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Petrogenesis of the melilititic and nephelinitic rock suites in the Lake Natron–Engaruka monogenetic volcanic field, northern Tanzania

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ABSTRACT

The Lake Natron–Engaruka Monogenetic Volcanic Field (LNE-MVF) in northern Tanzania consists of more than 150 vents of Upper Pleistocene to Holocene age that are scattered over an area of 2500 km^2. Here we describe the petrological characteristics of these eruptions in detail and link the magma chemistry to eruptive behavior when the magmas reach the surface. Erupted magmas are predominantly of melilititic or nephelinitic compositions (70 and 25%, respectively), together with minor amounts of basanites (5%). The melilititic magmas form by small degrees (1–2%) of partial melting of a metasomatized upper-mantle source (containing 1–4% garnet together with both amphibole and phlogopite). The melilitites ascend very rapidly through the lithosphere prior to eruption minimizing the effect of fractional crystallization and/or crustal contamination. These eruptions also frequently carry relatively large amounts of mantle debris to the surface which is also reflected in their bulk-rock compositions. The nephelinitic rock suite, on the other hand, forms by larger degrees of melting (2–4%) at higher levels of the sub-continental lithosphere containing less garnet ($\ll$1%). The scarcity of mantle debris in the nephelinitic eruption deposits, combined with the more evolved magma chemistry, indicates ponding in crustal reservoirs en-route to the surface. For many of the nephelinitic magmas this ponding resulted in fractional crystallization of predominantly olivine, which is also one of the principal phenocryst phases in these rocks. However, these periods of residence in the crust must have been short as none of the investigated rocks show any clear evidence of being affected by crustal contamination.

Within the LNE-MVF a rough correlation between magma chemistry and resulting volcanic landforms is recognized. Large maar volcanoes and tuff cones/rings are predominantly of melilititic composition, whereas the nephelinites typically form scoria cones. This is attributed to the fact that melilititic magmas can hold more CO_2 dissolved in the liquid compared to nephelinites, in combination with a rapid ascent from the upper mantle to the surface for the melilitites (<1–2 days). We interpret the violent exsolution of CO_2 (in response to rapid decompression) to be responsible for the higher explosivity of the melilititic eruptions compared to the nephelinitic magmas within the LNE-MVF.

1. Introduction

Monogenetic volcanic fields are characterized by discrete eruptions of small-volume magma batches (Walker, 1993). Although individual eruptions are generally short-lived, the overall longevity of monogenetic volcanic fields can exceed that of large central volcanoes (Németh, 2010). Considered on a global scale, basaltic compositions dominate the magmas erupted within monogenetic fields but many other compositions do also occur (e.g., Barker and Nixon, 1989; Hegner et al., 1995; Jung et al., 2005; Le Bas, 1978; Schmincke, 2007; Stoppa and Schiazza, 2013). Independent of composition, most of the erupted magmas in such systems have not been subject to long-time storage in crustal reservoirs (Németh, 2010, 2003). This minimizes the likelihood of crustal assimilation and/or significant fractional crystallization during ascent. Detailed petrological studies of monogenetic volcanic fields can, thus, provide important insights into both, (*i*) primary magma genesis, as well as (*ii*) the architecture of the sub-volcanic plumbing systems.

The Lake Natron–Engaruka monogenetic volcanic field (LNE-MVF) in northern Tanzania comprises more than 150 vents spread across an area of 2500 km^2 (Mattsson and Tripoli, 2011). Previous studies of <15 vents have indicated that the area is petrologically diverse, especially considering the limited spatial extent of the monogenetic volcanic field (Guest, 1953; Dawson and Powell, 1969; Dawson et al., 1985; Keller et al., 2006). Here we extend the existing dataset by presenting major element compositions from a total of 58 cones and detailed trace element analyses of 23 representative samples from the LNE-MVF. As indicated by previous studies, melilititic and nephelinitic compositions dominate the eruptive products although basanitic compositions do also occur in volumetrically minor amounts. In this paper, we focus on the melilititic and nephelinitic rock suites, although evolved nephelinites from the flank of the Oldoinyo Lengai volcano and basanites from the LNE-MVF are included for comparative purposes. We will disclose that the chemical petrological variability of the melilitites and nephelinites

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can be explained by a combination of variable degrees of melting of a metasomatized mantle source (forming the melilitites) and partial overprinting by subsequent fractional crystallization (for the nephelinitic series). The two dominant magma types show distinctively different behaviors upon eruption, with melilitites frequently being more explosive than the nephelinites. We attribute this to a combination of rapid decompression during ascent and the volatile rich nature of melilititic melts within the LNE-MVF.

2. Geological setting

The Lake Natron–Engaruka monogenetic volcanic field (LNE-MVF) is located in the Gregory Rift of northern Tanzania (Fig. 1). The monogenetic volcanic field comprises more than 150 small cones (i.e., scoria cones, tuff cones, tuff rings and maar–diatreme volcanoes; Mattsson and Tripoli, 2011). The LNE-MVF is delimited to the sides by four larger central volcanoes (i.e., Oldoinyo Lengai, Kerimasi, Ketumbeine, and Gelai; Fig. 1). Of these volcanoes, Gelai and Ketumbeine are predominantly of basaltic to basanitic composition (Dawson, 2008; Guest, 1953; Paslick et al., 1996), whereas Kerimasi and Oldoinyo Lengai are phonolitic–nephelinitic–carbonatitic (Dawson, 1962; Guest, 1953; Klaudius and Keller, 2006; Mariano and Roeder, 1983).

Volcanism in this area started around 8.1 Ma (Dawson, 2008) with voluminous extrusions of basanitic to nephelinitic lava flows (Neukirchen et al., 2010). The oldest rocks of the Kerimasi and Oldoinyo Lengai volcanoes have been dated to 0.4–0.6 Ma and 0.37 Ma, respectively (Hey, 1976; Macintyre et al., 1974). The Gelai and Ketumbeine volcanoes are slightly older (0.96 and 1.8 Ma, respectively; Dawson, 2008 and

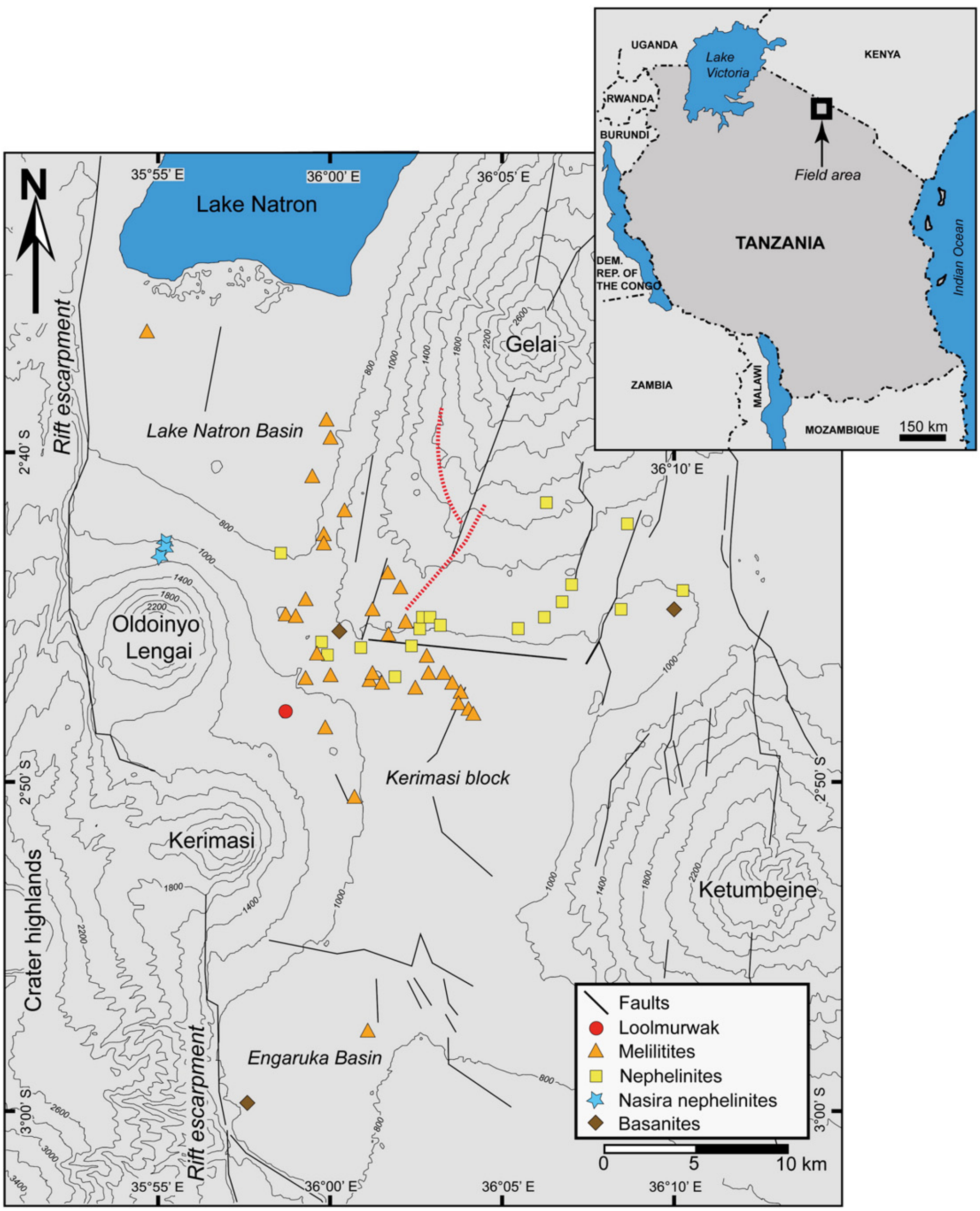

Fig. 1. Map showing the distribution of the sampled vents within the Lake Natron–Engaruka monogenetic volcanic field (LNE-MVF) as well as their compositional classification. The map is modified after Mattsson and Tripoli (2011). The red dashed line indicates the trend of the 2007 diking event at the Gelai volcano (Baer et al., 2008).