Planetary science

Magnetic fields from impacts

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ONE of the most spectacular discoveries of these early years of the age of space exploration is the ubiquitous record of cratering on ancient planetary surfaces. For those who seek to document the magnetic fields of the early Solar System, the cratering is of great interest because the impacts may have generated magnetic fields. Furthermore, if such impact-generated magnetic fields could explain observed magnetic results, planetary scientists would not have to invoke internally generated fields, dynamos and cores to explain the palaeomagnetic records of planets. Despite this interest, definitive laboratory-scale experimental work has been lacking in what is clearly a difficult area. But on page 50 of this issue¹, Crawford and Schultz report intriguing results on the generation of magnetic fields by low-angle, hypervelocity impacts in a low-field environment.

Their work was carried out using the NASA Ames vertical gun range, which fires centimetre-size metallic or plastic projectiles into an evacuated chamber at velocities of 3–7 km s⁻¹. The gun is mounted on a large A-frame so that it can fire through different ports to provide various impact angles. The authors carried out the experiments in a reduced field of about 500 nanotesla (nT) and at various higher field strengths. For comparison, the present field of the solar wind is a few nanoteslas. A powder target and a low angle of impact were used to enhance the production of a partially ionized cloud (see figure).

The authors monitored the magnetic fields with three coil arrays. The impacts generate vertical fields of up to 100 nT beneath the target in each experiment, regardless of the sign or magnitude of the ambient field. A vertical coil monitored toroidal fields of 100 and 1,000 nT generated above the target. These fields are also independent of the ambient field. The vertical coils down-range from the target measured compressed-ambient-field signatures which reversed in sign with the ambient field. The authors conclude that the spontaneous fields in the target area could be produced in a field-free environment by hypervelocity impacts, a conclusion which could be confirmed by more detailed field monitoring with devices such as miniaturized Hall probe detectors. The fields arise from currents which flow in the plasma in response to strong temperature and pressure gradients. This field generation is to be distinguished from field amplification by plasma compression (which I discussed in a previous News and Views article²).

These experiments join a substantial,

but not yet definitive body of work which seeks to establish whether impacts generate magnetic fields^{3,4}; whether such fields magnetize target materials; and whether this is important on planetary surfaces.

Experiments clearly show that impacts can magnetize materials when performed in ambient fields of the order of microteslas. Shock magnetization is the dominant mechanism of magnetization in material not heated substantially and

Luminous vapour cloud produced by a 15° impact at 4.76 km s⁻¹ of a 0.64 cm aluminium projectile on a powdered dolomite target. Magnetic search coils buried beneath and suspended above the target measured the magnetic signals generated during the event.

thermoremanent magnetization is acquired by material whose residual temperature is sufficiently high. In addition, new magnetic phases generated will acquire magnetization. It is less clear whether the fields discussed by Crawford and Schultz would be recorded. If the field were to coincide with the shock wave passing through the material, it could produce shock remanent magnetization. Indeed, the proposed vertical field may thus explain observations of shock magnetization made 15 years ago in our laboratory⁵.

It is also possible, as Crawford and Schultz suggest¹, that microscopic fragments heated by the impact might cool in the impact generated fields. But it seems unlikely that fields extant only for a few milliseconds could magnetize any substantial mass by this mechanism because the cooling would be insufficient.

As for the planetary effects of impact magnetization, impact craters on Earth have associated magnetic anomalies. Thus, in the geomagnetic field of tens of microteslas, crustal magnetization does take place. As a corollary, the absence of magnetic anomalies at a crater indicates strongly that the impact did not take place in the presence of such fields. There are abundant craters on the Moon. But studies of the magnetic fields associated

with them give little comfort to those who favour impact-generated magnetization. Lin has convincingly shown⁶ that the cratered regions are not in general more magnetic than the non-cratered. Indeed, the only basins and craters which have associated magnetic anomalies were formed when the Imbrium and other great basins were formed⁷, suggesting that only at this time ($3.6\text{--}3.9 \times 10^9$ years ago) did the Moon's surface experience a strong magnetic field of around a microtesla. It seems that the magnetization from fields generated by impacts could account for the magnetization of some lunar samples, but is unlikely to be a significant source of lunar magnetic anomalies.

Crawford and Schultz's suggestion that the magnetized glass on lunar sample 70019 records thermoremanent magnetization acquired in an impact-generated field is plausible, but not compelling. The sample was collected to see whether glass generated in a very young crater carries magnetization. If the scaling for the 3-m crater in which the glass was found is correct, the sample must have cooled in milliseconds to match the data. This has previously led Sugiura and colleagues to suggest that the glass might have come from a nearby larger crater⁸. Moreover, although the actual intensity determinations represent a noble effort to overcome the difficulties encountered in working with the lunar samples, they do not satisfy standard quality control tests of the method. Such questions should be studied in a long overdue re-examination of lunar samples with modern techniques.

The intriguing experimental results of Crawford and Schultz once again raise the issue of the importance of impacts as a source field for the magnetization of ancient planetary surfaces. Compression and amplification of ambient fields has been used to explain planetary surface magnetization, as a result of impacts of solid bodies^{9,10} or comets¹¹. This is likely to be an important mechanism. These new experimental results from Crawford and Schultz provide further evidence that the generation of magnetic fields by impacts could provide a mechanism for magnetization in very low-field environments. It remains to be seen whether the strong temperature and pressure gradients that drive the field generation can be scaled to large impacts on a planetary surface. □

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