A global map of the Martian magnetic field is computed using MGS magnetic measurements and an equivalent source approach. Sources are located arbitrarily (i.e. with a constant spacing) near the surface of Mars. The magnetic field and the magnetization (from the equivalent source solution) present similar features: magnetic anomalies are mostly located South of the crustal dichotomy, the largest craters as well as the largest volcanoes of the North hemisphere do not seem to present any significant magnetic anomaly. In one case at least, a volcanic edifice, Apollinaris Patera, seems to be associated with a magnetic anomaly. This volcano is located at (9.3°S, 174.4°E), North of Terra Cimmeria and Terra Sirenum, where the largest magnetic anomalies were detected. It rises about 5 km above the surrounding terranes. Its shape is a 200-km wide dome, with a 75-km wide caldera on its summit. This is one of the largest volcanoes in the Southern Hemisphere. It is associated with a relatively high gravity anomaly. Crater counts and stratigraphic relations suggest a middle Hesperian age for its younger flow, but it presumably had a long history. We present the modeling of the magnetic anomaly located above this volcano. We use a single equivalent source, located below the volcano. The direction of the magnetization of the source leads to a polar position (70° latitude) for the paleopole. Assuming that the last eruptive stages occurred while the Martian dipolar dynamo was still active, then this paleopole position would indicate that the Martian magnetic field was almost aligned on the present day rotation axis of the planet.

GP22A MCC: 2000 Tuesday 1340h

Extraterrestrial Paleomagnetism: Role of Impact Related Shock II *(joint with P)*

Presiding: **B Lin,** University of California, Berkeley**; D Mitchell,** University of California, Berkeley**; M Fuller,** HIGP-SOEST, University of Hawaii

GP22A-01 1340h

Paleomagnetic Records of the Moon and Mars

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The Moon and Mars afford two examples of major evolved solar system bodies for which we have paleomagnetic records, but no evidence for a presently active dynamo. The records from the Moon and Mars include satellite, or sub-satellite magnetic survey data and the paleomagnetism of samples brought to earth as meteorites. In addition, for the moon we have the record of the Apollo samples. We interpret the lunar paleomagnetic record in terms of a strong magnetic field era from approximately 3.85 - 3.65 Ga, when the surface field was comparable with earth's field and that outside of this period the field cannot be convincingly distinguished from background noise. Mars may also have had a relatively short period of a strong dynamo field, if the interpretation of the demagnetization effects of Hellas and Argyre and the estimates of their age are correct. Evidence from ALH 84001, is consistent with a surface field about an order of magnitude smaller than the earth's field. In comparing these surface fields it is perhaps worth noting that if the efficiency of the various dynamos are similar, being for example dependent upon the linear dimension of the source region, the surface fields will necessarily be larger on smaller bodies.

GP22A-02 1355h INVITED

Magnetic Tests For Magnetosome Chains In Martian Meteorite ALH84001

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Transmission electron microscopy studies have been used to argue that magnetites in carbonates from Martian meteorite ALH84001 have a composition and morphology indistinguishable from that of magnetotactic bacteria and their magnetofossils (1). It has even been claimed from scanning electron microscopy imaging that some ALH84001 magnetites are aligned in chains (2). If true, this would provide dramatic support for the magnetofossil hypothesis because alignment in chains is perhaps the most distinctive of the six crystallographic properties thought to be collectively unique to magnetosomes. The leading alternative hypothesis is that the ALH84001 magnetites are the inorganic products of shock-heating of the carbonates (3, 4). Here we use three rock magnetic techniqueslow-temperature cycling, the Moskowitz test (5), and ferromagnetic resonance (FMR)to demonstrate that most or all of the magnetites in ALH84001 are unusually pure and fine-grained but are not arranged in magnetosome chains. 1. K. L. Thomas-Keprta et al., Geochim. Cosmochim. Acta 64, 4049-4081 (2000). 2. I. E. Friedmann, J. Wierzchos, C. Ascaso, M. Winklhofer, Proc. Natl. Acad. Sci. USA 98, 2176-2181 (2001). 3. D. C. Golden et al., Am. Mineral. 83, 370-375 (2001). 4. D. J. Barber, E. R. D. Scott, Proc. Natl. Acad. Sci. USA 99, 6556-6561 (2002). 5. B. M. Moskowitz, R. B. Frankel, D. A. Bazylinski, Earth Planet. Sci. Lett. 120, 283-300 (1993).

GP22A-03 1410h

Magnetite Under Pressure: Direct Magnetic Measurements and Consequences for Meteorite Impacts

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New diamond anvil cell technology now makes it possible to directly measure magnetic properties of extremely small sample volumes under high pressures. Specifically, we have developed a "non-magnetic" beryllium-copper, membrane-type diamond cell that houses a system designed to measure the reversible magnetic susceptibility of micron-sized samples under pressures in excess of 30 GPa. By placing the cell in the confines of an electromagnet, we can measure reversible susceptibility as a function of applied field, with H varying from -1.2 T to +1.2 T. Because the integral of Xrev(H)dH is proportional to the magnetic moment (of the reversible part of the remanence, or Mrev), we can measure the reversible hysteresis parameters of ferromagnetic materials as a function of pressure. We find that magnetite reversible hysteresis parameters vary little below 1.0 GPa, while at higher pressures significant increases occur in bulk coercivity (Hc) and the ratio of saturation remanent magnetization (Mrs) to saturation magnetization (Ms). The magnetic properties of magnetite are not reversible upon pressure release. Moreover, the magnetic properties of magnetite under pressure and after pressure release are highly dependent on both domain state and the presence or absence of an external magnetic field. These factors should be taken into account when studying the magnetic signatures of meteorite impacts.

GP22A-04 1425h

Magnetic Effects of Impacts on the Moon

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Lunar Prospector (LP) electron reflectometer data indicate a variety of magnetic signatures associated with lunar impact sites, ranging from nearly complete demagnetization signatures to central magnetic anomalies. Smaller impact craters (D <∼150 km) of all ages show evidence of demagnetization, with a higher percentage of younger craters displaying clear symmetric demagnetization signatures. Among larger impact structures, those of Imbrian and younger age still tend to show demagnetization, while older impact sites of Nectarian and Pre-Nectarian age often have central magnetic anomalies (sometimes superimposed upon a larger demagnetized region) with peak fields ranging from a few nanotesla to ∼100 nT. Most demagnetization signatures extend beyond the main rim of the visible impact structure, sometimes to a distance of several main rim radii. Consideration of the peak shock pressures produced by impacts indicates that most of the demagnetized region should not be heated above the Curie point, therefore indicating the importance of shock demagnetization in producing the observed demagnetization signatures. Central magnetic anomalies, on the other hand, tend to lie inside the transient cavity region of larger impact structures, suggesting that these features could be produced by thermal remanence in impact melt rocks, shock remanence in the highly shocked central uplift regions, or a combination thereof. Careful analyses of magnetic features associated with lunar impact sites, and comparison with terrestrial data from both laboratory experiments and field work, can be used to constrain the age history and physical characteristics of lunar remanent magnetism.

GP22A-05 1440h INVITED

Origin of Lunar Crustal Magnetic Anomalies: Role of Impact Processes

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A combination of orbital, surface, and returned sample measurements shows that impact processes have exerted an important influence on the production and distribution of crustal magnetic field sources on the Moon. Unlike the Earth and Mars, where oxidizing conditions have predominated, the main ferromagnetic carriers in lunar materials are reduced metallic iron particles. These ferromagnetic carriers are sparse in igneous materials such as mare basalt but are concentrated in impact-generated breccias and fines through reduction of pre-existing iron silicates by shock and/or heat. Consistent with these laboratory results, surface magnetometer measurements at the Apollo landing sites yielded the largest surface fields (exceeding 300 nT) in a region dominated by the Cayley Formation and the Descartes highlands, both considered by planetary geologists to represent impact basin ejecta materials. Orbital studies such as those conducted by Lunar Prospector have provided additional evidence that impact basin ejecta (as opposed to smaller crater ejecta) are the main sources of the orbital anomalies. On the geologically less complex near side, correlations of orbital anomalies have been found with visible exposures of the Cayley, Descartes highlands, and Fra Mauro Formations, all interpreted as primary and/or secondary basin ejecta materials. On a larger scale, a general inverse relationship between large impact basin locations and crustal magnetic field strength is obtained such that fields are weak over the basins but are strong near their antipodes. A model for explaining the stronger fields near basin antipodes has been partially developed theoretically and involves the interaction of impact-produced plasmas with an ambient large-scale magnetic field. Since the basins in question are all older than 3.8 Gyr, the data can be interpreted as indicating an early lunar core dynamo. More definitive tests of this hypothesis are possible using existing data and will be described.

GP22A-06 1455h INVITED

A Mantle Dynamics Perspective on Generating an Early Lunar Dynamo

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We consider the early thermochemical history of the Moon and specifically address the question of how the Moon could have had an internally generated magnetic field suddenly 'switch-on' somewhat late in its evolution and then just as quickly 'switch-off'. It is commonly assumed the Moon never underwent mantle convection, given the majority of the surface geology is likely the original crust formed nearly simultaneous with the Moon. This can partially be explained by the fact that thermal evolution may well occur under the regime of stagnant-lid convection. Furthermore, there are a few clues that perhaps the Moon possessed a brief, internally generated magnetic field (Cisowski et al., 1983) and by implication, that the interior of the Moon was once convecting. Lunar samples returned from the Apollo missions provide a few which may contain a remnant thermal magnetism, possibly acquired during the Moon's 'magnetic era' (Cisowski et al., 1983). These samples also reveal the near side of the Moon contains large areas flooded with volcanic material, the lunar mare. These mare erupted during a pulse of magmatism beginning 0.5 billion years after the Moon had formed and mostly ended after 1 billion years of activity. We have recently shown (Stegman et al., 2003) that chemical overturn models suggested to explain the eruption of the Maria basalts may also account for the hitherto unexplained existence of a lunar magnetic field (core dynamo) at about the same time (3-4 billion years ago). In this presentation, we will specifically discuss the plausibility of such a model within the context of current uncertainties of Lunar properties (e.g. core size, core composition, initial conditions, etc.).

GP22A-07 1510h

Shock effects on Martian crustal magnetization near large impact basins

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The Martian crust has been subject to several very large meteoroid impacts. Shock pressures associated with these impacts may have demagnetized parts of the Martian crust to an extent determined by the shock resistance of the magnetic materials responsible for crustal sources. Impacts that form large basins generate pressures in excess of 1 GPa that extend several crater radii from the point of impact, beneath the surface. Near the surface, however, wave interference significantly reduces the pressure (1 GPa) experienced by crustal materials. Impact demagnetization experiments indicate that pressures of 1 GPa magnitude are sufficient to demagnetize most of the common magnetic minerals (magnetite, pyrrhotite). Titanohematite with ferrian ilmenite exsolution lamellae is the exception. According to our data, this mineral has the highest coercivity (>300 mT) and largest NRM intensity (1500 A/m). As such it is a leading candidate for Mars crustal magnetism, particularly in proximity to the large impact basins where pressures > 1 GPa may have been experienced. The presence of this mineral suggests that much of the deep Martian crust was oxidized at the time of acquisition of magnetic remanence. This would be an important constraint for Martian chemical evolution at the time of crustal formation.

GP22A-08 1525h

Evidence for Demagnetization of the Utopia Impact Basin on Mars

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One of the great surprises of the Mars Global Surveyor mission was the discovery of intensely magnetized crust [Acuña et al., Science 284, 790, 1999; Acuña et al., JGR 106, 23403, 2001]. The crustal fields are predominantly associated with the southern highlands, and impact demagnetization of the Hellas, Argyre, and Isidis basins indicates that Mars' crustal magnetic fields are among the oldest preserved geologic features on the planet. Much of the northern lowlands appears to be non-magnetic, except for relatively weak north polar anomalies and a few magnetic sources adjacent to the dichotomy boundary. The MGS Magnetometer measured crustal magnetic fields at altitudes from 100 to over 1000 km. Because of the long duration in the mapping orbit, the crustal field map at 400 km altitude is fully sampled on both the day and night hemispheres; however, the sampling is sparse at lower altitudes, and nearly all of those data were obtained on the sunlit hemisphere, where the solar wind distorts crustal fields and obscures those weaker than 30 nT. Thus, it is possible that weak crustal fields exist in the northern lowlands that have so far escaped detection. We have systematically searched for crustal magnetic fields in the northern lowlands using electron reflection magnetometry, which has a sensitivity similar to that of a magnetometer orbiting at 200 km altitude. We have detected several new magnetic features in the northern lowlands. Some of these appear to be northward extensions of previously identified magnetic sources along the dichotomy boundary. A group of magnetic sources form a partial ring around the Utopia basin perimeter, but no sources were detected within the basin itself. These observations suggest that the Utopia impact resulted in crustal demagnetization, and that the relatively weak magnetic sources in the northern lowlands are as old as those in the southern highlands.

GP22B MCC: 2000 Tuesday 1600h

High-Resolution Description of the Earth's Magnetic Field Time Variations Using Paleomagnetism and Archeomagnetism II

Presiding: **Y Gallet,** Institut de Physique du Globe de Paris**; M Korte,** GeoForschungsZentrum Potsdam

GP22B-01 1600h INVITED

Recent advances in the high-resolution description of time variations of the geomagnetic field in France and comparison with data of Western Europe.

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Archaeomagnetism can provide a high-resolution full-vector description of the geomagnetic field, but the uncertainties associated to the reference data pose some specific problems. Archaeomagnetic data from archaeological structures (sites) such as hearths, kilns or sets of potteries, bricks or tiles, generally exhibit large experimental errors and are associated with more or less well constrained dates given by stratigraphic sequences (relative chronology), archaeological evidences, historical records or chronometric methods (radiocarbon, thermoluminescence...). The aim is to combine these different sources of information in order to get the best estimate of the past geomagnetic field. Research in archaeomagnetism in France has been particularly productive during the last two decades and addressed different methodological aspects: data acquisition, magnetic corrections (in particular, correction of the TRM anisotropy and cooling rate effects), allowance for the dating uncertainties, curve estimation, application to dating and to geomagnetism. An efficient sampling policy in close co-operation with archaeologists (in the framework of rescue archaeology) associated with the development of new statistical tools (statistical modelling of the sampling strategies, new moving average techniques, Bayesian statistics applied to curve building), and with the study of the magnetic properties of baked clays, permits to significantly constrain the secular variation at century and millennium scales. Precise reference curves of the directional variations of the geomagnetic field over the last three thousand years can be defined. At the same time, studies of the intensity have been relaunched on sites in France and Middle East, with some particular attention on to cooling rate dependence of the thermoremanent magnetization. Comparisons with other recent results from Western Europe will be presented and applications to geomagnetic modelling and to dating will be discussed.

GP22B-02 1615h

On the possible occurrence of "archaeomagnetic jerks" in the geomagnetic field over the last three millennia

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Archeomagnetism can provide a high-resolution full-vector description of the Earth's magnetic field in the last several thousand years. We analyse the bulk of archeomagnetic data (both direction and intensity) obtained recently in Western Europe and the Eastern Mediterranean covering the last three millennia. We demonstrate a remarkable coincidence between sharp cusps in geomagnetic field direction and intensity maxima (2 clear ones at AD 200 and 1400; 2 less well constrained at about 800 BC and AD 800). These sharp changes may constitute a new feature of geomagnetic secular variation ("archeomagnetic jerks") with time characteristics intermediate between "geomagnetic jerks" and "magnetic excursions".

GP22B-03 1630h

Microwave archaeointensity results from Egyptian ceramics

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Using microwave power in place of temperature in a Thellier palaeointensity experiment we can avoid laboratory induced thermal alteration and improve the quality of palaeointensity determinations (Hill, Gratton and Shaw, 2002). In the present study we apply the microwave palaeointensity technique to a collection of Egyptian ceramics covering the time interval 3100 BC to 900 AD. We aligned the TRM field to be in the same direction as the NRM direction to avoid the effects of magnetic anisotropy. The new microwave results will be presented and compared to previous results obtained using conventional heating (Odah et al. 1995).

URL: http://www.liv.ac.uk/geomagnetism

GP22B-04 1645h INVITED

Holocene Paleomagnetic Secular Variation From Iceland (MD99-2269) : New Observations on Millennial to Centennial Scale Field Dynamics From North America to Europe

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Recent studies of lacustrine and estuarine sediments have demonstrated coherence millennial-scale paleomagnetic secular variations (PSV) patterns across

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