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Can Lamprophyres in LIPS Constrain Upper Mantle Plume Dynamics?

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Volatile-rich basanitic melts giving rise to camptonite lamprophyre swarms (Brown 1975) in the Orkney Islands, Northern Scotland, have been precisely dated by mantle xenolithic and autocrystic zircon U-Pb geochronology. The results show that melt generation in the mantle, recorded by xenocrystic zircon in camptonites, and emplacement, recorded by autocrystic zircon in a fractionated sannaitic dike, occurred within c. 5 m.y. from each other. The melt-generation zone of the lamprophyres has been modelled to be >90 km depth, in the garnet stability field (REEBOX PRO; Brown and Lesher 2016) and the zircons show Hf-isotopic evidence for the mixing of two suprachondritic sources, the most positive ε_{Hf}-values interpreted to represent influxing asthenospheric mantle. The xenocrystic nature of the zircons from the camptonite and of most of the zircons from the sannaite (?) is evidenced by the texture (sector zoned, homogeneous but also oscillatory zoned), the trace element chemistry (e.g. Grimes et al. 2015; Hoare et al. 2021), high Ti-in-zircon crystallisation temperatures (>900 °C; Crisp et al. 2023) and for the camptonites, the highly zircon-undersaturated nature of the melts (Crisp and Berry 2022). As the zircons in the camptonites were brought to the near surface in highly zircon-undersaturated melts they are also recorders of magma residence time (Zhang and Zu 2016), and hence ascent rates; in this case recording translithospheric magma ascent of around 15 m/s.

The Orkney dike swarm (Fig. 1) has been associated with the Skagerrak centred large igneous province (SCLIP; Torsvik et al. 2008; Lundmark et al. 2011). The main stage (normally represented by flood basalts in a LIP; e.g. Burgess et al. 2017) of the SCLIP is dated to c. 300 Ma (Torsvik et al. 2008; Corfu and Larsen 2020), and xenocrystic zircons in the Orkney camptonite dikes formed up to 7 m.y. prior to the main stage of the LIP. The formation of the mantle zircons can be interpreted as a process reflecting the first partial melting event associated

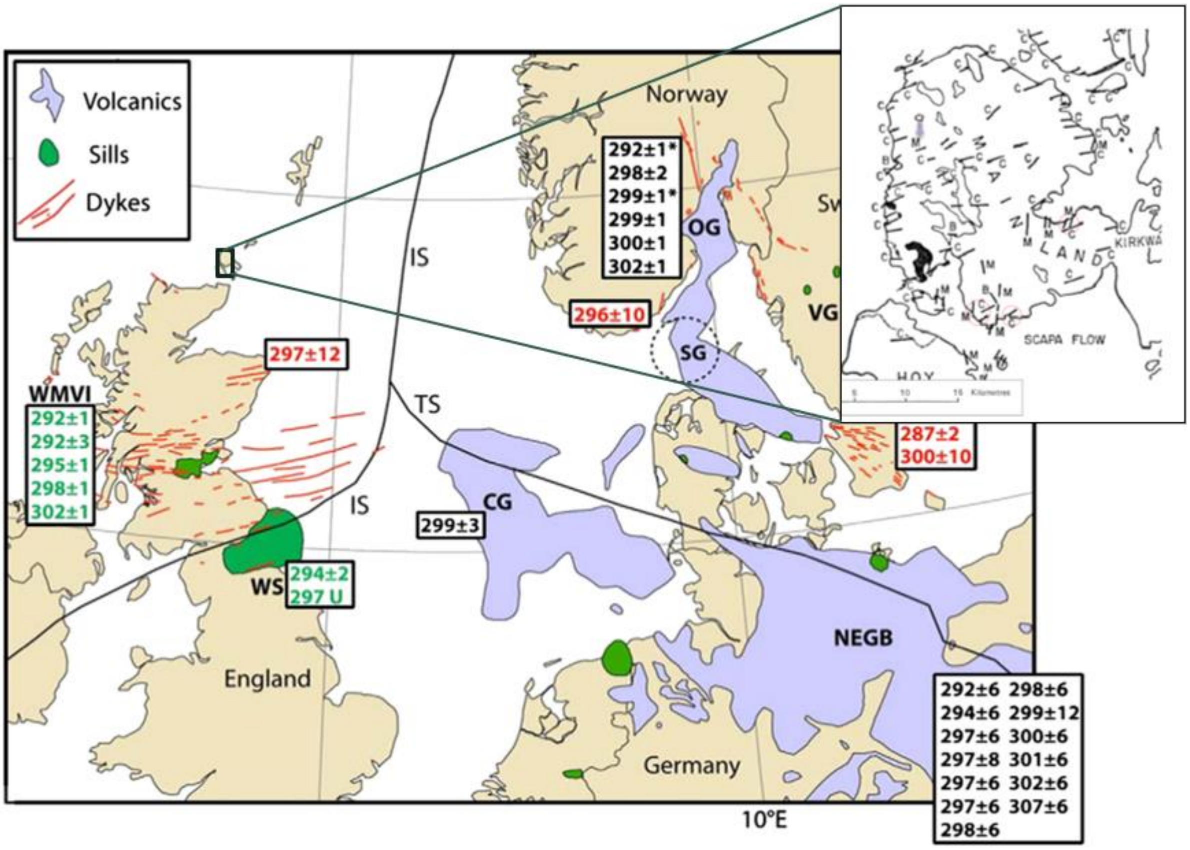

Fig. 1. Overview map of the Skagerak centred large igneous province (SCLIP) and inset showing the Orkney dike swarm(s). Modified from Torsvik et al. (2008) and Brown (1975).

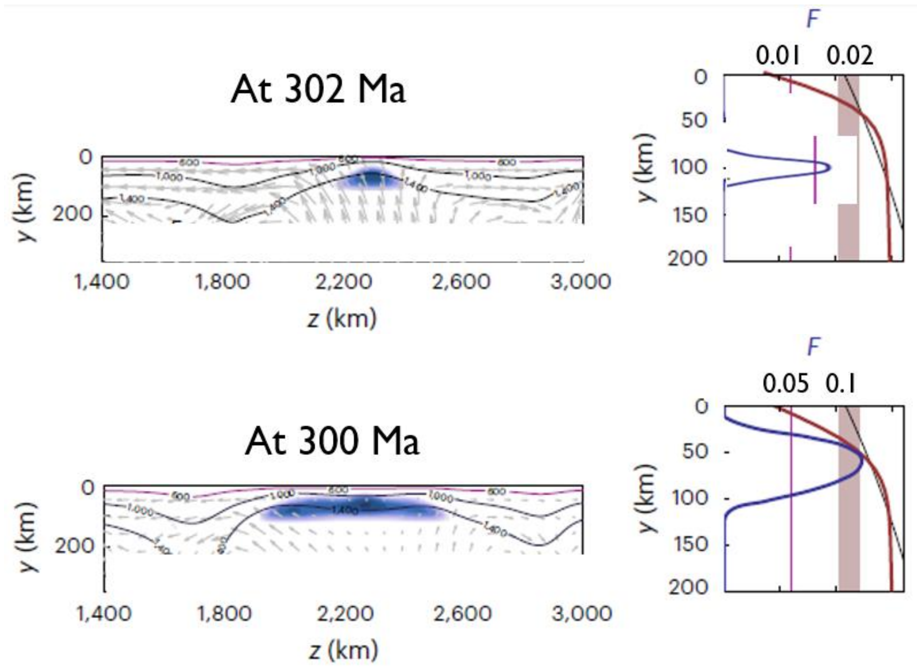

Fig. 2. Conceptual model showing mantle plume impingement at the base of the lithosphere beneath the Orkneys at 302 Ma (upper left panel) and at 300 Ma (lower left panel). At 302 Ma only the tip of the plume has reached the base lithosphere, whereas at 300 Ma the body of the plume has reached the base of the lithosphere. This is reflected in the melt fraction produced and the depth of melting displayed in the upper right panel for 302 Ma and the lower right panel for 300 Ma.

with elevated mantle temperature due to plume-lithosphere interaction (Fig. 2). As such, it places absolute time constraints on upper mantle plume dynamics as a function of mantle potential temperatures (Tp) during different stages of a LIP, determined by the plume ascent velocity in the upper mantle. The modelled conditions at the lamprophyre melt generating stage c. 2 m.y. before the onset of the flood basalt stage (Fig. 2, indicate a Tp of c. 1400 °C (REEBOX PRO; Brown and Lesher 2016). This can be compared to the Tp during the main stage of LIP volcanism, that are typical above 1500 °C occurring at shallower depths, of less than 50 km (e.g. Hole and Millett 2016). Recent, reliable estimates of the Tp at the B1 (main stage) phase of the SCLIP do not exist. However, a highly conservative estimate would be that the mantle potential T increased by 100 °C in 2 m.y., giving direct input into models estimating the plume ascent in the upper mantle, when also considering the shallowing of the melt column and lateral gradients within the plume head (Hole and Millett 2016). Hence, identifying and precisely dating lamprophyre magmas preceding basalt volcanism in LIPs globally provide new constraints to test models of upper mantle plume dynamics when combined with thermal models for plume-ambient mantle interaction.

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