New data on geology of the Southern Urals: a concise summary of research after the period of EUROPROBE activity

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Abstract.

The period of an official activity of the EUROPROBE commission was connected in the Urals with implementation of the URALIDES Program, that stimulated many qualified geologists from the Western research institutes and Universities to come to the region and work with local geologists at topical problems of the Uralian geology. The author tries to answer a question: what interesting results had been obtained in the Southern Urals in the last decade, after most of foreign researchers left the Urals, and how these results correspond to the scientific conclusions that had been reached before.

Key words: Urals, EUROPROBE, URSEIS−95, stratigraphy, tectonics, ophiolites, HP metamorphism, plumes.

1. Introduction.

The decade between 1992 and 2001 was of a special importance for the geology of the Urals. It was characterized by a sudden surge of a research activity from s of geologists and European geoscience communities. They came to see the Urals and apply their skills and knowedge to the better understanding of this famous and extraodnary rich region. Among the main reasons for this “invasion” one may mention the famous “perestroika “ and “glasnost”, followed by the transition to openness of the USSR society and free access to the Urals that previously was almost forbidden to foreigners before the 90s. The first meeting of EUROPROBE in the Urals (May of 1991) took place in the Beloyarsk city, in full view of its “top secret” nuclear power station, and the excursions (guided by me) went from the biggest industrial City, Sverdlovsk, in five directions. It was a time of great plans and optimistic hopes for better understanding and co-operation between nations. The geology, knowing no political boundaries, was a good ground for it.

The EUROPROBE program was initiated at the 27th International Geological Congress in Moscow, 1984, as a plan for multidisciplinary research in Europe, including the European part of the USSR and the whole Urals. The aim of the program, inherited from the earlier International Lithospheric Program (ILP), was a better understanding of the structure and tectonic evolution of the lithosphere of Europe and the dynamic processes that controlled its evolution through time. Following and enhancing the ILP plans, EUROPROBE went on with organization of seismic profiles aimed to reveal the deep structure of the most interesting regions. Along with these profiles, great attention was paid to integrated studies of geology, tectonics, geodynamics, geochemistry, petrology and isotopic age of magmatism and metamorphism, paleomagnetic and geothermal studies, basin analysis and some other topics. Among ten target areas of research, corresponding to ten projects, in which about 30 countries participated; URALIDES was selected as one of the most attractive. Some more research programs were approved and realized later, just before the end of the 10-year EUROPROBE Program or even several years later. The most closely related to URALIDES were the latest TIMPEBAR (Timan-Pechora-Barentsia) and POLAR URALS programs.

During the time of EUROPROBE activity, important financial support was received from the European Science Foundation (ESF), which provided a resource for the work of the Science and Management committees and allowed the running of annual workshops for every project, with some travel money budget. Support was also provided by INTAS (The International Association for Promotion of Co-operation of New Independent States). However, the main support was provided by the participants themselves, organized into individual research groups, often multi-national, funded from National Science Foundations and Councils of their respective countries.

In the Southern Urals, the main and most expensive task was the >400 km-long URSEIS−95 seismic profile, an integrated seismic experiment. The work was accomplished by co-operative efforts of International consortium (Russia, Germany, USA and Spain), with participation of Spetsgeofizika, Bazhenovskaya Expedition, Bashneftegeofizika (Russia), DEKORP GFZ and Karlsruhe University (Germany), INSTOC Cornell University (USA), ICTJA−CSIC (Barcelona, Spain). A combination of several methods was applied in this study. The CDP combined acquisition by means of vibration and explosion excitation was accompanied by a wide-angle experiment. All acquisition was performed during one field season of 1995, and the following processing and interpretation took several next years. The results were regularly published in the western and Russian literature. The profile was evaluated as an ambitious and successful project (Berzin et al.,1996; Carbonell et al., 1996; Echtler, 1996; Knapp et al. 1996, Morozov, ed., 2001 and others). Along with the geophysical research, significant geological field work was carried out. The most stable and long-lasting co-operation was organized in these years in the Southern Urals between the geologists of the Institute of Geology in Ufa (Ufimian Scientific Centre) and colleagues from the Instituto de la Ciencias de la Tierra Jaume Almera – CSIC, Barcelona; Universidad de Oviedo, Spain; Max-Planck-Institut für Kernphysik, Heidelberg, Germany; Institut für Geologische Wissenschaften und Geiseltalmuseum, Martin-Luther-Universität Halle-Wittenberg, Halle, Germany; Geologisches Institut der RWTH, Aachen; Technical University, Berlin; Institut fur Mineralogie, und Lagerstattenlehre Institut für Geologie, RWTH, Aachen, Germany; Institut für

Mineralogie und Geophysik, Ruhr-Universitat, Bochum, Germany; Geological Survey of Finland. More episodically several other teams worked in the Southern Urals, with a participation of geologists from the Institute of Geology and Geochemistry; Institute of Geophysics (RAS), Ekaterinburg; Geological Institute of Moscow(RAS); Moscow State University; Institute of Mineralogy, Miass. They co-operated with geologists from the Universities of Udine, Napoli, Modena and Genova, Italy; Natural History Museum, London; Southampton Oceanography Centre; NERC Isotopy Geosciences Laboratory, Keyworth, Nottingham, UK; Dalhousie University, Canada; BRGM, France; GFZ, Postdam, Germany; University of Granada, University of Jaén Spain; Geological Institute, ETH, Zurich, Switzerland; Uppsala University, Sweden. The teams have published tens of scientific papers in many leading peer-reviewed geological journals. In addition, several special issues of such journals, dedicated to the geology of the Urals were published (Pérez-Estaún, Brown, Gee, eds., 1997; Meyer, Kisters, Stroink, eds., 1999; Brown, Juhlin, Puchkov, eds, 2003).

The final events of the main EUROPROBE campaign were publications of two large volumes, partially summarizing the work that had been done (Gee and Stephenson, eds., 2006 and Pavlenkova, ed., 2006). Of special interest, concerning the developments in the URALIDES program as a whole, are the papers of Brown et al., Matte, Kashubin et al., Bosch et al. and Gee et al. in the first of the volumes, and Chapter 4, edited by Puchkov, Kashubin and Pérez-Estaún (2006) in the second volume.

The decade of 90s was very difficult for Russian geology. Yeltsin's political and economical reforms, realized under seemingly attractive slogans of democracy, market economy, privatization, etc, turned out to be an ill-conceived and badly organized adventure and led to destruction of industry (and Geological Survey as well), break-off of business ties, outright banditism, sharp drops of GDP and living standards, low financing and irregular payments of salaries in science and other factors that negatively influenced the level of scientific research in the country. In these conditions, the continued arrival of foreign colleagues that had funding for field research and laboratory analyses permitted the continuation of scientific studies of the Urals geology at a relatively decent level and progress. Although the USSR geologists belonged to one of the strongest professional communities in the world, providing knowledge of 1/6 of the world land area with its richest deposits, the co-operation with so many representatives of different, English-speaking scientific schools enriched them with many ideas of modern science and provided an impetus for a further development.

The aim of this paper is not to describe the achievements of this period, which are well known and easy to find in published English-language literature, and probably deserve a special analysis, but to summarize, at least partially, what interesting research that has been done in geology of the Southern Urals in the latest decade (2006−2016).

2. Stratigraphy. Although the stratigraphy was not the main focus of the URALIDES project, it had important implications for conclusions made in the structural and geodynamic studies of the Urals.

2.1. Precambrian. The Precambrian stratigraphy was always a priority with geologists of the Southern Urals, because the ~15 km-thick section of weakly metamorphosed Proterozoic sediments of the Bashkirian meganticlinorium was accepted as the stratotype of the Riphean, and is still part of the Russian Stratigraphic Code and General Stratigraphic Scale of Russia (GSSR), being widely used for geological mapping and prospecting. Works on this scale went on until recently (e.g., Kozlov, 2014). In the last decade, these studies were supported by more in depth studies of volcanism and isotope age determinations with application of modern methods, which were almost unavailable in earlier times, except for the valuable data obtained by U. Glasmacher under the URALIDES project.

The Riphean sediments comprise volcanic rocks of several successions, which permitted us to refine the stratigraphic scheme, based first of all on new isotopic ages, obtained with new techniques. Our work was stimulated by understanding that the International Scheme (ISS) of division of Meso- and Neoproterozoic into systems/periods of equal duration (200 Ma) contradicts the traditional principles of stratigraphy.

Until recently, the Riphean was subdivided into three systems (periods): the Lower − Burzyanian, Middle − Yurmatinian and Late − Karatavian. We added to it the Uppermost (Terminal) Arshinian system (see below). The isotope ages of the boundaries of these units were updated (Puchkov et al., 2014).

The base of the Riphean section is situated at 200 - 400 m lower than the volcanics of the Navysh Subformation, at the base of polymictic sandstones of the Ai Formation (Burzyanian series), which overlies the high-metamorphic grade Archean-Paleoproterozoic Taratash crystalline complex with an angular unconformity (Sergeeva et al., 2013). The isotopic study of events in the Taratash complex dates the last episode of granitisation at amphibolite facies conditions in the crystalline basement of this region as 1777 ± 79 Ma (Krasnobaev et al., 2011) and is also in accordance with data (Sindern et al., 2006; Ronkin et al., 2012) on the minimal age of granites of the complex (1800 Ma). It constrains the lower age limit for the base of the Riphean.

The age of the Navysh Formation at the western limb of the Taratash uplift was determined as 1752 ± 11 Ma, U-Pb analysis of them at SHRIMP II (VSEGEI) (Krasnobaev et al., 2013c).

At the base of the Middle Riphean (Yurmatinian system) the Mashak volcanogenic-terrigenous Formation is situated. Two zircon samples from Mashak rhyolites were analyzed by the U-Pb CA-IDTIMS method at Boise University (USA) and the dates of 1381.1 ± 0.7 Ma and 1380.2 ± 0.5 Ma were obtained (Puchkov et al., 2009). It was close to the precise date of the Main Bakal dike, sampled by us and analyzed in the isotope laboratory of Toronto University (Canada): 1385.3 ± 1.4 Ma (U-Pb method, baddeleyite) (Ernst et al., 2006). The dike cuts the Bakal Formation and is comagmatic to the Mashak basalts. A new series of U-Pb zircon analyses was made in VSEGEI (SHRIMP). An average weighted date of rhyolites for 4 samples was 1383 ± 3 Ma; a presence of rare ancient crystals was also registered (1597 ± 27 Ma) (Krasnobaev et al., 2013a). At the same time, two samples of zircons were sent to SHRIMP in Australia (one new and one—for a control). Both gave practically the same results: 1386 ± 5 and 1386 ± 6 Ma (Puchkov et al., 2013). This laboratory has also reported the presence of some older crystals: 1420 - 1550 Ma; they are interpreted as inherited from a substrate. All the dated samples are situated ca. 300 - 400 m above the base of the Yurmatinian series and therefore we proposed the age of the boundary between the Burzyanian and Yurmatinian series to be ca. 1400 Ma.

In the area of the Tirlyan syncline of the Southern Urals the Paleozoic sediments overlie unconformably a thick (up to 1.5 km) series of terrigenous deposits, including tillite-like conglomerates. In the middle of the section there is a considerable unit of volcanogenic and volcano-sedimentary deposits. It overlies an erosional contact with the Uk Formation of the Upper Riphean. Until recently, this series was described as the Arshinian Formation and belonging to the Lower Vendian . We suggested to change the rank of the unit and regard it as a series (Kozlov et al., 2011). The study of zircons extracted from the volcanic rocks of Igonino Formation of this series led us to conclude a polychronous character of the Arshinian volcanism, with two main stages of activity at levels of 707.0 ± 2.3 and 732.1 ± 1.7 Ma (Krasnobaev et al., 2012). Taking into account that the accepted age of the base of the Vendian is now at 600 ± 10 Ma and that of the Vendian/Riphean boundary is not older than 635 - 650 Ma, we suggest a new straton at the top of the Riphean − as the Terminal, uppermost Riphean.

These data permitted us to correlate the Riphean scheme with the Meso− and Neoproterozoic units of the ISS and also suggested a correlation with the Chinese scheme (Sinian to Changcheng units) (Table 1).

The Uralian section characterizes only the easternmost part of an extensive basin, which occupied in the Meso-Neoproterozoic a considerable part of the Volgo-Uralian oil and gas province (VUP), has a thickness of 0 to 10 km and concealed under a Paleozoic sedimentary cover, 2−3 km thick. In the Province, a couple of dozen deep boreholes penetrated the Proterozoic deposits, and it permitted the construction of the stratigraphic scheme of the VUP part of the basin, having the same fundamental features as of the Southern Urals, though differing in many details. The correlation between the Uralian and VUP stratigraphic schemes serves much for the refinement of the latter. Moreover, it was shown that a stratigraphic section of a unique 5−km deep borehole in the Urals, 1−Kulgunino (Kozlov et al., 2011), is transitional and can be described as a combination of the Uralian and platform schemes. As for the oil and gas prospects of the Riphean section, they are still uncertain, because the quantity of deep boreholes is insufficient. However, a possibility of discovering of new deep deposits cannot be discarded and needs a further consideration.

2.2. Paleozoic. The most important results in the stratigraphy of the Paleozoic during the last decades were connected with the study of conodonts along with knowledge of some other orthostratigraphic faunas. The results and their impact on the paleogeodynamics were summarized at the end of the 20th century by V. Puchkov (2000).

The progress in the stratigraphy of the Ordovician of the territory to the west of the Main Uralian Fault had been marked by the recent publication of Mavrinskaya and Yakupov (2016), based on conodonts and chitinozoans, with carbon isotope analysis, made in Syktyvkar isotope laboratory, revealing in the studied sections the global Hirnantian event. Of publications on stratigraphy of the Ordovician of the Sakmara allochthon, the book of Korinevsky (2013) and Ryazantsev' s thesis (2012) must be mentioned. The importance of the latter is that it contains proofs for the existence of the Ordovician Guberlya island arc, first suggested by Zonenshain et al., (1990).

The progress in Silurian stratigraphy where well-studied graptolites play the main role is not so conspicuous, with the exception of some episodic publications, where conodonts could be used.

The progress in the Devonian conodont-based stratigraphy, mainly in the Magnitogorsk zone, is much more evident and solid, being summarized in the books of Maslov and Artyushkova (2010), Artyushkova (2014), the results of long and intense work. The specific feature of this research was that the conodonts were collected in shale and jaspers among effusives, and work with such material needs a special approach in field and laboratory (see also Puchkov, 2000). The results of the work were demonstrated at the field excursion before the International Conference "Biostratigraphy, paleogeography and events in Devonian and Lower Carboniferous" (Artiushkova et al., 2011)

The most recent results of research on the stratigraphy of the Carboniferous and Permian deposits were summarized in the materials of the Carboniferous−Permian Congress in Kazan, 2015. The importance of Carboniferous and Lower Permian sections of the Southern Urals for the development of the International Stratigraphical Scheme was demonstrated in two field excursions: "Carboniferous… " (2015), and "Southern Urals. Deep water successions…" (2015).

Generally speaking (see the above references), the Southern Urals is extraordinarily "rich" with type sections and candidates for establishment of Global Section Stratotypes and Points (GSSP), compared to all other regions of Russia (Riphean stratotype and bases of Global stages: Serpukhovian, Asselian, Gzhelian, Sakmarian, Artinskian and Kungurian). The Bashkirian stage was also established in the Southern Urals, although its boundaries do not meet the very strict conditions for GSSP establishment. The work on all of them, with international participation, went on constantly during the last decade and before.

Mesozoic and Cenozoic stratigraphy has progressed slowly in the last decades, with the exception of the most young stratons, where the work of the Laboratory of Cenozoic in the IG USC RAS (Ufa) resulted in updated stratigraphic schemes of the Neogene and Quaternary, which also was favorable for a better understanding of the neo-orogenic stage of the Urals development (Danukalova et al., 2002, Puchkov, Danukalova, 2009 and some latest publications).

3. General geology, tectonics and geodynamics. Active work on the geology of the Urals and Cis-Urals was extended in the last decade by V. Puchkov and his colleagues. My personal experience in all tectonic zones and all latitudes of the Urals, obtained during more than a half-century-long research activity, permitted me to write a book with an analysis of the most important but insufficiently clarified questions of stratigraphy, tectonics, geodynamics and metallogeny and provide a general overview of the foldbelt, using all the available materials, including those obtained under the EUROPROBE Program (Puchkov, 2010). It was, in fact, an extension and enhancement of the previous book (Puchkov, 2000). The material of the recent book is organized according to a structural-historical principle. The book is divided, apart from an Introdiction and Conclusion, into 5 Chapters corresponding to 5 structural and historical stages, established in the whole territory: Archean-Paleoproterozoic, a time of formation of the Volgo-Uralia continent and its amalgamation with other blocks into Baltica continent; Riphean-Vendian (Meso- and Neoproterozoic), a stage that was finished with the formation of Timanides; Paleozoic-Early Mesozoic stage, corresponding to the development of the Uralides; Mid-Jurassic-Miocene platform stage; Pliocene-Quaternary neo-orogenic stage. When necessary, the actual questions of stratigraphy are discussed, schemes of structural zonation for every stage are given, problems of structural geology and geodynamics of sedimentary and magmatic complexes are arranged in a chronological order; every chapter is concluded with the characteristics of metallogeny, closely connected with the previous discussion. Ideologically, the book is based on plate and plume tectonics, in their modern versions. All captions for the figures in the book are bi-lingual; the book is provided with an English Summary. It is available at the site of the Institute of Geology, Ufa. In 2011 the book was awarded by Academician A.D. Archangelsky Premium for outstanding works in a regional geology.

The English−language summaries of Chapters 3–5 are published as (Puchkov, 2009b, 2013b), and an updated analysis of the Uralian metallogeny is given in a separate paper (Puchkov, 2016a).

3.1. Structural research. Progress was made in the research of the tectonics of the part of the Uralides concealed under the Mesozoic−Cenozoic cover of the West Siberian plate, based on geophysics and study of boreholes. Data were combined with the knowledge of the tectonics of the exposed part of Uralides and structural correlation was made (Ivanov et al., 2013).

Interpretation of seismic materials aiming at a better understanding of the deep structure of the Urals, that was an important chapter of the URALIDES Project, was also on going, including a re-interpretation of some parts of the regional URSEIS−95 and ESRU−SB−93−95 profiles. The Candidate of Science thesis of A.Rybalka (2015), who defended it successfully in the last year, was dedicated to the ESRU−SB−93−95 seismic profile. Being for many years a leading specialist in Bazhenovskaya expedition, he contributed much to the success of the work on this profile. Not dwelling much upon the results, I want to pick out one of the important conclusions of this work, that was absent in previous interpretations of the profile. It was a conclusion based on the presence of a reflector below the Urals, gently (under 30 degrees) dipping to the west , that is traced through the whole crust and upper mantle to a depth of about 80 km. It is situated just under the modern Urals Mountains and probably played an important role in their formation. In fact, underthrusting of the Transuralian block under the Urals could be the cause of the neo-orogenic movements. In the Southern Urals the presence of such underthrusting is not registered, but it could be explained by problems in the acquisition and correct interpretation of primary data.

Some additional work had been done for a better understanding of the URSEIS profile as well. As it was pointed out by Znamenskiy et al. (2013), the pattern of reflectors in the eastern part of the profile, to the east of Kartaly town and the Kartaly (Troitsk) regional fault, a typical flower structure is present, which supports and is evidence for the idea of a wide development of movements along strike-slip faults in this part of the Urals.

In the last years, the work on continued interpretation of seismic profiles crossing the footwall structures of the Main Uralian Fault, that was made by international teams, because new seismic profiles were obtained. So several new papers on this subject were published, supplying previous interpretations with some more details and ideas (Svetlakova et al., 2007, 2008; Puchkov, Svetlakova, 2014).

3.2. Plume tectonics. Very important innovations that appeared in (Puchkov, 2010) and the following publications (Puchkov et al., 2013, 2016; Puchkov, 2012, 2013c, 2016 b) was a theme of probable plume events in the Urals, a point that was not raised until the early years of the new century. Before these publications, some papers of a general theoretical trend, belonging to the same author, appeared as a contribution to a world−wide discussion: “Do plumes exist?” (Puchkov, 2003, 2009a and others).

Petrogenetic, geochemical studies and isotope age determinations of flood basalts, dolerites, trachybasalts, picrite-basalts, rapakivi granites, layered mafic-ultramafic intrusions and also alkaline and carbonatite magmatic complexes of the western zones of the Urals, along with coeval magmatic complexes of adjacent and faraway territories permits the identification of potential Large Igneous Province (LIP) candidates. Their petro-geochemical properties distinguish them from MOR and subduction types; they are characterized by wide areas of development, very short periods of activity and independence of earlier geological structures in the area (Ernst, 2014).

As mentioned before, in the Southern Urals near the base of the Lower Riphean (Uppermost Paleoproterozoic and Lower Mesoproterozoic), covering the crystalline Taratash complex dated as Archean and Lower Paleoproterozoic, there are volcanic deposits of the Navysh Subformation, represented mostly by trachybasalts. The age of the unit was determined as 1752±11Ma (SHRIMP, zircons) (Krasnobaev et al., 2013c). It turns out that volcanic rocks of the age range of 1750−1780 Ma are developed not only in some other places of Baltica, but also in Northern Africa, Siberia, Laurentia and North China, belonging to the Nuna supercontinent at that time (Puchkov, 2013c; Youbi et al. 2013). Therefore, they may belong to a LIP.

Higher up the section of the Riphean, at the base of the Middle Riphean (Mid−Mesoproterozoic), rhyolites of the Mashak Formation were dated by SHRIMP and CA-IDTIMS U−Pb methods in three isotopic laboratories as 1380−1385 Ma (see above). The same ages have been obtained for rapakivi granites, layered gabbro (Kusa−Kopan Intrusion), carbonatites (Sibirka) and dolerite dykes and sills that widely developed in the Southern Urals and are encountered in boreholes of

East European platform; magmatic rocks of the same age are traced to Greenland, Laurentia and Siberian cratons and represent the beginning the beginning of the Nuna supercontinent break-up (Ernst et al., 2008; Puchkov et al., 2013; Puchkov, 2013c; El Bahat, 2013).

Less confidently we may speak of the younger Neoproterozoic magmatic complexes of the Southern Urals as LIPs, dated as ca. 720 Ma (compare with data of Ernst, 2014; Ernst et al., 2016) and 680 Ma − Arshinian and Kiryabinka complexes (Kozlov et al., 2011; Krasnobaev et al., 2013b); they need further study (Puchkov, 2016a,b).

The study of dolerite dykes and volcanics in the western slope of the Urals has revealed three main Paleozoic volcanic events. The first one, represented by subalkaline volcanics is connected with a rift process that started at ca. 490 Ma, the beginning of the Ordovician, that led to oceanic spreading and formation of the Paleouralian ocean. This accompanied the formation of the Baltica passive margin (Puchkov, 2002) and can be attributed to a plume-connected volcanogenic type (Melancholina, 2011). The comparable and contemporaneous rifting events, accompanied by volcanism, took place in the Lower−Middle Ordovician along the eastern (in modern co-ordinates) margin of the Siberian continent (Bulgakova, 1991). As it is shown by paleomagnetic data (e.g. Svyazhina et al., 2003, Paverman, 2016), the “upside-down” position of the Siberia, and sub−longitudinal strike of the Uralian margin could suggest close, vis−a−vis positions of the margins, and their volcanism may belong to the same superplume episode, occuring above the same superswell.

The second episode was marked by an eruption of trachytes in the Bashkirian meganticlinorium, and was dated (SHRIMP, zircons) between 435 and 455 Ma. It can be correlated with the early stage of development of the Vishnevogorsk plume-related carbonatite complex (Puchkov, 2010, 2016 b; Puchkov et al., 2011; Nedosekova, 2012).

A younger dolerite and basalt complex is Devonian in age and is traced along the western slope of the Urals to Pay−Khoy and Novaya Zemlya. The rocks match excellently with the Middle−Upper Devonian volcano-intrusive complexes of the East European platform, including flood basalts, dolerite dykes, alkaline and carbonatite intrusions and kimberlites, and belong to the marginal part of the LIP called Kola−Dnieper (Ernst, 2014; Puchkov et al., 2016). The late, reliably dated stage of the Devonian magmatism of the East European platform and Urals−Novozemelian belt is Frasnianin in age. They are well correlated with the Yakutsk−Vilui plume episode in the Siberian Craton and probably represent a superplume derived from an active part of a single deep mantle LLSVP (Large Low Shear Wave Velocity Province), the so-called Tuzo superswell (Puchkov et al., 2016 and references therein).

3.3. Geology of ophiolites. Wide development of ophiolites, as association of peridotites, pyroxenites, gabbro, basalts and deep-water sediments (mostly cherty shales and jaspers), is the most characteristic feature of the Urals. Since the International Symposium on geology of ophiolites that took place in Moscow, 1973, and the International ophiolite excursion (Efimov et al., 1978), the idea of ophiolites as relics of an ancient oceanic crust became very popular among the Uralian geologists and stimulated a research activity in this direction. Several international groups of researchers worked in the Urals under the URALIDES Program, contributing to the knowledge of the geology of such outstanding objects as, first of all, the Kempirsay, Khabarny, Kraka and Nurali massifs in the Southern Urals and Voykar, Ray-is and Syum- Keu in the Polar Urals.

The summary of the EUROPROBE research as well as the earlier studies were given by Savelieva et al., (2006a). It was shown that different massifs belong to different geodynamic situations – Mid Oceanic Ridges, transition from epicontinental rift to a passive margin, or island arcs of different ages. The summary of isotopic age determinations (K−Ar, Sm−Nd, Rb−Sr, Sm−Nd , U−Pb systems), supported by paleontologic determinations of the ages of a sedimentary component of ophiolites permitted dating of the ophiolites to the limits of the Lower Ordovician−Upper Devonian, admitting that the younger, Devonian ages correspond mostly to the secondary processes of deformation and metamorphism. The Precambrian ages were attributed to the ophiolites of Timanides.

However, reliable Precambrian ages, obtained mostly by the U−Pb method from zircons, changed this simple picture. Zircons of Vendian age (585, 3±6 Ma) and a couple of zircons dated as 622±11 Ma plus one grain of 2552±25 Ma, were obtained from chromites from a small deposit in dunites of the Voykar massif (Savelieva et al., 2006 b). Puchkov (2006, 2010) discussed this problem in detail. He indicated that there were more examples of Precambrian isotopic dates (U−Pb, Sm−Nd, Re−Os) for ophiolites that were thought to be Paleozoic. The lower, peridotite part of the ophiolite sections, called by R.Coleman a “mantle tectonite”, appears to belong to very ancient, restitic mantle, that may preserve relict isotope ratios, corresponding to previous Wilson cycles, that are reflected only in the lower parts of the ophiolite sections. For example, ancient zircons were found in the Uralian ophiolites, forming an assembly of different–aged (from 2000 to 200 Ma) crystals, in dunites, lherzolites and garnet pyroxenites of Kraka massifs (Krasnobaev et al., 2008).

Broadly speaking, the presence of zircons in peridotites seemes to be enigmatic. Deficit of silica in peridotites should not permit the development of zircons – only baddeleyite should form. Therefore, basalt melts were needed to generate zircons. But where are they?

Batanova and Savelieva (2009) gave a review of ideas concerning the transport of basalt melts through the peridotite mantle in spreading zones. The hypothesis of migrating mantle magmas reacting with wall peridotites and the formation of replacive dunites as a result of this process was discussed. It was shown that dike-like dunites, forming nets within harzburgites and lherzolites, were the channels of basalt melts. In this case, zircons and chromites hosting them could be the refractory trace minerals, left by the basalt magma on its way from relatively deep places of partial melting in the mantle to the Earth's surface. The possible deep origin of these minerals is suggested by the presence of diamonds, discovered in chromites in some ophiolite peridotites, including the Ray-Is massif of the Urals (Yang et al., 2014).

The preservation of zircons that spent such a long time, within the extreme P–T conditions of the mantle also needs an explanation. Recent (Anfilogov et al., 2015) experimental studies elucidate the interaction between zircon crystals and dunite at 1400–1550C. It was shown that at 1400C no interaction of zircon with dunite takes place, and only at higher temperatures an interaction between zircon and olivine occurs, forming an eutectoid mixture of baddeleyite and pyroxene grains. Therefore zircon is very resistant to metamorphic changes, and it explains the coexistence of zircons of different ages, formed under repeating high-temperature processes.

3.4. Petrology and geochemistry of igneous and sedimentary rocks. Significant work was done by the group of G. Fershtater on the petrology and geochemistry of intrusive rocks of the eastern slope of the Urals, in collaboration with his colleagues from Granada (Spain) before and during EUROPROBE activities. The results were summed up recently in his monograph (Fershtater, 2013). More local, but very detailed studies of the geology, petrochemistry and chomite ore potential of peridotite Kraka, Talovsky, Mindyak and many other gabbro-peridotite massifs were described in the book of Saveliev et al.(2008). The petrology and geochemistry of intrusive rocks, volcanics and sedimentary successions, hosting them, in the Bashkirian meganticlinorium were summed up recently in the book of Kovalev et al. (2013). Simultaneously, a special book concerning the characteristics of the stratigraphy of the Mashak Formation in the stratotype and petrology of its volcanics was published by Ardislamov et al. (2013) The geology and petrogeochemistry of carbonaceous sediments of the Southern Urals were characterized in the monograph of Snachev et al. (2012)

Devonian and Carboniferous volcanic rocks of the Magnitogorsk zone, the variable geodynamic conditions of their origin and their position in the relic island arc of Paleozoic time were described in two comprehensive papers by papers of Kosarev et al. (2005, 2006).

3.5. Metamorphism. New data on the geology of HP−LT complexes. The classic HP−LT metamorphic *Maksiutovo* complex has attracted the attention of Russian petrologists at least since the 50s of the 20th century, and it was very popular with the participants of the URALIDES Project. More than a dozen papers were published, dedicated to different aspects of the geology, geochemistry and petrology of this outstanding eclogite-glaucophane complex. The general opinion, summed up and discussed by Puchkov (2010), is that this complex was formed in a process of Paleozoic subduction of oceanic crust and subsequent collision of an island arc and continental passive margin. As a consequence of the buoyancy of the subducted continental margin, the metamorphic complexes were uplifted from the depth of 50−70 km and exhumed to the earth's surface. Most of the isotopic age determinations, made by different methods, correspond to the Devonian time, and the beginning of exhumation is dated as ca. 375 Ma, supported by the information that glaucophane clastic grains appear in the Famennian Zilair flysch Formation.

More recently, additional work had been done to obtain more detailed information on the types of eclogites (e.g. Alekseev et al, 2006).

Later on, it was established (Kovalev et al., 2015) that protoliths of different varieties of high−pressure eclogites (high-Ti, moderate- and low-Ti eclogites, graphite eclogites, and eclogites of a layered body) were mafic magmatic rocks of different affinity and Paleozoic in age. The petrogeochemical study has shown that the eclogites are close to basalts that formed in different geodynamic settings – oceanic and subductional, and now they are juxtaposed. Thermodynamic calculations of mineral assemblages of eclogites showed that low-Ti eclogites (680–700C, 24 kbar), graphite eclogites (660–710C, 17–18.8 kbar), and eclogites of the layered body (610–730C,16–18 kbar; 410–430C, 12.5–13 kbar) formed at similar temperatures, but at a large scatter in pressure. It was concluded that the pressure variations were caused by the tectonic juxtaposition of bodies during exhumation of the eclogites formed at different depths of the subducted slab.

On the other hand, there existed an alternative point of view (Dobretsov et al., 1996), that the protolith of the rocks is Precambrian and experienced ultrahigh−pressure metamorphism (550–600 Ma); the final stage of the high−pressure metamorphism (320–385 Ma) occurred simultaneously with the metamorphic transformations of the ophiolites.

Meanwhile, new data have been presented on the conditions of origin and age of the Maksyutov metamorphic complex. The studies of zircons from garnet-glaucophane schists of the complex (Novotashlinskii area) (Krasnobaev et al., 2015) show that their substrate was constituted of magmatic gabbroids of Neoproterozoic age (670 Ma). The long-term evolution of zircons encompassed the interval from the Neoproterozoic until the Carboniferous (673.1 ± 5.4, 592.6 ± 9.4, 517.0 ± 7.4, 444.9 ± 4.7, and 323.0 ± 8.8 Ma) − i.e, from the Terminal Riphean till Vizean.

The study of Valizer et al. (2013, 2011) was concentrated on UHP jadeite−bearing eclogites, developed near the village of Karayanovo, and on spatially associated ultramafites also considered to have formed under eclogite-facies conditions. A comparison shows that the studied eclogite and ultramafic rocks followed a common *P–T–t* path. For the jadeite−bearing eclogites, two phases of elcogitization were recognized based on mineralogical data, petrographic observations, and isotope geochronology. The first UHP metamorphic stage (533 ±4.6 Ma, *P* > 4.4 GPa, *T* > 700°C) was defined by the assemblage jadeite + grossular-almandine + rutile ±phengite. This assemblage was later transformed into omphacite + grossular–almandine + phengite + albite + clinozoisite + titanite at a retrograde phase of stage I (392–485 ±2–4 Ma, *P* > 3.1–3.4 GPa, *T* > 633–740°C) with decreasing pressure and temperature. The second prograde phase (360 ±5 Ma, *P* > 1.1–2.2 GPa, *T* > 450–550°C) of HP metamorphism was marked by the development of a chlorite rim (almandine–grossular—pyrope–almandine–grossular, diopside, clinozoisite) around the eclogite body. The ultramafites are represented by olivine-enstatite and enstatite rocks. The thermodynamic parameters of formation of the paragenesis are estimated as 800–1240°C and 30–45 kbar. Geochronological data limits recorded in the zircons cover an interval of more than 2 billion years, between 2350 ± 53 Ma and Early Permian (284.9 ± 7.3 Ma), see above. In general, Paleoproterozoic ages characterize the primary basis of the protoliths, while the Permian zircons record the final transformations of previous generations and the formation of new generations. The intermediate age level (545.3 ± 5.5 Ma and 365.3 ± 4.2 Ma) divides the initial stages of formation–transformation of the substrate and the final stage of its metamorphism, caused by shear deformations. It is probable that this age boundary can be considered as an indicator of the UHP metamorphism.

These new data show that the problem of the history of the Maksyutovo complex is probably more complicated than was thought before.

Beloretsk HP−LT metamorphic complex (MCB) with eclogites within its core attracted attention of German geologists from several Universities and Institutes, working together with Russian team from the Institute of Geology, Ufa. The main results were presented in the paper of Glasmacher et al. (2001). The complex is situated in the eastern part of the Bashkirian meganticlinorium, and it contrasts with the wider western part of this structure, where metamorphism varies between diagenesis and lower stage of the greenschist facies. Three pre-Ordovician deformation phases were identified in the MCB. The first SE-vergent, isoclinal folding phase (D1) is younger than the intrusion of mafic dykes (Pb/Pb-single zircon: 1350 Ma) and older than the eclogite-facies metamorphism. It is thought that high P/low T eclogite-facies metamorphism is bracketed by D1 and the intrusion of the Akhmerovo granite (Pb/Pb-single zircon: 970 Ma). An extensional, sinistral, top-down-to-NW directed shearing (D2) is correlated with the first exhumation of the MCB. E-vergent folding and thrusting (D3) occurred at retrograde greenschist-facies metamorphic conditions. The tremolite 40Ar/39Ar cooling age (718±5 Ma) of amphibolitic eclogite and muscovite 40Ar/39Ar cooling ages (about 550 Ma) of mica schists indicate that a maximum temperature of 500±50 °C was not reached during the Neoproterozoic orogeny. The scheme of development of the MCB implies that it is different from the development of the western part of the meganticlinorium and therefore the MCB is supposed to be a terrane emplaced along a regional strike−slip fault.

The study of the Beloretsk complex went on after that. A.A.Krasnobaev et al (2008) reconsidered the age of the Akhmerovo granite intrusion; it was shown that the age of the intrusion is 1381±23 Ma; it corresponds to the Mashak level. The Pb/Pb-single zircon 970 Ma age probably has no geological sense, and therefore the idea that the MCB as an exotic terrane emplaced along a strike‒slip fault has not enough grounds.

The post‒graduate student of the Institute of Geology A. Galieva was invited to Aachen by W. Bauer, and this permitted her to make a series of microprobe and ICP Ms anslyses. This opportunity helped her to write and defend in 2004 a Candidate of Science dissertation on geology, petrology and conditions of origin of the eclogites of the Beloretsk complex. It was shown that the protolith of the eclogites was a series of sills. The host rocks of the eclogites are metamorphosed in the same facies. After that, all the rocks experienced a retrograde metamorphism.

The materials of A. Galieva were published in the book of A. Alexeiev et al. (2006) where an overview of metamorphic processes of the western slope of the Southern Urals was presented. Soon after that, another book of this author and his colleagues was published (Alexeiev et al., 2009), dealing specially with the general features of the MCB. In both books it was shown that the complex has a dome‒like structure and metamorphism is zonal, Barrowian-type, with isogrades of omfacite, garnet, biotite and chloritoid, having semi-concentric outlines in the western (exposed) part of the dome (the eastern part is concealed under weakly metamorphosed Paleozoic sediments). The eclogitic part of the complex, described by Alexeiev as a specific zoizite-omphacite facies, is different from the usual eclogite-glaucophane-schist metamorphism and has a transitional nature between it and the amphibolite (kyanite-sillimanite) facies.

PT-conditions of origin of the MCB complex were established and evolution of rocks formation reconstructed: from prograde metamorphism (650°C, 13 Kbap) to retrograde (500°C and 5-5.5 Kbar). The further progress of the study was presented in the paper of Kovalev and Timofeeva (2015). They have shown a clockwise P‒T‒t path of the metamorphism and suggested a geodynamic model of the complex, which included two stages, the first of which corresponded to riftogenic conditions at the time of 730‒710 Ma (may be plume-induced) and the second ‒ the main stage ‒ took place during the orogeny of Timanides, when the rocks experienced stress (or stress and lithostatic pressure). Therefore, the BMC was attributed to a collisional type.

4. Concluding remarks and acknowledgements

Not all the problems that were being solved during EUROPROBE and after the end of the URALIDES Program have been touched upon. For example, we did not discuss a lot of work done during these years under other international programs, especially those dedicated to the mineral deposits of the Urals (MinUrals, GEODE, CERCAMS and others). Resources were not the URALIDES priority. The co-operation of the Uralian geologists with the specialists from western countries was always fruitful and stimulating, and served for general progress of Earth Sciences. There is hope that this paper will be interesting, especially to many people who participated in the URALIDES Project and might wonder what happened after they left the Urals.

I wish to express, on behalf of all my colleagues, a deep gratitude to all those who worked with us in the field, exposing ourselves to changing and not always friendly weather, participated in long and exhausting trips, sharing a buckwheat porridge and ideas, helping to process and analyse samples. A special tribute of memory I want to pay to Andres Pérez-Estaún, an outstanding scientist and a good friend.

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References

Alexeiev A.A., Alexeieva G.V., Galieva A.R., and Kovalev S.G. Metamorphic Geology of the Western slope of the Southern Urals. Ed. by V.Puchkov. Ufa, Gilem, 212 pp, 2006. (In Russian).

Alexeiev A.A., Kovalev S.G., Timofeeva E.A. Beloretsk metamorphic complex. Ed. by Puchkov V. N. Ufa, Gilem, 2009. 175pp.

Anfilogov V. N., Krasnobaev A. A., Ryzhkov V. M., Kabanova L. Ya., Valizer P. M., and Blinov I. A.. Stability of Zircon in Dunite at 1400–1550^{o} C. Doklady Earth Sci. 2015, 464, 2, 963−967,

Ardislamov F.R., Saveliev D.E., Snachev A.V., and Puchkov V.N. The geology of the Mashak Formation of the Yamantau anticlinorium (Southern Urals). Ufa, DesignPr, 2013. 216 pp. (in Russian).

Artiyshkova O.V. Devonian conodonts from the volcanogenic-cherty deposits of the Magnitogorsk megazone of the Southern Urals. Ufa, DizainPress, 152 pp. ,2014 (in Russian).

Artiyshkova O.V., V.A. Maslov, V.N. Pazukhin, E.I. Kulagina, R.Ch. Tagarieva, L.I. Mizens, A.G. Mizens. Devonian and Lower Carboniferous type sections of the Western South Urals. pre-conference field excursion guidebooк. Ufa, Sterlitamak, Russia, July 20–25, 2011.91 pp.

Batanova V.G., and Savelieva G.N. Melt migration in the mantle beneath spreading zones and formation of replacive dunites: A review. Russian Geology and Geophysics, 50 (9), 992−1012, 2009.

Berzin, R., Oncken, O., Knapp, J.H., Pérez-Estaún, A., Hismatulin, T., Yunusov, N., and Lipilin, A. Orogenic evolution of the Ural Mountains: Results from an integrated seismic experiment. Science, 274, 220-221, 1996.

Brown, D., Juhlin, C.,and Puchkov, V. (Eds.), Mountain Building in the Uralides: Pangea to Present. American Geophysical Union, Geophysical Monograph 132, 286 pp, 2002.

Bulgakova M. D. The Early Paleozoic of the Northeast of the USSR (Rsedimentological analysis).Yakutsk, 102 pp.,1991. (in Russian).

Carbonell, R., Perez-Estaún, A., Gallart, J., Diaz, J., Kashubin, S., Mechie, J., Stadtlander, R., Schulze, A., Knapp, J.H., and Morozov, A.. A crustal root beneath the Urals: Wide-angle seismic evidence. Science, 274, 222-224, 1996.

Carboniferous reference sections: potential candidates for the base of the Serpukhovian GSSP and organic buildups, South Urals. Post-Congress C3 Trip: 16–19 August, 2015. A Field Guidebook of XVIII International Congress on the Carboniferous and Permian, August 11– 15, 2015, Kazan, Russia / E.I. Kulagina, S.V. Nikolaeva, E.N. Gorozhanina, N.A. Kucheva, T.I. Stepanova, A.S. Alekseev, B.C. Richards, V.N. Puchkov, N.N. Kochetova, V.M. Gorozhanin, and V.A. Konovalova. E.I. Kulagina and S.V. Nikolaeva (Eds). St. Petersburg: “Svoe izdatelstvo”, 90 pp., 2015.

Danukalova G.A., Yakovlev A.G., Puchkov V.N., Danukalov, N.K., Agadzhanyan A.K., van Kolfschoten Tp., Eremeev A.A., and Osipova E.M. Excursion Guide of the INQUA SEQS – 2002 conference, 30 June – 7 July, 2002, Ufa, Russia.(INQUA SEQS – 2002 conference "The Upper Pliocene – Pleistocene of the Southern Urals region and its significance for correlation of eastern and western parts of Europe"). Ufa: Dauria, 139 pp., 2002.

Dobretsov N. L., Shatsky V. S., Coleman R. G., Lennykh V. I., Valizer P. M., Liou J., Zhang R. and Beane R. J. Tectonic Setting and Petrology of Ultrahigh-Pressure Metamorphic Rocks in the Maksyutov Complex, Ural Mountains, Russia. Intern. Geol. Rev., 38 (2), 136−160, 1996.

Echtler, H.P., Stiller, M., Steinhoff, F., Krawczyk, C.M., Suleimanov, A., Spiridonov, V., Knapp, J.H., Menshikov, Y., Alvarez-Marron, J., and Yunusov, N., Preserved collisional crustal architecture of the Southern Urals – Vibroseis CMP-profiling. Science, 274. 224-226, 1996.

El Bahat A., Ikenne M., Søderlund U., Cousens B.,Youbi N., Ernst R., Soulaimani A., El Janati M. and Hafid A. U–Pb baddeleyite ages and geochemistry of dolerite dykes in the Bas Drâa Inlier of the Anti-Atlas of Morocco: Newly identified 1380 Ma event in the West African Craton. Lithos, 174. 85−98, 2013.

Ernst, R.E., Pease, V., Puchkov, V.N., Kozlov, V.I., Sergeeva, N.D., and Hamilton, M., Geochemical characterization of Precambrian magmatic suites of the southeastern margin of the East European craton, southern Urals, Russia. Geologichesky Sbornik (Geological Proceedings), 5. Ufimian Institute of Geology, Ufa, 2006, 119–161.

Ernst, R.E., Wingate, M.T.D., Buchan, K.L., & Li, Z.X. (). Global record of 1600–700 Ma Large Igneous Provinces (LIPs): implications for the reconstruction of the proposed Nuna (Columbia) and Rodinia supercontinents. Precambrian Research, 2008, 160: 159–178.

Ernst R. Large Igneous Provinces. Cambridge University Press, London, 653 pp. 2014.

Ernst, R.E,. Hamilton,M.A., Söderlund, U.,. Hanes, J.A., Gladkochub, D.P., Okrugin, A.V., Kolotilina,T., Mekhonoshin, A.S., Bleeker, W., LeCheminant, A.N., Buchan, K.L., Chamberlain,K.R., Didenko, A.N.,.Long-lived connection between southern Siberia and northern Laurentia in the Proterozoic. Nature Geoscience, 2016, 9: 464-469

Fershtater, G.B., Paleozoic Intrusive Magmatism of the Middle and South Urals. Uralian Branch, Russian Academy of Sciences, Ekaterinburg, 368pp., 2013 (in Russian).

Galieva A.R. Geology, petrology and conditions of origin of eclogites and host rocks of the Beloretsk metamorphic complex (Southern Urals). Dissertation of Candidate of Science (geology): 25.00.01, 25.00.04 Syktyvkar, 2004. 144 p.

Gao Linzhi, Geng Shufang, Jing Xiaozhong, Liu Yanxue and Zhang Heng. New Geological Time Scale of Proterozoic in China. Power Point Presentation. Beijing, 2012. (the original reference is in Chinese).

Gee D.G., Stephenson R.A., eds. European Lithosphere Geodynamics. Geol. Soc. London Memoir No.32. London, 662 pp., 2006.

Glasmacher U.A., Bauer W., Giese U., Reynolds P., Kober B.,Puchkov V., Stroink L., Alekseyev A. , Willner A.P., 2001. The metamorphic complex of Beloretzk, SW Urals, Russia — a terrane with a polyphase Meso- to Neoproterozoic thermo-dynamic evolution. Precambrian Res., 110,185−213.

Efimov A.A., Savelieva G.N., Yazeva R.G., Saveliev A.A., Lennykh V.I., and Puchkov V.N. The Guidebook of an excursion “Ophiolites of the Polar Urals” 1−15 August 1978. Moscow, GIN AS USSR, 62 pp., 1978.

Ivanov K.S., Puchkov V.N., Fyodorov Yu.N., Erokhin Yu.V., and Pogromskaya O.E. Tectonics of the Urals and adjacent part of the West-Siberian platform basement: main features of geology and development. Journal of Asian Earth Sciences. 72, 12−25, 2013.

Knapp, J.H., Steer, D.N., Brown, L.D., Berzin, R., Suleimanov, A., Stiller, M., Lüschen, E., Brown, D., Bulgakov, R., and Rybalka, A.V.. A lithosphere-scale image of the Southern Urals from explosion-source seismic reflection profiling in URSEIS ’95. Science, 274. 226-228, 1996.

Korinevsky V.G. Geological structure and stratigraphy of Lower Ordovician volcanogenic complexes of the Southern Urals. Ekaterinburg, Uralian Branch of RAS, 72 pp., 2013. (in Russian).

Kosarev A.M., Puchkov V.N.,and Seravkin I.B. Petrologo-geochemical features of the Early Devonian-Eifelian island-arc volcanics of the Magnitogorsk zone in the geodynamic context. Lithosphere, 4. 22-41, 2005 (in Russian).

Kosarev A.M., Puchkov V.N., and Seravkin I.B. Petrologo-geochemical features of the Middle Devonian – Early Carboniferous island-arc and collisional volcanics of the Magnitogorsk zone in the geodynamic context. Lithosphere, 1. 3-21, 2006 (in Russian).

Kovalev S.G., Timofeeva E.A. Thermodynamic conditions of formation and geodynamic reconstructions for eclogites of the Beloretsk complex (Southern Urals). Vestnik IG Komi SC UB RAS 2015, No 9. P. 3−10

Kovalev S.G., Timofeeva E. A., and Pindyurina E. O. Geochemistry of the Eclogites of the Maksyutov Complex, South Urals, and Genetic Nature of Their Protoliths. Geochemistry International, 53, 4, 285−311, 2015.

Kovalev S.G., Vysotsky I.V., Puchkov, V.N., Maslov A.V., and Gareev E.Z. Geochemical specialization of structure-material complexes of the Bashkirian meganticlinorium. Ufa, 135pp., 2013 (in Russian).

Kozlov, V.I., Puchkov, V.N., Krasnobaev, A.A. , and Sergeeva N.D. Arshinian −A New Straton of the Riphean in the Stratotypical Sections of the Southern Urals. Geologicheski Sbornik (Geological Proceedings), 9. Institute of Geology, Ufimian Sci, Centre RAS, 3-8, 2011a. (in Russian)

Kozlov, V.I., Puchkov, and Sergeeva, N. D. New subdivision scheme of the section of 1−Kulgunino borehole (Southern Urals). Ufa, IG USC RAS, 59 p., 2011b (in Russian)

Krasnobaev A.A., Kozlov V. I., Puchkov V. N., Rodionov N. V., Nekhorosheva A. G., and K. N. Kiseeva, The Akhmerovo Granite Massif:A Proxy of Mesoproterozoic Intrusive Magmatism in the Southern Urals. Doklady Earth Sciences, 2008, Vol. 418, No. 1, pp. 103–108.

Krasnobaev A. A., Rusin A. A., Rusin A. I., and Busharina S.V. Zircons of lherzolite-garnet pyroxenite-dunite complex of the Uzyan Kraka (S. Urals). Structural-material complexes and geodynamic problems of Precambrian in Phanerozoic orogens. Ekaterinburg, 2008, 58–61, (in Russian).

Krasnobaev, A. A., Kozlov, V. I., Puchkov, V. N., Busharina, S. V., Berezhnaya, N. G., and Nekhorosheva, A. G. Zirconology of Iron Quartzites of the Taratash Complex (Southern Urals). Dokl. Earth Sciences, 437,527-531, 2011 (in Russian).

Krasnobaev, A. A., Puchkov, V. N., Kozlov, V. I., Sergeeva, N. D., and Busharina, S. V. New data on zircon geochronology of the Arshinian volcanics (Southern Urals). Lithosfera*,* 4, 127-139, 2012 (in Russian).

Krasnobaev, A. A., Kozlov, V. I., Puchkov, V. N., Busharina, S. V., Sergeeva N. D., and Paderin I. P.. Zircon Geochronology of Mashak Volcanics and the Age of the Lower-Middle Boundary (Southern Urals). Stratigraphy. Geological correlation, 21 (5), 465-481, 2013a.

Krasnobaev, A.A., Puchkov, V.N., Sergeeva, N.D., and Lepekina, E.N. Zirconology of the Kiryabinka pyroxenite–gabbro complex (Southern Urals). Dokl. Earth Sci. 450 (1), 531–535, 2013b.

Krasnobaev, A. A., Puchkov, V. N., Kozlov, V. I., Sergeeva, N. D., Busharina, S. V., and Lepekhina, E. N.. Zirconology of Navysh Volcanic Rocks of the Ai Suite and the Problem of the Age of the Lower Riphean Boundary in the Southern Urals. Doklady Earth Sciences, 450 (1), 531−535, 2013c.

Krasnobaev A. A., Valizer P. M., Anfilogov V. N., and Busharina S. V. Zirconology of Garnet–Glaucophane Schists of the Maksyutov Complex (Southern Urals). Doklady Earth Sciences, 461, 2, 414–418, 2015.

Mavrinskaya T.M. and Yakupov R.R. Ordovician deposits of the western slope of the Southern Urals and their correlation based on conodonts and chitinozoans. Russian Geology and Geophysics, 57 (2), 265−281, 2016.

Maslov V.A. and Artiyshkova O.V. Stratigraphy and correlation of Devonian deposits of the Magnitogorsk megazone of the Southern Urals. Ufa, DizainPoiligraphService 288p., 2010 (in Russian)

Melankholina E.N. The comparative analysis of passive margins in the Northern and Central Atlantic. Geotectonics, 4, 80−105, 2011 (in Russian)

Meyer F.M. and Kisters A.F.M., eds. The understanding of the orogenic evolution of the Southern Urals. Geologische Rundschau (Intern. Journ. of Earth Sciences), 87,4, 497−616, 1999.

Morozov A.F., ed. The deep structure and geodynamics of the Southern Urals (URSEIS−95 Project). GERS, Tver', 250 pp., 2001 (in Russian)

Nedosekova, I.L. The age and sources of matter of the Ilmeny–Vishnevye Gory alkaline complex (Urals, Russia): geochemical and isotope Rb–Sr, Sm–Nd, U–Pb, Lu–Hf data. Lithosphere, 5. 77–95, 2012 (in Russian).

Paverman V.I. Paleomagnetism of the Middle Paleozoic of the South of the Siberan platform: geodynamic conclusions. Canidate of Sciences Thesis. Moscow, 26 pp. 2016 (in Russian).

Pavlenkova N.I., ed. Structure and dynamics of the lithosphere of the Eastern Europe. The research results under the EUROPROBE Programme. M.,GEOKART, GEOS, 736 pp, 2006.

Pérez-Estaún A., Brown, D., and Gee D.G. EUROPROBE's Uralides Project. Tectonophysics, 276 (1−4), 335 pp., 1977.

Puchkov V.N. Paleogeodynamics of the Southern and Middle Urals. Ufa, Dauria, 146 pp., 2000 (in Russian).

Puchkov, V. Paleozoic evolution of the East European continental margin involved into the Urals. Mountain Building in the Uralides: Pangea to the Present. AGU Geophys. Monogr. Ser. 132, 9–32, 2002.

Puchkov V.N. Plume and plate-tectonic mechanisms: mutual influence, interference, interaction and intertwining. Geophysical Research Letters, 5,14251, 2003.

Puchkov, V. N. On the age of the Uralian ophiolites. In: Ophiolites – geology, petrology, metallogeny and geodynamics. Ekaterinburg, IGG Ur B RAS, 121–129, 2006.

Puchkov V.N. The controversy over plumes: who is actually right? Geotectonics, 43, 1, 1-17, 2009a

Puchkov, V.N. The evolution of the Uralian orogeny**.** Geological Society, London, Special Publications, 327,161-195, 2009b.

Puchkov V.N. Geology of the Urals and Cis-Urals (actual problems of stratigraphy, tectonics, geodynamics and metallogeny). – Ufa: DesignPoligraphService, 280 pp., 2010. (In Russian). http://ig.ufaras.ru/File/PubTxt/books/Puchkov2010.pdf

Puchkov V.N. Dike swarms and related igneous complexes in the Urals. Geotectonics, 46, 1, 37-46, 2012.

Puchkov V.N. Plume events in the Urals //"RODINIA-2013: Supercontinental Cycles and Geodynamics". Moscow, MGU, 59, 2013a.

Puchkov V.N. Structural stages and evolution of the Urals. Mineralogy and Petrology, 107, 1, 3-37, 2013b.

Puchkov V., Plumes in the history of the Urals. Bull. of the Moscow Society of Nature Investigators, geological section, 4. 64−73, 2013c.

Puchkov V.N. General features relating to the occurrence of mineral deposits in the Urals: What, where, when and why. Ore Geology Reviews, 2016a, online. http://dx.doi.org/10.1016/j.oregeorev.2016.01.005

Puchkov V.N. Relationship between plume and plate tectonics. Geotectonics,2016, 50 (4): 425−438. (in press).

Puchkov V.N. and Svetlakova A.N. New data on tectonics of the western slope of the Southern Urals (based on reflection profile no. 4). Doklady Earth Sciences, 444, 2, 676-680, 2012.

Puchkov V.N, Kashubin S.N., and Pérez-Estaún A., eds. URALIDES Project: Structure and evolution of the Urals. In: Structure and dynamics of the lithosphere of the Eastern Europe. The research results under the EUROPROBE Programme. M.,GEOKART, GEOS, 345−490, 2006.

Puchkov V.N. and Danukalova G.A. The Late Pliocene and Pleistocene history of the Southern Urals region in the light of neotectonic data. Quaternary International, 201, 1-2, 4-12, 2009.

Puchkov V. N., Kozlov, V. I., and Krasnobaev, A. A., Paleozoic U-Pb SHRIMP- dates of magmatic rocks of Bashkirian meganticlinorium Geological Sbornik, Inst.Geol.RAS, 9, 36−43, 2011

Puchkov, V. N., Bogdanova, S. V., Ernst, R., , Kozlov V.I., Krasnobaev A.A., Soderlund, U., Wingate W.T.D., Postnikov A.V., and Sergeeva N.D. The ca. 1380 Ma Mashak Igneous Event of the Southern Urals. Lithos, 174, 109-124, 2013.

Puchkov, V. N. , Krasnobayev, A.A., and Sergeeva N.D. The New Data on Stratigraphy of the Riphean Stratotype in the Southern Urals, Russia. Journal of Geoscience and Environment Protection, 2, 108-116, 2014.

Puchkov V., Ernst R.E., Hamilton M.A., Söderlund U., and Sergeeva N. A Devonian >2000-km long dolerite swarm belt and associated basalts along the Urals-Novozemelian foldbelt: part of an East-European (Baltica) LIP tracing the Tuzo Superswell. GFF, 1, 6−16, 2016.

Reichow M.K., Saunders A.D., Pringle M.S., Al'Mukhamedov A.I. Medvedev A.Ya., Allen M.B., Andreichev V.L., Buslov M.M., Fedoseev G.S., Safonova I.Yu., Davies C.E., Fitton J.G., Inger S., Mitchell C., Puchkov V.N.,and Scott R.A. The timing and extent of the eruption of the Siberian

Traps large igneous province: Implications for the end-Permian environmental crisis // Earth and Planetary Sci. Letters,– Vol. 277, 1–2, 9–20, 2009b.

Ryazantsev, A.V. The Ordovician Complexes of the Western Part of the Magnitogorsk Megazone and Marginal Allochthons of the Southern Urals: Structure and Environments of Origin. Thes. of Candidate Dissertation Geological Institute RAS, Moscow, 32 pp., 2012. (in Russian).

Ronkin, Y.L., Sindern, S., Lepikhina, O.P., Isotopic geology of the most ancient formations of the Southern Urals. Lithosphere, 5, 50–76, 2012. (in Russian).

Rybalka A.V. Seismological model of the Earth's crust of the Middle Urals (after materials of the Middle Urals transect) Thesis of Candidate of Science dissertation, Ekaterinburg, 24 pp., 2015.

Savelieva, G.N., Puchkov, V.N., and Spadea, P., Ophiolites of the Urals. The Structure and Dynamics of Lithosphere of Eastern Europe: The Results of Research under the EUROPROBE Program. Issue 2. M., GEOKART, GEOS, 421–436, 2006a. (in Russian).

Savelieva G.N., Shishkin M.A., and Larionov A.N. Tectono-magmatic events of the Late Vendian in the mantle complexes of the ophiolits of the Polar Urals; U-Pb dating of zircons of chromites. In: Ophiolites – geology, petrology, metallogeny and geodynamics. Ekaterinburg, IGG Ur B RAS, 160–164, 2006b.

Sergeeva N.D., Puchkov V.N., Krasnobayev, A.A., and Ratov A.A. Limitotype of a stratigraphic boundary of the Lower Riphean in the Southern Urals. Geol. Sbornik, Inst.Geol.RAS, 11, 64-70, 2013.

Sindern, C., Ronkin, Yu. L., and Hetzel, R. Taratash and Aleksandrovka Metamorphic Complexes (Southern (Urals): T-t Restrictions. Inst. of Geology and Geochemistry, Uralian Branch of RAS. "Yezhegodnik-2005", 322-330, 2006 (In Russian)

Southern Urals. Deep water successions of the Carboniferous and Permian. A Field Guidebook of XVIII International Congress on Carboniferous and Permian. Pre-Congress A3 Trip, August, 6-10, 2015 / V.V. Chernykh, B.I. Chuvashov, V.I. Davydov, C.M. Henderson, S.Shen, M.D. Schmitz, G.M. Sungatullina, R.Kh. Sungatullin, J.E. Barrick, and O.P. Shilovsky – Kazan:Academy of Sciences of the Republic of Tatarstan Press, 88 pp., 2015.

Svetlakova A.N., Gorozhanina E.N., Puchkov V.N., Gorozhanin V.M., Karnaukhov S.M., Poberezhsky S.M., and Gorelikov V.I. The Perovsk-Kornilovka swell: a previously unknown large structural unit of the Orenburg cisural region. Doklady Earth Sciences, 412 (1), 49-52, 2007.

Svetlakova A.N. Gorozhanina E.N., Gorozhanin V.M., Razuvaev V.I., Puchkov V.N., Dnistryansky V.I., Gorelikov V.I., and Poberezhsky S.M. New data on the structure of the southern part of the cis-uralian foredeep according to results of seismic work. Doklady Earth Sciences, 423, (2), 1352-1356, 2008.

Svyazhina, I.A., Puchkov, V.N., Ivanov, K.S., and Petrov, G.A., Paleomagnetism of the Ordovician of the Urals. Uralian Branch of Russian Academy, Ekaterinburg ,136 pp., 2003 (in Russian).

The Geological Time Scale 2012, vol.1. Gradstein, F.M., et al., Eds., Elsevier, 1144pp., 2012.

Valizer P. M., Krasnobaev A. A., Rusin A. I. UltrahighPressure (UHP) Associations in Ultramafites of the Maksutov Complex (Southern Urals). Doklady Earth Sciences, 441, 2, 1645–1648, 2011.

Valizer P. M., Krasnobaev A. A., and Rusin A. I. UHPM Eclogite of the Maksyutov Complex (Southern Urals). Doklady Earth Sciences, Vol. 461, 1, 291–296, 2015.

Yang, J.S., Zhang, X.X., Xu, X.Z., Zhang, Z.M., Huang, Z., Robinson, P.T., Dilek, Y., and Griffin,W.L.,Diamonds and highly reduced minerals in ophiolitic mantle rocks and chromitites. 12th International Platinum Symposium. Abstracts. Institute of Geology and Geochemistry UB RAS, Yekaterinburg, 328–329, 2014.

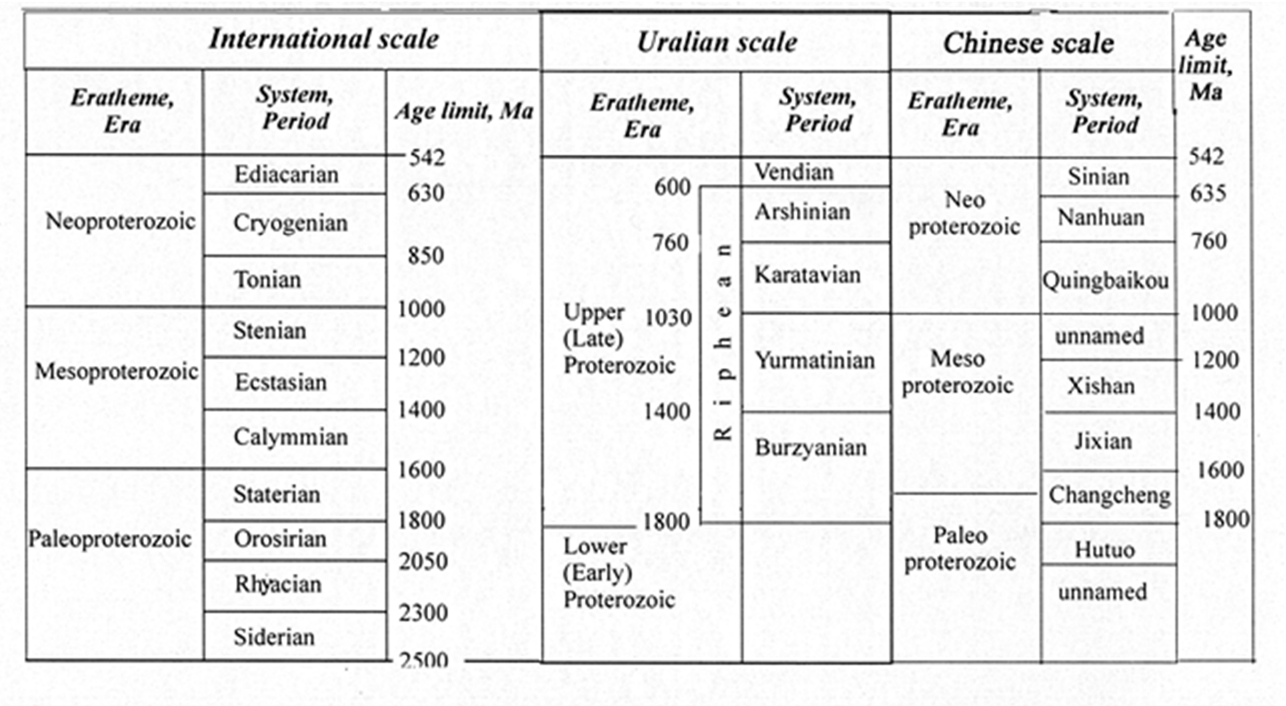
Youbi N., Kouyaté_D., Söderlund U., Ernst R.E., Soulamani A., Hafid A., IkenneM., El Bahat A., Bertrand E., Chaham K.R., Ben Abbou M., Mortaji A.,Tl Ghorfi M., Zouhair M., and El Janati M. The 1750 Ma Magmatic Event of the West African Craton (Anti-Atlas, Morocco). Precambrian Research, 238, 106−123, 2013.

Znamenskii S.E., Svetlakova A.N., and Puchkov V.N. The structural peculiarities of the Dzhetygara-Troitsk zone, Southern Urals (based on the URSEIS-95 profile) Doklady Earth Sci., 448, 1, 31-33, 2013.

Zonenshain L.P., Kuzmin M.I., and Natapov L.M. Geology of the USSR, a plate tectonic synthesis. – American Geophysical Union, Geodynamic Series, 21, 242 pp., 1990.

Table 1

Correlation between the International Stratigraphic Scheme of the Proterozoic of the World (The Geological…,2012), Regional Stratigraphic scheme of the Upper Proterozoic of the Urals (Puchkov et al., 2014) and Geological Time Scale of Proterozoic in China (Gao Linzhi et al., 2012).



International scale			Uralian scale				Chinese scale		Age limit, Ma
Eratheme, Era	**System, Period**	**Age limit, Ma**	**Eratheme, Era**			**System, Period**	**Eratheme, Era**	**System, Period**	
		542							542
Neoproterozoic	Ediacarian		Upper (Late) Proterozoic			Vendian	Neo proterozoic	Sinian	
		630		600					635
	Cryogenian				Riphean	Arshinian		Nanhuan	
		850		760					760
	Tonian					Karatavian		Quingbaikou	
		1000		1030					1000
Mesoproterozoic	Stenian					Yurmatinian	Meso proterozoic	unnamed	
		1200							1200
	Ecstasian							Xishan	
		1400		1400					1400
	Calymmian					Burzyanian		Jixian	
		1600							1600
Paleoproterozoic	Staterian							Changcheng	
		1800		1800					1800
	Orosirian		Lower (Early) Proterozoic				Paleo proterozoic	Hutuo	
		2050							
	Rhyacian							unnamed	
		2300							
	Siderian								
		2500							