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GEOLOGY

# Unique Lower Vendian Kel'tma Microbiota, Timan Ridge: New Evidence for the Paleontological Essence and Global Significance of the Vendian System

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The recognition of the Vendian as a terminal Precambrian system and the biostratigraphic subdivision of its upper part were an important step in constructing the general chronostratigraphic scale for the Upper Proterozoic ([1] and references therein). Unfortunately, no microbiota of the so-called Pertatataka type described from the Lower Vendian sections of southern China [2], central Australia [3], Spitsbergen [4], the Lesser Himalayas [5], where they occur slightly above Lower Vendian tillites, and from some formations in the interior areas of the Siberian Platform [6, 7] has yet been found in the stratotype region of the system, i.e., in the East European Platform. It is conceivable that its absence in Vendian type sections influenced the decision of the International Union of Geological Sciences to accept the Ediacarian System, instead of the Vendian one, as a terminal Precambrian unit of that kind. It was defined in southern Australia using quite different principles [8] and is significantly smaller in its stratigraphic range as compared with the Vendian System.

Recently, a diverse assemblage of organic-walled microfossils of the Pertatataka type was discovered in cores of borehole Kel'tminskaya-1 [9] drilled at the flank of the Vychegda Trough in the southern Timan region (Fig. 1a). The analysis of approximately 100 new samples from the most promising levels of the borehole section yielded substantially wider information on the generic composition of relevant microfossils, termed the Kel'tma microbiota, and its stratigraphic distribution substantiated by the discovery of characteristic Upper Riphean acanthomorphic acritarchs occurring in continuous stratigraphic succession below the location of the last microbiota.

In the Late Riphean, the Vychegda Trough of the Timan region and South Urals were elements of a common paleobasin. Therefore, the correlation between their sections meets no difficulties [10, 11]. Stratigraphic subdivision of the borehole Kel'tminsakaya-1 section is based on the Upper Precambrian stratigraphic scheme of the adjacent Dzhezhim Parma Uplift [12], which was applied for the correlation of the first microfossils found in this region [9]. According to this scheme, the pre-Upper Vendian borehole section comprises three units (Fig. 1b): (1) Yshkemes Formation (depth interval 3943–4902 m) composed of gray, partly clayey dolomites with interbeds of dark shales, siltstones, and rare sandstones; (2) Vapol Formation (interval 2910–3543 m) conformably overlying the Yshkemes Formation and consisting of light to greenish gray dolomitized limestones with stromatolitic limestone, gray shale, and siltstone interbeds and cherty concretions in the upper part; (3) Vychegda Formation (interval 2312–2910 m) resting upon the Vapol Formation with an erosional surface and represented by dominant gray to greenish gray shales and subordinate siltstones with conglomerates at the base and glauconitic sandstones at higher levels. The last formation is overlain, in turn, with erosion traces by Upper Vendian sediments: Ust'-Pinega Formation of siltstones and argillites (interval 1880–2312 m) that host acritarchs and filamentous microfossils of the Redkino Horizon (M.B. Burzin, private communication) and grade upward into substantially clayey sediments of the Kotlin Horizon (interval 1330–1880 m). Volcanogenic zircons from the middle and upper parts of the Redkino Horizon in northerly areas yielded U–Pb (SHRIMP) ages of 558 ± 1 and 555 ± 0.3 Ma [13].

Of significance for the assessment of the maximal stratigraphic range of the Vychegda Formation is the fact that Upper Riphean sediments of the South Urals, Polyudov Range, Timan, and neighboring areas demonstrate a similar succession of stromatolite taxa, which makes readily traceable particular biostratigraphic units (beds with stromatolites) [11]. M.E. Raaben determined *Inzera djejimi,* one of the Middle

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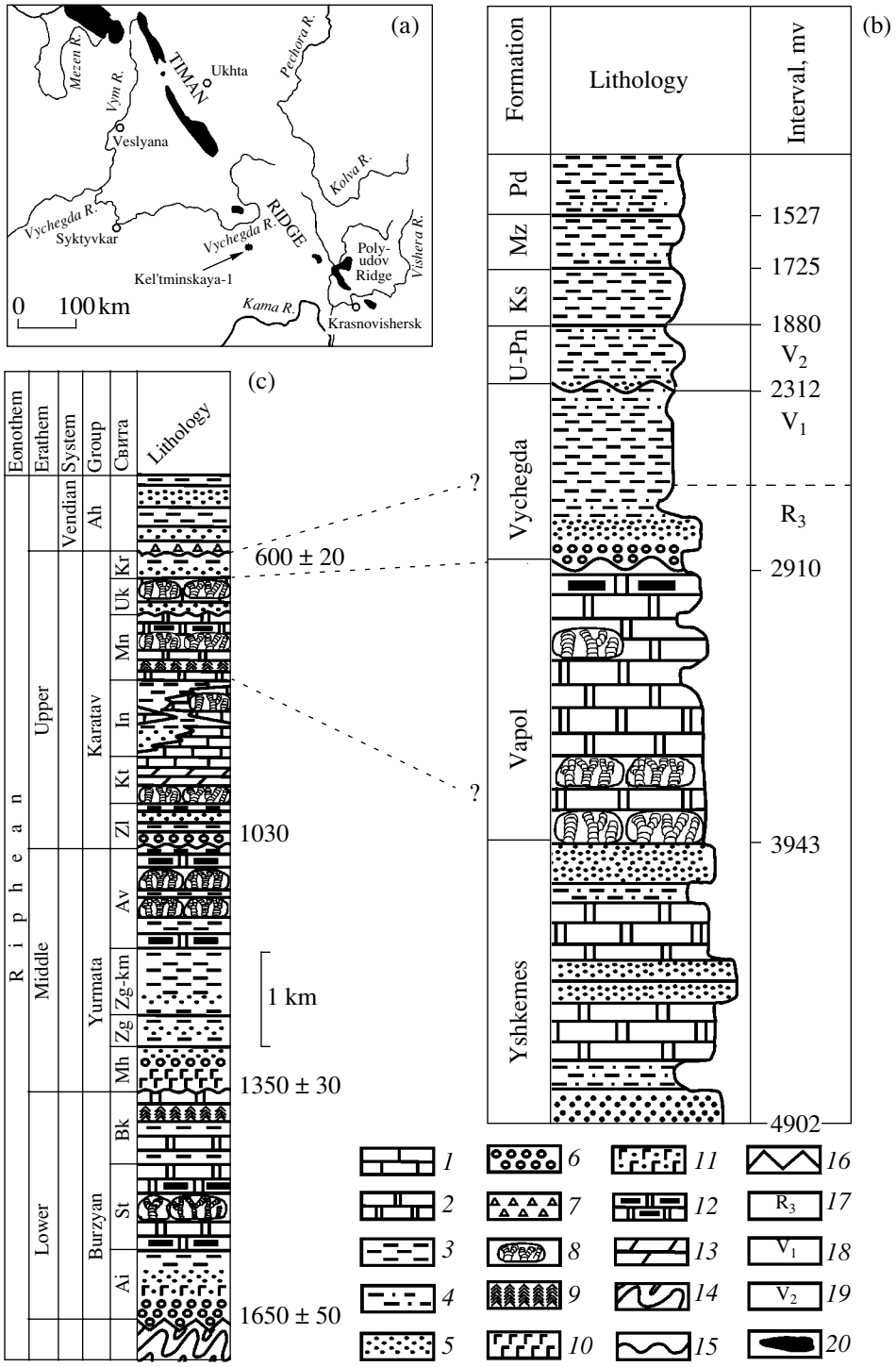


**Fig. 1.** (a) Location of borehole Kel'tminskaya-1, (b) schematic structure of its Upper Precambrian section, and (c) Riphean and Vendian stratotype section in the Southern Urals. (*1*) Limestone; (*2*) dolomite and limestone; (*3*) shale; (*4*) siltstone; (*5*) sandstone and gravelstone; (*6*) conglomerate; (*7*) tillite and tilloid; (*8*) bioherm with columnar stromatolites; (*9*) *Conophyton* stromatolite; (*10*) basic volcanics and dolerites; (*11*) tuff and tuffstone; (*12*) dolomite with cherty lenses and interbeds; (*13*) marl; (*14*) gneiss of the basement; (*15*) hiatus or unconformity; (*16*) azimuthal unconformity; (*17–19*) finds of organic remains: (*17*) Upper Riphean microfossils and annelidomorph *Parmia* (Lower Vychegda microbiota), (*18*) Lower Vendian microfossils from the upper part of the Vychegda Formation (Kel'tma microbiota), (*19*) Upper Vendian microfossils of the Redkino Horizon and soft-bodied Metazoa; (*20*) outcrops of Upper Proterozoic rocks. Abbreviations: (Ai) Ai, (St) Satka, (Bk) Bakal, (Mh) Mashak, (Zg) Zigal'ga, (Zg-km) Zigaza–Komarovo, (Av) Avzyan, (Zl) Zil'merdak, (Kt) Katav, (In) Inzer, (Mn) Min'yar, (Uk) Uk, (Kr) Krivaya Luka, (U-Pn) Ust'-Pinega, (Ks) Krasavino, (Mr) Mezen, (Pd) Padun formations, (Ah) Asha Group. Numbers on the right-hand side of the Riphean section of the South Urals correspond to the isotopic age of boundaries between general Upper Precambrian subdivisions (Ma). Sediments overlying the Vychegda Formation in Borehole Kel'tminskaya-1 and Vendian strata of the South Urals are shown out of scale.

Karatavian taxa from this succession, from the lower part of the Vapol Formation (interval 3905–3909 m). The species correlates this interval with the lower strata of the Pav'yuga (Bystrukha) Formation of the Dzhezhim Parma and Och Parma localities, where the occurrence of *I. djejimi* is followed higher in the section by the succession of three younger stromatolite beds. The stromatolite beds characterize in the Upper Riphean stratotype almost the entire Min'yar Formation except for its upper (Shubino) member. The middle part of the interval with this taxon is dated by the Pb–Pb method at 780 ± 85 Ma [14]. At the same time, the Vapol and Min'yar formations enclose silicified microfossils of a wide stratigraphic range, which, however, bear similar specific micromorphological features [12]. The aforementioned data show that the Vychegda Formation in the composite section is sandwiched between the Min'yar Formation and Redkino Horizon.

The Vychegda Formation hosts representative assemblages of microfossils confined to the interval 2502–2907 m. They are usually dominated by various leiosphaeridians, several *Siphonophicus* species, colonial coccoid forms, *Chuaria circularis* (Fig. 2b), *Asperatofilum experatus, Polytrichoides oligofilum* (Fig. 2e), *P. lineatus, Brevitrichoides bashkiricus, Navifusa majensis, Elatera binata* (Fig. 2k), *Eosolena anisocyta, Arctacellularia* sp., *Trachytrychoides* sp., *Fabiformis porosus, Cucumiforma* sp., *Glomovertella eniseica, Simia nerjenica*, short branching filaments (Fig. 2o), and some other forms. All these taxa are of wide stratigraphic distribution in the Upper Precambrian. They associate with *Caudosphaera expansa*, a peculiar species that represents a central body in the form of an opaque spheroid 200–300 μm across with unidirectional process 50–80 μm wide and 200–300 μm long (Fig. 2g).

The listed wide-range taxa are accompanied in the basal and uppermost layers of the interval of 2502–2907 m by morphotypes, which characterize a narrow stratigraphic range (Fig. 3). Their presence makes it possible to divide all the Vychegda microfossils into two groups, termed the Lower Vychegda (interval 2900–2907 m) and the Kel'tma (interval 2600–2692 m) microbiotas separated by the intermediate zone, which encloses only the above-mentioned wide-range taxa (interval 2728–2861 m). The Lower Vychegda microbiota includes the characteristic Upper Riphean index species *Trachyhystrichosphaera aimika; Prolatoforma aculeata* (Fig. 2p), peculiar microfossils with a central spheroid 250–400 μm across bearing a bunch of hairlike processes each 1–2 μm in diameter and up to 400 μm long (Fig. 2j); *Plicatidium latum; Taenitrichoides jarychevicus; Entosphaeroides* sp.; and the remains of annelidomorphs *Parmia anastassiae*, a presumable pre-Ediacarian Metazoa form (Fig. 2r). Thus, sediments with the Lower Vychegda biota correlate in the South Urals section with some part of the Kudash Horizon that terminates the Upper Riphean stratotype and consists of the Uk and Krivaya Luka formations. Such a correlation is based on new age estimates of the Lower Vychegda microbiota, the similarity between stromatolite successions in the Min'yar Formation of the South Urals and the Bystrukha (Pav'yuga) Formation of the Timan region, and the regional hiatus at the base of the Uk Formation. The Rb–Sr isochron age of unaltered glauconite from the Lower Uk Subformation is estimated at 644 ± 11 Ma [15].

In addition to the above-mentioned wide-range taxa, the younger Kel'tma microbiota includes abundant remains of phytoplankton microorganisms with morphologically complex processes that are characteristic only of the considered level. Dominant among them are acanthomorphic acritarchs *Alicesphaeridium medusoidum* represented by hollow one-layer envelopes 100–150 μm across with numerous heteromorphic processes (5–10 μm wide at the base and 10–25 μm long) splitting at their ends and opening to spheroid cavities (Figs. 2p, 2q, 2t, 2v, 2x). They are accompanied by other acanthomorphic acritarch genera characteristic of the Lower Vendian. These are *Tanarium* sp. represented by one-layer spheromorphic envelopes 100–200 μm across with numerous hollow conical nonbranching processes, which open into the spheroid cavity as well but are 5–8 μm wide at the base and 10–20 μm long (Fig. 2s); rarer *Echinosphaeridium* sp. in the form of opaque spheroids 120–150 μm across and surrounded by transparent processes 3–12 μm wide at the base and 10–20 μm long (Fig. 2l); and several other taxa known in the Pertatataka microbiotas: *Ericiasphaera* aff. *E. polystacha* (Fig. 2f), *Cavaspina acuminata, Polychedrosphaeridium echinatum, Asterocapsoides sinensis, Bavlinella faveolata* (Fig. 2w), and others. In addition, typical elements of the Kel'tma microbiota include relatively abundant morphologically complex forms still unknown in other microbiotas of the Pertatataka type. They are the following structures: (1) envelopes 200–450 μm across with large massive processes (100–150 μm wide at the base and 120–230 μm long) freely opening into spheroid cavities (Fig. 2m); (2) semitransparent spheroids (approximately 400 μm across) with isometric hemispheric processes 25–35 μm in size and surrounded by a common film (Fig. 2h); (3) large ellipsoids (up to 600 μm in diameter) with bipolar processes 60–140 μm wide at the base and up to 100–160 μm long (Fig. i); (4) tuberculous envelopes 120–150 (Fig. 2c) to 300–500 μm across; (5) opaque thin-walled spherical envelopes 110–230 μm in diameter with a longitudinal pylome-shaped slit (Fig. 2a); (6) multilayer envelopes (Fig. 2d); and (7) large cuticular structures of unclear taxonomic affinity.

In the taxonomic composition, the Kel'tma microbiota is generally similar to other Pertatataka-type microbiotas, although the former microbiota is more diverse owing to specific morphotypes unknown in other coeval assemblages and abundant *Alicesphaeridium medusoidum* developed as subordinate members in other localities of the microbiotas in question. Taking

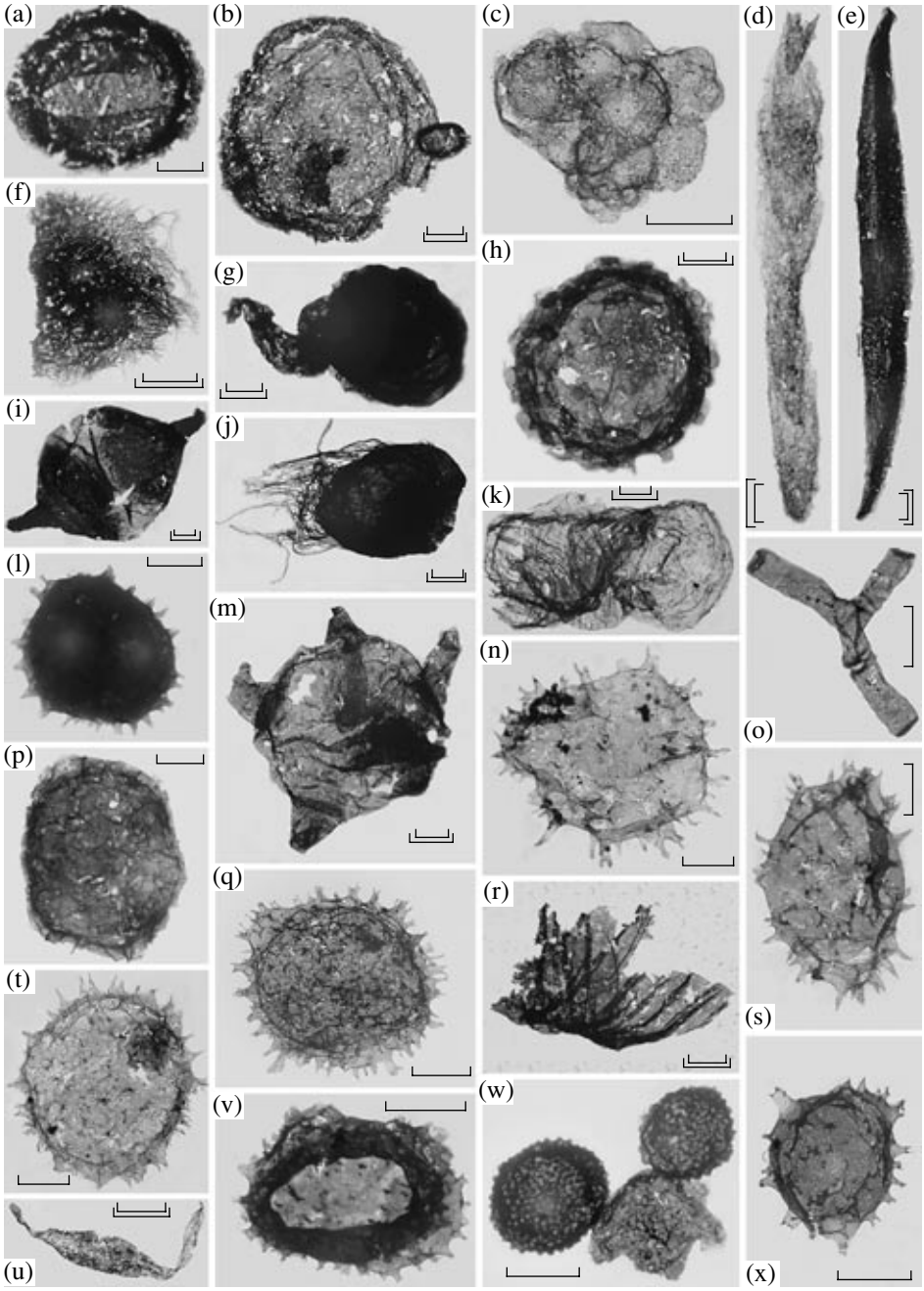


**Fig. 2.** Microfossils of the Vychegda Formation in borehole Kel'tminskaya-1.

(a) Envelope with thickened peripheral part and longitudinal pylome-shaped slit, specimen 2600-07-61-1-3; (b) *Chuaria circularis* Walcott, specimen 2647-49-69V-20-a; (c) envelope with numerous hemispheric processes, specimen 2600-07-62N2-31-6; (d) multilayer sheath, specimen 2647-49-69V-26-3; (e) *Polytrichoides lineatus* Hermann, specimen 2900-07-97-8-6; (f) *Ericiasphaera* aff. *E. polystacha*, specimen 2600-07-62N2-29-4; (g) *Caudosphaera expansa* Hermann et Timofeev, specimen 2900-07-96-3-7; (h) envelope with numerous spheroid bubbles located at its external surface and covered by a common thin film, specimen 2600-07-62N2-15-1; (j) ellipsoid envelope with two large separate processes located at poles and with the weakened zone (aperture) in the central part of the envelope, specimen 2685-92-A1-S2-N+; (i) large opaque envelope with a bunch of long thin hear-like processes, specimen 2900-07-97-7-2; (k) *Elatera binata* Hermann, specimen 2647-49-69-5-3; (l) *Echinosphaeridium* sp., specimen 2600-07-62N2-21-6; (m) spheromorphic envelope bearing several large processes, specimen 2600-07-62N2-11-4; (n, q, t, v, x) *Alicesphaeridium medusoidum* Zang: (n) specimen 2647-49-69V-12-3; (q) specimen 2600-07-62N2-11-2; (t) specimen 2647-49-68-1-SH; (v) specimen 2600-07-62N2-78-3; (x) specimen 2600-07-62N2-4-1; (o) branching *Stigonema*-like sheath, specimen 2647-49-69-18-5; (p) *Prolatoforma aculeata* Mikhailova, specimen 2900-07-97-12-1; (r) *Parmia anastassiae* Gnilovskaya, specimen 2900-07-97-4-4; (s) *Tanarium* sp., specimen 2647-49-69-14-1; (u) ellipsoids with two bipolar processes (probably poorly preserved taxon illustrated in Fig. 2i), specimen 2600-07-62N2-6-2; (w) *Bavlinella faveolata* Schepeleva, specimen 2600-07-62N2-78-3. All the illustrated specimens are stored at the Geological Institute (Moscow), collection 14700. Figs. 2e, 2g, 2j, 2p, and 2r illustrate the Lower Vychegda microfossil assemblage (Upper Riphean). Other figures illustrate the Kel'tma microfossil assemblage (Lower Vendian). Scale: single bar is 50 μm; double bar, 100 μm.

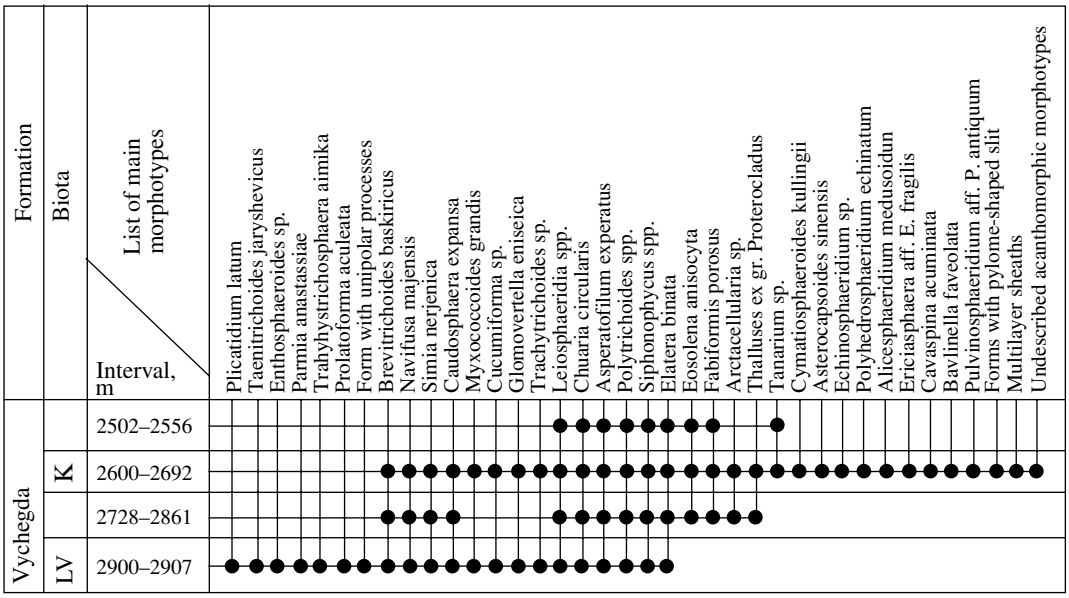


**Fig. 3.** Distribution of main morphotypes of organic-walled microfossils in the Vychegda Formation in borehole Kel'teminskaya-1. Microfossil assemblages: (LV) Lower Vychegda, (K) Kel'tma.

into consideration the taxonomic changes in the Pertatataka assemblages through different regions [2–7], the peculiar composition of the Kel'tma microbiota does not rule out its affiliation with Early Vendian microbiotas of the Pertatataka type. This inference is supported by the occurrence of many genera such as *Tanarium, Cavaspina, Ericiasphaera, Polychedrosphaeridium, Echinosphaeridium, Alicesphaeridium, Asterocapsoides*, and others in this microbiota, its stratigraphic position, and isotopic age (younger than $644 \pm 11$ and older than $558 \pm 1$ Ma).

The Kel'tma microbiota is of particular interest in connection with its position within the siliciclastic Vychegda Formation, lacking visible signs of unconformity. As was mentioned, basal layers of the formation (interval 2900–2907 m) host the Upper Riphean microfossil assemblage; the interval 2692–2900 m (the available core characterizes the interval 2728–2861 m) encloses an impoverished assemblage of a wide range of forms; the interval 2600–2692 m is marked by the appearance of the Lower Vendian microbiota. If future investigations confirm the lack of significant hiatuses within the Vychegda Formation, previously unknown Upper Riphean–Vendian boundary beds with microfossils can be defined in the southern Timan region. In this case, the interval with the impoverished microfossil assemblage, which reflects the extinction of Late Riphean microorganisms prior to the onset of the Early Vendian postglacial adaptive radiation of acanthomorphic acritarchs recorded in assemblages of the Pertatataka type, should correspond to the Varangerian (Laplandian) glaciation.

Thus, the discovery of the Kel'tma microbiota substantially increases the correlative potential of the Vendian stratotype as an international chronostratigraphic unit of the Terminal Proterozoic System. The relationships between the Upper Riphean and Lower Vendian microfossil assemblages established in the Timan region, if they are confirmed, offer an opportunity to determine the lower boundary of this system based on the biostratigraphic criterion, i.e., the appearance of particular microfossil taxa. Such an approach to solving cardinal problems of the Upper Precambrian stratigraphy is undoubtedly more promising as compared with the chemostratigraphic [8] or chronometric methods widely used nowadays.

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