A MODEL FOR THE FORMATION OF MAGNETIC ANOMALIES ANTIPODAL TO LUNAR IMPACT BASINS; L. L. Hood, Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona 85721.

Introduction: Maps of the distribution of lunar magnetic anomalies produced by the electron reflection method have shown that the largest concentrations of lunar crustal magnetization occur antipodal (diametrically opposite) to 4 relatively young large impact basins: Imbrium, Orientale, Serenitatis, and Crisium (1). Each of these regions is also marked geologically by the occurrence of (a) unusual grooved or pitted terrain that is believed to be the result of modification by converging seismic waves generated by the associated basin impact (2); and (b) swirl-like albedo markings of the Reiner Gamma class (e.g. ref. 3). By analogy with the mascons, which are directly correlated with young large lunar basins, these magnetization concentrations antipodal to young large lunar basins have been referred to as 'magcons'.

Model Description: In this paper, we develop a model for the formation of the magcons that considers the basin formation process, antipodal seismic modification effects, and the interaction of a thermally expanding impact-produced plasma cloud with an ambient magnetic field. As initial conditions, we assume the presence of a weak ambient field that has had time to diffuse into the highly electrically conducting lunar interior (Fig. 1A). The ambient field could in principle be produced by a weak former core dynamo but, for simplicity, only a spatially uniform interplanetary field oriented along the impact symmetry axis is considered here. Typical present-day interplanetary field amplitudes are in the range of 6-12 nT but may have been as large as 60-80 nT during the time of formation of Imbrian-aged basins. For the case of a basin-forming impact occurring at an incident velocity greater than about 10 km s⁻¹, partial vaporization and subsequent ionization of projectile and target material occurs leading to the formation of a thermally expanding vapor and plasma cloud (Fig. 1B,C). Previous detailed calculations of ionization rates and approximate electrical conductivities show that the magnetic Reynolds number of the expanding gas is >> 1 so, to first order, it is admissible to neglect diffusion of the field through the plasma cloud in comparison to advection. The internal energy density of the cloud is much greater than that of the ambient field; the field will therefore be excluded from the volume occupied by the highly conducting gas. As the gas expands around the Moon, field lines are tied to the highly conducting solid lunar interior but are forced away from the impact point external to the surface leading to a strong concentration of flux at the antipode (Fig. 1D,E). From conservation of flux alone, the field intensity within a circular zone of radius ~100 km near the basin antipode (comparable in size to the magcons) would be amplified by a factor of about 300. Field intensities as large as 0.1-0.2 G (1 G = 1 Oe = 10⁻⁴ T) are therefore expected for assumed ambient field amplitudes of 40-80 nT. If a former core dynamo provided significantly larger surface fields, then these estimates would be increased in proportion. As the compression approaches the antipode, plasma physical processes including reconnection of the compressed field and diffusion of the field into the dissipating plasma cloud must be considered and will eventually act to limit the maximum field amplitude.

Remanence Acquisition: Acquisition of magnetic remanence in the antipodal zone during the period of compressed field amplification may occur by one of several mechanisms: (a) Acquisition of shock remanence during the seismic modification process; (b) acquisition of shock remanence by impact of solid ejecta from the basin forming event; and (c) thermoremanence of subsurface magma intrusions released by antipodal crustal fracturing. To investigate the plausibility of each, the time scales characterizing these processes may be compared to the rate of expansion of a basin-forming impact plasma cloud and the time scale for decay of thermal energy within the cloud. The expansion velocity determines the approximate time for arrival of compressed ambient magnetic fields at the antipode while the internal energy decay determines the maximum length of time during which field amplification can persist. For the purpose of calculating the latter two quantities, we use a one-dimensional numerical model for the expansion of impact-produced vapor clouds which includes a geometrical spreading factor to translate the modeled linear expansion into an approximate spherical expansion (4). Results show that a nominal 100-km radius silicate (gabbroic anorthosite) impactor with an incident velocity of 15 km/sec produces a plasma cloud that expands to a distance comparable to half the lunar circumference in a time of ~200 sec and has an internal energy density that exceeds that needed to confine a compressed 1 G field for of the order of 10⁹ sec. For comparison, arrival times of seismic body waves with velocities of 8 km/sec would be about 8 minutes while those of surface waves with velocities of ~1.2 km/sec would be about 80 minutes. In the case of basin ejecta, ballistic calculations on a spherical
moon for ejection angles of 30° to 60° yield antipodal arrival times of 28–50 minutes (e.g. ref. 2). In the case of magmatic intrusions, the time scale for conductive heat loss and acquisition of thermal remanence is at least years and probably tens of years. Consequently, mechanisms (a) and (b) are viable while mechanism (c) requires considerably more time than appears realistic for plasma confinement of an ambient field.

If shock remanent magnetization (SRM) produced by seismic waves or by secondary basin ejecta impacts in antipodal zones is the primary remanence mechanism, then it is of interest to consider expected magnetization intensities for reasonable shock ranges and compressed ambient field amplitudes. In the case of antipodal seismic effects, theoretical calculations indicate that a basin-forming impact with energy ~10^{34} ergs would produce an antipodal seismic wave with a compressive stress of several hundred bars (2). These shock pressures are considerably below those at which stable SRM has been found to occur in shocked lunar soils (50–250 kbar; ref. 5). However, even weak shock ranges (~5 kbar) have been shown to produce magnetically soft SRM in several experiments (6). In the case of antipodal secondary ejecta deposition, peak shock pressures from secondary impacts produced by basin-forming events have previously been estimated as a function of ejecta range (e.g. Table 3 of ref. 4). The resulting shock pressures exceed 100 kbar and are therefore sufficiently strong that efficient acquisition of magnetically hard SRM is expected. By comparison with the experimental results of refs. 5, remanent magnetization intensities of the order of 10^{-4}–10^{-3} G cm^3 g^{-1} may be estimated. These levels are comparable to or larger than the largest magnetization intensities measured for returned samples and would be sufficient to account for the observed anomalies if a sufficiently large volume of material acquired SRM.