

# Cadmium isotopes in Apollo lunar samples: implication for sources of volatile elements and lunar surface dynamics

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We present TIMS double-spike Cd isotope data on lunar soils from the Mare Procellarum (Apollo 12) and Highland Anorthosite Terranes (Apollo 16), as well as two ferroan anorthosites (60015, 60025) and orange glass 74220. The advantage of the moderately volatile element Cd ( $T_{c_{50\%}}$ : 652K) compared to other volatile elements stems from its unique potential to trace both volatilization/condensation processes via its stable isotope composition and, lunar surface dynamics by quantifying  $^{113}\text{Cd}$  ( $n$ ,  $\gamma$ )  $^{114}\text{Cd}$  thermal neutron capture ( $n.c.$ ) effects that are induced by galactic cosmic rays (GCR) hitting the lunar surface.

A striking feature of highland and mare soils is their highly fractionated Cd isotope compositions ( $\epsilon^{112/110}\text{Cd}$ :  $\sim 0$  to +110) and large  $n.c.$  effects ( $\epsilon^{114/110}\text{Cd}_{nrm}$ : 0 to +15) compared to those of terrestrial rocks and carbonaceous chondrites, which most likely result from micrometeorite bombardment and variable degrees and durations of surface exposure to GCR, respectively. This is in stark contrast with the light Cd isotope enrichment of the orange glass and the cataclastic anorthosite resulting from condensation of a light-Cd vapor phase during lava fountaining and brecciation, respectively. In  $\epsilon^{112/110}\text{Cd}$ -[Cd] space, Apollo 12 and Apollo 16 soils display two distinct negative correlations that are best explained by mixing involving chemically and isotopically distinct components. The enrichment in heavy Cd isotopes and  $n.c.$  effects co-vary with the maturity index in mare soils, a relation not observed for the highland soils. These contrasting relationships reflect different evolutionary pathways, with reworking by meteorite bombardment largely responsible for the near-homogenous signature in Apollo 16 soils, while physical mixing between two components is the predominant process at the Apollo 12 site. This conclusion is supported by the strong correlation between  $n.c.$  effects and Cd stable isotope compositions defined by Apollo 12 soils. Importantly, this correlation intersects the Bulk Silicate Earth Cd isotope composition, lying close to that of the most immature and KREEP-rich soil 12033 at  $\epsilon^{114/110}\text{Cd}_{nrm} \approx 0$ . This result has important implications for the isotope fractionation mechanism of volatile elements at the lunar surface and provides insights into lunar versus terrestrial volatile element budgets and models for the formation of the Moon.