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THE VENDIAN OF THE BAIKAL-PATOM UPLAND, SIBERIA

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A large gap is documented in the Patom Upland, at the base of the Zherba Formation. The closely connected Tirbes Formation is now considered as its completing member. The Tinnaya Formation is separated from the Zherba and the overlying Nokhtuisk Formations by gaps. Small shelly fossils found there for the first time gave grounds for substantiation the lower boundary of the Cambrian at the bottom of the Nokhtuisk Formation and for referring the Tinnaya Formation to the Nemakit-Daldyn Stage of the Vendian. The more precise isotope chemostratigraphy of the Vendian-Cambrian deposits has shown that here, as in the other sections of the Siberian Platform, a negative marking excursion of $\delta^{13}C$ matches the paleontologically substantiated lower boundary of the Cambrian. The adjacent peaks helps to draw the boundaries of the *regularis* and *lenaicus* Zones and permit two conclusions. First, fossils of the *trisulcatus* Zone in the Siberian sections occur below the base of the Manykai Formation, whereas some representatives of the Ediacaran fauna penetrate there from below. Therefore, the Manykai Stage recognized on basis of this formation has no biostratigraphic sense and its lower boundary cannot be used for supporting the Vendian-Cambrian border. Second, the Zherba Formation corresponds to the Ediacaran Stage of the Khorbusuonka section of the Olenek uplift. The Lower Vendian deposits in the region were preserved only in paleodepressions. Their most complete section is known in the Bodaibo-Baikal pericratonic trough. The Lower Vendian is linked there, through gradual transitions, to the host rocks. Glacial formations and cap-dolomites are absent from it and, therefore, cannot be used as the bottom of the terminal Neoproterozoic of the International Scale. Quite promising for this purpose are pre-Vendian and intra-Vendian tectonic rearrangements whose ages reliably suggest that the Lower Vendian of the region formed in the interval from 650 to 612–620 Ma. Thus, the section of the Upper Vendian of the Baikal-Patom Upland is well substantiated by direct data at the Neoproterozoic III of the International Scale.

Vendian, paleontology, stages, zones, chemostratigraphy, zoning, correlation, International Scale, Patom Upland, Siberia

INTRODUCTION

When the General Siberian Scale of the Vendian was under development, the Baikal-Patom Upland received less attention than the other stratigraphic referents of the Siberian Platform. The reason is that the geographically separated key sections of this region were discordantly correlated with each other. As a result, not only dismembering of the Vendian but also location of its boundaries with adjacent parts of the Neoproterozoic and Cambrian gave rise to discussion. The same is true for the most comprehensively studied northern periphery of the region, the Patom Upland. Being easy to reach and having a simple structure of Neoptroterozoic deposits, its referent, the Late Precambrian Nokhtuisk section (Lena River between the mouths of the Bol'shoi Patom and Malyi Patom Rivers; Fig. 1), played an extremely important role in the development of the concept "Vendian" for the entire region under consideration. The sequence of bedding of stratigraphic units in this section was of no doubt after studies by Starostina [1]. However, they were named only by Predtechensky [2] as late as 1941. From bottom to top, they are as follows: Zherba, Tinnaya, and Pestrotsvet (Variegated) Formations. Later on (Fig. 2),

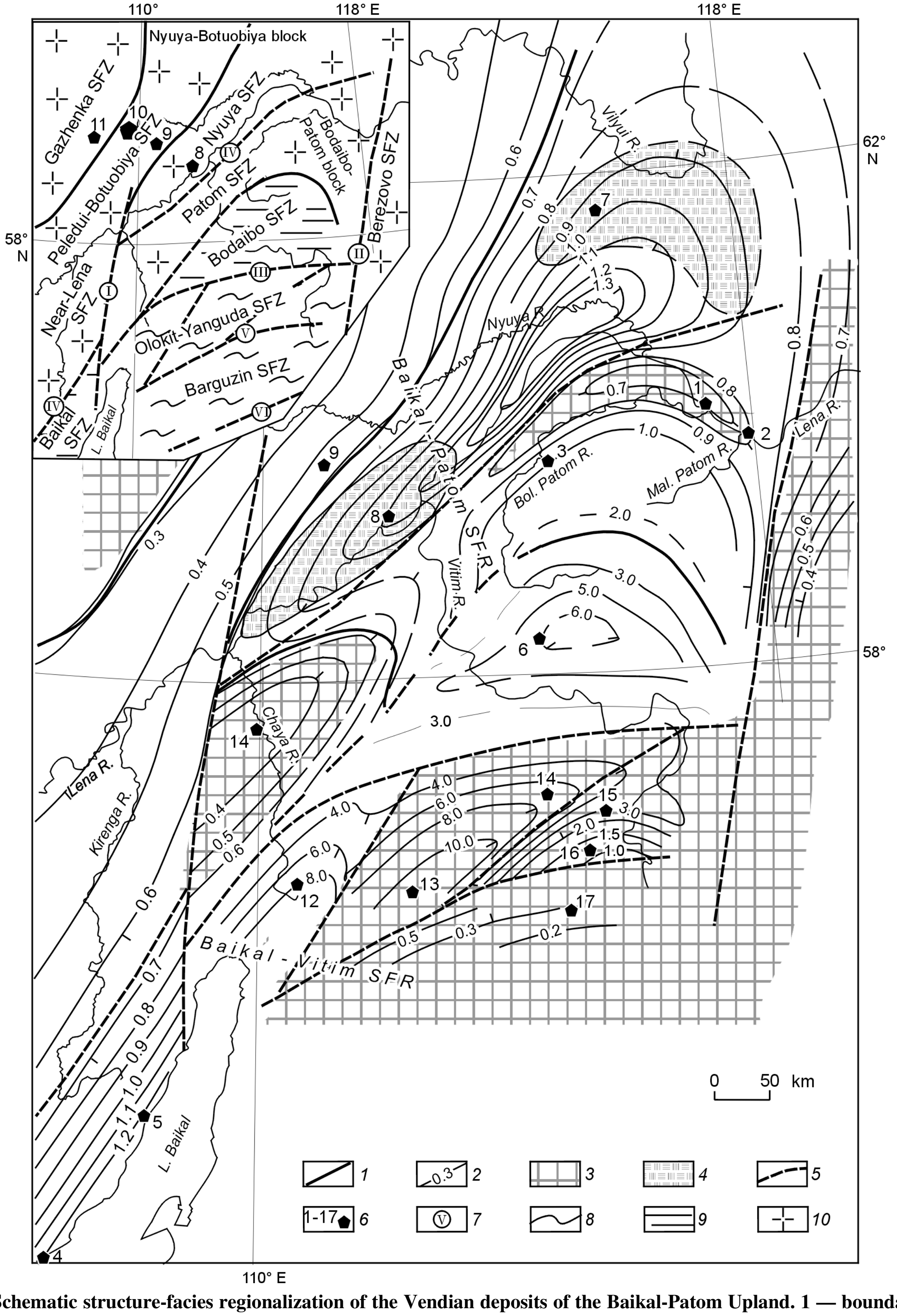


Fig. 1. Schematic structure-facies regionalization of the Vendian deposits of the Baikal-Patom Upland. 1 — boundaries of structure-facies regions and zones; 2 — isopachs of the Vendian deposits (in km); 3 — areas with no Lower Vendian deposits; 4 — areas of development of saliferous deposits in the Vendian; 5 — main faults; 6 — location of key sections and boreholes (see Figs. 2, 5, 6). In the inset: 7 — numbers of zones of tectonic disturbances: I — Kirenga-Chaya, II — Zhuya, III — Abchada-Vitim, IV — Baikal-Lena, V — Tompuda-Nechera, VI — Selenga-Vitim; 8 — accretion-collisional belt; 9 — pericratonic trough; 10 — cratonic structures.

the lower part of the Tinnaya Formation was distinguished as the Tirbes Formation [3], and the Pestrotsvet Formation was renamed as the Nokhtuisk one [4]. But the age of these units is still debatable. To say the truth, after the concept "Vendian complex" had been deeply ingrained in the region [5], the Zherba and Tinnaya Formations were not attributed to the Cambrian, but the question of exact location of the Vendian–Cambrian boundary continues to cause debates. Comparison of Pestrotsvet formations of the Patom Upland and Aldan Shield did not solved the question even in the most general form, before the Aldan Stage in its stratotype locality has been reduced to its upper substage [6] and called the Tommotian Stage in this volume [7]. However, since the skeletal fauna was known only near the middle of the thick Nokhtuisk Formation and indicated that this portion corresponded to the Atdabanian Stage, attempts were made to locate more precisely the Cambrian base by the transition from 4th to 5th complex of microphytoliths [8]. As a result, the lower subformation of the Nokhtuisk Formation remained in the Precambrian [4, 9, 10]. Recent data, however, demonstrate that the 4th and 5th complexes of microphytoliths do not regularly change in the sections, and in the folded framing and pericratonic troughs they are useless for locating the Cambrian-Precambrian boundary. Therefore, for correlation the Nokhtuisk and Pestrotsvet Formations in its stratotype we again preferred the appearance of red terrigenous material from their bottoms to locate this boundary in the Baikal-Patom Upland [11].

Still more questions appear in connection with the substantiation of the lower boundary of the Vendian in the Patom Upland. The resolutions of the 1962 Meeting put the Zherba and Tinnaya Formations were correlated with the Vendian of the Siberian hypostratotype of Late Precambrian in the Uchur-Maya district but the volume of the latter was then determined erroneously. Only the Ust'-Yudoma Formation was attributed to the Vendian complex while its underlying Ayim Formation of the Yudoma complex was considered to be of Riphean age. Accordingly, only the Lower Mot Subformation was dated by the Vendian in the Baikal region, while the Ushakovka Formation and its analogs were considered pre-Vendian. After the Lower Mot Formation had been proven to considerably match the Ushakovka Formation [9, 12], the Vendian volume in the Baikal-Patom Upland was determined much more precisely [10]. However, the problem of general subdivision of the Vendian system, the character of the Vendian relationships with underlying deposits and strict location of its boundaries in the section of separated structure-facies districts continue to be hotly discussed. Some stratigraphers believe that the Vendian is separated there from the upper Riphean or Baikalian by a principal event boundary, while the others suggest gradual transitions between them and even attribute some part of the Baikal complex to the Vendian.

This situation commanded us to carry out additional surveys in the region and, on the basis of the data obtained, to revise some earlier conclusions. As a result, the Baikal-Patom Upland not only became a promising referent of the Vendian stratigraphy in Siberia but also much contributed to understanding the essence of the terminal Precambrian subdivision in the General Scale.

LOWER BOUNDARY OF THE CAMBRIAN IN THE PATOM UPLAND

As noted above, the Vendian-Cambrian boundary is based on a lithostratigraphic correlation with the sections where this boundary is documented by direct data. The nearest ones lie at the middle reaches of the Aldan River, in the Olenek-Khorbusuonka-Muna-Tyung watershed, and in the western Anabar region, where paleontological and chemostratigraphic data are abundant [13]. This correlation is complicated by the fact that from mid-Aldan to Olekma, the stratigraphic volume of red rocks drastically reduces, coming to naught at the lower reaches of the Olekma [9]. The variegated rocks of the Nokhtuisk Formation of the Patom Upland along its periphery eastward (Olekma River), northward (Bilir Formation), and westward (Uspun Formation) are replaced by gray carbonates. In the range where such criterion as red color of rocks stops to work, it gives way to another criterion, occurrence of salts. On this basis, the Usol'ye Horizon was distinguished [4], from which the evident Lower Cambrian begins west of the Baikal-Patom Upland [4, 14]. Unfortunately, the salts appeared not always at the very bottom of this division. Along the periphery of the halmeic basin, the saliferous sequences are replaced, from bottom to top, by gray carbonates. Thus, north of the Patom Upland, salts appear only above the Bilir Formation and, at its western margin, only in the Upper Usol'ye Subformation containing rather high Cambrian fauna. In some regions (see Figs. 1 and 2) they are known from a lower stratigraphic level, much lower than the base of Cambrian [15]. However, the replacement of the Bilir Formation by red rocks both toward the Aldan Shield (Pestrotsvet Formation) and inward the Patom Upland (Nokhtuisk Formation) permits us to safely link the mass appearance of salts in the Irkut Amphitheater and in more westerly regions to a tectonis activity, resulting in red color of coeval rocks in other regions. Within the Siberian Platform, this boundary is thus a good marking horizon appropriate there for tracing the Vendian-Cambrian boundary.

Our investigations support this conclusion. At the bottom of the red Nokhtuisk Formation, lenses with visible small shelly fossils (SSF) were found for the first time (see Fig. 2), and the technique of chemical preparation

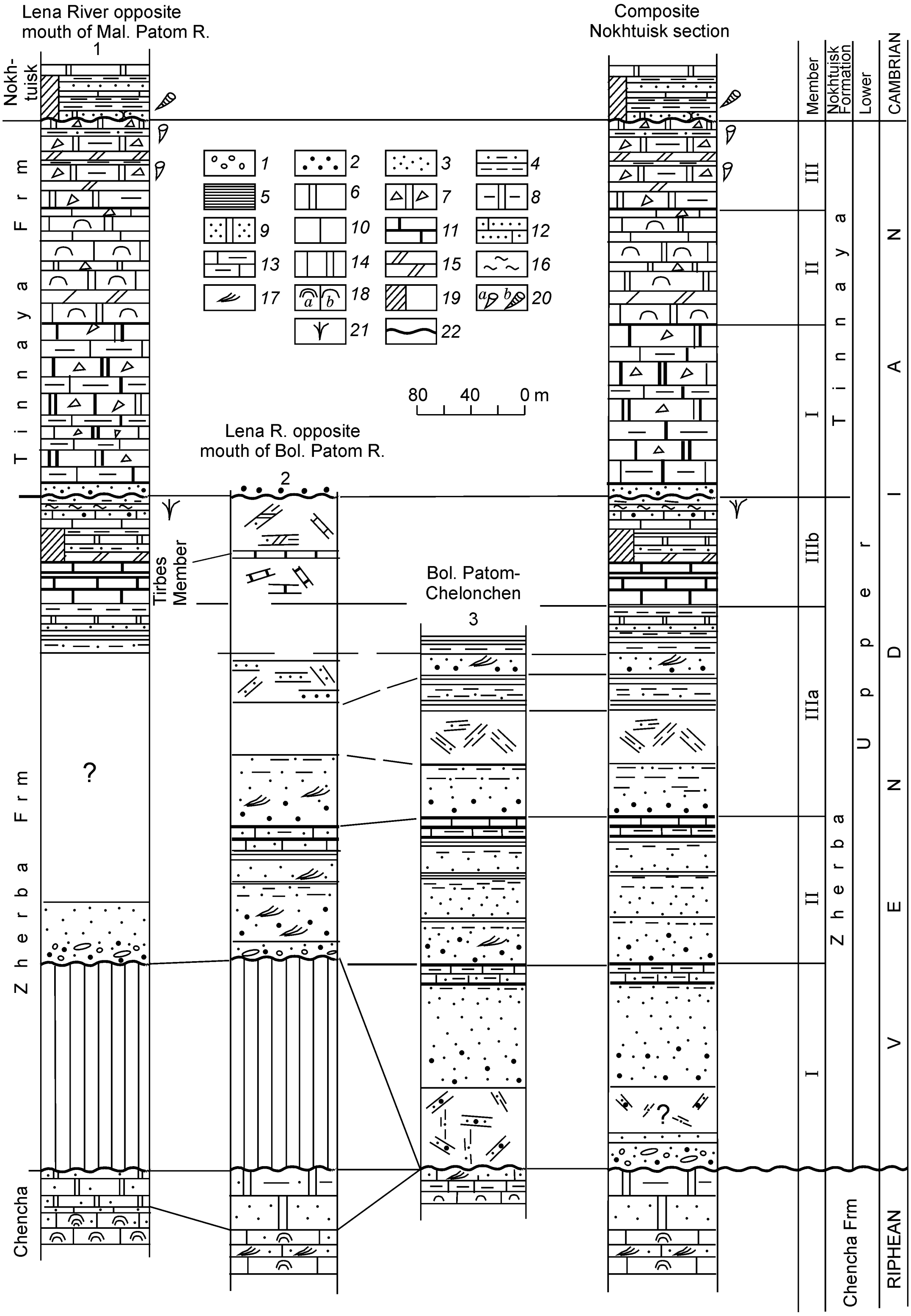


Fig. 2. Key Vendian sections in the basin of the Bol'shoi Patom and Lena Rivers. ***1*** **— conglomerates;** ***2*** **— coarse-grained sandstones, gravelstones;** ***3*** **— quartz sandstones;** ***4*** **— fine-grained sandstones and siltstones;** ***5*** **— silt-mudstones;** ***6–9*** **— dolomites:** ***6*** **— massive,** ***7*** **— detritus,** ***8*** **— clayey, sanded,** ***9*** **— stromatolite;** ***10–13*** **— limestones:** ***10*** **— gray,** ***11*** **— dark-gray, anthraconite, bituminous,** ***12*** **— sanded,** ***13*** **— clayey;** ***14*** **— lime dolomites, dolomitized limestones;** ***15*** **— marls;** ***16*** **— cherts;** ***17*** **— cross-bedding;** ***18*** **— stromatolite layering (*****a*****) and bioherms (*****b*****);** ***19*** **— variegated;** ***20*** **— findings of small shelly fossils of Nemakit-Daldyn Stage (*****a*****) and** ***sunnaginicus*** **Zone (*****b*****);** ***21*** **— silicified algae;** ***22*** **— unconformity boundaries.**

used by G.A. Karlova permitted finding of SSF in a wider range. Fossils of the Cambrian oldest zone, *sunnaginicus*, were discovered in the lower 50 m of the Nokhtuisk Formation, including: *Spinulitheca billingsi*, *Turcutheca crasseocochlia*, *Torellella* sp., *Latuochella maidipingensis*, *Conotheca* sp., *Hyolithellus* cf. *tschuskunensis*. From its very base, fragments of large shells appear, unknown in the Precambrian. Up the section, the list of SSF from the lower subformation of the Nokhtuisk Formation is supplemented with *Egdetheca* sp., *Halkieria* sp. and others, but the upper boundary of the *sunnaginicus* Zone has not been established from paleontological data yet. The upper 130 m of the Tinnaya Formation are characterized by: *Anabarites trisulcatus*, *Cambrotubulus* sp., *Protospongia*, *Chanceloria*. All these are known in the *trisulcatus* Zone but judging from the appearance of *Tiksitheca* sp. in the upper part of this interval, it partly belongs to the *antiqua* Zone. First findings of SSF of the Nemakit-Daldyn Stage are found 14 m below the roof of the Tinnaya Formation. Thus, the lower boundary of the Cambrian through the base of the *sunnaginicus* Zone virtually coincides with the bottom of the Nokhtuisk Formation, whereas the lower boundary of the Nemakit-Daldyn Stage, as in most other regions, remains still unclear.

The reported data well agree with the biostratigraphic boundaries established northward, in the field of the Bilir Formation. There, the Upper Bilir Subformation contains a rich complex of small shelly fossils: *Egdetheca aldanica*, *Hyolithellus tenius*, *H. vladimirovae*, *Allatheca concinna*, *Circotheca* sp., *Turcutheca* sp., *Spinulitheca billingsi*, *Sachites sacciformis*, *Tommotia* cf. *kozlowskii*. Higher, Archeocyathids occur: *Aldanocyathus* cf. *tkaschenkoi*, *Robustocyathus* cf. *novus* [16]. The coeval part of the Usol'ye Formation contains *Tumulocyathus* sp. and hyoliths *Majatheca* sp., *Ovalitheca* sp. [15].

The Lower Bilir Subformation contains *Circothecidae*, while *Conotheca mammilata*, *Turcutheca* sp., *Tiksitheca* sp., *Siphogonuchites* sp., *Anabarites trisulcatus* are found in the underlying Upper Yuryakh Subformation [16, 17]. These taxa evidence the Upper Tommotian age of the top of the Bilir Formation, and the rest of it exhausts the volume of this division, because the Upper Yuryakh Subformation already contains the complex of the *antiqua* Zone of the Nemakit-Daldyn Stage. Information about finding trilobite remains there was refuted by the experts participating in the workshop that was held at that time. Thus, the Yuryakh and the greatest part of the coeval Tinnaya Formation belongs to the Nemakit-Daldyn Stage of the Vendian, and Lower Tommotian Stage of Lower Cambrian begins since the base of the Usol'ye, Bilyar [17], and Nokhtuisk Formations.

There are no grounds for a large interruption between the Nemakit-Daldyn and Tommotian Stages, as supposed by some authors [18]. Despite the presence of erosional pockets in the roof of Tinnaya Formation and kaolinite in the clay fraction (hereafter, identified by G.M. Pisareva from the Institute of Petroleum Geology, Novosibirsk) from the bottom of Nokhtuisk Formation, the interruption there, as in other sections of Siberia, does not exceed in size one biostratigraphic zone and, therefore, cannot be established paleontologically [13]. The only exception is linked to faults conjugated with the suture separating the Uchur-Maya plate and Yudoma-Maya trough at the segment from the near-mouth part of the Yudoma River to the Belaya River, where the depth of the pre-Pestrotsvet erosion is rather considerable [19]. In the southern part of this region we estimated the thickness of the lost upper Yudoma Series at 60 m [20]. Now, however, Khomentovsky does not rule out that the top of the Ust'-Yudoma Formation could have been cut by overthrust. No serious events occurred at the boundary between the Tommotian and Nemakit-Daldyn Stages. In addition to the published data [17], the evidence is that along the periphery of the halmeic basin, this boundary runs inside a compositionally uniform sequence. Thus, the lower boundary of the Bilir Formation is rather tentative and is drawn at different levels by different authors [15, 21]. At the extremal southwest of the platform the first Lower Tommotian taxa in the Averinskaya borehole (30 km southwest of the town of Yeniseisk) appear in homogeneous carbonates, 20 m below the first salts (*Edgetheca* sp., *Ladatheca* sp., *Chancelloria*). By analogy, in the homogeneous carbonate unit, the boundary runs inside the Lebyazh'ya Formation in the north of the Yenisei Range, in the Platonovo Formation of the Turukhan Uplift, in the Sukharikha Formation of the Igarka-Noril'sk region, as well as in some other occurrences [7, 10].

It is necessary to say that the detailed correlation of the Vendian deposits underlying the beds with fossils is less reliable because the potential of other organic remains is much lower as compared with skeletal Metazoa. The same is true for all nonpaleontological methods of comparison of deposits. Nevertheless, below we will use these methods, as this is the adopted practice in the present-day stratigraphy of the Late Precambrian.

During the 2000 expeditions, we applied the isotope chemostratigraphy to testing of the upper Precambrian-lower Cambrian in the Nokhtuisk section of the Patom Upland. At present, the specimens closely collected (at an interval of 1 m) from the Nokhtuisk-to-Tinnaya transition beds (Fig. 3) and from the carbonate interbeds near the lower boundary of the Zherba Formation are all chemostratigraphically analyzed. The determinations were carried out by Ponomarchuk in the Laboratory of Radiogenic and Stable Isotopes of the UIGGM, Novosibirsk, using the decomposition in an orthophosphoric acid, with individual features of carbonates taken into account [22]. It was grounded earlier [23] that this interval of the section is appropriate for chemostratigraphic examinations. Using the

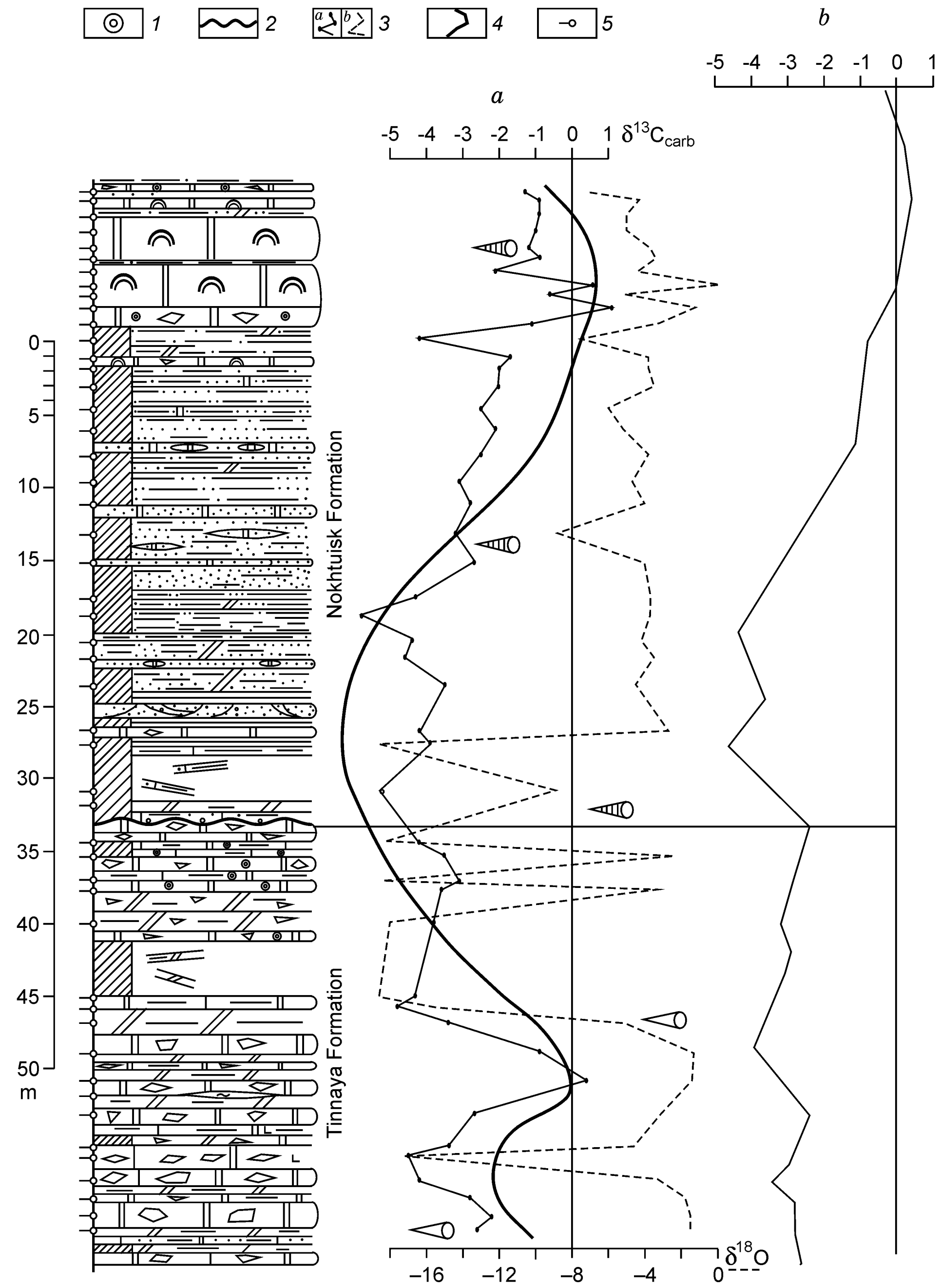
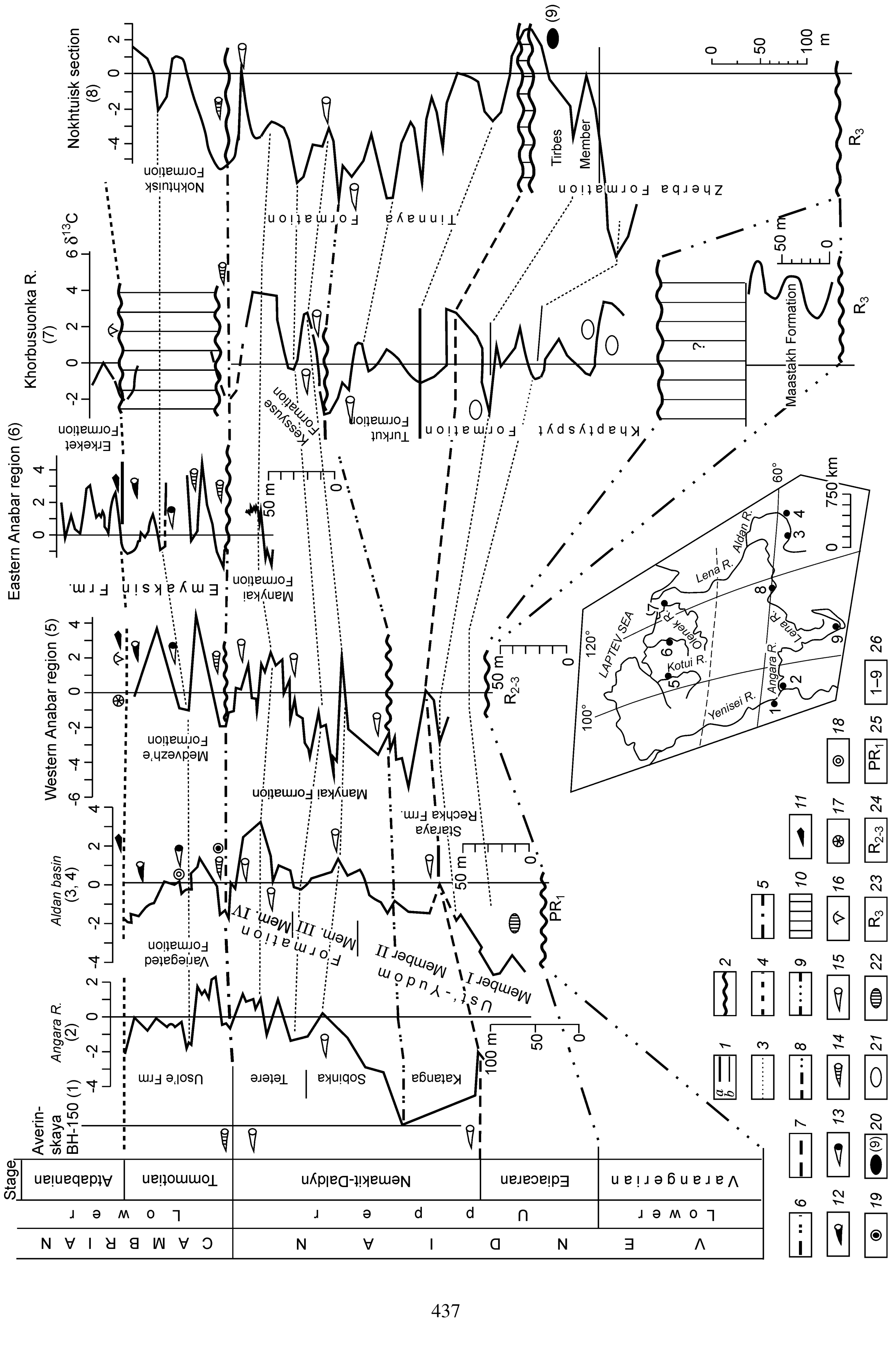


Fig. 3. Substantiation of the lower boundary of the Cambrian in the Nokhtuisk section. Chemostratigraphic curves: *a* — our data, *b* — after Pelechaty [23]; *1* — phytoliths; *2* — Precambrian-Cambrian boundary; *3a* — curve of δ^{13}C; *3b* — curve of δ^{18}O; *4* — generalized curve $\delta^{13}C_{carb}$; *5* — sampling localites. Other designations follow Figs. 2 and 4. Comments in text.

published data on the Tinnaya and Tirbes Formations [23], we can plot a curve for successive change of δ^{13}C for the whole part of the Vendian outcropped in the region (Fig. 4). Worthy of special attention is the upper part of this curve corresponding to that interval of the section where the lower SSF-based boundary of the Cambrian runs (see Fig. 3). Usually the curve plotted from the closely tested interval is characterized by a great deal of small secondary peaks, which are to be generalized, as made in Fig. 3. In the process, a large (up to –5) negative excursion is displayed, related to the Tinnaya-Nokhtuisk boundary. Thus, in the Nokhtuisk section as well as at the Aldan River, in the lower reaches of Angara River, and in the western Anabar region (see Fig. 4), a marking negative excursion $\delta^{13}C_{carb}$ is linked to the paleontologically substantiated lower boundary of the Cambrian running at the bottom of the Tommotian Stage [13]. Interpretation of recent publications permits us not only to enhance support for this conclusion but also to construct a general Siberian model for isotope chemostratigraphy of the Vendian-Cambrian deposits. Of exceptional interest is the succession of Vendian-Cambrian excursions $\delta^{13}C$ established along the Khorbusuonka River on the Olenek Uplift [24]. Unfortunately, the authors of this curve did not take into account two large breaks in the succession they characterized. One of them separates the Maastakh Formation from the basal beds of the Khatyspyt one. It is proven that each of these formations is a large sedimentary rhythm, one representing relics of the Lower Vendian and the other, most of the Upper Vendian. The large volume of the separating erosion is inferred from the fact that the basal beds of the second rhythm in different sections of the Olenek Uplift cut off either most of the carbonate deposits of the first rhythm or the whole Lower Vendian unit [25, 26]. The other washout, between the Kessyusa and Erkeket Formations, was noted nearly by all researchers of the region. But its volume is determined only from paleontological data. On the Olenek Uplift, the lower Cambrian boundary at the base of the *sunnaginicus* Zone runs 20–10 m below the roof of the Kessyusa Formation [17, 27]. The lower part of the overlying Erkeket Formation is less definetely characterized by paleontological data. At first glance, it contains only the taxa inherited from the Nemakit-Daldyn and Tommotian Stages [28]. A closer study reveals taxa from sufficiently high parts of the Tommotian Stage [27]. Moreover, along the Khorbusuonka River, we found fragments of trilobites 6 m above the base of the Erkeket Formation, and 5 m higher, forms of the second trilobite *Fallotaspis* Zone. Thus, most upper part of the Tommotian Stage here was eliminated by the pre-Atdabanian washout. Hence, the beginning of a large negative excursion at the topmost Kessyusa Formation [24] is natural to be considered a continuation of the chemostratigraphic marker of the bottom of the Tommotian Stage, while its termination falls already on the pre-Erkeket washout (see Fig. 4). Obviously, the negative excursion at the sole of the Erkeket Formation is not the termination of this marker [24] but records the beginning of a large negative excursion $\delta^{13}C$ at the bottom of the Atdabanian Stage.

The chemostratigraphic curve recently plotted for the eastern Anabar region [29] well fits our scheme. However, the biostratigraphic subdivision of the Manykai and Emyaksin Formations used for plotting this curve was based on the old biostratigraphic scheme by Val'kov [28], with no addition of new paleontological information. We repeatedly indicated that this scheme is not correct [13, 17]. The presence of such taxa as *Aldanella attleborensis*, *Philoxenella spiraliralis*, *Turcutheca cotuensis*, *Spinulitheca billingsi*, etc. in the lower 50 m of the Emyaksin Formation deny the idea of the pre-Sunnagin age of these deposits. In essence, Kuchinsky et al. [29] report only chemostratigraphic information to substantiate their stratigraphic scheme. But, as visible from Fig. 4, a large negative excursion in lower part of the Emyaksin Formation is identical to the chemostratigraphical marker in the base of *sunnaginicus* Zone, which is ubiquitously the onset of the Cambrian. The same figure shows that positive and negative peaks above and below the base of the *sunnaginicus* Zone coincide. Thus, the complex correlation of key sections in Fig. 4 can be used as a base to model the isotope chemostratigraphy of the Vendian-Cambrian beds. Not only distinct boundaries of the Tommotian Stage can be drawn, but all studied sections can be reliably divided into the *sunnaginicus*, *regularis*, and *laneicus* Zones, even with little or no paleontological material. Analysis of this model shows that the SSF of the Nemakit-Daldyn Stage are found below the bottom of the Manykai Formation not only in the Turkut Formation of the Olenek Upland [13, 17] but also in many other sections (see Fig. 4). Thus, the Manykai Stage distinguished on the basis of the Manykai Formation has no biostratigraphical sense.

Fig. 4. Chemostratigraphic model for the Vendian-Lower Cambrian deposits of the Siberian Platform. *1* — boundaries of units: *a* — formations, *b* — members; *2* — washouts; *3* — chemostratigraphic correlation lines; *4* — Atdabanian-Tommotian boundary; *5* — Precambrian-Cambrian boundary; *6* — Manykai Formation basement level; *7* — Nemakit-Daldyn Stage roof; *8* — boundary of Lower and Upper Vendian; *9* — lower boundary of Vendian; *10* — breaks in sedimentation; *11–15* — small shelly fossils: *11* — Atdabanian Stage, *12* — *Dokidocyathus lenaicus* Zone, *13* — *Dokidocyathus regularis* Zone, *14* — *sunnaginicus* Zone, *15* — Nemakit-Daldyn Stage; *16* — trilobites; *17–19* — archeocyathids: *17* — Atdabanian Stage, *18* — *regularis* Zone, *19* — *sunnaginicus* Zone; *20–22* — Ediacarian fossils: *20* — in Baikal region, section 9 in inset; *21* — Khorbosuonka River, *22* — Yudoma River; *23–25* — unit indices: *23* — Upper Riphean, *24* — Upper and Middle Riphean, *25* — Early Precambrian; *26* — referencing of sections in the inset. Information about sections 1–9: 1 — our data; 2–5 — see [13]; 6–8 — see text; 8–9 — Baikalian section, correlation with the Nokhtuisk Section see in Fig. 5 and text.

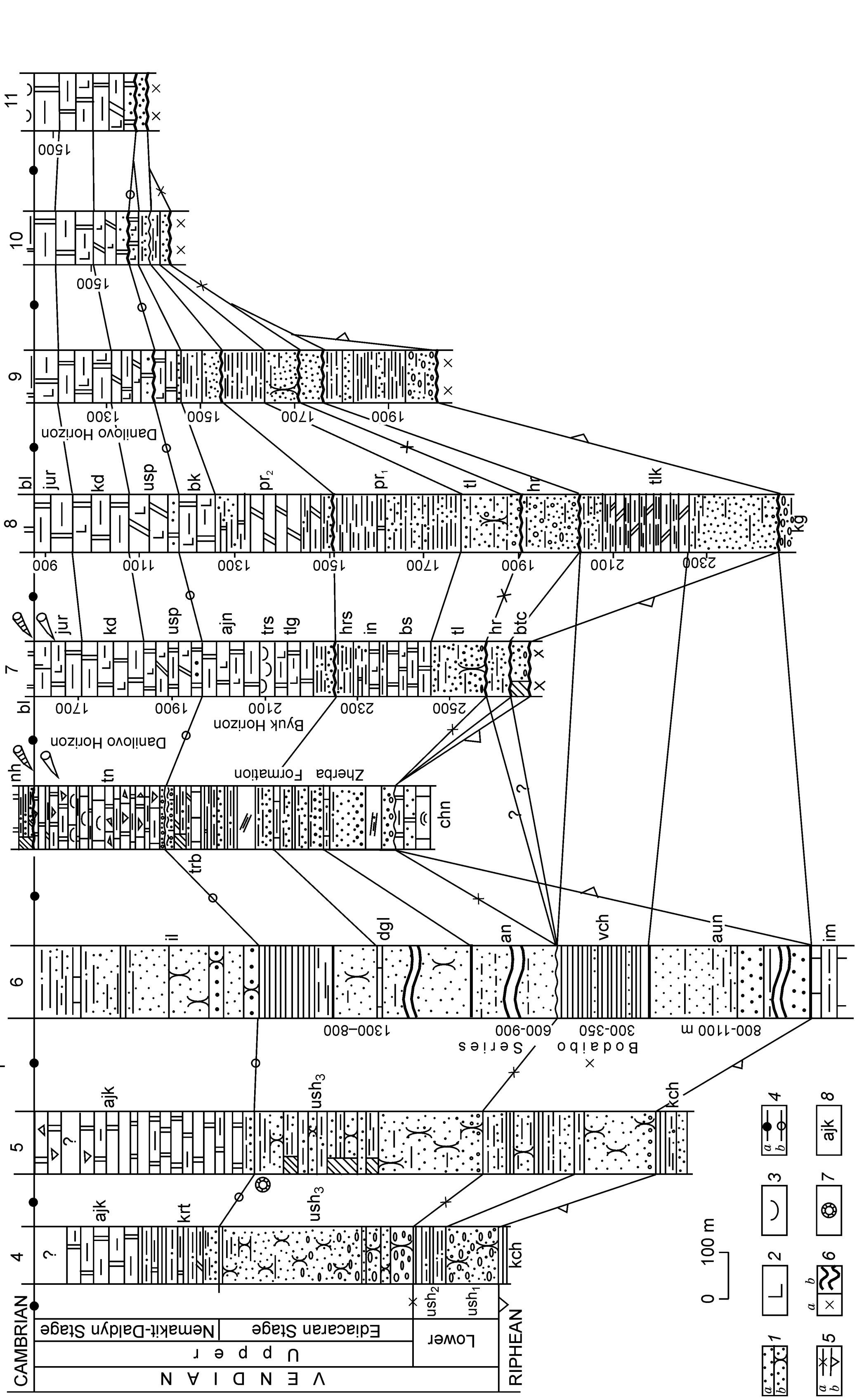

Stage
Averinskaya BH-150 (1)
Angara R. (2)
Aldan basin (3, 4)
Western Anabar region (5)
Eastern Anabar region (6)
Khorbusuonka R. (7)
Nokhtuisk section (8)
CAMBRIAN
VENDIAN
Lower
Upper
Atdabanian
Tomotian
Nemakit-Daldyn
Ediacaran
Varangerian
Usol'e Frm
Tetere
Sobinka
Katanga
Variegated Formation
Ust-Yudoma Formation
Member I
Member II
Mem. III
Mem. IV
Medvezh'e Formation
Manykai Formation
Staraya Rechka Frm.
Emyaksin Frm.
Erkeket Formation
Kessyuse Formation
Turkut Formation
Khaptyspyt Formation
Maastakh Formation
Nokhtuisk Formation
Tinnaya Formation
Zherba Formation
Tirbes Member
δ13C
LAPTEV SEA
Lena R.
Aldan R.
Olenek R.
Kotui R.
Angara R.
Yenisei R.
750 km

STRATIGRAPHICAL VOLUME OF THE VENDIAN IN THE PATOM UPLAND

The "Nokhtuisk section" usually sums up the information on two intersects of a synclinal fold, extended along the Lena valley opposite the mouths of the Bol'shoi Patom and Malyi Patom Rivers [30]. To characterize it, we additionally used the section along a tributary of the Bol'shoi Patom (Chelonchen River, see Figs. 1 and 2 [9, 30, 31]). After the upper boundary of the Vendian has been drawn, one of the main problems of the Late Precambrian stratigraphy of the Patom Upland is the stratigraphic volume of the Zherba Formation and character of its relationship with the Riphean Zhuya Series [10] or Baikalian [32, 33]. Initially, this formation was considered much younger than the Ushakovka Formation of in the Baikal region [5], which soon became a hypostratotype of the Vendian in southern Siberia. On the basis of the historical-geological data, we had long compared the Zherba Formation only with the upper subformation of the Ushakovka Formation [9, 32]. However, later, having no sufficient data for detailed correlation of these subdivisions, we followed many other authors [10] to compare the Zherba and Ushakovka Formations in full volumes [31, 34]. To substantiate this correlation, we distinguished the upper member of the Zherba sandstones as an analog of the Upper Ushakovka Subformation in the Nokhtuisk section and fine clastics of the Tirbes Formation, as a formal unit [11]. The sole of this subdivision was supposed to be the boundary between the lower and upper series of the Vendian System.

Our field works did not add much novelty into the previous description of the lithology of the main Vendian subdivisions of the Nokhtuisk section [30]. Hence, we will not repeat it in detail but will restrict ourselves to a more precise correlation of components of the Nokhtuisk section, to the specification of its main subdivisions and their relationships with the host rocks. The first principal problem we encountered was precise location of the lower boundary of the Vendian Zherba Formation with the carbonate rocks of the Chencha Formation, which officially dates from the Upper Riphean. The problem is that many researchers [9, 10, 30, 31] bind the onset of the Zherba Formation and the Vendian in the sections of the Patom Upland with 18–25 m thick member of dolomites, in places separated from the rest of the Chencha Formation by a thin bed of sandstones. The reason was that the dolomites contained the stromatoliths *Linella simica*, *L. zhuica*, *Dgerbia grumulosa* [31, 35], which were considered typical of the Vendian. Similar relationships are explained by the presence of a gradual transition between the Chencha and Zherba Formations and even permit some geologists to attribute the upper part of the Baikal Series and its analogs, the Taseeva and Oselok Series of the Yenisei Ridge and the Sayans, to the Vendian [36, 37]. But these arguments are in controversy with the data that since the Vendian (Yudomian), a principally new step had been developed not only in the Baikal-Patom Upland but also over the whole Siberian Platform [31, 32, 34]. It is associated with the cut-off of a thick unit of Riphean deposits in all directions from the Baikal-Patom trough and overlie by Vendian rocks even within its limits different Proterozoic units from the Akitkan Series to the Valyukhta and other formations of the Baikal Series [38]. Our data confirm the information on the essential events separating the Zherba sandstones and the underlying carbonates within the Patom Upland. There are erosional incisions at their contact deep to 0.5 m, filled with poorly sorted, coarse-grained sandstones, karst structures, several closely lying erosional surfaces and lenticular lenses of carbonate-sandy breccia-conglomerates. In addition, X-ray analysis in thin clay interbeds separating these formations displayed a noticeable amount of kaolinite (G.M. Pisareva, oral communication), which seems to be evidence that a crust of weathering was present at this border. Detailed study of the transition from dolomites to the underlying limestones of the Chencha Formation shows that the dolomites and limestones have the same textural and structural features; there are facies mutual transitions and signs of secondary dolomitization of limestones. The interbeds of terrigeneous rocks observed in dolomites [9] are made up of sandy and slime limestones rather than of quartz sandstones. On the contrary, the interbeds and

Fig. 5. Schematic correlation of Vendian deposits of the Baikal-Patom Upland. ***1*** **— composition of terrigenic rocks:** ***a*** **— quartz and arcose,** ***b*** **— polymictic;** ***2*** **— sulfates;** ***3*** **— rock-salt;** ***4*** **— boundaries of basement:** ***a*** **— Tommotian Stage,** ***b*** **— Nemakit-Daldyn Stage;** ***5*** **— boundaries of basement:** ***a*** **— Upper Vendian,** ***b*** **— Lower Vendian;** ***6*** **— pre-Riphean (*****a*****) and Riphean folded (*****b*****) basement;** ***7*** **— location of Ediacarian fauna;** ***8*** **— indices of formations and members: ajk — Ayankan, krt — Kurtun, ush — Ushakovka, kch — Kachergat, nh — Nokhtuisk, tn — Tinnaya; trb — Tirbes, gr — Zherba; chn — Chencha, us — Usol'e, tt — Tetere, sb — Sobinka, kt — Katanga, tr — Tir, np — Nepa, hm — Khamakin Horizon, bl — Bilir, jur — Yuryakh, kd — Kudulakh, usp — Uspun; members of Byuk Formation: ajn — Ayan, trs — Torsal', tlg — Telgespit; in — Ynakh, bs — Besyuryakh, hrs — Kharystan, hr — Khoronokh, btc — Betincha, im — Imnyakh, aun — Aunakit, vch — Vacha, an — Anangr, dgl — Dogaldyn, il — Iligir, old — Oldakit, avg — Avgol', mn — Manyukan, tk — Tukolama, sd — Sidel'ta, mm — Mamakan, gl — Gol'tsy. Other designations see in Fig. 2. Location of sections is shown in Fig. 1.**


Baikal SFZ
Bodaibo SFZ
Patom SFZ, composite section 1-3 (see Fig. 2)
Nyuya SFZ
Verkhnevilyuchanskaya BH-602
Parshinskaya BH-1
Peledui-Botuobiya SFZ
Talakanskaya BH-803
Tympuchikanskaya BH-2543
Nepa-Botuobiya arch
Preobrazhenskaya BH-138
CAMBRIAN
Nemakit-Daldyn Stage
Ediacaran Stage
V E N D I A N
U p p e r
Lower
RIPHEAN
Bodaibo Series
Danilovo Horizon
Byuk Horizon
Zherba Formation
100 m

carbonate lenses observed in the Zherba sandstones above the dolomite member are accumulations of fragments of rewashed dolomites whose cement is overfilled with quartz grains. The above data suggest that the described dolomite member crowns the Chencha Formation, has nothing in common with the Zherba sandstones, and is separated from them by a considerable gap.

Data on stromatoliths do not contradict this conclusion. Revision of their findings showed that the dolomite member proper contains only linellae, which are presently known to occur both in the Upper Riphean and in the Vendian. At the same time, findings of *Dgerbia grumulosa* originate from the sand-dolomitic rocks of the Zherba Formation and seem to prove its Vendian age.

The amount of the pre-Zherba gap can be estimated from correlation of the fragments making up the Nokhtuisk section. The Zherba Formation consists of three rhythms of variable thickness and composition (see Fig. 2). Rhythm I, composed of sufficiently coarse-grained quartz-feldspar sandstones, is developed only in the section along the Bol'shoi Patom, at the mouth of the Chelonchen Brook, which is southward in the zone of transition from the uplifted area toward the Bodaibo trough (see Figs. 1, 5). The roof of this rhythm contains interbeds of siltstones and carbonate rocks. The outpinching of the relevant lower member of the Zherba Formation northward, to the Lena valley suggests that the pre-Zherba gap exceeded there 120 m (thickness of Rhythm I in the Chelonchen section, see Fig. 2). The marker correlating the onset of Rhythm II of the Zherba Formation in the Chelonchen section is its basal coarse-grained member overlapping the carbonate beds of the Chelonchen Brook. Its thickness there is under 40 m. In the sections opposite the mouths of the Bol'shoi Patom and Malyi Patom Rivers, its analog is previously characterized basal beds, the onset of the Zherba Formation (see Fig. 2). Several closely lying erosional surfaces are indicative of the event character of this boundary. Rhythm II in the sections opposite the mouth of the Bol'shoi Patom River and the Chelonchen Brook is represented chiefly by sandstones, often with cross-bedding, at the top of which the number of siltstone interbeds increases, and interbeds and members of carbonates appear. Opposite the mouth of the Malyi Patom, a nonexposed interval corresponds to most of Rhythm II. The thickest Rhythm III, unlike the former two, has a transgressive and a regressive shoulders. The lower part of the transgressive shoulder is composed chiefly of coarse-grained, often cross-bedding sandstones. Their thickness reaches 40–70 m. All coarse-grained deposits of the Zherba Formation were formed under bar settings of shallow-water shelf. Higher lies a 30 m thick member of alternating quartz sandstones, siltstones, and mudstones. Interbeds of clayey dolomites and marls occur. The transgressive and regressive shoulders of the rhythm are separated by a member of black mudstones and marls grading into black bituminous limestones. The bituminous rocks are about 16 m thick. The section of Rhythm III is completed by a member of alternating (5 to 30 cm) variegated and dark siltstones, mudstones, clayey dolomites, as well as rare interbeds of black algal silica-phosphate rocks. The amount of carbonate rocks with an abundant admixture of quartz sand increases up the section. The clastics becomes coarser toward the roof of the member, where even gravelly interbeds occur.

Kokoulin [3] distinguished the rocks of the lower part of the regressive component of Rhythm III (about 120 m) as a formal unit, the Tirbes Formation. Later, some authors proposed to include in it the member of bituminous limestones. In terms of rhythmostratigraphy, this unit (in any volume) is a member completing the Zherba Formation.

Pelechaty [23] believes that the fine-grained rocks underlying and overlying the bituminous carbonates are turbidites associated with a ramp and transformed into clastic flows. However, the presence of cross-bedding, glyptomorphs after salt, alternation with shallow-water and algal carbonates, the absence of well-pronounced turbidite rhythms and, on the contrary, the presence of regressive sequences of clastic material in the beds make this hypothesis rather doubtful. Detailed correlation of the fragments composing the Nokhtuisk section (see Fig. 2) and reduced coarseness of the clastics from north inward the Baikal-Patom trough also contradict our idea of distinct bipartite structure of the Zherba Formation, making it similar to the section of the Ushakovka Formation in the Baikal region in a full volume [11].

The boundary between the Tinnaya Formation completing the Vendian section and the overlying Tirbes Member is slightly erosional. There is evidence of karsting at this boundary [23]. Moreover, we observed erosional pockets in the roof of the Zherba Formation, while more kaolinite is found in the bed of red-brown clays (10–15 cm) separating the formations under study, which seems to indicate the presence of weathering crust. We divide the Tinnaya Formation into three members. The lowest one begins with basal quartz gravelstones 9 m thick. The main part of the member is represented by dark-gray, fine-laminated, less frequently massive dolomites, which are often calcareous and clay-silty. Its total thickness reaches 130 m. The intermediate member typically contains light-gray, rather thick (0.53 m), massive, algal-bioherm limestones. Fine- and coarse-layered clayey dolomites are subordinate to them. The thickness of the member reaches 80 m. In composition and structure, the upper member is similar to the lower one, but the carbonates from its upper half contain an admixture of silty-clay material and interbeds of light-brown dolomite marls up to 1–3 m thick. The carbonates of this member are characterized by small caverns (up to 2 mm) and smell of bitumen on shock. A lenticular interbed of black cherts up to 15 cm thick is found at a distance of 20 m from the roof. The thickness of the upper member reaches 70 m.

The Tinnaya Formation is distinguished by abundant carbonate breccias. Pelechaty [23] used them for dismembering the formation. He named the members according to his understanding of their genesis: "chip" debris conglomerates; "raft" conglomerates (transferred plates), etc. This categorization is based on the idea of sediment sliding downslope from a remote ramp. The extent of supposed transportation is inferred from the terms debris and turbidite flows. We have a principally different idea of the nature of the Tinnaya breccias, often a dominating type of rocks of Members 1 and 3. It is based on common strike replacement of layered carbonates by breccias, among which intact strata remain. Concordant occurrence of packages of brecciated rocks among other their varieties is also typical. From our point of view, this indicates crushing of weakly lithified carbonate as a result of its transport for small, up to few tens of meters, distances. Another kind of breccias making up rather thick packages of uniform clay carbonate with a bulk of intricately shaped debris of centimeters to over one meter in size formed, most likely, by hypergenesis (see below).

The reported data on the structure of the Nokhtuisk section, the reference for the Patom Upland, indicate that the Vendian was preceded by an intense tectonic restructuring, after which a one-rhythm unit of Upper Vendian began to develop there asynchronously. Support for this conclusion comes from Fig. 4, where the chemostratigraphic framework contains not only SSF data but also findings of Ediacaran fossils. The Tirbes Member of the Zherba Formation in the column of the Patom Upland is supplemented by paleontological information on the coeval top of the Upper Ushakovka Subformation in the Baikal region [11; Fig. 5]: *Baikalina sessilis*, *B.* sp. n., *Pteridinium* sp., *Cylindrichnus* sp. [39]. Chemostratigraphic correlation puts these findings at the level of Ediacaran biota from the top of the Khatyspyt Formation of the Olenek Upland [40]. The data on Ediacaran fossils from the bottom of the Khatyspyt Formation [41] and from the first member of the Ust'-Yudoma Formation of the Uchur-Maya region [20] also characterize the lower part of the Zherba Formation. Thus, the whole Zherba Formation corresponds to the Ediacaran Stage of the Upper Vendian.

Yakshin [42] has collected and described a rich complex of algal remains from phosphate-siliceous rocks of the upper (Tirbes) member of the Zherba Formation: *Glomovertella ampla* Yaksch., *Oscillatoriopsis medius* Yaksch., *O. nochtuica* Yaksch., *O.* ex gr. *maxima* Y. Zang., *Stigonemopsis asymmetricus* Yaksch., *S. simplex* Yaksch., *S. compositus* Yaksch., *Palaeovaucheria lenaica* Yaksch., *Obruchevella parva* Reitl., *O. sibirica* Reitl., *Tinnajaphyton unifarium* Kol., *T. amplum* Yaksch., *Talakania* sp., *Catenuata implicata* Yaksch., *Matchaphyton parvulum* Kol., *Gomosphaeridium* sp., *Glenobothrydion*? sp., *Gloeodinopsis tchuchonoica* Kol., *Germinosphaera tatasii* Mikh., *Pterospermopsimorpha granulata* Mikh., *Rosula multilobata* Yaksch., *Caulis curvatus* Yaksch., *Fistularia volubila* Yaksch., *F. parva* Yaksch., *Columella clavata* Yaksch., *C.* sp., *Catenula simplex* Yaksch., *Koptchania lucida* Yaksch., *Tirbessia simplex* Yaksch., *T. obscura* Yaksch., *Nochtuija prima* Yaksch., *Botrys ramificatus* Yaksch., *Dabania aperta* Yaksch., *Karanchtchania binata* Yaksch., *Malopatomia composita* (Yaksch.).

This biota of the Tirbes Member is commonly represented by new taxa, which are presently considered endemics. At the same time, so intricately branching multicellular forms, occasionally very large, with sporangia, have not been observed in the Riphean yet. Of the above list, *Talakania* [43], *Glomovertella*, *Obruchevella parva*, *O. sibirica* [44, 45] are widespread in the Vendian, the latter two being known from the Lower Cambrian as well. Simpler Vaucheria [46] are known in the Upper Riphean, along with widespread *Pterospermopsimorpha granulata*, *Germinosphaera tadasii*, *Glocodiniopsis tchuchonoica* [45]. It is quite possible that in the future, the data on a rich complex of microfossils of the Tirbes Member will be an important link in the reconstruction of the Vendian stage of algal evolution. In any case, this Vendian complex is very different from the information about the uppermost Kachergat Formation in the Baikal region and the Olkhin Formation in the Irkutsk Sayans containing some transit (from Riphean to Vendian) forms of microfossils, on the basis of which the Vendian age of these deposit was erroneously suggested [34].

PRINCIPLES OF STRUCTURE-FACIES REGIONALIZATION OF THE VENDIAN OF THE BAIKAL-PATOM UPLAND

In all directions from the Nokhtuisk section, the structure, composition, thickness, and volume of the Vendian in the Baikal-Patom Upland or structure-facies area (SFA) experience considerable changes. Their regularities permitted us to compile schemes of structure-facies regionalization for the Vendian of this region [11, 47]. The above substantiated conclusion that the Zherba Formation corresponds only to the Upper Vendian alone requires that these scheme be updated.

The structure-facies zoning of the region is controlled by a network of large long-lived faults (see Fig. 1) responsible for the specific Vendian history of the separated blocks. As shown earlier, the main divisions of the

Baikal-Patom SFA in the Baikalian and Vendian are the Baikal-Patom and Baikal-Vitim structure-facies regions (SFR), which differ in the origins of their basements: continental or oceanic crust [47]. These SFZ's are separated by the deep-seated Abchada-Vitim fault. South of it, in the Baikal-Vitim SFR, the Vendian deposits rest discordantly on the underlying rocks, whereas north of it, in the Baikal-Patom SFR, they concordantly overlie the Baikalian.

In the Baikal-Patom SFR, the principal structure-facies taxon, of higher rank than SFZ, is the Bodaibo-Patom block [47], which is situated between the latitudinal Abchada-Vitim and Baikal-Lena faults; it is also bounded by the orthogonal Zhuya and Kirenga-Chaya faults (see Fig. 1). The tectonic movements along them, which began in the Baikalian and progressed in the lower Vendian [47], more intensely revived in the Paleozoic. This hinders the reconstruction of the Neoproterozoic history of the region, because the Early Precambrian uplifts were again denuded, which led in places to the inversion of paleostructures, complete washout of Late Precambrian deposits, and tectonic overlap of the principal transition zones. In general, in the Vendian the Bodaibo-Patom block united conjugate units: the uplifted Patom SFZ in the north and the downwarped Bodaibo SFZ in the south (see Figs. 1, 5). The principal differences between them were then determined by: (1) a general southward increase in thicknesses of coeval units; (2) appearance of older Vendian deposits in the Bodaibo SFZ; (3) certain differences in lithology of the beds to be compared (see Fig. 5). As long as it was adopted that the Zherba Formation corresponds to the whole Vendian, we were forced to suggest that a large sedimentary rhythm, the Aunakit and Vacha Formations, concordantly underlying the Anangr and Dogaldyn Formations, concordantly underlying analogs of the Zherba deposits in the Bodaibo SFZ, date from the pre-Vendian [47, 48]. But it is evident now that the stratigraphers who considered the Aunakit Formation as the onset of a new (Bodaibo) series were right, for this series covered the whole volume of the Vendian in the region [49]. In this division, the Aunakit-Vacha rhythm corresponds to a similar succession of Lower Vendian deposits in other regions of Siberia [32, 33]. The specific Vendian lithology of the Bodaibo-Patom block is considerably determined by the evolution of its tectonic framing. A huge volume of mature clastics for the Lower Vendian deposits of the Bodaibo trough was produced by erosion of the crystalline rocks of the uplifts exposed west, north, and east of it [49]. The pre-Upper Vendian activity of tectonic regime in the Baikal-Vitim SFR made it the main source of the clastics supplied to the Bodaibo trough. As the erosion level became deeper, polymictic rocks (Anangr, Dogaldyn, and Iligir Formations) increasingly more contributed to its Upper Vendian deposits (see Fig. 5).

Between the Baikal-Nepa fault and Nepa-Botuobiya arch, the Nyuya-Botuobiya block lies (see Fig. 1), which is composed of the inner Nyuya SFZ and outer Peledui-Botuobiya SFZ. The former is the Nyuya trough, the axial part of which is filled with Lower Vendian deposits — the Talakan Formation* and its analogs (see Fig. 5). Coarse-clastic rocks of its lower subformation and carbonate-interbedded fine clastics of the upper subformation form a rhythm absolutely similar to the lower- and middle-Ushakovka Subformations in the Baikal region, the Aunakit and Vacha Formations of the Bodaibo SFZ. They also have a similar stratigraphic location beneath an evident analog of the Upper Vendian Zherba Formation — the Talakh sandstones and, probably, their underlying Khoronokh coarse-grained rocks. The greater area of occurrence of the former as compared with the latter resembles the gradual Zherba transgression in the Patom Upland (see Fig. 2), though the data available are not sufficient to safely compare the Khoronokh Formation with the first rhythm of the Zherba Formation. The Khoronokh, Talakh, and overlying Lower Parshino Formation and their analogs (see Fig. 5) form an independent stratigraphic horizon. But there is no ground to call it Yukanda Horizon [11], because in the type locality it included the Lower Vendian deposits only [50]. A drastic decrease in coarseness of clastic deposits in the Tirbes Member of the Nokhtuisk section and the appearance there of a considerable amount of carbonate rocks makes it a potential analog of the compositionally similar Byuk Horizon in the Nyuya-Botuobiya block [11]. A specific feature of this block is the presence of thick members of Torsal salts in its deposits (see Fig. 5). Younger deposits, the Danilovo Horizon and lowermost Cambrian, are also characterized by higher contents of sulfates. At the same time, the faults bounding the Nyuya-Botuobiya block completely stopped to influence the sedimentation, and the carbonate deposits of the upper Upper Vendian, when passing into adjacent structures (Berezovo and Lena SFZ, Gazhenka SFZ of the Nepa-Botuobiya arch), experience practically no changes (transformation of rift trough into platform syneclise).

West of the Kirenga-Chaya fault, the Bodaibo SFZ continues into the Baikal SFZ [47]. The Aunakit and Vacha Formations in it correspond to the Lower Ushakovka and Middle Ushakovka Subformations, which previously were referred to as the Lower Vendian [11]. The composition, structure, and rhythmicity suggest that the Anangr and Dogaldyn Formations are coeval there to the Upper Ushakovka Subformation, whose correspondence to the Upper Vendian is inferred from remains of Ediacaran fauna. At last, the Iligir Formation is paralleled there by the Ayankan dolomites, the lower part of which is southward replaced by terrigenous rocks of

* As long as the Zherba Formation was thought to cover the whole Vendian volume, we were forced to date the Talakan Formation by the Riphean [11].

the Kurtun Formation [11]. The Nemakit-Daldyn division of the Baikal region is thus at the junction of the Bodaibo and Patom SFZ, where this division experiences similar changes (see Fig. 5). Unfortunately, the detailed correlation of these sections is difficult because the Vendian and post-Vendian movements along the Baikal-Lena and Kirenga-Chaya faults completely masked the southeastern extensions of the Patom and Nyuya SFZ's and brought the analogs of the Botuobiya and Bodaibo zones into an close contact (see Fig. 1, *5*).

In the Baikalian of the Baikal-Vitim SFR, the Barguzin microcontinent and the Mid-Vitim island arc were isolated as structure-facies zones [47]. After the pre-Vendian collision the whole Baikal-Vitim SFR was already a single structure, an uplift generally subject to denudation. The Vendian deposits in it are developed in separate troughs and depressions whose real outlines are hard to be restored. Two structure-facies zones, Barguzin and Olokit-Yanguda, and tentative subzones of the latter zone (see Figs. 1 and 6) are distinguished by the completeness of section, mainly, of Upper Vendian deposits. The Lower Vendian sediments (Avgol Formation and its analogs) remain rare. The reason is that the vast areas of the whole SFR were then provenances and in the regions where sedimentation occurred the Lower Vendian deposits were partly or completely eroded because of the pre-Upper Vendian events. Moreover, drastic changes (over an order of magnitude) in the Upper Vendian thickness in the conjugate sections are also due mostly to the gradual filling of depressions in the process of Upper Vendian transgression. We have no convincing grounds for detailed correlation of the Vendian deposits of the Baikal-Vitim SFR yet. The proposed version of correlation of the sections of different zones and subzones and their comparison with the conjugate sections of the Baikal-Patom SFR is based on remarkably similar three-rhythm structure of the Upper Vendian and one-rhythm structure of the Lower Vendian in the Olokit-Yanguda, Bodaibo, and Baikal SFZ's (see Fig. 6). This similarity is owing to repeated cycles of tectonic activity followed by relevant changes in denudation intensity in the region of the Baikal-Vitim uplift, which affected the sedimentation character in conjugate areas.

The history of development of the Baikal-Vitim SFR has special interest because the events that grounded it are helpful for understanding historico-geological sense and dismembering of the Vendian there. An intensive tectonic rearrangement occurred about the time of the Vendian-Baikalian transition, and, as a result, the pre-Vendian oceanic structures (island arcs, back- and fore-arc basins, microcontinents) were transformed into an intricate accretion-collisional orogenic complex of the Andean-type continental margin. Intensive magmatism and metamorphism continued there in the Vendian and Paleozoic. They give us valuable radiological dating of the main subdivisions of the Vendian. Thus, the time of the pre-Vendian accretionary events [47, 51, 52] is inferred from the North Muya eclogites associated with the Abchada-Vitim fault, 653±21 Ma (Sm-Nd method [53]), and from migmatites (autochthonous plagiogranites) of the Nyurundukan sequence of the North Baikal region, 652±2 Ma (U-Pb method [54]). The events related to the end of the lower Vendian collision were also well expressed in the Baikal-Vitim SFR to mark the boundary between the lower and upper Vendian. In the Olokit structure-facies subzone, where the Lower Vendian deposits (Avgol and Manyukan Formations) remained, the Upper Riphean Kholodnaya Formation overlies them with an evident unconformity [47]. The age of this event is inferred from ultramafic-mafic massifs and high-grade metamorphism associated with the resumption of strike-slip movements in the Abchada-Vitim fault zone [52]. The ages of these events obtained by the Sm-Nd and U-Pb methods are 627±25, 618±61, and 612±34 Ma [55–57]. The age of activization of this zone was also determined from enderbites, 617±5 Ma (Sm-Nd [58]), and plagiogranites, 577±50 Ma (Rb-Sr [59]).

In the Baikal-Patom SFR and in the interior parts of the Siberian Platform, washouts and gaps in sedimentation record only a reflection of the events well documented south of the Abchada-Vitim fault. But even in such expression, they appeared sufficient there to divide the Siberian Vendian into the lower and upper departments [50]. The structure-facies regionalization permitted us to reveal some details of paleogeography of the region having an effect on the specific character of sedimentation. It appeared, in particular, that it is hardly possible for the clastics deposited in the Patom SFZ to be brought from the vast uplifted slope of the Siberian Craton, where turbid and debris flows speeded up, as Pelechaty believed [23]. It was separated from the Patom uplift by the Nyuya trough consuming the drifted material (see Fig. 1, *5*). Mature rocks of the Zherba Formation could not form by erosion of the Baikal-Vitim uplift either, because polymictic material was transported from it to the Bodaibo-Baikal pericratonic trough. Most likely, the erosion affected a small terrane made up of crystalline-rock outcropted in the arch dividing the Bodaibo and Nyuya troughs. Though being gradually flooded by the Vendian transgression, they formed a complicate uplift, which for a long time isolated the Upper Vendian basin of the Nyuya-Botuobiya block from a southern open sea. As a result, the Nyuya-Botuobiya basin was salted and the Torsal salts were generated. This was also favored by relative rises related to the transverse zones of the Kirenga-Chaya and Zhuya transform faults (see Fig. 1) [47]. Denudation of all these uplifts in Nemakit-Daldyn time promoted the distribution of sulfate waters of the Nyuya SFZ far beyond. We think that, as a consequence, hypergenetic breccias appeared in the Tinnaya Formation.

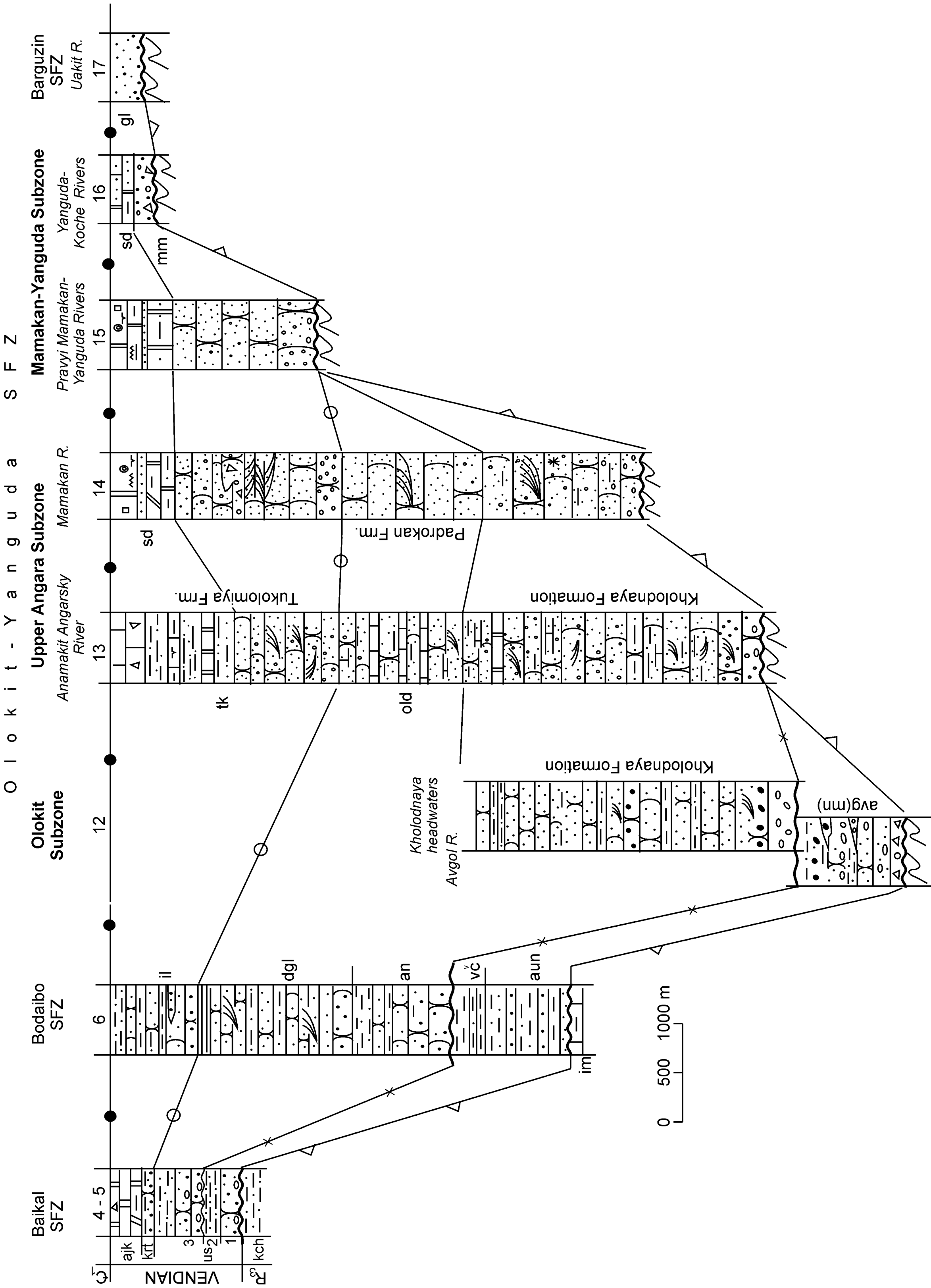


Fig. 6. Correlation of Vendian sections of the Baikal-Vitim SFR and pericratonic Baikal-Patom trough. Symbols follow Figs. 2 and 5. Location of sections is shown in Fig. 1.

CONCLUSIONS

The Vendian section of the Baikal-Patom Upland is unique. It integrates information on closely connected stratigraphic subdivisions of this age originated in a comparatively small but intricately built basin. The conditions of sedimentation in its different parts were principally different. They were governed by their tectonic nature from intracraton structures (Nyuya, Botuobiya, and Patom SFZ) through pericratonic Baikal-Bodaibo trough to orogenic complex of the Baikal-Vitim SFR with synsedimentary magmatism and metamorphism. As a result, the Vendian deposits of the region have rich complex characteristics. The above-mentioned structures were separated by longitudinal, long-lived zones of faulting — Selenga-Vitim, Tompuda-Nercha, Abchada-Vitim, and Baikal-Lena. The crossing Zhuya and Kirenga-Chaya zones considerably complicated the picture (see Fig. 1). Tectonic movements along first four faults transformed the oceanic structure of the Baikal-Vitim SFR, into the Vendian orogen. The intra-Vendian rearrangement gave rise to erosion, angular unconformities, magmatism, and metamorphism. Therefore, despite considerable and variable thickness of terrigenous deposits, filling separate troughs there, the Baikal-Vitim SFR was an upland. Its intense erosion in the Upper Vendian supplied polymictic clastics not only to the inner depressions but also to the adjacent Bodaibo-Baikal pericratonic trough. In this connection the sections, especially Lower Vendian ones, are far from being complete in this SFR. This defect is compensated by safe dating with the use of the U-Pb and Sm-Nd methods, yielding 650 Ma for the events separating the Baikalian and Vendian and 612–620 Ma for the intra-Vendian boundary. The sections of the pericratonic trough, on the contrary, are distinguished by extraordinary completeness. In them, the Baikalian, Lower and Upper Vendian often grade into one another [9, 49]. This suggests that both Varangerian, or Laplandian, glaciations are absent from the region under study. Therefore, though tillites, mixtites and problematica are found in the Oselok Series [36], this and the Taseeva Series (both completing the Baikalian) cannot be dated by the Vendian. Tillites have long been known in the Baikalian of the Siberian Platform [33], and Metazoa remains are now often documented from so ancient Late Precambrian deposits as the Belt Series of the Rocky Mountains [39]. Moreover, the workers of the Paleontological Institute M.A. Fedonkin and D.V. Grazhdankin, who have studied organic remains collected by Yu.K. Sovetov from the Oselok Series, informed us that the faunal imprints they had identified have nothing in common with the organisms described as remains of the Ediacaran fauna of the Vendian. Thus, the statement that the Upper Baikalian is of Vendian age is as groundless as an earlier attempt made on the basis of several transit taxa of microfossils. It was shown above that a complex of microfossils principally different from the Baikalian complex appears only in the Zherba Formation. Hence, we have no reasons to discredit the Riphean-Vendian boundary substantiated from a change in complex of stromatolites and to refer even the uppermost Chencha Formation and its analogs to the Vendian. It is well known that this formation is characterized from bottom to top by the Upper Riphean taxa of stromatolites and contains none of the Vendian forms [31]. Though the invertebrate Metazoa found by Sovetov [36] do not prove the Vendian age of the Oselok Series, they substantiate that the Vendian biota did not appear suddenly at the onset of the Vendian but had its predecessors in the Baikalian.

At last, despite their small thickness, the weakly deformed and virtually nonmetamorphosed Vendian deposits of intracraton depressions gave good grounds for dating and dismembering of the Upper Vendian by paleontological and chemostratigraphic methods (see Fig. 4). Finding and determination of small shelly fossils permitted us to locate the lower boundary of the Cambrian near the base of the Nokhtuisk Formation and to substantiate the presence below it deposits of the Nemakit-Daldyn Stage of the Vendian. The earlier findings of soft-bodied Metazoa from the uppermost Ushakovka Formation [11, 39] confirm that the top of the terrigenous section of the Vendian in this region belongs to the Ediacaran Stage. The detailed curve $\delta^{13}C$ in the Vendian-Cambrian range of the Nokhtuisk section revealed a distinct negative excursion near the Lower Cambrian boundary. This chemostratigraphic marker characterizes the bottom of the Tommotian Stage of the Cambrian nearly in all main Cambrian sections of the Siberian Platform [13]. The stratigraphic position and age of peaks $\delta^{13}C$ in the sections of the Vendian-Cambrian deposits of the Olenek Uplift and Eastern Anabar region were determined more precisely as compared with the initial estimates [24, 29], and this permitted us to supplement the scheme for comparison of the Nokhtuisk section curves with the earlier published information [13]. As a result, we obtained a general Siberian scheme of correlation of basic excursions of the curve $\delta^{13}C$ for the upper Vendian and lower Cambrian (see Fig. 4). It can be considered a chemostratigraphic model for this stratigraphic level. It well differs from the previous generalizations [23, 60] in the fact that the comparison of excursion peaks in it is confirmed by mass finding of small shelly and Ediacaran fossils. Analysis of this model shows that the SSF of the *trisulcatus* Zone many times occur below the sole of the Manykai Formation (see Fig. 4), which implies that the Manykai Stage distinguished in its stratigraphic range [27–29] has no biostratigraphic sense, and the preference should be given to the Nemakit-Daldyn Stage, with abundant Ediacaran fauna found below its base in Siberia.

According to the main parameters (presence of Ediacaran fossils and age of the lower boundary about 612–620 Ma), the upper Vendian of Siberia is close to the Ediacaran [61] or terminal Precambrian of the International Scale. The difference between them is reduced to two features. First, the Nemakit-Daldyn Stage in Siberia is part of the Vendian, though in the International Scale it belongs to the Cambrian. It is not possible, however, to use SSF for drawing the lower boundary of the Nemakit-Daldyn division in a correct way [13]. Taking into account this fact and recent information about the transit of Ediacaran fossils into beds with the Nemakit-Daldyn organics, we believe that the upper Vendian boundary along the sole of the *sunnaginicus* Zone is much more reliable than the upper boundary of the terminal Precambrian of the International Scale. The chemostratigraphy of the upper boundary of the Vendian is also qualitatively more definite (see Fig. 4) as compared with the characteristics proposed for the roof of the terminal Precambrian [60, 62]. Second, substantiation of the Siberian Vendian received no contribution from cap-carbonates that define the lower boundary of the terminal Precambrian of the International Scale. The Vendian glaciations was also absent from Siberia. For this reason alone, the principle of substantiation of the lower boundary of the terminal Precambrian by cap-carbonates in the International Scale is not universal. Therefore, worthy of note is our alternative approach to the substantiation of the lower boundary of the terminal Precambrian in a principally different volume, which corresponds to the Vendian on the basis of a tectonic rearrangement at its bottom and complexes of microfossils [33, 63]. Therefore, a hasty attempt to substitute the terminal Neoproterozoic for the Vendian in the general stratigraphic scale seems to be groundless.

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