**Introduction:** Apollo surface magnetometer measurements provided useful constraints on the origin of lunar crustal magnetism [1,2] and the electrical conductivity, thermal profile, and composition of the lunar mantle [3,4,5]. Apollo and Lunar Prospector orbital magnetometer (MAG) and electron reflectometer (ER) measurements have provided further constraints on the origin and nature of the crustal magnetism [6,7,8]. However, the fundamental issues of the existence and size of a lunar metallic core and whether a core dynamo field existed during early lunar history remain unresolved. In addition, the origin of unusual albedo markings (“swirls”) that are associated with the strongest anomalies remains poorly established [7,9].

Recent laboratory paleomagnetic studies on returned samples suggest that a steady dynamo field may have existed at ~ 4.2 Gyr [10]. But other laboratory studies [11] have raised questions about previous evidence for a “high-field” epoch from 3.6 to 3.9 Gyr [12]. Therefore, any additional evidence, such as that from orbital data, would be useful for confirming or denying the existence of a former dynamo.

Improved orbital measurements resulting from the Lunar Prospector (LP) mission have shown that (a) many orbital anomalies correlate with surface exposures of Imbrian-aged impact basin ejecta [6,7,8]; and (b) the largest concentrations of strong crustal fields occur antipodal to the last major basin-forming impacts [13]. Such a distribution can be explained by models that involve shock remanent magnetization in transient fields generated by impact plasmas and do not require a core dynamo [14].

However, there is one form of possible orbital evidence for an early core dynamo. It involves the detection of central magnetic anomalies in some Nectarian-aged basins [15]. In particular, there is a central anomaly in the early Nectarian basin, Moscovienne, that is seen in both the Lunar Prospector ER and MAG data (Figure 1). Similar central anomalies are present in many terrestrial impact basins and are attributed to natural remanent magnetization in the terrestrial dynamo field subsequent to the impact [16]. Further studies of lunar central basin anomalies and comparisons with their terrestrial counterparts are therefore needed to determine whether these anomalies provide evidence of a former lunar dynamo.

**Crustal Magnetism Application:** The depth and thickness of lunar crustal magnetic sources are important quantities for evaluating whether a steady core dynamo field existed when they formed. A shallow, surficial source (e.g., a deposit of basin ejecta no more than a few hundred meters thick) may have formed rapidly enough to have been magnetized via shock in a
transient field generated during the impact process (e.g., [14]). However, a source that is more than ~1 km thick or deep may imply formation over a longer time period in a steady field, e.g., by thermoremanent magnetization.

Constraints on the depth and/or thickness of a magnetic source body require vector magnetometer measurements at a minimum of two different altitudes [17]. Additional measurements at the surface would provide significantly stronger constraints. In the case of the Reiner Gamma anomaly, LP orbital measurements at altitudes of ~19 km and ~35 km have been used to infer that sources must be within a few km of the surface [18]. If future surface magnetometer measurements are obtained at the surface of this anomaly, the thickness and/or depth of the source could be determined more exactly.

To demonstrate the importance of surface magnetometer measurements in constraining the source volume and depth, we have carried out forward model calculations for the Descartes anomaly, which is the strongest single anomaly on the near side [7,8]. We consider two possible endmember source models: A point dipole at some unknown depth and a thin circular disk at the surface with an unknown diameter. Iteratively adjusting the model parameters (dipole moment, direction of magnetization, depth), a reasonable fit (rms: 1.87 nT) to the available LP MAG data at an altitude of ~35 km is obtained for a dipole centered at 60 km depth with a nearly eastward orientation. The field expected at the lunar surface if this model is valid is only 59 nT. For the thin circular disk model, a best fit (rms: 3.05 nT) is obtained for a disk radius of 70 km and a nearly eastward magnetization direction. In this case, the maximum surface field amplitude would be >1000 nT for an assumed thickness of ≤ 2 km. It is therefore clear that surface magnetometer measurements would be very valuable for constraining source models. In combination with orbital measurements at two or more different altitudes, the depth and/or thickness of the source could be estimated. Such an analysis would directly test the hypothesis (7) that the Descartes mountains, which are ejecta from the Imbrium basin, are sources of the anomaly.

A similar analysis of the Moscovianese anomaly (Figure 1) would yield similar results. Surface magnetometer measurements along a surface traverse or even at a single location would significantly constrain source models. In particular, such measurements in combination with existing orbital data at ~35 km altitude would allow an evaluation of whether the source consists of a thin layer of ejecta from a younger basin that lies beneath the mare surface or of a deeper-seated source associated with the formation of Moscovianese itself. If the latter model prevails, then the Moscovianese anomaly may represent significant orbital evidence for a former core dynamo.

**E.M. Sounding Application:** Apollo surface magnetometer data combined with data from the high orbiting Explorer 35 yielded significant constraints on lunar mantle electrical conductivity at depths greater than a few hundred km [3]. However, degradation with time of the Explorer 35 magnetometers allowed only analysis of Apollo 12 surface data. In addition, apparent offset errors were present in the surface magnetometer data at intervals of ~6 hours [3], which limited the accuracy of the sounding data at the lowest frequencies. In order obtain improved constraints on lunar thermal state and composition [4,5], it would therefore be valuable to obtain simultaneous, carefully intercalibrated, lunar surface and orbital magnetometer data in the future. Any measurements obtained by a magnetometer at a surface geophysical station could potentially be used for this purpose provided that a second magnetometer is in a high lunar orbit at the same time. For sounding of the shallow mantle (depths less than several hundred km), magnetotelluric methods, which require also surface measurements by an electric field probe, could be more effective than the dual magnetometer method [19]. For the e.m. sounding application, surface magnetometer measurements are best obtained at sites with weak crustal fields to avoid plasma interaction “noise” caused by the solar wind impingement on strong crustal fields.