combined with the small sizes of the SCF?s indicate that all SCF?s visible today were created geologically recently. Within a particular region the size distribution is quite narrow (3): no larger (older) or smaller (younger) features were seen indicating that some relatively abrupt change in environmental conditions initiated the growth of this particular population of features. Fingerprint terrain (1) are areas with evenly spaced parallel ridges, which are steeper on one side. These ridges may have small areas of water ice exposed in the intervening troughs. Their wavelength is on the order of 70-90m with the steep edges facing northeast although this varies from area to area. These features are smaller in scale than SCF?s and so may have information pertaining to more recent environmental events. We will present results from several avenues of research that we are pursuing: We are investigating the overall mass budget of the SRC. If the mass lost from expanding depressions is not condensed elsewhere on the cap then the SRC will disappear within a few Martian centuries. It seems unlikely to us that we are observing Mars at such a special time in its history. A large range of expansion rates is possible depending on the subsurface albedo profile (3,5). We will attempt to measure the subsurface albedo by examining images of exposed SCF walls. We are also improving our model to more accurately date features and by extension the environmental events that triggered their initiation. Previously we always initiated our modeled depressions from small pre-existing surface features. We are more closely investigating the genesis of SRC features and what environmental changes are required to cause them. We will continue to catalogue new population statistics for different regions in the SRC Each distinct feature population that we can identify may give us information on previous environmental events. Investigations into SRC features have the potential to describe changes in the Martian polar environment over timescales of millennia. It will provide a link from present conditions to longer-term variations in Martian climate, which are perhaps recorded in the layered deposits. [1] Thomas et al., Nature, 404. [2] Malin et al., Science, 294. [3] Byrne and Ingersoll, GRL, 30. [4] Malin and Edgett, JGR, 106. [5] Byrne and Ingersoll, Science, 299.

P32C MCC: 2008 Wednesday 1600h

Geological Evidence for Recent Climate Change on Mars II *(joint with A, C, GC)*

Presiding: **M A Mischna,** University of California, Los Angeles**; J Kargel,** U.S. Geological Survey

P32C-01 1600h

Modeling the HDO cycle in the Martian atmosphere.

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Among all the deuterated species of water, HDO has received much attention from scientists since its early measurement in the Martian atmosphere. Its current concentration, compared to terrestrial standards, suggests a significant loss of water that has escaped to space in the past. The study of HDO is intimately related to the past abundance of water and is therefore useful for understanding Mars' climate. As a first stage of a future modeling of atmospheric Deuterium (involving photo-chemical processes presently unaccounted for), we will present results from a GCM-based modeling of the HDO cycle. Significant seasonal and geographical variations of the HDO/H2O ratio are expected due to severe fractionation during condensation processes. Comparison with available measurements will be discussed.

P32C-02 1615h INVITED

Evidence for Non-Equilibrium Distributions of Water-Equivalent Hydrogen Deposits near the Surface of Mars

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Spatial distributions of water-equivalent hydrogen deposits within 45 degrees of the equator inferred from epithermal and fast neutron data, measured using the Neutron Spectrometer aboard Mars Odyssey, were compared with estimates of the annual-mean water-ice stability of surface soils, to search for evidence of recent climate change on Mars. A calculated stability factor given by the ratio of elevation-dependent near-surface atmospheric humidity to the annual-mean frost-point humidity for the soil, was used for this purpose. These estimates of potential distributions of subsurface ground-ice used new high-resolution maps of thermal inertia, albedo, and elevation from Mars Global Surveyor [Mellon et al., Icarus, submitted, 2003]. We found that all observed water-equivalent hydrogen deposits within about 40 degrees of the equator should be unstable. Furthermore, the model calculations show that although all such deposits are unstable, there should be a bias toward stability north of the equator. This bias is also not consistent with the neutron data. When these facts are coupled with the maximum observed water-equivalent hydrogen abundance of 13 percent by mass in a 10-degree diameter arc centered on 5 degrees latitude and +25 degrees east longitude, we are led to conclude that not only must atmospheric condition have been different in the recent past than is currently observed, but that our assumptions about the physical structure of subsurface soils near the equator must be different than we presently model.

P32C-03 1630h INVITED

The Formation of Martian Gullies by Near-Surface Ice Melting During Recent Periods of High Obliquity: Evidence from Gullies Distribution and Orientations

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We have performed a detailed statistical analysis of the gullies distribution and orientations as observed in the most recent MOC pictures (M01 to E18). It confirms the distribution of gullies poleward of about 30^o of latitude with poleward-facing slopes preferred. This agrees with our calculations showing that the only places on Mars where the daily mean temperature has been above the melting point of water during the past obliquity cycles are the mid and high latitudes above 30^o, especially on poleward-facing slopes. The fact that poleward-facing slopes receive more sunlight and get warmer at high obliquity in the summer is due to the pole being tilted toward the sun, i.e. in the southern hemisphere around summer solstice, the sun appears most of the time in the southern sky. The distribution also shows a decrease of the number of gullies with the increase of latitude which is likely due to the decrease of the number of steep slopes ($>25^o$) at high latitudes. Indeed, as observed on the Earth, gullies are initiated by wet landslides called debris flows, which form mainly at steep slopes. Thus, the hypothesis of formation of Martian gullies by recent near-surface ice melting during periods of higher obliquity shows a strong consistency between climate modeling, distribution of Martian gullies and terrestrial analogs.

P32C-04 1645h

Numerical modeling of Martian rock glaciers: Implications for recent climate change

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Numerous geologic features suggest the presence of rock glaciers on the surface of Mars. These features include lobate debris aprons, concentric crater fill, and lineated valley fill. The lateral extent of these rock glaciers can range from 5 km to over 20 km. Previous work has demonstrated that these features could not have formed in current Martian conditions (1). It has long been speculated that changes in Mars' orbital properties, namely its obliquity, eccentricity, and argument of perihelion, can result in dramatic changes to climate (2). Recent climate model studies have shown that at periods of increased obliquity north polar water ice is mobilized southward and deposit at low and mid latitudes (3). Mid latitude accumulation of ice would provide the necessary conditions for rock glaciers to form. A time-marching model is used to demonstrate the ability of ice and ice-rock mixtures to flow under a variety of possible Martian conditions. Input to this model is constrained by observations and results from the NASA Ames Mars GCM. Modeled glacier heights and lengths are compared to observed rock glacier morphologies. (1) Colaprete and Jakosky, [1998] (2) Jakosky et al., [1993, 1995] (3) Mischna et al. [2003]

P32C-05 1700h

Frequency of Steep Slopes on Mars: Evidence for Active Permafrost Layer at High Latitudes During High Obliquity Periods

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Mapping of the frequency of the steepest (above 20 deg) slopes on Mars showed that the steep slopes are much less frequent at high latitudes (above 50 deg in both hemispheres, excluding the polar caps) than in the equatorial zone (below 40 deg latitude). In the narrow transitional belts around 45 deg latitude in both hemispheres, we have found a strong asymmetry of steep slopes (Kreslavsky and Head, GRL, 30, 1815, 2003GL017795, 2003): steep equator-facing slopes are much more frequent than pole-facing ones. Costard et al. (Science, 295, 110-113, 2002) calculated that the day-average summer temperatures above the water freezing point can be reached only at high obliquity, and only at high latitudes or at pole-facing slopes at mid latitudes. They suggested that the summer-time melting of a tens-cm-thick permafrost layer could be responsible for gullies formation. We suggest that the repeating formation of active layer during summer in these areas at high obliquity is also responsible for a number of other features, including the absence of steep slopes: erosion (including gullies formation) at the presence of meltwater could preferentially eliminate the steepest slopes. Our study of morphology and topography of individual craters confirms this suggestion. The trend in the steep slope occurrence indicates the presence of ground ice or thin snow packs at least down to 35 deg latitude at high obliquity. The summertime insolation and hence the day-average temperature strongly depend not only on the latitude, obliquity and slope orientation, but also on the distance of Mars from the sun during summer, that is on Mars orbit eccentricity and the areocentric longitude of the Sun at perihelion. The perfect inter-hemisphere symmetry of the steep slope occurrence boundary indicates that this boundary reflects a cumulative result of a great number of geologically short episodes of high summer temperature maxima. Preservation of steep slopes at low latitudes indicates that Mars has never had a globally "warm" climate for a geologically appreciable duration at least since the Late Hesperian. This also restricts the former rotation pole location within 5-10 deg from the present one for the same time span.

P32C-06 1715h

Geologic Evidence for Late-Stage Equatorial Surface and Ground Ice on Mars

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New imagery data from the Mars Observer Camera suggest that the equatorial canyon of Valles Marineris contained surface and ground ice relatively late in Martian history. Some troughs (or chasmata) of Valles Marineris contain large mounds and mesas of interior layered deposits (ILDs) that formed in the Late Hesperian to Early Amazonian. Although the origin of the ILDs remains controversial, their characteristics suggest that the strongest hypotheses origin are lacustrine or volcanic processes; some workers have suggested a compromise origin, noting that many MOC observations of ILDs are similar to those of terrestrial sub-ice volcanoes that erupt in meltwater lakes. Lacustrine deposition and sub-ice volcanism require that chamata water or ice would have had to remain stable on the surface long enough to form either (1) extremely thick (1 km to > 4 km) deposits of fine-grained suspended lacustrine materials or (2) numerous sub-ice volcanic edifices with heights that compare to those of Hawaiian oceanic volcanoes. However, a dust cover on top of ice or an ice-covered lake could aid in preventing rapid sublimation. If the ILDs are sub-ice volcanoes than new MOLA topographic data can be used to (1) measure the heights of their subaerial caprock and (2) estimate corresponding volumes of ice. For example, the largest ILD mound in the 113,275 km3 void of Juventae Chasma resembles a capped sub-ice volcanic ridge. The mound is about 2 km high; with the highest point of the cap reaching an elevation of about +80 m. GIS measurement indicate that the maximum volume of ice below the elevation of +80 m is 56,423 km3, so roughly half of the Chasma could have been filled with ice. If the ILDs are lacustrine, then the heights of some other mounds that rival the surrounding plateau elevation would have required a volume of water almost equal to their enclosing chasma. Later in the Amazonian, after sublimation of any putative surface water or ice, MOC imagery attests to ground ice within some ILD mounds. Theatre-headed gullies cut into the flanks of mounds in Hebes, Juventae, Gangis, and Ophir Chasmata. At the MOC scale these gullies display no impact craters and could therefore be extremely young. Finally, one new image attests to possibly recent ground ice within floor material of Juventae Chasma. At the MOC scale, surfaces within this chasma have few impact craters, indicating a very young surface age. MOC image M0804669 shows some interesting geologic/geomorphic relations that occur within the chasma. For instance, on the south side of a chaotic knob, a talus deposit with a flat, possible pediment cap has been cut by late-stage erosion from wind, water, or ice. This relation indicates that relatively steady, talus-forming erosion was interrupted by a period of downcutting that incised the talus and caprock. On the north part of image M08-04669, an impact crater rim and its ejecta blanket are pitted with irregularly shaped depressions that appear similar to terrestrial thermokarst pits found in active glaciated and periglacial terrain due to the meltout of buried ice. The south end of this same image shows possible brittle fracture of channel-confined, dune-covered material. The possible thermokarst pits and brittle fractures may indicate melting of late-stage ground ice. Valles Marineris is a possible volcano-tectonic graben or collapse structure. Dark material within the chasma has been suggested to be very young volcanic material and MOC data appears to show several associated possible volcanic vents. Perhaps late-stage to recent volcanism drove water into the chasma, changed the local atmospheric circulation to create a unique microclimate, and issued forth a fine-grain, protective dust cover of dark ash.

P32C-07 1730h INVITED

Tropical Cold-Based Mountain Glaciers on Mars: Evidence for Significant Amazonian Climate Change

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Surface environmental conditions on Mars are presently extremely cold and hyper-arid, most equivalent to polar deserts on Earth. Coupling newly acquired Mars MOLA, THEMIS and MOC data with field-based observations regarding the flow, surface morphology, and depositional history of polar glaciers in Antarctica, we show that the multiple facies of extensive fan-shaped deposits on the western flanks of the Tharsis Montes and Olympus Mons, Tharsis Rise, are consistent with deposition from cold-based mountain glaciers. An outer ridged facies that consists of multiple laterally extensive, arcuate and parallel ridges, resting without disturbance on both well-preserved lava flows and impact craters, is interpreted as drop moraines formed at the margin of an ablating and predominantly receding cold-based glacier. Inward of the ridges lies a knobby facies that consists of irregular and closely spaced equidimensional knobs, each up to several kilometers in diameter; this facies is interpreted as a sublimation till derived from *in situ* downwasting of sediment-rich glacier ice. A third facies comprising distinctive convex outward lobes with concentric parallel ridges and aspect ratios elongated downslope likely represents rock-glacier deposits, some of which may still be underlain by a core of glacier ice, particularly at Olympus Mons. Taken together, these surficial deposits show that the western flanks of these volcanoes were occupied by extensive mountain glacial systems accumulating on, and emerging from, the slopes of the volcano in the case of the Tharsis Montes, or at the basal scarp in the case of Olympus Mons, and spreading downslope to form piedmont-like fans. These deposits occur in equatorial and near-equatorial regions where surface water ice is not currently stable. The presence of the tropical mountain glacier deposits suggests that several phases of late Amazonian-aged glaciation occurred in the equatorial Tharsis region. Recent climate models suggest that at obliquities approaching 45 degrees and greater, water ice is stable in tropical regions. Thus, these tropical mountain glaciers may record periods of unusually high obliquity in the recent history of Mars.

P32C-08 1745h

Did Glaciers Exist Recently on the Tharsis Montes?

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Previous studies have documented the presence of ridged features on the NW flanks of the Martian volcanoes Arsia, Pavonis, Ascraeus and Olympus Montes. Several hypotheses modes of formation for these features have been proposed, including an origin attributed to glacial activity. We examine the areographic distribution and relative age of the ridges using MOLA topography, THEMIS IR and VIS images and MOC images to assess their spatial and temporal relationships on the four volcanoes. The majority of the ridged facies have an aspect facing between 270° and 360°. The lowest elevation reached by the distal ridge on each volcano varies between -2,100 m below Mars datum on Olympus Mons and 3,000 m above datum on Pavonis Mons. The highest elevations also exhibit a wide range, from -1,686 m for Olympus Mons, to 1,970 m (Ascraeus Mons), 4,385 m (Pavonis Mons) and 5,496 m (Arsia Mons). MOLA topography and THEMIS images of Arsia Mons and Ascraeus Mons reveal different morphologies at the same elevation and aspect on each volcano, something that is not expected if the ridges resulted from a regional climate effect. At ∼5,000 m above datum, there is a distinct distal ridge on Arsia Mons, whereas the flank of Ascraeus Mons is dissected by large pits and pit chains and lacking any obvious ridges. Preliminary crater counts using MOC images indicate that the ridged facies on Arsia Mons may be significantly younger than the ridged facies on Ascraeus Mons, with Pavonis Mons falling between. In all cases, the ridged lobes have some superposed impact craters, indicating that these are not extremely young. These results suggest that a purely glacial origin for the ridges on the Tharsis Montes and Olympus Mons needs to be reexamined. Objections have been raised in the literature about a conventional rapidly emplaced flow origin for the ridges because the observed periodicity and regularity is not typically associated with turbulence. However, one of the alternative mechanisms we are investigating is the rapid release of sediment-laden water. It appears possible that the ridges formed as deposits from "roll-waves" that naturally occur in high flow rate debris flows, sediment-laden floods, and long run-out fluid flows.

P41A MCC: Level 1 Thursday 0830h

Faulting and Fault-Related Processes on Planetary Surfaces II Posters *(joint with T)*

Presiding: **P H Figueredo,** Arizona State University**; D A Young,** University of Minnesota at Duluth

P41A-0391 0830h POSTER

Processes of Planetary Faulting Revealed Through High-Resolution Topography

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Faulting generates clear topographic signals at the planetary surface that can be related to the style and geometry of the faults at depth. The displacement distribution along a fault (its offset at the surface) reveals the strength of rock adjacent to the fault's tipline, the deformability of the surroundings, mechanical interaction and incipient linkage with nearby faults, and the presence of mechanically significant subsurface layers. DEMs that portray the amplitude and position of surface topography (uplift and subsidence) due to fault slip can be inverted for depth of faulting, which for sufficiently large faults is related to the stability of frictional sliding and thereby to the paleogeothermal gradient at the time of faulting. Knowledge of the 3-D fault geometry of faults in a region is then easily converted into the magnitude and direction of brittle strain accommodated by the fault population. Displacement-length scaling relations contain information on fault interaction, subsurface stratification, and variations between planets. Examples from Mars illustrate the power and utility of topography as a tool in planetary structure and tectonics.

P41A-0392 0830h POSTER

Balanced crustal cross sections across wrinkle ridges on Solis Planum, Mars, from MOLA topography

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Models based on MOLA (Mars Orbiter Laser Altimeter) topographic data and Earth analogs indicate that wrinkle ridges are the surface expressions of folds that overlie blind thrust faults that collectively accommodate low bulk strains in comparison to terrestrial fold and thrust belts. Previous work based on elevation offsets across ridges and their backlimb geometry suggest blind thrusts on Solis Planum penetrate deeply into the Martian crust. As a continuation of this work, we undertook axial surface mapping and forward and inverse modeling of wrinkle ridge on Solis Planum using topographic data from MOLA in order to better constrain fault geometry and the depth at which thrust faults flatten. First and second derivative slope maps constructed along transects perpendicular to ridges on Solis Planum suggest wrinkle ridges there are defined by very gently curved (concave upward) and wide (10 km) backlimbs. We interpret these backlimbs as forming by uplift above listric blind thrusts that steepen towards the surface. Our maps also indicate that sharp bends are not present in backlimbs, suggesting that sharp bends in underlying thrusts are not present. The along-strike geometry of forelimbs of these ridges are interpreted as the surface expression of fault-propagation folds. Topographic profiles perpendicular to the strike of folds on Solis Planum yielded raw profiles, linearly detrended with respect to regional slope, and first and second derivative slopes were calculated. These topographic profiles and estimates for crustal thickness are then input into forward and inverse models in order to constrain the optimal depth to detachment and fault curvature for blind thrusts in Solis Planum.