Lithos 286–287 (2017) 75–91

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Trace element and isotopic composition of apatite in carbonatites from the Blue River area (British Columbia, Canada) and mineralogy of associated silicate rocks

Roger Mitchell [a,*], Thomas Chudy [b], Christopher R.M. McFarlane [c], Fu-Yuan Wu [d]

[a] Department of Geology, Lakehead University, 955 Oliver Road, Thunder Bay, Ontario P7B 5E1, Canada
[b] Department of Earth and Ocean Sciences, University of British Columbia, Earth Science Building, Vancouver, British Columbia V6T 1Z4, Canada
[c] Department of Earth Sciences, University of New Brunswick, 2 Bailey Drive, Fredericton, New Brunswick E3B 5A3, Canada
[d] Institute of Geology and Geophysics, Chinese Academy of Sciences, Beituchengxilu 19, Chaoyang, Beijing 100029, China

ARTICLE INFO

Article history:
Received 23 January 2017
Accepted 4 June 2017
Available online 16 June 2017

Keywords:
Carbonatites
Apatite
Trace elements
Sr–Nd isotopic composition
Depleted mantle
Blue River
Canadian Cordillera

ABSTRACT

Apatites from the Verity, Fir, Gum, Howard Creek and Felix carbonatites of the Blue River (British Columbia, Canada) area have been investigated with respect to their paragenesis, cathodoluminescence, trace element and Sr–Nd isotopic composition. Although all of the Blue River carbonatites were emplaced as sills prior to amphibolite grade metamorphism and have undergone deformation, in many instances magmatic textures and mineralogy are retained. Attempts to constrain the U–Pb age of the carbonatites by SIMS, TIMS and LA–ICP-MS studies of zircon and titanite were inconclusive as all samples investigated have experienced significant Pb loss during metamorphism. The carbonatites are associated with undersaturated calcite–titanite amphibole nepheline syenite only at Howard Creek although most contain clasts of disaggregated phoscorite-like rocks. Apatite from each intrusion is characterized by distinct, but wide ranges, in trace element composition. The Sr and Nd isotopic compositions define an array on a $^{87}Sr/^{86}Sr$ vs ε_{Nd} diagram at 350 Ma indicating derivation from depleted sub-lithospheric mantle. This array could reflect mixing of Sr and Nd derived from HIMU and EM1 mantle sources, and implies that depleted mantle underlies the Canadian Cordillera. Although individual occurrences of carbonatites in the Blue River region are mineralogically and geochemically similar they are not identical and thus cannot be considered as rocks formed from a single batch of parental magma at the same stage of magmatic evolution. However, a common origin is highly probable. The variations in the trace element content and isotopic composition of apatite from each occurrence suggest that each carbonatite represents a combination of derivation of the parental magma(s) from mineralogically and isotopically heterogeneous depleted mantle sources coupled with different stages of limited differentiation and mixing of these magmas. We do not consider these carbonatites as primary direct partial melts of the sub-lithospheric mantle which have ascended from the asthenosphere without modification of their composition.

1. Introduction

Carbonatites are rare magmatic rocks consisting of over 30 vol.% (Mitchell, 2005) or 50 vol.% (Woolley and Kempe, 1989) primary carbonate minerals. Intrusive carbonatites are typically genetically associated with undersaturated alkaline rocks of the ijolite or melilitolite suites. Although most carbonatites occur in intra-cratonic settings, where they are commonly associated with rift systems, there is now recognition that they can be found in other tectonic settings such as orogenic belts, e.g. the Canadian Cordillera (Pell and Simony, 1987) or oceanic islands, e.g. the Cape Verde Islands (De Ignacio et al., 2012; Hoernle et al., 2002). Intrusive carbonatite complexes are important in an economic context as they are hosts to niobium (Mitchell, 2015) and rare earth (Chakhmouradian and Zaitsev, 2012) mineralization, and from a petrological standpoint in that they are typically mantle-derived and provide information on the evolution of the asthenospheric and/or lithospheric mantle (Bell, 1998; Bell and Blenkinsop, 1987)

The Canadian Cordillera in British Columbia is host to seventeen alkaline complexes of which fourteen have accompanying carbonatites (Pell, 1987, 1994; Woolley and Kjarsgaard, 2008). Unlike many intra-cratonic carbonatite–alkaline rock complexes, the majority of the carbonatites in the Canadian Cordillera, apart from the Ice River Complex (Peterson and Currie, 1994), occur as sill-like bodies with only minor amounts of associated undersaturated rocks.

The eastern margins of the Cordillera which contain alkaline rocks and carbonatites have been subdivided by Pell (1987) and Pell and

* Corresponding author.
E-mail addresses: rmitchel@lakeheadu.ca (R. Mitchell), tchudy@eos.ubc.ca (T. Chudy), crmm@unb.ca (C.R.M. McFarlane), wufuyuan@mail.iggcas.ac.cn (F.-Y. Wu).

http://dx.doi.org/10.1016/j.lithos.2017.06.008
0024-4937/

Höy (1989) into three north-west trending belts: the Eastern; Central; and Western Belts. This work is concerned with carbonatites of the Blue River area which are located in the Central Belt. Here, sill-like discontinuous bodies have intruded Neoproterozoic strata of the Horsethief Creek Group (Pell and Simony, 1987) during Late Cambrian and Late Devonian-to-Early Carboniferous times (Millonig et al., 2012, 2013). Carbonatite emplacement was prior to deformation and metamorphism associated with the Late Jurassic Columbian orogeny. On the basis of structural studies, three deformational events are recognized in the Monashee Mountains area by Raeside and Simony (1983) and Sevigny and Simony (1989). Metamorphism occurred between ~50 and 160 Ma with maximum temperatures and pressures of ~550–700 °C at 7–8 kbar (Ghent and Villeneuve, 2006; Tinkham and Ghent, 2005).

The principal objectives of this study are: (1) to characterize the trace element and Sr–Nd isotopic geochemistry of apatite from carbonatites associated with undersaturated rocks (Howard Creek) and carbonatites without apparent silicate rock association such as the Verity, Gum, Fir and Felix carbonatites of the Blue River area; (2) to present a preliminary characterization of the mineralogy of the Howard Creek silicate rocks; (3) to provide some new geochronological data for titanite from Howard Creek, in order to determine the genetic relationships, if any, between these occurrences.

2. Blue River area carbonatites

2.1. Geological setting

General descriptions of the Blue River area carbonatites have been provided by Pell (1987, 1994). This work is concerned only with the Gum, Fir, Verity, Howard Creek, and Felix carbonatites (Fig. 1). There are approximately eighteen carbonatite occurrences in the Blue River area (Fig. 1) which typically consist of small (100 m) discontinuous outcrops of mostly dolomite and calcite carbonatites, although at Howard Creek and Paradise Lake undersaturated silicate rocks are also present (Pell, 1987). The exposure is very poor due to extensive weathering, the dense forestation at lower elevations, or cover by glacial deposits at higher altitudes. Consequently, the structure and geology of the carbonatites is inadequately characterized, although it is apparent that they form concordant folded sill-like bodies. Most of the carbonatite sills are between 1 and 5 m in thickness and can be traced, at most, for a few hundred meters along strike. The Fir carbonatite is the best studied (Chudy, 2013) and as shown by exploration diamond drilling the largest occurrence in the area. This carbonatite system extends over an area of 1 km by 4.5 km and consists of isoclinal recumbent folds of <5 m to 90 m thick sills with strike lengths of 50 m to 1100 m (Kulla and Hardy, 2015). The Gum carbonatite showing is 1700 m east of the Fir carbonatite and the Verity carbonatite approximately 11 km to the north (Fig. 1). The latter was in the past also the target for a small exploration program, including diamond drilling and prospecting, which showed that part of it has a similar mineralogical character as the Fir carbonatite. Undersaturated alkaline rocks strictly associated with these carbonatites have not been identified, but some banded calcic and alkaline amphibolites of unknown origin were observed in the vicinity. The Howard Creek occurrence, located approximately 18 km east of Verity, consists of several folded carbonatite sills and a titanite-bearing nepheline syenite dike (see below). A sodalite-bearing nepheline syenite is known from the Paradise Lake area ca. 3 km east of Verity (Pell, 1987; Mariano, A.N. *pers. comm.*), but the carbonatite sills in this region (minor biotite calcite carbonatites and dolomite carbonatites) are not in direct contact with the undersaturated rocks. The Felix carbonatite occurrence is in the southern part of the Blue River area, approximately 25 km south-southeast of Howard Creek, and consists of calcite carbonatite without syenitic or other undersaturated rocks.

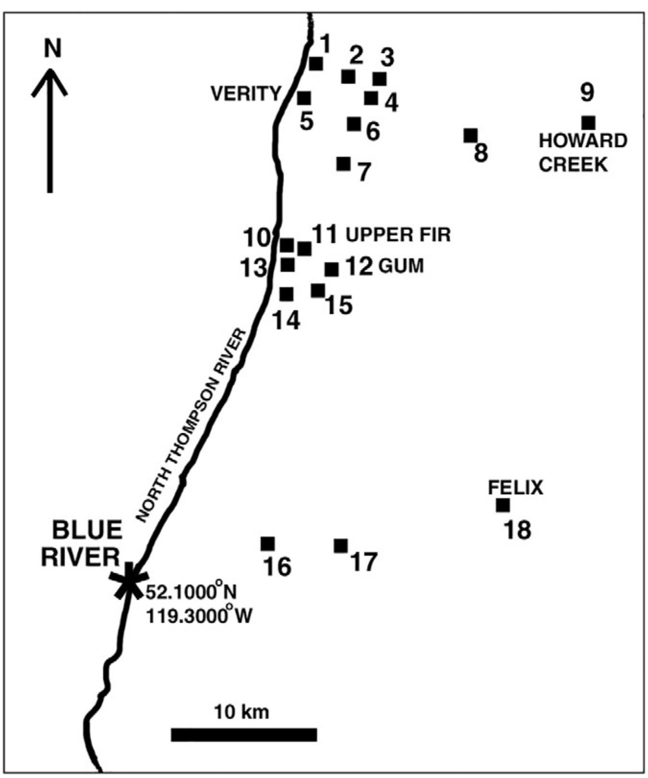

Fig. 1. Location of carbonatites in the Blue River region. 1 Mill; 2 Switch Creek; 3 Paradise; 4 Roadside; 5; Verity; 6; Serpentine Creek; 7 Pyramid; 8; Little Chicago; 9 Howard Creek; 10 Lower Fir; 11 Fir (also referred to in exploration reports as Upper Fir); 12 Gum; 13 Bone Creek; 14 Mona; 15 Hodgie Zone; 16; Mud Lake; 17 Mud Creek; 18 Felix.

As a consequence of the tectonism, the carbonatites in the Blue River area are generally strongly sheared and recrystallized; in particular the thinner sills of calcitic composition. The thicker dolomitic carbonatites, such as at Fir and Verity, are generally coarse grained and show, in parts, a gneissic texture indicative of equilibration during metamorphism (Chudy, 2013). In some instances, the development of retrograde shear zones in the form of mylonites and cataclastites has affected large portions of the carbonatite sills. Nevertheless, recent calcite-dolomite geothermometry studies (Chudy, 2013) obtained from the least deformed carbonatite samples give temperatures approximately 50 °C higher than those of the local regionally-metamorphosed dolomitic marbles (630–650 °C) and are interpreted to be those of magmatic crystallization. Subsequently, during retrograde conditions, the carbonates underwent re-equilibration with additional dolomite exsolution from magmatic calcite. Chudy (2013) has concluded that regardless of high grade metamorphism and recrystallization the Fir carbonatites essentially retain the paragenetic relationships and mineral compositions (e.g., amphiboles and Nb–Ta oxide phases) which formed during magmatic crystallization. Similar conclusions have been drawn by Lastochkin et al. (2011), O'Brien et al. (2015), and Mitchell and Smith (2017) for the Vesely (Russia), Siilinjarvi (Finland), and the Ashram Zone of the Eldor (Canada) metamorphosed carbonatite complexes, respectively.

2.2. Geochronology

The emplacement ages of the Blue River carbonatites are not well-constrained due to the effects of the multiple episodes of metamorphism at 160–52 Ma (Millonig et al., 2013) of the rocks and consequent open system behaviour of potential geochronometers as clearly revealed by initial studies using K–Ar methods on phlogopite and amphibole [80–205 Ma; see the summaries by Pell (1994) and Millonig et al. (2012)]. The best available geochronological data have been obtained by U–Th–Pb methods on zircons. From these studies Millonig et al. (2012, 2013) have concluded that the observed U–Pb data are best