The investigation and interpretation of the natural remanent magnetization (NRM) of lunar samples is made difficult because of the predominance of fine particles of metallic iron as a carrier of remanence and because for the most part the NRM was acquired in very weak fields. Thus, little of the basic data required for interpretation is available from paleomagnetic studies of the NRM of terrestrial rocks. Although the history of lunar samples is evidently complicated, it is likely that TRM has played some role in their magnetization. We have therefore investigated the TRM of lunar samples in very weak fields. Most of our work has been carried out with the breccia 10048-55(1), and the igneous rock 14053-48(2). We have also studied the TRM and NRM of a variety of possible analogues of lunar material, such as impactites, glasses and tektites. The magnetization of glass on 14047-47(2) is being compared with that of the rock in an attempt to distinguish between magnetization acquired at the time of formation of the rock and magnetization acquired subsequently.

Field Dependence of TRM: In order to interpret the NRM of lunar samples, it is important to know whether TRM is linear over the range of relevant fields. We have investigated the linearity of TRM of a variety of terrestrial samples and of the lunar breccia between 20$^\circ$ and 10$^\circ$ (1 oe). The samples were first heated to 800$^\circ$ C and then allowed to cool in the desired field. The experiment was carried out in a three-stage metal shield with Helmholtz coils inside the shield giving fine field control. To minimize sample degradation, heating was carried out in a hard vacuum. To monitor degradation, repeat determinations of TRM and control observations of saturation isothermal remanent magnetization (IRM) were made. The results showed that the TRM of all but one of the samples was essentially linear. They also revealed the progressive destruction of the carriers of remanence in the lunar breccia. Repeated heating reduced the magnitude of the TRM by approximately one-third and that of the saturation IRM by nearly two-thirds. The carriers which were destroyed were distributed evenly across the microscopic coercivity spectrum except for a disproportionately large amount in the very low coercivity range. Sample 14053-48 departs strongly from linearity in the range of fields investigated and departs from a simple power law relation in fields of a few tenths of an oersted. No destruction of magnetic carriers was observed during heating this rock.

Stability of TRM Against AF Demagnetization: AF demagnetization is a common method of analysis of NRM which serves as a means of eliminating undesirable soft contributions to remanence and as an indicator of the nature of the remanence. It is therefore of interest to obtain the AF demagnetization curves of TRM in a variety of fields and to compare them with NRM demagnetization curves. Preliminary results suggested that the TRM of the lunar samples in very weak fields was distinctively softer than TRM in higher fields.
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However, further work has negated this as a useful diagnostic characteristic of very weak field TRM in 10048-55. By multiple demagnetization with up to ten measurements for each AF field value, we have been able to show that the relative stability of TRM in a wide range of fields is similar. However, the saturation TRM is less stable than TRM which suggests that remanence is carried predominantly by the fine grain iron. The stability of 14053-48 is so low that it seems probable that remanence is carried by multidomain iron, a suggestion which is consistent with the observation that in this sample TRM is less stable than saturation TRM.

Stability of TRM Against Thermal Demagnetization: Thermal demagnetization of NRM, like AF demagnetization, serves to eliminate noise and to give information about the nature of the remanence. It discriminates between components of remanence on the basis of their blocking temperatures, that is the temperature at which the relaxation time of remanence of a single particle becomes long compared with the experiment time. The sample is demagnetized by thermal cycling in field free space (+ 2 γ). Components of remanence due to particles whose blocking temperatures are exceeded relax to give zero net moment. Remanence carried by particles with higher blocking temperatures is unaffected. Thermal demagnetization of TRM acquired in a variety of fields has been observed using the equipment described in the discussion of the field dependence of TRM. Demagnetization of 0.2 oe TRM in 10048-55 revealed that the TRM was fairly evenly distributed across the range of blocking temperatures with a slight enhancement at high temperatures near the Curie point. The same behavior was found in a 1000 γ TRM in this sample. In contrast, the blocking temperatures of TRM in 14053-48 are strongly field dependent. In a one oersted TRM, there is substantial blocking below 300° C, but one third of the magnetization is blocked between 700 and 800° C. In a 5000 γ field TRM, about one half of the remanence is blocked evenly across the temperature range up to 700° C and the other half is blocked between 700 and 800° C.

Comparison of TRM With NRM of Lunar Samples: We are able to compare the AF demagnetization of NRM and TRM of 10048-55 and the AF and thermal demagnetization of the NRM and TRM of 14053-48. The two AF demagnetization curves for 10048-55 are markedly dissimilar. Thus, the AF demagnetization of NRM decreases substantially in fields of tens of oersted. In contrast, the TRM decreases more slowly with increasing AF field and exhibits very little change in fields of less than 100 oe. It therefore seems unlikely that the NRM of this rock is entirely due to TRM. The AF demagnetization of the NRM of 14053-48 reveals that it is softer than TRM. The thermal demagnetization of NRM and TRM are somewhat similar, but a TRM of comparable magnitude to the NRM has more remanence blocked at very high temperature than does NRM. The field required to generate such a TRM is several tenths of an oersted, but it is unlikely that NRM is a simple thermoremanence. Thus, in the samples which we have studied the bulk of NRM is softer than TRM and in the one sample for which we have thermal demagnetization of NRM subtle differences between NRM and TRM are found. We have not seen any TRM which is as stable in demagnetization fields of a few hundred oersted as is the NRM of such specimens as 10047(4), 12002, 12017, 12021, 12038, 12051 and 12063(5).

Field Test of the NRM of Lunar Samples: In the face of the difficulty encountered in interpreting the NRM of the lunar samples, it is desirable to
design a test which places constraints on the time of acquisition of NRM. In principle, the occurrence of glass on certain samples should provide the possibility of one such test because of the difference of age between the rock and glass. Glass on 14047-47 is capable of carrying detectable remanence: the saturation IRM and the TRM acquired by the glass in a 0.1 oe field have been determined. Unfortunately, we have not yet been able to obtain a sufficiently large sample of glass to measure NRM. However, the NRM of the rock immediately below the glass is approximately one hundred times greater than that of the bulk NRM of the rock although its saturation IRM is similar to that of the rock. Moreover like the NRM of many lunar samples, it is more stable than IRM but less stable than TRM. Since the total mass of the sample is 15 mg of which between one fifth and one tenth is glass, the NRM is most probably a pTRM acquired at the time the glass cooled on the surface of the rock. The age of the glass is not yet known. However, it does appear that at the time the glass formed a substantial magnetic field was present at least in the immediate vicinity of the rock. This result is somewhat confused by the fact that the rock 14047 exhibits particularly strong viscosity. Nevertheless, by examining paleomagnetically suitable rocks with dated spatter important constraints may be placed on interpretations of the NRM of lunar samples.

Interpretation of the NRM of Lunar Samples: The lack of critical data precludes a satisfying interpretation of the NRM of lunar samples at this point. Yet, it does seem clear that it is not a simple TRM in the samples which we have studied. Moreover, without invoking implausibly large fields for IRM, it is in many instances difficult to explain the NRM in terms of a soft TRM superimposed upon a small stable TRM. We have therefore started to examine the characteristics of pTRM, i.e., the magnetization acquired by cooling through a limited temperature range below the Curie point in the presence of a magnetic field. In this way we have been able to obtain AF demagnetization curves similar to some observed in the lunar sample collection. Although we find difficulty in envisioning a process which could generate the necessary temperatures and fields it does appear that pTRM shows promise for duplicating the AF characteristics of NRM. It remains to be seen how well it duplicates thermal demagnetization curves. Another important possibility which should be investigated is the acquisition of pressure or shock remanent magnetization at elevated temperature. The ability to duplicate the basic characteristics of the NRM of the lunar samples in the laboratory could be an important aspect of our understanding of the phenomenon and until it can be done the implications of the NRM will inevitably remain somewhat equivocal.

(2) Nagata, T. et al., Abs. 3rd Lunar Science Conf.
(5) Strangway, D. W. et al., unpublished manuscript.