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GEOCHEMISTRY

Age of Zircons from Chromites in the Residual Ophiolitic Rocks as a Reflection of Upper Mantle Magmatic Events

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Geochronological dating of ophiolite rocks traditionally meets the following problems: (1) tectonic division of ophiolite complexes with subsequent juxtaposition of rocks of different ages [1]; (2) extremely low contents of radiogenic components in mantle residues of ultramafic rocks representing the earliest deep-seated complexes of ophiolite sequences; and (3) the disturbance of Sm/Nd and Rb/Sr systems in the rock-forming clino- and orthopyroxenes of residual ultramafic rocks [2], making it impossible to date mantle rocks associated with plutonic and volcanosedimentary complexes in a single ophiolite association. However, the problems of dating mantle residues of the earliest rocks of the ophiolite sequence could be solved by finding and dating zirconium minerals (zircon and baddeleyite). The presence of zircon in chromite ores and segregations from dunites and harzburgites was noted for some massifs, while U–Pb zircon ages on chromites from dunite–harzburgite complex of the Finero Massif, Western Alps showed a good agreement with geological data [3].

It is highly possible that processes related to the injection of melts through mantle are responsible for the formation of new mineral assemblages in mantle residues (for example, zircon, olivine, Cr-spinel, and clinopyroxene). The present paper reports the results of U–Pb zircon dating on chromite deposits and attempts to infer the timing of magmatic events in residual mantle ultramafic rocks of the Voikar–Syninsky ophiolite massif.

Ophiolite complexes of the Urals were formed during three stages of the Phanerozoic geodynamic evolution of the oceanic lithosphere: Early Ordovician spreading in the southern segment of a common Paleouralian basin; Ordovician rifting of the East European continental margin; and suprasubduction spreading in Early Devonian time, which was distinctly expressed in the polar segment of the Urals [4, 5]. At the same time, detailed studies of the geological structure of the Polar Urals, new isotope datings on the rocks of ophiolite complexes [6], and palinspastic reconstructions testify to the existence of an ancient (pre-Paleozoic) oceanic lithosphere along the margin of the East European plate [7].

Isotope datings on plutonic and dike complexes of ophiolites of the Voikar–Syninsky Massif (Polar Urals) are scarce. According to Sharma et al. [8], the Sm/Nd age of olivine websterites (εNd(T) = + 8.4) and gabbro is 387 ± 34 Ma. These authors noted extremely strong depletion of residual ultramafic rocks and depleted composition of basaltic magmas, which gave birth to all gabbroids and diabases of ophiolites. This is consistent with geological and petrological–geochemical data that suggest the formation of plutonic and dike complexes in a suprasubduction setting of the inter-arc basin. Tonalitic melts were simultaneously formed in the ensimatic island arc. The age of the tonalites, which intrude gabbro and diabases, is 395 ± 5 Ma (Rb/Sr monomineral isochron on biotite + amphibole + plagioclase and whole-rock samples with initial $^{87}Sr/^{86}Sr = 0.70385 \pm 0.00020$) [1]. The U–Pb age of zircons from palgiogranites, which terminate the crystallization of the dike complex, and, hence, the age of the entire dike complex, including various diabases and gabbrodiabases as well as thin plagiogranite stockworks was estimated at 490 ± 7 Ma [6].

Ophiolites of the Voikar–Syninsky Massif were integrated in the allochthonous system of rock complexes of the Tagil–Shchuch'ya (Late Ordovician–Early Silurian) and Voikar (Middle Silurian–Late Devonian) island arcs. According to geodynamic reconstructions for polar sector of uralides, ophiolites are large fragments of the crust and oceanic-type lithosphere, which was formed in Early–Middle Paleozoic back-arc and inter-arc marginal basins, including suprasubduction

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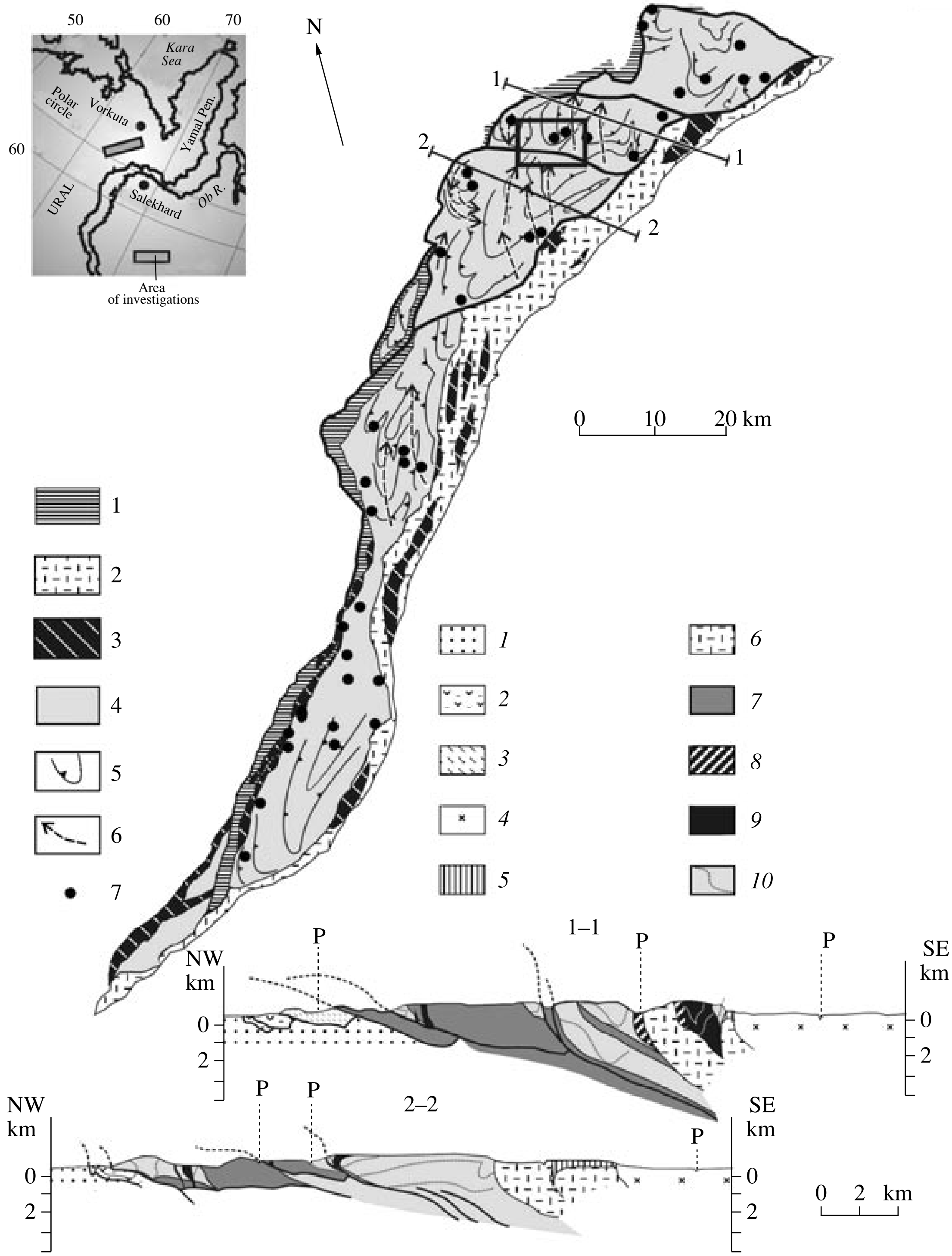

Fig. 1. Geological scheme of the Voikar–Syninsky ophiolite massif, Polar Urals. Box shows the position of the Paity zircon-bearing chromite occurrence. Symbols in the left part of the figure: (*1*) gabbro amphibolite and other metamorphic rocks; (*2*) undifferentiated gabbro, gabbronorite, gabbrodiabase, and diabase sheeted dikes; (*3*) dunite–wehrlite–clinopyroxenite complex; (*4*) harzburgite, dunite, and olivine–antigorite rocks; (*5*) banding; (*6*) lineation, (*7*) chromite occurrences. Symbols in the right part of the figure are ascribed to the geological sections 1–1 and 2–2: (*1*) Paleozoic sedimentary complexes of the Elets zone; (*2*) Early–Middle Paleozoic volcanosedimentary complexes of the Lemva zone; (*3*) metamorphic complexes at the ophiolite allochthon bottom; (*4*) tonalites; (*5*) diabases and gabbrodiabases of sheeted dike complex; (*6*) gabbro, olivine gabbro, gabbronorite, and amphibole gabbro; (*7*) olivine–antigorite rocks, (*8*) dunite–wehrlite and clinopyroxenite; (*9*) dunite; (*10*) harzburgite (dashed lines show the banding).

setting [4, 9, 10]. Ophiolites and the overlying and intruding island-arc complexes were overthrusted onto the continental margin of the East European Platform in the end of Middle–Late Paleozoic (Fig. 1).

Ultramafic mantle residues account for a significant (up to 6-km-thick) part of the ophiolite sequence. Predominant are harzburgites with low contents of CaO and Al_2O_3 (diopside not more than 1.5%) and accessory Cr-spinel (Cr# from 35 to 47). The high-Mg dunites (Cr# of spinel varies from 50 to 63) occupy about 20% of the massif area, while lherzolites form scarce small bodies among harzburgites. Chromite mineralization and diverse orebodies occur in harzburgites and dunites at different structural levels of the sequence. A lenticular–sheeted dunite body (0.6 × 2.5 km in size) recovered among harzburgites in the middle (relative to Moho discontinuity) part of the sequence contains a complex chromite lode associated with a stringer–disseminated chromite mineralization. The ore body (70 × 20 × 6 m in size) is composed of densely disseminated (70–90% Cr-spinel) and massive (>90% Cr-spinel) chromites. Cementing silicates are represented by serpentinized olivine ($Fo_{96–97}$) and the less common Cr-chlorite (kämmererite). The Cr-spinel has a high Cr content (Cr# varies from 67.8 to 73.8; Mg#, from 65.5 to 70.1). Accessory minerals are zircon, apatite, and transparent colorless sphalerite (wüstite), as well as sulfides of Fe and Ni (pyrrhotite, pyrite, and pentlandite). Cr-spinels contain thin inclusions of iridosmine, Os–Ir–Pt intermetallic compounds, and laurite.

Zircon morphology. Two types of zircon were found in the chromites. The predominant zircon of type I is represented by small (from 50–75 μm to 153 μm) prismatic, semitransparent to transparent, colorless euhedral (K_{el} 2.0–2.5) crystals with occasional bipyramidal terminations on prisms (Fig. 2). The grain surfaces are corroded in some places. In appearance, they are similar to those of zircons from plutonic gabbroids (E.V. Bibikova, private communication). Single grains of type II occur as rare xenomorphic (subrounded) fragments of prismatic pink-lilac grains (25–30 to 200–230 μm in size) with occasional corroded faces.

Method of local U–Pb analysis. U–Pb zircon dating was conducted on a SHRIMP-II ion microprobe at the Isotopic Research Center of the Karpinskii All-Russia Research Institute of Geology. Hand-picked zircon grains along with the TEMORA and 91500 standard zircons were cast in an epoxy mount and polished down to half section. After their examination in transmitted and reflected light, the grains were checked by cathodoluminescence analysis to reveal the internal structure of zircon and to select areas for analysis. The U–Pb ratios were measured according to the technique described in [11]. The beam size was 25 μm. The primary ion current of negatively charged molecular oxygen was 4.5 nA. Data were processed with the SQUID and ISOPLOT programs [11]; U–Pb ratios were normalized to 0.0668 in the TEMORA standard zircon with an age of 416.75 Ma.

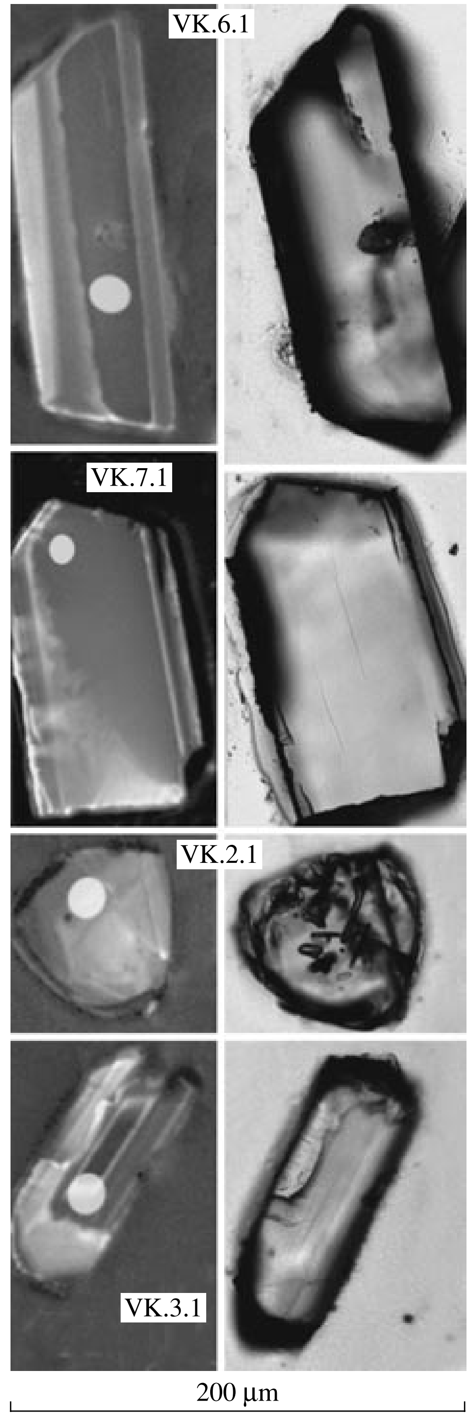

Fig. 2. Cathodoluminescence and optical (transmitted light) microimages of zircon. Numbers near zircon correspond to the analysis number presented in the table. The two upper zircons are grains syngenetic to chromites, while the two lower grains are xenocrysts.

Results of the analysis of nine zircon grains are shown in the table and Fig. 3. Seven grains have moderate contents of U (94–268 μg/t) and Th (53–393 μg/t)

Results of U–Pb analysis of zircons from chromites of the Paity orebody, Voikar–Syninsky Massif

Analysis no.	$^{206}Pb_c$, %	U, μg/g	Th, μg/g	$\frac{^{232}Th}{^{238}U}$	$^{206}Pb^*$, μg/g	(1) $\frac{^{206}Pb}{^{238}U}$ Age, Ma		(1) $\frac{^{238}U}{^{206}Pb^*}$	± %	(1) $\frac{^{207}Pb^*}{^{206}Pb^*}$	± %	(1) $\frac{^{207}Pb^*}{^{235}U}$	± %	(1) $\frac{^{206}Pb^*}{^{238}U}$	± %
1	0.00	98	118	1.25	7.87	578	± 8.2	10.66	1.5	0.06	3.5	0.776	3.8	0.0938	1.5
2	5.96	94	53	0.58	8.15	582	± 10	10.58	1.8	0.066	16	0.86	16	0.0945	1.8
3	0.10	130	151	1.20	10.6	582.9	± 7.3	10.57	1.3	0.0589	4.4	0.768	4.6	0.0946	1.3
4	0.49	138	166	1.25	11.3	583.2	± 7.4	10.56	1.3	0.0597	6.1	0.779	6.2	0.0947	1.3
5	–	268	393	1.51	21.8	584.2	± 6.9	10.54	1.2	0.0602	6.3	0.788	6.4	0.0949	1.2
6	0.31	131	167	1.32	10.9	593.3	± 8.4	10.37	1.5	0.0602	9.1	0.8	9.3	0.0964	1.5
7	2.09	106	140	1.36	9.01	594.6	± 8.6	10.35	1.5	0.0588	9.3	0.783	9.4	0.0966	1.5
8	1.11	325	441	1.40	28.6	622.1	± 5.6	9.871	0.94	0.0612	6	0.855	6.1	0.1013	0.94
9	0.07	144	77	0.55	60.6	2574	± 26	2.038	1.2	0.1687	0.82	11.42	1.5	0.4908	1.2

Errors are given at 1σ; Pb_c and Pb* are nonradiogenic and radiogenic lead, respectively. Error in standard calibration (TEMORA) is 0.18% (1σ). (1) Correction for Pb_c using measured ^{204}Pb.
Sample VK (numbers in the first column correspond to the zircon grains, some of which are shown in Fig. 2): (1) VK.5.1; (2) VK.4.1; (3) VK.1.1; (4) VK.7.1; (5) VK.6.1; (6) VK.9.1; (7) VK.8.1.; (8) VK.3.1; (9) VK.2.1.

at $^{232}Th/^{238}U$ = 1.25–1.50. In two other grains, $^{232}Th/^{238}U$ = 1.4 and 0.55, respectively. The U concentrations are 325 and 144 μg/t, respectively. In the concordia diagram (Fig. 3), the first seven zircon grains form a concordant cluster with an age of 585 ± 6 Ma. Two other zircon grains define concordant ages of 622 ± 11 and 2552 ± 25 Ma. The last zircon grain is a small (75 μm) equant fragment.

The presence of steady elevated Th/U values (>1.2) in the majority of zircon grains is an additional argument in support of the genetic homogeneity of the analyzed zircons, testifying to their noncrustal (mantle) origin. Thus, the zircon age of chromite ores in dunites is 585 ± 6 Ma, whereas the ages of two xenocrysts possibly correspond to the age of the host peridotites.

The appearance of zircons in chromites and their relation with the evolution of the ophiolite sequence could be explained as follows. The chromite ores are restricted to dunites (extreme residues) related to the partial melting of peridotites during extraction of residual harzburgites [12–14]. The harzburgites of the Voikar–Syninsky Massif show distinct textures of subsolidus ductile flow accompanied by brittle deformations. The high-temperature brittle deformation zones, concurrent with ductile deformation zones, are marked by stockworks of dunite, pyroxenite, and gabbro veins and scattered aggregates of diopside and plagioclase. These zones were interpreted in [4] as the pathways of melts and fluids percolating in the residue. The active interaction of hot residual harzburgites with the percolating basaltic melts produced dunites and chromite segregations. The residual portions of fractionated basaltic melts are typically enriched in incompatible trace and rare earth elements, in particular, zirconium (immobile HFSE and LREE).

The effect of enrichment of depleted harzburgites in these elements is considered in [14, 15]. In these works, the mineral and geochemical specifics of magnesian residues are explained by their interaction with the impregnating fractionated melts. The open-system melting implies interaction between residue and percolating melt, which results in the absorption of some components and release of others. This interaction in the melt–rock system presumably provoked the formation of zircons in chromite ores.

Since two gabbroid- and diabase-generating stages of the injection of basic magmas in the Voikar-Syninsky Massif are separated by metamorphic event [4], we can assume that the hot residual harzburgites actively and repeatedly interacted with migrating melts, resulting in the formation of dunite–chromite associations of different ages. It is reasonable to suggest that Paleozoic (including Early Devonian) island-arc complexes of the Polar Urals initially appeared on the pre-Paleozoic oceanic crust, which was reworked by the later magmatic events. As a result, the rocks formed in different geological epochs were locally conserved in the mantle residual complexes of ophiolite association.

Thus, the U–Pb zircon age of chromites (585 ± 6 Ma) marks the Vendian tectonomagmatic activity in the

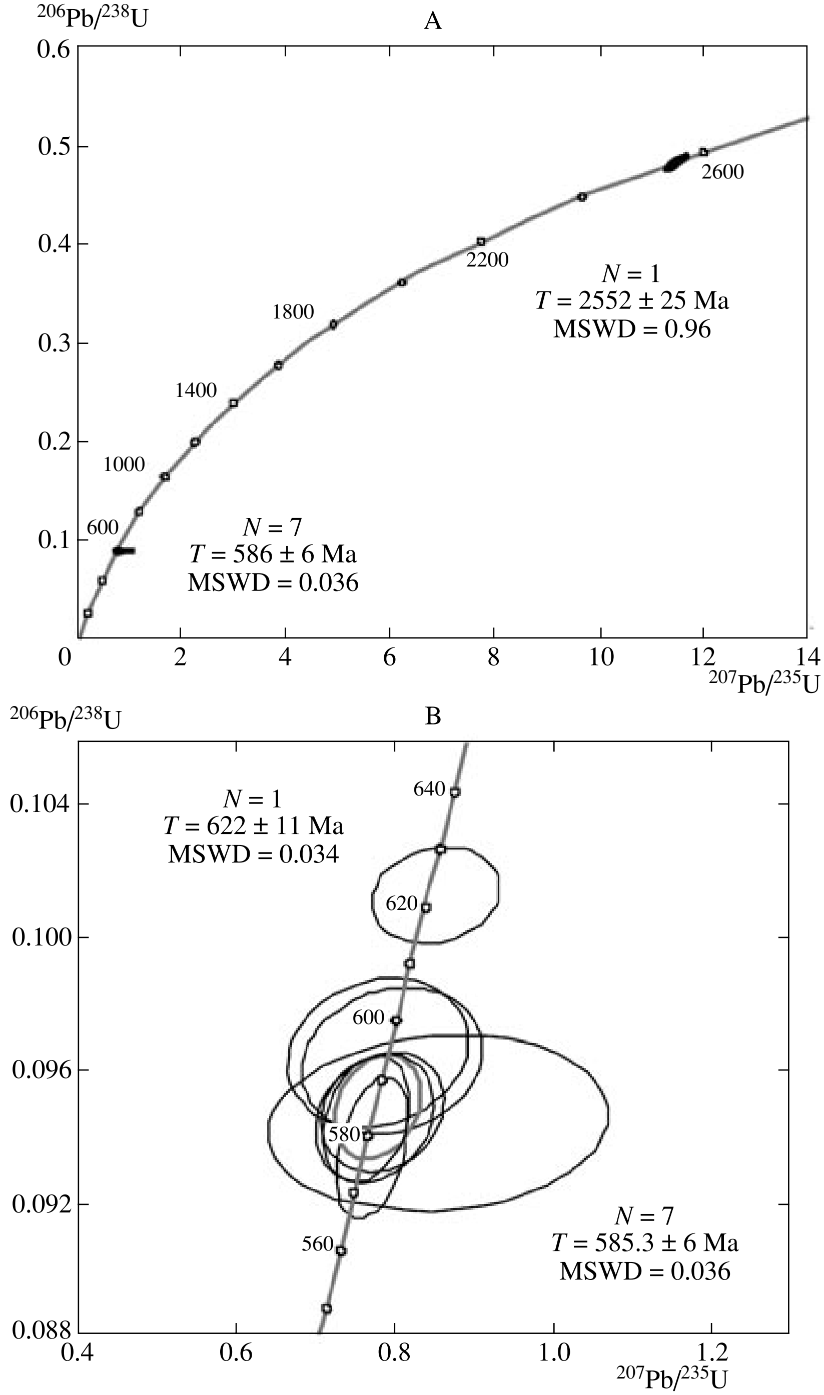

Fig. 3. Concordia diagram for zircons from chromites located in dunites, Mt. Paity, Voikar–Syninsky Massif. (A) Diagram for nine measured zircon grains, (B) detail of diagram A for seven measured grains. $T = 585 \pm 6$ Ma; MSWD = 0.036; the probability of concordance is 0.85.

upper mantle, when basaltic melts in the transition zone of the oceanic basin–East European plate percolated through mantle residues during their subsolidus ductile and brittle deformations.

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