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Phase relations in alkaline rocks: melilitite to phonolite fractionation in northern Tanzania

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Alkaline, SiO_2-undersaturated rocks originate from low-degree partial melting of metasomatized mantle sources. The East African Rift System is a prime area for studying their petrogenesis, because continuous rifting since ~45 Ma, along with heat transfer from the sublithospheric mantle to the crust, has driven diverse alkaline volcanism. In northern Tanzania, several volcanoes are present within a relatively small area (~34,500 km^2) and can be divided into two age groups: an older group (6 Ma to 1.2 Ma), dominated by basaltic to trachytic rocks, and a younger group (1.2 Ma to present), characterized by more nephelinitic, phonolitic, ±carbonatitic and ±melilititic compositions.

This study presents a detailed petrological investigation of melilitites, nephelinites, phonolites, and their plutonic inclusions from Kerimasi, Mosonik, and Shombole volcanoes, with comparisons to the neighbouring volcanoes Sadiman, Burko, and Oldoinyo Lengai. These volcanoes exhibit varying degrees of magma evolution, with X_{Mg} values ranging from ~0.7 in melilititic rocks, ~0.6–0.5 in primitive nephelinites, and <0.2 in evolved nephelinites and phonolites. As differentiation progresses, the rocks display depletion in MgO, CaO, FeO, TiO_2, and P_2O_5, along with increasing alkalis, Al_2O_3 and SiO_2, sometimes reaching peralkaline compositions ((Na + K)/Al > 1). The typical mineral assemblages vary with evolutionary stage: primitive rocks contain melilite + olivine + perovskite + Fe-Ti oxides; intermediate stages feature diopside + garnet + nepheline; evolved rocks include aegirine-augite + nepheline + feldspar + titanite; highly evolved rocks show sodalite-aenigmatite-eudialyte assemblages.

Textural and mineralogical differences reflect variations in differentiation pathways, influenced by storage conditions, and cooling history, as well as heterogeneous mantle sources and differences in partial melting. No clear petrological distinction exists between nephelinitic-phonolitic volcanoes that produced carbonatites (e.g., Oldoinyo Lengai, Shombole) and those producing only silicate rocks (e.g., Sadiman, Burko). Using thermodynamic modelling, we constrain and compare crystallization and storage conditions in terms of temperature (T), pressure (P), redox state (fO_2), silica activity ($aSiO_2$), and calcium activity (aCaO). Furthermore, we quantify phase relationships to distinguish between source characteristics and magma evolution pathways, providing insights into observed mineralogical variations and the genetic relationship of melilitites, nephelinites and phonolites.