ISSN 1068-7971

RUSSIAN GEOLOGY AND GEOPHYSICS

ГЕОЛОГИЯ И ГЕОФИЗИКА

1-2

Vol. 44, 2003

Special Issue

Relationships between Structures of the Urals, Kazakhstan, Altai-Sayan Region, and Basement of West Siberian Plate with Regard to Petroleum Potential

Siberian Branch, Russian Academy of Sciences/Novosibirsk

Russian Geology
and Geophysics
Vol. 44, No. 1-2. pp. 28-39, 2003

Geologiya
i Geofizika
UDC 551.24

URALIDES AND TIMANIDES: THEIR STRUCTURAL RELATIONSHIP AND POSITION IN THE GEOLOGIC HISTORY OF THE URAL-MONGOLIAN FOLD BELT

V.N. Puchkov

Institute ofGeology ofthe Ufa Research Center ofthe RAS, 16/2 ul. K. Marksa, Ufa, 450000, Russia

We substantiate theoretically that the Paleozoic-Early Mesozoic Ural-Pai-Khoi-Novaya Zemlya fold belt recognized as Uralides are not analogous to Hercynides (Variscides) and the preceding Late Vendian Timan folded structures and lower structural units of the Urals recognized as Timanides are not analogous to Baikalides. Uralides and underlying Timanides are noticeably distinguished from the other rocks of the Ural-Mongolian fold belt. The Ordovician rifting and subsequent drift of continents, resulted in the Paleouralian ocean, seriously disturbed the initially intimate relationship between Timanides and European Cadomides and brought the former into a closer proximity to Baikalides, which formed at a different time. The subsequent evolution of Uralides also proceeded mainly in antiphase with more eastern, initially remote parts of the Ural-Mongolian belt. However, from Carboniferous to Middle Jurassic, during the formation of Pangea, the East European, Kazakhstanian, and Siberian continents underwent collision, and new intimate structural relationships were established within the Ural-Mongolian fold belt

Rifting, continental drift, Uralides, Timanides, Ural-Mongolian fold belt

INTRODUCTION. URALIDES AND TIMANIDES

Uralides form a continuous fold belt, which originated at the place of the Paleouralian ocean as a result of diachronous collisional processes that started in the Late Devonian and terminated in the Jurassic.

The term "Uralides" has come into wide use just recently and owes its acceptance to a special program designed by the EUROPROBE Commission, which started about 10 years ago and was initially called "Uralides and Variscides". Later on, the logo was reduced to "Uralides" [1]. The new name discredits the traditional identification of the Urals as a Variscan, or Hercynian folded system, but we think there are good reasons to use it. Comparison, of the evolution of the Uralian orogen and Variscides/Hercynides of Western and Central Europe distinctly showed significant differences in the prehistory, duration, and character of collisional orogenic processes there.

The formation of Hercynides in Central Europe (the name "Hercynides" comes from the Harz Mountains) was preceded by two Caledonian collisions (identified as the Taconian and Acadian phases), which closed the Iapetus and Rheic oceans, and by rifting -and spreading, during which the Rhenohercynian (Devonian) ocean basin formed. The orogenic collision stage of formation of Variscides in Central Europe started in the Famennian and was accompanied by the formation of flysch. The latter permanently accumulated till approximately the late Early Carboniferous and then gave way to Middle-Late Carboniferous molasses: The continent-island-arc collision was quickly changed by continental collision, thus favoring continuity of the collisional process. In the Permian, subsequent volcanism and platform syneclises developed, and in the Triassic, red-colored molassoids formed. The Permo-Triassic events (perhaps, except for those in the earliest Permian) were not directly related to the formation of Variscides (i.e., to the Variscan collision and folding) but were caused by block deformations and postorogenic extension [3], i.e., by German-type deformations. In the Triassic, the European-Appalachian folded system was superimposed by grabens, whose development led, in particular, to the formation of the Atlantic Ocean [2-6]. The early Kimmerian movements in Central Europe are expressed as the "Old Kimmerian major discordance" in the basement of the Upper Keuper [7] (i.e., in the upper beds of the Upper Triassic), which, however, does not exceed 2° and rules out orogeny at this level. Thus, the Variscan orogenic movements related to folding and collision proceeded during the Famennian-Late Carboniferous.

On the western slope of the Southern Urals there are no signs of the Caledonian orogeny. The tectonic cycle here lasted much longer (it started in the Late Cambrian-Ordovician). Collisional processes were also more prolonged. In the Southern Urals, continent-island-arc collision, accompanied by the formation of flysch, started in the Famennian and terminated by the Early Carboniferous, but after a break, it resumed as continent-continent collision in the Middle Carboniferous (in the Northern Urals the accumulation of flysch and, correspondingly fold-thrust deformations started as late as the Early Visean). The accumulation of flysch ended by Kungurian time, giving way to salt and molasses. Collision, orogeny, and Alpine-type folding in the marginal zones of the Urals were still intense in the Late Carboniferous and Early Permian and attenuated as late as the end of the Permian (Upper Permian series in the marginal trough was still dislocated). Then, in the Early Triassic, new intense orogenic (but already rifting-related) processes, volcanism, and formation of molassoids took place. The last (Early Kimmerian) fold and thrust dislocations occurred in the Urals in the Early Jurassic [8-10].

The differences become still more distinct provided that the Pai-Khoi-Novaya Zemlya fold belt is considered part of Uralides. This zone is connected with the Urals by the latest Late Kimmerian continuous folded structures whereas the older Paleozoic collisional structures are absent here. This interpretation of Uralides is alternative to the recently proposed recognition of Pai-Khoides [11].

Nevertheless, the drastic difference between the seemingly related fold belts is not so unexplainable. The plate tectonics indicates that the stages of folding are not necessarily recognized from angular discordances because they were, as a rule, not momentary but prolonged. In addition, most of the tectonic stages and cycles had a regional rather than global character, and tectonic events and their change and duration were specific in each fold belt and even varied within a belt [12].

Distinguishing Uralides or other similar fold belts does not hamper recognition of long epochs of folding (Cadomian, Salairian, Taconian, Variscan, Early Kimmerian, etc.) in the history of fold belts, which are important for correlation of geodynamic processes and compilation of tectonic maps. It just emphasizes the uniqueness of each folded system and refines the duration and diachronous character of collision-folding processes taking place in the systems.

For the same reasons there is a tendency now to change the name of the Late Vendian fold belt preceding Uralides. Instead of the amorphous term "pre-Uralides" or the inexact and too general term "Baikalides" it is proposed to return to the proper name "Timanides" put forward by Shatsky [13]. This does not contradict the statement that Timanides are the result of folding nearly synchronous to the Cadomian one [8, 9, 14-16].

A great body of literature data that has appeared in recent years provides for a new insight into the structural relations in the Urals and other fold belts. Study of this problem should be started with the oldest fold belt, Timanides.

POSITION OF TIMANIDES IN THE LATE VENDIAN CONTINENTAL STRUCTURE

One of the major questions in study of the structural relationship of Timanides is whether there existed a supercontment (Pannotia, Vendia, Panterra) larger than Gondwana in the Late Vendian. Dalziel [17] was the first to suggest that in the late Proterozoic, after the break-up of the Rodinia supercontinent, all continents joined again for a short time. Later on, Nance and Murphy [18] returned to this idea and emphasized that the Gondwanan part of the presumed supercontinent Vendia was formed by Pan-African orogeny and was rimmed along the North African margin by Cadomian orogen. Puchkov [8, 19] reported on relics of Late Vendian fold belts (600-540 Ma) coeval with the Pan-African and Cadomian ones which have been preserved in the Urals and on the Taimyr Peninsula. He suggested the existence of more intimate relationships of Gondwana with Baltica and Siberia and considered them a single supercontinent, Panterra.

Nevertheless, most researchers concerned with the paleogeography of the Neoproterozoic and the history of supercontinents are only agreed that in the Vendian, some continents collided with each other, which led to the Pan-African orogeny and folding and the formation of Gondwana, with a Cadomian orogenic belt on its northern margin. At the same time, they believe that in the Vendian, Laurentia and the East European and Siberian continents (Baltica and Siberia) were located far from Gondwana and were separated from it and each other by oceans [20-22]. These reconstructions also show that the Paleouralian ocean formed in the Precambrian, which contradicts numerous data which I present below.

Comparison of the apparent pole ways for Laurentia and Baltica indicates that these paleocontinents were in contact with each other from the time of the formation of Rodinia to at least 620-630 Ma. Their apparent pole ways became obviously separated by 580 myr. These data agree with the ages of dike complexes in the nappes of Scandinavian Caledonides and in their foreland (580-650 Ma), including those breaking through the Vendian Varanger series with tillite-like conglomerates [21, 23]. They also conform to the early hypotheses of geologists that the Scandinavian part of the Iapetus ocean formed in the latest Proterozoic [24].

The absolute ages of rift igneous formations in the more southern part of the continental margin of Laurentia, corresponding to the modern Appalachia and Ouachita, partly coincide with the dates of Scandinavian dike complexes, but the other are older (730-550 Ma). This area has graben formations, including Lower and Upper Vendian terrigenous complexes and volcanic rocks. Bathyal complexes of passive continental margin (and, probably, ocean basin) here formed no later than the Early Cambrian [23, 25-27]. In general, the lapetus ocean was, most likely, opened no later than in the Vendian, at about the time of the Pan-African-Cadomian orogeny.

The southwestern (in modern coordinates) boundary of Baltica, known as the Teysseyre-Tornquist line (zone), might also have formed in the Late Vendian. This is evidenced by the widespread Volynian (Late Vendian) basalts and terrigenous sediments on the continental side of this margin (parallel to it). Their formation was followed by the origin of a passive continental margin in the Cambrian-Early Devonian and the change of shallow-water sediments by deep-water ones toward the inferred "Teysseyre ocean". Comparison of geological, paleobio-geographic, and paleomagnetic data for Baltica and the inferred terranes west of it [28-34] also supports the above hypothesis. Thus, Laurentia could not have been part of the Late Vendian continent because the lapetus ocean and, partly, the Teysseyre ocean formed earlier in the Vendian and divided it from Baltica. Nevertheless, recent investigations have revealed relics of the Cadomian orogen along the southern part of the Teysseyre-Tornquist margin (Upper Sudety-Malopolska-Dobrogea) (Vendian molasses contain zircons dated to 600-550 Ma; beneath them the continental basement is traceable [35-37]).

Data on the age of the southern margin of Baltica are rather scarce. With regard to the young age and spreading genesis of the Black Sea basin, of special interest are data on the Cadomian granites in northwestern Turkey. The relationship between the Precambrian basement and Paleozoic strata is best pronounced in the core of the Great Caucasus anticlinorium [38]. For example, in the Laba-Malka zone, Ordovician-Early Silurian sandstones, underlain by conglomerates with fragments of Cambrian archaeocyatid limestones, lie (with angular unconformity) over greenschists of the Baikalian (Cadomian?) basement. The Paleozoic sediments of the autochthone are overthrust by Ordovician?-Early Silurian ophiolites. From this and other exposed fragments of the Precambrian-Paleozoic basement we can assume that the area has preserved the Precambrian tectonic features typical of Central Europe. Nevertheless, it is unclear whether or not this margin itself was part of the Cadomian orogen.

The evolution of the eastern (Uralian) continental margin of Baltica has been sufficiently well studied [8, 24, 39]. The margin resulted from the destruction of a larger continent in the Late Cambrian-Early Ordovician. The Tremadoc sediments have well-pronounced features of graben formations. Rift zone originated on the Timanide structures (analogs of Cadomides) with a pronounced azimuthal unconformity and evolved into oceanic-spreading zone as early as the Arenigian. The pre-Uralian orogen is characterized by an incomplete structure even where azimuthal unconformity is absent (the southern half of the western slope of the Urals has preserved only externides of Timanides — the foreland of this orogen and, perhaps, a small terrane; neither ophiolites nor subduction complexes are present here [8, 16]). East of the Tagil-Magnitogorsk zone, the terranes constituting the eastern slope of the Variscan Urals preserve relics of Early Proterozoic blocks (after zircon dating [40]). but in general, their crust is relatively young (Early Proterozoic, according to some isotope ratios [41]). It is quite possible that these relics are fragments of the Cadomian orogen.

The evolution of the northern Paleozoic margin of Gondwana has much in common with that of the Uralian margin of Baltica. Numerous geological, biogeographic, and paleomagnetic data confirm that the Cadomian fold belt which rimmed the African part of Gondwana in the early Early Paleozoic was subjected to rifting in the Late Cambrian-Early Ordovician. This event, inferred from the presence of specific volcanogenic and terrigenous graben facies in the region, was followed by oceanic spreading and the formation of the Paleo-Tethys ocean (or Rheic ocean) and several microcontinents, which are often united into Avalonia (sometimes with separation of Western Avalonia and Eastern Avalonia) and Armorica. The latter also consists of individual terranes; therefore, some researchers distinguish the Armorican terrane association (ATA) or the Armorican archipelago. As in the Urals, the graben facies here evolved most intensely in the Tremadoc [42]. It is widely believed (though I do not support this hypothesis) that the taphrogenic margins and microcontinents resulted from splitting-off of part of the Gondwana margin rather than from break-up of a larger supercontinent [32-34].

The margins of the Siberian continent, like those of all other continents, are diachronous. The western periphery (in modern coordinates) is made up of Late Riphean and Vendian-Cambrian ophiolites and island-arc formations, indicating that the margin was open toward the Asian paleo-ocean in the mentioned epochs. As early as the Late Precambrian, it became wider as a result of collisions which produced the epi-Baikalian part of the Siberian Platform [43, 44]. The southern margin can be traced along the Dzhagdy-Tukuringra zone, where thick deep-water sedimentary and volcanosedimentary strata, indicating at least the suboceanic genesis of the zone, formed in the Cambrian and, partly, in the Ordovician. Parallel to it, Khain [43] traces the Late Vendian-Early Cambrian Transbaikalian-Okhotsk ophiolite belt. The Ordovician granite volcanism and evolution of molasses on this continental margin might have been related to the Salair phase of folding [45].

The eastern margin of the continent is concealed to a great extent by younger sediments. Its geology is of special interest because, according to paleomagnetic data, this margin faced Baltica in the Early Paleozoic. I treated its geology based on the hypotheses of the oceanic nature of the Alazei-Oloi megazone proposed by Natapov et al. [46] and Merzlyakov [47]. In the south and in the west, this zone borders the Yana-Kolyma megazone, most part of which hosts Cambrian and Ordovician shelf sediments similar to those of the Siberian Platform. The Ordovician shelf sediments rest upon the eroded surface of Cambrian and Precambrian deposits. In the Kolyma massif, there is an angular unconformity between the Lower Ordovician and Precambrian strata. At the boundary of the above-mentioned megazones (in the marginal uplifts of the Kolyma loop), Ordovician shelf facies pass into bathyal ones, containing subalkaline volcanics. This evidences that the eastern continental margin originated by the Early Ordovician [45, 48]. Recently, additional support for this has appeared [49]: Rift sedimentary and igneous complexes of Cambrian-Ordovician age have been distinguished in the Kharaulakh and Sette-Daban.

The northern margin of the Siberian continent is still unclear. In recent years, it has been assumed that Severnaya Zemlya (North Land) belonged to the individual Kara continent, or terrane [50]. This hypothesis was corroborated by paleomagnetic data [51], showing that, originated in the late Cambrian-Early Ordovician, the Kara terrane moved, rotating, as an independent continent (or as part of Baltica?) frome temperate southern latitudes to north until it collided with the Siberian continent in the Carboniferous. In this context, the bathyal zone that existed on Taimyr from Late Cambrian to Early Carboniferous [45] can be regarded not as an aulacogen but as the margin of the Siberian continent or as a zone parallel to this margin, which resulted from rifting in the Late Cambrian-Early Ordovician.

In general, it becomes clear that there were two stages of continental break-up in the Late Precambrian-Early Paleozoic: (1) The Late Riphean-Vendian stage, which determined the shape of Laurentia and, partly, Baltica (as shown above, it took place in the Appalachians, Greenland, Scandinavia, and, partly, in the Teysseyre-Tornquist zone). It manifested itself synchronously with rifting on the northeastern periphery of Gondwana, resulting in a series of terranes, which were later attached to the Kazakhstan continent and the Altai-Sayan region [44]. (2) The Late Cambrian-Early Ordovician stage, which took place on the southwestern, eastern, and southern(?) margins of Baltica, on the northwestern margin of Gondwana, and on the eastern and northern margins of Siberia. These two stages were related to the break-up of Rodinia and Panterra, respectively. The hypothesis of the synchronous Late Cambrian-Early Ordovician splitting-off of the margins of three remote continents rather than the break-up of one continent can be put forward but looks rather awkward.

The question of the existence and the shape of a Late Vendian supercontinent can be resolved based on paleotectonic reconstructions for 600-550 Ma — the assumed period between its formation and break-up.

The performed reconstruction for 550 Ma, refining my earlier hypotheses [8, 52] (Fig. 1), does not contradict the available paleomagnetic data and results of the new studies. To determine the position of Baltica at the end of this time, Didenko et al. [22] interpolated the dates between 580 and 480 Ma. Popov [53] studied paleomagnetism of the Vendian deposits of the Zimnii (Winter) coast of the White Sea (553±0.3 Ma, U-Pb dating), taking into account paleoclimatic and paleobiogeographic indicators, and placed Baltica into the low to temperate southern latitudes. The position of the Siberian continent was refined from data in [54]. When drawing the position of Baltica, however, we were based first of all on geological rather than paleomagnetic data.

If the above reasoning is true, then the structural relationships between Timanides are determined mainly by their temporal (600-550 Ma) and spatial proximity to the Late Vendian Cadomides of northwestern Gondwana. Possibly, their analogs are present in the subsided basement of the eastern (in modern coordinates) margin of the Siberian continent, which faced Baltica in the Vendian, and on Taimyr. Timanides are in no way related to the Vendian structures of the western margin of this continent which approached them in the Late Paleozoic or to the Precambrian terranes of Kazakhstanides. Moreover, these structures evolved in antiphase with Timanides (see below). Thus, the initially very intimate spatial relationships of Timanides with coeval fold belts were seriously disturbed by the Early Paleozoic rifting, which led to drift and rotation of continents. As a result of Paleozoic geodynamic processes, Timanides approached alien Late Proterozoic structural zones. We do not dwell here on the question of the origin of the East Uralian microcontinent because the available data on this subject are as yet scarce.

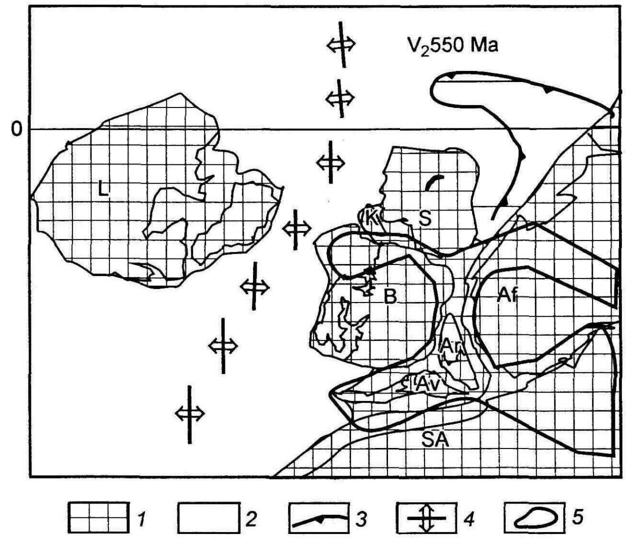

Fig. 1. Reconstruction of continents for 550 Ma (late Vendian) (after [52], with minor changes). ***1*** **— continental crust;** ***2*** **— oceanic crust;** ***3*** **— subduction zones;** ***4*** **— mid-ocean rifts (MOR); 5 — collision zones. Letters stand for continents; continental blocks, microcontinents, and their groups within the supercontinent: B — Baltica, S — Siberia, L — Laurentia, Af — Africa, SA — South America; Av — Avalonia, Ar — Armorica, K — Kara microcontinent**

URALIDES AND THEIR RELATIONSHIP WITH OTHER STRUCTURES OF THE URAL-MONGOLIAN FOLD BELT

As mentioned above, the formation of the fold belt of Uralides started in the Late Devonian with collision of the Magnitogorsk island arc and the passive margin of the East European continent. This was preceded by a series of geodynamic events described below [8].

1. The Late Cambrian-Early Ordovician. A linear rift system originated on Timanides, cutting them with a dramatic azimuthal discordance. Rifting was quickly followed by oceanic-floor spreading, which led to the formation of the Paleouralian ocean. At the same time a passive continental margin formed, which existed till the beginning of collision.

2. The Late Ordovician-Early Devonian. Origin and evolution of the Tagil island arc. The arc lived till the Early Devonian and probably was part of the same subduction zone that existed in the lapetus ocean and led to its closure. The subduction zone jammed, and this might have resulted in jumping of the arc within the Paleouralian ocean. In the Early Devonian, the volcanic activity of the Tagil arc gradually attenuated, and a carbonate shelf with accumulating bauxites formed on it. But these events are difficult to reconstruct in detail. We can just say that in the Urals there were no serious collisional events synchronous with the Salair and Taconian ones.

3. The late Early Devonian-early Late Devonian. Origin and evolution of the Magnitogorsk island arc, which cut the Tagil arc at an acute angle and partly incorporated it as a terrane, north of the Ufa amphitheater.

Then the events developed as follows (Fig. 2). As a result of subduction, directed from the East European continent, the sector of its passive margin corresponding to the South and Central Urals came into intimate contact with the Magnitogorsk island arc, thus initiating continent-arc collision. This event was described in detail in [8, 9, 55, 56]. It produced the southern segment of the oldest suture zone of Uralides, the Main Uralian Fault. The collision was accompanied by the formation of an accretionary complex, composed of a series of ophiolitic tectonic sheets, eclogite-glaucophane-schist metamorphic complex, and flysch (all the components of the complex were syngenetic to the collision) as well as by bathyal sediments stripped off the passive margin and thrust over the flysch. It resulted in jamming of the subduction zone and its jump to a new place. The latter was determined by the development of Early Carboniferous calc-alkalic series of the Transuralian Valerianovka, Aleksandrovka, and Tur'ya zones; according to geochemical data, the new subduction zone had a western dip [57]. The distinct rift character of contrasting subalkaline volcanic series of the Magnitogorsk synclinorium marks a zone of back-arc,

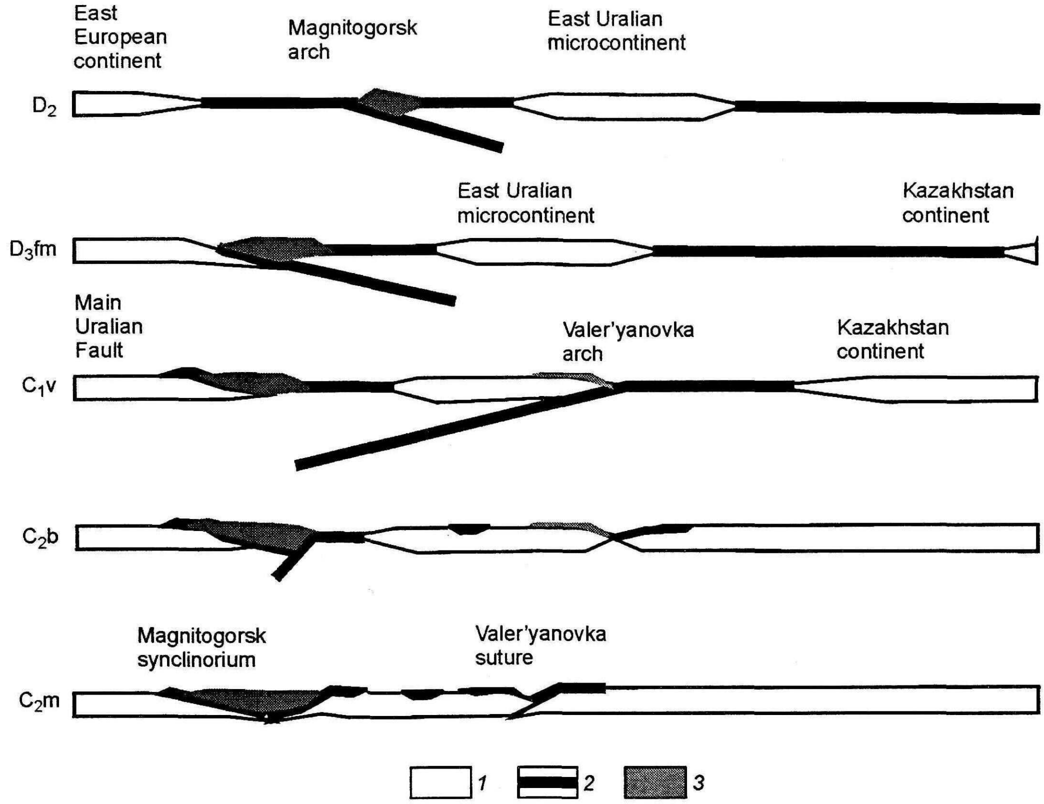

Fig. 2. Geodynamic profiles across the South Urals for the period from Middle Devonian to Middle Carboniferous (position of the profiles is shown in Fig. 3). ***1*** **— continental crust; 2 — oceanic crust and ophiolites in island-arc and continental crust;** ***3*** **— island-arc crust and island-arc complexes in continental crust. D_2 — Middle Devonian, D_3fm — Famennian, C_1V — Visean, C_2b — Bashkirian, C_2m — Moscovian.,**

or suprasubductional, extension [8] (Fig. 2). When collision of the East European and Kazakhstanian continents began in the Middle Carboniferous, this subduction zone became a suture separating Uralides from Kazakhstanides. Its position is projected beneath the axial part of the Turgai trough, where ultramafic massifs might have developed [58]. The existence of this subduction zone, most likely, predetermined the bivergent character of the Uralian orogen [59].

In the northern direction, the suture is traceable in the basement of the West Siberian Plate (ultramafic massifs have been distinguished near the cities of Tyumen' and Khanty-Mansiisk) and supposedly goes parallel to the structures of the exposed Urals along the western margin of the Mansi massif, where it joins the Ob'-Zaisan suture (Fig. 3).

In the southern direction, the Valerianovka suture passes to join the southern Tien Shan (North Fergana) suture. Prior to the junction, it must inevitably join the Main Uralian and East Magnitogorsk Faults because of the limited extension of the Magnitogorsk and East Uralian terranes.

The North Fergana suture was related to the subduction zone dipping northward [60]. This suggests its synvergent junction with the Valerianovka suture through a dextral transform fault, as follows from Tevelev's classification of shear zones [61]. This fault, if it exists, is hidden beneath the Meso-Cenozoic sediments of the Syrdar'ya basin.

Uralides are part of the Ural-Mongolian belt. Apparently, this should suggest their intimate relation to the other structures of the belt. But in fact, the situation is much more intricate. Considering the structural relations and correlation of the events during the tectonic evolution of Uralides and more eastern structures of the belt (i.e., on different sides of the Valerianovka suture and its continuity), we must note that initially, the early structures involved into Uralides might have occurred at great distances from all other structures and developed in antiphase

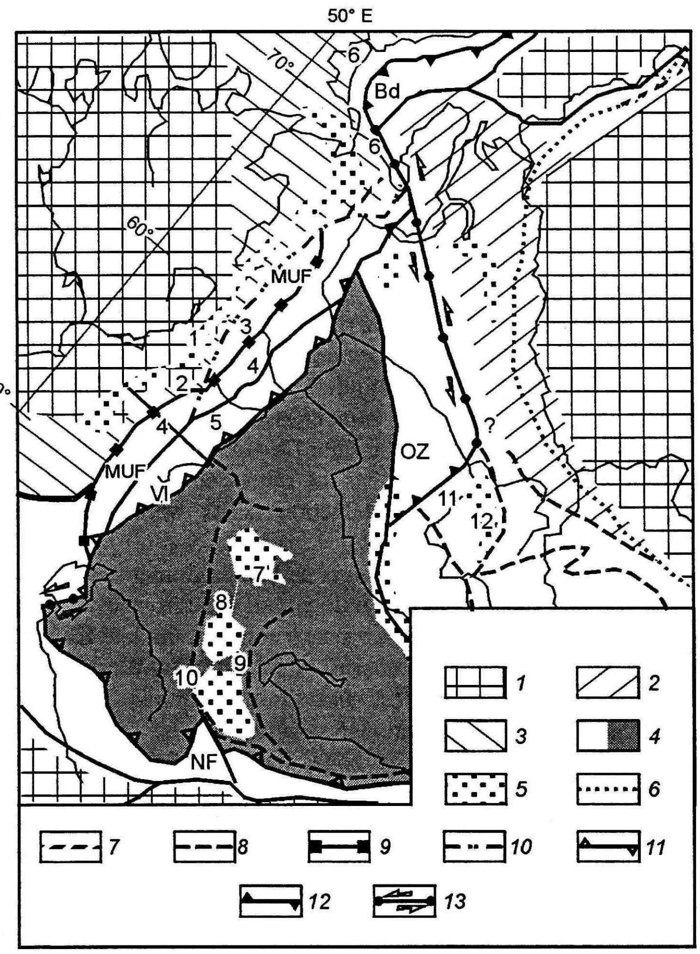

Fig. 3. Recent relationship of Uralides with Kazakhstan, Tien Shan, and Siberian structures. / — blocks of Archean-Early Proterozoic consolidation; 2 — Baikalides (area of predominantly Late Riphean-Early Vendian collision and folding); *3* — Timanides (area of Late Vendian collision and folding); *4* — structures of the Ural-Mongolian belt (area of Paleozoic and Early Jurassic collisions and folding). The Kazakhstan continent is hatched. Fold-thrust structures of forelands opposite to the Ob'-Zaisan and Main Uralian suture zones are not shown. 5 — Late Paleozoic molasses. *6-12* — suture zones (including the inferred ones): *6* — Late Riphean-Early Vendian; 7 — Late Vendian; *8* — Cambrian and Ordovician; *9* — Late Devonian; *10* — Early Visean; *11* — Middle Carboniferous faults (triangles show a dip for the Valerianovka and North Fergana sutures); *12* — Early Jurassic (triangles show a dip); *13* — inferred transform faults with the direction of movement Letters stand for suture zones: VI — Valerianovsk, MUF — Main Uralian Fault; NF — North Fergana; OZ — Ob'-Zaisan; Bd — Baidarata. Numbers stand for structural zones, 1-6: structural zones of Uralides. 1 — cis-Uralian foredeep; 2 — Central Ural zone; 3 — terrane of the Tagil island ark; 4 — terrane of the Magnitogorsk island arc; 5 — terrane of the East Uralian microcontinent and accretionary prism of the Valerianovka subduction zone; 6 — Pai-Khoi-Novaya Zemlya folded zone. 7-10: structural zones within the Kazakhstan continent 7-9 — molasse depressions: 7 — Teniz, 8 — Dzhezkazgan, 9 — Sarysu. 10 — Karatau zone of Late Paleozoic folding. 11 — Tom'-Kolyvan' zone of presumably Early Kimmerian folding. 12 — Late Paleozoic-Early Mesozoic Kuznetsk molasse trough.

with them. It is true that the Late Riphean taphrogenic structures and ophiolites were revealed not only in the Taimyr-Altai-Sayan belt and Kazakhstanides but in the northern Urals as well [9]. However, the epi-Baikalian framing of the Siberian continent, formed mainly by the Late Vendian, and the Late Vendian sediments in the

Baikal region are represented predominantly by carbonates and evaporates [62]. On the other hand, Timanides formed just in the Late Vendian, i.e., nearly synchronously with Cadomides. At the time when Timanides and Cadomides underwent collision and folding, grabens transformed into terranes of Central Kazakhstanides and the Altai-Sayan folded area. They originated no later than the early Vendian; later on, the Vendian graben facies gave way to Early Paleozoic deep-water sediments, whereas in the Urals there are no Cambrian deep-water sediments at all [25, 63].

In the Urals, there is no Cambrian (Salair) folding, whereas it is widespread on the southwestern and southern periphery of the Siberian continent [44, 45] and, on a smaller scale, in Kazakhstanides, where the collision of the Cambrian Boshchekul island arc with the Kokchetav microcontinent probably gave rise to diamondiferous eclogites [64-66]. The intense Late Cambrian-Early Ordovician rifting, which produced the passive margin of the East European continent [25], had no comparable manifestations in more eastern regions of the Ural-Mongolian belt. On the contrary, the latter were involved in the Middle-Late Ordovician (Taconian) folding, which actively participated in the formation of the Kazakhstanian continent and accretion of the Siberian continent. As for the Urals, the Taconian phase was not expressed there. The Late Devonian collision of the passive margin of the East European continent and the Magnitogorsk island arc over the subduction zone dipping from it have no analogs in the more eastern regions of the belt, where the subduction zones were inclined beneath the Siberian and Kazakhstanian continents.

In the Carboniferous the structures of the Ural-Mongolian belt agglomerated. At that time, the Kazakhstanian continent was pushed into the oceanic space between Baltica and Siberia, and their joint collision began, which led to the formation of the Valerianovka and Ob'-Zaisan suture zones in the late Early Carboniferous-early Middle Carboniferous. The sutures were not the absolute boundaries of folded belts. West of the suture of the Main Uralian Fault, there are the cis-Uralian foredeep, and West and Central Uralian structural zones belonging to the comparatively surficial, often thin-skinned deformational structure of the fold-thrust foreland belt. East of the Valerianovka zone and north of the North Fergana zone, the Late Paleozoic orogeny resulted not only in block-shaped but also in east-vergent Alpine-type thin-skinned deformations (as, e.g., in the Bolshoi Karatau Mountains [67]) homologous to fold and thrust foreland structures. In addition, a chain of Carboniferous-Permian molasse troughs (Teniz, Dzhezkazgan, and Sarysu) homologous to a foredeep formed. The structure of the Kazakhstanian continent, in turn, might have affected the processes in Uralides. For example, a specific feature of Uralides is extraordinary, atypical of the world's Paleozoic belts, preservation of island arcs. In particular, the Magnitogorsk arc contains even relics of arc structural zones [8]. This may be due to the minor rigidity of the crust of the young Kazakhstanian continent.

The Ob'-Zaisan suture at the boundary of Kazakhstanides with Rudny Altai is expressed as a zone of Carboniferous olistostromes, ophiolitic melange, and nappes (its description and references on this topic are given in [45]). To the north, the suture is traceable as far as the mid-Ob' region, where ultramafic rocks were found [68]. Farther north, it must join the Valerianovka zone, where Uralides, Kazakhstanides, probably, Salairides, and, most importantly, the epi-Baikalian part of the Siberian continent meet. This follows from drilling and seismic data obtained in the vast region west of the Yenisei [68-70]. A somewhat similar, though specific, concept of the Paleozoic tectonics of the West Siberian basement was proposed in [71]: (1) The Paleozoic tectonogenesis in West Siberia had an antiplate character. There was no oceanic crust as a whole in the region, and its fragments — spatial sectors — piled up and moved in the vertical direction only with squeezing of "excessive" terrigenous-igneous matter from orogen onto cratons in all directions. (2) It was established that the orogen was spreading laterally as a result of orogeny in the adjacent parts of the cratons. I do not agree with the first conclusion. The plate-tectonic mechanism of formation of the fold belts that submerge beneath the West Siberian cover in the northern direction casts no doubt. In the covered part of the region, the existence of these belts can only be inferred from data of rare boreholes. As for the second statement, the location of the largest Late Paleozoic molasse basins (Fig. 3) actually evidences that in the Late Paleozoic, the entire area of Paleozoides and adjacent cratons was involved in orogeny, which united different structures of the Ural-Mongolian belt.

North of the triple junction of the above-mentioned suture zones, the Siberian and East European continents seem to come into immediate contact along an unnamed (Baidarata?) suture zone, which, most likely, passes along Baidarata Bay parallel to the Pai-Khoi and then along the bend of the Novaya Zemlya fold belt. This zone might have formed only during the Early Kimmerian collision as a result of dislocations in the still weakly consolidated structure of Pangea. Figure 3 also shows the hypothetical relation between the Early Kimmerian dislocations in Novaya Zemlya and the Tom'-Kolyvan' folded zones through a transform fault.

CONCLUSIONS

Uralides and preceding Timanides occupy a special position in the Ural-Mongolian belt. The Ordovician rifting and subsequent drift of continents, which gave rise to the Paleouralian ocean, seriously disturbed the initially intimate relationship between Timanides and Cadomides. As a result, Timanides were brought into proximity with Baikalides differing slightly in age from them. The subsequent evolution of Uralides until the Devonian also proceeded mainly in antiphase with more eastern parts of the Ural-Mongolian belt. From Carboniferous to Middle Jurassic, during the formation of Pangea, the East European, Kazakhstanian, and Siberian continents underwent collision, and new intimate structural relationships were established within the belt.

Thus, the popular concept that Altaides are a single geodynamic system that has included the Ural structures since the Early Paleozoic [7 2] seems to be oversimplified and contradicting the actual facts. Uralides evolved independently of other structures situated east of them for a long period - till the early Middle Carboniferous; therefore, they can be distinguished as an individual structure. But the hypothesis of the oroclinal bend and squeezing of Kazakhstanides between the Siberian and East European cratons in the Late Paleozoic [72, 73] is certainly worthy of attention.

This paper is published within the limits of the terminating program "Uralides" of the EUROPROBE Commission. The work was financially supported by grant ICA2-CT-2000-10011 from the MinUrals Project of the European Community.

REFERENCES

1. Gee, D., and I.M. Artemieva (Eds.), *EUROPROBE 1992-2000,* 18 pp., Uppsala University, Sweden, 2000.
2. Lützner, H., F. Falk, and J. u. a. Ellenberg, Ubersicht über die Variszische Molasseentwicklung in Mitteleuropa und am Ural, Z *Geol. Wiss., Berlin,* 9, 1157-1167, 1979.
3. Schwab, M., The Harz Mountains, in *Sedimentary and tectonic structures in the Saxoturingian and Rhenohercynian Zones. Guidebook of Excursions,* 34-77, Central Inst. for Physics of the Earth, Potsdam, 1984.
4. Sheridan, R.E., The Atlantic passive margin, in *The Geology of North America — an overview,* 81-96, Boulder, USA, 1989.
5. Khain, V.E., *Tectonics of continents and oceans (2000)* [in Russian], 606 pp., Nauchnyi Mir, Moscow, 2001.
6. Franke, W., The Mid-European segment of the Variscides: tectonostratigraphic units, terrane boundaries and plate tectonic evolution, in *Orogenic processes: quantification and modelling in the Variscan belt. Geol. Soc. Spec. Publ., London,* 35-61, 2000.
7. Beutler, G., Verbreitung und Charakter der altkimmerischen Hauptdiskordanz in Mitteleuropa, Z. *Geol. Wiss., Berlin, 5,* 617-632, 1979.
8. Puchkov, V.N., *Paleogeodynamics of the South and Central Urals* [in Russian], 146 pp., Dauriya, Ufa, 2000.
9. Puchkov, V.N., Structure and geodynamics of the Uralian orogen, *Orogeny through time. Geol. Soc. Spec. Publ. No. 121, London,* 201-234, 1997.
10. Alvarez-Marron, J., Tectonic Processes during Collisional Ore Genesis from Comparison of the Southern Uralides with the Central Variscides, in *Mountain building in the Uralides: Pangea to the Present. AGU Geophys. Mono. Series,* 132, 60-72, 2002.
11. Yudin, V.V., *Orogeny in the northern Urals and Pai-Khoi* [in Russian], 286 pp., Nauka, Ekaterinburg, 1994.
12. Puchkov, V.N., Tectonic phases and cycles in the context of plate tectonics, *Geotektonika,* 4, 90-94, 1994.
13. Shatski, N.S., Major features of the structure and evolution of the East European Platform. Comparative tectonics of ancient platforms, paper 1, in *Academician Shatski. Selected works. Vol. 2* [in Russian], 369-425, Nauka, Moscow, 1964 (reprinted from *Izvestiya AN SSSR. Ser. Geol., 1,* 1946).
14. Gee, D., Overview of the Timanide orogen along the eastern margin of the East European craton, in *Abstr. of Joint Meeting of EUROPROBE TESZ, TIMPEBAR, Uralides and SW-Iberia Projects,* 19-20, METU, Ankara, 2001.
15. Puchkov, V., Preuralides, Timanides and the problem of the Late Vendian supercontinent, *ibid.,* 60.
16. Glasmacher, U., W. Bauer, U. Giese, P. Reynolds, B. Kober, V. Puchkov, L. Stroink, A. Alekseev, and A. Willner, The metamorphic complex of Beloretsk, SW Urals, Russia — a terrane with a polyphase Meso- to Neoproterozoic thermodynamic evolution, *Precam. Res.,* 110, 185-213, 2001.

17. Dalziel, I., On the organization of American plates in the Neoproterozoic and the breakout of Laurentia, *GSA Today*, 2, 11, 237-241, 1992.

18. Nance, R.D., and J.B. Murphy, Orogenic style and the configuration of supercontinents, in *Pangea: global environments and resources. Can. Soc. of Petroleum Geol, Memoirs 17,* 49-65, 1994.

19. Puchkov, V.N., Cadomides of the Urals and Taymyr: connections with Gondwanan Europe, in *Excursion Guide to Saxony, Thüringia, Bohemia: Abstracts. Schriften des Staatlichen Museums fur Mineralogie und Geologie zu Dresden*, 177-178, 1998.

20. Mossakovsky, A.A., Yu.M. Pushcharovsky, and S.V. Ruzhentsev, The spatial-temporal relations between the Pacific and Indian-Atlantic structures in the Late Precambrian and Vendian, *Dokl. RAN*, 350, 6, 799-802, 1996.

21. Torsvik, T.H., M.A. Smethurst, J.G. Meert, R. Van Der Voo, W. S. McKerrow, M. D. Brasier, B. A. Sturt, and H. J. Walderhaug, Continental break-up and collision in the Neoproterozoic and Paleozoic — a tale of Baltica and Laurentia, *Earth Sci. Rev.*, **40,** 229-258, 1996.

22. Didenko, A.N., S.A. Kurenkov, S.V. Ruzhentsev, V. A. Simonov, N. V. Lubnina, N. B. Kuznetsov, V.A. Aristov, and D. V. Borisenok, *Tectonic history of the Polar Urals* [in Russian], 191 pp., Nauka, Moscow, 2001.

23. Larson, S.A., The Sveconorvegian tectonic cycle — a review, in *Abstracts of the 31st IGC* [on CD], Rio de Janeiro, 2000.

24. Gee, D., A tectonic model for the central part of the Scandinavian Caledonides, *Amer. J. Sci.*, 275-A, 468-515, 1975.

25. Puchkov, V.N., *Bathyal complexes of the passive margins of geosynclines* [in Russian], 260 pp., Nauka, Moscow, 1979.

26. Rankin, D.W., A.A. Drake Jr., L. Glover, R. Goldsmith III, Leo M. Hall, D.P. Murray, N.M. Ratcliffe, J. Read, D. T. Secor Jr., and R. S. Stanley, Pre-orogenic terranes, in *The Geology of North America — The Appalachian-Ouachita orogen in the United Sates. Vol. F2,* GSA, 7-101, Boulder, Colorado, 1989.

27. Keppi, D.J., and R.D. Dallmeyer, *Tectonic map ofpre-Mesozoic terranes in Circum-Atlantic Phanerozoic orogens. IGCP Project 233,* Halifax, Nova Scotia, Canada, 1989.

28. Garetsky, R.G., The East European craton (EEC) adjoining the Tornquist-Teysseyre zone, in *EUROPROBE symposium, Jablonna,* 65-67, 1991.

29. Aleksandrowski, P., Pre-Variscan and Variscan terranes in SW Poland, in *Excursion Guide to Saxony, Thiiringia, Bohemia: Abstracts. Schriften des Staatlichen Museums fur Mineralogie und Geologie zu Dresden,* 93-95, 1998.

30. Lewandowski, M., Paleomagnetism of the Lower Palaeozoic rocks of the Holy Cross Mts: palaeo-geographic and geotectonic implications, in *EUROPROBE symposium, Jablonna,* 111-118, 1991.

31. Zeliaznievicz, A.F., Neoproterozoic orogen in southern Poland: Gondwanan or Baltican connection?, in *Excursion Guide to Saxony, Thiiringia, Bohemia: Abstracts. Schriften des Staatlichen Museums fur Mineralogie und Geologie zu Dresden*, 200-201, 1998.

32. Erdtmann, B.-D., Cambro-Ordovician evolution of the Northwestern Peri-Gondwana margin, in *Early Paleozoic evolution in N-W Gondwana. Serie Correlation Geologica,* 12, 85-106, 1996.

33. Paris, F., Palaeogeography of Northern Gondwana regions in the early Paleozoic: the verdict of the faunas, in *Excursion Guide to Saxony, Thiiringia, Bohemia. Abstracts. Schriften des Staatlichen Museums fur Mineralogie und Geologie zu Dresden,* 173-174, 1998.

34. Tait, J.A., M. Schatz, V. Bachtadze, and H. Soffel, Paleogeography of Paleozoic terranes in the Variscan and Alpine belt, *ibid.,* 192-193.

35. Zeliaznievicz, A., M. Grad, and A. Guterich, Late Proterozoic through Early Paleozoic crustal additions at the Teysseyre-Tornquist margin of Baltica: Geological and Geophysical data from Poland, in *Abstr. of Joint Meeting of EUROPROBE TESZ, TIMPEBAR, Uralides and SW-Iberia Projects,* 96-97, METU, Ankara, 2001.

36. Zeliaznievicz, A., A. Seghedi, M. Jachowicz, W. Bobinsky, Z. Bila, and S. Cwoidzinski, U-Pb SHRIMP data confirm the presence of a Vendian foreland flysch basin next to the East European craton, *ibid.,* 98-100.

37. Seghedi, A., T. Berza, M. Maruntiu, V. Iancu, and G. Oaie, Late Proterozoic-Early Paleozoic terranes of Moesia and surrounding orogenic belts, *ibid.*, 72-74.

38. Belov, A.A., *Tectonic evolution of the Alpine folded area in the Paleozoic* [in Russian], 212 pp., Nauka, Moscow, 1981.

39. Puchkov, V., Paleozoic evolution of the East European continental margin involved in the Uralide orogeny, in *Mountain building in the Uralides: Pangea to the Present, AGU Geophys. Mono. Series,* 132, 10-24, 2002.

40. Krasnobaev, A.A., V.M. Necheukhin, V.A. Davydov, and V.V. Sokolov, Zircon geochronology and

problem of terranes of the Uralian accretion-folded system, in *Uralian Collection of Mineralogical Works. No. 8* [in Russian], 196-206, IMIN RAN, Miass, 1998.

41. Popov, V.S., V.I. Bogatov, and D.Z. Zhuravlev, Possible sources of Hercynian granitic rocks of the Southern Urals: Sm-Nd and Rb-Sr isotope dates, in *Geology and prospects of widening the raw-material base of Bashkortostan and adjacent areas. Vol. 1* [in Russian], 168-172, IG UNTs RAN, Ufa, 2001.

42. Linnemann, U., V. Gehmlich, V. Tichomirowa, and B. Buschmann, Introduction to the Pre-Symposium Excursion (part I): the Peri-Gondwanan basement of the Saxothüringian Composite Terrane, in *Excursion Guide to Saxony, Thüringia, Bohemia: Abstracts. Schriften des Staatlichen Museums fur Mineralogie und Geologie zu Dresden,* 7-13, 1998.

43. Khain, V.E., The important regularity of evolution of intercontinental geosynclinal belts of Eurasia, *Geotektonika,* 1, 13-23, 1984.

44. Didenko, A.N., A.A. Mossakovskii, D.M. Pecherskii, S.V. Ruzhentsev, S.G. Samygin, and T.N. Kheraskova, Geodynamics of the Central-Asian Paleozoic oceans, *Geologiya i Geofizika (Russian Geology and Geophysics),* 35, 7-8, 59-75(48-61), 1994.

45. Puchkov, V.N., The Paleozoic Geology of Asiatic Russia and adjacent areas, in *Paleozoic of the World. Vol.B,* 3-110, Elsevier, Amsterdam-London, 1996.

46. Natapov, L.M., L.P. Zonenshain, V.S. Shul'gina, Geologic evolution of the Kolyma-Indigirka region and the problem of the Kolyma massif, *Geotektonika,* 4, 18-31, 1977.

47. Merzlyakov, V.M., *Geology of central regions of the northeastern USSR. Scientific report of ScD thesis* [in Russian], 32 pp., IgiG SO AN SSSR, Novosibirsk, 1986.

48. Bulgakova, M.D., *The Early Paleozoic in the northeastern USSR (sedimentological analysis)* [in Russian], 102 pp., YaNTs SO AN SSSR, Yakutsk, 1991.

49. Khudolei, A.K., and G.G. Serkina, The Early Paleozoic rifting on the eastern margin of the Siberian Platform: comparison of geological data and curves of tectonic subsidence of the basin bottom, in *Proceedings of the Meeting on tectonics and geophysics of lithosphere. Vol. II* [in Russian], 288-291, GEOS, Moscow, 2002.

50. Vernikovsky, V.A., Neoproterozoic and Early Paleozoic Taimyr Orogenic and Ophiolitic Belts, North Asia: A Review and Models for Their Formation, in *Proc. 30th Intern. Geol. Congr. Vol. 7,* 121-138, Beijing, 1997.

51. Metelkin, D.V., A.Yu. Kazansky, and V.A. Vernikovsky, A kinematic scenario for the evolution of the Kara plate in the Early Paleozoic, in *Paleomagnetism of rocks: theory, practice, and experiments. Abstracts* [in Russian], 39-41, Moscow-Borok, 2000.

52. Puchkov, V., Did the Late Vendian supercontinent exist?, in *Assembly and break-up of Rodinia Supercontinent: evidence from South Siberia,* 172-178, Irkutsk, 2001.

53. Popov, V.V., A.N. Khramov, and T.H. Torsvik, Paleomagnetism of Upper Vendian sedimentary rocks on the Zimnii coast of the White Sea, *Paleomagnetism of rocks: theory, practice, and experiments. Abstracts* [in Russian], 37-39, Moscow-Borok, 2000.

54. Smethhurst, M.A., A.N. Khramov, A.G. Iosifidi, and T.H. Torsvik, The Neoproterozoic and Paleozoic palaeomagnetic data for the Siberian paltform: from Rodinia to Pangea, *Earth Sci. Rev.,* 43, 1-24, 1998.

55. Alvarez-Marron, J., D. Brown, A. Perez-Estaún, V. Puchkov, and Y. Gorozhanina, Accretionary complex structure and kinematics during Paleozoic arc-continent collision in the southern Urals, *Tectonophysics*, 325, 175-191, 2000.

56. Brown, D., J. Alvarez-Marron, A. Perez-Estaún, V. Puchkov, P. Ayarza, and Y. Gorozhanina, Structure and evolution of the Magnitogorsk forearc basin: Insights into upper crustal processes during arc-continent collision in the southern Urals, *Tectonics,* 20, 364-375, 2001.

57. Kosarev, A.M., and V.N. Puchkov, Distribution of K, Ti, and Zr in the Silurian-Carboniferous volcanogenic formations of the Southern Urals in connection with the behavior of the Paleozoic subduction zone, in *Year-Book, 18*6-191, IG UNTs RAN, Ufa, 1997.

58. Abdulin, A.A. (Ed.), *Geology and mineral resources of the southeastern Turgai trough and Northern Ulytau* [in Russian], 231 pp., Nauka, Alma-Ata, 1984.

59. Puchkov, V.N., A.M. Kosarev, S.E. Znamenskii, N. Svetlakova, and V. I. Razuvaev, Geological interpretation of complex seismic profile URSEIS-95, in *Collection of geological works* [in Russian], 3-32, IG UNTs RAN, Ufa, 2001.

60. Burtman, V.S., *Structural evolution of Paleozoic folded systems* [in Russian], 164 pp., Nauka, Moscow, 1976.

61. Tevelev, A.V., *Tectonics and kinematics of shear zones. Abstracts of DSc thesis* [in Russian], 49 pp., MGU, Moscow, 2002.

62. Sokolov, B.S., and M. A. Fedonkin (Eds.), *The Vendian system. Historical, geological, and paleontological substantiation. Vol. 2. Stratigraphy and geologic processes* [in Russian], 227 pp., Nauka, Moscow, 1985.

63. Kheraskova, T.N., *Vendian-Cambrian formations of Caledonides in Asia* [in Russian], 247 pp., Nauka, Moscow, 1986.

64. Kheraskova, T.N., Structural relations between Kazakhstan and the Tien Shan in the late Riphean-Early Cambrian, in *Problems of geology of the Ural-Mongolian belt* [in Russian], 27-34, Izdatel'stvo Moskovskogo Universiteta, Moscow, 1998.

65. Degtyarev, K.E., *Tectonic evolution of the Early Paleozoic active margin in Kazakhstan* [in Russian], 123 pp., Nauka, Moscow, 1999.

66. Hermann, J., D. Rubatto, A. Korsakov, and V.S. Shatsky, Age and exhumation rate of diamondiferous, deeply subducted continental crust in the Kokchetav massif, Kazakhstan, in *Abstr. of the Fourth International eclogite field symposium,* 12-13, Novosibirsk, 1999.

67. Alexeiev, D.V., H.E. Cook, V.M. Buvtyshkin, L.Ya. Golub, and V.Ya. Zhaimina, Dynamics of Late Paleozoic collisions at the Southwestern margin of the Kazakhstanian paleocontinent: new evidence from the Bolshoi Karatau mountains (North-Western Tien Shan), in *EUG 9 Abstr.*, 345, Strasburg, 1997.

68. Deev, E.V., O.A. Votakh, S.Yu. Belyaev, S.V. Zinov'ev, and M.A. Levchuk, Tectonics of the basement of the mid-Ob' plate complex (West Siberia), *Geologiya i Geofizika (Russian Geology and Geophysics),* 42, 6, 968-978(920-929), 2001.

69. Girshgorn, L.Sh., V.G. Kabalyk, and V.S. Sosedkov, The Lower-Middle Paleozoic sedimentary basin in northern West Siberia, *Sovetskaya Geologiya,* 11, 65-67, 1987.

70. Kontorovich, A.E., A.S. Efimov, V.A. Krinin, A.V. Khomenko, L.G. Gilinskaya, V.P. Danilova, V.N. Melenevskii, E.A. Kostyreva, E.N. Makhneva, and N.T. Yudina, Geological and geochemical prerequisites of the Cambrian and Upper Proterozoic petroleum potential in southeastern West Siberia, *Geologiya i Geofizika (Russian Geology and Geophysics),* **41,** 12, 1615-1636(1559-1584), 2000.

71. Brekhuntsov, A.M. V.S. Bochkarev, V.N. Borodkin, and N.P. Deshchenya, Metodology and experience of recognizing main petroliferous objects in northern West Siberia at the present stage of petroleum field exploration, *Geologiya i Geofizika (Russian Geology and Geophysics),* **42,** 11-12, 1854-1863(1762-1772), 2001.

72. Yakubchuk, A., R. Seltmann, V. Shatov, and A. Cole, The Altaids: tectonic evolution and metallogeny, *SEG Newsletter,* 46, 7-15, 2001.

73. Sengör, A.M.C., B.A. Natal'in, and V.S. Burtman, Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia, *Nature,* **364,** 6435, 299-307, 1993.

Received 23 April 2002