



## Contrasting petrogenesis of spatially related carbonatites from Samalpatti and Sevattur, Tamil Nadu, India



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### ABSTRACT

Two Neoproterozoic carbonatite suites of spatially related carbonatites and associated silicate alkaline rocks from Sevattur and Samalpatti, south India, have been investigated in terms of petrography, chemistry and radiogenic–stable isotopic compositions in order to provide further constraints on their genesis. The cumulative evidence indicates that the Sevattur suite is derived from an enriched mantle source without significant post-emplacment modifications through crustal contamination and hydrothermal overprint. The stable (C, O) isotopic compositions confirm mantle origin of Sevattur carbonatites with only a modest difference to Paleoproterozoic Hogenakal carbonatite, emplaced in the same tectonic setting. On the contrary, multiple processes have shaped the petrography, chemistry and isotopic systematics of the Samalpatti suite. These include pre-emplacment interaction with the ambient crustal materials with more pronounced signatures of such a process in silicocarbonatites. Calc-silicate marbles present in the Samalpatti area could represent a possible evolved end member due to the inability of common silicate rocks (pyroxenites, granites, diorites) to comply with radiogenic isotopic constraints. In addition, Samalpatti carbonatites show a range of C–O isotopic compositions, and  $\delta^{13}\text{C}_{\text{V-PDB}}$  values between +1.8 and +4.1‰ found for a sub-suite of Samalpatti carbonatites belong to the highest values ever reported for magmatic carbonates. These heavy C–O isotopic signatures in Samalpatti carbonatites could be indicative of massive hydrothermal interaction with carbonated fluids. Unusual high-Cr silicocarbonatites, discovered at Samalpatti, seek their origin in the reaction of pyroxenites with enriched mantle-derived alkali-CO<sub>2</sub>-rich melts, as also evidenced by mantle-like O isotopic compositions. Field and petrographic observations as well as isotopic constraints must, however, be combined with the complex chemistry of incompatible trace elements as indicated from their non-uniform systematics in carbonatites and their individual fractions. We emphasise that, beside common carriers of REE like apatite, other phases may be important for incompatible element budgets, such as mckelveyite-(Nd) and kosmochlor, found in these carbonatites. Future targeted studies, including in-situ techniques, could help further constrain temporal and petrologic conditions of formation of Sevattur and Samalpatti carbonatite bodies.

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### 1. Introduction

Carbonatites are magmatic intrusive or extrusive rocks containing more than 50 modal % of carbonate minerals (Streckeisen, 1980). They usually have high Sr, Ba, Nb, P and light rare earth element (LREE) contents, often forming an important economic source of these elements (e.g., Castor, 2008; Mariano, 1989). Their global distribution is extensive and associated with a range of tectonic settings (e.g., orogenic, rift-related, oceanic) and with emplacement ages spanning from the

Archean–Paleoproterozoic to the present (Wooley and Kjarsgaard, 2008). The origin of carbonatite magmas has been attributed to three major processes or their combinations (Gittins, 1989; Jones et al., 2013, and references therein), namely: (1) melting of CO<sub>2</sub>-rich peridotite in the upper mantle, (2) separation of carbonatite melt from CO<sub>2</sub>-saturated silicate melts by liquid immiscibility, and (3) fractionation of carbonatite–nephelinite magmas at low pressures. However, crustal-derived carbonatites and/or carbonate-rich liquids have also been reported (Ferrero et al., 2016; Ganino et al., 2013; Lentz, 1999; Morteani et al., 2013; Wenzel et al., 2002). Although the ultimate source of carbon is likely the mantle, a non-negligible portion of carbon may be introduced via recycling (Barker, 1996). Carbonatite melts have extremely low viscosity and low liquidus temperatures of ~600–800 °C (Jones

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et al., 2013 and references therein; Wolff, 1994) permitting fast and efficient transport through the Earth's upper mantle with minimal interaction with ambient rocks. Primary mantle-derived carbonatites can thus provide unique information about the nature of their mantle source. In combination with their typically elevated Sr, Nd and Pb contents, carbonatite magmas are much less susceptible to modifications by assimilation and/or fractional crystallization processes common in silicate melts en route to the Earth's surface (e.g., Bell and Blenkinsop, 1987; Simonetti et al., 1995). Moreover, carbonatite liquids could represent an important metasomatic agent in the deep mantle (e.g., Baker and Wyllie, 1992; Brandl et al., 2015; Ionov et al., 1993; McCoy-West et al., 2015; Tappe et al., 2008; Weiss et al., 2016; Yaxley et al., 1991).

The Indian Peninsula has several occurrences of carbonatite bodies and associated alkaline silicate rocks. These complexes are hosted within different tectonic and lithostratigraphic units with ages spanning from late Paleoproterozoic (~2.4 Ga; Hogenakal Complex; Kumar et al., 1998) to broadly the K/T boundary (76–67 Ma; Amba Dongar; Duncan and Pyle, 1988; Srivastava, 1994). The Tamil Nadu region in southern India hosts several carbonatite bodies (e.g., Hogenakal, Samalpatti, Sevattur, Pakkanadu–Mulakkadu) which are closely associated with alkaline silicate rocks such as syenites, pyroxenites or dunites (Kumar et al., 1998; Miyazaki et al., 2000; Schleicher et al., 1998; Srivastava, 1998). This is in contrast to the carbonatite occurrences in north-western India associated with the Deccan trap basalts (e.g., Amba Dongar) or Proterozoic Newania dolomitic carbonatites. Major/trace element and isotopic studies of the Samalpatti, Sevattur and other complexes in Tamil Nadu have shown significant enrichments in light REE and variations in stable isotopic (C, O) compositions that are similar to mantle-derived carbonatitic melts (Pandit et al., 2002; Ray and Ramesh, 2006; Schleicher et al., 1998). However, some variations exist in the C–O isotopic systematics for Sevattur versus Samalpatti, which may attest to distinct post-emplacement processes for the latter complex. The Sr–Nd–Pb isotopic compositions of Tamil Nadu carbonatites appear to result from mixing of a depleted mantle reservoir and a U-enriched crustal or EMI-like component (Schleicher et al., 1998). However, a direct genetic link between carbonatites and alkaline silicate rocks and, in particular, the origin of abundant silicocarbonatites in the Samalpatti complex and their relation to normal carbonatites remain unclear.

In this study, we report an extensive dataset of petrographic and major/trace element analyses, together with Sr–Nd–Pb isotopic compositions of carbonatites, silicocarbonatites and associated alkaline rocks from the Samalpatti and Sevattur complexes in Tamil Nadu, southern India. In addition, C–O isotopic compositions are presented for chemically diverse carbonatites from both complexes. The combined dataset is used to constrain the distinct origins of carbonatite melts for Samalpatti and Sevattur bodies, as well as to provide models for the origin of chemically different types of silicocarbonatites, such as unusual Cr-rich varieties.

## 2. Carbonatites and alkaline rocks in Tamil Nadu

The carbonatite–alkaline complexes of Samalpatti and Sevattur belong to a large number of syenite, pyroxenite, dunite and carbonatite occurrences in the northern part of Tamil Nadu, southern India (Borodin et al., 1971; Krishnamurthy, 1977; Schleicher et al., 1998; Subramanian et al., 1978; Udas and Krishnamurthy, 1970; Viladkar and Subramanian, 1995), where they are located along the NE–SW trending lineament formed by the Koratti and Attur fault/shear zones (Grady, 1971; Srivastava, 1998). The lineament broadly coincides with the transition zone between the low-metamorphic grade Peninsular Gneisses to the north and the granulite facies rocks of the Southern Granulite Terrane (SGT) to the south (Kumar et al., 1998), and the boundary between the Billirangan Block and the Madras Block of the SGT. The gamut of geochronological data supports a Neoproterozoic age for the alkaline–carbonatite complexes in the Tamil Nadu region,

which can be related to coeval rifting events and alkaline magmatism within other blocks of the Rodinia supercontinent during its breakup (Pandit et al., 2002).

The Samalpatti complex has a size of >125 km<sup>2</sup> (Subramanian et al., 1978; Viladkar and Subramanian, 1995) and comprises syenites, carbonatites, silicocarbonatites, pyroxenites, alkali gabbros and serpentinized dunites, which intruded into hornblende–epidote gneisses (Fig. 1). The complex has a large central syenite body surrounded by a discontinuous ring of pyroxenites. The calcicocarbonatites and silicocarbonatites usually occur as elongated bodies, lenses and dykes or clusters of scattered ~10 cm-sized nodules in pyroxenites and syenites, which can be sampled at several localities (e.g., Jogipatti, Onnakarai; Srivastava, 1998). The exact age of the complex is poorly constrained with the sole K–Ar phlogopite age of 700 ± 30 Ma (Moralev et al., 1975). The origin of carbonatite–alkaline silicate rock association has been interpreted to result from the carbonate and silicate melt separation from a carbonated nephelinitic magma (Srivastava, 1998).

The crescent-shaped and inward dipping Sevattur carbonatite body also belongs to the cluster of several carbonatite occurrences located along the NE–SW trending Koratti and Attur fault/shear zones (Grady, 1971; Srivastava, 1998). It is sandwiched between pyroxenites in the west and northwest and trachytic syenite in the southwest and the east, respectively. Carbonatites together with syenites and associated mafic silicate rocks intruded into regional gneisses. The carbonatites are predominantly represented by calcite-types (sövite) accompanied by dolomite carbonatite (beforsite, rauhaugite) and contain apatite, magnetite, Fe-rich phlogopite, olivine, aegirine, Na-amphibole, pyrochlore, zircon and monazite as minor/accessory minerals (Kumar and Gopalan, 1991; Viladkar and Bismayer, 2014). The pyroxenite is commonly fenitized by carbonatite and syenite to biotite pyroxenite and/or phlogopite–apatite–magnetite pyroxenite (Krishnamurthy, 1988; Kumar and Gopalan, 1991). Several attempts have been made to establish the age of emplacement of the Sevattur carbonatite complex using the K–Ar (biotite, phlogopite; Moralev et al., 1975), Pb–Pb (pyrochlore; Nagpaul and Metha, 1975), and U–Pb fission track (apatite, zircon; Parthasarathy and Sankar Das, 1976). The reported ages vary widely between 845 and 600 Ma, which most likely reflects disturbance of the corresponding isotopic systems during metamorphic overprint. Kumar and Gopalan (1991) reported on a whole rock–mineral Rb–Sr age of 771 ± 18 Ma, which is similar to the whole rock Pb–Pb age of 801 ± 11 Ma obtained by Schleicher et al. (1997). Both these ages have been interpreted as the emplacement age of the carbonatite complex.

## 3. Analytical methods and samples

The summary for the studied samples is given in Supplementary Table 1. Major element compositions of the whole suite were determined by classical wet techniques (AAS, flame photometry, titration) at the Czech Geological Survey following the methods of DEMPÍROVÁ et al. (2010). Total sulfur and CO<sub>2</sub> contents were analysed by an *Eltra CS 500* C–S analyser, and F contents were determined after sample decomposition via pyrohydrolysis. The precision of major element determinations ranged between 5 and 10%. The accuracy of the analytical protocol was monitored by the analyses of JG-3 granodiorite (GSJ) and COQ-1 carbonatite (USGS).

Trace element concentrations for the entire suite were determined using an *Agilent 7900x* ICP-MS, housed at the Czech Geological Survey following Walther et al. (2016). Chromium and Ni contents in carbonatites, and V contents in the whole suite were determined by XRF due to severe spectral interferences during ICP-MS measurements. Reference rocks BHVO-2, JR-2, JG-2, JSy-1 and COQ-1 were analysed for quality control purposes and the results are listed in Supplementary Table 2.

The microanalyses of the rock forming minerals were performed at the Laboratory of electron microscopy and microanalysis at the Institute of Petrology and Structural Geology (Faculty of Science, Charles University, Prague, Czech Republic). The data were acquired using the FEG-

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