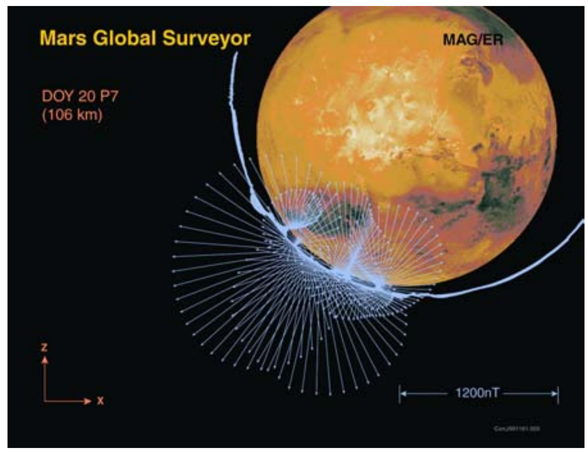
MARTIAN CRUSTAL MAGNETISM: WHAT HAVE WE LEARNED AFTER ~6 YEARS OF MGS OBSERVATIONS? M. H. Acuña[1], [1] NASA Goddard Space Flight Center, Laboratory for Extraterrestrial Physics, Code 695, Greenbelt, Maryland 20771, <mario.acuna@nasa.gov>

Introduction: The MAG/ER investigation aboard MGS has established conclusively that an internal, dynamo-generated field does not currently exist at Mars and discovered, unexpectedly, strong magnetization in the crust. An estimate of the upper limit of the current Mars dipole moment derived from the MGS data yields $M < \sim 2 \times 10^{17}$ A-m^2, which corresponds to a surface equatorial field strength of < 0.5 nT. The intense magnetization of the crust is closely associated with the ancient, heavily cratered high terrain, which lies south of Mars' dichotomy boundary. The correlation of magnetization with the old terrain and the role of impacts, which have modified the magnetic properties of the crust, constitute a new and powerful diagnostic tool that is providing a unique view into the early thermal history of the planet, which was almost totally unknown prior to the arrival of MGS. Data from the Lunar Prospector mission complement contemporary analyses and interpretation of crustal magnetism in planetary system bodies that do not currently possess core dynamos. The observation of "magnetic lineations" over Terra Sirenum (Sirenum Fossae) and Terra Cimmeria, are suggestive of tectonic processes observed at Earth in association with sea-floor spreading and geomagnetic field reversals. If this association is correct, it would indicate the possible existence of plate tectonics and magnetic field reversals in Mars' early history. Alternative models involving fault/graben formation associated with the fracturing of a thin, magnetized crustal layer by tectonic or volcanism-induced stresses, yield equally valid interpretations. To date, no reliable correlation between topography, geology and crustal magnetism has been established and the origin of these remarkable "Martian magnetic anomalies" remains a mystery.

Fundamental Questions: A wide range of questions about the internal constitution, thermal evolution and geology of Mars are suggested by the magnetic field observations and remain largely unanswered. The MGS results have shed considerable light into these fundamental issues, but a whole range of new, intriguing and unexpected challenges regarding Mars' early thermal and collisional history have arisen. The majority of the crustal magnetic sources lie south of the dichotomy boundary on the ancient, densely cratered terrain of the highlands and extend ~ 60° south of this boundary. Therefore, the formation of the dichotomy boundary must postdate the cessation of dynamo action because of the clear magnetic differentiation between the terrains on either side of the boundary. The absence of detectable crustal magnetization north of the dichotomy boundary, in spite of a widespread record of active volcanism and magmatic flows, suggests that dynamo action had ceased at this stage of thermal evolution and crustal differentiation. The southernmost limit of the crustal magnetization region appears to be associated with the destruction or modification of the magnetized crust by the impacts that created the Argyre and Hellas basins. Processes that took place after the cessation of dynamo action only modified the ancient, magnetized, thin crust through deep-reaching impacts, magmatic flows, tectonics, shock de-magnetization and/or reheating above the Curie point. Models of the intensely magnetized regions assume layer thickness of ~30km, located immediately below the surface, while models of the weaker sources detected in the northern hemisphere and located in the younger, Amazonian plains yield depths in excess of 100 km. Could these deep sources imply subduction of a magnetized layer in these areas?

The complexity of the sources found in the southern hemisphere is vividly illustrated in Figure 1 where the magnetic field vectors acquired along a southern MGS pass have been plotted on the trajectory of the spacecraft.

Figure 1



To complement this figure, a cut across Terra Sirenum modeled by finite element techniques is shown in Figure 2. The magnetization of the 30km thick "strips" can reach values as large as ~20 A/m, a factor of 20 larger than Earth's magnetic anomalies while the intensity of the field at the surface reaches values of ~20,000 nT

Figure 2

Timing of the Mars Dynamo: The magnetic field observations acquired over Hellas, Argyre, Isidis and other impact basins do not show the presence of magnetic fields suggesting that the core dynamo had ceased to operate when these basins were formed. The age of these basins is estimated to be >~4 Gyr and therefore Mars dynamo cessation has to coincide or predate this epoch. The analysis of detailed MGS magnetic field data shows that in spite of the evidence derived from MGS and other imaging observations for continuous volcanism throughout Martian history, magnetic data does not support a dynamo "re-start" or a late onset as suggested by Gerald Schubert and his coworkers. Therefore the lifetime of the dynamo, from planet accretion and core formation to cessation, cannot exceed ~300 to 500 Myr if our estimates of cratering ages are correct. This short time span represents a fundamental challenge and constraint for models of Mars' core dynamo and thermal evolution that involve different proposed rapid-cooling mechanisms and associated crust formation

Martian Solar Wind Interaction: From a solar system point of view, our knowledge of the nature of the interaction of Mars with the solar wind was incomplete until the arrival of MGS and the acquisition of close-in magnetic field data. The derived upper limit for the intrinsic magnetic moment given above demonstrates that the Martian solar wind interaction is dominated by the planet's ionosphere and atmosphere. Turbulent magnetic fields and energized charged particles are observed throughout the magnetosheath region and the absence of a internal field as well as the low gravity of the planet allow solar wind plasma to interact with this extended exosphere over large radial distances. Some solar wind electrons reach deep into the Martian ionosphere where they interact with the crustal magnetic fields leading to complex distributions which are being studied extensively at the present time. The detailed drapping geometry of the interplanetary magnetic field lines over the Martian obstacle is highly dependent upon upstream conditions, particularly, ram pressure. The MGS magnetic field data acquired in the mapping orbit have been used by a number of investigators to derive "proxy parameters" which allow an estimation of the upstream ram pressure thus providing an important monitoring function for other Mars orbiting investigations. Finally, the distribution of ionospheric and solar wind electrons over regions of weak crustal magnetization has provided some challenging clues that need to be reconciled with the in-situ magnetic field observations since they could play an important role in further constraining the timing of the Martian dynamo.

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