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Advances in Devonian, Carboniferous and Permian Research: Stratigraphy, Environments, Climate and Resources

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These proceedings of the InternationalStratigraphic Meeting are dedicated to all aspects of Upper Paleozoic stratigraphy, biotic and abiotic events and the evolution of sedimentary basins at that time, and their resources.

Cover: sketch by Roderick I. Murchison ‘The Gurmaya Hills, South Urals, approaching from the Steppes’ (Murchison *et al*., 1845)

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The Parastratotype of the Urzhumian Stage in the Vyatka-Kazan Region, East-European Platform

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Abstract

New multidisciplinary studies of the Urzhumian parastratotype confirm its reference status for the Vyatka-Kazan region of European Russia. The purely continental Urzhumian represents the upper unit of the Biarmian Series (Middle Permian) of the Geological Time Scale of Russia and is tentatively correlated with the Wordian of the International Chronostratigraphic Chart.

The lower part of the parastratotype corresponds to the Sulitsa Formation and consists of lacustrine red-bed continental rocks containing rare conchostracans and fish scales. The upper part of the parastratotype corresponds to the Isheevo Formation and is composed of red-colored alluvial-lacustrine terrigenous and clayey rocks with interbeds of microbial limestones. The clayey rocks often include a large number of paleosols of differing maturity, among which vertisols and calcisols prevail.

This part of the section contains a diverse fauna of non-marine ostracodes, bivalves, conchostracans, fishes and tetrapods.

The Urzhumian parastratotype includes the non-marine ostracode assemblage of the *Palaeodarwinula fragiliformis* Biozone, the non-marine bivalve assemblages of the *Palaeomutela krotowi, P. wohrmani* and *P. numerosa* Biozones, and the fish assemblage of the *Platysomus biarmicus-Kargalichthys efremovi* Biozone. This makes it possible to reliably correlate it with the numerous Urzhumian sections of the east of the East European Platform. New localities for fishes, amphibians and reptilians increase its correlation potential.

Keywords: Middle Permian, Urzhumian, biostratigraphy, non-marine bivalves, ostracodes, conchostracans, fish tetrapods

Introduction

The Urzhumian Stage corresponds to the upper part of the Biarmian Series (Middle Permian) of the Geological Time Scale of Russia. The Urzhumian is composed of purely continental red-bed (or variegated) succession and is tentatively correlated with the Wordian Stage of the International Chronostratigraphic Chart [1].

Before 2006, the Urzhumian composed the lower unit of the Tatarian Stage (Upper Permian) of the bipartite Permian System and was considered as a regional biostratigraphic horizon [2].

The parastratotype of the Urzhumian Stage is located in the Kazan area on the right bank of the Volga River (Fig. 1). The section (75 m) is logged on the right bank of the Volga River between the villages of Pechishchi and Naberezhnye Morkvashi, in the Cheremushka (‘Bird Cherry’) Gully (outcrops P01-P10), Trekhglavyi (‘Three-Headed’) Gully (outcrop P11), and Strela (‘Arrow’) Gully (outcrop P12-P13) (Fig. 1C).

Since the pioneering work of Roderick I. Murchison in the 1840s, this section has been investigated many times, in particular by Kazan geologists. Aleksey K. Gusev, Professor at Kazan University,

provided the first detailed paleontological sampling and lithological description in the 1950s but this work remained unpublished until 1996 [3]. His bed by bed fossil collections were eventually expanded and refined. Later, Gusev [4] subdivided the Urzhumian succession of this section into Sulitsa and Isheevo Formations and several lithological units. In 2013-2017, the Urzhumian parastratotype was studied again by the Laboratory of Stratigraphy, Kazan Federal University (e.g. [5], [6], [7], [8], etc.). In this article, we present the new data obtained in this study.

Geological background

In the parastratotype, the Urzhumian is composed of continental red-bed argillaceous and terrigenous rocks with many marl, limestone and dolomite intercalations. The frequent intercalation of the different colored rocks causes the variegated coloration of the succession.

The most characteristic lithological feature of the Urzhumian is the presence of quartzose sandstones and siltstones, which are absent in the underlying Kazanian and overlying Severodvinian.

Algal-microbial limestones and dolomites are usually riddled with numerous *in situ* voids of plant roots. Shales with greenish-grey and red spots of gleisation are usually overfilled with calcareous concretions (paleosol horizons). Shales and siltstones with lenticular lamination contain numerous ostracodes, bivalves, fish scales and tetrapods.

According to lithological features the Urzhumian succession is subdivided into Sulitsa and Isheevo Formations [3], [4].

The Sulitsa Formation (25 m) overlays gray-colored fossiliferous (marine and non-marine) dolomites of the Upper Kazanian and has been subdivided into six more or less distinct lithological units.

The Sulitsa Formation is mainly composed of basin (lacustrine) clayey and terrigenous rocks of dull brownish-brown coloration, which include numerous layers of variegated and light-colored marls, limestones and dolomites (“Urzhum flagstones”). Fossils are rare and represented only by conchostracans and fish scales. The rocks are characterized by the reverse polarity of the ancient magnetic field.

The Isheevo Formation (55 m) is represented by a rhythmic alternation of sandy-argillaceous and argillaceous-carbonate packets, which, in comparison with the Sulitsa Formation, are characterised by brighter colors. The formation includes numerous intervals of paleosol profiles. The argillaceous-carbonate packets often arm the slopes of the watersheds. The formation has been subdivided into seven lithological units, the names of which have been derived partly from the geographical localities of their type sections or from their lithological features. Fossils occur frequently; rocks are characterized by the alternating polarity of the ancient magnetic field.

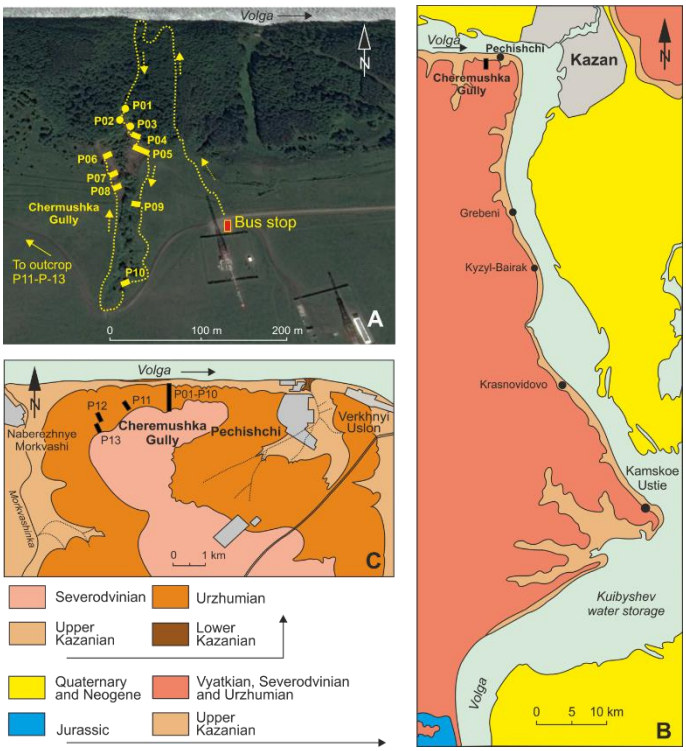

Fig. 1. The location of Urzhumian parastratotype: **(A)** space image of the Cheremuska Gully (Image © CNES/Astrium) showing the locations of the outcrops (P1-P10); **(B)** generalized geological map of the Volga-Kama region near the town of Kazan, Republic of Tatarstan, and **(C)** generalized geological map of the Pechishchi area.

The lower part of the section contains numerous thin bands (thickness 1-5 cm) of clayey breccias.

These rocks consist of angular silty-clayey debris lying (‘floating) in a clayey matrix. Gravel-sized lithoclasts are dispersed in the matrix and can be found together with clay coatings and occasional *in situ* roots. The coatings contrast with the matrix by their dark red, brown or green color and divide the layer into many angular fragments, forming the reticular structure of the rock.

Along the strike of the beds, the clayey breccias form a regular succession: (1) breccias, (2) silty-clay rocks with broken and subhorizontal sloping lamination, (3) silty-clay rocks with irregular undulated lamination and (4) silty-clay rocks with fine subhorizontal or horizontal lamination. Such a sequence indicates the subaerial transformation of the sediments without deep soil formation.

The section contains 17 paleosol profiles which are confined to red-colored argillaceous packets.

The paleosols usually include *in situ* roots, slickensides, calcareous nodules, spots of gleization, and blocky peds. The Isheevo Formation contains the largest number of paleosol profiles that are represented by the vertisols and calcisols. The vertisols are identified by wedge-shaped blocky peds and slickensides whereas calcisols are marked by accumulation of calcium carbonate [9]. The degree of development, or maturity, shows that most of the paleosols represents weakly or moderately developed types with I to II stages of carbonate accumulation, i.e. contain calcium carbonate in the form of powdery carbonate (I stage) or carbonate nodules (II stage) [10]. Stacking paleosols up to 3.5 m thick occur only in the Crimson Shale Member (Fig. 2).

Within this interval, each of the paleosol profiles contains a continuous calcrete horizon formed by coalescing nodules. These features coincide with the III to IV stages of carbonate accumulation [10].

The vertisols and calcisols of the Urzhumian parastratotype in the Cheremushka Gully are similar to those of Urzhumian stratotype (Monastery Ravine, Kazan Volga region) [8] and indicate a semi-arid climate with clear seasonality of precipitation [11]. This conclusion coincides with the distribution of fossils and geochemical data on carbon (dC^{13}) and oxygen (dO^{18}) isotopes indicating a gradual cooling and increase in humidity during the Urzhumian age [7], [12].

Erosional surfaces coinciding with the upper boundaries of breccias and paleosols are used as the main tool to determine the sedimentary cycles.

A sharp decrease in the $\delta^{13}C$ is fixed in the sedimentary carbonates from the bottom to the top of the section. In the lower 60 m of the section, the values of $\delta^{13}C$ change from 3.7‰ PDB at the bottom to -4.8‰ PDB and -8.4‰ PDB in the Cheremushka Member and in the Crimson Shale Member respectively. Up the section, a positive change in variations of $\delta^{13}C$ is observed.

Lower values of $\delta^{13}C$ correlate with a very light isotopic composition of oxygen that is characterized by a decrease of the values of $\delta^{18}O$ from 31-32‰ SMOW at the bottom of the section to 21.4‰ SMOW and 19.6‰ SMOW in the Cheremushka Member and in the Crimson Shale Member respectively. Thereby, two negative excursions in the stable isotopic composition of carbon and oxygen in the Cheremushka Member and in the Crimson Shale Member are revealed.

These excursions can be considered as global stratigraphic markers that suggest climate cooling and rising humidity [7], [12].

Biostratigraphy

Non-marine bivalves

The section exposed in Cheremushka Gully was established as a stratotype of three non-marine bivalve range Biozones based on species of *Palaeomutela* Amalitzky, 1892: *P. krotowi* Biozone, *P. wohrmani* Biozone and *P. numerosa* Biozone (Fig. 2) [13].

Palaeomutela krotowi Biozone. The lower and upper boundaries of the zone correspond to the first appearance data (FADs) of *P. krotowi* Netsch. and *P. wohrmani* Netsch., respectively. Characteristic bivalve species: *P. vjatkensis* Gusev, *P. doratioformis* Gusev, *Anadontella volgensis* (Gusev), *Prilukiella lata* (Netschajew). The *Palaeomutela krotowi* Zone is registered in the Volga–Ural, North Caspian, and Dvina-Mezen basins. On the basis of the occurrence of the index species, this unit may be correlated with the *Palaeomutela visenda-Palaeomutela meraca* Biozone (Talbei Formation) established in the Pechora basin.

Palaeomutela wohrmani Biozone. The lower and upper boundaries of the unit correspond to the FADs of *P. wohrmani* Netsch. and *P. numerosa* Gusev, respectively. The characteristic bivalve species are: *P. krotowi* Netsch., *P. extensiva* Gusev, *P. doratioformis* Gusev, *Anadontella uslonensis* (Gusev), *A. volgensis* (Gusev), *A. tscherdinzewi* (Gusev), *Prilukiella janischewskyi* Plotnikov, *Pr. subovata* (Jones), *Pr. nitida* Gusev, *Pr. mirabilis* Gusev, *Pr. pugnatoria* Gusev. The *Palaeomutela wohrmani* Biozone is documented in the Volga-Ural and Dvina-Mezen basins. The presence of *Anadontella* and *Prilukiella* species together allow this unit to be correlated with the *Palaeomutela visenda-Palaeomutela meraca* Biozone (Talbei Formation) of the Pechora Basin and with the A*nadontella supraphillipsii-Terciella certa* Biozone (Leninskian Regional Stage) of the Kuznetsk Basin [13], [14].

Palaeomutela numerosa Biozone. The lower and upper boundaries of the unit correspond to the FADs of *P. numerosa* Gusev and *P. keyserlingi* Amalitzky, respectively. Characteristic bivalve species: *P. verneuili* Amal., *P. semilunulata* Amal., *P. solenoides* Amal., *P. subparallela* Amal., *P. marposadica* Gusev, *P. tschuvashica* (Gusev).

The zone is recorded in the Volga-Ural and Dvina-Mezen basins of the East European Platform.

Non-marine ostracodes

The first ostracodes appear only in the lower part of the Isheevo Formation, in the Green Clay Member (Fig. 2). The ostracod assemblage here is fairly poor [15]. The most diversified ostracod assemblage is associated with the middle part of the Isheevo Formation. It comprises numerous, diverse species, very common in the Urzhumian of the East-European Platform: *Paleodarwinula tuba* (Mish.), *P.* aff. *fainae* (Bel.), *P.* aff. *perlonga* (Schn.), *P.* aff. *vicina* (Molost.), *P.* cf. *faba* (Mish.), *P. chramovi* (Gleb.), *P. elegantella* (Bel.), *P. elongata* (Lun.), *P.* ex gr. *alexandrinae* (Bel.), *P.* ex gr. *arida* (Molost.), *P.* ex gr. *defluxa* (Mish.), *P. fragiliformis* (Kash.), *P. fragilis angusta* (Schn.), *P. inornatina* (Bel.), *P. mera* (Starozh.), *P. obvia* (Molost.), *P. teodorovichi* (Bel.), *P. tichonovichi*

(Bel.), *P. torensis* (Kotsch.), *Permiana elongata* Schn., *Placidea* ex gr. *lutkevichi* (Spizh.), *Prasuchonella nasalis* (Schn.), *P. stelmachovi* (Spizh.), *Suchonellina inornata* Spizh.

The stratigraphic interval of the ostracodes assemblage is confined to the Upper Urzhumian, to the *Palaeodarwinula fragiliformis-Prasuchonella nasalis* Biozone.

The species *Suchonellina inornata* Spizh. appears at the top of the Isheevo Formation alongside with the typically Urzhumian assemblage. It is one of the index species of Severodvinian *Suchonellina inornata-Prasuchonella nasalis* Biozone.

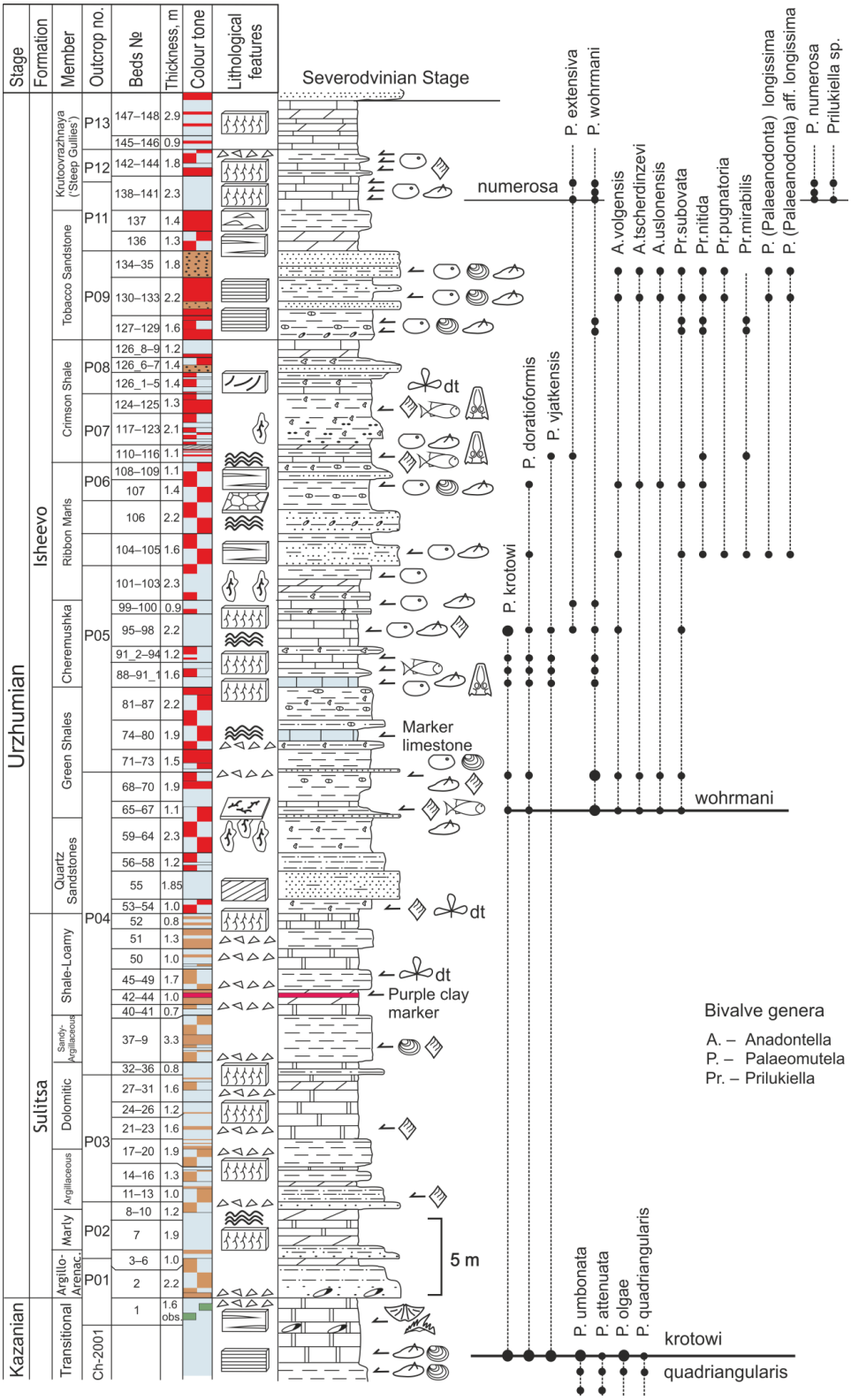

Fig. 2. Caption on the next page.

Conchostracans

The Kazanian Stage. The Transitional Member of the Upper Kazanian Substage contains the conchostracan *Curvacornutus* Tasch, 1961. Conchostracans occur on the bedding planes of greenish-gray clays preserving horizontal gently undulating lamination. The conchostracan shells are well preserved. Microsculpture is preserved on the shell surface in many cases. The umbones of all specimens possess the curved spine specific for the genus *Curvacornutus*. Sometimes, conchostracans occur on the bedding planes together with non-marine bivalves of the genus *Palaeomutela* Amalitzky. Adjacent dolomite layers contain specific Kazanian marine bivalves, brachiopods, and non-platform conodonts [16].

The Urzhumian Stage. The Sulitsa Formation includes two stratigraphic levels with conchostracans. The Clayish Member (beds no. 17-20) contains *Pseudestheria* cf. *itiliana* (Nov.).

The Sandy-Argillaceous Member (beds no. 37-39) contains *Ps.* cf. *itiliana* (Nov.), and *Palaeolimnadiopsis* cf. *lundongaense* (Nov.). The conchostracans occur on the bedding planes of brown and greyish-brown mudstones with horizontal and lenticular lamination. Shells are well preserved. All specimens of *P. lundongaense* possess a posterolateral curving of the growth lines and a specific pitted ornamentation. The adjacent thin interlayers of pink and gray marls include numerous voids of plant roots [7].

The Isheevo Formation contains four levels with conchostracans. The most abundant assemblages occur in the gray-colored mudstones of the Green Shales Member (bed no. 68). This assemblage includes *Pseudestheria* cf. *itiliana* (Nov.), *Curvacornutus meshaensis* Nov. and *Hemicycloleaia* cf. *rhodendorfi* Nov. The shells are well preserved. All specimens of *C. meshaensis* possess the specific curved spine on the umbo.

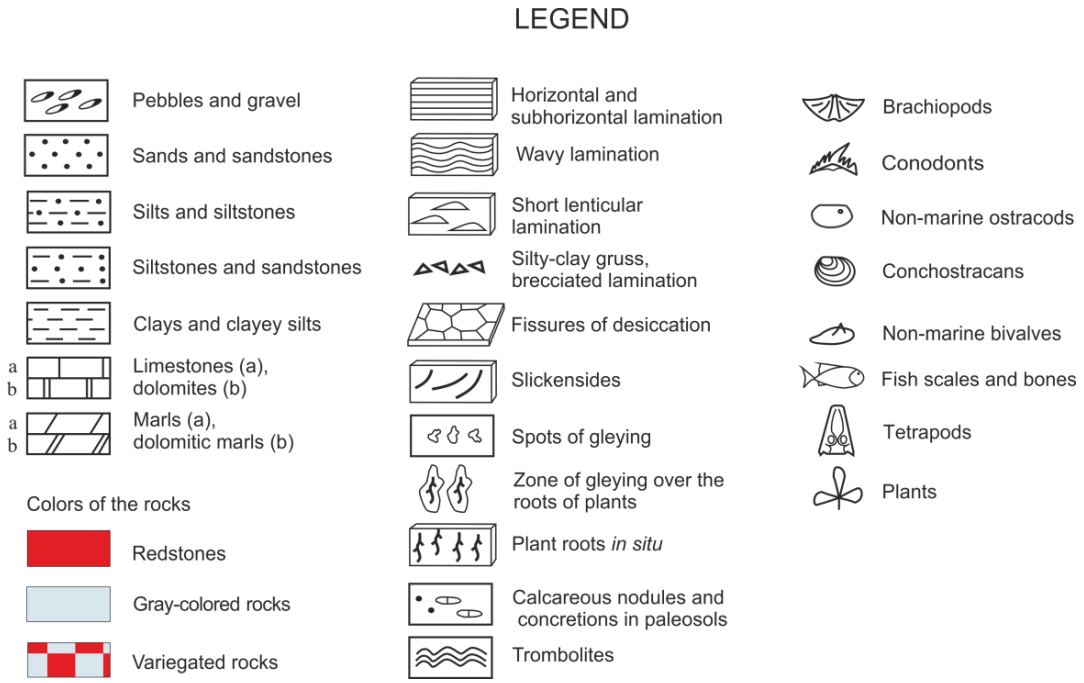

Fig. 2. Distribution of non-marine bivalves in the Urzhumian parastratotype logged in Cheremushka Gully (outcrops P01-P10), Trekhglavyi Gully (outcrop P11), and Strela Gully (outcrop P12-P13).

The Tobacco Sandstone Member includes three levels with conchostracans which are represented by a monospecific assemblage of well-preserved *Ps.* cf. *itiliana* (Nov.). Among the conchostracans, the bedding planes contain non-marine ostracodes and bivalves [7].

The species *Ps. itiliana*, *P. lundongaense*, *C. meshaensis* and *H. rhodendorfi* are specific to the Urzhumian conchostracan assemblage. The species *H. rhodendorfi* occurs in the Urzhumian of the Orenburg Region, as well as in the Vyatka River Basin and in the Kuznetsk coal Basin [17].

The species *C. meshaensis* occurs in the Kazan area [18]. The species *P. lundongaense* occurs in the Vologda Region and in the territory of the Sakha (Yakutia) Republic [18]. The species *Ps. itiliana* occurs in the Middle Volga Basin and in the Siberian Platform (Nizhnaya Tunguska River Basin) [19].

Fishes

The Urzhumian parastratotype contains six levels with identifiable actinopterygian remains. Four lower levels include only three common taxa: *Varialepis* cf. *orientalis* (Eichw.) (beds no. P04/53, P04/68, P04/67-2, P05/105), *Eurynotoides* sp. (bed no. P04/68), *Discordichthys spinifer* A. Minich (bed no. P04/67-2).

A diverse fish assemblage occurs in the tetrapod localities Cheremushka 1 (bed no. P07/112) and Cheremushka 2 (P07/125), coinciding with the Crimson Shale Member of the Isheevo Formation.

The locality Cheremushka 1 contains isolated, well preserved chondrichthyan teeth, scales, fin spines and cartilage fragments, as well as actinopterygian teeth, skull bones, and scales.

Chondrichthyans are represented by Sphenacanthidae gen. et sp. nov. earlier defined as *Xenosynechodus egloni* Glikman [20]; the hybodontiforms "*Lissodus*" cf. *zideki* (Johnson) and "*Polyacrodus*" sp.; Neoselachii gen. et sp. nov. Actinopterygian fishes include (% by all actinopterygian remains): *Varialepis bergi* A. Min. (58%), *Kargalichthys efremovi* Min. (8%), *Platysomus biarmicus* Eichw. (6%), *Samarichthys luxus* A. Min. (4%), *Burguklia* sp. (8%), *Discordichthys spinifer* A. Min. (2%), *Uranichthys pretoriensis* A. Min. (1%), *Kichkassia furcae* Min. (1%).

The locality Cheremushka 2 contains the following actinopterygian taxa: *Varialepis bergi* (11%), *Kargalichthys efremovi* (1%), *Platysomus biarmicus* (1%), *Samarichthys luxus* (<1%), *Burguklia* sp. (1%), *Discordichthys spinifer* (3%), *Uranichthys pretoriensis* (25%), *Kichkassia furcae* (20%), *Palaeostrugia rhombifera* (Eichw.) (<1%), *"Acrolepis" macroderma* (Eichw.) (<1%).

The remains of *Burguklia* sp. are the most interesting. The first appearance of this genus is fixed in the Early Permian of Siberia [21]. The occurrence of *Burguklia* sp. in the Urzhumian parastratotype indicates a connection and interchange between the Permian fish assemblages of Siberia and European Russia.

Diverse chondrichthyan and actinopterygian remains are recorded in the Gremyachka locality.

Numerous teeth and rare fin spines of a new taxon, Sphenacanthidae gen. et sp. nov.; the hybodontiforms *Omanoselache* sp., *Lissodus* cf. *minimus* (Agassiz), and "*Polyacrodus*" sp.; new neoselachian, hybodontiform scales and spines are found in that locality. The actinopterygians are attributed to *Discordichthys spinifer* (3%), *Acropholis* sp. (5%), *Varialepis* cf. *bergi* (<1%), *Kargalichthys efremovi* (<1%), *Platysomus biarmicus* (21%), *Samarichthys luxus* (<1%), *Burguklia* sp. (<1%), *Uranichthys pretoriensis* (37%), *Kichkassia furcae* (3%), *"Acrolepis" macroderma* (2%).

Some teeth of "*Lissodus*" and "*Polyacrodus*" have an abraded external surface. Several shark teeth and some scales of bony fishes bear partial traces of abrasion or post-mortal bioerosion. The intravital abrasion in the crushing teeth is extremely rare in those specimens. The preservation of fish remains indicates a typical allochthonous assemblage.

A new taxon of Sphenacanthidae has been found in the Late Kazanian-Severodvinian interval of the East European Platform. The hybodontiform *Omanoselache* was described for the first time from the Wordian of Oman [22]. The actinopterygian assemblage belongs to the *Platysomus biarmicus-Kargalichthys efremovi* Biozone that corresponds to the Urzhumian of European Russia.

Tetrapods

The Crimson Shale Member (Isheevo Formation) (outcrop P07, Fig. 3) contains two localities with vertebrate fauna, Cheremushka 1 and Cheremushka 2, corresponding to the Late Urzhumian age. The Member is represented by an alternation of microbial limestones and bright speckled clays predominantly of paleosol origin. The limestones are, usually, riddled with *in situ* voids of plant roots.

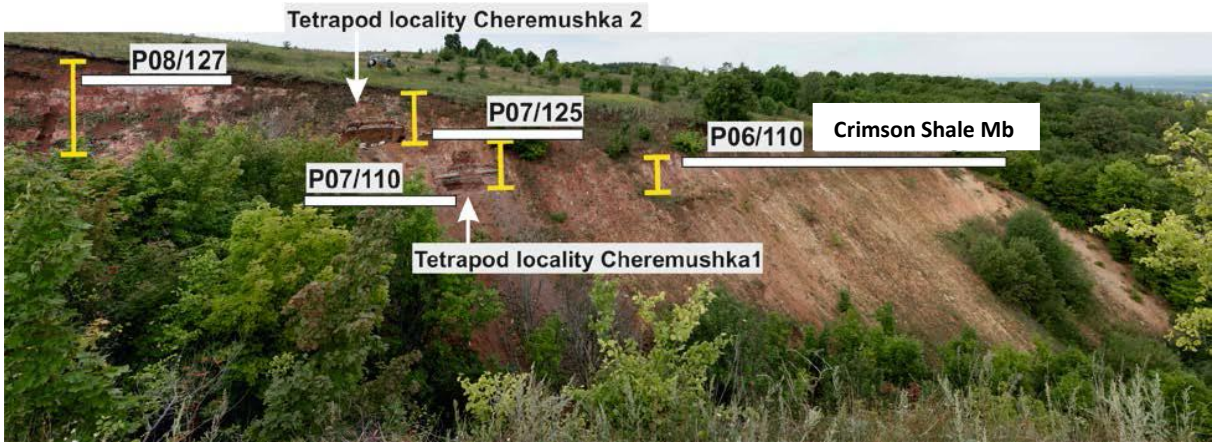

Fig. 3. Left slope of Cheremushka Gully and location of outcrops no. P06, P07, P08 and Cheremushka 1 and Cheremushka 2 tetrapod localities.

Tetrapod locality Cheremushka 1

Amphibians: *Leptoropha* sp. (Leptorophinae, Kotlassiidae, Seymouriamorpha) – rare disarticulated skeletons of juvenile specimens; Archegosauroidea fam. ind. (Temnospondyli) – sporadic disarticulated skeletons of juvenile specimens (in the clays), rare large bones in the gritstone crust overlaying the limestone (bed no. P07/110).

Reptiles: Dinocephalia fam. ind. – single tooth of carnivorous taxon in the gritstone crust overlaying bed no. P07/110.

The locality predominantly contains various lineages of juvenile amphibians, such as seymouriamorphs and temnospondyls, and is confined to the carbonate and argillaceous facies. The locality could be attributed to subautochthonous type due to the preservation of slightly deformed skulls and skeletons of juvenile amphibians. At the same time, the bones of adult animals are rare, and the percentage of reptilian taxa is very low.

Tetrapod locality Cheremushka 2 (the upper bone-bed level-the lens)

Amphibians: Archegosauroidea fam. ind. (Temnospondyli) – isolated bones; *Leptoropha* sp. (Kotlassiidae, Seymouriamorpha) – isolated cranial bones and teeth.

Reptiles: Anomodontia fam. ind. (Venyukoviidae?) – isolated jaw and teeth; Dinocephalia fam. ind. – single carnivore teeth; Bolosauria gen. ind. (Captorhinomorpha) – isolated dentary of juvenile.

The locality is restricted to argillaceous gritstone which forms the basement of the local alluvial lens. It contains a large number of disarticulated remains of amphibians and reptiles as well as fishes (Actinopterygii and Chondrichthyes) and represents a typical allochthonous assemblage.

Tetrapod locality Gremyachka

The new locality for vertebrate fauna is situated 1 km south of the head of the Cheremushka Gully and is confined to the Crimson Shales Member [5]. In this locality, the Crimson Shales Member has a more alluvial and lacustrine character. A thin bed (0.3 m) of dark gray (coal-like) lacustrine shale lies at the top of the succession and clearly differentiates this section from the reference one. The tetrapod locality belongs to this shale bed, as well as to the thin (0.15 m) underlying band of greenish-grey sandstone – the “main amphibian bed”.

Amphibians: Archegosauroidea fam. ind. (Temnospondyli) – isolated bones of differently sized animals.

Reptiles: Dinocephalia fam. ind. – fragments of cranial and postcranial bones and teeth.

The locality probably has an alluvial genesis. The bones of adult temnospondyls clearly predominate. Most of the bones have traces of destruction preceding burial, indicating the high energy of the water. Bones are preserved in disarticulated positions, so the locality can be considered as allochthonous. The black shale overlaying the 'main amphibian bed' of sandstone also contains tetrapod bones, which are included in flat dark-beige nodules, sometimes occurring as aggregations. It is most possible that the nodules represent large reptilian coprolites.

Conclusions

The lower boundary of the Urzhumian Stage is most confidently defined in the Cheremushka parastratotype section by non-marine bivalves and ostracodes.

The non-marine ostracode assemblage of the *Palaeodarwinula fragiliformis* Biozone, the non-marine bivalve assemblages of the *Palaeomutela krotowi*, *P. wohrmani* and *P. numerosa* Biozones make it possible to correlate the parastratotype with the numerous Urzhumian sections of the east of the East European platform.

The determination of the precise stratigraphic boundaries of the revealed fish and tetrapod Biozones requires further investigation.

The paleogeographic features of Early Urzhumian (Sulitsa Formation) may be interpreted as subaerial environments of plains resembling modern coastal or inland sabha.

The specific features of the paleosol profiles from the Isheevo Formation indicate, in general, a semi-arid climate with a clear seasonality of precipitation.

Negative excursions of the carbon and oxygen isotopes in Late Urzhumian (Isheevo Formation) suggest relative climate cooling and rising humidity, which is correlated with significant biodiversity at that time.

Acknowledgments

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