CENTRAL MAGNETIC ANOMALIES IN OLD LUNAR IMPACT BASINS: NEW CONSTRAINTS ON THE EARLIEST HISTORY OF THE FORMER CORE DYNAMO. L. L. Hood[1], H. Tsunakawa[2], and P. D. Spudis[3], [1]Lunar & Planetary Lab, 1629 E. University Blvd., Univ. of Arizona, Tucson, AZ 85721, USA; lon@lpl.arizona.edu, [2]Dept. of Earth & Planetary Sciences, Tokyo Institute of Technology, Tokyo, Japan, 152-8551, [3]Lunar & Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058.

Introduction: Most strong magnetic anomalies in the lunar highlands likely have a complex origin involving shock remanent magnetization (SRM) in short-lived magnetic fields amplified by impact processes [1,2]. However, other anomalies have previously been found in a number of impact basins, including Crisium, that probably have an origin involving thermoremanent magnetization (TRM) by slow cooling of impact melt in the presence of a long-lived, steady magnetic field [3,4]. The latter interpretation is supported by numerical impact simulations showing that basin-scale impacts raise the subsurface to a temperature exceeding the Curie temperature for lunar metallic FeNi remanence carriers for long time periods following the impact [e.g., 5]. Any pre-existing magnetization would therefore have been thermally erased. The location of the anomalies at the basin centers or in a symmetrical pattern around the basin centers provides empirical evidence that the anomalies are due to TRM of subsurface impact melt (rather than to SRM of superposed ejecta from later basin-forming events). Laboratory studies have also recently demonstrated that at least some igneous samples acquired TRM in a steady magnetic field with an amplitude of as much as 10 μT as early as 4.2 Gyr ago [6,7]. Taken together, these orbital and laboratory results represent strong evidence for the existence of an early lunar core dynamo.

Previous studies of orbital data have clearly identified central magnetic anomalies only within impact basins of Nectarian age, i.e., basins with relative ages between those of Imbrium and Nectaris [3,4]. The Imbrium impact occurred at ~ 3.85 Gyr [8]. The date of the Nectaris impact is more uncertain with estimates ranging from ~ 3.9 Gyr [9] to ~4.2 Gyr [10,11]. In this paper, we report results of an initial detailed analysis of low-altitude magnetometer measurements over a series of older (Pre-Nectarian) impact basins. In addition to Lunar Prospector (LP) data, we also utilize Kaguya (SELENE) data, which were obtained under quieter solar activity conditions. The purpose is to evaluate whether central anomalies are detectable in at least some of these older basins, implying that the dynamo existed during early lunar history prior to the Nectaris impact.

Results: Table 1 lists the 19 known Pre-Nectarian-aged lunar impact basins in order of increasing age up to Australe with center locations and main rim diameters according to Wilhelms [12]. Following Halekas et al. [3], relative age groups (P-7 to P-13) are also assigned. Basins within a given group have relative ages that are indistinguishable from those of others in the same group. For each basin, the best available data (lowest altitude and least amount of external field noise) was identified and the mission that produced it (LP or Kaguya) is indicated in column 5.

Table 1. Pre-Nectarian Impact Basins[1] (Post-Australe)

Name	Center Location	Main Rim Diam., km[1]	Rel. Age[1]	Best Data	Central Anomaly?	Mag. Index[2]
Apollo	36°S, 209°E	505	P-7	KG[3]	--	--
Grimaldi	5°S, 292°E	430	P-7	KG	NF, ML[3]	0.12
Freundlich-Sharanov	19°N, 175°E	600	P-8	LP	NF, ML	0.01
Birkhoff	59°N, 213°E	330	P-9	LP	Yes	0.12
Planck	58°S, 136°E	325	P-9	KG	NF, ML	0.76
Schiller-Zucchius	56°S, 315°E	325	P-9	KG	NF, ML	0.14
Amundsen-Ganswindt	81°S, 120°E	355	P-9	KG	--	--
Lorentz	34°N, 263°E	360	P-10	KG	Yes	0.13
Smythii	2°S, 87°E	840	P-11	KG	--	--
Coulomb-Sarton	52°N, 237°E	530	P-11	LP	Yes	0.16
Keeler-Heaviside	10°S, 162°E	780	P-12	KG	--	--
Poincare	35°S, 164°E	340	P-12	KG	--	--
Ingenii	34°S, 163°E	560	P-12	KG	--	--
Lomonosov-Fleming	19°N, 105°E	620	P-13	LP	--	--
Nubium	2°S, 345°E	690	P-13	KG	NF, ML	0.29
Fecunditatis	4°S, 52°E	690	P-13	KG	--	--
Mutus-Vlacq	52°S, 21°E	700	P-13	KG	--	--
Tranquillitatis	8°N, 31°E	775	P-13	KG	NF, ML	0.37
Australe	39°S, 93°E	880	P-13	LP	--	--

[1]Main rim diameters and relative ages are based on Wilhelms (1984). [2]Magnetic Index (see the text); [3]Abreviations: KG - Kaguya (SELENE); LP - Lunar Prospector; NF - Not Found; ML - Magnetic Low.

In many cases, basins of this age have been ``magnetically contaminated'' by superposed ejecta from later basin-forming events and are therefore not suitable for detecting relatively weak central anomalies. As an extreme example, the Ingenii basin is located near the Imbrium antipode where ejecta deposition in an amplified magnetic field has apparently produced strong anomalies [1,2]. Similarly, the Smythii basin is not far from the Orientale antipode and likely contains anomalies associated with ejecta deposition from that event. All basins where there is probable evidence for such contamination have therefore been excluded from the analysis, as indicated by dashes in the last two columns of Table 1.

For the remaining 9 basins, column 6 indicates whether central anomalies are found or whether only a magnetic low (ML) due to impact shock demagnetization is present. Three basins with relative ages ranging from P-9 to P-11 have probable central anomalies: Birkhoff, Lorentz, and Coulomb-Sarton. Figure 1 plots the radial field strength at an approximate altitude of 25 km as measured by the LP magnetometer over the oldest of these, the Coulomb-Sarton basin. The dark circle indicates the approximate outer rim location. The field map is superposed on a Clementine LIDAR shaded relief map in a polar stereographic projection. Although the central anomaly has a smoothed amplitude of only several tenths of a nanoTesla (nT) at this altitude, its existence is verified by repetition on adjacent orbit passes.

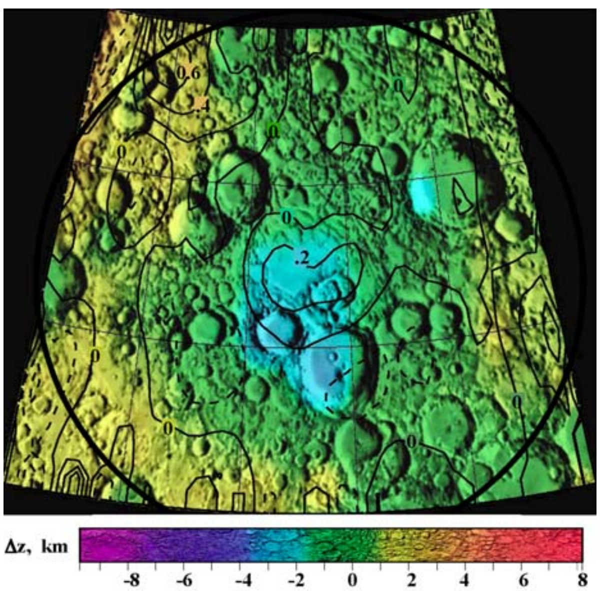

Figure 1. Radial field strength in nT at ~ 25 km altitude measured by the LP magnetometer over the Coulomb-Sarton basin. The contour interval is 0.2 nT.

Column 7 of Table 1 lists the value of a ``magnetic index'', defined as the mean absolute value of the radial field strength at 25 km altitude averaged over a rectangular area within the basin rim. The radial field component is used because the tangential components tend to have more external field noise. The three basins with central anomalies have rather low magnetic indices of 0.12, 0.13, and 0.16. This reflects the relative absence of superposed ejecta contamination within these basins, thereby allowing detection of weak central anomalies. Several other basins with only magnetic lows (Planck, Nubium, and Tranquillitatis) have higher values, suggesting that any weak central anomalies within these basins may be obscured by remaining superposed ejecta contamination. However, three others (Grimaldi, Freundlich-Sharanov, and Schiller-Zucchius) have low index values and no detected central anomalies. This is consistent with results for Nectarian-aged basins (4) which show that central anomalies are present for some basins but not for others, even though a dynamo field apparently existed in all cases.

Conclusions: Central magnetic anomalies are present in at least 3 Pre-Nectarian lunar impact basins with relative ages ranging from P-9 to P-11. Their central locations strongly suggest an origin involving TRM of subsurface impact melt in a long-lived, steady magnetizing field. All three basins are located in the northeast quadrant of the far side, which is less contaminated by stronger anomalies associated with ejecta from later basin-forming events. The existence of these central anomalies implies that a steady magnetizing field, presumably a core dynamo, existed at least as far back as the time of the Coulomb-Sarton impact.

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