Wenlock-Ludlow boundary sediments on Chernov uplift (Arctic region of Russia)

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Abstract

The article presents the results of a study of Wenlock-Ludlow boundary sediments in the river Padimeytyvis basin at Chernov uplift using paleontological, lithological and chemostratic methods. The results of paleontological studies allowed attributing to the Wenlock the carbonate stratum of the upper part of the section along the stream Bezymjannyi and establishing Wenlock-Ludlow boundary only in the section of the river Padimeytyvis. The results of studying the isotope $\delta^{13}\text{C}_{\text{carb}}$ in Wenlock-Ludlow boundary sediments are also presented. In the upper part of the section along the stream Bezymjannyi a positive C-isotopic shift of the curve which possibly marks the late Wenlock global biotic event of Mulde was observed.

Keywords: Ludlow, Wenlock, conodonts, brachiopods, Arctic region, Timan-Northern Ural region, isotope $\delta^{13}\text{C}_{\text{carb}}$

Kulcsszavak: Ludlow, Wenlock, conodonta, brachiopoda, sarkvidéki régió, Timán-Észak-Urál régió, $\delta^{13}\text{C}_{\text{carb}}$ izotóp.

1. Introduction

The study of the stratigraphy of the paleozoic sediments of Chernov uplift began in 1921 by the Northern Scientific and Trade Expedition where G. A. Chernov worked. The results of the study of Silurian sediments and collections of fossil fauna are given in field diaries, thematic reports and published works by G. A. Chernov [1-3], S. A. Knjazev [4], A. I. Ljashenko [5], N. I. Timonin [6], A. I. Antoshkina, T. M. Beznosova [7], T. L. Modzalevskaya [8], T. M. Beznosova [9-11], P. Mannik, V. A. Matveev [12-13], N. V. Maidl [14], V. Y. Lukin [15]. In these works, the conditions for the formation of sediments composing the section, their age are considered, and their own stratigraphic dissection schemes are proposed. Issues of stratigraphy of Wenlock deposits in the Podymeityvis River basin have been reviewed repeatedly. A variety of conclusions about the age of Wenlock-Ludlow boundary stratum in the section of Chernov uplift testifies to the complexity of its structure and biostratigraphic dissection, as shown by our subsequent detailed studies. The history of the study of Silurian strata at Chernov uplift is given in publications [9-12].

In the sections of the Mikhailov-Vaigach structural-facies zone and the Timan-Northern Ural region the Wenlock-Ludlow boundary is determined with considerable relativity since it has an indistinct paleontological and lithological characteristic [16]. According to the stratigraphic scheme of the Urals, the regional Wenlock-Ludlow boundary between in the Timan-Northern Ural region is relatively established in a lithologically homogeneous member by the appearance of the ostracods *Schreckia uralensis* Abush. at the base of the Padimeytyvis horizon [17].

The newly conducted studies of sedimentation conditions of Silurian sediments at Chernov uplift made it possible to substantiate

the stormy mode of sedimentation in Wenlock. A study of the collected fauna collections - the tabulate corals of brachiopods, ostracods, conodonts, vertebrates, the nature of changes in the behavior of isotope $\delta^{13}\text{C}_{\text{carb}}$ served to justify the Wenlock age of the Bezymjanny section and the Wenlock-Ludlow boundary in the section of the Podymeityvis River (Fig. 1). The established total thickness of Wenlock sediments at Chernov uplift is 300 m.

1. ábra A vizsgált szakasz földrajzi elhelyezkedése a Padimeytyvis folyó medencében
Fig. 1 Scheme of the location of the studied section in the Padimeytyvis River basin

2. Geological setting

In the modern structural and tectonic plan, the studied section is located within the Pre-Ural foredeep in the Podymeityvis River basin at Chernov uplift (Fig. 1). It is customary to consider the Chernov uplift as a narrow near-fault horst-like structure, stretching in a sub-latitudinal direction from the Ajachyaginsky structure in the southeast to Sinkin Nose in the northwest.

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On the whole, this is a near-thrust rootless structure formed as a result of the leaf-by-leaf stripping exposure in the cover of the Korotaikhinsky depression, confined to the incompetent Upper Ordovician member [6, 18].

3. Materials and methods

The material for this article was the collections of leaf-by-leaf samples collected by V. A. Matveev and P. Myannik during field work in 2010 and 2017. The collection of samples includes more than 53 samples with the remains of fossil macro- and microfauna, 44 samples for the isotope $\delta^{13}\text{C}_{\text{carb}}$.

The Wenlock section is opened along the Bezmyanny stream and continues with a gap on the river Padimeytyvis (left tributary of the Korotaikha River), where the Ludlow deposits are exposed. The studied Wenlock-Ludlow sections are located in the central part of the Chernov uplift in the Arctic part of the European North-East of Russia (Fig. 1). Organic remains were investigated by: T. M. Beznosova (brachiopods), P. Mannik (conodonts), V. Y. Lukin (tabulate corals), L. L. Shamsutdinova (ostracods), P. Mannik, L. V. Sokolova (conodonts), T. Märss (vertebrates). Lithological samples were studied by T. V. Maidl, stromatolites – by V. A. Matveev. Conclusions about the age of ostracods by A. F. Abushik [19] and stromatoporoids by O. V. Bogoyavlenskaya [7] were also taken into account.

The isotope $\delta^{13}\text{C}_{\text{carb}}$ in carbonate rocks was determined at the “Geoscience” of the Institute of Geology Komi SC UB RAS using a DELTA V Advantage mass spectrometer. The values of the isotope coefficients were determined in ppm (‰) according to the PDB standards NBS18 and NBS19 (TS-limestone) for carbon. The error in determining both coefficients did not exceed ± 0.1 ‰. The isotope $\delta^{13}\text{C}_{\text{carb}}$ was determined in 98 samples (sampling step 50 cm). The material for the isotope analysis was carbonate rocks, the least subjected to secondary transformations. Samples were obtained using a diamond drill with a diameter of 3.5 mm. Collections of fossil fauna remains are stored in the Museum named after A. A. Chernov of the Institute of Geology Komi SC UB RAS named after Academician N. P. Yushkin.

4. Results and discussion

The Wenlock-Ludlow boundary sediments are represented by the alternation of light brown to dark brown thin-layer limestones, platy with cracks of sediment drying, stromatolitic, clay, bioturbated limestones, containing numerous remains of ostracod shells, pelecipods, brachiopods, corals and other organisms.

The studied section thickness with a total capacity of 205 m was divided by us into six benches, three benches were identified along the Bezmyanny stream and three benches - along the Podimeytyvis River. The first five benches belong to Wenlock, the sixth bench to Ludlow (Fig. 2).

5. Brief description of the section on the Bezmyanny stream

Unit 1 (thickness 36 m) is composed of interbedded brownish limestones and fine-grained and micrograined and limestones, dolomitic bituminous limestones, limestone with flat pebble conglomerate, ostracodic and brachiopodic limestones, which

also contain fragments of trilobites, gastropods, pelicipods. Defined: brachiopods *Spirinella nordensis* (Ljashenko), conodonts *Ozarkodina kozhimica* Melnikov, *Panderodus* ex gr. *greenlandensis* Armstrong, *Oulodus kozimicus* Melnikov, ostracods *Cytherellina* aff. *inornata* (Abushik), *Lichwinia silurica* (Neckaja). The upper boundary of the bench is carried out at the base of the first layer of stromatolite limestones.

Unit II (thickness 32 m) is represented by the interbedded brown, dark brown, fine-, micro-grained argillaceous limestones with silty shaly limestones, alternating with light lumpy spotted and micro-laminated microbial-algal and fenestrian limestones with leaf-by-leaf silty and argillo-dolomitic with lithoclasts and dessication fissures at different levels. A tectonic disturbance 1.8 m thick is observed in the lower part of the bench.

2. ábra A fauna és a $\delta^{13}\text{C}$ izotópok eloszlása és a litológiai tulajdonságok a Padimeytyvis-folyó medencéjének Wenlock-Ludlow határmenti lerakódásaiban. 1-4 - mészkövek; 2 - agyagos; 3 - réteges; 5 - stromatolit; 6 - lapos-kavicsos konglomerátumok; 7 - sárrepedés; 8 - hullámjelű; 9 - stromatoporoid; 10 - tömeges táblás; 11 - elágazó táblás; 12 - kagylók; 13 - haslábuák; 14 - csigák; 15 - férgek; 16 - gerincesek

Fig. 2 Distribution of fauna, isotopes $\delta^{13}\text{C}_{\text{carb}}$ and lithological features in the Wenlock-Ludlow boundary deposits in the Padimeytyvis river basin. 1-4 - limestones; 2 - clayed; 3 - laminated; 5 - stromatolitic; 6 - flat-pebble conglomerates; 7 - mud cracks; 8 - wave ripple mark; 9 - stromatoporoid; 10 - massive tabulates; 11 - branched tabulates; 12 - brachiopods; 13 - gastropods; 14 - orthoceratids; 15 - ostracods; 16 - vertebrates

In the bench, a stratum with organogenic structures is developed, which is represented by stromatolitic structures and coral-stromatoporate biostromes with a total thickness of 31 m (Fig. 3, A). In the lower part of this stratum, limestones with stromatolites of various morphological structures occur: bun-shaped, dome-shaped and beds, reaching a diameter of 55 cm and a height of 25 cm (Fig. 3, B). Similar Wenlock stromatolite structures are known in the north of the Urals, Chernyshev uplift, Dolgyi Island and Saaremaa Island in Estonia [8, 11, 15].

3. ábra Korall-stromatoporoid biostroma (A (II. egység)); 1a - stromatoporoid kolónia; 1b - *Aulocystella aseptata* táblák (Barskaja, 1967); B - kupola alakú stromatolit (II. egység); C - peloid mészkő lapos belső törmelékkel (II. egység); D - mészkő biomorfa, subrodált kaotikus viharok (III. egység)

Fig. 3 Coral-stromatopore biostrome (A (Unit II)); 1a - colony of stromatopore; 1b - tabulate *Aulocystella aseptata* (Barskaja, 1967); B - dome-shaped stromatolite (Unit II); C - peloid limestone with flat introclasts (Unit II); D - limestone biomorphic with subrounded chaotic storm cone (Unit III)

4. ábra A Wenlock-Ludlow határlerakódások a Padimeityvis folyó szakaszán. A - Wenlock mészkő a mésztartalmú pala beékelődésekkel (IV. egység); B - *Lingula* sp. kagylósérgek; C - pelitormorf mészkő vékony bioklasztikus anyaggal (IV. egység); D - pelitormorf mészkő, bioturbált (IV. egység); E - pelitormorf mészkő a *Lingula* sp. kagylók hossz- és keresztirányú héjával (V. egység); F - mészkő bioklasztikus-pelitormorf jellegű, csontvázaival és kagylók héjaival (V. egység).

Fig. 4 Wenlock-Ludlow boundary deposits in the section of the Padimeityvis R. A - Wenlock limestones with intercalations of calcareous shales (Unit IV); B - brachiopod *Lingula* sp.; C - pelitomorphic limestone with thin bioclastic material (Unit IV); D - pelitomorphic limestone, bioturbated (Unit IV); E - pelitomorphic limestone with longitudinal and transverse shells of the brachiopod *Lingula* sp. (Unit V); F - limestone bioclastic-pelitomorphic with ostracods and brachiopod shells (Unit V)

Coral-stromatopore biostromes with stromatopore *Syringostromella egestica* Riab., *Ec. Fastigiatum* (Fig. 3, 1a and 1b), tubular tabulate corals *Aulocystella aseptata* Barskaja and dendritic tabulate corals *Riphaeolites lamelliformis* Klamann lie above.

Thin-bedded limestones with ostracods and brachiopods *Atrypoida linguata* (Bush) cover the biostrom; limestones with desiccation fissures and signs of undulation ripples lie above.

A similar structure of the Upper Wenlock section gap, comprising coral-stromatopore and stromatolite biostromes, was described by D. K. Patruncov et al. on the Dolgyi island [20]. The conodonts *Ozarkodina kozhimica* Melnikov, *Ctenognathodus* sp. are defined in the bench. The upper boundary of the bench is the biostrome roof.

Unit III (thickness 17 m) is composed of brown and light brown fine- and medium-grained limestones with interbeds of limestone bioclastic, micro-layered, argillaceous. The lower part of the bench is composed of unsorted-detrital, biomorphic limestones, in which ostracods predominate, and interbeds of limestone with flat-pebble conglomerate (tempestites?) (Fig. 3, C and D) and signs of undulation ripples are also observed. Brown, micro-fine-grained, aphanite limestones with interbeds of unsorted-detrital limestones, mainly ostracodic, prevail above. Brachiopods *Atrypoida linguata* (Bush), ostracods *Eukloedenella*, *Hermanina insignis* Abushik., conodonts *Ozarkodina kozhimica* Melnikov, *Ctenognathodus* sp. are defined.

The lithological structure features of this part of the Wenlock section (Benches I-III) suggest that its formation occurred in open shallow shelf conditions at low sea levels, with the prevalence of storm sedimentation and the general regressive orientation of the basin development [11].

Further, after a 100-110 m break, the section continues along the Podimeityvis River.

Unit IV (thickness 50 m) is composed of interbedded limestones of light brown pelitomorphic thin-bedded limestones (Fig. 4, A) containing a small amount of bioclastic material (Fig. 4, C), dark brown shaly limestones, argillaceous (1-5 cm) limestones and thin interbeds of calcareous argillaceous - shales. No visible fauna remains are found. When the rocks were dissolved on conodonts in the samples, the brachiopods *Lingula* sp. (Fig. 4, B) were found along with the conodonts of *Ozarkodina kozhimica* Melnikov.

Unit V (thickness 30 m) is composed of interbedded limestones of light brown micro-grained, thin-bedded to shaly with light brown massive, cryptocrystalline limestones, with semi-shelly fracture, and bioturbated limestones (Fig. 4, D). In the bench, single shells of brachiopods, gastropods, ostracods, and orthoceratide (1-5 cm) were found (Fig. 4, E). Brachiopods *Lingula*, conodonts *Ozarkodina kozhimica* Melnikov, *Ozarkodina anika* Viira et Einasto, 2003, *Ozarkodina cf. soegina* Viira et Einasto, 2003 were defined.

In the roof of this bench, the contact of thin-bedded limestones to shaly and bioturbated limestones is revealed. We consider this contact as the lithological Wenlock-Ludlow boundary. The paleontological boundary was drawn along the disappearance of the inarticulate brachiopods *Lingula* sp. and the appearance of the Ludlow brachiopods *Greenfieldia uberis* and numerous ostracods (Fig 4, F).

Unit VI (40 m thick) is composed of interbedded lumpy light brown limestones, thin-bedded limestones, dark gray bioclastic, pelitomorphic, bioturbated limestones with interbeds of dark brown shaly argillaceous. Four interbeds with stromatolithic dome-shaped structures of a diameter of 35 cm and a height of up to 15 cm are observed in the bench. On the weathered surface, it can be seen that the buildings are formed of a series of small dome-shaped and columnar structures, which are intergrown at the base, of a height of 7 cm and a diameter of up to 6 cm. Brachiopods *G. uberis*, *G. dissecta*, *M. attenuates*, *Atrypodea linguata* Buch, *Lingula* sp., Wenlock-Ludlow conodonts *Ozarkodina kozhimica*, *Ozarkodina soegina*, *Ozarkodina cf. anika* (Viira et Einasto, 2003) and vertebrates *Thelodus visvaldi* Karatajūtė-Talimaa et Märss, 2002, are defined in the bench limestones.

6. Biota of Wenlock-Ludlow boundary sediments

The sea basin level increase in the late Wenlock (Sheinwudian) contributed to the taxonomic diversity of the biota. The benthic communities were based on the brachiopods represented by the *Atrypodea linguata* atrypids and the first in Silur sperifirids of the *Spirinella nordensis*, which are known in Wenlock of the Dolgy and Gotland Islands, in Great Britain, Bohemia, Mongolia, Southern China, in Llandovery and Wenlock of North America and Ludlow of Estonia. Along with brachiopods the ostracods *Hermanina insignis* (Abushik), *Eukloedenella grandifabae* Abushik, as well as gastropods, pelecipods, coral and stromatoporoid communities that formed the biostromes [11, 19] were developed at that time. The gradual shallowing of the basin, the development of stromatolith-forming organisms negatively affected the existence of the *Spirinella* brachiopods belonging to the third benthic complex (B.C. 3) and *Atrypodea* belonging to B.C. 2 [21]. The increase in stromatolith interbeds observed upstream of the section, as well as desiccation fissures, indicates a progressive regression, as a result of which stromatoporoids, ostracods, pelecipods, ostracods disappeared.

Wenlock deposits (thickness about 100 m), which are opened in the section along the Podymeityvis River, represented by thin-bedded, argillaceous limestones, do not contain visible fauna remains. When dissolving conodonts samples in this strata, the valves of inarticulate brachiopods *Lingula* belonging to B.C. 1 were defined.

Transition from Wenlock to Ludlow in the section of the river Padimeityvis is recorded by the change of light brown, thin-bedded, argillaceous limestones containing Wenlock conodonts complex and *Lingula* brachiopods with a depleted composition of benthic fauna to lumpy argillaceous limestones of massive appearance enclosing the *Greenfieldia uberis* brachiopod community. The paleontological Wenlock-Ludlow boundary is determined by the updated fauna composition (brachiopods, ostracods, vertebrates) in lumpy argillaceous limestones that compose the lower part of the Padimeityvis Ludlow horizon. Limestones with brachiopod shells *Glassina dissecta* T. Modz., *Morinorhynchus attenuata* (Amsd.), *Atrypodea linguata* (Buch), *Greenfieldia uberis* T. Modz. form distinct marking layers, which are traced at the Ludlow base on the Western slope of the Polar and Northern Urals, on Chernyshev uplift and numerous well sections of the Timan-Pechora oil and gas province [10].

As for the vertebrates, the remains of the vertebrates *Thelodus visvaldi* were discovered in the section, which until now were known only on the Severnaya Zemlya [22].

The section interval of Wenlock-Ludlow boundary sediments with a thickness of 13.7 m is characterized by a mixed complex of the Ludlow benthic fauna and the Wenlock complex of conodonts. In Fig. 2, this section interval is highlighted in gray. Examples of joint finds of fauna remains of different ages are known at the Llandovery-Wenlock boundary at the Chernov uplift, as well as at the Ludlow-Pridoli boundary in the section of the western slope of the Subpolar Urals [23, 24, 11].

7. $\delta^{13}\text{C}_{\text{carb}}$ Isotope Analysis

The results of the isotope analysis, sequentially tied to the intervals of the section, showed the possibility of identifying four intervals with characteristic isotopic values that are consistent with paleontological and lithological data (Fig. 2).

Isotope characteristics of carbonates of the Wenlock-Ludlow boundary deposits in the river Padimeityvis basin showed that in Wenlock $\delta^{13}\text{C}_{\text{carb}}$ values are in the range from -9.51 to 1 ‰, and in Ludlow from -3 to 0 ‰.

In interval I, composed mainly of pelitomorphic, biolitic, lithoclastic, stromatolithic limestones, the isotope $\delta^{13}\text{C}_{\text{carb}}$ is characterized by negative values. The average value of the isotope coefficient for carbon is $\delta^{13}\text{C}_{\text{carb}}$ -5.15 ‰. Up the section, the isotope $\delta^{13}\text{C}_{\text{carb}}$ has wave-like oscillations; first, the carbon values fall from -4.35 to -7.5 ‰, which then increase to -3.8 ‰ and fall to -7.0 ‰.

In interval II, a sharp weighting of the isotope $\delta^{13}\text{C}_{\text{carb}}$ is observed, which begins at the base of the coral-stromatoporate biostrome (bed 101) $\delta^{13}\text{C}_{\text{carb}}$ -6.3 ... -0.6 ‰ and continues to the very top of the section, where it reaches maximum values + 1 ‰ (bad 109). The average isotope $\delta^{13}\text{C}_{\text{carb}}$ value for this interval is -1.18 ‰. A sharp shift of the isotope curve towards positive $\delta^{13}\text{C}_{\text{carb}}$ values may correspond to the Early Wenlock biotic and isotopic Mulde event. This event is characterized by the extinction of the graptolite and conodont fauna, as well as a double positive excursion of carbon isotopes, which lies in many sections of the world [25-28].

In interval III, the average value of the isotope coefficient for carbon is -4.48 ‰. The interval is characterized by two abnormal negative values $\delta^{13}\text{C}_{\text{carb}}$ -9.51 ... -9.10 ‰.

Interval IV. The average value of the carbon isotope coefficient for this interval is $\delta^{13}\text{C}_{\text{carb}}$ -2.98 ‰. In the lower part of the interval, two peaks of negative values of carbon isotopes -6.29 ... -6.93 ‰ are recorded. Above the section, the interval is characterized by a gradual weighting of the isotope $\delta^{13}\text{C}_{\text{carb}}$ -6.93...-0.13 ‰, which sets the trend in the positive direction of the curve.

Considering the extremely shallow deposits of the studied Wenlock-Ludlow boundary deposits, it can be assumed that the isotope-facilitated fresh water from the continent saturated with dissolved soil carbon dioxide during climate humidization periods and a corresponding increase in terrigenous runoff could influence the isotope values changes. A sharp weighting of the isotope $\delta^{13}\text{C}_{\text{carb}}$ at the base of the coral-stromatoporate biostrome, unlike the lying above and below values, may indicate a change of water in the sedimentation basin from desalted to

normal marine [29, 30]. Such an effect is also associated with an increase in the biological productivity of the reservoir, due to warming and an increase of the sea level, which is correlated with lithological data (sequential change of layers with stromatolitic structures to coral-stromatoporate biostroms and then to limestones with diverse benthic fauna). Sharp spasmodic shifts of the isotonic curve in the studied section indicate significant changes in the characteristics of the medium of Wenlock-Ludlow boundary sedimentation in the Timan-Northern Ural Sea Basin.

8. Conclusions

The conducted studies supplemented the paleontological and sedimentological characteristics of Wenlock-Ludlow boundary deposits. For the first time, Wenlock-Ludlow boundary deposits received paleontological and chemostratigraphic evidence. The established thickness of Wenlock sediments at the Chernov uplift is 300 m. Two intervals were traced in the boundary deposits in which the brachiopod communities change from benthic complex 1 in Wenlock to benthic complex 2 in Ludlow. The established anomalous excursions of carbon isotopes in the section can serve as reliable chronostratigraphic benchmarks for regional and global correlation of Wenlock sections. The results of the study confirm and complete the conclusions of G. A. Chernov on the links of the Timan-Northern Ural Sea Basin with the Baltic and Western Europe basins.

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