HISTORY OF DEVELOPMENT OF INTRUSIVE MAGMATISM IN THE URALIAN PLATINUM-BEARING BELT ON THE GROUNDS OF TO U-Pb DATING OF ZIRCONS FROM ROCKS, FORMING DIKES IN THE DUNITES OF KAMENUSHESKI MASSIF (MIDDLE URAL, RUSSIA)

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Dikes of contrasting composition occur in the rocks of dunite-clinopyroxenite-gabbro intrusions along with the predominant rocks of the Uralian Platinum Belt, such as dunites, wherlites, clinopyroxenites, and gabbros. Hornblendites, gabbros, plagioaplites, and granites are among the rocks composing these dikes. The formation sequence of these dikes can be used to establish evolution patterns of intrusive magmatism, both within the Uralian Platinum belt and the Tagil island paleo-arc.

It is worth to be noted that the age of the dunite bodies, which are an integral part of the dunite-clinopyroxenite-gabbro intrusives, currently remains controversial (Efimov, 2009; Fershter et al., 2009; Anikina et al., 2012; Fershtater, 2013). And if isotope methods in most cases do not reliably determine the time beginning of the formation of dunite-clinopyroxenite-gabbro massifs, then the time of the end of their formation can be established with a high degree of confidence (Gottman et al., 2011). At the same time, the analysis of the formation sequence of different composition dikes can serve as a basis for assessing the evolution of intrusive magmatism within the Uralian Platinum belt.

The low degree of geologic certainty, the maximum possible number of various dike bodies (from wehrlites to granites) and the high degree of exposure of the Kamenushensky clinopyroxenite-dunite massif dunite "core" make this object most suitable for determining both relative and absolute age of dike bodies from among all massifs of Uralian Platinum belt. It is important to note that the evolution of intrusive magmatism within the Uralian Platinum belt and Tagil volcanic arc is studied in detail (Ivanov, 1998; Fershtater, 2013). This allows us to compare the results with already known facts. However, most researchers compare and correlate the results of their studies conducted for spatially separated geological bodies while the relationships between them are not clearly established. The results of our research, based on the presented geological data and, above all, an analysis of the intersecting relationships of geological bodies, allow for the first time for the Ural Platinum Belt to unambiguously characterize the sequence of different geological bodies formation, and subsequently to consider the evolution of intrusive magmatism using the example of a local geological object.

The relative age of dike and vein bodies in the dunites of the Kamenushensky massif was determined based on an analysis of their field relations. This became possible due to the high percentage of available polygons for geological observation. Clearly fixed and unambiguously interpreted spatial relationships of geological bodies within the dunite "core" of the Kamenushensky massif became a reliable basis for determining the age of rock formation using isotope methods. Such studies cannot be conducted for most massifs PBB due to either strong insufficient exposure and overlap with quaternary sediments, or weak distribution of dikes that do not intersect with each other.

Chromitites are the earliest veins in the dunites of the Kamenushensky massif, as in most zonal dunite-clinopyroxenite massifs. Some of them are syngenetic to the dunites and form vein-disseminated bodies, the other part forms epigenetic cutting veins (Zavaritsky, 1935). Chromitites are crossed by diopside veins (Stepanov et al., 2018). In turn, dunites containing clusters of chromite and diopside veinlets are crossed by a system of hornbendite and gabbro dikes. The most recent are dikes of biotite-containing granites, characterized by intersecting boundaries in relation to all the previously listed rocks. At the same time, the granites intruding caused the metasomatic processing in dunites with the formation of chlorite-actinolite alteration and the alteration of the gabbro to chlorite-epidote rock. In order to establish the upper age limit of intrusive magmatism within the dunite "core" of the Kamenushensky massif, it is advisable to examine in detail the hornblendites, gabbro, and granites composing the most recent dikes.

To solve the problems posed, zircons from gabbro-pegmatites, gornbendites and granites were studied. Zircon is widely distributed as an accessory mineral in all types of studied rocks. In dikes of gabbro-pegmatites, short-prismatic euhedral zircon grains were found, whose size may exceed 200 microns. Cathodoluminescence (CL) images reveal their course zonal and sectoral structure. Zircons are intergrown with pargasite and apatite, and, somewhat less often, they can be found separately from mafic minerals. Secondary inclusions of chlorite and epidote often occur along the cracks. Zircon from hornblendite dikes, in comparison with zircon from gabbro-pegmatite, is characterized by somewhat greater elongation and not so pronounced in the CL zonal and, especially, sectoral structure. At the same time, Hf zoning is a characteristic feature of hornblendite zircons. In the hornblende, zircon was found in accretion with albite, potassium-sodium feldspar and ilmenite. Zircons from granite dikes are characterized by a long prismatic appearance, weakly expressed, blunt-angled faces of a bipyramid, and the lack of zonal structure in CL, probably due to the extremely high concentrations of U and Th. Zircons grow together with titanite and quartz. Most rich in U zircons are partially metamict and host the inclusion of Ce-monazite, xenotime, and uraninite.

Thus, zircons from different types of rocks differ in morphological and anatomical features and a set of accompanying minerals found in the form of inclusions or accretions. In general, the investigated zircons differ in the number of impurity elements and, above all, in uranium and thorium. The zircons from gabbro-pegmatites are characterized by the lowest U contents: 30–206 g / t and Th: 7–130 g / t Th / U = 0.25–0.72. The content of U and Th in zircons from gornbendites is slightly higher than in zircon from gabbro-pegmatite - 25–573 and 12–256 g / t, respectively Th / U = 0.42–0.65. The highest U and Th contents among all the objects under consideration: 2,051–26,449 and 287–6,021 g / t, respectively, are inherent in zircons from granites and granite pegmatites. At the same time, Th / U ratios are the lowest, varying from which, as a rule, is characteristic of zircons from metamorphic and metasomatic rocks (Zircon, 2003).

The results of the U-Pb analysis of zircon are presented in the figure. The concordant U-Pb age, calculated on the base of 15 analytical points from 7 grains of zircons from gabbro-pegmatite from sample KR-7 (fig. a), was 418.3 ± 4.5 Ma (MSWD = 0.16). The concordant U-Pb age calculated on the base of 14 analytical points from 7 grains of zircons from hornblendites of sample KR-14 (fig. b) was 421.0 ± 2.4 Ma (MSWD = 0.97). Within the limits of errors in the determination of the age values, obtained for zircons from gabbro-pegmatites and hornblendites, is coincided. On the U-Pb diagram with concordia, 7 points of the isotopic composition of zircons from granites are located on concordia, and 9 points are located along the “reverse discordia” line (fig. c). Zircons from this sample, as described above, are characterized by extremely high concentrations of uranium. Williams and Hergt (2000) showed that in measurements on SIMS (SHRIMP) at concentrations of U over ~ 2500 ppm, the so-called “U-Pb matrix effect” occurs. This leads to a significant variation of isotopic ratios and, as a rule, overestimation of the $^{206}Pb/^{238}U$ ages. Thus, we believe that the U-Pb ages of 9 points with uranium concentrations above 3000 ppm are overestimated and do not accept them for calculations. At the same time, the weighted average $^{207}Pb/^{206}Pb$ age of zircons (fig. d), obtained over the entire set of measured points (n = 16) was 385.0 ± 6.3 Ma (MSWD = 0.96). The concordant U-Pb age, calculated by 7 points with the lowest concentrations of uranium (2051-3099 g / t), was 393.2 ± 2.5 Ma (MSWD = 0.109).

The age characteristics of rocks composing dunite-clinopyroxenite-gabbro complexes are widely discussed. The most controversial remains the question of the dunites formation time. The first isotope data on the age characteristics of ultramafic rocks were obtained in the study of zircons from the dunites of the Yudinskiy body, which is part of the Kytlym intrusion (Bea et al., 2001). At the same time, the ages obtained cover a wide range from the Archaean to the Upper Paleozoic. Further attempts (Malitch et al., 2009) of dating zircons from dunites, in general, did not allow us to reach a consensus on the formation time of the ultramafic part of the dunite-clinopyroxenite-gabbro series. However, if the age of the dunite-clinopyroxenite-gabbro intrusives formation remains the subject of discussion, then the time for the development of igneous rocks completion can be established with a high degree of confidence.

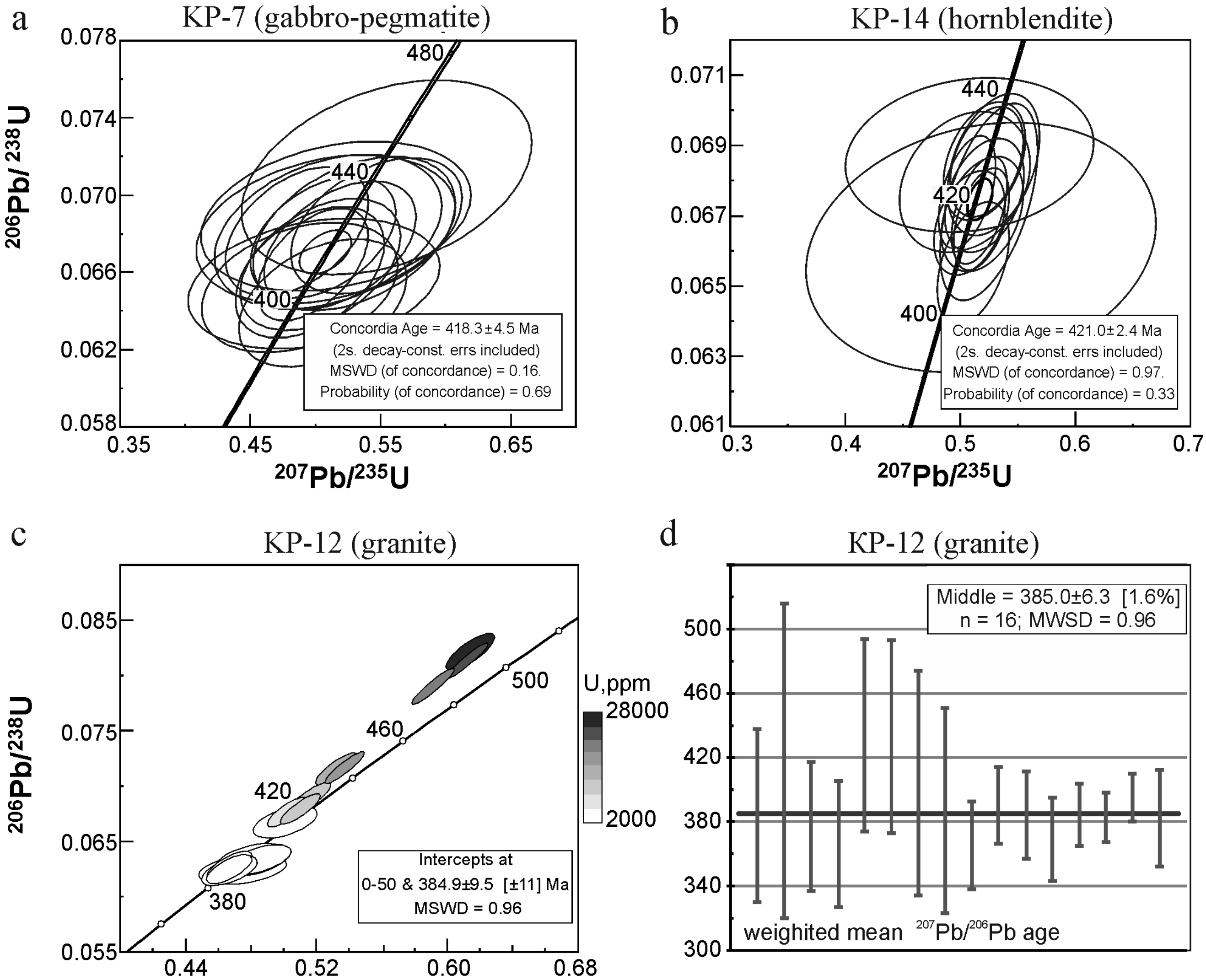

Figure. U-Pb diagrams with concordia (a – c) for zircons from gabbro-pegmatites (KP-7), mountain blendites (KP – 14) and granites (KP-12), and weighted average age of $^{207}Pb/^{206}Pb$ of zircons from granites (d).

In various sources, the upper age of ultramafic-mafic series formation, based on the study of the Svetloborsky dike complex (Ivanov, Kaleganov, 1993) and Kytlymsky (Pushkarev, Ronkin, 2014; Pushkarev et al., 2018) massifs can be assessed as Late Silurian. The results of our research are consistent with the data predecessors. However, it is important to emphasize that in the study of the dike complex in the dunite "core" of the Kamenushensky massif, Late Silurian age is characteristic both for gabbro-pegmatites, which are supposedly late differentiates of the dunite-clinopyroxenite-gabbro series, and for hornblendites, which likely are the differentiates of the gabbro series. For the latter, an age of 421 ± 2.4 Ma was obtained, which is close to the crystallization time of the residual melt, which forms when a gabbro series is formed in the gabbronorite intrusions (Bosch et al., 2006). It is this age that was adopted as the time for the formation of a gabbro (gabbronorite) complex as part of the Ural Platinum Belt (Anikina et al., 2010). Thus, the upper border of the dunite-clinopyroxene-gabbro series intrusion and the time of active development of the gabbro series is within the time span from 423.4 Ma to 413.5 Ma.

The completion of intrusive magmatism within the Tagil volcanic arc is associated with the introduction of the gabbro-diorite-granite Auerbach complex (Krasnobayev, Fershter, 2013). The age of 400–405 Ma is set for them (Fershter, 2013). A more ancient age is inherent in granites and other rocks of the leucogabbro-anorthosite-plagiogranite series, associated with the partial melting of previously formed gabbroids. Their formation fits into the time interval from 425 to 415 million years (Fershtater, 2013). By their geochemical parameters, the granites composing dikes in the dunites of the

Kamenushensky massif are like the anatectic granites of the Uralian Platinum Belt. According to zircon dating, they have an age of 384 ± 0.5 Ma. Thus, the processes of partial melting of gabbro and the formation of anatectic granites within the Uralian Platinum Belt did not end at 415 million years, as was assumed earlier, but continued throughout the entire period of the formation of the Tagil volcanic zone. These processes accompanied the transition from calc-alkaline island-arc magmatism to tholeiitic basaltic magmatism under back-arc spreading conditions, which culminated in the formation of riftogenic fine-grained amphibolite gabbro about 350 million years ago (Fershter, 2013). However, it is necessary to emphasize that zircons from granites, by the characteristics of their structure and composition and due to extremely high uranium contents and low uranium-thorium ratio can have a metasomatic nature (Zircon, 2003). The enrichment of zircons from granites with uranium can be associated with the influence of residual fluid accumulated during the differentiation of melts or the redistribution of a substance as a result of regional or contact metamorphism. The regularities of the structure of granitoid bodies in dunites, petrochemical and petrographic features of the studied granites (metasomatic transformations are not manifested), as well as the history of the geological development of the region, excludes the possibility of significant transformation processes of granites that could disturb the U-Pb system in zircons.

References

Anikina E.V., Alekseev A.V. Mineralogical and geochemical characteristics of gold-palladium mineralization in the Volkov gabbro-diorite massif (Ural Platinum-bearing Belt) // Lithosphere, 2010, № 5, p. 75 – 100 (In Russian).

Anikina E.V., Krasnobaev A.A., Rusin A.I., Busharina S.V., Kapitonov I.N., Lokhov K.I., Isotope-geochemical characteristics of zircon from dunite, clinopyroxenite and gabbro of the Ural Platinum-bearing Belt // Doklady Earth Scinces. 2012, V. 443, № 2, p. 513–516.

Gottman I.A., Pushkarev E.V., Kudryashov N.M. About the upper age boundary of the formation of dunites of the East – Habarninsky gabbro – ultramafic complex in the Southern Urals according to the U – Pb age of zircons from vein gornblenditov // Doklady Earth Scinces, 2011, vol. 438, No. 1, p. 539–597.

Efimov A.A. Platinum belt of the Urals: the current state of ideas about the geology, nature and history of the formation of a unique Russian object // Ultrabasite-basite complexes of folded regions and related fields, 2009, vol. 1, p. 176 – 179 (in Russian).

Ivanov K.S. The main features of the geological history (1.6–0.2 billion years) and the structure of the Urals. Ekaterinburg: IGG Ural Branch of the Russian Academy of Sciences, 1998. 252 p (in Russian).

Ivanov OK, Kaleganov B.A. // Reports of the Academy of Sciences, 1993, vol. 328, No. 6, p. 720-724 (in Russian).

Malich K.N., Efimov A.A., Ronkin Yu.L. Archean U-Pb isotope age of zircon dunites of the Nizhny Tagil massif (Ural Platinum Belt) // Doklady Earth Scinces, 2009, vol. 427 № 1, p. 851–855.

Stepanov S.Yu., Palamarchuk R.S., Khanin D.A., Varlamov D.A., Antonov A.V. The Distribution and form of finding the elements of the platinum group in the chromitites of the Svetloborsky, Veresoborsk and Kamenushensky clinopyroxenite-dunite massifs (Middle Urals) // Moscow University Bulletin. Series 4: geology. 2018, V. 73, №. 5, pp. 527–537.

Pushkarev E.V., Gottman I.A., Travin A.V., Yudin D.S. The age of the final stage of ultrabasic magmatism in the Ural Platinum Belt // Methods and geological results of studying isotopic geochronometric systems of minerals and rocks, 2018, p. 270 –273 (in Russian).

Pushkarev E.V., Ronkin, Yu.L., Yudin, DS, Travin, AV, Lepekhina, OP The formation time of nepheline tylaites in the Ural Platinum Belt: Sm – Nd–, Rb – Sr–, U – Pb–, 40Ar – 39Ar and K – Ar isotope datings and their limitations // Doklady Earth Scinces, 2014, vol. 455, № 1 , pp. 312–316.

Fershter G.B., Krasnobaev A.A., Bea F., Montero P., Levin V.Ya., Kholodnov V.V. Isotope-geochemical features and age of zircons from dunites of the Ural massifs of the platinum-bearing type, petrogenetic consequences // Petrology 2009, V. 17, № 5, pp. 539–558.

Fershter GB, Krasnobaev AA, Bea F., Montero P., Borodina N.S. Intrusive magmatism of the early stages of development of the Ural epiokeanic orogen: U-Pb geochronology (LA-ICP-MS, Nordsim, Shrinp-II), geochemistry, evolutionary laws // Geochemistry international, 2009, №. 2, pp. 143–162.

Fershter GB Paleozoic intrusive magmatism of the Middle and Southern Urals. Ekaterinburg: Due to the RIO UB RAS, 2013. 368 p. (in Russian)

Bea F., Fershtater G.B., Montero P., Whitehouse M., Levin V.Ya., Scarrow J.H., Austreim H. Pushkarev E.V. Recycling of continental crust into the mantle as revealed by Kytlym dunite zircons, Ural Mountains, Russia // Terra nova. 2001. P. 407-412.

Bosch D., Bruguier O., Efimov A.A., Krasnobayev A.A. (2006) U-Pb Silurian age for a gabbro of the Platinumbearing Belt of the Middle Urals (Russia): evidens for beginning of closure of the Uralian Ocean. In: Memoirs Geol. Soc. London, 32, 443-448.

Williams I.S., Hergt J.M. U-Pb dating of Tasmanian dolerites: a cautionary tale of SHRIMP analysis of high-U zircons // Beyond 2000: New Frontiers in Isotope Geoscience. Abstracts and Proceedings. Eds. J.D. Woodhead, J.M. Hergt, W.P. Noble. Lorne, 2000. P. 185-188.

Editors: John M. Hanchar, Paul W.O. Hoskin. Zircon // Reviews in Mineralogy and Geochemistry. Mineralogical Society of America. 2003. Vol. 53.