

The Terminal Permian in European Russia: Vyaznikovian Horizon, Nedubrovo Member, and Permian–Triassic Boundary

V. R. Lozovsky^a, Yu. P. Balabanov^b, E. V. Karasev^c, I. V. Novikov^{c, d},
A. G. Ponomarenko^c, and O. P. Yaroshenko^e

^a Russian State Geological Prospecting University, ul. Miklukho-Maklaya 23, Moscow, 117997 Russia

^b Kazan Federal University, Kazan, Russia

^c Paleontological Institute, Russian Academy of Sciences, Profsoyuznaya ul. 123, Moscow, 117997 Russia

^d University of Dodoma, Tanzania

^e Geological Institute, Russian Academy of Sciences, Staromonetny per. 35, Moscow, 119017 Russia

e-mail: vlozovsiy@yandex.ru, karasev@paleo.ru, balabanov-geo@mail.ru

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Abstract—The comprehensive analysis of the data obtained on terrestrial vertebrata, ostracods, entomologic fauna, megafloora, and microflora in deposits of the Vyaznikovian Horizon and Nedubrovo Member, as well as the paleomagnetic data measured in enclosing rocks, confirms heterogeneity of these deposits. Accordingly, it is necessary to distinguish these two stratons in the terminal Permian of the East European Platform. The combined sequence of Triassic–Permian boundary deposits in the Moscow Syncline, which is considered to be the most complete sequence in the East European Platform, is as follows (from bottom upward): Vyatkian deposits; Vyaznikovian Horizon, including Sokovka and Zhukovo members; Nedubrovo Member (Upper Permian); Astashikha and Ryabi members of the Vokhmian Horizon (Lower Triassic). None of the sequences of Permian–Triassic boundary deposits known in the area of study characterizes this sequence in full volume. In the north, the Triassic deposits are underlain by the Nedubrovo Member; in the south (the Klyazma River basin), the sections are underlain by the Vyaznikovian Horizon. The Permian–Triassic boundary adopted in the General Stratigraphic Scale of Russia for continental deposits of the East European platform (the lower boundary of the Astashikha Member) is more ancient than the one adopted in the International Stratigraphic Chart. The same geological situation is observed in the German Basin and other localities where Triassic continental deposits are developed. The ways of solving this problem are discussed in this article.

Keywords: Permian, Triassic, entomofauna, terrestrial vertebrata, ostracods, macroflora, miospore complexes, petromagnetism

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INTRODUCTION

The sequences of Permian–Triassic transitional continental deposits exposed in the Moscow Syncline are highly saturated with different organic remnants (terrestrial vertebrata, ostracods, conchostracans, mega- and microflora, insects, etc.). Because of this, these sections differ from similar sequences worldwide. This is a reason why they are of importance for comprehensive study to reveal the Permian–Triassic boundary in continental deposits. Using a complex of methods, a similar composite section was described in (Lozovsky, 2013; Lozovsky and Korchagin, 2013). The chronostratigraphic sequence proposed by Lozovsky for the Permian–Triassic boundary includes Vyatkian deposits, the Vyazniki Horizon, and the Nedubrovo, Astashikha, and Ryabi members of the Vokhmian Horizon. The Vyaznikian Horizon and Nedubrovo Member occupy the central position in this sequence. They formed at the turn of the geological evolution

which occurred in the boundary region between the East European Platform and the Uralian orogen. At the end of the Permian, this territory was uplifted, which resulted in its drying (Ignatiev, 1962). In Lozovsky's opinion, there were specific conditions of sedimentation of the Nedubrovo Member caused by an impact event. The preservation of this member in the Kichmenga River basin can be easily explained by block movements on the wing of the Sukhonsky shaft. Rejuvenated sedimentation in the Vyaznikovian time was locally confined only to the basins of rivers flowing from the Urals. Throughout the rest of the platform, sedimentation was absent or it was locally manifested. In the Early Triassic, sedimentation occurred throughout the entire East European Platform.

The sequence of geological events at the Permian–Triassic boundary proposed by Lozovsky (2013) was accepted by Arefiev et al. (2015). These authors used this sequence as a basis for construction of a $\delta^{13}\text{C}$ isotope curve for the Permian–Triassic boundary in depos-

its of the Moscow Syncline. Interpretation of this sequence by Sennikov and Golubev (2014) was in contradiction with the Lozovsky's idea. On one hand, this interpretation was "in good agreement with the interpretation of the reference section of the Zhukov ravine" (Sennikov and Golubev, 2014, p. 61); on the other hand, these authors consider that the upper (Zhukovo) sandy unit of the Vyaznikovian sequence is a facies analog of the Nedubrovo Member (Golubev and Sennikov, 2015). This problem is discussed below.

In this connection, we should note that the well-exposed Sukhona–Northern Dvina sequence (Arefiev et al., 2015), which was demonstrated to participants of the XVIII International Permian–Carbonaceous Geological Congress, is incomplete in its upper part, where the Vyaznikovian Horizon is missing. In the stratigraphic scheme of the terminal Permian (Arefiev et al., 2015, fig. 6, p. 11), the Komaritsa Member is conformably overlain by the Nedubrovo Member. There is a gap, corresponding to the Vyaznikovian Horizon, at the boundary between these units. This gap is observable in the section located between the villages of Glebovo and Vaganovo, where Nedubrovian gray deposits with flora remnants are overlain by basal sands with conglomerates at the lower boundary. The latter sharply unconformably overlies Komaritsa marls.¹

Because of existing differences in the paleontological characteristics, we do not consider the Nedubrovo Member as a facies analog of Vyaznikovian sands containing the *Archosaurus rossicus* Zone (Golubev and Sennikov, 2015). In contrast to the Vyaznikovian Horizon, the Nedubrovo Member contains no remnants of terrestrial vertebrata. Moreover, these strata significantly differ in paleofloristic, entomological, and ostracods complexes, as well as in paleomagnetic characteristics. Accordingly, we can consider them as separate chronostratigraphic subdivisions. This work is aimed at demonstrating that these strata must be included in the General Stratigraphic Scale of Russia as independent subdivisions in order to determine the exact position of the Permian–Triassic boundary.

VYAZNIKOVIAN HORIZON AND NEDUBROVO MEMBER

The analysis of the late Tatarian fauna of terrestrial vertebrata shows the possibility to distinguish an independent Vyaznikovian Horizon in the upper part of the Tatarian Stage (Shishkin, 1990). Later, this term was adopted in the scientific literature, while N.I. Strok and T.E. Gorbatkina included the underlying deposits, which do not contain the Vyaznikovian tetrapod complex (*Archosaurus rossicus* Zone after (Ivakhnenko et al., 1997), in the Vyaznikovian Horizon as well (*Reshenie...*, 1990, p. 37). Along with sandy deposits containing vertebrata remains, the Vyaznikovian Hori-

zon includes underlying clayey-siltstone members containing plant complexes, ostracods, insects, etc. This horizon was considered as the "Vyaznikovian Stage" in (Lozovsky and Kukhtinov, 2007), the "Zhukovian Horizon" in (Sennikov and Golubev, 2010), and the "Vladimirian Stage" in (Naugolnykh, 2005).

The stratotype of the Vyaznikovian Horizon is located in the marginal zone of the Moscow Syncline (the Klyazma River basin), where a few sequences are cropped out along the right bank of the river between towns of Vyazniki and Gorokhovets (Zhukov ravine). These outcrops contain a rich complex of organic remnants characterizing the Vyaznikovian faunistic complex of the like-named stratotypical region.

The Vyaznikovian deposits occupy the specific stratigraphic position in the sequence between faunistically characterized Late Permian Vyatkian and Early Triassic Vokhmian deposits. Their deposition was preceded a long-term stratigraphic gap, which resulted in the formation of the erosional surface. This is confirmed by unconformable overlap of the Vyaznikovian deposits on different-depth levels of the Vyatkian Stage up to the uppermost level of the Severodvinian Horizon (Lozovsky, 2011; Golubev et al., 2012).²

The lower parts of paleoincisions, which we called the Sokovka Member, are represented by gray thinly laminated clays and siltstones with plant detritus accumulated in oxbow and oxbow swamp relief depressions. The upper part of the Vyaznikovian deposits (Zhukovo Member) is largely made of cross-stratified polymictic sands of channel alluvium containing intercalations of gravellites and conglomerates with clayey pebbles and boulders of local rock varieties (midstream facies).

According to the dip and azimuth of the oblique bedding in alluvial sands, they were deposited in river channels of southwestern orientation (Golubev et al., 2005).

The above alluvial flow from the Klyazma River basin is traced further to the northeast. Sandy alluvial deposits, similar to the Zhukovo Member, are cropped out in the area of the settlement of Voskresenskoe (Vetluga River basin). These deposits contain the Vyaznikovian assemblage of terrestrial vertebrata (Lozovsky and Blom, 1998, p. 11). Lithologically similar sandy formations were described in the core of well 14 Pereprava (depth interval of 20–48 m) (Ignatiev, 1962). At a distance of 150 km to the southeast (near the village of Purly, Nizhny Novgorod oblast), the sandy-gravellite deposits ("pugi") containing pebbles of local clays, marls, and sandstones, as well as Uralian chert and jasper, are exposed. These deposits contain vertebrates of the Vyaznikovian assemblage (*Archosaurus rossicus* Zone). In our opinion, these conglomerates belong to the upper part of the Uralian paleoflow transporting sediments throughout the plain of the

¹ Only the uppermost part of the basal sand beds is exposed in the sections near the village of Nedubrovo.

² Some researchers (Molostovskaya, 2010; Sennikov and Golubev, 2010) assumed erroneously that the Urzhumian deposits in the Zhukov ravine sequence are overlain by only Vyatkian deposits.

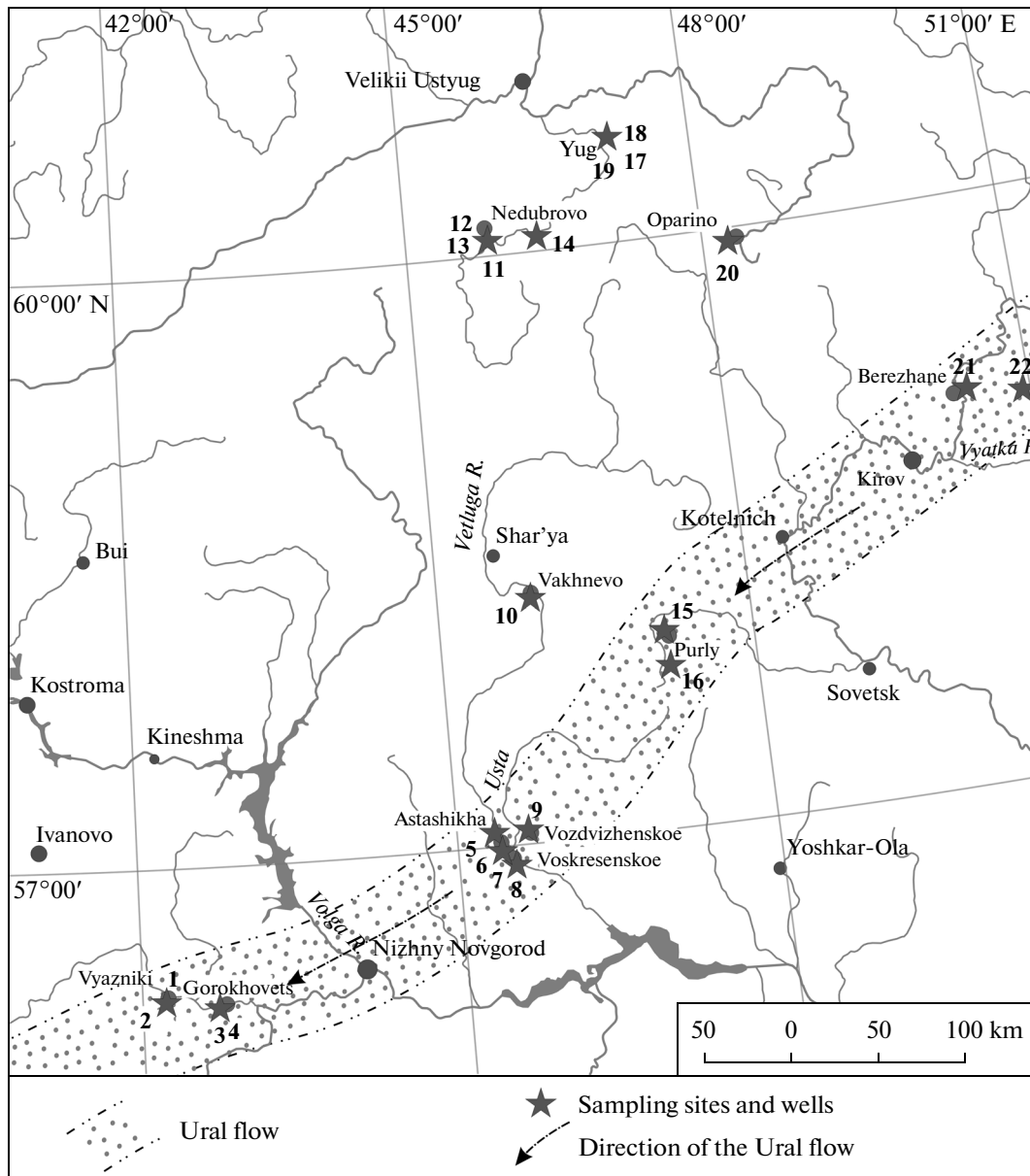


Fig. 1. Scheme of arrangement of localities and wells. Localities and wells: (1) Sokovka; (2) Balymotikha; (3) Zhukov ravine; (4) Slukino; (5) Astashikha; (6) Znamenskoe; (7) Scherbachikhinskoe; (8) Voskresenskoe; (9) well 14 Pereprava; (10) well 457 Vakhnevo; (11) Kuzmino; (12) Nedubrovo; (13) Glebovo and Vaganovo; (14) Yontala (Anan'ino); (15) Purly; (16) Tonshaevo; (17) Sholga; (18) Podsaraitsa; (19) Fominovo; (20) Oparino; (21) Berezhane; (22) Zalazna.

Moscow Syncline in the Vyaznikovian time and called the Main Ural paleoflow (Lozovsky et al., 2015) (Fig. 1). Moreover, we consider that the Tonshaevo locality composed of sandstones, gravellites, and conglomerates is lithologically similar to the Vyaznikovian Horizon, containing *Annatherapsidis* aff. *permirus* (Amalitzki) and unidentified remnants of large dicynodonts. V.K. Golubev (*Stratotipicheskii...*, 2001, p. 123) noted an absence of pareiasaurs and gorgonorprians in this complex, which is typical of the Vyaznikovian complex. According to this, he conditionally attributed this locality to the ancient Sokolki complex. The

upper reaches of the Uralian flow are noted in the Vyatka River basin (Berezhane locality), where Vyaznikovian (after V.K. Golubev; *Stratotipicheskii...*, 2001) sandstones and conglomerates containing bones of *Chroniosuschida* gen. indet. and complete skulls of *Vivaxosaurus permirus* Kalandadze et Kurkin and *Delectosaurus berezhanensis* Kurkin (Kurkin, 2001) are cropped out. A.V. Gomankov described the strato-type of the Vyatkian Horizon in the Vyatka River basin (*Stratotipicheskii...*, 2001). However, despite the paleontological data obtained, this locality was attributed to the Bykovian Beds, comprising the lower part of the

Vyatikian Horizon. In our opinion, since polymictic sands composing a lens in the marginal part of this locality are similar to sandstones of the Zhukov Member exposed in the Klyazma River basin (Golubev et al., 2012), there are all grounds to believe its Vyaznikian age.

Throughout the greater part of the rest of the Cis-Urals, deposits of the Vokhmian Horizon unconformable overlie the Vyatikian marls and, accordingly, the Vyaznikovian deposits are missing in fact. On the basis of their lithological properties, they can be conditionally distinguished in the Yug River basin near the village of Vakhnevo (well 457) (Lozovsky et al., 2014) and near the village of Oparino (Lozovsky and Kukhtinov, 2007).

The Nedubrovian deposits were first described as an independent lower member of the Vokhmian Formation (Lower Triassic) in the central part of the Moscow Syncline (village of Nedubrovo, left bank of the Kichmenga River, left tributary of the Yug River) (Lozovsky et al., 2001b, 2014). It was assumed that these deposits are younger than the Vyaznikovian deposits. This was confirmed by Afonin (2003) as a result of studying the Nedubrovian palynocomplex. Krassilov and Karasev (Karasev, 2009; Krassilov and Karasev, 2009) revealed the stratigraphic sequence of paleofloristic assemblages at the Permian–Triassic boundary: Vyatikian–Vyaznikovian–Nedubrovian–Vokhmian. Considering the fact that the Vyaznikovian Horizon and Nedubrovo Member occupy a similar stratigraphic position between faunistically characterized Late Permian Vyatikian and Early Triassic Vokhmian deposits and they are characterized by negative magnetization, we assume that these complexes are coeval. To solve this problem, let us discuss two main questions: (1) Are there in the Nedubrovo section analogs of the Vyaznikovian deposits, and (2) are there in the Zhukov ravine sequence analogs of the Nedubrovo Member? It is quite easy to answer the first question since the Nedubrovo Member directly overlies the Vyatikian marls without any signs of the Vyaznikovian deposits. In order to answer the second question, we should discuss in detail the paleontological characteristics of each of the strata under consideration.

THE CHARACTERISTICS OF FAUNISTICAL COMPLEXES OF PERMIAN–TRIASSIC BOUNDARY DEPOSITS

Terrestrial vertebrates. As noted above, terrestrial vertebrates from the terminal Permian deposits exposed near the town of Vyazniki were distinguished as a specific Vyaznikovian assemblage (Archosaurus rossicus Zone), which was described in detail in (Ivakhnenko et al., 1997; Ochev and Shishkin, 1998; Ivakhnenko, 2001; Sennikov and Golubev, 2008). This assemblage is represented in full volume in the locality Vyazniki-2, where *Dvinosaurus egregious* Shishkin, *Rhaphalodon* aff. *tverdochlebovae* Ivakhnenko, *Kotlasia* cf. *prima* Amalitzky, *Elginia* sp., *Bystrowiana per-*

mira Vjuschkov, *Uralerpeton tverdochlebovae* Golubev, *Archosaurus rossicus* Tatarinov, *Moschowhaisia vjuschkovi* Tatarinov, and *Dicynodon* sp. were described.

A more depleted but quite representative complex was described in deposits of the Zhukov ravine sequence (Sennikov and Golubev, 2010), where bivalves and fish remnants were collected (determinations by A.V. Minikh and M.G. Minikh): *Isadia aristovens* A. Minich, *Mutovinia sennikovi* A. Minich, *Strelnia* sp., *Saurichthys* sp., *Gnathorhiza* sp., *Evenkia* (?) sp. (Newell et al., 2010). Lozovsky found a tusk of *Dicynodon* sp. and the carapace of a Chronosuchid amphibian *Uralerpeton* (?) sp. (determinations by V.K. Golubev) in the sandy member of the Vyaznikovian deposits (settlement of Voskresenskoe) (*Granitsa...*, 1998; Lozovsky and Kukhtinov, 2007). A complete skull found in this locality by M.P. Arefiev was first identified as *Daptocephalus* sp. and reidentified later as a new genus and species *Delectosaurus arefievi* Kurkin by Kurkin (2001). Dicynodonts are common in fact in all localities of the Vyaznikovian Horizon (Vyazniki, Purly, Voskresenskoe, Zhukov ravine, etc.) and it is considered to be one of most essential elements of this horizon. Dicynodonts increase in number east of Voskresenskoe toward the Ural Mountains. This can be easily explained by the fact that this elevated area was favorable habitat area for these herbivores. In addition, it should be noted that all species of Vyaznikovian dicynodonts, including those from localities of Voskresenskoe and Berezhane described by A.A. Kurkin, are attributed to the general genus *Dicynodon* (Lucas, 2005), which characterizes the youngest biochron of the Permian (Platbergian),³ which has worldwide distribution.

Vertebrates were not found in deposits of the Nedubrovo Member. The correlation of basal conglomerates exposed in a ravine between the villages of Glebovo and Vaganovo and those in the Kichmenga River basin near the village of Kuzmino (Lozovsky et al., 2014) was not confirmed since the latter contain the typical Early Triassic (Vokhmian) vertebrate assemblage: tetrapods *Tupilakosaurus* sp. and *Vonhuenia* (?) sp., as well as unidentified remnants of reptilian and fish *Saurichthys* sp. and *Blomolepis* (?) sp. (Sennikov and Golubev, 2014). In our opinion, conglomerates in the Kuzmino locality should be correlated with basal Triassic conglomerates, overlying the Nedubrovo Member (village of Nedubrovo) (Lozovsky et al., 2014, Fig. 2).

The Astashikha Member is relatively depleted in vertebrate remnants. The lower part of the stratotype sequence near the village of Astashikha yielded incomplete skeleton of a dicynodont described as *Lystrosaurus georgi* by Kalandadze (1975). In addition, skull fragments of *Lystrosauridae* gen. indet. larger than that of *Lystrosaurus georgi* were found in this outcrop, but there is no exact stratigraphic position of

³ Corresponding to Vyaznikovian assemblage and Sokolki subassemblage (Ivakhnenko et al., 1997).

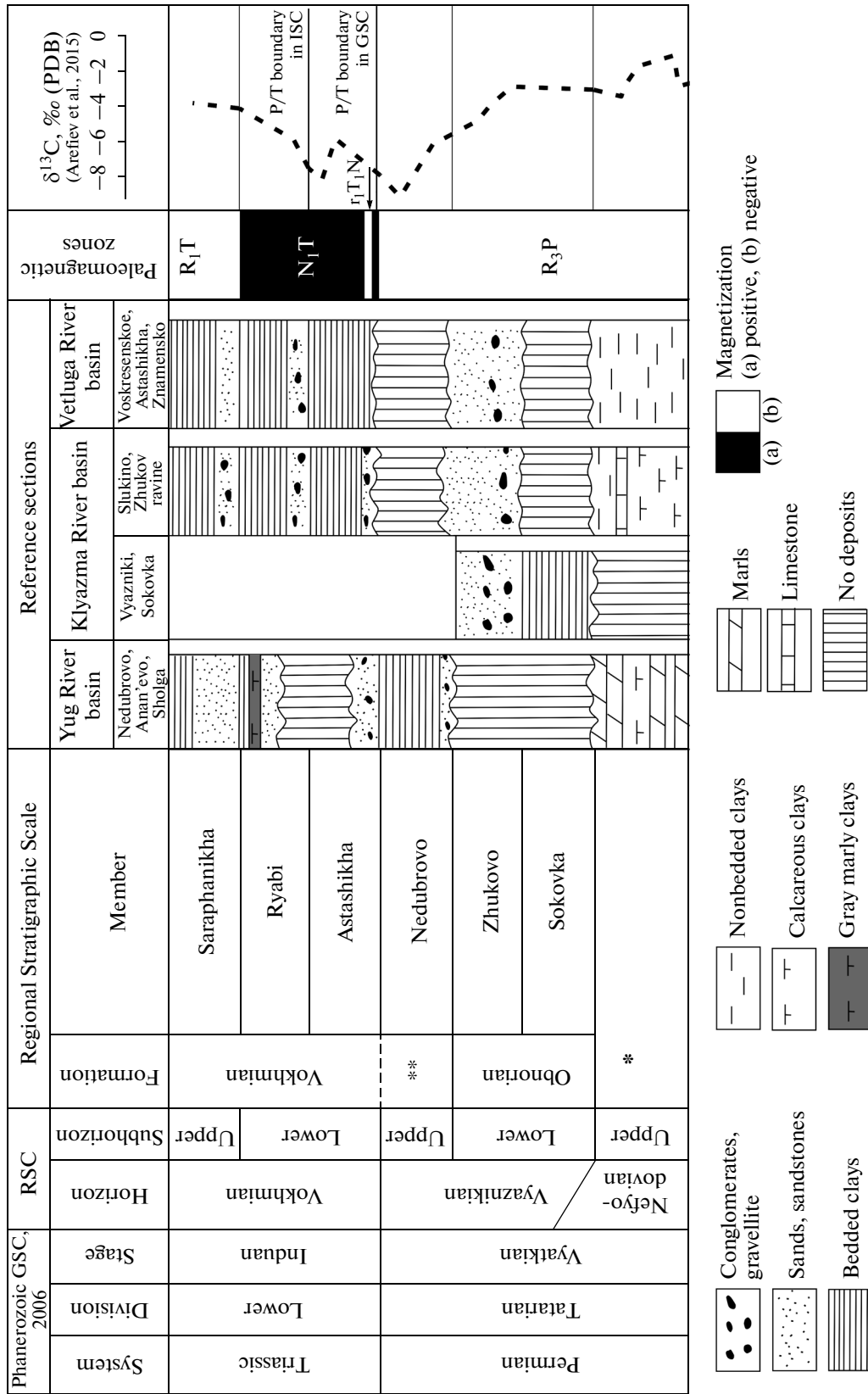


Fig. 2. Stratigraphic scheme of Permian–Triassic boundary deposits of the East European Platform. The vertical scale is arbitrary. (*) For different regions the local stratigraphic schemes are adopted: in the Yug River basin, this interval corresponds to the Salarevo Formation and Komaritsa Member; in the Vetluga River basin, to the Vyatkian Formation; in the Klyazma River basin, to the Obnorian Formation and Gorokhovets Member. (***) This interval was earlier included in the Vokhmian Formation (Lozovsky et al., 2001a); then, it was excluded from this formation and attributed to the Permian (Lozovsky et al., 2014). Abbreviations: GSC—General Stratigraphic Chart, RSC—Regional Stratigraphic Scale, ISC—International Stratigraphic Chart.

these findings (Sennikov and Novikov, 2011). Remnants of lystrosauruses, not determined to genus, were also found in the Astashikha Member in the Puchezh locality, Upper Volga River basin (Lozovsky and Zharkov, 1998; Sennikov and Novikov, 2011).

In connection with the prevailing opinion about the Triassic age of this genus (Lozovsky, 1983), the occurrence of remnants of lystrosauruses in deposits of the Astashikha Member was a reason to attribute this part of the sequence to the Lower Triassic.

The recent detailed studies showed that ancient lystrosauruses appeared at the end of Permian in South Africa (the uppermost part of the Balfour Formation) and northwestern China (Sinjian Province, Guodiken Formation), where they existed together with dicynodonts up to the Permian–Triassic boundary (Olson, 1989; Retallack et al., 2003; Smith and Botha, 2005; Ward et al., 2005; Botha and Smith, 2007; Metcalfe et al., 2009). As is now accepted, disappearance of the latter marks the Permian–Triassic boundary in continental deposits of these regions. It is likely that the first occurrence of the lystrosaurus in Eastern Europe was a bit later than in Gondwana (South Africa) and China, namely, in the Early Triassic.

The locality Zhukov ravine-2, an analog of the Astashikha Member in the Klyazma River basin yielded a tetrapod assemblage typical of *Tupilakosaurus* fauna: *Tupilakosaurus* sp., *Axitectum vjushkovi* Shishkin et Novikov, *Contritosaurus* sp., and *Proterosuchidae* gen. indet. (Sennikov and Golubev, 2014). The index element of the *Tupilakosaurus* fauna (genus *Tupilakosaurus* (*T.* sp.)) was described in the localities Kuzmino (see text above), Podsaraitsa, Sholga, and Fominovo in the Yug River basin, where country deposits are correlated with the Astashikha Member of the Vetluga River basin (Lozovsky et al., 2014).

The vertebrate assemblage from the Ryabi Member is attributed to the *Tupilakosaurus* fauna as well. Finds of *Tupilakosaurus* sp., *Contritosaurus* sp., and paleoniscoid fish *Blomolepis wetlugensis* were made in the basal beds of the Ryabi Member in outcrops near the villages of Znamenskoe and Shcherbachikha (Vetluga River basin) (Blom, 1968; Selezneva and Lozovsky, 1986). In addition, the Ryabi deposits in the upper part of the sequence near the village of Astashikha yielded remnants of *Tupilakosaurus* sp. and lystrosaurids, not determined to genus (Ochev, 1992; Sennikov and Novikov, 2011).

Finally, it should be said that significant changes occurred in the vertebrate fauna composition at the Permian–Triassic boundary (Ochev and Shishkin, 1998; Benton et al., 2004; etc.). The Triassic tetrapod assemblage (*Tupilakosaurus* fauna) from the basal beds of the Vokhmian Horizon of the East European Platform and its analogs in the Southern Cis-Urals are highly different, first of all, in systematic composition from the preceding late Vyatkian Vyazniki tetrapod assemblage ascribed to the terminal Permian. For both of these assemblages, there are only two generic reli-

ably determined assemblages (bystrowianids and proterosuchids) at probable absence of common genera.

Ostracods. Ostracods from the Nefyodovian Horizon of the Vyatkian Stage studied by I.I. Molostovskaya (*Stratotipicheskii...*, 2001; pp. 97–110) are attributed to the Wjatkellina fragilloides–Schonellina typica Zone. The Vyaznikovian ostracod assemblages occupy the intermediate position between Wjatkellina fragilloides–Schonellina typica and Darwinula mera–Gerdalia variabilis zones. The latter was identified by Mishina (1966) in Lower Triassic deposits of the Vokhmian Horizon. The Vyaznikovian ostracods assemblage was first studied by Kukhtinov in deposits of the Sokovka Member of the Vokhmian Horizon (Kukhtinov et al., 2008). As a whole, this quite diverse assemblage includes 93 species: 39 species of six Permian genera and 54 species of two Triassic genera (*Darwinula* and *Gerdalia*). Quantitatively, Permian genera, especially *Whipplella svijazhyca* (Sharapova), dominate over Triassic ones.

The somewhat depleted fossil assemblages in the Zhukovo Member were identified in two outcrops (nos. 1027 and 1013) of the sequence of the Zhukov ravine by D.A. Kukhtinov (Golubev et al., 2012). In general, this assemblage is similar to the above-described one and has 18 common species. The Zhukovo assemblage occupies the transitional position between Late Permian and Lower Triassic assemblages and is characterized by predominance of species of the genus *Volganella*. The ostracods assemblage from the Nedubrovo Member, also described by D.A. Kukhtinov, is likely younger and represented by species of the genus *Gerdalia* (*G. wetlugensis* Belous., *G. noinskyi* Belous., *G. longa* Belous., *G. triassiana* Belous., *G. rara* Belous., *G. clara* Misch., *G. rixosa* Misch.) and rare *Darwinula*. Deposits containing this assemblage belong to the Darwinula mera–Gerdalia variabilis Zone (Lozovsky et al., 2001a). Fossil-rich assemblages of this zone, represented by species of the genera *Darwinula* at a minor amount of *Gerdalia*, were described by Mishina (1966) in well cores of deposits of the Vokhmian Horizon (Kostroma oblast) and by D.A. Kukhtinov from the Astashikha Member of the same horizon (*Granitsa...*, 1998, p. 94).

Macroflora. The Late Permian flora widespread throughout the European Russia was called Tatarian on the basis of the dominating genus of peltaspermalean pteridosperms *Tatarina* in floristic assemblages (Meyen and Gomankov, 1986). Gomankov (2002) subdivided the Tatarian flora into three floristic assemblages (from bottom upward): Kotelnichi, Aleksandrovska, and Vokhmian. The Vokhmian floristic complex corresponds to the flourishing of the Tatarian flora and it is similar to the Vyaznikovian and Nedubrovoian complexes in its taxonomic composition. At the Vyaznikovian and partly Nedubrovoian levels, the predominance of peltaspermalean pteridosperms characteristic of the Tatarian flora of the East European Platform and Cis-Urals is preserved (Gomankov and Meyen, 1986). In 2005, the first data on the Vyazni-

kovian floristic assemblage (a new genus *Vjaznikopteris* Naugolnykh) and a few new species of genera typical of the Tatarian flora were published (Naugolnykh, 2005). Karasev and Krassilov (2007) studied in detail scale leaf shoots known in the Vyaznikovian floristic assemblage and attributed them to a new genus *Permophyllocladus* Krassilov et Karasev.

Dominants of the Vyaznikovian paleofloristic assemblage are leaves of the genus *Permophyllocladus* and species *Vjaznikopteris rigida* Naugolnykh. Leaves of *Tatarina conspicua* Gomankov et Meyen and *Aequistomia aequalis* Meyen, typical of the Vokhmian assemblage, are in a subordinate amount in the Vyaznikovian assemblage. In association with leaves of peltaspermalean pteridosperms, sphenopsid shoots of *Peltaspermum capitatum* Naugolnykh and numerous dispersed seeds were found. Leaves of *Sphenobaiera* sp. and seed-bearing organs of *Stiphorus ovatum* occur in single specimens; conifers are represented by fragments of leaves of *Ullmannia* cf. *frumentaria* and *Quadrocladus* sp. In the middle part of the plant-bearing lens is an interlayer with rather numerous shoots of horsetail *Neocalamites* cf. *mansfeldicus*, which, according to Naugolnykh (2006), are close to the Zechstein forms. The *Permophyllocladus* leaves are highly similar to leaves of the genus *Germaropteris* Kustatscher, Kerp et Van Konijnenburg-van Cittert from Upper Permian deposits of North Italy (Kustatscher et al., 2014). In addition, the Vyaznikovian assemblage is characterized by much evidence of intense interaction of parasitic arthropods with plants (Krassilov and Karasev, 2008).

In (Krassilov et al., 1999b), the first data on the complex of plant remnants from the Nedubrovo locality were published. According to these data, the Nedubrobian floristic assemblage contains species of the late Tatarian flora of the East European Platform (*Tatarina conspicua* S. Meyen, *Phylladoderma* (*Aequistomia*) *annulata* S. Meyen), as well as species of the European Zechstein (*Ullmannia* cf. *bronnii* Goepert, *Quadrocladus* cf. *solmsii* (Gothan et Nagathard) Schweitzer, etc.). Karasev (2009) described a new genus of peltaspermalean ovuliferous organs *Navipelta* Karasev, which are similar in their morphology to seed-bearing discoid peltasperms, but they are characterized by bilateral symmetry and an exaggerated development of the secretion system. Similar ovuliferous organs *Vetlugospermum rhombicum* Naugolnykh were described in deposits of the Anisimovo Member of the Vokhmian Formation (Spasskoe locality, Vetluga River) (Naugolnykh, 2012). At the Nedubrobian level, the Zechstein elements represented by leaves of *Quadrocladus solmsii* and *Ullmannia bronnii* and megaspores of *Otynisporites eotriassicus* and *O. tuberculatus* prevail. The Late Permian element of the Tatarian flora *T. conspicua* and leaves of the genus *Permophyllocladus*, typical of Vyatkian and Vyaznikovian deposits and close to the genus *Germaropteris*, common to the Permian of Western Europe, also play an important role.

Thus, Vyaznikovian and Nedubrobian assemblages include species typical of the Tatarian flora of the East European platform and Zechstein flora of Europe, as well as new species unique to these systems. Distinctive features of the Vyaznikovian complex are *Vjaznikopteris rigida* leaves; those of the Nedubrobian assemblage are *Navipelta resinifera* seed-bearing organs and *Otynisporites eotriassicus* and *Otynisporites tuberculatus* megaspores.

Karasev and Turnau (2014) studied the dispersed megaspores from the Ryabi Member of the Vokhmian Formation (Sholga locality). The taxonomic composition of the megaspore complex includes *Otynisporites* sp. cf., *O. eotriassicus* Fuglewicz and *O. tuberculatus* Fuglewicz, which were traced also in the underlying Nedubrovo Member. The rest of the megaspore species are represented by *Maexisporites pyramidalis* Fuglewicz, *Maexisporites grosstriletus* (Liu, Zhu et Ouyang) Karasev et Turnau, *Maexisporites meditectatus* Karasev et Turnau, *M. rugulaeferus* Karasev et Turnau, and *Otynisporites maculosus* Karasev et Turnau. In addition, such species as *Trileites* sp., *Bacutriteles* sp., *Hughesisporites* spp., and *Verrutriteles?* spp. were identified. Except for genera *Dijkstraia* and *Narkisporites* described in Middle Triassic deposits in Europe, this megaspore assemblage is represented by taxa characteristic of the upper part of *Otynisporites eotriassicus* Zone of the Baltic Formation in Poland (Marcinkiewicz et al., 2014). The predominance of residues of heterosporous plants in deposits and the increase in their taxonomic diversity in deposits of the Induan Stage are probably connected with the mass dissemination of spores identified in the study of the Permian–Triassic deposits of Greenland, Norway, and Pakistan (Hochuli et al., 2010; Hermann et al., 2012). The mass distribution of the spores is characteristic of the third phase of the change of plant successions, when the role of pteridosperms and conifers was significantly reduced, while an increase in the proportion of lycopsids took place (Schneebeil-Hermann et al., 2013).

Miospore complexes. According to the data from O.P. Yaroshenko, there is a difference in miospore assemblages in the Vyaznikovian and Nedubrobian deposits. The former contain the complex *Lueckisporites virkkiae*–*Scutasporites* cf. *unicus*, described by Afonin (2005) from the Sokovka area near Vyazniki. In addition, Sample 143/1-1 from this complex provided by M.P. Arefiev was studied by Yaroshenko. The assemblage is characterized by a significant role of pollen represented by bisaccate ribbed forms *Protohaploxylinus* sp., *P. latissimus* (Luber) Samoilovich, *P. perfectus* (Naumova) Samoilovich, and *P. samoilovichii* (Jans.) Hart and nonribbed forms *Alisporites* sp., *A. splendens* (Jizba) Foster, *Klausipollenites* sp., *K. schaubergeri* (Potonie et Klaus) Jansonius, *Platysaccus* sp., *Sulcatisporites* sp., and *Vitreisporites* sp.

The pollen of *Lunatisporites pellucidus* (Goubin) Balme and especially two taxa *Lueckisporites virkkiae* Potonie et Klaus and *Scutasporites* cf. *unicus* Klaus

plays a significant role in taeniate pollen of the Vyaznikovian palynocomplex. The pollen of these species and the genus *Lunatisporites* are considered typical of the Tatarian Stage (Gomankov, 2001). The monosaccate pollen of *Cordaites* sp., *Florinites* sp., and *Bascanisporites* sp. and ribbed pollen, like *Vittatina*, are represented by only a few specimens. Among spores, *Apiculatisporis* plays an insignificant role. Such species as *Calamospora* sp., *Osmundacidites* sp., *Retitriletes* sp., and *Limatulasporites fossulatus* (Balme) Helby et Foster are represented by only single specimens. In addition, there are finds of algae *Reduviasporonites* sp. and *Inaperturopollenites*. In general, the Permian age of the Vyaznikovian assemblage is quite reliable.

The stratotype of the Nedubrovo Member yields the assemblage of *Cycadopites* sp.—*Klausipollenites schaubergeri* (Lozovsky et al., 2001a; Afonin, 2001). The assemblage is characterized by a large amount of monocolpate pollen of *Cycadopites* (about 30%) and bisaccate pollen of *Klausipollenites schaubergeri* (about 25%) in paragenesis with bisaccate pollen of *Alisporites* sp., *Falcisporites zapfei* Potonie et Klaus, *F. nuthalensis* (Clarke) Balme, *Klausipollenites* sp., and *Platysaccus* sp.; in addition, it is characterized by a significant role of *Striatoabieites richteri* (Klaus) Hart, *Lunatisporites noviaulensis* (Leschik) Foster, *L. pellucidus* (Goubin) Helby, and *L. transversundatus* (Jans.) Fisher. However, the number of representatives of *Lueckisporites* and *Scutasporites* is markedly reduced in comparison with the assemblage from the Vyaznikovian Horizon. It is likely that numerous finds of pollen of *Cycadopites*, *Klausipollenites*, and *Ephedripites* in this assemblage are evidence of the progressive evolution of the pollen of these genera beginning from the more ancient Molomian Member of the Vyatkian Horizon. The pollen of *Ephedripites* is characterized by the appearance of *E. permasensis* Yaroshenko, described earlier in deposits of the Sarafanikha Member (Yaroshenko and Lozovsky, 1997).

In contrast to the above-described assemblages, this assemblage is characterized by the first occurrence of the following spores: *Densoisporites playfordii* (Balme) Dettmann, *Punctatisporites triassicus* Schulz, *Leptolepidites jonkeri* (Jans.) Yarosh. et Golub., *Proprisporites pocockii* Jans., *Pechorosporites disertus* Yarosh. et Golub., *Rewanispora foveolata* de Jersey, *Kraeuselisporites* sp., and *Lundbladispota* sp., which are characteristic mainly of the Lower Triassic. There are representatives of plankton organisms of *Reduviasporonites*, *Pilasporites*, and *Inaperturopollenites nebulosus* Balme. The Permian–Triassic deposits are characterized by the increase in the proportion of *Reduviasporonites*, previously regarded as the remains of fungi (a “mushroom episode”). Subsequently, it was reliably proved that they belong to the green algae (Krassilov et al., 1999a; Afonin et al., 2001). Finds of typical Zechstein pollen of *Klausipollenites schaubergeri*, *Lueckisporites virkkiae*, *Scutasporites* cf. *unicus*, and *Falcisporites zapfei* with abundant *Cycadop-*

ites in association with Early Triassic spores allow us to attribute the Nedubrovo microflora to the youngest Permian or Permian–Triassic transitional age.

There is no doubt that the Triassic assemblage of *Densoisporites complicatus*–*Ephedripites* spp. was identified in deposits of the middle and upper parts of the Astashikha Member opened by well 185 (depth 132 m) near the village of Okatovo, well 5 (depth 160 m) near the village Anyug of the Kologrivy district, and well 86 (int. 90–94 m) near the village Ryabinovtsy of the Pyshchug district of the Kostroma oblast, as well as from the Ryabi Member (exposure 42) on the right bank of the Yug River near the village of Sholga (Podosinovsky district, Vyatka oblast). This assemblage is characterized by more diverse miospore composition as compared to the above-described complex. This is caused significant development of cavate spores of *Densoisporites complicatus* Balme and *D. ex gr. complicatus*, the proportion of which in some spectra is over 20%. As shown above, the first occurrence of these spores was noted in deposits of the Molomian Member. Along with them, the following cavate spores appear: *Kraeuselisporites saeptatus* Balme, *Lundbladispota brevicula* Balme, *L. obsolete* Balme, *L. willmotti* Balme, *Pechorosporites* sp., *P. coronatus* Yarosh. et Golub., *Densoisporites nejbürgii* (Schulz) Balme, and *Aratrisporites* sp., as well as *Uvaesporites imperialis* (Jans.) Utting and representatives of *Campotriletes* spp. typical of the Triassic. There are also *D. playfordii*, *P. disertus*, *R. foveolata*, *Proprisporites pocockii*, *Leptolepidites jonkeri*, and *Crustaesporites globosus* Leschik, which occur in the complex of the Nedubrovo Member. In the pollen assemblage, the genus *Ephedripites* spp. prevails, reaching 30% in the individual spectra. There still existed bisaccate pollen represented by ribbed forms *Protohaploxylinus* spp., *Striatoabieites* sp., and *Striatopodocarpites* sp. and by nonribbed forms *Klausipollenites* sp., *K. schaubergeri*, *Platysaccus* sp., and others. The proportion of ribbed forms is somewhat lower than that of taeniate pollen of *L. noviaulensis*, *L. pellucidus*, *L. transversundatus*, and *L. hexagonalis*.

Despite the shift in the ratio of pollen in favor of the genus of *Lunatisporites*, the role of the Permian pollen (*Klausipollenites* and *Protohaploxylinus*) in this assemblage is still notable. This can be explained by the fact that pollen like *Protohaploxylinus* was also produced by Triassic conifers (Meyen, 1992). The Permian pollen (*Lueckisporites*, *Vittatina*, and *Cordaitina*) occurs as single specimens. A large proportion in this assemblage is represented by planktonic organisms: *Reduviasporonites chalastus*, *Inaperturopollenites nebulosus*, *Maculatasporites* sp., *Pilasporites*, and *Leiosphaeridia*.

Krassilov and Karasev (2009) showed that, at the Permian–Triassic boundary, changes in plant assemblages in the sequences of the Moscow Syncline were gradual. The study of palynological assemblages and mesofossils identified in Permian–Triassic sediments of Pakistan also showed that the change of vegetation in the Southern Hemisphere occurred gradually rather

than catastrophically (Hermann et al., 2010, 2012). For this region, it was proposed that there were four phases of changes of plant assemblages at the Permian–Triassic boundary (Schneebeli-Hermann et al., 2015) which can be traced in the Northern Hemisphere. The first phase (Late Permian) was characterized by the mass distribution of pteridosperms and conifers and was completed by a relatively short-term peak of spreading of spore plants. At the territory of the Moscow Syncline, this peak corresponds to the flourishing of the Tatarian flora and ends at the first spore peak, which appears to be reflected in the palynological spectra and megaspore assemblage from the Eleonora locality (the lower part of the Vyaznikovian Horizon) (Arefiev and Yaroshenko, 2015). The second phase was characterized by a change in the taxonomic composition and a gradual reduction in the diversity of gymnosperms. In the Northern Hemisphere, the second phase is likely reflected in the compositions of the Vyaznikovian and Nedubrovian floristic assemblages. The third phase is characterized by a significant reduction in the proportion of pteridosperms and conifers against the background of an increasing share of lycopsid plants. This phase is represented by a diverse megaspore complex of lycopsids of the Ryabi Member in the Sholga locality and is also well identified in the palynological spectra. The fourth phase is characterized by the mass predominance of spore plants. In the Northern Hemisphere, it corresponds to the mass distribution of lycopsids of the genus *Pleuromeia* in deposits of the Rybinsk Horizon (Dobruskina, 1982).

Entomofauna. To date, considerable efforts have been made to study the insect remains from sequences whose age is close to the Permian–Triassic boundary. As a result, the collective monograph describing 112 families (28 new genera and 111 species) was published (Aristov et al., 2013). According to the analysis of the insect fauna, the age of the group of Vyazniki sequences is defined as the terminal Permian, while the Nedubrovo locality was assigned to the group of transitional Permian–Triassic sequences. The latter also includes sequences in intertrap formations of the Tunguska basin and the sequence Babii Kamien in the Kuzbass. Recently, a study of new finds of remnants of beetles from the Nedubrovo sequence was completed (Ponomarenko, 2015).

To analyze the changes in insect diversity, a new method was proposed (Rasnitsyn et al., 2013). This method can be used to distinguish sequences varying in the age from Middle Permian to Lower Triassic. Owing to this, 115 families of insects from 15 local complexes in Europe, Asia, Australia, and South Africa were reviewed. It was established that, by the end of Vyatkian time, the morphology of the insect fauna became clearly post-Paleozoic and the variety of insects in Vyatkian time was reduced by half. If we consider transitional families existing before and after the time period when they were absent, then one can

make a conclusion that there was no mass extinction of insects at the Permian–Triassic boundary and in the Early Triassic. The stratigraphic positions of the Vyazniki and Nedubrovo localities in the sequence remains the same: the former belongs to the terminal Permian, and the latter falls in the group of transitional Permian–Triassic sequences.

Collection of insect remnants from the group of the Vyazniki localities is about 220 specimens belonging to 11 orders: Thripida (Lophyoneurida), Neuroptera, Panorpida, Homoptera, Paleomanteida, Coleoptera, Trichoptera, Blattida, Grylloblattida, Orthoptera, and Forficulida (Protelytroptera). Cockroaches dominate (65% of insect remnants); leafhoppers and grylloblattidae (17 and 8%, respectively) are in subordinate amounts. Remains of beetles described in the Vyazniki localities are from the following families: Asiocoleidae (*Tetracoleus sennikovi*), Rhombocoleidae (*Erunakiceps angustus*), Schizocoleidae (*Uscatocoleus rhynchophorus*, *U. eurypygus*, *Pseudochrysomelites major*, *Metrohrhynchites baculum*, *M. elongatus*), and Permosynidae (*Hydrobiites tillyardi*, *H. vladimiri*, *Permosynelata*, *P. tillyardi*) (Ponomarenko, 2011). The first remnants of beetles found in these localities were attributed to the family of the formal Permosynidae, representatives of which, unlike the rest of the Permian beetles, have elytra with narrow grooves. This structure is typical of most of the elytra of modern beetles. In European Russia, these beetles were also found in the upper Vyatkian Aristovo locality (Ponomarenko, 2003) and in Nedubrovo (Ponomarenko, 2015). They do not occur in known Lower Triassic sequences, but they appear again as rare forms beginning in the Anisian and become common in the Carnian and Norian. For the first time, such elytrons were described from the Belmont locality (terminal Permian, Newcastle series; Australia; Tillyard, 1924), where permosynids dominates among beetles. They are especially abundant in the Babii Kamien locality (Mal'tseva Formation, Kuzbass). There are two different opinions on the age of this locality: Early Triassic and Late Triassic. Some researchers draw the Permian–Triassic boundary inside the sequence of this location. Owing to the lack of finds of permosynids in the Early Triassic deposits, the Permian age of this locality is preferable. Permosynids in Erunakian deposits of Kuzbass are less abundant (Rodendorf, 1961). The most ancient representatives of permosynids were found in the Ipina Formation (South China). These deposits were earlier attributed to the Wuchiapingian, but now they are ascribed to the end of the Middle Permian (Lin et al., 2010). Permosynids rapidly spread widely through all areas where Late Permian beetles were found. In addition to these localities, they were found in the Normandy Formation (South Africa) and the Yaman-Us locality (Southern Mongolia).

The formal family Schizocoleidae was proposed for elytra of Permian beetles with a smooth surface and characteristic short longitudinal schiza along the outer

margin. Some modern water beetles have on this place a ventrite, which links the elytra with the abdomen to trap air bubbles. This structure is not always visible on the outer elytral surface; therefore, smooth elytra without it are attributed to this family. Schizocoleids from the Vyaznikovian Horizon are very diverse. Here, there is also a typical Permian *Uscatocoleus* and *Pseudohydrophilites* typical of depleted Early Triassic localities, as well as *Metryorhynchus*, whose the first occurrence is noted in the Middle Triassic.

The occurrence of rhombocoleids is quite unexpected, since they are characteristic of the Urzhumian and Severodvinian sequences, but they were not found in other Vyatkian localities. On the contrary, the occurrence of *Aziokoleida* is quite expected. The genus *Tetracoleus* found in Vyaznikovian deposits was previously described in Anisian deposits of the Northern Urals. Unidentified species of this genus occur in the Aristovo locality; a similar elytron was found in Belmont.

The Vyaznikovian deposits yielded Palaeomanteida *Balymotikha deterior* Aristov et Rasnitsyn; scorpionflies *Nedubrovia deformis*, *Paranedubrovia novokshonovi*, *P. minutissima*, and *Mesopsyche incompleta* (Bashkuev, 2011); caddisflies *Cladochoristella ryzhkova* and *Prorhyacophila rasnitsyni* Aristov et Sukatshева; and Grylloblattidae *Chauliodites afonini* Aristov and *Klyazmia karasevi* Aristov. Analysis of the entomofauna from the Vyaznikovian deposits shows that it is almost predominantly of Permian age.

The Nedubrovo Member contain both Permian and Triassic species. The collection studied contains about 200 specimens. Representatives of eight orders of insects were found: Psocoptera, Hemiptera, Palaeomanteida, Coleoptera, Panorpida, Blattida, Grylloblattida, and Orthoptera. Hemiptera (25%) and Blattida (21%) dominate; Grylloblattida (17%) and Panorpida and Coleoptera (14% each) are in subordinate amounts. Psocoptera, Palaeomanteida, and Orthoptera are rare. In total, about 20 families were identified. The analysis of insect families belonging to the Permian–Triassic boundary confirmed the transitional nature of this assemblage of insects (Rasnitsyn et al., 2013).

Along with the Nedubrovo locality, this group of localities of transitional flora includes a few localities from intertrap deposits of the Tunguska basin and the well-known Babii Kamiien locality (Kuznetsk Basin). Recently, palaeoentomologists at the Paleontological Institute of the Russian Academy of Sciences have assumed the Permian age of deposits at these localities. Evaluation of localities of the transitive complex is very difficult because of the almost complete absence of finds of insect remnants in the Lower Triassic. There are only three Lower Triassic localities: Yontala (Anan'ino), Zalazna, and Tikhvinskoe; they yielded a minor number of remnants.

The Nedubrovian deposits yielded beetles *Proterocupes nedubrovensis*, *P. major*, *Artematopodites lozovskii*, *Dinoharpasus latus*, *Tetracoleus golubevi*, *Uscatocoleus*

hirsutus, *U. minor*, *U. artus*, *Pseudochrysomelites latissimus*, *P. convexus*, and *P. circumflexus* (Ponomarenko, 2015). In addition, scorpionfly *Nedubrovia mostovskii* was detected, which was described as *Mesopanorpodus* in (Novokshonov et al., 2004). Along with the Nedubrovian deposits, this genus was described in Severodvinian deposits (Isady) and intertrappean Tunguska deposits (Bashkuev, 2011). Also, Grylloblattidae *Chauliodites kitshmendensis* Aristov, *Ch. nedubrovensis* Aristov (Chaulioditidae; Aristov, 2013), and *Protoblattogryllus nedubrovensis* Aristov (Blattogryllidae; Aristov, 2011) were found. The first family is common in Late Permian and Early Triassic localities; in the Tikhvinskoe and intertrap localities of the Tunguska Basin, only representatives of this family were described.

All the remains of beetles (Coleoptera) in the Nedubrovo Member are fragmented owing to their transport over a long distance. They are of a very small size (usually about 1 mm), which is typical of most beetles from the transitional localities. Because of this, they have to be studied under an electron microscope. The structural features of these beetles cannot be identified with confidence under a light microscope. In total, 21 remains out of 23 were studied; two remnants were represented by abdominal segments and were not determined. Beetle remains are represented by four families, five to six genera, and eight to nine species, that is, about 2.5 specimens on average per species. This indicates a rather low diversity of insects: lower than in the Permian, but apparently higher than in the Early Triassic. The proportions of families are as follows: Asiocoleidae 4%, Schizocoleidae 62%, Cupedidae 25%, and Permosynidae 9%. All these families were found in Vyatkian sequences. Sequences of the Lower Triassic deposits yielded only representatives of the formal family Schizocoleidae. Permosynidae, which dominated in the upper Vyatkian localities, occupy the penultimate position in the Nedubrovo locality. Thus, beetles from the Nedubrovo locality resemble in most features Permian species, but along with this, there are several Early Triassic features: a smaller size, a greater number of schizophoroid beetles, and a lesser number of permosynids. The most common genus is *Pseudochrysomelites*, characteristic of the Early Triassic.

A comparative study of insects of these two stratons allows the following conclusions: (1) the Vyaznikovian and Nedubrovian types of entomofauna significantly differ in taxonomic composition; (2) the Nedubrovian assemblage is closer to the Triassic assemblages than to the Vyaznikovian assemblage and has transitional Permian–Triassic character; (3) there is a high diversity of families of beetles in the Permian, but not in the Lower Triassic; only in the Middle Triassic did beetles become more diverse.

There are no insect remnants in deposits of the Astashikha and Ryabi members, which can be explained by the change in burial conditions after the global Permian–Triassic crisis (Lozovsky, 2013). They

were identified by Sukacheva in the Sarafanikha Member (Yontala locality, Yug River), including an incomplete wing of the grylloblattid *Yontala camura* Aristov (Aristov, 2005). According to the general appearance of nervuration, this species is similar to representatives of the family Chaulioditidae, but the grylloblattid from the same location has a feature which is not characteristic of other species of this family. Because of this, it was not included in the general description of the family. In addition, we found a cockroach wing and five remnants of poorly preserved beetles belonging to the same species. The beetles are quite large, up to 5 mm long; elytra are smooth, 3–4 mm long. Similar beetles, probably of the same species, were identified in the Eksinian Formation of the Anakit locality, the Siberian Platform (Lozovsky et al., 2014).

PETROMAGNETISM

Deposits of the Vyatkian Stage are characterized of relatively low magnetic properties: the average magnetic susceptibility value (χ_{av}) in deposits of the Glebovo ravine is 57×10^{-5} SI units, the natural remanent magnetization (NRM) value (J_{nav}) is 7.3×10^{-3} A/m.

The paleomagnetic properties of the Vyaznikovian deposits were studied by Yu.P. Balabanov in three sections. The lower part of these deposits—Sokovsky Member—in an outcrop near the village of Sokovka is characterized by the following values: $\chi_{av} = 23.1 \times 10^{-5}$ SI units and $J_{nav} = 2.88 \times 10^{-3}$ A/m. The overlying Zhukovo Member composed of sandy alluvium deposits of the riverbed facies with thin red clay intercalations in an outcrop near the town of Vyazniki have similar ferromagnetic properties: $\chi_{av} = 28.6 \times 10^{-5}$ SI units and $J_{nav} = 4.5 \times 10^{-3}$ A/m.

According to Golubev and Sennikov (2015), the deposits of the Zhukovo Member (Zhukov ravine) comprise a sandy lens with inclusions of thin red clay intercalations resembling clays in the Vyazniki locality. They are characterized by the following parameters: $\chi_{av} = 25.1 \times 10^{-5}$ SI units and $J_{nav} = 6.84 \times 10^{-3}$ A/m.

As follows from the above, the two members of the Vyaznikovian Horizon cropping out in all three sections (Vyazniki, Sokovka, and Zhukov ravine) are characterized by approximately the same magnetic susceptibility and NRM values.

The transition to deposits of the Nedubrovo Member is expressed in a sharp increase in these parameters. This is most clearly displayed in the basal layers of the member represented by dark red ferruginous sandstone: the magnetic susceptibility value varies from 118×10^{-5} to 812×10^{-5} SI units, averaging 360×10^{-5} SI units; the NRM value varies from 27.5×10^{-3} A/m to 238.1×10^{-3} A/m, averaging 133.8×10^{-3} A/m (Murav'ev and Balabanov, 2009). Consequently, the Nedubrovo deposits compared to the Vyaznikovian ones are characterized by an order of magnitude higher magnetic susceptibility and NRM values. It should also be noted that the

deposits of the uppermost part of the Vyatkian Stage of the Vyaznikovian Horizon and the Nedubrovo Member are negatively magnetized and they are attributed to Zone R₃P.

According to paleomagnetic data, the magnetization in Lower Triassic basal beds overlapping the Nedubrovo Member is reversed. Accordingly, these deposits are attributed to Zone NIT1. The paleomagnetic properties of deposits of the Astashikha Member were studied in outcrops near the villages of Astashikha, Znamenskoe, Scherbachikhinskoe, and Voskresenskoe.

In general, the Astashikha Member is characterized by relatively higher magnetic properties: the magnetic susceptibility varies from 13.5×10^{-5} to 140.8×10^{-5} SI units, averaging 75.4×10^{-5} SI units; the NRM value varies from 2.5×10^{-3} to 83.0×10^{-3} A/m, averaging 45.2×10^{-3} A/m. However, these values are significantly lower than those in the Nedubrovo Member. In an outcrop near the village of Astashikha, a thin interval of deposits with negative magnetization attributed to Subzone rNIT1 within Zone NIT1 was revealed. The overlying deposits of the Ryabi Member are also characterized by positive magnetization and are attributed to the same Zone NIT1. The deposits of the Sarafanikha Member are characterized by the change in magnetization sign and they are assigned to Zone RIT1. The similar paleomagnetic section of Triassic deposits near the village of Slukino (area of the Zhukov ravine) was compiled by Balabanov (Fig. 2).

Thus, an increase in magnetic susceptibility and NRM values from the Vyatkian and Vyaznikovian to Nedubrovo deposits is observed; at the same time, the paleomagnetic parameters in the latter reach maximum values, whereas the basal layers of the Triassic deposits (Astashikha Member) are characterized by the decrease in paleomagnetic parameters.

WHERE TO DRAW

THE PERMIAN–TRIASSIC BOUNDARY?

The Triassic system was established by F.A. von Alberti in 1834 in continental deposits of the German Basin (Alberti, 1834). Its lower boundary was drawn between the lower variegated sandstone (Buntsandstein) and Bröckelshiefer. According to the modern stratigraphic scheme of Germany, it corresponds to the boundary between Calvörde and Fulda formations. Later, it turned out that it was impossible to use the German scheme for the Tethys, where exclusively Triassic marine facies are developed. For a long time, the Permian–Triassic boundary in marine sediments in the Tethys area and beyond was drawn on the basis of the first occurrence of the ammonoid genus *Otoceras* (Mojsisovics et al, 1895; Tozer, 1967, 1972; etc.).

The history of this issue is described in detail in a number of papers (Tozer, 1967; Shevyrev and Lozovsky, 1998; etc.). Later, conodonts began to play a leading role in studying the stratigraphy of the Paleozoic and Early Mesozoic. The International Strati-

graphic Commission recently approved the decision to draw the Permian–Triassic boundary at the base of Bed 27 in the Meishan sequence (South China), where the first occurrence of conodonts *Hindeodus parvus* Kozur et Pjatakova was established (Yin et al., 2001). This decision was met with mixed reaction of the geological community. In particular, it was suggested that this decision contradicts the historical precedence rules (Karaulov and Lozovsky, 2002; Oleinikov and Gavrilov, 2008; etc.), as it became evident that the level selected in South China turned out to be above the lower boundary of the Triassic system according to Alberti's data (Kozur and Bachmann, 2005; Lozovsky, 2010).

The study of the carbon isotopic composition in the Permian–Triassic boundary beds in many regions worldwide showed there exists the C-isotope minimum near the adopted boundary (Korte and Kozur, 2010; etc.). Zakharov et al. (2014) found that the negative C isotope excursion is within the *Otoceras concavum* Zone, previously attributed in full volume to the Triassic (Tozer, 1967), in the Verkhoyansk sequences, as well as in other sequences of the Boreal Realm, where Permian and Triassic boundary layers are cropped out. This level, corresponding to the *Hindeodus parvus* Zone, lies in the sequences of both basins above the traditional Permian–Triassic boundary. This is clearly seen on the global correlation diagram of the Permian–Triassic boundary deposits based on carbon isotope and paleontological data (Zakharov et al., 2014, fig. 6). The traditional Permian–Triassic boundary is quite distinct and is drawn between formations or along the erosional surface in the case of unconformable overlying of Triassic deposits on underlying sediments (Arctic Canada, Kashmir). This level in the Meishan sequence lies between Beds 25 and 26: Bed 25 (white clay), commonly referred to as the ash bed, is sharply replaced by dark gray calcareous shales (black clay) of Bed 26. Ammonites *Otoceras* ? sp., *Hypophiceras* cf. *martini* Trumphy, *H. changxingense* Wang, *Metophiceras* sp., and *Pseudogastrioceras* sp. identified in these beds are evidence of the Early Triassic age of the enclosing deposits. This allows one to compare the enclosing deposits with the Greenland *Hypophiceras triviale* Zone and, therefore, to draw the traditional Permian–Triassic boundary in the Meishan section at the lower boundary of Bed 26. The most significant negative C isotope excursion was noted in Bed 25 immediately below the Permian–Triassic boundary (Takahashi et al., 2014). The data available on the paleomagnetic properties of Bed 25 are contradictory, but we assume that deposits of this bed have negative magnetization (Karaulov and Lozovsky, 2002), as evidenced in (*The Paleozoic-Mesozoic...*, 1996) and confirmed by the data obtained for the coeval Nedubrovo Member (see above).

Throughout the greater part of the Chinese platform, Bed 25 is absent and Bed 26 overlies Bed 24 (Yin et al., 2014, fig. 4, p. 5) This stratigraphic hiatus could

have resulted from the Late Permian regression. The sharp transitional boundary between the white clay and the black clay formations, which we consider as being the Permian–Triassic boundary, and the presence of the above-described stratigraphic hiatus make it impossible to find here a level of the global stratotype of the Permian–Triassic boundary which would satisfy all requirements (Remane et al., 1996). Similar problems are characteristic of all sections worldwide (Shevyrev and Lozovsky, 1998).

The most significant changes in the biota composition in the Moscow Syncline were revealed at the boundary between the Nedubrovo Member and the Vokhmian Horizon: the change of the magnetic field polarity and a distinct negative C isotope excursion just below this boundary (Arefiev et al., 2015) This allowed us to correlate the Nedubrovo Member with Bed 25 of the Meishan section. This may indicate that the Permian–Triassic boundary occupies the same position in both continental and marine deposits.

In order to avoid the existence of two different Triassic boundaries in the General Stratigraphic Scale of Russia and the International Stratigraphic Chart, we propose to use the experience of creating the regional stratigraphic scheme of Germany developed on the lithostratigraphic basis, where the Lower Triassic boundary is drawn on the lower boundary of the Calvörde Formation, lower than the Triassic lower boundary in the International Stratigraphic Chart (Manfred Menning, 2016, personal communication).

CONCLUSIONS

(1) Correlation of the most representative and well-reported sequences of Permian–Triassic boundary deposits shows that there is no unified sequence within the East European Platform where the continuous sequence of deposits at this boundary could be traced (Fig. 2). This can be explained by the complex history of tectonic movements of separates parts of the platform and the Uralian orogen structure at the Permian–Triassic boundary.

(2) The compiled summary section of the Permian–Triassic boundary deposits in the Moscow Syncline is as follows: Vyatkian deposits–Vyazniki Horizon, including Sokovka and Zhukovo members–Nedubrovo Member–Astashikha and Ryabi members of the Vokhmian Horizon.

(3) The Vyaznikovian Horizon and the Nedubrovo Member are separate stratigraphic units with individual paleontological (palynological and entomological) and petromagnetic features. At the same time, there is no doubt that Nedubrovian deposits are younger than Vyaznikovian ones.

(4) The accumulation of Vyaznikovian deposits was preceded by a hiatus, during which the territory of the Russian Plain experienced a short-term rise as a result of the uplift of the Ural Mountains. As a result, at the beginning of the Vyaznikovian time, erosional relief

formed with accumulation of depression and flood-plain oxbow facies (Sokovka Member) and then channel-flow deposits (Zhukovo Member). The Nedubrovo Member formed under specific conditions during the Permian–Triassic crisis. It was preserved in full volume only on the wing of the Sukhonsky shaft in the Kichmenga River basin.

(5) The paleontological, paleomagnetic, and C isotope data available on Permian–Triassic boundary deposits obtained in different regions of the world, including the Moscow Syncline, allow us to speak in favor of the Permian–Triassic boundary position at the base of Bed 26 in the Meishan section. The significant C isotope minimum revealed is considered to be a good marker for its establishment.

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