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Iron Mössbauer spectra of Lava From Jeju Island and Its Similarities to Moon Basalts*

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We report the result of measurements of the ^{57}Fe Mössbauer spectrum for powder samples of lava taken from four widely separated sites on Jeju island. The spectra consist of well defined quadrupole doublets having a 2+ charge state and indicate the presence of olivine, chinopyroxene, and ilmenite. In addition we find a six line magnetically split hyperfine pattern characteristic of impure hematite, with considerable line broadening and reduced internal field. The observed spectra have a remarkable similarity to those found for moon basalts. A recently popularized "collision ejection" model for the moon formation would be consistent with our observations. The data is a particularly simple and direct illustration of the well-known fact that the iron silicates and ilmenite found on the moon are very similar in composition and relative abundance to that found on earth.

1. Introduction

Although a detailed study of the petrology and geochemistry of Jeju Island, which is approximately 60 miles south of the Korean coast, has been carried out by Lee [1], to date no Mossbauer spectra of the volcanic ash of Jeju have been reported. It is the purpose of this communication to present such data and to show the striking similarity to Mossbauer spectra taken from the lunar seas.

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The present study of the volcanic lava of Jeju Island by means of Mossbauer spectroscopy using ^{57}Fe adds interesting new information on the earth's mantle. There have been several measurements of the ^{57}Fe Mossbauer spectra of moon rocks [2-6], although we have found no detailed Mossbauer studies on volcanic lava which would serve as a basis for a simple comparison between the earth's mantle and moon samples.

2. Experimental

Lava taken from the ancient eruptions of Jeju volcanic peak Mt. Halla were taken from four different locations on the island. Sample A was taken from the South, B and D from the West, and C from the north of the center of the volcano. The measurements were carrid out with a cobalt-57 in rhodium source (initially 25 mCi) versus the lava samples, which were prepared by taking the finely ground powder and encapsulating it in plastic disks 1⅛ inches in diameter.

The Mössbauer spectra were run with a transducer using a feedback circuit to control the motion. Samples A-D were investigated at room temperature and at 78 K using a cryogenic liquid nitrogen facility.

The data were analyzed using a computer least square fit, assuming Lorentzian line shapes for each peak in the observed spectra.

3. Results and discussion

A measurement over the velocity range plus to minus 10 millimeters per second wsa taken for sample A-D at room temperature and at liquid nitrogen temperature. The visibly evident features of the spectra consist of three sets of quadrupole doublets most clearly observed in samples B and D, with a sizeable 6-line component of the ferromagnet, ferric oxide having large line broadening indicative of impurity metal dopants. In order to better resolve the quadrupole doublets in the central portion of the spectra, specimens B and D were rerun with a reduced velocity range so as to permit a curve fit to each of the quadrupole doublets. The spectra for sample D, having a reduced velocity range to enhance resolution, are shown in fig. 1 and the Mössbauer parameters corresponding to the best fit of this data along with that taken for sample B are given in table 1. The spectral fit to the data is revealed by the solid line shown.

The central pattern has three major components : olivine, clinopyroxene and ilmenite, and values of isomer shifts and quadrupole splittings correspond closely to those reported by Runcorn et al. [2] observed with lunar samples at 78 K, when account for differences in sources is taken into account with regard to the tabulated isomer shifts. Similar patterns for moon basalts have been reported by other investigators and variations in composition of moon rock observed using the Mossbauer effect from sample to sample are comparable to the variations which we observed within different samples of rock taken from Jeju Island. The Mössbauer transmission spectrum observed by Herzenberg and Riley [6] for a powder sample of lunar rock taken from the ocean of storms (Apollo 12) shows the same three sets of quadrupole doublets (their figure 11) as we find for basalt taken from four widely divergent locations on Jeju Island.

The data in table 1 were fitted with the constraints that each Fe^{2+} quadrupole doublet has the same width for the left and right peaks. Also, the Fe_2O_3 pattern was fitted with the constraints that all linewidths were equal and the ratio of the splitting of the outer pair of peaks (2, 5) to the inner pair (3, 4) was set to 3.67 in keeping with the known excited and ground state nuclear moments of ^{57}Fe.

The widths of the olivine and limenite doublets are between 0.3 to 0.4mm/s and are as narrow as could be expected for Lorentzian fits with the absorbers used. The pyroxene linewidth ranged between 0.5 and 0.6mm/s and this can be understood because we did not try to fit separate lines for site one and site two hyperfine spectra. From the areas under each component spectrum we can determine the relative fraction of each component which will nearly scale with the areas of 77 K.

Our results for sample B imply that the olivine, clinopyroxene, ilmenite and hematite are persent in ratios of 25%, 34%, 17%, and 24%, respectively. For site D the ratio of these iron minerals was 6%, 62%, 5%, and 27%, respectively. These ratios are in the same range as given by Binder [7] for lunar basalts.

The broad linewidth (1.3mm/s) of the hematite component of the spectrum is believed to be the result of nonmagnetic impurities such as aluminum, which reduce the net exchange interaction and cause a local reduction in the hyperfine field at the iron nuclei. The mean peak positions are 87% of that found for pure hematite at room temperature, which is again indicative of non magnetic impurities reducing the net exchange interaction and the mean internal hyperfine field.

4. Conclusion

The collision ejection mode [8, 9] of the moon's formation would indicate that specific parts of the earth's mantle prior to collision are now a part of the moon's surface. The basic lava of Jeju Island spectra reveal four components : ferric oxide, olivine, clinopyroxene, and ilmenite with the relative amounts of the last three being similar to that found on the sufaces of the moon [7]. The major difference between the Mossbauer spectra and those of moon basalts is the replacement of iron metal observed in moon rock with impure ferric oxide $(Fe, M)_2O_3$, with probable dopants such as aluminum or other impurities, which noticeably broadens the hematite lines oberved, and reduces the hyperfine interaction. This apparent difference can be accounted for on the basis of surface oxidation of metallic iron following volcanic deposition of lava on the earth's surface. The amount of this component which can be gauged by the relative areas under the component spectra is relatively greater than the iron found in moon rocks. This is in accordance with the well-known fact that the moon has a significant depletion of siderophile elements compared to the upper mantle of earth.

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Fig. 1. Mössbauer spectra for sample D taken from Jeju Island: (a) at 77 K and (b) at 297 K. The outer quadrupole doublet is associated with olivine and site 1 clinopyroxene, the middle doublet with site 2 clinopyroxene, and the inner doublet with ilmenite.

Table 1. Mössbauer parameters for lava samples taken from Jeju Island.

Sample	Temp (K)	Mineral[a]	Peak positions (mm/s)	Line-widths (mm/s)	Total Area (%)	Rel. area $(\frac{A_{left}}{A_{right}})$	*I. S.*[d] (mm/s)	*Q. S.* (mm/s)
B	77	OL+CPI	-0.48, 2.54	0.38	42%	1.03	1.06(1)	3.02(1)
		CP2	-0.02, 2.02	0.65	17%	3.11[b]	0.48(4)[b]	2.04(4)
		IL	0.55, 1.57	0.49	17%	2.38[b]	0.99(3)	1.02(3)
		H	-4.32, -0.84, 1.86, 5.26	0.97	24%[c]			
D	77	OL+CPI	-0.48, 2.55	0.37	37%	0.98	1.05(1)	3.03(1)
		CP2	-0.03, 2.02	0.56	32%	1.44	0.85(1)	1.99(4)
		IL	0.55, 1.51	0.34	5%	1.47	0.94(2)	0.96(2)
		H	-4.15, -0.67, 1.77, 5.17	1.36.	27%[c]			
D	297	OL+CPI	0.50, 2.32	0.34	35%	1.02	0.90(1)	2.82(1)
		CP2	-0.06, 1.89	0.52	41%	1.32	0.78(1)	1.95(1)
		IL	0.53, 1.17	0.38	11%	1.19	0.82(1)	0.82(1)
		H	-0.360, -1.20, 1.31, 4.71	1.33	13%[c]			

[a] CPI=Clinopyroxene Site MI, OL=Olivine, IL=Ilmenite, H=Hemite, CP2=Clinopyroxene Site M2

[b] Shows problem with this component although the small % effect in this case amplified errors and reduced the accuracy of fitted parameters.

[c] Total area under 4 peaks×2 to give area of six-finger pattern.

[d] As measured with respect to our ^{57}Co : Rh source. [Fe, M]$_2$O$_3$ (M=Metallic components other than Fe).