IMPACTOR MATERIAL AS AN ORIGIN FOR LUNAR ANTIPODAL MAGNETIC ANOMALIES. S. Wakita1*, B. C. Johnson1, I. Garrick-Bethell2,3, and T. M. Davison4, 1Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN, USA 2Department of Earth and Planetary Sciences, University of California, Santa Cruz, CA, USA. 3School of Space Research, Kyung Hee University, Korea. 4Department of Earth Science and Engineering, Imperial College London, London, UK (*swakita@purdue.edu).

Introduction: The Moon has several magnetic anomalies antipodal to lunar basins [1-5]. Some of these anomalies represent the strongest magnetic fields measured from lunar orbit (i.e. Gerasimovich [3]). The details of how these basin-antipodal magnetic anomalies formed are debated [4, 5]. If they are in fact associated with basin formation, their magnetization age may be constrained, thereby providing information about the lunar dynamo at a specific point in time. Here we simulate oblique impacts at high resolution and find that antipodal ejecta are dominated by impactor material. We argue that hot iron-rich impactor material in antipodal ejecta is a natural explanation of antipodal magnetic anomalies.

Antipodal ejecta: We calculate the trajectory of impact ejecta using their velocity and ejection angles via ballistic equations [5, 6]. When the ejecta have a suitable velocity and ejection angle, they can reach the antipode of the impact basin [6]. The range of such velocity is between the escape velocity of the target object ($v_{esc} = 2.34$ km/s) and the velocity for the circular orbit ($v_{circ} = 1.68$ km/s) and the ejection angle must be less than 45° (in the absence of planetary rotation). We derive the ejecta velocity and ejection angles from head-on and oblique impacts using numerical simulations, then calculate the ejecta’s trajectory.

Methods: We simulate spherical impactors striking a flat target using the iSALE-3D shock physics code [7, 8]. We use Lagrangian tracer particles to track the ejecta and determine their origin. In this initial work, we fix the impact velocity as 17.4 km/s, which is the average impact velocity on the Moon [9], the radius of impactor as 50 km. For a typical 45° impact the resultant basin would be ~1100 km in diameter. The impactor and target are both assumed to be dunite [10]. Our simulations have a resolution of 1 km or 50 cells per projectile radius. We define the impact angle as the degree from the horizontal. Using the above settings, we examine impacts with the angles of 90° (head-on), 45°, and 30°.

After ballistic ejection, ejecta travel elliptically over the Moon’s surface [6]. We take the velocity of ejecta when they reach 50 km height, then we solve the analytical equations for their trajectory [5, 6]. Note that the rotation of the Moon will influence the travel of the ejecta as previously suggested [5, 6]. In this initial work, we calculate the ballistic trajectory of ejecta on a non-rotating object.

Figure 1: Distribution of the ejecta from an oblique impact of 30°. Color represents travel time of ejecta in hours. Arrows in right hand side depict the direction of impactor and the impact site. Ejecta with shorter travel times are underneath ejecta with longer travel times. Light grey circles mark every 30° in latitude.

Results: Figure 1 shows the ejecta distribution of the oblique impact of 30°. The right panel represents the impact hemisphere, and the left one represents the antipodal hemisphere. The travel times of the ejecta become longer as they approach the antipode. The travel time is less than 2 hours on the impact hemisphere. For the impact angles explored here, the earliest antipodal ejecta arrives 10 hours after the impact, while late arriving ejecta may take more than a week to reach the antipode, during which the Moon may rotate significantly.

The distribution of antipodal ejecta has a strong dependence on impact angle. We show the ejecta distributions of the antipodal hemisphere in Figure 2. As expected, ejecta are distributed symmetrically in the case of head-on impact while most of the ejecta are distributed to the right of the antipode in the case of oblique impacts (Figure 2). During an oblique impact, the fast ejecta are preferentially ejected in the downrange direction. Although antipodal ejecta are rather limited in the case of head-on impacts, oblique impacts produce abundant antipodal ejecta (Figure 2). More oblique impacts (lower impact angle) eject material at lower angles, and material ejected at lower angles can more easily reach the antipode. This result is consistent with previous work [5].

One potential important aspect of antipodal ejecta for understanding magnetic anomalies is the ejecta’s provenance or original location (Figure 2). Some antipodal ejecta come from the relatively shallow depths in
the target. However, antipodal ejecta is dominated by impactor material (55% for 30° and 99% for 45°). The assumed impactor material, dunite, is similar to ordinary chondrites [11].

If the impactor contains magnetic materials (e.g., ordinary chondrites are 20-30 wt% iron [12]) and this material was near the Curie temperature upon emplacement, it could have recorded the ancient lunar magnetic field. In future work, we will determine the temperature of antipodal ejecta after release from high pressure and consider the cooling time scale of this material. Order of magnitude estimates suggest meter scale fragments have a cooling timescale similar to the expected travel time. Our results indicate that antipodal ejecta dominated by impactor material may efficiently record the ancient lunar magnetic field.

Discussions: Lunar magnetic anomalies antipodal to basins are slightly shifted from the actual antipode of the basins [4-6]. A study based on analytical calculations of ejection velocities reported how the rotation of the Moon shifts the location where antipodal ejecta are emplaced [5]. Including the effect of the rotation (and impact location) is the subject of ongoing work. As a test, we will compare our results to the antipode of Tycho crater, which exhibits an anomalous rock abundance that is displaced from the antipode [13]. Low altitude measurements of the magnetic field [14] around antipodal anomalies would act as a strong test for the impactor origin hypothesis.

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Figure 2: Provenance depth of ejecta landing on the Moon’s antipodal hemisphere. Top halves of each panel represent ejecta from the impactor (red points), and the bottom halves represent material from the target (colored according to depth in the target). Note that some ejecta overlap: ejecta from 10 km depth are emplaced underneath ejecta from 20 km and 30 km depth.