MAGNETIC SIGNATURES OF LUNAR IMPACT CRATERS. X. Yang[1] and M. A. Wieczorek [2], [1] School of Earth and Space Sciences, Peking University, Beijing, China (xiyang@pku.edu.cn), [2] Observatoire de la Côte d'Azur, Laboratoire Lagrange, Nice, France (mark.wieczorek@oca.eu).

Introduction: The lunar core once generated a global magnetic field that magnetized portions of the lunar crust. Paleomagnetic analyses of Apollo rock samples reveal that the lunar dynamo operated from at least 4.25 Ga to sometime between 1.92 Ga and 0.8 Ga [1-2]. Crustal magnetism derived from orbital magnetic field data shows there are strong magnetic anomalies that are mostly concentrated on the lunar farside, as well as broad magnetic low that correlates with the Procellarum KREEP Terrane [3].

Impact cratering is one process that could either magnetize or demagnetize the crust. If the age of the crater could be determined, this process would help constrain the evolution of the lunar dynamo. A recent investigation shows that only five Nectarian impact basins contain clear magnetic anomalies [4]. For smaller impact craters, previous studies have detected both demagnetization [5] and magnetization [6] signatures. However, there lacks a comprehensive classification of crater magnetic signals based on the most recent global magnetic field models. In this study, we systematically analyze the magnetic signatures of lunar craters with diameters greater than 90 km. We start by designing a classification scheme with selected typical samples and the results are then analyzed in terms of crater location, diameter, and age.

Method: We use the crater database from [7], and an updated version of [8] is used to determine the crater age, when available. The total magnetic field data from the model of Tsunakawa et al. [9] is used as our primary dataset, and the model of Ravat et al. [10] is used to confirm the magnetic signature of the investigated craters. In addition to the magnetic field data, topography and a shaded relief map from Lunar Orbiter Laser Altimeter were consulted to help determine if the magnetic signatures are correlated with the impact crater or not. For example, some craters may have been superposed by younger smaller craters, buried by lavas, and/or might be highly asymmetric with respect to the crater rim.

Craters are classified into three different types: Magnetized craters (with a central magnetic high, perhaps surrounded by a magnetic low that extends to the crater rim), demagnetized craters (with a magnetic low interior of the crater rim), and no signal craters. For magnetized and demagnetized craters, their signal fidelity is divided into three levels: Certain, probable, and possible.

Certain craters are impact craters with a magnetic high or low in the crater interior that is symmetric, with respect to the crater center, clearly different statistically than the surroundings, and whose origin is certainly related to the crater. *Probable craters* are only probably related to the crater. The magnetic high or low is either not symmetric with the topographic depression, or there is some doubt that the magnetic signature is statistically different from the surrounding terrain. *Possible craters* have a magnetic signature that is only more likely than not to be related to the crater and is only marginally different from that of the surroundings.

Two authors of this work classified the data independently, after developing this classification scheme and agreeing on typical examples for each class. To test the statistical robustness of our classification, and to assess the likelihood of false detections, a second synthetic magnetic field map was created by rotating the geographic coordinate frame of the Moon. When classifying each crater, both the real and synthetic magnetic fields were analyzed. The classifications derived from the synthetic field were used to quantify the number of expected false detections for each crater class and were used to debias the observations of the real data. We found that the number of false positives from the synthetic map was comparable to the number of detections in the real data when the crater diameter was smaller than 90 km. Therefore, we only report the results of craters with a diameter >90 km.

Results: In total, we analyzed 418 craters and only 54 craters were classified as magnetized or demagnetized by at least one of the analysts. Of these, 31 were classified as magnetized craters by at least one analyst and 20 of these were consistent with both analysts. 23 craters are classified as demagnetized craters by both of the analysts, with 7 of these being consistent with both analysts.

As is presented in Fig.1, demagnetized craters tend to concentrate in the region where there are pre-existing strong fields on the lunar farside. One possible explanation for this is that the magnetic sources in this region are shallow (as suggested by [3]) and that these craters either excavated the shallow magnetized materials or were capable of demagnetizing them [11]. In contrast to demagnetized craters, magnetized craters concentrate on the southern hemisphere and appear to be uniformly distributed in longitude. This observation suggests that they were magnetized by a global magnetic field, though the paucity of magnetized craters in the northern hemisphere is somewhat enigmatic.

We further investigated the magnetized and demagnetized craters as a function of crater diameter and age. Fig. 2 shows the average debiased results of analysts. We plot the debiased percentage of each class, which is simply the number of real detections minus the number of false detections, with the result divided by the total number of craters in the class. For the few cases where the number of false detections is greater than the observations, we set the value to 0. In this figure, we consider all craters that are classified as possible, probable and certain.

In Fig. 2a, we plot the debiased percentage of magnetized and demagnetized craters as a function of crater diameter, D. The fraction of magnetized and demagnetized craters with D < 128 km are similar with both being less than 5%. For craters in the diameter interval 181 < D < 256 km, about 20% of these are magnetized and none are demagnetized. In contrast, for the largest craters, D > 256 km, about 20% of the craters are demagnetized, and none are magnetized. These results indicate that magnetic signatures are rarely associated with impact craters with diameters less than about 180 km. The larger craters are more commonly associated with a magnetic signature, but there are comparably fewer of these in number.

The debiased percentages of magnetized craters of pre-Nectarian, Nectarian, and Imbrian age are all less than about 6%. For the demagnetized craters, however, the percentage increases with decreasing age, from about 2% for pre-Nectarian, 4% for Nectarian, and more than 10% for Imbrian and Eratosthenian. The approximately constant fraction of magnetized craters from the pre-Nectarian to Imbrian periods is consistent with a dynamo operating over this time interval, and the lack of magnetized craters in the Eratosthenian and Copernican is consistent either with the lack of a dynamo or considerably weaker field strengths. These observations are consistent with paleomagnetic data that imply the dynamo field strength decreased by at least an order-of-magnitude at about 3.2 Ga [12], and then extinguished before 0.8 Ga [2].

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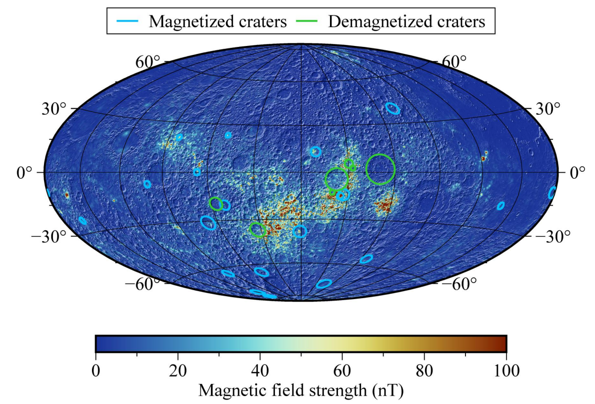

Figure 1: Spatial distribution of magnetized and demagnetized craters superposed on a global map of the magnetic field strength of the Moon [9]. Circles correspond to the crater rim, with magnetized craters are shown in blue and demagnetized craters in green. Plotted craters correspond to all possible, probable, and certain craters of both analysts.

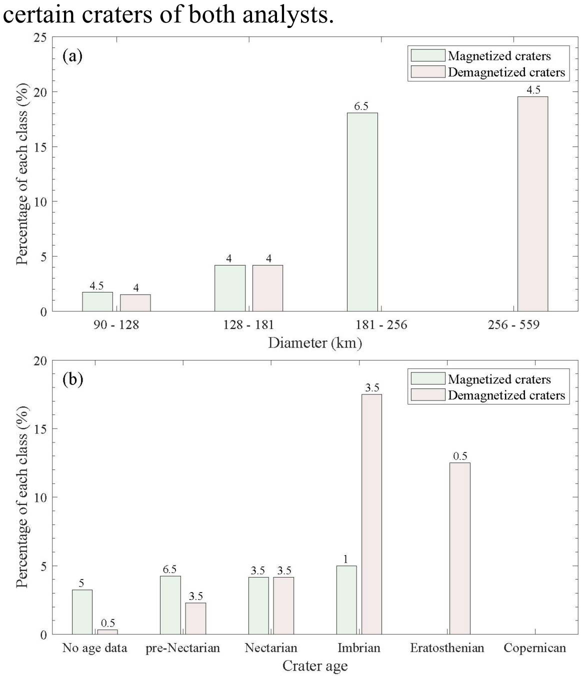

Figure 2: Debiased percentages of magnetized and demagnetized craters as a function of (a) crater diameter and (b) crater age. Green bars show the results of magnetized craters, and red bars show the results of demagnetized craters. The number above each bar is the absolute number of craters in the class.