THE MARS CRUSTAL MAGNETIC FIELD IN HIGH DEFINITION. J. E. P. Connerney[1] and J. R. Espley[1], [1]Solar System Exploration Division, Code 695.0, Goddard Space Flight Center, Greenbelt, MD 20771 (jack.connerney@nasa.gov).

Introduction: Mars Global Surveyor's (MGS) magnetometer observed regions of strongly magnetized crust on Mars [1]. The most intense crustal fields were observed above the ancient southern highlands [2] but significant fields were observed over the entire crust, but for (1) regions characterized by voluminous volcanic flows (Elysium, Olympus Mons, Tharsis) and (2) the largest impact basins (e.g., Hellas, Argyre, Isidis, Utopia, Chryse). With the exception of those regions subsequently demagnetized by volcanic emplacement and large impacts, the entire crust bears the magnetic imprint acquired ~4B years ago when it cooled in the presence of the now-extinct dynamo [3]. The Mars crust is at least 20 times more intensely magnetized, on average, than the Earth's crust.

The magnetic imprint in the Mars crust is most readily interpreted in the context of plate tectonics: (1) magnetic lineations observed in the southern highlands are reminiscent of those observed on Earth above a mid-ocean ridge [2], formed by crustal spreading in the presence of a reversing dynamo; (2) the magnetic imprint in Meridiani reveals a pair of great faults (displaced magnetic contours) that are consistent with the properties of transform faults [3], which are unique to plate tectonics; and (3) the sheer magnitude of the magnetic field observed above the Mars crust requires a mechanism that imparts a uniform magnetization of great intensity and large spatial scale to essentially the entire upper crust. No alternative mechanism can compete with the efficiency of crustal spreading in the presence of a global field in this regard.

When MGS arrived at Mars in 1997, it began a slow process of aerobraking in order to circularize its orbit. During more than a thousand aerobraking orbits, MGS sampled the magnetic field at altitudes as low as ~100 km. From 1999 to 2006 (when MGS was lost), observations were made from the near circular mapping orbit at an altitude of ~400 km. The mapping orbit observations are dramatically oversampled in latitude and longitude. Using quiet night-time observations, sampling statistics, and along track differencing to eliminate external fields, a global map of the crustal magnetic field with extraordinary signal-to-noise was compiled [3]. The crustal magnetic field of Mars has been mapped globally with far greater accuracy than is possible for Earth, where the crustal signal is but a tiny fraction of the main dipole field (<1/1000).

Thus we have at our disposal an interesting combination of datasets; we have sparse data scattered unevenly about the planet but passing relatively close to the crustal sources (aerobraking) and nearly complete, very accurate knowledge of the vector field on a closed surface at approximately fixed, but more distant, altitude (mapping data). Potential field theory [4] assures us that the latter set provides a powerful means of extrapolating the field throughout a region devoid of sources. Aerobraking data is also of great interest since it was acquired at much lower altitudes (80-200 km) and therefore more readily evidences variations of smaller spatial scale. The aerobraking data is sparsely distributed, and since it was usually acquired during daytime illumination, it may contain relatively large, time-varying fields due to the solar wind interaction. For interpretative purposes it would be most useful to have a continuous representation of the field with the fidelity of the mapping orbit data and spatial resolution of the aerobraking data. By analytic downward continuation of the mapping orbit data, we can achieve this goal.

Downward Continuation: Analytic continuation of potential field measurements (gravity, magnetic, etc.) obtained at one distance above the source to another (toward or away from the source, i.e., downward or upward continuation) has oft been used, particularly in exploration geophysics [4]. Upward continuation is essentially a smoothing function and maps, at higher altitudes, the contribution of the most extended sources, attenuating features of small spatial scale (as well as noise). Upward continuation is easy, and as boring as it is easy. Downward continuation, on the other hand, is essentially a differencing operation (not unlike "sharpening" an image) that magnifies features of small spatial scale (alas, noise also). In downward continuation, the signal becomes larger and features of smaller spatial scale dominate. In principle, this is exactly what we want - to increase the spatial resolution of our magnetic maps. In practice however, observations contain noise, however slight, from a variety sources (measurement noise, residual solar wind and spacecraft fields, etc.). Thus one needs to find a means of avoiding excessive amplification of noise if one is to successfully use downward continuation. This has always been the challenge in downward continuation of geophysical potential field data.

One common method of taming downward continuation is to simply remove wavenumbers above some selected critical wavenumber in the Fourier domain before continuation. This method was used with some success [5] in downward continuation of observations in the southern highlands, but by definition it arbitrarily limits the achievable spatial resolution of the result. In contrast, we have tamed the downward continuation beast by substituting an iterative upward continuation method [6] for downward continuation. In essence, an estimate of the field at low altitude (100 km) is upward continued and compared with the observations (at 400 km). The difference between the upward continued estimate and the observed field results in a correction to the estimate, which is upward continued for the next comparison. This iterative process continues until the upward continued estimate and the observed field agree to within some RMS criteria (typically a few tenths of a nT). We then have a representation of the field at 100 km altitude that is consistent with the observations at 400 km altitude. We will refer to this as "downward continued" data, to avoid confusion.

Since we have some admittedly sparse aerobraking data at the altitude to which we are continuing the mapping observations, we can compare the downward continued field with that observed during aerobraking at similar altitude ("ground-truth"). It's all good.

Downward Continuation of Mars Observations: We have downward continued the mapping orbit data over a number of regions of interest on Mars. We briefly discuss two of these regions.

Meridiani. Following the discovery of lineated magnetic features in Terras Sirenum and Cimmeria, attributed to crustal spreading in the presence of a reversing dynamo [2], we searched for other evidence of an early era of plate tectonics on Mars. The mapping orbit data, compiled as described previously, provided the first observations in support of the crustal spreading hypothesis when a pair of transform faults was identified in the magnetic imprint in Meridiani [3]. Figure 1 shows a comparison of the magnetic imprint at 400 km above Meridiani and the same data continued down to 100 km, where, with increased spatial resolution afforded by downward continuation, the great faults remain.

Southern Highlands. Another region of interest is the area of strong crustal fields in the southern highlands that yielded low-altitude observations modeled by Connerney and colleagues [2] and subsequently (using mapping observations) by Jurdy and Stefanick [5]. The three figures in Figure 2 illustrate the increased spatial resolution afforded by downward continuation of the mapping orbit observations. A comparison of the downward continued data with observations acquired in the vicinity of the reference surface (100 km) during aerobraking demonstrates that the downward continuation yields a result in substantial agreement with observations.

Conclusions: We have applied an iterative downward continuation method to extract increased spatial resolution from the MGS mapping orbit data. The observations retain the characteristics of a crust formed by crustal spreading in the presence of a reversing dynamo.

References: [1] Acuña M.H. et al. (1999), *Science*, *284*, 790-793. [2] Connerney, J.E.P, et al. (1999), *Science*, *284*, 794-798. [3] Connerney, J. E. P. et al. (2005), *PNAS*, *102*, doi / 10.1073 / pnas.0507469102. [4] Blakely, R. J. (1995), *Potential Theory in Gravity & Magnetic Applications*, Cambridge University Press. [5] Jurdy, D. M., and M. Stefanick (2004), *JGR*, *109*, doi:10.1029/ 2004JE002277. [6] Xu, Shi-zhe, et al., (2007), *Geophysical Prospecting*, *55*, 883-889, doi:10.1111/j.1365-2478.2007.00634.x.

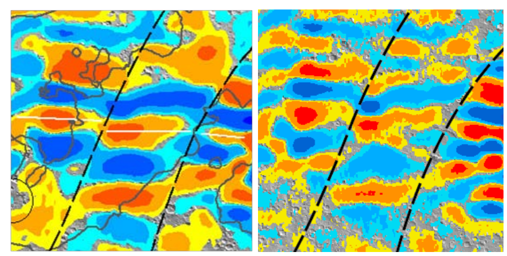

Figure 1 Left panel shows original mapping orbit data at 400 km altitude within +/- 30 deg lat/lon of 0,0 from reference [3], dashed lines indicating putative transform faults in Meridiani. At right data is downward continued to 100 km. Increased spatial resolution reveals additional lineated features, of smaller spatial scale; offset magnetic contours (transform faults) remain.

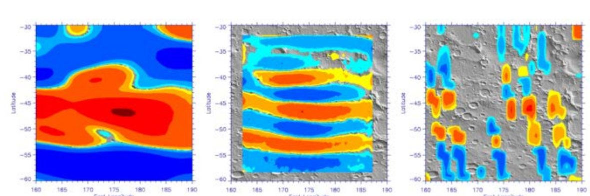

Figure 2 Leftmost panel shows original mapping orbit data (delta Br) color contoured at 400 km altitude from -30 deg to -60 deg latitude and within +/-15 deg of 175 e. longitude. Middle plot shows data downward continued to 100 km altitude against a background of MOLA shaded topography, edge effects blanked. Rightmost plot shows data from aerobraking passes at comparable altitude (80 to 120 km) color contoured as per downward continued data. On the right we plot the negative of the theta component of B, which, to within a constant, is comparable to delta Br, for a narrow range of spatial wavenumbers (see ref [3].