Hercynian structural features in the West Transbaikalia region

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[1] This paper presents new data for the structure and age of the Paleozoic rocks in the Ikat-Bagdarin zone of the West Transbaikalia region. Reported for the first time is the wide development of various Devonian and Carboniferous rocks. A model is proposed for the tectonic evolution of this structural zone, based on the view that the Tocher rift basin began to form during the Late Devonian in the Caledonian basement and was completed during the Late Carboniferous–Early Permian in connection with the formation of the nappe-fold structure of the region and with the intrusion of the Angara-Vitim batholith granites. *INDEX TERMS:* 3040 Marine Geology and Geophysics: Plate tectonics; 3099 Marine Geology and Geophysics: General or miscellaneous; 8038 Structural Geology: Regional crustal structure; 8108 Tectonophysics: Continental tectonics: compressional; 9320 Geographic Location: Asia; *KEYWORDS:* Tectonics, continental crust, accretion, Transbaikalia.

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Introduction

[2] The Central Asia Foldbelt is a combination of Precambrian microcontinents and age-varying fold belts which had been formed in the region of the former Paleoasian Ocean. The northern branch of this foldbelt (Sayan-Baikal region), bordering the Siberian Craton, includes the Tuva-Mongol and Baikal-Muya microcontinents and the Caledonian structures mountains of the East Sayan and West Transbaikalia regions. The Tuva-Mongol microcontinent was formed during the Riphean and Vendian [*Kuzmichev,* 2004]. A sedimentary cover mostly of carbonate rocks was formed there during the Vendian-Cambrian period. Its collision with the Siberian Craton occurred during the Vendian-Cambrian time. It is obvious that the Baikal-Muya microcontinent and the Tuva-Mongol one existed in Riphean time as one structural feature. It was only at the Riphean-Vendian boundary that these microcontinents were separated from one another, and it was only during the Vendian that the Baikal-Muya microcontinent was accreted to the Siberian Craton.

[3] The Sayan-Baikal Caledonides proper exist at the present time as a complex system of tectonic zones (terrains), their numbers, boundaries, and geodynamic conditions being interpreted in different ways by different authors. In this paper we agree with the pattern offered by *Belichenko and Geletiy* [2004], who distinguished the following zones in the West Baikal Caledonides (Figure 1): the Dzhida, Khamar-Daban, Olkhon, Bargusin, Ikat (Ikat-Bagdarin), and Eravnin (Udino-Vitim) zones.

[4] The Dzhida zone is believed to have been a paleooceanic basin, located between the Tuva-Mongol continent and the Khamar-Daban passive margin of the Siberian paleocontinent. This basin existed at least from the Riphean to the Ordovician. During the Silurian (or, possibly, Devonian) the Dzhida nappe-fold belt was formed in its place as result of a microcontinent-continent collision [*Gordienko and Kuzmin,* 1999; *Gordienko and Mikhaltsev,* 2001].

[5] The Olkhon zone is a collision system [*Fedorovskii et al.,* 1995; *Mekhonoshin et al.,* 2004], which had formed in the Early Paleozoic as a result of two tectonic episodes: (1) the collision between the island-arc and a continental block with the Early Precambrian continental crust and (2) the later combination of the oceanic rock complexes with the composite terrain, which had been formed by that time and, finally, their obduction over the edge of the Siberian Continent.

[6] The Bargusin zone is distinguished by the wide development of metamorphic rocks, which have not been dated, and of the granitoids of the Angara-Vitim batholith (330–290 Ma [*Yarmolyuk et al.,* 1997]). The stratified rock sequences are represented here by terrigenous rocks which are usually preserved as the sagging batholith tops. *Belichenko and Geletiy* [2004] believe that the metamorphic rocks of

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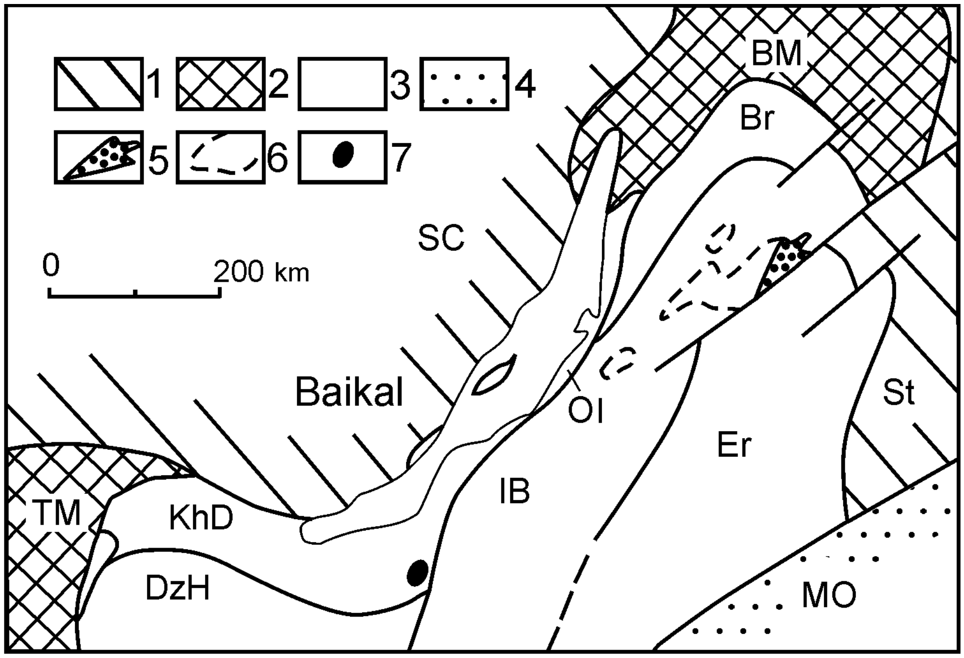

Figure 1. Schematic map of the West Transbaikalia tectonic zones [after *Belichenko and Geletiy,* 2004] with the additions of the authors of this paper: (1) Siberian Paleocontinent (SC – Siberian Craton, St – Stanovoj range); (2) Precambrian Microcontinents: Tuva-Mongol (TM) and Baikal-Muya (BM); (3) West Transbaikalia Caledonides with the Dzhina (Dzh), Khamar-Daban (KhD), Olkhon (Ol), Bargusin (Br), Ikat-Bagdarin (IB), and Eravnin (Er) zones; (4) Mongol-Okhotsk belt (MO); (5) Bagdarin synform; (6) the area underlain by the rocks of the Tocher formation and its analogs; (7) the area of the Urma formation stratotype.

the Bargusin ridge continue the metamorphic rocks of the Khamar-Daban range and of the Olkhon zone, mostly dated Ordovician. In this case, it is believed that the Bargusin metamorphic rocks mark the accretion zone along the periphery of the Baikal-Muya microcontinent.

[7] The Eravnin zone is usually interpreted as an ensialic island arc [*Gordienko,* 2004; *Gusev and Khain,* 1995]. Its basement is composed of Riphean metamorphic rocks [*Bulgatov et al.,* 2004]. The island arc rocks andesite, dacite, rhyolite, and scarce basaltoids, including lenses of limestone with archaeocyathes.

[8] The Ikat (Ikat-Bagdarin) zone occupies the internal area of the West Transbaikalia region, where the wide-spread rocks are the granitoids of the Angara-Vitim batholith and metamorphic rocks of still unknown age. The stratified rocks of this zone are represented mainly by carbonate and terrigenous rocks which had been preserved as isolated patches in the granitoid tops. As a rule, these are relatively poorly metamorphosed rocks which were dated Vendian-Cambrian (potentially Early Ordovician) [*Belichenko,* 1977; *Butov,* 1996 and etc.].

[9] At the present time, the West Transbaikalia region with its numerous granitoid bodies and metamorphic rock fields is usually classified as an Early Caledonian accretion-collision structural feature which had been formed from the Proterozoic to the Ordovician, when a terrain collage was formed along the southern edge of the Siberian continent (in modern coordinates), these terrains differing in their lithology and structure and being composed of differently metamorphosed sedimentary and igneous rocks. Some authors suggest the role of Late Caledonian (S-D) or even Hercynian (PZ_3) movements which contributed to the formation of this structural feature [*Belichenko and Geletiy,* 2004; *Butov,* 1996; *Gordienko and Kuzmin,* 1999; *Nikitin and Nenakhov,* 2004]. Yet, this problem remains to be unsolved because of the indefinite ages of many of the above-mentioned rock sequences. In this connection, their dating and space-time correlation is highly significant.

[10] In this sense, of great interest is the northern part of the Ikat-Bagdarin zone (Vitim Highland), where several areas of relatively poorly metamorphic Paleozoic rocks are concentrated in the area between the Bolshoy Amalat and Zipikan rivers. The largest of them is the area along the left bank of the Malyi Amalat river (in the Bagdarin, Aunik, Tocher, and Usoy river basin). In structural terms, this area is a graben-type syncline (synform) extending in the NE direction over a distance of 100 km with the maximum width of some 30–40 km. This zone is bounded from the north and south by the Zipikan and Amalat blocks composed of various Proterozoic (?) gneisses, schists, and marbles, cut by numerous granitoid bodies ranging from Proterozoic to Upper Paleozoic in age.

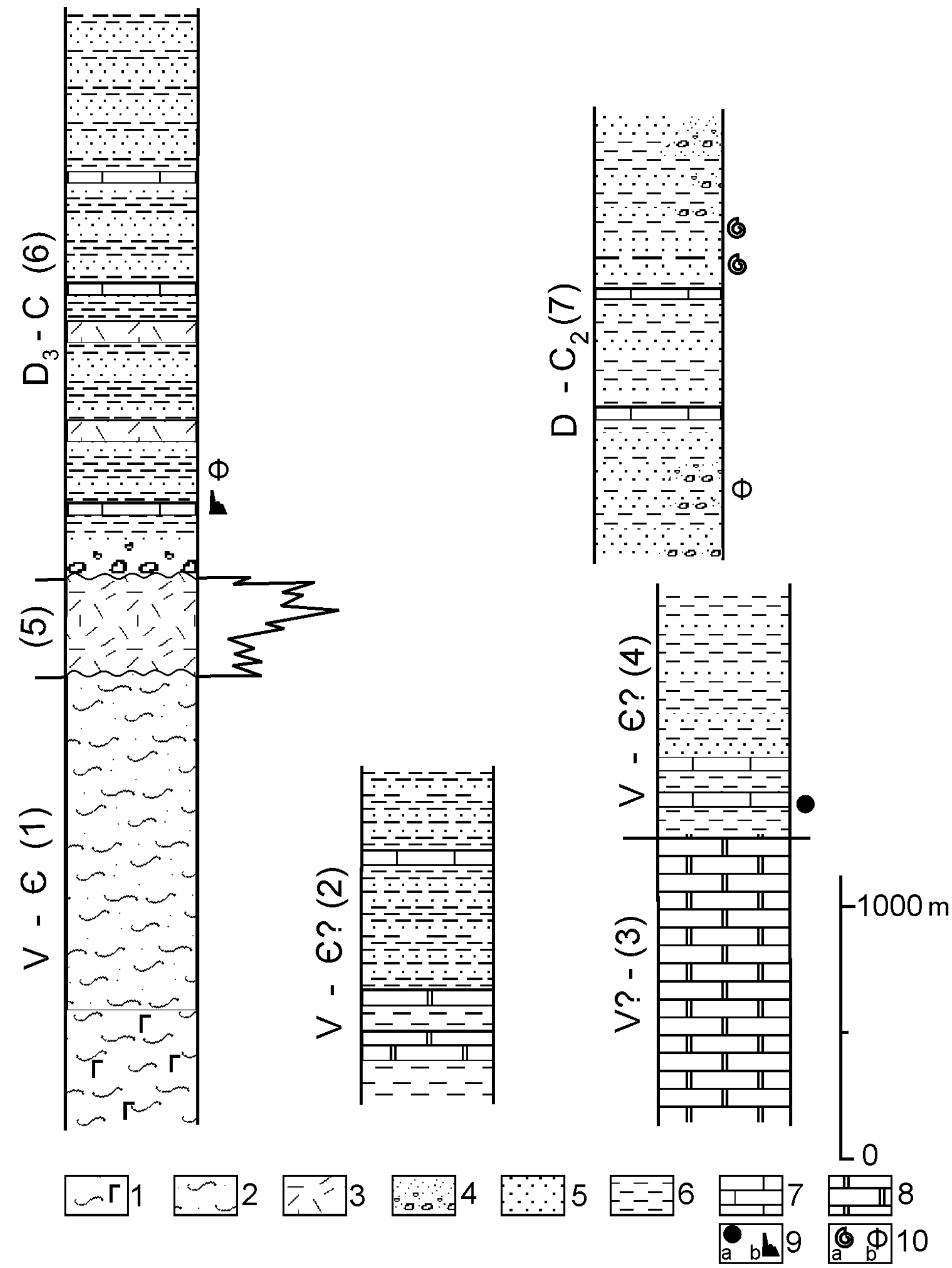

Figure 2. Comparison of the Vendian(?)-Paleozoic rock sequences of the Bagdarin synform: (1) amphibolite and metabasic rocks; (2) metagraywacke and schists; (3) rhyolite, dacite, and their epiclastic rocks; (4) conglomerate and gritstone; (5) sandstone; (6) aleuropelite and shale; (7) limestone; (8) dolomite; (9) sites where the remnants of problematic (a) and conodonts (b); (10) sites where the remnants of bryozoans (a) and flora (b) collection sites. The numbers in the rock columns denote: (1) Sivokon formation (V-Є?), (3) Orochen formation (V?), (4) Yaksha formation (V-Є?), (5) bimodal effusive-epiclastic rocks, (6) Tocher formation (D_3-C), (7) Bagdarin formation (D-C_2).

Discussion

[11] Below follows the description of the Bagdarin synform which represents a system of deformed tectonic slabs, ranked as the following rock complexes (Figure 2).

[12] The *Sivokon-Tocher complex* includes the rocks of the Sivokon (Suvanihin) and Tocher formations. They compose the lower slab outcropping in the form of an uninterrupted band along the southern slope of the Shaman ridge (in the upper reaches of the Tocher, Aunik, and Bagdarin rivers).

The base of this rock sequence is composed of amphibolite, schist, acid volcanic rocks, and marble of the Sivokon formation which was dated Proterozoic [*Yanshin,* 1983] or Vendian–Early Cambrian [*Belichenko,* 1977]. Spacially associated with these rocks are the individual outcrops of serpentinized peridotite and dunite, gabbro, gabbro-norite, and gabbro-diabase [*Mitrofanov and Mitrofanova,* 1983]. For the time being, only the rocks of the Shaman gabbroid massif have been dated: 545±19 Ma [*Rytsk et al.,* 2003].

[13] The Sivokon rock sequence in the middle course of the Aunik river is composed of:

[14] (1) amphibolite and apobasalt greenschist (the visible thickness of 70–80 m).

[15] (2) quartz-chlorite-sericite, quartz-sericite, and albite-epidote-chlorite shistes, microquartzites and phyllitized acid epiclastic rocks (the visible thickness of 300–400 m).

[16] These rocks are overlain transgressively by polymictic conglomerates which were interpreted in this study as the basal layer of the Tocher formation.

[17] The Sivokon deposits are most abundant in the upper reaches of the Usoy river and in the Toloy-Usoy R. divide. Outcropping at the base of this rock sequence are apobasalt orthoschists including microquartzite layers and lenses. This rock sequence also includes metadiabase and metadolerite bodies. On the whole, the basaltoids of the lower rock sequence are classified as a constituent of the ophiolite association. It is characteristic that the outcrops of serpentinized ultrabasic rocks and gabbroids are restricted to this rock sequence. The visible thickness of the lower rock sequence is at least 300–400 m.

[18] The upper rock sequence of the Sivokon formation is represented mainly by graywacke including sandy limestone interbeds. It also includes metadiabase, quartz and plagiophyre, felsite and plagiogranite bodies. The total thickness of this rock sequence appears to be 1200–1500 m.

[19] In the upper reaches of the Usoy river, the outcrops of volcanic rocks are associated with the deposits of the Sivokon formation. These are mainly more or less schistose violet rhyolites and their tuff, which include ignimbrite-like varieties interbedded with volcanomictic sandstone, gritstone, and conglomerate layers. The pebbles in the latter are represented by quartz and plagioporphyry, felsite, various acid tuff, vein quartz, microquartzite, and less frequent diabase. In some areas this rock sequence includes basalt flows with a visible thickness of 400–450 m. They are usually ranked as the members of the Sivokon formation. At the same time it should be noted that no stratigraphic relations of the volcanic rocks with the Sivokon deposits have been proved: in all areas they showed tectonic relations. This allows us to rank these volcanic epiclastic deposits as an independent stratigraphic unit which, in our opinion, begins a new cycle in the rock complex discussed, associated with the accumulation of the Tocher rocks.

[20] As mentioned above, the basal rock sequence of the Tocher formation includes a basal conglomerate layer. In the Aunik R. basin they were found as individual indigenous rock outcrops, yet, are more often found as large block debris. The conglomerates vary from medium- and large-pebble types to boulder ones. The pebbles of intermediate to good roundness are represented by granite, vein quartz, quartzite, amphibolite, altered basalt, various schists, acid volcanics, sandstone, and occasional marble. The conglomerates are usually 50–60 m thick. At the left bank of the Usoy R. upper reaches, the conglomerates are 30 m to 100 m thick, rest on the basalts of the lower rock sequence of the Sivokon formation and are composed, almost exclusively, of their pebbles.

[21] Earlier, the Tocher formation rocks were dated Cambrian [*Belichenko,* 1977; *Yanshin,* 1983: to name but a few]. New data were reported by *Fedorov et al.* [1986], who dated these rocks silurian-devonian (S-D) on the basis of the plant remains and conodonts collected from the sandstones in the lower part of this formation.

[22] The rocks of the Tocher formation were studied recently (V. A. Aristov et al., in press, 2005) in the upper reaches of the Aunik R., where they occur as the following rock sequence:

[23] (1) The basal conglomerates are overlain by gray and dark gray phyllites interbedded with polymictic schistose sandstones. There are thin (5–10 cm) interlayers of marmorized limestone. The bedrock outcrop, located at the base of the western slope of the 1369.4 height (the left side of the Aunik R. valley) was found to include an interlayer of this limestone containing poorly preserved *Palmatolepis* sp. and *Polygnathus* sp. conodonts of late Devonian, potentially Famennian age. The thickness of these rocks is roughly 300–350 m.

[24] (2) The quartz-feldspar or polymictic sandstones (with grains of quartz, feldspar, mica, amphibole, and altered basic, intermediate, and acid volcanics), alternating rhythmically with quartz siltstones and shales; there are occasional interlayers of dark gray, slightly bituminous limestone, totaling 900–1000 m in thickness.

[25] (3) Gray polymictic coarse-bedded sandstone including phyllite members and individual interlayers of black bituminous limestone. The visible thickness is 800–900 m.

[26] All of these three rock sequences show more or less numerous outcrops of quartz plagioclase porphyry, felsite, and granite porphyry. These are mainly subvolcanic bodies, usually highly cataclastic, concordant with the general faulted and folded structural feature composed of the rocks of the Tocher formation.

[27] Proceeding from the above evidence we dated the lower rocks of the Tocher formation Late Devonian. Taking into account the large thickness of this formation, it can be assumed that the upper part of this rock sequence has a Carboniferous age.

[28] The two lower rock sequences represent a flyschoid rock series. The amount of the coarse arkose and volcanomictic clastic material grew in time, resulting in the fact that the upper part of the Tocher rock sequence is composed of a relatively coarse terrigenous material (the distal facies were replaced by proximal ones).

[29] The *Orochen-Yaksha rock complex* includes the sediments of the Orochen (Tilim) and Yaksha formations, as well as a black-shale series, the rocks of which compose the SE slope of the Shaman ridge in the source area of the Aunik river. The rocks of the Orochen formation were dated by different authors from the Late Riphean to the Early Cambrian [*Belichenko,* 1977; *Butov,* 1996]. The rocks of the Yaksha

formation were dated Early-Middle Cambrian.

[30] The Orochen formation is composed of yellowish gray to white, often highly brecciated dolomite marble. Its typical feature is the abundance of algal rocks. The limestone beds are highly occasional. There are also layers of carbonaceous-argillaceous, occasionally siliceous schists with phosphate. The maximum visible thickness of this formation is as large as 800–1000 m.

[31] The rocks of the Yaksha formation rest with a gradual transition on the Orochen dolomite. The following rocks are exposed in the stratotype along the Middle Yaksha creek:

[32] (1) Gray mostly arcose, phyllitized sandstones, alternating with siltstones and shales, with the interbeds, less than 5 m thick, of bituminous marmorized limestone. The interbed of aphanitic limestone, resting about 10–15 m above the contact with the Orochen dolomite, was found to contain *Siphogonuchites* sp. (*S. cf. triangularis* is as identified by Yu. E. Demidenko, Paleontological Institute, Russian Academy), known from the Vendian-Lower Cambrian rocks. The thickness of these rocks varies from 250 m to 300 m.

[33] (2) Terrigenous rock sequence represented by the rhythmic alternation of sandstone, siltstone, and shale with single occasional interlayers of limestone. The thickness of the exposed rocks is 450–500 m.

[34] A somewhat different rock sequence was found along the Aunik, Bolshoi Kiro, and Krutoj creeks (the right bank of the Bagdarin river). The dolomite, attributed to the Orochen formation, is overlain there by a sequence of mainly marmorized limestone beds, dominated by massive or coarse-bedded, gray and light-gray rocks, often brecciated and marmorized. There are subordinate layers of siliceous shale. Because of the high brecciation, complex structure, the absence of distinct markers, and usually poor erosion, no layer-by-layer sequence could be reconstructed. It should be noted, however, that *Rothpletzella* sp. algae remains (S-D) indentified by V. A. Luchinina (Institute of Oil and Gas Geology, Novosibirsk) were collected from the rocks referred to the Orochen Formation. In the Yaksha limestone were found contain bryozoan *Ceramopora* sp. (O-S) and tabulates *Graciolopora* sp. (*Siringoporida*), as well as poorly preserved *Pachypora* (?) sp. (S_2-D_2), identified by V. A. Luchinina (Institute of Oil and Gas Geology, Novosibirsk) and by T. T. Sharkova (Moscow University of Geology and Geological Exploration).

[35] Thus, proceeding from the above data, the lower age limit of the upper rocks of the Orochen formation can be taken to be Middle Ordovician. Accordingly, the age of the Yaksha limestones falls within the Ordovician-Devonian age interval. At the same time it should be mentioned that any space-time correlation of the stratotype rock sequences of the Orochen and Yaksha formations with the rocks of the Bagdarin R. right bank is difficult because of their fragmentary and poorly preserved fossils. Therefore, this issue remain to be open and calls for further study. In this paper we accept the decisions of our predecessors concerning the Vendian-Cambrian (possibly Ordovician) age of the Orochen and Yaksha formations.

[36] As mentioned above, the black shale of the Shaman ridge can be attributed to the rock complex discussed. Basically, this is a sequence of highly deformed black shale and occasional siliceous shale with interlayers of phyllitized siltstone and fine-grained sandstone. This rock sequence also includes interbeds (as thick as 3 m) of brown, yellow-gray, and white dolomite marble, and also of black argillaceous limestone. Since this rock sequence is poor in fossils, its correlation with the rocks of the Orochen and Yaksha formations is conventional. In particular, the finding of dolomite marble in this rock sequence allows one to admit that the black shale series may belong, at least partially, to the Orochen formation. If this correlation proves to be true, we can admit that the black shale series had accumulated in some depression, the southern side of which (in modern coordinates) must have been composed of shallow-sea (shelf-type) substantially carbonate deposits.

[37] The *Bagdarin rock complex (formation)* is a thick rock series of almost exclusively terrigenous variegated deposits, distinguished by the predominance of comparatively poorly phyllitized sandstones. Its age was placed into the Cambrian-Ordovician age interval [*Belichenko,* 1977; *Yanshin,* 1983]. Its rocks rest on the rocks of the Orochen and Yaksha formations. However, all of the observed contacts of these rocks were found to be tectonic ones.

[38] One of the most complete rock sequences of the Bagdarin formation was studied along the Aunik river (V. A. Aristov et al., in press, 2005). It was found to consist of three rock sequences.

[39] The lower rock sequence is represented mainly by variegated (red and green) sandstones interbedded with violet siltstones, aleuropelites, and shales. Also found there were individual thin (<5 cm) tuffaceous siltstone and tuffite layers. The upper part of this rock sequence includes individual layers (less than 0.8–1 m thick) of pink aphanite limestone. This rock sequence has a maximum thickness of 400 m.

[40] The intermediate rock sequence is composed of interbedded dark gray shale, fine-grained phyllitized sandstone, and siltstone, including the interlayers and lenses (10–20 cm) of black aphanite limestone. These rocks are 180–200 m thick.

[41] The upper rock sequence is composed mostly of red polymictic, medium- to fine-grained sandstones, occurring as beds up to 5 m thick. There are numerous thin (<10 cm) interlayers of calcareous siltstone, from which bryozoan remains were collected at the water divide area of the Aunik river and the Alekseevskiy creek. They were identified by G. V. Goryunova (Institute of Paleontology, Russian Academy) as trepostomides and rabdomesides of the *Rhabdomeson* and *Primorella* genera. Also identified by her were the cross-sections of phenestellides and fistulomesides. All of these organic remains dated the rocks enclosing them as Carboniferous. These rocks are as thick as 500 m.

[42] The sandstones discussed are the main rocks of this sequence. These are mostly gray, medium- to fine-grained, layered and well sorted rocks with a ferruginous argillaceous-carbonate cement. The clastic material is dominated by the its arkose type, being represented by quartz, feldspar, and mica. The lithic material consists of the fragments of structurally different acid effusive rocks, siltstone, sandstone, mica schist, and occasional carbonate. Volcanomictic sandstones are subordinate.

[43] We studied a similar rock sequence in the upper

reaches of the Usoy river and in the water-divide area of the Usoy and Bolshaya Yaksha rivers. The distinctive feature of this rock sequence is the predominance of coarse-clastic terrigenous rocks.

[44] The lower red-color rock sequence is represented by the interbedding of small-pebble conglomerates, gritstones, and coarse-grained sandstones, followed upward by medium-grained calcareous sandstones, up to sandy limestones. This rock sequence includes interlayers of volcanomictic sandstone, tephroid, and tuffaceous siltstone. Flora remains were collected from the sandstone in the mouth of the Bolshaya Yaksha creek. As follows from the conclusion of S. V. Naugolnykh (Geological Institute of the Russian Academy of Sciences), "they are morphologically similar to propteridophyte sprouts, yet, their poor preservation precludes their more exact identification; propteriodiphytes are known from Upper Silurian and Devonian rocks". This rock sequence has a maximum thickness of 600 m.

[45] The intermediate (gray-color) rock sequence is composed of quartz-feldspar sandstones, interbedded with black phyllitized siltstones, and includes gray oolitic limestone beds, up to 3 m thick. This rock sequence is 200–250 m thick.

[46] The upper red-color rock sequence is composed of monotonously alternating sandstones and siltstones with polymictic gritstone interbeds and lenses in the top. These rocks have a maximum thickness of 500 m.

[47] The clastic material in the rocks of this formation is similar to the clastics mentioned above, namely, grains of quartz, feldspar, mica, and amphibole. The lithic components are basic, intermediate, and acid volcanic rocks, various granitoids, shale, sandstone, and siltstone.

[48] Bryozoans remains were collected in the upper reaches of the Bolshaya Yaksha creek from the sandstones of the upper rock sequence, identified by R. V. Goryunova (Institute of Paleontology, Russian Academy of Sciences) as *Rhombotrypella* sp., *Ascopora* sp., *Rhabdomeson* sp., *Primorella* sp., and *Fistulipora* sp. Also found there were poorly preserved fusulinids. The taxonometric composition of these bryozoans allows one to date their host rocks Carboniferous, possibly, Middle Carboniferous, because the *Rhabdomeson*, *Primorella*, and *Ascopora* genera are known since the Lower Carboniferous, and the *Rhombotrypella*, since the Middle Carboniferous.

[49] The Bagdarin formation is characterized by a number of its specific features, namely, by the relatively fresh appearance of the rocks composing it and by the wide development of red terrigenous rocks, often having a polymictic and arcose composition. The presence of intraformation breaks, coarse oblique bedding, ripple marks, as well as of oolitic and algal limestones, suggest the predominance of the shallow-sea sedimentation conditions, which had been accompanied by the partial recompensation of the sea basin and by the addition of edaphic clastic material (fragments of red sandstone and aleuropelite), composing significant rock volumes at some levels of the rock sequence. Apparently, the Bagdarin basin was distinguished by its unstable sedimentation: some periods were marked by the substantial addition of some coarse-clastic material. Its rock sequence shows two sedimentation cycles. The transgressive cycle was marked by the replacement of the relatively coarse red-color terrigenous deposits of the lower rock sequence by the gray, deeper-sea, fine-grained deposits, which were replaced again by the coarse-grained rocks of the upper rock sequence (regressive cycle).

[50] The *Usoy formation rocks* are not widely developed in the territory of the region discussed, where they occur as individual tectonic wedges at the left bank of the Usoy river. In the main this is an effusive-epiclastic rock sequence composed of rhyolite, trachyrhyolite, trachydacite, andesite, and less common basalt, its tuff, and volcanomictic rocks. In terms of its lithology and age, the Usoy formation is similar to the Oldynda one. It was dated Lower Cambrian [*Belichenko,* 1977; *Butov,* 1996] and is interpreted as an island-arc rock series. We admit that in the area of the Bagdarin synform the Usoy volcanic rocks are allochthonous, their source area being the Eravnin zone.

[51] The Bagdarin synform is a complex, fold-nappe structural feature where the rock complexes mentioned above are brought together as a package of tectonic slabs (Figures 3 and 4). The lower structural element of this package (relative autochthon) consists of the rocks of the Sivokon-Tocher complex, which are overthrust by the rocks of the Orochen, Yaksha, Usoy, and Bagdarin formations. The rocks of both complexes are folded into second-order anti- and synforms oriented in the northeast direction. In the southwest and northeast (outside of the map presented here), this structural feature is restricted by a series of transverse normal faults along which the folds mentioned above have end-to-end connections with the protrusions of the crystalline basement.

[52] The outcrops of rocks composing this relative autochthon are concentrated along the northwestern edge of the Bagdarin synform. They are deformed to a system of NW-facing folds. There is a kind of a lithic control of these faults determining their disharmonic pattern. The rocks of the Sivokon formation are deformed mainly to lit-par-lit, often complex-configuration flow folds, including recumbent or nearly recumbent folds. On the contrary, the Tocher sandstones and siltstones are deformed to a system of steep, narrow (<200 m), high-amplitude folds. They have irregular cross-sections with the concentration of redundant rock masses in the fold hinges, which complicate the high-order folds, cause interbed cleavage, and numerous upthrust faults. The more competent quartz porphyry and granite porphyry bodies occur as wedges, generally concordant with the axial surfaces of these folds, intermittent along the strike. In map view, the latter have a spindle-shape form reflecting the lateral redistribution of the deformed rock masses (macroboudinage).

[53] The allochthon rock complex occupies the southeastern part of the Bagdarin synform. It consists of a series of tectonic slabs resting on the various rock sequences of the autochthon. The following nappes have been identified there (upwards): the Lower Bagdarin, Usoy, Orochen-Yaksha, and Upper Bagdarin (composed of the rocks of the formations having the same names). As has been mentioned above, the package of these sheets is deformed to a system of anti- and synforms. Exposed in the former are the rocks of the autochthon and of the lower slabs, and those

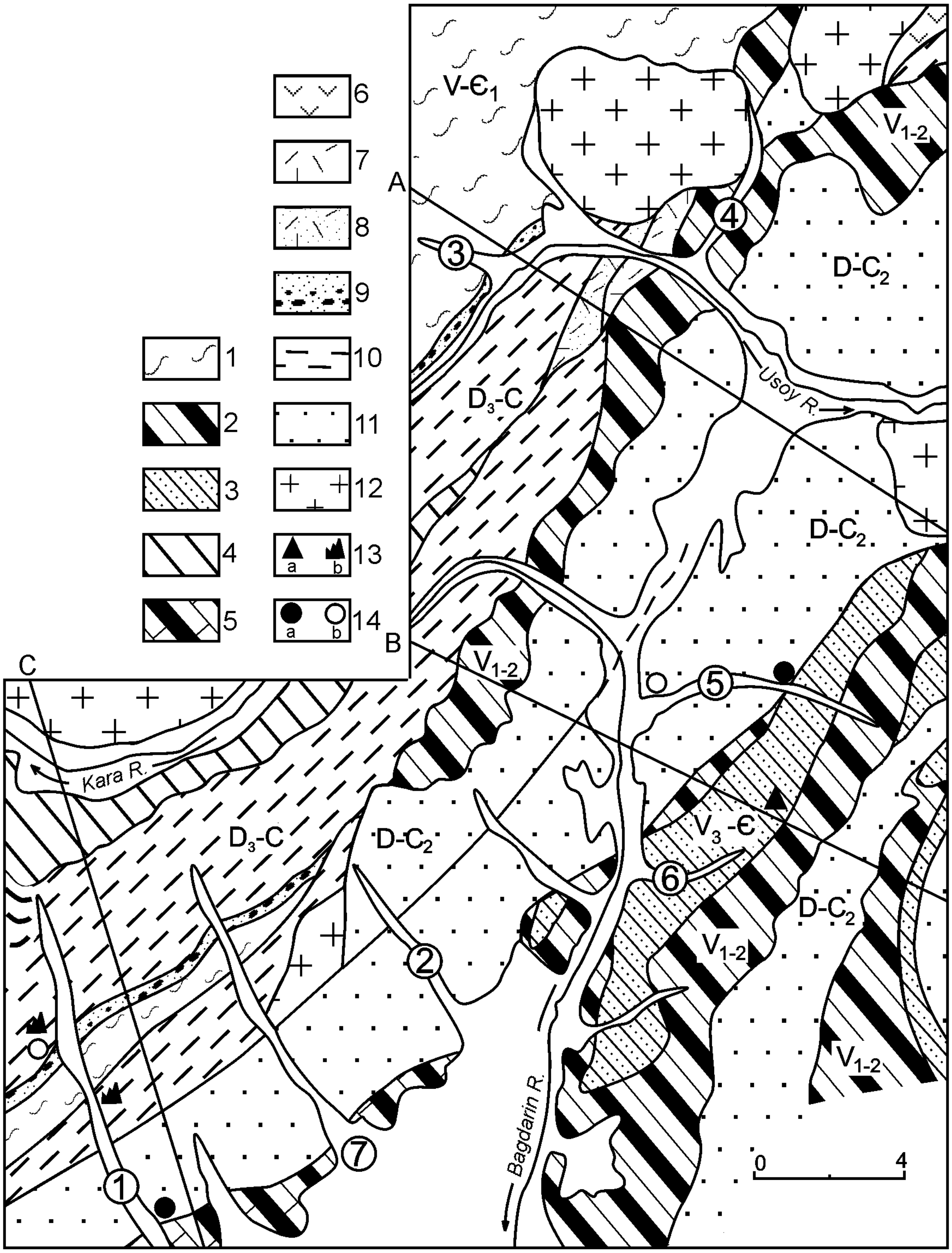

Figure 3. Schematic geological map of the Bagdarin synform. (1) Metabasalts and graywacke (Sivokon formation, V-$Є_1$); (2) dolomite (Orochen formation, V_{1-2}); (3) sandstone, siltstone, and limestone (Yaksha formation, V_3-Є?); (4) black shale (V-Є?) of the Shaman range series; (5) dolomite and limestone (ranked as the analogs of the Orochen-Yaksha rocks, O_2-D_2?); (6) andesite and dacite of the Usoy formation, Є?); (7) bimodal effusive rock sequence; (8) bimodal epiclastic rocks; (9) basal conglomerates (Tocher formation, D_3); (10) flyschoid rocks (Tocher formation, D_3-C); (11) variegated terrigenous rocks (Bagdarin formation, D-C_2); (12) granite; (13) sampling sites of problematic fossil remains (a) and conodonts (b); (14) sampling sites of macrofauna (a) and flora (b) remains. The figures in the map denote: (1) Aunik R., (2) Krutoy Cr., (3) Glubokiy Cr., (4) Endoda R., (5) Bolshaya Yaksha R., (6) Middle Yaksha R., (7) Bolshoy Kiro Cr.

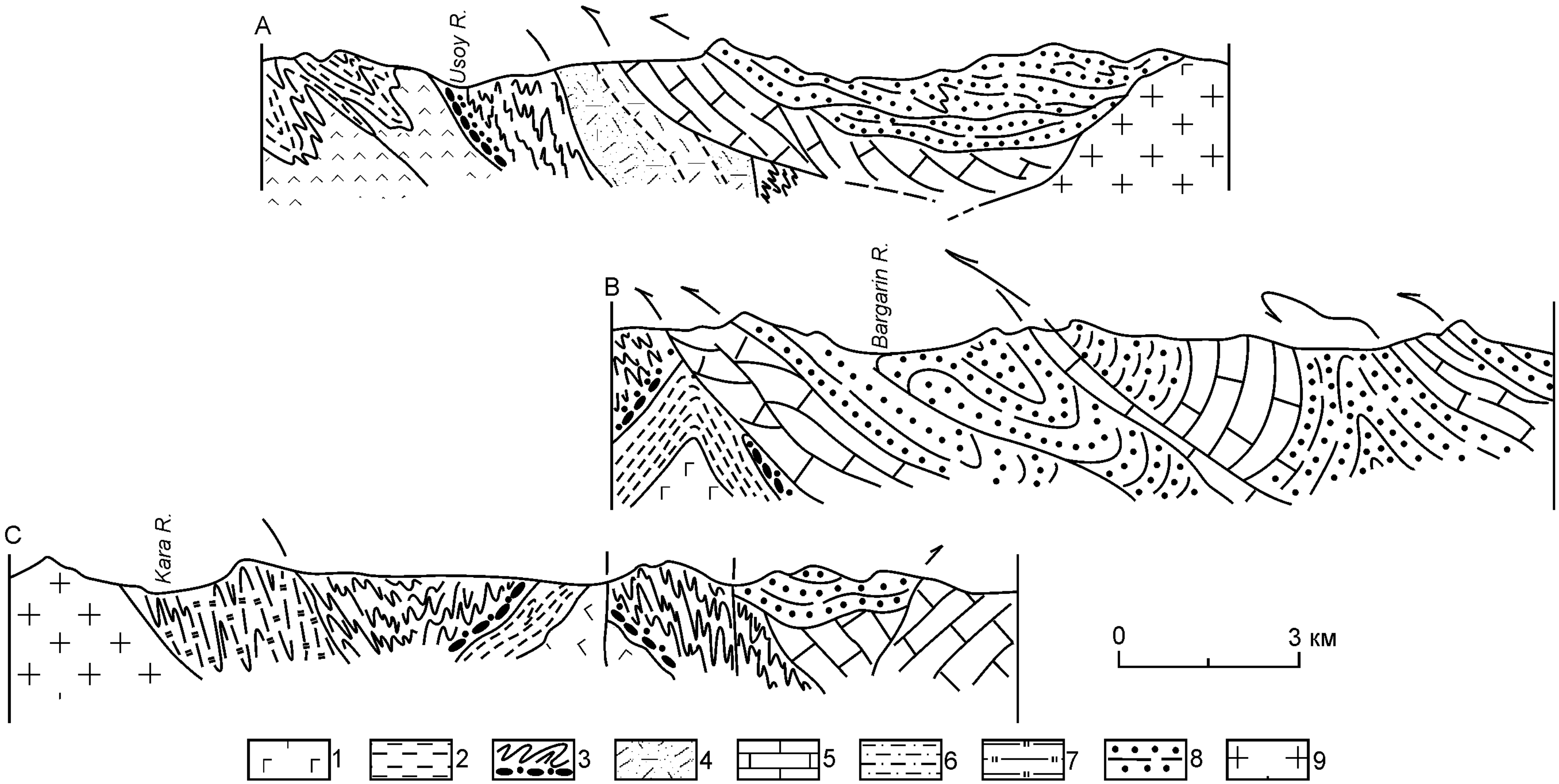

Figure 4. Geological profiles across the Bagdarin synform: (1–3) relative autochthon: (1) metabasalts (lower sequence of the Sivokon formation, V-Є$_1$?), (2) metagraywacke (the upper rock sequence of the Sivokon formation, Є), (3) flyschoid rock sequence (Tocher formation, D_3-C), (4–8) allochthon: (4) rhyolite and its epiclastic material, (5) dolomite (Orochen formation, V?), (6) sandstone, aleuropelite, and limestone (Yaksha formation, V-Є), (7) black shale series (V-Є), (8) variegated terrigenous rock sequence (Bagdarin formation, D-C_2); (9) granite. The profiles are: (A) Tocher antiform, (B) Aunik-Usoy synform, (C) Yaksha synform.

in the latter are the rocks of the upper slabs. These are the Tocher and Yaksha antiforms and the Aunik-Usoy synform located between them (see Figure 4). These are large, morphologically simple folds, elongated along the general strike of the Bagdarin structural feature. The intranappe dislocations are also fairly simple and are controlled mainly by the lithology of their rocks. The Orochen massive and coarse-bedded dolomites are highly broken, often occurring as tectonic breccias, characterized by volumetric cataclasis, the complete recrystallization of the carbonate, and its lit-par-lit flow. In this case the rock is a structureless mass enclosing more or less large (up to a few hundred meters) blocks of relatively fresh rocks with a preserved original texture (stromatolitic, oncolitic, and other varieties). The bedded rocks of the Yaksha and Bagdarin formations are deformed to morphologically variable, small, NW-overturned folds. This structural pattern may vary along the strike. For instance, at the left side of the Usoy river, the internal structure of the Upper Bagdarin slab is a simple monocline with its rock layers rarely dipping more than 40° (usually 10°–30°).

[54] Proceeding from this evidence, the sequence of the rock deformation during the structural shaping of the Bagdarin area can be reduced to the following pattern. The allochthonous rock masses moved from SE to NW (in modern coordinates), being thrust over the different-level rocks of the autochthon. The structural isolation of the allochthon was associated with the breaking of its rocks from the crystalline basement, which was followed later by their delamination. The differentiated movements of the nappe slabs involved their structural reworking and caused various intranappe disturbances. Later, the resulting nappe package was deformed, along with the rocks of the relative autochthon, into a system of anti- and synforms, complicated by second-order overthrusts. This produced slabs restricted to the underthrust (northwestern) limbs of the antiforms. The most advanced happened to be the upper slabs, the visible distance of their movements being 20–25 km.

[55] The formation of the Bagdarin structural feature was a complex, multistage, and obviously long-lasting process. Participating in the resulting fold-nappe structural feature are the rocks of the Bagdarin formation, the Carboniferous age of which, including the Middle Carboniferous, being substantiated very well. In other words, it can be stated that the formation of this fold-nappe structural feature began in post-Carboniferous time. It should be taken into account that the territory of the Bagdarin synform includes several granite massifs (Kara, Usoy, etc.) belonging to the system of the Angara-Vitim batholith which was formed in the time interval of 320–280 million years (C_2-P_1) [*Yarmolyuk et al.,* 1997]. These granite massifs occur as isometric bodies, discordant relative to the fault-fold structural features and cutting the rocks composing them (including the rocks of the Bagdarin formation). The above data suggest the conclusion that the Bagdarin synform structural features were formed from the end of the Carboniferous to the beginning of the Early Permian, that is, during the Hercynean Epoch.

[56] The rocks of the Vitim Upland (the northern part of the Ikat-Bagdarin zone) can be classified into two Caledonian and Hercynian structural stages. The former stage combines the rocks of Neoproterozoic, Cambrian, and possibly Ordovician and Silurian ages, known as the Sivokon, Orochen, Yaksha, and Usoy formations and their analogs. It is believed that during these periods of time this zone was a trough with the crust of the oceanic (or suboceanic) type (Abaga oceanic terrain [*Parfenov et al.,* 1996]). Some authors [*Belichenko and Geletiy,* 2004; *Gusev and Khain,* 1995] classify this trough as a back-arc basin (named as the Udino-Vitim or Abaga-Bagdarin basin), which had been located in the back of the Eravnin island arc. Generally, we agree with this view. The analysis of the data available suggests the following series of paleotectonic structural features (from NW to SE in modern coordinates): the back-arc basin (Orochen formation) – the slope and foot of the Eravnin ensialic arc (the black-shale series of the Shaman ridge) – the shelf part of the arc (Orochen and Yaksha formations and their analogs) – the island-arc rock complex proper (Usoy and Oldynda formations).

[57] The Hercynian structural stage of this region includes the rocks of the Tocher and Bagdarin formations. They fill a large trough which can be referred to as the Tocher trough. The Tocher formation is composed of flyschoid rocks which mark its axial, deepest segment. Generally, the deposits of the Bagdarin formation, synchronous with the Tocher variegated terrigenous rocks, accumulated in the southeastern side of the basin. These are mostly coastal-marine and partially terrestrial rocks. It should be noted that the rocks similar in age (D_3) and in the type and structure of their sequence are known in the Minor Khamar-Daban area. These are the rocks of the Urma formation, which have been fairly well studied. *Filimonov et al.* [1999] and *Minina* [2003] proved that this rock sequence also consisted of three parts: the lower red rocks, the intermediate gray rocks, and the upper red rocks. Being very similar to the rocks of the Bagdarin formation, the rocks of the Urma formation were identified as the rocks of the "lagunal-coastal" type ("old red sandstone"). They are represented by linear sea-shore facies. It is believed that the Urma paleobasin is similar to the Devonian basins of the Minusinsk type and seem to be of rift origin [*Filimonov et al.,* 1999].

[58] To sum up, the Tocher trough has been formed in the Transbaikalia region since the Late Devonian as a large Hercynian structural feature filled with thick terrigenous rocks. This trough is believed to be of rift origin. Characteristic in this aspect is the accumulation of a bimodal effusive-epiclastic rock sequence at the boundary between the Sivokon and Tocher formations, which seems to have recorded the onset of the formation of this trough in the Caledonian basement. Its closure began at the Middle-Late Carboniferous boundary. The processes of tectonic crowding ("intraplate collision") resulted in the structural overlapping of the Eravnin arc and the Tocher trough and ended in the Late Carboniferous–Early Permian with the intrusion of the Angara-Vitim batholith granites.

[59] It is worth mentioning that the Middle-Late Paleozoic intraplate rifting operated in some other parts of the Transbaikalia Caledonides. As follows from the data available for the Uakit area of the Baikal-Muya microcontinent [*Nikitin and Nenakhov,* 2004], where the system of rift basins had originated in the Late Devonian (possibly at

the Frasnian-Famennian boundary), the collision (orogenic) period began there at the end of the Middle Carboniferous and terminated in the Late Paleozoic by the intrusion of the Vitimkan granitoids. In the south of the West Transbaikalia region (Dzhida zone), the results of our survey proved the presence of intricately deformed tectonic slabs composed of intricately deformed terrigenous rocks with plant remains dating the rocks Late Carboniferous–Permian. The space-time correlation of the Devonian–Late Paleozoic rocks in space and time is difficult for the lack of data on their distribution. Yet, the data available suggest the fairly wide development of thick marine terrigenous rocks (including flysch), which accumulated in a system of troughs that had been formed during the Devonian–Late Paleozoic in the region of the Transbaikalia Caledonides.

Conclusion

[60] 1. The West Transbaikalia region is usually classified as the combination of the Precambrian microcontinents and Caledonian terrains which were formed were thrust over the Siberian Paleocontinent during the Early Paleozoic. In the West Transbaikalia Caledonides the Ikat-Bagdarin zone is a nappe-fold structural feature where different rock complexes are combined tectonically. For the first time, this study proved the wide development of Upper Devonian and Carboniferous rocks along with the Neoproterozoic and Lower Paleozoic rocks.

[61] 2. Mapped in the northern part of the zone (Bagdarin area) were the rocks of two Caledonian and Hercynian structural stages. The Caledonian stage includes Neoproterozoic and Lower Paleozoic rocks. In terms of paleotectonics, they seem to have accumulated in a back-arc basin with the oceanic (or suboceanic) crust (Sivokon formation), on the slope and shelf of the ensialic island arc (black shale series of the Orochen and Yaksha formations) and in the island-arc proper (Usoy formation). The Hercynian stage is represented by the terrigenous deposits of the Tocher and Bagdarin formations (D-C) filling the Tocher trough which had been formed in the Caledonian heterogenic basement.

[62] 3. The example of the Bagdarin synform proves that the fold-nappe structure of the region was formed during the Carboniferous-Early Permian time interval, its formation being completed by the intrusion of the Late Paleozoic granites. The nappes were formed during a few stages, namely, the breaking of the Orochen, Usoy, and Bagdarin rocks from their crystalline basement, and their delamination and thrusting in the form of a slab series over the rocks of the relative autochthon (Sivokon and Tocher formations). Later, this slab package was deformed to a system of anti- and synforms with their subsequent separation into a series of reshuffled slabs. The structural evolution of this region is believed to have been associated with some intraplate collision which resulted in the extinction of the Tocher trough and its transformation to a Hercynian fold-nappe structural feature.

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