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Isotopic–Geochemical Features and Age of Zircons in Dunites of the Platinum-Bearing Type Uralian Massifs: Petrogenetic Implications

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Abstract—This paper presents results of isotopic (Cameca IMS1270 NORDSIM and SHRIMP-II ion microprobes) and geochemical (LA-ICP MS) study of zircons in three dunite samples of the Uralian–Alaskan-type massifs of the Urals: Kosva, Sakharin, and Eastern Khabarny. The zircons in the dunites share common features. Each sample contains the following genetic and age groups of zircons: (1) xenogenic zircons of the Archean and Proterozoic age; (2) zircons of magmatic appearance, which in age and geochemistry are close to the zircons from associated gabbroids; (3) postmagmatic zircons that presumably crystallized from hydrothermal solutions. The xenogenic zircons of the Archean age in each of three samples comprise transparent fragments, which are depleted in U and other trace elements and presumably have mantle origin. Xenogenic zircons of the Proterozoic age (1500–2000 Ma) occur as oval grains with surface abrasion, the traces of their redeposition. The geochemical features of the xenogenic zircons unequivocally demonstrate their affiliation to the continental crust—the basement of the Uralian orogen.

The zircons of magmatic habit in all the dunite samples are close in age to the associated gabbroids (Ma): 435–432 Ma in the Kosva Massif, 378–374 in the Sakharin Massif, and 407–402 Ma in the Eastern Khabarny Massif, and mark the age of dunite formation. In addition, the magmatic zircons from dunites and associated gabbroids share similar geochemical features. These data could serve as additional argument in support of cumulate origin of dunites in the Uralian–Alaskan-type complexes.

The postmagmatic zircons are most enriched in trace elements and were presumably formed from a fluid phase, which was responsible for the recrystallization of dunites and redistribution of Cr-spinel and PGE mineralization.

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INTRODUCTION

Numerous geochemical and isotopic data on zircons were mainly obtained in order to determine the age of magmatic rocks. At the same time, it became obvious that detailed study of this mineral provides insight in the conditions of their formation and transformation. Moreover, with accumulating data of local methods, researchers understood that adequate interpretation of isotopic data is impossible without complex morphological and geochemical study. All these facts have attracted a great interest in zircon, which presently became one of major targets in petrology and mineralogy.

Most of age zircon determinations were made for granitoids and metamorphic rocks; zircons from basic rocks are less studied, while data on zircon dating of ultramafic rocks are practically absent, except for kimberlites. Few publications such as the work devoted to zircons in the dunite of the Kosva massif of the Platinum Belt of the Urals (Bea et al., 2001), dating of zircons from chromitites in the residual ophiolite dunites of the Voikar–Syn'ya Massif, the Polar Urals (Savelieva et al., 2007), and study of Italian geologists on zircons from peridotites of the Ivrea zone (Grieco et al., 2001) demonstrate importance and informativeness of study of zircons in ultramafic rocks. This primarily concerns dunites, which are the key object for understanding the genesis of most ultramafic-bearing associations.

Indeed, dunites are the only rocks that occur in all ultramafic-bearing associations. They are presented as extreme residues in the areas of mafic magmatism in the oceanic crust, or as the Moho cumulates at the crust–mantle boundary (Nikolas, 1989). In the continental lithosphere, dunites in association with clinopyroxenites occur in the pipe-like intrusions such as Konder or Ingali, in the layered intrusions, or in the Uralian-Alaskan-type zoned massifs. This paper is dedicated to the dunites of the last type.

The few number of publications on zircons in ultramafic rocks is related to its extremely low content in these rocks and difficulties related to its separation, in particular, possible contamination by foreign zircons during crushing or separation on concentration table. Therefore, special techniques were utilized to avoid contamination at all stages of zircon extraction.

We studied three zircon samples from dunites: one sample from the Kosva Massif of the Platinum Ural belt (Bear et al., 2001), and two samples from the Sakharin and Eastern Khabarny massifs of the South Urals.

Dunite sample (Kt355) 150 kg in weight was taken from the borehole entered in the Kosva Massif, the fragment of the large Kytlym Massif. Sample was concentrated at the technological laboratory of OAO "Uralian Central Laboratory" by method described in detail in (Bea et al., 2001). The results were controlled by dissolution of 1 kg of dunite sample in a hot HF vapor with subsequent washing in HCl solution (University of Granda, Span). This dissolution confirmed that dunite contains zircons and some other minerals. Twenty grains of zircon were separated from sample and studied.

Two other samples were taken from the quarry in the Sakharin silicate nickel deposit (sample K1836) and from quarry 5/2 mined for chromite ores in the Khabarny Massif (sample K1832). In both cases, samples about 200 kg weight each were taken from the disintegrated dunite below the clay zone of the weathering profile. Taken material was sieved and washed in the river water. Obtained slime was subjected to hand electromagnetic separation and finally treated in heavy liquids. Such technique excluded its contact with machinery and possible contamination by foreign material. As to preservation of zircons in the weathering crust, the many year experience of A.A. Krasnobaev showed that the zircon is preserved in the lowermost horizons of the crust, where the rocks retained their primary structures. Each sample yielded 30–50 zircons.

The age of zircons from the gabbro and dunites of the Eastern Khabarny and Sakharin massifs was determined on a SHRIMP-II ion microprobe at the Karpinskii All-Russia Research Institute of Geology (analysts A.N. Larionov, N.V. Rodionov, and N.G. Berezhnaya). The technique of the analysis was reported in (Larionov et al., 2004). Zircons from dunites of the Kosva Massif from the Platinum belt of the Urals were analyzed on a Cameca IMS1270 (NORDSIM, Stokholm, Sweden, analyst F. Bea) as well as by Kober Pb–Pb method at the University of Granada, Spain (analyst P. Montero). The analytical procedure was described in detail in (Bea, 2001).

The trace element composition of zircons was determined by LA-ICP MS at the University of Granada, Spain. LA-ICP-MS was carried out on a Mecantec 213-nm laser equipped with Agilent7500s spectrometer in a helium atmosphere. Zr and Si were used as internal standards. The absolute concentrations of elements were measured accurate to about 3%.

The composition of minerals in the dunite of the Kosva Massif was analyzed on a Cameca with accuracy about ±4% for contents less than 1 wt % (University of Granada, analyst H. Molina Palma).

GEOLOGICAL–GEOCHEMICAL CHARACTERISTICS OF THE ROCKS

All three studied dunite samples were taken from the platinum-bearing type massifs that are widely spread on the Urals. Most of these massifs form the known Platinum belt of the Urals (PBU). In the foreign literature, the massifs of this type are called as the Uralian–Alaskan type. They are characterized by concentrically zoned structure and association of dunites with clinopyroxenites, with wehrlite as predominant peridotites. Orthopyroxene is scarce in the ultramafic rocks, but occurs in significant amounts in the gabbroids.

This paper is focused on the dunites from the Kosva Massif (PBU) and two largest South Urals massifs: Sakharin and East Khabarny. The Kosva Massif is practically adjoins the main Ural Suture—the Main Ural Fault (MUF) in the east. The Eastern Khabarny Massif is located in the Sakmara Zone, in an allochthon located west of the MUF, and the Sakharin Massif is located in the eastern limb of the Magnitogorsk volcanogenic zone of the southwestern megablock approximately 100 km east of the MUF zone (Fig. 1a).

The Kosva dunite–clinopyroxenite massif represents the southwestern fragment of the large Kytlym massif of PBU (Fig. 1b). The massif was studied by many researchers, in particular, by A.A. Efimov and L.P. Efimov (1967) and O.K. Ivanov (1997), who compiled the detailed geological map of the massif on scales of 1:50000 and 1:25000, respectively. The massif is composed mainly of dunites, olivine clinopyroxenites, and nepheline-bearing tylaites. The dunites form two isolated bodies among clinopyroxenites, in contact with which they grade into wehrlites. Dunite sample (Kt355) for dating was taken from the borehole drilled in the eastern dunite body.

The composition of the dunite is listed in Table 1. The extent of serpentinization of the rock widely varies up to 30%. Besides olivine with f = Fe/(Fe+Mg) = 0.10–0.11, the rock contains clinopyroxene (f = 0.07–0.08), Ti-bearing Cr-spinel with variable Cr content (Table 2), and, occasionally, phlogopite. There are also scarce grains of andradite–grossular garnet, rutile, green spinel, corundum, zircon, and Cl and F-rich apatite. Most accessory minerals were crystallized at the fluid-assisted late stages of dunite formation, as was recorded during study of the postmagmatic Pt-rich chromitite segregations in dunites (Anikina et al., 2001; Pushkarev et al., 2007).

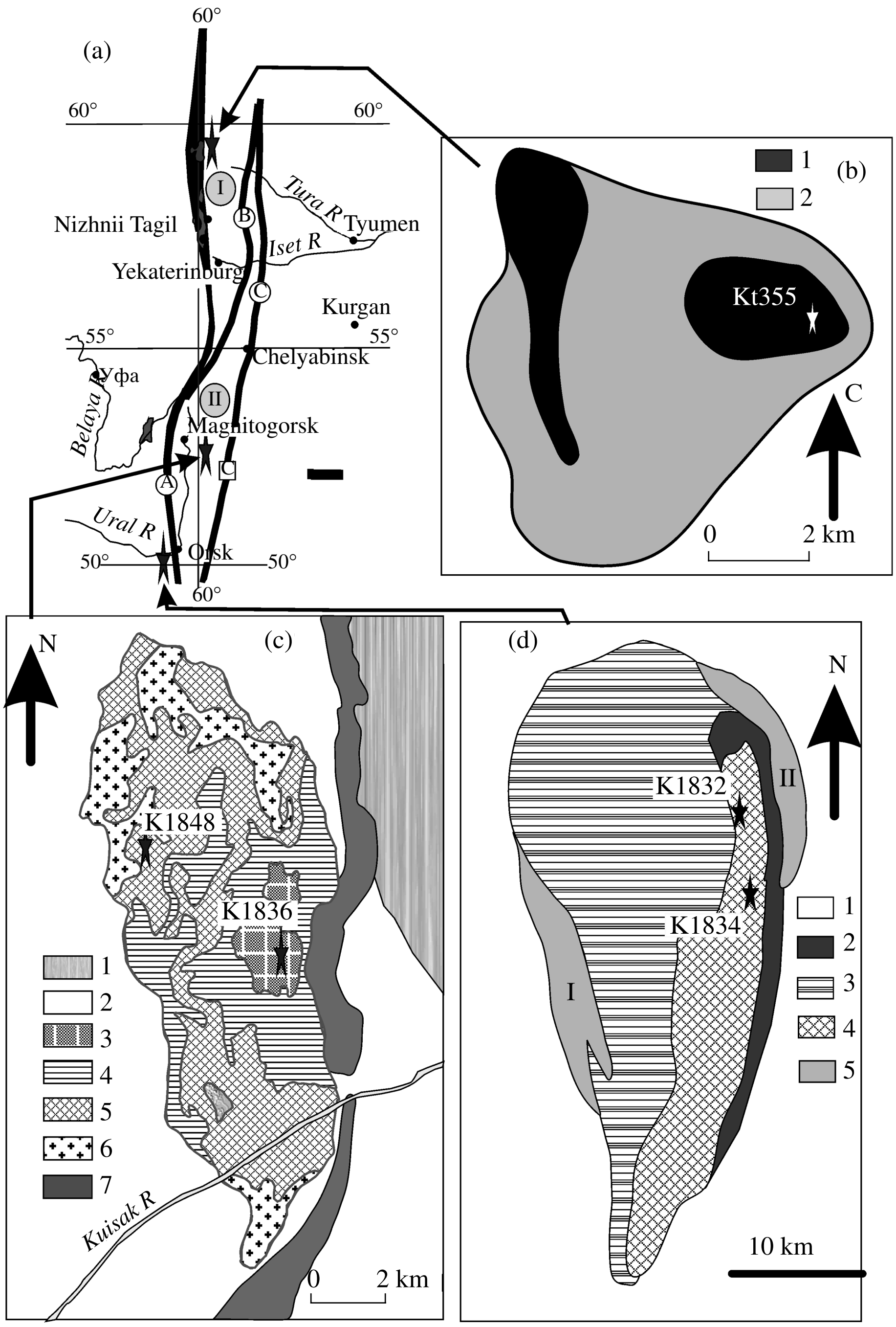

Fig. 1. Geological schemes.

(a) Position of the studied massifs in the main tectonomagmatic structures of the Urals.

(I, II) northwestern (I) and southeastern (II) island-arc continental megablocks (Fershtater, 1992); main sutures: (A) Main Ural Fault; (B) Northern Mauk, (C) North Chelyabinsk. Asterisks show the studied massifs.

(b) Kosva Massif (Efimov and Efimova, 1967).

(1) dunites, (2) wehrlites, clynopyroxenites, and tylaites

(c) Sakharin Massif (scheme compiled using materials of the Magnitogorsk Geological Prospecting Expedition and geological survey on a scale of 1:50000 under the leadership of Yu.N. Zamigi).

(1) chlorite and micaceous schists; (2) volcanic rocks of mainly Devonian age; (3–6) rocks of the Sakharin Massif: dunites (3), clinopyroxenites (4), gabbroids (5), syenites and granosyenites (6); (7) serpentinites

(d) Khabarny allochthon (scheme was compiled using data of geological surveys and thematical works).

(1) host volcanogenic-sedimentary rocks of O_2–D_2 age, (2) amphibolites, (3) dunite–harzburgitic mantle tectonites, (4) Eastern Khabarny dunite–clinopyroxenite–websterite–gabbronorite layered massif, (5) the Kirpichninskii (I) and Akkerman (II) dunite–wehrlite–clinopyroxenite–gabbro–plagiogranitoid layered massifs.

In schemes (b, c, d), the asterisks show the sampling locality, while numerals, their numbers.

Table 1. Content of major (wt %) and trace (ppm) elements in the studied dunites and gabbroids

Components	Kt355	K1836	K1848	K1832	K1834
SiO_2	38.15	37.3	52.71	38.54	47.55
TiO_2	0.06	0.04	0.819	0.06	0.98
Al_2O_3	0.51	0.90	12.13	0.88	16.67
Fe_2O_3	5.12	7.32	11.57	6.67	4.95
FeO	6.78	2.41	n.d.	3.30	6.66
MnO	0.19	0.14	0.187	0.13	0.18
MgO	40.58	39.11	7.01	37.57	7.10
CaO	1.31	0.98	9.85	0.05	10.14
Na_2O	0.08	0.14	2.3	0.30	2.31
K_2O	0.03	0.04	1.53	0.02	1.82
P_2O_5	0.01	0.01	0.29	0.02	0.43
L.O.I.	7.1	11.09	1.40	12.59	1.03
Li	2.03	0.92	1.83	0.22	8.98
Rb	0.82	0.30	23.59	0.64	45.30
Cs	0.02	0.02	0.59	0.11	0.55
Be	0.18	0.11	0.56	0.13	1.01
Sr	5.565	9.13	248.61	13.06	855
Ba	11.3	0.95	327.36	12.08	344
Sc	11.017	7.73	31.83	11.65	20.54
V	22.44	9.49	199.60	40.09	415
Cr	3146	1192	236	1110	73
Co	138	103	33	108	44
Ni	1381	2400	87.51	1407	55.60
Cu	39.65	3.13	50.72	10.57	114.20
Zn	57.03	33.74	102.50	44.69	123.80
Ga	1.34	0.25	12.83	0.92	22.60
Y	0.56	0.44	15.74	0.99	15.86
Nb	0.16	0.09	3.78	0.10	3.11
Ta	0.053	0.09	0.28	0.08	0.63
Zr	6.10	3.10	24.02	4.51	20.65
Hf	0.32	0.12	1.07	0.19	0.75
Mo	0.07	0.19	1.14	0.20	1.23
Pb	0.30	1.11	2.59	1.26	4.33
U	0.01	0.06	0.97	0.09	1.42
Th	0.09	0.13	0.33	0.07	1.71
La	0.13	0.34	7.15	0.19	9.54
Ce	0.37	0.73	14.85	0.48	20.57
Pr	0.06	0.09	2.02	0.07	3.31
Nd	0.30	0.30	9.11	0.37	13.12
Sm	0.12	0.14	2.40	0.11	3.10
Eu	0.03	0.02	0.86	0.03	0.95
Gd	0.13	0.10	2.89	0.14	2.76
Tb	0.02	0.01	0.46	0.03	0.42
Dy	0.12	0.10	3.09	0.17	2.71
Ho	0.03	0.02	0.64	0.04	0.58
Er	0.07	0.05	1.83	0.11	1.35
Tm	0.012	0.01	0.28	0.02	0.23
Yb	0.079	0.04	1.90	0.11	1.38
Lu	0.015	0.01	0.29	0.02	0.29

Note: Sample Kt355—dunite from the Kosva Massif; sample K1836 and K1848 are the dunite and monzogabbro from the Sakharin Massif; samples K1832 and K1834 are the dunite and gabbronorite from the Eastern Khabarny Massif.

Such minerals as kyanite, staurolite, and corundum were presumably entrapped by parental melt from the wall rocks.

The Sakharin dunite–clinopyroxenite–monzogabbro–granosyenite massif (Fig. 1c) is located 40 km east of the Magnitogorsk town, in the eastern limb of the Magnitogorsk volcanogenic zone. The massif is located among mainly Devonian volcanics, which contain widespread rocks of elevated alkalinity and considered as the rocks of mature island arc (Yazeva and Bochkarev, 1998). The core of the massif is made up of phlogopite-bearing dunite, weathering crust of which is mined for silicate nickel. Significant thickness of dunites is confirmed by the borehole that entered the underlying rodingitized diabases at a depth more than 1 km. The clinopyroxenites are mainly represented by amphibole-bearing varieties, and form discontinuous band at the contact of gabbroids and dunites, as well a small bodies within gabbroids. Most of them are cumulates. The most part of the massif is occupied by hornblende and biotite–hornblende (often with relicts of clino- and orthopyroxene) monzogabbro (Table 1). The gabbroids are cut by numerous veins of hornblende and biotite–hornblende quartz syenites and granosyenites—their intrachamber derivatives.

Sample of dunite (K1836) was taken at a depth of about 25 m from quarry at the Sakharin silicate nickel deposit, in the lower rubble zone of the weathering profile at the contact with weakly weathered dunite. Dunite contains 85% serpentine. In addition to olivine with $f = 0.09$, paniculate serpentine, brucite, and magnetite, the rock contains subordinate amounts of Cr-spinel, interstitial diopside, and phlogopite. Heavy fraction (> 3.3 g/cm^3), in addition to zircon, contains kyanite (occasionally with numerous graphite inclusions), blue corundum, almandine garnet, moissanite, rutile, apatite, leucoxene, titanite, i.e. approximately the same minerals as sample of the Kosva dunite.

Sample of monzogabbro (K1848) was taken from exposure in the northwestern part of the massif. It has a hypidiomorphic texture and consists of otho- and clinopyroxene, hornblende, biotite, plagioclase $An_{50–30}$, orthoclase, and magnetite.

The Eastern Khabarny dunite–clinopyroxenite–websterite–gabbro massif is located in the eastern part of the Khabarny harzburgite massif (Fig. 1d), and together with harzburgites is in overturned position (Ruzhentsev, 1976). The massif has a multiple structure and consists of at least four large units (from top downward in the modern position): gabbronorite, websterite, clinopyroxenite, and wehrlite–dunite (*Petrology…*, 1991; Fershtater, 2004).

Dunite sample (K1832) was taken in the northwestern part of the dunite unit, in quarry 5/2 mined for chromite ores, whereas amphibolized gabbronorite (sample K1834) was sampled in the upper reaches of Kholodny Creek, in the northeastern part of the gabbronorite body—amphibolized gabbronorite.

Table 2. Chemical composition of minerals from the dunite (Kt355) of the Kosva massif

Components	*Ol*	*Ol*	*Cpx*_C	*Cpx*_R	*Cpx*_C	*Cpx*_R	Cr-*Shl*	Cr-*Shl*	*Gros*
SiO_2	40.23	40.34	52.61	52.88	52.25	52.38	0.03	0.03	36.39
Al_2O_3	0.01	0	1.78	1.56	2.16	2.16	17.89	12.63	6.89
TiO_2	0	0.01	0.15	0.15	0.29	0.26	0.51	0.19	0.13
FeO	9.4	10.43	2.7	2.62	2.68	2.75	20	18.42	20.29
MnO	0.2	0.21	0.04	0.08	0.04	0.07	0.37	0.44	0.61
MgO	47.46	47.5	16.18	16.44	15.75	15.85	13.15	11.79	0.14
CaO	0.23	0.22	24.01	24.15	24.19	24.28	0	0	32.32
Na_2O	0.04	0	0.36	0.34	0.32	0.3	0	0	0.01
K_2O	0.06	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.02
Cr_2O_3	0.04	0.03	0.65	0.49	0.54	0.51	46.66	55.4	0.03
NiO	0.18	0.23	0.03	0.04	0.04	0.02	0.17	0.06	0
Total	98.04	99.16	98.64	98.89	98.46	98.71	98.85	99.05	97.04
Fe/(Fe + Mg)	0.10	0.11	0.08	0.08	0.09	0.09	0.46	0.46	0.99

Note: Mineral abbreviations: (*Ol*) olivine, (*Cpx*) clinopyroxene (C is the grain core, R is the rim), Cr-*Shl* is the Cr-spinel, *Gross* is grossular.

Strongly serpentinized dunite has a typical composition (Table 1). The Fe mole fraction of olivine varies within 0.08–0.1. Cr-spinel is represented by high-Cr low-Ti variety. Clinopyroxene and phlogopite occur in minor amounts (*Petrology…*, 1991). As is seen in small domains that avoided serpentinization, the rocks were recrystallized into fine-grained granoblastic rocks.

The heavy fraction, besides zircon, contains such minerals as kyanite, green spinel, ilmenite, titanite, and apatite.

The gabbronorite is represented by amphibole-bearing variety (about 15% hornblende) consisting of clinopyroxene predominating over orthopyroxene, plagioclase $An_{60–45}$, and subordinate biotite, orthoclase, and magnetite. Texture is gabbroid. Detailed study showed that hornblende was last to crystallize in the gabbronorite (*Petrology…*, 1991). The amphibolization zones are accentuated by migmatite-like veins of anatectic granitoids formed in response to obduction of the hot Eastern Khabarny Massif in continental crust. The age of zircons from these obduction-related granites accounts for 387 Ma (Fershtater and Krasnobaev, 2007), which is close to the age of zircon from the studied gabbronorite.

The described objects share some common features typical of the Uralian–Alaskan-type intrusions: (1) association of dunites with calcium ultramafic rocks (wehrlites and clinopyroxenites, often with magnetite); (2) concentrically zoned structure of massifs with dunite core and clinopyroxene rims; (3) common presence of K-feldspar-bearing gabbroids often of elevated alkalinity; (4) elevated contents of strontium, barium, and other large-ion lithophile elements in the rocks.

Geochemical features of dunites and associated gabbroids are shown in the corresponding diagrams (Fig. 2).

ZIRCONS FROM DUNITES AND ASSOCIATED GABBROIDS

The morphology of the studied zircons was described in detail in (Krasnobaev et al., 2008). Below we consider their isotopic and geochemical characteristics.

Dunite Kt3554 from the Kosva Massif contains polychronous association of zircons. Zircons of the Archean and Proterozoic ages are represented by pink rounded grains showing typical abrasion surface. They are of xenogenic origin. Two grains analyzed on a NORDSIM define an U–Pb age of 1802 ± 5 Ma (Fig. 3a, Table 3), whereas $^{207}Pb/^{206}Pb$ age of two other grains determined by Kober method accounted for 2827 ± 6 and 2838 ± 10 Ma (Bea et al., 2001). The following age group (432–435 Ma) is represented by fragments of concentrically-zoned (Fig. 3b) low-U crystals. In age, they are similar to zircons from the gabbroids and volcanics of the Tagil volcanogenic zone, that are most abundant in the Platinum belt of the Urals (Krasnobaev et al., 2007). Zircons with ages less than 370 Ma (Fig. 3c, 3d) are most abundant among dated zircons (Fig. 3e). These are variably corroded crystals with varying U content. They were presumably crystallized from hydrothermal solutions at postmagmatic stage within an age interval of 370–350 Ma. In addition to the young age, this assumption is supported by the presence of low-temperature accessory minerals associated with segregations of Cr-spinels and PGE in dunite.

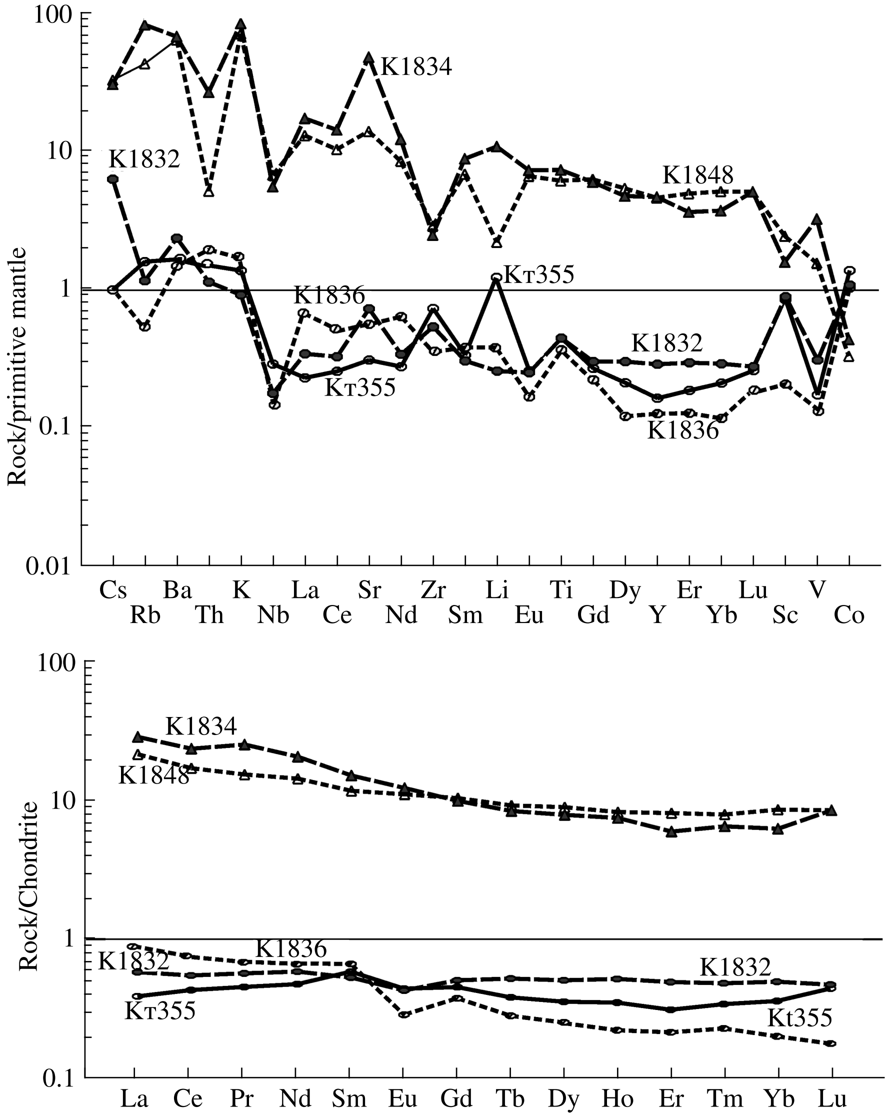

Fig. 2. Trace, including rare-earth element, distribution pattern in the studied dunites and associated gabbroids. Normalizing values are taken from (McDonough and Sun, 1995). Compositions of the rocks are taken from Table 1.

In geochemistry, some zircons from dunite Kt355 (Fig. 4, Table4) are similar with zircons of dunite K1832 of supposedly magmatic origin from the Eastern Khabarny Massif, but differ in a wide scatter of trace elements. By analogy with other dunites, we can suggest that zircons enriched in trace elements were formed at the postmagmatic stage during hydrothermal recrystallization of dunite.

Dunite K1836 from the Sakharin Massif contains two distinct zircon groups of different age. The first group is represented by pinkish and yellowish weakly transparent grains, which are either strongly corroded (Fig. 5, grain 2) and preserve relicts of abrasion relief or form rounded cores overgrowing by crystalline shells (grain 7). They are of Proterozoic age (1517–1687) Ma and have elevated U content (Table 5). Among single transparent fragments of zircon, one grain analyzed by laser ablation at the University of Granada, Spain, defined an U–Pb age of 3200 Ma (composition is presented in Table 4, analysis 8). Other dated grains are represented by thinly-zoned varieties with sectorial zoning (Fig. 5, grains 6, 9, 4) dated at 378–374 Ma. They typically have lower Ti content than the Proterozoic crystals, though some grains have higher contents (Table 5).

Geochemical features of zircons (Table 4, Fig. 6) were studied by LA-ICP MS. Zircons with an age of 378–374 Ma have fairly narrow variations in trace element composition. The U content in the aforementioned fragment of transparent ancient zircon is an order of magnitude lower than that in the Paleozoic and Proterozoic varieties, being close to those found in the mantle zircons from kimberlites.

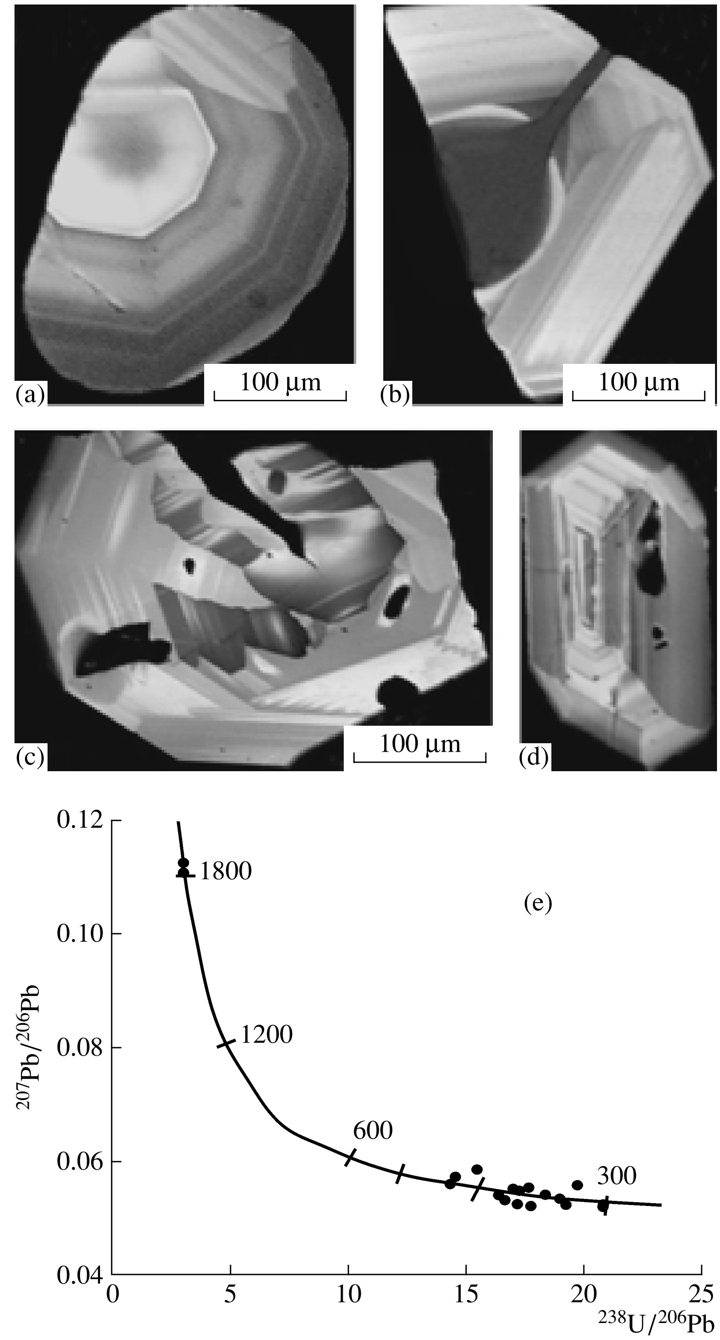

Fig. 3. Cathodoluminescent images of zircons and concordia diagram $^{207}Pb/^{206}Pb$–$^{238}U/^{206}Pb$ for zircons from dunite of the Kosva Massif.

(a–d) images of representative zircon grains of distinguished age groups (Ma): 1800 (a), 435–432 (b), < 307 (c, d). (e) plot with concordia. See text for explanation.

Zoned zircons from *monzogabbro K1848* of the Sakharin Massif have approximately the same or lower U contents than the Paleozoic zircons from dunites, at close ages varying within a narrow range of 388–377 Ma (Fig. 5, Table 5). In terms of trace element composition, the zircons from monzogabbro are close to the Paleozoic zircons from dunite K1836 (Fig. 6b, Table 4). At the same time, zircons from gabbro strongly differ in elevated contents of Ti, Nb, and Ta (Table 4), which reflects the higher contents of these elements in the gabbro as compared to dunites and indicates some compositional specifics of zircons from these rocks.

Approximately the same association of zircons was found in *Dunite K1832* from the Eastern Khabarny Massif. One low-U grain is represented by angular fragment (grain 3 in Fig. 7). This grain has an Archean

Table 3. Age of zircon from the dunite (sample Kt355) of the Kosva Massif

Grain number	U, ppn	$^{232}Th/^{238}U$	Pb, ppm	$^{206}Pb_c$, %	$^{207}Pb/^{206}Pb$	Error, %	$^{206}Pb/^{238}U$	Error, %	Age. Ma	
									$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
4.1*	54	0.44	4	0.39	0.05232	2.44	0.0561	4.3	352 ± 14	
4.2	106	0.6	7	0.13	0.0553	1.48	0.0564	4.28	352 ± 14	
6.1	277	0.25	18	0.12	0.0543	0.96	0.0584	4.28	365 ± 15	
6.2	89	0.61	6	0.25	0.0536	1.55	0.0584	4.27	365 ± 15	
7.1	71	0.78	5	0.17	0.0550	2.09	0.0588	4.29	367 ± 15	
7.2	99	0.72	7	0.2	0.0537	1.53	0.0590	4.29	369 ± 15	
8.1	52	0.44	4	0.32	0.0524	2.12	0.0599	4.28	375 ± 15	
9.1	104	1.01	8	0.34	0.0538	1.47	0.0609	4.28	381 ± 16	
11.1	63	0.4	5	0.17	0.0571	1.8	0.0695	4.27	432 ± 18	
12.1	57	0.37	5	0.15	0.0562	2.32	0.0699	4.29	435 ± 18	
13.1	331	1.31	166	0.02	0.1102	0.29	0.35	4.27	1802 ± 5	
14.1	143	1.56	75	0.03	0.1102	0.41	0.3507	4.27	1802 ± 5	
15										2827 ± 6**
16										2838 ± 10**

Note: Analyses were made on a Cameca IMS1270 ion microprobe (NORDSIM, Stockholm). $^{206}Pb_c$ is the correction for common lead using ^{204}Pb.

* Here and in Table 5, the first numeral denotes the number of grain, and the second numeral is the number of analyzed point.** Age was obtained by the method of subsequent heating of individual grains (Kober method).

age of 2808 ± 26 Ma, which is close to the age of the oldest zircons from Kosva dunite Kt355. The grains of the Proterozoic age are well rounded; some of them occur as core rimmed by Paleozoic matrix in the polychronous crystals (grains 9 and 6, Fig. 7), while others

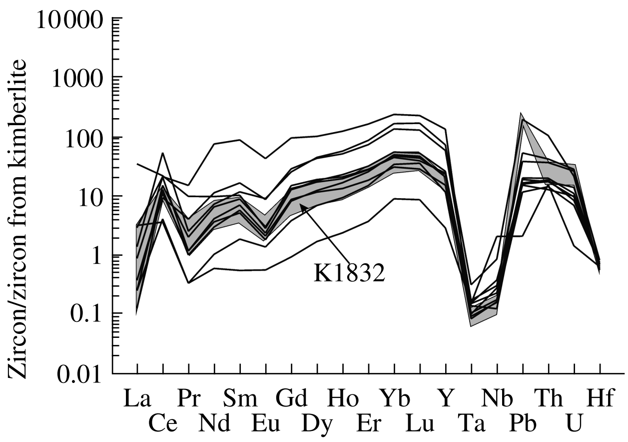

Fig. 4. Trace-element distribution in the zircons from the dunite (sample Kt355) from the Kosva Massif normalized to zircon from kimberlites (Belousova et al., 1998).

Gray field is the compositional field of the magmatic zircons from dunite (sample K1832) of the Eastern Khabarny Massif.

form separate crystals (grain 2). Both the zircons have high U content, which is also observed in the Paleozoic varieties and differ the zircons of the Eastern Khabarny dunite from those of the Sakharin Massif (Table 5). The rim of a rounded fragment (grain 9.1, 1911 Ma in Fig. 7) has a concordant age of 461 Ma. Separate grains with this age were not found. The Paleozoic zircons are most abundant in dunite and represented by zoned short-prismatic grains of magmatic habit with an age of 407–402 ± 4 Ma (Fig. 7, points 1.1, 4.1, 5.1, Table 5); the oldest of them were strongly corroded (for instance, grain 1 in Fig. 7). The high-U crystals with an age of less than 400 Ma are unzoned and presumably correspond to postmagmatic stage of dunite evolution. Some of them (for instance, grain 6 in Fig. 7) overgrow the rounded ancient zircons.

Geochemical features of zircons with an age of 407–402 Ma are shown in Fig. 8a and Table 4 (analyses 16–19). Narrow variations in trace element composition sharply differ these zircons from secondary zircons with an age younger than 400 Ma. The latter show the higher contents of trace elements and extremely wide scatter reaching three orders of magnitudes in the LREE part (Fig. 8b, Table 4, analyses 20–23). Ancient zircons (Fig. 8c) have higher contents of most trace elements than the Paleozoic varieties, which is especially notable for Nb and Ta contents. These geochemical signatures of the ancient zircons presumably indicate their crustal origin and presumable affiliation to the base-

Table 4. Contents of trace elements (ppm) in the individual grains from the studied dunites and associated gabbroids

Elements	Kosva Massif							Sakharin Massif							
	dunite							dunite					monzogabbro		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P	171	187	150	179	577	240	242	182	163	139	142	130	248	164	3687
Ti	43.0	11.8	14.2	7.1	103	15.9	12.9	16.2	0.26	1.97	1.54	0.93	319.8	58	24.4
Y	741	707	464	632	4063	2218	794	338	367	291	446	223	854	403	784
Nb	0.5	0.5	0.5	1.1	0.8	2.5	0.7	1.12	0.19	0.28	0.18	0.23	1.2	0.52	2.67
Ta	0.2	0.3	0.2	0.4	0.2	0.8	0.4	0.32	0.11	0.14	0.14	0.08	0.23	0.19	0.43
La	2.7	0.0	0.0	0.0	0.2	0.1	0.1	0.03	0.01	0.01	0.08	0.01	0.59	0.13	4.73
Ce	18.7	13.0	11.0	9.5	18.1	45.8	17.8	34.6	3.71	4.09	6.44	1.66	6.98	8.01	47.8
Pr	0.6	0.1	0.1	0.1	0.9	0.2	0.1	0.08	0.04	0.02	0.22	0.01	0.24	0.08	2.5
Nd	3.8	2.5	1.2	1.4	28.8	2.8	1.6	1.63	0.54	0.28	2.43	0.24	1.59	1.34	24.6
Sm	5.4	4.7	3.0	2.7	45.8	6.1	3.7	2.79	0.99	0.47	2.9	0.48	1.69	2.4	23.1
Eu	1.0	1.1	0.8	0.7	15.2	3.2	0.8	0.62	0.56	0.29	0.87	0.31	0.62	0.62	8.59
Gd	21.8	19.4	12.7	11.9	137.9	37.1	18.7	9.9	4.9	2.5	7.7	2.4	8.2	8.6	51.7
Tb	7.0	6.2	4.1	4.2	39.9	14.8	6.3	2.6	1.6	1	2.3	0.8	2.9	2.3	10.3
Dy	76.7	70.0	47.3	50.5	411.7	181.5	73.5	32.5	24	17.5	31.6	13.1	49.3	32.6	90.4
Ho	26.4	24.7	16.8	21.2	156.0	71.9	28.9	10.4	9.6	8	11.6	5.7	19.9	11.3	18.9
Er	118.2	116.1	77.2	107.2	683.0	360.6	133.0	51	58	52	63	41	126	63	73
Tm	27.0	27.4	18.2	27.1	151.5	87.3	30.0	10	14.3	14.5	16.4	10.8	32	14.2	12.2
Yb	248.7	262.5	171.1	275.2	1318	920.4	305.8	102	178	181	187	154	335	134	85
Lu	40.5	44.9	29.4	48.4	233.2	174.9	54.6	15	34	36	34	29	64	23	13
Hf	9831	9139	9289	8997	10708	7783	9300	9633	7523	7266	8382	6561	9342	9690	7971
Pb	4.7	4.6	3.3	4.3	15.1	55.7	5.7	14	4	9	12	2	6	10	8
Th	66	62	51	45	149	370	71	39	33	54	98	12	28	65	121
U	82	94	67	96	272	207	107	25	54	167	248	34	89	155	154

Elements	Eastern Khabarny Massif													
	dunite (magmatic zircon)				dunite (secondary zircon)				dunite (xenogenic zircon)			gabbronorite		
	16	17	18	19	20	21	22	23	24	25	26	27	28	29
P	306	204	253	258	546	346	1879	625	433	266	146	34	25	165
Ti	3.32	2.31	2.77	1.7	29.42	25.1	330.2	76.83	19.67	7.43	229	4.3	3.98	8.41
Y	1046	475	973	721	1304	2417	6746	1864	1174	751	764	109	100	415
Nb	0.53	0.35	0.51	0.68	1.76	3.68	36.68	3.07	2.32	1.36	2.28	0.65	0.66	0.52
Ta	0.27	0.19	0.24	0.34	0.62	1.32	3.54	0.51	0.85	0.6	0.64	0.38	0.32	0.23
La	0.04	0.03	0.04	0.01	9.11	1.63	429.8	76.28	0.14	0.13	0.7	0.01	0	0.01
Ce	11.63	9.1	10.4	10.7	293	153	3157	853	38.6	18.9	19.4	2.44	2.26	6.68
Pr	0.25	0.11	0.27	0.08	7.94	2.54	276.3	71.89	0.24	0.19	0.25	0.01	0.01	0.05
Nd	4.31	1.53	4.14	1.52	52	35	1729	462	3.94	2.58	2.65	0.22	0.2	0.91
Sm	6.61	2.35	6.28	3	23	38	619	171	6.68	5.03	4.15	0.44	0.37	2
Eu	2.17	0.79	2.06	0.99	5.89	15.5	126.1	38.94	1.97	1.29	0.36	0.24	0.2	0.57
Gd	24.9	9	24.4	12.6	36.4	102	541	152	28.06	23.15	19.8	1.96	1.68	7.52
Tb	7.5	2.9	7.1	4.2	9.21	24.8	95.8	25.6	8.6	6.9	6.05	0.6	0.49	2.02
Dy	90.4	37.3	86.8	56.2	104	252	761	206	107	78.9	83.5	9.01	7.74	29.74
Ho	32.9	14.3	30.6	22	36	76	185	51	38	24.81	26.1	3.24	2.69	10.09
Er	163	77	152	119	191	338	754	213	191	113	130	19	17	60
Tm	36	17.5	33	28	47	72	154	44	42	23	26	4	4	13
Yb	348	176	320	277	506	697	1409	424	425	218	244	53	47	136
Lu	65	35	59	53	89	116	212	65	70	35	33	8	7	23
Hf	11318	9549	9265	9738	21317	23090	29881	19730	12651	11763	8888	6131	6256	10162
Pb	64	49	59	60	444	335	432	257	181	87	218	12	11	13
Th	152	77	155	95	821	1582	12519	1503	93	41	40	20	17	75
U	274	210	259	272	2058	1666	4749	1683	124	79	106	60	46	254

Note: Analysis 8 was made in zircon 058 of the Archean age, analyses 27 and 28 were made in zircons 048 and 008 of the Proterozoic age (Table 5). See text for other explanation.

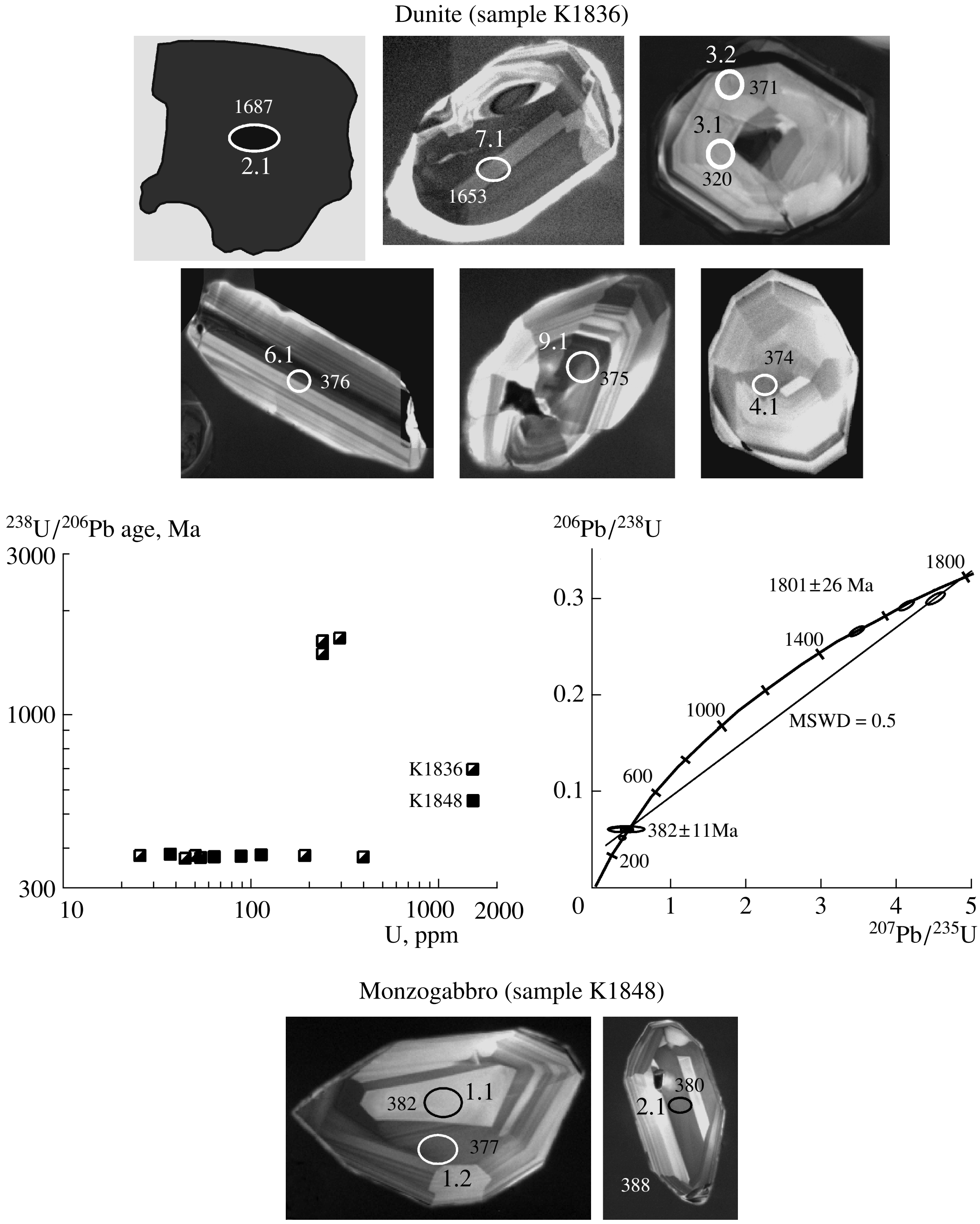

Fig. 5. Cathodoluminescent image of zircons and diagram age–U content for the dunite (sample K1836) and monzogabbro (sample K1848) of the Sakharin Massif, as well as diagram $^{206}Pb/^{238}U$–$^{207}Pb/^{235}U$ with concordia and discordia for dunite (sample K1836). Here and in Fig. 7, numbers near circles and ellipses marking the points of age determination are the grain number (first number) and number of analysis in this point (second number), as well as the age, Ma. Numbers correspond to grain numbers in Table 5. The size of circles and short axis of ovals is about 20 μm. See text for other explanation.

ment of the Uralian orogen. The low Th and U contents, however, do not exclude the different interpretation of their genesis.

The Paleozoic zircons in the *gabbro-norite K1834* are dated within 389–392 ± 4 Ma and represented by short-prismatic crystals with well expressed growth zoning (Fig. 7). The contents of U and most other trace elements vary within the same range, as those in the zircons from dunite with an age of 407–402 Ma (Fig. 7d, Table 4, analysis 29). These zircons were presumably formed at the late stages of the gabbronorite formation: crystallization of H_2O-rich melts, which provided the presence of hornblende in the studied gabbronorites. The formation of aqueous melts of gabbronorite composition accompanied the obduction of the Khabarny allochthon with the Eastern Khabarny Massif on the

Table 5. U–Pb age of zircons from the dunites and related gabbroids of the Sakharin and Eastern Khabarny massifs

Grain number	$^{206}Pb_c$, %	U, ppm	Th, ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$, ppm	$^{238}U/^{206}Pb^*$	±, %	$^{207}Pb^*/^{206}Pb^*$	±, %	$^{207}Pb^*/^{235}U$	±, %	$^{206}Pb^*/^{238}U$	±, %	Error	Age, Ma	
															$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
Sakharin Massif, dunite (sample K1836)																
3.1	0.33	104	121	1.20	4.6	19.625	1.2	0.0513	4.3	0.36	4.5	0.0510	1.2	0.264	320 ± ± 4	255 ± ± 99
3.2	2.11	44	29	0.68	2.3	16.863	1.7	0.0420	18.9	0.34	19.0	0.0593	1.7	0.090	371 ± ± 6	227 ± ± 124
4.1	0.46	54	35	0.67	2.8	16.763	1.4	0.0506	6.4	0.42	6.5	0.0597	1.4	0.209	373 ± ± 5	223 ± ± 148
9.1	0.09	390	530	1.40	20.1	16.703	0.9	0.0535	1.8	0.44	2.0	0.0599	0.9	0.459	375 ± ± 3	351 ± ± 41
6.1	0.18	192	129	0.69	9.9	16.649	1.0	0.0527	3.3	0.44	3.4	0.0601	1.0	0.295	376 ± ± 4	317 ± ± 74
5.1	0.56	50	22	0.46	2.6	16.544	1.4	0.0545	6.1	0.45	6.3	0.0604	1.4	0.224	378 ± ± 5	390 ± ± 137
1.1	1.55	26	11	0.46	1.4	16.538	2.2	0.0496	23.5	0.41	23.6	0.0605	2.2	0.093	378 ± ± 8	176 ± ± 547
8.1	0.02	238	102	0.44	54.3	3.768	0.9	0.0948	0.6	3.47	1.1	0.2654	0.9	0.824	1517 ± ± 12	1523 ± ± 11
7.1	0.02	238	181	0.79	59.7	3.420	0.9	0.1021	0.6	4.12	1.0	0.2924	0.9	0.839	1653 ± ± 13	1663 ± ± 10
2.1	0.03	293	113	0.40	75.2	3.343	0.9	0.1091	0.6	4.50	1.1	0.2991	0.9	0.820	1687 ± ± 13	1785 ± ± 11
058**	28	39		14											3200**	
Sakharin Massif, gabbro (sample K1848)																
1.2	0.48	88	60	0.71	4.6	16.616	1.2	0.0511	5.4	0.42	5.5	0.0602	1.2	0.225	382 ± ± 5	247 ± ± 123
2.1	0.70	112	82	0.75	5.9	16.462	1.2	0.0504	7.0	0.42	7.1	0.0607	1.2	0.169	377 ± ± 5	214 ± ± 163
1.1	0.00	37	15	0.41	1.9	16.396	1.6	0.0555	4.3	0.47	4.6	0.0610	1.6	0.349	380 ± ± 4	431 ± ± 96
2.2	0.00	46	17	0.38	2.4	16.136	1.7	0.0554	3.9	0.47	4.2	0.0620	1.7	0.393	388 ± ± 6	427 ± ± 87
Eastern Khabarny Massif, dunite (sample K1832)																
8.1	0.61	1332	580	0.45	59.8	19.245	0.9	0.0533	1.9	0.38	2.1	0.0520	0.9	0.422	326 ± ± 3	343 ± ± 42
6.1	–	734	209	0.29	38.7	16.294	0.9	0.0548	1.0	0.46	1.3	0.0614	0.9	0.661	384 ± ± 3	406 ± ± 22
10.1	0.05	314	102	0.34	17.1	15.753	0.9	0.0544	1.6	0.48	1.8	0.0635	0.9	0.508	397 ± ± 4	389 ± ± 35
7.1	0.00	246	78	0.33	13.5	15.615	1.0	0.0548	1.5	0.48	1.8	0.0640	1.0	0.547	400 ± ± 4	405 ± ± 33
11.1	0.06	342	183	0.55	18.9	15.551	0.9	0.0545	1.4	0.48	1.6	0.0643	0.9	0.556	402 ± ± 4	392 ± ± 31
5.1	0.00	271	116	0.44	15.0	15.514	0.9	0.0549	1.4	0.49	1.7	0.0645	0.9	0.558	403 ± ± 4	407 ± ± 31

Table 5. (Contd.)

Grain number	$^{206}Pb_c$, %	U, ppm	Th, ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$, ppm	$^{238}U/^{206}Pb^*$	±, %	$^{207}Pb^*/^{206}Pb^*$	±, %	$^{207}Pb^*/^{235}U$	±, %	$^{206}Pb^*/^{238}U$	±, %	Error	Age, Ma	
4.1	0.09	217	82	0.39	12.1	15.438	1.0	0.0541	1.8	0.48	2.1	0.0648	1.0	0.465	405 ± ± 4	375 ± ± 41
1.1	0.00	171	59	0.36	9.6	15.338	1.0	0.0552	1.8	0.50	2.0	0.0652	1.0	0.506	407 ± ± 4	421 ± ± 39
9.2	0.64	919	178	0.20	58.9	13.479	0.9	0.0562	1.8	0.57	2.0	0.0742	0.9	0.435	461 ± ± 4	461 ± ± 40
9.1	0.04	467	218	0.48	138.6	2.898	0.9	0.1337	0.6	6.36	1.1	0.3450	0.9	0.813	1911 ± ± 14	2147 ± ± 11
2.1	0.22	892	278	0.32	299.6	2.565	0.8	0.1784	0.2	9.58	0.9	0.3896	0.8	0.961	2121 ± ± 15	2638 ± ± 4
3.1	0.00	24	38	1.64	11.2	1.832	1.2	0.1974	1.0	14.85	1.5	0.5459	1.2	0.761	2808 ± ± 26	2805 ± ± 16
Eastern Khabarny Massif, gabbronorite (sample K1834)																
4.1	0.11	277	141	0.52	14.8	16.071	1.0	0.0542	1.9	0.46	2.1	0.0622	1.0	0.469	389 ± ± 4	377 ± ± 42
1.2	0.00	148	43	0.30	7.9	16.055	1.0	0.0550	2.1	0.47	2.3	0.0623	1.0	0.446	390 ± ± 4	414 ± ± 47
6.1	0.12	194	90	0.48	10.4	16.029	1.1	0.0541	2.2	0.47	2.4	0.0624	1.1	0.433	390 ± ± 4	377 ± ± 49
5.1	0.00	276	143	0.53	14.8	16.006	1.0	0.0547	1.6	0.47	1.8	0.0625	1.0	0.521	391 ± ± 4	400 ± ± 35
1.1	0.00	152	59	0.40	8.2	15.966	1.0	0.0554	2.0	0.48	2.3	0.0626	1.0	0.451	392 ± ± 4	427 ± ± 46
2.1	0.07	356	180	0.52	19.2	15.960	0.9	0.0545	1.5	0.47	1.8	0.0627	0.9	0.527	392 ± ± 4	394 ± ± 33
5.2	–	235	86	0.38	12.7	15.935	1.0	0.0546	1.7	0.47	1.9	0.0628	1.0	0.499	392 ± ± 4	398 ± ± 38
008**	46	17.4		10.8											1554**	
010**	48	18		11.2											1541**	
048**	60	20		12											1343**	
050**	59	20.5		11.9											1350**	

Note: Pb_c and Pb^* are common and radiogenic led, correspondingly, corrected for ^{204}Pb. $D = 100\{[t(^{207}Pb/^{206}Pb)]/[t(^{206}Pb/^{238}U)] - 1\}$.
** Contents of elements and U–Pb ages were obtained by LA-ICP MS

continental rocks. This tectonic event was responsible for the formation of the obduction-related granites, the products of partial melting of continental crust at the base of hot allochthon (Fershtater and Krasnobaev, 2007). The age of these granites is 387 Ma, i.e., very close to the age of gabbronorite K1834.

The LA-ICP MS study of zircons from gabbronorite revealed the presence of Proterozoic crystals within an age of 1350–1500 Ma, which strongly differ from the Paleozoic zircons from the same gabbronorite and from Proterozoic zircons in dunite K1832 in lower content of all trace elements, except for Nb and Ta (Fig. 8d, Table 4, analyses 27, 28, and Table 5).

DISCUSSION

Aforementioned data showed the similarity of zircon populations in three studied dunite samples. Each sample contains the following genetic and age zircon groups: (1) residual mantle (?) of the Archean age, (2) xenogenic zircons of the Proterozoic age, (3) zircons having magmatic habit and close in age and geochemistry to zircons from associated gabbroids; (4) postmagmatic zircons that crystallized from hydrothermal solutions accompanying dunite recrystallization.

The established fact is new and represents a great significance for understanding the genesis of dunite in the Uralian–Alaskan-type complexes, which are of great metallogenic importance, given their association with deposits of PGE, Fe, Cu, V, and other metals.

The Archean zircons represented by fragments of transparent low-U crystals similar to grain 3 from dunite of the Eastern Khabarny Massif (Fig. 7) are *residual* xenocrysts that were captured from mantle protolith of dunites. We suggest that the low U content in these zircons close to that in kimberlite zircons (Belousova et al., 1998) facilitated well preservation of these crystals. These grains are few in number and, in many cases, it was difficult to determine the age and geochemical characteristics in one grain.

Zircons of the second group are wider spread. They have Proterozoic age and presumably xenogenic nature. They show oval shape and traces of surface abrasion, which indicates their redeposition. These zircons often occur as cores of polygenous zircons with outer Paleozoic rims. Some of them were strongly corroded by melt that crystallized olivine in dunite. The morphology of the Proterozoic grains together with their geochemical signatures points to crustal, presumably continental origin. An important conclusion from this fact is that the parental melt of dunites was contaminated during its ascent through crust.

Zircons of magmatic habit (euhedral and variably transparent) were derived from basic or tylaitic melt that generated dunite. They show characteristic magmatic zoning caused by alternation of variably expressed zones, and, occasionally, diffuse (obscure) sectorial zoning. In all studied dunite samples, these zircons are similar in age to zircons from associated gabbroids: 435–432 Ma in the dunite of the Kosva Massif, 378–374 Ma in the dunite from the Sakharin Massif, and 407–402 Ma in the dunite of the Eastern Khabarny Massif. The ages of zircons from gabbroids of the corresponding massif fall in the same interval (Table 5, Figs. 5, 7). The genetic link of gabbroid and dunite zircons is emphasized by their geochemical similarity. It is distinctly seen in Fig. 9 that zircons in the gabbroids and dunites from the same massif are clustered together, separately from zircons from other massifs. The zircons from dunite and monzogabbro of the Sakharin Massif are significantly more depleted in Hf, Th, U as compared to the Paleozoic magmatic zircons from dunite and gabbronorite of the Eastern Khabarny Massif (Table 5, Figs. 6, 8, 9). This fact indicates a genetic relation of dunites and gabbroids, which form common geological bodies—massifs of the Uralian–Alaskan type. The P and Y contents in the studied zircons show a positive correlation, with P/Y ratio approximately corresponding to that in xenotime; hence, the contents of these elements are determined by degree of zircon replacement by xenotime (Krasnobaev, 1986).

At the same time, different chemical composition of the dunites and gabbroids determined compositional specifics of primary zircons, for instance, lowered contents of Ti, Nb, and Ta in zircon from dunites.

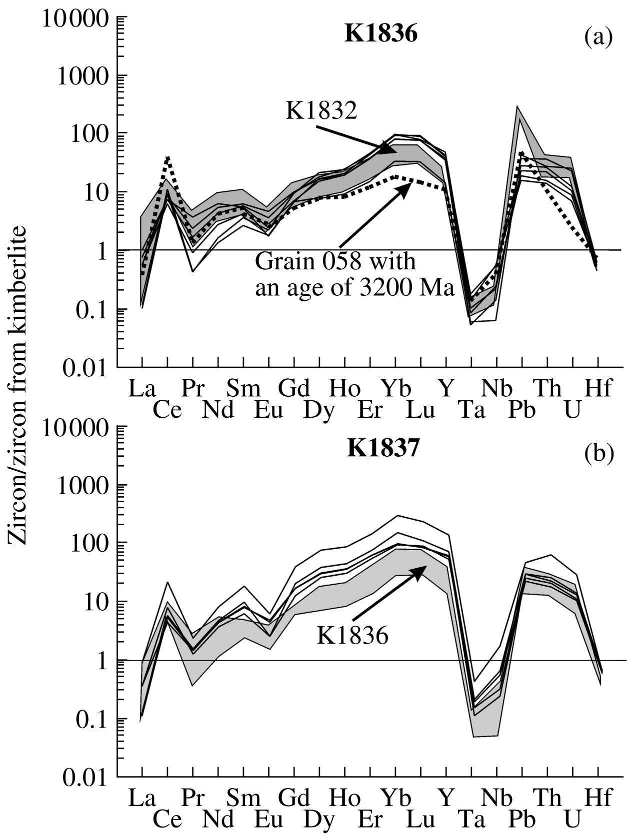

Fig. 6. Trace-element distribution in the zircons from the dunite (sample K1836) and monzogabbro (sample K1837) of the Sakharin Massif normalized to that in zircons from kimberlite (Belousova et al., 1998).

Field in the diagram (a) is the composition of zircon from dunite of the Eastern Khabarny Massif, diagram (b) shows the composition of zircon from the dunite of the Sakharin Massif.

Postmagmatic zircons are younger in age than zircons of magmatic habit. Detailed study of these zircons in the dunites from the Eastern Khabarny Massif showed that they sharply differ from xenogenic (Fig. 8c) and magmatic (8a) zircons in high contents of all trace elements at their wider variations (Fig. 8b). They were presumably crystallized from fluid phase formed at the postmagmatic stage of dunite evolution.

This interpretation is supported by studies of chromite and PGE mineralization in the dunites of the Platinum Belt of the Urals (Anikina et al., 2001; Pushkarev et al., 2007), which showed that chromitites contain low-temperature and low-pressure mineral assemblages, which accompanied the recrystallization of dunite and segregation of Cr-spinels and PGE. The presence of such assemblages indicates a significant role of fluid in the postmagmatic evolution of dunite, while accumulation of zircon in the dunite chromitites (Savel'eva et al., 2007) testifies that the formation of considered postmagmatic zircons was presumably related to the recrystallization of dunites in their

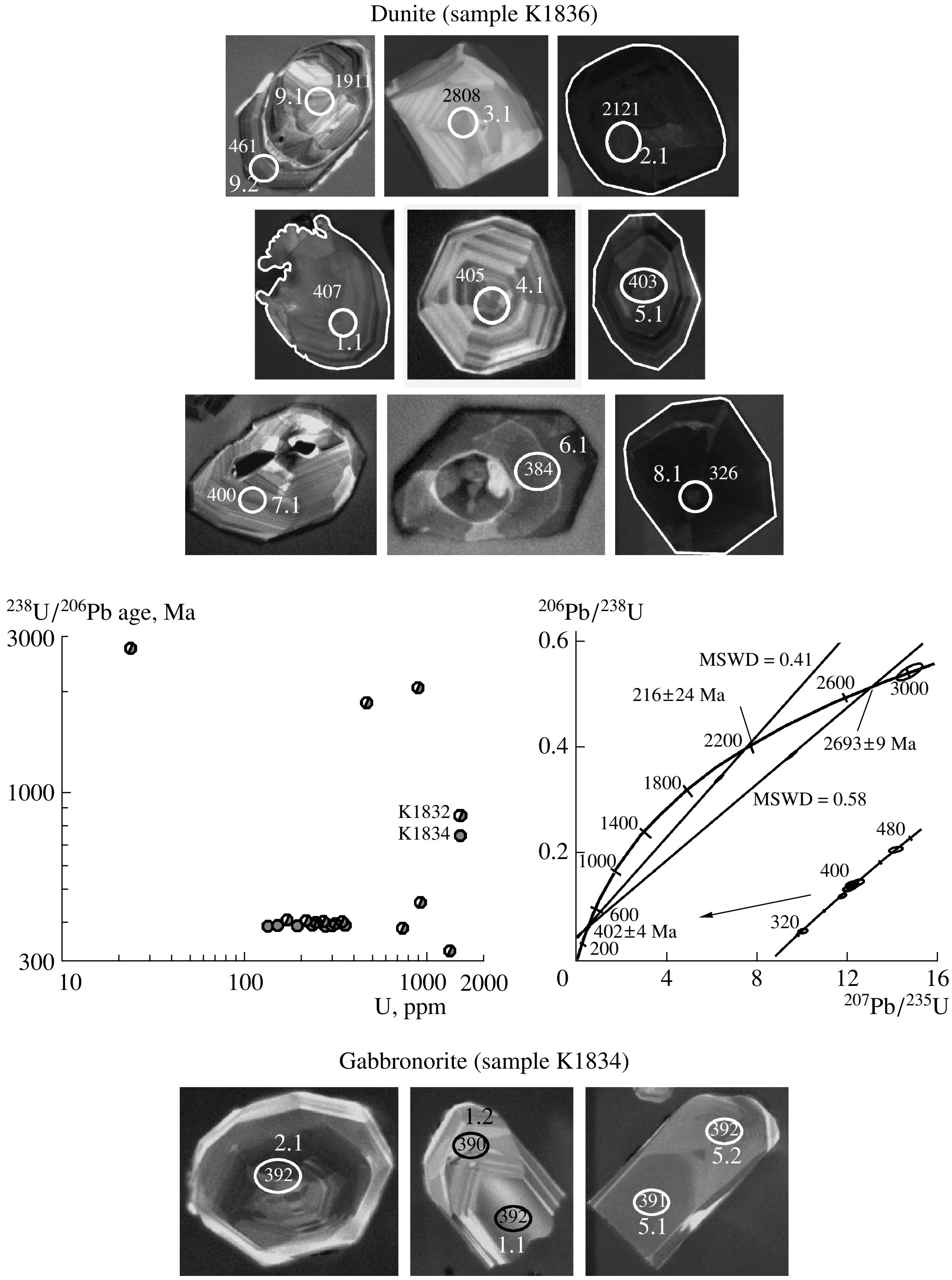

Fig. 7. Cathodoluminescent image of zircons and diagram age–U content for the dunite (sample K1832) and gabbronorite (sample K1834) of the Eastern Khabarny Massif, as well as diagram $^{206}Pb/^{238}U$–$^{207}Pb/^{235}U$ with concordia and discordia for dunite (sample K1832).

For other explanations, see captions for Fig. 5 and text.

present-day position. If this is the case, the time gap between magmatic stage of dunite formation and postmagmatic processes that produced Cr-spinel and PGE mineralization, was no less than 20 Ma.

A great body of data accumulated owing to the development of local study of individual zircon grains showed that subsolidus and postmagmatic recrystallization of zircon is widely spread phenomenon in all

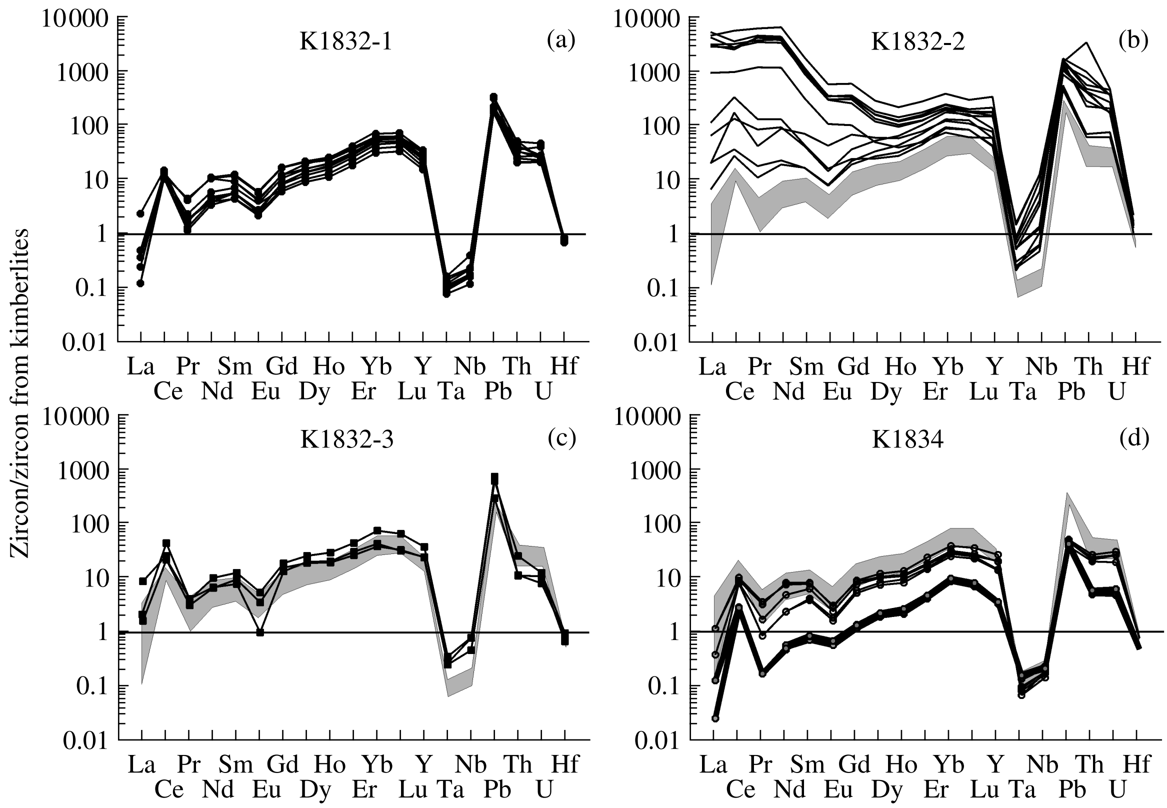

Fig. 8. Trace-element distribution in the zircons from dunite (sample K1832) and gabbronorite (sample K1834) of the Eastern Khabarny Massif, normalized to zircon from kimberlites (Belousova et al., 1998).

(a) magmatic zircons from dunite with an age of 407–402 Ma; (b) postmagmatic zircons from dunite; (c) xenogenic "rounded" zircons from dunite, (d) zircons from gabbronorite, solid lines show zircons with an age of 1500 Ma, which are characterized by low contents of most elements.

Gray field in the diagrams (b–d) includes the compositions of magmatic zircons from dunite (sample K1832).

rock types (for instance, Hoskin and Black, 2000; Bomparola et al., 2005, and references therein). The study of zircons made it possible to date the transformation stages and correlate them with geological events. In particular, the wide development of zircons with an age of 360 Ma and younger zircons in the dunites of the Kosva Massif (Table 5) is possibly caused by the formation of fine-grained hornblende gabbro with an age of 350 Ma in the western part of the Platinum Belt (Fershtater et al., 1999; Fershtater et al., in press). The fact that dunite Kt355 contains such specific postmagmatic minerals as andradite–grossular garnet, spinel, rutile, partly zircon serves as evidence of hydrothermal transformation of dunites, and zircons allow the dating of these processes. Zircons with age of 397–384 Ma in the dunite of the Eastern Khabarny Massif were presumably related with amphiboliztaion of the gabbronorites and formation of anatectic obduction-related granites, i.e., with events having the same age (Fershtater and Krasnobaev, 2007).

Obtained age data on zircon populations found in the dunites from the Uralian–Alaskan complexes are schematically shown in Fig. 10. The types of zircons versus the distance of the studied massifs from the Main Ural Fault in the latitudinal direction demonstrate the lateral variations of zircon populations of different age.

GENESIS OF DUNITES IN THE MAGMATIC COMPLEXES OF THE URALIAN–ALASKAN TYPE

The concentrically zoned structure of the dunite–clinopyroxenite–gabbro massifs of the Platinum belt, isometric shape of most of them, strike and dip of banding in the massifs, as well as data of magnetometric, gravimetric, and profile seismic survey suggest that the massifs observed at the modern erosion level represent the pipe-like bodies with approximately similar primary structure (Fershtater et al., 1999). The dunite core of these pipes subsequently grades into clinopyroxenites and gabbroids. This model primary structure suggests that the main varieties of the rocks of magmatic series were derived by dynamic fractionation during melt emplacement along extended channel; during this process, the early dunite cumulates were concentrated in the central part of magmatic column and surrounded by the later rocks—wehrlites and olivine clinopyroxenites.

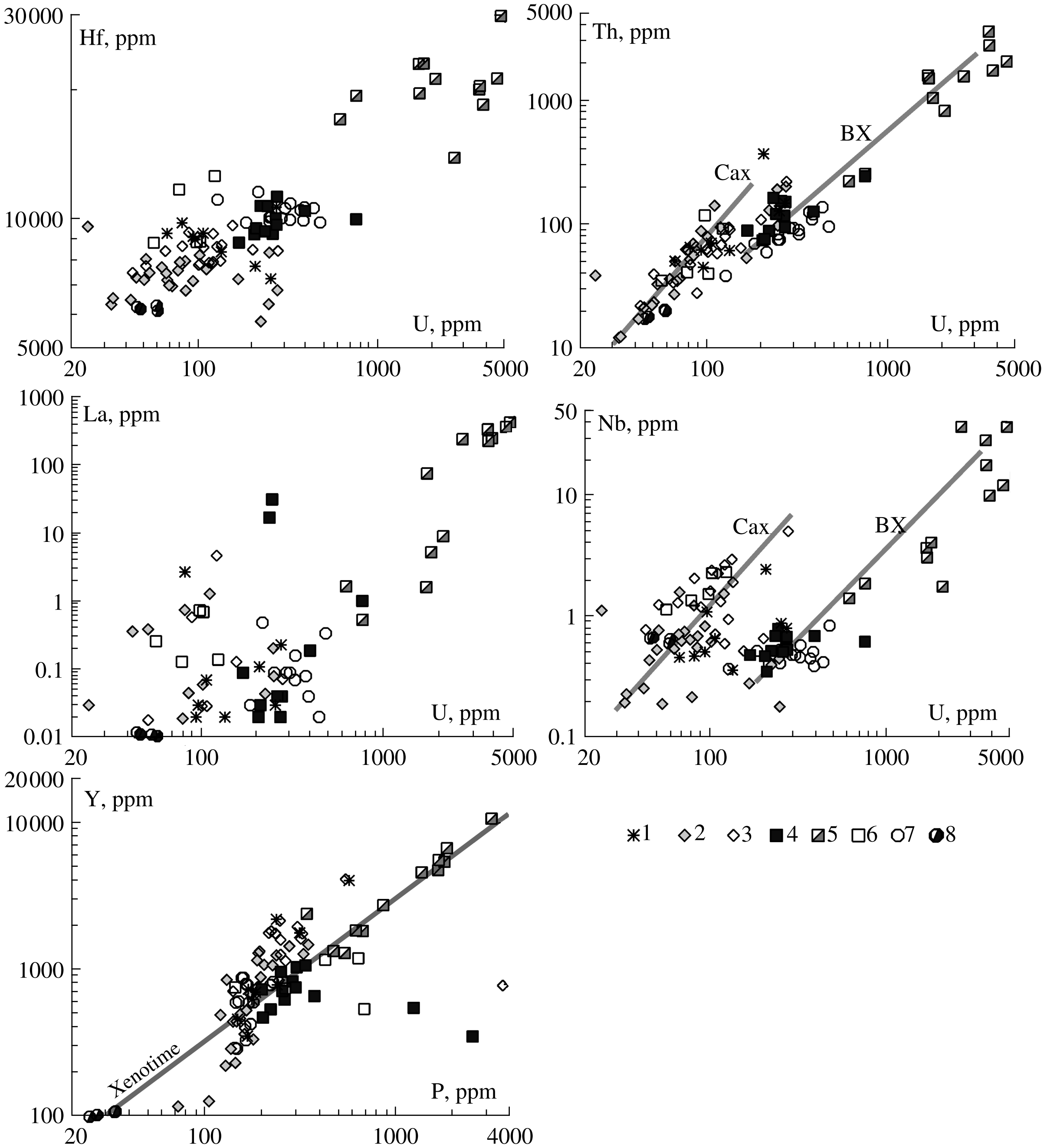

Fig. 9. Diagrams U–Hf, U–la, U–Th, U–Nb, and P–Y for zircons from the dunite (sample Kt355) of the Kosva Massif and from the dunites and associated gabbroids of the Sakharin Massif (samples K1836 and K1848) and Eastern Khabarny Massif (samples K1832 and K1835).

Zircons: (1) from the dunite of the Kosva Massif; (2, 3) from dunite (2) and monzogabbro (3) of the Sakharin Massif; (4–8) from dunite and gabbronorite of the Eastern Khabarny Massif: magmatic (4), postmagmatic (5), and xenogenic (6) zircons from dunite; Paleozoic, magmatic (7) and Proterozoic xenogenic (8) zircons from gabbronorite.

Indexes Sak and EKh denotes the variation lines for zircons from the Sakharin and Eastern Khabarny massifs, respectively.

Trace element data, including REE and PGE, support the assumption of leading role of crystallization differentiation in the genesis of this series. The main question is the composition of parental melt. However, no reliable geological data are available to solve this problem. Based on textural and mineral features, the plagioclase-bearing olivine pyroxenites—tylaites, in a first approximation, can be taken as the parental melt (Pushkarev and Fershtater, 1993; Fershtater et al., 1999).

Thus, presented data on zircons confirm assumption that the dunites from the Uralian–Alaskan-type massifs, unlike dunites in the ophiolite dunite–harzburgite complexes, are not mantle residue, but represent crustally contaminated cumulate rocks (Fershtater et al., 1999). The above considered general features of zircons from the dunites can be best explained by cumulate model.

The xenogenic zircons were entrapped by the melt from the host rocks, which, according to the age and geochemistry of zircons, presumably belonged to the Proterozoic basement of the Uralian orogen. The presence of kyanite in dunites of all three samples confirms the inference on xenogenic nature of zircons. During subsequent crystallization, these minerals precipitated from high temperature low-viscosity magma together with olivine and Cr-spinel and were incorporated in the dunite.

The Proterozoic xenogenic zircons in the dunites vary in age. Dunites from the western part of the Urals contain zircons with an age of more than 1800 Ma, while dunites from the Sakharin Massif in the eastern part of the Urals contain younger zircons (Fig. 10). These fragmentary data testify that the crystalline basement in the western and eastern parts of the Urals differs in age and possibly origin, being represented by the basement of the East European platform and Kazakhstan continent, respectively.

The Archean zircons of supposedly mantle origin were presumably captured by melt that percolated through mantle and crystallized olivine of dunites. However, the amount of these zircons in the rocks is not high enough to estimate the nature and composition of parental mantle rocks.

The magmatic zircons found in the dunites were formed from the melt, which already crystallized olivine and became compositionally similar to gabbro. This presumably explains the close age and geochemical characteristics of these zircons in dunites and associated gabbroids. These features of zircons unambiguously indicate a genetic link between the dunites and gabbroids.

The wide development of postmagamtic zircons in the dunites is explained by intense fluid-assisted recrystalliztaion of dunites and associated structural rebuilding and segregation of Cr-spinels and PGE minerals within a temperature range of 900–400°C (Pushkarev et al., 2007). Presented data indicate that cooling and accommodation of the dunites to the crustal structures lasted for up to 50 Ma.

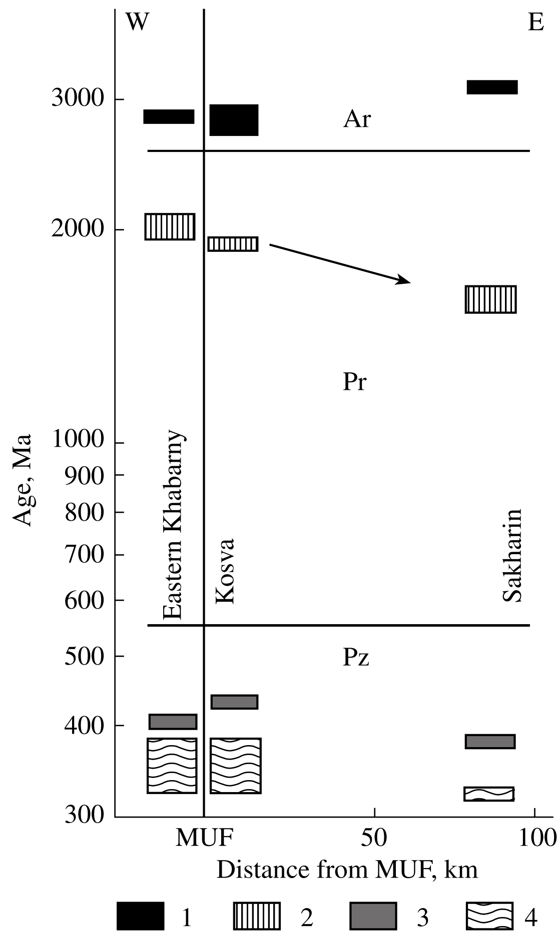

Fig. 10. U–Pb diagram for zircons from dunites versus distance of the massif to the west (W) and east (E) from the Main Ural Fault (MUF).

Zircon populations: (1) mantle, (2) xenogenic (presumably captured from the basement of the Uralian orogen), (3) magmatic zircons that record the time of crystallization and accumulation of olivine from the basic melt, (4) postmagmatic zircons marking the age of dunite recrystallization and segregation of Cr-spinels and PGE.

Arrow shows the possible change in the basement age across the Urals.

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