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Lunar magnetism

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Abstract

We have completed a reexamination of the old Apollo paleomagnetic data using modern techniques of analysis and presentation. When new measurements are available, the agreement between them and the old Apollo era data is strikingly good. The principal result is that several samples appear to be carrying primary natural remanent magnetization (NRM) acquired on the Moon and recording an early lunar dynamo field. This field reached levels greater than the present Earth's surface field. It may have switched on by 4.2 Ga and lasted for several hundred million years, but this suggestion requires additional testing. Such a history for a dynamo in so small a core may be problematic for a convection driven core and require another driving force.

1. Introduction

The development of new and improved techniques of analysis has made results of lunar paleomagnetism more reliable. However there are fundamental difficulties in lunar studies compared with terrestrial work. For example, the Fe and FeNi carriers of natural remanent magnetization (NRM) in lunar samples are poorer paleomagnetic recorders than the iron oxides and sulphides in terrestrial samples because of the small size range of single domain particles in these metals. A second problem is the possible role of shock effects from impacts. This has led to a reexamination of shock remanent magnetism (SRM) and shock demagnetization at higher shock levels than formerly. Yet it appears that shock in Mare basalts is in general less than a few GPa, and the SRM can be identified and eliminated. Moreover in melt rocks and melt breccias the effects of shock are so profound that an essentially new rock is formed, which can carry primary NRM acquired as it cools. The situation in the regolith breccias formed by impact related shock of few GPa is less clear. Finally, heating lunar samples without producing irreversible changes, which invalidate thermal demagnetization (TD), has proved very difficult. This has led to increased dependence upon AF demagnetization (AFD) to eliminate noise and the determination of AFD characteristics to distinguish possible mechanisms of magnetization of NRM.

2. Methods and Results

We require the following minimal criteria to be satisfied before accepting results as a reliable paleomagnetic record. There should be no petrologic evidence of shock of >5 GPa. Second AFD, or TD should be successful in isolating a single direction of NRM as demagnetization continues to completion. The third criterion requires agreement in direction and intensity of NRM between sub-samples from a single rock sample. Fourth and finally the AFD, or TD characteristics of NRM should be consistent with thermal remanent magnetization (TRM).

2.1 Mare basalts

Among the Mare Basalts, Apollo 11 sample 10020 satisfies these criteria. It is a low K basalt, from the oldest group of Apollo 11 samples, with an age of ~3.7 Ga. In a recent study by Shea et al. [1], a single direction was isolated after elimination of soft noise and found to be stable to 260 mT. Similar results were obtained from mutually oriented samples. The intensity from normalization with TRM proxies was ~60 microT and hence similar to the terrestrial surface field. This is also similar to earlier results form the Apollo days. Additional analyses of Mare Basalts 10017 and 10049 gave similar results [2]. Other important recent results have come from Cournède et al., [3]. The fields recorded by the basalts of Apollo 11 and Apollo 17 are stronger than those recorded by Apollo 12 and Apollo 15 basalts. Indeed it is not clear that any reliable records have come from these younger samples.

2.2 Breccias

The histories of breccias are more complicated than those of mare basalts and their NRM is harder to interpret. For regolith breccias, interpretations are complicated because of their strong superparamagnetic components and their complex, polymict lithologies. It would be unwise to use these samples for paleointensity estimates unless one can be sure that the NRM was entirely acquired as TRM during cooling after the shock event, as may be the case for 15498. In contrast, the melt rock and melt breccias, which include samples formed at high temperatures far above the Curie point of any magnetic carriers, have an excellent chance of recording lunar fields faithfully as they cool. This cooling may have taken place in a melt pool in a simple crater, or in a melt layer in a complex crater. Such samples would then have been excavated and deposited in the regolith and some appear to have recorded strong fields, but more work needs to be done to test this suggestion. Other melt rocks and melt breccias have had more complicated histories and appear to have been deposited in ejecta blankets, where final cooling took place. A useful, if imperfect, analogy may be pyroclastic volcanic deposits. The samples from the Apollo 17 layered boulder 1 at station 2 may provide an example of such a history. If a pTRM can be related to this secondary cooling, then we will be able to recover a record of the field during this cooling event. Samples such as 62235 and 72215 may provide just such a record, with Apollo-era and modern estimates of fields around 100 microT.

3. Summary and Conclusions

The results described above confirm the suggestion made by Runcorn and colleagues [7] early in the Apollo days that there was a lunar dynamo field, which decreased in intensity over the age span from ~3.9 Ga to ~3.0 Ga. An important additional data point has been provided by Garrick-Bethell et al., [6], who obtained an intensity of 10's of microT for the 4.2 Ga norite 76535. This may turn out to be the oldest unshocked lunar sample available to us. It was shown that the Argon system, which was used for the age determination of the sample was closed soon after initial cooling and that subsequently the sample has not been heated significantly. While it is important to test this result with other ancient samples, we provisionally conclude that the dynamo switched on very early in lunar history prior to 4.2 G and lasted until between ~3.5 to 3.3 Ga. Given this history of the lunar field, it is hard to see how the cooling of so small a core could have provided the necessary energy for dynamo action lasting between 700 or 900 million years. This result has led to other suggestions to keep the fluid core sufficiently stirred to give dynamo action, such as precession [8].

4. References

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