton)

The focus of the workshop was naturally on current mission data, which largely concerns surface features and compositions and volatile budgets. Mars has remnants of an ancient surface, for more than does the Earth. Mars therefore gives us an opportunity to link processes of formation and internal processes to surface features and compositions perhaps more directly than on Earth. A number of researchers are addressing problems of internal evolution and links to surface manifestations. We now have several models for early accretion and differentiation, production and longevity of a core dynamo, production of basaltic crust, and partitioning of initial and secondary volatile contents into the atmosphere (with their effects on climate) and loss to space. Each of these topics informs and is informed by remote sensing and rover data. We hope interdisciplinary collaborations become richer as models become more sophisticated and specific and as mission data continue to come in. The atmosphere, hydrosphere, solid parts of the planet, and the core are a coupled system. The framework for the origin and evolution of life on Mars can only be understood within this context of "Mars System Science." In future, geophysical measurements of the planet, most particularly seismic and heat flow measurements, would greatly further our basic understanding of Mars as we do not know with any precision the basic compositional layering of the planet, its present thermal state, and its energy potential for driving tectonic, volcanic, and atmospheric processes.

Notes from moderated discussion

- What are the questions from the data coming from the missions in terms of physics and chemistry of internal processes?
- How big is the core and what is the volume of the crust? Geophysical measurements that would be most valuable include:
    - Seismology—would help define the depth of the olivine transition in the mantle, the nature and depth of the core-mantle boundary, the lithospheric depth, and regions of activity in the planet; and
    - Heat flow—to constrain temperature profiles and modes of heat transport in the planet, as well as lithospheric thickness.
- How iron rich and aluminum poor is the mantle? What are the physical implications not based on the Martian meteorites?
- What are the structures and compositions of the Martian crust?
- We have made significant and positive progress in answering some but not all of these questions on the nature of the Martian interior and geologic history.
- Global average of potassium and thorium of Mars is double that of the Earth—iron is higher on Mars – these are fundamental properties of the planet that originated at accretion and indicate first-order differences in terrestrial planet formation.
- Early history—we don't see it all—infill of the Utopia Basin, for example, obscured older crust.
- Potential for plate tectonics in early history—do the magnetic signatures indicate early plate tectonics or not? Is that question put to bed?
- Gamma ray data indicates a large diversity of the composition of the crust; we need to differentiate alteration processes from primary igneous processes.

- We need chronology of the earliest crust of Mars.
- Some researchers maintain that there is nothing older than 4.0 Ga visible on Mars, that the Late Heavy Bombardment that affected the Moon so clearly must also have obliterated older records on Mars.
- Rocks on the Moon preserve the record earlier than 4.0, therefore the question for Mars is not whether there is older material, but simply how large it might be: Hand-sample? Terrane?
- If sample return occurs it should be planned to help determine the chronology of events on Mars.
- What is the most valuable sample we can collect? Can we actually find a sample at the phyllosilicate and sulfate locations?
- Can a dynamo last longer than a few hundred million years on Mars?
- Plate tectonics– crater chronology does not rule out plate tectonics earlier than 3.9 Ga. This would change the age constraints on the dynamo.
- We have learned a fantastic amount from Martian meteorites, and will continue to learn more even from the samples we have. Antarctic searches should continue to be funded; we will almost certainly find additional unique samples, and this is far more cost-effective than planetary sample return, and faster.
- What volatiles are (were) involved, besides water, in the martian hydrologic cycle? How can we determine this from remote sensing and *in situ* observations?
- What is implied by the increase in elastic thickness over time for the evolution of interior volatiles?
- Volatiles released into the atmosphere can perturb the climate – CO_2, H_2O, SO_2, H_2S, CH_4. How important is this, particularly for the latter part of the Noachian? How important was Tharsis outgassing?

5. THE MARTIAN CLIMATE AND ATMOSPHERE: VARIATIONS IN TIME AND SPACE

<u>Session Chair's Summary (</u><u>S. W. Bougher)</u>

This session included papers and discussion focusing on past Martian climate changes, present Mars climate and its variations over observable solar cycle, inter-annual and seasonal timescales, and Mars upper atmosphere climate features and their variability. Ancient Mars climate changes are being investigated with the aid of multi-dimensional models (i.e. volatile evolution studies) and various proxy indicators (e.g. erosion rates and crater statistics). The present Martian climate (i.e. lower atmosphere temperatures and the dust, water, CO2 cycles) is being studied with measurements by successive spacecraft missions to the planet (i.e. MGS, Odyssey, MERs, MEX, and MRO). This recent pattern of monitoring is important to continue, and is contributing to the development of a modern Martian climatology. Lastly, Mars upper atmosphere measurements are not sufficient to define a modern climatology. "Opportunity" science consisting of limited observations (i.e. both spatially and temporally) is important to pursue and is providing many fundamental discoveries that characterize the structure and variations of the Mars upper atmosphere. In particular, recent evidence shows that the Mars lower and upper atmospheres are coupled thermally, dynamically, and chemically. GCM modeling frameworks are evolving to properly capture the "whole atmosphere" coupling processes that are required to explain these observed variations in the Martian upper atmosphere.

It is clear that the monitoring of Martian lower atmosphere has been very successful, and must be continued with future spacecraft missions to the planet. A network of landed meteorology (MET) stations is also needed to contribute essential "ground truth" to this monitoring program. Boundary layer meteorology is also critical to address, possibly with a MET network, but also with MET packages on all future landers to the planet. The latter is a possibility that is achievable in the near future.

Real progress on the development of a Mars upper atmosphere climatology awaits a dedicated mission to address this region of the atmosphere and its associated volatile escape rates. A final selection of an aeronomy mission for the 2011 Mars Scout opportunity is clearly a giant step in the right direction.

Session Chair's Summary (Forget)

This first session on Mars present and past climate systems was very diverse.

1) A first part was dedicated to climate change on various timescale including the very long term (early Mars vs. today), the "periodic" climate changes resulting from orbital and obliquity planet parameters (with two talks dedicated to the low obliquity climate, to be completed with other talks presented in the polar cap sessions on Thursday morning), and the 10 to 100 years variations which may be apparent in the variations of the residual CO2 southern polar caps, for instance.
2) A second part was focused on Mars upper atmosphere, thermosphere and ionosphere. Until recently, the Martian atmosphere between ~70 and 200 km was very poorly known, with very little observations available. Now, the Mars Express SPICAM UV spectrometers and the accelerometer data obtained in-situ by MGS, MO, and MRO are providing unprecedented measurements which help to constrain this part of the atmosphere. These observations suggest that the current state of the art models are not yet able to reproduce and understand the observations…

The various talks had thus in common to raise a lot of questions and enigma. The discussion focused on various aspects of the session:

- Early Mars Climate models (e.g. Mischna et al. in the session) are now incorporating SO2, CH4, impacts influences in 3D models. More ongoing work will be at last published in the near future. Among many problems, an outstanding one is the calculation of the Greenhouse effect with relatively thick (> 0.5 bar) CO2 atmosphere as possible on early Mars: CO2-CO2Collision induced absorption may play a key role in the radiative transfer, but there is little lab measurements available to calculate this accurately.
- A usual question was raised : Where is the CO2 to give higher pressures in the past? The most likely answer seems to be : Atmospheric escape of all volatiles
- A discussion was started about the suggestion by Paige et al. that low obliquity on Mars did not trigger a collapse of the CO2 atmosphere into CO2 polar caps :

- “Even at 1mbar pressure, micrometeorites have to traverse significant atmosphere. Lack of micrometeorites doesn’t rule out atmospheric collapse.”
    - There are current controversies about current population of the impactors. Uncertainties in scaling from Earth fluxes of micrometeorites, as well as larger sizes.
    - Particle trajectory in low-pressure atmosphere over long distances. Where does confidence in this model come from?
    - Optical measurements of bolides traveling through analogous regions of the Earth’s atmosphere. Also some models exist. But for the smaller size ranges, the particles are stronger and less prone to breakup.
    - Robust solution for past spin/orbit parameters are one thing to query. Also models of low-obliquity atmosphere.
    - Components of CO_2 condensation understood from present condition (somewhat). Other, less well-known components such as albedo variations exist.
    - Simple models may over-predict amplitudes of variations in parameters like pressures.
- Another part of the discussion was about Golombek et al. work on Erosion rates: “We don’t know how long the rocks have been on the surface. Possibility of rocks being covered and exposed, not monotonic erosion”.
- The possibility of climate variations on the 100 years time scale (resulting in variations in the residual south CO_2 caps, as well as variations in the occurences of planetary encircling dust storms, etc...) suggested a question to the entire community: are there other surface clues that could help climate scientists to constrain these climates variations ?
- One more enigma was recalled by Ann Sprague from the GRS team. The 6 time argon enrichment (due to CO_2 depletion) in the southern polar night cannot be reproduced by the numerous 3D models (GCM) that has tried so far !

<u>Notes from moderated discussion</u>

- Great diversity of topics, but in common: Lots of questions about past climate, atmospheric evolution, recent evolution, upper atmosphere.
- Past climate models (e.g. Mischna) now incorporating SO_2, CH_4, impacts influences on early atmosphere.
- Greenhouse effect on early Mars: Is collision induced adsorption included in paleo-GCM models? No lab measurements exist to solve this.
- Low-obliquity climate: Budget of CO_2 available for present and past climates. Total polar cap reservoir can only increase pressure slightly. Where is the CO_2 to give higher pressures in the past?
    - Atmospheric escape of all volatiles
- Even at 1mbar pressure, micrometeorites have to traverse significant atmosphere. Lack of micrometeorites doesn’t rule out atmospheric collapse.
- There are current controversies about current population of the impactors. Uncertainties in scaling from Earth fluxes of micrometeorites, as well as larger sizes.
- Particle trajectory in low-pressure atmosphere over long distances. Where does confidence in this model come from?

    - Optical measurements of bolides traveling through analagous regions of the Earth's atmosphere. Also some models exist. But for the smaller size ranges, the particles are stronger and less prone to breakup.
- Robust solution for past spin/orbit parameters are one thing to query. Also models of low-obliquity atmosphere.
    - Components of CO2 condensation understood from present condition (somewhat). Other, less well-known components such as albedo variations exist.
- Simple models may over-predict amplitudes of variations in parameters like pressures.
- We have reasonably robust predictions, but we don't have understanding some of the finer details
- Erosion rates: We don't know how long the rocks have been on the surface. Possibility of rocks being covered and exposed, not monotonic erosion.
- Two models of Mars paleo-climate involving nitrates run: thin model / thick model. Both may give rise to nitrate formation. Nitrates should be present (observable). Sources for atmospheric gasses a necessary component to have isotopic ratios come out properly.

6. MODERN MARS: WEATHER, ATMOSPHERIC CHEMISTRY, GEOLOGIC PROCESSES, AND WATER CYCLE

Session Chairs' Summary (Rich Zurek and Leslie Tamppari, with assistance from Michael Mischna)

The content of this session addressed contemporary weather on Mars through explorations by present and recent spacecraft (MRO, MEX and MGS) as well as through ground-based observations and numerical modeling. Talks were of a highly diverse nature, but focused primarily on atmospheric aerosols, the global water cycle and short-term change of the martian surface.

It is apparent that the martian dust cycle (including quiescent years) is highly variable, yet characterization of its behavior is critical to future human exploration activities. Possible interruption of the MER missions by a global-scale dust storm (July/August 2007) indicates the important role dust will, and should, play in future mission design. This also argues strongly for continued acquisition of atmospheric data, ideally by every Mars spacecraft. Present orbiter coverage, due to orbital restrictions, is limited to fixed local times, and it was noted that expanded diurnal coverage would be a desirable capability of future missions. One example of how to do this would be through a networked mission with multiple landed stations. Additionally, the value of small, simple atmospheric instruments (e.g. radio science data) was stressed. An example of extracting value-added products from extant data was presented, which outlined attempts to extract vertical profiles of dust abundance from MGS TES data. The Mars Climate Sounder (MCS) can obtain a similar product, lengthening our measurement baseline.

A significant outstanding question continues to center around the presence of trace gases in the martian atmosphere, including water vapor and methane. The detection of trace gases has been identified as a high priority science question, and, indeed, MSO has been scoped to possibly address this question. There is not universal consensus that this is the best path to pursue with MSO, however. Numerous spacecraft-borne instruments are currently capable of observing water vapor in the martian atmosphere, including SPICAM, OMEGA and PFS on Mars Express and MCS on MRO. What is consistent between these instruments is the "back-end" inclusion of some level of atmospheric modeling, either through radiative transfer calculations, or with full general circulation models (GCMs). For the latter, it was demonstrated that the assumptions made in the GCMs critically influence their results. For example, the size and shape of a model's north polar residual cap dictates how "wet" the model will be. Recent observations of the water vapor content of the martian atmosphere suggest it may be drier than previously assumed. GCMs are capable of reproducing this new, drier state, however such capability reinforces the point that these models are only as good as the assumptions that go into them. Subtle changes in surface albedo introduced by the dust cycle may also reduce the water abundance of the atmosphere. These time-varying changes ought to be considered in future implementations of GCMs to provide more faithful representations of the true atmosphere and surface.

The discovery of active gullies, as indicated by 'bright gully deposits' (BGDs) is an exciting new discovery that shows the surface of Mars is presently active. It remains uncertain whether BGDs are dry-based (mass wasting) or wet-based (water flow), although laboratory experiments and radiometric measurements to infer dust grain size can be used to determine whether water is capable of generating these deposits under martian environmental conditions.

Notes from moderated discussion

- Remaining issues
    - Mismatch between modeling and data—need progress on both fronts
    - Data: Near-surface atmosphere
        - Surface-based networks
    - Models: Boundary Layer processes, including surface-atmosphere exchange of dust and volatiles
- What more do we need and why?
    - Do we need longer-term data sets?
        - Every Mars landing cycle is unique, more so in the dusty season
        - Every Mars annual cycle we can get is a positive
        - Characterization on a year-to-year basis is very important to human exploration
    - Do we need expanded diurnal coverage?
    - Do we need more tracers in the models? Integrated feedback?
- Are we doing the right things to find the answers?
    - Do we need a surface network? Concurrent with orbiter measurements?
    - Should every lander have atmospheric capabilities? Which ones?
- Surface humidity measurements are important and have not been done before PHX
- More modeling of slices through atmosphere during different seasons
- Will help answer whether or not the argon is concentrated close to the surface or is mixed with altitude
- We've been rather unsuccessful in getting simple instruments with small data volumes on spacecraft. E.g., radio science
- Long term measurements of wind magnitude and direction near the surface
- Important for EDL and human exploration
- How long is long-term?
- Methane question - what is the status?

- Does the Mars community agree that this measurement is important and worth doing with MSO?
- Trace gases are high priority, were defined as such in the past, and should be pursued again
- What is the surface energy distribution of dust particles in the atmosphere? Are they very oxidizing?
- What do we need to be able to discriminate between the dry or wet flow models for the bright gully deposits?
    - More modeling and looking for BGDs in images
    - More physical experiments under Martian conditions as to whether or not water can actually do that work?
- Can measure albedo of bright deposits, we need to quantify how bright or dark these are. This will help constrain grain size
- Are we still measuring gases in the Martian meteorites? Are we keeping up with the analyses of these trapped gases?

7. THE NORTH AND SOUTH POLAR LAYERED DEPOSITS, CIRCUMPOLAR REGIONS, AND CHANGES WITH TIME

Session Chairs' Summary (Stephen Clifford and Wendy Calvin)

As the planet's principal cold traps, the Martian polar regions have accumulated extensive mantles of ice and dust that cover individual areas >10^6 km^2 and total as much as 3–4 km thick. From the small number of superposed craters found on their surface, these layered deposits are thought to be comparatively young—preserving a record of the seasonal and climatic cycling of atmospheric CO_2, H_2O, and dust spanning the past ~10^5–10^8 years. For this reason, the Martian polar layered deposits (PLD) may serve as a Rosetta Stone for understanding the geologic and climatic history of the planet.

The issues addressed by the ten talks presented during this session, and the subsequent discussion, covered a wide range – encompassed by the following key questions[1]:

- What are the physical characteristics of the PLD and how are the different geologic units within, beneath, and surrounding the PLD related?
- How old are the PLD? And what are their glacial, fluvial, depositional and erosional histories?
- What are the mass and energy budgets of the PLD, and what processes control these budgets on seasonal and longer timescales?
- What chronology, compositional variability, and record of climatic change is expressed in the stratigraphy of the PLD?

[1] Originally identified by the participants in the 4th International Conference on Mars Polar Science and Exploration, Davos, Switzerland, October 2006.

- How have volatiles and dust been exchanged between polar and non-polar reservoirs? And how has this exchange affected the past and present distribution of surface and subsurface ice?

The talks by Y. Langevin, W. Calvin, and P. Thomas, addressed the composition, properties, and general nature of both the seasonal and residual polar ice caps based on their spectral characteristics and a combination of both high-resolution and synoptic imaging. A much different and larger-scale perspective on the nature of the PLD was provided in the talks on the MARSIS (J. Plaut) and SHARAD (R. Phillips) radar sounding investigations, which have provided a first look at the basal topography and internal layered structure of both caps. Key findings of these investigation include an no evidence of lithospheric deflection beneath the caps or of basal melting – observations which suggest both a low geothermal heat flow and thick lithosphere.

Evidence that the south PLD once covered an area more than 1.5x its present size was presented by J. Head, who discussed evidence that the PLD experienced significant volcano-ice interactions that resulted in the generation of massive amounts of meltwater during the Hesperian.

The obliquity-driven exchange of water between the planet's polar and non-polar reservoirs was addressed by F. Forget, who noted that there is now excellent agreement between the areas of deposition predicted at high-obliquity by climate models and the geologic evidence for glaciation at tropical and temperate latitudes associated with the volcanoes in Tharsis. F. Montmessin argued that the loss of water from such non-polar reservoirs at low-obliquity, and it cold-trapping at the poles, was the most reasonable explanation for the origin of the perennial water ice deposits discovered by the OMEGA instrument within the South PLD.

Other evidence of the distribution of subsurface, and potentially exchangeable, H_2O was discussed during the presentations by J. Banfield and M. Mellon. Banfield noted that an analysis of thermal inertia data from the TES and THEMIS IR spectrometers, combined with soil H_2O column abundances derived from the Gamma Ray Spectrometer (GRS) data, suggested that the local distribution of subsurface ice at temperate latitudes exhibits considerable spatial heterogeneity, although, on a broader scale, it appears reasonably consistent with the distribution expected from atmospheric exchange. Mellon showed that the geographic distribution and morphology of polygonally patterned ground observed by the HiRISE instrument is also consistent with model predictions, providing further evidence that the shallow subsurface of Mars at temperate and polar latitudes may host a vast reservoir of H2O that may be exchanges with other polar and non-polar reservoirs as the obliquity of Mars varies.

Other point and questions that were raised during the subsequent moderated discussion included:

<u>Notes from moderated discussion</u>

- There is a critical need for more lab experiments. Those that have been done to date have often failed to simulate reality, especially with regard to the physical properties of ice and how they affect the deposition process.
- What is the density of the seasonal CO_2 deposit and how does it vary over the caps?
- How did the Polar Layered Deposits (PLD) form? How are the individual layers built? How do metamorphic processes affect the state of water ice? And how stable are the layers to sublimation and erosion?

- We are near the limits of what remote sensing can tell us about the nature of the PLD. The future polar exploration should emphasize both the in situ analysis of multiple layers (by drilling, sending a cryobot to melt its way through the PLD, or traversing down a polar scarp with a rover) and sample return.
- The residual ice caps are often discussed as if they were not connected to the underlying layered deposits. Perrhaps they are part of the same process?
- To date, orbital radar sounding:
  - Sees no evidence of lithospheric deflection beneath the polar caps, which may suggest the planet's current geothermal heat flow is very low. In situ measurements are needed.
  - Indicates that the volume-averaged dust content of the polar ice must be low (<20%) but there may be significant stratigraphic variability. May require in situ measurements.
  - Has failed to reveal any evidence of current polar basal melting, which may be due to low heat flow. Basal melting in small local areas or under more favorable past conditions is not ruled out.
    - Has also failed to detect any evidence of groundwater elsewhere on the planet. Various possible explanations exist (heat flux, lack of groundwater, detection limits of current instrumentation). Additional data is needed to discriminate among these possibilities.
- Currently observed changes in the extent of the South residual ice cap may be related to climate change, having implications for understanding and addressing the scientific and political aspects of this same issue on Earth.
- Stratigraphy of PLD is believed to be correlated to climate variability, but this connection needs to be confirmed – including relationship to orbital and short-term (decadal-scale and interannual) variations. Short-term variability is in particular need of further stud (e.g., why do slopes streaks appear more prevalent today than several years ago?).
- There are no good geologic constraints on layer ages within the PLD. Should establish a geologic chronology independent of the inferred relationship to astronomically-induced climate change.
- The current mass and energy balance of the PLD is one of the most critical unknowns. What is its relationship to geographic and temporal variations in albedo and deposition?
- Trough formation may be rapid compared to other processes affecting the mass balance of the PLD, for this reasons they may be good targets for further study.
- What roles do atmospheric variability and global weather patterns play in the evolution of the PLD?
  - Need to make direct measurements of winds on Mars at multiple locations.
  - Will require a meteorological network mission, including stations at the poles.
- (included above)
- Relatively simple models do not explain the observed albedo— need to combine interannual variability, atmospheric dynamics, and admixture of periodic dust storms.
- (included above)Variability is observed on a wide range of scales and time frames. Need longer term observations to constrain decadal and interannual variability. Local scale variations (slope streaks) appear particularly erratic.
- (included above) (included above)(included above)We need to understand atmospheric variability and weather patterns in order to begin to understand polar deposits

8. MARS ASTROBIOLOGY AND UPCOMING MISSIONS

Session Chairs' Summary (David Des Marais and Phil Christensen)

This session hosted five talks on astrobiology and six on future missions. Regarding astrobiology, current missions have focused on assessing the distribution and characteristics of environments, past and present, that might have sustained microbial life, or still might do so. Habitable environments must simultaneously provide not only liquid water but also the necessary energy source(s) and biochemical ingredients. Des Marais et al. concluded from observations by MER Spirit that habitable environments might have existed in Gusev crater at least intermittently in the distant past. Gibson argued from his global assessment of the early history of Earth and Mars that ancient Mars must have been habitable. C. McKay et al. outlined why the Martian polar subsurface might be habitable even today and/or in the recent past. Thomas-Keprta et al. presented microscopic observations of carbon and iron species in ALH84001, indicating that ALH84001 and other meteorites can continue to inform us about ancient Mars. Eigenbrode et al. reviewed the value of crustal organic carbon inventories and compounds as biosignatures and stressed their potentially enormous information contents.

Regarding future missions, Conley and Race summarized our obligations under international planetary protection treaties to maintain the biological isolation between Earth and Mars and thereby also to preserve Mars as an uncontaminated potentially second example of life. Aspects of these obligations include appropriate spacecraft design and cleaning as well as classification of regions on Mars regarding their potential to sustain extant microbes. The Phoenix mission was summarized by Smith et al. (overview), Tamppari et al. (atmospheric observations) and Arvidson et al. (site selection). Phoenix is indeed an exciting opportunity to understand the exchange of volatile species between the regolith and atmosphere and to survey and characterize carbon and other life-relevant compounds that might be sequestered in the ice. Golombek et al. and Clegg et al. discussed site selection and the Laser Induced Breakdown Spectroscopy for the 2009 Mars Science Laboratory mission. All of these talks heralded the emerging age of Mars exploration where increasingly sophisticated morphologic, mineralogical and chemical observations will continue to unveil the evolution of Mars and its astrobiological potential. Many of these themes were carried forward in the poster session, with additional perspectives offered from theoretical and experimental results.

This session indicated clearly that diverse, state-of-the-art observations can and must continue at Mars, both in orbit and *in situ*, in order to benefit fully from earlier findings and to extend the thread of discovery. Significant further discoveries will become ever more challenging to achieve but they will probably also become ever more profound. Advances in remote sensing and spacecraft technology are needed to improve site selection and site access. Capable *in situ* science instruments are essential identify the very best samples to include among those very few that can be returned to Earth. A key science objective therefore will be to achieve a first MSR mission that returns a diverse suite of carefully selected samples that will in turn perpetuate and enhance this golden age of Mars exploration.

Notes from moderated discussion

- "Special Regions" are places on Mars that have the potential to sustain life either today or in the future. Any spacecraft that visits a special region must meet stringent planetary protection requirements to avoid forward biological contamination of the site. A set of criteria should be developed whereby regions on Mars could be assessed and, in perhaps many cases, exempted from “Special Regions” status.

  - A spacecraft visiting a special region must be as clean as were the Viking landers.
  - Future missions should assess the probability of life of Mars with an eye towards how risky it actually would be to send humans. We should locate landing sites that we can exempt from “Special Regions” designation.
  - If we find out that there is no possibility of us contaminating Mars biologically, then the regulations will be relaxed significantly. (DJD comment: this is highly unlikely; it is virtually impossible to prove something of this nature.)

- What precursor missions do we need before a sample return mission? What kinds of samples do we want/need to return? This is a crucial topic for ongoing dialog in the Mars science community.
- According to Planetary Protection protocols, is MSR a prerequisite for a human mission?
  - MSR is an extremely desirable requirement because its findings could enhance the human mission.
  - Planetary Protection considerations would benefit from returned samples by perhaps increasing the probability that humans will be safe when they go, and by understanding the composition of the dust and its implications for spacecraft design.
  - Would you prefer a sample from a special region? A range of opinions was expressed.
- Organic detection limits were discussed both for spacecraft and in an Earth-based laboratory. What detection limits are practical on a spacecraft? Can we quantify it, for example for fatty acids?
  - Realistic detection limits for flight instruments that are being developed will not be as low as what can be achieved in a laboratory on Earth.
  - We will address certain sets of questions that can be addressed at a certain level of detection.
- The ability to disentangle contamination from Earth is important, especially when you are dealing with very low detect limits. Modern flight instruments will probably detect Earth-based organic contamination during their missions.
- What is the potential for studying slope streaks? pH? Water activity?
  - The compositions of any fluids on Mars are important. Brines can be active at -60^{o}C. Compositions can reveal fluid source regions, their history and their astrobiological potential.
- Special regions– recent developments have helped clarify the constraints
  - Any extant fluids probably do not have the water activities that some had previously thought, therefore more places on the surface might not qualify as Special Regions.
- Are we making the right measurements and developing the right flight instruments? Instruments on the landing missions should share more common ground with the types of instruments that we are using to find/pick the landing sites in the first place
  - e.g., landed instruments doing spectroscopy in the VIS, NIR and MIR
- What is our future strategy to obtain visual observations across a broad range of spatial scales?
  - Remote sensing, surface cameras, microscopic imagers, true microscopes

    - ExoMars and MSL would expand the range of scales
    - What about missions beyond these?

9. MARTIAN STRATIGRAPHY AND SEDIMENTOLOGY: READING THE SEDIMENTARY RECORD

Session Chairs' Summary (Oded Aharonson and Scott McLennan)
The 10 talks in the session were diverse in nature, but had a common theme of understanding surficial processes and the sedimentary rock record of Mars. Seven of the talks dealt with the sedimentary record at Meridiani Planum, two with deposits at the Spirit landing site and one examined cratering age analysis to date resurfacing history. In addition, more than 30 papers in the various poster sessions also dealt with these themes. The observational tools vary among physical, morphological, geochemical and spectral and over many orders of magnitudes in scale. These observations in turn provide a much firmer foundation for various laboratory and theoretical modeling studies. The recent explosion of high resolution data both from orbit and from the ground allows probing the third dimension of martian crust, thereby permitting the stratigraphic architecture of sedimentary deposits to be better constrained and interpreted. In addition, it is clear that integrating results from orbit with the detailed studies on the surface and in the laboratory provide greatly increased understanding.

The general discussion that followed the formal session was wide-ranging but largely focused on several important issues that face the study of sedimentary environments on Mars. The major themes that came out of this discussion included the following:

1. Progress that has been made in understanding sedimentology, stratigraphy and dating surfaces;
2. Absolute and relative dating of the sedimentary record;
3. Scales and nature of observations required for documenting sedimentary materials on the surface (orbital and landed) and landing site selection in sedimentary terrains;
4. Issues associated with sample caching sedimentary materials both in general and for MSL in particular;
5. Issues related to characterizing and sampling sedimentary terrains for sample return;

Notes from moderated discussion

- Progress being made in several areas, particularly: sedimentology, stratigraphy, age dating of surfaces using crater chronology.
- Big Problem: In dealing with sedimentary sequences on Mars – we cannot age date sedimentary rocks with any currently available techniques.
    - They tend to be friable, erosion happens quickly.
    - Even with nicely layered strata, the scale is too small to get good crater counting statistics.
- Place particular emphasis on going to places and flying techniques which could tell us more about the age of sedimentary sequences. Selecting MSL site we should keep in mind sample caching.

  - Some techniques for age dating may be available if these rocks ever come back to Earth.
- We have an advantage on earth because of scale and fossil record, but even on Earth, absolute dating of the age of sedimentation directly from sedimentary sequences is cutting-edge.
- Total mass to be returned from a sample return mission: Several hundred grams. What should we sample in the sites we're looking at now?
  - With modern analytical capabilities, every sand grain can be considered as a rock.
- Difficulties in using sample-return motivations for landing site selection. Currently, cache will stay on the rover. Perhaps cache should be dropped for later retrieval.
- We are currently studying microscopic samples from Stardust mission, showing much information can be gained even from random samples
- Samples to be cached, if returned to earth, will be the best pre-characterized samples of any planetary body yet.
- We can do a lot (chemically, isotopically) with small samples. But to understand sedimentalogical information, **context** within texture of the deposit must be known.
- Can you suggest a sampling criterion to distinguish between three hypotheses for Meridiani region formation?
  - Texture-preserving samples (hand-sample sizes)
  - Diagnostic mineralogy (XRD)
  - mm-scale textures – need chemical/mineralogical analysis on this same scale.
- For sample return, just grains may not be enough. We seek 'hand-sample' with context and textures.
- Much of the evidence for diagenesis at Meridiani comes from MI images –scenes that are only a few cm across. These show effects of grain coatings, and mineral reprecipitation; information which would be lost in a powder.
- MSR may be able to collect intact pieces of rock, rock chips, powder. Currently, MSL may only obtain powder.
- Must think about 'requirements' and separate that from implementation. We have to be clever about in-situ observation, because return will be very expensive.
- A good exercise: look at Meridiani and Gusev details and ask: what 300g would we collect to maximize returns?
- We have just found in the last few weeks at Gusev some of the most valuable rocks of the mission (Sol 1250). Per haps 50 x 10g samples would be a good representative suite from Gusev.
- Jarosite has many possible stable isotopes, water isotopes included as well. Zircon is a very good mineral for dating.
  - Getting one zircon grain can require sifting through large volumes of sample.
- Current instrumentation to do in-situ petrography: micro-OMEGA, micro-TES, micro-Raman. Doing mm and sum-mm scale mineralogy imminent and desirable in order to pre-screen materials on the surface before selection for return.
- Interpretation on Earth is never done using a single structure; we seek context and perspective. At Meridiani we invest significant resources in developing scenarios to reconstruct 3-d structures with adequate imaging. A single image of a sedimentary structure is ambiguous.

- Victoria crater has allowed us to get orthogonal images of the same bed, allowing determination of a consistent paleo-flow direction.
- At almost every promontory at Victoria we have acquired long-baseline stereo ranging constraining the topography of faces.
- The 5th International Mars Conference was dominated by MGS results, the 6th dominated by Odyssey observations. In Mars 7 we have multiple platforms which overlap, looking at the same sites from multiple angles, filters, scales. We can now synthesize better interpretations.
- MSL team is encouraged to set up imaging plans making the best of our experiences from Endurance, Home Plate, where 3-D stereo reconstructions have proven valuable.
- Instrumental progress on miniaturized age-dating tools. MSL should be able to characterize grains as they go into the cache, so that we are able to evaluate the value of the samples in the cache.