MAGNETIC SIGNATURES OF LUNAR MULTI-RINGED IMPACT BASINS: NEW CONSTRAINTS ON THE TIMING OF THE PUTATIVE LUNAR DYNAMO M. E. Purucker[1], J. W. Head[2], and J. S. Halekas[3], [1]Raytheon at Planetary Geodynamics Lab, GSFC (Code 698, GSFC/NASA, Greenbelt, MD 20771 purucker@geomag.gsfc.nasa.gov) , [2]Dept. Geol. Sci., Brown University , Providence, RI 02912 (James_Head@brown.edu), [3]Space Sciences Lab, Univ. Cal. Berkeley, CA 94720 (jazzman@ssl.berkeley.edu).

Introduction: New, and more detailed maps [1,2] of the crustal magnetic field of the Moon using the Lunar Prospector (LP) Magnetometer (MAG) and Electron Reflectometer (ER) make possible the development of independent magnetic chronologies of lunar ringed impact basins, and an assessment of the presence of ambient magnetic fields during basin development. The results from both the MAG and ER suggest the presence of a magnetic era in Nectarian times, possibly due to a lunar core dynamo, as first suggested by [3] from ER results. Published paleointensity interpretations from Apollo samples suggest a later magnetic era, in late Nectarian and Imbrian times, but recent results [4] using modern techniques suggest substantial revisions to this chronology.

Two new maps: The MAG and ER maps were made from data acquired during the low-altitude phase of the LP mission. The MAG map is developed using a novel, correlative technique, after first removing a simple model of the external magnetic field. The technique uses internal dipoles as basis functions and exploits LPs orbit geometry; incorporating vector component data from immediately adjacent passes into the model. These adjacent passes are closely separated in space and time and are thus characteristic of a particular lunar regime. Each dipole model thus represents the correlative parts of three adjacent passes, and provides an analytic means of upward/downward continuing the data. Combining these individual models, we develop a model for the wake and tail regimes in which more than 99% of the 720x720 grids covering the lunar surface are filled. Using the Driscoll and Healy sampling theorem [4] we develop a spherical harmonic degree 178 model, and estimate that terms below about degree 150 are robust. Polar regions are considered to be the least reliable.

The ER map represents estimates of surface magnetic field magnitude, determined by utilizing measurements of adiabatically reflected electrons to remotely sense crustal magnetic fields at the surface. This map is completely corrected for the effects of near-surface electric field, which also reflect electrons. The surface location for each observation from orbit is determined by a straight line magnetic field trace. The magnitude for moderate fields (a few nT to tens of nTs) is more reliable than those for higher fields. The magnitudes determined using the ER technique are lower limits.

While the two maps match up well qualitatively, we do not expect them to correspond exactly, since the ER map should have more sensitivity to localized incoherent magnetization at the surface, while the MAG map should have more sensitivity to more coherent and/or deep-seated magnetization.

Magnetic consequences of impacts: Excavation and heating alter magnetization over the entire impact basin, at least for basins with a size comparable to the thickness of the lunar crust. Subsequent cooling can produce a thermoremanent magnetization in the direction of, and proportional to, the ambient magnetic field. Shock from the impact can either reduce or enhance magnetization, depending on the ambient magnetic field, and the magnetic properties of the shocked rock. For the large impact basins, these processes should be visible in the satellite record of the magnetic field. Simple scaling arguments suggest that basins with sizes in excess of 30 (100) km should be visible with the MAG (ER) technique. We therefore examine the magnetic signature of the known ringed impact basins compiled by [6], all of which are in excesss of 300 km in diameter.

Large basin magnetic signatures and inferred chronology:

We consider the magnetic signature of the 33 impact structures compiled by [6]. Their names, relative ages, and magnetic signatures are given in Table 1 and can be identified in the new maps presented in Figure 1. The broad scale features of both the ER and MAG maps can be seen to be similar, and in 21 of the 33 basins analyzed in the table below, the relative magnetic field strengths are also found to be the same. All Imbrian-age basins show weaker magnetic fields inside the basin rim than in the immediately adjacent terrain, and we see no evidence of central anomalies. In contrast, 8 of the 11 Nectarian basins show evidence, in either the MAG or ER, or both, of stronger fields inside the basin rim and/or a central anomaly. The magnetic signature in pre-Nectarian basins is more complex, but in general they show little evidence of stronger magnetic fields inside the basin rim.

Basin	Age	MAG	ER	C.A.
Orientale	1-I	W	W	No
Schrodinger	2-I	W	W	No
Imbrium	3-I	W	W	No
Bailly	4-N	S	S	Yes
Hertzprung	4-N	W	W	No
Serenitatis	4-N	S	NC	In MAG
Crisium	4-N	S	S	In ER
Humorum	4-N	S	W	No
Humboldtianum	4-N	S	S	Yes
Mendeleev	5-N	NC	W	No
Mendel-Rydberg	6-N	S	S	No
Korolev	6-N	NC	NC	No
Moscovienese	6-N	S	S	No
Nectaris	6-N	W	W	Yes
Apollo	7-pN	NC	NC	No
Grimaldi	7-pN	W	W	No
Freundlich-Sharonov	8-pN	W	NC	No
Birkhoff	9-pN	W	NC	No
Planck	9-pN	W	NC	No
Schiller-Zucchius	9-pN	NC	NC	No
Lorentz	10-pN	NC	W	No
Smythii	11-pN	NC	NC	No
Couloumb-Sarton	11-pN	NC	W	No
Keeler-Heaviside	11-pN	NC	NC	No
Poincare	12-pN	NC	W	No
Ingenii	12-pN	NC	NC	No
Lomonosov-Fleming	13-pN	S	S	No
Nubium	13-pN	NC	W	No
Fecunditatis	13-pN	NC	NC	No
Mutus-Vlacq	13-pN	NC	NC	No
Tranquillitatis	13-pN	W	NC	No
Australe	13-pN	NC	S	No
South Pole-Aitken	15-pN	S	S	No

Table 1. Relative ages of known ringed impact basins on the Moon, and their associated magnetic properties as inferred from MAG [2] and ER [1] measurements from Lunar Prospector as shown in Figure 1. The relative ages of the basins proceed from youngest (class 1) to oldest (Class 15) on the basis of photogeologic observations related to degradational state and crater density (adapted from [6]). I=Imbrian, N=Nectarian, pN=preNectarian. Basins can not be accurately ranked within a group. Magnetic properties include whether the magnetic field as measured by MAG and ER is stronger (S), weaker (W), or unchanged (NC) compared to the immediately adjacent terrain. Also tabulated is whether the basins exhibit a central anomaly (C.A.).

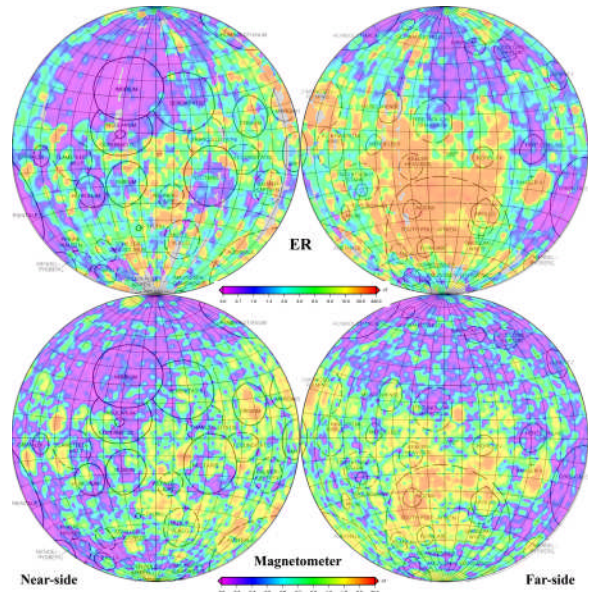

Figure 1. Magnitude of magnetic field measured by the Magnetometer (MAG) and Electron Reflectometer (ER) instruments onboard Lunar Prospector (LP). All measurements are based on low-altitude LP data from wake and tail times. The resolution of the MAG data is ½ degree in latitude, and 1 degree in longitude. The ER data are binned on 1 degree centers, and boxcar smoothed over 3 x 3 degrees. The ER fields are estimated at the lunar surface, the MAG at 30 km. nt = nanoTeslas.

Implications for the early Moon: The evidence presented here strongly suggests the existence of a magnetic era in Nectarian times, amplifying and confirming the results of [3]. We tentatively associate the magnetic era with a lunar dynamo [7], although other explanations remain possible, and timing issues need to be re-examined in light of these new data, and the paleointensity results of [4].

References: [1] Mitchell D. L et al. (in press) *Icarus* [2] Purucker M. E (in review) *Icarus* [3] Halekas J.S. et al., (2003) *Meteoritics & Planetary Science*, 38(4), 1-14 [4] Lawrence K.P. et al. (2007) *EOS Trans. AGU*, 88(52) [5] Driscoll J.R. (1994) *Adv App. Math.*, 15(2), 202-250. [6] Wilhelms (1987) *USGS Prof Paper 1348*, 302 pp. [7] Stegman, D.R. et al. (2003), *Nature*, 143-146.