Magmatic complexes of the Urals as suspect parts of Large Igneous Provinces

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Abstract. 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 Urals permit to put forward a preliminary list of objects – “candidates” at being attributed to Large Igneous Provinces (LIPs) – manifestations of superplume activity. Their petro-geochemical properties distinguish them from spreading and subduction types, and are closer to epicontinental rift zones. They are characterized by wide areas of development and very short periods of activity. In the Southern Urals near the base of the Lower Riphean (Uppermost Paleoproterozoic and Lower Mesoproterozoic) there are volcanic deposits of the Navysh Subformation, represented by trachybasalts. The age of the unit was determined as 1752 ± 11 Ma. Volcanic rocks of the age level of 1750−1780 Ma are developed not only in some other places of Baltica, but also in the Northern Africa, Siberia, Laurentia (parts of Nuna supercontinent). 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 basalt-rhyolite Mashak Formation were dated as 1380−1385 Ma. The same ages have also rapakivi granites, layered gabbro, carbonatites and dolerite dykes developed in the Southern Urals and encountered in boreholes of the East European platform; magmatic rocks of the same age are traced to Laurentia and Siberian cratons and date the beginning of Nuna supercontinent break-up. Less confidently we may speak of the younger Neoproterozoic magmatic complexes of the Southern Urals as LIPs, dated as ca. 720 Ma and 680 Ma (Arshinian and Kiryabinka complexes); they need a further study. The next in the succession of magmatic episodes, represented by subalkaline volcanics, is connected with a rift process that started at ca. 490 Ma, that led to oceanic spreading and formation of the Paleouralian ocean. The second Paleozoic episode was marked by an eruption of trachytes and carbonatites and is dated between 435 and 455 Ma. The younger complex is Devonian in age and is traced along the western slope of the Urals to Pay−Khoy and Novaya Zemlya. They belong to the LIP called Kola−Dnieper. The last but not the least are the Lower Triassic flood basalts and dykes traced from the easternmost parts of the Southern and Middle Urals to the western margin of the Polar Urals.

1. Introduction

The analysis of plume activity in history of ancient orogenic belts encounters some specific difficulties. The ancient plumes have cooled a long time ago, and therefore it is impossible to apply seismotomographic methods to unravel them. The magmatic complexes, the main manifestations of plumes, are partly eroded and partly concealed under younger sediments; very often they are subjected to strong deformations. Such classical features of individual plumes as time-progressive volcanic
Chains are as a rule not revealed in orogens. Although the bulk of magmatic rocks of plumes is represented by flood basalts and dolerite dykes, plume magmatism is variable and may include trachybasalts, picrite-basalts, rapakivi granites, layered mafic-ultramafic intrusions and also alkaline, carbonatite and kimberlite magmatic complexes [1]. Fortunately, enough the petro-geochemical properties of plume complexes distinguish them from spreading and subduction types, while many epicontinental rifts, accompanied by specific volcanism, may indicate plume activity. In case of large-scale plume events called superplumes they occupy wide areas called LIPs (Large Igneous Provinces) and are characterized by very short periods of activity. These features help to reveal ancient plumes even in foldbelts.

2. Problems of plume identification in the Urals

Very important innovation that appeared in [2] and some more recent publications of this author was a theme of probable plume events in the Urals, a point that was not raised until the early years of the new century. During the last decade, a considerable progress was achieved in the study of petrogeochemistry of magmatic rocks of the western slope of the Urals, and their isotopic ages became more accurate owing to the application of modern methods and new instrumental base. In many cases, these data do not contradict the idea of their plume nature. Of course, the areas of their development (mostly some parts of the western slope of the Urals) are not so wide to attribute them to LIPs, but they can be correlated with simultaneous magmatic events in some other regions. LIPs and corresponding superplumes are characterized by short life times, and the maximum of their activity corresponds to 10−15 Ma [1, 3, 4]. In addition, the identified even-aged magmatic complexes can be placed on reconstructions of ancient supercontinents (Pangea, Rodinia, Nuna), demonstrating their relatively compact primary positions above hypothetical superswells.

3. Suspect plumes in the Urals

The most promising candidates to plumes are magmatic complexes of the western slope of the Urals and its northern prolongation – foldbelts of Pai-Khoy and Novaya Zemlya. Eight complexes can be established provisionally as material witnesses of plume and superplume episodes in the history of this part of the Urals.

3.1 Navysh episode

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 (Fig.1). The age of the unit was determined as 1752±11 Ma (SHRIMP, zircons) [5]. It is shown that volcanic rocks of the age range of 1750−1780 Ma are developed in some other places of Baltica, and also in the Northern Africa, Siberia, Laurentia, parts of the Nuna supercontinent at that time [3], [6]. Therefore, they may belong to a LIP.

3.2 Mashak episode

Higher up the section of the Riphean, at the Middle Riphean (Mid−Mesoproterozoic) base, rhyolites of the Mashak Formation were dated by SHRIMP and CA-IDTIMS U−Pb methods in three isotopic laboratories as 1380−1385 Ma. The same ages are also basalts, 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 of the Nuna supercontinent break-up [3], [7].
Figure 1. Riphean (Meso− and Neoproterozoic magmatic complexes probably of plume nature in the Central Uralian zone of the Southern and Middle Urals. In grey colour is shown a scheme of tectonic zonation of the Urals (after fig.11 in [2]): A− Preuralian foredeep, B – West Uralian folded zone, C− Central Uralian zone, D– Tagil-Magnitogorsk zone, E– East Uralian zone, F–Transuralian zone. The symbols under the scheme: 1−volcanics of the Navysh Formation of the Lower Riphean, ~1750 Ma, 2– Magmatic complexes of the Middle Riphean, 1380–1385Ma (Mashak level); 3 – magmatic complexes of the Igonino event (Terminal Riphean), 710–740 Ma, 4 – Magmatic complexes of the Kiryabinka event, 670–680 Ma (Terminal Riphean).

Figure 2. Paleozoic and Traissic magmatic complexes probably of plume nature in the Urals and Pai−Khoy. A scheme of tectonic zonation of the Urals is shown in grey (after [2], see Fig.1). Symbols under the scheme: 1. Kidryas complex: Early and Middle Ordovician volcanics of rift type, corresponding to passive continental margin of a volcanic type; 2 – Ushat complex: Ordovician−Silurian volcanics and carbonatites; 3– Devonian dykes and volcanics; 4 – areas of development of flood basalts and sampling points of isotope-dated volcanics in them.
3.3 Igonino episode
Recently, the stratigraphy of the upper part of the Riphean was reconsidered. A new straton, the Terminal (Uppermost) Riphean (RF₄) was established instead of the Arshinian Formation or rather Series, that used to be the Lower Vendian. The series was subdivided into four formations, mostly terrigenous in composition, but with a volcanic Igonino Formation, the second from the bottom. The study of zircons from this formation gave two peaks: 707.0±2.3 Ma and 732.1±1.7 Ma [8]. Comparable ages have nearby granite massifs Barangulovo and Mazara, layered gabbro-ultramafic Sarana intrusion in the Middle Urals, and also Misaelga ferrogabbrodiabase-picrite differentiated intrusions in the Taratash uplift (726 ± 13Ma, Rb-Sr method). In the 1-Kipchak borehole, on the East European platform, lava flows are dated as 730 Ma (R−Sr method). All these magmatic rocks may belong to a hypothetical LIP with a median age 720 Ma, developed on a fragment of breaking-up Rodinia supercontinent.

3.4 Kiryabinka episode
Somewhat younger is the Proterozoic Kiryabinka layered peridotite-pyroxenite-gabbro intrusion, situated at the North-Eastern margin of the Bashkirian meganticlinorium (680±3.4 Ma, zircons, U−Pb method) [9]. The even-aged magmatic rocks are found toward South from this point in the Bashkirian meganticlinorium (Krivaya Luka) and toward North, in the Middle Urals – Schegrovitsk trachybasalt, Zhuravlik wehlite-gabbro-granodiorite and Troitsk granitoid formations. In the East European platform, comparable ages belong to basites of the Onega graben. They may be the parts of a concealed LIP.

3.5 Kidryas episode
It is represented by subalkaline volcanics connected with a rift process that started at ca. 490 Ma, and led to oceanic spreading and formation of the Paleouralian ocean. This accompanied the formation of the Baltica passive margin [10] and can be attributed to a plume-connected volcanogenic type [11]. 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 [12]. As it is shown by paleomagnetic data (e.g. [13], [14]), 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, occurring above the same superswell.

3.6 Ushat episode
It 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, principal stage of development of the Vishnevogorsk plume-related carbonatite complex ([2], [15], [16], [17]).

3.7 Devonian magmatic series
Probably it consists of several episodes, and the Frasnian is the strongest one. The Middle–Upper Devonian dolerite and basalt complex 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 ([1], [18]). 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 demonstrate an influence of a single superswell called Tuzo ([18] and references therein).
3.8 Uralo−Siberian LIP and superplume

Last, but not least, are the Lower Triassic flood basalts, dolerite and rhyolite dikes traced from the easternmost parts of the Southern and Middle Urals to the western margin of the Polar Urals. It became evident that they belong to the Uralo-Siberian LIP, developed above the “African” superswell ([2], [19]).

4. Results and conclusions

The main result of the present research at this stage is a perspective of examination of the new idea of a considerable role of plume tectonics in geological processes of the Urals. The idea is certainly worth of a further study, and may be fruitful not only for a general theory of the Earth development, but also for the understanding of regularities in genesis and localization of mineral deposits [4].

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