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Evidence for the Voluminous Silicic Volcanic Activity in the Permian–Triassic West Siberia

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Abstract
Permian–Triassic rifts of the West Siberian basin compose one of the largest continental rift systems in the world. They are nearly coeval to the Siberian Traps Large Igneous Province and mark the final stage of the amalgamation of the Northern Eurasia. Presence of acidic volcanic rocks along the mafic lavas is a specific feature of the West Siberian region. However, at this moment, felsic volcanics of this area are poorly studied. Here we present the first representative data on petrography, geochemistry, and U–Pb ages for silicic volcanic rocks from the drill cores of the deep boreholes in the Frolov-Krasnoleninsky region (the central part of the West Siberian basin). The largest rift structure of

this area is Rogozhnikov-Nazym graben, composed of rhyolite-dacitic lavas. Lavas constitute the major part of the volcanic pile, while tuffs are subordinate (up to 15%). According to the seismic and well-logging data, the thickness of felsic volcanic rocks exceeds 0.7 km. Whole-rock chemistry of the silicic volcanic rocks of the Rogozhnikov-Nazym graben and other smaller rifts is very similar and corresponds to post-collisional extensional tectonic setting. Zircons from rhyolites and dacites yielded U–Pb (SHRIMP-II) ages ranging from 254 ± 2 to 248.2 ± 1.3 Ma (Late Permian–Early Triassic). Thus, volcanic activity in the Frolov-Krasnoleninsky region was nearly coeval to the main phase of the Siberian Traps emplacement in the Siberian platform.

Keywords West Siberian basin – Continental rifts – Permian–Triassic boundary – Silicic volcanic activity

1 Introduction

Permian–Triassic volcanic rocks are widespread in the West Siberian basin and compose the upper structural floor of the Pre-Jurassic tectonic units. These volcanics are products of a widescale rifting stage, which is considered to be linked with the emplacement of Siberian Traps Large Igneous Province (LIP) (Reichow et al., 2009). The most prominent differences of the Permian–Triassic rocks of West Siberia from the Traps of the Siberian platform are: (1) their confinement mainly to multiple rift structures and (2) a significant part of silicic rocks which hardly occur within the Siberian platform. Permian–Triassic volcanic rocks are poorly accessible for the direct observation in the West Siberian basin, because the Pre-Jurassic basement is overlain by the thick sedimentary cover and is cut only with a limited number of deep boreholes. Therefore, volume and area of distribution of silicic volcanics, their relationships with basalts, and duration of magmatic activity are still poorly constrained.

Within this work, we studied volcanic rocks from the drill core of wells in the Frolov-Krasnoleninsky region (the central part of the West Siberia). In this area, silicic volcanics compose the large Rogozhnikov-Nazym graben, which is located at the junction of the Krasnoleninsky uplift and Frolov depression, and are widespread in many small rift-like structures (Fig. 1).

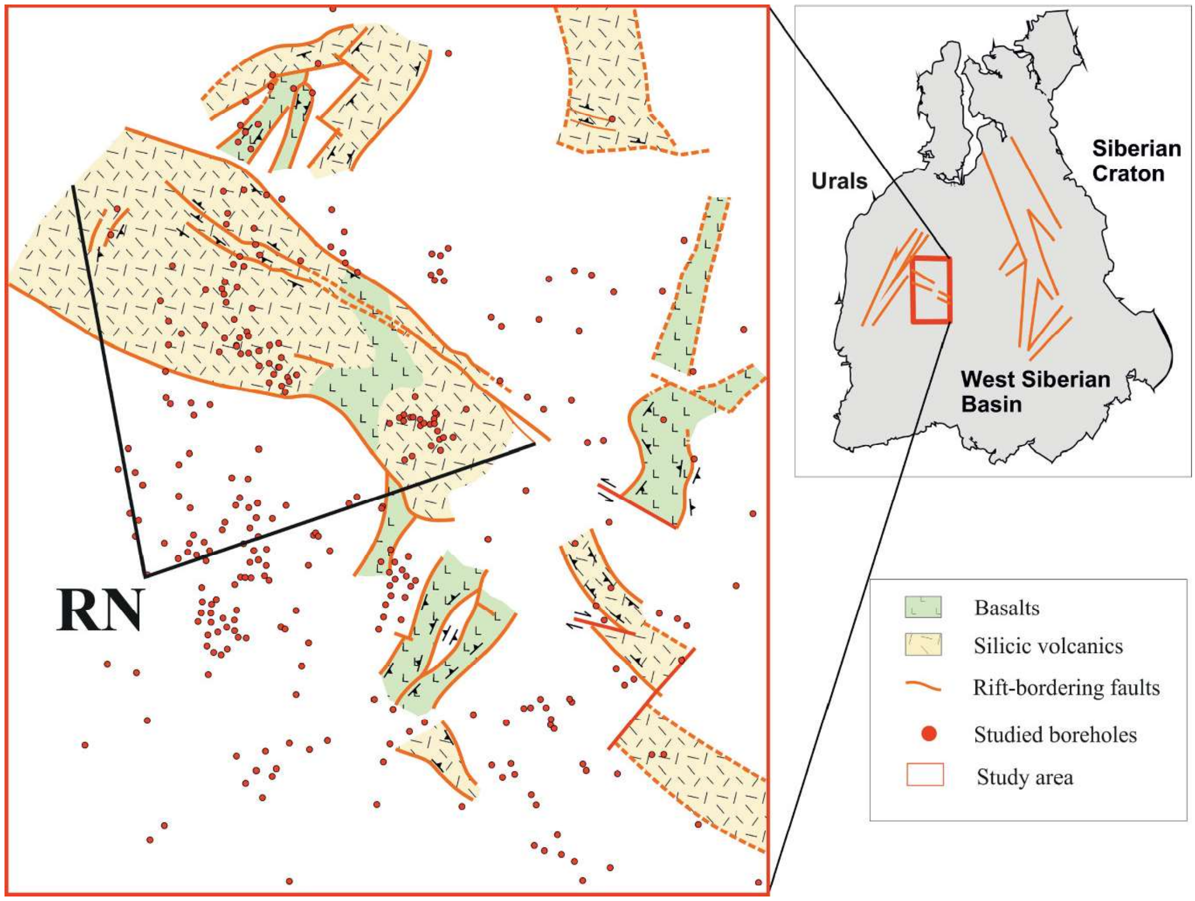

Fig. 1 Sketch map of the rift structures in the Permian–Triassic complex of the Frolov-Krasnoleninsky region. RN—Rogozhnikov-Nazym graben

2 Materials and Methods

Here we present the first results of the comprehensive investigation of Permian–Triassic silicic volcanic rocks of the West Siberia. We performed the macroscopic analysis of drill cores from more than 30 boreholes and petrographic investigation of about 400 thin sections, as well as interpretation of well-logging, geochemical, and U–Pb data. To analyze the spatial distribution of volcanic rocks we used 2D and 3D seismic data. The main 3D volume is about 900 km^2 and 4.5 km in depth. 2D seismic surveys are about 2000 km in summary length. Major and trace element concentrations in rocks were analyzed using

X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS), respectively. Analyses were performed at the Institute of Microelectronics Technology and High Purity Materials of Russian Academy of Sciences (ICP-MS) and at the Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry of Russian Academy of Sciences (XRF). U–Pb dating of zircons was performed on a sensitive high-resolution ion microprobe (SHRIMP-II) at the Center for Isotope Research (Karpinsky All-Russia Research Geological Institute, St. Petersburg). Zircon standard TEMORA [$^{206}Pb/^{238}U = 0.0668$ corresponding to 416.75 ± 0.24 Ma (Black et al., 2003)] was used to calibrate the U/Pb ratios, and zircon standard 91,500 (U = 81.2 ppm) was used for the calibration of U content.

3 Results

Acidic lavas and brecciated lavas (rhyolites, dacites, and rhyodacites) are predominant among the volcanic rocks of the Rogozhnikov-Nazym graben. Lavas usually have a porphyritic texture and contain phenocrysts of feldspars and occasionally quartz. Mafic phenocrysts are subordinate and represented by hornblende, rarely biotite or pyroxene. Lavas display massive, foliated, and perlitic structures. Felsic volcaniclastic rocks are rare and vary from ash tuffs to breccia with very diverse composition of clasts.

Other rift structures are composed of petrographically similar felsic volcanic rocks, mainly rhyolitic and dacitic lavas. In some boreholes we found porphyritic basalts and basaltic andesites, widespread in the Permian–Triassic rifts of West Siberian basin (Fig. 1). However, it should be noted that we did not find intercalated mafic and felsic volcanics in any studied borehole.

At seismic sections, Permian–Triassic volcanic rocks of the Rogozhnikov-Nazym graben correspond to gently dipping reflections, which form a series of calderas or a volcano-tectonic depression cut by steep faults. According to the seismic data, the total thickness of the volcanic pile exceeds 700 m. Felsic lavas form thick volcanic bodies, which can be traced at seismic profiles for 5–10 km. The thickness of individual bodies laterally varies from 70–80 to 10–20 m. We interpret these bodies as series of lava flows, marking the local eruptive centers.

Weathering crusts (10–25 m thick) are identified at the top of volcanic rocks and within thick lava piles. In some sections we found 3–5 weathering crusts within lava sequences. These levels may correspond to prolonged gaps between volcanic eruptions. Finally, volcaniclastic rocks form thin (5–25 m) horizons, traced across the entire studied area (> 10 km).

Geochemical peculiarities of volcanic rocks from the Rogozhnikov-Nazym graben and other studied areas of felsic volcanic activity are very uniform and close to each other. The most important features are: (1) predominance of acidic rocks (rhyolites, dacites, and trachydacites) mainly of high-potassium series (Fig. 2a); (2) negative anomaly in Ta-Nb, enrichment in Pb, possibly indicating the relics of supra-subduction tectonic setting (Fig. 2b); and (3) high enrichment in all incompatible elements. Based on these geochemical features, we suggest that this volcanic complex was emplaced in a post-collisional rifting geodynamic setting.

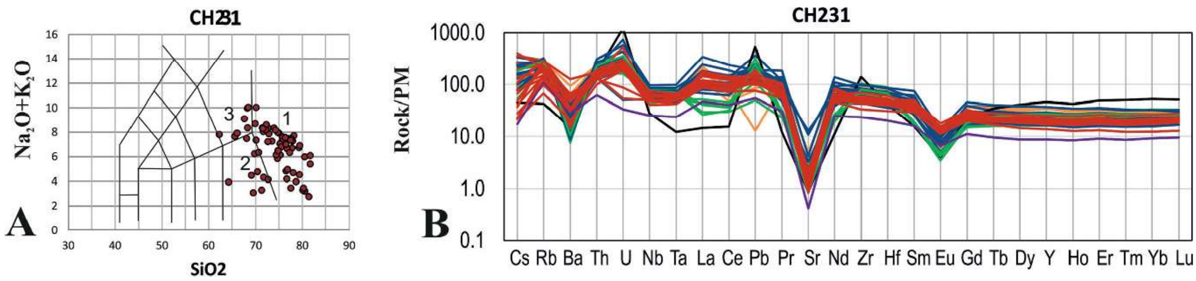

Fig. 2 Geochemical features of volcanic rocks. **a** TAS-diagram (Le Maitre, 2022) for volcanic rocks from one of the boreholes of the Rogozhnikov-Nazym graben; 1—Rhyolites, 2—Dacites, 3—Trachydacites. **b** PM-normalized [primitive mantle composition from Sun and McDonough (1989)] spectra of incompatible elements for the same borehole (different colors correspond to different depths in the borehole without dividing by rock types)

Nine zircon probes from rhyolites and dacites of the Rogozhnikov-Nazym graben and other structures yielded U–Pb ages ranging from 254 ± 2 to 248.2 ± 1.3 Ma, corresponding to the latest Permian–earliest Triassic (Fig. 3). The mean square weighted deviation varies from 0.045–0.13 to 3.2–5, and the probability of concordance is 0.025–0.83. Taking into account the error margins, we may assume that the total duration of felsic magmatic activity was not less than 2.5 M yr. However, it should be noted that the oldest and the youngest ages seem to be the least reliable due to the high MSWD and low probability of concordance.

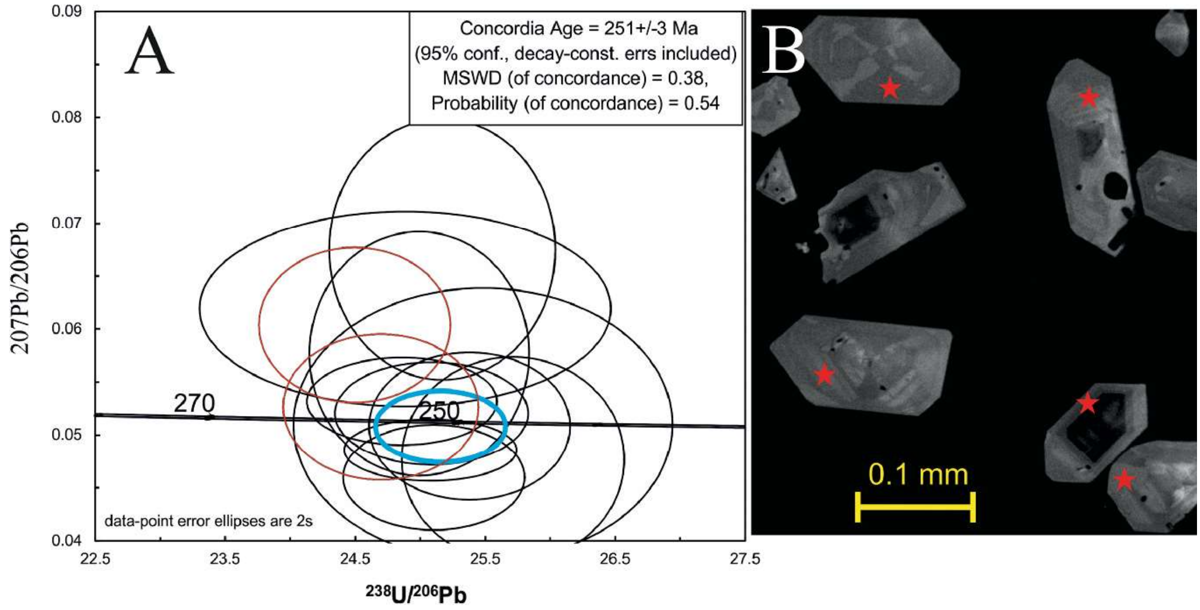

Fig. 3 Results of U–Pb dating. **a** Concordia diagrams for one of the probes. **b** Cathodo luminescence images of zircons from the same probe. Points of analysis are shown as stars

4 Discussion

Analysis of facies and thicknesses of volcanic rocks reveals multiple local eruptive centers, which are marked by thick lava piles. The size of individual volcanic edifices is 1–5 km, typical for the modern felsic volcanic provinces. Volcaniclastic rocks constitute up to 15% of the volcanic province. Such a low proportion of products of explosive eruptions is uncommon for supra-subduction tectonic setting (Rittman, 1962) and favors an extensional post-collisional setting.

Layers of epiclastic volcanogenic sedimentary deposits among lavas and tuffs are rare and thin (< 1 m). This indicates the high intense volcanic activity and poorly dissected relief during eruptions, probably due to fast filling of local topographic depressions by lava and pyroclastic flows. Similar paleogeographic conditions were reported for felsic volcanic centers of the Okhotsk-Chukotka volcanic belt (Tikhomirov, 2021).

5 Conclusions

Eruptions of felsic volcanic rocks of the Rogozhnikov-Nazym graben and other smaller rifts took place near the Permian–Triassic boundary. Geochemical and paleogeographic features indicate a tectonic setting consistent with post-collisional rifting, probably marking the final stage of the amalgamation of Northern Eurasia. The exclusively acidic composition of volcanic rocks makes the Rogozhnikov-Nazym graben and related structures similar to Silicic Large Igneous Provinces (Bryan & Ernst, 2008). The new age constraints show that silicic rocks of the West Siberia are nearly coeval to the Siberian Traps LIP.

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