The Paleomagnetic Record of the Apollo Breccias.

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The breccias have some of the strongest Natural Remanent Magnetism (NRM) of all the Apollo samples and the range of their ages back to at least 4.3 By. means that their NRM may allow us to trace the history of a possible lunar dynamo before the time of the mare formation.

The breccias fall predominantly into three main groups according to their saturation remanent magnetism (IRMs) (fig. 1). Regolith and fragmental breccias have the highest IRMs, followed by melt rocks and melt breccias, and finally cataclastic anorthositic highland rocks, which have the weakest IRMs. On the Day plot (fig. 2) the regolith breccias plot with the soils in the single domain (SD) to superparamagnetic (SPM) trend, whereas the melt rocks and melt breccias plot towards the mare basalts SD to multidomain (MD) trend.

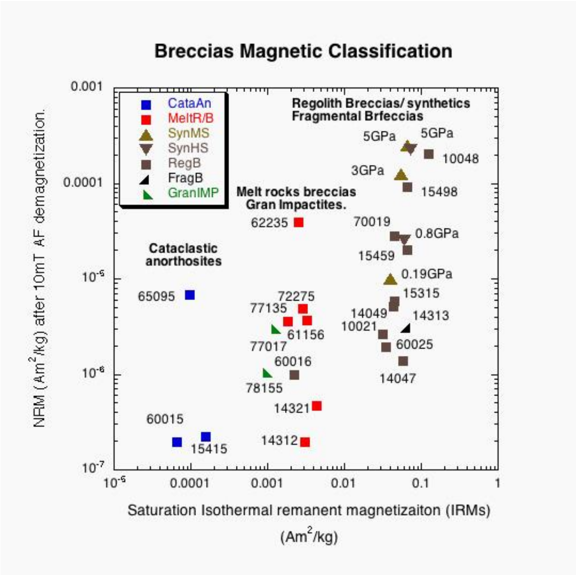

Fig. 1. Magnetic classification of the breccias based on IRMs and NRM.

The regolith breccias have the simplest history. They have IRMs values of 0.05 - 0.2 Am^2/kg with a weak increase from the most friable to the most indurated. The NRM increases by two orders of magnitude following the same trend (fig.1). Synthetic breccias, made by shocking lunar soils up to a few GPa, fall within the same ranges of IRMs and NRM as the regolith breccias. Evidently, this level of shock of a few tenths to a few GPa must have been common on the lunar surface and brought about the lithification of many regolith breccias.

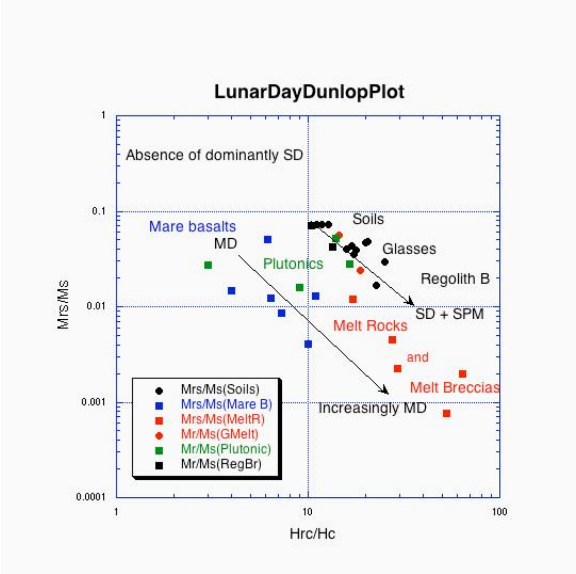

Fig.2.DayDunlop plot of bulk hysteretic properties.

The NRM of regolith breccias is a combination of shock remanent magnetism (SRM) acquired during shock lithification and of thermal remanent magnetism (TRM), or partial TRM depending upon the residual temperature after the shock event. However, with their fine iron in the superparamagnetic and near superparamagnetic grain sizes, they are prone to acquiring viscous remanent magnetism (VRM) in the geomagnetic field. It would be unwise to use these regolith breccias for paleointensity estimates, unless one can be sure that the NRM is entirely a TRM acquired during cooling after the shock event. The fragmental breccias are like the regolith breccias formed by impact lithification, but do not have the soil content of the regolith breccias. Their NRM is similarly difficult to relate to ambient fields during shock lithification.

Of all the Apollo samples, other than the mare basalts, the melt rocks and melt breccias are the most likely to have acquired a simple primary NRM recording a lunar field as they cooled. However, melt rock and melt breccias may have complicated histories.

In the simplest scenario, melt rocks initially cool in a basalt melt pool in a simple crater, or in a layer of melt in a complex crater. Such samples would then have been excavated and deposited in the regolith. Again in the simplest case, there would be no major modification of their primary NRM, which would be the TRM acquired during initial cooling plus some minor secondary NRM. Samples 14310, 68416, 77017 and 77135 may have had such simple histories, and some of them appear to record strong fields, but more work is needed to test this suggestion

As the layered boulder 1 from Apollo 17 Station 2 demonstrates melt rocks and breccias can be found with more complicated histories. This layered boulder appears to have rolled down from the massif from high on the layered South Massif. The samples were taken from different layers (fig.3).

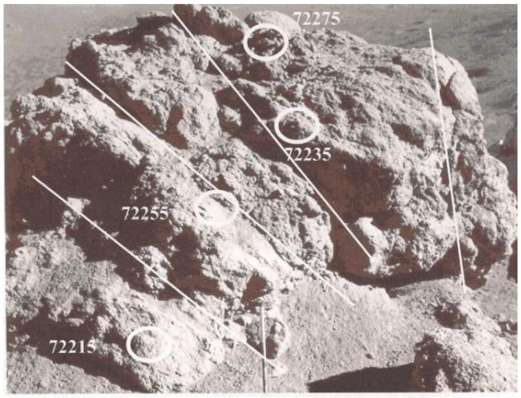

Fig.3, Apollo 17 Layered Boulder 1 at Station.2.

A plausible history of the boulder is that the bedded ejecta were deposits from a single major basin forming event and were laid down either from ballistic trajectories, or from a base surge like aftermath of that event [1]. Thus the various layers may have been deposited at different temperatures, but all were at elevated temperatures.

The work of Banerjee and Switts [2], which took into account the available fieldwork on this boulder allows a more detailed analysis of the NRM of the various samples than has been possible elsewhere. They pointed out that the directions of the NRM of 72255 and 72275 were similar, although they came from different layers of the boulder. They therefore concluded that the NRM of these samples was recording the same field and that a major part of the NRM was acquired after deposition in the South Massif. This was a pTRM, during cooling from about 450-500^{o}C in the ejecta blanket caused by the basin forming event. Following their discussion, we suggest that the field in which they cooled was approximately 100μT, as demonstrated by the paleointensity determination of 72215 [3]. This study also yielded a very low paleointensity of the order of μT for the NRM blocked above 500^{o}C.

The interpretation of the NRM of the samples from this Apollo 17 boulder may provide a key to the NRM of other melt rocks and melt breccias. For example the behavior of the NRM of 62235, which is the most extensively studied of all the Apollo samples, is very similar to that of 72215. However, that sample was found as an individual block on the rim of Buster crater. We therefore lack explicit evidence of any second event, such as the one which formed the Apollo 17 boulder. However, numerous studies of its NRM have yielded blocking temperatures up to about 500^{o}C with paleointensities of around 100μT for the moment blocked up to this temperature and a much weaker intensity of the order of μT for magnetization blocked above 500^{o}C - essentially identical with 72215.

The similarity of the behavior of the NRM of samples from the Apollo 17 boulder and from 62235 is striking and the interpretation of the bulk of the NRM as a pTRM acquired after deposition in an ejecta blanket is pleasingly simple, but it raises a difficult question. Why does the magnetization blocked at the highest temperature record so weak a field?

The weak high temperature blocked moment may be a record of a lunar wide field at around 3.9 By., but if so, it is inconsistent with other determinations of lunar fields at this time. It may also be a remanent magnetization acquired in transit during basin formation in a base surge like event, when the sample was tumbling, or be a combination of moments from individually randomly magnetized clasts, whose high temperature NRM survived the event. Neither answer is satisfactorily demonstrated, and these ideas need further investigation.

In contrast to the difficulty in interpreting the high temperature moment, the pTRM which makes up the bulk of the magnetization appears to be a straightforward record of a field of around 100μT. The paleointensity estimate is essentially constant from about 500^{o}C to 200^{o}C.

We therefore suggest as a working hypothesis to be tested by analysis of additional samples that a lunar dynamo field of approximately 100 μT was recorded by the pTRM of 62235 at 3.83By and by the pTRM of 72215 at 3.88By and that these deposits were laid down at a temperature of approximately 500^{o}C.

References: [1]Stoeser et al., (1974), Proc. LPSC5, 1, 355-377. [2] Banerjee and Switts, (1975), The Moon, 14,473-481.[3] Lawrence et al., (2008), PEPI,168, 71-87.