provided a comprehensive view of the south polar-layered deposits, facilitating comparisons in surface variations as a function of season. The MARIE instrument has detected radiation signatures from the high solar activity during the first 18 months of operations, including events with significantly different signatures at Mars and Earth. The orbiter has played a key role as a data relay platform for the Mars Exploration Rovers. In addition, coordinated observations between the rovers and Odyssey allow ground truthing of the orbital data. The nominal Odyssey science mission will cover 917 days, until August 2004. Extended mission operations appear to be feasible, given the current inventory of propellant. Goals for a possible extended mission include inter-annual comparative observations, global high- resolution mapping by the THEMIS visible camera, and synergistic science and operations support for other Mars missions.

U43A-06 1445h INVITED

The Martian Radiation Environment Experiment – Results and Status

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Ionizing radiation in space presents a potentially serious health hazard to astronauts on long-duration missions. Missions that take humans outside the geomagnetosphere (which provides significant shielding for crews in low-Earth orbit) are of particular concern. A mission to Mars would expose a crew to a substantial radiation dose from high-energy heavy ions in the Galactic Cosmic Radiation (GCR). Though not expected to cause acute effects, such exposures might endanger the long-term health of crewmembers, leading to increased risk of late effects such as cancer and cataract. Since the biological effects of these ions are not well understood, NASA cannot yet specify career limits for deep-space missions. While ground-based research in radiobiology continues, it is necessary to characterize the radiation field on the Martian surface. This is determined by the radiation incident on the top of the Martian atmosphere, the transmission properties of the atmosphere, and the production of secondary particles (neutrons in particular) in the upper part of the surface. The Martian Radiation Environment Experiment (MARIE), aboard the 2001 Mars Odyssey spacecraft, has returned the first detailed measurements of the radiation field incident on the atmosphere. MARIE consists of a stack of silicon charged-particle detectors, designed to measure the nearly-constant flux of energetic Galactic Cosmic Rays (GCR) and intermittent Solar Particle Events (SPE). The detector is optimized for the detection of solar protons and helium in the energy range from 30 to 75 MeV/nucleon, though higher energies and heavier ions are also detected. Despite considerable uncertainties in data normalization, the measured dose agrees with model calculations, to an accuracy well within the (conservatively) estimated errors. As of this writing (Feb. 2004), MARIE is off, having sustained damage during the large Solar Particle Event of Oct. 29, 2003. Attempts to recover the instrument will resume in the near future. If MARIE cannot be recovered, other instruments aboard Odyssey are sensitive to energetic charged particles and can be used to continue Odyssey's radiation monitoring program. We will report on the status of these efforts, in addition to giving an overview of the 20 months of MARIE data that were successfully recorded.

U44A CC: 517 A Thursday 1530h

New Views of Mars and Its Environment II

Presiding: **C M Weitz,** Planetary Science Institute**; J F Bell,** Cornell University

U44A-01 1530h

Geology of the Mars Exploration Rover

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The second of NASA's two Mars Exploration Rover spacecraft landed successfully on January 24, 2004 within the classical low albedo region Sinus Meridiani. The landing site has been confirmed by a variety of localization methods including direct orbital imaging to be within a small 22-m diameter crater at 1.95°S, 354.47°E. The crater has a maximum depth of only about 3 m, and is surrounded by a large expanse of flat, low albedo plains materials that have been shown from orbital spectroscopy to contain significant abundances of gray crystalline hematite. Initial Pancam imaging studies of the crater and the surrounding plains (where visible above the crater rim) reveal the average 750 nm albedo of the soils to be 0.15+/-0.02, consistent with the low bolometric albedo of the region derived previously from orbit. This is the darkest site yet visited by a landed Mars spacecraft, and high resolution Pancam and Microscopic Imager (MI) observations of the soils reveal the presence of sand-sized grains that are consistent with orbital near-IR and mid-IR telescopic and orbital predictions for the physical properties of this site. There have been several wonderful geologic surprises, however. First, the rover fortuitously landed only a few meters from an outcrop of brighter, redder deposits that may turn out to be only rarely exposed in this region. The deposits crop out roughly halfway up the inside of the crater wall and extend vertically only a few tens of cm but laterally around roughly half the circumference (about 30 m) of the crater's NW to NE rim sector. The outcrop appears to consist mostly of well-indurated or possibly lithified materials, some of which exhibit fine laminae/layers on the sub-cm scale. Smaller fractions of the exposed outcrop stratigraphy appear to consist of tabular or massive materials. The origin of the laminae is unknown, but aeolian, fluvial, and volcanic processes are being considered and more definitive evidence from observations of potential sedimentary structures is being pursued. At the scale of the MI images the outcrop materials appear to have undergone significant differential erosion, suggesting compositional diversity within the layers that is as yet unconfirmed by direct measurements. The second surprise is the discovery of a population of well sorted spherical grains ("spherules"), typically several mm in diameter, that have been observed to vary in relative abundance from place to place within the crater but generally increase in relative abundance closer to the outcrop. In some places the spherules can be seen to be randomly distributed or even overdispersed within the laminated matrix of the outcrop, and/or eroding directly out of the outcrop itself, suggesting that their origin is intimately tied to the origin of those deposits. Hypotheses for spherule origin include volcanic (e.g., accretionary lapilli), impact (impact spherules, tektites), or chemical precipitation (concretions, pisoliths), all of which are being explored and tested in detail as new imaging and compositional data are obtained. For example, no evidence has yet been found that the spherules are aggregated, in layers or otherwise, or (where broken spherules are seen) that they are themselves composed of concentric or laminated structures. This argues against an impact spherule/lapilli or oolite/pisolite origin, but certainly not conclusively. After exploring the outcrop the rover will most likely leave the crater and explore the surrounding plains. The goal of this next phase of the rover's mission will be to search for and determine the origin of the hematite deposits and other layered/outcropping materials thought to be part of the potentially aqueous sedimentary rocks mapped from orbit in this region of Mars.

U44A-02 1545h

Characteristics of the Soils at Meridiani Planum, Mars

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We have used the Pancam and Microscopic Imager on the Opportunity rover at Meridiani Planum to understand the soil characteristics within the 20 m diameter crater where the rover landed. The majority of the soils consist of a well sorted lag deposit composed of millimeter-size grains of multiple sources superimposed on a finer soil matrix. The millimeter-size grains vary in size and morphology across the crater floor, with the largest (2-10 mm diameter) and most spherical grains adjacent to the layered outcrop, and smaller, more irregular sizes moving away from the outcrop towards the center of the crater. The soil right next to the lander is mostly composed of very fine grains (avg. 150 microns) with larger grains between 1 and 2 mm in diameter. Adjacent to the outcrop, the soils are dominated by spherules that have weathered out intact from the layered outcrop. It's likely that some of the non-spherule millimeter grains represent outcrop material that has been weathered to finer particle sizes and subsequently mixed into the soil. Underlying the spherules is a darker, finer soil that is spectrally similar to the soils near the lander. Undisturbed hematite-poor and hematite-rich soils, as determined by the Mini-TES instrument, show no significant differences in grain shapes or sizes. Rover wheel tracks show that the spherules and millimeter-size grains have been pushed down into the finer soil by the movement of the rover, but they have not been crushed. A similar effect was seen both from the Mossbauer contact plate after it was pushed into the soil, and also in the airbag bounce marks where the larger spherules have disappeared within the bounce marks, most likely due to burial, and there is a corresponding lower hematite signature. A 10 cm deep trench dug by a rover wheel reveals a brighter substrate on the trench floor, and a bumpy texture of soil with embedded shiny spherules in the upper wall. The brighter trench floor may be a photometric effect from the compaction rather than a distinct soil type. Linear ripples spaced 5-8 cm apart are concentrated adjacent to the lander and near the center of the crater. The ripples lack the millimeter-size grains visible throughout the crater floor. Intra-ripple soil within the larger ripples contains patches of brighter material that is spectrally distinct from all other soils and rocks thus far analyzed by Pancam, including the layered outcrop. Based upon orbital images of the landing site, the crater floor has a lower albedo than the terrain outside the crater. Consequently, the soils we have analyzed thus far inside the crater may either contain a higher percentage of darker grains or they may not be representative of the soils covering the plains of Meridiani Planum.

U44A-03 1600h

Mineralogy and Geochemistry at the Meridiani Landing Site, Mars

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The Mars Exploration Rover (MER) Opportunity landed in Meridiani Planum on January 24, 2004 (PST). The scientific rationale for selecting this landing site (1.95 S, 354.47 E) centered on the discovery by the orbiting Thermal Emission Spectrometer of 10-20% grey crystalline hematite in association with basaltic rocks in this region. Formation of hematite requires either precipitation in iron-rich waters or thermal oxidation of iron-bearing volcanic rocks. Each MER rover carries instruments well suited for in situ and remote analyses of iron-rich materials. The mast-mounted visible/near-infrared multispectral Pancam system and thermal infrared Mini-TES spectrometer in combination with the arm-mounted alpha particle x-ray spectrometer (APXS), Moessbauer spectrometer (MB), Microscopic Imager (MI), and Rock Abrasion Tool (RAT) deliver complementary detailed information on the morphology, mineralogy and composition of the materials at this site. The exposure of relatively high albedo bedrock materials on the western crater rim and low albedo soils in the crater have been the main focus during the first 25 sols of rover operations. Results thus far include: (1) Subtle variability in the ferric and ferrous absorption features observed by Pancam in the soil and bedrock, consistent with poorly crystalline iron phases; (2) Confirmation by Mini-TES of gray hematite-rich soils, with hematite-free soils consistent with basalt; (3) Discovery of small (1-5 mm) grayish spherules embedded in and weathering from the bedrock, with as yet undetermined composition; (4) Moessbauer spectra consistent with olivine and a weak magnetic phase in the soils; (5) APXS soil data consistent with a basaltic composition and with S and Cl levels similar to other landing sites. Among current hypotheses for the bedrock formation, some involve fine-grained basaltic sediments as starting materials that underwent either (a) cementation by minerals and growth of spherical concretions; (b) alteration by acidic hydrothermal solutions; or (c) evaporative mineral precipitation followed by subsequent reworking of sediments by aqueous activity. Alternative hypotheses include impact ejecta deposits and/or hydrovolcanic deposition forming lapilli subjected to hydrothermal alteration.

U44A-04 1615h

Following the Sulfur using the Athena Payload on the Mars Exploration Rover Spirit.

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The Mars Exploration Rover (MER) Spirit landed in Gusev crater to begin investigating how water shaped the surface by using the Athena Payload. Two types of aqueous processes are being investigated at Gusev: recent processes involving transient liquid water and ancient processes of intermittent fluvial or lacustrine sedimentation. In addition to looking for direct mineralogical and morphological indicators of aqueous processes we are also looking at the abundance, distribution, mineralogy, and texture of sulfur compounds. An understanding of modern and ancient water at Gusev will help us develop a model for the timing, duration, and abundance of water. Preliminary results with Spirit found sulfur-rich "cemented" soils at Gusev, similar to the materials at the Viking I, II, and Pathfinder sites. The soils at Gusev have a honeycomb texture that in places look like tubes. This points toward a sulfate (perhaps with chloride) cement that formed in place. This is a relatively recent process where cement forms along capillaries. The source of water may either be from thin films associated with either atmospheric sources (top down model) or with subsurface sources (bottom up). Both models are being investigated by looking for trends in the sulfur (and other salt) concentration at a range of locations. Correlation of salt with depth or other soil characteristics such as grain size, texture, mineralogy, spectral properties, and mechanical strength of the apparent cemented material may permit the distinction between these models, estimate the ages of the crusts, and determine the amount of water needed to mobilize these salts. In addition to this relatively modern water-sulfate cycle, we are trying to determine if other older fluvial sedimentation processes have occurred and if they involved sulfates. A wide variety of processes may account for the sulfur-rich soils (e.g. salt rich ground waters, volcanic aerosols, or aeolian deposition of salt-rich fines). By comparing different types of materials at Gusev we may be able to identify any anomalous signature due to ancient fluvial processes. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

U44A-05 1630h

Soil and Rock Physical Properties at the Mars Exploration Rovers Landing Sites

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Soil and rock physical properties are being investigated by the Mars Exploration Rovers (MER) at Gusev crater (Spirit) and Meridiani Planum (Opportunity). These investigations are being conducted by the MER Athena Science Payload and the mobility systems on each rover. Physical properties of soil units are characterized by observations of wheel tracks (sinkage and tread casts). Images of rover wheel tracks in Gusev crater suggested a variety of surface textures. Traverses through depressions resulted in well-defined wheel track casts, suggesting that finer-grained materials accumulate in these depressions. In other areas, wheel tracks were not as defined and instead, some blocky fragments (e.g., 5-10 mm thick) of soil-like materials were displaced by the wheels. There were areas where small rocks (e.g., 1-3 cm) were pressed into weakly indurated or "crust" material. Soil and rock exposures are very different at Opportunity's landing site within a shallow 20 m crater at Meridiani. Outcrops of very fine-grained bedrock are found around the interior walls of the crater. The dominant soil unit within the crater is dark, fine-sand sized materials littered with larger spherules and spherule fragments (e.g., 1-10 mm); some of these spherules appear to be weathering out of the outcrop. A small-scale rippled soil unit seemingly lacking spherules located near the lowest part of the crater is probably a concentration of the fine-sand sized particles transported and partly reworked by wind. Assessment of initial rover tracks combined with observations of wheel slippage on sloping surfaces suggest that soil cohesion in the uppermost near subsurface material is low, and that finer particles (e.g., less than 30 microns) are also present along with the fine sand-sized particles. Additional investigations are underway to characterize rates of atmospheric dust deposition on the rovers, soil physical properties by trenching into targets of opportunity (e.g., soils, bedforms), surface textural and compositional properties by conducting thermal inertia surveys and photometric observations, soil properties related to rover trafficability, terrain properties by sampling telemetry engineering data during rover traverse, and rock physical properties by grinding into rocks with the Rock Abrasion Tool (i.e., measuring joules required to remove a unit volume of rock and then compared to terrestrial samples).

U44A-06 1645h

Martian Weather Analysis and Forecasts from Multiple Spacecraft Observations

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There is now a small fleet of spacecraft orbiting Mars with instruments that make observations relevant to the atmosphere. Chief among these is the Mars Global Surveyor (MGS) Thermal Emission Spectrometer that takes up to 6 nadir infrared spectra every three seconds from a low, circular, polar orbit, with occasional limb scans. The MGS also includes a Horizon Sensor that makes side-looking broadband 15 micrometer measurements, and a Radio Science experiment that determines the atmospheric structure from occasional radio occultations. From a different orbit, at a different time of day, the Mars Odyssey THEMIS instrument makes downward looking broadband 15 micrometer measurements. The Mars Express will add infrared and ultraviolet observations of the atmosphere from a highly elliptical orbit. All of these spacecraft carry cameras that observe ice and dust clouds. While none of the instruments or observing patterns is optimized for atmospheric science, the sum total of the data is more than enough to specify all of the parameters in a low resolution Martian general circulation model. We can therefore make use of data assimilation techniques (like those used in operational weather prediction on Earth) to deduce the full atmospheric state (4-dimensional temperatures, geopotential heights, winds, water vapor, dust, clouds, and surface pressure). The payoff is enormous: retrievals of atmospheric parameters are no longer independent of each other (and underdetermined), but are constrained by physical laws; the data assimilation product is a compact physical state that can reproduce the much more extensive spectral data (to within the observational errors); calibration can be addressed from the internal consistency of the observations of a given instrument; validation (in the absence of ground truth) is performed by detailed comparison of the data from different instruments and different platforms (even when there are no co-incident observations); data quality control emerges naturally from the observation weighting scheme which rejects data that disagrees violently with both other measurements and the forecast model; and real-time weather forecasts can be made available for a host of operational purposes (aerobraking, aerocapture, gliding, ballooning, dust storm warnings). All of these are made practical—given the limited computational resources that can be devoted to Martian weather forecasting—by an observation space sequential assimilation technique, using a transformed extended Kalman filter that weights both model forecasts and observational errors by agreement with the data. Forecast errors are less than 4 K and should improve with more sophisticated predictive models.

U51A CC: 517 A Friday 0830h

Frontiers and Challenges in Deep Earth Dynamics I

Presiding: **A M Forte,** Universit du Qubec Montral**; J Park,** Yale University

U51A-01 0830h INVITED

Thermal entrainment of an eclogitic mantle component in slabs and plumes

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Geochemical studies of basaltic volcanism indicate the presence of recycled oceanic crust in the source of ocean island basalts. In particular the Re-Os and oxygen isotopic systems can be used to identify basaltic components and parts of the mantle that have interacted with seawater in the past. An important set of conceptual models for the chemical evolution of the Earth is is build on the suggestion that oceanic crust forms the main form of introduction of heterogeneity into the mantle system. The subduction of oceanic crust also introduces an important chemical buoyancy force into the mantle, particularly due to the high density contrast between eclogite, the high pressure form of basalt, and the surrounding upper mantle. This strong density contrast allows the oceanic crust to sink to the base of the mantle where it ages before being entrained in rising mantle plumes.
Experimental petrology indicates that the high density contrast between eclogite and mantle is maintained in the upper mantle and transition zone and that eclogite is compositionally less dense than the surrounding perovskite and magnesiowuestite in the uppermost parts of the lower mantle. This raises a number of important dynamical questions regarding the potential of eclogite recycling into the lower mantle and the provenance of the recycled crust component in hot spot island basalts. Previous work has suggested that the strong negative thermal buoyancy of sinking slabs will force the eclogitic crust through the top of the upper mantle, unless a rheological separation between the strong oceanic crust and cold core of the subducting slab can be maintained by the presence of relatively warm and weak peridotite (Van Keken, Karato and Yuen, GRL, 1995). Tomographic images of subducting slabs often reveal complex morphology, such as in the case of the Tonga slab, which is likely caused by the slowing down of the sinking of the slab due to the thermodynamical consequences of the 670 km phase change and the increase of viscosity into the lower mantle. This dynamical behavior will also increase the chance that a proportion of the eclogitic crust remains at the base of the transition zone.
We use high resolution finite element models to study the possibility for survival of eclogitic crust in the upper mantle upon subduction as a function of the slab buoyancy flux, thermodynamical properties of the 670 km phase transition, rheology of the slab and ambient mantle, and changes in tectonic evolution of the slab. Preliminary results suggest a strong diversity of recycling scenarios, which suggests that at least some of the subducted oceanic crust remains in the transition zone. This provides an additional region that can contribute to the observed recycled crust component in oceanic island basalts.

U51A-02 0855h INVITED

Isotopic Heterogeneity in the Mantle: in Search of the Final Explanation

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Since the 1960's, it has been known that the mantle is isotopically heterogeneous. However, mid-ocean ridge basalts (MORBs) that make up the bulk of the oceanic crust (OC) exhibit a relatively uniform isotopic composition. With the use of the Sm-Nd isotopic system, it became clear that their mantle source had been depleted by melt extraction to form the continental crust (CC) over geologic time. This source was therefore named the depleted mantle (DM). Mass balance considerations based on Nd and Sr isotopic data showed that the DM extended through only about 30% of the mantle, and that the lower mantle could in principle mostly be primitive and undifferentiated. These models depended on using the most frequent Nd and Sr isotopic values of MORBs as estimates of average DM source composition. Basalts from ocean islands show a much wider range in isotopic composition than MORBs. By considering Nd, Sr and Pb isotope data for these two groups of basalts, it was shown that the isotopic composition space could be described rather well by four isotopic components: DMM, HIMU, EMI, EMII. Also many of the data arrays pointed toward an isotopic component called FOZO, that was suggested to comprise the lower mantle. Such a composition of the lower mantle would imply that the Earth has a non-chondritic Sm/Nd ratio. We have extended the reservoir models to take into account mantle heterogeneities by keeping track of all subreservoirs in DM. In our model DM, we consider four classes of subreservoirs: residues after CC and OC melt extraction as well as recycled CC and OC. These are real components, but their variability in Sr, Nd and Pb isotope compositions is much larger and different from the observed isotopic variations in young basalts. The results of our current analysis show that apparent isotopic components (DMM, HIMU, EMI, EMII) are non-existent or fictitious components/reservoirs, while the most frequent MORB isotopic compositions faithfully record the average composition of the depleted mantle (DM). We show that the isotopic composition of FOZO corresponds closely to