Goldschmidt 2023 Abstract
https://doi.org/10.7185/gold2023.18568

The importance of alkali-H_2O-carbonate interactions in magmatic systems:A case study from Ol'Doinyo Lengai

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Understanding the interactions between H_2O and CO_2, the two most abundant volatile species in the solid Earth, within magmatic systems is critical to many issues including pluton solidification, eruption triggering, ore deposition, and even natural carbon sequestration. Ol'Doinyo Lengai (ODL), the only active carbonatite volcano on Earth, is known for erupting natrocarbonatite—melt inclusions in ODL rocks have >10wt.% H_2O[1] testifying to the water-rich nature of the system. Experiments at 1kbar evidence the importance of alkali-H_2O-CO_3 interactions at ODL. Temperature gradient experiments show continuous differentiation down to 350°C with systematic change in major elements matching the compositional zoning of nephelinites at ODL. Furthermore, phase equilibria experiments show hydrous peralkaline liquid with carbonate co-existing with nepheline and feldspar down to 330°C[2]. Notably without carbonate, melt only exists above ~750°C suggesting that carbonate plays an essential role in increasing water solubility in silicate liquids.

A model of ODL based on hydrous carbonate-silicate liquids was proposed to explain its magmatic cycling[2]: 1) nephelinite magmas emplace as sills; 2) hydrous carbonate (+silicate) liquid at 450°C buoyantly separates from sills within a thermal gradient reaction zone resulting in natrocarbonatite effusion; 3) H_2O builds up in nephelinite melt leading to explosive eruption. We present three pieces of evidence consistent with this model. First, analyses of uranium series disequilibria show prominent parent-daughter fractionations, including for very short-lived nuclides, consistent with a reactive flow process involving hydrous carbonate liquid. $(^{238}U/^{230}Th)>1$ but $(^{235}U/^{231}Pa)<1$ in natrocarbonatite probably indicates the liquid is not simply carbonate melt or hydrous solution. Second, stable isotope ratios of Fe and U show significant differences between silicate liquids (isotopically heavy) and natrocarbonatite (light) with interpretation being heavy Fe is removed into Fe^{+3} bearing phases upon ascent. Notably melanite garnet separates have heavy $d^{56}Fe$ consistent with this model. Finally, examination of trace element patterns between high and low temperatures parts of the temperature gradient experiment match up well with observed natrocarbonatite-nephelinite pairs.

[1]. DeMoor et al. EPSL 361, 2013. [2]. Lundstrom et al. Front. Earth Sci 2022.