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Late Cretaceous ultramafic lamprophyres and carbonatites from the Delitzsch Complex, Germany

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ABSTRACT

The Delitzsch Complex consists of late Cretaceous ultramafic lamprophyres and carbonatitic rocks. They form dikes and diatremes, emplaced into Palaeozoic to lower Permian volcanic and sedimentary rocks, and are covered by up to 120 m thick sequences of Tertiary sedimentary rocks. The complex includes a diversity of magmatic and subvolcanic rocks. The lithologies range from monchiquites and alkali picrites to dolomite– and calcite–carbonatites (rauhaugites, beforsites, and alvikites), and ultramafic lamprophyres (alnöites, aillikites). Contact relationships and the distribution of xenolithic material indicate that phases of carbonatitic and ultramafic lamprophyre magmatism overlapped. New U–Pb ages (72 ± 1 Ma on baddeleyite) from a dolomite–carbonatite (beforsite), Rb–Sr ages (73 ± 2 Ma on phlogopite) from an ultramafic lamprophyre (alnöite) in combination with modeling of the effect of the initial $^{87}Sr/^{86}Sr$ of phlogopite on the isochron ages of dolomite– and calcite–carbonatites demonstrate: (1) a short duration of magmatic activity for the main phases of the subvolcanic emplacement of the Delitzsch Complex; (2) phlogopite crystals in carbonatites of the Delitzsch Complex are xenocrysts; (3) the calculated initial $^{87}Sr/^{86}Sr$ composition of xenocrystic phlogopite equals the initial Sr composition of phlogopite from the alnöite.

1. Introduction

Alkaline rocks and associated carbonatites are unique samples that provide direct insight into the geochemical and isotopic development of the Earth's mantle and constraints for the processes leading to its spatial heterogeneity. Alkaline complexes associated with carbonatites are known from all over the world and several studies using the Sr, Nd, and Pb isotopic as well as trace element compositions of these rocks, focused on the petrogenetic relationship among these rocks. The isotopic characteristics of carbonatites are well documented (i.e. Nelson et al., 1988; Bell and Blenkinsop, 1989) and have been interpreted to reflect mixing products of material derived from the hypothetical (HIMU and EM1) mantle end-members (Bell et al., 1998) with Sr isotopic compositions typically less than $\varepsilon_{Sr} = 10$, although there are carbonatites documented that exceed this value (e.g. Harmer and Gittins, 1998). A recurrent issue in carbonatite genesis is (e.g. Gittins, 1989) whether (i) carbonatites are 'secondary' melts, which were generated by liquid immiscibility or (ii) carbonate melts were derived from a partially molten carbonated mantle peridotite. Experimental data are equivocal. Immiscibility seems to occur at shallower depths, whereas at greater mantle depths a primary carbonate melt is more likely to be generated (e.g. Kiseeva et al., 2012). If carbonatitic melts are produced by partial melting of a carbonated mantle peridotite, the spatial relationship with alkaline rocks in terms of a cogenetic evolution should be reevaluated (Harmer, 1997). A second issue, long debated, is the temporal relation between ultramafic rocks and related carbonatites in alkaline complexes (e.g. Nelson et al., 1987). Geochronologic studies of alkaline complexes (e.g. Tappe et al., 2009, 2011) support a close genetic relationship between carbonatites and alkaline rocks. The temporal evolution of such complexes seems to be a centerpiece for understanding the mechanisms that are involved to form these relatively rare and small magmatic bodies as it puts important constrains to the still open debate of carbonatite genesis and its relationship to associated alkaline rocks. Importantly, results from experimental studies and conditions of carbonatite genesis should be verified on existing field relations between alkaline rocks and carbonatites to evaluate the reliability of these models.

The Delitzsch ultramafic lamprophyre–carbonatite Complex provides new insights into the relationships between carbonate and silicate-dominated ultramafic rocks in alkaline massifs, in particular among carbonatites and various types of ultramafic lamprophyres. The complex is located in the eastern part of Germany and kept secret for a long time by the former GDR, because of its potential for REE, Nb–Ta, and U deposits. The Delitzsch Complex was discovered during uranium exploration and is probably the largest Mid-European carbonatite body. The carbonatitic and ultramafic rocks from dikes were first found by Meissner (1967) in drill cores. Over 500 drill holes were sunk in the 1970s and 1980s (Seifert et al., 2000) and the cores were meticulously sampled by the SDAG Wismut Company (Soviet/East-German Uranium mining Co.) to assess the economic

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potential of the area. Although petrographic, geochemical, and isotopic investigations of the complex started immediately after it had been found, the results of these early investigations were not available except for internal reports — many of them in Russian. The exploration of the Storkwitz diatreme in combination with geologic, petrographic, geochemical, and isotopic investigations of the Delitzsch Complex started in the 1980s by a cooperation between geologists of the SDAG Wismut Company and the Geological Survey of East Germany (Zentrales Geologisches Institut, Berlin). These early investigations eventually were summarized by Röllig et al. (1989, 1990, 1995) and Wasternack (2008), who presented detailed geological, lithological, as well as the first geological multi-stage eruption sequence scheme of the Delitzsch Complex (Table 1). Wand et al. (1989) presented the first isotope data and demonstrated that $\delta^{18}O$, $\delta^{13}C$ and initial $^{87}Sr/^{86}Sr$ of the rocks fall in the 'carbonatite' field. First modern results of mineral composition, petrography and geothermobarometry of the rock types were published by Seifert et al. (2000). Röllig et al. (1990) also refers to K/Ar phlogopite ages published in various Russian SDAG Wismut reports in the 1970s and 1980s. These K/Ar phlogopite ages of the alnöite and the dolomite–carbonatite breccia, which were interpreted to date the time of emplacement encompassing a range from 110 Ma to 70 Ma (Kozyrev, 1977; Fedoriziev et al., 1989). This broad age range was interpreted as evidence for a long-lived magma system beneath the complex, producing the intrusive sequence established on the basis of cross-cutting relationships (Röllig et al., 1995).

Twenty years after the German reunification, the age of the Delitzsch Complex is still only poorly known and there are only a few, modern petrographic, geochemical and isotopical descriptions of the complex. Previous K–Ar ages are unreliable for three reasons: (i) large age ranges are recorded — even for samples from the same dike, (ii) the lack of documentation of the original data and the correction procedures in the unpublished reports of Kozyrev et al. (1977) and Fedoriziev et al. (1989), and (iii) the possibility of the presence of excess radiogenic argon. New U–Pb and Rb–Sr ages from different rocks from this area supersede earlier K–Ar ages and give insights into the temporal development of the Delitzsch Complex and the relations between carbonatites and ultramafic lamprophyres.

2. Geological setting

The Delitzsch Complex is located at the southern border of the Mid-German Crystalline Zone, which represents the former suture between Laurussia and Gondwana, being active during the closure of the Rheic Ocean during the Variscan Orogeny (Fig. 1a). The Delitzsch Complex is situated in the so-called Wrench and Thrust Zone (cf. Kroner et al., 2007; Kroner et al., 2010), which includes Palaeozoic sedimentary rocks that have been deposited on the Cadomian basement and were strongly reworked during the Variscan orogeny. Variscan structural elements were repeatedly reactivated during reorganization of the regional stress field, such as the development of the Oslo Rift, the opening of the Tethys and the Atlantic, and the Alpine Orogeny. These tectonic reactivations of older elements led to the formation of various horst and graben structures with up to 3 km of uplift (Wagner, et al., 1997). The Delitzsch Complex is situated on the intersection of an E–W trending structural low and a seismically active long-lived N–S trending zone (Bankwitz et al., 2003), which is characterized today by low magnitude swarm earthquakes.

Carbonatites and ultramafic lamprophyres, developed as distinct geological bodies forming dikes, sills and pipe-shaped small intrusions (Röllig et al., 1990) have been found in an area of more than 450 km^2 (Wasternack, 2008). They are overlain by up to 120 m thick sequences of Tertiary sedimentary rocks (Standke, 1995). The Delitzsch Complex is emplaced into a heterogeneous series of Palaeozoic to lower Permian volcanic and sedimentary rocks. Dikes of alnöites, monchiquites, aillikites, dolomite– and calcite–carbonatite, as well as the small diatremes of Storkwitz and Serbitz near Delitzsch (Fig. 1c) give evidence for subvolcanic intrusions in the depth range up to 600 m (Wasternack, 2008). The diatremes of Storkwitz and Serbitz are characterized by intrusive dolomite–carbonatite breccias containing abundant angular xenoliths of metamorphic, igneous, and metasedimentary rocks, as well as rounded xenoliths of coarse-grained dolomite–carbonatite (rauhaugite), fenites, and glimmerites, suggesting that carbonatites and related lamprophyres occur at greater depths than sampled by the drilling campaign. According to Röllig et al. (1995), the Delitzsch Complex is characterized by a multi-stage intrusive sequence, summarized in Table 1.

3. Sample descriptions and petrography

Sample selection is based on the eruption sequence according to Röllig et al. (1995) to include the entire compositional range and time sequence of subvolcanic magmatism (Table 1). Furthermore, sampling was restricted to rocks with the least indication for contamination. Nonetheless, most samples show abundant xenoliths or xenocrysts of crustal wall-rocks that had been acquired during the

Table 1
The multi-stage eruption sequence (I = oldest, VI = youngest) for the Delitzsch UML-CR complex, Germany, according to Röllig et al. (1995).

Stage	Event	Depth level[a]	Rock types	Sample (location)
I	Intrusion of carbonatitic magma body	Hypabyssal	Dolomite–carbonatite	–
II	Intrusion of ultramafic and alkali lamprophyres	Subvolcanic	Ultramafic lamprophyres (alnöite, aillikite, monchiquites)	ALN 51°33′11″N 12°17′31″E
III	Formation of diatremes ('intrusive breccia')	Subvolcanic	Dolomite–carbonatite (beforsite) with xenoliths (UML and dolomitecarbonatite)	W2 51°32′05″N 12°17′26″E
IV	Intrusion of lamprophyres within diatremes of stage III	Subvolcanic	Ultramafic and alkalilamprophyres	–
V	Formation of beforsite dikes	Subvolcanic	Dolomite–carbonatite (beforsites) without xenoliths	5551-2, -7, -10 51°32′05″N 12°17′26″E
VI	Formation of carbonate dikes	Subvolcanic	Calcite–carbonatite (alvikite), partly with xenoliths	SER 51°33′24″N 12°14′48″E KMD6, KMD8 51°32′05″N 12°17′26″E

[a] Depth level according to Röllig et al. (1995), based on depth in drill core and textural relation.