

BRACKETING THE END OF THE MARTIAN DYNAMO: THE AGES AND MAGNETIC SIGNATURES OF HELLAS AND LADON BASINS. R. J. Lillis^{1,2}, H.V. Frey³, M. Manga⁴, D.L. Mitchell¹, R.P. Lin^{1,2}, M.H. Acuna³, ¹UC Berkeley Space Science Laboratory, ²UC Berkeley Department of Physics, Berkeley, CA 94720 ³NASA Goddard Space Flight Center, Greenbelt, MD 20771 ⁴UC Berkeley Department of Earth and Planetary sciences, Berkeley, CA 94720 (EMAIL: rlillis@ssl.berkeley.edu)

Summary: The Ladon basin is the only basin on Mars which shows the clear effects of impact demagnetization (like the giant basins Hellas, Argyre, Utopia and Isidis) but which also contains a significant central magnetic anomaly, as determined by electron reflection (ER) magnetometry. This suggests thermoremanent magnetization of the cooling central melt pool in the presence of a dynamo-driven magnetic field. We use visible and buried craters to compare crater retention ages (CRAs) of the Ladon basin and the demagnetized Hellas Basin (assumed to have formed after the end of the dynamo era) and conclude that the Martian dynamo ceased between the CRAs of $N(100) = 9.9 - 13.7$, corresponding to a Hartmann-Neukum time of $4.07 \pm 0.03 - 4.15 \pm 0.05$ Gyr ago.

Introduction: Present-day Mars does not possess an active core dynamo and associated global magnetic field. However, the discovery of intensely magnetized crust in Mars' Southern hemisphere [1] implies that a Martian dynamo has existed in the past [2,3]. Resolving the history of the Martian core dynamo is important for understanding the evolution of the planet's interior. Moreover, because the global magnetic field provided by an active dynamo can shield the atmosphere from erosion by the solar wind [4], it may have influenced past Martian climate.

Electron Reflection (ER) Magnetometry is based on the magnetic mirror effect, that is, the reflection of charged particles from regions of increased magnetic field strength. By comparing the pitch angle distribution of electrons moving toward the planetary surface with the distribution of those electrons reflected from the surface, the increase in the magnetic field strength can be determined. Here ~ 2.6 million measurements of 90-400 eV electrons over 6 years have been combined to produce a map of the field magnitude $|B|$, due to *crustal* sources only, at 170km altitude (the approximate stopping altitude for these electrons). It has an r.m.s. error of 30%, an intrinsic resolution of ~ 150 km or ~ 2.5 degrees of latitude and a 1-V detection threshold for crustal fields of ~ 2.5 nT [5].

Magnetic Signatures of Basins: The heating and shock from a large meteorite impact can demagnetize the entire depth of crust over an area comparable to the final size of the impact basin [6,7]. As the central melt pool solidifies, some fraction will crystallize into mag-

netic minerals (what fraction depends on the oxidation state of the target material). As the mineral cools below its Curie point it acquires a thermoremanent magnetization (TRM) aligned with the direction of, and with a magnitude positively dependent on the strength of the local ambient magnetic field. This magnetization (or lack thereof) is preserved in the crust and can be detected by spacecraft measurements.

The Hellas Basin is the largest clearly visible impact crater in the solar system and was formed near the end of the Late Heavy bombardment. Magnetic maps from both the magnetometer and electron reflectometer show there are no significant magnetic sources within the basin at all. The general consensus is that the global dynamo magnetic field had ceased to exist by the time of the Hellas impact [1].



Fig 1: The top panel shows the ER magnetic map of the north and eastern rim of the Hellas Basin. The bottom panel shows the portion of the basin rim used for determining its crater retention age.

The Ladon Basin is a very degraded, multi-ringed basin, approximately 900 km in diameter and centered at 330 degrees east, 18 degrees south. Two large ba-

sins are superimposed on it: the Holden basin to the south and the Margaritifer Chaos basin to the north-east. Fig 2 shows the clear demagnetized region associated with the Ladon basin and the central magnetic anomaly shifted to the ESE from the basin center by approximately 200 km. Given that it is equivalent in size to the completely demagnetized Isidis basin, the most likely explanation is that the Ladon impact shock-demagnetized the crust out to approximately one basin radius, after which the central part of the basin was remagnetized in a significant global magnetic field. This was probably due to a sufficient fraction of magnetic minerals crystallizing out of the pool of impact melt and acquiring a magnetization strong enough to produce the observed anomaly, a lower bound of which we calculate to be 1.5 A/m.

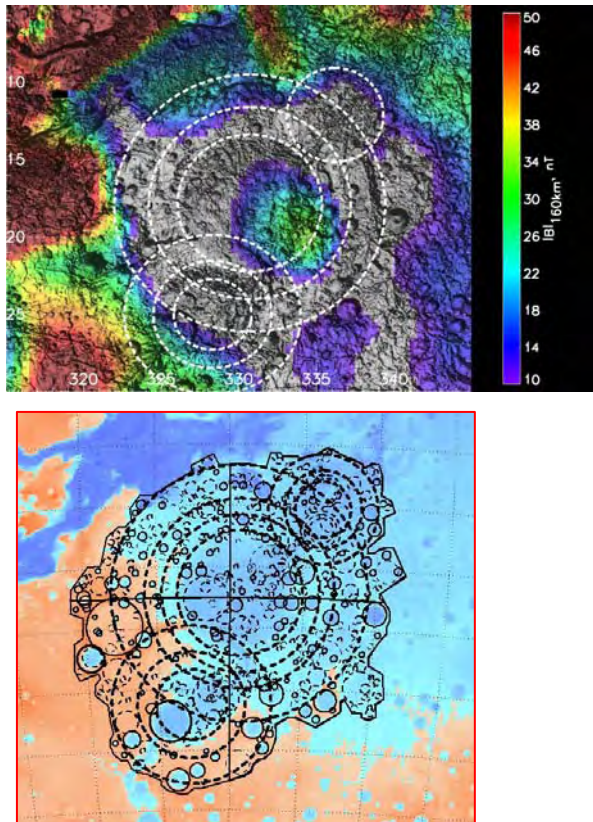


Figure 2: The top panel shows the ER magnetic map of the Ladon basin. The bottom panel shows area used for determining its crater retention age.

Since only 100 km of the observed shift of the central magnetic anomaly could be accounted for by the magnetization direction, it is possible the melt pool was asymmetric or it suffered subsequent hydrothermal alteration or that the anomaly was created separately later, perhaps by a crystallizing deep magma

chamber, though the lack of any sign of surface of volcanism speaks against this latter possibility.

Crater Retention Ages: Using quasi-circular depressions (QCDs) identified in MOLA data as proxies for buried craters[8], we carried out a comparison of total crater population (visible + buried) for the Holden-Ladon region and Hellas, using the areas shown in figures 1 and 2. Figure 3 shows the cumulative size frequency curves. Over the 30-100 km diameter the two curves are identical within their errors. Because these curves are so similar to cumulative frequency curves for other very old areas of Mars, they may represent actual saturation over this diameter range. At $D > 100$ km, Holden-Ladon basins continue to follow the -2 power law trend, but the Hellas points plot lower than the trend. While this could be due to poor statistics in the larger size range for Hellas, both counting areas are the same (~ 1.2 M sq km). Thus we suggest this may represent a real age difference: if the -2 power law trend indicates saturation, Ladon has undergone (near) saturation to larger diameter craters than has Hellas *because it is older than Hellas*. If we use the $N(100)$ values of 9.9 and 13.8 for Hellas and Ladon respectively and convert to Hartmann-Neukum derived age [9], we get 4.07 ± 0.03 Gyr and 4.15 ± 0.05 Gyr, thereby indicating that the Martian dynamo ceased or weakened significantly during this time period.

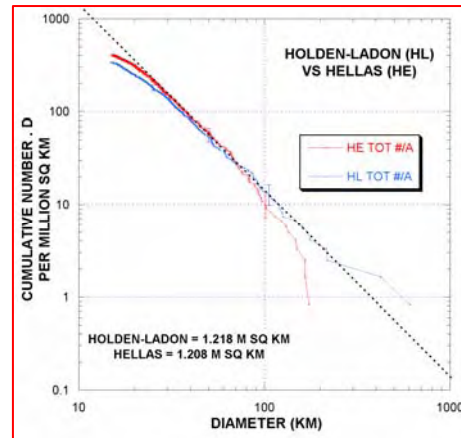


Fig 3: Crater size-frequency curves for Hellas (red) and Ladon (blue). See above text for discussion.

References: [1] M.H. Acuna et al., *Science* (1998), [2] M.H. Acuna et al., *JGR* (2001), [3] J.E.P Connerney, *Science* (1999), [4] K.S. Hutchins et al, *JGR* (1997), [5] R.J.Lillis et al, *GRL* (2004), [6] L.L. Hood et al, *GRL* (2003), [7] J.S. Halekas et al, *JGR* (2001), [8] H.V Frey et al, *GRL* (2002), to sleep hot [9] W.K. Hartmann & G. Neukum, *Space Science Reviews*, (2001)