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Lithospheric mantle evolution monitored by overlapping large igneous provinces: Case study in southern Africa

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A B S T R A C T

Most of the studies on the large igneous provinces (LIPs) focus on Phanerozoic times, and in particular, those related to the disruption of Pangea (e.g. CAMP, Karoo, Parana–Etendeka) while Precambrian LIPs (e.g. Ventersdorpf, Fortescue) remain less studied. Although the investigation of Precambrian LIPs is difficult because they are relatively poorly preserved, assessment of their geochemical characteristics in parallel with younger overlapping LIP is fundamental for monitoring the evolution of the mantle composition through time. Recent $^{40}Ar/^{39}Ar$ dating of the Okavango giant dyke swarm (and related sills) in southern Africa showed that ~90% of the dykes were emplaced at 179±1 Ma and belong to the Karoo large igneous province whereas ~10% of dykes yielded Proterozoic ages (~1–1.1 Ga). Here, we provide new major, trace and rare earth elements analyses of the low-Ti Proterozoic Okavango dyke swarm (PODS) that suggest, combined with age data, a cognate origin with the 1.1 Ga Umkondo large igneous province (UIP), southern Africa.

The geochemical characteristics of the PODS and UIP basalts are comparable to those of overlapping low-Ti Karoo basalts, and suggest that both LIPs were derived from similar enriched mantle sources. A mantle plume origin for these LIPs is not easily reconciled with the geochemical dataset and the coincidence of two compositionally similar mantle plumes acting 900 Myr apart is unlikely. Instead, we propose that the Umkondo and Karoo large igneous provinces monitored the slight evolution of a shallow enriched lithospheric mantle from Proterozoic to Jurassic.

1. Introduction

The Continental Flood Basalts (CFBs) consist of a large volume of magma (on the order of several million km^3) emplaced over a relatively brief time span. Whereas most of the studies focus on the Phanerozoic CFBs and particularly those related to the Pangea disruption (e.g. Central Atlantic Magmatic Province (CAMP), Karoo–Ferrar, Parana–Etendeka, Deccan; see for instance Hawkesworth et al., 1999; Courtillot and Renne, 2003), Precambrian CFBs such as Ventersdorpf, Fortescue, Umkondo (Eriksson et al., 2002; Ernst and Buchan, 2003) remain less studied. Precambrian CFBs are frequently highly deformed and eroded and are mostly represented by dykes, sills, layered intrusions, and more rarely, minor remnants of flood basalts (Ernst and Buchan, 2003). Although the investigation of Precambrian CFBs is hindered by their poorly preserved character, their study is fundamental for monitoring the evolution of the mantle composition through time. This is particularly relevant when old CFBs are spatially overlapped by younger ones (Iacumin et al., 2003).

Recent geochronological studies of the Okavango giant dyke swarm (Le Gall et al., 2005; Fig. 1) (and related sill satellites) showed that ~90% of the dykes were emplaced at 179±1 Ma (n=14; Le Gall et al., 2002, Jourdan et al., 2004, 2005) and belong to the Karoo large igneous province. However, it has also been demonstrated that the swarm includes ~10% of Proterozoic dykes (Jourdan et al., 2004). The latter yielded a wide range of imprecise $^{40}Ar/^{39}Ar$ "speedy step-heating" (2–3 heating steps on few plagioclase minerals used only to discriminate Jurassic and Precambrian dykes; Jourdan et al., 2004) ages ranging from 850 to 1700 Ma. One plateau age (959±5 Ma) and one weighted-mean age (983±4 Ma), both possibly suffering of some Ar perturbation, approximate the emplacement age of the swarm. In addition, this study showed that, in the Karoo case, geochemistry can be used to discriminate between Jurassic and Proterozoic populations. Whereas Karoo dykes were shown to be exclusively high-Ti tholeiites (TiO_2-2 wt.%), the Proterozoic Okavango dyke swarm and related sills (PODS hereafter) consist only of low TiO_2 (<2 wt.%) tholeiites. The latter are compositionally similar to the Karoo low-Ti basaltic sub-province that represents the prevailing volume of the Karoo LIP (Jourdan et al., 2007). The purpose of the initial study was to demonstrate that the Jurassic dyke swarm was emplaced following a reactivated direction and does

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not represent a primary Jurassic structure (Jourdan et al., 2004). However, little consideration was given to the Proterozoic dykes and their geodynamic significance. Here, we provide new major, trace and rare earth elements analyses of the Precambrian dykes. We will discuss two hypotheses for the PODS origin: (1) it is part of the recently discovered 1.1 Ga Umkondo igneous province (UIP, Hanson et al., 1998) or (2) it belongs to a Kibaran post-orogenic rifting. In a second part, we compare the composition of the PODS and the low-Ti Karoo Jurassic magmatism in order to monitor the evolution of the underlying mantle through time.

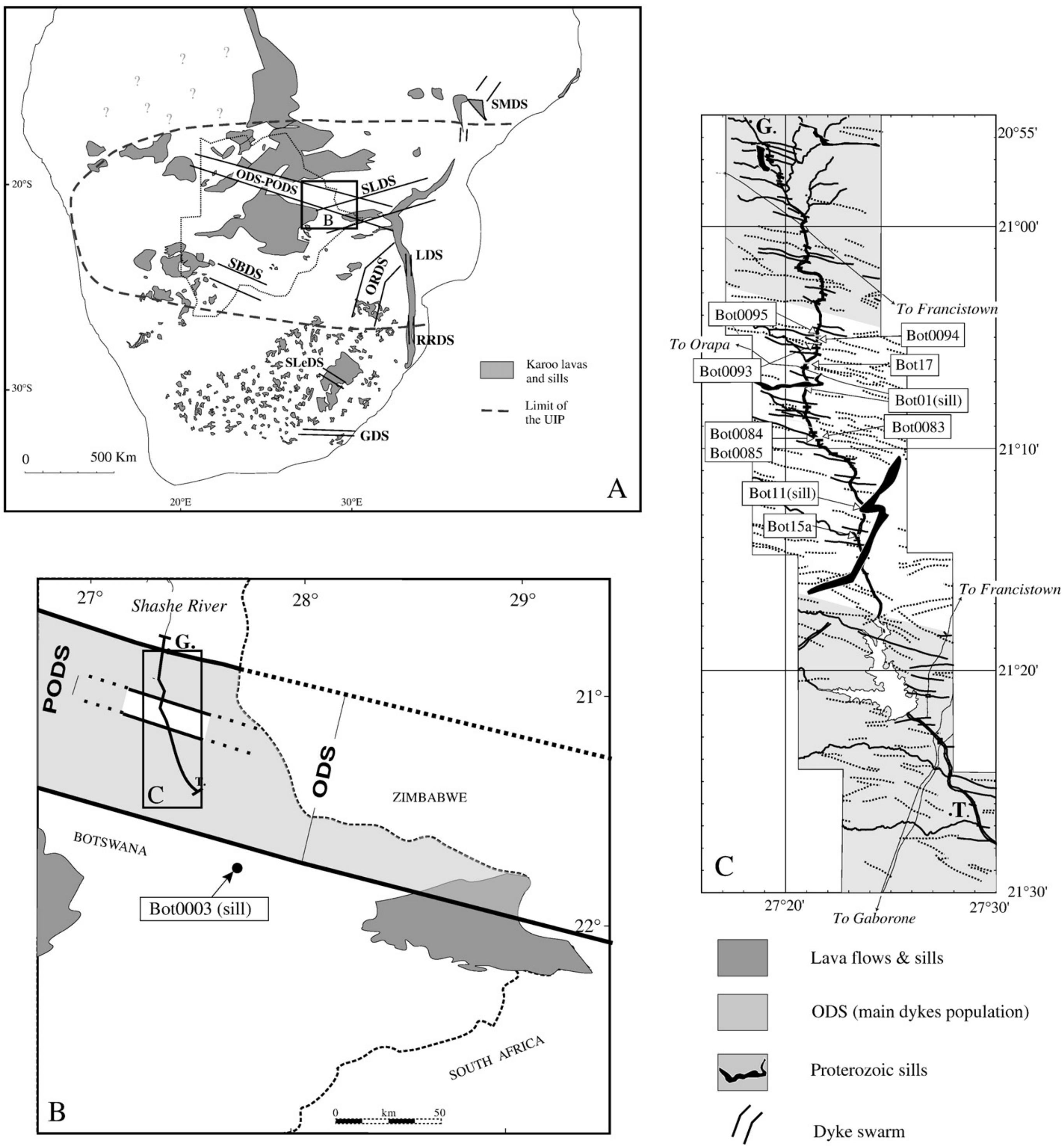

Fig. 1. A) Distribution of the Karoo magmatism and major related dyke swarms (modified after Jourdan et al., 2004 and references inside). ODS: Okavango dyke swarm; PODS: Proterozoic Okavango dyke swarm; ORDS: Olifants River dyke swarm; SBDS: South Botswana dyke swarm; SLDS: Sabi–Limpopo dyke swarm; SleDS: South Lesotho dyke swarm; SMDS: South Malawi dyke swarm; RRDS: Rooi Rand dyke swarm; LDS: Lebombo dyke swarm; GDS: Gap dyke swarm. Dotted line corresponds to Botswana border. Thick dashed line corresponds to the hypothesized limit of the Umkondo large igneous province (UIP; cf. Fig. 10). B) Sketch map of northeastern Botswana showing the N110° oriented ODS-PODS and location of Bot0003 sample. Lava flows exposures are indicated. C) 100-km long section along the Shashe River, with the location of Proterozoic samples only (modified after Jourdan et al., 2004).