

abrupt boundaries suggesting that it exists within a stratigraphic layer. The Aram Chaos hematite appears to be within a closed basin around which outflow channels are common suggesting an aqueous origin. In both sites, the hematite appears to be part of layered, sedimentary rock units that suggest aqueous environments (Christensen, et al., 2001).

The Lake Superior type BIF occurs in four principal facies: sulfide, carbonate, silicate, and oxide (James, 1954). These facies grade into each other in the field reflecting changes in the oxidation state of the water and occur as thin laminae alternating with chert layers. The mm scale laminations of these rocks will not be evident in large-scale (3km x 6km) TES spectra. The iron-rich minerals present in each facies are possible auxiliary minerals for the low albedo hematite regions on Mars. These minerals are: pyrite in the sulfide facies, siderite in the carbonate facies, minnesotaite and stilpnomelane in the silicate facies, and magnetite and hematite in the oxide facies.

A field trip to the Lake Superior type deposits in the Marquette and Gogebic iron districts of Michigan has provided a thorough rock sampling of the different facies, including several types of crystalline, gray hematite. Micaceous, specular hematite with a schistose texture is highly metamorphosed and is probably not seen on the surface of Mars. Bulk, gray crystalline hematite occurs in relatively unmetamorphosed BIF and retains its sedimentary layer nature. It also displays a microplaty texture in some samples that is most likely the result of low-grade burial metamorphism. Some of the bulk, gray crystalline hematite displays magnetic properties suggesting some mixture of magnetite and hematite. The spectra of these bulk samples may be better analogs for Mars than pure mineral phases. The spectra of these samples will be presented and compared to what TES has observed.

P61D-11 1145h

Thermal Infrared Airborne Field Studies: Applications to the Mars Global Surveyor Thermal Emission Spectrometer

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A primary goal of the Mars exploration program is to reconnoiter the planet from orbit using infrared remote sensing. Currently the Global Surveyor Thermal Emission Spectrometer (TES) and the 2001 Mars Odyssey 9-band radiometer THEMIS provide this capability. Landing site selection and modeling of the geologic and climate history depend on accurate interpretations of these data sets.

Interpretations use terrestrial analog remote sensing and laboratory studies. Until recently, there have been no airborne thermal infrared spectrometer (hyperspectral) data sets available to NASA researchers that are comparable to TES. As a result, studies relied on airborne multi-channel radiometer (multispectral) measurements (e.g. TIMS, MASTER). A radiometer has the advantage that measurement of broad bands makes it easier to measure with higher sensitivity. However, radiometers lack the spectral resolution to investigate details of spectral signatures. This gap may be partially addressed using field samples collected and measured in the laboratory. However, that leaves questions unanswered about the field environment and potentially leaves important complicating issues undiscovered.

Two questions that haunt thermal infrared remote sensing investigations of Mars are: (1) If a mineral is not detected in a given data set, how definitively should we state that it is not there? (2) When does the method provide quantitative mineral mapping?

In order to address these questions, we began collaborating with Department of Defense (DoD) oriented researchers and drawing on the unique instrumentation they developed. Both Mars and DoD researchers have a common need to identify materials without benefit of ground truth. Such collaborations provide a fresh perspective as well as unique data. Our work addresses uncertainties in stand-off identification of solid phase surface materials when the identification must proceed without benefit of ground truth. We will report on the results applied to TES, with a focus on the two primary questions above.

We use images recorded by a unique airborne imaging spectrometer, the Spatially Enhanced Broadband Array Spectrograph System. SEBASS uses cooled prisms to measure 2.4-5.3 and 7.6-13.5 microns. Each range is measured in 128 channels, with a spectral resolution of 7 wavenumbers at 890 wavenumbers, and a one

milliradian field of view per pixel. SEBASS operates as a pushbroom instrument, using two 128 x 128 detector arrays, and the entire optical bench is cooled to 4K using liquid helium. It is operated by The Aerospace Corporation, which is a non-profit Federally Funded Research and Development Center. Images are typically 128 pixels wide and 2000 pixels long, measured with a surface spatial resolution of 1 or 2 square meters. TES measures 6.5-50 microns in 143 channels, with a spectral resolution of 10 or 20 wavenumbers.

Issues that affect the spectral signature include surface roughness, particle size, coatings, reflected downwelling radiance, atmospheric transmission, and atmospheric reemission. A full understanding of these effects is required in order to determine the uncertainties in field interpretations, whether terrestrially or on Mars. SEBASS data fill this need by measuring with a sensitivity comparable to laboratory data, and sufficient spectral resolution to examine subtle spectral effects that are not resolvable in multi-channel radiometer data.

URL: <http://www.lpi.usra.edu/science/kirkland>

P62A MCC: Hall D Saturday 1330h

Mars Geology and Geophysics Posters (joint with H, T, V)

Presiding: C F Yoder, Jet Propulsion

Laboratory; L R Gaddis, U.S.

Geological Survey

P62A-0359 1330h POSTER

The Colorado Plateau of Mars: Layered Sedimentary Rocks of North Terra Meridiani

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The upper crust of Mars is layered. The layers are seen mostly in crater and trough walls. Terra Meridiani is exceptional, with regional-scale outcrops covering at least 300,000 km², an area larger than the Colorado Plateau (~260,000 km²). Hundreds of Mars Global Surveyor (MGS) Mars Orbiter Camera 1.5-6 m/pixel images were targeted to document the physical, geologic, and geomorphic properties of layered outcrops in Terra Meridiani and SW Arabia (9°N-3°S, 10°W-9°E). The layers have differing physical properties: when eroded, some produce mesas, buttes, and cliffs; they can have differing albedos; they have mappable stratigraphic relations; and some have characteristic, erosional geomorphic expressions identifiable throughout the region (marker beds). The bedding is essentially horizontal, individual layers can be up to 10s of meters thick; groupings of similar layers can be > 200 m thick. Unconformities, marking periods of erosion/non-deposition, are recognized by buried and partly exhumed impact craters ranging in diameter from ~0.1 km to > 30 km. A 1989 thermal infrared Phobos 2 Thermoscan image shows the layering and that the outcrops are colder than their surroundings at mid-day. Their thermal inertia, from MGS Thermal Emission Spectrometer data, is 410-490 J m⁻² K⁻¹ s^{-0.5}, values indicating coarse/very coarse sand if the materials are unconsolidated (they are not), or solid, indurated material with a patchy, thin covering of eolian debris and/or a thin regolith of outcrop weathering products. The layered materials are sedimentary, and they are rock. Large craters (10-30 km dia.) being exhumed from within the layered units have within them 10s to 100s of thin, uniform beds; these suggest the depositional environment inside was different from outside the craters. Observations in SW Arabia show that very large craters (> 100 km dia.) may have once been buried and later exhumed. The thinly-bedded layers in these craters may be reworked sediment derived from intercrater layered material that once lay topographically and stratigraphically above the crater rims. The hematite in central Terra Meridiani observed by TES is part of a mantle that overlies previously-eroded light-toned layered rock.

P62A-0360 1330h POSTER

Estimation of the Age of the Tharsis Volcanic Highrise on Mars From Long-Term Polar Wander Modeling

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The Tharsis volcanic complex forms a dominant positive mass anomaly on the surface of Mars. Murray and Malin (1973) have suggested that the inertia perturbation formed by the growth of such a large mass excess has led to a secular long-term motion of the rotation axis of Mars, resulting in a net polar wander of 10° - 20° in the last hundred million years. The present location of the Tharsis complex around the Martian equator is envisioned to be a direct consequence of this long-term polar motion. More recently, Spada et al. (1996) have quantitatively shown that this long-term polar wandering on Mars is feasible indeed.

We use Spada et al.'s long-term polar wander formulations, which are based on normal-mode viscoelastic relaxation models in combination with the Liouville equations, to constrain the age of the Tharsis highrise. The Mars model consists of an inviscid core, viscoelastic mantle and elastic lithosphere. Mantle viscosity, lithospheric thickness and formation history of the highrise are varied in the simulations. The set of solutions is constrained by the requirement that the highrise should reach the equator during its life-span and the polar wander should amount 10° - 20° in the last hundred million years. From these simulations we derive an age of the Tharsis construct of 130 - 340 million years, depending on Martian mantle viscosity, lithospheric thickness and formation history of the volcanic complex.

P62A-0361 1330h POSTER

Geologic Analysis of a Possible Oasis and Environs in the Valles Marineris, Mars

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We used Mars Global Surveyor data from TES, MOC, and MOLA to examine the geologic history of a region of interior layered deposits on the floor of western Candor Chasma in the Valles Marineris, Mars. This site was characterized by Geissler et al. (1993, Icarus 106) as having an unusual reddish color in multispectral images from Viking and Phobos missions. The red color was associated with two 20-km-long depressions and was thought to indicate the presence of crystalline ferric oxides (possibly hematite) in the layered deposits. Assuming that water was required to form the iron oxides via aqueous or hydrothermal alteration, these depressions may mark the site of a local oasis involving ponding or groundwater seepage in the canyon.

Thermal inertia and dust index images from TES data of west Candor Chasma indicate that mantling and obscuration of local outcrops is not significant in the region of the possible oasis. To characterize the mineralogy of this area, we use multiple-endmember spectral mixture analysis (MESMA) to deconvolve TES emissivity data relative to laboratory spectra of minerals. This method identifies the minimum number of components (4 to 5) required to model the spectrum of each pixel in the spectral ranges of 307-507 cm⁻¹ and 825-1301 cm⁻¹ (66 TES channels) through iterative comparisons to a 33-component mineral spectral library. This library, adapted from that of ASU, includes pyroxenes, plagioclase feldspars, clays, micas, amphiboles, sulfates, carbonates, olivines, K-spar, gray hematite, and volcanic glass, plus 5 atmospheric end-members and a blackbody. Although nanophase red hematite is undistinguished at TES wavelengths, mineral abundance maps indicate the presence of other Fe-rich minerals (such as nontronite and Fe-smectite) at this site. Gray hematite, hi-Ca clinopyroxene, Fe-rich olivine, and hi-Ca plagioclase minerals are also observed within layered deposits in the canyon walls and interior, as well as in dark materials at the base of canyon walls. These results suggest that we are mapping sites of alteration and volcanism in west Candor Chasma with the TES data. We are currently performing photo-clinometric modeling of coregistered MOC (6 m/pixel) and MOLA (500 m/pixel) data via the method of Soderblom et al. (2002, LPS #1254) to evaluate the orientation and possible origin of this layered deposit.

P62A-0362 1330h POSTER

Constraints on the Derivation of Cerberus Plains Floodwaters From Cerberus Volcanics

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Based on calculations of volatile release from estimated total volumes of Cerberus Plains (CP) volcanics and estimated water content of martian basalts, Plescia [1] proposed that water vapor released by CP volcanism may have precipitated over the plains and produced fluvial systems. Since refined measurements of the dimensions of individual lava flows based on MOLA data is now possible, the dimensions of the youngest flows are easy to measure and lower bounds on the dimensions of older, embayed flows can be determined. If magmatically derived water vapor from individual volcanic events precipitated over the plains and provided the water for outflow events, then the mass of dissolved water should equal or exceed the mass of flood waters.

Lava flows embaying Marte Valles (MV) extend for at least 1200 km, are roughly 40 km in width within the MV outflow channel, and have flow fronts approximately 25m high. The total volume for these flows is $1.2 \times 10^3 \text{ km}^3$. Assuming a bulk density of 2000 kg/m^3 and 0.5 wt% H_2O content, this equates to $1.2 \times 10^3 \text{ kg H}_2\text{O}$. Burr et al. [2] estimated a discharge of $5 \times 10^6 \text{ m}^3/\text{s}$ for MV. If all the erupted water vapor were instantly condensed at the vent, it could provide the MV discharge rate for only about an hour. These values may overestimate the quantities of water released if the lavas were not devolatilized completely. It is also unlikely that all the H_2O in the lava would contribute to MV flood waters as some of the water would likely be precipitated regionally and result in widespread networks of dendritic channels; networks of small dendritic channels are noted in the vicinity of MV [2], but they are confined to just a few locales. Additionally, it may be unlikely that all the volatiles were released simultaneously as the eruption duration of CP lavas was likely on the order of years [3]. For these reasons, we conclude that condensation from the eruption plume could not form the major erosional flood channels seen in the CP.

If the lavas are allowed to devolatilize at depth, water may be allowed to collect over time. Lentz et al. [4] show petrologic evidence for water exsolution for Shergottite parent magmas at depths between 4 and 6 km. Burr et al. [2] calculated that, from the lack of observed topographic subsidence, water for hours-long duration floods may have originated as shallow as a few kilometers deep, consistent with depths at which H_2O may begin to exsolve from magmas. However, it is difficult for water vapor to condense and collect close to the magma body. If water that carved the fluvial systems of the CP were exsolved from CP magmas, then water would have to exsolve at depth, possibly due to pressure induced exsolution or co-exsolution with CO_2 , and migrate away from the magma body until it condenses in a cooler location. While special processes may occur at depth to generate liquid water from CP magmas, it seems more probable that the bulk of water that carved the fluvial systems of the CP is not derived from those magmas.

[1] Plescia, J.B., *Icarus* 104, 20-32, 1993. [2] Burr, D.M. et al., *Icarus* 159, 53-73, 2002. [3] Keszeihelyi et al., *JGR* 105, 15027-15050. [4] Lentz, R.F.C. et al., *Geochim. Cosmochim. Acta* 65, 4551-4565, 2001.

P62A-0363 1330h POSTER

Mars Rover Image Data Prioritization for Increased Mission Science Return

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Rover traverse distances are increasing at a faster rate than downlink capacity is increasing. As this trend continues, the quantity of data that can be returned to Earth per meter of traverse is reduced. The capacity of the rover to collect data, however, remains high. This circumstance leads to an opportunity to increase mission science return by carefully selecting the data with the highest science interest for downlink. We have developed an onboard science analysis technology for increasing science return from missions. Our technology evaluates the geologic data gathered by the rover, and prioritizes this data for transmission, so that the data with the highest science value is transmitted to Earth. Although our techniques are applicable to a wide range of data modalities, our initial emphasis has focused on image analysis, since images consume a large percentage of downlink bandwidth. We have further focused our foundational work on rocks. Rocks are among the primary features populating the local Martian landscape. Characterization and understanding of rocks on the surface is a first step leading towards more complex in situ regional geological assessments by the rover.

Data prioritization involves two processes: the identification of significant features in the data and the use of these features to assess the scientific value of the data. In our current application, we locate rocks in the

image data and then extract properties of each rock, including albedo, visual texture and shape. These properties are then used to prioritize the rocks and thereby prioritize the images of the rocks. Three prioritization methods have been developed: identification of key target signatures, novelty detection, and sampling representative rocks. The use of these three methods ensures that three exploratory science objectives are met. First, objects known to be of very high interest, such as indicators of water, will be immediately recognized if encountered. Second, unexpected objects that may lead to key discoveries will be noted. It is, however, also important to have an understanding of the typical characteristics of the region. Our final prioritization method selects the most representative rocks for the downlink queue.

As NASA continues to increase the number of high data volume missions simultaneously operating, an onboard mechanism for the prioritization of data tagged for downlink that can increase the science content returned for a fixed bandwidth will be invaluable to scientists who will continue to compete for downlink time.

P62A-0364 1330h POSTER

The Geologists Field Assistant: Developing an Innovative Science Analysis System for Exploring the Surface of Mars

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We are developing science analysis algorithms to interface with a Geologists Field Assistant (GFA) device that will allow robotic or human remote explorers to better sense and explore their surroundings during limited surface excursions. Our algorithms will interpret spectral and imaging data obtained by various sensors. The algorithms, for example, will identify key minerals, rocks, and sediments from mid-IR, Raman, and visible/near-IR spectra as well as from high-resolution and microscopic images to help interpret data and to provide high-level advice to the remote explorer.

A key task for human or robotic explorers on the surface of Mars is choosing which particular rock or mineral samples should be selected for more intensive study. The usual challenges of such a task are compounded by the lack of sensory input available to a suited astronaut or the limited downlink bandwidth available to a rover. Additional challenges facing a human mission include limited surface time and the similarities in appearance of important minerals (e.g. carbonates, silicates, salts). Yet the choice of which sample to collect is critical.

A top-level system allows multiple inputs from raw sensor data output by imagers and spectrometers (visible/near-IR, mid-IR, and Raman) as well as human opinion to identify rock and mineral samples. Our prototype image analysis system identifies some igneous and metamorphic rocks from texture and color information. Spectral analysis algorithms have also been developed that successfully identify quartz, silica polymorphs, calcite, pyroxene, and jarosite from both visible/near-IR and mid-IR spectra. We have also developed spectral recognizers that identify high-iron pyroxenes and iron-bearing minerals using visible/near-IR spectra only.

We are building a combined image and spectral database of rocks and minerals with which to continue development of our algorithms. Future plans include developing algorithms to identify key igneous, sedimentary, and some metamorphic rocks.

P62A-0365 1330h POSTER

Topographic Analysis of Martian Impact Craters

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We have used the 1/64th degree digital elevation model of Mars obtained from the Mars Orbiter Laser Altimeter (MOLA) to measure the dimensions of impact craters on the Northern Plains of Mars. Our objective is to search for spatial variations in crater geometry (e.g., the depth/diameter ratio or ejecta volume/crater volume ratio) that might indicate variations in target properties or the resurfacing history of Mars with time. Our initial analysis is focused on the Northern Plains because of the apparent uniform surface material and relatively constant elevation (about -3.8 to -5.2 km relative to the MOLA datum). We have studied craters in three different areas: Utopia Planitia (90 craters between 0.8 km to 39.8 km dia., over the latitude range 12N to 60N), Acidalia Planitia (49 craters 7.4 to 58.9 km dia., 33N to 61N) and Amazonis Planitia (61 craters 0.9 to 26.8 km dia., 23N to 61N). We measured the following parameters from the MOLA data using an in-house software package written in IDL by Harold Garbeil (Univ. Hawaii): (a) crater latitude and longitude; (b) crater diameter; (c) crater maximum and average depth; (d) crater cavity volume; (e) crater rim crest height and volume; and (f) average thickness and total volume of the inner ejecta layer. These parameters are measured relative to a user-defined surface that lies around the perimeter of the crater beyond the range of the ejecta layers.

These data reveal some fascinating aspects of Martian cratering that were only hinted at from analysis of Viking Orbiter images. We find evidence for: (1) a progressive decrease towards higher latitudes in the depth/diameter ratio for craters of a comparable size; (2) the volume of the inner ejecta layers often exceeds the crater cavity volume, particularly in the case of craters equatorward of 34N; (3) two trends exist in the crater diameter/volume ratio, with the transition occurring at the diameter range 6 to 18 km; (4) there is little correlation between average rim height and crater diameter; (5) ejecta volume and crater rim volume are weakly correlated, but examples can be found where this ratio varies by more than 3 orders of magnitude; (6) little difference between the three geographic regions appears to exist. We also note that we have found an additional 48 craters where the crater floor is at a higher elevation than either the ejecta deposits or the surrounding plain. The implications of these observations will be discussed.

P62A-0366 1330h POSTER

Update on the Small Craters Origin of the Martian Meteorites

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The small craters model for launch of the Martian meteorites was presented in 1999 [1-3]. The model was based upon hydrodynamic computer code impact simulations showing that the launch efficiency of Martian material should be age-dependent. It was easiest to launch material from intact (young) material, harder from material covered by a thin regolith, and truly difficult from terrain covered by a deep regolith. The minimum required crater diameter for the above was 3 km, 7 km, and 20 km respectively. Even though little of Mars is covered by Shergottite-epoch (S) terrain, the smaller size limit for meteorite-launching events means there are actually more candidate source craters on this terrain formed in the last 10 Ma than on the heavily cratered southern highlands. This bias was sufficient to explain the origin of the 13 Martian meteorites known at the time as fragments from 6 or 7 impact events. The samples in hand were assigned to impact events as follows: 1) EETA79001 launched 0.8Ma, 2) DaG 476 launched 1.3 Ma, 3) Shergotty, Zagami, and QUE94201 all launched 2.1 Ma, 4) ALHA77005, Y793605, and LEW88516 all launched 3.9 Ma, 5) Nakhla, Lafayette, and Gobernador Valadares all launched 11 Ma, 5a) Chassigny launched 11.6 Ma, possibly with the Nakhlates, and 6) ALH84001 launched 14.4 Ma.

Because the model explained both the relative and absolute abundances of the samples in hand, there followed a number of predictions. 1) The new Martian samples should continue to over-represent the youngest terranes. 2) Additional samples from ancient terrain, if any, should be source crater-paired with ALH84001, rather than representing new impacts. 3) New samples of Nakhlate-age should represent source craters in roughly the same proportion as did the first three Nakhlates and Chassigny in 1999. 4) New meteorites from young terrain should represent additional impacts with much older CRE ages than those already observed. 5) Martian meteorites with two-stage CRE histories should continue to be unknown.

Since 1999, 13 additional Martian meteorites have been identified, 10 S and 3 N. None appear to be ancient as is ALH84001. Thus the first two predictions still stand. CRE data are currently available only for 4 new S and 1 new N. Of those, the Nakhlate NWA 817 has a CRE age consistent with launch in the same event as N/Lafayette/GV [4]. Therefore at most the new samples represent 2 new impact events for 1.3 Ga material. Of the new S, it appears that the SaU stones with a CRE age of about 1.5 Ma can be source-crater paired with the DaG stones[5]. NWA 480, with a CRE age of 2.4 Ma may represent a new event, or be paired

with S/Zagami/QUE[4] as can Los Angeles[6]. Dhofar 019 has a CRE age of about 20 Ma and is assigned to its own impact [7]. Hence the new S samples represent at least 1 though no more than 6 new impact events. Hence, the number of source craters for S continues to outpace that of N and one of those has the oldest known CRE age for any Martian meteorite. Thus predictions 3 and 4 still hold. Lastly, none of the new samples are reported to have a two-stage CRE history, matching the last prediction. This last prediction is basic to the small craters model and is exceedingly difficult to explain in a model requiring in-space breakup events. To summarize, the number of known Martian meteorites has doubled since the small craters model was proposed. Geochemical analyses are available for a portion of these, the data from which are entirely consistent with the small craters model.

1. Head and Melosh, (1999) LPSC 30. 2. Head, J.N. (1999) PhD Dissertation, U. Arizona. 3. Head et al., submitted. 4. Marty et al. (2001) MAPS 36 A122-123. 5. Pasch et al. (2000) MAPS 35 A124. 6. Nishiizumi (2000) MAPS 35 A120. 7. Shukolyukov et al. (2000) MAPS 35 A147

P62A-0367 1330h POSTER

Simulation of the Effect of Topography and Crustal Thickness on the Martian Seismograms by the Coupled Method.

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Whereas the past 4 decades of Mars exploration have provided much information about the Martian surface, its interior structure remains relatively unknown. Most of our knowledge of the interior come from gravity data, which is intrinsically non-unique and thus requires many model assumptions, such as mean depths. As demonstrated for the Earth and the Moon, seismology seems the most effective tool to investigate the details of the Martian interior.

Although the subsurface structure is poorly constrained, it is clear that there are tremendous lateral variations in the crustal thickness, such as the North-South dichotomy and the Tharsis province, which may have significant consequences for the interpretation of seismic data. Recent progress in numerical methods allow us to compute seismograms in models with such variations of shallow structure.

To tackle this problem we compute synthetic seismograms using a recently developed numerical method, the coupled modal solution (MS)-spectral elements method (SEM), which is particularly well-suited to our problem. The Mars model is divided into two domains. To reduce the numerical cost of discretizing the entire model, the displacement field is computed only in the outer shell by SEM. The inner part is discretized as a development into a modal solution of the traction at the interface between the two domains. SEM combines the geometrical flexibility of finite elements and the superior accuracy of high-degree polynomial methods. In this way, a complicated geometry at the free-surface or strong lateral variations of the velocity model can be accommodated.

In this study, we compute seismograms in the spherical reference Mars model of Sohl and Spohn (1997) and compare them with those for models which include crustal thickness and topography variations to spherical degree 50. The goal is to assess the effects of shallow structure on future Martian seismic records. The idea is to improve the extraction of data in order to obtain the best possible 1-D model. Finally, some differences between Martian and terrestrial seismicity will be shown.

P62A-0368 1330h POSTER

JPL Mars Gravity Fields: Recent Model Changes and Results

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Over the past year there have been improvements in the models that affect the determination of the gravity field of Mars. The most notable change in the Mars gravity modeling is the change in the Mars orientation model. We have switched from the IAU coordinate system (either 1991 or 2000, e.g. Seidelmann et al., *Celest. Mech. & Dyn. Astron.* 82, 2002) to the coordinate system used by Mars Pathfinder (Folkner et al., *Science* 278, 1997). The new orientation model of Mars includes rigid-body nutation, seasonal spin variations, and polar motion. The Mars Pathfinder and Viking lander data have been merged with the MGS tracking data to help constrain the Mars orientation. Other model improvements include the Mars ephemeris and spacecraft component pointing. Together, these model changes have produced promising seasonal trends in the gravity field of Mars as well as detection of the tidal Love number and a new precession solution. In addition, four days of Mars Odyssey tracking data just after completion of aerobraking are included in the more recent gravity solution. This data contains some high frequency gravity information from a 200x500 km orbit with periapse near the equator.

P62A-0369 1330h POSTER

The Size of Mars Fluid Core From Mars k_2 Love Number Obtained From Analysis of MGS Doppler Tracking.

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The solar tidal deformation of Mars, measured by its k_2 potential Love number, has been obtained from analysis of MGS radio tracking. The observed $k_2 = 0.164 \pm -0.016$ is large enough to rule out a solid iron core. The inferred core radius R_c (1600km $< R_c < 1900$ km) is remarkably independent of interior properties such as temperature, composition (as measured by the molar ratio $Mg/(M+Fe)$) and crustal thickness, even after correcting for atmospheric thermal tides, mantle anelasticity, spin pole nutations and seasonal changes in shape from ice cap ablation/accretion. One critical model feature is the ability to isolate the second degree and mth order harmonic components: semidiurnal ($m = 2$), diurnal ($m = 1$) and long period ($m = 0$) and solve for independent k_{2m} parameters. Detection of tides depends on finding reliable, long period signatures since short period changes are too small. A crucial tidal signature is a secular drift in spacecraft orbit inclination related to the sun-synchronous spacecraft orbit and which is seen only in the $m = 2$ tide. In order to minimize the effect of along-track changes on a solution for k_{22} , the drag model solves for a daily coefficient and thus effectively minimizes the influence of the along-track residual signature on this solution parameter. The k_{21} and k_{22} coefficients primarily affect the orbit node (k_{21} has an annual variation) where it is strongly mixed with seasonal changes in Mars even zonal gravity harmonics (J_2, J_4). The odd gravity harmonics (J_3, J_5) are detected through seasonal changes in orbit eccentricity where the influences of tides are weak. The observed J_3, J_5 amplitudes are consistent with estimates of ice cap mass only if the cap thickness increases with latitude and the south cap is significantly larger than the north cap.

P62A-0370 1330h POSTER

Early Plate Tectonics Versus Single-Plate Tectonics on Mars: Constraints From Magnetic Field Observations and Crust Evolution

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The consequences of an early epoch of plate tectonics on Mars followed by single-plate tectonics with stagnant lid mantle convection on both crust production and magnetic field generation have been studied with parameterized mantle convection models. It is difficult to find models that can reasonably explain both rapid early crust formation, as is required by geological and geophysical observations, and an early magnetic field that is widely accepted as the cause for the observed magnetic anomalies. Dating of crust provinces and topography and gravity data suggest a crust production rate monotonically declining through the Noachian and Hesperian and a present-day crust thickness of more than 50 km. Plate tectonics cools the mantle and core efficiently and the core may easily generate an early magnetic field. Given a sufficiently weak mantle rheology, plate tectonics can explain a field even if the core is not initially superheated with respect to the mantle. Because the crust production rate is proportional to temperature, however, an early efficient cooling will frustrate later crust production. Volcanic crust formation following plate tectonics is only possible if plate tectonics heat transfer is inefficient. This is possible if the mantle rheology is very stiff as for a dry Martian mantle but then the magnetic field is left unexplained unless there is a substantial initial superheating of the core. If one accepts the initial superheating then, as we will show, a simple thermal evolution model with monotonic cooling of the planet due to stagnant lid mantle convection underneath a single plate throughout the evolution can better reconcile early crust formation and magnetic field generation.

P62A-0371 1330h POSTER

Theoretical Traveltime Curves for Mars

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Seismic traveltime curves are computed for several published interior structure models of Mars. The sensitivity of these curves to compositional parameters is examined as is the potential for using seismic data to constrain composition.

The model of Zharkov and Gudkova (2000) produced a core shadow zone at epicentral distances of 103° to 141° . Zero-offset core reflection times for PcP and ScS were 394 s and 730 s, respectively. This model invoked a ferric number $(Fe/(Fe+Mg) \times 100)$ of 20 for the mantle silicates and an Fe-FeS liquid core containing 14.5 wt.% S and 0.48 wt.% H. A thin (50 km) perovskite layer overlies the core-mantle boundary at a depth of 1642 km. The moment of inertia factor (C/MR^2) and Fe/Si ratio calculated for this model agree well with the Mars Pathfinder value of 0.3662 and the chondritic Fe/Si ratio of 1.71, respectively.

The strongest influences on the traveltime curves are due to those factors that control core size: the iron molar fraction (X_{Fe}) of the mantle and the sulphur content of the core. With a 1% increase in X_{Fe} , the epicentral onset of the shadow zone increased by 3° and the vertical PcP traveltime increased by 7.5 s. Increasing the sulphur content of the core enlarges it, resulting in a larger shadow zone and decreased reflection times. A 1% (wt.) increase in core sulphur decreased the epicentral onset of the shadow zone by 0.5° and decreased the PcP time by 3.2 s. At large sulphur values, the core-mantle boundary is too shallow to allow for a high-velocity perovskite lower mantle.

Further work planned in this study will examine other seismic phases and the sensitivity of these results to the moment of inertia, the state of the core (liquid, solid, or both) and the strength of seismic velocity discontinuities due to mineralogical phase changes in the mantle.

P62A-0372 1330h POSTER

Modeling Major Southern Hemisphere Martian Magnetic Anomalies

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In this study we report modeling results for anomalies within the region of high field strength in the southern hemisphere of Mars, between 130°E and 240°E. A high resolution magnetic field map of the southern hemisphere produced using mapping phase (approx. 380-450 km altitude) Mars Global Surveyor data has been used to determine the approximate locations of the anomalies within the cluster. An iterative modeling technique (Hood and Zakharian, JGR, v. 206, p. 14601, 2001) has then been applied (assuming circular sources of uniform magnetization and variable diameter) to estimate approximate bulk directions of magnetization, paleomagnetic pole positions and lower limits on bulk magnetization. The estimation of the lower limits on bulk magnetization for the strongest Martian anomalies will indicate whether the presence of unusually highly magnetized material is necessary to explain Martian crustal anomalies or whether they can be explained by large areas of lower bulk magnetization materials. Models for the southern hemisphere anomaly cluster and required bulk magnetizations will be presented at the time of the conference.

P62A-0373 1330h POSTER

Evidence for Weak Crustal Magnetic Fields Over the Hellas Basin

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The Electron Reflectometer (ER) onboard Mars Global Surveyor (MGS) detected a plasma boundary between the ionosphere and the solar wind as the latter is diverted around and past the planet [Mitchell *et al.*, GRL **27**, 1871, 2000; Mitchell *et al.* JGR **106**, 23419, 2001]. Above this boundary the 10-1000 eV electron population is dominated by solar wind electrons, while below the boundary it is dominated by ionospheric photoelectrons. This "photoelectron boundary", or PEB, is sensitive to pressure variations and moves vertically in response to changes in the ionospheric pressure from below and the solar wind pressure from above.

The PEB is also sensitive to crustal magnetic fields, which locally increase the total ionospheric pressure and positively bias the PEB altitude. A map of the PEB altitude closely resembles maps of the crustal magnetic field intensity measured at 400 km by the MGS Magnetometer. As expected, the best correlation is between the PEB altitude and the horizontal magnetic field component, which provides vertical pressure support.

We have analyzed more than 4.8 million electron spectra obtained in the mapping orbit, covering over 1.5 Martian years. We have empirically modeled and removed systematic variations in the PEB altitude associated with the solar wind interaction, thus isolating perturbations caused by crustal magnetic fields. We find a PEB altitude bias over the Hellas basin that is consistent with a horizontal magnetic field with an intensity of several nanotesla at 400 km altitude. This is compatible with upper limits to the horizontal crustal field strength set by MGS Magnetometer measurements. Weak crustal magnetic fields within the Hellas basin suggest that a weak Martian dynamo was still present when that basin cooled. No detectable PEB or magnetic signature is observed over the younger Argyre basin.

P62A-0374 1330h POSTER

Timing the Martian Dynamo II: Impact Basins, Edge Effects and Volcanic Edifices

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The discovery by Mars Global Surveyor of strongly magnetized regions within Mars crust, demonstrated the past existence of an Earth-like dynamo operating in its core and which is now extinct. Because of this

intensity Mars crustal magnetization is attributed to thermoremanence (TRM) as the molten material cooled in the presence of the field. A determination of the epoch when this dynamo ceased to operate provides a strong constraint for models of the interior of Mars and its thermal evolution. The close correlation that exists between the magnetized terrain and its age, derived from the cratering record and accepted Lunar/Martian chronology estimates, strongly suggests that the dynamo had ceased to operate when the northern lowlands and dichotomy boundary were formed. Moreover, the absence of magnetization within the Hellas, Argyre and Isidis impact basins also suggests that the dynamo was extinct when they were formed, very early in the planets history. Did the Mars dynamo die and restart at a later epoch when an inner core solidified as some authors have suggested based on Lunar paleomagnetic data? This paper will review the different arguments and present analyses of Mars Global Surveyor, Lunar Prospector and paleomagnetic data which support (or not) the interpretations.

P62B MCC: 131 Saturday 1330h

Closing the Loop: Remote Analysis of Terrestrial and Planetary Surfaces I (joint with V)

Presiding: J Mustard, Brown University; M Ramsey, University of Pittsburgh

P62B-01 1330h

Testing the Foundation: A Blind Test of the Hapke Model

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In order to maximize the remote sensing return from airborne or space based observations of the Earth and terrestrial planets, the foundations of our conceptions must be ruthlessly tested. The connections between space-based, ground-based, and laboratory studies all rely upon fundamental theories and models of the interaction between light and geologic surfaces. The most ubiquitous models are those developed by Hapke [Theory of Reflectance and Emittance Spectroscopy, 1993; Icarus, 2002]. We conducted a blind test of the model using the Bloomsburg University Goniometer (B.U.G.) Laboratory [Shepard, LPSC abstract, 2001; see associated URL]. The first author selected and measured the spectro-photometric behavior of well characterized powder samples. The results of the measurements were sent in the blind to the second author who fit the data using the Hapke [1993, 2002] model and made quantitative and comparative estimates of the surface roughness, grain size, sample bulk porosity, and albedo. These estimates were compared with the known properties. A similar blind methodology is suggested for testing our abilities to extract meaningful data using terrestrial analog sites.

URL: <http://factstaff.bloomu.edu/mshepard>

P62B-02 1345h INVITED

Measured vs. Modeled: The Importance of Model Evaluation in Closing the Loop Between Laboratory and Remote Sensing Spectral Measurements

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With the vast quantities of spectral data returned from current and future planetary missions in this decade it is tempting to focus chiefly on the analysis of these data, searching out exciting new discoveries. However, the knowledge derived from rigorous laboratory research is critically important to the accurate, quantitative interpretation of remote sensing data and must not be neglected during periods of intense planetary exploration. Some of the laboratory work that provides this knowledge is initiated independently of existing remote sensing data, motivated by obvious gaps in our spectral libraries or our understanding of certain processes or conditions affecting the spectral measurement. Other laboratory studies may arise out

of discoveries made in the course of analyzing new remote sensing data and point us in new directions that were not obvious routes of exploration before the discovery was made. Regardless of the inspiration for the laboratory research, it is important that we undertake these studies with the goal of applying them to the quantitative analysis of remote sensing data. Achieving this goal requires rigorous testing of compositional and mixing models using a wide variety and large number of samples. The most important products of these tests are well-defined model uncertainties, not only under laboratory conditions, but also under conditions that simulate remote sensing conditions, e.g., spectral resolution, signal-to-noise, elimination of regions obscured by atmospheric absorption, complex mixtures, etc. This presentation will describe existing models, current research, and future directions for laboratory spectroscopy studies that support remote sensing observations, focusing on the need for quantitative analyses that will assure the greater planetary science community that the results we publish are quantitative and useful, and fully close the loop between the laboratory and remote sensing data.

P62B-03 1400h

A Complete First Order Model of the Near-Infrared Spectral Reflectance of the Moon

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Introduction: The spectral reflectance properties of the Moon are governed by the minerals and glasses composing the lunar regolith, their physical state, and the optical effects of soil maturity. Work by Hapke and others has provided all the tools necessary to produce a model of near-IR spectra of the Moon within simplifying assumptions. We have produced such a model and are beginning to apply it to lunar science problems. Two classes of problems are amenable to immediate use: determining compositions of lunar surface regions using groundbased and Clementine data, and understanding the detection limits for minerals and rock types using existing and planned data sets. Model: Our model is based on the equations of Hapke [1] who showed how the visible and near-IR spectra of mixtures of minerals could be computed from their optical constants at arbitrary grain sizes and relative abundances, and recently it was shown how the method of Hapke [1] could be modified to include the effects of submicroscopic particles [2].

In the forward implementation of the model, the chemistry of minerals, grain sizes, modal abundances and abundance of submicroscopic iron are defined. From the mineral and glass chemistries optical constants are computed, which are then modified by submicroscopic iron coatings. These modified optical constants are then converted to single scattering albedo and mixed according to their modal abundances. Qualitatively, the model produces spectra which closely mimic the appearance of lunar spectra, sharing albedo, continuum slope, and spectral contrast, as well as the shape of the absorption features. Validation of the forward model is proceeding using the spectra and analyses of [3]. The validation will determine, for example, when the model prescribes a certain grain size, or grain size distribution, how this optical grain size corresponds to that measured via sieving.

A recently introduced application of this model is to determine detection limits for minerals as a function of soil maturity and data quality (signal to noise ratio). In this process we model a particular soil composition, ensuring that the model spectrum lies within the field of measured lunar spectral properties. We then vary modal and chemical properties to determine the magnitude of the differential signal that can be detected by a remote sensor. Our preliminary results suggest that 10% differences in mineralogy can only be detected for the most immature surfaces at the 1% precision of Clementine and groundbased data. Future lunar missions should feature sensors with much higher signal to noise ratios.

References: [1] Hapke, B., Theory of Reflectance and Emittance Spectroscopy, Cambridge Univ. Press, Cambridge, 1993. [2] Hapke, B., J. Geophys. Res., **106**, E5, 10,039-10,074, 2001. [3] Taylor L. A., Pieters C. M., Keller L. P., Morris R.V., McKay D. S. (2001), J. Geophys. Res. **106**, 27,985-27,999.

P62B-04 1415h INVITED

A physical model and inversion approach for remote measurement of snow properties.

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A physical model has been developed for the spectral reflectance of snow based on the complex refractive index of ice. Mie scattering calculations have been