

between 25° and 25°S, planetocentric. The equatorial region (15°N to 15°S) is much cooler than the rest of the planet in both the troposphere and the stratosphere, with a slightly warmer band detectable in the upper stratosphere within 1–2° latitude of the equator. Besides the prominent zonal wave structure in Saturn's troposphere, the most prominent zonal features are those which are observable at 5.2 μm, showing the optical thickness of clouds at the NH₃ condensation level. Distinct brightening of the ring system is apparent as a function of placement in orbit, with the coolest portion of the rings being those in shadow behind the planet. Ring brightness as a function of distance from the planet generally follows the same qualitative trend of optical thickness as in the visible.

P31A CC: 519 B Wednesday 0830h

Magnetic Field of Planetary Lithosphere I (joint with GP)

Presiding: M Purucker, NASA
Goddard Space Flight Center; J
Arkani-Hamed, McGill University

P31A-01 0830h INVITED

Mars' Magnetic Lithosphere: Candidate Minerals

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Mars' southern-hemisphere magnetic anomalies require a large Martian magnetic field at the time the lithosphere acquired thermoremanent magnetization (TRM), large magnetic mineral concentrations compared to Earth's lithosphere, a mineral or minerals whose grain size and resulting domain structure generate intense TRM, and/or a high Curie temperature and deep Curie-point isotherm. Based on Martian meteorites and spectroscopy of the Martian surface, the magnetic minerals likely to be important in Mars' lithosphere are magnetite, hematite and pyrrhotite. Martian anomalies are likely an integrated effect over a depth interval of 20-30 km. Pyrrhotite has a low Curie point (320°C) and is found only in specialized settings on Earth, although demagnetization around Hellas and Argyre craters may favor pressure-induced cycling of near-surface pyrrhotite through its 2.8 GPa phase transition. More promising as deeper sources are magnetite and hematite, which are ubiquitous on Earth and have high Curie points (580 and 675°C). TRM of magnetite decreases inversely with increasing grain size, while the opposite is true for hematite. The two minerals have the same TRM intensity around 10-20 micrometers, close to both the upper limit for pseudo-single-domain (PSD) behavior in magnetite and the critical single-domain size of hematite. The lack of any substantial self-demagnetizing field permits a TRM in multidomain hematite orders of magnitude larger than the TRM of multidomain magnetite for field strengths like the Earth's. Either single-domain/PSD magnetite or multidomain hematite could explain strong anomalies. Single-domain magnetite requires less concentration but has restrictively small (submicron) grain sizes. Recently single-domain hematite has been found to have more intense TRM than previously measured, and it too could be viable. Depending on magmatic conditions, fine-grained magnetite and hematite can occur as segregated phases within titanomagnetite and titanohematite. Ultrafine subdivision might give rise to lamellar magnetism, as reported for terrestrial titanohematites. Thermoviscous magnetization is probably negligible for Mars because of the small present field and the minor enhancement of TRM that likely occurred in ancient fields.

P31A-02 0900h INVITED

A review of our knowledge of the crustal magnetic field of Mars

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The data collected by the magnetometer experiment aboard the Mars Global Surveyor since 14 September 1997 have been used by numerous investigators to define the structure of that field, which has turned out to

be only of crustal origin to the accuracy of the observations. The various techniques used include representations by spherical harmonics of the global potential function, averages of field at altitude, or by magnetized elements at the surface. Data were collected from the highly elliptical braking orbits down to an altitude of 102 km from the planet's surface during mainly daytime conditions. Such data were found to contain contributions from the interactions of the planetary atmosphere with the solar wind, including ionospheric currents so generated. After being placed into a "mapping" orbit in March 1999 it was then possible to utilize data from the dark side, presumably nearly free of such external influences, but the lowest altitudes were no less than about 365 km and ranged up to about 435 km. The local times since then have been kept to nearly 2 pm and 2 am for non-polar latitudes. This review evaluates the accuracy of the models and maps of field, and estimated magnetization parameter derived from the data and models.

URL: <http://geomag.gfdi.fsu.edu/mars/index.html>

P31A-03 0930h

A Coherent Magnetic Field Model of the Martian Crust

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The tangential components of the magnetic field of Mars measured by Mars Global Surveyor (MGS) have appreciable contributions from the external magnetic field than the radial component. The immense amount of data acquired during the mapping phase of MGS provides good opportunity to derive a more accurate model of the magnetic potential field of the Martian crust using only the least contaminated radial component data. For this purpose the radial component data measured since the satellite resumed its mapping phase are divided into 2 sets of data, acquired from March 1999 to February 2001, and from February 2001 to April 2003. Each set is expanded in spherical harmonics using harmonics of degree up to 65, and their most repeatable signatures are selected through covariance analysis. The model tangential components derived from the model potential field are significantly different from those of the observed ones. Not only their small-scale features are different, but also their global scale features specified by spherical harmonics of degree 1-3 show appreciable differences, indicating the global scale external magnetic field contribution. Although the external field has negligible contribution to the strong anomalies of the south hemisphere, it may have appreciable contribution to the weak magnetic anomalies. The more reliable magnetic field model allows us to downward continue the anomalies to the surface of the planet and better delineate the relationship between the tectonic processes and the magnetic anomalies of Mars. The downward continued maps show numerous small scale magnetic anomalies over the northern lowlands, but no significant anomalies inside the giant impact basins.

P31A-04 0945h

Correlated Magnetic and Gravity Anomalies West of the Isidis Basin, Mars and Implications for Plains Magnetism

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The magnetic field of Mars reflects strong crustal magnetism resulting from an ancient internal field. The crustal anomaly pattern parallels the geologic dichotomy in that most of the anomalies detected by the Mars Global Surveyor are located within the presumably older southern highlands while the northern lowlands has weak or no magnetic signature at satellite altitudes. We have analyzed a section of the dichotomy boundary whose geology has been studied extensively in order to examine the implications of correlations between gravity and magnetic anomalies for the regional distribution of magnetic sources. The study area contains some of the strongest magnetic anomalies observed outside the area of high-amplitude anomalies

found within the Terrae Cimmeria and Sirenum sector of the southern highlands. Several strong magnetic and gravity anomalies in the area of the Ismenius quadrangle are associated with a mapped normal fault, but the magnetic and gravity peaks and troughs are out of phase. The isostatic gravity anomalies indicate high density bodies flanking the mapped normal fault. If we assume common sources of both the gravity and magnetic anomalies, and a coherent direction of magnetization within a spatially variable source layer, we achieve the best fit to both the gravity and magnetic fields using a low inclination for the magnetization direction (30 degrees), in general agreement with published paleoleopole estimates for Mars. This solution requires a continuous magnetic source layer extending north beneath the plains to avoid a large edge effect anomaly; this layer produces near-zero field away from the fault. An alternate model assumes that the gravity anomalies correspond to areas of demagnetization of a preexisting continuous magnetic source layer. This model fits best for an inclination near -45 degrees and does not require a source layer in the northern plains. Candidate geologic processes that could have produced such source distributions in the study area include extension and volcanic intrusion focused near the dichotomy boundary, and hydrothermal alteration which created, destroyed, or reduced the magnetism. The product of layer thickness and magnetic intensity implied by these models is roughly 5-10 times less than inferred in the highly magnetized region of the southern highlands, indicating significantly different genesis or evolution of the crust occurred in that region as compared to the rest of Mars.

P32A CC: 519 B Wednesday 1030h

Emerging Views of Mars: Formation, Evolution, and Current State I (joint with GP, T, V, C, NG)

Presiding: D Stegman, Monash University; M Jellinek, University of Toronto

P32A-01 1030h INVITED

Mars Magnetic Field: Implications for Crustal Formation and Evolution

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One of the most dramatic discoveries of the Mars Global Surveyor (MGS) mission is that of crustal magnetic field sources of multiple scales, strength and geometry. Current global field models exhibit similar large-scale features: intense magnetic fields (requiring crustal magnetizations approximately an order of magnitude greater than on Earth) over the Noachian-age Terra Cimmeria southern hemisphere region, weaker isolated anomalies over the northern hemisphere and over other southern hemisphere areas, and a general paucity of strong magnetic fields over the major impact basins. Challenges in constructing such models include the variable maximum spatial resolution in the magnetic field data, and the removal of magnetic fields of non-crustal origin. Three hypotheses for the timing of a dynamo have been proposed. In the first hypothesis, dynamo onset post-dates the youngest observed impact basins on Mars. In the second hypothesis, the dynamo is short-lived, with onset in the early Noachian and cessation prior to the formation of Argyre and Hellas. In the third hypothesis, early Noachian dynamo onset is invoked, but duration into the late Noachian or early Hesperian is permitted. Fundamental to distinguishing among these various hypotheses and to explaining the observed global distribution of magnetic anomaly amplitudes is establishing the relative timing of crustal formation, the duration of any dynamo regime (and indeed the driving mechanism for such a dynamo), and the effect of post-emplacement crustal modification on any acquired magnetic remanence. Accordingly, in this talk we review progress in addressing the following issues essential to understanding the history of Mars' magnetic field: (1) The timing of crustal formation in northern and southern hemispheres. (2) A quantitative assessment of magnetic anomalies in the major impact basins (specifically Hellas and Argyre). (3) Potential candidates for the magnetic carrier, along with rock magnetic properties that are important to remanent acquisition and any subsequent demagnetization. (4) An assessment of the effectiveness of thermal, hydrothermal, and shock demagnetization mechanisms, and geographically where these may have been active. (5) Energetics available to drive a martian dynamo. Based on

current understanding, our preferred hypothesis is an early short-lived global magnetic field. Open questions critical to further progress include the relative timing of dynamo cessation and the onset of Tharsis magmatism, and the process(es) responsible for formation of the dichotomy.

P32A-02 1045h INVITED

Martian Igneous Compositions Revealed by MGS-TES and Mars Odyssey THEMIS

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Most rock-forming minerals have distinctive absorptions in the thermal infrared portion of the spectrum (roughly 5-50 microns). This useful property is the primary motivation for sending a series of thermal infrared instruments to Mars: The Thermal Emission Spectrometer (TES) on the Mars Global Surveyor, the Thermal Emission Imaging System (THEMIS) on the Mars Odyssey, and the Miniature Thermal Emission Spectrometers on the two Mars Exploration Rover spacecraft. The massive volume of data returned from these instruments has provided the means to determine the global and local scale mineralogical compositions of the Martian surface. A broad question that the Martian surface mineralogy addresses is: What is the timing and extent of igneous processes on a planet that does not have plate tectonics? TES data has revealed that the Martian surface displays a striking hemispheric dichotomy in surface composition. Basalts or basaltic andesites similar in bulk composition to those commonly found on Earth dominate the southern highlands. A more silica rich surface that closely matches typical terrestrial basaltic andesites or andesites is present everywhere on the planet, though the highest concentrations are found within the younger northern lowlands. Though this dichotomy may be explained by two different igneous compositions, the high-silica glass in the more silicic composition could instead be a secondary mineral related to an alteration process rather than volcanism. Regardless of the source of the glass, Martian meteorite compositions are not typical of much of Martian igneous compositions. Mars Odyssey THEMIS data has exposed local scale compositional variability and provided an enhanced spatial context for the TES results. Layered olivine rich units appear in Valles Marineris, Ares Valles, and Nili Fossae. A quartz and feldspar lithology appears near the central peaks of two craters in Syrtis Major. In addition, a spectrally distinct unit is associated with surface units near Apollinaris Patera. The combined mineralogical information provided by TES with the geologic context provided by THEMIS have provided a picture that is emerging that Mars is perhaps more interesting than expected from an igneous perspective. A variety of processes and mechanisms must be present to produce the range of compositions seen from orbit.

P32A-03 1100h

Tharsis Bulge: Melt Migration in a Giant Mantle Plume

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Tharsis bulge formed through major volcanic activities in Noachian and early Hesperian, although minor volcanism likely continued to the recent past. There is a general consensus that major part of the Tharsis rise has been produced by basaltic flows. Syria planum has been identified as a long-lived (Noachian to early Amazonian) region of volcanism and tectonic activity on Tharsis, which emplaced voluminous sheet lavas on Mars in late Hesperian. Two sets of complex radial tectonic structures have originated from the planum. One set has resulted in the well-developed Valles Marineris, occurred in the Noachian and the tectonics continued at least to Hesperian. The other has produced the Claritas Fossae and Thaumasia normal faults and complex grabens, formed in Noachian to Amazonian. Both tectonic sets cut through the original volcanic structure of Tharsis bulge, they occurred later than the prominent volcanism that created the major part of the bulge. We studied the dynamics of a giant mantle plume in a compressible Martian mantle model, using a temperature and pressure dependent mantle viscosity, a temperature dependent thermal conductivity, and a pressure dependent thermal expansion coefficient in an axis-symmetric cylindrical coordinate system. We investigated the criteria required to produce a giant plume at the base of the mantle that could ascend fast and produce a large amount of basaltic melt within 500 Myr of the

planet's history. The plume partially melts as it ascends through the mantle. Because of its very high buoyancy, the melt moves upward through the partially molten porous plume much faster than the bulk solid residue of the plume. This causes a vast amount of volcanism well before the bulk part of the plume impinges the overlying lithosphere. The volcanism continues at relatively lower rate as the plume further ascends. The bulk solid residue of the plume finally impinges the lithosphere and exerts strong tension, creating tectonic features.

P32A-04 1115h INVITED

Buried and Visible Impact Basins on Mars: Constraints on the Timing of Major Events in Early Martian History

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The large population of buried impact basins found in MOLA elevation data on Mars provides compelling evidence for a "pre-Noachian" crust below the oldest visible Early Noachian surface units, and lowland crust below the younger plains that is Early Noachian in age, older than much of the visible highlands, but not as old as the buried "pre-Noachian" highlands. The large (D greater than 200 km) buried basins are suggested by "Quasi-Circular Depressions" (QCDs) that are not apparent in image data, and include features up to 3000 km diameter in both the lowlands (Utopia) and highlands (a newly found "Ares Basin"). There are about a dozen QCDs larger than 1000 km diameter which we can place in a relative age sequence based on superimposed smaller QCD. This and the N(200) crater retention age for the highlands and lowlands provide a chronology for early Mars, including when the global magnetic field may have died. The youngest and most obvious large basins (Hellas, Argyre, Isidis) lack magnetic anomalies within their main rings and may have formed after the magnetic field died. These all have an N(200) less than 2.5. The oldest, most subdued basins (including Ares) with N(200) greater than about 4.0 have many strong magnetic anomalies within their main ring and likely formed before the main magnetic field died. Intermediate age, "lowland-making" basins (Utopia, Chryse, Acidalia) have only a few weak anomalies. These, and the lowlands they created, occurred at about N(200) about 3.0-3.2.

P32A-05 1130h

Growth of the hemispheric dichotomy and the cessation of plate tectonics on Mars

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Although Mars is currently not tectonically active, it may have experienced plate tectonics early in its history. The southern hemisphere of Mars possesses a thick crust which probably renders the lithosphere positively buoyant. We present numerical and scaling arguments which show that if the area of positively buoyant lithosphere grows beyond a critical fraction, plate tectonics will stop. Heat transfer through the buoyant lithosphere is inefficient which causes mean mantle temperatures to increase as the surface area of buoyant lithosphere increases. The resulting reduction in mantle viscosity reduces shear stresses; if these shear stresses drop below the yield strength of the lithosphere, plate motions will cease and the planet will behave as a one-plate system. Thus, the end of plate tectonics on Mars may be a natural consequence of the growth of the southern highlands. The implications of this model for volcanism will also be explored.

P32A-06 1145h INVITED

Evidence for Pervasive Cold Climates Throughout Most of Mars History

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Evidence from a variety of sources suggests that Mars has a significant water inventory. However, it appears that this inventory has been frozen throughout much of Mars history. Infrared spectral mapping by the TES and THEMIS orbital instruments has shown that the martian surface is dominated by unweathered volcanic rocks, including olivine-rich basalts in numerous areas. THEMIS 100-m scale multispectral imaging reveals compositional variations at these scales. However these compositional differences are due to differences in the composition of igneous materials. Regions of high (20 percent) olivine abundance basalts have been mapped at the scales of individual flows and rock layers, including exposures at multiple layers with the Valles Marineris system, demonstrating that large regions of Mars have not experienced significant surface or sub-surface water at any time in their history. THEMIS has not detected mineralogical evidence for carbonate rock layers at 100-m scales, despite the discovery by the MGS TES of minor carbonate in the martian dust. The existing carbonates can be produced by surface-atmosphere interactions, without requiring the presence and erosion of a carbonate rock source. THEMIS imaging has, however, shown evidence for extensive ice deposits in the mid- to high-latitude regions, some of which show evidence for recent downslope flow. These mantles preferentially occur on pole-facing slopes in mid-latitudes and are interpreted to be remnants of once-extensive snows deposited during recent periods of high obliquity. Melting of these deposits during intervening warmer periods may form the young gullies that are also observed at these latitudes. A pervasive surface mantle found from 30 to 50° in both hemispheres has been interpreted by Mustard et al. (2001) to result from ice-cemented soils that have formed recently and are currently being devolatilized. The poleward transition from a dissected to continuous surface on this mantle corresponds to a sharp increase in near-surface ice abundance seen by the GRS, suggesting that the mid-latitude portion of these mid-latitude mantles may be the same ice-rich material detected by the GRS at high latitudes, but whose upper few meters have been thoroughly desiccated. Together these observations suggest extensive mid-latitude surface ice deposits that come and go on time scales of 50,000 to several million years. Limited melting may occur in these deposits, but the low temperatures and short durations of liquid water appear to have severely limited the degree of global chemical weathering.

P33A CC: 220 C-E Wednesday 1330h

Magnetic Field of Planetary Lithosphere II Posters (joint with GP)

Presiding: M Purucker, NASA

Goddard Space Flight Center; J Arkani-Hamed, McGill University

P33A-01 1330h POSTER

Annihilators at Mars: Are there Alternative but Reasonable Magnetization Distributions in the Martian crust that Explain the MGS Magnetic Field Observations

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There are an infinity of magnetization distributions that produce no external magnetic field, a result demonstrated by Runcorn to bring attention to the non-uniqueness inherent in the interpretation of lunar magnetic field observations. These distributions have been given the name annihilators. Runcorn's example, that of a uniformly magnetized spherical shell, is not a reasonable explanation for the Mars that we think we know. But other, more reasonable, annihilators have been proposed for the Earth. But those are not appropriate for the Martian case because of the absence of a dominant present day core field. We concentrate in this talk on two questions: 1) How do we ensure uniqueness in our inversions?, and 2) what alternative, but still reasonable, magnetization distributions might explain the Martian magnetic field observations?