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Exploration of the REE enrichment and negative Ce anomaly in volcanic rocks from Seulawah Agam, Indonesia

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Eleven volcanic rocks were collected from Seulawah Agam, an active arc volcano in Sumatra, Indonesia. Among them, four samples contain significantly elevated concentrations of rare earth elements (REEs; e.g., La_N=348-762 and Yb_N=53-123), but the concentration of cerium is less enriched, resulting in extremely negative Ce anomalies (Ce/Ce*: 0.67-0.28). These four 'anomalous' samples (SiO_2: 55.5-59.6 wt.%) show no significant difference in major or trace elements (other than REE) from the other seven 'normal' samples (SiO_2: 48.4-62.4 wt.%). Moreover, our petrographic analyses indicate that these anomalous samples uniquely contain a REE-bearing hydrous phosphate mineral.

Such highly negative Ce anomalies associated with elevated REE concentrations have occasionally been reported in arc systems, e.g., Central American Volcanic Arc [1], Kiwitahi Chain [2]. For a long time, the cause of this phenomenon was simply considered to be the result of weathering. We compiled these reports and concluded that the occurrence is independent of rock type and climate, i.e., not spatially restricted to tropical area. Some Quaternary arc volcanic rocks from Tecuamburro, Guatemala, and from Seulawah Agam have this geochemical feature, demonstrating that this phenomenon can be generated in a short period of time.

Frey et al. (2013) [3] attributed the REE enrichment to the presence of a REE-bearing phosphate mineral in the Tertiary volcanic rocks. However, the deposition of such mineral in arc volcanic rocks is a rare event, unlike weathering, which is a common process on the Earth's surface. A recent experiment [4] shows that under hydrothermal conditions (T = 250°C), REE-bearing chloride-rich solution can react with apatite to form rhabdophane, a REE-rich hydrous phosphate mineral. This process may provide an alternative explanation for the REE enrichment and Ce depletion in arc volcanic rocks.

[1] Patino et al. (2003), *Chemical Geology* 202, 343-364.

[2] Kuschel, Smith (1992), *Geochimica et Cosmochimica Acta* 56, 3951-3955.

[3] Frey et al. (2013), *Chemical Geology* 347, 135-152.

[4] Strzelecki et al. (2022), *Nature Geoscience* 15, 327-333.