THE ISOTOPIC VARIATIONS OF POTASSIUM AND IRON IN APOLLO 17 DOUBLE DRIVE TUBE 73001/2 AND THEIR IMPLICATIONS FOR REGOLITH HISTORY AND SPACE WEATHERING.

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Introduction: Space weathering is the cumulative effect of micrometeorite impacts, solar wind spallation, and solar/galactic cosmic ray irradiation on the surface materials of airless planetary bodies, which over time produce physical and chemical alteration [1]. The extent and depth of this alteration are not well constrained. Previous studies have shown lunar soils are enriched in heavier isotopes relative to lunar rocks for isotopes of O, S, Se, Si, Cl, K, Fe, Cu, Zn, and Cd [2-17] indicating preferential evaporation and loss into space of the lighter isotopes of these elements during space weathering. These extreme isotopic fractionations in lunar soils are mainly observed for highly and moderately volatile elements, whereas isotopes of more refractory elements show little fractionation [18-20]. The importance of element volatility points to vaporization by micrometeorite impacts as the primary mechanism for isotopic fractionations in lunar soils.

Micrometeorite impacts produce nanophase Fe metal grains (np-Fe^o) in lunar soil [21-22]. I_S/FeO is a quantitative index of maturity that uses the ratio of np-Fe^o (I_S), measured via ferromagnetic resonance (FMR), over the total iron concentration [23]. A positive correlation has been observed between S, Si, O, Cu, and Fe isotopic compositions and soil maturity [4,10,17]. Only recently, with improved analytical techniques, has a correlation between maturity and K isotopic fractionation been observed [24].

The Apollo 17 drive tube 73001/2 is a part of the Apollo Next Generation Sample Analysis Program (ANGSA). It sampled the light mantle at Station 3, considered a landslide deposit off the South Massif of the Taurus Littrow Valley [25]. The estimated age of the light mantle emplacement event is between 70 and 110 Ma [26]. The thickness of this light mantle deposit at this location is still unknown. In addition, two landslide events have been proposed, suggesting that a "young" light mantle is on top of an "old" light mantle [26]. Whether 73001/2 has sampled both "young" and "old" light mantle is also unknown. We used high-precision K and Fe isotope measurements to produce a continuous depth profile for the drive tube 73001/2 and provide some constraints on these issues. The results were also used to quantitatively model the near surface volatile depletion and isotopic fractionation processes on airless bodies.

Samples and Methods: As a part of ANGSA, the 73001 and 73002 drive tubes were opened in 2022 and 2019 respectively. Each was longitudinally dissected in three passes, with each pass divided into 0.5-cm wide intervals [27]. Before isotope analysis, FMR measurements were made on 50 mg of the < 1 mm grain size fraction from each interval of dissection Pass 2; 45 mg were then dissolved in acid solution. Approximately 14 mg of the dissolved samples were used for major and trace elemental analysis [28]. The remaining solutions were saved for isotope analyses.

Potassium isotope analyses were conducted on 71 and Fe isotope analyses were conducted on 60 intervals from Pass 2. From the previously prepared solutions [28] approximately 3 mg of dissolved sample were used for K isotope analysis and 1.75 mg for Fe isotope analysis. The K isotope analytical procedure was adapted from [29] and used three columns filled with AG50W-X8 cation exchange resin to remove matrix elements. The Fe isotope analytical procedure was adapted from [30] and used two columns filled AG1-X8 anion exchange resin to separate Fe from the matrix. Isotope analyses were performed using a Thermo Scientific Neptune *Plus* Multiple-Collector Inductively-Coupled-Plasma Mass-Spectrometer (MC-ICP-MS) with an Elemental Scientific APEX Omega as the sample introduction system. For the Fe isotope analysis, the APEX was used without added nitrogen. Measurements were taken on the left "shoulder" of the peaks to avoid isobaric interferences.

Results and Discussion: We found that the top of the core is enriched in heavy K isotopes, with the surface having the highest δ^{41}K value (3.48 ± 0.05 ‰). There is significant variation in the top 7 cm of the core where the K isotopes become progressively lighter to a depth of about 7 cm. Below 7 cm, there is little variation, with an average δ^{41}K value of 0.15 ± 0.05 ‰ (**Fig. 1**). We found a strong correlation between K isotopes and both I_S/FeO and OMAT maturity indexes suggesting K isotopes are fractionated by space weathering in lunar regolith. Kinetic fractionation during micrometeorite impacts was modeled using simple Rayleigh fractionation and found to match the K isotopes measured in the top 7 cm of the core (**Fig. 2**).

For Fe, we found that the top of the core is slightly enriched in heavy isotopes, whereas the rest of the core shows no variation. The average δ^{56}Fe value for the top

7 cm is 0.15 ± 0.02 ‰, while the average for the bottom 44 cm is 0.11 ± 0.02 ‰. The top 7 cm of 73001/2 are characterized by higher Fe, Ti, Sc, Cr, and V concentrations, which has been attributed to higher percentages of high-Ti basalt components in the soil [28]. Previous studies of lunar samples found that high-Ti basalts are rich in heavy Fe isotopes [16]. We modeled mixing between a high-Ti basalt component and the average of the bottom core as well as Rayleigh fractionation during space weathering. We attribute the Fe isotopic fractionation and elevated Fe concentration at the top of the core to the combined effects of space weathering by vaporization owing to micrometeorite impacts and component mixing with a higher fraction of the high-Ti basalt component.

The lack of a paleo space weathering horizon (**Fig. 1**) indicates that a single landslide event was sampled by the core and that 73001/2 did not reach pre-landslide regolith. This uniformity indicates that the thickness of the light mantle at Station 3 is greater than 70.6 cm, the depth which the drive tube reached [31].

Here, we demonstrate that K and Fe isotopes are tracers for space weathering on airless bodies and show that this process could chemically alters lunar soils near the surface. Such alteration should be taken into account if we wish to return samples unaffected by space weathering from the Moon with the Artemis program.

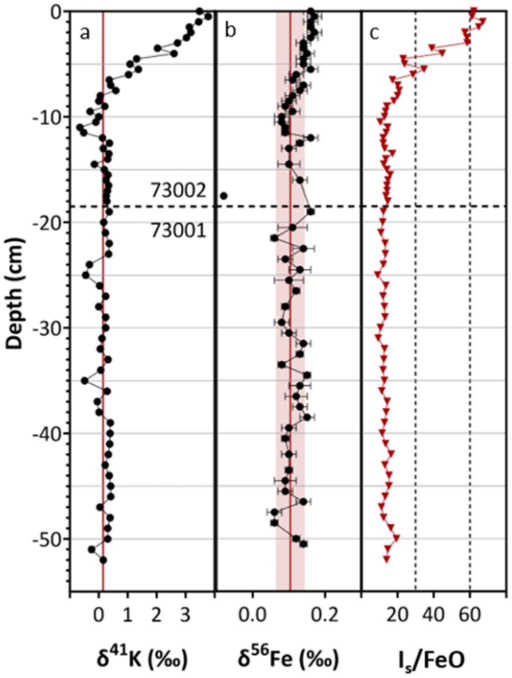

Figure 1. (a) K isotopes reported in δ^{41}K (‰) relative to NIST SRM 3141a versus depth beneath surface, where 0 cm is the lunar surface. Depths are after extrusion which compressed the core [27]. Error bars are smaller than data points. (b) Iron isotopes reported in δ^{56}Fe (‰) relative to IRMM-014. Error bars represent two standard error. The red lines represent the average values of the bottom 44 cm (shaded region is the analytical uncertainty). (c) I_S/FeO maturity index versus depth [32].

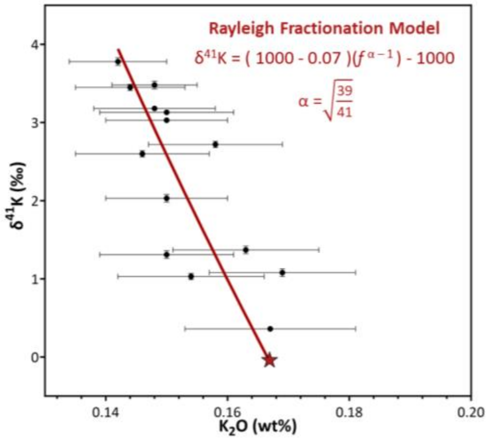

Figure 2. K_2O wt.% [28] versus δ^{41}K (‰) for the top 7 cm of 73002. Red line shows Rayleigh fractionation for ideal evaporation under vacuum where alpha is the fractionation factor. Red star represents initial isotopic composition of –0.07 ‰, which is the bulk Moon K isotopic composition [33].

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