

Mg ISOTOPE FRACTIONATION IN LUNAR SOILS

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Previous work has established the presence of large mass dependent enrichments in $^{18}\text{O}/^{16}\text{O}$ and $^{30}\text{Si}/^{28}\text{Si}$ isotope ratios in lunar soils for the initial O_2 and Si extracted by partial reaction with fluorine [1,2]. The data showed a progressive decrease in the magnitude of the enrichment as increasing amounts of material were removed. The anomalous oxygen and silicon are believed to reside on coatings on the surfaces of soil grains and appear to be correlated with concentrations of solar-wind H_2 . Similar mass dependent enrichments in ^{34}S relative to ^{32}S were established in grain size separates[3]. The magnitude of the S anomalies increased with decreasing grain size and were also correlated with the concentration of solar-wind implanted nitrogen. Anomalies in K have also been reported in bulk soils[4]. For these elements the maximum magnitude of fractionation per mass unit appears to decrease with increasing mass starting from O (2.5%), Si (1.3%), S (1.0%) to K (0.7%) .

In contrast to the large mass fractionation effects in O, Si, S, and K, attempts to extract Ca from lunar soils have failed to show isotope effects of similar magnitude[5]. The largest effect of $0.8 \pm 0.2\%$ amu⁻¹ enrichment in the heavier isotopes was obtained for a partially fluorinated and subsequently water leached sample. Smaller effects were also established for two samples which were not fluorinated. One sample was leached using dilute HCl and the other was leached in water. These samples showed $0.45 \pm 0.1\%$ and $0.52 \pm 0.2\%$ amu⁻¹ effects respectively. The magnitude of the Ca effects decreased with increasing amounts of leached Ca in agreement with the trend established for O and Si. No reasonable physical process could be invoked to account for these observations except either 1) the analytical procedures used did not extract the fractionated Ca; or 2) highly soluble bulk phases diluted the anomalous surface fraction of Ca. By general consensus the large effects in O, Si, S and K were attributed to sputtering effects by the solar wind. As sputtered material is expected to be enriched in the lighter isotopes a further mechanism depending on the energy-gravity balance between the kinetic energy of the sputtered atoms and the gravitational attraction of the Moon was invoked to sort out the sputtered atoms. The lighter species had sufficient energy to escape the Moon whereas the heavier isotopes settled back on the surface to produce the observed heavy isotope enrichment[6]. Subsequent laboratory sputtering experiments revealed large heavy and light isotope enrichment in Ca[7]. However, as only one isotope ratio was measured, the effects could only be assumed to be mass dependent.

In an attempt to shed further light on the problem we have tried to extract Mg from lunar soils using water leaches. Small amounts (20-40 mg) of soil from 4 different samples (14163,831; 15021,50; 15271,126 and 66081,117) were rinsed in 1ml of reagent water and centrifuged for about 5 min. The leachate (labelled as A) was removed and mixed with HF and HNO_3 to ensure complete dissolution of any suspended fine grained particles. The amount of Mg leached was determined with an ICP spectrometer. The centrifuge tube was refilled with 1ml of water and after 1 hr the whole process was repeated. This leachate was labelled B. Leach C was obtained in a similar manner but after 4 days of water immersion. A 20 ng aliquote of each sample was directly loaded on 'V' filaments for Mg isotope analysis. The data are listed in the Table.

The column labelled fractionation shows the raw $^{25}\text{Mg}/^{24}\text{Mg}$ data relative to the mean value for 9 standards analysed at the same time as the lunar samples. The spread in the raw $^{25}\text{Mg}/^{24}\text{Mg}$ ratio for standards is well within $\pm 1.5\%$ per mass unit and this band represents our analytical capability for resolving intrinsic mass fractionation effects from systematic errors of measurement. All of the $^{25}\text{Mg}/^{24}\text{Mg}$ data for aqueous soil leaches are close to or within the $\pm 1.5\%$ band. In sharp contrast to the data for O, Si, S, and K we do not see any large mass dependent isotope effects in any of the leaches. The Mg data are qualitatively consistent with the results of the Ca experiments[5], in that if there are Mg isotope effects of the order of 1% or less we would not be able to resolve them with our present analytical precision. It may be argued that, in the absence of partial fluorination experiments for the present samples, the anomalous Mg may have been overwhelmed by Mg leached from easily soluble bulk phases with normal Mg isotope composition. However, we note that in two Ca leaches which did not involve fluorination, statistically significant Ca effects were measured which were only about 40% smaller than the

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maximum obtained in one experiment involving F₂. Furthermore, the isotope effects in S and K were obtained in bulk soils or grain size separates. The notion that volatility could explain the difference in results for S and K as opposed to Ca is not applicable to Mg and Si as both are almost equally refractory. Experiments are currently underway to determine whether fluorination does have any significant effect on the source of leached Mg. Laboratory sputtering experiments with keV ion beams show the presence of isotope effects in Mg as excesses in ²⁶Mg for low intensity bombardment[8]. The soil data for ²⁶Mg, following normalisation to remove mass fractionation, are listed in the Table and within errors are indistinguishable from normal Mg composition.

We have demonstrated the absence of any significant mass fractionation effects in Mg in lunar soils which show much larger effects in O and Si. Our data are consistent with the results of Ca experiments on the same soil samples. We cannot offer any plausible explanation for the difference in results for O, Si, S, and K as opposed to Mg and Ca except that:

- 1) The present leaching procedures do not remove significant amounts of isotopically fractionated Mg.
- 2) The water leached Mg contains a significant contribution from easily soluble bulk phases with normal Mg isotope composition.

References:

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Mg isotopic composition of water leaches from Lunar soils

Sample	Mg leached [‡] (μg)	Fractionation* Δ(²⁵ Mg/ ²⁴ Mg)% _{AMU} -1	δ(²⁶ Mg/ ²⁴ Mg) [§] ±2s.d.
H ₂ O Leach A			
² 14163	3.4	-0.3	0.0±0.2
15021	1.6	1.0	-0.1±0.2
15271	2.3	-0.1	0.3±0.2
66081	1.1	1.7	0.0±0.2
H ₂ O Leach B			
² 14163	1.7	1.0	0.1±0.2
15021	1.1	-0.4	0.2±0.2
15271	2.5	0.6	0.0±0.2
66081	1.2	0.9	-0.3±0.2
H ₂ O Leach C			
² 14163	1.6	0.0	0.4±0.3
15021	0.8	0.3	0.0±0.2
15271	1.4	0.7	0.3±0.2
66081	1.0	1.4	-0.5±0.4

[‡]Mg leached determined by ICP. *Δ(²⁵Mg/²⁴Mg)=[(²⁵Mg/²⁴Mg)_{meas} / (²⁵Mg/²⁴Mg)_s - 1]x1000, where s denotes the grand mean value: ²⁵Mg/²⁴Mg=0.123681 for raw data determined from standards. Reproducibility for repeat runs is better than ±1.5‰ per mu. [§]Residual following normalisation to remove mass fractionation. Grand mean value for 9 standards run during the same period as the Lunar soil samples is δ(²⁶Mg/²⁴Mg)=0.141410.