BULK IRON CONTENTS OF HIGHLAND AGGLUTINATES.

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In order to resolve controversies concerning the enrichment vs. non-enrichment (1,2) of ferromagnesian elements in glassy agglutinates, we recently undertook the major element analysis of an extensive suite of magnetic, density and particle size separates of two Mare soils 12023 and 15601 (3). Highly magnetic, low density fractions, considered to be pure agglutinates on the basis of microscopic examination and carbon, rare gas and magnetic measurements, were found to be depleted in iron, magnesium and titanium but enriched in aluminium. The iron depletion in agglutinates from fine particle sizes was often quite substantial, up to 6% FeO. A model involving the incorporation of very fine non-native material into agglutinates at the very surface of an evolving Mare regolith was proposed to explain the observations. In conjunction with the studies on Mare materials, we looked at three agglutinate fractions obtained by careful density and magnetic separations of size fractions of highland soils. Two of the samples analysed were enriched in ferromagnesian elements. We have now extended our studies on highland materials to include eight soils. As before, our policy has been to measure, as far as possible, the composition of pure end members. Samples having a variety of magnetic properties and densities in a number of size fractions have been examined. The separation methods and techniques for analysis were as described previously (3). Because only limited amounts of bulk starting materials (often less than 0.3g) were available, some of the most magnetic fractions could not be obtained in amounts sufficient for elemental analysis. Some fractions studied were close to the minimum requirements, hence errors are sometimes greater than we would have wished. In this paper, due to space limitations and because our method is optimised to produce the best results for iron, we quote only results for this element.

The combined results for the samples investigated are presented in Tables 1,2 and 3. All material whichmoves more than 1.5mm to our magnetic separator, with the exception of that from sample 66040, is enriched in iron relative to the bulk material of the same size range. The more magnetic a sample (the greater its collection distance), the more enriched it is in iron (Table 2). In general, magnetic material from ρ = 2.6-2.96 density fraction shows a greater enrichment in iron than $\rho<2.6$ fractions. Not surprisingly, the higher density material is collected at a smaller magnetic separation distance. We can be quite sure that the enrichments observed in the magnetic fractions are not due to the concentration of ferromagnesian minerals because these species should be found among the $\rho>$ 2.96 materials. As can be seen from Tables 2 and 3, the highest density fraction is very enriched in iron, even after removal of the rusty metal fragments by magnetic separations, in keeping with the above hypothesis. Binocular microscopic examination of our separates suggests that any material with a magnetic separation distance $M \geq 2.0$ may be considered as essentially pure, highly vesicular, complex particles. Thus, we conclude that at the Apollo 16 site glassy agglutinates are enriched in iron relative to bulk soils. Our detailed study confirms the analytical findings of Rhodes et al. (2) which were based on a considerably less rigourous separation scheme. From the Tables, it can be seen that the extent to which iron is increased in abundance in pure agglutinates is at least 1% by wt.FeO. Greater enrichment may be possible for the most mature agglutinates. Some samples contained material with higher magnetic susceptibilities which has not yet been subject to chemical analysis. For example, M3.0 and M3.0 and M2.5 fractions were isolated from the $\rho < 2.6$ and 2.6-2.96 density ranges respectively of 68501.(4).

Although we support the analytical conclusions of Rhodes et al. (2) with respect to iron, we are unable to endorse the mechanism which they proposed to account for the observed enrichments. The extensive electron microprobe studies made by the Taylor group (1) were unable to reveal substantial differences between glass and the bulk material, thus selective melting has probably not occurred. To rationalise the Fe, Mg and Ti depletion discovered in Mare agglutinates, we suggested that the gradual and continuous addition of non-native material to the upper 1-2mm of the regolith, the active site for agglutinate formation, is a possibility. We cannot rule out addition of fine grained material to the surface of the highland site, but for the following reasons we believe that it is unlikely this type of process is the major source of the excess iron in Apollo 16 agglutinates: (i) None of the smoke sized fractions have iron contents which are significantly greater than those measured for material in the 106-150μm size range. (ii) Similarily, fine agglutinates are not enriched in iron relative to coarse agglutinates. The alternative which we have put forward (3) to the above mechanisms is that sample mixing has occurred at the Apollo 16 site. Mature Cayley Plains soil with FeO content 5.7 to 6.0 has been diluted with immature N and S Ray Crater debris containing less iron. The current results support this hypothesis. If the results from small samples are excluded, the 106-150μm, $\rho < 2.6$, agglutinates have FeO contents which are much more tightly grouped than the bulk size fractions from which they were derived (Table 1). The two 106-150μm, $\rho = 2.6-2.96$ agglutinate fractions studied are also very similar. A possible interpretation would be that all the agglutinates from the different A 16 soils have a common provenance. We previously suggested that the greatest differences in respect of FeO content occur for immature samples. The North Ray Crater rim soils 63501 and 67701 (Tables 1 and 2) have very little magnetic material and are thus immature. However the substantial enrichments in FeO of these small fractions relative to the bulk samples implies that the agglutinates were not derived from maturation of N Ray ejecta but existed prior to the cratering event. Agglutinates from a relatively mature sample eg. 68501 have a chemistry closely similar to the bulk soil. Magnetic susceptibility and isothermal remanent magnetisation investigations of agglutinates from 68501 demonstrate that in the most magnetic samples ca. 40% of the total iron is in the reduced state(4). The reduction process, whatever its mechanism, must have fractionated oxygen relative to iron. This inevitably means that agglutinates are enriched in Fe compared to the pristine rock fragments which were the initial starting material for the production of the Apollo 16 regolith.

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References (1) Via and Taylor (1977) P7LSC, p. 319; (2) Rhodes et al. (1976) P6LSC, p. 2291; (3) Woodcock and Pillinger, P9LSC in press; (4) Fallick et al., this volume.

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Table 1. FeO content (wt %) of Apollo 16, 106-150µm bulk sieved fractions, smoke sized particles and agglutinates.

sample	106-150µm	smoke sized grains	agglutinates (106-150µm) $\rho<2.6$ $M^{+}2.5$	2.6-2.96 M2.0
60501	4.6	-	5.5	6.2
61161	4.7	4.6	5.6	-
63501	3.9	4.0	5.1*	-
64421	4.4	4.4	5.3	-
66040	5.8	-	5.5	-
67701	3.3	3.3	7.8*	-
68121	5.2	-	5.9	-
68501	4.9	5.1**	5.3	6.1

\+ distance of collection using magnetic separator (in mm)
* sample ca. 0.4 mg or less ** < 10µm sieve fraction.

Table 2. FeO content (wt.%) of density/magnetic separates of 106-150µm grains from soils 60501 and 63501.

fraction		sample 60501	63501
$\rho<2.6$	M2.5	5.5	5.1
	2.0	5.0	4.8
	1.5	4.9	4.5
	1.0	4.8	4.2
	MT	4.2	3.2
	NM	2.3	
$\rho=2.6-2.96$	M2.0	6.2	-
	1.5	5.3	7.2
	1.0	5.1	5.6
	MT	3.8	4.5
	NM	1.9	2.5
$\rho>2.96$		14.2	13.8
bulk		4.6	4.4

Table 3. FeO content (wt %) of density/magnetic separates from 68501 size fractions.

size (µm)	bulk	$\rho<2.6$ M2.5	$\rho=2.6-2.96$ M2.0	$\rho>2.96$*
150-250	5.2	5.8	-	9.2
106-150	4.9	5.3	6.1	11.2
77-106	5.0	5.7	6.1	8.6
53-77	5.1	6.1	6.3	9.9
40-53	5.1	5.9	5.5	11.8
30-40	5.8	-	5.6	11.3
20-30	5.5	4.9	5.8	12.5
10-20	5.4	-	-	-
<10	5.0	-	-	-

*very highly magnetic rusty grains (M>3.0) removed by magnetic separation.