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GEOLOGY

# Loz'va Dislocations of the North Transural Region: A Response to Neotectonic Underthrusting of the West Siberian Platform beneath the Urals

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Recent data point to the nonrigid behavior of lithospheric plates, the Eurasian plate included [1–6]. The plates have undergone different degrees of deformations and fragmentation into smaller plates (subplates, microplates, miniplates, and so on). These deformations are heterogeneous. The oceanic part of the composite plate is often detached from the continental part. Fragments of the continental crust (continents and microcontinents) behave frequently as more rigid deformation "tools" (indenters). The continental blocks also show features of heterogeneous behavior: the cratons appear to be more rigid, while young platforms are more frequently subjected to repeated superimposed deformations.

In this connection, intracontinental sutures, such as the neotectonic Urals located precisely at the center of the Eurasian lithospheric plate, are of particular interest. The well-known dislocations of Jurassic–Eocene sequences at the North Urals–West Siberian Plate boundary represented by a system of gentle linear meridional folds dipping toward the West Siberian Plate [7–9] provide information important for understanding the dynamics of this structure and factors responsible for its formation. In the south, dislocations start approximately at the latitude of Serov, where the recent Uralian orogen narrows in the northernly direction. However, they are best manifested in the northern Transural region, where the adjacent segment of the recent Urals has a very narrow and rectilinear shape. In the east, this segment is separated from the West Siberian Plain by an escarp. In the north, the dislocations are traceable up to the Polar Urals. This entire system of structures lacks a common name. In this paper, they are called Loz'va dislocations based on the Loz'va fault located in the middle part of the system.

In the south near Serov, the dislocations are represented by several large linear folds. The highest Serov Swell with the Paleozoic core towers for 500 m above the cover base (Fig. 1). The limbs of Cretaceous–Eocene anticlines dip at 10°–15°. A higher dip angle is typical of eastern limbs, and those facing the West Siberian Depression are steepest. No significant step is observed between Paleozoic and Cretaceous–Eocene fields in this area, and the western boundary of the dislocation zone is only outlined by the appearance of Cretaceous flat synclines within outcrops of Paleozoic rocks.

North of Krasnotur'insk, these folds dip steeply near the rectilinear NW-trending flexure. The width of the dislocation zone decreases drastically in this area from 20–30 km to several kilometers. At the same time, the eastern slope of the Urals composed of Paleozoic rocks becomes steeper and the dip of fold limbs increases to 20°–30°. Moreover, this area is distinguished from the Serov segment by the presence of the western vergence. The folds become narrower and are accompanied by numerous steep faults that are interpreted by mapping geologists as steep normal faults. North of the Marsyaty Settlement, the zone gradually becomes wider. The folds make up a northward-opening virgation, where the folds make up echelon arranged in accordance with the sinistral strike-slip fault. However, they are again truncated in the north by the diagonal NNW-trending flexure. According to geological survey data, the folds are replaced in the northern Ivdel–Loz'vinskaya Pristan–Polunochnoe segment by the tectonic contact of the North Ural Paleozoids with the narrow flexure-type Jurassic–Cenozoic band of the West Siberian Plate. This tectonic contact is defined as the Loz'va fault mentioned above. Its kinematics is unclear so far: it is interpreted either as a normal fault [7, 8], or a reverse fault, or even as an overthrust (G.V. Vakhrushev,

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1960). One can only see a steep (up to overturned) dip of Cretaceous–Paleocene beds at rare outcrops [7, 8].

In general, the stepwise (in plan view) pattern of the dislocation zone in this segment (i.e., its repeated sharp narrowing of obliquely oriented NW-trending flexures near the Urals and widening away from the flexures) and the echelon arrangement of folds in accordance with the sinistral shear strain suggest that the neotectonic structure is related to sublatitudinal compression in the form of sinistral shear transpression. Change in the vergence of folds at the transition to the opposite limb of the assumed strike-slip fault also becomes clear.

In the northernmost segment (north of the Burmantovo Settlement), the Loz'va dislocation zone widens again to form a diverging and northward dipping virgation, the cross section of which shows three to five folds [8] (Fig. 1, inset). Similar to the southern segment, the northern segment is composed of a Paleozoic top (Fig. 2). However, the amplitude of structures is lower (up to 200–300 m) here. All these features indicate gradual attenuation of dislocations in the northerly direction. Noteworthy is some northeastward deviation in the orientation of linear structures and opposite (westward) exposition of flexures and faults. According to [8], the regional structure includes horsts and grabens of the basement, while Jurassic–Paleogene beds of the cover make up box-shaped enveloping folds. Faults in the basement are subvertical, whereas the dip of adjacent beds increases to 20°–30° (nearly vertical in some places). Hence, the block tectonics in this area is hardly related to the sublatitudinal extension. This tectonic pattern is most likely related to vertical (keyboard) dislocations of blocks or even sublatitudinal compression. It is interesting that V.A. Lider mapped a system of diagonal NW-oriented faults interpreted as normal faults. However, their northern limbs are always displaced systematically to the northwest (Fig. 2). Such a uniform displacement (sometimes fold axes are also characterized by this displacement pattern) implies the development of strike-slip (sinistral in the given case) faults, which continue the structural patterns described for the southern part of the dislocation zone.

Thus, interpretations of geodynamics of the macrostructure of the Loz'va dislocations are rather ambiguous. On the one hand, some of its features, such as the linear configuration and echelon arrangement of folds, obliquely oriented faults with presumable strike-slip

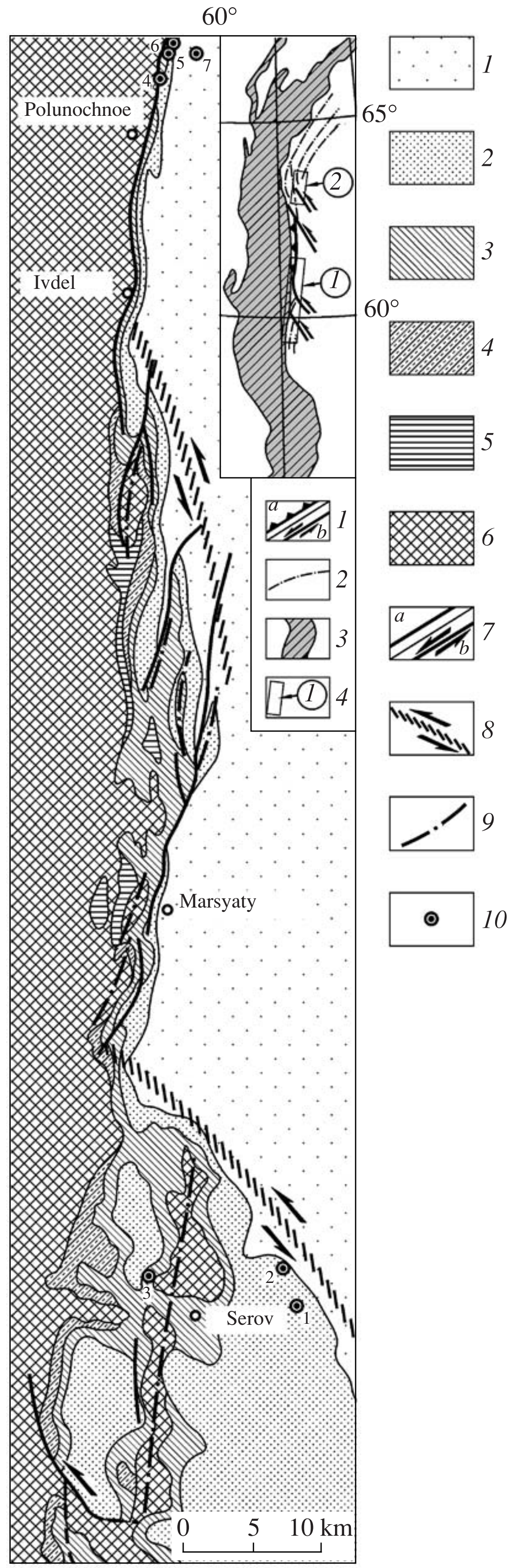


**Fig. 1.** Geological map of the southern Loz'va dislocation zone (based on materials of the State geological mapping at scale 1 : 200 000). Inset demonstrates schematic position of dislocations. (*1*) Upper Eocene–Quaternary (undivided); (*2*) Lower–Middle Eocene; (*3*) Paleocene; (*4*) Cretaceous; (*5*) Middle–Upper Jurassic; (*6*) Paleozoic; (*7*) faults: (*a*) with unclear kinematics, (*b*) assumed strike-slip faults (interpretation by Kopp); (*8*) wide flexures with presumed shear strain kinematics; (*9*) axes of anticlines; (*10*) observation points. Legend for the inset: (*1*) neotectonic faults: (*a*) reverse faults, (*b*) strike-slip faults; (*2*) strike of neotectonic folds; (*3*) contour of the Urals; (*4*) locations of Figs. 1 and 2.

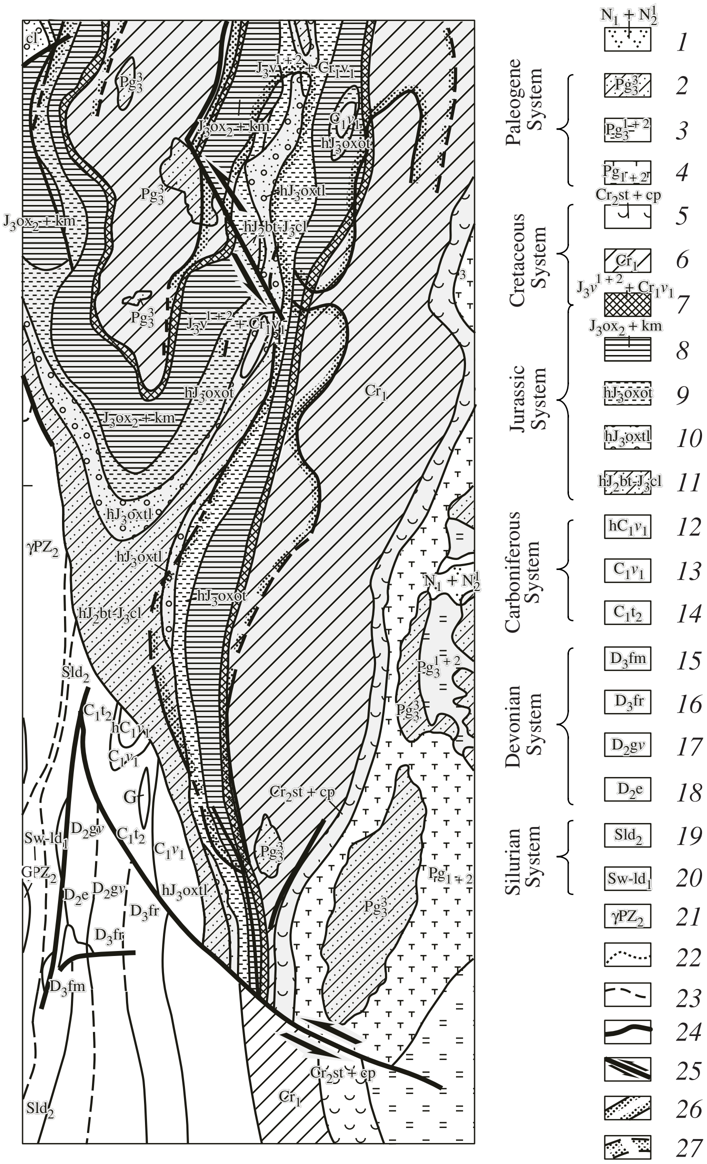


**Fig. 2.** Geological map of a sector of the Sos'va brown coal basin [8]. (*1*) Neogene; (*2*) Upper Oligocene; (*3*) Lower–Middle Oligocene; (*4*) Paleocene–Eocene; (*5*) Upper Cretaceous; (*6*) Lower Cretaceous; (*7–11*) Jurassic: (*7*) Tithonian and Volgian stages, (*8*) Oxfordian–Kimmeridgian, (*9*) Oxfordian (Otor'inskaya Formation), (*10*) Oxfordian (Tol'inskaya Formation, (*11*) Bathonian–Callovian; (*12–14*) Carboniferous: (*12*) Lower Visean (coaliferous formation), (*13*) Lower Visean (undivided), (*14*) Tournaisian; (*15–18*) Devonian: (*15*) Famennian, (*16*) Frasnian, (*17*) Givetian, (*18*) Eifelian; (*19, 20*) Silurian: (*19*) Ludlovian, (*20*) Wenlockian; (*21*) Middle Paleozoic granites; (*22*) geological boundaries; (*23*) the same (assumed); (*24*) faults; (*25*) the same, strike-slip faults (kinematic interpretation by Kopp); (*26*) contours of areas with commercial coal; (*27*) the same (assumed).

displacement, steep and even subvertical dips of beds, and uniform vergence of folds sustained at least within blocks separated by assumed strike-slip faults, may indicate that the macrostructure was developed with the participation of horizontal sublatitudinal compression oriented normally to the strike of the neotectonic Uralian orogen. One can assume the following scenario: north of Serov, a block of the West Siberian Depression moved along a system of sinistral strike-slip fault zones to northwest, where its displacement was compensated by stronger compression in the Loz'va regional fault (reverse or overthrust fault) zone. To the north, the displacement gradually attenuated and dispersed as virgation that was also associated with the sinistral strike-slip faulting. On the other hand, such an interpretation cannot explain the very gentle (a few degrees or even fractions of degree) dip of beds in most of the dislocation zone, which is inconsistent with the compression-related origin of the structure, insignificant amplitude of folds, and their association with faults in the basement. At the same time, the last feature rules out some factors, such as diapirism, glaciodislocations, and slumping,

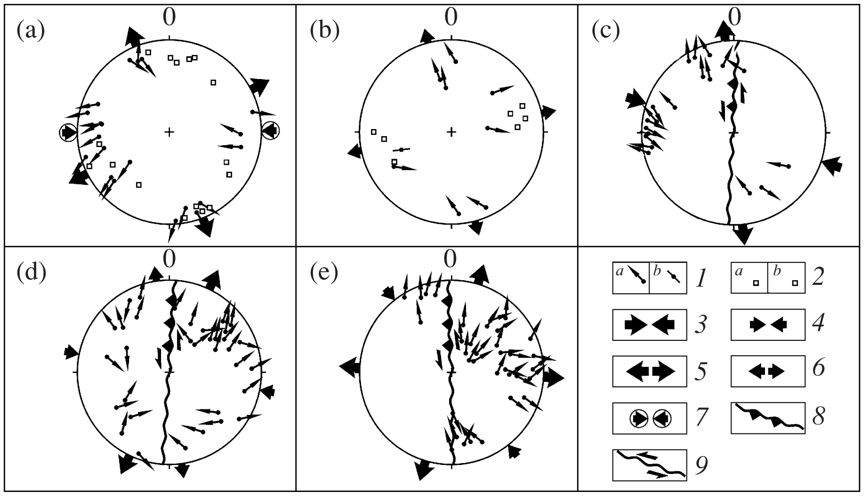


**Fig. 3.** Stereograms of fracturing. Observation points: (a) Abandoned Upper Cretaceous sand quarry southeast of the Rudnichnyi Settlement, (b) outcrops of Paleocene sands in the Mezhevoe Ravine, (c) Loz'vinskaya Pristan (Paleocene clays and sandstones), (d) Tyn'inskii manganese ore quarry, western excavation (Paleocene clays and sandstones), (e) the same, eastern excavation. (*1*, *2*) Poles of mesotectonic structures (Cretaceous–Paleocene rocks are shown by black shade; Quaternary sediments, by gray shade): (*1*) slickensides: (*a*) with slickenlines, (*b*) with slickenlines with unclear displacement direction (distinct fins are lacking), (*2*) breakaway and pull-apart faults: (*a*) breakaway without apparent filling, (*b*) veins; (*3*) direction of prevalent horizontal compression; (*4*) the same (secondary); (*5*) direction of prevalent horizontal extension; (*6*) the same (secondary); (*7*) horizontal projection of steep compression axes; (*8, 9*) orientation of the Loz'va regional fault (based on the relief) at the observation point derived from the relief (assumed sign of the fault displacement based on the character of mesotectonic deformations): (*8*) reverse fault, (*9*) sinistral strike-slip fault.

in processes of folding. Mobilization of the basement indicates participation of powerful deep-seated tectonic stresses in the formation of Loz'va dislocations.

We carried out measurements of slickensides and tectonic striation at all known (although rare) Cretaceous–Paleogene outcrops between Serov and the Burmantovo Settlement. These measurements yielded additional data on the dynamics of the structure formation. The ensembles of mesotectonic structures (Fig. 3) depend apparently on the morphology of macrostructures in the observation area.

In the south, where dislocations are represented by gentle folds, fracturing kinematics was studied in quarries and Cretaceous–Paleogene outcrops northwest and east of Serov (Figs. 3a, 3b, respectively). In this area, structural parageneses are consistent with low-angle dips of beds. They are largely represented by subvertical (and inclined) normal and oblique faults, as well as by tensile faults filled with carbonate cement of sandstones. These faults record elongation oriented along the meridional (350°–0°) and sublatitudinal (70°–95°) directions. Compression structures represented by steep submeridional reverse thrusts are registered only at the western observation point (Fig. 3a) near the neotectonic Uralian orogen. This feature implies some intensification of horizontal compression in this area. However, scarcity of exposures makes it difficult to check this interpretation.

We obtained more definite results for the northern (Ivdel–Polunochnoe) segment of the dislocation zone, where a system of subparallel folds is replaced by the narrow and steep Loz'va fault-line flexure morphologically manifested as a meridional neotectonic step of the western wall of the Loz'va River valley. Subvertical (up to overturned in some places) Paleocene beds are observed at the well-known outcrop of the Loz'va River bank at the northern end of the Loz'vinskaya Pristan site. According to our observations, this outcrop includes two or three small strongly compressed submeridional folds complicated by reverse faults. The cores and limbs of these folds are subjected to crushing and boudinage, respectively. The morphological features of such folds indicate their origin from lateral compression. This is also evident from the system of mesotectonic structures represented by two conjugate systems of submeridional (0°–10°) reverse faults with the sinistral shear strain component and a system of sublatitudinal (80°–90°) normal faults (Fig. 3c). Both systems form a distinct structural paragenesis that suggests WNW-oriented compression and associated NNE-oriented extension. Diagonal orientation of axes of contraction and elongation (relative to the Loz'va fault) indicates that the paragenesis has both reverse fault and sinistral strike-slip components. The observation point is located at 50–100 m from the Paleozoic–Cenozoic tectonic contact and is most representative in terms of deformations in the fault zone.

Paleocene Mn-bearing sandstones exposed at the Tyn'inskii quarry at a distance of several kilometers to the north are located 300–400 m away from the tectonic contact. At the western wall of the quarry (Fig. 3d), the beds show an eastern dip (20°–30°). Like at the previous observation point, the faults are mainly represented by inclined overthrust and reverse strike-slip faults (sinistral and dextral) associated with normal faults and sinistral oblique faults. All these mesotectonic faults are characterized by appreciable variation in the strike and are grouped into local systems, testifying to the superposition of different strain fields. At the same time, the western excavation (Fig. 3d) located closer to Paleozoic outcrops is dominated by WNW-oriented compression (like in the Loz'vinskaya Pristan area) and a similar NNE- to NE-oriented extension. In the eastern excavation (Fig. 3e), the shear stress is oriented in the northwestern direction, while the extension slightly deviates to the northeast. As a whole, measurements of slickensides in the Tyn'inskii quarry confirm the overthrust–sinistral strike-slip character of the Loz'va fault. The shear component increases in the western excavation located near the Loz'va fault. The sinistral shear strain component dominates in the remote eastern excavation.

Despite the fragmentary pattern of mesotectonic structures studied, the results indicate that at least the central segment of the dislocation zone (the Loz'va fault area) formed with a substantial contribution of subhorizontal stresses. In addition, their orientation (relative to the recent Urals, approximately transverse or slightly diagonal compression and longitudinal extension) corresponds to the orientation established for the Southern Urals [10]. This fact confirms the nonrandom character in the Loz'va dislocation zone. However, the Northern Urals is characterized by a more distinct diagonal (WNW) direction of tectonic contraction, which points to a recent sinistral shear strain along the Urals in the studied segment. In the Southern Urals, the shear strain component is also expressed, but the component commonly turns out to be dextral if the southernmost part of the Southern Urals is omitted. As in the Southern Urals, neotectonic deformations in the study region are characterized by irregular development in space: narrow zones with the development of reverse faults (for example, the Loz'va fault-line flexure) alternate with areas of shear strain and the extension regime. According to the available data, the shear strain component is most widespread and the gentle morphology of neotectonic linear folds is likely related to their shear strain nature.

Thus, elucidation of the genesis and tectonic setting of the Loz'va dislocations should be based on the fact that they are related to sublatitudinal compression and sinistral shear strain. The analysis of the available information on kinematics of lithospheric plates and blocks of the corresponding segment of Eurasia indicates the existence of conditions favorable for such a stress regime.

The region located southeast of the Urals is under the influence of the indenter represented by the Indian Plate. It was known long ago from works of Peive et al. [11] that alpine sinistral strike-slip faults extend far to the northern part of Central Asia. The immediate impact of activated blocks of the Peri-Indian collision zone (Central Kazakhstan and others) explains compression of Mugodzhary and the Southern Urals [10]. Further northward, neotectonic mobilization involved the sedimentary cover of the West Siberian Platform. Although these deformations are partly attributed to diapirism [12], they also include the basement in some areas. In addition, these deformations developed synchronously with folding in the southern collision region. In general, the activated neotectonic blocks of Central Asia and West Siberia, which are bounded by dextral strike-slip faults, migrated to northwest. However, closer to the western margin of the Peri-Indian collision area, the trajectory of their motion should progressively deviate westward to approach the latitudinal direction. Undoubtedly, such a transformation of the displacement vector was also promoted by the existence of the meridional eastern margin of the East European Platform, which served as a rigid stop for moving blocks of the Peri-Indian region.

One can also see signs of some autonomous southeastward displacement of the East European segment of Eurasia from the spreading axis in the Arctic between the dextral strike-slip fault (confined to the Tornquist line) in the southeast and sinistral strike-slip fault in the east (along the Urals) [2, 3]. The scale of this displacement was incomparable with that of movements of blocks in the Peri-Indian collision region. Moreover, the southeastward displacement was substantially older (terminal Eocene–Early Miocene). However, this displacement was oriented obliquely relative to the Urals and directed against the northwestward-moving blocks of Central Asia and Siberia. Therefore, at some stage (particulary, in the Oligocene–Early Miocene), the southeastward displacement could have served as an additional factor responsible for sublatitudinal compression accompanied by the sinistral shear strain. In any case, paleogeographic data indicate that the present-day Uralian orogen already served in the Oligocene as a stable provenance for the West Siberian and Turgai basins. Moreover, its eastern slope was already complicated by longitudinal ridges and river valleys at that time. Unfortunately, the upper age limit of post-Middle Eocene Loz'va dislocations is unknown thus far: some authors refer them to the Oligocene [8], while other researchers extend their age up to the Miocene [9]. We believe that these structures should also evolve in the terminal Miocene–Quaternary (by analogy with similar folds in the Turgai Trough).

We assume that the eastern vergence of structures in the Loz'va zone (as in the Turgai Trough and Southern Urals [10]) is related to regional heterogeneity of the deformed medium. The influence zone of Alpine stresses included a large meridional crustal gradient (margin of the East European Platform), where the thick buoyant crust contacted with the thin, heavy West Siberian crust that subsided continuously during the entire Mesozoic and Cenozoic. In such a situation, inclination of the deep thrust fault, which accommodated the deformation-related crustal thickening in the convergence zone, should only be oriented to the west. Geophysical arguments in favor of underthrusting of the West Siberian crust beneath the Urals are cited in [13, 14]: the existence of an abrupt subsidence of the asthenospheric top along the present-day eastern Urals [13] and a linear cold anomaly located approximately in the same area [14].

The synthesis of all the available paleogeographic and geomorphologic data suggests the following idea. The general free underthrusting of the West Siberian and Central Asian lithosphere beneath the East European Platform (and subsequently beneath the recent Urals), which was fostered by specific features of the deformed medium, has been in progress since the Oligocene. During this period, the underthrusting was accompanied by the growth of a steep east-facing geomorphologic escarp, which is preserved in the topography until present. However, lack of free space in the intraplate convergence zone provoked the thrust shear strain of the hanging wall and the formation of the retrothrust fault that was inclined in the eastern direction toward the main thrust zone. This is evident from the westward migration of the axis of the recent South Ural arch accompanied by the following processes: rapid growth of side ridges (megaanticlines) that are now even higher than the main watershed [10]; avalanche-type growth of the orogen during the terminal Pliocene–Quaternary [15]; and westward convexity of the South Ural and North Ural arcs, which were bordered by synthetic strike-slip faults and thrusted over the Uralian Foredeep and Russian Platform.

The westward overthrusting of the Urals commenced or at least accelerated in the terminal Miocene–Pliocene. This is most likely explained by the compression of the lithosphere beneath the East European Platform. This compression related to pressure of the Arabian indenter [3] was intensified precisely at that time due to collision-related closure of the Greater Caucasus marginal sea during the Sarmatian Age. The deficiency of free space should have hampered the influx from the east of material beneath the platform. Therefore, instead of the decelerated movement of the footwall of the deep thrust, the overthrust component of its hanging wall was activated. This process stimulated the anomalous growth of the neotectonic orogen and its compensatory thrust shear strain with the formation of overthrusts of western vergence (retrothrusts) and strike-slip faults. Both types of faults promoted the excess material accumulated in the convergence zone to be distributed over a larger area.

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