general aviation, while Martian dust devils are potentially harmful to spacecraft Landers.

Our group has been conducting field projects to understand the electrification of dust devils and the contribution of dry convection and dust devils to the vertical transport heat and aerosol (mineral dust). Our initial results show that dust devils produce heat fluxes that are about two orders of magnitude larger than the background ambient flux. Indeed, it suggests that most of the vertical heat transport in active convective layers is done by coherent convective plumes. We will discuss our measurement techniques and summarize our most important results.

P51A-0341 0830h POSTER

Field Studies of Very-Near Surface Dust Devil Processes

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This work continues a long term research program into the fundamental very near-surface processes of dust devil vortices, especially in support of the ASU Vortex Simulator, as well as landed Martian missions such as MER and the Mars Express Beagle 2. Field experiments conducted in southern Nevada chased and directly sampled over 40 vortices with a profiling instrument array that extended down to the desert floor. Pressure, temperature, and horizontal/vertical wind speed and direction sensors reveal a complex microenvironment operating at the base of these thermal vortices. Preliminary analysis indicates that vortex inflow is stratified and fluctuates rapidly in a manner that contributes substantially to soil erosion and upward transport. Our report will characterize vortex dynamics and relate them to observed surface geologic and aerodynamic conditions as determined by complementary in-situ wind tunnel studies, among others.

P51A-0342 0830h POSTER

Measurements of Dust Devil Lower Structure and Properties, El Dorado Valley, Nevada, June 2002

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We report the results of a recent field campaign in Nevada, USA, carried out to investigate the lower structure (less than 2m) and dust lofting mechanisms of terrestrial dust devils. Over several days, an instrumented platform was repeatedly deployed from the back of a pickup truck into the path of oncoming dust devils. Around 40 events were recorded, including core penetrations of large and small dust devils, close misses and periods of ambient background conditions before and after dust devil events, and during periods of dust devil inactivity. The platform deployed consisted of a 2 by 1m base with a 2m mast and carried a total of 24 instruments. The instrument suite consisted of horizontal wind profiling down to 5mm above surface, vertical wind speed and direction, temperature and pressure profiling, airborne and saltating particle recorders, vertical electric field gradient measurements, and upward looking UV sensors. We present preliminary results of profiles for several events, together with details of ambient conditions required for dust devil formation.

P51A-0343 0830h POSTER

Dust Devil Track Occurrence in Argyre Planitia.

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Martian dust devil tracks were first observed in Viking Orbiter images [Thomas et al., 1985]. While the interpretation of these features was at first controversial, it is now widely accepted that the tracks are formed by the passage of small convective vortices (dust devils). As the dust devils travel across the surface the atmosphere is loaded with fine particles creating a visible trail inferred to be removal or deposition of material [Greeley et al., 2001].

Mars Global Surveyor (MGS) Mars Orbital Camera (MOC) images of dust devil tracks in Argyre Planitia were used to asses dust devil track abundance as a function of Martian season as well as elevation using Mars Orbiter Laser Altimeter (MOLA) data. Argyre Planitia is a large impact basin in the southern hemisphere (55° to 33°W and 35° to 58°S), with topographic relief of 7 km with the median at 1km. We have studied the 564 Narrow Angle MOC images (taken as of summer 2002) covering the area. The images were divided into two categories: those with devil tracks and those without. The Ls (solar longitude degrees as a fraction of orbit) and elevation of all of the images with and without devil tracks were noted. The elevation was recorded at the center point of each MOC image using MOLA data.

A polar plot of all of the images shows a statistically random distribution throughout the Martian year. A context map of the images shows a representative distribution over the area of the crater itself. A polar plot of dust devil track occurrence within the area observed shows a major concentration of tracks between Ls 200° and 360° (southern spring to late summer). A seasonal breakdown of devil track occurrence as a percentage of total area observed yields: fall 11.25%, winter 2.24%, spring 27.21%, and summer 46.49%. We therefore conclude that dust devils tracks are formed preferentially in summer and are destroyed, fade or are covered, over a period of a few months.

The elevation of all 564 images was measured and 1km bins were used to calculate the percent of occurrence. We discovered that, at 3km 0% of the observed area contain dust devil tracks, 2km 7.69%, 1km 12.90%, at Datum 15.95%, 1km 8.97%, -2km 28.92%, -3km% 50.00%, -4km 50.00%. Independent of the season a majority of the devil tracks were observed below 3km. Therefore elevation is a key factor governing the formation of dust devils or their ability to produce tracks.

Our interpretation of these results is that dust devils are much more likely to form during the summer and, as suggested by recent experiments [Balme et al., 2002], that they are more efficient at moving materials on the surface in areas where the atmospheric pressure is greatest (in the lowest elevations). The short timescale for disappearance of tracks suggests that the distinct albedo variations of the tracks result from only the removal or deposition of a very thin layer of material.

Thomas. P. et al., 1985, Science v. 230 Greeley. R. et al., 2001, LPSC XXXII Balme. M. et al., 2002, LPSC XXXIII

P51B MCC: Hall D Friday 0830h

Mystery of the Martian Rivers Posters *(joint with C, H)*

Presiding: **O B Toon,** University of Colorado**; T Colaprete,** NASA Ames Research Center

P51B-0344 0830h INVITED POSTER

The Valley Networks on Mars

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Despite three decades of exploration, the valley networks on Mars still seem to raise more questions than they answer. Valley systems have formed in the southern highlands, along some regions of the dichotomy boundary and the south rim of Valles Marineris, around the rim of some impact craters, and on the flanks of some volcanoes. They are found on some of the oldest and youngest terrains as well as on intermediate aged surfaces.

There is surprisingly little consensus as to the formation and the paleoclimatic implications of the valley networks. Did the valleys require a persistent solar-driven atmospheric hydrological cycle involving precipitation, surface runoff, infiltration and groundwater outflow as they typically do on Earth? Or are they the result of magmatic or impact-driven thermal cycling of ground water involving persistent outflow and subsequent runoff? Are they the result of some other process(es)? Ground-water sapping, surface-water runoff, debris flows, wind erosion, and formation mechanisms involving other fluids have been proposed. Until such basic questions as these are definitively answered, their significance for understanding paleoclimatic change on Mars remains cloudy.

I will review what is known about valley networks using data from both past and current missions. I will discuss what we have learned about their morphology, environments in which they formed, their spatial and temporal associations, possible formation mechanisms, relation to outflow channel and gully formation, as well as the possible implications for past climate change on Mars. Finally I will discuss how future, meter to submeter scale imaging and other remote sensing observations may shed new light on the debate over the origin of these enigmatic features.

P51B-0345 0830h INVITED POSTER

Greenhouse Models of Early Mars Climate

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Nearly all authors agree that Mars early (pre-3.8 Ga) surface was wet, as evidenced by many signs of flowing water on its heavily cratered southern highlands. Exactly what this implies about the early martian climate is a topic of ongoing debate. Some authors (1) have argued for a warm, nearly Earth-like climate; others (2) have suggested that the mean surface temperature could have been significantly below freezing. Here, I argue that the wetter early Mars was, the higher its mean surface temperature must have been in order to create the observed fluvial features. A planet with a large ocean, like Earth, would need to have a mean surface temperature at or above 0oC in order to avoid freezing over entirely. For a low-obliquity planet like Earth, ice albedo feedback causes the climate to become unstable when the polar caps extend equatorward of 30o (3). Mars has a highly variable obliquity, but the same reasoning is still likely to apply.

If, indeed, Mars had an Earth-like early climate, then it must have had a substantial atmospheric greenhouse effect. Solar luminosity increased from about 70 percent of its present value at 4.6 Ga to 0.75 times present at 3.8 Ga (4). Gaseous CO2-H2O atmospheres can produce surface temperatures no higher than 225 K during this time (5). Radiative heating by CO2 ice clouds might raise this temperature somewhat (6). Obtaining surface temperatures above freezing with this mechanism, though, requires nearly 100 percent cloud cover, which is highly unlikely for condensation clouds. A methane greenhouse is a more attractive mechanism. The combination of a few bars of CO2, along with a few tenths of a percent CH4, could have kept early martian surface temperatures above freezing. This would probably have required a biogenic source for methane, however, as abiogenic sources are unlikely to have been strong enough to maintain such concentrations in the face of photolysis by solar UV radiation. Although admittedly speculative, such a mechanism could explain the fluvial features that we see today.

References: 1) Pollack, J. B., Kasting, J. F., Richardson, S. M. & Poliakoff, K. Icarus 71, 203-224 (1987). 2) McKay, C. P. & Stoker, C. R. Rev. Geophys. 27, 189-214 (1989). 3) Caldeira, K. & Kasting, J. F. Nature 359, 226-228 (1992). 4) Gough, D. O. Solar Phys. 74, 21-34 (1981). 5) Kasting, J. F. Icarus 94, 1-13 (1991). 6) Forget, F. & Pierrehumbert, R. T. Science 278, 1273-1276 (1997).

P51B-0346 0830h INVITED POSTER

Carbon dioxide clouds in an early dense Martian atmosphere

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We use a time dependent, microphysical cloud model to study the formation of carbon dioxide clouds

in the Martian atmosphere. Laboratory studies by Glandorf et al. (2002) show that high critical supersaturations are required for cloud particle nucleation and that surface kinetic growth is not limited. These conditions, which are similar to those for cirrus clouds on Earth, lead to the formation of carbon dioxide ice particles with radii greater than 500 μm and concentrations less than 0.1 cm^{-3} for typical atmospheric conditions. Within the current Martian atmosphere, CO_2 cloud formation is possible at the poles during winter and possibly at high altitudes in the tropics. In both cases, temperature perturbations of several degrees below the CO_2 saturation temperature are required to nucleate new cloud particles suggesting that dynamical processes are the most common initiators of carbon dioxide clouds rather than diabatic cooling. The microphysical cloud model, coupled to a two-stream radiative transfer model, is used to reexamine the impact of CO_2 clouds on the surface temperature within a dense CO_2 atmosphere. The formation of carbon dioxide clouds leads to a warmer surface than what would be expected for clear sky conditions, but it also warms the atmosphere. The amount of surface warming is sensitive to the presence of dust and water vapor in the atmosphere, both of which act to dampen cloud effects. The radiative warming of the atmosphere associated with cloud formation, as well as latent heating, work to dissipate the clouds when present. In these simulations, clouds never last for periods much longer than several days, limiting their overall effectiveness for warming the surface. The time average cloud optical depth is approximately unity leading to a 5 - 10 K surface warming, depending on the surface pressure. The surface temperature does not rise above the freezing point of liquid water even for pressures as high as 5 bars, at a solar luminosity of 75% the current value. Our model shows that warming of the surface-atmosphere system by carbon dioxide clouds is self-limiting, since by heating the air the clouds cause themselves to dissipate. However, further analysis of the climatic effects of carbon dioxide clouds considering their global distribution and properties is warranted.

P51B-0347 0830h POSTER

The Seasonal Cycle of the Hadley Cell on Early Mars

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Radiative-convective models of the mean surface temperature of Early Mars indicate unambiguously that without cloud effects the surface would be too cold to support extensive surface flow of liquid water. Rather more ambiguously, they indicate that above freezing surface temperatures might be possible under certain circumstances if CO2 cloud effects are taken into account; the result is highly dependent on cloud microphysics however. A proper consideration of the problem with or without clouds requires consideration of the geographic and seasonal variation of the surface temperature of the planet.

In this presentation, I will discuss the problem in the context of axisymmetric models of the Early Mars climate, using both simulations and idealized Hadley cell theory. The emphasis will be on the asymmetric Hadley cells that occur during the Solstice conditions, with a particular eye to determining the extent of the planet that may be above freezing with and without cloud effects. The seasonal cycle is estimated to be weaker than that of Present Mars, but stronger than that of Earth, owing to the lack of a planetary ocean but presence of a thick CO2 atmospere. This allows hot spots to develop in high latitude summer regions, but also allows a very cold polar night. The possible role of clouds in limiting the polar night chill is discussed.

P51B-0348 0830h POSTER

Latent Heat Release and Mass Loss in Baroclinic Waves on Early Mars

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Interpretation of ancient fluvial features on the surface of Mars requires a better understanding of the Early Mars climate, and baroclinic eddies (or "storms") would be a key feature of the midlatitude atmosphere. Such eddies would affect the climate by transporting heat, transporting CO_2, stimulating CO_2 precipitation, and modulating cloud formation. We present some preliminary results on baroclinic instability in a hypothetical dense CO_2 Early Mars atmosphere, focusing on the novel features arising from this situation. These features include the latent heat release in a deep condensing layer (making for a particularly extreme form of moist baroclinic instability), and pressure alterations due to significant loss of mass in precipitating system. The stability of zonal flows in a two dimensional (x-z) quasigeostrophic model is examined. The model assumes a saturated "cloud" layer above about 2 scale heights (28 km). The zonal mean zonal wind is jet-like in the vertical with the profile $\overline{u} = \alpha z e^{-\frac{z}{H}}$. The zonal mean temperature at the surface is constant (280K) and decays adiabatically with height until the saturation pressure is reached. In the condensing layer, the basic state temperature is given by the moist adiabat, $T_S = \frac{-a}{b - \ln\left(\frac{p}{p_o}\right)}$. Normal mode calculations are performed in the absence of condensation. Initial value calculations are also performed in which the effect of latent heat release and mass loss accompanying condensation is included. Growth rates for both the normal mode and initial value problem are found as a function of the zonal scale (wavenumber). Various eddy characteristics are discussed.

P51B-0349 0830h INVITED POSTER

Formation of Rivers From the Effects of Large Impacts on Mars

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The Martian valley networks formed near the end of the period of heavy bombardment, 3.5 billion years ago. The largest impacts produced global blankets of hot ejecta meters to hundreds of meters thick; much of this initially >2000 K. The hot ejecta warm the surface, keeping it above the freezing point of water for decades or millenia, depending on impactor size, and cause shallow subsurface or polar ice to evaporate or melt. Large impacts also inject steam directly into the atmosphere from the crater or from water innate to the impactor. From all sources, a typical 100 (200, 250) km asteroid injects 2 (9, 16) m precipitable water into the atmosphere, which eventually rain out at 2 m/yr. The rains from a large impact would form rivers and contribute to recharging aquifers. The rarity and brevity of these events thwart the development of mature drainage systems, which are rare on Mars

P51B-0350 0830h POSTER

Rivers and Lakes Without Rain on Mars

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One puzzle of the martian rivers is the presence of rivers and lakes and the apparent absence of erosion that would be caused by rain. This has lead many to suggest that the source of water was groundwater sapping or subsurface ice melt. Here we explore an alternative hydrological model for Mars based on the hydrology of the dry valleys of Antarctica. These valleys have a mean annual temperature of about -20^{o}C and only about 50-100 degree-days above freezing in the summer. Precipitation occurs only as snow and the production of meltwater results from the occasional days above freezing. The liquid water accumulates in ice-covered lakes stabilized by the thick ice covers. The result is rivers and lakes without rain.

P51B-0351 0830h INVITED POSTER

Mars: Long-term Evolution of the Surface of a Dry, Windy Planet

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The uniformitarian case is made for Mars. Processes active in the current epoch include impacts, volcanism, wind, ice condensation/sublimation, and probable localized liquid water flow in gully forming events. The amount of carbon dioxide available at the surface at the end of heavy bombardment was likely to have amounted to only 50-100 hPa. Because water ice would have been partly protected from impact erosion, as much as several hundred meters of equivalent ocean may have been present, but impacts coupled with atmospheric transport would have moved almost all ice to polar and subpolar deposits well before the end of heavy bombardment. Most of the carbon dioxide would have been frozen into polar deposits although orbital parameter variations would have caused occasional release and periods of relatively high atmospheric pressure. Surface pressure would never have been high enough to sustain a warm wet climate, but because wind stress is very sensitive to pressure, aeolian surface modification in the Noachian and early Hesperian would often have been far more effective than today. Reservoirs of C, O, and H would subsequently have declined to their present levels as a result of atmospheric escape. During and after heavy bombardment, volcanism, ice deposition, and redistribution of dust by wind and impacts would have produced widespread and deep layering that has been continuously subject to erosion by impacts, sublimation, and wind action. Lava, possibly locally associated with juvenile water and lahars, could have formed large outflow channels in equatorial regions. These would have initially resembled volcanic outflow channels on Venus, but would have been subsequently modified and streamlined by atmospheric deposition and deflation. The origin of valley network features is varied and generally obscure, but volcanic processes, debris flows, and subsequent modification by atmospheric deposition and deflation could account for many of them. As discussed by Segura et al. (2002, this session), brief liquid water flows due to very large early impacts could also have produced some valley network features.

This hypothesis is consistent with the low abundances of heavy noble gases, apparent absence of carbonates, paucity of aqueous minerals, immense post-Noachian low latitude outflow channel features, evidence for widespread sedimentation and erosion, and theoretical problems with models calling for an early warm climate. It is argued that it deserves consideration along with hypotheses that entail massive liquid water flows or warm climates in the past.

P51B-0352 0830h POSTER

Aeolian Processes and Long Period Climate Change on Mars

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Wind deflation and deposition are powerful agents of surface change in the present Mars climate regime. Recent studies indicate that, while the distribution of regions of potential deflation (or erosion) and deposition is remarkably insensitive to changes in orbital parameters (obliquity, timing of perhelion passage, etc.), rates of eolian surface modification may be highly sensitive to these parameters even if the atmospheric mass remains constant. But atmospheric mass is likely to be sensitive to obliquity, especially if a significant mass of carbon dioxide can be stored in the regolith. Deflation and erosion are highly sensitive to surface pressure, so feedback between orbit variations and surface pressure can greatly enhance the sensitivity of aeolian modification rates to orbital parameters. We use statistics derived from a 1 Gyr orbital integration of the spin axis of Mars, coupled with 3-D global circulation models at a variety of pressures, to explore this feedback. A 1-D energy balance model is employed to illuminate the gross characteristics of long-term wind erosion and deposition on Gyr timescales. Finally, surface textural features in high resolution images from the Mars Global Surveyor Mars Orbital Camera (MOC) are examined in the light of the orbital integrations and model results.

P51B-0353 0830h INVITED POSTER

Noachian River Systems Interpreted as Ephemeral Products of Unsteady Impact-Induced Atmospheres on a cold dry Mars

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In a conventional warm and wet model for early Mars, a thick CO2 atmosphere persisted for much of the Noachian, steadily diminishing over a timescale of 100-500 Ma. Slow erosion occurred under a steady-state atmosphere, and ample time was available for the origin and adaptation of life to surface conditions. Large impacts occurred at a slowly decreasing rate, but they are not important to the climatic model and merely provide surface topography for the climate to weather and erode. Expected products of such a history would be extensive carbonate rock layers in crater lake sediments, and possible associated biological fossils. Meanwhile, terrain degradation should record the duration and intensity of fluid activity. In this model, conditions on Mars may even have been Earth-like.

However, on Mars we see no surface deposits of carbonate rock, at the 10% detection limit of TES and preliminary THEMIS data. Furthermore, the degree of erosion and drainage network integration is strictly limited compared to even quite young terrains on Earth. Measuring topographic maturity, we compare Martian and Terrestrial terrains. We find that the Noachian terrains are comparable to modern Terrestrial systems of only 1-20 Ma age. This implies that average Noachian erosion rates were 1-5% those on Earth today, even in arid or frigid environments. Therefore, conditions on Mars cannot have been remotely Earth-like, if they were steady-state. Alternatively, Earth-like conditions could have persisted for only a tiny fraction of the Noachian, yet they appear to extend over the entire Noachian epoch.

To resolve this discrepancy, we develop a model where the steady-state of Noachian Mars is an arid, cryogenic, barren surface under the Faint Young Sun, at least 10 K cooler than modern Mars. Permafrost of both water ice and CO2 is stable planetwide, and the volatiles are frozen into the upper crust, or developed as ice sheets on the surface.

Major impacts onto this surface can deliver energy equivalent to 10e2 to 10e4 years of sunlight on a timescale of minutes to hours. The primary and secondary impacts lead to instantaneous shock heating of shallow icy layers and slower conductive heating from superposed ejecta blankets.

In the aftermath of a large impact, global heating and outgassing of ices will occur, developing a thick CO2 atmosphere with locally abundant liquid water. The atmosphere is essentially boosted into a higher energy state by the impact, but the atmosphere is not permanently self-sustaining. As the residual heat of the impact dies away, and the planet continues its cycle of obliquity changes, the atmosphere collapses on a timescale of 10e3 to 10e6 years. On collapse, the atmosphere freezes out again as surface ices, restoring the status quo ante.

In this model, the Noachian erosion is caused by a number (10-100) of short-lived climatic cycles, with an integrated duration of 1-10 Ma, spread over the 100-500 Ma span of the Noachian. This explains the limited degree of fluvial erosion and the lack of carbonate rock at surface. Ephemeral impact-induced atmospheres are responsible for the erosion and deposition of material on Noachian Mars, and the end of large impacts necessarily ends the era of ephemeral atmospheres and river systems on Mars. The implications for astrobiology are obvious - In this model, the surface has essentially always been inhospitable to life, and the brief clement episodes are unlikely to allow surface life to evolve. The search for fossil life on Mars should therefore focus on subsurface niches.

P51B-0354 0830h INVITED POSTER

CO2-based Flows on Ancient and Modern Mars.

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Outburst flood channels from the Hesperian and Amazonian Epochs of Mars have conventionally been interpreted as evidence for catastrophic release of groundwater and surface floods akin to jokulhlaups. The Channeled Scablands of Washington state, USA are a type example of this mechanism. However, on Mars there are problems with storage of the large volumes of water in the subsurface, and little evidence for surface impoundments. To explain the volume of erosion requires multiple floods from each source area, which leads to problems of recharge on a cryogenic planet.

An alternative model for the floods has been developed in the last few years that explains the outbursts as the violent escape of pressurized liquid CO2, rather than liquid water. The CO2 is trapped underground beneath frozen icy regolith (permafrost) up to 1 km thick, which provides an effective topseal. When the outburst begins, explosive degassing generates a debris cloud akin to a volcanic pyroclastic flow, but at cryogenic temperature. The cloud flows downhill as a density flow, and could potentially erode the observed channels on Mars. Other terrestrial analogues include submarine density flows, which display considerable morphological similarities to Martian channels.

There remain some significant problems with CO2-based flow models. To date, no numerical flow model has been offered to support the intuitive conceptual model, and the degree of erosion vs deposition does not match expectation from small-scale flows on Earth. Progress on a numerical flow model will be discussed briefly, as well as scaling relationships that may explain the degree of erosion seen in the channels of Mars.

Acknowledging these shortcomings, we nonetheless suggest that the implications of a cold, dry, CO2-based flow model are so significant that the model deserves more attention from the geophysical and planetary science communities. If the model is sustainable, then the implications for the volatile history and thermal evolution of Mars surface and atmosphere are significant and the exobiological outcomes are profound.

We also see evidence for CO2-based flows on modern Mars, where I present evidence that flows occur during the springtime thaw of dry ice groundcover. MOC images show "before" and "after" images of flow events in Sisyphi Cavi (70 degrees south, and within the seasonal CO2 polecap). Thin channelised flows occur while surface temperatures are still <200 K, implying that water cannot be responsible, even with eutectic brines. Instead, I suggest that the transition of dry ice to the gas phase acts a lubricant allowing energetic downslope motion of small debris flows. Other channels on sand dunes in Russell Crater are modelled as plough-marks from the collapse of CO2 ice cornices and the sliding and tumbling of ice blocks 10m across.

URL: http://www.earthsci.unimelb.edu.au/mars/Enter.html

P51B-0355 0830h INVITED POSTER

Recent Gullies on Mars: Observations and Theories

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Malin and Edgett [2000] reported geologic features resembling terrestrial water-carved gullies in the mid and high latitudes of Mars. They occur poleward of about 30 latitude, primarily in the southern hemisphere. More often they are reported on poleward facing slopes than equatorward facing slopes, though they occur on all orientations of slopes. The morphology of the gullies varies but typically consists of a source region "alcove" of order 100 m wide, v-shaped channels of order 10 m wide leading from the alcove, and a depositional fan. The source regions appear to originate a few hundred meters or less from the top of the local slope and are frequently, but not always, associated with exposed strata of material that appear to exhibit significant cohesive strength. Erosion is best explained by a fluid of some sort and water is considered the most likely candidate from a morphological standpoint. These features are believed to be geologically young by their superposition atop dunes and permafrost polygons; how young is difficult to determine, though a range of older than 20 years to younger than 1 million years is suggested.

Models for the formation of these features are diverse, ranging from the canonical water-driven erosion of soil and rock, to both liquid or gaseous carbon-dioxide outbursts, to dry debris flows and wind erosion. Sources of fluid for mobilizing the soil are also diverse, including melting surface ice or snow deposits, melting of near-surface ground ice, and shallow or deep aquifers of water or brines, as well as melting subsurface dry-ice or clathrate deposits. Any viable model needs to be consistent with the breadth of geomorphic observations and should fit within the constraints of the martian climate and thermophysical processes that occur. Models for the formation of martian gullies will be reviewed and discussed in the context of observational data.

P51B-0356 0830h POSTER

Gullies on Mars and Constraints Imposed by Mars Global Surveyor (MGS) Data

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The discovery of geologically recent gully features on Mars [Malin and Edgett 2000] has spawned a wide variety of proposed theories of their origin including water versus carbon dioxide based erosion and shallow versus deep fluid sources. To test the validity of such gully formation mechanisms, data from the Mars Global Surveyor spacecraft has been analyzed to uncover trends in the dimensional and physical properties of the gullies and their surrounding terrain. Over 100 Mars Orbiter Camera (MOC) images containing clear evidence of gully landforms, distributed in the southern mid and high latitudes, have been analyzed in combination with Mars Orbiter Laser Altimeter (MOLA) data to provide quantitative measurements of numerous gully characteristics. Parameters measured include apparent source depth and distribution, vertical and horizontal dimensions, slopes, compass orientations, and present-day climatic conditions. Observed trends will be presented and compared with several proposed mechanisms of gully formation to place additional constraints on such gully models.

P51B-0357 0830h POSTER

Oceans on Mars: An Assessment of the Observational Evidence and Possible Fate

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If the large Late Hesperian outflow channels were eroded by extensive floods, as appears likely, then large bodies of water must have once occupied the northern plains during that period. Previous estimates of the sizes of bodies of water in the northern lowlands range up to 3 x 10**8 km**3.Several contacts have been previously mapped around the edges of the northern plains and interpreted to be shorelines remaining from these former standing bodies of water. We examine the elevations and geologic relations along these contacts in detail and find little support for their interpretation as shorelines. Some contacts are clearly of volcanic origin, and all have significant variations in elevation. Better support for the former presence of water over large parts of the northern plains is provided by the Vastitas Borealis Formation (VBF). Most of the post-Noachian fill within the northern basin is volcanic ridged plains of Lower Hesperian age. Overlying this is the VBF, a thin veneer of material of Upper Hesperian age that may have been deposited from large floods. Support for this interpretation is the similarity in age between the outflow channels and the VBF, the presence of the VBF at the lower ends of the outflow channels, and identification of numerous features in the outcrop areas of the VBF that are suggestive of basal melting of an ice sheet. To cover the area over which the VBF is exposed would require 2.3 x 10**7 km**3 of water. Spread over the entire surface of Mars, this volume is equal to a global equivalent layer (GEL) 156 m deep. We find no support for the larger estimates of ocean volumes that range up to 3 x 10**8 km**3 and which imply comparable amounts of water per unit area as are currently present on the surface of the Earth. Under present climatic conditions on Mars an ocean would freeze in a geologically short time period (10**4 yrs), then would sublimate away at rates strongly dependent on the presence or absence of debris on the ice surface. The present VBF is plausibly interpreted as a sublimation residue from the ponded outflow channel effluents. The fate of a volume of water thought to have been emplaced by the outflow channels (2.3 x 10**7 km**3) is largely accounted for by the presence of other present reservoirs on the planet. An approximately 20-30 m GEL of water is estimated to be in the present polar caps, and 50 m GEL may have escaped to space since the Hesperian, leaving 80 m GEL unaccounted for. This amount may be partly trapped in other volatile-rich deposits on the surface, and a significant amount could readily have reentered the groundwater system by south polar basal melting and may have been progressively cold-trapped at the base of a growing cryosphere.

P51B-0358 0830h POSTER

How Intensive was Fluvial Erosion during the Martian Noachian?

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The most important process forming the Noachian landscape was impact cratering, but this landscape has been strongly modified by fluvial, igneous, tectonic, and eolian processes. Most of the valley networks on the highlands date to the late Noachian and early Hesperian; many of these, however, appear to have resulted from late-stage incision into earlier, more extensive Noachian basin fills and alluvial fans. The morphology of most degraded highland impact craters less than 200 km in diameter is consistent with infilling by 0.5 to 1 km of fluvial deposits eroded from interior crater walls, presumably by runoff erosion. Evidence for large Noachian lakes on the highlands supports widespread precipitation. These degraded craters are superimposed upon a broader landscape of basins and ridges typically 200+ km in size (e.g., Frey et al., GRL 29(10), 2002). This broadly rolling landscape is best interpreted as being an earliest Noachian cratered landscape smoothed by ejecta deposition from basin scale impacts (e.g., Hellas, Argyre, and Isidis) and possibly pyroclastic airfall deposits. The mantled basins, presumably ancient impact craters, often consist of multiple coalesced impact basins, but they generally lack rims between the constituent impact basins. This pattern suggests that extensive fluvial erosion leading to basin integration occurred even during the earliest Noachian and prior to the basin mantling events.

P51B-0359 0830h POSTER

Recent (Late Amazonian) Fluvial Features in Southeastern Elysium, Mars

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Cerberus Fossae, a major northwest trending tensional fracture in Elysium, has acted as a conduit for water in the very recent past (Late Amazonian). This same fracture system has also acted as a conduit for the release of the lavas that formed the Cerberus Plains. Water was released by the fracture in three locations in both catastrophic and non-catastrophic manners. At the northwest end of the fracture, two sources (Athabasca and Grjota Valles) formed as the result of catastrophic flow away from the fracture carving channel systems hundreds of km long and tens of km wide. Both sources are at the same elevation 2.3 to 2.5 km suggesting they tapped the same reservoir beneath the Elysium rise. The third source is at the southeast end of Cerberus Fossae, southwest of Orcus Patera (Rahway Valles) which forms an extensive valley network. Some of these valleys begin at the fossae, others begin on the adjacent level plain to the north. This source is at a different elevation (-3.0 km) and apparently tapped a different, shallow reservoir. A shallow reservoir is suggested as there appear to be multiple sources over a broad area, possibly allowing headward erosion of some of the valleys by sapping, in addition to the larger (volume / rate) flows from the Cerberus Fossae fractures.

Cerberus Fossae must have tapped two distinct reservoirs to release the water as the sources are restricted to a narrow elevation range, are at different elevations, and there are no release points between the two. Age relations suggest that all of the sources were active at the same point in geologic time. As faulting along the Cerberus Fossae trend has occurred repeatedly through time, the water must have been available for release only during the most recent episode of tectonism. Absolute timing, based on crater counts, is broadly constrained as only between 144 and 1700 Ma.

These three fluvial channels can be integrated into a single fluvial system that exceeds 2500 km in length and extends across the Cerberus Plains through Marte Valles and into Amazonis. The presence of young catastrophic flood channels and valley networks indicate that significant quantities of water have been released in the recent past.

P51B-0360 0830h INVITED POSTER

Mars: Fluvial Erosion Driven by Magmatism

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Mars at present has a thin, dry, and cold atmosphere relative to Earths. The cold temperatures suggest that any subsurface water (perhaps combined with carbon dioxide as clathrate) would likely be frozen within a couple kilometers or more of the surface. This condition may have been prevalent following widespread fluvial dissection that formed numerous valley networks in highland rocks during the Noachian. The sources of some ancient and of most relatively young valley systems, particularly the large outflow channels, occur within or near volcanic rocks or display morphologic evidence for volcanic and/or tectonic associations. Such geologic relations have led many investigators to propose that magmatic activity has been a significant (if not dominant) driver of younger fluvial erosion on the surface of Mars. Magmatism may have provided the heat to raise local subsurface temperatures to near or above the freezing point of water; furthermore, intrusive activity may have fractured aquifers that provided conduits for release of substantial volumes of ground volatiles. Evidence of such interactions includes lengthy outflow channels sourced from fissures or depressions in volcanic rocks of the Tharsis/Valles Marineris, Elysium, and eastern Hellas regions. Depressions filled with chaotic terrain at the heads of the circum-Chryse outflow channels may be sites where large volumes of magmatic material may have interacted with water and perhaps carbon dioxide in rocks beneath the cryosphere, leading to catastrophic expulsion of the volatiles and collapse of country rock. Other evidence for magmatically driven erosion may include the low Hellas rim areas, where Malea and Hesperia Plana reside, and the channeled flanks of possible Noachian volcanoes in Thaumasia (south Tharsis region). Mars Global Surveyors MOLA topography data and MOC images and Mars Odysseys THEMIS images are providing new insights into the possible interactions between magmatism and fluvial erosion on Mars.

P51B-0361 0830h POSTER

Altimetry-based analysis of valley systems on Mars

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Measurements from the Mars Orbiter Laser Altimeter on board the Mars Global Surveyor were used to construct high-resolution longitudinal profiles of several Martian valley systems. Additionally, several lower-resolution profiles were generated. Used in conjunction with altimetry cross-sections and imaging data, these profiles allow the geomorphic characterization of valley networks. In particular, the question of groundwater sapping versus surface runoff as the dominant formation mechanism can be addressed. Most valleys examined in this study exhibited linear longitudinal profiles; however, Nirgal Vallis was found to have a convex profile while Bahram Vallis was concave. The former is indicative of decreasing discharge with increasing distance, while the latter is indicative of indicative of increasing discharge with increasing distance. There are strong indications that there is a correlation between the shape of the longitudinal profile and the age and origin of the valley system.

P51B-0362 0830h POSTER

No Mystery! Water Carved the Outflow Channels on Mars

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The enormous outflow channels of Chryse Planitia provide the best evidence that large amounts of water were once released onto the martian surface. The role of water has recently been challenged by the White Mars hypothesis, which claims that the channels were cut by CO2 gas-supported debris flows that also resurfaced the northern plains. Hoffman [Icarus, 2000] refers to a volumetric "misfit" between outburst channels and the chaos source zones. He explains that chaos collapse "...involves regolith alone which generates its own fluids from liquid CO2 and CO2-bearing ices within its own volume." Hoffman [LPSC 32, #1257] argues that release of liquid CO2 produced Aromatum Chaos, and a hypothetical energetic "jet" of gas and debris carved Ravi Vallis. He notes that water would have had to be locally recharged in many episodes to provide enough discharge to form the chaos and channel. However, these assertions appear incorrect because the fluid source was a distant surface impoundment, not local recharge. Carr [Water on Mars, 1996] describes a 400-km-long zone of subsidence that extends northward from Ganges Chasma to the source of Shalbatana Vallis. MOLA data reveal that this subsidence also extends eastward to Aromatum Chaos, the source of Ravi Vallis. The field relations show that a liquid-filled impoundment in Ganges Chasma drained northward via subterranean flowpaths to maintain surface flows in Shalbatana and Ravi Valles. The fact that the flows began at a surface impoundment virtually eliminates liquid CO2 as the flowing agent. Liquid CO2 would not be stable at the surface unless the atmospheric pressure exceeded 5 atm. A recent study by Stewart and Nimmo [JGR, in press] suggests that CO2 in liquid, solid, or clathrate form could not be preserved within the crust over geologic time. Liquid water is much closer to its stability field even on present-day Mars. Large outflow channels, such as Kasei and Tiu-Simud Valles, likely formed through the release of floodwaters dammed by ice and debris, analogous to the scabland flooding of eastern Washington. The water sources were probably ice-covered impoundments in ancestral Valles Marineris canyons. Subice volcanism was a possible source of heat to create liquid water. The former existence of transient water bodies near the surface can help to calibrate models of a volcanic-hydrologic climax during the Hesperian.

P51C MCC: 270 Friday 0830h

Fundamental Discoveries in Planetary Science: The Color of Worlds I *(joint with V)*

Presiding: **C Pieters,** Brown University**; J B Adams,** University of Washington

P51C-01 0840h INVITED

Remote Compositional Analysis: The Coming of Age

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Remote mineralogical analysis of planetary surfaces was attempted more than a century ago. This involved spectroscopy of regions on, mostly, the lunar surface, using groundbased telescopes and of rocks and minerals in the laboratory. However, it was not until the 1960s that science and technology developed to the point of allowing reflectance spectroscopy to become a quantitative technique. Some of us were luck enough to appear on this scene, young and energetic and with supporting funds available to take advantage of these advances to further the knowledge of molecules and minerals in the solar system. Electronic light detectors became available and the near IR portion of the spectrum was quantitatively accessed so that specific absorption bands could be detected in the reflectance spectrum, begging interpretation. At the same time, the physics of the interaction of light and minerals was becoming much better understood, allowing interpretation. Geochemists and geologists became interested and helped place these discoveries in the context of solar system science. Major successes resulted mostly from a few scientists who accomplished some expertise in all three areas. This allowed identification of many minerals and their crystal state using the reflectance spectra. The early emphasis was on the Moon because of its proximity to Earth and the Apollo Program. Reflectance spectra of the Moon were obtained in the late 60s and early 70s that showed absorption features and these features were interpreted, for example, to suggest a basaltic composition for the maria with high titanium content in some places. The Apollo Program produced samples and their reflectance spectra were measured in the laboratory. Comparisons with telescopic measurements indicated very good agreement and confirmed remote mineralogical interpretations. With confidence gained, we proceeded to explore the mineralogy of the Moon and derived interpretations therefrom. This success gave us confidence to proceed to other solar system objects, including asteroids and satellites, work that some of us carry on to this day and hopefully well into the future.

P51C-02 0940h INVITED

Summer Moonshine and Beyond

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Determining the composition of planetary surfaces remotely has been a major scientific and technological challenge throughout the history of planetary science and astronomy. In the 1960's Tom McCord, working with Bruce Murray at Caltech, began working with then state-of-the-art photometric instrumentation to make an order of magnitude leap in the precision of reflection spectroscopy measurements for the Moon. Not only did he have to overcome major technological and engineering challenges, he had to apply the developing science of solid-state crystal field theory to understand the compositional implication of his measurements. At the time many astronomers and chemists were skeptical that unique identifications could be made, feeling that 'you can make anything any color you want with a few impurities'. Tom's work laid the observational and analytic groundwork for much of the current discipline of remote sensing in the visible and near infrared wavelengths. His equipment and expertise were initially applied to a survey of potential Apollo landing sites (Summer Moonshine), where I first was introduced to the techniques of reflection spectroscopy (and a piece of the moon in Serenitatis soon to be infamous for all Tom's associates). Since then his techniques and observations have been applied to essentially every part of the solar system, and he, his associates and students have played major roles on most of the major planetary exploration missions of the last three decades.