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Impact-generated magnetic fields on the Moon : a magnetohydrodynamic numerical investigation

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Natural remanent magnetization has been identified in lunar rocks, the lunar crust, and a diversity of meteorites. Much of this magnetization is thought to have been produced by cooling a core dynamo mag-netic field. However, the identification of lunar crustal magnetic anomalies at the antipodes of four of the five youngest large (>600 km diameter) impact basins has motivated the alternative hypothesis that the lunar crust could have been magnetized by the impacts. In particular, it has been proposed that highly conducting ionized vapor produced by a basin-forming impact interacts with the ambient solar wind plasma surrounding the Moon to amplify the ambient solar wind magnetic field or any core dynamo field. In this picture, as the ionized vapor cloud expands around the Moon, it pushes and compresses the solar wind plasma into a small region at the antipodal point. The conservation of magnetic flux then leads to an enhanced magnetic field in the compressed plasma. This field can then be recorded as shock remanent magnetization by crustal materials at the antipodal point following the impact of converging basin ejecta.

A key requirement for the impact-generated fields hypothesis is that the compressed field be suffi-ciently strong to explain the lunar paleointensities (at least tens of μT) and maintained at the antipodal point for a sufficiently long time (several hours) for the ejecta to arrive and impact the surface. Previous simulations of the expansion of the vapor cloud found that the enhanced field will be strong enough (per-haps reaching hundreds of μT) and will remain at the antipodal site for a sufficiently long time (>1 day) for the arrival of incoming ejecta. However, these studies did not include an explicit calculation of the interaction of the magnetized solar wind plasma with the vapor cloud. Rather, the cloud evolution under the lunar gravity was simulated in the purely hydrodynamic regime. The vapor cloud structure at certain times was used to derive a simplified picture of what the effects would be on an ambient magnetized plasma using general magnetohydrodynamic (MHD) arguments. The solar wind drag acting on the cloud, as well as MHD effects such as field lines stretching and magnetic reconnection were not taken into ac-count.

With the advances made in computational MHD models in recent years, we can now revisit these ear-lier important models. Our goal is to perform the first MHD simulations of an impact-generated vapor cloud expanding in the solar wind around the Moon, using BATSRUS, a 3D highly-parallelized versatile MHD code developed at the University of Michigan, in order to self-consistently test the previous estima-tions of the strength and duration of the magnetic field enhancement at the antipodal points. We will con-sider different MHD processes, such as: 1) the finite resistivity of the lunar mantle 2) magnetic diffusion between the solar wind and the initially non-magnetized cloud, 3) magnetic reconnection at the antipode, and 4) viscous drag and the transport of magnetic flux due to solar wind motion, and 4) MHD instabili-ties. This will allow us to systematically examine whether impact-generated fields can indeed be respon-sible for the formation of crustal field enhancements on the Moon.