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GEOLOGY

Structure and Nature of the Conjugation of the Urals and Western Siberia

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The Uralian Foldbelt is a natural western boundary of the West Siberian Petroliferous Megabasin. Lithotectonic zones making up the eastern sector of the Urals have a general NNE trend. They successively plunge beneath Mesozoic and Cenozoic sediments of the megabasin from south to north. The character of the boundary between the Urals and West Siberian Megabasin so far remains equivocal. The nature and localization of the eastern Uralian Foldbelt boundary always was the most difficult and debatable problem in the regional tectonics. The study of the boundary zone and geological complexes of the eastern Urals is crucial for the interpretation of the basement structure beneath the West Siberian Megabasin and history of its evolution [1].

In 2001–2003, we carried out comprehensive geological and geophysical investigations at the conjugation of western Siberia with the northern and Near-Polar Urals. A geological map at a scale of 1 : 500 000 has been compiled for the pre-Jurassic basement of the North Sos'va area (Fig. 1), and a large body of new information on the problem has been obtained. The studied area extends for 300 km along meridian and has a width of 110 km covering the Tagil Megasynclinorium filled with Paleozoic rocks, which are exposed in the extreme west of the territory. Deep drilling and aeromagnetic survey results, gravity anomalies in the Graaf–Hunter reduction presented at a scale of 1 : 200 000, and seismic data were used in compiling the map. Three large tectonic units and three structural stages, respectively, are recognized in the territory under study.

The Uralian Foldbelt, which underwent at least two phases of collision and folding, makes up the lower structural stage. The Tagil Megasynclinorium includes the following geological complexes [2, 3]: (1) Upper Ordovician tholeiitic basalts, (2) Upper Ordovician and lower Llandoverian sodic basalts and plagiorhyolites with massive sulfide deposits, (3) continuously differentiated (rhyolite–andesite–basalt) upper Llandoverian–lower Wenlockian island-arc complex (Pavda and Immenovka formations and their analogues), (4) upper Wenlockian–lower Ludlovian subalkaline basaltic andesites (Goroblagodat Formation and its analogues), (5) Upper Silurian–Lower Devonian basalt (trachybasalt–trachyte) complex, and (6) Lower–Middle Devonian subalkaline andesite–basalt complex. In general, volcanic rocks of the Tagil Megasynclinorium form a common series of the evolving island arc.

Based on geological and geophysical evidence the unexposed study area has been divided into two fields of presumably Lower Silurian andesites and basalts. Volcanic rocks and comagmatic diorite and granodiorite were penetrated by boreholes Vol'ya 271 and Sangitur 267, 268, and 269. The overlying basalt–trachyte formation likely fills volcanic depressions.

Complexes comparable to granitoids and gneisses of the East Uralian Uplift are recognized in the extreme

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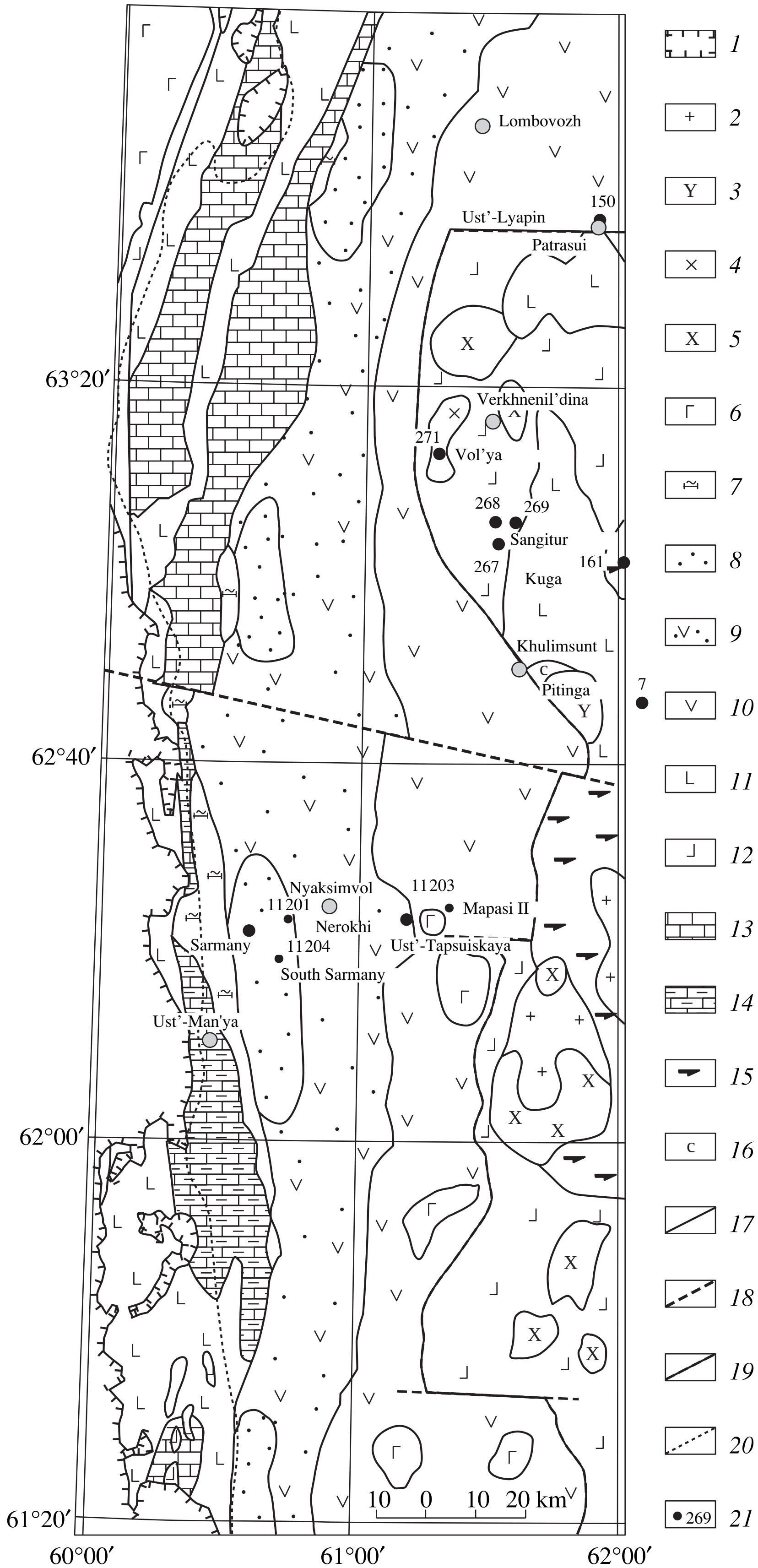
Fig. 1. Geological map of the pre-Jurassic basement of the North Sos'va district. Compiled by K.S. Ivanov, V.V. Kormil'tsev, and Yu.N. Fedorov using the geological and geophysical data of E.M. Anan'eva, V.S. Bochkarev, I.I. Vernik, I.D. Sobolev, and others. (*1*) Paleozoic basement exposed on the day surface; (*2*) Late Paleozoic granitoids; (*3*) Late Silurian–Early Devonian syenite; (*4*) granodiorite; (*5*) diorite; (*6*) gabbro; (*7*) serpentinite; (*8*) synclines filled with Upper Triassic terrigenous rocks; (*9*) Triassic basaltic–terrigenous formation; (*10*) Triassic basaltic formation; (*11*) Middle Paleozoic volcanosedimentary formations; (*12*) Lower Silurian basaltic–andesitic formation; (*13*) Upper Devonian limestone; (*14*) Tournaisian and Visean terrigenous and carbonate rocks; (*15*) gneisses and schists; (*16*) skarn; faults: (*17*) proved, (*18*) inferred; (*19*) other geological boundaries; (*20*) 100-m contour line of pre-Jurassic basement surface; (*21*) deep boreholes.


Lombovozh
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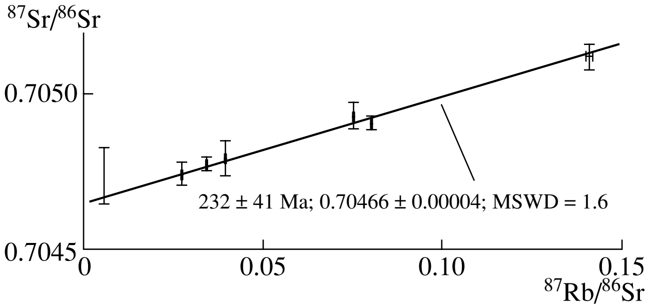

Fig. 2. The Rb–Sr isochron for basalts from the Borehole Nerokhi 11201.

east of the map on the basis of large regional negative gravity anomaly and extension of the Main granitic axis of the Urals. Local, nearly equant negative gravity anomalies are interpreted as Late Paleozoic granitic plutons surrounded by gneisses and schists.

The North Sos'va Graben, which extends for more than 400 km in the meridional direction and has a width of 20–60 km, is regarded as the middle structural stage and the main structural unit of the territory. This is a younger, Triassic extensional structure superimposed upon the Ural complexes. The graben is clearly expressed in gravity field as a region of lowered gravity force values. Tectonic graben boundaries are especially distinct and marked by extended linear serpentinite bodies at the western margin.

We divide rocks of the graben into three (lower basaltic, basaltic–terrigenous, and upper terrigenous) formations. The Upper Triassic age of the upper formation is established from the spore and pollen complex. The Middle Triassic age of the basaltic–terrigenous formation is supported by K–Ar, Rb–Sr, and Sm-Nd isotopic methods (see below). In general, the number and thickness of sedimentary members systematically increase upsection. They are largely composed of polymictic sandstones produced by the erosion of Triassic volcanics.

We studied new deep boreholes (down to 4.5 km). Boreholes Sarmany 1, Nerokhi 11201, and South Sarmany 11204 were drilled in a syncline with the greatest thickness of terrigenous and basaltic–terrigenous formations. Borehole Mapasi 11203 penetrated the lower basaltic formation. Borehole Ust'-Tapsui 4 was drilled in the lower part of the basaltic–terrigenous formation. These boreholes have important implications for providing insights into the geology of this vast region and adjacent territories. They considerably expand reliable data on the deep structure and evolution of the region.

The studied basaltic rocks are sufficiently fresh. They include plagioclase ($An_{59–65}$), augite (Fe index 0.29–0.33), magnetite, apatite, chlorite, and other minerals. Their geochemical signature (based on ICP-MS data) corresponds to intraplate tholeiites and allows subdivision into two types. Rocks of the first type from the basaltic–terrigenous formation are characterized by a steep REE pattern (La/YB = 8–9) and negative Sr, Hf, Th, U, Nb, and Ti anomalies. Rocks of the second type from the lower basaltic formation reveal a less evolved REE pattern (La/YB = 4–5), negative Hf and Nb anomalies, and positive Sr anomaly.

Basalts from boreholes Nerokhi 11201 and Ust'-Tapsui 4 yield typical Triassic values of isotopic age (208–250 Ma) with a marked scattering probably caused by Ar instability in groundmass of volcanic rocks. The average estimate for basalts from the Borehole Nerokhi 11201 (interval 2029–4145 m) is 229 ± 12 Ma and approximately corresponds to the upper Middle Triassic. The basalts reveal rejuvenation with increasing L.O.I. values that reflect the secondary alteration degree of rocks. Taking this trend into account, the average age of basalts from Borehole Ust'-Tapsui 4 may be accepted as 233 ± 12 Ma.

The obtained K–Ar datings have been verified by other precision methods. The Sm–Nd and Rb–Sr isochrons were constructed for basalts from the most representative Borehole Nerokhi 11201 (this has been done for the first time in the study of the West Siberian basement). The Rb, Sr, Sm, and Nd contents and their isotopic compositions were determined with isotopic dilution and measured on a Finnigan MAT-262 mass spectrometer. The samples studied demonstrate a narrow range of isotope ratios. Despite the uncertainties caused by the narrow range, both geochronometers yielded close age values of 234 and 232 Ma, respectively (Fig. 2). Hence, the volcanics penetrated by Borehole Nerokhi 11201 may confidently be dated as Middle Triassic.

The isotopic age is consistent with results of palynological investigations. The spore and pollen complex from the interval of 2018–2038 m in Borehole Nerokhi 11201 (base of the sandy–clayey formation overlying the basalts) is characterized by the predominance of rather diverse gymnosperm pollen: *Protohaploxypinus*, *Klausipollenites*, *Florinites*, *Tanaeaesporites*, and others. *Cycadopites* and *Ginkgocycadophytus* pollen are also abundant in polynological complexes. *Leiotriletes* spores are sparse. The content of *Dipteridaceae* and *Duplexisporites* does not exceed 5–6%. According to S.I. Purtova and N.K. Glushko, this complex is related to the Norian Stage of the Upper Triassic. Ladinian and Carnian (?) sediments are suggested from palynological data on Borehole Sarmany 1 and the lower portion of the Triassic terrigenous section (2588–2598 m). Terrigenous rocks from the interval of 2445–2459 m in Borehole South Sarmany 11204 are considered to be Norian and, probably, upper Carnian.

Thus, the terrigenous formation, which rests upon the Middle Triassic basic volcanics, varies in age from Ladinian to Norian. This testifies to the stratigraphic unconformity between the mainly Upper Triassic terrigenous rocks and underlying Middle Triassic volcanics. In addition to the stratigraphic unconformity, the angular unconformity is confidently established based on 2D CDP time sections (Fig. 3). The lower volcanic

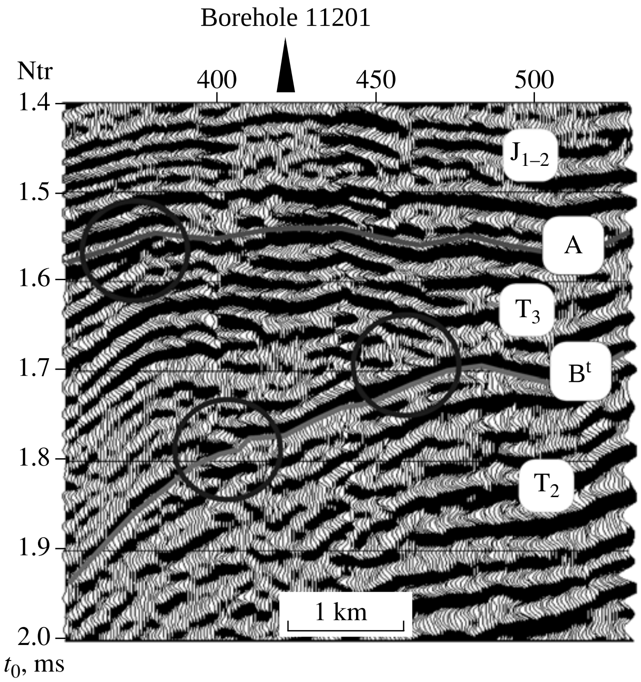

Fig. 3. The 2D CDP time section across the North Sos'va Graben (from W to E, a fragment of 2097140 profile of the Sarmany area). Reflecting horizons: (A) basement of Jurassic rocks, (B^t) basement of the Upper Triassic terrigenous formation. Overlap and onlap seismic events indicating angular and stratigraphic unconformities are shown in circles. (J_{1-2}, T_3, T_2) Rock age indices. Cone indicates location of Borehole Nerokhi 11201.

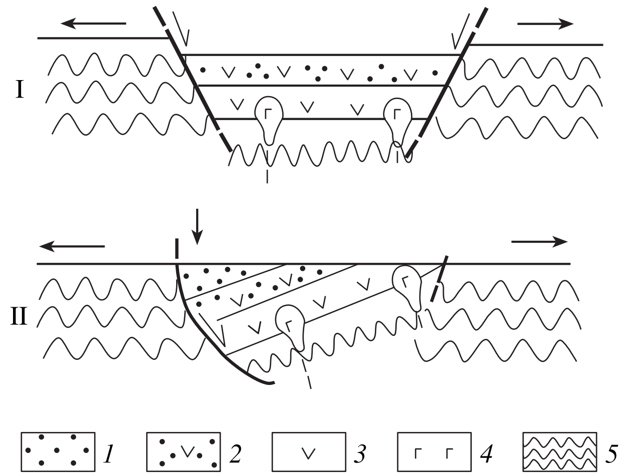

Fig. 4. Schematic model of the North Sos'va Graben evolution. (*1*) Upper Triassic terrigenous formation; (*2*) Middle Triassic basaltic–terrigenous formation; (*3*) Lower–Middle Triassic basaltic formation; (*4*) gabbro; (*5*) folded Paleozoic rocks. Stage I (Early–Middle Triassic): limited postcollision extension of the Urals; formation of a graben bounded by normal faults; deposition of basaltic and basaltic–terrigenous formations. Stage II (Late Triassic): formation of asymmetric half-graben; continuation of submeridional extension (its axis is located in the east); listric faulting along the western graben wall; rotation of a large crustal block along this fault and exposure of the lower beds filling the graben; subsidence of near-fault synclines filled with Upper Triassic terrigenous sediments in the western part of the graben.

formations are developed more extensively than the upper terrigenous formation. This is clearly seen on the time sections and geological map of the pre-Jurassic basement of the North Sos'va district. The Upper Triassic beds are overlapped by Bathonian and Callovian–Oxfordian rocks, suggesting a significant stratigraphic unconformity. An appreciable angular unconformity is recorded on time sections.

The North Sos'va Graben is generally asymmetric. The lower basaltic formation crops out as a ~10-km-wide zone on the pre-Jurassic surface in the east. The basaltic–terrigenous formation crops out to the west, and the uppermost Upper Triassic synclines are localized over its western part. The 2D CDP time sections clearly demonstrate that the upper portion of the Triassic section becomes older eastward and is unconformably overlain by Middle–Upper Jurassic sediments.

Thus, progressively lower beds of graben filling crop out on the pre-Jurassic surface eastward from the graben. Such a rotation of large crustal blocks as a result of their displacement and rotation along listric faults is typical of extension regions. In consistence with model sections based on drilling data, as well as density of sedimentary cover, Triassic and Paleozoic rocks, the geotectonic setting mentioned above indicates a listric character of the western boundary fault. Normal faulting and rotation along the boundary created the present-day structure. As follows from the graben asymmetry, the main regional extension axis should be located to the east of the area under consideration. Figure 4 shows a schematic of two-stage model of the North Sos'va Graben formation fitting the geological and geophysical data.

The scenario of the evolution of other, so far poorly studied Triassic half-grabens extensively developed in the West Siberian Megabasin is probably similar. It is evident that Triassic volcanism is a result of disperse rifting related to the nearly latitudinal extension of the Urals and West Siberian Megabasin.

The upper structural stage of this territory is composed of Jurassic and younger sediments of the West Siberian Megabasin reaching 1.5 km in thickness. The sediments are undeformed and persistent over a great distance. Therefore, based on the observed variations of gravity and magnetic fields, drilling data, and experience of mapping in the Urals we can accomplish mapping of the basement.

The performed investigations indicate that the boundary between the Uralian Foldbelt and West Siberian Petroliferous Megabasin extends along the normal fault that borders the North Sos'va Graben in the west. This boundary is not only spatial but also temporal: the Urals are older and serve as a basement of western Siberia. It is evident that the Triassic postcollisional geotectonic stage (sublatitudinal extension), which terminated the evolution of the Urals, and the formation of the West Siberian Megabasin are closely related to each other. A certain similarity in the structure and evolution of the two greatest geotectonic triads (North American Platform–Appalachians–Atlantic and Russian Platform–Urals–West Siberian Megabasin) is outlined.

In both cases, the foldbelt is formed as a result of collision with the eastern margin ancient craton and the subsequent postcollision extension gives rise to the formation of a vast young basin in the east.

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