

Structural Patterns of Pre-Uralides in the Enganepe Uplift (Polar Urals) As a Reflection of the Cambrian Collision of Baltica and Arctida

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The East European Platform (EEP) is bordered by the Ural foldbelt of Hercynides on the east and the Pechora Plate (PP) with the adjacent Barents Sea shelf in the northeast. The upper horizons of the Earth's crust in the Urals, PP, and Barents shelf are characterized by a two-level structure. The lower stratigraphic–structural level consists of Late Precambrian complexes (Pre-Uralides–Timanides), whereas the upper level is composed of PostCambrian complexes.

In terms of the composition and structure, Pre-Uralide–Timanide complexes are subdivided into two groups [4]. The first group (southwestern Pre-Uralides–Timanides) is mainly represented by sedimentary rocks. These rock complexes outcrop in Timan and compose a part of the adjacent PP basement. In the southeast, the complexes are traced in the Urals (Kvarkush anticlinorium and Bashkir Uplift). In the northwest, they outcrop in the northeastern Baltic Shield (Kildin Island and Rybachii, Srednii, and Varanger peninsulas) and take part in the structure of adjacent areas of the Barents Shelf.

The second group (northeastern Pre-Uralides–Timanides) includes not only sedimentary rocks, but also volcanic and volcanosedimentary complexes, granitoids, gabbroids, and rare ophiolites. These complexes make up the northeastern part of the PP basement and outcrop within several positive structures in the northern part of the western slope of the Urals (e.g., the Enganepe Uplift). The available arguments allow correlation of Late Precambrian complexes of the Wedel Jarlsberg Land (WJL) on southwestern Spitsber-

gen with the Pre-Uralide–Timanide complexes. The boundary between Pre-Uralides–Timanides of the SW and NE types is represented by the Pechora–Ilych–Chiksha fault zone of the PP basement, which is clearly established by geological and geophysical data [1, 4, 11] and traced both southeastward to the Urals and north-westward to the Barents Sea.

To interpret the structural features of Pre-Uralides–Timanides, we elaborated a tectonic scenario for the Late Precambrian–Cambrian evolution of the northeastern and eastern framing of the EEP [2, 4]. The key point is the Vendian/Cambrian collision of two paleocontinents: Baltica (the Late Precambrian skeleton of the EEP) and Arctida. As a result of this collision, the divergent Pre-Uralide–Timanide orogen emerged in the collision zone; complexes of the Timan passive margin of Baltica and the Bol'shaya Zemlya active margin of Arctida were overthrust southwestward and northeastward, respectively (hereinafter, present-day coordinates are implied), far into the colliding paleocontinents.

This work presents results of our detailed structural–geological observations carried out in the Enganepe Uplift region and comparative analysis of the structural parageneses of Pre-Uralides–Timanides of the Enganepe Uplift and other parts of the northeastern framing of the EEP. These results confirm the collision of Baltica and Arctida in the Cambrian.

Structure of the Enganepe Uplift. Salient of Pre-Uralides–Timanides of the Enganepe Uplift represents a core of the NE-trending Enganepe anticline (Fig. 1). Its limbs are composed of Uralides (Late Cambrian–Late Paleozoic complexes). Uralides overlie the Pre-Uralide–Timanide complexes with an unconformity and basal horizons at the base. The Pre-Uralide–Timanide complexes include irregularly dislocated and metamorphosed (up to the greenschist facies) heterogeneous sedimentary, volcanosedimentary, and volcanic rocks [3, 15] enclosing rare gabbrodolerite and rhyolite bodies. The SHRIMP isotopic dating of single zircon

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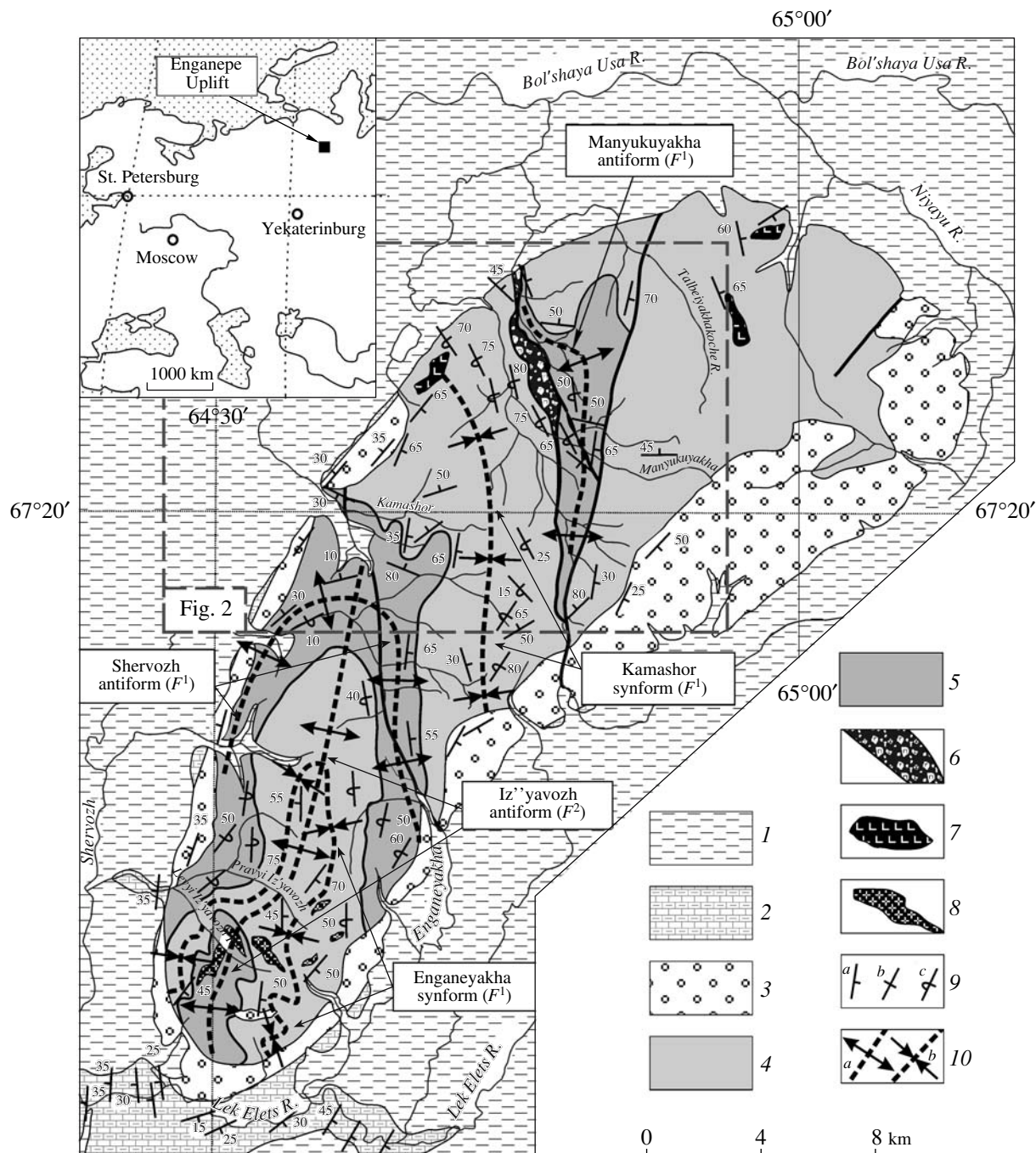


Fig. 1. Geological structure of the Enganepe Uplift. Based on our original data and materials of K.G. Voinovskii-Kruger, V.N. Gesse, A.A. Savel'eva, B.Ya. Dembovskii, M.A. Shishkin, O.N. Malykh, I.M. Malykh, P.E. Popov, et al. (1) Cenozoic loose sediments; (2–3) Uralides: (2) Middle Ordovician–Upper Paleozoic carbonaceous and terrigenous–clayey rocks, (3) Upper Cambrian(?)–Lower Ordovician terrigenous rocks (Manitanyrd Formation); (4–8) Pre-Uralide–Timanide complexes: (4) Upper Riphean–Vendian(?) volcanosedimentary and volcanogenic rocks often altered into apovolcanic greenschists (Bedamel Group), (5) Upper Riphian–Vendian clayey–terrigenous rocks and shales formed after them (Enganepe Formation), (6) serpentinitic melange (undivided), (7) gabbro and gabbrodolerites, (8) rhyolites; (9) strike and dip of bedding and schistosity: (a) oblique, (b) vertical, (c) overturned bedding; (10) axes of major (a) antiforms and (b) synforms. Synforms and antiforms: (F^1) early (Pre-Uralian–Timan) folds, (F^2) late (Uralian) folds.

crystals from rhyolites of several isolated subvolcanic bodies on the southern edge of the uplift yielded an age of 555–522 Ma [9], which is the upper age limit of the

Pre-Uralides–Timanides in the Enganepe Uplift. The boundary of complexes of different compositions on the watershed of the Manyukuyakha and Yaneskewlek-

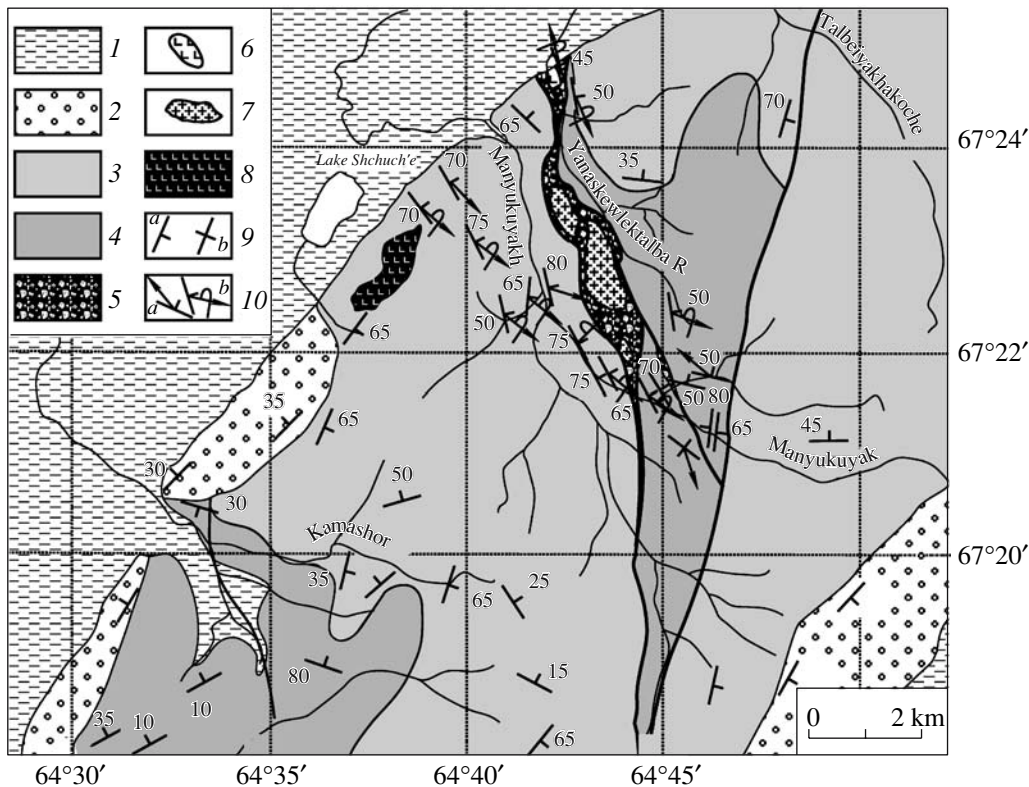


Fig. 2. Geological structure of the northwestern part of the Enganepe Uplift. (1) Cenozoic loose sediments; (2) Upper Cambrian (?)–Lower Ordovician terrigenous rocks (Manitanyrd Formation); (3) Upper Riphean–Vendian(?) volcanosedimentary and volcanogenic rocks, often altered into apovolcanic greenschists (Bedamel Group); (4) Upper Riphean–Vendian(?) clayey–terrigenous rocks and shales formed after them (Enganepe Formation); (5–7) serpentinitic melange: (5) serpentinitic matrix of melange (undivided), (6, 7) blocks in the melange structure composed of: (6) granitoids, (7) gabbroids; (8) gabbrodolerites; (9) strike and dip of bedding and schistosity: (a) oblique, (b) vertical bedding; (10) bedding of linear structural elements: (a) dip of linearity, (b) dip of asymmetrical fold hinges.

talba rivers (northwest of the Enganepe Uplift) hosts a serpentinite melange body with ultrabasic, gabbroid, and plagiogranite blocks. These rocks represent a genetically common melange of an ophiolite assemblage with the upper age limit estimated at ~670 Ma [8].

Layered rocks of the Enganepe Uplift are represented by two complexes: (i) basalts, andesites, dacites, and rhyolites, as well as their tuffs and tuffites, which are sometimes altered into greenschists (known in the regional geological literature as the Upper Riphean–Vendian Bedamel Group); (ii) siliceous and clayey rocks, mudstones and siltstones, quartzose clastic and subarkosic sandstones with rare horizons of clastic conglomerates (diamictites).

The structure of Pre-Uralides–Timanides is conformal, in general, to the structure of Uralides in the southern area of the uplift (south of the Kamashor River). The core of the Hercynian NNE-striking Enganepe anticline encloses Pre-Uralides–Timanides dislocated into a positive NNE-striking fold (Iz'yavozh antiform). The core of the antiform (upper reaches of the Levyy Iz'yavozh River) includes sedimentary rocks of the Enganepe sequence. They are overlain structurally by volcanogenic rocks of the Bedamel Group (Fig. 1). At

the northern margin of the Iz'yavozh antiform and in its western and eastern limbs (basins of upper reaches of the Shervozh River on the west and the Enganeyakha River on the east), the Bedamel volcanic rocks are overlain structurally by sedimentary rocks similar to those in the antiform core. In turn, these sedimentary rocks of the Enganepe Formation are also overlain structurally by the Bedamel volcanic rocks at the source of the Shervozh River and on the left wall of the Kamashor River valley (Fig. 1).

Thus, volcanics of the Bedamel Group occur at different structural levels in the south of the Enganepe Uplift: they are structurally underlain or overlain by sedimentary rocks of the Enganepe sequence. Therefore, the whole structure can be interpreted as an antiform packet of large-amplitude lying isoclinal folds. Volcanogenic and sedimentary sequences in the packet are of the same age. Hence, these heterogeneous complexes were first tectonically juxtaposed into one nappe complex, which later was folded into a packet of lying isoclinal folds. Ultimately, the whole packet was dislocated along with Uralides into a simple antiform at the Hercynian stage.

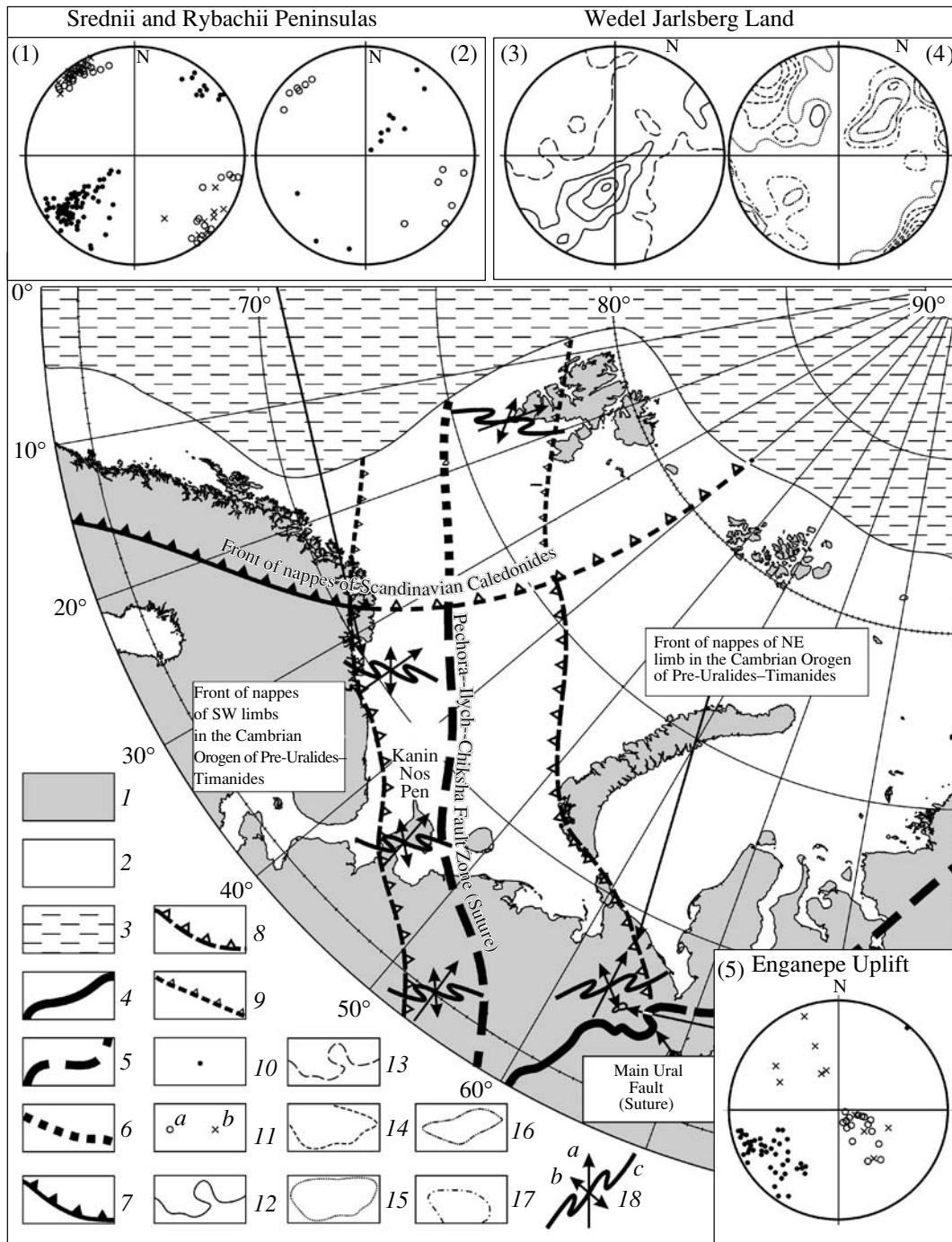


Fig. 3. Some tectonic elements in the western sector of the Arctic region and results of detailed structural studies of Pre-Uralide–Timanide complexes. (1) Continents and islands; (2) shelves and epicontinental seas; (3) oceans (basins with oceanic crust); (4–6) suture zones (sutures): (4) exposed, (5) stratigraphically overlain, (6) tectonically overlain; (7–9) fronts of nappes: (7) exposed, (8) stratigraphically overlain, (9) tectonically overlain; (10, 11) spatial orientation of structural elements shown in diagrams 1, 2 (after [5, 14]), and 5 inserted at the scheme edges: (10) schistosity, (11) linear structural elements: (a) hinges of asymmetrical folds, (b) linearity of bedding and schistosity intersection; (12–16) isolines (spacing 2%) of spatial orientation of structural elements in Upper Precambrian complexes of the Wedel Jarlsbergen Land (diagrams 3 and 4) after [10]: (12) isolines of normals to schistosity, (13) zero isoline for concentrations of normals to schistosity measurements, (14) isolines of long axes of “stretched” pebbles, (15) zero isoline of long axes of “stretched” pebbles, (16) isolines of short axes of “stretched” pebbles; (17) zero isoline for concentrations of measurements of short axes in “stretched” pebbles; (18) qualitative spatial characteristic of asymmetrical folds in Upper Precambrian complexes of relicts in the Pre-Uralide–Timanide orogen: (a) northward direction, (b) strike of hinges of asymmetrical folds, (c) vergence direction of cascades of asymmetrical folds in Pre-Uralide–Timanide complexes. Shown at the scheme edges are diagrams of spatial orientation of plane and linear structural elements of Upper Precambrian complexes: (1) Srednii Peninsula [14], (2) Rybachii Peninsula [5], (3) Wedel Jarlsberg Land [10], (4) southeastern Spitsbergen [10], (5) Enganepe Uplift.

In the northern part of the Enganepe Uplift north of the Kamashor River basin (Fig. 1), the Pre-Uralide–Timanide structure is represented by a fragment of the eastern limb of the Iz'yavozh antiform. This fragment is located near the northeastern closure of the antiform. In this fragment (Fig. 2), interrelations between Enganepe sedimentary rocks and Bedamel volcanic rocks are generally similar to those in the south of the uplift. Rocks of the Enganepe sequence exposed in the Yanaskewlektalba River Valley and in the middle course of the Manyukuyakha River represent the core of the WSW-overtaken Manyukuyakha antiform. The Enganepe sequence is structurally underlain (via the serpentinitic melange zone) in the west-southwest and overlain in the north-northeast by volcanic rocks of the Bedamel Group.

Results of structural studies. The structural paragenesis of the Bedamel greenschists, sedimentary rocks of the Enganepe sequence, and rocks of the sandwiched serpentinitic melange zone was studied on the south-southeastern limb of the Manyukuyakha antiform (Fig. 2) in exposures along the Manyukuyakha River and its tributaries (Fig. 3, diagram 5).

The schistosity (S^1) of rocks dips mainly northeastward at angles varying from 35° – 40° to 90° . The schistosity surface shows mineral linearity (L^1) represented by elongated aggregates of chlorite and amphibole, as well as juxtaposed NW- to SE-striking deformation linearity with variable (gentle to steep) dip angles. Schistosity S^1 is deformed into asymmetrical folds (F^1) or their cascades with hinges dipping southwestward. The section of folds along the dip of their hinges exhibits an S-shaped configuration. The geometric pattern of the folds indicates their formation during the thrusting of rocks of the Bedamel Group over rocks of the Enganepe sequence along the SWS-overtaken thrust of the northeastern vergence. The nappe–thrust nature of relationships between the Bedamel Group and the Enganepe sequence is emphasized by the serpentinitic melange that marks the boundary between them (Fig. 2).

Within the area of structural studies, we have revealed several simple open symmetrical folds (F^2) with the amplitude up to 1–1.5 m and hinges dipping northwestward. Schistosity acquires the NE–SW strike on limbs of folds. A similar strike and dip are typical of rocks of the Manitanyrd Formation in basal horizons of Uralides. Rocks of the Manitanyrd Formation probably acquired this mode of occurrence due to Hercynian folding.

Thus, the general structure of Pre-Uralides–Timanides of the Enganepe Uplift represents an antiform (F^2) packet of lying isoclinal folds (F^1). This antiform bend (Iz'yavozh antiform) is located in the core of the Hercynian Enganepe anticline. It is evident that the late structural paragenesis in the Enganepe Pre-Uralides–Timanides formed at the Hercynian stage, whereas the early paragenesis can be related to the Cambrian collision of Baltica and Arctida.

Comparison of structural parageneses of Pre-Uralides–Timanides. The southwestern limb of the Pre-Uralide–Timanide orogen is mainly composed of Late Precambrian complexes of the Timan passive margin of Baltica, and its fold–thrust dislocations are characterized by the southwestern vergence (Fig. 3). This is reliably established in the Timan part of the PP basement [7], as well as on the Kanin Nos [12], Srednii, and Rybachii [5, 14] peninsulas, based on the pattern of schistosity, the character of asymmetrical folds, and so on (Fig. 3, diagrams 1, 2). The northeastern limb of the orogen is characterized by the NW- and NE-oriented nappe–fold dislocations recorded in Pre-Uralides–Timanides of the Enganepe Uplift (Fig. 3, diagram 5). A similar structural paragenesis was revealed in Late Precambrian complexes of the WJL [10], which were dislocated into a major NE-striking anticlinorium of the northeastern vergence with numerous cascades of asymmetrical folds of different amplitude, analogous strike, and vergence on its limbs (Fig. 3, diagram 3). The study of orientations of short and long axes of deformed (“stretched”) pebbles in Late Precambrian diamictites of the WJL (Fig. 3, diagram 4) showed [10] that Late Precambrian complexes developed here were dislocated under conditions of SW- to NE-oriented compression. It is significant to note the following facts: (1) the direction of compression, the strike of folds of Late Precambrian complexes of the WJL, and their vergence do not correspond in the least to the strike of the front of nappes of Scandinavian Caledonides (Fig. 3); (2) the early structural paragenesis in Late Precambrian complexes of the WJL is generally similar to that in Pre-Uralides–Timanides of the Enganepe Uplift.

CONCLUSIONS

The structural paragenesis of Pre-Uralides–Timanides of the Enganepe Uplift and its similarity with parageneses in Late Precambrian complexes of the WJL indicate that relicts of the northeastern limb of the Cambrian Pre-Uralide–Timanide orogen are exposed in both spatially isolated parts of the northeastern framing of the EEP. The Enganepe Uplift represents the core of the Hercynian anticline of the same name, whereas the protrusion of Late Precambrian complexes of the WJL represents a window (antiform core) where these complexes protrude Caledonide nappes.

The vergence of folds and faults of Pre-Uralides–Timanides in the Srednii and Rybachii peninsulas [5, 14], Kanin Nos [12] Peninsula, and the Timan zone of the PP basement [7] is a mirror-type reflection of folding of Late Precambrian complexes of the Enganepe Uplift and WJL. Thus, the vergence characterizes the southwestern and northeastern limbs, respectively, of the wide divergent Cambrian (collisional orogenic) belt of Pre-Uralides–Timanides.

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