ISSN 0031-0301, Paleontological Journal, 2012, Vol. 46, No. 3, pp. 313–323. © Pleiades Publishing, Ltd., 2012.
Original Russian Text © A.G. Sennikov, V.K. Golubev, 2012, published in Paleontologicheskii Zhurnal, 2012, No. 3, pp. 88–89.

On the Faunal Verification of the Permo–Triassic Boundary in Continental Deposits of Eastern Europe: 1. Gorokhovets–Zhukov Ravine

A. G. Sennikov and V. K. Golubev

Borissiak Paleontological Institute, Russian Academy of Sciences, Profsoyuznaya ul. 123, Moscow, 117997 Russia
e-mail: sennikov@paleo.ru, vg@paleo.ru

Received June 02, 2011

Abstract—A reference section of the Permian and Triassic continental deposits of the Zhukov ravine near the town of Gorokhovets (Vladimir Region) is described and new tetrapod localities are characterized. The position of the Permian–Triassic boundary in this section is recognized and its faunal substantiation based on vertebrates is provided for the first time. The Zhukov ravine section is unique in the fact that it shows a thick stratigraphically continuous succession of the Permo–Triassic boundary beds, with three successive tetrapod zones: the terminal Permian *Chroniosuchus paradoxus* and *Archosaurus rossicus* zones and the Early Triassic *Tupilakosaurus wetlugensis* Zone.

Keywords: Permo–Triassic boundary, vertebrate fauna, ecological crisis, Eastern Europe, Zhukov ravine section.

DOI: 10.1134/S003103011203015X

INTRODUCTION

The global ecological crisis at the Paleozoic–Mesozoic boundary was most pronounced in the history of the Earth (Erwin, 2000; Benton, 2003). Mass extinctions were both in the sea and on land. However, the ecological crisis on the land is less completely understood. The revelation of causes and developmental course of the crisis requires the study of the most complete, continuous sections of boundary continental beds of the Permian and Triassic which are characterized by fossils in the beds both underlying and overlying the boundary. In the East Europe Platform, there are only a few presently known localities where the Permo–Triassic boundary beds (Vyatkian and Vokhmian regional stages) outcrop and are easy to examine. The overwhelming majority of these sections are poorly paleontologically characterized and many of them are stratigraphically incomplete because of intraformation erosion (*Granitsa permi i triasa* ..., 1998). A rare example of a stratigraphically continuous succession, with paleontologically evidenced Permo–Triassic boundary, is the Zhukov ravine section near the town of Gorokhovets in the Vladimir Region (Figs. 1, 2). This section was discovered and described for the first time by N.M. Sibirtsev at the end of the 19th century. Subsequently, it was repeatedly visited and investigated by many geologists and paleontologists and, in 1960, in the course of geological survey, it was described as the reference section of the central region of the Moscow Syneclise.

DESCRIPTION OF THE SECTION

The section is located in a large, deep, canyon-like ravine, which cuts the right bank of the Klyazma River between the villages of Arefino and Slukino, 1 km southwest of the town of Gorokhovets. Based on the material of geological studies of T.E. Gorbatkina and N.I. Strok, the following beds were recognized here upward in the section:

(1) Reddish brown clay and aleurite, with a sand interbed (about 1 m thick) in the upper part; 9–10 m of exposed thickness.

(2) Gray and yellowish gray, clumpy limestone, with traces of plant roots; 1.2–1.5 m thick.

(3) Reddish brown, grayish brown or spotty clay and aleurite, with a sand interbed (about 1.5 m thick) at the base and many marl interbeds (up to 1 m thick) in the middle part; 12 m thick.

(4) Yellowish and greenish gray, horizontal and oblique, polymineral sand layers. The lower boundary is uneven, erosive; 1–6 m thick.

(5) Reddish brown clay and aleurite, with marl and sand interbeds; 3–6 m thick.

(6) Gray, brownish gray, thick-layered, bituminous limestone, with many cavities of plant roots of *Radicites* cf. *sukhonensis*; 0.4–1.2 m thick.

(7) Reddish brown clay and aleurite; 4 m thick.

(8) Reddish and yellowish brown, obliquely bedded sand, with conglomerate interbeds with clayey shingles and gravel. The lower boundary is uneven, erosive;

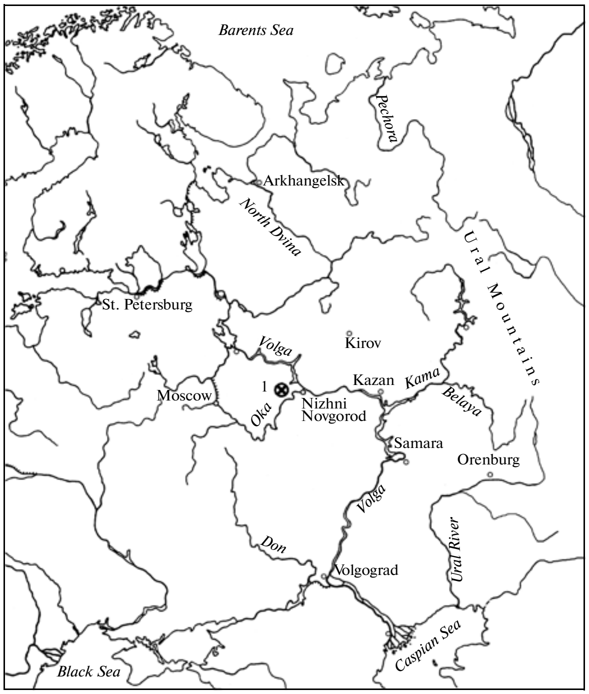

Fig. 1. Geographical position of the group of localities of Vyazniki and Gorokhovets–Zhukov ravine (1).

arranged in a lens (filling of a paleochannel), which cuts deep (up to 10 m) into underlying deposits; up to 11 m thick.

(9) Interbedding reddish brown clumpy clays and aleurites, with traces of plant roots (paleosol) and many sand interbeds (up to 2–3 m thick); up to 25 m of exposed thickness.

The deposits described are divided into two large members (Strok et al., 1984; Sennikov and Golubev, 2010). The lower member (Beds 1–7, 35–40 m thick) is composed of silty–clayey deposits, with marl and limestone layers and rare sand interbeds. The upper member (Beds 8 and 9, 35–40 m thick) begins with a system of large lenses of obliquely bedded sand of channel genesis, which cut into the underlying member, and is crowned by interbedding sand, clay, and aleurite with many paleosols.

BIOSTRATIGRAPHY

In sand lenses of the Zhukov ravine, Sibirtsev (1896) revealed remains of treelike plants, palaeoniscid scales, and "bones of lizards" and assigned the enclosing beds to the Upper Permian. This was based on the correlation with the regional scheme of Permian continental deposits developed by V.P. Amalitzky in the neighboring Nizhni Novgorod Region.

In the 1960s, as a result of geological survey in the Zhukov ravine section, the boundary between the Permian and Triassic was established in the basal layers of the thickest (11 m thick) sand lens (Bed 8), which is located at the base of the upper sandy–clayey member. This position of the boundary was evidenced by a shift in ostracode assemblages and paleomagnetic and lithogenetic data (beginning of a new sedimentation cycle). The Permian part of the section was referred to the Severodvinian Regional Stage (stage according to the modern General Stratigraphic Scale, accepted and used in Russia) based on ostracodes and geological data, and the Triassic part, to the Vokhmian Regional Stage. Thus, it was proposed that, in this region, a significant stratigraphic gap was at the Permian–Triassic boundary, which corresponds to the entire Vyatkian Stage (Strok et al., 1984).

Recent studies in the vicinity of Vyazniki and Gorokhovets contributed much to the improvement of the stratigraphic picture. The vertebrate fauna discovered by B.P. Vjushkov in the Vyazniki localities was dated terminal Permian (Late Vyatkian) (Ivakhnenko, 1990; Shishkin, 1990). Since 2003, Vyazniki has yielded fossil ostracodes, conchostracans, bivalves, insects, macroflora, and a palynological assemblage. The data on all groups have confirmed the terminal Permian age of enclosing beds (Sennikov and Golubev, 2006a, 2006b, 2007).

In 1999, in the northwestern part of the town of Gorokhovets (in the area of Gorodishchi), Sennikov discovered a new locality (Gorokhovets) with the Sokolki Vertebrate Assemblage (dated Late Vyatkian) (Sennikov et al., 2003). The section of this locality is easily correlated based on the marking upper limestone layer with the Zhukov ravine section, located 2 km southwest (Fig. 2). In the Gorokhovets locality, which contains Late Vyatkian ostracodes (Sennikov et al., 2002), this limestone is located 5–7 m above polymineral sands with fishes and tetrapods. Thus, Bed 4 in the Zhukov ravine section unequivocally corresponds to the bone bed of sand and conglomerates of the Gorokhovets locality with tetrapods of the Vyatkian *Chroniosuchus paradoxus* Zone.

As a result of reexamination of ostracodes, Molostovskaya (Newell et al., 2010) concluded that the lower clayey member of the Zhukov ravine section should be dated Vyatkian.

In 2001 and 2003, Sennikov, Golubev, and V.V. Bulanov found fossil fishes and unidentifiable tetrapods in conglomerate interbeds of a thick obliquely bedded sand lens (Bed 8) at the base of the upper sandy–clayey member of the Zhukov ravine section, which was previously dated Lower Triassic (Strok et al., 1984). In 2009 and 2010, Golubev and Sennikov found and collected in the same sand lens (Bed 8) many fragmentary specimens of tetrapods, including the brachyopoid labyrinthodont *Dvinosaurus* sp. (Figs. 3e, 3f), kotlassiomorph *Karpinskiosaurus secundus* (Amalitzky) (Figs. 3a–3d), chroniosuchid *Uralerpeton tverdochlebovae* Golubev (Fig. 4), a dicynodont

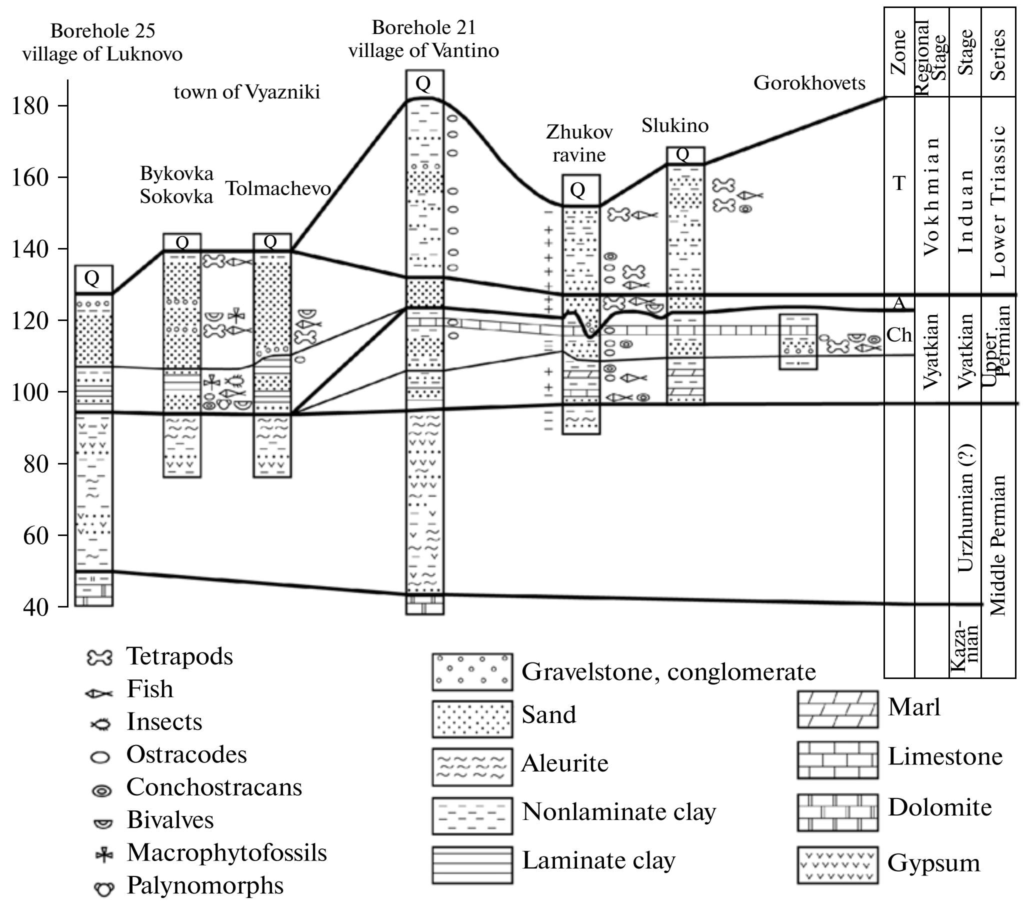

Fig. 2. Correlation of sections of the Permian–Triassic boundary beds in the vicinity of Vyazniki and Gorokhovets (after Strok et al., 1984, with changes and additions). Tetrapod zones: (*Ch*) *Chroniosuchus paradoxus* Zone, (*A*) *Archosaurus rossicus* Zone, and (*T*) *Tupilakosaurus wetlugensis* Zone.

of the subfamily Dicynodontinae (Figs. 5a, 5b), a therocephal close to *Moschowhaitsia* (Figs. 5c–5h), fishes, ostracodes, and bivalves (Golubev and Sennikov, 2010; Sennikov and Golubev, 2010). A.V. and M.G. Minikhs, who participated in 2009 in the study of the Zhukov ravine, determined these fishes as *Isadia aristoviensis* A. Minich, *Mutovinia sennikovi* A. Minich, *Strelnia* sp., *Saurichthys* sp., *Gnathorhiza* sp., and *Evenkia* (?) sp. (Newell et al., 2010). The underlying deposits (Beds 1, 3, 5, 6, 7) have yielded fishes, ostracodes, conchostracans, bivalves, and plants and the overlying deposits (Bed 9) contained undoubtedly Early Triassic (Vokhmian) tetrapods: the brachyopoid labyrinthodont *Tupilakosaurus* sp. (Figs. 6a, 6b), chroniosuchian Bystrowianidae gen. indet. (Figs. 6c, 6d), procolophone *Contritosaurus* sp. (Fig. 6e), small archaic diapsids (possibly eosuchians), the thecodont Proterosuchidae gen. indet., fishes, ostracodes, and conchostracans (Sennikov and Golubev, 2010).

In gullies near the village of Slukino, which is situated between the Zhukov ravine and Gorokhovets localities, two new localities of Early Triassic (Vokhmian) tetrapods, including *Contritosaurus* sp., *Tupilakosaurus* sp., and small archaic diapsids, were discovered. The bone beds in these gullies are composed of interbedding clays, aleurites, and sands with many paleosols. These deposits correspond to the upper (Triassic) part of the Zhukov ravine section and partially overlies it (Golubev and Sennikov, 2010).

New data on vertebrates refine the position of the Permo–Triassic boundary in the vicinity of Gorokhovets. In the Zhukov ravine section, this boundary passes within the upper sandy–clayey member, in the lower part of Bed 9, below interbedding clays and sands with paleosols, within a 4–5-m-thick segment of the section just above a thick layer of sandy channel lenses (Bed 8). Bed 4 should be referred to the upper part of the Vyatkian Regional Stage (*Chroniosuchus paradoxus* Tetrapod Zone). Beds 5–7 are tentatively referred to the same stratigraphic segment. Based on the data on vertebrates, Bed 8 is compared to the terminal Permian *Archosaurus rossicus* Tetrapod Zone, its tetrapod fauna is correlated with the Vyazniki Assemblage and the fish fauna with the *Gnathorhiza*

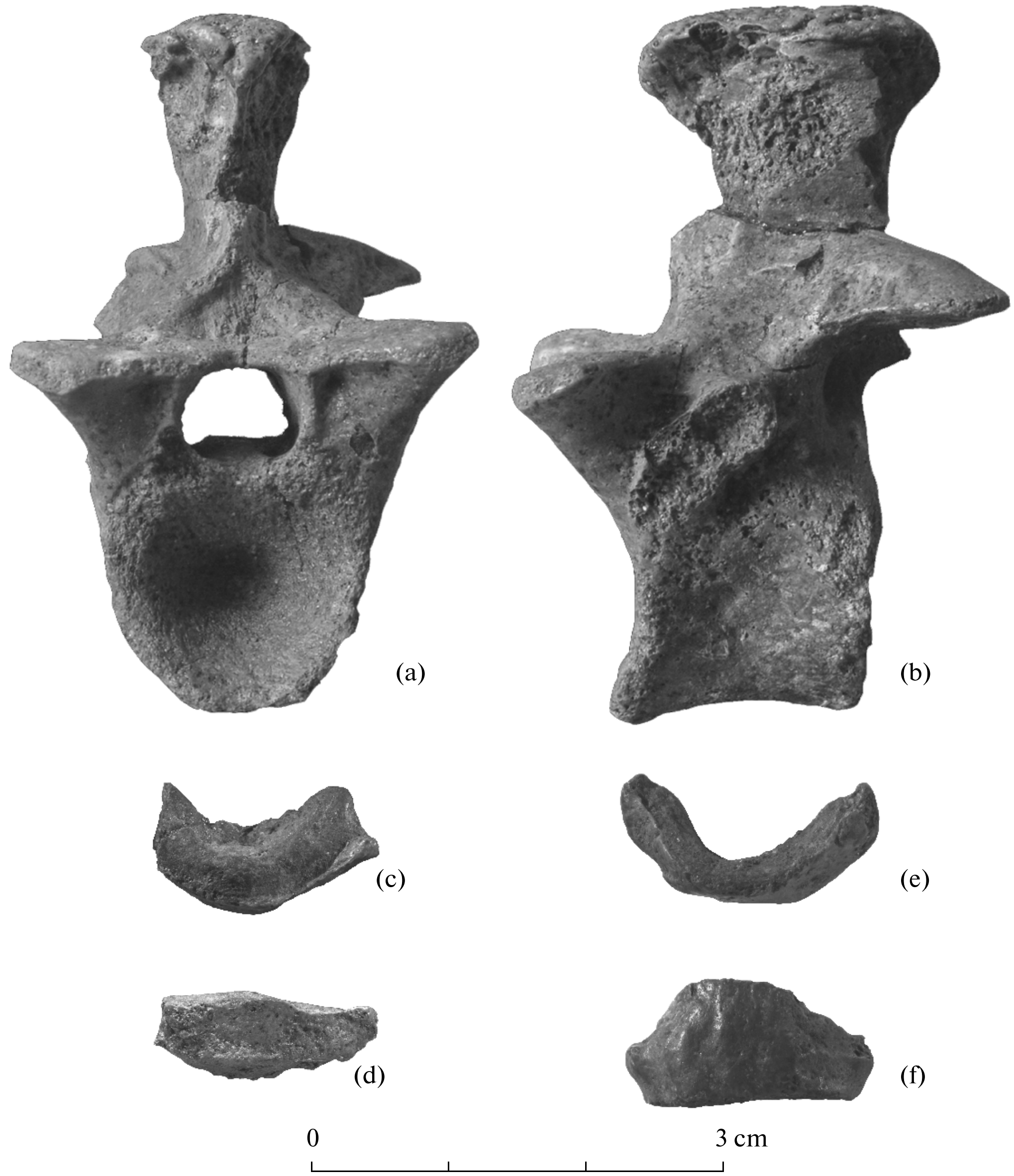

Fig. 3. Vertebrae of amphibians: (a–d) *Karpinskiosaurus secundus* (Amalitzky): (a, b) specimen PIN, no. 5350/3, dorsal vertebra: (a) anterior and (b) right lateral views; (c, d) specimen PIN, no. 5350/10, intercenter: (c) anterior and (d) ventral views; (e, f) *Dvinosaurus* sp., specimen PIN, no. 5350/9, intercenter: (e) anterior and (f) ventral views; Vladimir Region, Gorokhovetskii District, Zhukov Ovrag-1-A locality; Upper Permian, Vyatkian Stage, Upper Vyatkian Substage.

otschevi–Mutovinia sennikovi Assemblage (Minikh and Minikh, 2009). The basic part of Bed 9 is characterized by Early Triassic ostracodes and tetrapods (Spasskoe Assemblage) and corresponds to the Vokhmian Regional Stage of the Lower Triassic. The stratigraphical position of the lower part of Bed 9 remains uncertain.

Paleomagnetic characteristics confirm the assignment of the upper part of the Zhukov ravine section to the Vokhmian Regional Stage of the Lower Triassic. The zone of normal magnetization (N_1T) is recorded here based on the data of both E.A. Molostovsky (Strok et al., 1984) and the last studies of Yu.P. Balabanov, who participated in 2009 in the study of the Zhukov ravine (Minikh et al., 2011). The absence of distinct traces of a gap in sedimentation during the formation of the upper sandy–clayey member between terminal Permian Bed 8 and Lower Triassic (Vokhmian) Bed 9 suggests that it was formed by a single cycle of sedimentation (Strok et al., 1984; Sennikov and Golubev, 2011). All the above is evidence that the Triassic part of the Zhukov ravine section should be referred to the lowermost part of the Vokhmian Formation.

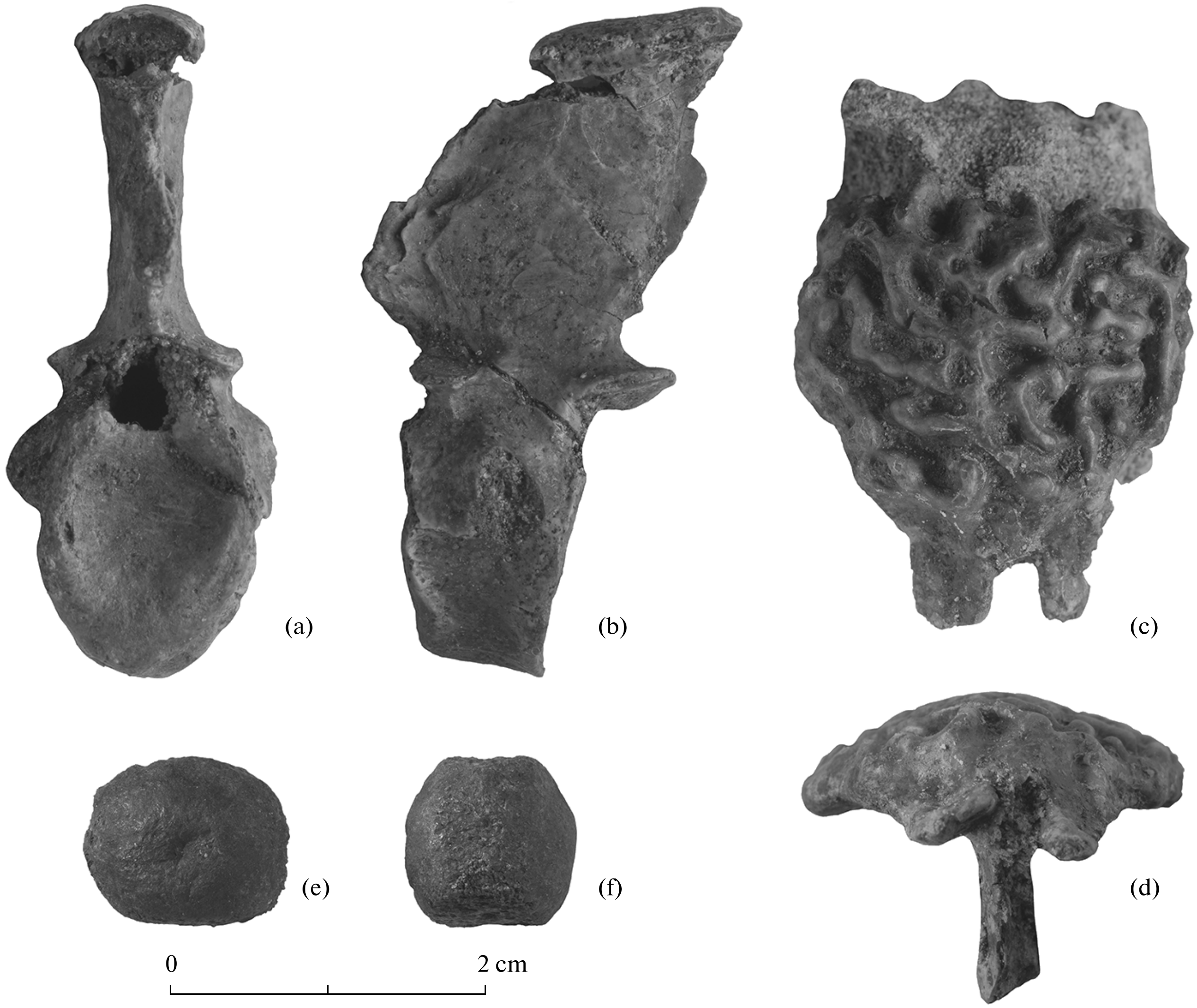

Fig. 4. *Uralerpeton tverdochlebovae* Golubev: (a, b) specimen PIN, no. 5350/16, anterior caudal vertebra: (a) anterior and (b) left lateral views; (c, d) specimen PIN, no. 5350/14, thoracic scute: (c) dorsal and (d) posterior views; (e, f) specimen PIN, no. 5350/4, intercenter: (e) anterior and (f) left lateral views; Vladimir Region, Gorokhovetskii District, Zhukov Ovrag-1-A locality; Upper Permian, Vyatkian Stage, Upper Vyatkian Substage.

TAPHONOMY OF TETRAPOD LOCALITIES

Upper Permian Localities

Vertebrates of the terminal Permian Vyazniki Assemblage are recorded in Bed 8 in the middle part of both slopes of the ravine. These localities are of fluvial (channel) genesis. The diverse biota, including plants, various abundant invertebrates, fishes, amphibians, and reptiles, some of which were relatively large, is evidence of favorable conditions for life in this region during the formation of localities. This could have been an extensive river lowland with a system of channels of constant and temporary streams alternating with sandy and marshy oozy banks and somewhat elevated areas.

In the section of the Zhukov Ovrag-1-A locality (right slope of the ravine), obliquely bedded channel sands and conglomerates of Bed 8 form a deep (at least 11 m) erosive incut reaching clays of Bed 5. A marking layer of gray limestones, underlying and overlying red clays (the upper part of Bed 5 and Beds 6 and 7) are eroded here and virtually absent. Apparently, the deepest channel line of the stream passed in the Vyazniki Time along the modern right slope of the ravine. In this locality, vertebrates are rare and extremely fragmentary. The lower bone-bearing level is at the base of the obliquely bedded sandy lens of Bed 8 in interbeds and lenses of clayey conglomerates, where isolated bones and scales of fishes, small rare mostly undeterminable bone fragments of tetrapods, and coprolites have been recorded. The upper bone-bearing level is located 6–8 m higher, in the upper part of Bed 8 in interbeds and lenses of clayey conglomerates, gravelstones, and sandstones or aleurites with clayey shingles and gravel. The nonuniform, fine-lenticular upper bone-bearing level is probably represented by deposits of shores and shoals of the channel, which were formed during extinction of stream activity. These deposits are distinguished by nonuniform and rhythmic structure, the presence of many lenticular interbeds (which were probably formed in individual channels and depressions produced by streams wandering on shoals), and thin silted interbeds, particularly well developed in marginal parts of lenses. The presence of deposits of different granulometric characteristics, ranging from aleurites to gravelstones and fine-pebble conglomerates, is evidence of unstable intensity of streams. In these channels and depressions on the bottom of shallow water bodies in the periods of increased floods and intensified water current, clayey conglomerates and gravelstones were accumulated and fossils were buried. Many bone remains were recorded at the boundaries of two layers differing in granulometric characters (for example, conglomerate and sand); this suggests that burials were connected with changes in current intensity (energy of stream). Abundant coprolites (Figs. 7b–7d) prevail here and are accompanied by isolated fish bones and scales and small isolated and fragmentary bones of tetrapods: vertebrae, teeth, bony scutes, and limb bones (Figs. 3–5). Before falling in the burial, vertebrate remains probably underwent maceration mostly under subaquatic conditions (which follows from the character of preservation of the bone surface and the fact that they are represented by isolated and fragmentary specimens) and, then, were rapidly buried without long transportation, since most of the specimens are nonrounded bones. Considerable variegation and changes in the color of enclosing rocks, particularly around coprolites and bones, are evidence that deposits contain abundant buried organic substance, including soft tissues of vertebrates, which were retained after incomplete maceration.

In the section of the Zhukov Ovrag-1-B locality (left slope of the ravine), Bed 8 is relatively thin (2–3 m thick), consists of interbedding conglomerates, sands, and sandstones with silty–clayey interbeds. The underlying beds (5, 6, and 7) are not cut; they are observed at the level of the lower and middle parts of Bed 8, which outcrops on the opposite slope of the ravine. Probably, in the Vyazniki Time, the modern left slope was a peripheral shore part of the same paleochannel, with a relatively weak current and insignificant erosion of underlying beds. This area is rich in coprolites (Fig. 7a); it has yielded isolated bones and scales of fishes and small isolated and fragmentary bones of tetrapods. An interesting example is a vertebra of *Karpinskiosaurus secundus* (Amalitzky) which was buried at the boundary between two layers with different granulometric parameters (conglomerate and clay) probably at the moment of the change in the intensity of current.

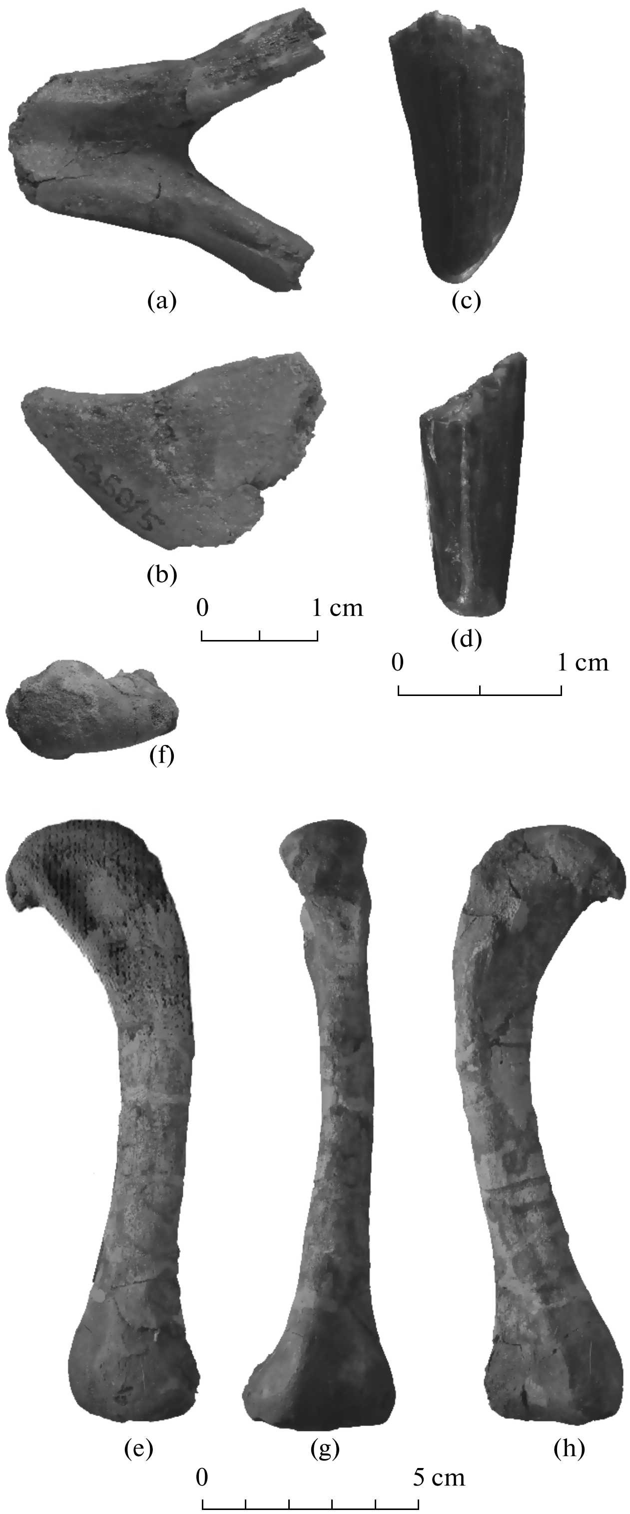

Fig. 5. Theromorpha: (a, b) Dicynodontinae gen. indet., specimen PIN, no. 5350/5, lower jaw symphysis: (a) dorsal and (b) left lateral views; (c–h) *Moschowhaitsia* (?) sp.: (c, d) specimen PIN, no. 5350/12, canine: (c) lateral and (d) posterior views; (e–h) specimen PIN, no. 5350/11, left femur: (e) dorsal (lateral), (f) proximal, (g) cranial, and (h) ventral (medial) sides; Vladimir Region, Gorokhovetskii District, Zhukov Ovrag-1-A locality; Upper Permian, Vyatkian Stage, Upper Vyatkian Substage.

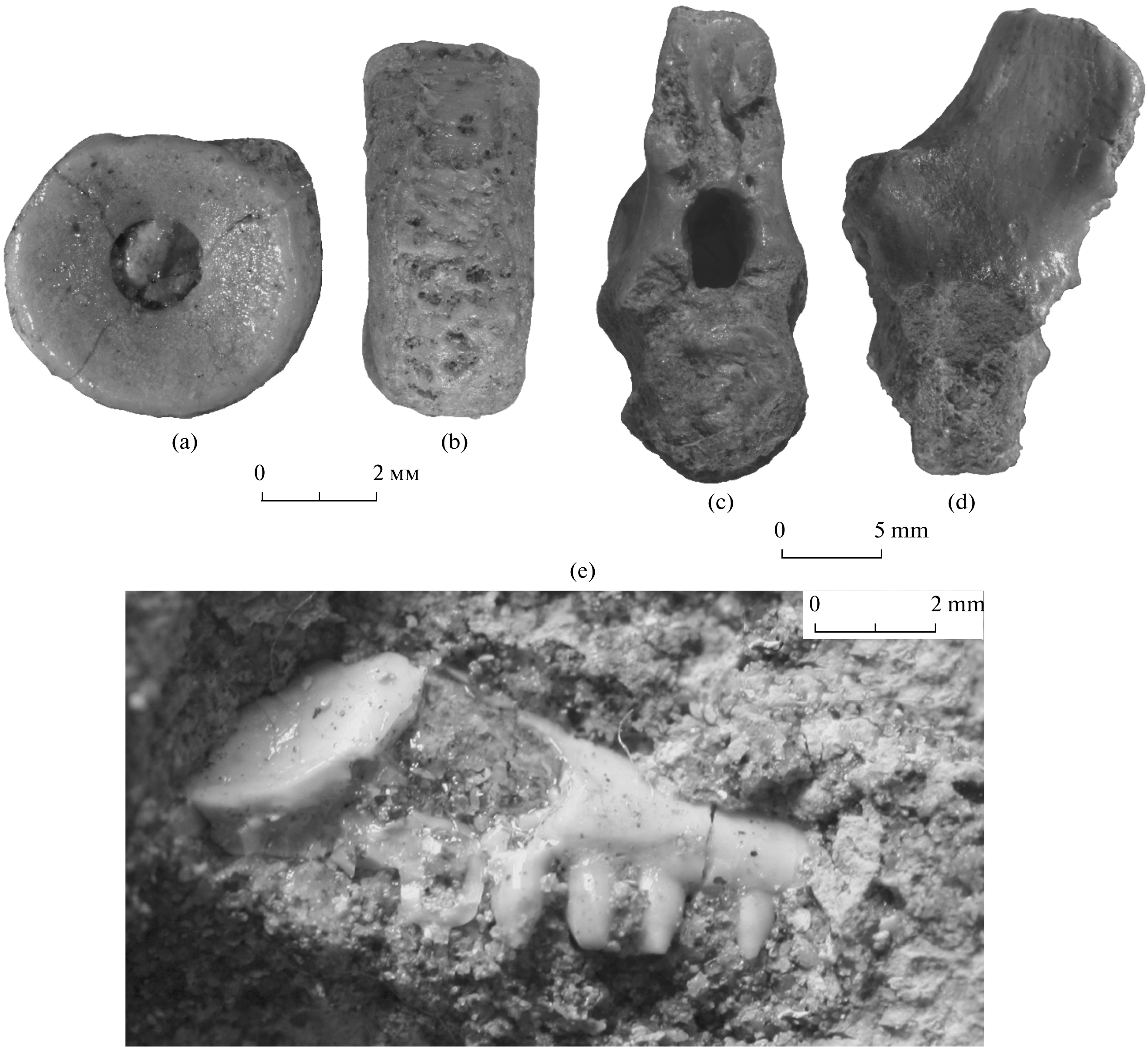

Fig. 6. Early Triassic vertebrates: (a, b) *Tupilakosaurus* sp.: (a) specimen PIN, no. 5351/4, vertebra, anterior view, (b) specimen PIN, no. 5351/3, vertebra, left lateral view; (c, d) Bystrowianidae gen. indet., specimen PIN, no. 5351/2, anterior caudal vertebra: (c) posterior and (d) left lateral views; Zhukov Ovrag-2 locality; (e) *Contritosaurus* sp., specimen PIN, no. 5352/1, left maxilla, lateral view; Vladimir Region, Gorokhovetskii District, Zhukov Ovrag-3 locality; Lower Triassic, Induan Stage, Vetlugian Regional Superstage, Vokhmian Regional Stage.

Lower Triassic Localities

Vertebrates of the Spasskoe (Vokhmian) Assemblage of the basal Triassic from Bed 9 occurred at several levels in the middle and upper parts of the Zhukov ravine (Zhukov Ovrag-2 and -3 localities) and in the Slukino and Staroe Slukino localities. All specimens are extremely small compared with specimens of the terminal Permian Vyazniki Assemblage (Bed 8). Lower Triassic localities have only yielded isolated bones and scales of fishes and small isolated and fragmentary bones of tetrapods (Fig. 6). The bone beds are recorded in both sandy gravelite and soil–silt interbeds. A different, rhythmic character of sand–siltstone–clayey interbedding deposits, the appearance of paleosols, and changes in the character of oryctocoenoses are evidence of shifts not only in the biota, but also in biotopes and conditions of fossil burials. These Early Triassic localities were formed on an alluvial lowland, probably periodically flooded plain, in the deposits of temporary streams, wandering channels, and temporary water bodies, where sandy gravel material was accumulated. The absence of well pronounced intense paleochannels is evidence that

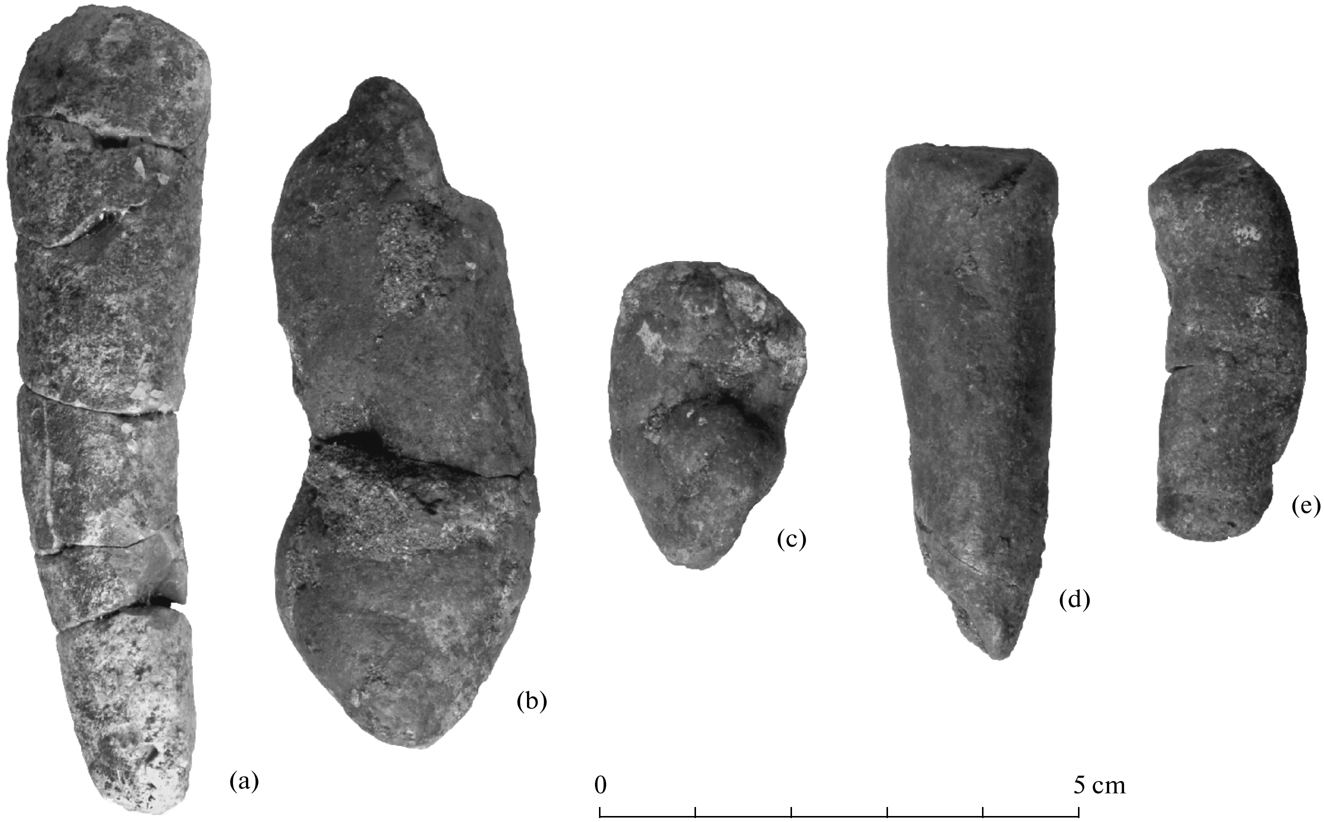

Fig. 7. Vertebrate coprolites: (a) specimen PIN, no. 5390/4, Zhukov Ovrag-1-B locality; (b–e) specimens PIN, nos. 5350/47, 48, 49, 50; Vladimir Region, Gorokhovetskii District, Zhukov Ovrag-1-A locality; Upper Permian, Vyatkian Stage, Upper Vyatkian Substage.

streams of that time were less regulated and wandering streams prevailed. However, as rather rarely occurred, fossil vertebrates were also buried in oozy deposits, which were subsequently transformed into clumpy aleurites of soil horizons. The insignificant roundness and generally random spatial orientation of bone remains are evidence of rather rapid and, in places, instantaneous deposition of the sedimentary material in depressions of the floodplain surface. Small amphibians and reptiles, with a slender skeleton, were rapidly macerated after death, transported for a short distance, and buried.

PALEOCOENOLOGY OF TETRAPODS

The oryctocoenoses of Zhukov Ovrag-1 are dominated by aquatic tetrapods (Fig. 8). Chroniosuchids and kotlassiomorphs prevail, therocephals are rather abundant, and dvinosaurs and dicynodonts are represented by a few specimens. A similar structure is characteristic of oryctocoenoses of the Poteryakha type (subtype B), developing in riverside and lacustrine biotopes unfavorable for large terrestrial tetrapods (Golubev, 2009). In the considerable prevalence of aquatic forms, this oryctocoenosis resembles a closely situated, but somewhat more ancient oryctocoenosis of Gorokhovets (Sennikov et al., 2003). This is evidence that, at the end of the Permian, conditions in tetrapod habitats near Gorokhovets remained almost constant during a significant part of the Late Vyatkian Time.

On the contrary, the Sokovka oryctocoenosis of the same age as Zhukov Ovrag-1 was dominated by dvinosaurs and dicynodonts, while chroniosuchids are rare (Fig. 8). In this and other oryctocoenoses located in the vicinity of Vyazniki, which is situated 40 km west of Gorokhovets (Vyazniki-1, Bykovka, Metallist, Yartsevo), kotlassiomorphs are very rare, although predators, including the earliest thecodonts and diverse therocephals, are rather abundant. Sokovka belongs to oryctocoenoses of the Sokolki type, which are characteristic of riverside and adjacent elevated biotopes.

In the Late Permian–Early Triassic, river flows were mostly directed from the east to the west (following the Recent cardinal points). Thus, presuming that the Vyazniki and Gorokhovets regions were situated in the same river valley (which is highly probable), the first was apparently located downstream from the second. Therefore, it is possible to assume that the Vyazniki region was at least in as lowland conditions as Gorokhovets. However, in Vyazniki ecosystems, terrestrial tetrapods played a significant role, suggesting

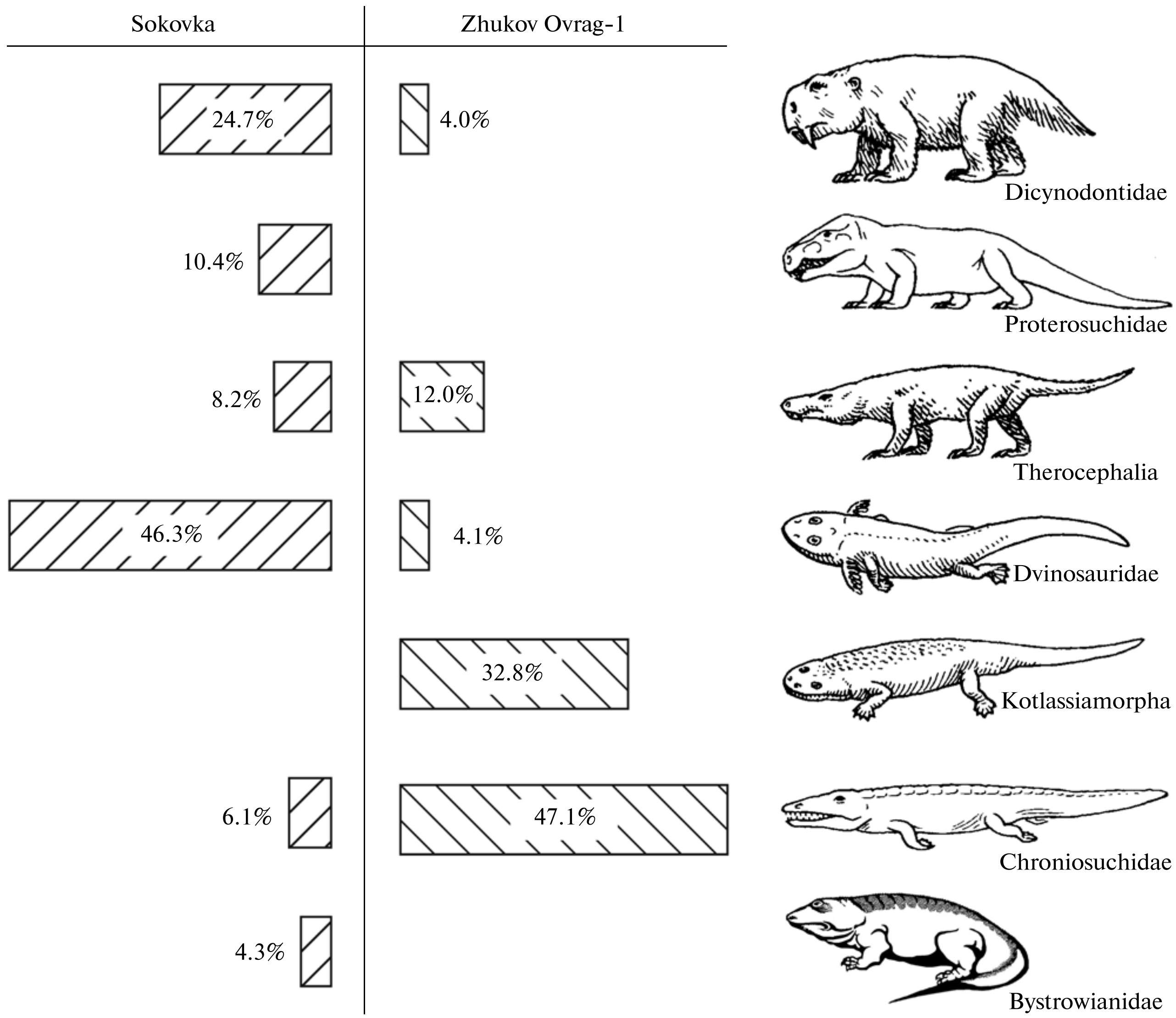

Fig. 8. Percentage of fossil specimens of different tetrapod groups in the Sokovka and Zhukov Ovrag-1 localities.

that respective ecotopes were less flooded. Apparently, Vyazniki was located in a marginal part of the river valley, with a more dissected terrain rather than in the central part, as Gorokhovets. In this area, lowlands alternated with rather extensive and relatively elevated sites suitable for large terrestrial tetrapods. During dry seasons, terrestrial tetrapods could have migrated from these "highlands" to drying rivers, where they formed rich thanatocenoses.

A distinctive feature of Early Triassic localities in the vicinity of Gorokhovets is abundant remains of relatively terrestrial tetrapods, including reptiles, the number of which is the same as, or, in places, greater than, the number of true aquatic tupilakosaurs. In all other localities with the Spasskoe Assamblage, particularly rich ones, where quantitative ratios of different groups are possible to estimate, tupilakosaurs strongly prevail and sometimes form monotaxon associations. The presence of many paleosols in the Lower Triassic beds is also evidence of significant changes in this region at the Permo–Triassic boundary. Both paleontological and lithogenetic data suggest that biotopes became less watered. These changes occurred within an extensive area, which, judging from geological data, expanded easterly at least to the Vetluga Basin, southerly to the right bank of the Oka River, and northerly to the town of Puchezh.

In general, the Spasskoe tupilakosaurian tetrapod assemblage is a typical postcrisis assemblage, which is characterized by a sharply impoverished taxonomic composition, the presence of extremely small, sometimes poorly specialized taxa. With reference to ecology, this means that the structure of continental communities at the beginning of the Triassic was considerably simplified; aquatic tetrapod communities included a single taxon (dominated by *Tupilakosau-*

rus), terrestrial communities had lost the dominant block, while the subdominant block was rather diverse.

CONCLUSIONS

The discovery of new Permian and Triassic vertebrate localities in the vicinity of Gorokhovets is of great significance for the faunal characteristics of the Permo–Triassic boundary in continental deposits. One more tetrapod locality (Vyazniki) has been discovered; it corresponds to the first stage of ecological crisis in tetrapod community at the Permo–Triassic boundary. Early Triassic localities with a Spasskoe (tupilakosaurian) vertebrate assemblage is recorded for the first time at the lower reaches of the Klyazma River. This suggests that both Vyazniki and Spasskoe tetrapod faunas had a wider distribution.

Gorokhovets displays an extremely rare section of European Russia where the position of the Permo–Triassic boundary was recognized based on different faunal groups (ostracodes, tetrapods, and fishes), and members of all groups are recorded here both below and above this boundary (in 2011, we discovered a similar section on the right bank of the Oka River in Nizhni Novgorod: Sennikov and Golubev, 2011a, 2011b). The Gorokhovets section is unique in the presence of a thick outcrop (about 70 m) accessible for direct investigation of Permo–Triassic boundary beds, with three successive tetrapod zones. In the Zhukov ravine section and neighboring Slukino and Gorokhovets sections, the beds with a terminal Permian Vyazniki vertebrate fauna (*Archosaurus rossicus* Zone) are underlain and overlain by sedimentary rocks with faunas of the *Chroniosuchus paradoxus* and *Tupilakosaurus wetlugensis* zones, respectively. These data strongly suggest that this section at the Permo–Triassic boundary is stratigraphically complete, without a trace of breaks in sedimentation, catastrophic shifts, or deterioration of natural conditions, for example, aridity.

Further examination of the reference section of the Permo–Triassic boundary beds in the vicinity of Vyazniki and Gorokhovets will provide an opportunity of modeling the ecological crisis on land at the Paleozoic–Mesozoic boundary in Eastern Europe. Important lines of future investigation are comparisons of East European sections of continental boundary beds of the Permian and Triassic and tetrapod faunas of that time with thoroughly investigated sections and faunas of South Africa and correlation with the global stratigraphic chart. This will reveal general and endemic features of changes in the continental biota during the global crisis on different continents and synchronism or asynchronism of these processes relative to each other and the marine biota.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research, project nos. 09-05-01009, 10-05-00611, 11-04-01055, 12-05-00262, and 12-05-00862; and the Program of Basic Research of the Presidium of the Russian Academy of Sciences no. 15 “The Origin of the Biosphere and Evolution of the Geobiological Systems,” Subprogram 2.

REFERENCES

Benton, M.J., *When Life Nearly Died: The Greatest Mass Extinction of All Time*, London: Thames and Hudson, 2003.

Erwin, D.H., *Extinction: How Life on Earth Nearly Ended 250 Million Years Ago*, Princeton: Princeton Univ. Press, 2000.

Golubev, V.K., Permian Terrestrial Vertebrates from the Southeastern Russian Plate, in *Verkhnii paleozoi Rossii: stratigrafiya i fatsial'nyi analiz. Materialy Vtoroi Vserossiiskoi konferentsii, posvyashchennoi 175-letiyu so dnya rozhdeniya Nikolaya Alekseevicha Golovkinskogo (1834–1897) (Kazan', 27–30 sentyabrya 2009 g.)* (Second All-Russia Conference Dedicated to the 175th Anniversary of the Birthday of Nikolai Alekseevich Golovkinskii (1834–1897): The Upper Paleozoic of Russia: Stratigraphy and Facies Analysis, Kazan, September 27–30, 2009), Kazan: Kazan. Gos. Univ., 2009, pp. 174–175.

Golubev, V.K. and Sennikov, A.G., A Unique Section of the Permian and Triassic Boundary Beds in the Eastern Vladimir Region, in *Paleostrat-2010. Godichnoe sobranie sektsii paleontologii MOIP i Moskovskogo otdeleniya paleontologicheskogo obshchestva (Moskva, 25–26 yanvarya 2010 g.). Programma i tezisy dokladov* (Paleostrat-2010: Annual Meeting of the Paleontological Section of the Moscow Society of Nature Explores and the Moscow Section of the Paleontological Society, Moscow, January 25–26, 2010), Moscow: Paleontol. Inst Ross. Akad. Nauk, 2010, pp. 19–20.

Granitsa permi i triasa v kontinental'nykh seriyakh Vostochnoi Evropy (The Permian and Triassic Boundary in the Continental Sequences of Eastern Europe) Lozovskii, V.R. and Esaulov, N.K, Eds., Moscow: GEOS, 1998.

Ivakhnenko, M.F., Faunal Tetrapod Assemblages of the Late Permian of Eastern Europe, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1990, vol. 65, no. 6, pp. 55–59.

Minikh, A.V., Golubev, V.K., Kukhtinov, D.A., et al., On the Characteristics of the Reference Section of the Permian–Triassic Boundary Beds in the Zhukov Ravine (Vladimir Region, Klyazma River Basin), in *Permskaya sistema: stratigrafiya, paleontologiya, paleogeografiya, geodinamika i mineral'nye resursy. Sb. mater. Mezhdunar. nauch. konf., posvyashchennoi 170-letiyu so dnya otkrytiya permskoi sistemy (5–9 sentyabrya 2011 g., Perm')* (International Scientific Conference Devoted to the 170th Anniversary of the Discovery of the Permian System: Permian System: Stratigraphy, Paleontology, Paleogeography, Geodynamics, and Mineral Resources, September 5–9, 2011, Perm), Perm: Perm. Gos. Univ., 2011, pp. 133–138.

Minikh, A.V. and Minikh, M.G., *Ikhtiofauna permi Evropeiskoi Rossii* (Permian Ichthyofauna of European Russia), Saratov: Nauka, 2009.

Newell, A.J., Sennikov, A.G., Benton, M.J., et al., Disruption of Playa–Lacustrine Depositional Systems at the

Permo-Triassic Boundary: Evidence from Vyazniki and Gorokhovets on the Russian Platform, *J. Geol. Soc.*, 2010, vol. 167, pp. 695–716.

Sennikov, A.G. and Golubev, V.K., Vyazniki Fauna: Features of the Ecological Crisis, *Priroda (Moscow, Russ. Fed.)*, 2006a, no. 7, pp. 39–48.

Sennikov, A.G. and Golubev, V.K., Vyazniki Biotic Assemblage of the Terminal Permian, *Paleontol. J.*, 2006b, vol. 40, suppl. no. 4, pp. 475–481.

Sennikov, A.G. and Golubev, V.K., Vyazniki Stage in the History of the Permian Continental Biota of Eastern Europe, in *Verkhnii paleozoi Rossii: stratigrafiya i paleontologiya. Materialy Vserossiiskoi konferentsii, 25-27 sentyabrya 2007 g.* (All-Russia Conference on the Upper Paleozoic of Russia: Stratigraphy and Paleontology, September 25–27, 2007), Kazan: Kazan. Gos. Univ., 2007, pp. 284–291.

Sennikov, A.G. and Golubev, V.K., Permian–Triassic Boundary Beds in the Vicinity of the Towns of Vyazniki and Gorokhovets (Vladimir Region), in *Paleontologiya i stratigrafiya permi i triasa Severnoi Evrazii. Materialy V Mezhdunarodnoi konferentsii, posvyashchennoi 150-letiyu so dnya rozhdeniya Vladimira Prokhorovicha Amalitskogo (1860–1917). Moskva, 22–23 noyabrya 2010 g.* (5th International Conference Devoted to the 150th Anniversary of the Birthday of Vladimir Prokhorovich Amalitzky (1860–1917): Permian and Triassic Paleontology and Stratigraphy of Northern Eurasia), Moscow, 2010, pp. 102–107.

Sennikov, A.G. and Golubev, V.K., Discovery of the Triassic in Nizhni Novgorod, in *Permskaya sistema: stratigrafiya, paleontologiya, paleogeografiya, geodinamika i mineral'nye resursy. Sb. mater. Mezhdunar. nauch. konf., posvyashchennoi 170-letiyu so dnya otkrytiya permskoi sistemy (5-9 sentyabrya 2011 g., Perm')* (International Scientific Conference Devoted to the 170th Anniversary of the Discovery of the Permian System: Permian System: Stratigraphy, Paleontology, Paleogeography, Geodynamics, and Mineral Resources, September 5–9, 2011, Perm), Perm: Perm. Gos. Univ., 2011a, pp. 307–312.

Sennikov, A.G. and Golubev, V.K., Occurrence of the Lower Triassic (Vokhmian) on the Right Bank of the Oka River in the City of Nizhni Novgorod, in *Pozvonochnye paleozoya i mezozoya Evrazii: evolyutsiya, smena soobshchestv, tafonomiya i paleogeografiya. Materialy konferentsii, posvyashchennoi 80-letiyu so dnya rozhdeniya Vitaliya Georgievicha Ocheva (1931–2004) (6 dekabrya 2011 g., PIN RAN, Moskva)* (Conference Devoted to the 80th Anniversary of the Birthday of Vitalii Georgievich Ochev (1931–2004): Vertebrates from the Paleozoic and Mesozoic of Eurasia: Evolution, Replacements of Communities, Taphonomy, and Paleogeography, December 6, 2011, Paleontol. Inst. Ross. Akad. Nauk, Moscow), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 2011b, pp. 44–47.

Sennikov, A.G., Gubin, Yu.M., Golubev, V.K., et al., A New Oryctocoenosis of Aquatic Community of Late Permian Vertebrates of Central Russia, *Paleontol. Zh.*, 2003, no. 4, pp. 80–88.

Sennikov, A.G., Kukhtinov, D.A., and Mintsev, G.V., New Data on the Late Permian Vertebrate Locality of Gorokhovets (Vladimir Region), in *Vserossiiskaya konferentsiya "Tatarskii yarus Evropeiskoi Rossii: problemy stratigrafii i korrelyatsii s morskoi teticheskoi shkaloi" (Moskva, 19–21 noyabrya 2002 g.)* (All-Russia Conference on the Tatarian Stage of European Russia: Problems of Stratigraphy and Correlation with the Marine Tethyan Scale, Moscow, November 19–21, 2002), Moscow: Geol. Inst. Ross. Akad. Nauk, 2002, p. 39.

Shishkin, M.A., On the Triplicate Division of the Upper Tatarian Substage of the Upper Permian Based on the Terrestrial Vertebrate Fauna, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1990, vol. 65, no. 2, p. 117.

Sibirtsev, N.M., General Geological Map of Russia, 72nd Sheet: Vladimir, Nizhnii Novgorod, Murom: Geological Studies in the Oka–Klyazma Basin, *Tr. Geol. Kom.*, 1896, vol. 15, part 2, pp. 1–283.

Strok, N.I., Gorbatkina, T.E., and Lozovskii, V.R., *Verkhnepermskie i triasovye otlozheniya Moskovskoi sineklizy* (Upper Permian and Triassic Deposits of the Moscow Syneclise), Moscow: Nedra, 1984.