A VERY SMALL LUNAR MAGNETIC ANOMALY: NEW HIGH RESOLUTION MAGNETIC FIELD MEASUREMENTS AND SPECRAL PROPERTIES

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Introduction: When Lunar Prospector (LP) arrived at the Moon, it collected magnetic field measurements from January 8, 1998, to July 31, 1999 [1]. The original magnetic field data were collected at a 9 Hz sampling rate, but the published data were downsampled to 0.2 Hz to match the spin period of the spacecraft. The 0.2 Hz data are adequate for many purposes, including determining the global-scale magnetic properties of the Moon. They correspond to a surface spatial resolution of ~ 8 km when the spacecraft is at an altitude of tens of kilometers. However, when the spacecraft altitude approaches ~ 16 km, which is fairly common, a 0.2 Hz sampling rate approaches the Nyquist sampling rate, assuming that the field structure changes horizontally at the same rate as it changes with altitude. Thus magnetic anomalies are barely sampled at an adequate rate at this altitude. A higher resolution data set would provide greater resolving power for small magnetic anomalies.

In this study, we use calibrated, previously unreleased 9 Hz LP data to investigate a very small swirl feature (1.0˚S, 298.6˚E) located in south-west Oceanus Procellarum, which we refer to as the octopus (Fig. 1). The dimensions of the octopus are approximately 10 km x 20 km with a peak magnetic field of only 3-4 nT at 17.9 km altitude. The octopus region has albedo markings characteristic of swirls, and there is no distinct topography on the surface. Here we examine how the high resolution magnetic field is associated with the albedo markings at this swirl-type anomaly. We will also attempt to use the magnetic field structure and albedo markings to infer the depth of magnetization, and ultimately the anomaly's formation mechanism.

Methods: We used LP three-axis magnetometer 9 Hz data of 23rd of February 1999 (990223) and 23rd of March 1999 (990323) to investigate the magnetic fields at the octopus. The 990223 data include 1660 measurement at 17.9 km altitude and the 990323 data include 1659 measurement at 17.4 km altitude. These two orbit passes are in a magnetically quiet time in the lunar wake. For subtraction of the background IMF, we use a running average method [2] that subtracts 5 minute mean fields from each data point. We also compare 5 minute running average data with upstream ACE satellite IMF data. Also, we use Clementine 750 and 950 nm data to search for characteristic swirl spectral trends [3].

Results: Figure 2 shows two orbit passes of x, y, z components, the total magnetic field, and just the horizontal component of the field (local coordinates) from -6˚ to 4˚ latitude. These two orbits show repeated signals which indicate crustal magnetic field at the octopus. At -1˚ latitude is the center of the octopus and its magnetic field measurement is shown clearly and repeatedly. Hence, these field oscillations are not a variation of the IMF. We also observe low-frequency oscillations of 0.2 Hz and ~0.4 Hz in the spacecraft data (Fig. 3). These oscillations are likely imperfectly removed spacecraft field artifacts. However, their amplitude is very low, < 0.2 nT, and thus they do not affect our interpretations of the spatial variation of the field. Nor do we anticipate that they will pose a problem when these data are used for inversions for the source body characteristics.

Figure 1 shows spectral properties of selected regions. The black and the magenta pixels are background maturity trends, analogous to OMAT [4, 5]. On the other hand, cyan, blue, and red pixels are taken from high albedo anomaly regions. These exhibit 750-950 nm reflectance trends that are characteristic of Reiner Gamma, Mare Marginis, and Mare Ingenii swirls [2, 6], confirming that the octopus is indeed a swirl.

Discussion: The octopus is perhaps the smallest lunar magnetic anomaly observed from orbit, to date. A key future goal will be to use the small size of the anomaly to argue for the shallowness of the magnetic source bodies, and thereby their formation mechanism. For example, Hemingway and Garrick-Bethell (2012) discuss how the albedo pattern can be associated with horizontal rates of changes in the field, and thereby the depth of the equivalent dipole source [7 (see their Fig.1), 8], Beak et al. (2016) discuss the depth of magnetic field sources [2]. For example, if the octopus is modeled as a vertically magnetized dipole, and the ~ 5 km bright-dark-bright transition in the center of the swirl represents a transition from strong, to weak, to strong horizontal fields (as the field data in Fig.2 show), then the equivalent dipole burial depth is ~ 5 km [7]. Such a shallow depth might support the iron-rich ejecta hypothesis for the origin of some magnetic anomalies

[9]. A dipole buried at 5 km must have a magnetic moment of ~10^{12} Am^2 to produce several nanotesla fields at the spacecraft altitude. A magnetized sphere of radius 5 km would imply a minimum rock magnetization of ~ 2 A/m.

Future work will perform more detailed inversions for the octopus source body characteristics and depth, with the hope of better constraining its formation mechanism, and other swirls in the western Oceanus Procellarum region.

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References: [1] Lin., et al., (1998), *Science*, 281, 1480-1484. [2] Baek et al., (2016) submitted to *JGR*. [3] Garrick-Bethell et al., (2011), *Icarus* 208, 480-492. [4] Lucey P.G et al., (1995), *Science*, 268, 1150-1153. [5] Lucey P.G et al., (2000), *JGR*. 105, 20, 397-20, 305. [6] Hemingway et al., (2015), *Icarus*, 261, 66-79. [7] Hemingway and Garrick-Bethell, (2012), *JGR*. 117, E10012. [8] Hemingway and Tikoo, 2017, this volume. [9] M. Wieczorek et al., (2012) *Science*, 335, 1212-1215.

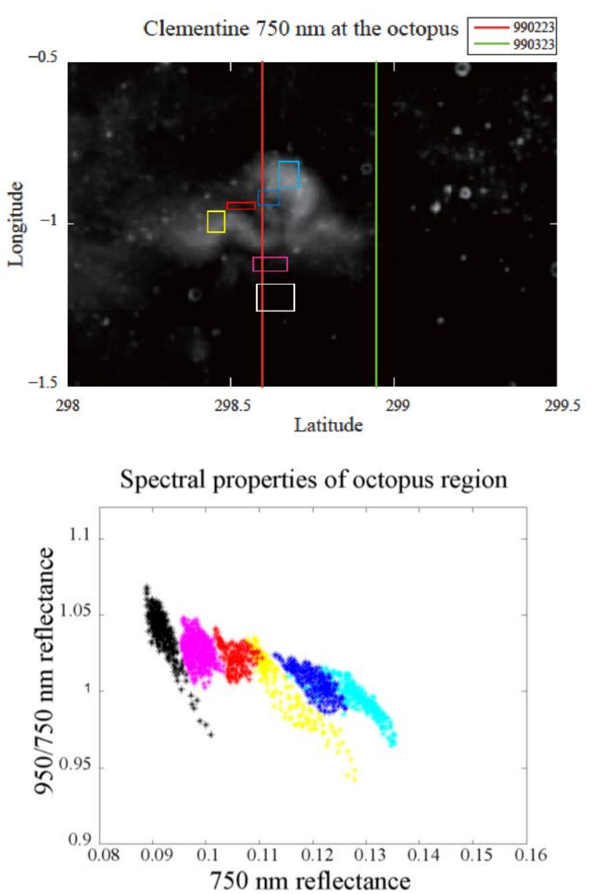

Figure 1. Clementine V2 750 nm map at the octopus and Two orbit passes are over the octopus (above). The characteristic swirl trend is illustrated by two trend (below): the background trend (black and magneta) and the swirl trend (cyan, blue, yellow and red).

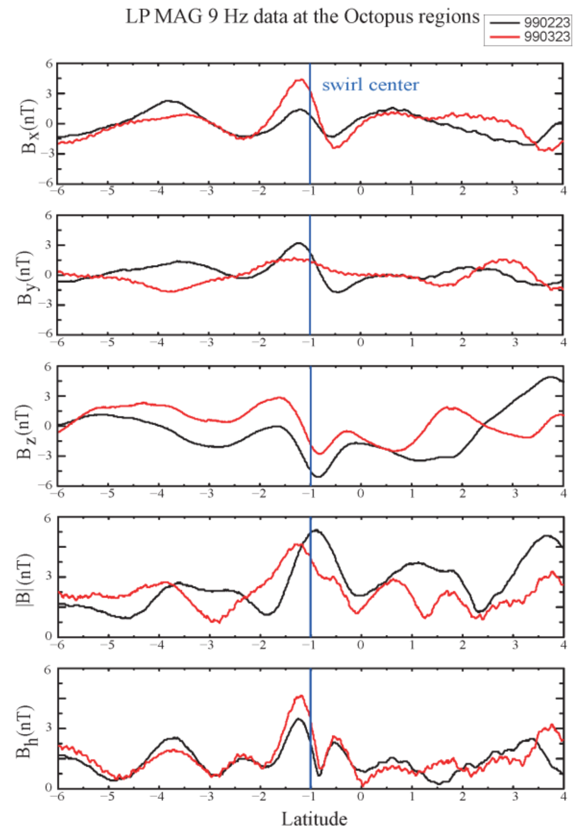

Figure 2. 9 Hz LP magnetometer data taken over the magnetic anomaly at the octopus swirl (see Fig. 1). Both orbit passes show clear repeatability at -1˚, the center of the octopus swirl.

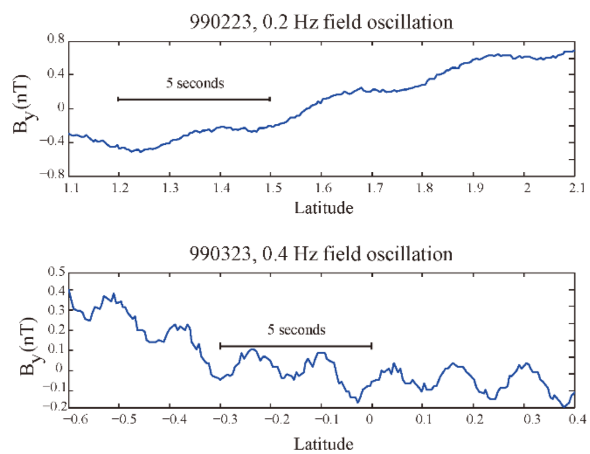

Figure 3. Low amplitude (≤ 0.2 nT), low frequency oscillations in the measurement field, likely an artifact of the spacecraft spin.