**PALEOMAGNETISM OF IMPACT GLASS AND SPHERULES FROM LONAR CRATER, INDIA.**

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**Introduction:** The origin and sources of magnetic fields on the asteroids and Moon for the last 3 billion years are largely unknown because most extraterrestrial samples which might provide paleomagnetic records predate this epoch. An exception is the small amount of nearly ubiquitous melt which has been continuously created by hypervelocity impactors over most of solar system history [1].

To date fewer than a dozen paleomagnetic measurements have been conducted on recent (<3 Ga) lunar impact glasses. Surprisingly, these have indicated that there may have been substantial (microtesla) fields on the Moon within the last few hundred million years. Because it is unlikely that there was a dynamo on the Moon this recently, it has been speculated that this paleomagnetism is the product of transient, impact-amplified plasma fields [2]. To assess the impact field and the dynamo hypotheses, many more lunar glasses of a variety of ages must be analyzed.

Before attempting such a program, it is important to use terrestrial analogs to demonstrate that impact glasses can provide accurate paleointensity records. Towards this end, in January 2005 and 2006 we collected thousands of samples of basaltic glass from the perimeter of Lonar Crater, a 1.8 km diameter impact crater which formed approximately 50,000 years ago in the Deccan Traps in Maharashtra, India. This project is part of a multidisciplinary planetary science effort [3] to map, date, structurally characterize, and study the paleomagnetism of what is the only fresh impact crater on the Earth in a basaltic target.

**Lonar Glass:** We collected basaltic impact glass [4] from six localities situated several hundred meters to the east, west and north of the crater rim [3]. Glasses from the east and west rim have rounded features and are between 0.01 and 1 cm in size, indicating that they are fläden and impact spherules formed from molten ejecta that cooled in mid-air while subject to rotational and aerodynamic forces (Fig. 1). The ranges of shapes are nearly identical to that found in lunar regolith.

Paleomagnetic data on the glasses as well as surrounding unmelted Deccan basalt [5] were acquired in the MIT Paleomagnetism Laboratory. Hysteresis measurements indicate that the glasses are strongly magnetic (saturation remanence of ~2 A $m^{-1}$). The glasses have a squareness of 0.2, a ratio of coercivity of remanence to coercivity of 2, a ratio of initial susceptibility to saturation remanence of 0.007, and have

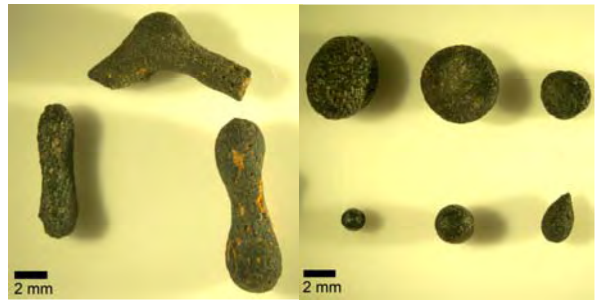


**Figure 1.** Basaltic impact spherules with a variety of splash forms recovered from Lonar Crater, India. Note dumbbells (bottom of left photo) and pancake-toroid forms (top middle and center of right photo).

no significant remanence anisotropy. Thermal demagnetization (Fig. 2) indicates a Curie point of ~520 °C and isothermal remanent magnetization (IRM) acquisition saturates at ~300 mT. These observations indicate that crystals of single domain and superparamagnetic low-Ti titanomagnetite are likely the primary ferromagnetic constituents. These characteristics are ideal for recording paleofields with high fidelity.

**Natural remanent magnetization.** We have conducted alternating field and thermal demagnetization on three dozen glass samples ranging from 1 to 30 mm in diameter. All glasses carry a natural remanent magnetization (NRM). Given their high temperature origin and lack of evidence for secondary minerals, this should be a thermoremanent magnetization acquired during primary cooling. Because glasses smaller than several mm in diameter exhibit rounded, rotationally sculpted forms, they solidified while airborne. We therefore hypothesized at the start of these experiments that their magnetization was acquired while translating and spinning.

During thermal demagnetization, large (>1 cm diameter), irregularly shaped glasses, which should have cooled at least partly after landing (cooling timescale to room temperature of several minutes or more), exhibit one or more low blocking temperature magnetization components and a stable high blocking temperature direction (Fig. 2 Top). Thermal demagnetization up to the Curie point typially reduces the moments by a factor of 10-100. The rounded samples also usually have a stable low blocking temperature component, but after even mild (100-300°C) heating their moments exhibit large (tens of degrees) changes in direction with little decrease in moment intensity (Fig. 2 Bottom). Thermal demagnetization up to the Curie point

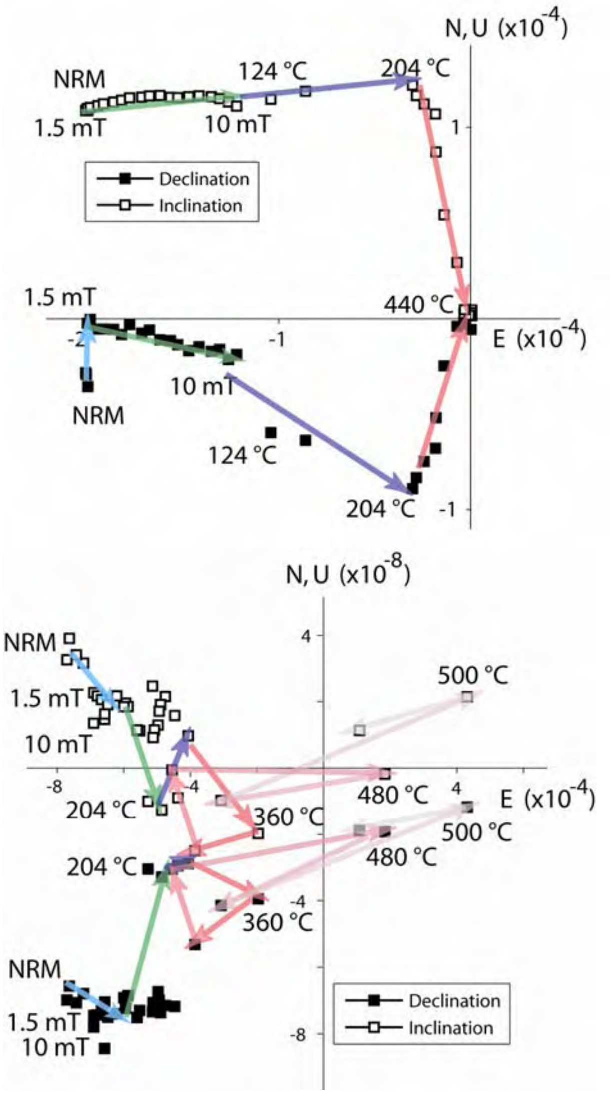


**Figure 2.** Zijderveld diagram for Lonar glasses, showing evolution of natural remanent magnetization during alternating field and thermal demagnetization as projected on arbitrary horizontal and vertical planes. (**Top**) Large (1.5 cm diameter) irregular glass (sample LONGL-34). (**Bottom**) Small (~ 1 mm x 4 mm) glass dumbbell with long axis oriented north and horizontal (sample LONGL-49). For nearly all samples, alternating field demagnetization to 1.5 mT removes a low-coercivity component (light blue). Subsequent AF demagnetization to 10 mT removes one or more higher coercivity components (green). While thermal demagnetization removes one or more low temperature components (purple, deep red). Small (< several mm sized) glasses appear to have multiple high temperature components (ligher red colors).

only reduces the moment intensity by a factor of 2-4.

Ratios of NRM to saturation isothermal remanent magnetization (sIRM) for the small glasses are only 0.5-1×$10^{-3}$, while the large glasses have ratios twice as large. These are nearly an order of magnitude smaller than that measured for nearby Deccan basalt [5] and for submarine basaltic glass [6]. This indicates the Lonar samples are inefficiently magnetized.

**Conclusions:**

*A new type of magnetic remanence?* Essentially all natural samples carrying a thermoremanence that have been previously studied using paleomagnetic techniques were nearly stationary during the time that they acquired their magnetization. Probably the simplest interpretation of the unusual demagnetization behavior of the Lonar glasses is that it is the result of progressive removal of different magnetization components that were blocked while the orientation of these spinning and translating samples changed relative to the paleofield. We are continuing to test this hypothesis with additional rock magnetic and petrographic analyses. Such a motional magnetization process has to our knowlesge never before been previously described in natural samples. Although it should be extremely rare on Earth, it may be one of the most common modes of remanence acquisition on the surfaces of small extraterrestrial bodies during the last several billion years.

*Planetary paleointensity records and impact-generated fields.* The NRM/sIRM ratio is roughly proportional to the intensity of the field which magnetized a sample, with a ratio of ~1% indictive of an Earth-strength (several tens of microtesla) field [7,8]. Therefore, the low NRM/sIRM ratios of the glasses indicate that (a) there is no evidence of impact-generated paleofields substantially greater than several tens of μT at Lonar crater, consistent with our studies of Lonar basalt cores [5], and (b) the glasses slightly underestimate the intensity of the field in which they cooled, probably due to the effects of rotation during cooling. Paleointensity from small spherules likely provide lower limits on the paleointensity of any fields in which they formed. Given the near complete lack of knowledge about the recent evolution of paleofields on extraterrestrial bodies, we expect that the paleointensity records in glassy impactites (particularly large spherules and stationary melt sheets) will be extremely valuable because these are among the few young planetary samples.

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