CLUSTER ANALYSIS OF LUNAR MAGNETISM, GRAVITY ANOMALIES, AND TOPOLOGY.

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Lunar crustal magnetization has been known since the return of lunar samples during the Apollo program [Fuller and Cisowski, 1987]. Magnetometer and electron reflectometer (ER) measurements on Apollo subsatellites revealed hundreds of magnetic anomalies and associated the largest and strongest ones with antipodal regions of large impact events from the Nectarian and Lower Imbrian system [Coleman et al. 1972, Lin et al. 1979, 1988]. Whereas the Apollo data are limited to within about +/- 20 degrees of the equator, the ER data on Lunar Prospector (LP) provide global coverage of crustal magnetic fields [Lin et. al. 1998].

The ER technique [Anderson et. al. 1976] is based on the reflection of ambient electrons from crustal magnetic fields. The electron reflection coefficient constraints the ratio of the total magnetic field strength at the surface to that at the spacecraft. Hence, the surface magnetic field strength can be derived from measurements of the reflection coefficient and magnetic field at the spacecraft. The ER instrument on LP allows a resolution of about 5 km and a sensitivity of about 0.2 nT. With the global coverage of the LP data comparisons with global surface properties are possible.

If we want to explain crustal magnetization, we need to identify the source region. The magnetization can potentially be present from the surface to several tens of kilometers depth (down to the Curie isotherm). Gravity data provide information about subsurface structures, including mass concentrations, subsurface density distributions and crustal thickness. The lunar crustal thickness varies from about 20 to > 100 km. The upper several kilometers have been reworked or disrupted by impact processing [Stoeffler and Ryder 2001, USGS 1971-199].

To investigate whether the magnetization is related to subsurface structures, we analyzed the correlation between our magnetic field data and the gravity and topological data from Clementine obtained from the Planetary Data System [Neumann et al., 1996, Lemoine, et al., 1997, Smith et al., 1997]. We chose effective crustal thickness, free-air gravity anomalies, Bougier gravity anomalies, and elevation since each of these properties reflect a different aspect of the lunar crust. However, comparison of the magnetic field data with each one of these crustal properties in turn did not show a significant correlation, suggesting that any relationship, if it exists, is more complex. The multivariate statistical method of cluster analysis is designed to identify such correlations among multiple parameters simultaneously. The identification of nonrandom patterns might suggest hypotheses. A well known cluster analysis example is the classification of stars in the Hertzsprung-Russel-diagram.

It is the fundamental idea of the cluster analysis, that if a data set separates into distinct groups, different rules may apply for each group. In contrast to discriminate function analysis, the groups or clusters are not the predetermined input , but the result of the analysis. [Dillon, 1984, Kaufman, 1990]. A data set consists of a number of data objects (n) or entry points and a number of attributes or variables (p). In our analysis, the object points correspond to the positions on the moons surface. The cluster analysis searches for similarity of data objects within a cluster and dissimilarity between data objects from different clusters. To avoid artifacts by comparing data of different magnitudes all attributes are standardized [Romesburg, 1984]. The measure of dissimilarity/ similarity is the distance in the p-dimensional attribute space between the objects. Each cluster is characterized by the mean or centroid. For our analysis we used standardized data, that have a mean of zero and a variance of 1. The metric of similarity was determined as the Euclidean distance. To group the data, we used a nonhierarchical method, which combines the closest data in a given number of clusters by minimizing the distances.

As with any statistical method the choice of data is critical. We compared the results of the cluster analysis with different sets of attributes, but a fixed number of clusters. As we repeated this with a different number of clusters between 3 and 10, we found the best distinction using 5 or 6 clusters. No combination of attributes led to ideally homogeneous groups.

No cluster shows clear indications of subsurface sources of magnetization. Crustal thickness and elevation remain highly variant in all clusters. Higher magnetization ($B > 50$ nT) can be found where the crust is very thin. However, a trend remains consistent. The figure shows the result of the analysis with directly measured attributes (magnetic field strength , gravity , and elevation), with clusters ordered by the magnetic field component of the centroid. One cluster (1) coincides with large impact basins, has almost no magnetic field and dominant gravity values. The largest magnetic field data ($B > 40$ nT) are typical for clusters (4,5), which match with antipodal areas of large impact basins. These clusters are the most distinct and invariant against analy-

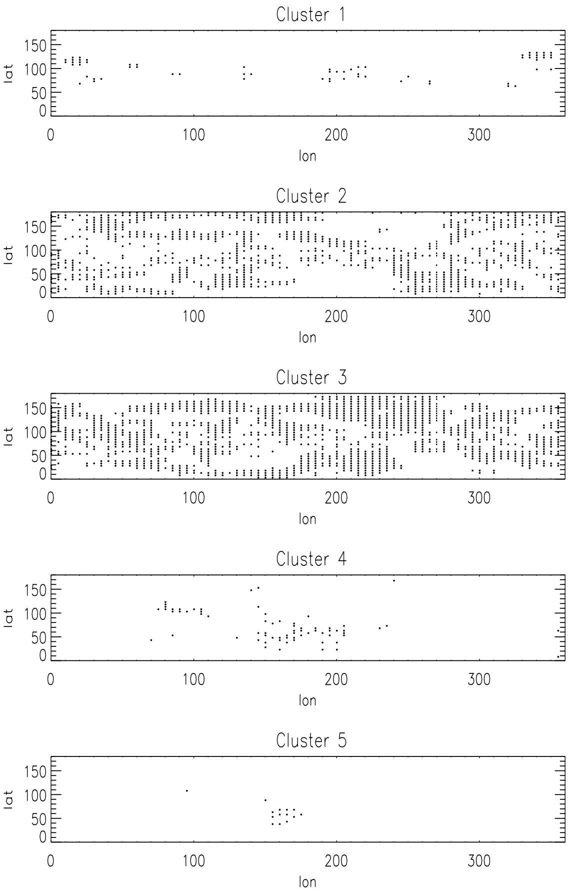

Figure 1: Cluster analysis of magnetic field strength, gravity, and elevation, lunar surface positions of the elements of each cluster .

sis conditions. The remaining majority of the data does not form very stable and distinct clusters (2,3). All attributes are fluctuating significantly. In general, the low magnetic field data (about 1 nT) correspond with moderate gravity values, and moderate magnetic field data (about 2-3 nT) are associated with lower gravity.

This outcome of the cluster analysis suggests different mechanisms are required to explain the magnetization pattern. Indeed, the tendency of the clusters 1,4, and 5 supports the theory of demagnetization at large impact basins and enhanced magnetization at the antipodal sites [Mitchell et al., 2001, Hood et al., 2001, Halekas et al., 2001a]. The large variation of parameters in clusters 2 and 3 might be explained if the magnetization exists in a relatively thin layer near the surface as suggested by Halekas et al., 2001b. Thus cluster analysis seems to be a promising tool to direct further investigation needed to unfold the present magnetization pattern.

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