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Structural–Kinematic Parageneses of the Basement and Cover at the Southeastern Margin of the Baltic Shield

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Abstract—Through, long-lived structural–kinematic parageneses were established in the southeastern marginal part of the Baltic Shield on the basis of structural studies. These parageneses were formed and periodically rejuvenated from at least the Paleoproterozoic until the neotectonic stage of the evolution of this territory. A series of consecutive tectonic events related to the vertical and horizontal mobility of rocks of the crystalline basement and sedimentary cover had important implications for the formation of present-day structure of the southeastern margin of the Baltic Shield. These tectonic displacements developed for an extremely long time with retention of the main kinematic tendencies. At the end of the Paleoproterozoic, the volcanic and sedimentary rocks of the Vetreny Belt underwent tectonic stacking as a result of the countermotion of the crystalline masses of the Vodlozero Massif and the Belomorian–Lapland Belt. The clockwise rotation and lateral displacement of the Vodlozero Massif to the northeast provided the left-lateral transpression of the Vetreny Belt. Under these conditions, the Paleoproterozoic sequences experienced squeezing in the southeastern direction. This kinematic tendency was retained at the subsequent evolutional stages and eventually was recorded in the structure of the present-day boundary between the Baltic Shield and the Russian Platform.

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GENERAL STATEMENTS

The structural transformation of the basements of ancient and young platforms has attracted the attention of researchers for a long time [1, 6, 19]. As was shown in recent years, the continental crust of the intraplate regions has a high 3D mobility that gives rise to the formation of structural assemblies and parageneses of different ranks from the largest basins and uplifts, strike-slip zones and related depressions, and thrust and normal fault systems to various deformational meso- and mesostructural patterns that pervade the crystalline basement and platform cover. Until now, the study of these structural elements that are related to the plate stage of evolution commonly was limited by the statement of fact of their occurrence. In due time, it was a novelty, because shifted the traditional concept of passive intraplate tectonics [5, 7, 9, 11–13, 15, 24]. However, the factors and mechanisms of 3D intraplate tectonics remain a matter of debate. One of the most interesting problems concerns the mode of tectonic movements in the platform basement and the response of deposition and subsequent evolution of sedimentary cover to these movements. To settle this problem, its is necessary to augment the geological and structural database on the basis of new research methods, in particular, the technique of structural–kinematic analysis.

The southeastern margin of the Baltic Shield is attractive in this respect. Structural–kinematic studies were not performed here previously. The available geological–structural and cartographic information is controversial because of the poor exposure of this territory. However, precisely this region provides a good opportunity to reveal important features of the intraplate evolution of the East European Platform in the form of strikingly expressed through structural parageneses of the basement and cover. Southerly, in the areas overlapped by sedimentary cover of the Russian Plate, such investigations are hardly possible. However, the principles of analyzing basement structural features that penetrate into the cover and their remote sensing that was elaborated for the territory under consideration may be spread over the overlapped areas.

GEOLOGICAL OVERVIEW

The studied territory embraces the marginal parts of the Baltic (Fennoscandian) Shield and the Russian Plate: the two largest tectonic elements of the East European Craton (Fig. 1). Three structural stages are distinguished distinctly [3]. The lower stage is composed of Archean granite–greenstone and Paleoproterozoic volcanic–sedimentary complexes that underwent folding and metamorphism and form the crystalline basement of the platform. The middle stage comprises undeformed Riphean and Lower Vendian sediments that are retained in separate graben-like troughs, in particular, in the Onega Graben of the Belomorian Rift System, and are overlapped by platform sedimentary cover. Both structural stages crop out in

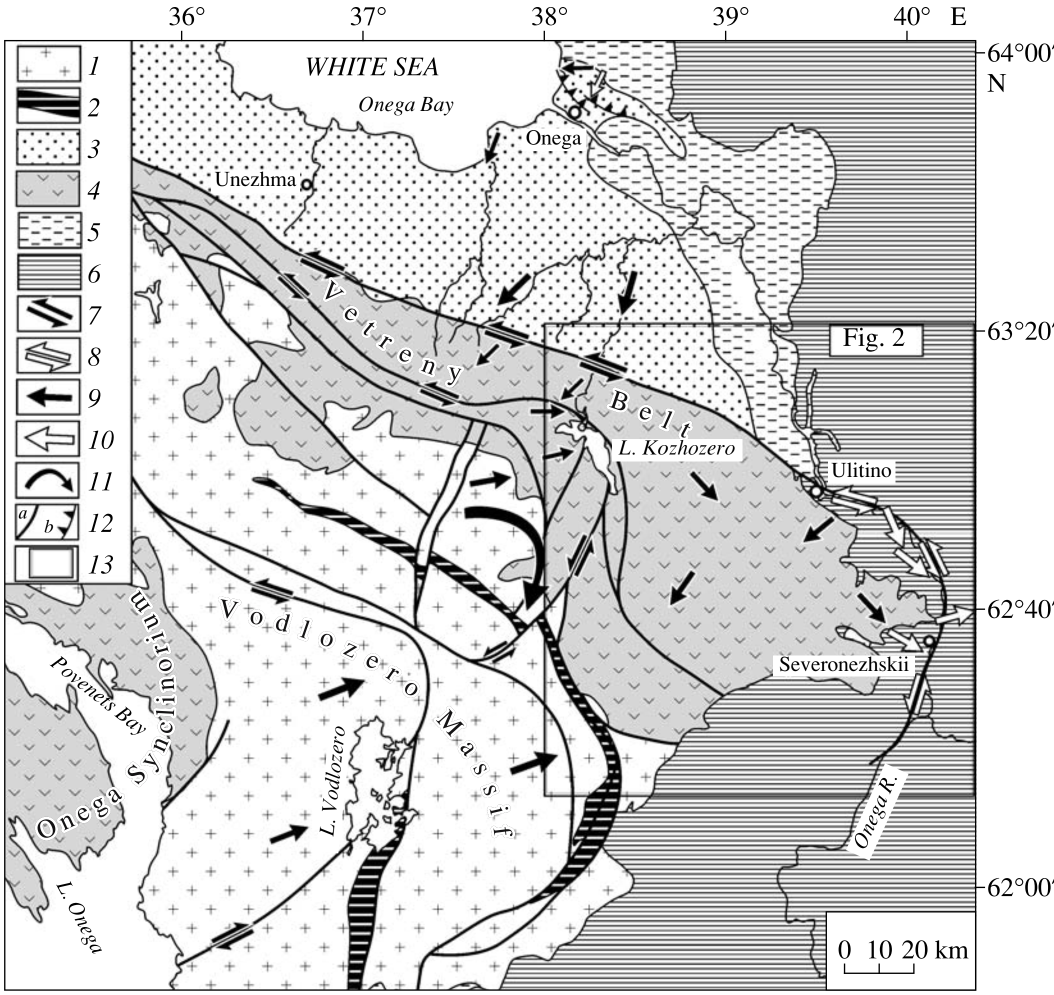

Fig. 1. Geological–structural scheme of the southeastern margin of the Baltic Shield. (*1, 2*) Archean rocks of the Vodlozero Massif: (*1*) gneissose granite, (*2*) greenstone complex; (*3*) Archean granite gneiss of the Belomorian–Lapland Belt; (*4*) Paleoproterozoic volcanic and sedimentary sequences; (*5, 6*) sedimentary complexes of the cover of the Russian Plate: (*5*) Upper Vendian and (*6*) Paleozoic; (*7, 8*) direction of strike-slip displacements in the (*7*) basement and (*8*) sedimentary cover; (*9, 10*) direction of near horizontal displacements in the (*9*) basement and (*10*) sedimentary cover; (*11*) inferred direction of rotation of the Vodlozero Massif; (*12a*) strike-slip and reverse–strike-slip faults and (*12b*) thrust faults; (*13*) area of detailed study shown in Fig. 2.

the Baltic Shield. The upper structural stage is the nearly horizontally lying Upper Vendian and Phanerozoic sedimentary rocks that make up the continuous cover of the Russian Plate.

The present-day boundary of the Baltic Shield corresponds to the outer contour of the sedimentary cover of the Russian Plate. The nature of this boundary is questionable. Most geologists agree that this boundary is erosional rather than tectonic. This view is based on the facies features and mode of occurrence of the Upper Vendian and Paleozoic rocks, which indicate that the sedimentary basins that existed during the deposition of the cover of the Russian Plate were much wider than the areas that are now occupied by the respective sediments and that overlap the southern portion of the Baltic Shield [3, 26]. However, this statement does not come into conflict with evidence for the occurrence of faults and bends in the basement and cover rocks along the present-day Baltic Shield boundary, which locally appears as a low-angle tectonic step [2]. In addition to these structural elements related to vertical displacements, the lateral juts of the crystalline basement that invaded the cover attract special interest. One of the largest juts is located in the middle reaches of the Onega River at the southeastern closure and at the location where the mountain ridge of the Vetreny Belt plunges beneath the cover of the Russian Plate (Fig. 1).

Let us consider the specific structural features of the lithotectonic complexes that occur at the southeastern margin of the Baltic Shield.

Lithotectonic complexes of the basement. In the southeastern part of the Baltic Shield, the crystalline basement is exposed in (1) the Vodlozero Massif of Archean granite–greenstone complexes (a part of the Karelian Craton) and (2) the Belomorian–Lapland Belt, located in the given territory and composed of

Neoarchean polymetamorphic gneisses and amphibolites of the Belomorian Group (Belomorides) [20, 22]. These domains are separated by the complexly built tectonic zone of the Vetreny Belt (the mountain ridge of the same name). The boundary zone is composed of Paleoproterozoic volcanic and sedimentary sequences (Fig. 1). The belt extends for more than 250 km and has a width of 10–50 km in the northwest and up to 80 km at its southeastern ending, where the belt is overlain by the Paleozoic cover. The Paleoproterozoic rocks of the Vetreny Belt comprise the systems of tectonic slices and sheets bounded by thrust faults and strike-slip fault zones. In many places, the tectonically juxtaposed sequences make up the monoclines that dip northward and northeastward at angles of 20°–60°. However, in the narrow tight segments of the belt, the systems of steeply dipping, often fan-shaped reverse and strike-slip faults are observed.

Until recently, the Vetreny Belt was regarded as a synclinorium with the northeastern wall cut off by a reverse–strike-slip fault [3, 4, 10, 22]. The monoclinal sequence of the Paleoproterozoic sequences observed in many sections of the belt are considered a common stratigraphic section typical of the Karelides. The following stratigraphic units (superunits) were recognized from the southwest to the northeast (from bottom to top): (1) Sumian terrigenous rocks and basaltic andesites, (2) Sariolian polymictic conglomerates, (3) Jatulian terrigenous–carbonate rocks and basic volcanics, (4) Ludicovian terrigenous rocks and carbonaceous slates, and (5) komatiites and basaltic komatiites of the Vetreny Belt Formation as the upper part of the Ludicovian Superunit [3, 10, 22, 25]. The U–Pb zircon age of basaltic andesite from the lower part of this section was estimated at 2437 ± 3 Ma [28]. The volcanic rocks of the Vetreny Belt Formation that occupy the uppermost structural position were dated at 2410 ± 34 and 2449 ± 35 Ma (Sm–Nd isochron for rocks and minerals) and at 2424 ± 178 Ma (Pb–Pb age of a whole rock sample) [3, 18, 21]. The geochronological data testify that the entire section considered above is markedly different from the commonly accepted sections of the Karelides and was likely formed in the Sumian over a very short time span of 10–20 Ma [28]. The structural data furnish evidence that the belt has an asymmetric, imbricate thrust structure and consists of tectonically juxtaposed rock complexes, probably close in age, that follow one another from the southwest to the northeast [21]. The Vetreny Belt Formation is the upper allochthonous sheet or a hanging wall of the synform overturned to the southwest.

According to the geological and geophysical data, the Belomorian gneisses are thrust over the Paleoproterozoic complexes of the Vetreny Belt along the deep (transcrustal) fault that plunges to the northeast [2–4, 21, 22]. However, in the present-day structure, these relationships are complicated by a younger steeply dipping zone of strike-slip dislocations that provided near-vertical foliation and lensing of rocks within a wide (hundreds of meters) tract and controls the general linear outlines of the northeastern boundary of the Vetreny Belt (Fig. 1).

The contour of the southern boundary of the exposed Paleoproterozoic rocks is more complex and broadly consistent with the occurrence of rocks gently dipping to the northeast. In the central and northeastern segments of the Vetreny Belt, its southeastern wall undergoes arcuate bending in plan view that corresponds to pinches of the belt and lateral pulling-out of granite–greenstone complexes of the Vodlozero Massif to the east and northeast (Fig. 1). The most striking system of arcuate structural elements originates at the arcuate bend of Povenets Bay of Lake Onega and is traced farther to the northeast as the bend of the northeastern wall of the Paleoproterozoic Povenets Synclinorium. The arcuate structural pattern is evident in the conformable orientation of gneissic banding and fault planes within the Vodlozero Massif and, finally, in horseshoe-shaped (in plan view) systems of faults in the central part of the Vetreny Belt, which undergoes (near Lake Kozhozero) appreciable pinching here.

The Povenets–Kozhozero system of arcuate structural elements has important implications for the regional kinematic evolution. The interpretation of satellite images allowed recognition of the Kozhozero ring structure in the northeastern portion of this system. The morphology of the ring structure suggests clockwise rotation of a large massif of Archean rocks [17]. To the east of this rotation structure, the width of the exposed Paleoproterozoic rocks increases several times and reaches 80 km (Fig. 1). The structure of this segment of the belt remains almost unexplored because of its poor exposure and difficulty in access. Basaltic komatiites of the Vetreny Belt Formation occur here as a large lateral jut of crystalline basement, which enters in the southeastern direction into the field of the Paleozoic sedimentary cover of the Russian Platform (Fig. 1).

Lithotectonic complexes of sedimentary cover. The sedimentary complexes of the cover of the Russian Plate are characterized in the study territory by a number of lithostratigraphic heterogeneities expressed in the specific features of the spatial distribution of sediments and their facies transitions, in the appearance of local breaks in sedimentation, and in the variable depth of denudation of the basement and cover. The most substantial variations in the cover structure are spatially related to structural barriers of various ranks. The aforementioned jut of the Baltic Shield at the extension of the ridge of the Vetreny Belt (termed below as a jut of the Vetreny Belt) is such a barrier. Precisely here, many stratigraphic units of the cover are missed and particular sequences experience deep denudation and facies transitions.

The Onega River valley smoothly turns round this basement inlier, while deeply incising the overlying Phanerozoic sedimentary rocks, which overlap the crystalline rocks of the basement with scouring and

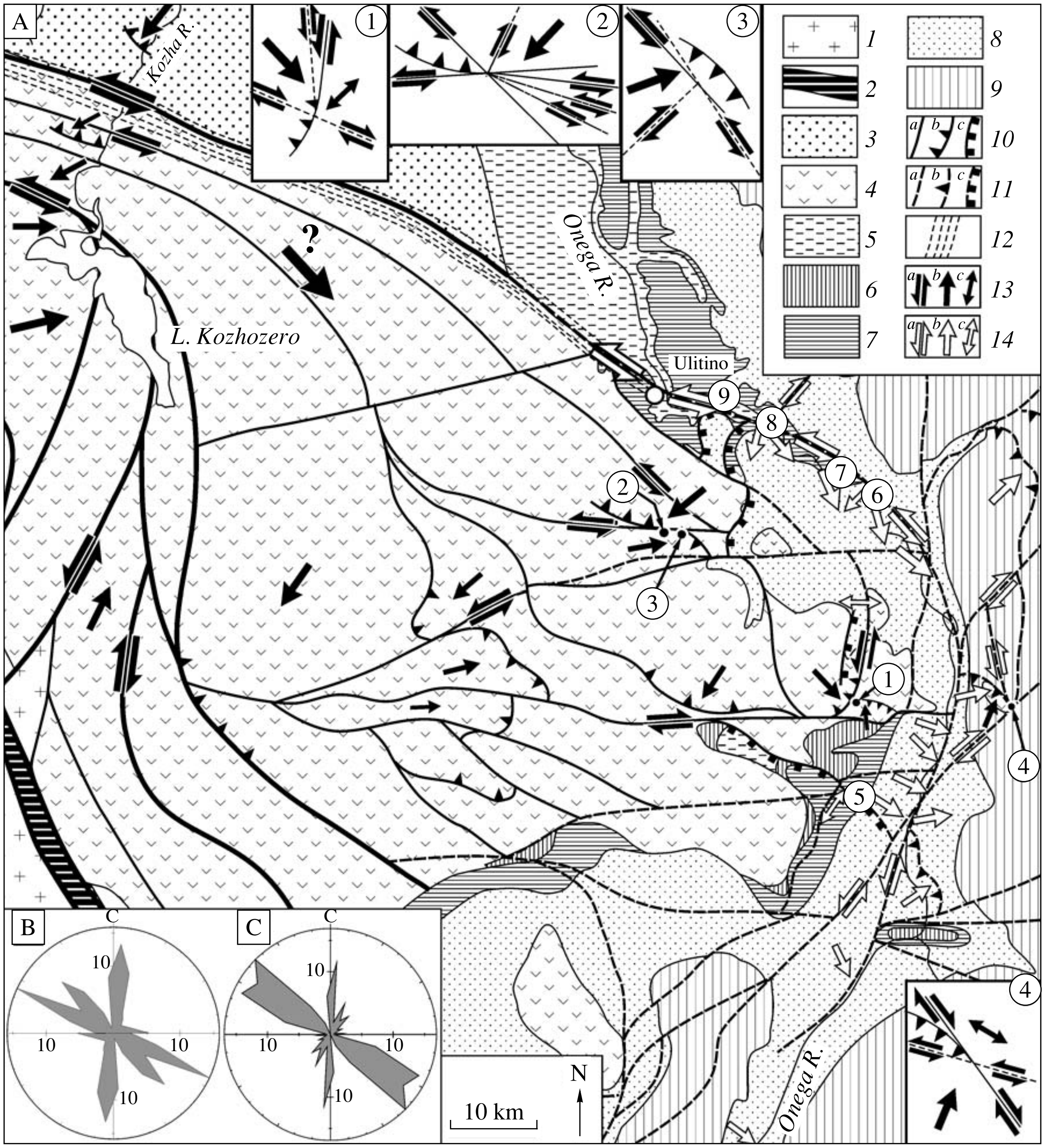

Fig. 2. (A) Geological–structural scheme of the southeastern ending of the Vetreny Belt and its framework, (B) rose diagram of the orientation of fractures and schistosity in basement rocks and (C) in sedimentary cover. (*1, 2*) Archean rocks of the Vodlozero Massif: (*1*) gneissose granite, (*2*) greenstone complex; (*3*) Archean granite gneiss of the Belomorian–Lapland Belt; (*4*) Paleoproterozoic volcanic and sedimentary sequences; (*5, 9*) sedimentary complexes of the cover of the Russian Plate: (*5*) Upper Vendian terrigenous rocks, (*6*) Upper Devonian sandshale rocks, (*7*) Lower Carboniferous carbonate–terrigenous, clayey, and bauxite-bearing rocks, (*8*) Middle Carboniferous terrigenous–carbonate and carbonate rocks, (*9*) Upper Carboniferous carbonate rocks; (*10*) faults: (*a*) reverse–strike-slip, (*b*) thrust, and (*c*) normal; (*11*) low-amplitude faults: (*a*) reverse–strike-slip, (*b*) thrust, and (*c*) normal; (*12*) foliation and fracture zones; (*13*) direction of (*a*) strike-slip and (*b*) near-horizontal displacements and (*c*) extension in basement rocks; (*14*) direction of (*a*) strike-slip and (*b*) near-horizontal displacements and (*c*) extension in sedimentary cover. Integral kinematic situations in key areas (numerals in panel A and in insets): 1, Mt. Myandukha; 2 and 3, the area located to the south of the settlement of Ulitino; 4, Bulatovsky open pit; 5, open pit at the Iksa bauxite deposit; 6, Malaya Golova Rapids of the Onega River; 7, the area near the village of Kirillovka; 8, the area 12 km east of Ulitino; 9, the area 7–8 km east of Ulitino.

sharp unconformity. These primary stratigraphic relationships are often complicated by faults that penetrated from the basement into the sedimentary cover (Fig. 2).

No specific information on the character of dislocations of the sedimentary cover of this region has been published until now. Only local disturbances of the general low-angle (fractions of degree) plunging of sedimentary rocks to the east–southeast with a gradual increase in their thickness were noted. Such structural features that complicate the cover are located immediately to the south of the studied territory and comprise the gentle Kil'ozero and Vozhe–Lacha swells and folds with dip angles of 5°–7° (the Andomsky dislocations) related to flexural folds in the Devonian rocks along the boundary with the basement [2, 3].

In the territory under consideration, the cover of the Russian Plate consists of the Vendian, Upper Devonian (Frasnian), and Carboniferous (Visean–Serpukhovian, Moscovian, Kasimovian, and Gzhelian) sedimentary rocks [3]. Virtually all stratigraphic units mentioned above are divided by unconformities, surfaces of scouring, and breaks in sedimentation; some of them bear a local character.

The Upper Vendian is composed of varicolored sandstone, mudstone, and siltstone and less frequent conglomerate with pebbles of the rocks belonging to the Vetreny Belt and Belomorian gneisses. Within this belt, the Vendian sediments are retained only in a small NW-trending graben-like basin (Fig. 2). The Frasnian sediments (sand, siltstone, and gray clay) are exposed locally and retained in small depressions of the basement surface in the central and southern portions of the crystalline jut.

The Lower Carboniferous sediments make up the continuous cover and overlie, with scouring, the basement, Vendian, and Devonian rocks. In the Vetreny Belt and on its slopes, the upper Visean and Serpukhovian units are known. The older unit largely consists of varicolored bauxite, kaolin clay, sand, and siltstone in addition to lenses and interlayers of marlstone, limestone, and dolomite. In these sediments, reaching 85 m in thickness, numerous growth faults, syngenetic fractures, and slump folds are observed in combination with epigenetic deformations (see below). These continental sediments of lacustrine and swamp facies make up ore-bearing zones that host the Iksa, Plesetsk, and Denislavsky bauxite deposits, localized at the extension of the buried basement of the Vetreny Belt. The bauxites are the products of weathering of the Paleoproterozoic basic rocks. The concentration of ore material was provided by tectonic zones permeable to the fluids that facilitated multifold redeposition and secondary enrichment of weathered rocks in local depressions and through graben-like sinks in the basement surface and the Upper Vendian and Devonian rocks [3]. The Lower Carboniferous section is crowned by a 15- to 20-m member of the Serpukhovian sandy dolomite replaced with brown spotty clay and siltstone on the northern slope of the jut of the Vetreny Belt.

The Moscovian sediments (85 m) transgressively overlie the Lower Carboniferous sediments or directly overlie the basement at the northwestern wall of the jut of the Vetreny Belt. Finely crystalline and cryptocrystalline, organogenic clastic, pseudoolitic, and foraminiferal limestones are predominant; dolomite and dolostones that replace limestone are noted as well. The number of clay and marlstone interbeds appreciably increases on the northern slope of the crystalline jut. The Middle Carboniferous rocks are distinguished by widespread pervasive brecciation, silification, and dolomitization.

The Upper Carboniferous rocks (the Kasimovian and Gzhelian stages) largely rest upon the Moscovian sediments and locally overlap with signs of deep scouring of the basement rocks. The discontinuous layer of basal conglomerate underlies the severely karstificated and dolomitized limestone and dolomite with interbeds of calcareous clay and dolomitic marlstone. In many cases, carbonate rocks are strongly foliated and mylonitized up to the appearance of ground limestone. The thickness of the Upper Carboniferous sediments reaches 130 m.

The structure of the sedimentary cover and the spatial distribution of the particular stratigraphic units therein indicate that the jut of the Baltic Shield that corresponds to the southeastern ending of the Vetreny Belt evolved over a long time, periodically invading the region of platform sedimentation as a rise. The uplifting led to the local scouring of sedimentary cover in some cases and to the long-term breaks in sedimentation and changes in facies settings in other cases. The high tectonic activity of this segment of the Baltic Shield margin led to the staged exogenic metasomatism during bauxite deposition in the Early Carboniferous, widespread brecciation and karst formation, and silification and dilomitization of the Middle and Upper Carboniferous sediments.

In addition, the manifestations of neotectonic activity related to vertical block displacements were reported [3, 16, 22]. The structure of the Onega River valley that rounds the jut of the Vetreny Belt in the east allows us to suggest a certain role of lateral displacements in the formation of the present-day boundary of the Baltic Shield. In this place, the meridional river turns round the jut and deeply cuts down the bedrocks, while mainly washing away the right bank probably owing to the active emergence of the ridge of the Vetreny Belt and its propagation in the southeastern direction, in other words, to the vertical and lateral displacements of basement rocks.

To characterize specific tectonic features of the study area in more detail, let us consider structural–kinematic parageneses of the crystalline basement and sedimentary cover within the jut of the Vetreny Belt and its framework.

STRUCTURAL–KINEMATIC PARAGENESES

The detailed structural investigations were performed in the basin of the Onega River; in the Vetreny Belt, along the coast of Onega Bay of the White Sea; at the headwaters of the Kozha River, close to Lake Kozhozero; and in the northwestern part of ridge of the

Vetreny Belt (Fig. 1). The investigations were based on structural–kinematic analysis; the mode of application of this method was considered in [8]. The most informative data that characterize specific features and relationships of the structural–kinematic parageneses of the basement and cover have been obtained for the southeastern ending of the ridge of the Vetreny Belt and in the area where this ridge plunges beneath the cover of the Russian Plate (Fig. 2A). In this territory, the structural–kinematic parageneses of each lithotectonic complex were correlated and then were combined into the following spatiotemporal groups: (i) syn- and postmetamorphic parageneses of the Paleoproterozoic rocks of the crystalline basement and (ii) synsedimentation–diagenetic and metagenetic deformational structures of the Vendian, Paleozoic, and Quaternary sediments. The description of the structural parageneses that were combined into the two main groups that correspond to the structural stages (basement and cover) is given below.

Structural–kinematic parageneses of the basement. In the territory under consideration, the rocks of the crystalline basement are largely composed of basaltic komatiites of the Vetreny Belt Formation. The gneissose granites and gneisses of the Belomorian Group occur in the northwestern part of the study area. In the jut of the Vetreny Belt, basaltic flows occupy a vast plateau, which at present comprises boggy woodland with sporadic rocks. The study of this difficult-to-access area began with interpretation of aerial photographs that allowed us to trace the master faults. The subsequent field study of key objects clarified the results of the interpretation. Finally, the geological–structural map was compiled for this territory; the insets to this map show integral kinematic situations for some key localities (Fig. 2).

In most cases, the lava flows lie gently and make up uniform and monotonous volcanic sequences. Pillow lavas are commonly observed at tops and bottoms of volcanic flows, while massive basaltic komatiites occur in the central portions of the flows. Lava breccias are no less abundant; silicites fill the spaces between pillows. The rocks underwent greenstone alteration (epidotization, transformation into spilites) and nonuniformly distributed metamorphism under conditions of the initial actinolite–chlorite subfacies of greenschist facies.

The advanced greenschist metamorphism developed along synmetamorphic faults accompanied by foliation that grades into characteristic tectonites: actinolite–chlorite schists; quartz–chlorite metasomatic rocks; and silicified, epidotized, and carbonated cataclasites and blastomylonites.

The structural elements pertaining to the brittle–ductile transition that were detected in the dislocation zones of dynamometamorphic tectonites of greenschist facies served as the basis for recognition of synmetamorphic structural–kinematic parageneses. According to the isotopic data, the Paleoproterozoic complexes of the Karelian Craton underwent Svecofennian metamorphism 1.9–1.8 Ga ago [22, 25]. The structure and composition of tectonites described in this paper form the entire basis for their correlation with Svecofennian deformation and metamorphism.

Synmetamorphic structural–kinematic parageneses. The thermodynamic conditions of the initial greenschist facies and the rheological properties of the relatively homogeneous and poorly layered volcanic sequence of the Vetreny Belt Formation predetermined the features of the Svecofennian deformational structural elements. No clearly expressed folds were observed in the studied territory. Its tectonic style is characterized by fault systems that frame lenticular massifs of various ranks that are composed of slightly deformed rocks (Fig. 2A).

Within vast fields, the deformation of basaltic komatiites is instable and adapted to the primary structure of rocks, being localized between pillows and along boundaries of lava flows. Silicites and siliceous segregations that fill the space between pillows are often foliated and reveal fluidal structures, which undergo squeezing-out and pumping from one cavity to another. In some cases, the fluidal structure emphasizes complex and partly chaotic displacements with elements of rotation of particular pillows in lavas (Fig. 3A). Thereby, the entire massif experiences deformation typical of the granulated medium. There are indications that such dislocations are of a tectonic character. Thin foliation zones in silicites often penetrate into marginal parts of lava pillows and balls and occasionally cut them off along flasers of schists.

With an increase in the intensity of deformation along spatially persistent fault zones, the primary structure of rocks loses its decisive role and undergoes gradual obliteration by through systems of foliation and lensing (Fig. 3B). The pillow lavas reveal a gradual transition from the deformation typical of a granulated medium to rocks with sigmoid and lenticular crushed pillows framed by partly linearized foliation zones and, further, to the completely foliated rocks that have lost their initial structure.

The zones of synmetamorphic faulting from a few meters to tens of meters wide are traced for many kilometers. They are made up of densely spaced gentle and steep faults of higher orders that form the lenticular–loop and rhomb-shaped block systems (Fig. 3C). The sutures of these faults either are narrow (1–5 cm) shear zones with blastomylonite flasers or are accompanied by foliation and fine lensing of rocks with formation of actinolite–chlorite dynamoschists. The foliation in fault zones is often oblique like mesoscopic C–S structures, which serve as good kinematic indicators (Fig. 3E). Similar structural elements observed at the microscopic level (1–3 mm) are recorded in the orientation of chlorite flakes and actinolite prisms. Shadowlike relict fragments of the deformed pillow parting retained in foliation zones commonly have a sigmoid shape, which is

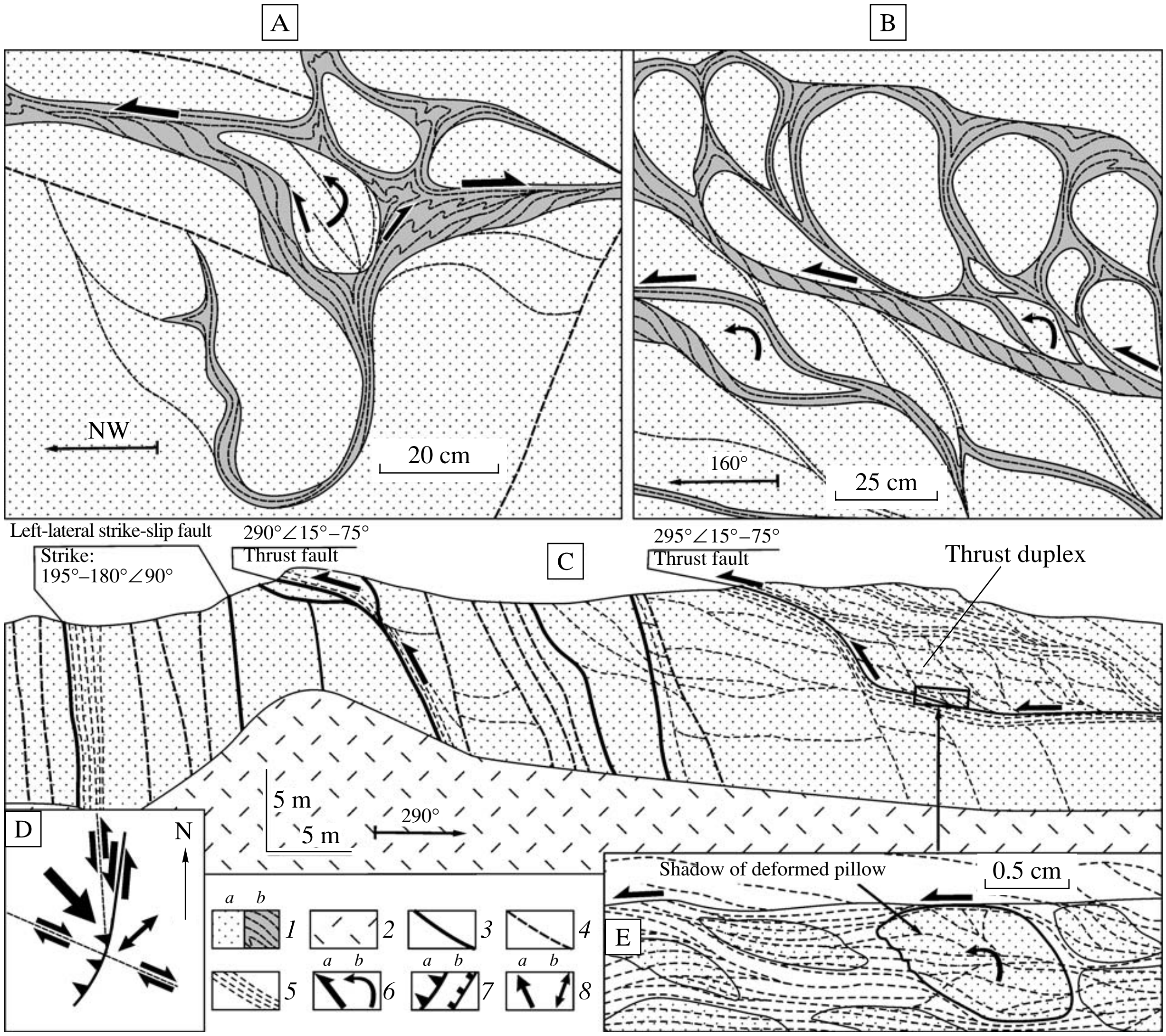

Fig. 3. Synmetamorphic structural parageneses in basaltic komatiite of the Vetreny Belt Formation (in section view). (A) Structural elements related to unstable deformations and chaotic displacements; (B) structural elements in the zone of foliation near the thrust fault; (C) section that illustrates the structure of the thrust–strike-slip fault zone near Mount Myandukha; (D) general kinematic situation near Mount Myandukha: a conceptual scheme (in plan view); (E) close-up that illustrates the structure of the foliation zone in basaltic komatiite. (*1*) Rocks: (*a*) basaltic komatiite and (*b*) foliated silicite of the Vetreny Belt Formation; (*2*) dump; (*3*) master and (*4*) auxiliary faults; (*5*) foliation and fracture zones; (*6*) direction of (*a*) displacement and (*b*) rotation. In panel D: (*7*) faults: (*a*) thrust and (*b*) normal faults; (*8*) direction of (*a*) near-horizontal displacement and (*b*) extension.

consistent with the character of displacement (Fig. 3E). In walls of high-order faults, basaltic komatiites are intensely fragmented into lenses and occasionally form systems of thrust and strike-slip duplexes (Fig. 3C).

The fault surfaces of high orders often are stepwise in section view. In some segments, they are gently dipping, having adjusted to the bedding-plane parting, whereas elsewhere they gradually become steep (Fig. 3C). As follows from the aforementioned kinematic indicators, in steep segments of stepwise faults, the displacements bear a reverse–strike-slip character, whereas in low-angle segments they correspond to thrust–strike-slip and thrust faults. The steep faults of higher orders with only strike-slip components of motion look somewhat alien in the section. Their relationships with stepwise structural elements are dual: In some cases, strike-slip faults cut off the stepwise faults, whereas in other cases they are cut by thrust faults (Fig. 3C). Thus, the strike-slip and thrust faults may be regarded either as results of different stages of deformation or as conjugate structural elements making up a common paragenesis (Fig. 3D). In our opinion, the latter variant is more probable, and in many cases, the specific features of faults indicate a common thrust–strike-slip character of displacements along the master faults. Thereby, it is assumed that, at the Svecofennian time, the tectonic displacements repeated as kinematic pulses of thrust, strike-slip, and combined thrust–strike-slip or reverse–strike-slip character. During analysis of the spatial distribution of strike-slip and thrust faults in particular areas, it is possible to reconstruct local kinematic situations and directions of relative tectonic displacements of rock massifs (Fig. 3D). Summarizing these data in the form of a geological structural map makes it is possible to estimate the common dynamic setting of strike-slip and thrust displacements over a vast territory.

The statistical analysis of orientations of fault planes of different ranks shows that the NW-, N–S-, and W–E-trending faults are predominant in the southeastern part of the Vetreny Belt (Fig. 2B). The tectonic displacements in this region bear a complex character, and the kinematic situations are widely variable. A relatively consistent kinematic style was indicated in the northwest of this territory in the upper reaches of the Kozha River, where the structural elements of the Vetreny Belt are pinched. The NW-trending left-lateral strike-slip faults sharply dominate here along with thrusting in the southwestern direction (Fig. 2A). In the southeastern part of the belt, the directions of slipping and thrusting are variable (Fig. 2A, insets *1–4*). Thrusting oriented in the southwestern, eastern and southeastern, and northern directions is documented. The strike-slip components of displacements are likewise diverse. The dislocations conformable to the outer contours of the jut of the Vetreny Belt are distinguished by predominance of the left-lateral displacements. Other faults are oriented in an irregular manner, and their kinematics depends on the local dynamic conditions.

In general, it may be stated that the southeastern ending of the Vetreny Belt is characterized by a complex tectonic collage and variously oriented tectonic lenses and sheets. The belt narrows northwestward near the Kozhozero arc, and the structural elements become linear and uniform in their kinematics.

Postmetamorphic structural parageneses. The younger "dry" tectonites without substantial mineral alteration develop in fault zones that cut mafic sequences. Kakirites, fractured rocks, cataclasites, and breccias related to postmetamorphic brittle failure pertain to this category of structural elements. In many cases, fracture zones inherit the planes of synmetamorphic faults. The age of postmetamorphic structural parageneses is usually unknown. With the use of a body of indirect evidence (correlation, penetration in the sedimentary cover), it may be suggested that some postmetamorphic structural elements in the basement were formed contemporaneously with deformation of the sedimentary cover of the Russian Plate. The observations in the zones of exposed contact between the basement and cover confirm this suggestion. Consider the results of examination of the Bulatovsky open pit that strips a local jut of the crystalline basement contacting the Upper Carboniferous sedimentary rocks (Fig. 2, area 4).

In the Bulatovsky open pit 15–20 m in depth, the basaltic komatiites of the Vetreny Belt Formation are overlapped with scouring and basal conglomerate by sediments of the Kasimovian Stage (Fig. 4A). The Paleoproterozoic volcanic rocks are cut by a system of synmetamorphic strike-slip and thrust–strike-slip stepwise faults similar in many respects to those described above (Fig. 4B). Virtually all these faults, which are marked by tectonites formed under conditions of greenschist facies, are inherited by postmetamorphic fracture zones and locally developed cataclasites. The auxiliary fractures—Riedel shears and tension cracks—develop along the master surfaces of reactivated thrust and strike-slip faults, thus allowing establishment of the direction of postmetamorphic displacements (Fig. 4B). In most cases, the kinematics of thrusting is generally retained, whereas strike-slip faults often reveal inversion (Figs. 4E, 4F). Some of the strike-slip and thrust faults are traced in the Paleozoic sedimentary rocks (Fig. 4A).

The Upper Carboniferous basal conglomerate overlaps the basement with indications of scouring. These poorly sorted boulder and pebble conglomerate and conglobreccia consist of fragments of the underlying volcanic rocks bound by sandy–carbonate cement and occasionally by organic detritus. Conglomerate fills depressions and narrow graben-like sinks of the basement surface. Such a graben is traced in the southern part of the open pit (Fig. 4A). In the hanging wall of the thrust fault, basaltic komatiite is cut by fracture systems that make up thrust duplexes. The trapezoid jointing in the frontal zone of thrust sheet grades into a train of fragments of the same shape contained in basal conglomerate. The transgressively overlying organogenic clastic limestone of the Kasimovian Stage is likewise involved in the graben-like sink overlain by a thrust sheet. The limestone is severely brecciated and crushed, thus forming a wedge-shaped body. This structural assembly may be interpreted as a result of the following events: (1) local extension and formation of small graben-like depressions that complicate the surface of the ancient peneplain; (2) synsedimentation overthrusting of basaltic komatiites during their brecciation and collapse into local depressions (channels of water streams), where conglobreccia was deposited; (3) marine transgression and formation of continuous cover of carbonate sediments; and (4) resumption of thrusting in basement rocks and postsedimentation dislocations in the sedimentary cover.

The thrust dislocations entered from basement rocks into carbonate sediments of the continuous, gently lying cover. They are expressed here as foliation zones and mesoscopic C–S structures kinematically conformable to displacements in the basement (Fig. 4D). In addition, through thrusts are noted in the northeastern part of the open pit within a vast field of conglomerates with discrete islands of Paleoproterozoic volcanic rocks that occasionally thrust over conglomerate (Fig. 4A).

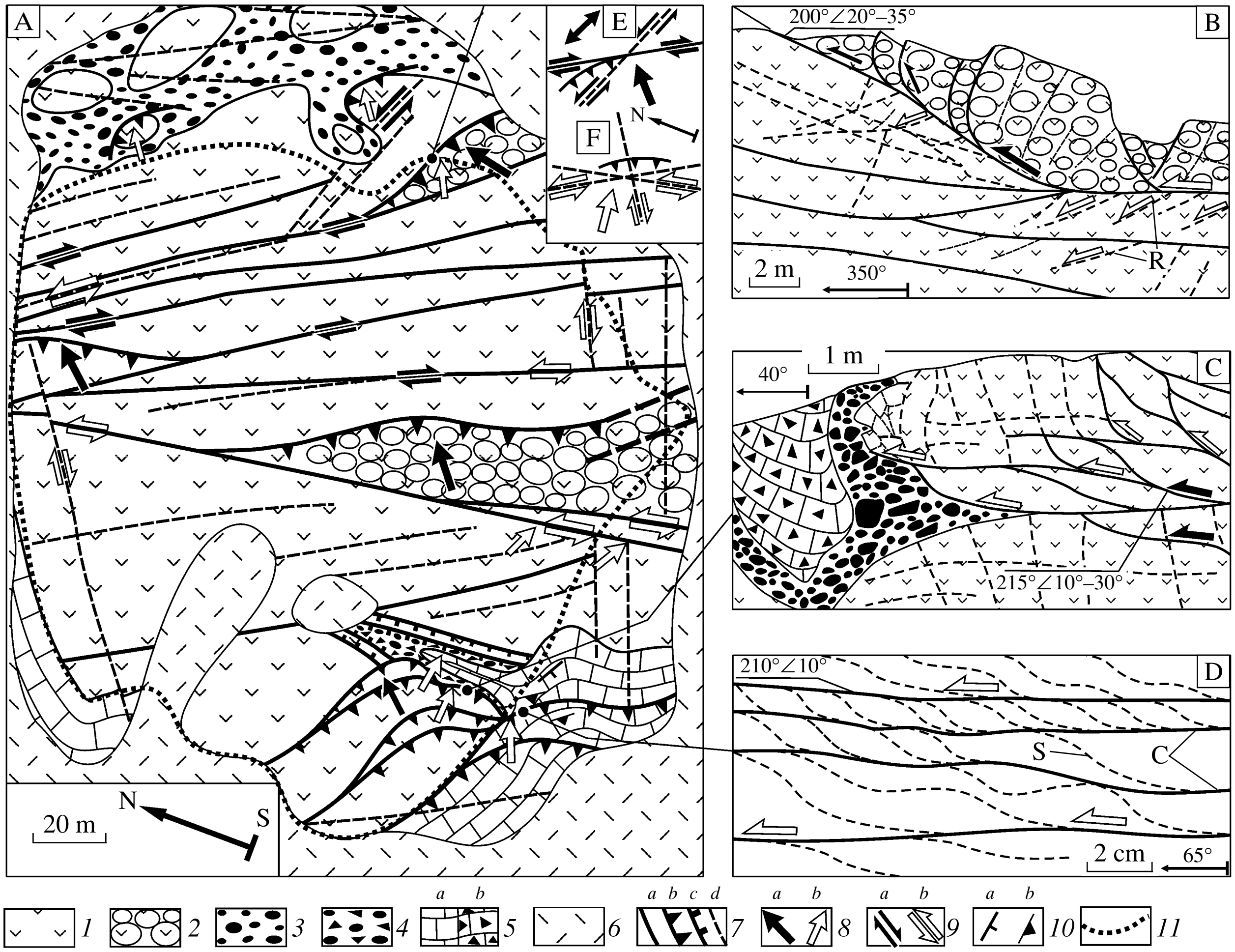

Fig. 4. (A) Geological–structural scheme of the Bulatovsky open pit; (B–D) fragments of structural elements in the basement and cover. Integral kinematic situations in the (E) basement and (F) cover in the vicinity of the Bulatovsky open pit. (*1*) Massive and (*2*) pillow lavas of the Vetreny Belt Formation; (*3*) Upper Carboniferous basal conglomerate and (*4*) conglobreccia; (*5*) Upper Carboniferous (*a*) limestone and (*b*) limestone breccia; (*6*) Quaternary loose sediments; (*7*) faults: (*a*) reverse–strike-slip, (*b*) thrust, and (*c*) normal, (*d*) fracture zone; (*8*) directions of near-horizontal displacements in the (*a*) basement and (*b*) cover; (*9*) directions of strike-slip displacements in the (*a*) basement and (*b*) cover; (*10*) strike and dip of (*a*) bedding and (*b*) schistosity; (*11*) contour of the open pit as in 2005. Letters in figures: S, schistosity; C, master strike-slip faults; R, Riedel shears.

Thus, we have the grounds to suggest that some part of the postmetamorphic structural elements of the basement is of a through character and was inherited from the older faults progressively that penetrated into the sedimentary cover at different stages of its deposition and subsequent evolution.

Structural–kinematic parageneses of the cover. The Vendian and Phanerozoic sedimentary rocks of the cover of the Russian Plate overlie the basement of the Vetreny Belt and gently (fractions of a degree, rarely a few degrees) plunge to the east and southeast, while being sporadically disturbed by folds with dip angles of 4°–10° at their limbs. The sedimentary cover occupies a territory with a typical platform topography somewhat complicated by glacial aggradational landforms and neotectonic morphostructures. The beds of predominant carbonate rocks armor vast planation surfaces. The less abundant sandshale and calcareous clayey rocks mark the rheologically weakened levels of the Paleozoic sedimentary column. The most representative outcrops of the Vendian and Paleozoic rocks occur at the walls of the Onega River valley, which incises down to 20–40 m in the sedimentary cover near the jut of the Vetreny Belt.

The sedimentary rocks are characterized by nonuniform lithification and discrete and diverse authigenic mineral formation, irrespective of their occurrence in the lower or upper part of the section. The alteration largely corresponds to various grades of catagenesis. The background lithogenesis of subsidence (diagenesis and catagenesis) is occasionally distorted by superimposed epigenetic metagenesis. For example, the poorly lithified Upper Devonian clay and sand in the lower part of the section is overlain by the well lithified beds of the Carboniferous mudstone and sandstone that locally underwent secondary kaolinization, silification, and

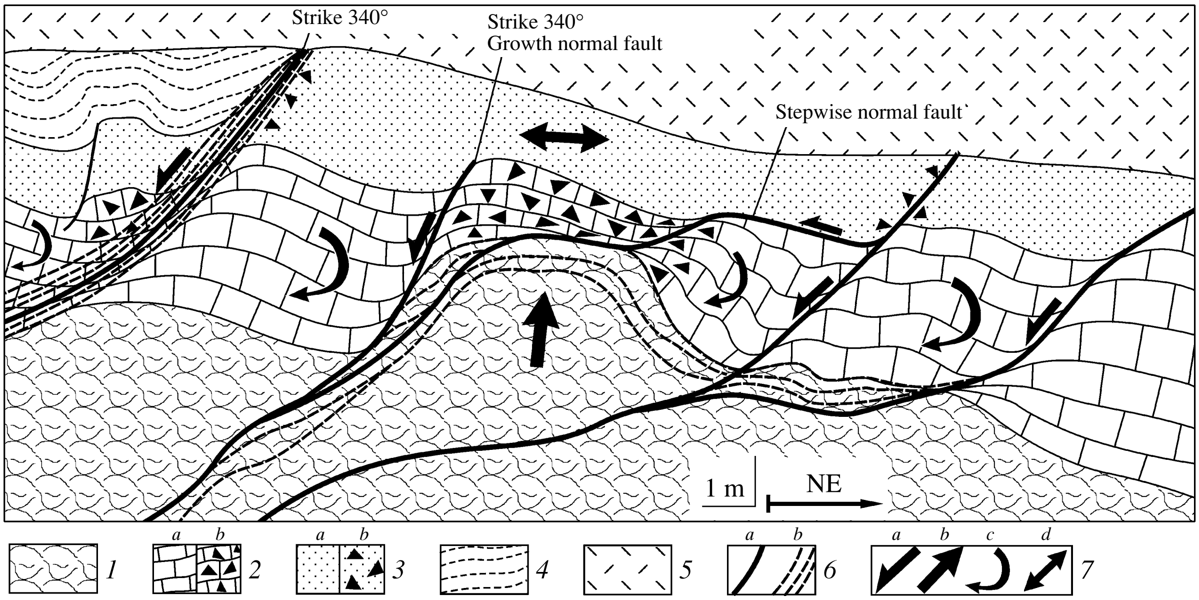

Fig. 5. Geological–structural section across the Lower Carbonaceous sedimentary rocks in the Iksa open pit. The location of the open pit in Fig. 2 is indicated by the numeral 5. (*1*) Visean bauxite-bearing clay; (*2–4*) Serpukhovian Stage: (*2a*) dolomitized limestone and (*2b*) brecciated limestone, (*3a*) calcareous sandstone and (*3b*) brecciated sandstone; (*4*) shale; (*5*) dump; (*6a*) faults and (*6b*) zones of schistosity; (*7*) directions of (*a, b*) displacement of rocks, (*c*) rotation of blocks, (*d*) extension.

carbonation of the early stage; recrystallization of quartz in limestone; and transformation of clay minerals in hydromica (late metagenetic alteration) [14, 27]. In some cases, the Lower Carboniferous sandstone grades along the strike into quartzitic sandstone and secondary quartzite, while the organogenic detrital limestone grades into marmorized and dolomitized rocks. In addition, the appearance of ore clusters in the Visean bauxite-bearing sequence pertains to the phenomena of this category.

The anomalous secondary alteration is clearly related to structural factors, and the metagenetic rocks may be regarded as tectonites, while the related structural elements may be regarded as parageneses of metagenetic stage. Some rocks that experienced synsedimentation and diagenetic alteration may be considered tectonites as well.

Synsedimentation–diagenetic structural parageneses were noted in many stratigraphic units of the platform cover. The intraformational normal faults in the Lower Carboniferous sediments, which are commonly traced within a few beds and wane in the overlying sediments, while being occasionally cut off by surfaces of scouring, serve as an example (Fig. 5). Collapsed structural features, stratigraphic lapouts, and pinch-outs of beds may be observed along buried scarps of such faults. Sedimentary breccia and fragments of broken beds that "float" in clay matrix and that probably were formed as a result of slumping of poorly lithified sediments from slopes of an active tectonic scarp occur in close to the faults (Fig. 6A).

Small asymmetric folds of submarine slumping and synsedimentation and diagenetic structural elements related to the injection of plastic sediments in tension cracks of competent beds and to the redistribution of components of rocks by infiltration of pore fluid along fractures often occur in the spatial association with these structural elements (Figs. 6A, 6B). With consideration for the localization of such structural features in the zones affected by synsedimentation normal faults, it may be suggested that these features were formed under lateral extension induced by the growth of the tectonic escarpment. The poorly lithified sediments were involved in slumping and collapse on its slope. Structural parageneses of this kind were noted in the Visean and Serpukhovian varicolored sediments and in the clayey and marly interbeds alternating with the Moscovian limestones.

The low-amplitude structures of thrusting of basement rocks over the Upper Carboniferous basal layers with downfall breccia in the frontal portion of the thrust sheet were mentioned above (Fig. 4C). These synsedimentation thrust faults continued to develop after lithification of sediments. A similar situation is noted for many other synsedimentation–diagenetic structural elements, which were appreciably distorted by late tectonic transformation after lithification. For example, the synsedimentation normal faults in the Lower Carboniferous sediments are often accompanied by late normal faults of the same configuration (Fig. 5). As a result, we often fail to estimate the kinematic features of synsedimentation structural elements. In many cases, the dynamic tendencies that developed in the

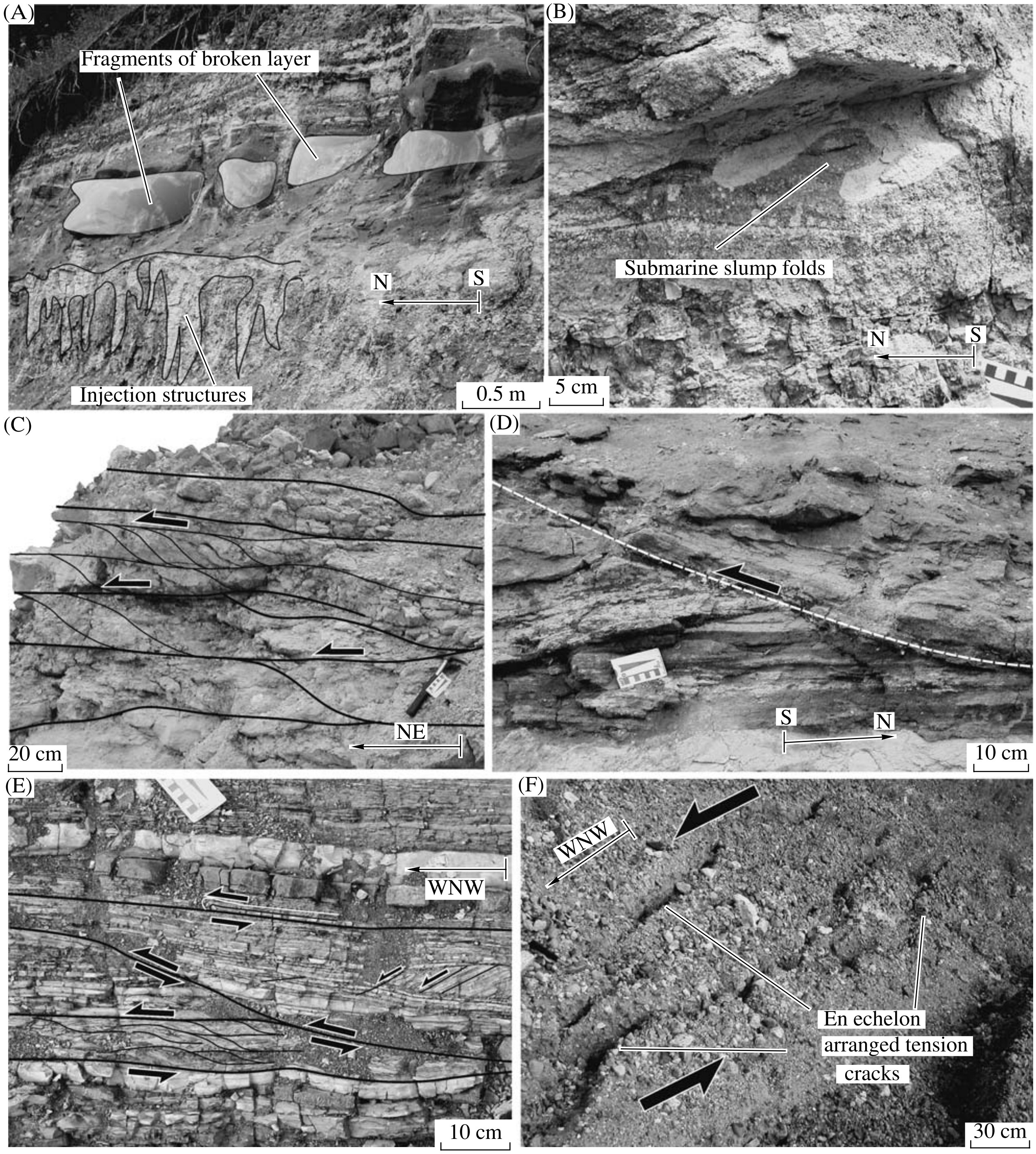

Fig. 6. Structures of rocks in the Vendian–Phanerozoic sedimentary cover. (A, B) Synsedimentation–diagenetic structures in the Lower Carboniferous terrigenous rock (in section view); (C, D) structures related to the bedding-plane horizontal displacements: (C) C–S structures in the Upper Carboniferous limestone, (D) thrust duplex in the Lower Carboniferous sedimentary rock; (E, F) structures related to the left-lateral strike-slip displacements in a through fault zone that cuts (E) Upper Vendian terrigenous rock and (F) Quaternary sediments (in plan view).

course of sedimentation appeared again at the metagenetic stage of rock evolution.

Metagenetic structural parageneses. The metagenetic alteration of rocks observed in the studied territory are an indicator of their tectonic transformation. Remobilization and recrystallization of siliceous and carbonate materials with formation of quartzitic sandstones, secondary quartzites, marmorized limestones, and quartz and carbonate veins; recrystallization of clay minerals with formation of hydromica, kaolin, etc.; and various structural and textural modifications of rocks are widespread phenomena in fault zones that cut the Vendian and Paleozoic sedimentary rocks. Tectonites that originated at the metagenetic stage serve as the basis for recognition of metagenetic structural parageneses.

The Vendian and Paleozoic sedimentary rocks are cut by numerous low-amplitude faults, which are readily interpreted in aerial photographs and satellite images and control the present-day platform morphostructures, including linear segments of stream channels, chains of small lakes and swamps, low-angle topographic steps, and sharp boundaries of changing landscapes. These attributes are a reflection of the system of dislocations in the central part of the Onega River valley and the arcuate structural zone that surrounds the jut of the Vetreny Belt (Fig. 2A). These dislocations were observed in bank outcrops. The breccia, fracture, and foliation zones noted here in sedimentary rocks are accompanied by secondary metagenetic alteration of rocks; some geomorphic indications of faulting are revealed as well. The northern segment of this fault is best expressed near the settlement of Ulitino (Fig. 2A, area 9). The fault zone is traced from this locality to the northwest, passing from the sedimentary cover into basement rocks and merging with the first-order fault that separates the Vetreny and Belomorian–Lapland belts.

In addition, the sedimentary cover is dissected by other faults of various orientations. Some of them are distinctly traced in basement rocks and often control the narrow graben-like sinks filled with sediments at the surface of the basement. A fragment of one of such zones is exposed in the Lower Carboniferous rocks in the open pit at the Iksa bauxite deposit (Fig. 2A, area 5).

A system of stepwise normal faults observed here cuts the Visean and Serpukhovian sedimentary rocks (Fig. 5). Some of these faults have a synsedimentation character, while others bear all attributes of their formation after lithification of sediments and are accompanied by metagenetic transformation. Carbonate rocks undergo brecciation and foliation along fault sutures and reveal remobilization of carbonate material, which, being redistributed, heals fissures, cements fragments in breccia, and undergoes transformation into marmorized rocks. Penetrating from carbonate rocks into bauxite-bearing clayey deposits, the normal faults are refracted and sharply flattened, occasionally being adapted to the roof of plastic unit. Such refraction is a cause of stepwise morphology and listric configuration of faults in particular segments. The blocks displaced along listric surfaces underwent rotation (torsion) around the horizontal axis in the hanging wall of the fault (Fig. 5). The bauxite-bearing sedimentary rocks are foliated in fault zones and enriched in hydromica. Beyond the fault zones, they are a lumpy plastic clay disrupted and distorted by chaotic fractures. The destruction of the overlying carbonate beds provokes the formation of clay diapir-anticlines with brecciation, recrystallization of rocks, and redistribution of carbonate material in their apical portions (Fig. 5). This fault zone strikes in the northwestern direction and penetrates into the basement rocks as a narrow graben-like sink. Most likely, this highly permeable structural element was a favorable factor for the secondary enrichment of ore at its intersection with bauxite-bearing sediments.

The statistical analysis of the orientation of fractures, foliation zones, and other tectonic features in the sedimentary cover shows appreciable predominance of tectonic lines of the northwestern and near-meridional directions (Fig. 2C). The same may be said about the basement (Fig. 2B).

In addition to the faults considered above, the bedding-plane dislocations are widespread in the sedimentary cover. They are expressed in near-horizontal zones of 3D brecciation with accompanying sliding, lensing, and foliation of the C–S type (Fig. 6C, 6D). The thick (up to 10 m) stratiform zones similar in morphology to tectonic melange are characteristic of the Lower Carboniferous terrigenous rocks. The competent interbeds of calcareous sandstone that occur in clay matrix undergo brecciation and secondary silification and carbonation. Thereby, they undergo tectonic fragmentation and rotation with the formation of domino-type structures (Fig. 7A).

No less characteristic is the formation of tectonic swells of competent beds in melange zones that is due to the development of thrust duplexes (Fig. 7B). The structural elements of bed doubling, similar in many respects, are formed in the systems of low-amplitude stepwise thrust faults that jump from one stratigraphic level to another (Figs. 7C, 6D). In their low-angle segments, these fault zones are conformable to bedding planes, while the steeper segments cut these planes with development of asymmetric thrust-related folds. An interesting feature of these structural forms of tangential compression is their intercalation with the units that experienced tangential extension and boudinage (Fig. 7C). Thereby, the region of the maximum thinning of the layer with boudins is located between the segments that underwent the strongest thrusting and stacking. Such a combination of compression and extension related to the balanced nonuniform tectonic flow cannot be explained by the direct effect of an outer stamp-type source of stress.

Similar series of structural elements were noted in the Middle Carboniferous carbonate–clayey units, where the beds of calcareous sandstone fragmented into asymmetric boudins intercalated with plastic calcareous shales that have oblique foliation systems and C–S structures (Fig. 7D). The character of the lensing of competent interlayers allows us to suggest that particular units periodically occurred under conditions of lateral extension, while undergoing boudinage, or in the

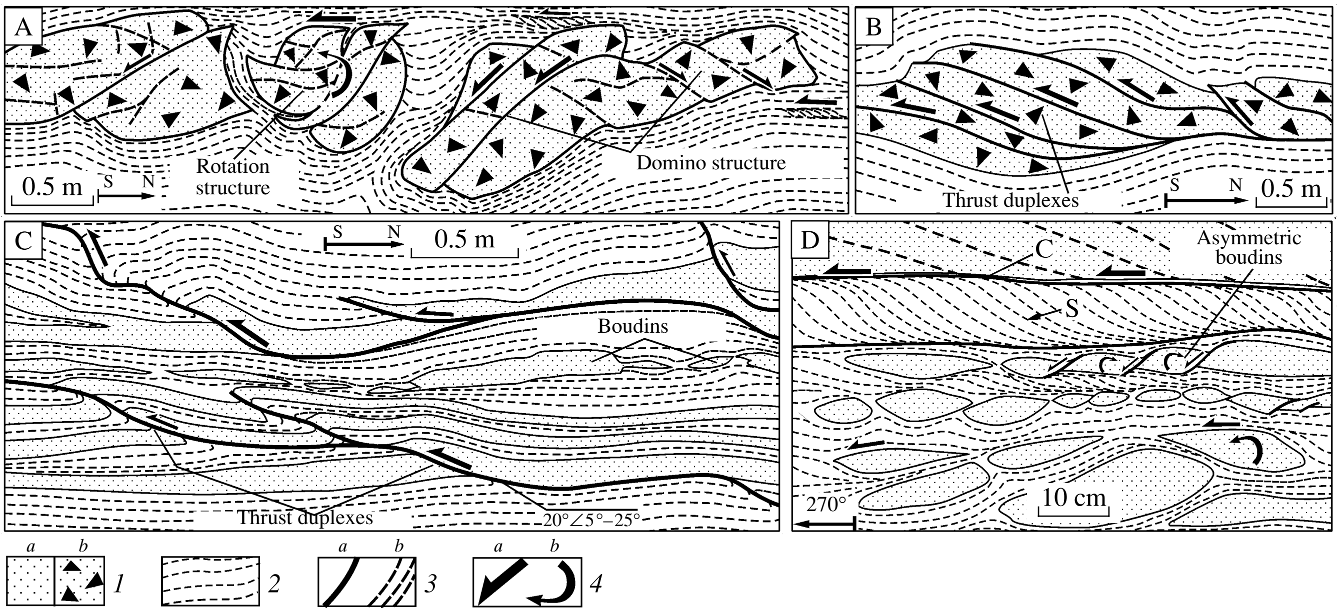

Fig. 7. Fragments of structures in the Carboniferous rocks (in section view). (A–C) Fragments of melange zones in the Lower Carboniferous terrigenous rocks; (D) structures of diagonal foliation and lensing of carbonate–clayey and sandstone interbeds in the Middle Carboniferous limestone. The locations of structures A, B, C, and D are indicated in Fig. 2 by the numerals 7, 8, 8, and 6, respectively. Calcareous (*1a*) sandstone and (*1b*) breccia, (*2*) foliated carbonate–clayey rock, (*3a*) faults and (*3b*) fractures; (*4*) direction of (*a*) displacement and (*b*) rotation.

region of local tangential compression, where they experienced the inverse process of hummocking of the fragmented lenses (Fig. 7D, lower part). The inversion of deformation conditions related to the migration of local tectonic stresses of different types through the section are difficult to explain in terms of the traditional dynamic models.

Established on the basis of kinematic indicators (Fig. 7), the directions of lateral displacement along the zones of tectonic flow are shown in the geological–structural scheme (Fig. 2A).

The results obtained indicate that the sedimentary cover of the territory under consideration underwent structural transformations of the metagenetic stage. A question arises whether these structural elements were coeval. The answer may be found on the basis of examining a group of exposures along the banks of the Onega River 7–8 km east of the settlement of Ulitino (Fig. 2A, area 9). In the continuous section, the Upper Vendian siltstone and mudstone; the basal conglomerate and sandstone of the Lower Carboniferous; and the Quaternary sand, gravel, and loam are exposed here, being divided by unconformities. In some outcrops, the beds are nearly horizontal and undeformed. However, in the fault zone exposed in the river channel, the situation is different (Fig. 8). The beds dip here at various angles and form both small and relatively large fault-line folds. In addition, the beds are complicated by zones of brecciation, cataclasis, foliation, and blastomylonites with C–S structures (in the Vendian and Carboniferous sediments) and opening tension cracks (T) and shear fractures (S) with auxiliary Riedel shears (in Quaternary sediments) (Figs. 6E, 6F). The sedimentary units of different age are separated by angular and structural unconformities (Fig. 8). Although the faults are of a through character, they are expressed in the rock complexes of different age in a special manner. The Vendian sediments are the most tectonized, the Carboniferous rocks are deformed to a lesser extent, and the Quaternary sediments are the least deformed (Figs. 6E, 6F). The kinematic indicators show the left-lateral displacements in all rocks. These displacements repeatedly resumed in the lower units and formed a single pulse in Quaternary sediments. The tension cracks in the Carboniferous conglobreccia are filled with gangue minerals and are crescent in shape, thus indicating their multifold rotation and rejuvenation (Fig. 8). Similar structures in Quaternary sediments are en echelon arranged open fissures without subsequent modification by posthumous movements (Figs. 6F, 8). These data indicate that structural elements of the metagenetic stage were formed locally in the zones dynamically affected by faults before and after deposition of the Lower Carboniferous sediments and were rejuvenated during the neotectonic stage.

As was mentioned above, the fault zone in the Onega River valley is traced from Ulitino northwestward to the basement rocks, where it merges with the regional left-lateral strike-slip fault zone that separates the Vetreny and Belomorian–Lapland belts. Low-amplitude left-lateral offsets were noted in the sedi-

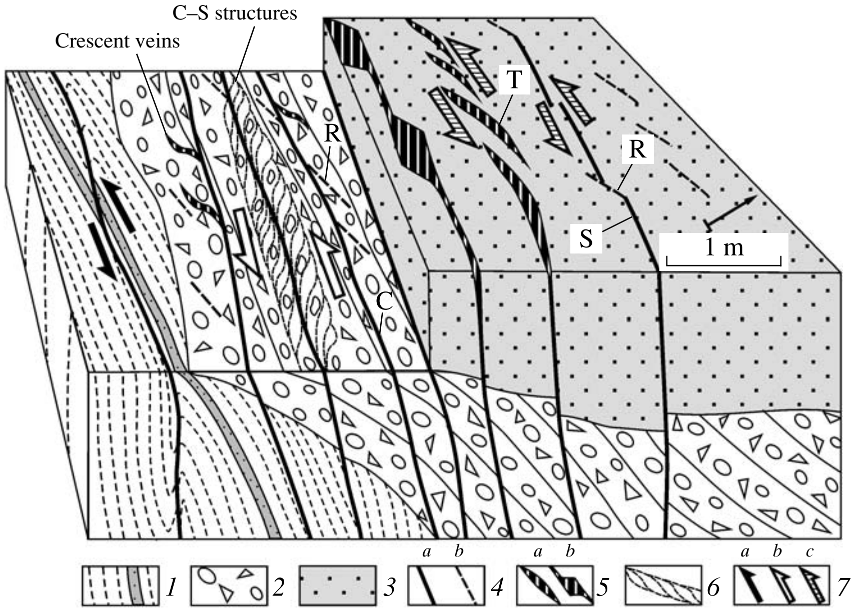

Fig. 8. Block diagram that illustrates structural relationships between the Upper Vendian, Lower Carboniferous, and Quaternary rocks in the zone of strike-slip dislocations. The location of the area is indicated in Fig. 2 by the numeral 9. (*1*) Upper Vendian shale, siltstone, and sandstone; (*2*) Lower Carboniferous and silicified conglomerate; (*3*) Quaternary sand, gravel, and loam; (*4a*) faults, (*4b*) fracture and foliation systems; (*5a*) fractures and (*5b*) tension cracks; (*6*) zones of foliation with C–S structures; (*7*) directions of displacement in (*a*) Vendian, (*b*) Carboniferous, and (*c*) Quaternary sedimentary rocks. Structural elements (letters in figure): S, main shears; R, Riedel shears; and T, tension cracks.

mentary cover over the entire arcuate segment of the fault zone that bends round the jut of the Vetreny Belt (Fig. 2A). In summary, it may be stated that this through fault zone originated at the end of the Paleoproterozoic as a left-lateral strike-slip fault and continued to develop under the same kinematic conditions in the Paleozoic and during the neotectonic stage.

DISCUSSION

The available data show that a succession of tectonic events related to the differential vertical and horizontal mobility of the crystalline basement rocks and sedimentary cover had important implications for the formation of the present-day structure of the southeastern margin of the Baltic Shield. These tectonic movements lasted for a long time, from at least the Late Paleoproterozoic until the neotectonic stage of evolution of the East European Platform. There are grounds to suggest that the tectonic evolution of the study region bore an inherited character. The structural units formed afterward in the Early Precambrian experienced periodic remobilization that affected sedimentation and caused subsequent tectonic transformation of the sedimentary cover. Here, we are not dealing with a simple inheritance of the older structural grain. More important are the data that indicate the long-term existence or periodic resumption of the same kinematic tendencies of the structural evolution. Let us trace these tendencies on the basis of available information on the structure of the Vetreny Belt and its framework.

The structure of the Vetreny Belt was formed as a result of tectonic stacking of the Paleoproterozoic sequences related to the Svecofennian collision, when the initial volcanic–sedimentary trough (probably underlain by oceanic crust) was squeezed between the Belomorian gneisses in the north and the granite–greenstone complexes of the Vodlozero Massif [2, 21]. Thereby, the tectonic displacements within the Vetreny Belt bore a thrust–strike-slip character and repeated many times as tectonic pulses of the thrust, strike-slip, and complex thrust–strike-slip types, probably corresponding to different stages of deformation. The belt underwent the maximum squeezing in its northeastern and central segments, where arcuate structural features were related to the lateral pushing-out of crystalline rocks of the Vodlozero Massif (Fig. 1). In these segments, the thrust–strike-slip tectonic elements are strongly linearized and characterized by the prevalence of left-lateral offsets.

Toward the southeast, the Vetreny Belt widens several times and passes into the region of collage tectonics with differently oriented tectonic lenses and sheets. Thus, it may be suggested that the Paleoproterozoic sequences in the northwestern segment of the belt, having undergone intense compression, were squeezed out in the lateral direction to the region of relative dynamic unloading in the southeastern ending of the Vetreny Belt. The rather steady manifestation of left-lateral offsets along the zone that bounds the Vetreny Belt in the northeast may be explained by clockwise rotation of the Vodlozero Massif against the background of its pushing-out to the northeast. This interpretation partly agrees with the version proposed in [17]. In addition, the rotation should be accommodated along the system of arcuate strike-slip faults that transect the massif and bound its margins (Fig. 1).

Thus, the available data allow us to propose the hypothesis that the evolution of the Vodlozero Massif at the Svecofennian time was controlled by two kinematic factors: rotation and lateral displacement to the northeast. Such kinematics provided tectonic squeezing of Paleoproterozoic sequences of the Vetreny Belt to the southeast. This kinematic tendency most likely was retained or periodically resumed at the subsequent stages of tectonic evolution and eventually reflected in the structure of the present-day boundary of the Baltic Shield and the Russian Plate. The large lateral jut of the shield that complicates this boundary at the southeastern ending of the Vetreny Belt probably is the result of the resumption of the kinematic conditions that took place at the end of the Paleoproterozoic.

The structure of the sedimentary cover of the Russian Plate and the spatial distribution of sedimentary units therein indicate that the jut of the Vetreny Belt evolved for a long time, while periodically invading the region of platform sedimentation as an uplift and giving rise to the local scouring of sediments, to breaks in sedimentation on the crest of the uplift, and to facies shifts at its margins. The synsedimentation structural elements of the tectonic origin indicate the periodic activation of tectonic movements during Paleozoic sedimentation. The postmetamorphic structural features of the crystalline basement that were revealed in the jut of the Vetreny Belt inherited the older synmetamorphic faults and often penetrated into the sedimentary cover. There are indications that these faults were activated at the synsedimentation stage and during the subsequent metagenetic transformations of rocks. Many synsedimentation structural elements in the cover were formed owing to the remobilization of faults in the basement.

The high tectonic activity of the studied segment of the margin of the Baltic Shield was recorded in the staged exogenic metasomatic alteration during the Early Carboniferous epoch of bauxite formation and in the distortion of the normal catagenetic zoning of sediments by the appearance of local metagenetic alteration of rocks that occurred throughout the column of the Vendian and Paleozoic sedimentary rocks. As follows from our experience, such anomalies are commonly related to tectonic factors: the occurrence of highly permeable zones, elastic and ductile deformation, and activation of domal structures in the basement [14, 27]. All these factors were revealed during the study of metagenetically altered rocks. In particular, it has been shown that lithotectonic parageneses at the metagenetic stage were formed locally in the zones of dynamic effects of strike-slip, thrust, and bedding-plane faults. The periodic waning and resumption of tectonic movements are recorded in local structural unconformities between the stratigraphic complexes deformed to various extents (Fig. 8).

The inherited evolution of the metagenetic structural parageneses controlled by remobilization of faults in the basement is evident in many considered cases. In this regard, they may be defined as superposition parageneses [23], as confirmed by statistical processing of measured structural elements in the basement rocks and the sedimentary cover (Figs. 2B, 2C).

The inherited development of faults is expressed not only in their geometric persistence but also in the kinematic coordination of the tectonite structures of Svecofennian, Paleozoic, and even Quaternary ages (Figs. 8, 4B–4D). Such coordination is especially distinct along the zone of strike-slip dislocations that frames the Paleoproterozoic sequences of the Vetreny Belt in the northeast and penetrates the sedimentary cover as an arcuate structural element that surrounds the basement inlier. This through tectonic zone originated as a left-lateral strike-slip fault at the end of the Paleoproterozoic and continued to develop under the same kinematic conditions in the Paleozoic and during the neotectonic stage. The uniform left-lateral displacements along the entire extent of this zone, including its arcuate bend, may be explained by the long-term indentor effect of the Vodlozero Massif and its clockwise rotation (Fig. 1). These long-term tectonic movements apparently were the main cause of the formation and ongoing activation of the jut of the Vetreny Belt.

The character of displacements along the zones of bedding-plane dislocations in the Paleozoic cover is less understandable. In the northern part of the jut of the Vetreny Belt, the uppermost sedimentary beds are displaced largely to the southeast relative to the underlying beds, i.e., obliquely to the buried slope of the jut. In its eastern framework, the displacements are oriented in the eastern bearings, in the direction of the jut's plunging (Fig. 2A). If the latter case may be explained by gravitational slipping of the sedimentary cover downslope of the growing jut, the character displacement on the northern slopes is probably controlled by another mechanism.

The complex combination of the structural elements of tangential compression and extension in the zones of bedding-plane dislocations that bear indications of tectonic flow cannot be interpreted in terms of the direct effect of the outer source of stress (Figs. 7C, 7D). In addition, the absence of clearly expressed folds in the sedimentary cover, which hardly can transmit stresses for a great distance, refutes the version of simple stamp pressure on sedimentary rocks. Indeed, the spontaneous and chaotic tectonic flow is possible, but the ordered orientation of flow requires some other explanation.

The crystalline basement rocks that underlie the sediments may be a material that transmits tectonic stress for a distance. With this possibility in mind, a couple of mechanisms providing the bedding-plane slip may be proposed: (1) the activation of faults in basement rocks and their penetration into sedimentary cover as stepwise dislocations that are adapted to plastic units and that jump from one stratigraphic level to another and (2) the development of tectonic flow within the sedimentary cover provoked by earthquakes in the basement and by the transfer of seismic energy as a wave.

In our opinion, these mechanisms are consistent with the results of observations, and their joint action cannot be ruled out. In this case, the direction of the bedding-plane slip directly reflects the displacement of the underlying crystalline basement rocks and shows that, in the Phanerozoic, the jut of the Vetreny Belt continued to propagate periodically to the east and southeast probably as a result of retention of the kinematic tendency that existed at the end of the Paleoproterozoic. The deformation of other kinematics at the plate stage was reduced by unknown reasons. All this excites wonder and leads to the following question: What was the cause of such a long retention of the same kinematic regime in a local area of the lithospheric plate? One possible interpretation of this phenomenon consists in the suggestion that the remobilized basement structural features served as a "rail" that predetermined the mobility of the sedimentary cover. In this case, the common dynamic conditions will be realized in common kinematic tendencies owing to blocking of particular structures and favorable conditions of development of other structural elements.

CONCLUSIONS

The superposition (long-lived) structural kinematic parageneses, which were formed and periodically renewed from the Paleoproterozoic to the neotectonic stage of evolution, have been established in the southeastern marginal part of the Baltic Shield. These parageneses are expressed in synmetamorphic structural elements in the Precambrian complexes, in synsedimentation and metagenetic structural features of the Vendian–Paleozoic sedimentary cover, and in the Quaternary sediments. These structural elements demonstrate the geometric and, in some places, kinematic inheritance of their evolution.

The succession of tectonic events related to the differential vertical and lateral mobility of the crystalline basement rocks and the sedimentary cover had important implications for the formation of the present-day structure of the southeastern margin of the Baltic Shield. This succession embraces a long interval from the Neoproterozoic to the neotectonic stage.

The countermotions of crystalline masses of the Vodlozero Massif and the Belomorian–Lapland Belt provided the tectonic stacking of volcanic and sedimentary sequences of the Vetreny Belt, which is situated between these tectonic units. Thereby, the Vodlozero Massif underwent displacement to the northeast and clockwise rotation, thus providing the left-lateral transpression within the Vetreny Belt and the squeezing-out of the Paleoproterozoic rocks to the southeast. This kinematic tendency likely repeated at the platform evolutional stages and eventually was reflected in the structure of the present-day boundary between the Baltic Shield and the Russian Platform.

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