

icy bodies. For those bodies, however, detailed observations coupled with theory and laboratory work have resolved the uncertainties leading to new understanding of their evolution through surface observations. We are on the threshold of a new assault on the martian surface, with high spatial resolution thermal (THEMIS), hyperspectral vis-NIR on global (OMEGA) to local scales (CRISM), and very high spatial resolution lander spectrometers. Will Mars wither under the assault and finally reveal its inner secrets: the carbonates, the mineralogically rich hydrothermal systems, and the preserved water-rich environments that must be there?

## P51C-09 1145h INVITED

### Environmental Mapping with Imaging Spectroscopy of the World Trade Center Area After the September 11, 2001 Attack

Roger N Clark<sup>1</sup> (303-236-1332; rclark@usgs.gov);

Gregg A Swayze<sup>1</sup>; T Hoefen<sup>1</sup>; E Livo<sup>1</sup>; S Sutley<sup>1</sup>; G Meeker<sup>1</sup>; G Plumlee<sup>1</sup>; I Brownfield<sup>1</sup>; P Hageman<sup>1</sup>; P Lamothe<sup>1</sup>; C Gent<sup>1</sup>; L Morath<sup>1</sup>; J Taggart<sup>1</sup>; T Theodorakos<sup>1</sup>; M Adams<sup>1</sup>; R Green<sup>2</sup>; B Pavri<sup>2</sup>; C Sarture<sup>2</sup>; S Vance<sup>3</sup>; J Boardman<sup>4</sup>

<sup>1</sup>U.S. Geological Survey, MS 964 Box 25046 Federal Center, Lakewood, CO 80225, United States

<sup>2</sup>JPL, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

<sup>3</sup>US EPA, Region 8 999 18th street, Denver, CO 80202, United States

<sup>4</sup>Analytical Imaging and Geophysics, 2800 N. 6th St., Boulder, CO 80287, United States

The Airborne Visible / Infrared Imaging Spectrometer (AVIRIS), a hyperspectral remote sensing instrument, was flown by JPL/NASA over the World Trade Center (WTC) area on September 16, 18, 22, and 23, 2001. A 2-person USGS crew collected samples of dusts and airfall debris from more than 35 localities within a 1-km radius of the World Trade Center site on the evenings of September 17 and 18, 2001. The AVIRIS data, field spectrometer data collected in areas away from the WTC, and information derived from field samples in and around the WTC were used to calibrate, provide ground truth, and map the debris and its composition in the lower Manhattan area with 2x4-meter sampling. Laboratory analyses and the AVIRIS mapping results indicate the dusts are variable in composition, both on a fine scale within individual samples and on a coarser spatial scale based on direction and distance from the WTC. Replicate mineralogical and chemical analyses of material from the same sample reveal variability that presumably is due to the heterogeneous mixture of different materials comprising the dusts. The spatial variability is observed at large scales of tens of meters to centimeter and smaller scales. AVIRIS mapping suggests that materials with higher iron content settled to the south-southeast of the building 2 collapse center. Chrysotile may occur primarily (but not exclusively) in a discontinuous pattern radially in west, north, and easterly directions, perhaps at distances greater than 3/4 kilometer from ground zero. Although only trace levels of chrysotile asbestos have been detected in the dust and airfall samples studied to date, the presence of up to 20 volume % chrysotile asbestos in material coating steel beams in the WTC debris, and the potential areas indicated in the AVIRIS mineral maps, indicate that asbestos can be found in localized concentrations.

URL: <http://speclab.cr.usgs.gov>

## P52A MCC: Hall D Friday 1330h

### Deciphering Mars's Paleoclimate: Observations and Models Posters (joint with A, PP)

**Presiding:** A R Vasavada, University of California, Los Angeles; M I Richardson, California Institute of Technology

## P52A-0363 1330h POSTER

### Orbital forcing, paleoclimates, and the Martian polar layered deposits.

Jacques Laskar<sup>1</sup> (laskar@bdl.fr)

Benjamin Levrard<sup>1</sup> (Benjamin.Levrard@bdl.fr)

John F. Mustard<sup>2</sup> (John.Mustard@Brown.edu)

<sup>1</sup>Astronomie et Systèmes Dynamiques, IMC-CNRS UMR8028, 77 Av. Denfert-Rochereau, Paris 75014, France

<sup>2</sup>Department of Geological Department of Geological Sciences, Box 1846, Brown University, Providence, RI 02912, United States

Since the first images of polar regions of Mars revealed alternating bright-dark layers there has been speculation that their formation is tied to the orbital forcing of climate, but uncertainties of more than two orders of magnitude remained in the deposition time scale.

We have analyzed the profile of radiance extracted from MOC image M00-02100. The layers evident in this image are representative of one long trough in the northern cap located near 279°W 86°N from which several other MOC images were acquired and show a consistent stratigraphy over a strike of more than 100 km. A very apparent feature in this profile is the presence of three nearly identical cycles (N1, N2, N3), on top of which are some higher frequency variations. As the time scale for the accumulation of these layers is very poorly constrained, we have searched for the best fit with the insolation variations deduced from a new solution for the orbital and spin evolution of Mars, including all 9 main planets, the Moon as a separate object, Earth and solar oblateness, and the effect of general relativity. The obliquity and precession of Mars axis were computed using initial conditions deduced from the Pathfinder mission. The main uncertainty in the obliquity solution arises from the initial precession frequency ( $p = -7.576 \pm 0.035$  arcsec/year) (Folkner *et al.*, 1997). Despite Mars obliquity is chaotic, the chaotic behavior of the solution becomes only significant beyond 10Ma, and we found that all solutions within the precession uncertainty lead to a large increase of obliquity after 5 Ma.

We have used this constraint to exclude the possibility that the observed cycles (N1, N2, N3) are related to the large  $\approx 2.4$  Ma eccentricity modulation, and assume that they are more closely related to the climatic precession and obliquity cycles. We thus obtain for the best fit, an average deposition rate of 0.05 cm/yr for the most recent 250 m thick deposit of the North ice polar cap.

Ref. Laskar, J., Levrard, B., Mustard, J.F. : 2002, Orbital forcing of the martian polar layered deposits, *Nature*, in press

## P52A-0364 1330h POSTER

### GROOVED TERRAIN NEAR THE SOUTH POLE OF MARS; Clue to an Unmodeled Amazonian Climate-Episode?

Zane Crawford<sup>2</sup> (zane.crawford@colorado.edu)

Bruce Murray<sup>1</sup> (bcm@caltech.edu)

Shane Byrne<sup>1</sup> (shane@gps.caltech.edu)

Michelle Koutnik<sup>3</sup> (mkoutnik@gps.caltech.edu)

<sup>1</sup>Caltech, 1200 E. California Blvd, Pasadena, Ca 91106, United States

<sup>2</sup>University of Colorado at Boulder Department of Geology, UCB 399, Boulder, CO 80309-03, United States

<sup>3</sup>University of Washington, Seattle, Seattle, WA 98195, United States

We have used detailed MOLA profiles and precisely co-located MOC/NA images to study extensively the large-scale aligned grooves and peculiar crosscutting features apparent on the surface of the South Polar Layered Deposits in the vicinity of 83-87 S, 190-240 W and also at the head of Chasma Australe at 86-87 S, 265-270 W. We denote these features informally as the South Polar Grooved Terrain Images of the grooves, and associated peculiar cross-cutting ridges which we informally term snakes, are available at <http://www.gps.caltech.edu/marsurf/polar/wirebrush.html> and will be illustrated during the talk.

These surficial grooves, which we have found only in the South, are very likely of exogenic origin, in contrast to the snakes which appear to us to be of deformational origin. The grooves very probably testify to an unrecognized past Amazonian south polar environmental episode which conceivably could have involved unusual past winds, or ancient ice sheet motion, or episodes of catastrophic flooding originating from beneath earlier water-ice residual caps. Any such origins would have profound implications for past Amazonian climate episodes not yet recognized nor modeled.

For example, the large-scale curvature of the grooves might suggest Coriolis effects on strong ( $\approx 80$  m/sec) downslope polar winds, but the grooves appear to pass across rather than around local topography. In contrast, ancient ice sheets characterized by vigorous ice streams conceivably could have carved grooves across the underlying terrain, as Lucchitta [2001] has suggested may have been the case in Kasai Valles. Indeed, Head and colleagues [e.g., Head and Pratt, 2001; Milkovich *et al.*, 2002; Ghatan and Head, 2002] argue

for extensive Hesperian-age meltback and glacial flow of earlier Hesperian ice-rich sediments near the South Pole due to volcanism and possibly climate change. However, the Amazonian grooves also occur at the head of Chasma Australe. Did ancient ice sheets also create Chasma Australe rather than, say, sub-ice catastrophic flooding analogous to Jökullhlaup events in Iceland as has been argued for Chasma Australe by Anguita *et al.* [2000] and also by Fishbaugh and Head [2002] for the very similar northern polar feature Chasma Boreale?

We will evaluate such possibilities and their relative paleoclimate significance in this presentation.

URL: <http://www.gps.caltech.edu/~marsurf/polar/wirebrush.html>

## P52A-0365 1330h POSTER

### Discrete Climatic Events on Timescales of Decades to Centuries: Clues from Polar Landforms

Shane Byrne<sup>1</sup> (626-395-6447; shane@gps.caltech.edu)

Andrew P Ingersoll<sup>1</sup> (626-395-6167; api@gps.caltech.edu)

<sup>1</sup>Caltech, 1200 East California BLVD MC 150-21, Pasadena, CA 91125, United States

Recent observations indicate fast (meters per year) evolution of features, named Swiss-cheese for their morphologic appearance, on the surface of the southern residual frost cap [Malin *et al.*, Science, 2001]. The onset of growth of these features may be responding in a sensitive way to changes in Martian climatic conditions on the timescales of decades to centuries.

We have developed a model to examine the growth and development of the Swiss-cheese depressions. Swiss-cheese features were first identified by Thomas *et al.* [Science, 2000] using Mars Orbiter Camera imagery. They have flat floors and steep sided walls. Their lateral sizes are of the order of a few hundred meters. They are quite shallow with shadow and MOLA measurements indicating a depth of about 8 meters. Although the depressions are fairly circular the smaller ones do display a slight but consistent asymmetry in the form of a small cusp which points poleward indicating that the origin of these features is connected with insolation. As the seasonal frost disappears their walls appear to darken considerably relative to the surrounding terrain. The flat interior of the depression however does not appear to change in this way.

There is a clear size division between smaller and larger depressions. Our modeling indicates that the growth timescales of the small-size population are on the order of a few Martian decades to centuries. This populations has a narrow size distribution with most of the depressions in any one area being roughly the same size. The similar size of adjacent depressions argues for some discrete climatic event which triggered this form of erosion of the cap. Larger depressions in other parts of the cap display an interior moat which indicates their walls have begun to be eroded outward after a period of inactivity or perhaps deposition. The width of these moats along with the observed expansion rates of the depressions [Malin *et al.*, Science, 2001] indicates that these larger depressions were reactivated close to the same time as the smaller ones began forming. It is possible therefore that the same climatic event is responsible in both cases.

Modeling these quickly evolving polar landforms can offer clues to Martian climatic events on timescales of decades to centuries. Changes in orbital parameters on these timescales are negligible, implying that Mars' climate has some intrinsically variability. It seems unlikely that we happen to be observing Mars during a single short-lived episode of Swiss-cheese growth. A more likely possibility is that this is part of a longer term cyclic process containing many of these climatic events. We report on these possible events and develop some scenarios of the recent history of Mars' climate and southern residual cap.

URL: <http://www.gps.caltech.edu/~shane>

## P52A-0366 1330h POSTER

### The Response of the Martian Circulation to Orbital Parameter Variations

Junjun Liu<sup>1</sup> (626-395-6960; ljj@gps.caltech.edu)

Mark Ian Richardson<sup>1</sup> (626-395-6720; mir@gps.caltech.edu)

R. John Wilson<sup>2</sup> (609-452-6592; rjw@gfdl.noaa.gov)

<sup>1</sup>Division of Geological and Planetary Sciences, California Institute of Technology, MC 150-21 1200 E. California Blvd., Pasadena, CA 91125, United States

<sup>2</sup>NOAA/Geophysical Fluid Dynamics Laboratory, P.O. Box 308, Princeton, NJ 08542, United States

The circulation of the Martian atmosphere may be substantially affected by changes in orbital parameters.

Such changes will undoubtedly alter the seasonal distribution of incident solar radiation on time scales greater than  $10^5$  years, and hence the forcing of the atmospheric circulation. For this investigation, we focus on the response of the general circulation to changes in obliquity, eccentricity, and argument of perihelion. We use the Geophysical Fluid Dynamics Laboratory (GFDL) Mars General Circulation Model (GCM) to examine changes in the nature of the Hadley circulation, polar jets, and eddies as orbital elements are varied.

A number of basic findings emerge from the simulations. For example, the Hadley cell exhibits strongly non-continuous variation with obliquity. As obliquity is increased from  $0^\circ$ , the northern summer circulation retains an equinoctial-like dual cell pattern until obliquity exceeds  $10^\circ$ . Only after that does the dominant cross-equatorial cell pattern emerge. Conversely, the southern hemisphere summer cell develops a strong cross-equatorial pattern at obliquities below  $5^\circ$ . This starkly asymmetric Hadley cell behaviour results from the global mean topographic slope. The simulations also highlight other ways in which topography places a control on the extent and strength of the Martian Hadley circulations. The polar jet is also affected by changes in obliquity. For obliquities above  $45^\circ$ , we find that the expanded and strengthened descending branch of the Hadley cell adiabatically warms the polar regions, reducing the latitudinal temperature gradient and decreasing the strength of the corresponding polar jet.

#### P52A-0367 1330h POSTER

##### Orbitally-Induced, Quasi-Periodic Climate Change on Mars: Modelling Changes in the Global Cycling of Water and Carbon Dioxide

Michael A. Mischna<sup>1</sup> (310-825-6168; mischna@ucla.edu)

Mark I Richardson<sup>2</sup> (626-395-6720; mir@gps.caltech.edu)

R John Wilson<sup>3</sup> (609-452-6592; rjw@gfdl.noaa.gov)

<sup>1</sup>UCLA, 595 Charles E. Young Drive East, Los Angeles, CA 90095, United States

<sup>2</sup>California Institute of Technology, MC 150-21 1200 E. California Blvd., Pasadena, CA 91125, United States

<sup>3</sup>Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration PO Box 308, Princeton, NJ 08542, United States

Mars' orbital parameters (obliquity, eccentricity and argument of perihelion) are thought to have varied substantially on time scales  $>10^5$  years. Such variations, especially in obliquity, may drastically affect the circulation of the atmosphere and volatile cycling. In this study, we focus on the response of the water and carbon dioxide cycles to changes in these orbital parameters, chiefly obliquity. The study employs the Geophysical Fluid Dynamics Laboratory Mars General Circulation Model, conducting simulations over a range of orbital states to examine changes in the cycling and deposition of these volatiles. This model contains full 3D accounting of atmospheric water and carbon dioxide as well as a basic dust cycle.

The present martian obliquity is  $25^\circ$ , though it is believed to have recently varied between  $15^\circ$  and  $45^\circ$  degrees. Our simulations look at present martian conditions, only with obliquity varying between  $5^\circ$  and  $60^\circ$  degrees. Simulations are run out until water and carbon dioxide budgets have reached equilibrium—typically 30-40 years.

As expected, volatile cycling on Mars increases with obliquity, as the polar caps are exposed to increased insolation, leading to greater seasonal ice caps and ultimately development of surface water ice in the now thermally favorable low latitudes. By  $45^\circ$ , water ice is stable in a broad band just north of the equator. Such an ice distribution has potential implications for the surface wind pattern through the ice-albedo effect on surface heating. Permanent polar CO<sub>2</sub> caps are not stable under present conditions, but we find CO<sub>2</sub> cap growth and corresponding atmospheric deflation to be evident at very low obliquities. We find that for most choices of orbital conditions, the northern hemisphere remains the stable pole for water ice, a result of the martian topographic dichotomy.

We have begun to look at the impact of desorbed CO<sub>2</sub> and H<sub>2</sub>O ice from the regolith on climatic conditions. Present estimates of the volatile abundance in the regolith vary greatly, but recent Mars Odyssey results hint at large abundances of water ice in the martian high-latitude regolith. The results of this study should better define models of polar volatile evolution, specifically those of layered terrain formation.

The radiative feedback effects of increased atmospheric CO<sub>2</sub> and H<sub>2</sub>O from the polar caps and regoliths has yet to be examined. Future plans include more accurate representations of dust injection and radiative transfer to tackle this problem.

#### P52A-0368 1330h POSTER

##### Obliquity-coupled Atmospheric Variations and the Small Cratering Record on Mars

Virgil L. Sharpton<sup>1</sup> (907-474-6663; buck.sharpton@gi.alaska.edu)

John E. Chappelow<sup>1</sup> (907-474-5661; john.chappelow@gi.alaska.edu)

<sup>1</sup>Geophysical Institute, PO Box 757320 University of Alaska Fairbanks, Fairbanks, AK 99775-7320, United States

Mars, at its current obliquity of 25.2 degrees, has an atmosphere of 6.1 mbar (density of 0.021 kg/m<sup>3</sup>) at reference elevation. Several workers have shown that Mars experiences severe obliquity oscillations on time scales of less than 100 kyr resulting in cyclical growth and retreat of the polar CO<sub>2</sub> ice caps. Our calculations and those of others indicate that this has a profound effect on the density of the predominantly CO<sub>2</sub> atmosphere. For instance, a conservative treatment of orbital properties indicates obliquity oscillations ranging between 15 and 35 degrees generate atmospheric pressures of 0.3 and 30 mbar, respectively. Other models, taking into consideration resonance effects, predict minimum obliquities approaching zero. At such times, any CO<sub>2</sub> would be cold-trapped at the poles and Mars atmosphere would essentially vanish. At the other extreme, the maximum predicted obliquity of 51.4 degrees would eradicate the permanent CO<sub>2</sub> polar caps and create an atmosphere of 35 mbar (0.093 kg/m<sup>3</sup>). Higher atmospheric densities enhance atmospheric filtering so that fewer meter-scale impactors reach the surface ballistically and somewhat larger projectiles would produce craters with anomalous morphologies indicative of atmospheric breakup and dispersion. So, times of high obliquity will show a depletion of small craters, indicated by a down-turn in conventional size-frequency curves. During times of low obliquity, however, crater production would be more lunar-like. Consequently, production rates for the smallest resolvable martian craters show temporal variations unlike those expected for any other terrestrial planet. This effect should be considered when using such craters to understand recent geological history of Mars.

#### P52A-0369 1330h POSTER

##### Variations in the 3 $\mu$ m bound water band on Mars from ground based high spectral resolution spectroscopy.

Diana L. Blaney<sup>1</sup> (818-354-5419; Diana.Blaney@jpl.nasa.gov)

David A. Glenar<sup>2</sup> (Dave.Glenar@gssc.nasa.gov)

Gordon L. Bjoraker<sup>2</sup> (Gordon.L.Bjoraker@gssc.nasa.gov)

<sup>1</sup>NASA Jet Propulsion Laboratory, 4800 Oak Grove Dr. MS 183-501, Pasadena, CA 91109

<sup>2</sup>NASA Goddard Space Flight Center, Code 693, Greenbelt, Md 20771

Imaging spectroscopy of Mars from 2.19 to 4.12  $\mu$ m at high spectral resolution ( $\lambda/\Delta\lambda$  800-2300) were collected in April 1999 using the cryogenic long slit spectrometer at the KPNO 2.2 m telescope. These data have been used to model the cloud optical depth, particle sizes, and ice aerosol content of the aphelion cloud belt and to monitor diurnal changes in clouds (Glenar et al. 2002, in press Icarus). The detailed modeling of cloud properties permits us to now identify regions where the atmosphere is clear and to look for variations in the 3  $\mu$ m bound water band on the Martian surface. Observations of the same locations of the planet under different viewing geometries (and local times of day) permit independent verification of shape of the surface feature and quantify viewing angle effects. The high spectral resolution also enables the identification of atmospheric features, solar lines, residual telluric absorptions, and weak surface features. Initial analysis has focused on regions north of  $30^\circ$ N latitude (outside the aphelion cloud belt) between  $\sim 150^\circ$  and  $300^\circ$  West, and away from orographic clouds.

TES has identified two crustal units: Type I (basaltic) and Type II (basaltic andesite) (Banfield et al. 2000). Recently, an alternative interpretation has been suggested for the Type II unit as a weakly altered basalt (Wyatt and McSwen 2002). One region in our data set ( $\sim 30^\circ$ - $50^\circ$  N latitude and  $\sim 260^\circ$ - $280^\circ$  W longitude) was mapped as Type II. Careful comparison of the Type II material to the Type I basaltic unit and the Martian bright regions should permit an assessment of the relative hydration state of the Type II materials and help resolve this debate. The attempt to identify Type I regions that are cloud free in our data set is underway but may be problematic due to its association with volcanos (which develop orographic clouds) and to its equatorial distribution affected by the aphelion cloud belt. Additionally, other effects such as grain size, cementation, and viewing geometry need to be accessed before directly comparing band depths. No evidence for carbonates has been found.

#### P52A-0370 1330h POSTER

##### TES Hyperspectral Mapping of Putative Martian Paleolake Basins in the Aeolis Quadrangle

K. Stockstill<sup>1</sup> (kstockst@utk.edu)

J. Moersch<sup>1</sup>

S. Ruff<sup>2</sup>

A. Baldrige<sup>2</sup>

J. Farmer<sup>2</sup>

<sup>1</sup>Univ. Tennessee, Dept. Geol. Sci. 306 G.S. Bldg., Knoxville, TN 37996, United States

<sup>2</sup>Arizona State Univ., Dept. Geol. Sci., Tempe, AZ 85287, United States

Introduction: Several studies have argued that geomorphic evidence supports the existence of paleolake basins on Mars. Previous workers have compiled a list of proposed paleolake basins in impact craters, with some basins displaying alternating bands of light and dark albedo materials conformal with the basin margins. These workers have suggested that the bright materials may be evaporite deposits. Thus far, TES searches for aqueously derived minerals on a global scale have only detected coarse-grained crystalline hematite. We are currently conducting a regional study to search for small exposures of evaporite minerals within putative paleolake basins in the Aeolis quadrangle. Detection of evaporites on Mars would provide key constraints on its paleoclimate.

Approach: The spectra for each target are assembled into a hyperspectral cubes. Because we expect the spectral features of evaporite minerals to be extremely subtle, we preserve individual unprocessed emissivity spectra as far into the processing chain as possible.

A principle component analysis (PCA) algorithm is run on the hyperspectral cubes. The resultant PCA images have some contiguous areas where similar PCA values span several orbits, which we interpret to represent real spectral units at the surface. In other instances, similar PCA values are confined to specific orbit tracks, which we interpret to represent inter-orbital atmospheric variations. We re-assemble the hyperspectral cubes from the original set of spectra using an algorithm that rejects all spectra from orbital tracks strongly affected by atmosphere. This process is repeated until most of the color variations in the PCA images appear to be associated with spectral units on the ground.

The final PCA images are used to define regions of interest that correspond to spectral units in the scenes. Averaged spectra from each region of interest are extracted and examined to see what spectral features distinguish these units from each other. Automated spectral matching algorithms using library spectra of evaporite minerals are also run on the original emissivity hyperspectral cubes to provide another means of detection.

We will present the results of our detailed hyperspectral analyses of 35 proposed paleolake basins in the Aeolis Quadrangle.

#### P52A-0371 1330h POSTER

##### Warming Early Mars With CH<sub>4</sub>

Hilary L. Justh<sup>1</sup> (814-865-6717; justh@essc.psu.edu)

James F. Kasting<sup>1</sup> (814-865-3207; kasting@essc.psu.edu)

<sup>1</sup>Penn State University, Department of Geosciences, Deike Building, University Park, PA 16802, United States

The nature of the ancient climate of Mars remains one of the fundamental unresolved problems in martian research. While the present environment is hostile to life, images from the Mariner, Viking and Mars Global Surveyor missions, have shown geologic features on the martian surface that seem to indicate an earlier period of hydrologic activity. The fact that ancient valley networks and degraded craters have been seen on the martian surface indicates that the early martian climate may have been more Earth-like, with a warmer surface temperature. The presence of liquid water would require a greenhouse effect much larger than needed at present, as the solar constant,  $S_0$ , was 25% lower 3.8 billion years ago when the channels are thought to have formed (1,2). Previous calculations have shown that gaseous CO<sub>2</sub> and H<sub>2</sub>O alone could not have warmed the martian surface to the temperature needed to account for the presence of liquid water (3). It has been hypothesized that a CO<sub>2</sub>-H<sub>2</sub>O atmosphere could keep early Mars warm if it was filled with CO<sub>2</sub> ice clouds in the upper martian troposphere (4). Obtaining mean martian surface temperatures above 273 K would require nearly 100% cloud cover, a condition that is unrealistic for condensation clouds on early Mars. Any reduction in cloud cover makes it difficult to achieve warm martian surface temperatures except at high pressures and CO<sub>2</sub> clouds could cool the martian surface if they were low and optically thick (5).

CO<sub>2</sub> and CH<sub>4</sub> have been suggested as important greenhouse gases on the early Earth. Our research focuses on the effects of increased concentrations of atmospheric greenhouse gases on the surface temperature of early Mars, with emphasis on the reduced greenhouse gas, CH<sub>4</sub>. To investigate the possible warming effect of CH<sub>4</sub>, we modified a one-dimensional, radiative-convective climate model used in previous studies of the early martian climate (5). New cloud-free temperature profiles for various surface pressures and CH<sub>4</sub> mixing ratios will be presented. This use of climate modeling is important since it is the fundamental way that the magnitude of possible geochemical and biological CH<sub>4</sub> sources can be related to predicted CH<sub>4</sub> concentrations in the early martian atmosphere.

References: 1) Gough, D. O. *Solar Physics* 74, 21-34 (1981). 2) Carr, M. H. *Water on Mars* (1996). 3) Kasting, J. F. *Icarus* 94, 1-13 (1991). 4) Forget, F., and Pierrehumbert R. T. *Science* 278, 1273-1276 (1997). 5) Mischna, M. A., Kasting J. F., Pavlov A., and Freedman R. *Icarus* 145, 546-554 (2000).

## P52B MCC: 270 Friday 1330h

### Stable Isotopes and the Search for Life in the Solar System I (joint with B, V)

**Presiding:** J P Greenwood, Yale University; L Leshin, Arizona State University

## P52B-01 1330h INVITED

### Vapor Pressure Isotope Effects and the Stable Isotope Geochemistry of the Martian Surface

John M Eiler (626-395-6942; eiler@gps.caltech.edu)

Division of Geological and Planetary Sciences, California Institute of Technology, 1200 E. California Blvd, Pasadena, CA 91125, United States

The stable isotope geochemistry of light elements (H, C, N, O and S) is a tool in the search for evidence of life on bodies other than the earth for several reasons: the elements in question are used by all known or easily imagined life forms; several mass spectrometric and spectroscopic methods for measuring their isotopic compositions exist and are appropriate for in situ analysis on other planets; it is known that 'vital effects' generate large (percent) isotopic fractionations; and studies of extant and former life on earth provide models for interpreting such data. However, the evidence stable isotope geochemistry provides is generally interpretable as a signature for life only in the context of a rich understanding of isotopic variations produced by non biological processes in the same environments.

Several candidates in the search for extra-terrestrial life (Mars and the Jovian satellites) are bodies having volatile-element geochemical cycles that operate at lower temperatures than the earth's surface and involve phase-changes that do not occur on the earth (e.g., condensation/sublimation of CO<sub>2</sub>). We review new experimental data (both recently published and unpublished) describing isotopic fractionations accompanying phase changes of CO<sub>2</sub>, H<sub>2</sub>O below 240 K, NH<sub>3</sub> and CO, compile them with previous data to derive general principles of low-temperature stable isotope fractionations, and discuss their significance for the stable isotope geochemistry of the surface of Mars. One example of the issues constrained by these data (the Martian CO<sub>2</sub> cycle) is discussed here.

The Martian surface is strongly influenced by condensation/sublimation and adsorption/desorption of CO<sub>2</sub>. The isotopic consequences of these processes are an attractive goal for in situ observations of atmosphere, ice and/or adsorbed gas because they provide a record of Martian atmospheric dynamics and atmosphere-surface interactions over a range of time-scales. Furthermore, these isotopic signals naturally must be understood before one could confidently identify carbon or oxygen isotope evidence for life. Recent experiments indicate that both ice/vapor and adsorbate/vapor phase changes produce oxygen isotope fractionations of the same direction and magnitude as those for condensation/evaporation of water vapor in the earth's atmosphere. This suggests that seasonal and longer-term cycles of condensation and release of CO<sub>2</sub> produce variations of order 10 ‰ in d18O. The current seasonal cycle of ice-cap formation and sublimation likely produces a similar-magnitude latitudinal gradient in the d18O of CO<sub>2</sub>. This gradient must be sensitive to mixing between high- and low-latitude air and therefore provides a constraint on martian atmospheric circulation. In contrast, carbon isotopes of CO<sub>2</sub> are not measurably fractionated by condensation/sublimation of ice and should be invariant in a martian atmosphere in which this is the only major phase change. Adsorption significantly (ca. 1 to 2 ‰) concentrates <sup>13</sup>CO<sub>2</sub> into the vapor phase and <sup>12</sup>CO<sub>2</sub> into adsorbate. This is opposite in direction to all familiar vapor-pressure isotope effects. Thus, cycles of adsorption/desorption of CO<sub>2</sub>

have a unique isotopic signature that should be distinguishable for other processes influencing the Martian atmosphere. Measurements of the variation in d13C of CO<sub>2</sub> would constrain the extent to which the atmosphere and surface interact by adsorption/desorption processes.

## P52B-02 1345h INVITED

### Organic and Isotopic Signatures of Life: Lessons from the Early Earth

Katherine H. Freeman<sup>1</sup> (814-863-8177; kate@essc.psu.edu)

Jennifer L. Eigenbrode<sup>1</sup> (eigenbro@geosc.psu.edu)

Christopher H. House<sup>1</sup> (chouse@geosc.psu.edu)

<sup>1</sup>Dept. of Geosciences and The Penn State Astrobiology Research Center, The Pennsylvania State University, University Park, PA 16802, United States

In the study of life on earth, isotopic analyses of organic biomarkers provide essential insight to their biological and environmental provenance. Isotopic analyses of organic materials on other planets present a number of challenges, both analytical and interpretive. Prebiotic planetary organic materials can derive from condensation reactions and by delivery through meteorites or interplanetary dust, with the relative importance of each influenced by the oxidation state of the atmosphere. Material delivered to planets can have an interstellar origin, although it is dominated by compounds influenced by the formation of the solar system. Each of these processes impact molecular isotopic signatures and must be considered in life-detection strategies. Pronounced effects are observed for hydrogen isotopes, with smaller fractionations observed for other elements. Theoretical, laboratory and observational studies of non-terrestrial materials are essential to further understand molecular isotopic heterogeneity associated with these exclusively abiotic processes.

Studies of Archean-aged samples provide an important resource for interpreting molecular isotopic patterns as signatures of life processes. Carbon assimilation and biomass synthesis from simple precursor compounds typically discriminate against <sup>13</sup>C. This generality, however, is complicated by the observations of a wide range of fractionation factors associated with important microbial carbon-uptake processes. Metabolic processes further distribute isotopic signatures, such that wide isotopic heterogeneity is observed among cellular biochemical constituents. In addition, preservation/contamination concerns dominate studies of very ancient organic matter, as they likely will in life-detection studies. However, both biochemical heterogeneity and sample integrity can be addressed by considering patterns from different paleoenvironments. Molecular results demonstrate that Late Archean microbial life on this planet was diverse, and ecological controls on element cycling dominate interpretations of molecular isotopic signatures. Is ecology universal? The answer may be the key to understanding life signatures elsewhere.

## P52B-03 1400h INVITED

### Pre-3.5 Ga terrestrial sediments as test cases in the search for life in the solar system

Stephen J Mojzsis (303-492-5014; mojzsis@colorado.edu)

University of Colorado, Dept. Geological Sciences NASA Astrobiology Center, Boulder, CO 80309-0399, United States

The general approach to understanding the early development of life on Earth has been to establish the antiquity of rocks by identifying radiometrically dateable sequences containing morphologically classifiable fossils (morphofossils). While this approach has served us well for nearly a century, classical micropaleontological methods used to interpret the Proterozoic (2.5 - 0.54 Ga) record of life are unsatisfactory in studying the early Archean (>3.2 Ga) record, which has been obscured by metamorphism. To gather insights into earlier traces of life, we must see past the limitations of the morphofossil record and recognize the value of chemical fossils. One such approach has been to utilize the strong fractionation that metabolic activity of organisms imparts to light stable isotope ratios (<sup>13</sup>C/<sup>12</sup>C, <sup>15</sup>N/<sup>14</sup>N, <sup>34</sup>S/<sup>32</sup>S). The importance of such searches is that they provide a natural test bed for planning the kinds of analyses to be performed on samples returned from elsewhere, even if such searches have had mixed success in ancient terrestrial rocks. For example, the atmosphere, carbon products of mantle degassing and carbonate in water on Earth define the inorganic pool of carbon from which bioorganic carbon is isotopically fractionated. Mass balance calculations demonstrate that the average isotopic composition of terrestrial carbon is ~ δ<sup>13</sup>C = -6 ‰ and therefore typical metabolic fractionations from this starting value results in δ<sup>13</sup>C (biomass) < -27 ‰. However, problems arise

when applying the assumptions based on the terrestrial chemofossil record to another planet. Mars is the strongest candidate for a second planetary biosphere in the solar system. If an ancient biosphere did exist on Mars, returned samples might be expected to yield data that challenge many assumptions about what constitutes an isotopic biosignature. Mars appears to be different from the Earth. The isotopic values for the various reservoirs of carbon, nitrogen and sulfur on Mars have been extrapolated from the study of martian meteorites and from remote spectroscopic measurements of the atmosphere. Carbonate carbon in martian meteorites has values that range at least between δ<sup>13</sup>C = +7 to +42 ‰, which are interpreted to represent the isotopic values of carbonate formed in equilibrium with isotopically heavy (~ +40 ‰) CO<sub>2</sub> in the Mars atmosphere and carbon released from martian meteorites at the high temperature stage of step-heating experiments (above 700 C) has δ<sup>13</sup>C values between -30 and -15 ‰, which may represent magmatic values. Depending on the different starting values of the inorganic reservoirs of carbon on Mars described above, possible martian biotic carbon residues would be expected to be either isotopically heavier on average (δ<sup>13</sup>C > +5 ‰) or much lighter (δ<sup>13</sup>C < -40 ‰) than terrestrial life (average δ<sup>13</sup>C = -40 ‰ in the early Archean). Interpreting isotopic values for N and S on Mars present their own unique difficulties. Furthermore, all of these values may have changed over time as the martian atmosphere evolved, which behaves us to link the age of a sample and its geologic context with a specific isotopic signal as we would do with ancient terranes on the Earth. A silver-lining to all of this is that exploring the above possibilities might have the added benefit of differentiating between terrestrial contamination of a returned sample of Mars and the true remains of past martian biota.

## P52B-04 1415h INVITED

### Strategies for Life Detection Using Sulfur Isotopes

James Farquhar<sup>1</sup> (301-405-1434; jfarquha@essic.umd.edu)

David T. Johnston<sup>1</sup> (301-405-8611; dtj@Glue.umd.edu)

<sup>1</sup>ESSIC and Department of Geology, University of Maryland, College Park, MD 20742

Accurate evaluation of sulfur isotope fractionations as tracers of biological activity requires knowledge of: (1) the isotopic composition of reservoirs of inorganic sulfur species (e.g., sulfide, sulfate, elemental sulfur); (2) competing mechanisms that may produce sulfur isotope variations of non-biological origin; and (3) any isotopic signatures that can be uniquely linked to specific biological processes. We show how consideration of these three characteristics in terms of multiple sulfur isotopes may validate claims that certain sulfur isotopic signatures are biological.

For the most part, studies that have focused on the biological implications of variations in sulfur isotope compositions have only considered the quantity δ<sup>34</sup>S. We propose that it is critical to take into account δ<sup>33</sup>S variations as well. The consideration of multiple sulfur isotopes may help identify the sources of sulfur used by organisms because certain sulfur reservoirs possess anomalous and characteristic Δ<sup>33</sup>S compositions (Δ<sup>33</sup>S expresses the deviation from a mass fractionation array through δ<sup>33</sup>S = 0 and δ<sup>34</sup>S = 0 and is approximated by δ<sup>33</sup>S<sub>measured</sub> - 0.515 × δ<sup>34</sup>S<sub>measured</sub>). Measurement of δ<sup>33</sup>S adds an additional mass-balance constraint on an organism's metabolic reaction network and may identify a particular pathway for sulfur through this network. Most importantly, the observation of systematic Δ<sup>33</sup>S variations may produce definitive evidence for or against specific biological fractionation processes. The latter of these is possible because of small but measurable differences in mass dependent fractionation arrays that are associated with different fractionation processes. For example, it has been shown that the kinetic fractionation attending certain biological processes imparts Δ<sup>33</sup>S signatures that are distinct from those produced by abiotic processes. Although further experimental study will be required to determine whether similar Δ<sup>33</sup>S differences are characteristic of all biological fractionation processes, many biological processes have kinetic components and, accordingly, should produce a unique, case-specific fractionation of multiple sulfur isotopes.

## P52B-05 1430h INVITED

### OXYGEN ISOTOPE BIOMARKERS IN THE SEARCH FOR EXTRATERRESTRIAL LIFE

Ruth E Blake (203-436-3420; Ruth.Blake@yale.edu)  
Yale University, P.O. Box 208109, New Haven, CT 06520-8109, United States