It is generally accepted that the very fine grained single domain iron droplets disseminated throughout the agglutinitc portions of lunar soil fines are produced during surface exposure, although there is no consensus of opinion as to the formation mechanism for the droplets. Study of this iron is thus important because it may lead to elucidation of regolith evolution behaviour through knowledge of constraints which can be inferred from the process(es) which produce the droplets. For example, reduction mechanisms and the role of shock might be more clearly defined, and information gained as to how droplet populations evolve: is individual grain coarsening important as well as addition of fresh generations of droplets?

Recently, Mehta and Goldstein (1), using STEM, have studied metal particles in the glassy portions of three highland samples and have distinguished iron from different sources according to the Ni content. Morris (2) has modelled the various components of the total metallic iron concentration, viz. source material metal, micrometeorite iron, and metal derived from ferrous iron during maturation. Of particular interest to us, since they are believed to be the host phase of hydrolysable carbon, are the essentially Ni-free metallic Fe droplets in the size range \( \lesssim 330 \, \mu m \) which comprise Morris' third category and may constitute 40\% of the total amount of metal in bulk soil (2). Our approach, following Stephenson (3,4,5) has been to characterise superparamagnetic grains \( \lesssim 130 \, \mu m \) by measurement of the magnetic susceptibility \( \chi \), and single domain grains \( 130-330 \, \mu m \) by measurement of their isothermal remanent magnetisation IRM. We previously noted (6) that for six varied soils, IRM plotted linearly against \( \chi \) with a gradient (m) which was, to a certain extent, site dependent. Within 12023, m was found to be a function of soil size fraction (6) and variations in m were also found (7) amongst the 75-106 \( \mu m \) size fraction of six Apollo 16 soils. Whilst the former may reflect the agglutinate production profile across soil particle size, the latter was hypothesised to be related to the degree of exposure and was discussed in terms of grain coarsening during maturation.

We have now determined \( \chi \) and IRM on a further 85 samples from the 75-106 \( \mu m \) size fraction of an additional seven Apollo 16 soils. In the Table we present the results of the individual linear regression analyses of the \( \chi \) and IRM data on the density and magnetic separates of the various soils (n denotes the number of samples, m the gradient, c the intercept and r the correlation coefficient; errors are 1\%). Experimental compatibility with earlier work is demonstrated by the agreement of the 68501 data with those found previously (6,7). The range in m values amongst Apollo 16 soils is now extended to over ten units. We have also attempted to provide a quantitative basis for understanding the IRM-\( \chi \) relationship and its consequences by a theoretical consideration of the magnetic properties of small spherical iron droplets. To do this, one must assume a size distribution of the metal particles. As discussed in (7), prior evidence favoured an inverse square distribution whereby the number \( N(v) \) of individuals of volume \( v \) is given by \( N(v) = \beta v^\chi \) with \( \chi = -2 \). Now adopting notation similar to (3,4) we can write:

\[
\chi = \frac{\beta}{3kT} \int v^2 N(v) \, dv; \quad \text{IRM} = \frac{\beta}{2} \int vN(v) \, dv
\]
VERY FINE IRON IN APOLLO 16 SOILS

Fallick, A.E. et al.

The limits of integration in the first case are \( V_{\text{min}} \) to \( V_x \) and in the second case \( V_x \) to \( V_{\text{max}} \), where \( V_{\text{max}} \) is the single domain - multidomain boundary at around 330 Å diameter, \( V_x \) the blocking volume for superparamagnetic iron grains corresponding to 130 Å diameter, and \( V_{\text{min}} \) is the minimum size of droplet we need to consider, which will be determined either by a lower bound to \( N(v) \) or by a value appropriate to a single iron atom. We combine the above three expressions to eliminate \( \beta \) and obtain:

\[
\text{IRM} = \frac{3kT}{2\gamma} \ln \frac{V_{\text{max}}/V_x}{V_x/V_{\text{min}}} x
\]

so that, according to this model, the IRM-\( x \) relationship should have a constant gradient \( m \) irrespective of soil particle size, chemistry or maturity. This conflict with observations could be resolved by allowing the integration limits to vary, perhaps with Ni content of the Fe (R.M. Housley, pers. comm.) but we know of no evidence for this and it seems unlikely on several grounds. For example, for the 12 of our Apollo 16 soil suite for which there are published bulk nitrogen concentrations, there is an excellent correlation between \( N_\phi \) and 75-106 \( \mu \)m bulk \( x \), which shows that \( x \) is indeed a consistent measure of reduced iron metal. Furthermore, consideration of the dependence of the concentration of hydrolysable carbon on \( x \) (6,7) argues against a systematic variation in the size range of iron droplets which \( x \) samples. Although these arguments are highly cogent, they do not unequivocally exclude the possibility that, say, the superparamagnetic blocking volume is dependent on inter-sample differences in Ni concentration of the iron. Instead, we prefer to relax the size distribution constraint and allow small deviations from inverse square functionality parameterised by letting \( x = -2 + \epsilon \). Then \( N(v) \) can be expanded in a Taylor Series in \( \epsilon \) and one finds a new IRM-\( x \) relationship with a gradient which depends on \( \epsilon \) (the mathematical form of the expression for \( x \) depends on the number of terms retained in the expansion).

On this view, one important aspect of IRM-\( x \) studies is then the potential for recognising trends in the systematic departure from inverse square distribution within and amongst soil samples. Little attention appears to have been given to explaining the observed (approximate!) inverse square droplet size distribution on the basis of the various proposed droplet formation mechanisms, but the possibility is now open for regarding second order terms in the distribution (as manifested by the influence of \( \epsilon \) on \( m \)) to be used as a more sensitive probe of the formation and evolution of metal grains. To exemplify, combinations of production processes (e.g. chemical and shock reduction), or grain coarsening during maturation, could quite conceivably lead to a flatter distribution (\( \epsilon > 0 \)) than that corresponding to \( x = -2 \). This analysis shows that in our previous discussion (7) of grain coarsening the emphasis on the importance of particles crossing the superparamagnetic blocking volume was somewhat misplaced: the quantitative approach followed here deals quite naturally with the formerly troublesome volume dependence of \( x \). However, a drawback to the model is that it does not predict the frequently encountered IRM intercept (c). The origin of this is thus still problematic, though empirical advance has been made (vide infra).

Grouping together all of our 75-106 \( \mu \)m Apollo 16 data, the 141 samples define an IRM-\( x \) line with \( m = 17.5 \pm 0.4, c = 9.4 \pm 1.5 \) and \( r = 0.96 \). This value of \( m \) is very similar to that found for 12023(18.0 \pm 2.1) but quite distinct from the 15601 and 10086 values (27.2 \pm 3.7 and 31.6 \pm 1.1 respectively). The nature of the fine tuning afforded by \( m \) variations on a given size fraction of a suite of soils of similar chemistry is then apparent from
the present Table and the results reported last year (7). On the basis of our original six samples we tentatively suggested that \( m \) was related to maturity (note that Table 1 of (7) has misprinted 56 for 80 as \( \text{FeO} \) for \( 60501 \)). Such an interpretation is consistent with the expanded data set: bulk \( N_2 \) plots against \( m/\text{FeO} \) with a correlation coefficient of -0.82 which, for 12 samples, is significant above the 0.1% level. Moreover, \( m \) and \( c \) again appear to be anticorrelated (\( r = -0.74 \) for \( n = 13 \)). However, we remain cautious in the interpretation of these findings, and in particular of deducing the consequences for \( \varepsilon \) variations. Heymann and coworkers (8,9,10) have recognised that, on the grounds of rare gas systematics, Apollo 16 soils can be divided into three major groups with characteristic chemistry and history. This leads to apparent chemical correlations which are presumably of no physical significance: for 37 soils \( \text{FeO} \) is correlated to \( N_2 \) with \( r = 0.74 \) and for our 12 sample subset \( r = 0.91 \) (this point is implicit in (11)). We would rather await a test on the validity of our approach by direct experimental determination of iron droplet size distributions.

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References:

6. Fallick et al. (1979), P1OLPSC, p. 1469.
8. Heymann et al. (1975), LSVP, 361.
9. Heymann et al. (1975), The Moon, 13, 81.

Table

Correlation of IRM with \( \chi \) for 75-106 \( \mu \)m fraction of seven Apollo 16 soils.

<table>
<thead>
<tr>
<th>Soil</th>
<th>n</th>
<th>( m )</th>
<th>( c )</th>
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<tr>
<td>67941</td>
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<td>24.0±1.8</td>
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<tr>
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<td>13</td>
<td>15.2±1.7</td>
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