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U-Pb ID-TIMS age of the Tiksheozero carbonatite: expression of 2.0 Ga alkaline magmatism in Karelia, Russia

Research article

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Abstract: The Tiksheozero carbonatite in northern Russian Karelia is a transitional type between alkaline ultramafic - carbonatitic and alkaline gabbroic suites. The complex is dominated by pyroxenite with a variety of subordinate mafic and ultramafic phases and nepheline syenite. Carbonatite occurs in a main central body and in veins. In this study we have obtained a reliable age for the complex by single grain ID-TIMS U-Pb analyses of zircon and baddeleyite. The age of 1999 ± 5 Ma is important because it places the emplacement of the alkaline complexes in the context of craton-wide extension and break-up events which preceded the initiation of a major Paleoproterozoic orogenic cycle. The Paleoproterozoic age also emphasizes the fact that not all members of the Kola alkaline province are of Paleozoic age.

Keywords: carbonatite • zircon • baddeleyite • U-Pb age • Paleoproterozoic • Karelia • Russia

1. Introduction

Alkalic complexes are a widespread and ubiquitous component of the continental crust in the northern regions of the Fennoscandian Shield. The majority, including the economically most important ones, formed in the Paleozoic but there are also several older generations reaching into the Paleoproterozoic and the Neoarchean [1–8]. Alkalic complexes witness episodes of mantle activity, generally related to extensional tectonic processes in the crust [e.g. [9]]. Hence, knowing the precise ages of emplacement plays an important role in reconstructions of crustal evolution and orogenic events. The present study was focused on obtaining the age of the Tiksheozero intrusion in Karelia, in order to resolve the significance of age discrepancies revealed by different dating approaches, as elaborated more in detail below.

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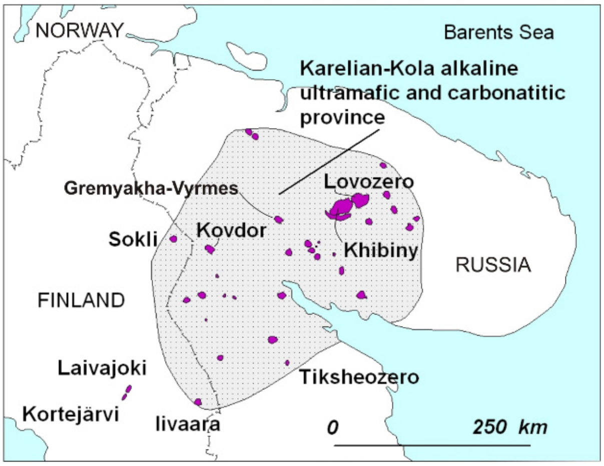

Figure 1. Alkaline complexes and carbonatites in Kola peninsula, northern Russian Karelia and northeastern Finland, after [12, 13].

2. The Tiksheozero intrusion

One of the most important Paleoproterozoic alkalic complexes of the region is the Tiksheozero massif. It is located in northern Russian Karelia (Fig. 1) and belongs to the Karelian-Kola alkaline ultramafic and carbonatitic province, being, in terms of silicate rock composition, referred to as the transitional type between the alkaline ultramafic - carbonatitic and alkaline gabbroid rock assemblages [10]. At different levels, the Tiksheozero intrusion displays weaker differentiation than the Paleozoic ultramafic-alkaline rocks and carbonatites of the Kola Peninsula. The region contains only a few other Paleoproterozoic alkaline massifs, such as Gremyakha Vyrmes [11] and the Laivajoki and Kortejärvi carbonatites [12] on the Finnish side of the border (Fig. 1). The Tiksheozero intrusion (Fig. 2) presents a north-south trending, bowl-shaped body over an area of ca. 20 km^2, and is split up into three large blocks: the Tiksheozero, Central, and Shapkozero blocks. They are composed dominantly of pyroxenite (80%), together with olivinite, ijolite, teralite, alkaline gabbro, gabbronorite, and nepheline syenite. The core of the Central block consists of carbonatite occurring as a large body of ca. 2 km^2 and numerous carbonatite veins. The carbonatite cuts gabbronorite.

The large, tabular carbonatitic body is gently dipping with an uneven upper contact complicated by bulges and apophyses, and by strike-slip faults (Fig. 2). Carbonatite can be detected by local negative gravimetric anomalies. The carbonatites cut the stratigraphy of the intrusion and are variously expressed in the local topography. The spatial arrangement of the carbonatitic bodies is accounted for by local N-trending fractures. They are in turn intersected by oblique northeastern and northwestern faults.

The carbonatitic body is dominated by fine-to-medium-grained, grey and light grey, banded, occasionally massive and spotted varieties connected by gradual transitions with coarser-grained, leucocratic, pink and pinkish-white carbonatites. The pink carbonatite forms veinlets that cut the grey carbonatite. The contact between the carbonatite and the host rock is sharp with pronounced exocontact aureoles represented by pyroxenite metasomatically altered into katophorite-carbonate rock, zeolite aggregates with sodalite, albite, prehnite and aegirine after alkaline rocks, and with albite and aegirine after granitoid rocks. The host rock is often brecciated and cemented with carbonate substance. The thickness of the exocontact aureoles varies greatly, but is normally more than 10 m, at least in discontinuous zones. Mylonite developed in the exocontact of the carbonatite points to a tectonically active setting during the formation of the carbonatite. It is usually represented by dark green, fine-grained amphibole-Mg-carbonate or biotite-amphibole-Mg-carbonate schists with richterite. The carbonatite commonly contains xenoliths of the host rock with variable dimensions and degrees of alteration, from large blocks with sharp outlines to small angular fragments in the form of aggregates of minerals of different colors.

Calcitic carbonatites predominate, while dolomite-(ankerite)-calcitic and dolomitic carbonatites are subordinate. The latter are typical on the flanks of the carbonatitic body, and occur among the calcitic carbonatites as bands with a thickness of up to 5 m, or at the contact between the carbonatitic bodies and Mg-rich host rocks. Coarse-grained to pegmatitic varieties of the calcitic carbonatite (sevite) bond shatter zones in the pyroxenites, form tiny veins escaping into the gabbronorite, and appear in the central part of the carbonatitic body.

The average mineral composition of the carbonatite is as follows: calcite - 70%, apatite - 9%, dolomite - 9%, magnetite - 5%, phlogopite – ca. 3%, amphibole - ca. 4%, and some pyrochlore. Massive carbonatite has widespread taxitic structures associated with uneven distribution of magnetite and silicate minerals that produce spotty patterns or dark speckles in the light background of the carbonatitic rock. Geochemically it is characterized by relatively low concentrations of rare-earth elements, Sr and radioactivity. Main ore components are iron, concentrated in magnetite, and phosphorus in apatite. The content of Nb can increase locally up to 0.05-0.08% reflecting its high concentration in pyrochlore. Local increases in zirconium are related to the presence of zircon and baddeleyite [13].

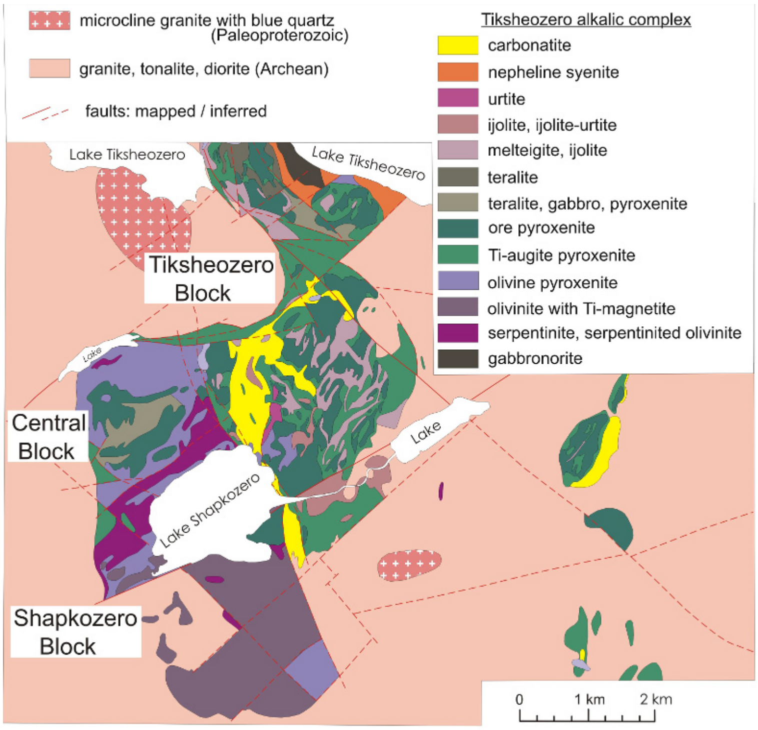

Figure 2. Geological map of the Tiksheozero alkalic complex displaying the geometry of the carbonatite body, compiled by V. Shchiptsov and N. Shchiptsova [13].

Apatite formed in two stages: magmatically and metasomatically (or autometasomatically). Magmatic apatite consists of moderately elongated, prismatic crystals, whereas metasomatic apatite is generally short-columnar and tabular. The grains are strongly fractured and microcracks are filled with carbonate, generally interspersed with magnetite and sulfides (mainly pyrite) as well as locally phlogopite and biotite, amphibole, and pyrochlore. They have low concentrations of U and Òh, and hence non-radiogenic lead [14].

Calcite contains mostly 0.4-0.8% Sr, but Sr enrichments (up to 1.58%) are recorded in the carbonatitic veinlets of the exocontact aureoles of large carbonatitic bodies in the zeolite alkaline rocks. The Sr/Ba ratio of 7-8 in calcite corresponds to that in the early carbonatites of the world's intrusions [13]. The isotopic composition of calcites shows uniform values of $\delta^{13}C$ = -5.48 to - 5.82 and $\delta^{18}O$ = 11.6 to 12.6, which do not exceed those recorded for hypabyssal carbonatites [15], and confirm an endogenous origin [16, 17]. Similar $\delta^{13}C$ = -5, but much lower $\delta^{18}O$ = 6.9, were reported by [18], with the higher values possibly reflecting superimposed alteration effects.

3. Previous geochronology

A number of studies have investigated the geochronology of the Tiksheozero complex. The results are variable, showing that it is Paleoproterozoic, but many isotopic systems were affected by disturbances after emplacement, both in the Paleoproterozic and in the Paleozoic [[7, 18], and references therein]. For example, the zircon U-Pb data reported by [7] demonstrate both types of disturbances, one set of data showing 50-70% discordance towards a Paleozoic event. A Devonian U-Pb age has also been reported for perovskite by [19], which relates it to a metasomatic overprint possibly related to the alkaline activity in Kola and Karelia. By contrast, baddeleyite yielded concordant U-Pb ion probe data giving an average $^{207}Pb/^{206}Pb$ age of 1995 ±10 Ma [20]. Apatite preserves the primary signature fitting a 1.98 Ga isochron in a $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ diagram [14] although its U-Pb system was clearly disturbed [7]. In this paper, we report ID-TIMS U-Pb results on zircon and baddeleyite from carbonatite that provide a reliable age for emplacement of the Tiksheozero complex.

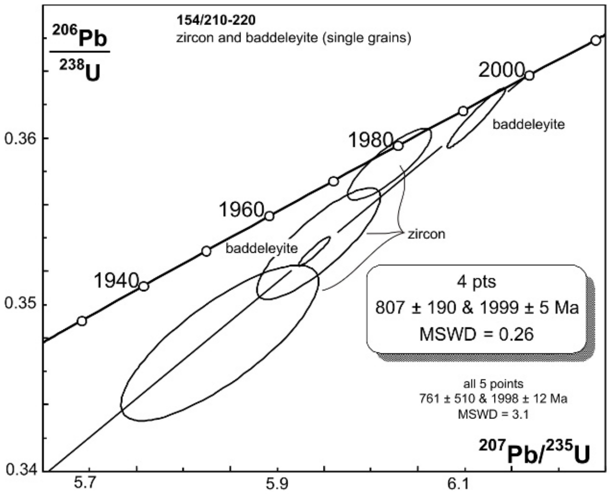

Figure 3. Concordia diagram with U-Pb data for the Tisksheozero carbonatite. Ellipses indicate the 2 sigma uncertainty. Plotting and regression of the data were done with the program Isoplot [41].

4. Analytical procedure and results

Zircon and baddeleyite were separated from carbonatite from one borehole through the complex and subjected to air abrasion before analysis [21]. The analyses were carried out by ID-TIMS following the basic procedure of Krogh [22] as described for the Oslo laboratory in [23]. Decay constants are from [24].

The baddeleyite selected for analysis consisted of very dark brown, translucent to opaque fragments. The two single grains contain 130 and 240 ppm U, show the typical extremely low Th/U ratios of baddeleyite [1] and yield data points that are 0.5 and 2.1% discordant (Table 1). Zircon consisted of very clear and transparent fragments with few visible crystal faces. The three studied grains have much less U (6 – 22 ppm) but higher Th/U (1.6 – 4) than baddeleyite. The degree of discordance is comparable. Because of the low amounts of U and Pb, the zircon data are significantly less precise than those for baddeleyite, which therefore controls the discordia line through four data points. The discordia line has an MSWD of 0.26 and gives an upper intercept age of 1999 ±5 Ma and a lower intercept age of 807 ±190 Ma (Fig. 3). The third zircon analysis is technically concordant but deviates somewhat to the left of the line. Together with the 800 Ma lower intercept age of the line, the deviation to the left suggests that the grains were affected by an early Pb loss event in the Proterozoic before undergoing new Pb loss in the Paleozoic. Therefore the 800 Ma lower intercept age is considered to be geologically meaningless and simply reflect the effect of superimposed disturbances, the type of events that affected much more strongly the isotopic data from previous studies [[7, 18] and references therein].

5. Implications of the age

The upper intercept age of 1999 ±5 Ma corresponds to that reported for baddeleyite by [20] and is more precise and least affected by secondary disturbances than most other dating attempts of the complex. It indicates formation of the Tiksheozero alkalic complex near the end of a period of major extension across the Archean cratons of the Fennoscandian Shield but also recorded variously across the Archean nuclei of Laurentia. Events closely in age include extrusion of the Pechenga picritic basalts and the Pilguyarvi layered intrusion in the Pechenga Belt, Kola Peninsula, gabbro and diabase in central Finnish Lapland at Home-Jolhikko, Pittarova, Kulkujärvi, and the Mjelde-Skorelvvatn belt in Norway [25–28]. Although there is some uncertainty about the exact age, it appears that the Kortejärvi and Laivajoki carbonatites [29] farther west in Finland may be coeval to Tiksheozero (2020 Ma, unpublished data by Kouvo, quoted by [12] and references therein). Younger (1980-1950 Ma) mafic activity is represented by the Onega continental flood basalts in Karelia, possibly the suggested extension of the Central Lapland greenstone belt into the Karasjok belt in northern Norway [30, 31] and the Horsmanaho and Huutoniemi gabbros from the Outokumpu ophiolite, Jormua ophiolite and Koli-Kalimo mafic dyke swarm in Finland [32–35]. In Laurentia these episodes correspond to formation of the Portuniq ophiolite, granodiorite and rhyolite of the Povungnituq Group, and the Minto and part of the Scourie dyke swarms [36–39] Most of these events can be related to crustal extension and rifting, some rifts probably developing into oceanic basins such as the Pechenga-Imandra-Varzuga Ocean [40] The Onega continental flood basalts have been interpreted as representing the product of a mantle plume [31].

The exact nature of the process that lead to the development of the Tiksheozero carbonatite is not entirely understood, but there is little doubt that it originated from melting of the mantle [18]. As stated above, the geometry of the complex is controlled by faults implying that extension or transtension was an important factor controlling its emplacement. To conclude, the 1999 ±5 Ma age of the Tiksheozero carbonatite marks an important event of extension that caused rupturing and mantle melting and was registered all across the Neoarchean nuclei of the Karelian and Laurentian cratons (Kenorland).

Table 1. ID-TIMS U-Pb data for single zircon (Z) and baddeleyite (B) grains from the Tiksheozero carbonatite.

Min.	Weight	U	Th/U	Pbc	206/204	207/235	2σ	206/238	2σ	rho	207/206	2σ	206/238	2σ	207/235	2σ	207/206	2σ	Disc.
	[ug]	[ppm]		[pg]			[abs]		[abs]			[abs]		[abs]		[abs]		[abs]	[%]
B	1	240	0.04	0.5	11521	6.112	0.025	0.3612	0.0015	0.96	0.12273	0.00014	1987.9	7.0	1992.0	3.6	1996.3	2.1	0.5
Z	1	22	4.04	0.7	677	5.944	0.054	0.3537	0.0027	0.84	0.12190	0.00061	1952.1	13.0	1967.8	7.8	1984.3	8.8	1.9
B	4	131	0.06	1.5	7852	5.940	0.014	0.3532	0.0007	0.94	0.12196	0.00010	1949.9	3.4	1967.0	2.0	1985.2	1.4	2.1
Z	1	6	1.62	0.4	359	5.839	0.086	0.3477	0.0038	0.79	0.12179	0.00110	1923.6	18.2	1952.2	12.7	1982.6	15.9	3.4
Z	1	20	3.56	0.4	1001	6.020	0.037	0.3584	0.0017	0.84	0.12181	0.00040	1974.7	8.3	1978.7	5.3	1983.0	5.8	0.5

Notes: Th/U model ratio estimated from 206/208 ratio. Pbc is the total common Pb in the analysis as is considered to be entirely due to blank. The 206/204 ratio is corrected for fractionation and spike, all the other ratios are corrected for fractionation, spike, and common Pb. Disc. = degree of discordance.

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