XVIII International Congress
on the Carboniferous and Permian

Type and reference sections of the Permian–Triassic continental sequences of the East European Platform: main isotope, magnetic, and biotic events

Sukhona and Severnaya Dvina Rivers field trip

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PIN RAS – Paleontological Institute of the Russian Academy of Sciences
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NHM St.AOBM – Natural History Museum of the St. Alexius Orthodox Brotherhood of Mercy (Yaroslavl region)
KPM – Kotel'nich paleontological museum

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Introduction

The best section of the Permian continental sequence of the Russian Platform is located in the Sukhona and Malaya Severnaya Dvina Rivers Basin, Vologda Region. This territory is situated in the north-eastern part of the Moscow Basin (Syncline), on the Sukhona Swell (Fig. 1). It is a tectonically active area (uplift). As a result, the Sukhona River is actively cutting into the bedrock and forming high beauty outcrops (up to 60 m) for a distance of 100 km. The outcrops stretch along the river banks for many kilometers (Fig. 2) and allow tracing of the marker beds for a long distance and level-by-level correlation of many sections. Monocline bedding layers make it possible to see a stratigraphically continuous succession of continental deposits from the upper Urzhumian of the Biarmian Series to the Vokhmian of the Lower Triassic, i.e., from the upper Wordian to the Induan (Figs. 3, 4). These deposits were formed in different facial zones in conditions of semiarid-subhumid climate and are rich in fossils

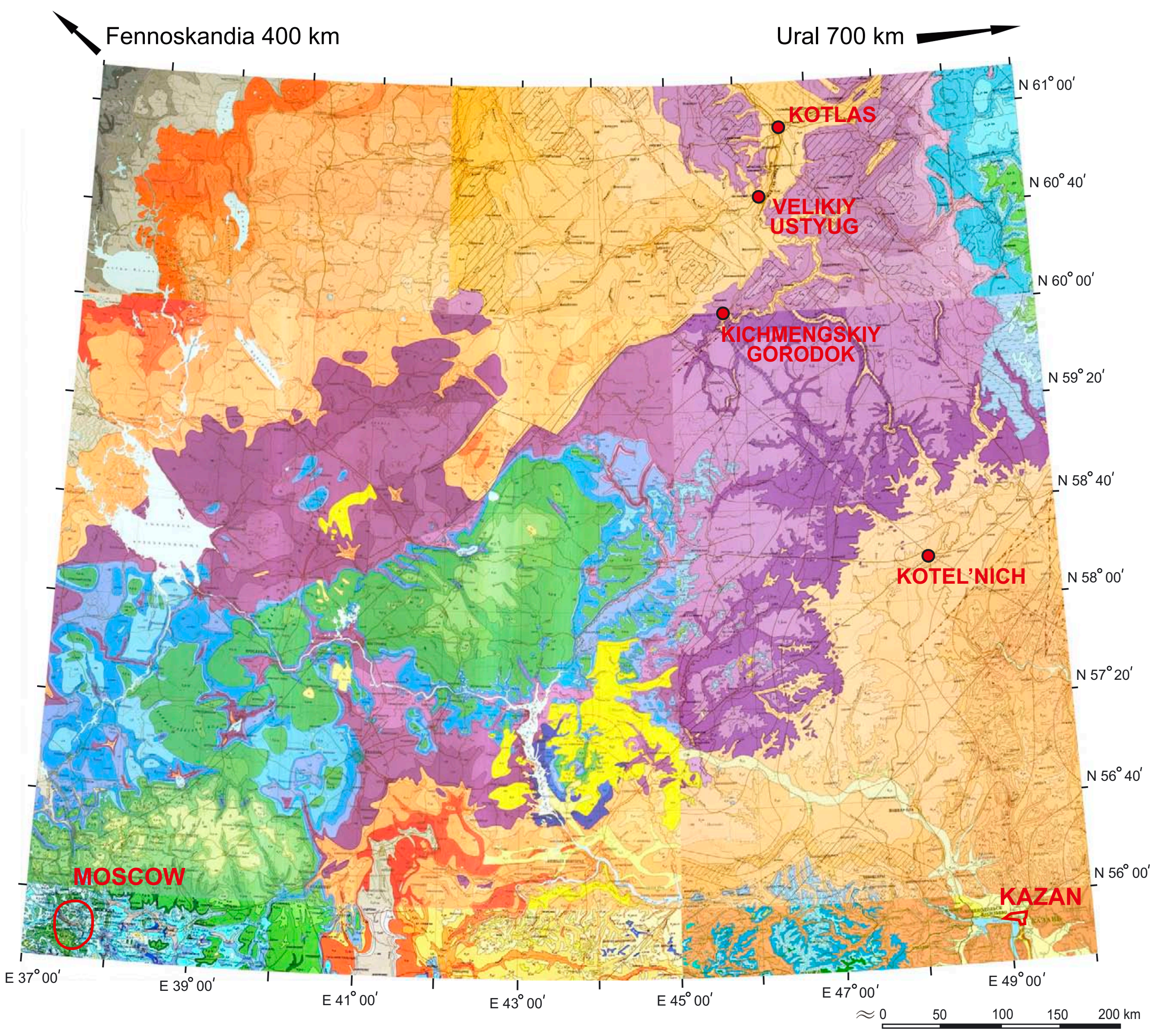


Fig. 1. Geological map of the central and eastern parts of the Moscow Basin.

of algae, higher plants, ostracods, conchostracans, insects, bivalves, gastropods, fishes, and tetrapods. They have been repeatedly described in detail, and stratified into a number of regional and local units (Amalitzky, 1897; Edemsky, 1928; Lutkevich, 1931, 1938, 1939, 1955; Mazarovich, 1946; Ignatiev, 1962; Pakhtusova, 1966; Strok and Buslovich, 1979; Reference Section…, 1981; Upper Permian…, 1984; Verzilin et al., 1993; Golubev, 1998, 2000; Tatarian beds…, 2001).

The Sukhona and Malaya Severnaya Dvina River Basin is the type region for the Tatarian Series. The stratotype of the Severodvinian Stage, the boundary-stratotype and hypostratotype of the Vyatkian Stage are located here.

The Severodvinian Stage was recognized by E.I. Tikhvinskaya (1948). In 2004, it was established by the Permian Commission of the Interdepartmental Stratigraphic Committee of Russia as the lower stage of the Tatarian Series (Commission on the Permian…, 2006). The stratotype sections are located along the Sukhona River from the Verkhnyaya Tozma site to the Krasavino site (Fig. 2). The lower boundary of the Severodvinian Stage is established at the base of the *Suchonellina inornata – Prasuchonella nasalis* Ostracod Zone. The boundary stratotype is a section in the Monastery Ravine, in Tatarstan. The Severodvinian is subdivided into Lower and Upper Substages, which correspond respectively to the *Suchonellina inornata – Prasuchonella nasalis* Ostracod Zone and the *Suchonellina inornata – Prasuchonella stelmachovi* Ostracod Zone.

The Vyatkian Stage was recognized by V.I. Ignatiev (1962). In 2004, it was established by the Permian Commission of the Interdepartmental

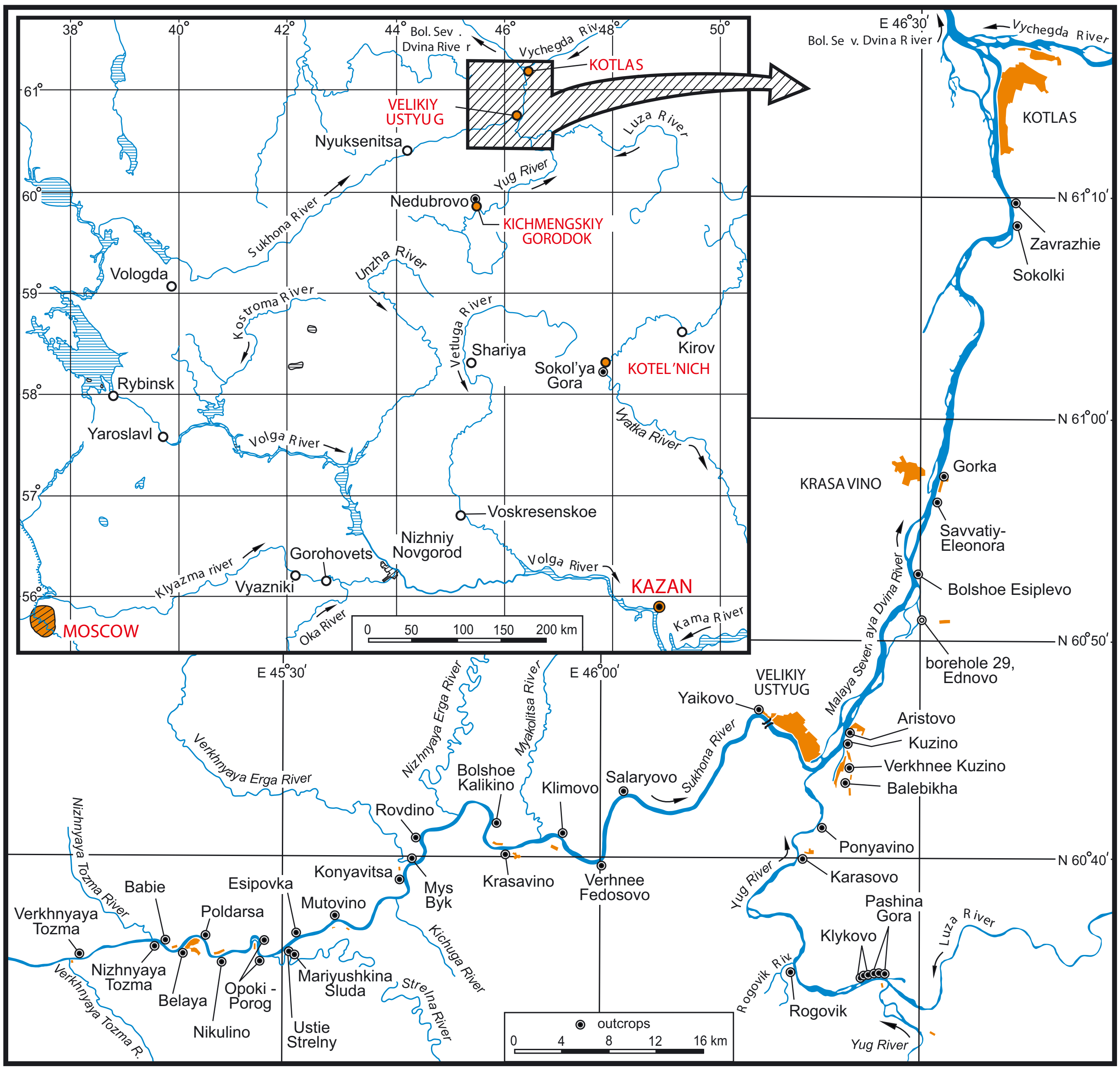


Fig. 2. Location of the Permian and Triassic sections in the Sukhona, Malaya Severnaya Dvina and Yug rivers basin.

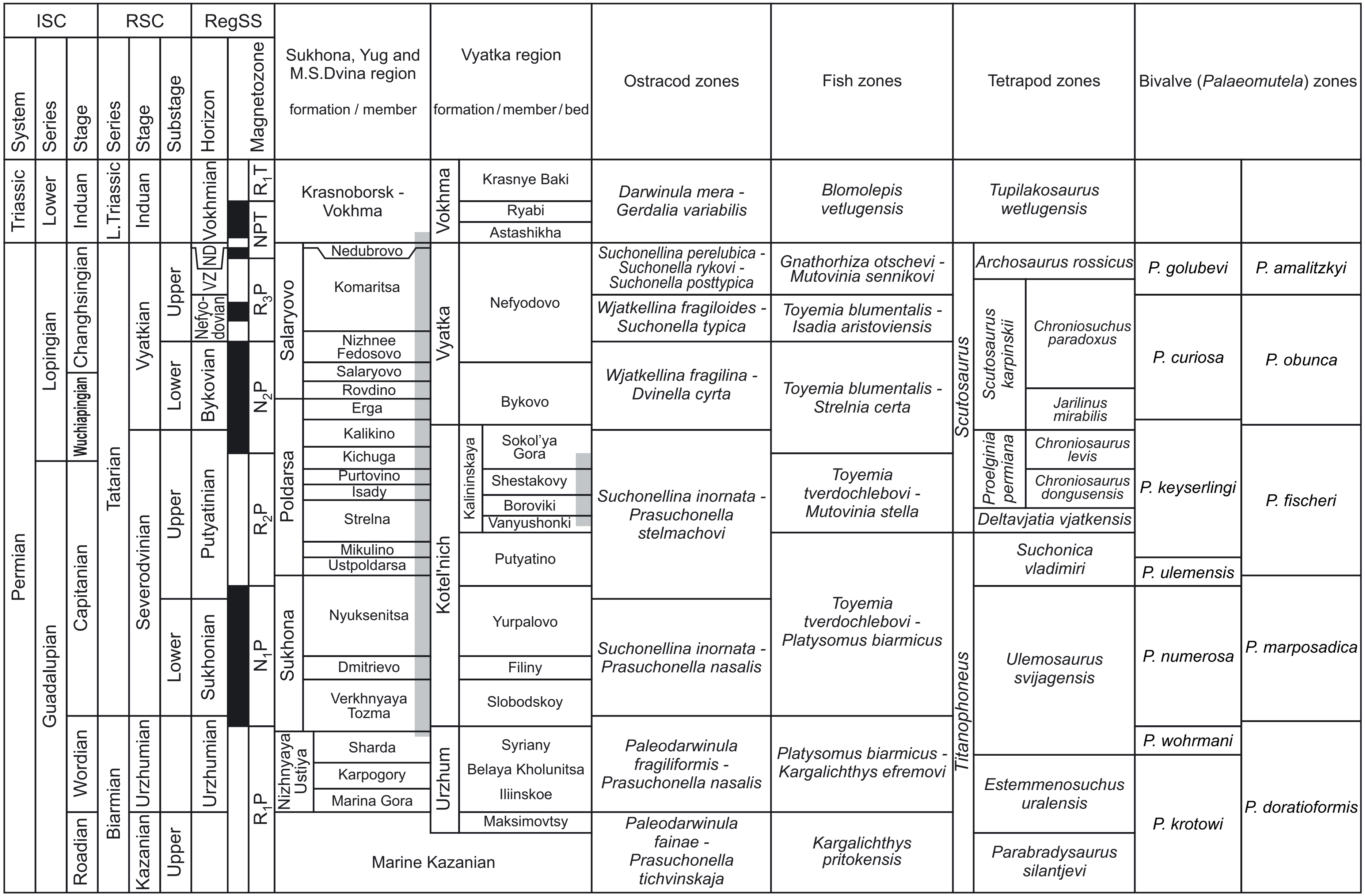


Fig. 3. Middle Permian – Lower Triassic stratigraphic chart of the East European platform. ISC – International Stratigraphic Scale, L.Triassic – Lower Triassic, ND – beds with Nedubrovian biota, RSC –General Stratigraphic Scale of Russia, RegSS – Regional Stratigraphic Scale of East European Platform, VZ – beds with Vyaznikian biota.

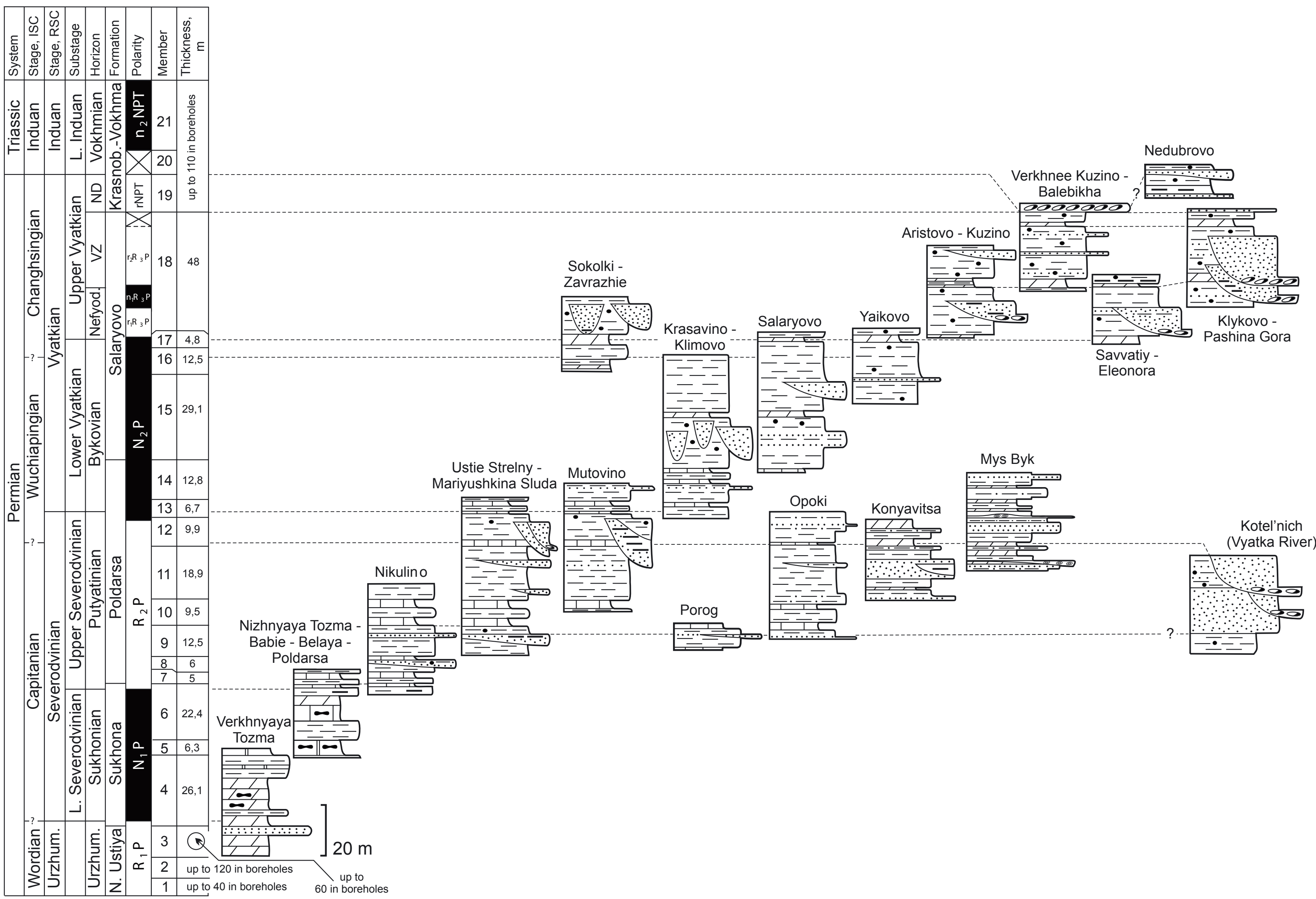


Fig. 4. Correlation of the Permian and Lower Triassic outcrops on the Sukhona, Malaya Severnaya Dvina, Yug, and Vyatka rivers. ISC – International Stratigraphic Scale, Krasnob.–Vokhma – Krasnoborsk–Vokma Formation, N. Ustiya – Nizhnyaya Ustiya Formation, ND – beds with Nedubrovian biota, Nefyod. – Nefyodovian, RSC –General Stratigraphic Scale of Russia, Urzhum. – Urzhumian, VZ – beds with Vyaznikian biota. Member: 1 – Marina Gora, 2 – Karpogory, 3 – Sharda, 4 – Verkhnyaya Tozma, 5 – Dmitrievo, 6 – Nyuksenitsa, 7 – Ustpoldarsa, 8 – Mikulino, 9 – Strelna, 10 – Isady, 11 – Purtovino, 12 – Kichuga, 13 – Kalikino, 14 – Erga, 15 – Rovdino, 16 – Salaryovo, 17 – Nizhnee Fedosovo, 18 – Komaritsa, 19 – Nedubrovo, 20 – Astashikha, 21 – Ryabi.

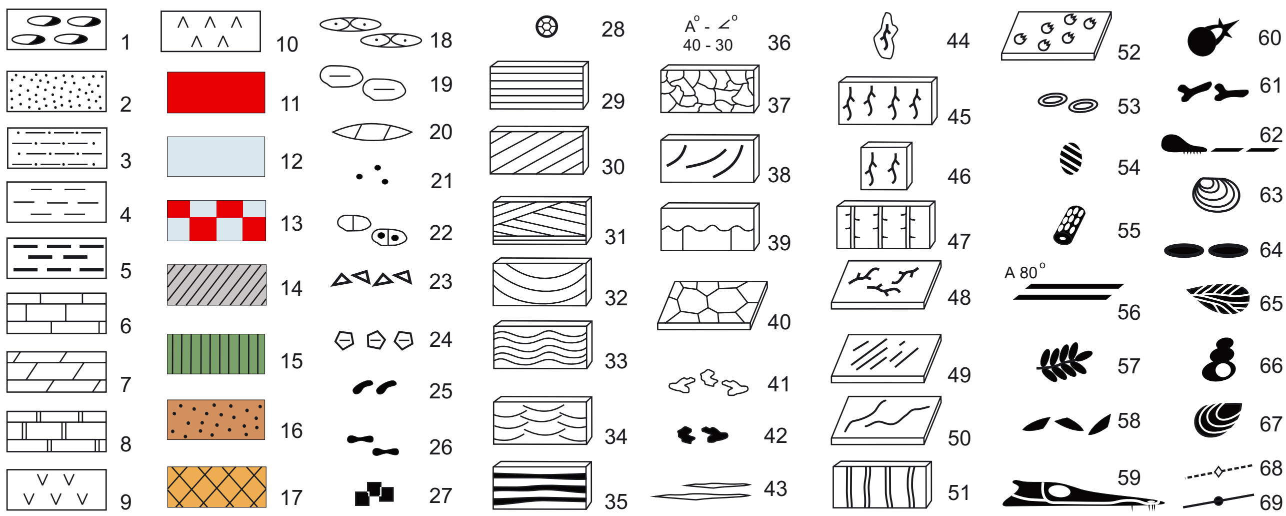


Fig. 5. Explanations: 1 – gravel and pebbles, gravelstone, 2 – sand and sandstone, 3 – silt and siltstone, 4 – clay and mudstone, 5 – clay and silty clay, enriched by organic carbon, 6 – limestone, 7 – marl, 8 – dolomite, 9 – gypsum, 10 – anhydrite, 11 – red rocks, 12 – light grey, bluish-grey and white rocks, 13 – variegated, mainly red with bluish-grey spots rocks, 14 – dark grey rocks, enriched by organic carbon, 15 – dark-green rocks, 16 – brown and greyish-green sands, 17 – yellow, orange and light brown sands, 18 – sandstone concretions, 19 – mudstone concretions, 20 – marl lenses, 21 – paleosol carbonate nodules, 22 – individual carbonate concretions, including composed of carbonate nodules, 23 – silty-clay breccia composed of angular silty-clay and carbonate chips, 24 – silty-clay blocky breccias, 25 – siderite concretions, 26 – flint concretions, 27 – crystals and concretions of pyrite, 28 – magnetite microspherules, 29 – horizontal bedding, 30 – diagonal cross bedding, 31 – wedge-shaped angular cross bedding of large scale, 32 – trough cross bedding, 33 – ripple lamination, 34 – ripple cross lamination, 35 – graded bedding, rhythmic alternation of sand, silt and clay, 36 – strike and dip angles of diagonal laminas, 37 – clay coatings, 38 – slickensides, 39 – old karst, 40 – mud cracks, 41 – bluish gleyed spots, 42 – radish relict spots in bluish rocks, 43 – lenticular bluish and pale-bluish gleyed zones, 44 – pale-bluish gleyed spots over roots of plants, 45 – plant roots *Radicites erraticus in situ*, 46 – single plant roots *Radicites erraticus in situ*, 47 – plant roots *Radicites sukhonensis in situ*, 48 – allochtonous roots, 49 – drag marks, 50 – horizontal trace fossils, 51 – vertical trace fossils, 52 – tetrapod footprints, 53 – oncolites, including over shells of bivalves, 54 – charophytes, 55 – thallomes of algae (?), 56 – shoots of plants and orientation of there axes, 57 – leaves, 58 – coal and plant detritus, 59 – tetrapods of aquatic communities, 60 – tetrapods of terrestrial communities, 61 – non-identifiable tetrapods, 62 – scales and fish bones, 63 – conchostracans, 64 – ostracods, 65 – insects, 66 – gastropods, 67 – bivalves, 68, 69 – carbon and oxygen isotope composition: 68 – in sedimentary carbonates, 69 – in pedogenic carbonates.

Stratigraphic Committee of Russia as the upper stage of the Tatarian Series (Commission on the Permian …, 2006). The stratotype section is located along the Vyatka River upstream of the Putyatino site, Kirov Region. The sections on the Sukhona River between the Mutovino site and the town of Velikiy Ustyug and the sections along the Malaya Severnaya Dvina River were established as the composite hypostratotype section of the Vyatkian Stage. The lower boundary of the Vyatkian Stage is established at the base of the *Wjatkellina fragilina – Dvinella cyrta* Ostracod Zone. The boundary-stratotype is the Mutovino section on the Sukhona River (see below). The Vyatkian is subdivided into Lower and Upper Substages. The Lower Vyatkian corresponds to the *Wjatkellina fragilina – Dvinella cyrta* Ostracod Zone, and the Upper Vyatkian to the *Wjatkellina fragiloides – Suchonella typica* and *Suchonellina perelubica – Suchonella rykovi – Suchonella posttypica* Ostracod Zones.

In the Sukhona and Malaya Severnaya Dvina Rivers Basin, the Permo-Triassic sequence presents a stratigraphically continuous succession of the Tatarian paleomagnetic and ostracod zones. All major events in the history of the Tatarian plants, bivalves, fishes, and tetrapods are observed in the fossil record of this region. The Permian-Triassic succession in the Sukhona and Malaya Severnaya Dvina Rivers is unique in the fact that it combines quality of geological exposures, abundance and diversity of fossils and a history of detailed study.

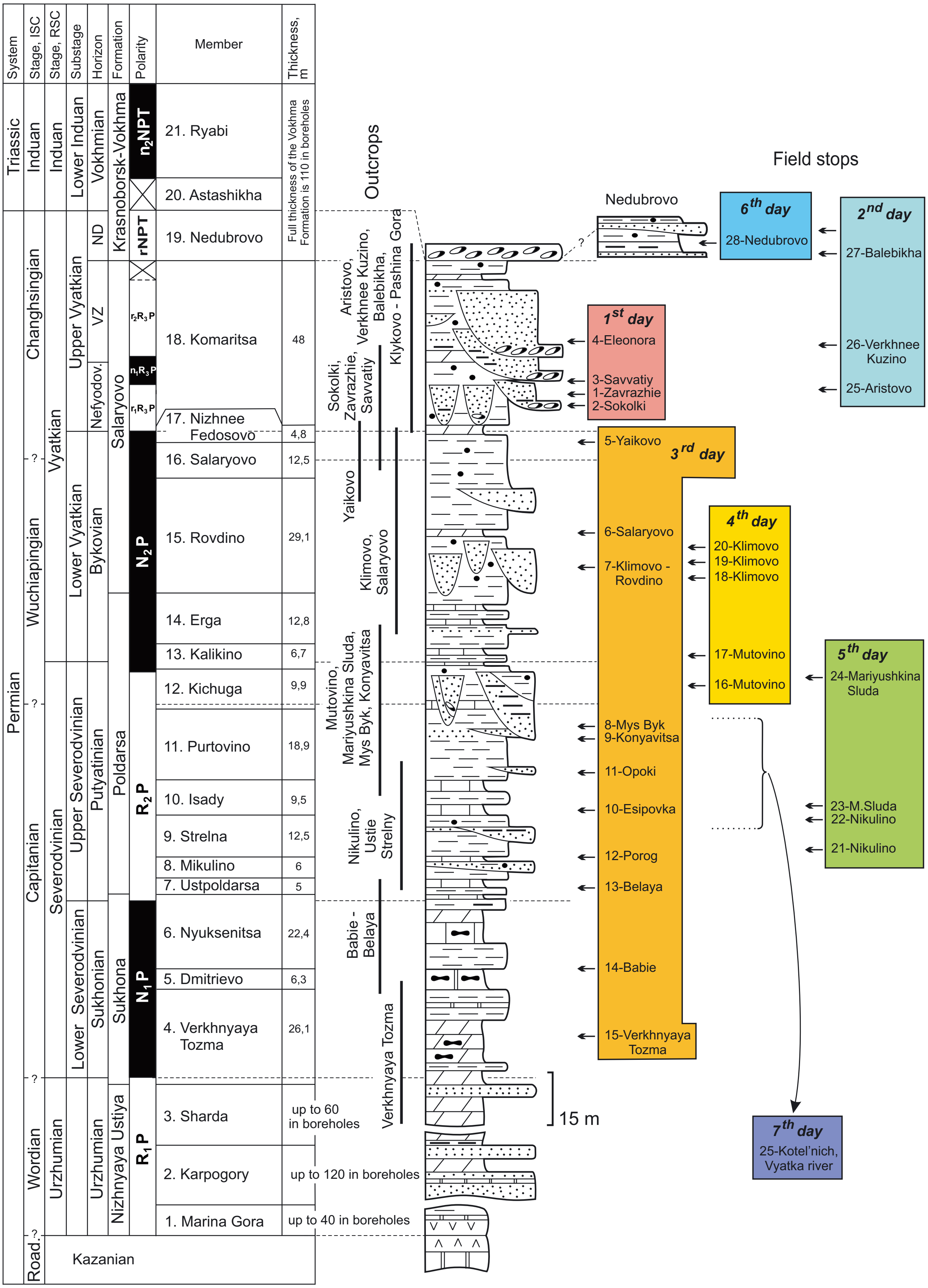


Fig. 6. Composite section of the Permian and lowermost Triassic of the Sukhona, Malaya Severnaya Dvina and Yug rivers basins. ISC – International Stratigraphic Scale, ND – beds with Nedubrovian biota, RSC – General Stratigraphic Scale of Russia, Road – Roadian, VZ – beds with Vyaznikian biota.

Part I
Middle Permian – Lower Triassic continental sections of the Sukhona, Malaya Severnaya Dvina, Kichmenga and Vyatka rivers

Verkhnyaya Tozma Outcrop

Location: the left bank of the Sukhona River opposite of the Verkhnyaya Tozma site, 10 km upstream from the settlement of Poldarsa.

Coordinates, WGS 84: N 60.5825°, E 45.21159°

Stratigraphy. The Kiaman and Illawarra magnetic hiperzone boundary occurs at the bottom of bed 19. The Biarmian-Tatarian (=Urzhumian-Severodvinian) boundary is probably located at the same level.

In the mouth of the ravine, near the western end of the outcrop, the following beds have been recognized above the water level (from bottom to top) (Figs. 7, 8).

NIZHNYAYA USTIYA FORMATION

Sharda Member

1-3. Marl, grey, indistinctly horizontal-laminated, dolomitic. Apparent thickness 1.7 m.

4. Clay, light grey, calcareous, with transition into light red clay with sand interbeds. Thickness 1.3 m.

5. Decimetre-scale alternation of dolomite and marl. Dolomite, grey, dark grey, cavernous, with autochthonous plant root traces. Marl, grey, dolomitic. Thickness 2 m.

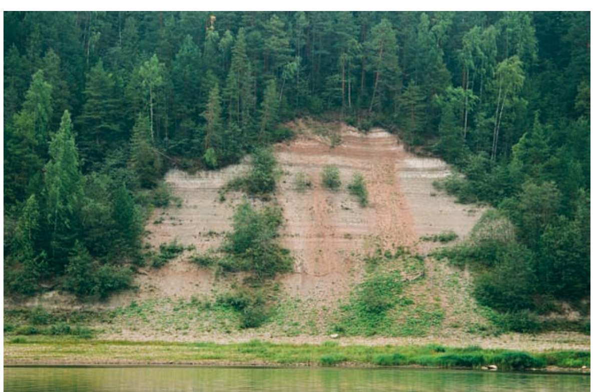


Fig. 7. Verkhnyaya Tozma outcrop.

6. Marl, light grey, with greenish grey, grey, yellowish grey, light grey, white interbeds, horizontal-laminated. Thickness 1.8 m.

7. Marl, yellowish grey, horizontal-laminated, dolomitic, strongly silty, with lenses of calcareous sand and gravel (up to 2 m long and up to 0.2 m thick). Thickness 1.2 m.

8-9. Sand, white, light grey, quartz. Thickness 1.5 m.

10. Marl, light grey, horizontal-laminated. Thickness 0.9 m.

11. Silt, reddish brown, with a flaser bed of dark grey clay. Thickness 1.4 m.

12. Sandstone, brown, light brown, very fine, with rare thin (mm) interbeds of dark brown clay. Thickness 1.3 m.

13-14. Sand and sandstone, white, light grey, quartz, with interbeds of dark grey clay in the upper part of the bed. Thickness 0.75 m.

150-200 m downstream from this point, the following deposits overlie bed 14:

SUKHONA FORMATION

Verkhnyaya Tozma Member

15. Clay, brown, reddish brown, sandy. Thickness 0.8 m.

16. Marl, grey, dark grey, dolomitic, with transition into dolomite, with downward straight burrows like *Scolithos* isp. up to 1 cm in diameter. Thickness 0.8 m.

17. Silt, brown, reddish brown, clayey. Thickness 0.3 m.

18. Marl, grey, horizontal-laminated, dolomitic, with transition into dolomite. Thickness 0.7 m.

19. Silt, brown, reddish brown, clayey, calcareous, horizontal-laminated. Thickness 1.4 m.

20. Clay, pink, in some areas grey, light grey, silty, calcareous, with transition into marl, with downward straight burrows like *Scolithos* isp. up to 1 cm in diameter. Thickness 0.4 m.

21. Clay, red, silty, horizontal-laminated. Thickness 0.5 m.

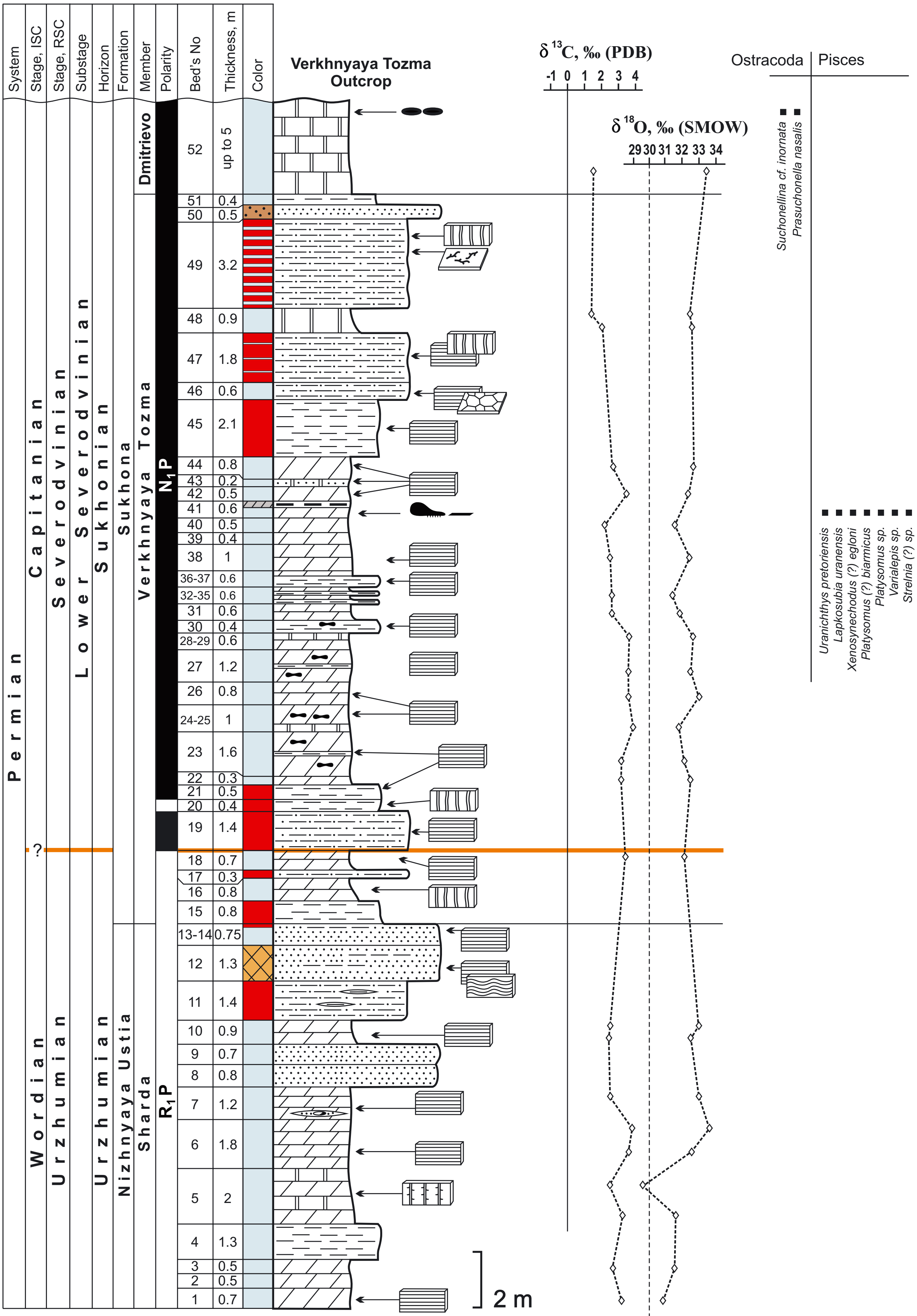


Fig. 8. Verkhnyaya Tozma section with lithological, isotopic, and paleontological data.

22-29. Marl, with interbeds of dolomite. Marl, grey, horizontal-laminated, with thin (mm) dark grey clayey interbeds, with red flint concretions up to 30 cm in diameter. Dolomite, white, grey, cavernous. Thickness 5.5 m.

30. Clay, grey, horizontal-laminated, calcareous, with transition into marl, with flint concretions up to 20 cm in diameter. Thickness 0.4 m.

31-36. Alternation of grey calcareous clay and grey marl. Thickness 1.7 m.

37-40. Marl, grey, horizontal-laminated. Thickness 2.0 m.

41. Clay, grey, dark grey, strongly calcareous, with transition into marl, with thin (5 mm) layer of black plastic clay in the upper part of the bed. Tetrapods. Fishes: *Uranichthys pretoriensis* A.Minich, *Varialepis* sp., *Xenosynechodus* (?) *egloni* Glückman, *Strelnia* (?) sp., *Platysomus* (?) *biarmicus* Eichwald, *Platysomus* sp., *Lapkosubia uranensis* A.Minich. Thickness 0.6 m.

42. Marl, grey, horizontal-laminated. Thickness 0.5 m.

43. Dolomite, white, indistinctly horizontal-laminated, with calcareous sandy grains, with transition into dolomitic sand. Thickness 0.2 m.

44. Marl, grey, thickly horizontal-laminated. Thickness 0.8 m.

45. Clay, brown, horizontal-laminated, silty, calcareous. Thickness 2.1 m.

46. Silt, light grey, light pink, thinly horizontal-laminated, calcareous, with transition into silty marl, with desiccation cracks. Thickness 0.6 m.

47. Silt, brown, reddish brown, thinly horizontal-laminated, calcareous, with downward straight burrows like *Scolithos* isp. up to 1 cm in diameter. Thickness 1.8 m.

48. Dolomite, white, massive. Thickness 0.9 m.

49. Alternation of red, brown clays, red, brown, horizontal-laminated silts and grey, white carbonate rocks, with doubtful allochtonous plant roots in the upper part of the bed, with downward burrows like *Scolithos* isp. up to 1 cm in diameter. Thickness 3.2 m.

50. Sand, greenish brown, light brown, horizontal-laminated, very fine, with thin clayey interbeds. Thickness 0.5 m.

51. Clay, grey, silty, horizontal-laminated. Thickness 0.4 m.

Dmitrievo Member

52. White dolomite. Ostracods: *Suchonellina* cf. *inornata* Spizharskyi, *Prasuchonella nasalis* (Sharapova). Apparent thickness up to 5 m.

Nizhnyaya Tozma, Babie, and Belaya Outcrops

Location: left and right banks of the Sukhona River for a distance of 2.5 kilometres west from settlement of Poldarsa.

Coordinates, WGS 84: Nizhnyaya Tozma outcrop, right river bank – N 60.59524°, E 45.33939°; Babie outcrop, left river bank – N 60.59591°, E 45.34664°; Belaya outcrops, right river bank, site no. 149A – N 60.58747°, E 45.36663°, site no. 149B – N 60.58936°, E 45.37668°.

Stratigraphy. The N_1P-R_2P magnetic orthozones boundary occurs at the bottom of bed 21. The Lower-Upper Severodvinian boundary is probably located at the same level.

Babie Outcrop. The following beds have been recognized above the water level (from bottom to top) (Fig. 9).

SUKHONA FORMATION

Verkhnyaya Tozma Member

1. Silt, red, reddish brown, in some areas horizontal-laminated. Apparent thickness 0.5 m.

Dmitrievo Member

2-3. Dolomitic limestone and dolomite, white, light grey, light yellowish, with large concretions grey and reddish brown flint up to 0.3 m thick and up to 0.8 m long, in some areas with downward burrows like *Scolithos* isp. up to 10 cm long and up to 1 cm in diameter (Fig. 9, photos 1, 2), in some areas with autochthonous plant roots similar to *Radicites sukhonensis* Aref’ev et Naugolnykh, 1988. Thickness 6.3 m.

Nyuksenitsa Member

4-5. Clay, red, silty, with allochtonous plant roots. Thickness 3.4 m.

6. Marl, light grey, with interbeds of limestone. Thickness 0.6 m.

7. Clay, grey, greenish grey, horizontal-laminated. Thickness 0.3 m.

8. Clay, red, silty. Thickness 0.9 m.

9-10. Marl, grey, in some areas pinkish, horizontal-laminated. Thickness 1.2 m.

11. Clay, pink, pinkish red. Thickness 0.8 m.

Beds 4-11 form a red-coloured clay unit. This unit exposes on the right river bank, site no. 149A.

Here, an interbed of clay with small pale bluish mottles and numerous autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, 1988 (Fig. 9, photo 3) locates in the middle part of the unit. This interbed is the earliest gleysol in the Sukhona area. Gleysols are very common in the overlying Permian beds. Paleosol thickness 0.4 m.

12-14. Dolomite, dolomitic limestone and marl, white, light grey, rarely dark grey, with allochtonous and autochthonous plant roots close to *Radicites sukhonensis* Aref'ev et Naugolnykh, with concretions of grey flint up to 0.4 m in size. Thickness 3.5 m.

15. Clay, light grey. Thickness 0.4 m.

16-17. Dolomitic marl, limestone and dolomite, white, light grey. Thickness 2.4 m.

18. Clay, brown, reddish brown, silty, calcareous, with numerous autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, 1988. Thickness 0.3 m.

19. Limestone, white, light grey, pinkish, in some areas brecciated, with flint concretions. Thickness 1.1 m.

20-22. Clay, grey, dark grey, red, brownish red, horizontal-laminated, silty, with allochtonous and single autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Grey-coloured rocks are more calcareous, with transition into marl. In screes the rocks with plant fossils of Tatarina flora (Fig. 48) were found. Apparent thickness 3.9 m.

Bed 18 is a paleosol. It is very good marker bed, easily recognized on the far bank in the Belaya outcrop as a dark green gley horizon. The following deposits overlie bed 18 here, Belaya outcrop, no. 149A (Fig. 9, photo 5).

149A/5-149A/12. Marl, light brown, brown, reddish brown, pink, with numerous allochtonous plant roots, with single downward autochthonous plant roots, with interbeds of breccia and dolomite white, light grey, with allochtonous plant roots and with dark grey and brownish red flint concretions. Thickness 6.6 m.

Mainly grey-coloured deposits overlie bed 149A/12, Belaya outcrop, no. 149B (Fig. 9, photo 4).

149B/13. Marl, light grey, greenish grey. Thickness 0.3 m.

149B/14. Dolomite, light grey, light greenish grey, horizontal-laminated, with interbed of calcareous sand. Thickness 0.2 m.

14B/15. Marl, light grey, horizontal-laminated, with transition into dolomite with flint concretions. Thickness 0.8 m.

14B/16. Clay, brownish-greenish, brownish dark grey, with small pink mottles. Thickness 0.8 m.

POLDARSA FORMATION

Ustpoldarsa Member

149B/17. Clay, red, silty, calcareous, brecciated in the bottom. Thickness 1.1 m.

149B/18. Clay, light greenish grey, light brown in the bottom of the bed, thinly horizontal-laminated, with fish fossils. Thickness 0.25 m.

149B/19. Limestone, light grey, horizontal-laminated, with ostracods and fishes. Fishes: *Uranichthys* sp., *Varialepis stanislavi* A.Minich, *Geryonichthys* sp. Thickness 0.12 m.

149B/20-149B/21. Clay, brown, pale brown, with ostracods. Thickness 0.25

149B/22-149B/25. Clay, grey, greenish grey, horizontal-laminated, silty, calcareous, with fossils of ostracods, fishes and bivalves. Thickness 0.52 m.

149B/26. Limestone, light grey, marl-like. Thickness 0.05 m.

149B/27. Clay, light grey, calcareous. Thickness 0.48 m.

149B/28. Marl, light grey, horizontal-laminated, with allochtonous plant roots. Ostracods: Thickness 0.13 m.

149B/29. Marl, light grey, thinly horizontal-laminated, flaggy. Thickness 0.15 m.

149B/30. Limestone, light grey, with greenish clayey inclusions. Ostracods: *Bairdia sukhonica* Molostovskaya, *Prasuchonella sulacensis* (Starozhilova), *Suchonellina parallela* Spizharskyi, *S. inornata* Spizharskyi, *Permiana elongata* (Posner), *Darwonuloides* sp. Thickness 0.22 m.

149B/31. Clay, light grey, calcareous. Thickness 0.25 m.

149B/32. Limestone, white, light grey, with greenish clayey inclusions. Thickness 0.04 m.

149B/33-38. Clay, light grey, greenish grey, indistinctly horizontal-laminated, calcareous, with interbed of light grey marl. Thickness 0.85 m.

149B/39-41. Limestone, light grey. Ostracods: *Prasuchonella* cf. *nasalis* (Sharapova), *Suchonellina parallela* Spizharskyi. Thickness 0.7 m.

Mikulino Member

149B/42. Silty clay and clayey silt, dark violet, dark cherry-red, thinly horizontal-laminated. Ostracods: *Prasuchonella* sp., *Sinusuella* cf. *vjatkensis* (Posner), *Suchonellina* cf. *inornata* Spizharskyi. Apparent thickness 0.7 m.

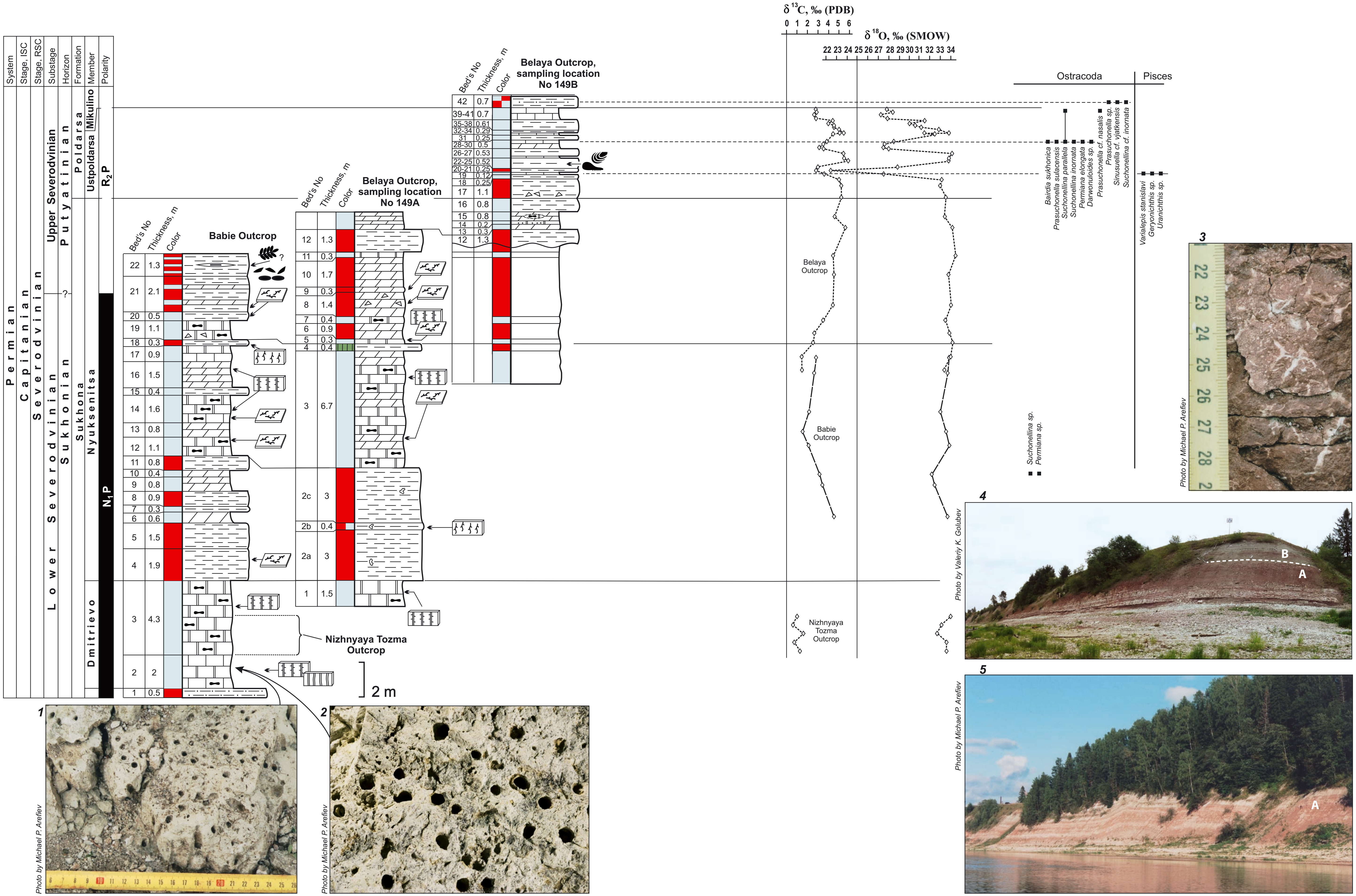


Fig. 9. Nizhnyaya Tozma, Babie and Belaya sections with lithological, isotopic, and paleontological data. Photos: 1, 2 – vertical trace fossils (2 – NHM St.AOBM No. 3367/3); 3 – paleosol with small spots of gley, bed No. 149A/2b; 4, 5 – eastern (4) and western (5) parts of the Belaya outcrop with position of boundary Sukhona formation (A) and Poldarsa formation (B).

Nikulino Outcrop

Location: right bank of the Sukhona River near eastern margin of Poldarsa settlement, opposite Nikulino village.

Coordinates, WGS 84: N 60.58385°, E 45.43092°

Stratigraphy. Upper Severodvinian (Capitanian). R_2P magnetic orthozone.

The following beds are exposed above the water level (Fig. 10).

SUKHONA FORMATION

Nyuksenitsa Member

1. Clay, greenish grey, massive, calcareous. Apparent thickness 0.5 m.

POLDARSA FORMATION

Ustpoldarsa Member

2. Clay, tile-red, wine red, massive. Thickness 1.2 m.

3. Clay, grey green, massive, calcareous. Tetrapods (Poldarsa locality): *Suchonica vladimiri* Golubev. Fishes (Poldarsa locality): *Strelnia certa* A.Minich, *Isadia suchonensis* A.Minich, *Geryonichthys* (?) *longus* A.Minich, *Varialepis stanislavi* A.Minich, *Platysomus biarmicus* Eichwald, *Xenosynechodus* (?) *egloni* Glückman. Coprolites, bivalves. Thickness 0.6 m.

4. Marl, greenish grey, massive, with interbeds of calcareous dirty pink, horizontal-laminated clay (5 cm) and greenish grey, massive, thick-platy limestone. Thickness 1.65 m.

5-7. Limestone, greenish grey, horizontal-laminated, clayey, flaggy, with thin interbeds of green clay and green marl. Thickness 0.95 m.

POLDARSA FORMATION

Mikulino Member

8. Clay, wine-red brown with bluish, green and yellow mottles and streaks, horizontal-laminated or massive, with plant roots, with lenses of sandstone and siltstone in upper part of the bed. Thickness 0.8 m.

9-10. Sandstone, dirty cherry-red with large grey and dirty-green-yellow mottles, massive, with lenses of grey sandstone. Conchostracans, fishes. Thickness 1.15-1.3 m.

11. Siltstone, cherry-red with numerous bluish and ochreous mottles, massive, strongly clayey, with calcareous nodules, with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh (Fig. 10, photo 2). This is a paleosol complex, which consists of several paleosols downstream from this point. Ostracods: *Permiana elongata* (Posner), *Prasuchonella sulacensis* (Starozhilova), *P.* ex gr. *sulacensis* (Starozhilova), *Suchonellina* ex gr. *futschiki* (Kashevarova), *S. parallela* Spizharskyi, *S.* ex gr. *parallela* Spizharskyi, *S. inornata* Spizharskyi, *Tscherdynzeviana* sp. Fishes (locality of Mikulino-1): *Geryonichthys longus* A. Minich, *Geryonichthys* sp., *Xenosynechodus* sp., *Platysomus biarmicus* Eichwald, *Platysomus* sp. Charophytes. Thickness 1.1 m.

12-14. Limestone, greenish grey, cherry-red grey, massive, with autochthonous plant roots *Radicites sukhonensis* Aref'ev et Naugolnykh, with interbed of clay cherry-red violet, massive. Charophytes. Ostracods: *Permiana oblonga* (Posner), *Prasuchonella* ex gr. *sulacensis* (Starozhilova), *Suchonellina* cf. *futschiki* (Kashevarova), *S.* cf. *inornata* Spizharskyi, *S.* cf. *parallela* Spizharskyi. Thickness 2.15 m.

15-16. Marl, brown grey, massive, clayey in upper part of the bed, with interbeds of grey massive, horizontal-laminated limestone. Thickness 0.8-1.95 m.

Strelna Member

17. Clay, dark brown, massive, weakly silty in some areas, horizontal-laminated, with interbeds of greenish grey, silty clay and light brown clay. Thickness 1.35-1.6 m.

18. Marl, greenish grey, horizontal-laminated, flaggy. Thickness 1.75-1.85 m.

19. Clay, reddish brown, bright, massive. Thickness 1.25-1.4 m.

20. Clay, grey, green grey, horizontal-laminated, plastic, with interbeds of pinkish grey, massive, clayey limestone, pinkish grey clay and green, very fine sandstone. Fishes (locality of Mikulino-2): *Geryonichthys longus* A.Minich, *Mutovinia stella* Minich. Ostracods: *Prasuchonella sulacensis* (Starozhilova), *P.* ex gr. *sulacensis* (Starozhilova), *Suchonellina* cf. *spizharsri* (Posner), *S. parallela* Spizharskyi *S.* ex gr. *parallela* Spizharskyi, *S. inornata* Spizharskyi. Thickness 0.7 m.

21-24. Clay, brown, massive, with one interbed of greenish grey, silty clay and one interbed of grey, very fine sandstone (12 cm). Ostracods: *Prasuchonella* ex gr. *stelmachovi* (Spizharskyi), *P. sulacensis* (Starozhilova), *Suchonellina parallela* Spizharskyi, *S.* ex gr. *parallela* Spizharskyi, *S. inornata* Spizharskyi. Thickness 1.65 m.

25. Marl, greenish light grey, with light beige mottles, massive. Thickness 0.5 m.

26. Clay, brown, massive, in some areas weakly silty, with interbed of grey brown, fine, horizontal-laminated sandstone (10 cm). Thickness 1.05 m.

27-28. Sandstone, in the lower part of the bed grey brown, horizontal-laminated, very fine; in the uppermost part of the bed light grey, fine, massive, flaggy. In the lower part the bed includes interbed of marl (0-25 cm) grey green, brown, horizontal-laminated, with ostracods *Darwinuloides* sp., *Prasuchonella* ex gr. *stelmachovi* (Spizharskyi), *P. stelmachovi* (Spizharskyi), *Suchonellina parallela* Spizharskyi, *S.* ex gr. *parallela* Spizharskyi, *S. inornata* Spizharskyi. Thickness 0.45-0.95 m.

29. Clay, red brown, massive, nonsilty. Thickness 0.45-0.8 m.

30. Sandstone, light grey, white, massive, very fine. Thickness 0.25-0.65 m.

31. Marl, greenish grey, massive, weakly silty, platy, thin-platy in the lower part of the bed. Ostracods: *Prasuchonella* cf. *stelmachovi* (Spizharskyi), *Suchonellina* cf. *futschiki* (Kashevarova), *S.* cf. *parallela* Spizharskyi. Thickness 0.28-0.4 m.

32. Siltstone, brown, massive, clayey, with interbeds of red brown, silty clay, in some areas with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh and bluish-greenish gley mottles. It's paleosol, which is correlated with Ustie Strelny paleosols (Fig.12). Ostracods: *Prasuchonella stelmachovi* (Spizharskyi), *P.* cf. *stelmachovi* (Spizharskyi), *P.* sp., *Suchonellina* cf. *inornata* Spizharskyi, *S.* cf. *parallela* Spizharskyi. Thickness 1.65 m.

Isady Member

33-35. Clay, green with small cherry-red mottles, massive, in the middle part of the bed with interbed of limestone (2 cm) beige, mottled, massive, with ostracods *Clinocypris* (?) sp., *Permiana elongata* (Posner), *Prasuchonella stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Suchonellina* ex gr. *spizharskyi* (Posner), *S. inornata* Spizharskyi, *S. parallela* Spizharskyi, with charophytes in upper part of the bed. Thickness 0.85 m.

36. Limestone, grey, horizontal-laminated, with plant roots *Radicites sukhonensis* Aref'ev et Naugolnykh, with interbeds of clayey limestone, greenish grey marl and dark-green-grey and cherry-red clay. Thickness 2.5 m.

37. Clay, reddish brown, massive, with interbed of (13 cm) brown grey clay in the middle part of the bed. Ostracods: *Prasuchonella stelmachovi* (Spizharskyi), *Suchonellina* cf. *inornata* Spizharskyi. Thickness 1.15 m.

38. Clay, light brown, brown grey, massive. Thickness 1.8 m.

39. Clay, light-coloured, green grey, with grey brown interbeds, massive, with horizontal transition into pale-pink, mottled clay, with rare plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 1.45 m.

40-46. Alternation of limestone and marl. Limestone, green grey, massive, thick-platy. Marl, beige grey with cherry-red mottles and interbeds, massive, thick-platy. In the middle part of the bed there is an interbed of brown, strongly silty clay (10 cm). Charophytes. Ostracods: *Clinocypris* (?) sp., *Prasuchonella stelmachovi* (Spizharskyi), *P.* cf. *stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Suchonellina parallela* Spizharskyi, *S.* cf. *parallela* Spizharskyi, *S.* ex gr. *spizharskyi* (Posner), *S. inornata* Spizharskyi. Thickness 1.95 m.

Purtovino Member

47. Clay, red brown, mottled, plastic, with numerous allochtonous plant roots in the uppermost part of the bed. Thickness 0.18 m.

48. Clay, grey brown, coarse, strongly calcareous, with interbed of brown grey, mottled, massive, thick-platy, weak bituminous limestone (15 cm). Bivalves. Ostracods: *Permiana oblonga* (Posner), *Prasuchonella stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Sinusuella* cf. *vjatkensis* (Posner), *Suchonellina* cf. *parallela* Spizharskyi, *S. inornata* Spizharskyi. Thickness 0.9 m.

49. Siltstone, red brown, horizontal-laminated, clayey, in the uppermost part of the bed with interbed of marl (7 cm) dark cherry-red grey, friable, massive, with plant roots. Ostracods: *Prasuchonella* sp., *Permiana oblonga* (Posner). Thickness 1.3 m.

50. Siltstone, brown red, massive, friable. Thickness 0.6 m.

51. Siltstone, greenish yellowish grey, massive, weak sandy, with allochtonous plant roots. Ostracods: *Prasuchonella* sp., *Suchonellina inornata* Spizharskyi *S.* cf. *inornata* Spizharskyi, *S.* cf. *spizharskyi* (Posner). Thickness 0.25 m.

52. Clay, brown yellow, yellow green cherry-red, mottled, friable, with interbeds of greenish yellowish grey, horizontal-laminated marl. In upper part of the bed yellowish green, horizontal-laminated siltstone locates. Coprolites. Thickness 0.45 m.

In beds 48-52 vertebrate fossils, numerous bivalves and plant leaves and stems were found. Fishes (locality of Mikulino-3): *Isadia* sp., *Sludalepis spinosa* A.Minich, *Toyemia tverdochlebovi* Minich. Tetrapods (locality Mikulino): *Chroniosaurus dongusensis* Tverdochlebova, *Microphon exigius* Ivachnenko, *Proelginia* sp., *Dvinosaurus* sp.

53. Clay, tile-red, horizontal-laminated or massive, nonsilty, non-plastic, claystone-like. Thickness 2.35 m.

54. Siltstone, brown red, massive. Apparent thickness 1.5 m.

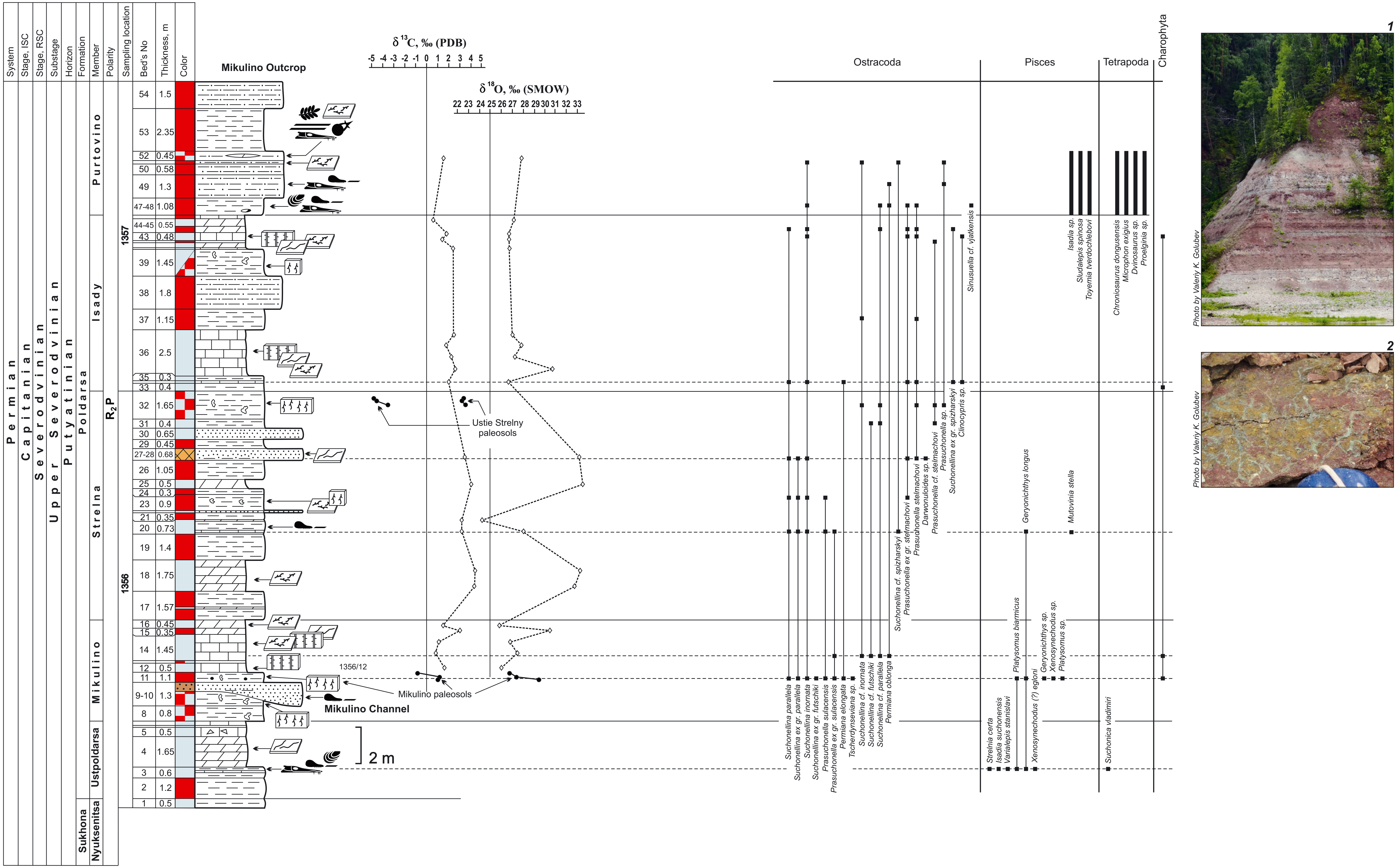


Fig. 10. Nikulino section with lithological, isotopic, and paleontological data. 1 – Nikulino outcrop, sampling location No. 1357; 2 – paleosol with distinctive ocher and residual red-coloured spots permeated roots *in situ* (Mikulino Member). The Poldarsa Formation usually underlines different pedogenic profiles.

Opoki and Porog Outcrops

Location: left bank of the Sukhona River opposite Opoki village.

Coordinates, WGS 84: N 60.59472°, E 45.49409°

Stratigraphy. Upper Severodvinian. Capitanian-Wuchiapingian transition.

The following beds have been recognized (from bottom to top), site V.G. no. 31 (Fig. 11).

POLDARSA FORMATION

Strelna Member

1. Sandstone, brown red, brown grey, horizontal-laminated, very fine. On the left bank of the Sukhona River, in 600 m to west, in Opoki outcrop (N 60.59265°, E 45.4824°), this bed changes into an alluvial lens. Apparent thickness 0.6 m.

Recent colluvium.

2. Clay, light brown, red brown, cherry-red with green mottles, with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. It is a paleosol, which is correlated with the Ustie Strelny paleosols (Fig.12). Apparent thickness 1.4 m.

Isady Member

3. Marl, dark grey with reddish and white interbeds, horizontal-laminated, flaggy. Thickness 0.2 m.

4-6. Limestone, grey, greenish grey, massive, thick-platy, with plant roots *Radicites sukhonensis* Aref'ev et Naugolnykh, with interbed of wine-red, cherry-red, with green mottles and green and grey interbeds, horizontal-laminated clay and grey green and cherry-red marl. Thickness 2.0-2.1 m.

7. Siltstone, greyish brown, massive, clayey. Thickness 0.75 m.

8. Marl, grey, greenish grey in the lower part, horizontal-laminated, clayey. Thickness 0.5 m.

9. Clay, variegated, brown red and green grey, indistinctly horizontal-laminated. Thickness 3.5 m.

10. Limestone, greenish grey, with green intercalations, massive, thick-platy. Thickness 0.3 m.

11. Clay, light green, massive. Thickness 0.7-0.8 m.

12. Limestone, grey, dark grey, with green mottles and streaks, massive, clayey, weakly cavernous, flag-like. Thickness 0.7 m.

13. Clay, grey brown, massive. Thickness 0.65 m.

14. Limestone, dark grey, light grey, massive, flaggy, with bituminous interbeds, with interbed of cherry-red and dark green grey, massive clay. Thickness 1.9 m.

Purtovino Member

15. Siltstone, dark cherry-red, yellowish brown, greenish grey, grey, horizontal-laminated, clayey. In the uppermost part of the bed interbed (15 cm) of dark cherry-red siltstone, yellowish green, fine sandstone and red brown and yellow grey, thinly horizontal-laminated clay. Thickness 0.9 m.

16. Siltstone, dark brown, yellowish light brown, massive, with numerous allochtonous plant roots. Thickness 1.75-2.0 m.

17. Siltstone, brown red, massive. Thickness 1.4-1.6 m.

18. Limestone, grey, greenish grey, dark grey, massive, thick-platy. Thickness 0.5 m.

19. Siltstone, brown red in the lower part, brown grey in the upper part, massive. Thickness 0.95 m.

20. Clay, red brown, with grey dark cherry-red interbeds in the lower part, massive, silty, with numerous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, with one interbed of grey limestone (10 cm) with numerous allochtonous plant roots and one interbed of yellowish light grey, massive marl (45 cm) in the middle part of the bed. Thickness 4.6 m.

21. Siltstone, brown red, massive or indistinctly horizontal-laminated, clayey. Thickness 2.45 m.

22. Clay, brown red, massive, with numerous interbeds (10 cm) of green, massive siltstone and bluish-greenish-yellow-brown, grey, massive, very fine, silty sandstone, with two interbeds (5-10 cm) of limestone greenish grey. Thickness 3.35 m.

At the upper boundary of bed 22 lens of greenish siltstone is located. Length of lens is 30 m, thickness is 1.8 m.

Site M.A. no. 23, the following deposits overlie bed 22:

15. Clay, brown. Thickness 1.45 m.

14. Clay, greenish in some areas brown or reddish. Thickness 0.5 m.

13. Clay, red. Thickness 3 m.

Kichuga Member

12. Clay, green, pale green, silty. Thickness 1.2 m.

11. Clay, reddish brown, variegated, with numerous autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 1.2 m.

10. Clay, pale greenish, with brown mottles in the bottom, strongly calcareous in the uppermost part. Thickness 0.4 m.

9. Limestone, white, with large green streaks. Thickness 0.25 m.

8. Clay, red, strongly sandy, with interbed of grey siltstone in the upper part of the bed. Thickness 3.2 m.

7. Sandstone, pale greenish. Thickness 0.15 m.

6-5. Siltstone, pink light green, clayey, with plant fossils, with burrows. Thickness 0.5 m.

4. Clay, brown, horizontal-laminated, strongly silty. Thickness 0.45 m.

3. Siltstone, pale green. Thickness 0.25 m.

2. Siltstone, pink, with pale greenish interbeds, horizontal-laminated. Thickness 1.8 m.

1. Sand, white, very fine, quartz. Apparent thickness 0.5 m.

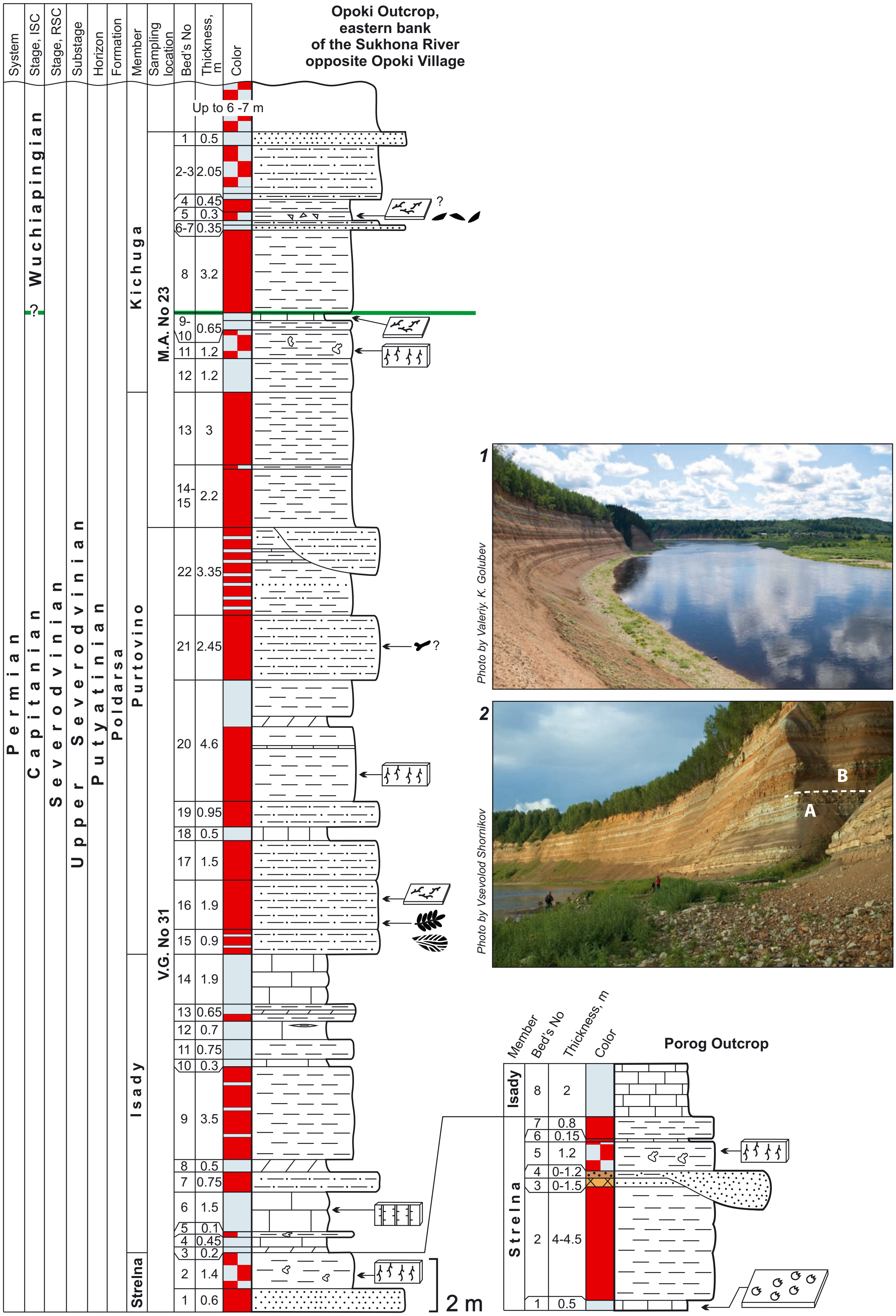


Fig. 11. Opoki section with lithological data. 1 – left bank of the Sukhons River, view to the south on the right bank and the village of Opoki; ruins of the dam built by prisoners of Stalin's prison camp "Opokstroy" (1940-1947) visible in front of the houses. 2 – left bank of the Sukhona River, view to the north: A – Isady Member, B – Purtovino Member.

Mariyushkina Sluda, Ustie Strelny, and Esipovka Outcrops

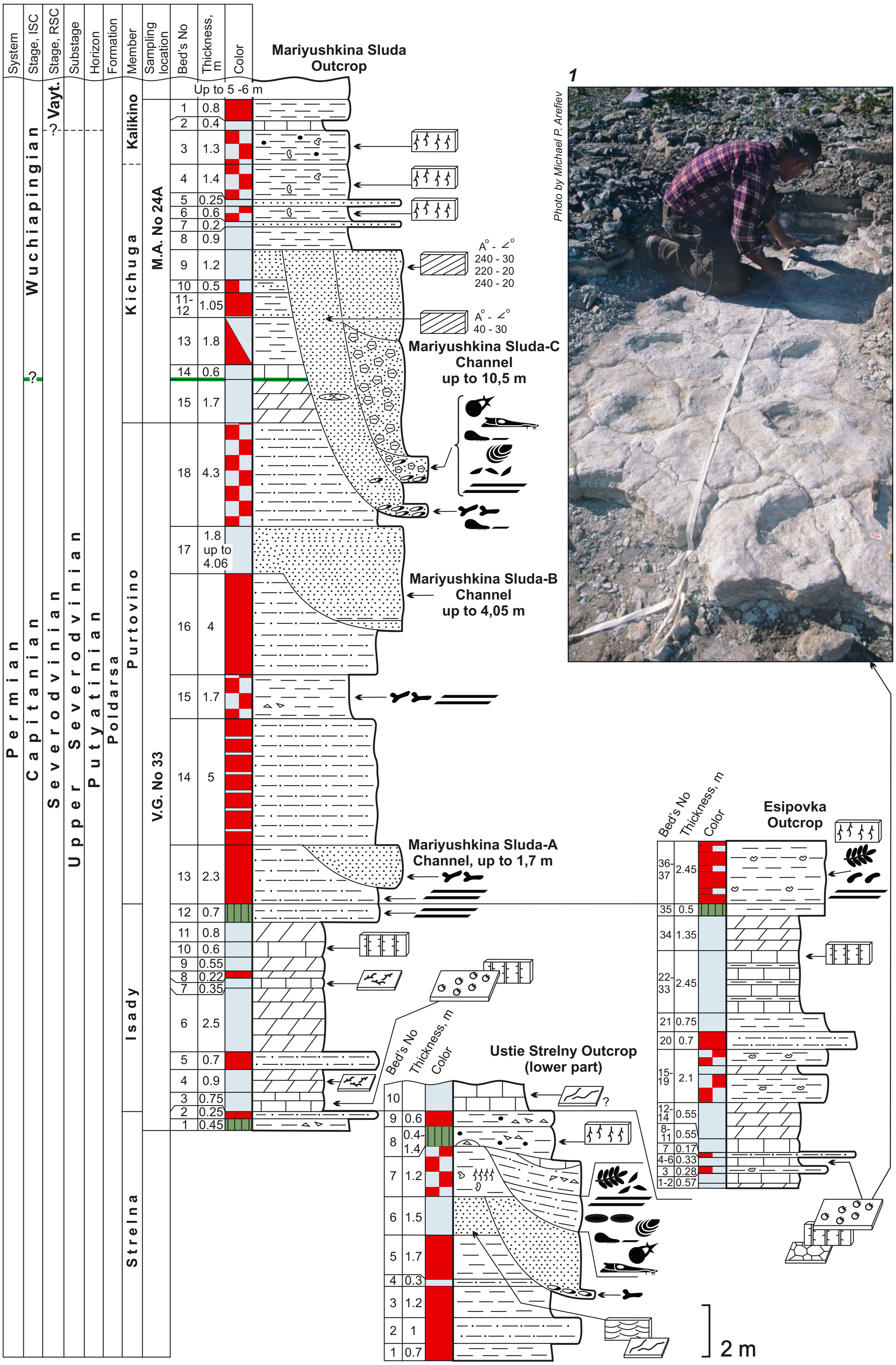


Fig. 12. Mariyushkina Sluda, Ustie Strelny, and Esipovka sections with lithological and paleontological data.
1 – footprints of *Sukhonopus primus* Gubin et Bulanov.

Location: right bank of the Strelna River in 0.5 km upstream of Gorodok site.

Coordinates, WGS 84: N 60.58895°, E 45.53205°

Stratigraphy. Upper Severodvinian. Capitanian-Wuchiapingian transition.

The following beds have been recognized above the water level (from bottom to top), site V.G. No. 33 (fig 12).

POLDARSA FORMATION

Strelna Member

1. Clay, bluish dark green, massive, friable, calcareous, with numerous lenses of coarse clay. Apparent thickness 0.45 m.

2. Siltstone, brownish pink, wave-like laminated. Thickness 0.16-0.25 m.

Isady Member

3. Limestone, greenish grey, flaggy, indistinctly horizontal-laminated, with autochthonous plant roots *Radicites sukhonensis*, with tetrapod footprints *Sukhonopus primus*. Numerous tetrapod footprints are exposed on the left bank of the Sukhona River in Esipovka outcrop (Figs. 12, 14). Thickness 0.69-0.75 m.

4. Marl, light grey with greenish mottles and streaks, massive. Thickness 0.9 m.

5. Siltstone, brown red, horizontal or cross-laminated, with weak sandy or clayey interbeds, with thin (up to 15 cm) long (up to 100 m) lenses of gravelstone grey and brown red, calcareous. Thickness 0.7 m.

6. Marl, grey, horizontal-laminated or massive. Thickness 2.5 m.

7-11. Alternation of marl and limestone. Marl, light grey, pink, horizontal-laminated. Limestone, dark grey, massive, thin-platy, with green clay streaks (plant roots). Thickness 2.52.

12. Siltstone, green, dark green, massive, with plant fossils in the upper part of the bed, with interbed (28 cm) of dark grey limestone and cherry-red grey marl. Thickness 0.7 m.

Purtovino Member

13. Siltstone, cherry-red dark brown, massive, clayey, weak sandy in the upper part of the bed, with plant and fish fossils. In the uppermost part of the bed (0.2 m) the rock transit into bluish grey with brown mottles, horizontal-laminated, very fine sandstone, with lens (up to 1.7 m thick, up to 30 m long) of reddish greenish yellow, cross-laminated, fine, polymictic sandstone, with rare tetrapod bones. Thickness 2.3 m.

14. Siltstone, brown red with grey, bluish grey and pink interbeds, in upper part of the bed clayey, reddish dark brown, massive. Thickness 5.0 m.

15. Clay, pink with bluish grey mottles, massive or horizontal-laminated, silty. Tetrapods, plants. Thickness 1.7 m.

16. Siltstone, brown red, horizontal-laminated. Thickness 4.0 m.

17. Sandstone, bluish green grey, massive, fine, clayey. Thickness 1,85 m.

18. Siltstone, red, with thin bluish horizontal interlayers, horizontal-laminated. Thickness 4.3 m.

Several hundred meters downstream, site M.A. No. 24A, the following deposits overlie bed VG33/18:

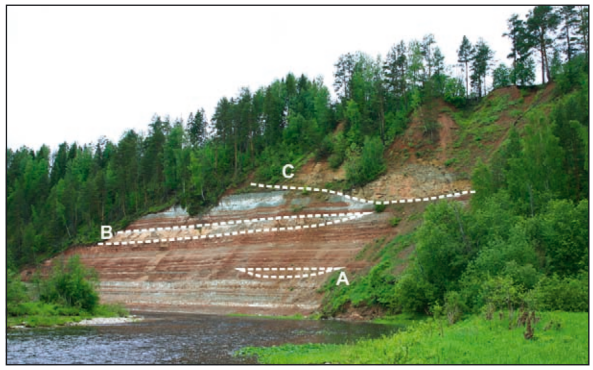


Photo by Valeryi V. Bulanov

Fig. 13. Mariyushkina Sluda section on the Strelna River contains three fluvial channels.

Kichuga Member

15. Marl, greenish with brown interbed. Thickness 1.7 m.

14. Limestone, greenish grey with interbeds of marl in the middle part of the bed. Thickness 0.6 m.

13-11. Clay, red, weak sandy. Thickness 2.85 m.

10. Alternation of sandstone and clay, thickness of interbeds 4-7 cm. Sandstone, greenish, clayey. Clay, brown, weak sandy. Thickness 0.5 m.

9. Sandstone, greenish bluish, clayey. Thickness 1.2 m.

The thickness of bed 9 increases north-east. The bed cuts into the underlying deposits to bed VG33/18 and forms a large sand lens. The north-eastern basal part of the lens is gently sloping; the south-western part is steeper. Fossils of bivalves, fishes and tetrapods were found in the lens deposits. Fishes (locality of Strelnia): *Toyemia tverdochlebovi* Minich, *Strelnia certa* A.Minich, *Mutovinia stella* Minich, *Geryonichthys longus* A.Minich, *Sludalepis spinosa* A.Minich, *Plotnikovichthys gorodokensis* A.Minich. Tetrapods (locality of Mariyushkina Sluda-C): *Chroniosaurus levis* Golubev, *Sludica bulanovi* Ivachnenko, *Dvinosaurus* sp., *Pareiasauridae* gen. indet., *Gorgonopia* fam. indet.

8. Clay, greenish bluish, sandy. Thickness 0.9 m.

7. Sandstone, greenish bluish, clayey. Thickness 0.2 m.

6. Clay, pink, variegated, with numerous plant roots. Thickness 0.6 m.

5. Sandstone, greenish bluish, very fine, friable. Thickness 0.25 m.

4. Clay, variegated, whitish, with autochthonous plant roots *Radicites erraticus*. Thickness 1.4 m.

3. Clay, variegated, red with bluish mottles, with calcareous nodules, with autochthonous plant roots *Radicites erraticus*. Thickness 1.3 m.

Kalikino Member

2. Limestone, dirty grey, pink. Thickness 0.4 m.

1. Clay, red. Apparent thickness 0.8 m.

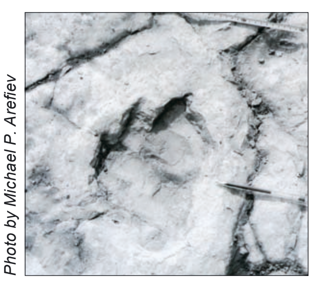


Photo by Michael P. Arefiev

Fig. 14. Footprint *Sukhonopus primus* Gubin et Bulanov, Esipovka Locality.

Mutovino (=Isady) Outcrop

Severodvinian-Vyatkian boundary-stratotype section

Location: The left bank of the Sukhona River in 0.6 km downstream of the village of Purtovino.

Coordinates, WGS 84: N 60.61463°, E 45.6194°

Stratigraphy. The Mutovino section was accepted as the boundary-stratotype and hypostratotype of the Vyatkian Stage, Tatarian Series, Permian System. The lower boundary of the Vyatkian Stage was fixed at the base of bed 75 (Commission on the Permian..., 2006). The R_2P and N_2P magnethic orthozones boundary occurs at the bottom of bed 65a. Based on magnetostratigraphic and chemostratigraphic data, the lower boundary of the Lopingian Series and Wuchiapingian Stage is located in the lower part of Kichuga Member, i.e. in the upper part of the Upper Severodvinian.

The following beds have been recognized above the water level (from bottom to top) (Figs.15, 16):

POLDARSA FORMATION

Isady Member

1a. Sandstone, greenish-grey, fine-grained, quartz, cross-bedded. Thickness 0.8 m.

1b. Clay, brown with pale-bluish spots, massive, silty, weakly calcareous, with small bluish-grey streaked, possible, formed over the plant roots of plants.Thickness 0.4-0.75 m.

2. Clay calcareous, grey, massive, strongly. Thickness 0.6-0.7 m.

3. Limestone, grey, with green interbeds, massive, thick-platy, strong, with small thin plant root voids, with interbeds and lenses of clayey limestone, purple silty clay, and grey massive calcareous clay. Ostracods: *Prasuchonella stelmachovi* (Spizharskyi), *P.* cf. *stelmachovi* (Spizharskyi), *Suchonellina parallela* Spizharskyi, *S. inornata* Spizharskyi, *S.* cf. *inornata* Spizharskyi, *S.* sp., *Darwinuloides* cf. *sentjakensis* (Sharapova), *Permiana cf. oblonga* (Posner), *Sinusuella* cf. *ignota* Spizharskyi. Thickness 2.5-2.75 m.

Purtovino Member

4-7. Clay, dark grey, with a cherry tinge, massive, calcareous, with grey worm-shaped streaks (plant roots), with interbeds (up to 0.1 m thick) of grey massive limestone with brown streaks. Charophyta. Bivalve. Ostracods: *Darwinuloides* cf. *sentjakensis* (Sharapova), *Permiana cf. oblonga* (Posner), *Prasuchonella stelmachovi* (Spizharskyi), *Sinusuella ignota* Spizharskyi, *S.* cf. *ignota* Spizharskyi, *S.* sp., *Suchonellina inornata* Spizharskyi, *S. parallela* Spizharskyi, *S.* sp. Thickness 0.67-0.8 m.

8. Siltstone clayey, grey, massive. Thickness 0.5-0.6 m.

9-13. Clay calcareous, dark brown with green spots, massive; in the lower part of the bed (0.15 m), with an interbed of grey-green massive clayey limestone with plant root voids; in the upper part of the bed, with an interbed of massive calcareous clay with fine brown–red intertwining streaks (0.35 m). Thickness 1.43-1.70 m.

14. Clay, reddish brown with green polka dots (sporadic regularly circular spots up to 10 mm in diameter, representing gleization areas around organic detritus), massive, nonplastic, silty. Bivalve. Ostracods: *Suchonellina* sp., *Prasuchonella* sp. Fishes. Tetrapods: Chroniosuchidae gen.indet., Pareiasauridae gen.indet. Thickness 1.45-1.85 m.

15. Siltstone, grey-brown, with irregular dull greenish mottles, massive, clayey, 1.3-1.45 m thick.

16-20. Alternation of clays: (1) pink, thin-layer, strongly calcareous clay and (2) red-brown clay with sparse green polka dots up to 10 mm in diameter, massive, weakly silty. Thickness 1.45 m.

21. Clay, grey, with a bluish tint in the outcrop, thin-layer horizontally, nonsilty. The lower boundary of the bed is sharp. Ostracods: *Prasuchonella stelmachovi* (Spizharskyi), *Suchonellina parallela* Spizharskyi, *S. futschiki* (Kashevarova), *S.* sp., *Sinusuella* cf. *ignota* Spizharskyi. Thickness 0.65-0.8 m.

22. Siltstone, grey, light brown-grey, undulating laminated, with desiccation cracks, with remains of the plants *Tatarina* sp., *Permotheca* sp., *Phyllododerma* sp., *Taeniopteris* (?) sp., *Samaropsis* sp., *Carpolithes* sp. Thickness 0.8-1.1 m.

23. Clay, red-dark brown, massive. Thickness 0.2-0.6 m.

24. Clay, light grey, bluish grey, with many thick light brown interbeds in the lower part and spots in the upper part of the bed, fine-undulating laminated, with silty interbeds. Thickness 0.55-0.65 m.

25. Clay, red-brown, with greenish grey spots, massive, indistinctly horizontal-laminated in the upper part of the bed, slightly silty, calcareous. Thickness 1.6-1.7 m.

26. Sandstone, grey, horizontal-laminated, feldspar-quartz, very fine-grained, thin-platy. Thickness 0.5-0.6 m.

27-36. Siltstone, red-brown, with beige and grey spots and interbeds and areas and interbeds with dark grey and brown streaks (plant roots), massive or indistinctly horizontal-laminated, sandy and clayey. There are interbeds of sandstone (up to 0.4 m thick) and clay (up to 0.4 m thick). Grey, greyish green, beige, light brown, brown sandstone,

Fig. 15. Mutovino Outcrop. A – Capitanian–Wuchiapingian boundary, B – Severodvinian–Vyatkian boundary, C – eastern part of the Mutovino Channel.

with vertical, short, light grey streaks (plant roots), horizontal-laminated, very fine-grained, friable, with desiccation cracks filled with dark brown clay. Brownish grey and red-brown clay, with indistinct dark grey spots and stains, with short worm-shaped streaks of red-brown (diameter less than 1 mm) and dark grey (more than 1 mm in diameter) colour (plant roots), massive, nonplastic, silty, calcareous, with a weak bituminous smell. The middle part of bed 36 shows channels of even width (up to 8 mm), rounded in cross section, filled with light grey loose sand and outlined by a 2-mm-wide gleization zone of greenish dark brown colour. Ostracods: *Suchonellina parallela* Spizharskyi, *S. futschiki* (Kashevarova), *S.* ex gr. *spizharskyi* (Posner), *Prasuchonella stelmachovi* (Spizharskyi), *Sinusuella* aff. *ignota* Spizharskyi. Thickness 3.7-3.9 m.

37-43. Clay, brown, with distinct rounded greenish grey spots ('polka dots') up to 2 cm in diameter, with grey worm-shaped streaks of plant roots (interbeds), massive, nonplastic, silty (interbeds), with interbeds (up to 20 cm) of beige, massive, nonplastic clay. Ostracods: *Suchonellina* ex gr. *inornata* Spizharskyi, *S* ex gr *parallela* Spizharskyi, *S.* ex gr. *spizharskyi* (Posner), *S. futschiki* (Kashevarova), *Prasuchonella stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Darwinuloides* sp. Thickness 2.6-2.7 m.

Kichuga Member

44-50. Clay, greyish green, with grey and green horizontal streaks of plant roots (up to 1 cm wide, up to three orders of branching), horizontal-laminated, nonplastic, calcareous, with interbeds (up to 0.5 m thick) of beige grey, grey-green, undulating laminated, moderately strong, clayey, thinly platy limestone, with subvertical plant root voids (up to 2 cm in diameter), often filled with green loose clayey mass or calcite crystals. Ostracods: *Prasuchonella* cf. *stelmachovi* (Spizharskyi), *P.* sp., *Suchonellina* sp., *Sinusuella* sp. Thickness 1.95 m.

51-57. Clay red-brown, massive in the lower part and horizontal-laminated in the upper part, silty (content of the clastic fraction increases towards the upper boundary of the bed), nonplastic. Ostracods: *Sinusuella* sp. Thickness 2.2-2.1 m.

58-63. Interbedding clay and sandstone. Red-brown, massive or indistinctly horizontal-laminated, unevenly silty and sandy, nonplastic clay, with interbeds with thick grey streaks of plant roots. Grey-green, horizontal-laminated, very fine-grained, oligomictic, friable sandstone. Thickness 1.05-1.80 m.

64. Sandstone, grey-green, massive to thinly laminated and gently cross-laminated, very fine- to fine-grained, oligomictic, friable. Interbeds are of stronger, platy sandstone, with many fine plant root voids (less than 1 mm in diameter). Some interbeds are several centimeters thick, with interbedding principal rock of the bed and red-brown clay with fine streaks and channels of plant roots. Bivalve. Ostracods: *Clinocypris* sp., *Prasuchonella stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Suchonellina inornata* Spizharskyi, *S.* ex gr. *inornata* Spizharskyi, *S. parallela* Spizharskyi. Thickness 2.25-2.30 m.

The bed 64 increases in thickness upstream from the place described and forms the large lens (channel) of sand, clay, and siltstone deposits, containing abundant fossil plant remains, ostracods, conchostracans, insects, bivalves, fishes, and tetrapods. This site is referred to by the names Mutovino, Isady, and Purtovino (Edemsky, 1928; Efremov and Vjuschkov, 1955; Olferiev, 1974; Reference Section…, 1981; Upper Permian…, 1984; Gomankov and Meyen, 1986; Minikh and Minikh, 1989, 2009, 2014; Verzilin et al., 1993; Ivakhnenko et al., 1997; Golubev, 1998, 2000; Tatarian beds…, 2001; Aristov et al., 2013). The lens is asymmetrical: the western basal part is gently sloping; the eastern part is steeper. At the level of its maximum thickness, the lens cuts into the underlying deposits to bed 24. It is formed mostly of fine rocks: clay, siltstone (prevailing), and very fine- to fine-grained sandstone. The deposits are variegated. Grey deposits prevail. Red and brown rocks are rare, represented mostly by clays. Yellow deposits, strongly carbonaceous siltstones and conglomerates, are much more widespread. In some areas rocks are pyritized and include numerous carbonized wood fragments. Ostracods: *Prasuchonella stelmachovi* (Spizharskyi), *Prasuchonella* ex gr. *stelmachovi* (Spizharskyi), *Si-*

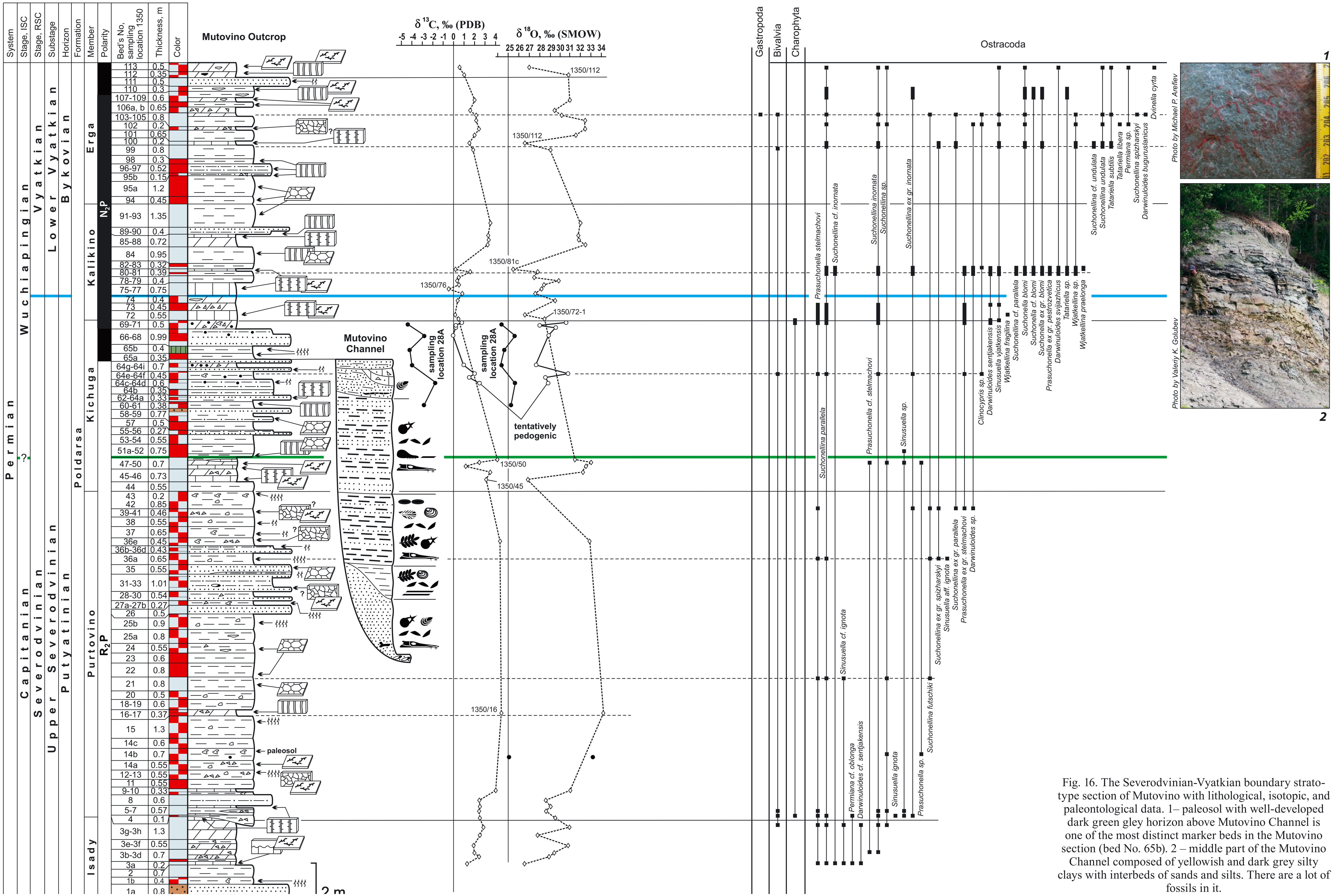


Fig. 16. The Severodvinian-Vyatkian boundary stratotype section of Mutovino with lithological, isotopic, and paleontological data. 1– paleosol with well-developed dark green gley horizon above Mutovino Channel is one of the most distinct marker beds in the Mutovino section (bed No. 65b). 2 – middle part of the Mutovino Channel composed of yellowish and dark grey silty clays with interbeds of sands and silts. There are a lot of fossils in it.

nusuella ignota Spizharskyi, *S. vjatkensis* (Posner), *Suchonellina inornata* Spizharskyi, *S. parallela* Spizharsky, *S. undulata* (Mishina), *S.* ex gr. *futschiki* (Kashevarova), *S.* ex gr. *spizharskyi* (Posner). Bivalves: *Palaeomutela subparallela* Amalitzky, *P. verneuili* (Amalitzky), *P. semilunulata* Amalitzky, *Palaeanodonta novoculchumica* (Kuloeva), *P.* ex gr. *trapezoidalis* (Amalitzky), *Opokiella tschernyschewi* Plotnikov. Fishes: *Toyemia tverdochlebovi* Minich, *Toyemia* sp., *Mutovinia stella* Minich, *Isadia suchonensis* A.Minich, *Isadia* ex gr. *suchonensis* A.Minich, *Isadia aristoviensis* A.Minich, *Isadia* sp., *Strelnia certa* A.Minich, *Strelnia* (?) sp., *Varialepis* ex gr. *stanislavi* A.Minich, *Geryonichthys* sp., Eurynotoidiidae gen. indet. Tetrapods: *Chroniosaurus levis* Golubev, *Dvinosaurus* aff. *primus* Amalitzky, *Microphon* sp., *Microphon arcanus* Bulanov, Gorgonopidae gen. indet., Pareiasauridae gen. indet.

65a. Clay, reddish brown, with sporadic, fine, short grey streaks of plant roots, indistinctly horizontal-laminated, nonplastic, strongly silty, with an interbed (1 cm thick) of greyish green, very fine-grained sandstone. Thickness 0.3-0.5 m.

65b-66. Clay, dark green, with numerous red spots and, in the upper part, also with fine red worm-shaped streaks of plant roots, massive, nonplastic, silty, with interbeds (up to 4.5 cm thick) of greenish grey, massive, very fine-grained, oligomictic sandstone. Thickness 0.2-0.55 m.

67. Sandy siltstone, orange red, brownish red, brown, indistinctly undulating-laminated, frail,, alternating basally with beige very fine-grained sandstone. Thickness 0.35-0.85 m.

68. Sandstone mixed with clay; in the lower part of the bed, grey-light brown; in the upper part grey-green, with primary lamination interrupted by post-sedimentary processes, very fine-grained, with streaks and interbeds of clay, which is dark brown and greenish grey (relicts of the former clayey layers), oligomictic, moderately strong, with beige and grey obscure, poorly visible streaks of plant roots varying in size and thickness. Thickness 0.15-0.35 m.

69. Marl, pink-grey, purple grey, brownish grey, massive, detrital, with well-rounded gravel of dark brown and, considerably less often, greenish dark grey clay, with sporadic horizontal green streaks of plant roots, moderately strong; the lower boundary of the bed is sharp, undulating. Thickness 0.15-0.25 m.

70. Marl grey, detrital, with a tinge of purple, massive or with indistinct discontinuous undulate lamination, with rare gravel-scale clasts of dark brown and beige brown marl, with numerous horizontal flat broad clayey streaks (plant roots), moderately strong; the lower boundary of the bed is sharp, undulate Thickness 0.15-0.20 m.

71. Marl pink-brown, with beige brown and dark brown mainly horizontal streaks of plant roots, indistinctly horizontal-laminated, unevenly calcareous (in some areas, with transitions into pink-dark brown clay; with the carbonate content increasing upward in the section), moderately strong; the lower boundary of the bed is hardly visible, drawn across the line where underlying rocks of fragmentary texture disappear. Ostracods: *Prasuchonella stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Suchonellina parallela* Spizharskyi, *S. inornata* Spizharskyi, *Sinusuella vjatkensis* (Posner), *Darwinuloides sentjakensis* (Sharapova). Thickness 0.10-0.25 m.

Kalikino Member

72. Limestone clayey, purple grey, undulating laminated, unevenly; in some areas, strongly clayey, grey-purple, undulating laminated, frail, can be crumbled by hand; in some areas, mostly in the upper part of the bed, weakly clayey, grey, massive, very strong, with fine vertical plant root voids. The lower boundary of the bed is gradual. Ostracods: *Prasuchonella stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Suchonellina inornata* Spizharskyi, *S. parallela* Spizharskyi, *Sinusuella vjatkensis* (Posner), *Darwinuloides sentjakensis* (Sharapova), *Wjatkellina fragilina* (Belousova). Thickness 0.45-0.55 m.

73. Clay, grey-dark brown, brown-grey, dark grey, red-brown (colours with irregularly sharp gradual transitions between them, giving the rock a pale, not bright, unclear aspect), massive, nonplastic, with a dense network of fine beige streaks of plant roots and thick (up to 2 mm) vertical plant root voids, filled with a bright green loose clayey mass. The lower boundary of the bed is indistinct. Charophyta. Ostracods: *Suchonellina inornata* Spizharskyi, *S. parallela* Spizharskyi, *Prasuchonella stelmachovi* (Spizharskyi), *P.* ex gr. *stelmachovi* (Spizharskyi), *Sinusuella vjatkensis* (Posner), *Darwinuloides sentjakensis* (Sharapova). Thickness 0.15-0.45 m.

74. Clay, brown, with greenish dark grey large (centimeter-scale to decimeter-scale) shapeless inexpressive pale spots, with massive, silty, nonplastic streaks formed by plant roots (vertical: bright brown, fine, long; horizontal: brown and greyish green). At the base of the bed, clay is grey-green. The lower boundary of the bed is moderately expressed, with parting. Thickness 0.4-0.45 m.

75-82. Interbedding limestone and clay. Limestone, grey, with a greenish tinge, with green horizontal streaks of plant roots, with fine dark green clayey interbeds, massive or undulating laminated, clayey, with horizontal and vertical weakly tortuous plant root voids (up to 4 mm in diameter), moderately strong. Greenish grey clay, with horizontal brown and green, undulating laminated, unevenly calcareous (in some areas with transition to marl), nonplastic, silty streaks of plant roots. Ostracods: *Clinocypris* sp., *Darwinuloides sentjakensis* (Sharapova), *Darwinuloides svijazhicus* (Sharapova), *D.* cf. *svijazhicus* (Sharapova), *D.* sp., *Prasuchonella* ex gr. *pestrozvetica* (Starozhilova), *P.* ex gr. *stelmachovi* (Spizharskyi), *Suchonella blomi* Molostovskaya, *S.* cf. *blomi* Molostovskaya, *S.* ex gr. *blomi* Molostovskaya, *Suchonellina inornata* Spizharskyi, *S.* cf. *inornata* Spizharskyi, *S.* ex gr.*inornata* Spizharskyi, *S. parallela* Spizharskyi, *S.* cf. *parallela* Spizharskyi, *S.* sp., *Sinusuella vjatkensis* (Posner), *S.* cf. *vjatkensis* (Posner), *Tatariella* sp., *Wjatkellina praelonga* (Zekina), *W.* sp. Thickness 1.5-1.7 m.

83-90. Clay, grey, greenish grey, with purple grey, thin-horizontal-laminated (seasonal) or massive (in the lower part of the rock matter), nonplastic, calcareous, silty to a varying extent (non-silty interbeds are darker) interbeds. The upper part contains a greenish grey, horizontal-laminated marl layer (14 cm thick), with a varying extent of carbonate content (from calcareous clay below to clayey limestone above), with small (millimeter-scale) caverns and subvertical channels (up to 9 mm in diameter, on average 4-5 mm) formed by plant roots, confined to the upper, more calcareous part of the bed. The bed roof contains greenish grey, massive, very fine-grained, oligomictic sand (10 cm thick). Thickness 2.15-2.2 m.

91-93. Clay, green-grey, with cyclic stripes. In cyclites, colours replace each other upward in the section as follows: light grey, beige, greenish grey, grey-green, dark grey, greenish dark grey. The transition from light to darker types of clay (within each cyclite) is extremely gradual, while the transition from dark to light types (boundaries between cyclites) is sharp. The cyclites are 1-40 mm thick, on average 3-4 mm thick. Clay ranges from pure (dark interbeds) to strongly sandy-silty (light interbeds), calcareous, nonplastic. In the upper part of the strata, the tinge of green in dark interbeds is gradually replaced by tinge of brown, and desiccation crack appear. Thickness 1.3-1.35 m.

Erga Member

94-95. Clay, brown, horizontal-laminated, silty, nonplastic, similar in structure to beds 91-93. The proportion of grey layers decreases upwards in the section; the lamination becomes thicker and discontinuous; in some interbeds the rock looks massive; the number of desiccation cracks increases. Dark brown, regularly circular spots 5-8 mm in diameter frequently occur on the surfaces of layers; they are distinctly visible against the beige background of the base rock, but are usually impossible to trace deep into the rock. The lower boundary is unsharp. Thickness 1.8 m.

96-98. Clay, orange brown, massive, nonplastic, strongly silty, interbeds with lighter streaks around fine (less than 1 mm in diameter) channels (? plant roots), at the base and at the top with a transition to clayey siltstone. The lower boundary is sharp. Thickness 0.85 m.

99. Clay greenish grey, with a tinge of brownish in the lower part of the bed, with fine (less than 1 mm), short (one or several centimeters) horizontal weakly wavy brown-red streaks, very indistinct thin-undulating laminated, almost massive, almost nonsilty, calcareous. Bivalve. Ostracods: *Sinusuella vjatkensis* (Posner), *Suchonella blomi* Molostovskaya, *Suchonellina* ex gr. *spizharskyi* (Posner), *S.* ex gr.*parallela* Spizharskyi, *S. inornata* Spizharskyi, *S. parallela* Spizharskyi, *S. undulata* (Mishina), *Tatariella subtilis* Mishina. Thickness 0.8 m.

100. Limestone, dark grey, massive, in places, with relict discontinuous horizontal undulating lamination, strong, with plant root voids, which are filled with a greenish beige loose clayey matter. At the top of the bed, clayey, not strong, loose, platy. The lower boundary of the bed is indistinct. Ostracods: *Sinusuella vjatkensis* (Posner), *S. blomi* Molostovskaya,*Suchonella* ex gr. *blomi* Molostovskaya, *Suchonellina* cf. *undulata* (Mishina), *S. inornata* Spizharskyi, *S. parallela* Spizharskyi, *Wjatkellina* sp. Thickness 0.2-0.22 m.

101. Clay, grey-green, with brownish spots and interbeds, horizontal-laminated (as in bed 91, but bedding is less pronounced and often discontinuous), silty to a varying extent; in the lower part of the bed (20 cm thick), with interbeds with fine marl gravel. Thickness 0.65-0.70 m.

102-105. Clay, grey, with a tinge of greenish, with red, fine intertwining massive, nonplastic, calcareous streaks. Bivalve. Gastropods. Ostracods: *Clinocypris* sp., *Darwinuloides buguruslanicus* Kashevarova, *D.* sp., *Permiana* sp., *Suchonellina parallela* Spizharskyi, *S.* ex gr. *parallela* Spizharskyi, *S. spizharskyi* (Posner), *S. futschiki* (Kashevarova), *S. inornata* Spizharskyi, *S. undulata* (Mishina), *S.* sp., *Tatariella* cf. *subtilis* Mishina, *T. libera* Mishina, *Suchonella blomi* Molostovskaya, *Sinusuella vjatkensis* (Posner), *Wjatkellina* sp. Thickness 0.95-1 m.

106-108. Clay, red-brown, with small, short tortuous beige streaks of plant roots in the upper part, massive, nonplastic, with silty interbeds. Ostracods: *Suchonellina* ex gr.*inornata* Spizharskyi, *Suchonella blomi* Molostovskaya, *S.* ex gr. *blomi* Molostovskaya. Thickness 0.95-1.1 m.

109. Clay, red-brown, with many pale-bluish different shapes spots, massive, silty, calcareous, with traces of invertebrate. Ostracods: *Suchonella blomi* Molostovskaya, *S.* sp., *Suchonellina* cf. *inornata* Spizharskyi, *S.* ex gr. *inornata* Spizharskyi, *S. parallela* Spizharskyi, *S.* ex gr.*parallela* Spizharskyi. Thickness 0.15 m.

110. Clay, red-brown, with pale-bluish spots, similar to bed 109, horizontal-laminated, calcareous, with vertical traces of invertebrate, with allochthonous plant roots in the lower part of the bed and autochthonous plant roots in the upper part of bed. Ostracods: *Suchonella* cf. *blomi* Molostovskaya, *Suchonellina* cf. *inornata* Spizharskyi, *Tatariella* sp. Thickness 0.3 m.

111. Sandstone, greenish grey, fine-grained, indistinct horizontal-laminated, platy calcareous, with thin autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 0.5 m.

112. Marl clayey, greenish grey with numerous pale-pink spots, strong silt, with rare vertical traces of invertebrates, and numerous plant roots. Thickness 0.35 m.

113. Marl, pale pink, brown-pink with a light greenish, greenish-grey in the upper part yellowish spots, massive or indistinct horizontal-laminated, with allochthonous plant roots. Bivalve. Ostracods: *Suchonella blomi* Molostovskaya, *Darwinuloides svijazhicus* (Sharapova), *Sinusuella* cf. *vjatkensis* (Posner), *Suchonellina parallela* Spizharskyi, *S. undulata* (Mishina), *S. inornata* Spizharskyi, *S.* sp., *Permiana* sp., *Dvinella cyrta* (Zekina), *Tatariella subtilis* Mishina. Thickness 0.5 m.

Further upwards, to the bank line, the area is soddy; 1.5 m of thickness.

Mys Byk and Konyavitsa Outcrops

Location: left bank of the Sukhona River between Pecherza village and the mouth of the Verkhnyaya Erga River.

Coordinates, WGS 84: Mys Byk outcrop – N 60.6602°, E 45.71853°; Konyavitsa outcrop – N 60.65256°, E 45.706°.

Stratigraphy. Severodvinian-Vyatkian and Capitanian-Wuchiapingian transitions. Based on correlation with the Mutovino section, the Severodvinian-Vyatkian boundary corresponds to the bottom of bed 38; the Capitanian-Wuchiapingian boundary is located at the base of bed 25.

Konyavitsa outcrop; the following units have been recognized above the water level (from bottom to top) (Figs 17, 18).

POLDARSA FORMATION

Purtovino Member

Silty clay and silt, brown, reddish brown, light bluish, with two sand interbeds. The first interbed at the base of the outcrop is composed of sand, grey, beige, spotted and with a thickness of 1.5 m. The second interbed at the middle of the Member is composed of sand brownish grey, yellowish grey, pale bluish, with a total thickness of 6.65 m. In the southwest direction, the sands become mostly yellow; they include lenses, folded thin interbeds of greenish-grey sands, silts and silty clays with plant remains, ostracods and conchostracans.

Fig. 17. Mys Byk outcrop is one of the most magic place on the Sukhona River.

In the northeast direction, in the Mys Byk outcrop (Fig. 18) the Member becomes more carbonate-rich. It is composed of light-grey marl, clay and limestone. Red-coloured clays, silts and sands are present to a much lesser extent. The deposits include lenses of oncolite conglomerate (0.25-2.6 m thick). Oncolites are mainly formed around the valves and shells of bivalves (Fig. 18, photo 1), up to 5 cm long. In a layer they are oriented mostly horizontally, often in close contact with each other, in a carbonate silty-clay matrix.

Apparent thickness 21.35 m.

Kichuga Member

Marl, light grey, with lenses of limestone. Terrigenous unit of red clay, dark brown silt and greenish-grey sand composes the middle part of the Member.

In the northeast direction, in the Mys Byk outcrop, terrigenous deposits are also distributed in the upper part of the Member. The role of brown, grey, brownish-grey sand is increases particularly strongly here. Sands reach a total thickness of 3 m.

Thickness 6.0-6.15 m.

Kalikino Member

Mys Byk outcrop

Clay and marl, mostly grey, greenish-grey, horizontal-laminated, with thin limestone interbeds, with interbeds of conglomerate consisting of oncolites formed around the valves and the shells of bivalves at the bottom of the Member. Thickness 7.25 m.

Erga Member

Clays and silts brown, reddish-brown, often distinctly thinly horizontal-laminated, rarely mottled, with mud cracks up to 7 cm deep. Grey-coloured carbonate rocks are represented by thin beds of marl and limestone in the middle part of the Member. Grey and variegated horizontal-laminated sand lies at the top of the outcrop and has a thickness of about 1 m. There are many ostracod fossils throughout the Member. Apparent thickness 8.15 m.

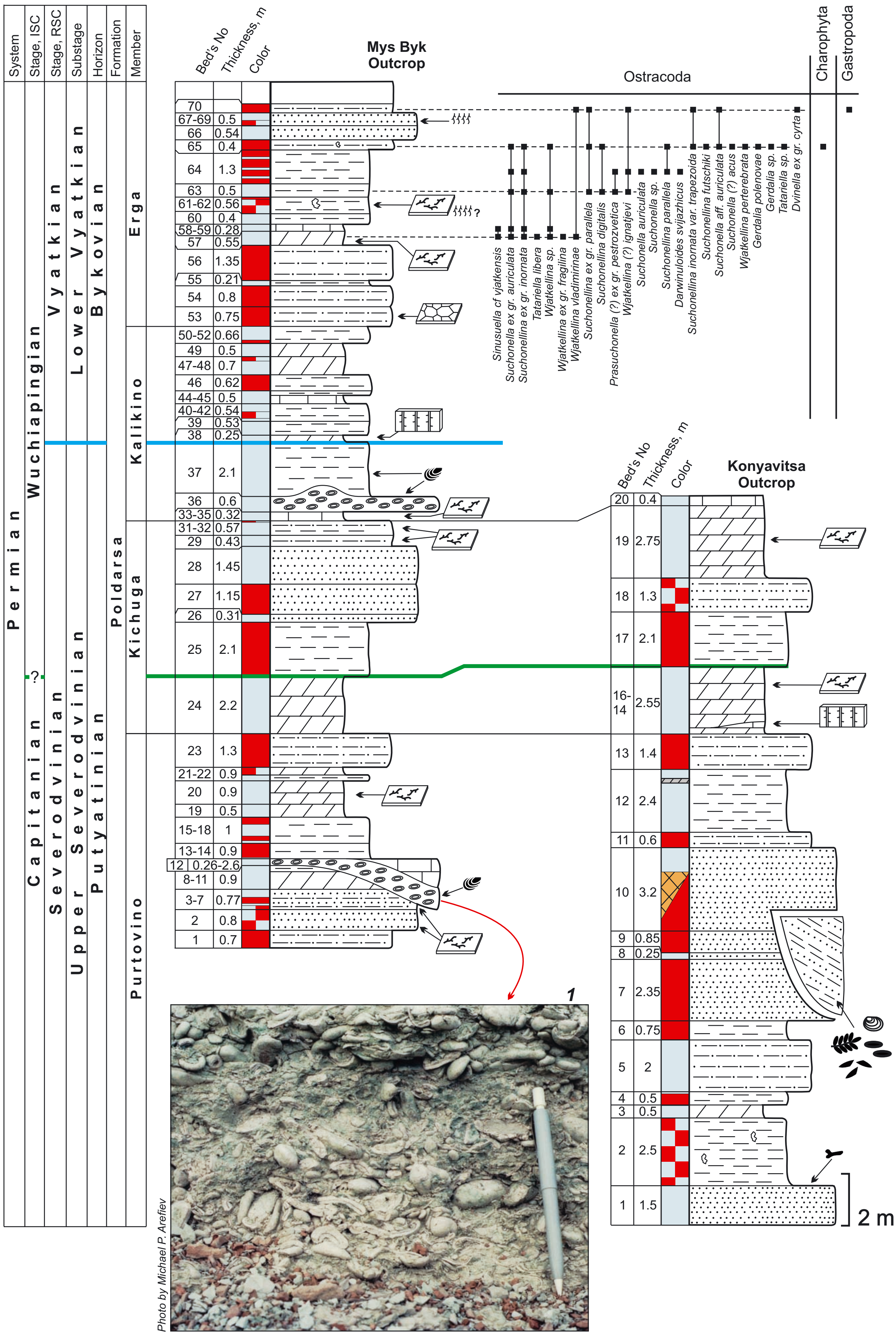


Fig. 18. Mys Byk and Konyavitsa sections with lithological and paleontological data.
1 – oncolites formed around the shells of bivalves.

Klimovo Outcrop

Location: left bank of the Sukhona River opposite Klimovo village.

Coordinates, WGS 84: N 60.67917°, E 45.94677°.

Stratigraphy. Lower Vyatkian (Wuchiapingian).

The following beds have been recognized (from bottom to top) (fig 21).

POLDARSA FORMATION

Erga Member

0. Clay, pink brown, silty, calcareous. Apparent thickness 1.5 m.

1. Clay, light grey, beige in the lower part, calcareous, with pink allochtonous plant roots, with interbed of limestone light grey, with autochthonous plant roots. Thickness 0.65-1.50 m.

2. Clay, brown with bluish mottles, silty, with allochtonous plant roots. Thickness 1.2 m.

3. Clay, variegated, dark brown with dark greenish mottles, massive, silty, with rare small brown streaks, probably, plant root traces. Thickness 1.3 m.

4-6. Clay, brown, light brown, light grey, calcareous, silty, with greenish allochtonous plant roots. In the lower part silt, pale greenish, calcareous. Thickness 0.55-0.70 m.

7. Limestone, grey, with greenish or brownish allochtonous plant roots, with interbed of pink brown, calcareous clay. Thickness 1.15 m.

8-12. Clay, light brown, brown, calcareous, with downward burrows like *Scolithos* isp., with interbed of grey, horizontal-laminated marl. Thickness 0.50-0.75 m.

13-19. Limestone, light grey, horizontal-laminated, thin-platy, with numerous green allochtonous plant roots, with interbeds of clay and marl. Clay, light grey, calcareous, red in the middle part of the bed. Marl, grey (3 cm). Thickness 0.85-1.20 m.

20-21. Clay, red (in the lower part of the bed), dark grey with brown and dark grey mottles (in upper part of the bed), strongly silty, with ostracods, bivalves, gastropods, fishes, and tetrapods. Thickness 0.50-0.55 m.

22. Clay, brownish red, massive, silty, with downward fissures highlighted by bluish haloes. Thickness 1.75 m.

23. Silt, grey, clayey, calcareous, with brown allochtonous plant roots. Thickness 0.2 m.

24. Clay, brown, silty, with downward fissures highlighted by bluish haloes. Thickness 0.8 m.

25. Siltstone, dark grey, strongly calcareous, with transition into bituminous limestone, with numerous plant roots. Gastropods. Ostracods: *Suchonellina inornata* Spizharskyi, *S. parallela* Spizharskyi, *Sinusuella vjatkensis* (Posner), *Dvinella cyrta* (Zekina). Thickness 0.23 m.

SALARYOVO FORMATION

Rovdino Member

26. Clay, red, silty, calcareous. Thickness 0.43 m.

27. Siltstone, light grey. Thickness 0.3 m.

28. Clay, reddish brown, silty, calcareous, with calcareous nodules and concretions. Thickness 0.45 m.

29. Siltstone, light grey, strongly calcareous, with allochtonous plant roots. Thickness 0.4 m.

30. Clay, reddish brown, silty, calcareous. Thickness 1.3 m.

31-32. Clay, dark grey, yellowish grey, with yellowish-dark-grey and black mottles, strongly silty. Gastropods. Ostracods: *Dvinella cyrta* (Zekina), *Darwinuloides svijazhicus* (Sharapova), *Gerdalia* sp., *Suchonellina* sp., *Wjatkellina* sp. Thickness 0.24 m.

33. Clay, brown, horizontal-laminated, silty, calcareous, with fossils of plants, fishes, and tetrapods. Tetrapods: Chroniosuchidae gen.indet., Gorgonopidae gen.indet. Thickness 0.50-0.55 m.

34. Sandstone, brown, very fine, polymictic, clayey, calcareous. Thickness 0.95-1 m.

35. Clay, reddish brown, silty, calcareous. Thickness 0.50-0.65 m.

36. Sand brown, polymictic, very fine, clayey, calcareous. Thickness 0.70-0.93 m.

37-44. Clay, variegated, reddish brown, silty, calcareous, with calcareous nodules, with numerous autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh as thin bluish streaks, with interbeds of silt bluish and greenish brown, reddish brown in the middle part of the interbed, horizontal-laminated. Thickness 2.5-3.3 m.

45. Sand brown, greenish brown, very fine, polymictic. Thickness 0.05-0.15 m.

From the bottom of bed 46, the Klimovo paleosol complex starts. It consists of seven paleosol profiles (Inozemtsev and Targulian, 2010)

Paleosol profile K-1

46. Clay, variegated, reddish brown with bluish mottles, in upper part of the bed yellowish with thin bluish streaks of autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, calcareous, with calcareous nodules. Thickness 0.20-1.1 m.

47. Sand brown, very fine, polymictic, calcareous. Thickness 0-0.4 m.

48-49. Clay, variegated, reddish brown in the lower part and pale bluish in the upper part, with downward bluish mottles, with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, calcareous, with calcareous nodules. Thickness 0.95 m.

50-51. Paleosol profile K-2. Clay, variegated, reddish brown with middle gley mottles in the upper part of the bed, bluish grey, with numerous bluish downward and red mottles in the lower part, silty, calcareous, with calcareous nodules, with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 1.1 m.

52-53. Paleosol profile K-3. Clay, variegated, in the lower part mainly reddish brown, with numerous downward bluish grey mottles, in the lower part mainy bluish grey with small reddish mottles, with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, silty, calcareous, with calcareous nodules. Thickness 0.7 m.

54-55. Paleosol profile K-4. Clay, variegated brownish red with bluish mottles in the lower part, light blue with rare red mottles in the upper part of the bed, silty, calcareous, with calcareous nodules and autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 0.5 m.

56-58. Paleosol profile K-5. Clay, brownish red in the upper part of the bed, variegated with numerous bluish mottles in the lower part, silty, non-calcareous, with calcareous nodules, with rare bluish plant roots *Radicites erraticus* Aref'ev et Naugolnykh, with interbed of dark grey and black clay in the uppermost part of the bed. Thickness 1 m.

59-60. Paleosol profile K-6. Clay, variegated, reddish brown with downward bluish grey mottles in the lower part, light blue with numerous red mottles in the upper part of the bed, silty, calcareous, with bluish streaks of autochthonous plant roots *Radi-cites erraticus* Aref'ev et Naugolnykh, with nume-rous calcareous nodules. Thickness 2.9 m.

61. Paleosol profile K-7. Clay, pinkish red, silty, calcareous, with calcareous nodules. The deposits are the lower horizons of eroded paleosol profile K-7. Thickness 0.5-0.7 m.

Bed 61 terminates the Klimovo paleosol complex.

62. Marl, grey, yellowish grey, in some areas with more dark mottles, bituminous, silty, with allochtonous plant fossils. Gastropods. Ostracods: *Sinusuella vjatkensis* (Posner), *Dvinella cyrta* (Zekina), *Darwinuloides svijazhicus* (Sharapova), *Suchonellina* sp., *Tatariella libera* Mishina. Thickness 0.35-2.70 m.

Gully upstream from Klimovo-2 Channel (N 60.67898°, E 45.9488°), the following deposits overlie bed 62:

63. Clay, brownish red, reddish brown, silty, calcareous, with horizontal burrows *Planolithes isp.* Thickness 0.4 m.

64. Clay, brown, silty, calcareous, with allochtonous thin brown plant roots. Thickness 0.6 m.

65. Silt, brown grey, calcareous, with allochtonous plant roots. Thickness 0.20-0.26 m.

66. Clay, brown, silty, calcareous, with light brown and whitish allochtonous plant roots. Thickness 1.0 m.

67-68. Silt, light brown, strongly clayey, calcareous, thinly horizontal-laminated in the lower part of the bed, with numerous allochtonous plant roots *Radicites* sp. in the upper part of the bed. Thickness 1.3-1.6 m.

69. Clay, variegated, brownish red with pale bluish gley mottles, silty, calcareous, with calcareous nodules, with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Gastropods. Ostracods: *Darwinuloides svijazhicus* (Sharapova), *Suchonellina* sp., *Suchonella* cf. *auriculata* (Sharapova), *Wjatkellina accuminata* (Belousova). Thickness 0.45-0.50 m.

70. Clay, brown, silty, calcareous, with numerous whitish streaks of allochtonous plant roots. Thickness 1.3-1.6 m.

71. Clay, brown, with numerous whitish streaks of allochtonous plant roots. Thickness 2 m.

72. Clay, reddish brown, with bluish grey mottles in the uppermost part of the bed, silty. Thickness 2.3 m.

73. Clay, pinkish red, with rare large gley mottles. Thickness 2.30-2.65 m.

Fig. 19. Prof. Victor O. Targulian stands on a cambisol containing imprints of plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Klimovo pedocomplex (about 9 m in total thickness) marks flash flood sediments.

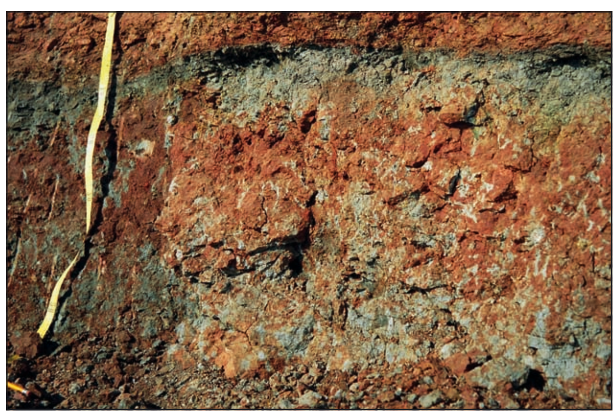
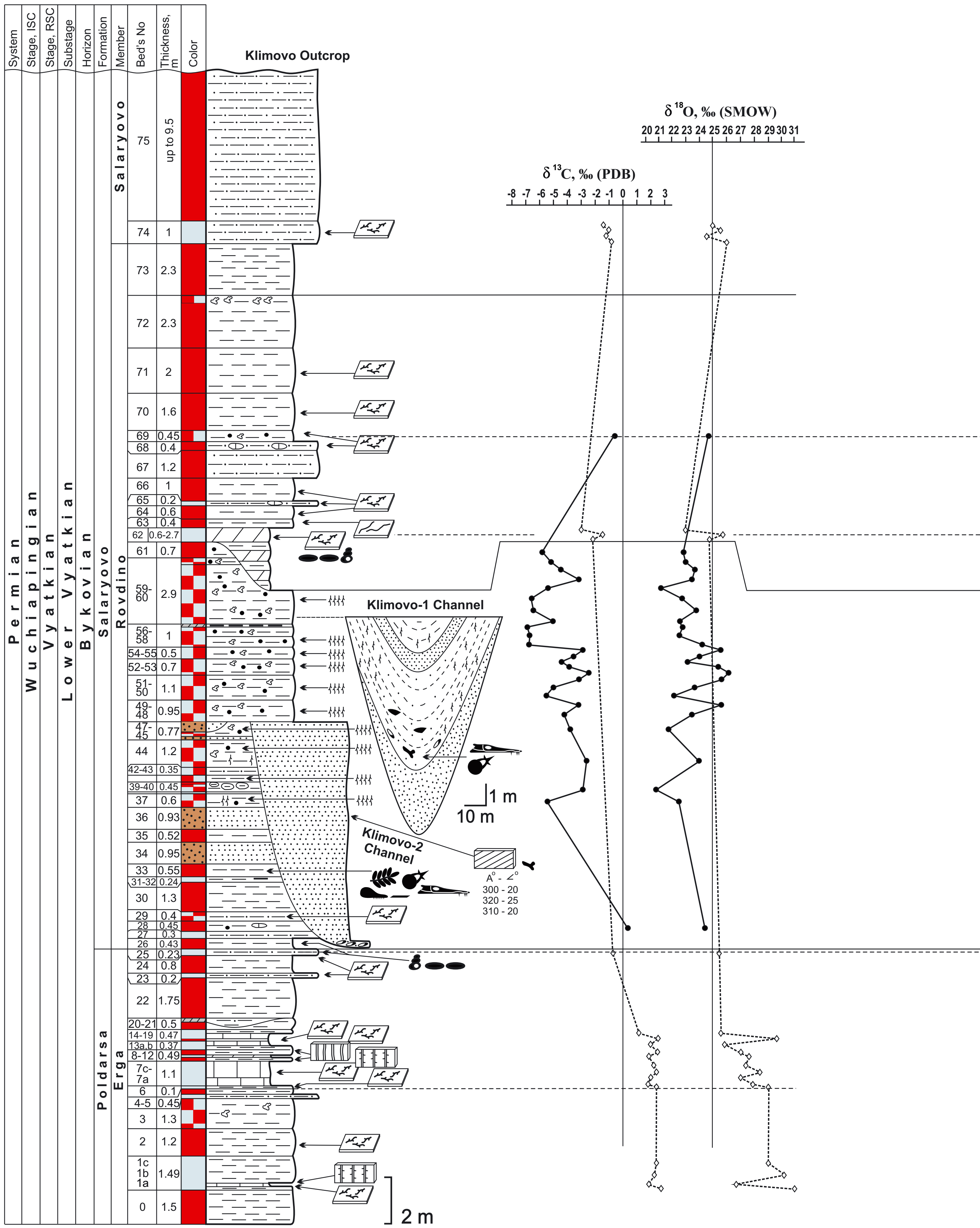
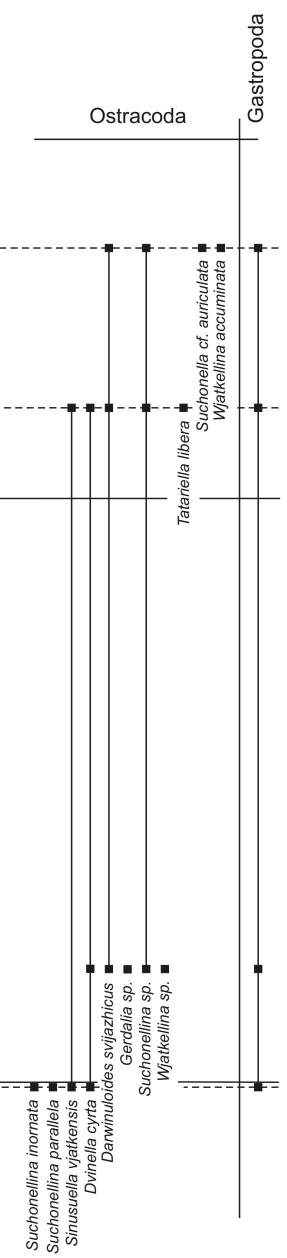


Fig. 20. Mature cambisols with accumulative-eluvial-gley horizon A, enriched C_{org} (dark horizon), Salarevo site, analogue beds No. 57-58 in the Klimovo section.





1

Salaryovo Member

74. Silt, light grey, strongly calcareous, in some areas with transition into siltstone and marl, with numerous brown and yellowish allochtonous plant roots. Thickness 0.6-1.0 m.

75. Silt, brown, very monotonous, calcareous, with cube-shaped quasi-cleavage, forming a vertical wall. Apparent thickness 9.5-9.7 m.

Two alluvial channels are exposed in Klimovo outcrop. Large Klimovo-2 Channel is located in the upstream part of the outcrop. It cuts into the underlying deposits to bed 25. The deposits overlying the channel begin with bed 47. The channel is formed by brown polymictic sandstones with rare cross-series of north-western oblique direction. At the level of the maximum cut of the channel, its lowermost part is composed of gravelstone up to 25 cm thick. The channel is distinctly asymmetrical: the north-western basal part, which is positioned upstream the river, is steeper; the south-eastern part is gently sloping (Fig. 21, photo 1). The maximum thickness of the channel is 10 m.

Klimovo-1 Channel is located more than 200 m downstream from the Klimovo-2 Channel (Fig. 21, photo 2). It cuts into the underlying deposits to bed 35. The top of the channel is located 3.2 m lower than the bottom of bed 62. The channel is complex in structure. It is formed by sandstones, clayey sandstones, with interbeds of silts, clays, including clays with autochthonous plant roots. Sandstones include gravel, phytodetritus, coals, bones of fishes and tetrapod *Dvinosaurus* sp., Chroniosuchidae gen. indet., Pareiasauridae gen. indet., *Leogorgon klimovensis* Ivachnenko, Dicynodontidae gen.indet. The channel is located at the level of the middle part of Klimovo paleosol complex. Sandy interbeds of the channel are alternated with silty and clay ones, which laterally change into the Klimovo paleosol complex. The maximum thickness of the channel is 9.5 m.

2

Fig. 21. Klimovo section with lithological, isotopic, and paleontological data. 1 – Klimovo-1 Channel, length and thickness are about 70 and 9.5 m. 2 – Klimovo-2 Channel, length and thickness are about 200 and 10 m.

Sokolki – Zavrazhie Outcrops

Location: right bank of the Malaya Severnaya Dvina River, 2-6 km upstream from town of Kotlas.

Coordinates, WGS 84: Sokolki outcrop – N 61.1458°, E 46.64396°; Zavrazhie outcrop – N 61.1753°, E 46.63182°.

Stratigraphy. Lower-Upper Vyatkian transition (Changhsingian).

Two large sand lenses (channels) are exposed in a steep river bank for a distance of 4 km. In the late 19th century in the southern lens of Sokolki Pr. Vladimir P. Amalitzky found an abundant Permian fauna of amphibians and reptiles (Figs. 22, 23; photo 2, 47). Several large units of rocks form a sequence here. These units are clearly visible from a distance, and visually traced along the river bank (Fig. 23). The oldest deposits are exposed at the bottom Sokolki outcrop. The following beds are recognized above the water level.

SALARYOVO FORMATION

Salaryovo Member

0. Clay, light grey, bluish grey, strongly calcareous, with brown, red-coloured interbeds, silty, with allochtonous plant roots, with interbeds of marl. The bed is exposed in the Sokolki outcrop. To the north, downstream from this place, it disappears under the river. Apparent thickness up to 5 m.

In Zavrazhie outcrop, the following beds were recognized:

1-5. Clay, reddish brown with bluish grey interbeds and light bluish mottles, calcareous, silty, with lenses and interbeds of light grey silts and clays up to 0.3 m thick, with transition into marl and limestones. Limestone lenses and concretions project distinctly from the river bank wall. Thickness 5.3 m.

Nizhnee Fedosovo Member

6. Clay, light grey, bluish grey, silty strongly calcareous, with transition into marl and limestone, with rare interbeds of red, raspberry-red and variegated silty clay. Limestone with allochtonous and autochthonous plant roots *Radicites sukhonensis* Aref'ev et Naugolnykh, 1988. Thickness 5.5 m.

Komaritsa Member

7-20. Clay, variegated, red with bluish interbeds and mottles, silty, calcareous, with soil calcareous concretions up to 0.4 m in diameter, with autochthonous plant roots *Radicites sukhonensis* Aref'ev et Naugolnykh. In the upper part of the bed interbeds of sand up to 0.2 m thick and interbeds of bluish silt up to 0.8 m thick are located. Apparent thickness up to 19 m.

The Sokolki and Zavrazhie channels cut into the underlying deposits to beds 7-14. They are formed by brown sand with indistinct cross-series. Large sandstone concretions up to 3 m long are located in the Sokolki lens. It is in these concretions that Pr. V.P. Amalitzky found Permian tetrapod skeletons. Tetrapods: *Dvinosaurus primus* Amalitzky, *Kotlassia prima* Amalitzky, *Karpinskiosaurus secundus* Amalitzky, *Chroniosuchus licharevi* Riabinin, *Scutosaurus karpinskii* Amalitzky, *S. tuberculatus* Amalitzky, *Inostrancevia alexandri* Amalitzky, *I. latifrons* Pravoslavlev, *Pravoslavlevia parva* Pravoslavlev, *Dicynodon amalitzkii* Sushkin, *Dicynodon trautscholdi* Amalitzky, *Elph borealis* Kurkin, *Annatherapsidus petri* Amalitzky, *Dvinia prima* Amalitzky. Today in the place of Amalitzky's excavation in the years 1899-1914, a large depression is situated (Fig. 23, photo 1). The Sokolki lens is 10.5 m thick and 80 m long.

On Zavrazhie site, remains of tetrapods *Dvinosaurus primus* Amalitzky, *Chroniosuchus licharevi* Riabinin, *Scutosaurus karpinskii* Amalitzky, *Inostrancevia latifrons* Pravoslavlev, *Dicynodon trautscholdi* Amalitzky were found. At the bottom of the bone bearing lens, a grey unit of alternation of dark grey sands, silty clays and yellowish clayey silts (1-10 cm thick) is located. The rocks are rich in C_{org}. Clay, includes fossils of plants and ostracods. Thickness of the grey-coloured unit is 1.8 m. Maximum thickness of Zavrazhie channel is 12 m, length 150 m.

Fig. 22. Excavations by Professor Vladimir P. Amalitsky at the beginning of 20th century in the Sokolki Channel.

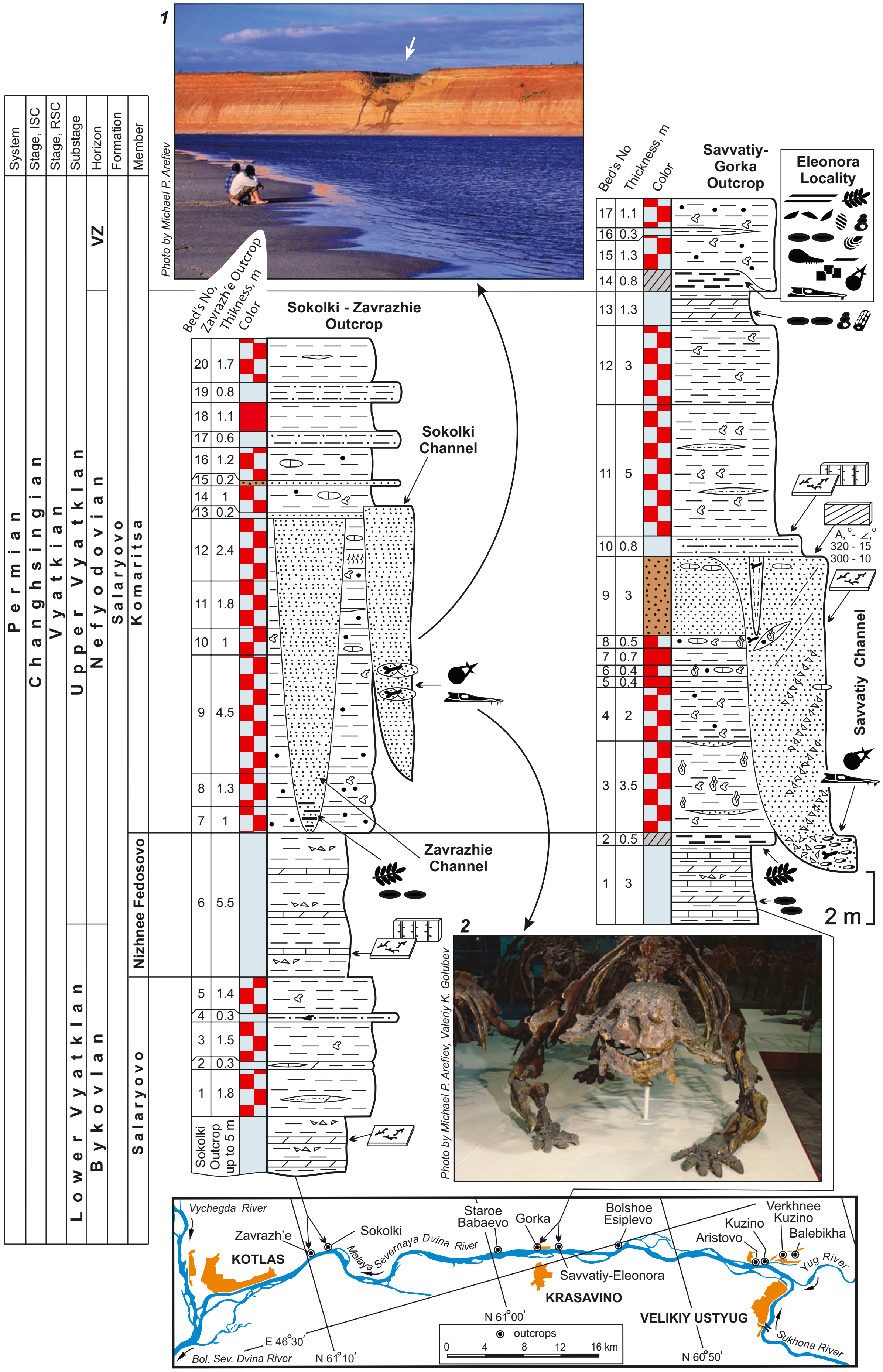


Fig. 23. Sokolki-Zavrazhie and Savvatiy-Gorka sections with lithological and paleontological data. VZ – beds with Vyaznikian biota. 1 – Sokolki Channel, where Professor Vladimir P. Amalitzky discovered the famous Upper Permian amphibian and reptile fauna. 2 – *Scutosaurus karpinskii* (Amalitzky) from the excavation of Prof. Vladimir P. Amalitzky in the Sokolki Channel.

Savvatiy – Gorka Outcrops

Location: right bank of the Malaya Severnaya Dvina River opposite the town of Krasavino.

Coordinates, WGS 84: Savvatiy Channel – N 60.9374°, E 46.51861°; Eleonora locality – N 60.94414°, E 46.52395°.

Stratigraphy. Lower-Upper Vyatkian transition (Changhsingian).

Savvatiy Channel outcrop

The following beds have been recognized (from bottom to top) (Figs. 23, 29).

SALARYOVO FORMATION

Nizhnee Fedosovo Member

1. Clay, light grey, silty, calcareous, with transition into marl and limestone. Marl, with allochtonous plant roots. Limestone, white, grey to black, with interbeds of pink, light pink, red clay. Apparent thickness 3 m.

Komaritsa Member

2. Clay, dark grey, dark brown, rich in C_{org}, with coals. Fossils of plant leaves were found in this bed near the village of Gorka. Thickness 0.5 m.

3. Clay, reddish brown, silty, with several levels of bluish gley mottles, with plant roots *Radicites erraticus* Aref'ev et Naugolnykh, with two levels of brown sand channels up to 0.4 m thick. Near Gorka village, sand lenses increase up to to 2 m thick. Thickness 3.5 m.

4-8. Clay, variegated, red, silty, calcareous, with several paleosol profiles, with autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, with numerous calcareous nodules. In bed 8, palygorskite was found. Thickness 4 m.

9. Sand, brown, very fine, clayey. Thickness 3 m.

The top of bed 9 is correlated with the top of the sand Savvatiy Channel (Fig. 24A). The channel is distinctly asymmetrical: the northern basal part, which is positioned downstream in the river, is steeper (15-20°); the southern part is gently sloping. In the southern part of channel, the sandstone is thick cross-bedded, with interlayers of red-coloured silty clay up to 1 cm thick. In the northern part of the Channel, a small red clayey silt channel up to 3 m thick is located in uppermost part of the Savvatiy lens. Beneath the small lens, bones of tetrapods *Dvinosaurus primus* Amalitzky,

Fig. 24. Savvatiy Channel (A) is embedded in the carbonate paleosols (B).

Chroniosuchus licharevi (Riabinin), *Scutosaurus* cf. *tuberculatus* Amalitzky, *Annatherapsidus* cf. *petri* (Amalitzky), *Elginiidae* gen. indet. were found. This locality is referred to by several different names: Savvatiy, Medvedkovo, Gorka (Efremov and Vjuschkov, 1955).The thickness of the Savvatiy lens is 12 m, its apparent length is 300 m.

10. Silt, light grey, pale bluish, calcareous, with autochthonous and allochtonous plant roots. Thickness 0.8 m.

11-12. Clay, red with rare bluish gley mottles, silty. Thickness 8 m.

13. Clay, light grey, strongly calcareous, with interbeds of marl, with calcareous remains of uncertain systematic position, probably, of charophytes (Fig. 25). Gastropods. Ostracods: *Suchonellina compacta* (Starozh.), *S.* aff. *alia* Mishin. *S.*aff. *mera* (Mishin.), *S.* sp., *Suchonella ovalis* Kotschet., *S.* sp., *Tatariella* ex gr. *libera* Mishin., *W.(?) fragiloides* var. *prima* (Zekin. et Jankovsk.), *Sinusuella vjatkensis* (Posner), *Volganella magna* (Spizhar.). Thickness 1.3 m.

14 (Eleonora Locality, Fig. 26). Clay, dark grey, plastic, silty, in some areas horizontal-laminated, rich in C_{org}, with palinomorphs, phytoleims and pyritized wood debris. Charophyts. Gastropods. Bivalves: *Palaeomutela golubevi* Silantiev (Fig. 26, B). Ostracods: *Suchonellina compacta* (Starozh.), *S.* ex gr. *parallela* Spizhar., *S.*aff. *spizharskyi* (Posner), *S.* ex gr. *mera* (Mishin.), *Wjatkellina vladimirinae* (Bel.), *W.(?) ignatjevi* (Zekin. et Jankovsk.), *W.(?) fragiloides* var. *prima* (Zekin. et Jankovsk.), *W.* sp. *Gerdalia* sp., *Suchonella typica* Spizhar., *Volganella magna* (Spizhar.). Pisces: *Isadia aristoviensis* A.Minich, *I. arefievi* A. Minich, *Isadia* sp., *Toyemia blumentalis* A.Minich, *Strelnia* sp., *Mutovinia sennikovi* A.Minich. Tetrapods: *Scutosaurus* (?) sp., *Microphon* sp., Chroniosuchidae gen. indet., Dicynodontidae gen.indet., Microsauria fam. indet. Thickness 0-0.8 m.

15-17. Clay, red with bluish mottles, silty, calcareous, in some areas with numerous calcareous nodules. It is a complex of several partly eroded paleosols. Apparent thickness 2.7 m.

Photo by Elena A. Voronkova

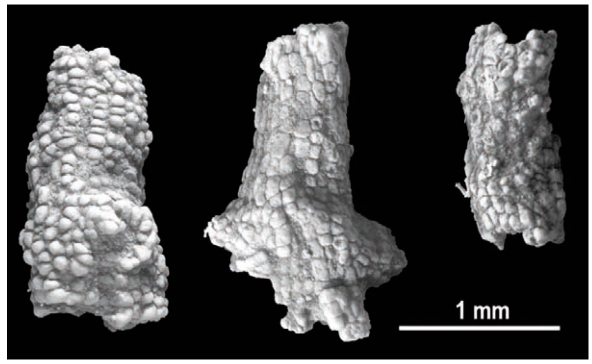


Fig. 25. Problematic fossils from the sedimentary carbonates of the Komaritsa Member, probably thallomes of charophytes. Salaryovo formation, Staroe Babaevo site, equivalent to bed No. 13 at the Savvatiy section.

Photo by Valeriy K. Golubev

Photo by Michael P. Arefiev

Fig. 26. Eleonora Locality (A) and bivalves from it (B).

Aristovo, Verkhnee Kuzino, and Balebikha Outcrops

Location: right bank of the Malaya Severnaya Dvina River between Aristovo village and Balebikha village, opposite town of the Velikiy Ustyug.

Coordinates, WGS 84**:** Aristovo–Kuzino outcrop – N 60.76346°, E 46.38601°; Verkhnee Kuzino outcrop – N 60.73499°, E 46.39011°; Balebikha outcrop – N 60.72648°, E 46.38855°.

Stratigraphy. The sequences are formed by the uppermost Permian (Changhsingian) and lowermost Triassic (Induan) deposits.

The oldest deposits are exposed at low water near Aristovo village. They are represented by the white, light grey clay and marl of the Nizhnee Fedosovo Member. The Komaritsa Member overlies the Nizhnee Fedosovo Member.

Aristovo–Kuzino outcrops

Site no. 154 (N 60.75642°, E 46.381°), the following beds have been recognized (from bottom to top).

SALARYOVO FORMATION

Komaritsa Member

154/1-154/8. Clay, variegated, brownish red with bluish gley mottles up to 50 cm in diameter, silty, calcareous, with small autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, with calcareous nodules (up to 1-2 cm in diameter) and concretions (up to 10 cm in diameter). These are several paleosol profiles. Apparent thickness 4.3 m.

154/9. Clay, red with rare bluish mottles, silty, calcareous, with rare calcareous nodules. Gastropods. Ostracods: *Placidea lutkevichi* (Spizharskyi), *Suchonellina* ex gr. *parallela* Spizharskyi, *S.* ex gr. *perelubica* (Starozhilova), *S. trapezoida* (Sharapova), *Suchonella mishinae* Molostovskaya, *S. typica* Spizharskyi, *S.* sp., *Wjatkellina* (?) *fragilodes* (Zekina), *W.* sp. Thickness 4.3 m.

Photo by Michael P. Arefiev, 1994

Fig. 27. Thick gravelstone at the bottom of the Aristovo Channel.

154/10. Sand, light grey, weakly greenish very fine, with transition into silt, with interbeds of brown clay. Thickness 0.7 m.

154/11. Silt, brown, dark brown, strongly clayey. Thickness 0.7 m.

Beds 154/10-154/11 are correlated with the sand of Aristovo Channel in Aristovo outcrop. At the bottom of Aristovo Channel, gravelstones and conglomerates with well-rounded gravel and pebbles of red-coloured and grey-coloured calcareous rocks are located (Fig. 27). They include numerous shells of bivalves (Fig. 28), carbonized wood debris, fish and tetrapod fossils. Fishes: *Toyemia blumentalis* A.Minich, *Toyemia* sp., *Isadia aristoviensis* A.Minich, Discordichthyidae gen. indet. Tetrapods: *Dvinosaurus primus* Amalitzky, Karpinskiosauridae gen. indet., *Scutosaurus* cf. *tuberculatus* Amalitzky, *Chroniosuchus licharevi* Riabinin, *Inostrancevia* cf. *latifrons* Pravoslavlev, *Annatherapsidus* cf. *petri* (Amalitzky), Dicynodontidae gen. indet. The thickness of the gravelstone is 1.8 m. The overlying deposits are composed of brown, dark grey, greenish grey sands and sandstones. Sands and sandstones are polymictic, with gravel and carbonized wood debris, with numerous bivalve shells and molds in some areas. The prevai-ling dip azimuth of the cross series is northwestern. Sands include one or two lenses of dark grey clay up to 1.5 m thick. The oldest lens includes numerous phytoleims, remains of charophytes, ostracods, conchostracans, insects, gastropods and bivalves. Ostracods: *Gerdalia noinskyi* Belousova, *G. palenovi* Belousova, *Placidea lutkevichi* (Spizharskyi), *Suchonella mishinae* Molostovskaya, *S. typica* Spizharskyi, *Suchonellina* ex gr. *parallela* Spizharskyi, *S. parvaeformis* (Kashevarova), *S. perelubica* (Starozhilova), *S. trapezoida* (Sharapova), *S.* sp., *Wjatkellina* (?) *fragilodes* (Zekina), *W. ignatjevi* (Zekina et Janovskaya), *W.* sp. The thickness of Aristovo Channel is 7.5 m, length 200 m. A more detailed description of the lens was provided by Verzilin et al. (1993).

154/12-154/14. Paleosol profile. Clay, variegated, silty, red with rare irregular gley mottles in the lower part, light blue with brown mottles, calcareous nodules and plant roots *Radicites erraticus* Aref'ev et Naugolnykh in upper part of the bed. Thickness 1.5 m.

154/15. Clay, red, raspberry-red, with bluish mottles, silty, with numerous calcareous nodules and concretions up to 10 cm in diameter (Fig. 29, photo 3). There are lower horizons of calcareous paleosol. Thickness 1 m.

Near Aristovo pier, site no. 42A, (N 60.76494°, E 46.38725°), the following deposits overlie bed 154/15:

42A/9-42A/11. Clay, variegated, red, light blue, with bluish gley mottles, silty, with calcareous nodules and concretions up to 20 cm long, with single autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. These are 2-3 partly eroded paleosol profiles. Thickness 3.3 m.

Site no. 42B, N 60.76346°, E 46.38601°), the following deposits overlie bed 42A/11:

42B/6. Clay, light grey, silty, calcareous, with transition into marl, with three interbeds of white limestone, with numerous ostracods, gastropods and fossil remains of uncertain systematic position (see Fig.26 for similar). Thickness 1.1 m.

42B/7-42B/9. Clay, red, with red, bluish, pinkish, yellowish mottles, silty, with small calcareous nodules. Thickness 2.9 m.

42B/10. Clay, light grey, silty, calcareous, with transition into marl and limestone. Limestone, white, with large autochthonous plant roots *Radicites sukhonensis* Aref'ev et Naugolnykh up to 20 cm long and up to 1 cm in diameter. Ostracods: *Darwinuloides svijazhicus* (Sharapova), *Suchonella mishinae* Molostovskaya, *S. typica* Spizharskyi, *Suchonellina* ex gr. *parallela* Spizharskyi. Thickness 1.1 m.

Beds 42B/6-42B/10 form a light-grey calcareous unit, which is exposed near Verkhnee Kuzino village and on the Yug River.

Site no. 42F (N 60.759°, E 46.3831°), the following deposits overlie bed 42B/10:

42F/2-42F/3. Clay, brown, with bluish, yellowish ochreous mottles, silty, with calcareous nodules and bluish and red-coloured streaks of autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Ostracods: *Darwinuloides svijazhicus* (Sharapova), *Gerdalia* sp., *Suchonellina* ex gr. *dubia* (Starozhilova), *S.* ex gr. *parallela* Spizharskyi, *S.* sp., *S. parvaeformis* (Kashevarova), *Suchonella mishinae* Molostovskaya, *S. typica* Spizharskyi, *S.* sp., *Wjatkellina fragilodes* (Zekina), *W. praelonga* (Zekina), *W.* sp. Thickness 0.7 m.

Fig. 28. Bivalves from the Aristovo Channel.

42F/4. Clay, brownish grey, in some areas with brown and grey mottles, silty, in some areas thinly horizontal-laminated, probably, with low content of C_{org}. Bivalves, Gastropods. Ostracods: *Darwinuloides svijazhicus* (Sharapova), *Gerdalia* sp., *Suchonella* sp., *Suchonellina* sp., *Wjatkellina* sp.Thickness 0.4 m.

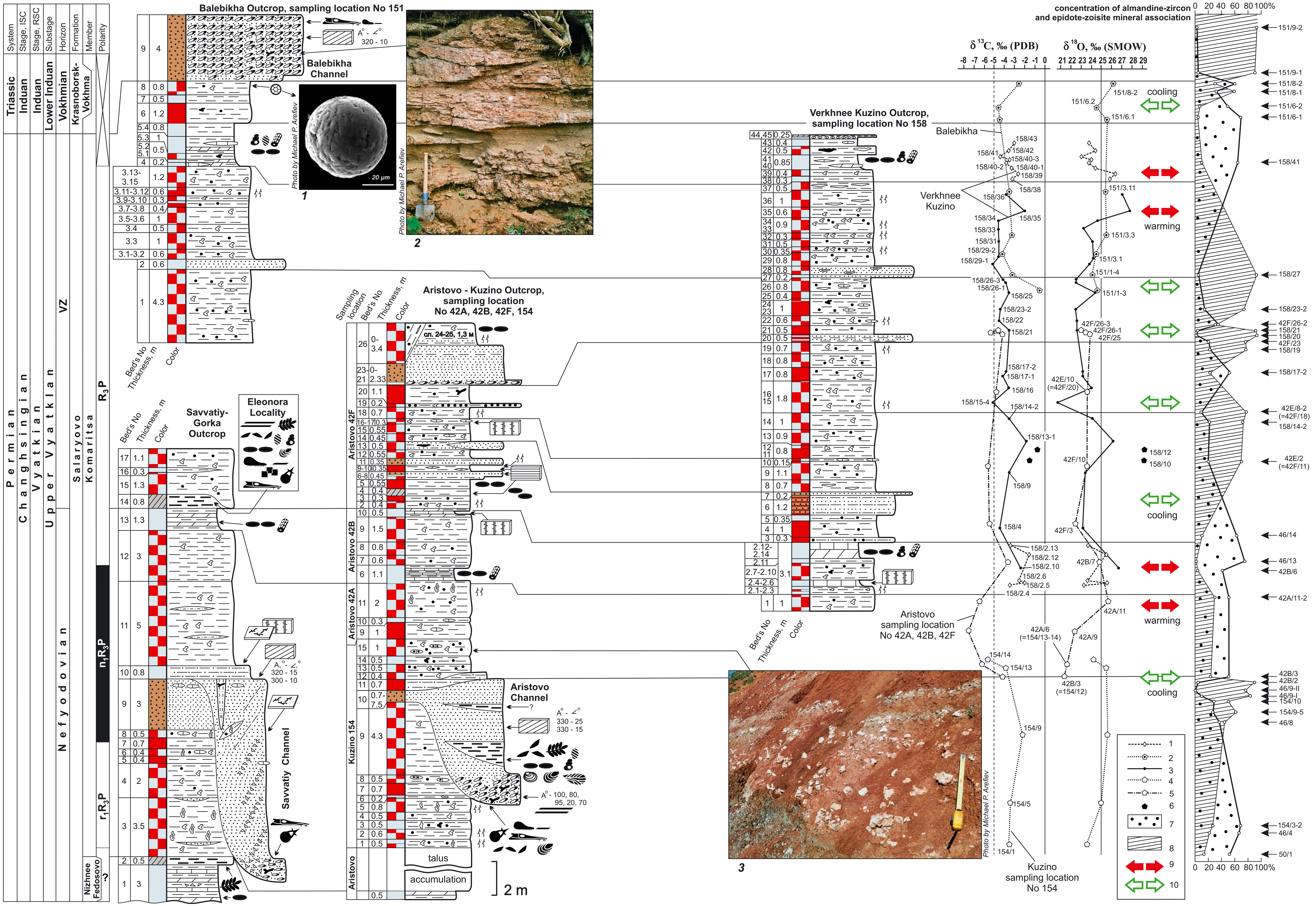
42F/5. Clay, brown, silty. Thickness 0.55 m.

42F/6-42F/13. Alternation of sand and clay. Sand, brown, light greenish light bluish, horizontal-laminated, very fine, polymictic. Clay, brown, reddish brown, with bluish interbeds, horizontal-laminated, silty, in some areas with bluish mottles, calcareous nodules and autochthonous plant roots, with lenses of pink marl up to 2 cm thick. Thickness 2.15 m.

42F/14-42F/15. Clay, silty, brownish red, with bluish mottles, with numerous calcareous nodules (up to 2-4 cm in diameter) and concretions (up to 15 cm in diameter). These are lower horizons of the partly eroded paleosol profile. Gastropods. Ostracods: *Suchonella mishinae* Molostovskaya, *S.* sp. Thickness 1 m.

42F/16-42F/17. Clay, mainy light brownish red, with numerous bluish mottles, with light grey calcareous concretions, probably, with remains of autochthonous plant roots *Radicites* sp. Thickness 0.3 m.

Fig. 29. Savvatiy-Gorka, Aristovo, Kuzino, Verkhnee Kuzino, and Balebikha sections with lithological, isotopic, and sedimentological data. VZ – beds with the Vyaznikian biota. Photos: 1 – high-Ti magnetite microspherule, Balebikha site; 2 – gravelstone at the bottom of the Balebikha Channel, Balebikha site; 3 – caliche, Aristovo site. Key: 1-6 – carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope composition of pedogenic and sedimentary carbonates: 1 – sedimentary carbonates, 2 – pedogenic carbonates, Balebikha site, sampling location No. 151, 3 – pedogenic carbonates, Verkhnee Kuzino site, sampling location No. 158, 4 – pedogenic carbonates, Kuzino site, sampling locations No. 154, 5 – pedogenic carbonates, Aristovo site, sampling locations No. 42, 6 – carbonate concretions probably of sedimentary genesis characterized by the heavy isotopic composition of oxygen; 7-10 – mineral abundancies of the heavy fraction and its correlation with the isotopic content of carbonates: 7 – almandine-zircon mineral association, 8 – epidote-zoisite mineral association, 9 – decrease in $\delta^{18}O$ values in pedogenic carbonates and increase of epidote-zoisite association, 10 – increase in $\delta^{18}O$ values in pedogenic carbonates and increase of almandine-zircon association.


Balebikha Outcrop, sampling location No 151
Balebikha Channel
Photo by Michael P. Arefiev
20 μm
1
2
3
Verkhnee Kuzino Outcrop, sampling location No 158
Aristovo - Kuzino Outcrop, sampling location No 42A, 42B, 42F, 154
Savvatiy-Gorka Outcrop
Eleonora Locality
Savvatiy Channel
Aristovo Channel
Aristovo sampling location No 42A, 42B, 42F
Kuzino sampling location No 154
Verkhnee Kuzino
Balebikha
System
Stage, ISC
Stage, RSC
Substage
Horizon
Formation
Member
Polarity
Triassic
Induan
Induan
Lower Induan
Vokhmian
Krasnoborsk-Vokhma
Permian
Changhsingian
Vyatkian
Upper Vyatkian
Nefyodovian
Salaryovo
Komaritsa
Nizhnee Fedosovo
Bed's No
Thickness, m
Color
Sampling location
talus
accumulation
2 m
δ13C, ‰ (PDB)
δ18O, ‰ (SMOW)
concentration of almandine-zircon and epidote-zoisite mineral association
cooling
warming

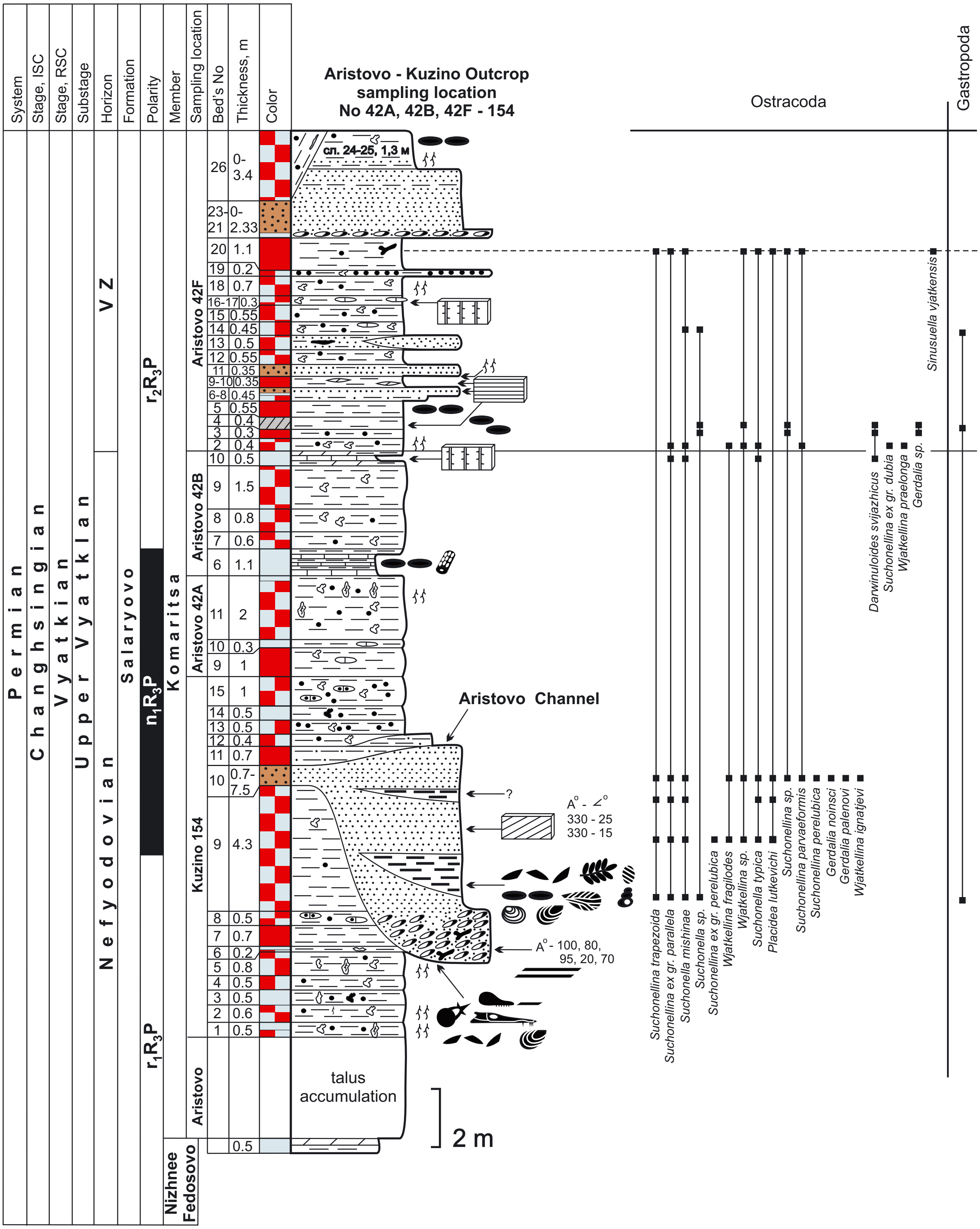


Fig. 30. Aristovo sections with paleomagnetic and paleontological data. VZ – beds with Vyaznikian biota.

42F/18. Clay, light brownish red, with rare bluish mottles, with calcareous concretions up to 5 cm in diameter and autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 0.7 m.

42F/19. Conglomerate, light grey, with red mottles, with calcareous pebbles up to 3 cm in diameter, with transition into light grey clay with calcareous pebbles and gravels. This is partly eroded paleosol. Thickness 0.2 m.

42F/20. Clay, dark reddish brown, silty, with single calcareous nodules up to 5 cm in diameter. These are lower horizons of the paleosol profile. Gastropods. Ostracods: *Placidea lutkevichi* (Spizharskyi), *Sinusuella vjatkensis* (Posner), *Suchonella mishinae* Molostovskaya, *S. typica* Spizharskyi, *Suchonellina* ex gr. *parallela* Spizharskyi, *S. parvaeformis* (Kashevarova), *S. trapezoida* (Sharapova), *S.* sp., *Wjatkellina* sp. Thickness 1.1 m.

42F/21-42F/23. Sand, brown, greenish brown, light greenish horizontal-laminated, fine, polymictic, with single clay interbeds up to 2 cm thick, with light bluish gravelstone 3 cm thick in the bottom of the bed. Thickness 2.33 m.

Verkhnee Kuzino Outcrop

More upper layers are exposed south of Verkhnee Kuzino village. In the gully, two light grey calcareous marker units are located in sequence. The following deposits overlie the sand layers, which are correlated with beds 42F/21-42F/23:

158/21-158/26. Clay, variegated, brownish red with blue, brown, yellowish mottles, silty, calcareous, with calcareous nodules and concretions up to 20 cm in diameter, with small autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. This represents several partly eroded paleosol profiles. Thickness 3.3 m.

158/27-158/28. Sand, bluish, with reddish mottles, very fine, polymictic. Thickness 1 m.

158/29-158/35. Clay, brown, brownish red, in some areas with numerous pale bluish mottles, silty, calcareous, in some levels with numerous light grey calcareous nodules 2-4 cm in diameter, with numerous bluish and light grey streaks of autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. This represents several paleosol profiles. Thickness 3.45 m.

158/36-158/37. Clay, reddish brown with numerous pale bluish and light brown mottles, silty, calcareous, with rare calcareous nodules, in some areas with thin horizontal interbeds of silt, with rare autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 1.5 m.

158/38-158/43. Clay, light grey, with brownish pink interbeds, silty, calcareous, with numerous ostracods, gastropods and remains of uncertain systematic position, with transition into marl and limestone. Limestone, dark grey, light grey, bituminous, up to 5-10 cm thick. Thickness 2.45 m.

Fig. 31. Numerous Ural cherts
in the Lower Triassic Balebikha Channel.

Balebikha Outcrop

The section near Balebikha village (=Rukavishnikova Gora site) terminates the Permian-Triassic sequence in the Sukhona River basin. The following deposits overlie the second light grey calcareous-clayey unit of Komaritsa Member:

151/6. Clay, red, with yellowish brown small (mm) mottles, silty, with very small calcareous nodules. Thickness 1.2 m.

151/7. Clay, light grey, calcareous. Thickness 0.5 m.

151/8. Clay, red, with single small gley mottles and small calcareous nodules up to several mm in diameter, with high-Ti magnetite microspherules up to several tens of microns in diameter, probably of cosmic origin, in the upper part of the bed (Fig. 29, photo 2; Fig. 36; Arefiev and Shkurskiy, 2012). Thickness 0.8 m.

LOWER TRIASSIC, INDUAN STAGE

KRASNOBORSK-VOKHMA FORMATION

151/9. Conglomerate, gravelstone, and sandstone of the Balebikha Channel (Fig. 29, photo 2). Sandstone, brown and greenish brown, cross-bedded, with numerous clayey-calcareous pebbles and gravels; the prevailing dip azimuth of the oblique laminae is north-western. Conglomerate and gravelstone, red, bluish in the bottom of bed (20 cm), with numerous well-rounded black flints up to 2 cm in diameter (Fig. 31). Lower Triassic (Induan) vertebrate remains were found in the bed. Fishes: *Saurichthys* sp. Tetrapods: *Tupilakosaurus* sp. Apparent thickness 4 m.

Nedubrovo Outcrop

Location: left bank of the Kichmenga River near Nedubrovo village, 7 km north-west of Kichmengskiy Gorodok town.

Coordinates, WGS 84**:** N 60.04521°; E 45.74047°.

Stratigraphy. Permian-Triassic transition.

The following beds are recognized above the water level (Fig. 32):

VOKHMA FORMATION

Nedubrovo Member

1. Sandstone, brown, horizontal-laminated, fine, polymictic. Probably this bed is the upper part of the sand channel, which lies largely underwater. Apparent thickness 0.5 m.

2. Silt, cherry-red, clayey, calcareous, horizontal-laminated. Thickness 0.6 m.

3. Clay, red, silty, horizontal-laminated. Thickness 0.3 m.

4-6. Alternation of silt and silty clay with interbeds of very fine sand. Sand and silt, yellowish grey, with tints of light brown, horizontal-laminated. Clay, dark grey (Fig. 32, photo 4). Deposits include palinomorphs, phytodetritus, wood fragments, remains of ostracods and insects. Interbeds of light yellow marl up to 2 cm thick are located in the middle part of the bed (Fig. 32, photo 5). Thickness 4 m.

7. Silt and silty clay, brown, with thin horizontal and undulating lamination. Thickness 0.5 m.

8. Clay, brownish red, silty, with desiccation cracks filled with bluish silt and sand. Thickness 1.2 m.

9. Clay, brownish red with bluish gley mottles up to 5 cm in diameter, with calcareous concretions and autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh. Thickness 2.6 m.

LOWER TRIASSIC, INDUAN STAGE

Astashikha Member

10. Sand, brown, reddish brown, very fine, polymictic, clayey, with thin interbeds of red clay up to 1-2 cm thick, with lens of light yellow friable marl up to 1 cm thick. Thickness 0.9 m.

Downstream from the described point, the bed increases in thickness and cuts the underlying deposits to a depth of 3 m.

In the nearest outcrops, Lower Triassic tetrapod remains, *Tupilakosaurus* sp.*,* were found in the sandstone correlated with bed 10 (Lozovsky et al., 2001, 2014).

11. Clay, red with numerous bluish gley mottles (Fig. 32, photo 1), with numerous calcareous nodules, interbeds and lenses of bluish silts (Fig. 32, photo 2). Thickness 2.3 m.

Beds 4 and 6 are characterized by unique assemblages of megaspores, miospores, remains of leaves and insects (Fig. 32, photos 6, 7). Based on these paleontological data, Nedubrovo Member is correlated with the uppermost Changhsingian Stage. Isotopic ($\delta^{13}C$, $\delta^{18}O$) characteristic is also unique. In bed 4 $\delta^{13}C$ value is the lowest for Urzhumian-Vyatkian and Lower Olenekian sedimentary carbonates of East-European platform. In sample 133/9-9 $\delta^{13}C$ the value is the lowest for pedogenic carbonates of this stratigraphic level of the north-east Moscow syncline (Aref'ev et al., 2015). Based on these isotopic data, the level of the end-Permian extinction in marine ecosystems, which is located in the uppermost Changhsingian (Takahashi et al., 2010; Sun et al., 2012), corresponds to the Nedubrovo Member.

Fig. 32. Nedubrovo section with lithological, isotopic, and paleontological data. ND – beds with Nedubrovian biota. Photos: 1, 2 – lowermost Triassic variegated rocks: 1 – spotted eluvial-gley horizon of thin paleosol, 2 – bluish gley lenses enriched silt and transformed into an independent layer of silt at the bottom; 3 – Nedubrovo outcrop; 4-7 – Permian part of the section: 4 – alternation of sand, silt and clay, 5 – marl lens with a minimum $\delta^{13}C$ value in sedimentary carbonates of post-Kazanian Permo-Triassic deposits of the Moscow Basin, 6, 7 – megaspores *Otynisporites eotriassicus* Fuglewicz.

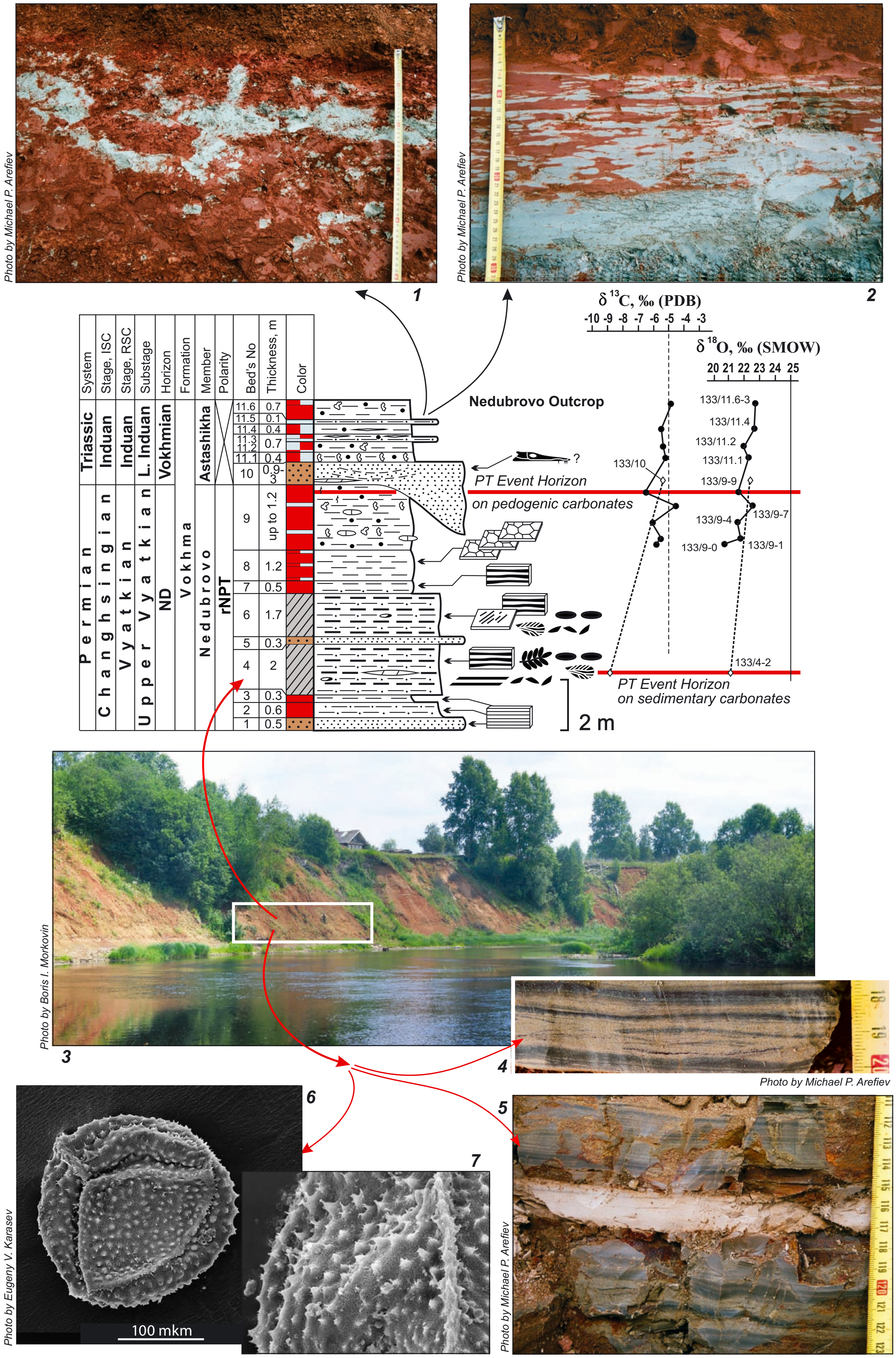


Photo by Michael P. Arefiev
1
Photo by Michael P. Arefiev
2
δ13C, ‰ (PDB)
-10 -9 -8 -7 -6 -5 -4 -3
δ18O, ‰ (SMOW)
20 21 22 23 24 25
System
Stage, ISC
Stage, RSC
Substage
Horizon
Formation
Member
Polarity
Bed's No
Thickness, m
Color
Triassic
Induan
Induan
L. Induan
Vokhmian
Astashikha
Permian
Changhsingian
Vyatkian
Upper Vyatkian
ND
Vokhma
Nedubrovo
rNPT
11.6 0.7
11.5 0.1
11.4 0.4
11.3 0.7
11.2
11.1 0.4
10 0.9-3
9 up to 1.2
8 1.2
7 0.5
6 1.7
5 0.3
4 2
3 0.3
2 0.6
1 0.5
Nedubrovo Outcrop
?
PT Event Horizon
on pedogenic carbonates
PT Event Horizon
on sedimentary carbonates
2 m
133/11.6-3
133/11.4
133/11.2
133/11.1
133/10
133/9-9
133/9-7
133/9-4
133/9-0
133/9-1
133/4-2
Photo by Boris I. Morkovin
3
4
Photo by Michael P. Arefiev
5
Photo by Michael P. Arefiev
6
7
Photo by Eugeny V. Karasev
100 mkm

Location: right bank of the Vyatka River near the villages of Rvachi, Vanyushonki, and Boroviki, 14-16 km downstream from Kotel'nich.

Coordinates, WGS 84: Boroviki outcrop – N 58.15297°, E 48.35553°; Vanyushonki outcrop – N 58.15878°, E 48.35103°; Sokol'ya Gora – N 58.161°, E 48.34881°; Rvachi outcrop – N 58.1665°, E 48.34217°.

Stratigraphy. Upper Severodvinian. Capitanian–Wuchiapingian transition.

Four Beds of the Kalininskaya Member of the Kotel'nich Formation are exposed on the right river bank for a distance of 15-20 km downstream from Kotel'nich. The best outcrops are located between Rvachi village and Boroviki village. The sequence is described below (from bottom to top) (Fig. 33).

KOTEL'NICH FORMATION

Kalininskaya Member

Vanyushonki Bed

Vanyushonki (beds No. 191/1-191/8) and Boroviki (beds No. 192/2-192/5, Fig. 33) outcrops.

Clay, red, brownish red, with various bluish mottles, silty, with small autochthonous plant roots *Radicites erraticus* Aref'ev et Naugolnykh, with calcareous nodules (1-3 cm) and concretions (up to 20 cm), with skeletons of tetrapods (Kotel'nich locality). Apparent thickness 10 m.

Traces of paleopedogenic processes regularly present in red-coloured rocks, which were probably formed on floodplains or in shallow ephemeral lakes (Benton et al., 2012).

Boroviki Bed

Boroviki outcrop, site no. 192

192/6. Sand, light blue, very fine. Thickness 0.5 m.

192/7-192/14. Sandstone, light brown with red and bluish mottles, very fine, with clayey layers, in some areas strongly clayey, with grains clayey gravel up to 1 cm in diameter. Clayey levels change into lenses of variegated clay up to 1.7 m thick. One of these lenses is visually traced downstream from Sokol'ya Gora Channel. Wedge-shaped sets of low-angle cross-bedded sands are regularly visible at this level. Thickness 8.95 m.

192/15. Sandstone, yellowish brown, cross-laminated (Fig. 33), very fine, with local cuts filled with sand deposits up to 30 cm in depth. Apparent thickness 5.5 m.

The entire Boroviki Bed is exposed near Rvachi village. Its maximum thickness is 19 m. The Bed forms a very large lens up to 10 km long. It has many features that suggest a predominantly aeolian origin, although some features may have a fluvial origin (Tverdokhlebov and Shminke, 1990; Coffa, 1999; Benton et al., 2012).

Shestakovy Bed

Rvachi outcrop, site no. 189.

189/3-189/8. Clay, silty, red, reddish brown, with numerous calcareous nodules, with interbeds and lenses of bluish silty clays. Thickness 4.15 m.

189/9-189/16. Clay, silty, red, brownish red with bluish mottles, with small calcareous nodules (up to 1.5 cm in size), with interbeds of bluish and brown sands (0.01-1.2 m). Apparent thickness 6.5 m.

The thickness of the Shestakovy Bed is strongly variable. Maximum thickness is 20 m.

The primary lithology of the Shestakovy Bed is similar to the Vanyushonki Bed. The thin beds of sandstone have been interpreted by Tverdokhlebov (2009) as distributary channels within an inland delta or terminal fan.

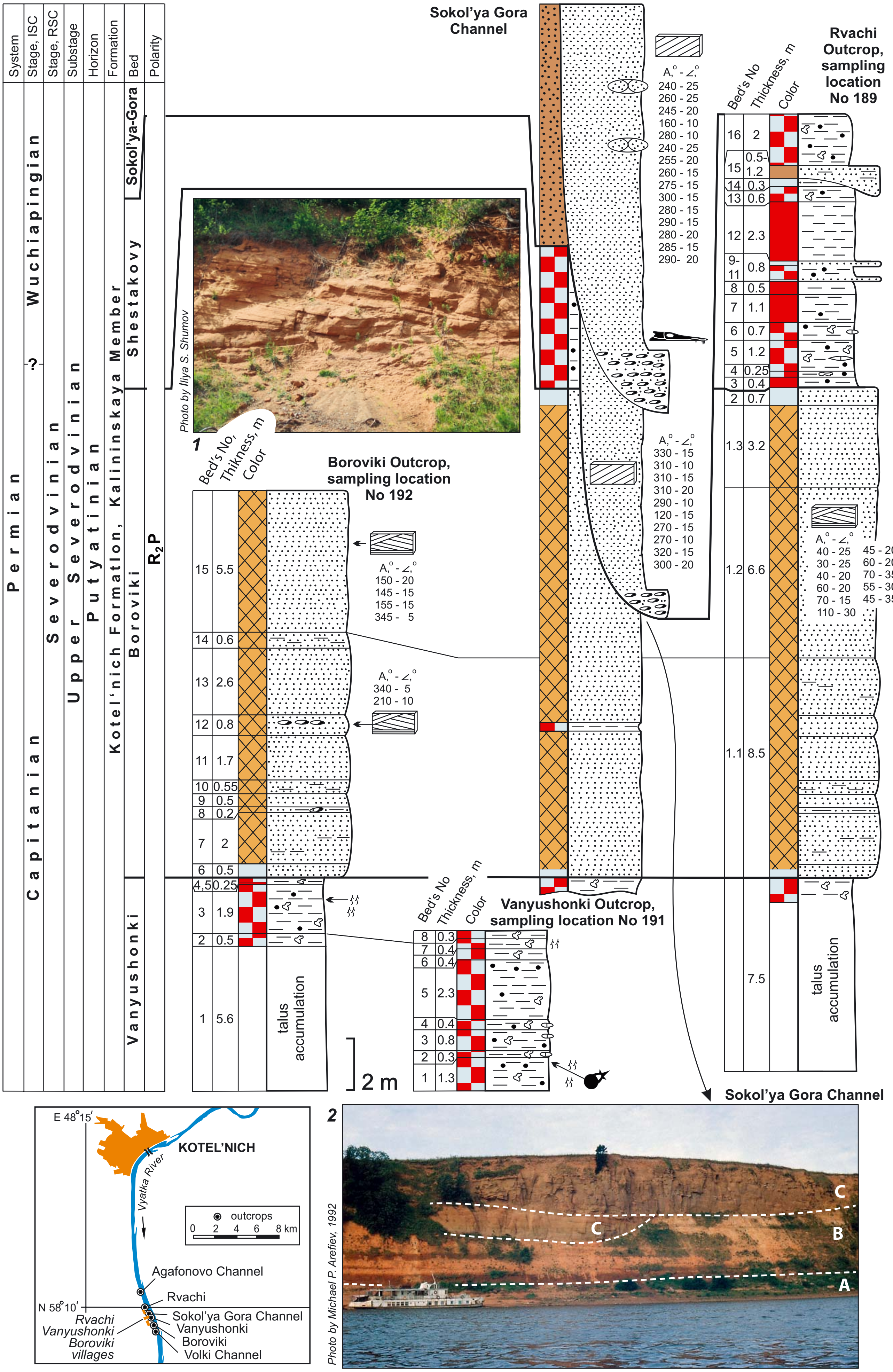
Sokol'ya-Gora Bed

Sokol'ya Gora outcrop

Large alluvial channels cut into the Shestakovy Bed and Boroviki Bed. Channels form the Sokol'ya-Gora Bed. These deposits are most typical in Sokol'ya Gora outcrop. On this site, the Bed is formed by two sand channels cutting one another. The bottom part (up to 1.1 m) of the lower channels of the Sokol'ya Gora-1 is composed of conglomerates and gravelstones with rounded red-coloured clay and orange sandstone gravels and pebbles. The overlying deposits are formed by brown, cross-bedded, polymictic sandstone, with a prevailing western dip azimuth of the cross series. The thickness of Sokol'ya Gora-1 Channel is no less than 8 m.

The bottom part (up to 2.3 m) of the upper channel of Sokol'ya Gora-2 is composed of conglomerates, gravelstones and gravelly sandstones.

Fig. 33. Kotel'nich section. Photos: 1 – wedge-shaped sets of low-angle cross-bedded sand probably aeolian origin, Boroviki Member; 2 – Sokol'ya Gora outcrop: A – Vanyushonki Bed, B – Boroviki Bed, C – Sokol'ya Gora Bed.


System
Stage, ISC
Stage, RSC
Substage
Horizon
Formation
Bed
Polarity
Permian
Capitanian
?
Wuchiapingian
Severodvinian
Upper Severodvinian
Putyatinian
Kotel'nich Formation, Kalininskaya Member
Vanyushonki
Boroviki
Shestakovy
Sokol'ya-Gora
R_2P
Sokol'ya Gora Channel
Photo by Iliya S. Shumov
1
Bed's No, Thikness, m, Color
Boroviki Outcrop, sampling location No 192
Vanyushonki Outcrop, sampling location No 191
Rvachi Outcrop, sampling location No 189
Bed's No
Thickness, m
Color
talus accumulation
2 m
A,° - ∠,°
2
Photo by Michael P. Arefiev, 1992
A
B
C
E 48°15′
N 58°10′
KOTEL'NICH
Vyatka River
outcrops
0 2 4 6 8 km
Agafonovo Channel
Rvachi
Sokol'ya Gora Channel
Vanyushonki
Boroviki
Volki Channel
Rvachi
Vanyushonki
Boroviki
villages

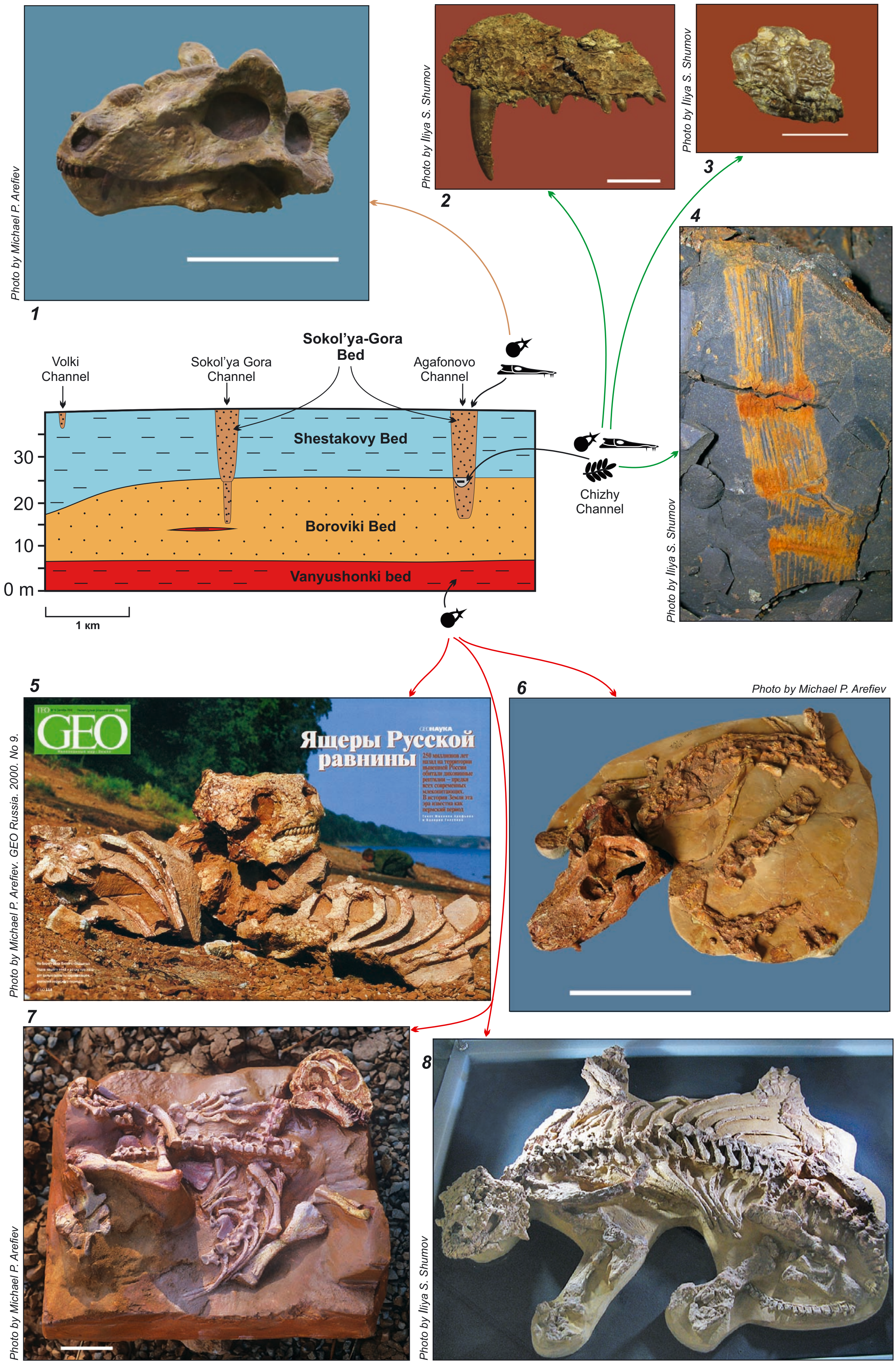


Photo by Michael P. Arefiev
1
Photo by Iliya S. Shumov
2
Photo by Iliya S. Shumov
3
4
Photo by Iliya S. Shumov
Sokol'ya-Gora
Bed
Volki
Channel
Sokol'ya Gora
Channel
Agafonovo
Channel
Shestakovy Bed
Boroviki Bed
Vanyushonki bed
Chizhy
Channel
30
20
10
0 m
1 км
5
GEO
Ящеры Русской
равнины
Photo by Michael P. Arefiev. GEO Russia. 2000. No 9.
6
Photo by Michael P. Arefiev
7
Photo by Michael P. Arefiev
8
Photo by Iliya S. Shumov

The overlying deposits are formed of sandstone similar to that in the Sokol'ya Gora-1 lens. The thickness of Sokol'ya Gora-2 lens is 16 m. The total thickness of the Sokol'ya-Gora Bed in the Sokol'ya Gora outcrop is 24 m.

Some authors identified the Chizhi Bed in the Kotel'nich sequence (Coffa, 1999; Benton et al., 2012). This Bed includes a small lens of dark-grey silty clay located near Agafonovo site. It is believed that the Bed is located between the Boroviki Bed and the Shestakovy Bed. In our opinion, the Chizhi Channel deposits belong to the Sokol'ya-Gora Bed.

Vanyushonki Bed. Tetrapods of Kotel'nich Locality (Fig. 34): pareiasaurs *Deltavjatia vjatkensis* (Hartmann-Weinberg), nycteroleterins *Emeroleter levis* Ivachnenko, gorgonopians *Viatkogorgon ivakhnenkoi* Tatarinov, galeopids *Suminia getmanovi* Ivachnenko, therocephalians *Kotelcephalon viatkensis* Tatarinov, *Viatkosuchus sumini* Tatarinov, *Scalopodontes kotelnichi* Tatarinov, *Perplexisaurus foveatus* Tatarinov, *Karenites ornamentatus* Tatarinov, *Muchia microdenta* Ivachnenko. Pareiasaur remains are dominant.

Shestakovo Bed. Tetrapods: pareiasaurs *Deltavjatia* cf. *vjatkensis* (Hartmann-Weinberg), gorgonopians *Viatkogorgon ivakhnenkoi* Tatarinov, dicynodonts *Australobarbarus kotelnitshi* Kurkin, *A. platycephalus* Kurkin.

Sokol'ya-Gora Bed. In the sandstones of Sokol'ya Gora, Agafonovo and Chizhy lenses, the temnospondyls *Dvinosaurus primus* Amalitzky, anthracosaurs *Chroniosaurus levis* Golubev, pareiasaurs *Proelginia* cf. *permiana* Hartmann-Weinberg, gorgonopians *Proburnetia viatkensis* Tatarinov were found (Fig. 34, photos 1-3).

In Chizhy lens the plant macrofossils were found: *Algites* sp. AVG-1, *Phyllotheca* aff. *turnaensis* Gorelova, *Paracalamites* sp. (Fig. 34, photo 4), *Pecopteris* sp. AVG-1, *Peltaspermopsis* (?) sp., *Alicospermum* sp., *Tatarina conspicua* S. Meyen, *Phylladoderma (Aequistomia)* sp. indet., *Permotheca sardykense* Zalessky, *Pursongia beloussovae* (Radczenko) Gomankov et S. Meyen, *Geinitzia* sp. (Goman'kov, 1997).

In the spore-pollen spectrum obtained from the same plant-bearing deposits, the most common are the ribbed, quasi-saccate pollen genus *Protohaploxypinus* (*P. dvinensis* (Sedova) Hart – 32.8%, other genera – 12.9%), *Vitreisporites pallidus* (Reissinger) Nilsson (17.2%). There is a relatively high (8.1%) content of mono-saccate pollen, which is close to the genus *Cladaitina*. Ribbed, non-saccate pollen (the genera *Vittatina* and *Weylandites*), as well as *Vesicaspora* ex gr. *magnalis* (Andreyeva) Hart are present in small amounts (about 4%). An archaic element of the Kotel'nich spectrum can probably be considered the spore type *Neoraistrickia*, very rare in the Tatarian Series of the East European platform, but quite usual for the Upper Permian deposits of Siberia (Goman'kov, 1997).

The Kotel'nich sequence corresponds to the Strelna – Kichuga Members of the Poldarsa Formation of the Sukhona River.

Fig. 34. Paleontological characteristic of the Severodvinian (Capitanian) near Kotel'nich town. 1 – scull of *Proburnetia viatkensis* Tatarinov, holotype PIN No. 2416/1, scale bars 10 cm; 2 – praemaxilla of *Viatkogorgon ivakhnenkoi* Tatarinov, scale bars 1 cm; 3 – *Chroniosaurus* sp., scale bars 1 cm; 4 – isolated pith cast of *Paracalamites* sp., length 8 cm; 5 – the skull and part of skeleton of pareiasaur *Deltavjatia vjatkensis* (Hartmann-Weinberg) lie on a bedding plane of red clay on the Vyatka River bank, KPM No. 23, the length of the skull 27 cm. These clays, of Severodvinian age, yielded all the Kotel'nich Locality skeletons. Original photograph by M. Arefiev, GEO Russia Magazine, 2000, № 9. Fossil remains were brought to the bank of the Vyatka River from the local paleontological museum for a photoshoot; 6 – skeleton of therocephalian *Viatkosuchus sumini* Tatarinov, holotype PIN No. 2212/13, scale bars 10 cm; 7 – skeleton of galeopid *Suminia getmanovi* Ivachnenko, holotype PIN No. 2212/10, scale bars 10 cm; 8 – skeleton of pareiasaur *Deltavjatia vjatkensis* (Hartmann-Weinberg), KPM No. 23, the length 90 cm.

Part II
Main Middle Permian – Lower Triassic isotope, paleomagnetic, and biotic events

Isotope ($\delta^{13}C$, $\delta^{18}O$) and sedimentological characteristics

The first isotope geochemical data from the Permo-Triassic beds of the Moscow Basin (MB) were published by Foster and Afonin (2005) for a single section of Nedubrovo. The authors reported the data only for carbon. Later studies covered the interval from the Urzhumian to Upper Olenekian throughout MB and analyzed the isotope composition of carbon and oxygen (Arefiev, Golubev, 2014; Arefiev et al., 2015). Detailed isotope characteristics ($\delta^{13}C$, $\delta^{18}O$) of the Permian on the Sukhona and Malaya Severnaya Dvina rivers and the Yug River Basin have recently been obtained. These new data are reported in the present paper (Figs. 8, 9, 10, 16, 21, 29, 32) and generalized in Fig. 35.

The isotope composition of carbon and oxygen was analyzed in samples of sedimentary carbonates: dolomites, dolomitic limestones, limestones, marls, light grey carbonate clays, and carbonate paleosol concretions. The study has revealed a wide range of $\delta^{13}C$ and $\delta^{18}O$ values, corresponding to global and local paleo environmental changes.

URZHUMIAN STAGE (WORDIAN)

In the Nizhnyaya Ustiya Formation (Urzhumian, Wordian), $\delta^{13}C$ in sedimentary carbonates ranges from 2.4 to 3.9‰ PDB, $\delta^{18}O$ shows a heavy oxygen isotope composition within 29.6-33.7‰ SMOW (Fig. 8).

SEVERODVINIAN STAGE (CAPITANIAN)

Lower Severodvinian Substage (Lower Capitanian)

In the Sukhona Formation, samples of sedimentary carbonates fall within a range from 0.7‰ to 34.2‰ for carbon and from 31.4 to 34.2‰ SMOW for oxygen. The analyses have shown fluctuations of $\delta^{13}C$ and stable weighting of the oxygen isotope composition (Figs. 8, 9).

The parameters of Lower Severodvinian and Urzhumian samples are close to those of the deposits of salty or brackish-water lakes (Leng, Marshal, 2004). They are also characteristic of shallow evaporite Permian water bodies of Western and Eastern Europe (Perit, Magariz, 1990; Kuleshov, Sedaeva, 2009; Kuleshov et al., 2011; Sungatullin et al., 2014). The heavy isotope composition of oxygen is evidence of marine transgression, after which ocean water preserved in residual water bodies underwent additional weighting with intense evaporation in closed or semiclosed conditions.

Upper Severodvinian Substage (Upper Capitanian – Lower Wuchiapingian)

At the base of the Upper Severodvinian Substage, considerable changes in isotope geochemical history of the region are recorded. In sedimentary carbonates, a distinct trend towards lightening of the isotope composition of carbon and oxygen is observed; upward in the section, the curves of $\delta^{13}C$ and $\delta^{18}O$ variations show distinct rhythms. In the Ustpoldarsa Member (Fig. 9), the carbon values decrease to one-third (2.8‰) and increase to a maximum of 5.8‰. Synchronous fluctuations of $\delta^{18}O$ values change within a wider range from 27.2 (in one case, the value is abnormally low, 22.3‰) to 34.1‰. Upward in the section, pedogenic carbonates appear in the Mikulino paleosols. Here $\delta^{13}C$ ranges from –0.9 to 1.1‰ and $\delta^{18}O$, from 26.8 to 29.4‰.

Up to the roof of the Severodvinian Stage, sedimentary carbonates still show clear rhythmicity (Figs. 10, 16). From the base of the Strelna Member to the lower part of the Kalikino Member, $\delta^{13}C$ and $\delta^{18}O$ in sedimentary carbonates range from 0.2 to 4.6‰ and from 24.2 to 34.1‰, respectively. Pedogenic carbonates from the Ustie Strelny outcrop have shown $\delta^{13}C$ ranging from –4.8 to –3.7‰ and $\delta^{18}O$ from 22.2 to 22.7‰, which are considerably lower than the values in sedimentary carbonates of the Severodvinian Stage. In the Purtovino Member, paleosols regularly occur, although pedogenic nodules have only been found in one of them. The sample has shown unexpectedly high values of $\delta^{13}C$=5.4‰ and $\delta^{18}O$=33.2‰.

In the roof of the Severodvinian Stage, paleosols are accompanied by beds with abundant carbonate pebbles passing into conglomerate. In the Mutovino outcrop, samples from this stratigraphic interval were analyzed on two sites: the beds just above the Mutovino lens (sampling location no. 28A, Fig. 16) and their stratigraphic analogues situated at a distance of approximately 700 m, where most of the samples for isotope analysis were collected (sampling location no. 1350). $\delta^{13}C$ and $\delta^{18}O$ obtained in carbonates from SL no. 1350 are very close to the range corresponding to sedimentary carbonates of this level. Probably, calcic gravel and pebble frequently contain sedimentary carbonate matter. In SL no. 28, the values of carbon and oxygen are lower ($\delta^{13}C$=–4.3…–1.8‰, $\delta^{18}O$=24.3…25.7‰), suggesting more profound processes of pedogenesis, which developed just above the Mutovino channel filled with deposits.

In general, in the Late Severodvinian, $\delta^{13}C$ decreased. The lightest isotope composition of carbon is recorded in the roof of the stage (0.2‰ in sedimentary carbonates and –4.3‰ in pedogenic carbonates). However, at the beginning of the Late Severodvinian, carbonates with high $\delta^{13}C$ (up to 5.8‰) were deposited. The heaviest isotope composition of carbon in the whole investigated part of the post-Kazanian Permo–Triassic (Wordian–Olenekian) beds of the East European Platform is recorded here (Arefiev et al., 2015; Arefiev, Silantiev, 2014; Kearsey et al., 2012); thus, it is possible to correlate the middle part of the Severodvinian Stage with the Kamura event in marine sections (Isozaki et al., 2007).

It is probable that rhythmic fluctuations of $\delta^{18}O$ were caused by periodic cooling and humidification which alternated with warming. Samples of sedimentary carbonates with a very light isotope composition of oxygen (to $\delta^{18}O$=22.3‰) are evidence of considerable inflow in the basin of fresh water (Leng, Marshall, 2004), which probably intensified during cooling and humidification. An increase in the river runoff could have caused considerable lightening of oxygen in the water of shallow well-warmed lakes. Periodic accumulation of carbonates with $\delta^{18}O$ about 34‰ is evidence of renewal of intense evaporitization in local conditions. It is noteworthy that, in each isotope geochemical cyclite of the Late Severodvinian, fluctuations of the isotope composition of carbon and oxygen are similar, suggesting that they were caused by the same factors; consequently, the rhythms in sedimentation in this interval were also accounted for by common factors.

The data on cooling obtained on the basis of sedimentary carbonates agree with the isotope geochemical characteristics of pedogenic carbonates. Since cooling results in a decrease in the $\delta^{18}O$ content in atmospheric waters (Leng, Marshall, 2004), a decrease in the mean annual temperature also causes a decrease in $\delta^{18}O$ in soil carbonates (Levin et al., 2004; Kovda et al., 2014). The lightest isotope composition of oxygen is revealed in paleosol carbonates of the Strelna Member, which has yielded a sample of sedimentary carbonate with a low $\delta^{18}O$=24.2‰ (Mikulino outcrop, sample 1356/20-2), indicating fresh water. This probably suggests that the Late Severodvinian peak of regional cooling occurred in the Strelna episode.

In turn, the Severodvinian cooling correlates with the Kamura event and probably results from the same factors, since the Kamura event is also considered to have been caused by cooling (Isozaki et al., 2007). Note that in the Late Wordian – Late Capitanian, the P4 glacial episode is recorded in eastern Australia (Fielding et al., 2008), which probably coincided with a global cooling.

VYATKIAN STAGE (LOPINGIAN)

Lower Vyatkian Substage (Wuchiapingian)

In the Lower Vyatkian Substage, $\delta^{13}C$ and $\delta^{18}O$ continued to decrease. The isotope geochemical characteristics of the substage vary considerably over the section. In sedimentary carbonates of the Poldarsa Formation, $\delta^{13}C$ ranges from –0.3 to 3.4‰ and $\delta^{18}O$, from 25.6 to 32.5‰ (Figs. 16, 21). In the Salaryovo Formation, $\delta^{13}C$ ranges from –4.3 to 0.7‰ and $\delta^{18}O$ vary from 23.0 to 29.1‰ (all samples analyzed from the Nizhnee Fedosovo Member without division into the Lower and Upper Vyatkian substages are taken into account).

In paleosol carbonates of the Rovdino Member, $\delta^{13}C$ ranges from –6.9 to 0.4‰ and, according to new data, $\delta^{18}O$ ranges from 20.7 to 26.1‰ (Fig. 32), considerably lower than in the Severodvinian Stage. Upward in the section, in the upper part of the Rovdino Member and in the Salaryovo Member, $\delta^{13}C$ in pedogenic carbonates fluctuates approximately within its former range (from –6.0 to 0.5‰), and the isotope composition of oxygen shows considerable weighting, $\delta^{18}O$ ranges from 23.0 to 30.3‰ (Yaikovo and Verkhnee Fedosovo outcrops).

In the Lower Vyatkian Substage, $\delta^{13}C$ tends to decrease. At the base of the Vyatkian strata, sedimentary carbonates show negative carbon excursion (–0.3‰). This is the minimum value for all underlying deposits. However, at the boundary of the Lower and Upper Vyatkian Substage, $\delta^{13}C$ in sedimentary carbonates decreases to –4.3‰. At the transition to the Salaryovo Formation, which was mostly deposited in conditions of an alluvial plain, with small frequently drying up lakes, pedogenic and sedimentary carbonates show significant lightening of the oxygen isotope composition. This is evidence of a recurrent fall in temperature, which was more pronounced than in the Severodvinian Time. Weighting of the oxygen isotope composition in paleosol carbonates, occurring upward in the section, is evidence of a returning fluctuation towards warming.

Upper Vyatkian Substage (Changhsingian)

At the transition to the Upper Vyatkian Substage, the isotope composition of carbon and oxygen in sedimentary and pedogenic carbonates shows considerable lightening. Sedimentary carbonates of the Nefyodovian horizon show fluctuations of $\delta^{13}C$ from –3.4 to –1.7‰ and $\delta^{18}O$, from 23.2 to 26.6‰ (Nizhnee Fedosovo Member is excluded). In pedogenic

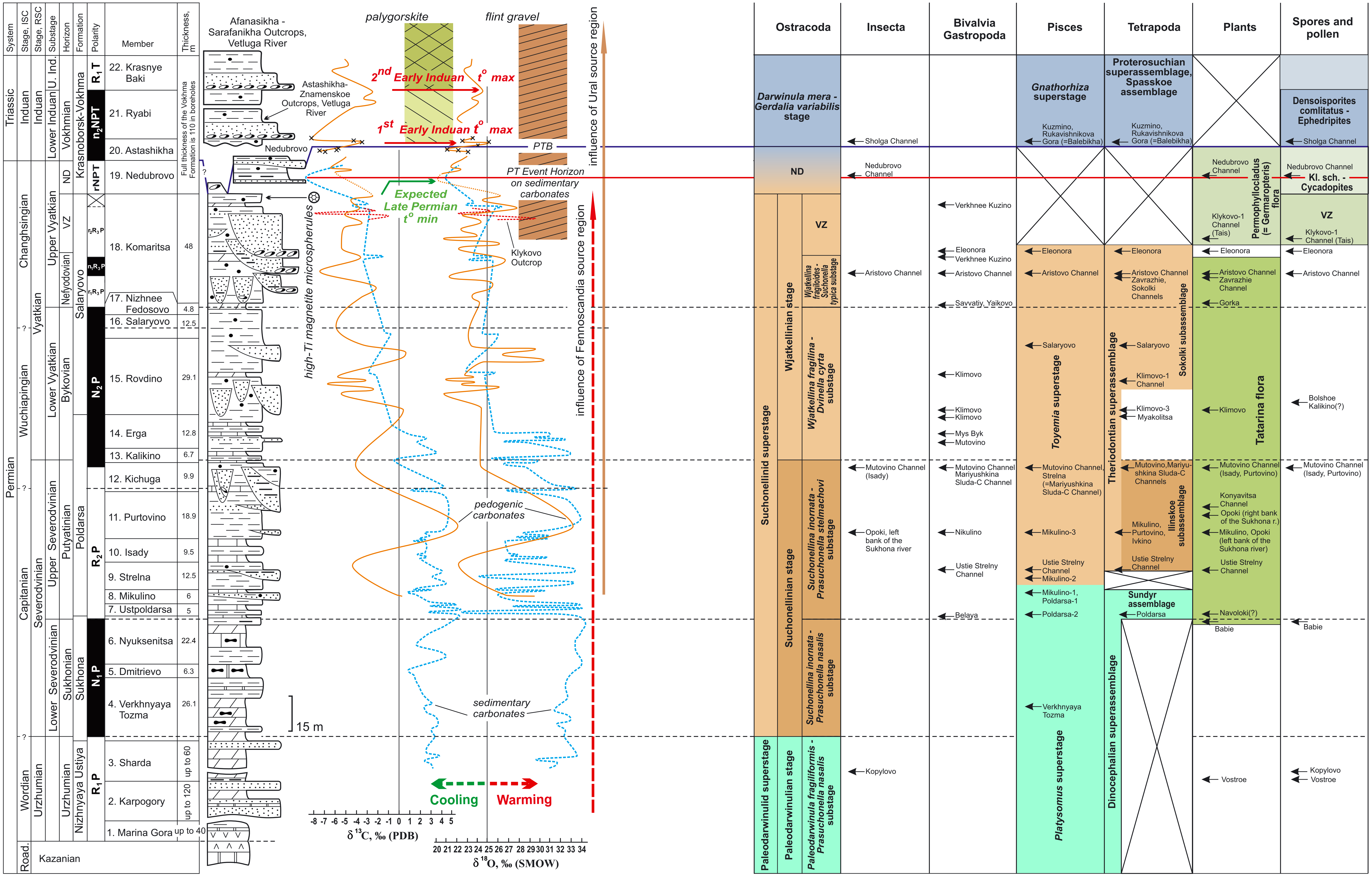


Fig. 35. Isotopic, sedimentological and paleontological characteristic of the Permian and lowermost Triassic of the Moscow Syncline. Left part – carbon and oxygen of sedimentary and pedogenic carbonates. Oxygen isotopes show thermal minimum under the top of the Changhsingian and two thermal maxima in the Late Induan. Isotope data correlate with the data from dominant source regions and with the anomaly of high-Ti magnetite micro-spherules. Right part – assemblages of Permian biota and main biotic events. ISC – International Stratigraphic Scale, Kl. sch. – *Klausipollenites schaubergeri*, ND – beds with Nedubrovian biota, Road. – Roadian, SC – General Stratigraphic Scale of Russia, VZ – beds with Vyaznikian biota.

carbonates, the isotope compositions of carbon and oxygen are lighter; $\delta^{13}C$ ranges from –7.5 to –2.2‰. Bed 42A/9 located several meters below the roof of the Nefyodovian horizon shows negative excursion, $\delta^{13}C$=–7.5‰; $\delta^{18}O$ in paleosol carbonates ranges from 21.3 to 25.7 (maximum is 26.6‰ in a clay nodule located between the limestone and marl layers).

In sedimentary carbonates of the beds with the Vyaznikian biota of the Aristovo–Balebikha section, $\delta^{13}C$ decreases, ranging from –4.4 to –2.7‰; $\delta^{18}O$ remains close to the former range, from 23.1 to 26.5‰. In pedogenic carbonates, $\delta^{13}C$ varies from –5.1 to –1.9‰, lightening of the oxygen isotope composition is observed again. $\delta^{18}O$ vary from 20.8 to 27.8‰ and almost all values are lower than 25‰. In the neighboring section of Klykovo–Pashina Gora (Yug River), in the beds with the Vyaznikian biota, the range of $\delta^{13}C$ in pedogenic carbonates is wider (from –8.0 to –1.0‰). The only sample analyzed (–8.0‰) showed negative second-order excursion; $\delta^{18}O$ ranges from 22.2 to 29.4‰.

In general, a decrease in $\delta^{13}C$ in the Nefyodovian horizon and beds with the Vyazniki biota may be connected with the onset of the global geochemical processes which occurred at the end of the Permian. A decrease in $\delta^{18}O$ is treated as a result of cooling. Carbonates with a heavy isotope composition of oxygen, >29‰, are almost completely absent at this level. In the majority of samples of sedimentary and pedogenic carbonates, $\delta^{18}O$ is below 26.5‰, suggesting interruption of evaporitization, which repeatedly occurred even in the first half of the Vyatkian Age.

The variation curve of $\delta^{18}O$ in the beds with the Vyaznikian biota (Fig. 29) shows several negative second-order excursions. The first episode is recorded in sample 42F/3 (22.3‰), which approximately corresponds to sample 158/4 from the Verkhnee Kuzino outcrop (23.1‰). The second excursion is revealed in sample 158/15-4 (20.8‰, the minimum value in the entire section). The succeeding point in Bed 42F/26-3 (23‰) in the Verkhnee Kuzino outcrop at this level also shows distinct lightening of the isotope composition of oxygen down to 22.4‰ (sample 158/23-2). The fourth excursion to 22.5‰ is recorded in Bed 158/26-1. The excursions approximately correspond to the levels enriched with sand. A decrease in $\delta^{18}O$ in Bed 158/15-4 correlated with the sand bed in the Klykovo–Pashina Gora section. The cooling episodes clearly correlates with activation of the river system, which was probably caused by humidification.

The isotope composition of carbon and oxygen lightens upward in the section and reaches a minimum in the Nedubrovo Member just under the roof of the Vyatkian Stage (Changhsingian). Sedimentary carbonates in the Nedubrovo section are represented by thin marl interbeds and lenses; $\delta^{13}C$ decreases there to –8.8‰ and $\delta^{18}O$, to 21.1‰ (Fig. 32). In pedogenic carbonates, $\delta^{13}C$ ranges from –6.5 to –4.6‰ and $\delta^{18}O$, from 20.6 to 21.7‰.

$\delta^{18}O$=–8.8‰ is the minimum value for sedimentary carbonates of the Permian–Early Induan beds in the eastern part of MB. $\delta^{18}O$=–6.5‰ is minimum for pedogenic carbonates of the Permian – Early Olenekian beds of the northeastern part of MB. Available data allow the establishment in the Nedubrovo member of a negative excursion of $\delta^{13}C$, which is evidence of the event horizon of the Late Permian extinction and corresponds to negative excursion in the ash bed no. 25 of stratotype section at the Permian-Triassic boundary of Meishan (Takahashi et al., 2010). In the diagram (Fig. 35), this level is drawn based on sedimentary carbonates. The system data based on the isotope composition of oxygen are evidence of a Late Permian (Late Changsingian) temperature minimum, which is recorded in the Nedubrovo member.

INDUAN STAGE

The overlying Astashikha member of the Nedubrovo section shows a weighted isotope composition of carbon and oxygen. In a marl sample from a sand member, $\delta^{13}C$ is –5.3‰ and $\delta^{18}O$ is 22.4‰. In pedogenic carbonates, $\delta^{13}C$ ranges from –5.6 to –4.9‰ and $\delta^{18}O$, from 21.9 to 22.7‰.

Additional isotope geochemical data on the Astashikha member have been obtained in the southeastern part of MB near the Voskresenskoe and Krasnye Baki towns on the Vetluga River approximately 500 km south of the Sukhona and Severnaya Dvina River Basin (Fig. 2). In the Astashikha section, $\delta^{13}C$ in a sedimentary marl sample is –7,9‰. In paleosol carbonates, $\delta^{13}C$ varies from –8.3 to –3.5‰. At the same time, some samples mostly from the lower part of the outcrop are lighter with reference to carbon than the lightest soil carbonates in Nedubrovo section (Arefiev et al., 2015, fig. 1, outcrop no. 35a). However, we should take into account recent data of Yu.P. Balabanov that the lower part of the Astashikha outcrop is characterized by reverse paleomagnetic polarity, as in the Nedubrovo section, and can be correlated with the Nedubrovo member. Therefore, the minimum $\delta^{13}C$ values revealed probably correlate with the global negative carbon excursion just under the roof of the Changhsingian Stage.

In a sedimentary marl sample from in the Astashikha section, $\delta^{18}O$ is 22.7‰ and, in pedogenic carbonates, varies from 21.2 to 25.2‰. The heaviest oxygen isotope composition in the Vokhma Formation is recorded here; it is indicative of the Early Induan warming. This level apparently correlates with the Early Induan temperature maximum, which has been revealed in marine sections in the roof of the *Isarciella isarcica* Zone (Sun et al., 2012) and corresponds to bed no. 29 in Meishan (Hongfu et al., 2001). Since the Permian–Triassic boundary (ISC) occupies an intermediate position between the event level and temperature optimum (Sun et al., 2012), these data suggest that it passes between the Nedubrovo and Astashikha members

(Fig. 35). This is the middle level of the Astashikha section, approximately 3 m below the sole of the Ryabi beds. In the upper part of the Ryabi beds, in the middle of the Induan Stage, the second temperature optimum has been revealed (Fig. 35, Afanasikha–Sarafanikha section), which probably more closely corresponds to the Induan temperature optimum revealed in marine sections.

In general, the isotope data distinctly show that, since the latter half of the Severodvinian Age, the Late Permian Time was characterized by well-pronounced temperature fluctuations. Incidental falls in temperature caused humidification and activation of the river system. Repeated warming phases resulted in evaporitization of water in small local lakes, accumulation of carbonates with a heavy isotope composition of oxygen. Temperature fluctuations occurred against a background of general cooling, which reached a peak in the Nedubrovo Time. In the Nedubrovo section, the level of the Late Permian temperature minimum approximately coincides with the global negative excursion of $\delta^{13}C$, that is, with the event horizon of the Late Permian extinction. However, with a more thorough examination of paleotemperature fluctuations, it should be taken into account that a decrease in temperature caused intense accumulation of sand. Based on this, it is possible to assume that the Late Permian temperature minimum apparently coincided with the beginning of the Nedubrovo episode. The data on regional cooling at the end of the Vyatkian Time agree with the data on a considerable fall in temperature during the Wuchiapingian–Changhsingian Time, which were obtained in marine sections (Chen et al., 2013).

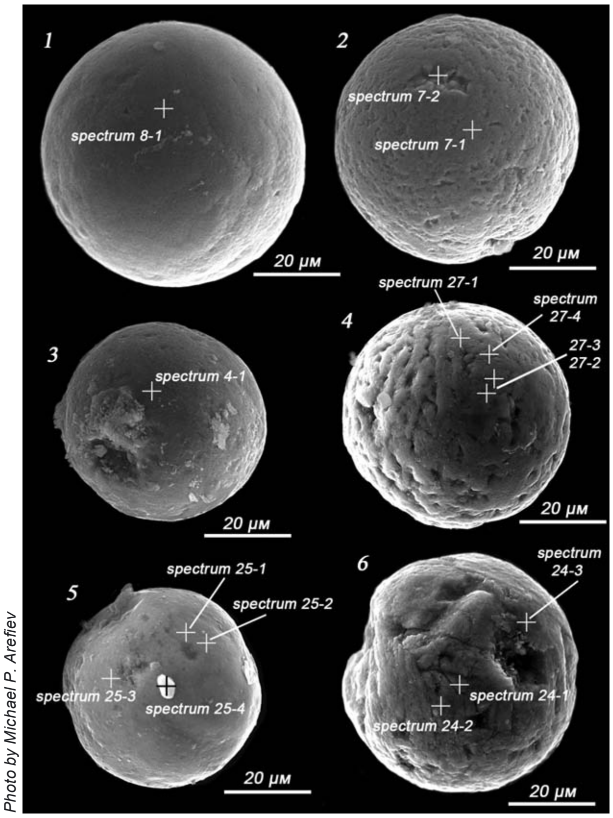


Photo by Michael P. Arefiev

Fig. 36. High-Ti magnetite microspherules probably of extra-terrestrial origin. Uppermost Vyatkian in the Balebikha section (Changhsingian).

A warming at the Permian–Triassic boundary is recorded at two levels with relatively high $\delta^{18}O$ in pedogenic carbonates. The levels correlate with a temperature optimum that was recorded in Early Triassic marine sections (Sun et al., 2012). However, based on available values of $\delta^{18}O$, the maximum Early Induan temperatures in MB did not exceed the background Late Permian paleotemperatures. In the majority of Induan samples, $\delta^{18}O$ vary within 22-25‰, without abrupt excursions; this apparently suggests that, in the Induan Time, long-term evaporation (evaporitization) did not prevail over precipitation, in contrast to the situation in the Permian.

Sedimentological data supplement the results of isotope studies. The cooling episodes correlate with activation of alluvial inflow from the Ural source region. This pattern is observed from the beginning of the Late Severodvinian (Fig. 35, Fig. 29, right curve). As usual incidental falls in temperature were accompanied by expansion of Ural sand, with the dominating epidote–zoisite association of accessory minerals, which are characteristic of the Ural source region (Strok, Trofimova, 1976). During warmings, carbonate sedimentation renewed. The warming episodes were accompanied by expansion of the almandine-zirconium association, which, along with the overpressured metamorphism minerals staurolite and kyanite, are evidence of a Fennoscandia source region (Grossgeim et al., 1984).

During a new profound cooling in the Vyaznikian Time, gravelstones with flints brought from the Urals for a distance of more than 700 km appeared for the first time. Siliceous gravelstones are characteristic of the Vyaznikian–Induan beds in the eastern part of MB. In the Vyaznikian Time in the Yug River valley (Pashin Gora outcrop), large sand channels 20 m thick or more appeared for the first time, marking the extremely high energy of the Ural River system. Similar large sandy river channels with huge conglomerates (up to 7 m of total thickness) are characteristic of the Induan Stage of the eastern part of MB and northerly regions.

The Vyaznikian beds correlate with the anomaly of high titanic magnetite spherules in the Balebikha outcrop (Fig. 36; Arefiev, Shkurskiy, 2012). A high concentration of similar microspherules has been recorded in a number of Late Permian marine and continental sections (Jin et al., 2000; Korchagin et al., 2010; Lozovsky, 2013 with data of Kozur, Bachmann, 2005; Zhang et al., 2014). Although opinions differ as to the nature of these structures, the high concentration of Ti, which is characteristic of them, is evidence for their extra-

Table 1. Weight contents of elements of the microspherules.

Spectrum No	Weight contents of elements, %									
	Si	Ti	Al	Fe	Mn	Mg	Ca	Na	K	O
4-1	1.08	38.42	0.22	25.65			0.15			34.49
7-1	1.60	13.76	0.59	56.37						27.68
7-2	5.72	17.90	2.14	40.21		0.95			0.46	32.62
8-1	1.59	26.18	0.19	39.41	1.46					31.18
24-1	0.93	26.95	0.5	21.73	0.96		0.22			48.72
24-2	1.3	23.01	0.75	18.71	0.68	0.68	0.20	1.09		53.57
24-3	3.53	35.77	1.93	27.3	0.58	0.91	0.37			29.62
25-1	1.13	24.56	0.67	23.54	0.60	0.86				48.64
25-2	0.82	30.63	0.63	32.39	0.88	0.75			0.28	33.62
25-3	0.84	16.72	0.59	18.58	0.51	1.71				61.06
25-4	2.17	25.06	1.51	9.11		0.85				61.31
27-1	0.4	26.23	0.41	15.56	0.32					57.08
27-2	0.26	33.0	0.46	10.82						55.46
27-3	0.31	35.13		12.45						52.11
27-4	0.45	27.01	0.51	22.25	0.68					49.1

terrestrial origin (Zhang et al., 2014). Examples with weight contents of elements of the microspherules are shown in Fig. 36 and in the Table 1. Probably, the anomaly is evidence of an increased influx of space matter at the end of the Permian, which could have been connected with cooling and humidification.

Finally, climatic changes at the Permian-Triassic boundary correlate naturally with changes in the composition of the clayey fraction. The main emphasis is made on clay mineralogy of different pedons. Two kinds of smectite, illite, chlorite, kaolinite, and palygorskite have been recorded. However, the ratios of these minerals are different (Arefiev et al., 2012).

The earliest Severodvinian pedons are characterized by low charge smectite and illite. Chlorite and kaolinite were found in trace quantities. In the middle and uppermost parts of the Severodvinian, high charge smectite is present; chlorite and kaolinite are in trace quantities. The Vyatkian beds (without the Nedubrovo Member) are usually characterized by low charge smectite with chlorite and kaolinite, without illite. The Nedubrovo pedons are characterized by low charge smectite. Chlorite and kaolinite were found in trace quantities.

The Induan deposits contain palygorskite. However, abundant palygorskite was recorded in the inner Ryabi Member of the Vokhma Formation (Fig. 35). The earlier Induan pedons usually contain the same mineral complex as the inner beds, with the Vyaznikian and Nedubrovian biotas and palygorskite in trace quantities. Appearance of abundant palygorskite in the Ryabi and Krasnye Baki members can indicate aridity stress above the Permian–Triassic boundary. However, the relatively low values of $\delta^{18}O$ in pedogenic carbonates suggest that there were certain additional processes other than aridization.

The paleomagnetic properties and zonation in the Permian succession of the Sukhona River basin are complicated. Several large 40-100 m thick intercalated zones of normal and reversed polarity are recognized here. Among them the orthozones R_1P, N_1P, R_2P, N_2P, R_3P, and NPT are established (Reference Section…, 1981; Tatarian beds..., 2001; Lozovsky et al., 2014) (Figs. 4, 6, 35). The orthozone R_1P belongs to the upper part of the Kiaman Hyperzone. All the above orthozones are included in the Illawarra Hyperzone.

Only the upper part of the orthozones R_1P of visible thickness of 20 m is exposed in the Verkhnyaya Tozma locality and belongs to the upper Nizhnyaya Ustiya Formation (Fig. 8).

A striking change in the paleomagnetic succession occurs at the bottom of the Sukhona Formation where the first Permian normal orthozone N_1P 46-47 m thick is recorded (Fig. 35). This zone consists of the Verkhnyaya Tozma, Dmitrievo and lower part of Nyuksenitsa Members (Figs. 8, 9). The lower boundary of this zone, i.e. Kiaman-Illawarra boundary, is an additional marker of the bottom of the Severodvinian Stage and the lower boundary of the Biarmian Series.

In the lower Nyuksenitsa Member, 5-6 meters below the bottom of the Poldarsa Formation, the normal polarity zone is replaced by reversed polarity zone, where the second orthozone R_2P begins (Fig. 9). This zone is composed of the upper Nyuksenitsa Member of Sukhona Formation and Ustpoldarsa, Mikulino, Strelna, Isady, Purtovino, and Kichuga Members of Poldarsa Formation (Figs. 9, 16). The thickness of this zone is 65 m (Fig. 35). The boundary between the N_1P and R_2P paleomagnetic zones is an additional marker of the bottom of Upper Severodvinian substage.

Next in the succession, lies the N_2P paleomagnetic zone 65-m thick. It spreads over the Kalikino and Erga Members of the Poldarsa Formation and Rovdino, Salaryovo, and the lower part of the Nizhnee Fedosovo Members of the Salaryovo Formation (Fig. 35). The bottom of this paleomagnetic zone occurs slightly below the Severodvinian-Vyatkian boundary and is an additional marker of the lower boundary of the Vyatkian Stage (Fig. 16).

Following upwards R_3P orthozone is equal to the nearly entire Komaritsa Member of the Salaryovo Formation (Fig. 35). This zone has been found in the Aristovo and Verkhnee Kuzino localities on the right bank of Malaya Severnaya Dvina River, across the mouth of the Sukona River (Figs. 29, 30). The apparent thickness of R_3P orthozone is 50 meters. Its bottom appears slightly below the lower boundary of the Upper Vyatkian Substage. In the middle part of the orthozone R_3P at the level of Aristovo sand lens the subzone of normal polarity 8.5 m thick has been recognized.

The studied magnitostratigraphic succession ended with orthozone NPT (Fig. 35), which has been established in the sections along the Yug River. In some sections in the East European Platform, the subzone of reversed polarity rNPT is recognized. This subzone occurs at the Permian-Triassic boundary transition and extent uppermost Vyatkain and lowermost Vokhmian Stages (Fig. 3). In Nedubrovo section, the Nedubrovo Member possessed reversed polarity and perhaps belongs to rNPT subzone (Fig. 32).

Ostracods

Two great phases are defined in the development of the Permian non-marine ostracods fauna of European Russia: the Paleodarwinulid Superstage and the Suchonellinid Superstage (Tatarian beds..., 2001; Molostovskaya, 2005) (Fig. 35). The boundary of these phases corresponds to the boundary between the Biarmian and Tatarian Series. It is a turning point in the development of the superfamily Darwinulacea and is characterized by the disappearance of the ostracod family Paleodarwinulidae, massive radiation of ostracods of the new family Suchonellinidae, and the appearance of new family Cytherissinellidae.

There are Suchonellinian (Severodvinian) and Wjatkellinian (Vyatkian) stages defined in the Suchonellinid superstage. The Suchonellinian stage is characterized by the coexistence of the genera *Suchonellina* and *Prasuchonella*. It corresponds stratigraphically to the Severodvinian and is marked by the zonal ostracod assemblages: *Suchonellina inornata – Prasuchonella nasalis* and *Suchonellina inornata – Prasuchonella stelmachovi*. The two assemblages have similar generic composition and differ only at the species level. They correspond to the Lower Severodvinian and the Upper Severodvinian respectively.

The Wjatkellinian stage is characterized by the coexistence of genus *Suchonellina*, *Wjatkellina*, *Suchonella*. Major evolutionary changes of ostracods mark the beginning of this stage. New families appeared: Suchonellidae in the superfamily Suchonellacea, Gerdaliidae in the superfamily Darwinulacea, Glorianellidae in the superfamily Cyteracea, and two new genera, *Permianella* and *Unzhiella*, in the superfamily Permianacea. The Wjatkellinian stage corresponds to the Vyatkian. There are two phases in the Wjatkellinian stage. The early phase is represented by the *Wjatkellina fragilina – Dvinella cyrta* assemblage. Deposits with this assemblage are highlighted in the Lower Vyatkian. The late phase is represented by the *Wjatkellina fragiloides – Suchonella typica* assemblage and characterizes the lower part of the Upper Vyatkian substage.

Fig. 37. Ostracods from Belaya and Mutovino outcrops, Poldarsa Formation, Severodvinian – Vyatkian (Capitanian – Wuchiapingian):

1 – *Suchonellina parallela* Spazharskyi, 1939, PIN No. 5519/1364–13: 1a – right view, 1b – dorsal view, Mutovino outcrop, bed No. 64h, sample 1350–64h; Kichuga Member, Upper Severodvinian (Wuchiapingian).

2, 3 – *Prasuchonella sulacensis* (Starozhilova, 1967): 2 – PIN No. 5519/132612–54: 2a – left view, 2b – dorsal view; 3 – PIN No. 5519/132612–47: 3a – right view, 3b – dorsal view; Poldarsa outcrop, bed No. 30, sample 1355–26E–12; Ustpoldarsa Member, Upper Severodvinian (Capitanian).

4 – *Suchonellina inornata* Spizharskyi, 1937, PIN No. 5519/1326–12, right valve; Poldarsa outcrop, bed No. 30, sample 1355–26E–12; Ustpoldarsa Member, Upper Severodvinian (Capitanian).

5 – *Darwinuloides sentjakensis* (Sharapova, 1948), PIN No. 5519/1217–23: 5a – left valve, 5b – dorsal view; Mutovino outcrop, bed No. 72, sample 1203–17; Kalikino Member, Upper Severodvinian (Wuchiapingian).

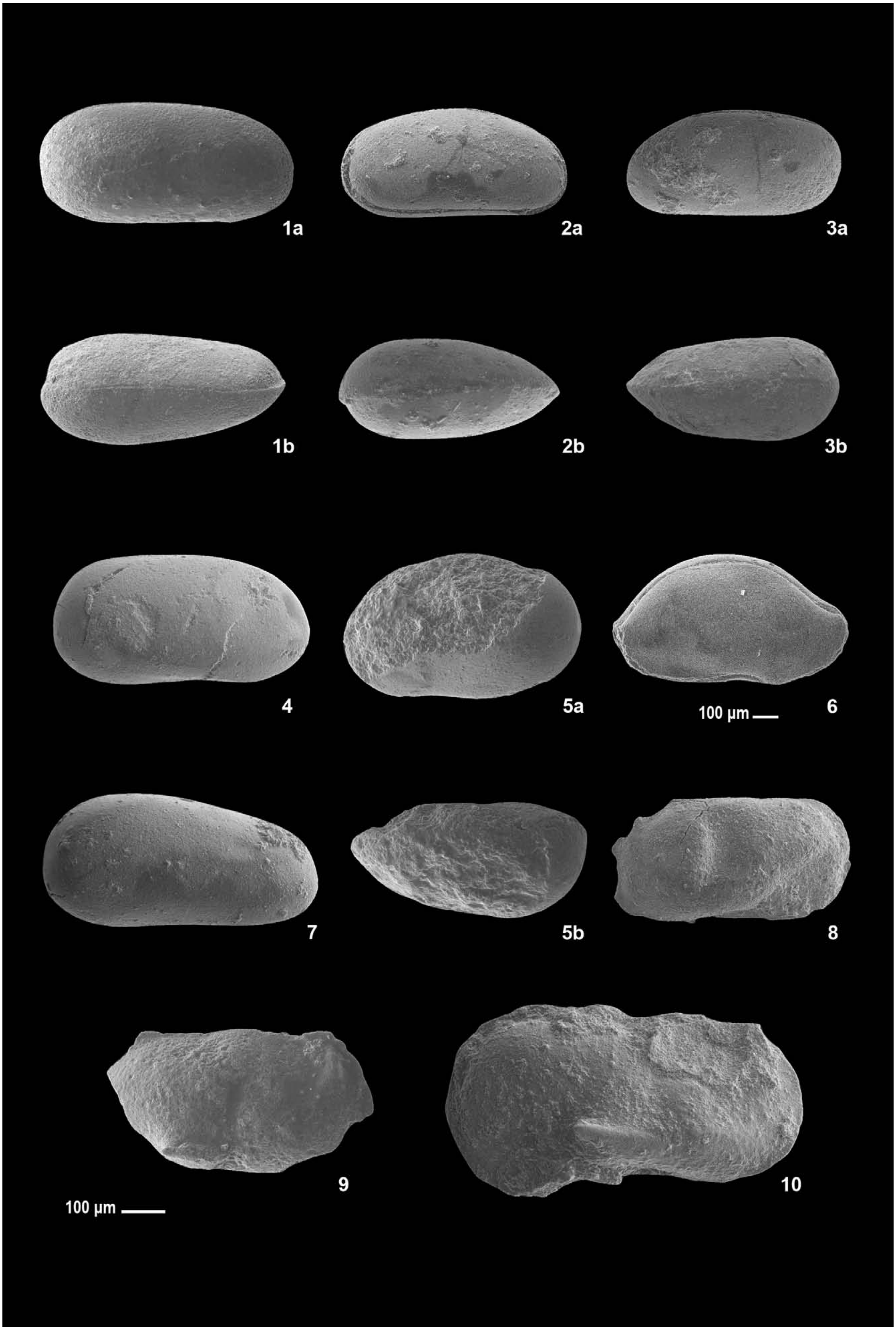
6 – *Bairdia sukhonica* Molostovskaya, 2014, holotype SSU No. K12–1, right valve; Belaya outcrop; Ustpoldarsa Member, Upper Severodvinian (Capitanian).

7 – *Suchonellina digitalis* (Mishina, 1961), PIN No. 5519/132612–1, right valve; Poldarsa outcrop, bed No. 30, sample 1355–26E–12; Ustpoldarsa Member, Upper Severodvinian (Capitanian).

8 – *Sinusuella ignota* Spizharskyi, 1939, PIN No. 5519/1226D–95, right valve; Poldarsa outcrop, bed No. 30, sample 1355–26D–1; Ustpoldarsa Member, Upper Severodvinian (Capitanian).

9 – *Permiana oblonga* (Posner, 1948), PIN 5519/133a–33, right valve; Mutovino outcrop, bed No. 3a, sample 1350–3a bottom; Isady Member, Upper Severodvinian (Capitanian).

10 – *Permiana elongata* (Posner, 1948), PIN No. 5519/1326E12–2; right valve; Poldarsa outcrop, bed No. 30, sample 1355–26E–12; Ustpoldarsa Member, Upper Severodvinian (Capitanian).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In the Permian sediments of the Sukhona River basin, ostracods are distributed very unevenly (Reference Section..., 1981; Tatarian beds..., 2001) (Figs. 8-10, 16, 17, 21, 23, 29, 30). Their remains have not been found in the Nizhnyaya Ustiya Formation. The overlying sediments are characterized by ostracods of only the Suhonnelinid fauna. Thus, the most important event in the history of the Permian ostracods is not preserved in the Sukhona sections.

In the Sukhona Formation, ostracods are rare. This interval of sequence in the Sukhona River basin is characterized by *Suchonellina inornata – Prasuchonella nasalis* ostracod assemblage. In the Verkhnyaya Tozma, Dmitrievo and Nyuksenitsa Members, remains of the ostracods *Suchonellina inornata* Spizharskyi, *S.* cf. *inornata* Spizharskyi, *S. futschiki* (Kashevarova), *S.* ex gr. *parallela* Spizharskyi, *S. spizharskyi* (Posner), *S.* ex gr. *undulata* (Mishina), *S. daedala* (Mishina), *Paleodarwinula* cf. *elongate* (Lunjak), *P.* ex gr. *teodovichi* (Belousova), *Prasuchonella nasalis* (Sharapova), *Darwinuloidea* ex gr. *buguruslanicus* (Kashevarova), *D.* sp., *Permiana oblonga* (Posner), *Sinusuella vjatkensis* (Posner) were found. The richest associations are located in the Dmitrievo Member.

In the Poldarsa Formation, ostracods were already very widespread. In the Ustpoldarsa, Mikulino, Strelna, Purtovina, Kichuga Members and the lower part of the Kalikino Member, numerous ostracods of the *Suchonellina inornata – Prasuchonella stelmachovi* assemblage were found. This stratigraphic level is characterized by *Bairdia sukhonica* Molostovskaya (Fig. 37), *Clinocypris* (?) sp., *Darwinuloides sentjakensis* (Sharapova) (Fig. 37), *Darwinuloides* cf. *sentjakensis* (Sharapova), *Darwinuloides* sp., *Prasuchonella stelmachovi* (Spizharskyi) (Fig. 38), *P.* ex gr. *stelmachovi* (Spizharskyi), *P.* cf. *stelmachovi* (Spizharskyi), *P. sulacensis* (Starozhilova) (Fig. 37), *P.* ex gr. *sulacensis* (Starozhilova), *P.* cf. *nasalis* (Sharapova), *Permiana elongata* (Posner) (Fig. 37), *P. oblonga* (Posner) (Fig. 37), *P.* cf. *oblonga* (Posner), *Suchonellina inornata* Spizhar-

Fig. 38. Ostracods from the Mutovino, Krasavino and Bolshoe Kalikino outcrops, Poldarsa Formation, Severodvinian – Vyatkian (Capitanian – Wuchiapingian):

1 – *Suchonellina undulata* (Mishina, 1961), PIN No. 5519/13103–38: 1a – right view, 1b – dorsal view; Mutovino outcrop, bed No. 103, sample 1350–103; Erga Member, Lower Vyatkian (Wuchiapingian).

2 – *Suchonella blomi* Molostovskaya, 2001; paratype SSU No. 6–318/1: 2a – right view, 2b – dorsal view; Krasavino outcrop, bed 227–29, sample 10; Erga Member, Lower Vyatkian (Wuchiapingian).

3, 4 – *Prasuchonella stelmachovi* (Spizharskyi, 1939): 3 – PIN No. 5519/12113–14, left valve; Mutovino outcrop, bed No. 72, sample 1203–11v; Kalikino Member, Upper Severodvinian (Wuchiapingian). 4 – PIN No. 5519/1364–16, dorsal view, Mutovino outcrop, bed No 64h, sample 1350–64h; Kichuga Member, Upper Severodvinian (Wuchiapingian).

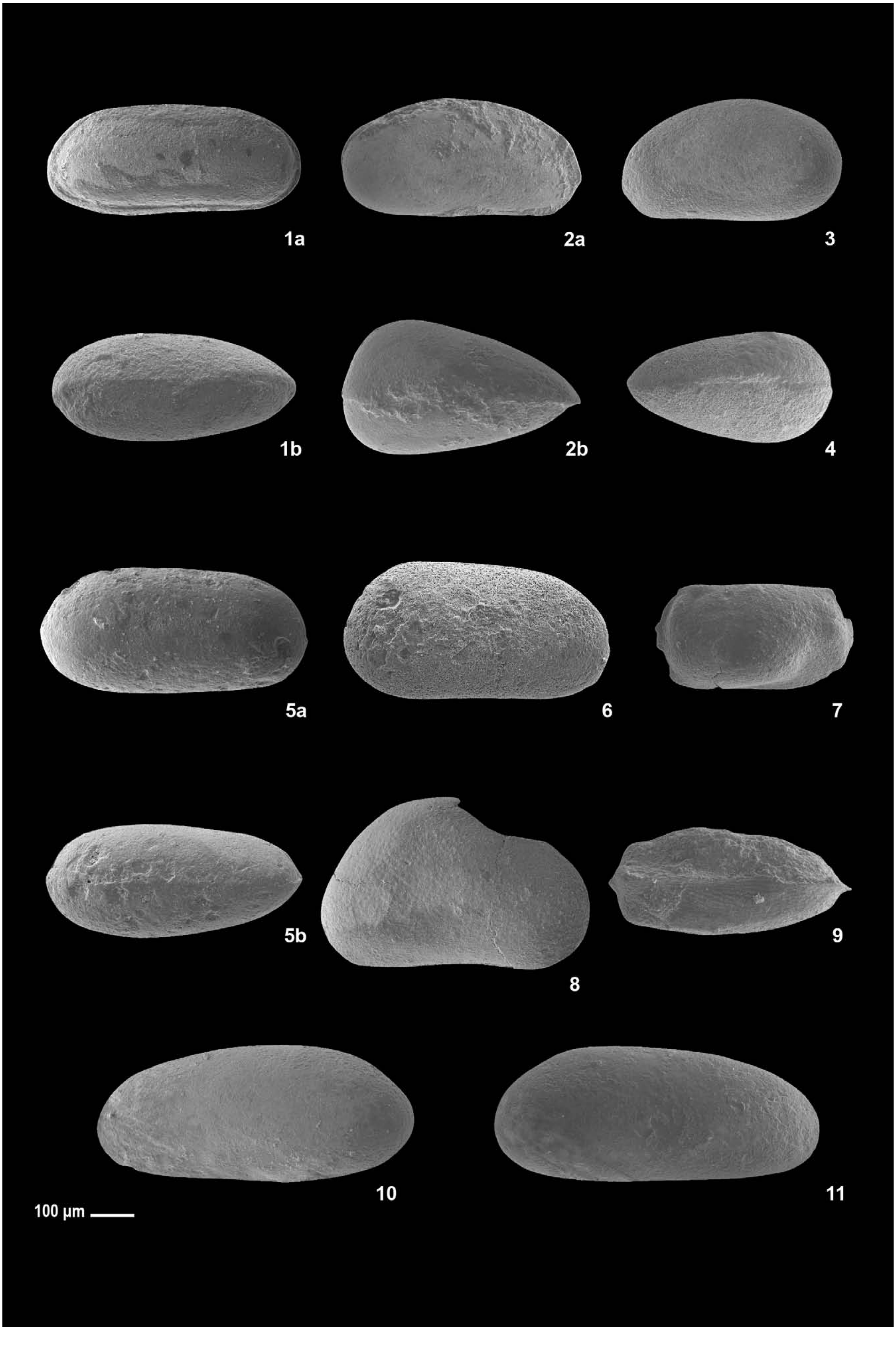
5 – *Suchonellina parallela* Spizharskyi, 1939, PIN No. 5519/1364–11: 5a – right view, 5b – dorsal view; Mutovino outcrop, bed No. 64h, sample 1350–64h; Kichuga Member.

6 – *Suchonellina inornata* Spizharskyi, 1937, PIN No. 5519/122–3, right valve; Mutovino outcrop, bed No. 64h, sample 1203–2; Kichuga Member, Upper Severodvinian (Wuchiapingian).

7, 9 – *Sinusuella vajtkensis* (Posner, 1948): 7 – PIN No. 5519/12192–31, left valve; Mutovino outcrop, bed No. 82, sample 1203–19c; 9 – PIN No. № 5519/12172–24, dorsal view, Mutovino outcrop, bed No. 80, sample 1203–17в; Kalikino Member, Lower Vyatkian (Wuchiapingian).

8 – *Clinocypris* (?) sp., PIN No. 5519/13105–51, right valve; Mutovino outcrop, bed No 105, sample No. 1350–105; Erga Member, Lower Vyatkian (Wuchiapingian).

10, 11 – *Wjatkellina praelonga* (Zekina, 1972): 10 – PIN No. 5519/142–68, right valve; 11 – PIN No. 5519/142–69, left valve; Bolshoe Kalikino outcrop, bed No VG1443/2a, sample 1443–2a; Kichuga Member, Upper Severodvinian (Wuchiapingian).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skyi (Fig. 37), *S.* cf. *inornata* Spizharskyi, *S.* ex gr. *inornata* Spizharskyi, *S. parallela* Spizharskyi (Fig. 37), *S.* cf. *parallela* Spizharskyi, *S.* ex gr *parallela* Spizharskyi, *S.* cf. *spizharskyi* (Posner), *S.* ex gr. *spizharskyi* (Posner), *S. futschiki* (Kashevarova), *S.* cf. *futschiki* (Kashevarova), *S.* ex gr. *futschiki* (Kashevarova), *Sinusuella ignota* Spizharskyi (Fig. 37), *S.* cf. *ignota* Spizharskyi, *S.* aff. *ignota* Spizharskyi, *S. vjatkensis* (Posner), *S.* cf. *vjatkensis* (Posner), *Tscherdynzeviana* sp., *Wjatkellina fragilina* (Belousova) (Fig. 39).

In Kalikino – early Erga time the diversity of ostracods in the Sukhona River basin significantly increased. A new – Wjatkellinian – stage of their development had begun. The lower boundary of beds with Wjatkellinian ostracod fauna was validated as the lower boundary of Vyatkian (Subcommission on the Permian..., 2006). The Vyatkian boundary-stratotype was chosen on the Sukhona River (Fig. 15). The lower boundary of the Vyatkian stage is fixed at the bottom of layer 75 in the Mutovino section (Fig. 16). *Suchonella blomi* Molostovskaya, a characteristic representative of the early Wjatkellinian fauna, first appears at this level.

Kalikino and Erga Members of Poldarsa Formation and Rovdino, Salaryovo and lower part of Nizhnee Fedosovo Members of Salaryovo Formation are characterized by ostracods of *Wjatkellina fragilina – Dvinella cyrta* assemblage. The following ostracods were found here: *Clinocypris* (?) sp. (Fig. 38), *Darwinuloides svijazhicus* (Sharapova) (Fig. 39), *D.* cf. *svijazhicus* (Sharapova), *D. buguruslanicus* Kashevarova, *D. sentjakensis* (Sharapova), *Dvinella cyrta* (Zekina) (Fig. 39), *D.* ex gr. *cyrta* (Zekina), *Gerdalia polenovae* Belousova, *Gerdalia* sp. (Fig. 39), *Prasuchonella* ex gr. *stelmachovi* (Spizharskyi), *Permiana* sp., *Suchonella blomi* Molostovskaya (Fig. 38), *S.* ex gr. *blomi* Molostovskaya, *S.* cf. *blomi* Molostovskaya, *S. auriculata* (Sharapova), *S.* cf. *auriculata* (Sharapova) (Fig. 39), *S.* ex gr. *auriculata* (Sharapova), *S.* aff. *auriculata* (Sharapova), *S.* (?) *acus* (Mishina), *Suchonellina inornata* Spizharskyi, *S.* cf. *inornata* Spizharskyi, *S.* ex gr. *inornata* Spizharskyi, *S. inornata* var. *trapezoida* (Zekina), *S. parallela* Spizharskyi, *S* cf. *parallela* Spizharskyi, *S.* ex gr. *parallela* Spizharskyi, *S. digitalis* (Mishina), *S. futschiki* (Kashevarova), *S. spizhar-*

Fig. 39. Ostracods from Mutovino, Bolshoe Kalikino, Klimovo and Yaikovo outcrops, Poldarsa and Salaryovo Formations, Severodvinian – Vyatkian (Capitanian – Wuchiapingian):

1, 2 – *Tatariella libera* Mishina, 1967: 1 – PIN No. 5519/13103–49, right view; 2 – PIN No. 5519/13103–50, dorsal view; Mutovino outcrop, bed No. 103, sample No. 1350–103; Erga Member, Lower Vyatkian (Wuchiapingian).

3 – *Suchonella* cf. *auriculata* (Sharapova, 1948), PIN No. 5519/1460–45: 3a – right view, 3b – dorsal view; Klimovo outcrop, bed No. 60–61, sample 1442–6061; Rovdino Member, Lower Vyatkian (Wuchiapingian).

4, 5 – *Dvinella cyrta* (Zekina, 1972): 4 – PIN No. 5519/1450–38, right view; Klimovo outcrop, bed No. 50, sample 1442–50–1; Rovdino Member, Lower Vyatkian (Wuchiapingian); 5 – PIN No. 5519/141–72, dorsal view; Yaikovo, bed No. M.P.A. 41/13, sample 1427–1; Nizhnee Fedosovo Member, Lower Vytkian (Wuchiapingian).

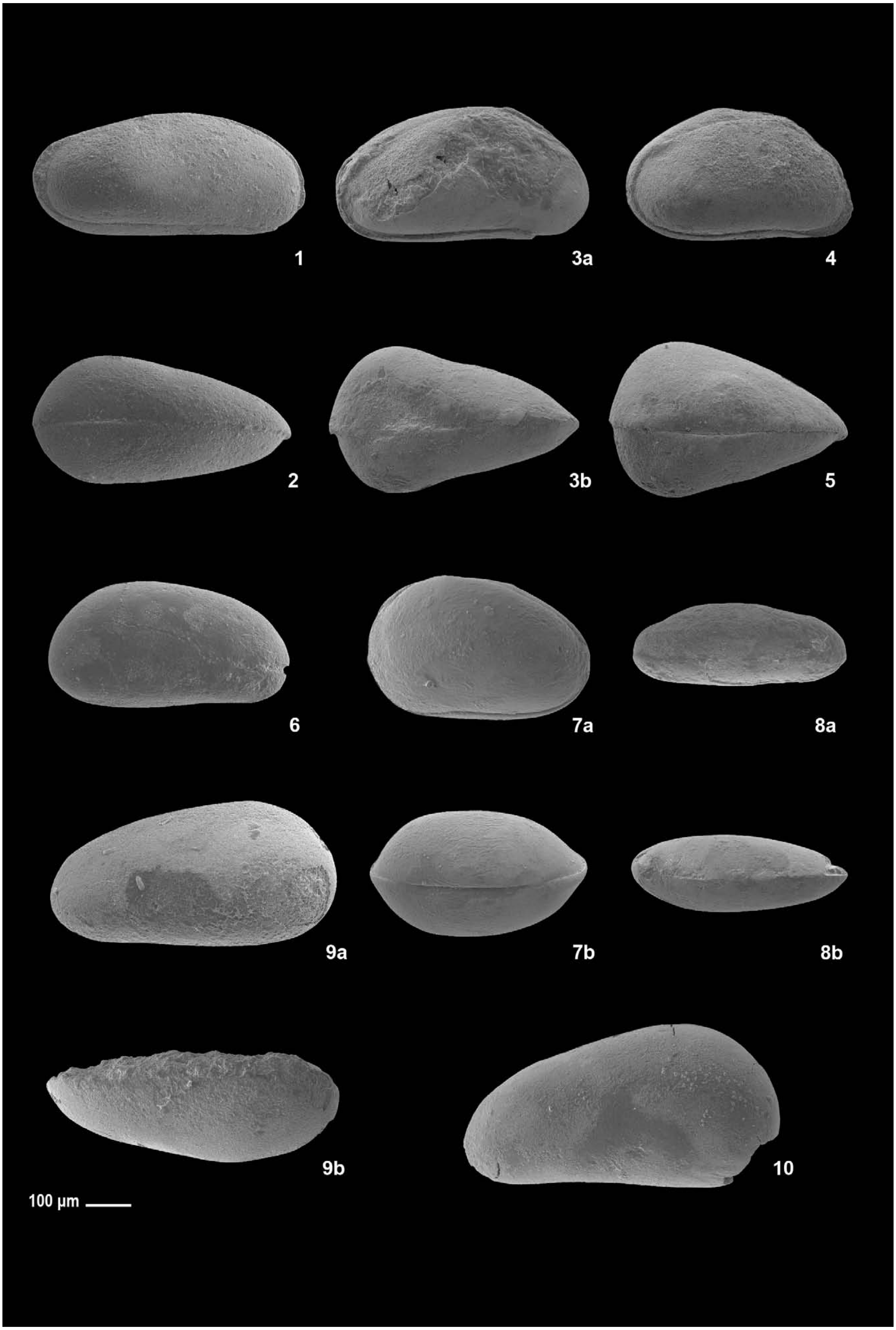
6 – *Wjatkellina fragilis* (Schneider, 1948), PIN No. 5519/145–68, right valve; Bolshoe Kalikino outcrop, bed No. 5, sample 1443–5 bottom; Kalikino Member, Lower Vyatkian (Wuchiapingian).

7 – *Darwinuloides svijazhicus* (Sharapova, 1948), PIN No. 5519/1429–31: 7a – left view, 7b – dorsal view; Klimovo outcrop, bed No. 29–30, sample 1442–2930; Rovdino Member, Lower Vyatkian (Wuchiapingian).

8 – *Gerdalia* sp., PIN No. 5519/1429–125: 8a – right view, 8b – dorsal view; Klimovo outcrop, bed No. 29–30, sample 1442–2930; Rovdino Member, Lower Vyatkian (Wuchiapingian).

9 – *Wjatkellina fragilina* (Belousova, 1961), PIN No. 5519/12112–21: 9a – left valve, 9b – dorsal view; Mutovino outcrop, bed No. 72, sample 1203–11c; Kalikino Member, Upper Severodvinian (Wuchiapingian).

10 – *Wjatkellina accuminata* (Belousova, 1961), PIN No. 5519/1460–79, left valve; Klimovo outcrop, bed No. 60–61, sample 1442–6061, Rovdino Member, Lower Vyatkian (Wuchiapingian).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skyi (Posner), *S.* ex gr. *spizharskyi* (Posner), *S. undulata* (Mishina) (Fig. 38), *S.* cf. *undulata* (Mishina), *Sinusuella vjatkensis* (Posner) (Fig. 38), *S.* cf *vjatkensis* (Posner), *Tatariella subtilis* Mishina., *T.* cf. *subtilis* Mishina, *T. libera* Mishina (Fig. 39), *Wjatkellina* (?) *ignatjevi* (Zekina et Janovskaya), *W. vladimirinae* (Belousova), *W. accuminata* (Belousova) (Fig. 39), *W.* ex gr. *fragilina* (Belousova), *W. perterebrata* (Belousova), *W. praelonga* (Zekina) (Fig. 38).

The upper part of Permian succession, upper part of Nezhnee Fedosovo Member and Komaritsa Member of Salaryovo Formation is characterized by ostracods of the *Wjatkellina fragiloides – Suchonella typica* assemblage. The following ostracods are distributed at this stratigraphic level: *Darwinuloides svijazhicus* (Sharapova), *Gerdalia palenovi* Belousova, *G. noinsci* Belousova, *Gerdalia* sp., *Placidea lutkevichi* (Spizharskyi) (Fig. 40), *Suchonella mishinae* Molostovskaya (Fig. 40), *S. typica* Spizharskyi (Fig. 40), *S. ovalis* Kotschetkova, *Suchonellina trapezoida* (Sharapova) (Fig. 40), *S. compacta* (Starozhilova), *S. parvaeformis* (Kashevarova), *S. perelubica* (Starozhilova), *S.* aff. *alia* Mishina, *S.* aff. *mera* (Mishina), *S.* ex gr. *mera* (Mishina), *S.* ex gr. *dubia* (Starozhilova), *S.* ex gr. *parallela* Spizharskyi, *S.* ex gr. *perelubica* (Starozhilova), *S.* aff. *spizharskyi* (Posner), *Sinusuella vjatkensis* (Posner) (Fig. 40), *Tatariella* ex gr. *libera* Mishina, *Volganella magna* (Spizharskyi), *Wjatkellina fragilodes* (Zekina), *W.* (?) *fragiloides* var. *prima* (Zekina et Jankovskaya), *W. ignatjevi* (Zekina et Janovskaya), *W. praelonga* (Zekina), *W. vladimirinae* (Belousova).

Fig. 40. Ostracods from Aristovo and Skaryatino outcrops, Salaryovo Formation, Vyatkian (Wuchiapingian – Changhsingian):

1, 2 – *Suchonella mishinae* Molostovskaya, 2001: 1 – PIN No. 5519/ 4222–85:1a – left view, 1b – dorsal view; 2 PIN No. 5519/4222–111: 2a – right view, 2b – dorsal view, Aristovo outcrop, Aristovo Channel, sample 42C/2–2; Komaritsa Member, Upper Vyatkian (Changhsingian).

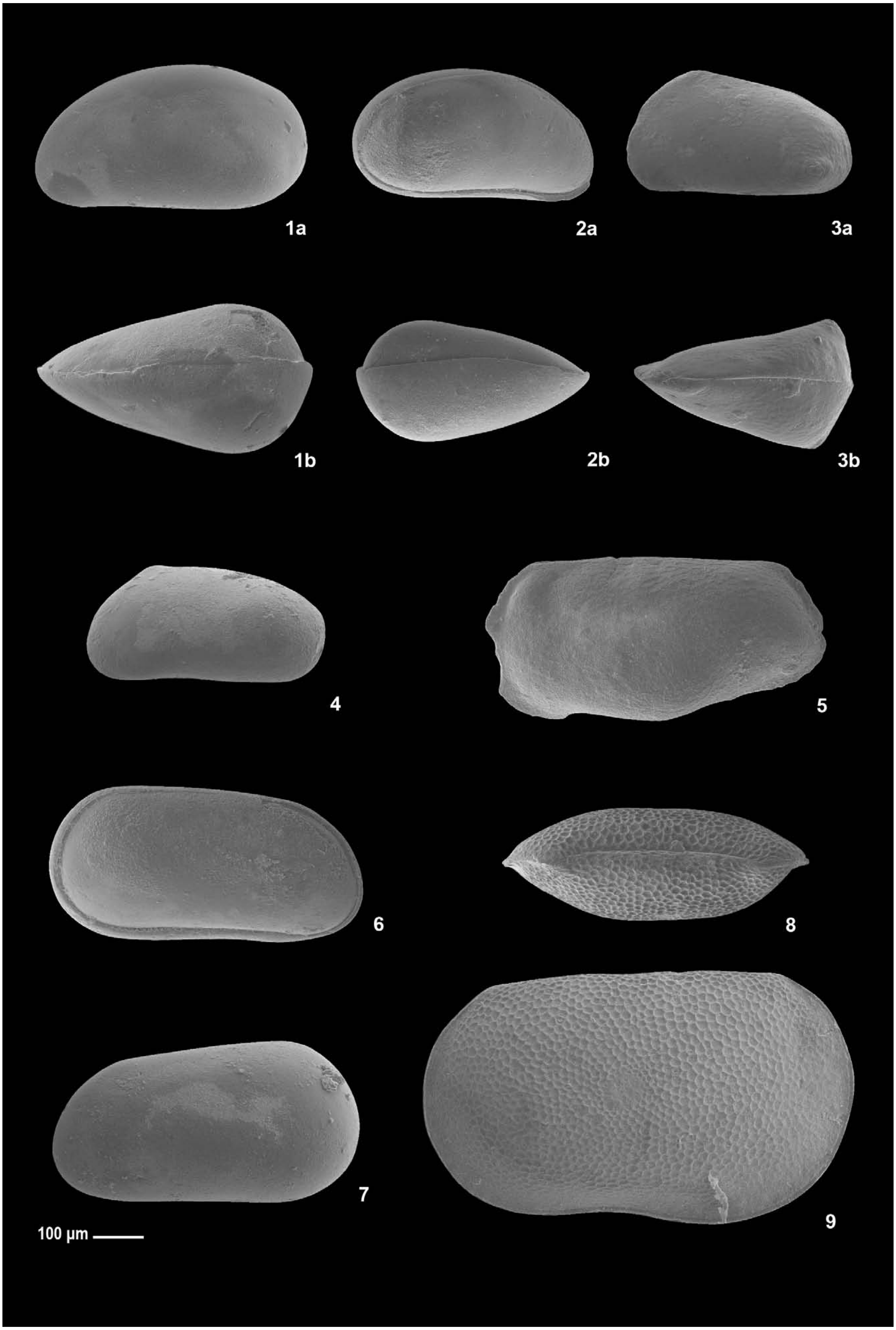
3 – *Suchonella typica* Spizharskyi, 1937, PIN No. 5519/4222–91: 3a – left view, 3b – dorsal view; Aristovo outcrop, Aristovo Channel, sample 42C/2–2; Komaritsa Member, Upper Vyatkian (Changhsingian).

4 – *Suchonella auriculata* (Sharapova, 1948), SSU, left view; Skaryatino outcrop, bed No. 38, sample 23; Erga Member, Lower Vyatkian (Wuchiapingian).

5 – *Sinusuella* aff. *vjatkensis* (Posner, 1948), PIN No.5519/4222–57, left valve; Aristovo outcrop, Aristovo Channel, sample 42C/2–2; Komaritsa Member.

6, 7 – *Suchonellina trapezoida* (Sharapova, 1948): 6 – PIN No. 5519/4222–55, right view; 7 – PIN No. 5519/4222–51, left view, Aristovo outcrop, Aristovo Channel, sample 42C/2–2; Komaritsa Member, Upper Vyatkian (Changhsingian).

8, 9 – *Placidea lutkevichi* (Spizharskyi, 1939): 8 – PIN No. 5519/4222–65, dorsal view; 9 – PIN No. № 5519/4222–59, left view; Aristovo outcrop, Aristovo Channel, sample 42C/2–2; Komaritsa Member, Upper Vyatkian (Changhsingian).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Insects and Chelicerates

At present five insect localities are known from the Sukhona River basin. They are Kopylovo, Opoki, Isady, Aristovo, and Nedubrovo (Aristov et al., 2013) (Fig. 35). Representative insect faunas were found in localities of Isady, Aristovo, and Nedubrovo only. These localities form a single assemblage. There is no essential evolutional distinctions between its faunas.

Kopylovo locality. Left bank of the Sukhona River 1.2 km downstream from the village of Kopylovo, 1.3 km upstream from mouth of the Yurmenga River; N 60°35'25.19", E 45°06'56.23". Verkhnyaya Tozma Member, Sukhona Formation; lowermost Lower Severodvinian (Roadian-Capitanian). The pronotum of Grylloblattida fam. indet. was found here.

Opoki locality. Left bank of the Sukhona River opposite Opoki village, straight upstream mouth of Svyatoy Rill; N 60°35'40.61'', E 45°29'37.89". Isady Member, Poldarsa Formation; Upper Severodvinian (Capitanian). An elytron of Hemiptera fam. indet. was found in this locality.

Isady. Mutovino Chanel (Figs. 15, 41, 42). Kichuga Member, Poldarsa Formation; uppermost Upper Severodvinian (lowermost Wuchiapingian). It is the largest known Upper Permian fossil insect locality in the world. More than four thousand fossil insect specimens were found in this locality. To date, the insects described and reported from this locality include members of no less than 69 families, 81 genera, and 105 species, representing 26 orders (Aristov et al., 2013). In addition to the insects, the fossils found in Isady include rather infrequent remains of the cuticle of scorpions and one fossil centipede (Chilopoda). The list of the insect families and genera from this locality includes: Dasyleptidae gen. indet., Protereismatidae (*Alexandrinia*, 1 species), Misthodotidae (*Misthodotes* 1 species), Permolestidae gen. indet., Kennedyidae gen. indet., Caloneuridae (*Issadistica*, 2 species, *Euthygramma* sp.), Hypoperlidae (*Idelopsocus*, 1 species), Ischnoneuridae (*Strephoptilus*, 2 species), Calvertiellidae gen. indet., Moravohymenidae (*Issadohymen*, 1 species), Psocidiidae gen. indet., Lophioneuridae gen. indet., Protopsyllidiidae gen. indet., Ingruidae gen. indet., Scytinopteridae gen. indet., Stenoviciidae gen. indet., Pereboriidae gen. indet., Dunstaniidae gen. indet., Prosbolidae gen. indet., Dysmorphoptilidae gen. indet., Progonocimicidae gen. indet., Coleorrhyncha fam. gen. indet., Permosialidae (*Epimastax*, 1 species), Palaeomanteidae (?*Tridelopterum*, 1 species), Permembiidae (*Issapaloptera*, 1 species, *Neembia*, 1 species), Permocupedidae (*Protocupoides*, 1 species), Taldycupedidae (*Taldycupes*, 1 species, *Simmondsia*, 1 species), Asiocoleidae (*Bicoleus*, 1 species, *Tetracoleus*, 1 species), Rhombocoleidae (*Karakanocoleus*, 1 species, *Erunakicupes*, 1 species, *Rossocoleus*, 1 species), Schizocoleidae (*Schizocoleus*, 1 species, *Uskatocoleus*, 3 species, *Pseudochrysomelites*, 4 species), Parasialidae gen. indet., Permithonidae (*Permithonopsis* sp.), Jurinidae (*Issadelytron*, 1 species), Glosselytridae (?*Karajurina*, 1 species), Permochoristidae (*Agetopanorpa*, 1 species, *Neudolbenus*, 2 species, *Tatarakara*, 1 species, *Mesochorista*, 1 species, *Permeca*, 2 species), Mesopsychidae (*Permopsyche*, 2 species), Nedubroviidae (*Nedubrovia*, 1 species), Permotanyderidae gen. indet., ?Robinjohniidae gen. indet., Cladochoristidae (*Cladochorista*, 1 species), Idelinellidae (*Permeoblatta*, 1 species), Soyanopteridae (*Poldarsia*, 1 species), Eoblattida incertae familiae

Fig. 41. Fossil insects from the locality of Isady, Mutovino Channel, Poldarsa Formation, Kichuga Member, uppermost Upper Severodvinian (Wuchiapingian).

1 – *Permopsyche issadensis* Bashkuev, 2011 (Mecoptera: Mesopsychidae), holotype PIN No. 3840/336.

2 – *Tatarakara variomaculata* Bashkuev, 2013 (Mecoptera: Permochoristidae), holotype PIN No. 3840/1427.

3 – *Nedubrovia shcherbakovi* Bashkuev, 2011 (Mecoptera: Nedubroviidae), holotype PIN No. 3840/1337.

4 – Protopsyllydiidae gen. indet. (Hemiptera: Sternorrhyncha: Psyllomorpha), specimen PIN No. 3840/468.

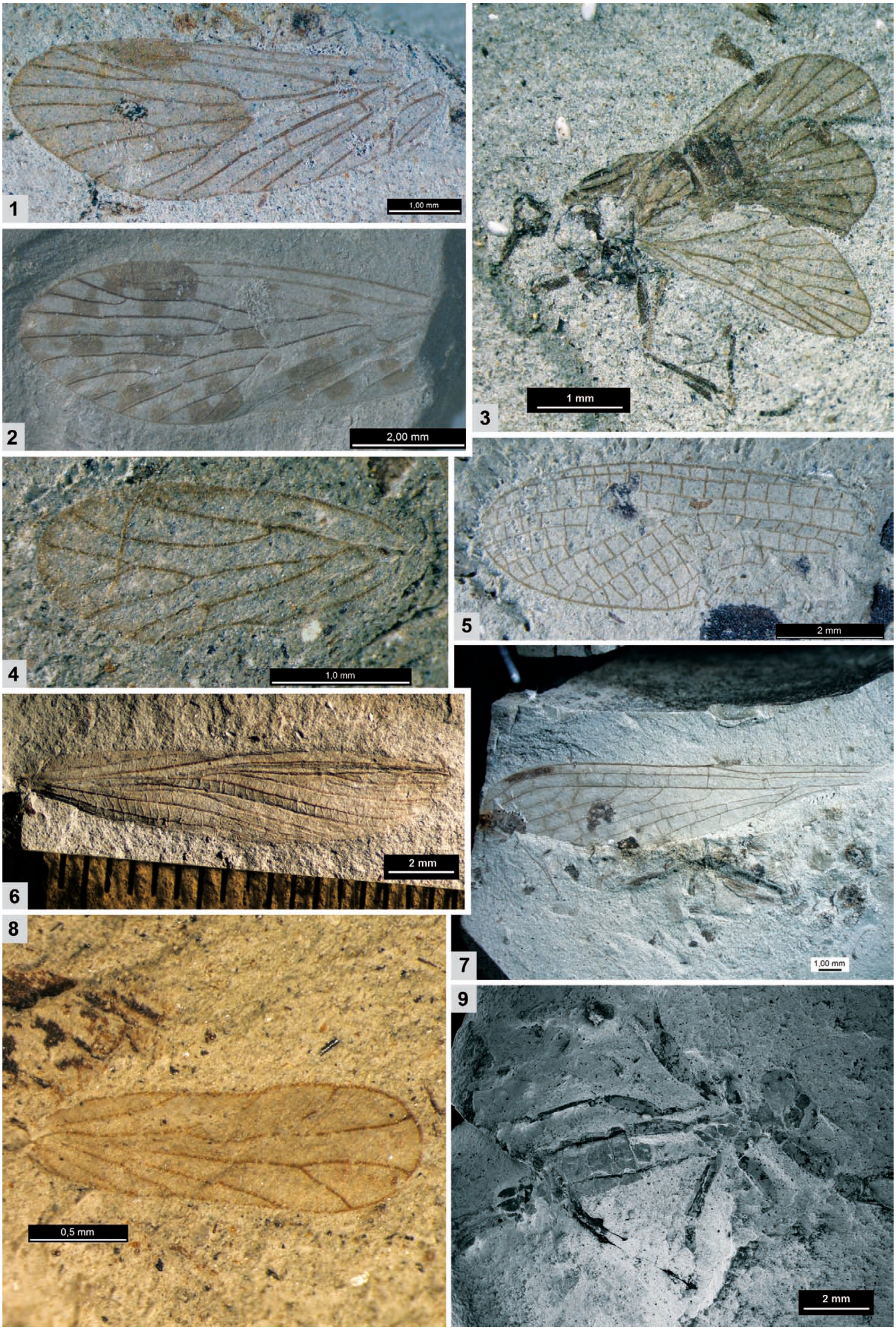
5 – *Misthodotes* sp. (Ephemeroptera: Misthodotidae), specimen PIN No. 3840/2623.

6 – *Isadyphasma bashkuevi* Gorochov, 2013 (Phasmatoptera: ?Permophasmatidae), holotype PIN No. 3840/507.

7 – Kennedyidae gen. et sp. (Odonata: Protozygoptera), specimen PIN No. 3840/1685.

8 – Lophioneuridae gen. indet. (Thripida: Lophioneurida), specimen PIN No. 3840/2786.

9 – unidentified enigmatic insect larva, specimen PIN No. 3840/647.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(*Issadische*, 1 species), Mutoviidae (*Mutovia*, 1 species), Phylloblattidae (*Aissoblatta* sp.), Caloblattinidae (*Caloblattina* sp.), Argentinoblattidae (*Voltziablatta* sp.), Subioblattidae gen. indet., Chauliodititidae (*Chauliodites*, 4 species, *Parachauliodites*, 1 species, *Purtovinia*, 1 species, *Permyak*, 1 species), Geinitziidae (*Geinitzia*, 1 species, *Shurabia*, 1 species, *Sukhonia*, 1 species), Cacurgidae (*Kitchuga*, 1 species), Liomopteridae (*Liomopterites*, 1 species, *Sylvaella*, 1 species, *Liomofrater*, 1 species), Mesorthopteridae (*Mesoidelia*, 1 species), Permotermopsidae (*Permofossilis*, 1 species), Megakhosaridae (*Parakhosara*, 3 species, *Megakhosarodes*, 1 species, *Abbrevikhosara*, 1 species), Blattogryllidae (*Baharellinus*, 2 species), Tunguskapteridae (*Issadoptera*, 2 species), Kortshakoliidae (*Vologdoptera*, 1 species), Permulidae (*Mezenalicula*, 1 species), Grylloblattida incertae sedis (*Sukhonoptera*, 1 species, *Issadonympha*, 1 species, *Kenguronympha*, 1 species), Eusteniidae (*Boreoperlidium*, 1 species), Euxenoperlidae (?*Gondwanoperlidium* sp.), Palaeoperlidae (*Properla*, 1 species, *Kargaloperla*, 2 species), Tshekardoperlidae (*Issadoperla*, 1 species), Perlomorpha incertae familia (*Mirumoperla*, 1 species), Palaeonemouridae (*Palaeonemoura*, 3 species, *Palaeotaeniopterix*, 9 species, *Palaeonemourisca*, 2 species, *Vottaknemoura*, 1 species), Dermelytridae gen. et sp., Permelcanidae (*Meselcana*, 1 species), Pruvostitidae (*Suchonoedischia*, 1 species), Proparagryllacrididae (*Archifergania*, 1 species), Deinotitanidae (*Monstrotitan*, 1 species), ?Permophasmatidae (*Issadyphasma*, 3 species), Alexarasniidae (*Alexarasnia*, 1 species).

Aristovo. Aristovo Channel (Figs. 29, 30, 42). Komaritsa Member, Salaryovo Formation, Upper Vyatkian (Changhsingian). The insect fossils come from oxbow lake deposits. Specimens found in argillites include plant remains, conchostracans, ostracods, chelicerates, and insects. The collection of about 250 specimens consists mostly of Blattida, which comprise about 90% of specimens. In addition to Blattida, rather infrequent Hemiptera, Coleoptera, Panorpida, Grylloblattida, and Perlida have been found in the locality. The list of insect families and genera from this locality includes: Stenoviciidae gen. indet., Dunstaniidae gen. indet., Asiocoleidae (*Tetracoleus*, 1 species), Schizocoleidae gen. indet., Permosynidae gen. indet., Permochoristidae (*Mesochorista* sp., *Tatarakara* sp., *Petromantis* sp.), Permotanyderidae gen. indet., Phylloblattidae (*Aissoblatta* sp.), Mutoviidae gen. indet., Chauliodititidae (*Chauliodites*, 1 species, *Dvinopedes*, 1 species), Liomopteridae (*Expartolioma*, 1 species), Megakhosaridae gen. indet., Palaeonemouridae gen. indet.

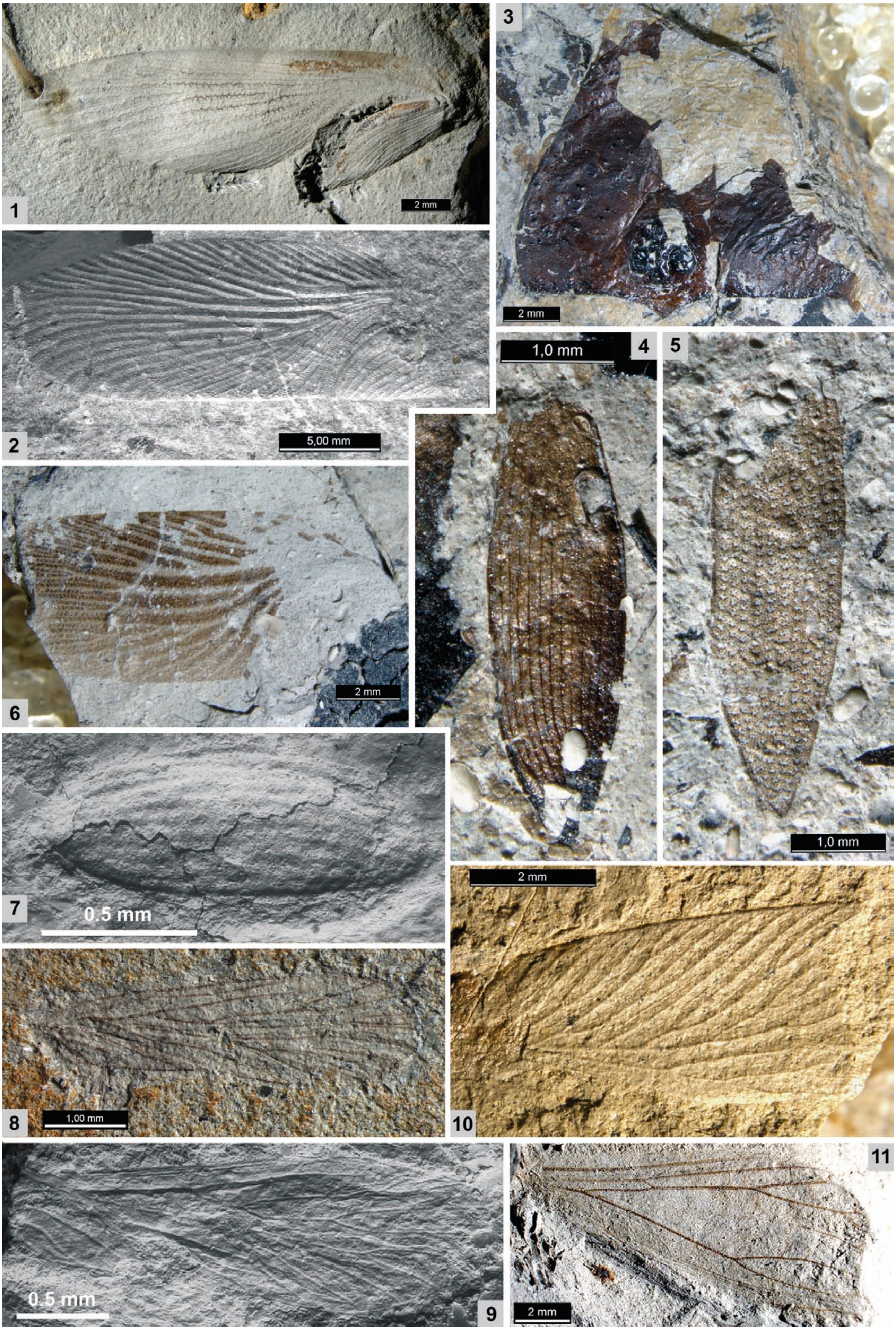
Nedubrovo (Figs. 32, 42). Nedubrovo Member, Vokhma Formation; uppermost Upper Vyatkian (uppermost Changhsingian). Arthropod fossils come from smectite clays with an admixture of ash matter deposited in an oxbow lake or a shallow and rather large lake. It includes plant remains, conchostracans, ostracods, scorpions, and insects. The material includes about 200 specimens. They represent the following orders: Psocida, Hemiptera, Palaeomanteida, Coleoptera, Panorpida, Blattida, Grylloblattida, and Orthoptera. The dominant orders are Hemiptera (25%) and Blattida (21%); Grylloblattida (17%), Panorpida, and Coleoptera (14% each) are less abundant. Psocoptera, Palaeomanteida, and Orthoptera are rather infrequent. The list of insect families and genera from this locality includes: Archescitinidae gen. indet., Surijokocixiidae gen. indet., Scytinipteridae gen. indet., Progonocimicidae gen. indet., Palaeomanteidae (*Delopterum* sp.), Permosialidae gen. indet., Schizocoleidae (*Palademosyne*, 1 species), Taldycupedidae gen. indet., Nedubroviidae (*Nedubrovia*, 1 species), Permochoristidae gen. indet., Mesopsychidae gen. indet., Permotanyderidae gen. indet., "Argentinoblattidae" (Voltziablatta gen. indet.), Phylloblattidae gen. indet., Chauliodititidae (*Chauliodites*, 2 species), Blattogryllidae (*Protoblattogryllus*, 1 species), Permelcanidae gen. indet.

Fig. 42. Fossil arthropods from the localities of Isady, Aristovo and Nedubrovo.

1, 2, 11 – Isady Locality, Mutovino Channel, Poldarsa Formations, Kichuga Member, uppermost Upper Severodvinian (Wuchiapingian): 1 – *Mutovia intercalaria* Vršanský et Aristov, 2012 (Blattodea: Mutoviidae), paratype PIN No. 3840/52; 2 – Phylloblattidae gen. indet. (Blattodea), specimen PIN No. 3840/858; 11 – Blattogryllidae gen. indet. (Grylloblattida), specimen PIN No. № 3840/2356.

3–6 – Aristovo Locality, Aristovo Channel, Salaryovo Formation, Komaritsa Member, Upper Vyatkian (Changhsingian): 3 – presumable scorpion carapace; 4 – *Permosyne* sp. (Coleoptera: Permosynidae), specimen PIN No. 3446/66; 5 – Asiocoleidae gen. indet. (Coleoptera), specimen PIN No. 3446/59; 6 – ?*Aissoblatta* sp. (Blattodea: Phylloblattidae).

7–10 – Nedubrovo Locality, Vokhma Formation, Nedubrovo Member, uppermost Upper Vyatkian (upper part of the Changhsingian): 7 – *Proterocupes nedubrovensis* Ponomarenko, 2015 (Coleoptera: Cupedidoidea inc. fam.), holotype PIN No. 4811/64; 8 – *Nedubrovia mostovskii* (Novokshonov, Sukacheva et Aristov, 2004) (Mecoptera: Nedubroviidae), holotype PIN No. 4811/20; 9 – *Permotanyderus rakitovi* Bashkuev, 2015 (Mecoptera: Permotanyderidae), holotype PIN No. 4811/53. 10 – Blattodea fam. indet., PIN No. 4811/129.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Fishes

There are three large stages in the Permian – Lower Triassic evolution of the fish fauna from European Russia. These are *Platysomus*, *Toyemia*, and *Gnathorhiza* Superstages. Localities of all these fish faunas are known in the Sukhona River basin (Fig. 35).

The Middle Permian – Lower Triassic of Sukhona region are rich in fish fossils. To date more than 30 fish localities have been found in this area (Reference Section…, 1981; Tatarian beds ..., 2001; Minikh and Minikh, 2009; Minikh, 2014).

The lower part of the Permian sequence is characterized by the *Platysomus* Superasssemblage (Fig. 35). Ten localities of this fauna are situated in the Nizhnyaya Ustiya, Sukhona and the lower Poldarsa Formations. The fish assemblage consists of *Acrolepis* sp., *Geryonichthys longus* A.Minich, *Geryonichthys* sp., *Isadia suchonensis* A. Minich, *Kichkassia furkae* Minich, *Lapkosubia uranensis* A. Minich, *Platysomus biarmicus* Eichwald, *Platysomus* sp., *Strelnia certa* A. Minich, *Strelnia* (?) sp., *Uranichthys pretoriensis* A.Minich, *Uranichthys* sp., *Varialepis stanislavi* A. Minich, *Varialepis* sp., *Xenosynechodus* (?) *egloni* Glückman, *Xenosynechodus* sp., Discordichthyidae gen. indet., Eurynotoidiidae gen. indet., Palaeoniscidae gen. indet. The youngest localities of the *Platysomus* fauna are found in Mikulino Member of Poldarsa Formation (Fig. 10).

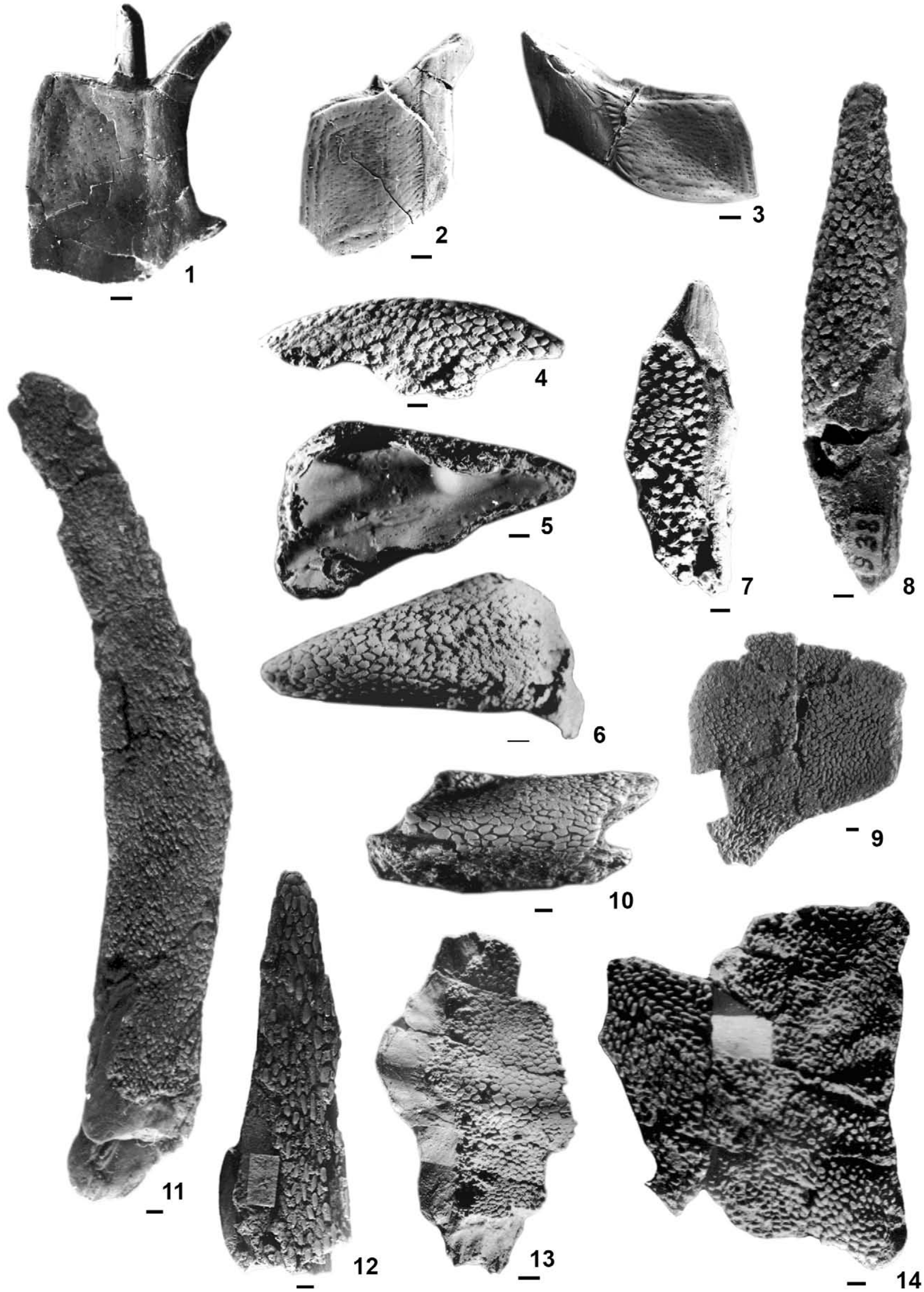
The overlying Permian deposits are characterized by the *Toyemia* Superassemblage (Fig. 35). The *Platysomus–Toyemia* boundary is one of the greatest events in the Permian history of the East European ichthyofauna. In the Sukhona River basin, the fish fauna is considerably renewed at the level of the Strelna Member of the Poldarsa Formation. At the upper part of this Member, *Toyemia* and *Mutovinia*, the most characteristic representatives of the Late Severodvinian-Vyatkian ichthyofauna, appear for the first time and become widespread (Fig.10). Earlier deposits are characterized by ichthyolites of sharks and *Platysomus* (deep-bodied actinopterygians). These fishes occur in almost all well-studied localities of the Kazanian, Urzhumian, and Lower Severodvinian. On the Sukhona River, the last appearance of this fauna is observed in the Mikulino Member of the Poldarsa Formation. Up the section, *Platysomus* disappears from the fossil record, while sharks appear again only in the terminal beds of the Vyatkian Stage and are recorded at this

Fig. 43. Fish remains from the Mutovino Channel, Poldarsa Formation, Kichuga Member, the Upper Severodvinian (Wuchiapingian).

1-3 – *Toyemia tverdochlebovi* Minich, scales from the different part of body, SSU No. 104-Б/1103-1, 2, 3;

4-9 – *Mutovinia stella* Minich: 4-6 –distal element of the pectoral fin, SSU No. №104-Б/1325-5: 4 – lateral view, 5 – bottom view, 6 – upper view; 7 – scale, holotype SSU No.104-Б/1102-1; 8 – dorsal fin spike, lateral view, SSU No.104-Б/938; 9 – SSU No.104-Б/1325-8, supraorbito-postorbitale;

10-14 – *Geryonichthys longus* A. Minich: 10 – bone element of the pectoral fin, upper view, SSU No.104-Б/1325-6; 11 – ventral fin spike, lateral view, holotype SSU No. № 104-Б/898; 12 – dorsal fin spike, lateral view, SSU No. 104-Б/940; 13 – infraorbitale, SSU No.104-Б/1325-4; 14 – operculum, SSU No.104-Б/1325-1. Scale bars 1 mm.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stratigraphic level in only one locality (Vyazniki) of the Vladimir Region. Only in the Early Triassic, during the Induan and Early Olenekian, sharks became a rather usual element of the East European ichthyofauna.

In the Sukhona River basin, more than 20 localities of the *Toyemia* Superassemblage fishes have been found (Fig. 35). The following fossil fishes are recorded in this stratigraphical level: *Boreolepis tataricus* Esin, *Geryonichthys longus* A.Minich (Fig. 43), *Geryonichthys* sp., *Isadia arefievi* A.Minich (Fig. 44), *Isadia aristoviensis* A.Minich, *Isadia suchonensis* A. Minich (Fig. 44), *Isadia* ex gr. *suchonensis* A.Minich, *Isadia* sp., *Lapkosubia* sp., *Mutovinia sennikovi* A.Minich, *Mutovinia stella* Minich (Fig. 43), *Plotnikovichthys gorodokensis* A. Minich (Fig. 44), *Sludalepis spinosa* A. Minich (Fig. 44), *Strelnia certa* A. Minich (Fig. 44), *Strelnia* sp., *Suchonichthys molini* A. Minich, *Toyemia blumentalis* A. Minich, *Toyemia tverdochlebovi* Minich (Fig. 43), *Toyemia* sp., *Varialepis* ex gr. *stanislavi* A. Minich, Discordichthyidae gen. indet., Elonichthyidae gen. indet., Eurynotoidiidae gen. ind., Eurynotoidiidae gen. indet., Palaeoniscidae gen. indet., Varialepididae gen. indet.

The next serious change in the evolution of the ichthyofauna occurs at Permian–Triassic boundary. Most every Permian fishes disappear at this boundary. The Lower Triassic *Gnathorhiza* Superassemblage is characterized by a sharply depleted taxonomic structure. In the basin of the Yug and Malaya Severnaya Dvina rivers, fossil remains of *Saurichthys* sp. and *Blomolepis* (?) sp. have been found in the lower Krasnoborsk and Vokhma Formations.

Fig. 44. Fish remains from the Poldarsa and Salaryovo Formations.

1-4 – *Isadia arefievi* A.Minich, teeth, Eleonora Locality, Salaryovo Formation, Komaritsa Member, the Upper Vyatkian, beds with Vyaznikian biota (Changhsingian): 1 – holotype SSU No. 104-Б/3319-1: 1a – labial view, 1b – lateral view, 1c – lingual view; 2 – SSU No. 104-Б/3318-1: 2a – labial view, 2b – lateral view; 3 – SSU No. 104-Б/3303: 3a – labial view, 3b – lateral view; 4 – crown of the tooth, SSU No. № 104-Б/ 3319-2: 4a – labial view, 4b – lingual view;

5, 6 – *Sludalepis spinosa* A.Minich, Mariyushkina Sluda-C Channel, Strelna Locality, Poldarsa Formation, Kichuga Member, uppermost Severodvinian (Wuchiapingian): 5 – lateral scale of front part of body, holotype SSU No. 104-Б/1322-1; 6 – dorsal scale, SSU No. № 104-Б/1322-3;

7-10 – *Strelnia certa* A.Minich, Ustie Strelny Locality, Poldarsa Formation, Strelna Member, the Upper Severodvinian (Capitanian): 7 – lateral scale of middle part of body, SSU No. 104-Б/1326-3; 8 – scale of back part of body, SSU No. 104-Б/1326-6; 9 – lateral scale of front part of body, holotype SSU No. 104-Б/1326-1; 10 – scales of dorsal part of body just behind the head, SSU No. 104-Б/1101-1;

11 – *Plotnikovichthys gorodokensis* A.Minich, lateral scale of front part of body, holotype SSU No. 104-Б/1322-4, Mariyushkina Sluda-C Channel, Strelna Locality, Poldarsa Formation, Kichuga Member, uppermost Severodvinian (Wuchiapingian);

12-14 – *Isadia suchonensis* A.Minich, Mutovino Channel, Poldarsa Formation, Kichuga Member, uppermost Severodvinian (Wuchiapingian), holotype SSU No. 104-Б/Р-2: 12 – lateral scale of middle part of body, 13 – head, 14 – upper jaw with teeth (fragment).

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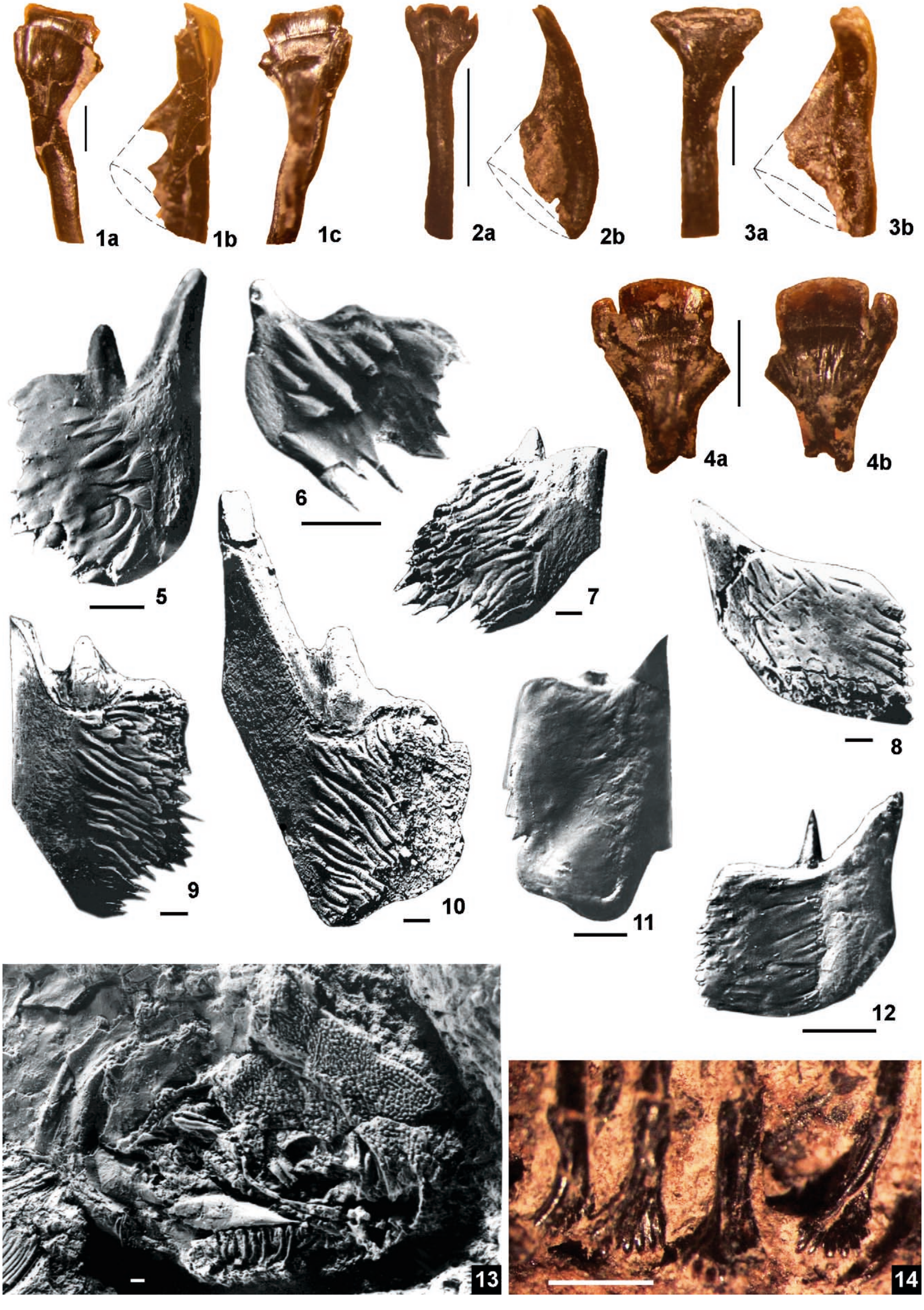
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Tetrapods

Two significant events can be recognized in the Permian history of the tetrapod community in Eastern Europe. These are the Severodvinian and Permian-Triassic crises (Ivakhnenko et al., 1997; Golubev, 2000, 2000a, 2005). Evidence of both of these events is preserved in the fossil record of the region of the Sukhona and Vyatka Rivers (Fig. 35).

Severodvinian (Capitanian) crisis. From the Late Ufimian to Early Severodvinian, Eastern Europe was inhabited by a Dinocephalian tetrapod fauna. The aquatic block of the Dinocephalian community was formed of archegosauroid temnospondyls. In the early Dinocephalian time, aquatic communities also included dissorophoid temnospondyls and seymouriamorph parareptiles and, in the late Dinocephalian time, there were lanthanosuchid parareptiles. Terrestrial Dinocephalian communities were formed of abundant small parareptiles, primitive gorgonopians, and diverse dinocephalians. In the Severodvinian Age, the Dinocephalian fauna was replaced by the Theriodontian fauna, which dominated until the terminal Permian. In the Theriodontian fauna, aquatic communities were formed of various relict groups, i.e., chroniosuchian anthracosaurs, seymouriamorph parareptiles, and brachiopoid temnospondyls (Figs. 45, 46). Terrestrial Theriodontian communities were formed of pareiasaurs, dicynodonts, gorgonopians, therocephalians, and cynodonts (Figs. 45-47). In the overwhelming majority of cases, these were descendants of tetrapods emigrating from Gondwana to occupy Eurasia after the extinction of the Dinocephalian fauna. In Eastern Europe, the first Theriodontian fauna is the Kotel'nich assemblage (Fig. 34).

Replacement of the Dinocephalian fauna by the Theriodontian fauna was the greatest reorganization of the tetrapod community of Eastern Europe in the Permian Period. During this reorganization, the former (Dinocephalian) community was completely disrupted and the next (Theriodontian) community was composed of new elements, which did not exist in the previous community. Similar transformations involved all presently known Permian terrestrial communities of tetrapods; during the Severodvinian (Capitanian) Time, dinocephalians became extinct throughout the world and were replaced by pareiasaurs, dicynodonts, and gorgonopians.

In Eastern Europe, the transformation of tetrapod faunas passed through several stages. In the Early Severodvinian Epoch, the aquatic Dinocephalian community was disrupted; archegosauroids and lanthanosuchoids disappeared. This stage is not observed in the Sukhona River sections. In the Nizhnyaya Ustiya and Sukhona formations, fossil tetrapods were not found. In the Early Severodvinian Epoch, this area of the Moscow Syncline appar-

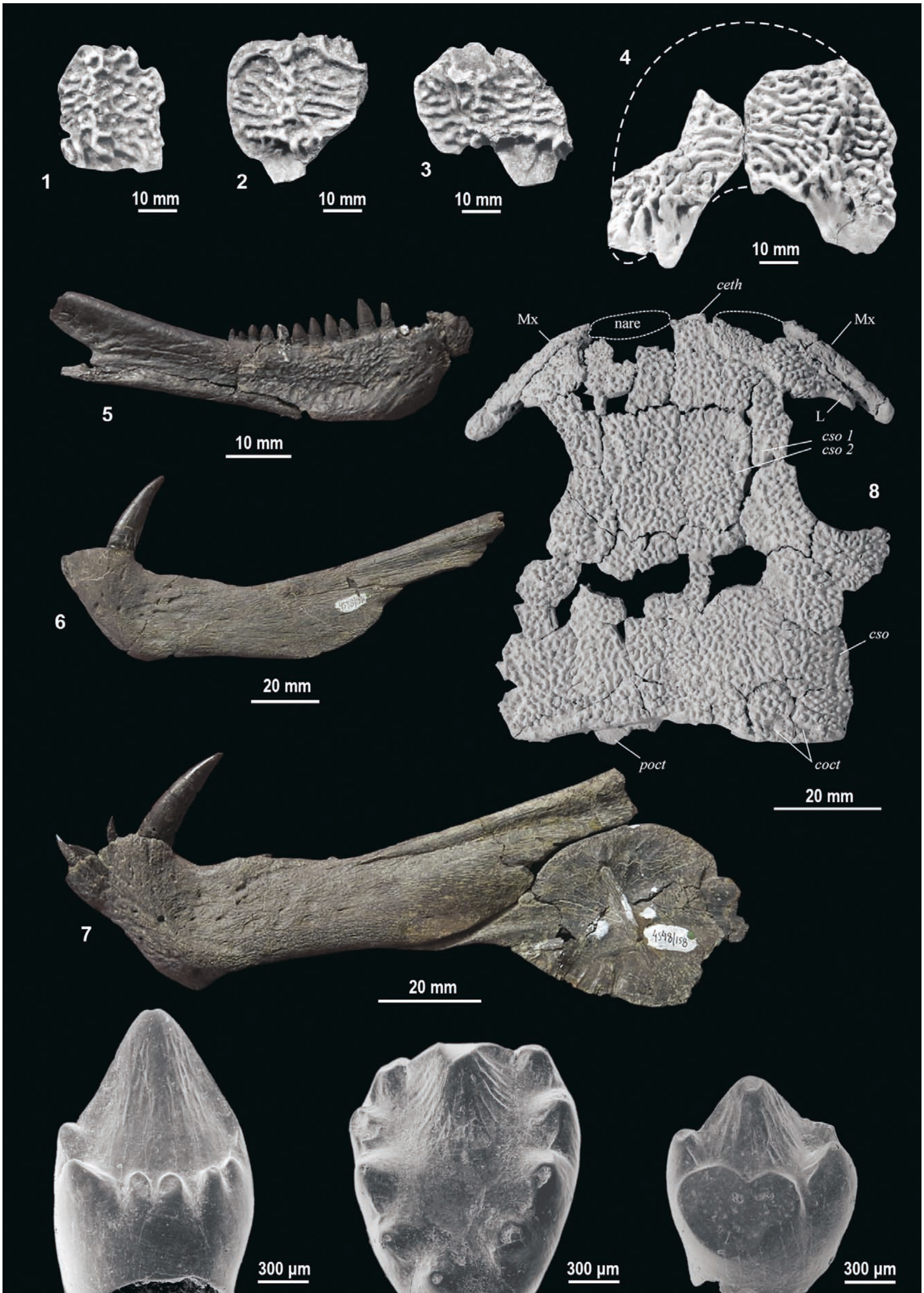
Fig. 45. Tetrapod remains from the Poldarsa formation of the Sukhona River, Upper Severodvinian (Capitanian – bottom of Wuchiapingian).

1-4 – chroniosuchian *Suchonica vladimiri* Golubev is the most ancient Permian tetrapods from the Sukhona River basin, scutes of the dorsal armor from above, Poldarsa Locality, Ustpoldarsa Member, Upper Severodvinian (Capitanian): 1 – paratype PIN No. 4611/10, 2 – paratype PIN No. 4611/8, 3 – paratype PIN No. 4611/9, 4 – anterior scute, holotype PIN No. 4611/1;

5-8 – tetrapod remains from the Ustie Strelny Locality, Strelna Member, Upper Severodvinian (Capitanian): 5 – *Ustia atra* Ivachnenko, right dentary, holotype PIN No. 4548/155, 6, 7 – *Suchogorgon golubevi* Tatarinov: 6 – left dentary, PIN No. 4548/158, 7 – lower jaw, left view, PIN Nos. SSU 104B/1767 and 4548/158, 8 – *Microphon exiguus* Ivachnenko, skull roof, dorsal view, PIN No. 4548/140;

9-11 – cynodont *Sludica bulanovi* Ivachnenko, teeth, Mariyushkina Sluda-C Locality, Kichuga Member, Upper Severodvinian, (bottom of Wuchiapingian): 9 – paratype PIN No. 4412/22, 10 – holotype PIN No. 4412/20, 11 – paratype PIN No. 4412/21.

Photos by Valeriy K. Golubev (1-4), Michael P. Arefiev (5-7), Valeriy V. Bulanov (8-11).



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ently lacked habitats suitable for tetrapods. Later, in the middle Severodvinian Time, a new aquatic community with typical representatives of the Theriodontian fauna, including chroniosuchians, seymouriamorphs, and brachiopoids, was formed. This stage of East European tetrapod phylocoenogenesis is represented by the transitional Sundyr Assemblage, in which the terrestrial community remains Dinocephalian but the aquatic community is already Theriodontian (Golubev et al., 2015). On the Sukhona River, fossils of Sundyr tetrapods were found at the base of the Ustpoldarsa Member of the Poldarsa Formation (Poldarsa Locality). These are bones of the chroniosuchid anthracosaurian amphibian *Suchonica vladimiri* Golubev (Figs. 10, 45).

The succeeding stage is characterized by complete disruption of the Dinocephalian terrestrial communities and the extinction of dinocephalians. In the final stage, tetrapods expanded from Gondwana and formed a new terrestrial community of Gondwanan immigrants. This stage had been reached by the end of the late Strelna Time. Tetrapods of Gondwanan origin, i.e., galeopids and gorgonopids (Fig. 45), appeared for the first time in the terminal Strelna Member of the Ustie Strelny locality.

Thus, the Severodvinian reorganization of the tetrapod community occurred during the formation of the Nyuksenitsa, Ustpoldarsa, Mikulino, and Strelna Members.

The upper Poldarsa Formation and Salaryovo Formation are characterized by tetrapods of the Sokolki assemblage. More than 50 localities are known from this area. In the Poldarsa Formation, remains of tetrapods of the Iliinskoe subassemblage were found, i.e., *Chroniosaurus dongusensis* Tverdochlebova, *Ch. levis* Golubev (Fig. 46), *Dvinosaurus primus* Amalitzky (Fig. 46), *Microphon exiguus* Ivachnenko (Fig. 45), *Niuksenitia sukhonensis* Tatarinov, *Proelginia* sp. (Fig. 46), *Sludica bulanovi* Ivachnenko (Fig. 45), *Suchogorgon golubevi* Tatarinov (Fig. 45), *Suminia* cf. *getmanovi* Ivachnenko, *Ustia atra* Ivachnenko (Fig. 45). In the Salaryovo Formation, the following fossil tetrapods of the Sokolki subassemblage are recorded: *Annatherapsidus petri* (Amalitzky) (Fig. 47), *Chroniosuchus licharevi* (Riabinin), *Dicynodon amalitzkii* Sushkin, *Dicynodon trautscholdi* Amalitzky (Fig. 47), *Dicynodon* sp. (Fig. 46), *Dvinia prima* Amalitzky (Fig. 47), *Elph borealis* Kurkin, *Inostranzevia alexandri* Amalitzky

Fig. 46. Tetrapod remains from the Poldarsa and Salaryovo Formations, Sukhona and Malaya Severnaya Dvina rivers.

1-7 – the most typical tetrapods of aquatic community from the Mutovino Channel, Mutovino Locality, Poldarsa Formations, Kichuga Member, the top of the Severodvinian (lower part of the Wuchiapingian): 1-4, 6 – chroniosuchian *Chroniosaurus levis* Golubev: 1-3 – scutes of the dorsal armor from above: 1 – holotype PIN No. SSU 104B/1102, 2 – paratype PIN No. SSU 104B/1100, 3 – paratype PIN No. SSU 104B/1097, 4, 6 – parts of lower jaws; 5 – temnospondyl amphibian *Dvinosaurus primus* Amalitzky, right dentary. 7 – pareiasaur *Proelginia* sp., osteoderm.

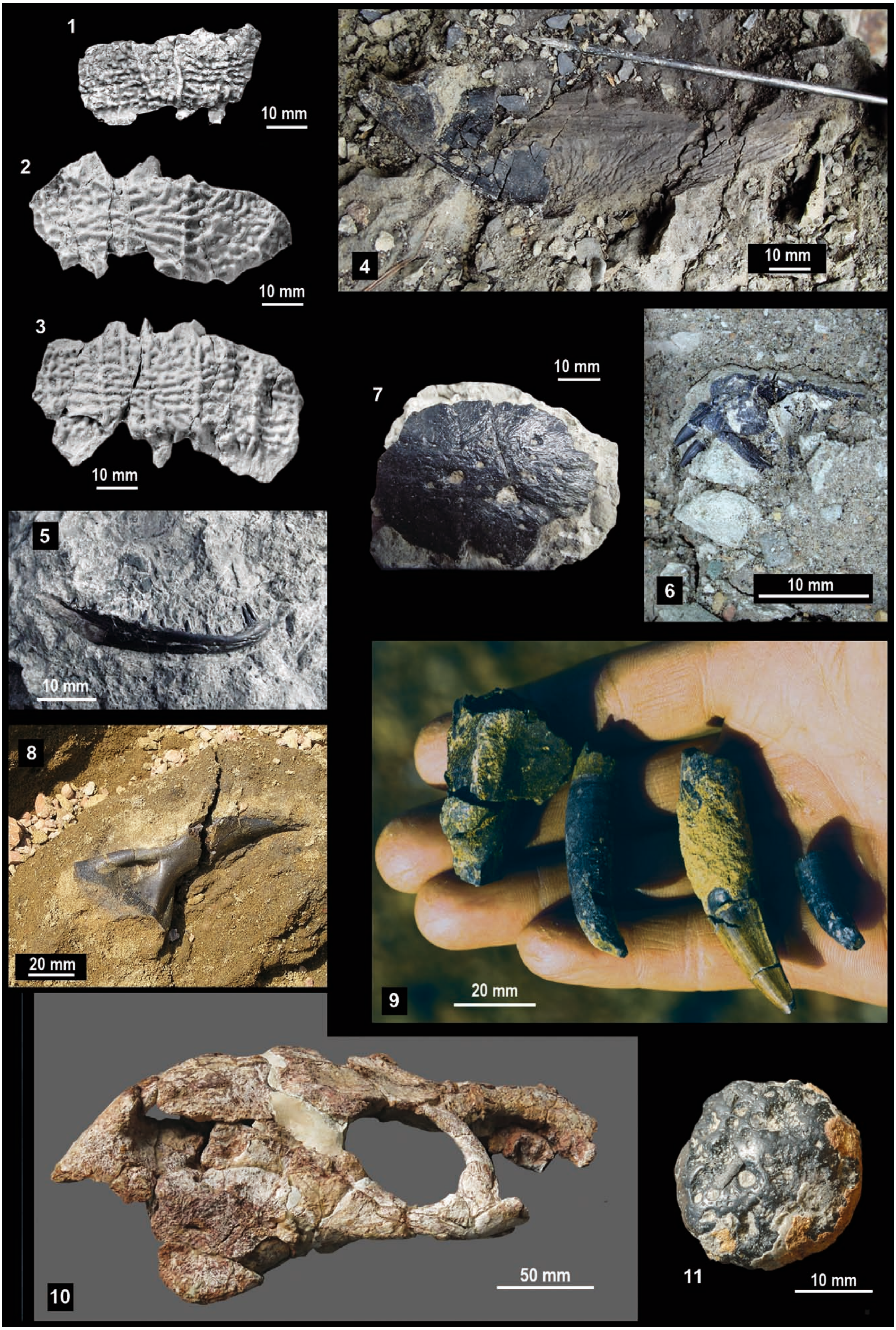
8, 9 – tetrapod remains of terrestrial community from the Klimovo Locality, Salaryovo Formation, Rovdino Member, Lower Vyatkian (Wuchiapingian): 8 – dicynodontian humerus, 9 – cani nes of dicynodonts and incisor of gorgonopian *Leogorgon klimovensis* Ivachnenko (second from left, PIN No. 4549/14).

10 – scull of *Dicynodon* sp., PIN No. 4725/1, Krasavino Locality, Salaryovo Formation, Komaritsa Member, Upper Vyatkian (Changhsingian).

11 – osteoderm of pareiasaur *Scutosaurus* sp., Eleonora Locality, Salaryovo Formation, Komaritsa Member, Upper Vyatkian, beds with Vyaznikian biota (Changhsingian).

Photos by Valeriy K. Golubev (1-3, 8), Nikolay G. Zverkov (4-7), Michael P. Arefiev (9-11).

As well illustrated pictures tetrapods of terrestrial communities are widely distributed in the transition from Poldarsa Formation to Salaryovo Formation.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(Fig. 47), *I. latifrons* Pravoslavlev, *Karpinskiosauru secundus* (Amalitzky), *Kotlassia prima* Amalitzky (Fig. 47), *Leogorgon klimovensis* Ivachnenko (Fig. 46), *Obirkovia gladiator* Bulanov et Jashina, *Pravoslavlevia parva* (Pravoslavlev), *Scutosaurus karpinskii* (Amalitzky) (Figs. 23, 47), *S. tuberculatus* (Amalitzky), *Suchonosaurus minimus* Tverdochlebova et Ivachnenko

Permian-Triassic crisis. This event is subdivided into two stages. At first, major changes occurred only in the terrestrial community. Pareiasaurs and gorgonopians disappeared from the dominant block, and the role of leading large predators was assumed by thecodonts (appearing in the fossil record for the first time) and therocephalians. Bystrowianids appeared in the subdominant block. This is the first phase of a local ecological crisis in the tetrapod community. It is represented by the Vyazniki Assemblage, although this stage was not observed in the Sukhona River region. No localities for tetrapods of this assemblage were found here.

The second stage of the crisis was connected with great changes in the total composition of the tetrapod fauna. All local groups, widely spread in the Permian, disappear, but many rare groups persist (bystrowianids, procolophons, thecodonts). The Lower Triassic tetrapod communities of the Proterosuchian fauna is characterized by a sharply impoverished taxonomic composition and the presence of extremely small, sometimes poorly specialized taxa. It is a typical postcrisis assemblage. In the ecological context, 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 *Tupilakosaurus*), terrestrial communities had lost the large-sized reptiles, while the small- and middle-sized reptiles became rather diverse. The localities of the Proterosuchian fauna were found in the Balebikha section and in the Vokhmian deposits of Nedubrovo section area. These sites yielded fossil bones of temnospondyls *Tupilakosaurus* sp. and proterosuchids *Vonhuenia* (?) sp.

Fig. 47. Tetrapod remains from the Sokolki Locality, excavated by prof. V. Amalitzky. Collection of Borissiak Paleontological Institute. Salaryovo Formation, Komaritsa Member, Upper Vyatkian (Changhsingian).

1-3 – gorgonopian *Inostranzevia alexandri* Amalitzky: 1 - skeleton, PIN No. 2005/1588, 2 – scull, 3 – teeth.

4, 5 – skeletons of pareiasaur *Scutosaurus karpinskii* (Amalitzky).

6 – scull of seymouriamorph *Kotlassia prima* Amalitzky, holotype PIN No. 2005/74.

7 – scull of therocephalian *Annatherapsidus petri* (Amalitzky), lectotype PIN No. 2005/1993.

8 – scull of cynodont *Dvinia prima* Amalitzky, PIN No. 2005/2469.

9 – scull of dicynodont *Dicynodon trautscholdi* Amalitzky, holotype PIN No. 2005/1.

Photos by Andrey A. Ermakov (1, 4) and Valeriy V. Bulanov (6).


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In the 1920s–1930s, M.D. Zalessky described the flora of the Malaya Severnaya Dvina River Basin, and published several papers based on collections made by Amalitzky (Zalessky, 1937).

Gomankov and Meyen (1986) monographically studied the flora of the East European Platform and the Fore-Urals, and named it the *Tatarina*-flora after the dominant leaf genus *Tatarina* (Fig. 35). However, there are several localities in the Sukhona and Malaya Severnaya Dvina Rivers Basin where the plant assemblages are dominated by spores, pollen and other plant remains, but where the leaves of *Tatarina* or *Pursongia* are not found. The uniqueness of the plant assemblages of the *Tatarina*-flora made it possible to recognize the Subangara paleofloristic area (Meyen, 1987). Material from the rich localities of the Sukhona and Malaya Severnaya Dvina Rivers Basin was used to demonstrate exceptional phylogenetic significance of peltasperms as a possible ancestral group of several Mesozoic gymnosperms, and for showing parallelisms in the development of Permian peltasperms and conifers. Following the disappearance in the Severodvinian of the so-called Siberian cordaites (Vojnovskyales) the flora of this region more closely resembled that of Central Europe than of Angaraland, and was assigned to the ecotonal Eurangarian realm in the classification of Krassilov (2000).

Gomankov (2002) traced and identified changes in the floristic assemblages clearly marked at the boundaries of the Urzhumian, Severodvinian and Vyatkian Stages. These floristic assemblages correspond to the phases of the Late Permian florogenesis.

Photo by Michael P. Arefiev

Fig. 48. The most ancient evidence of the *Tatarina* flora from Sukhona River. Leaf of the pteridosperm *Pursongia* sp. (right) and stem of the equisetophyte *Equisetites* sp. (left). MNH St.ABM No. 3367/10, Babie Locality, Sukhona Formation, Nyuksenitsa Member, bottom of the Upper Severodvinian (Capitanian).

Photo by Michael P. Arefiev

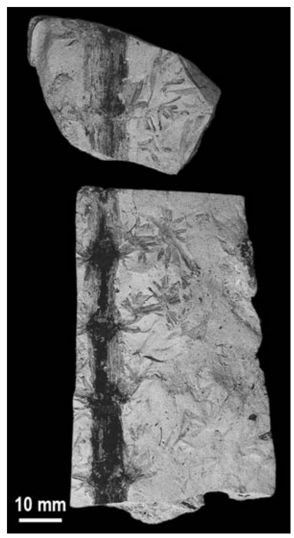

Fig. 49. A stem of *Neocalamites tubulatus* Naugolnykh, a member of a monodominant near-water community. Ustie Strelny Locality, Poldarsa Formation, Strelna Member, Upper Severodvinian (Capitanian). Scale bar 10 mm. MSU No. 276/251.

Fig. 50. Plant remains from the Opoki Locality, Poldarsa Formation, Upper Severodvinian (Capitanian):

1–3 – fragments of pinnae *Dvinopteridium edemskii* (Zalessky) Naugolnykh.

4–5 – fragment of vegetative shoots of lycopsids *Fasciostomia* sp. showing leaf cushions.

6–8 – the leaves of *Fasciostomia* sp.

1–8 – left bank of the Sukhona River, Opoki Locality, point no.V.G. No. 31, lower part of Purtovino Member.

9 – the leaf of the problematic fossil plant *Acanthopteridium spinimarginalis* Naugolnykh et Arefiev, right bank of the Sukhona River, probably upper part of Purtovino Member.

Scale bars: 1, 5, 8, 9 – 10 mm, 2, 3, 4, 6 – 10 mm, 7 – 1 mm.

Photos by Eugeny V. Karasev (1–8) and Michael P. Arefiev (9).


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Vostroe Locality (Fig. 35)

Plant remains from the Vostroe Locality are mostly fragments of one type of linear leaf with dorsal grooves, which can be attributed to the Rufloriaceae (*s. l.*). Gomankov (2001) considered that this assemblage characterized the lower part of the Urzhumian.

Babie Locality

Leaves of the pteridosperm *Pursongia* sp. (formal genus for impressions of *Tatarina*-like leaves) and a stem fragment of *Equisetites* sp. have been found loose in the Babie Locality (Figs. 9, 48). These occurrences are probably the earliest evidence of the *Tatarina* flora from sediments of Severodvinian age in the Sukhona basin. The palynological assemblage is dominated by taeniate bisaccate pollen grains (*Protohaploxypinus* and *Striatoabietites*) and striated asaccate pollen (*Vittatina* and *Weylandites*), bisaccate pollen *Vesicaspora aërifera* (Andreyeva) Hart, *Lueckisporites virkkiae* Potonié et Klaus, *Vitreisporites pallidus* (Ressinger) Nilson and others. This stratigraphic level probably corresponds to the upper part of the Nyuksenitsa Member of the Sukhona Formation (Arefiev et al., 2012).

Navoloki Locality

The plant remains at the Navoloki Locality were found in the western part of the group of Permian sections of the Sukhona River, probably near the lower boundary of the Poldarsa Formation. The remains include leaves, shoots and generative organs of plants extracted from the four (or five) levels in the Navoloki section. The assemblage is dominated by leaves of *Pursongia beloussovae* (Radczenko) Gomankov et Meyen (Gomankov, 2001).

Ustie Strelny Locality

Horsetails dominate the Strelna Member of the Ustie Strelny Locality (Fig. 12). Gomankov (2001) identified impressions of stems of *Paracalamites* and *Neocalamites* and leafy shoots close to the genus *Asterophyllites*. Large "septate" casts were originally identified as *Artisia* (?) sp. Naugolnykh recognized the leafy shoots as *Phyllotheca* sp. (Arefiev, Naugolnykh, 1998). Naugolnykh (2009) re-described them as a new species *Neocalamites tubulatus* (Fig. 49), noting that this plant dominated in this flora.

Opoki Locality (left bank)

Plant remains in the locality are represented by well-preserved impressions; compressions are not preserved. Numerous remains of leaves and bark of the lycopsid *Fasciostomia* sp. (Fig. 50, 4-8) were collected from the bottom of the Purtovino Member (Gomankov, 2001) (Fig. 11). The horsetails *Paracalamites* sp. and fragments of pinnae of the fern *Dvinopteridium edemskii* (Zalessky) Naugolnykh are less frequent (Fig. 50, 1-3).

Opoki Locality (right bank)

The peculiar leaves of *Acanthopteridium spinimarginalis* Naugolnykh et Arefiev were found loose in the talus of the Opoki section (Naugolnykh, Arefiev, 1999) and identified as incertae sedis. The leaf edges bear small spikes that may be a xeromorphic feature (Fig. 50, 9) (Naugolnykh, Arefiev, 1999). The bed where *Acanthopteridium spinimarginalis* was found approximately corresponds to the upper part of the Purtovino Member (Fig. 11).

Konyavitsa Locality

This locality was discovered in 2014. The lens of grey clay contains linear-lanceolate leaves of *Pursongia* sp. and stem casts of *Neocalamites* sp. (Fig. 17).

Mutovino (=Isady) Locality

Fossil plants from the Mutovino Channel (Fig. 15) are dominated by shoots of the conifer *Quadrocladus schweitzeri* Meyen, 1986 (Fig. 51, 5-6) in association with strobili of *Dvinostrobus sagittalis* Gomankov et Meyen (Fig. 51, 4). Subdominant fossils include leaves of the peltasperms *Tatarina conspicua* Gomankov and Meyen (Fig. 51, 7-9) associated with peltate ovuliphores of *Peltaspermopsis* cf. *buevichae* Gomankov and Meyen (Fig. 51, 2-3), seeds of *Salpingocarpus bicornutus* Meyen, *Salpingocarpus variabilis* Meyen and sporangia of *Permotheca striatifera* and *Permotheca vesicasporoides* Meyen, Esaulova et Gomankov (Gomankov, Meyen, 1986). There are also abundant leaves of the cardiolepids *Phylladoderma (subgenus Aequistomia) annulata* Meyen, *Phylladoderma (A.) rastorguevii* Meyen and *Phylladoderma (A.) trichophora* Meyen. In addition, Gomankov and Meyen (1986) reported on leaves of the *Rhaphidopteris* type and fragmentary leaves of uncertain systematic position *Arisada densa* Meyen. Spore-bearing plants are represented

Fig. 51. Plant remains from Isady Locality, Mutovino Channel, Poldarsa Formation, Kichuga Member, uppermost Upper Severodvinian (Wuchiapingian).

1 – leaf of morphogenus *Taeniopteris* sp. produced by ferns or seed ferns, PIN No. 5339/182.

Peltaspermalean pteridosperms:

2, 3 – peltate ovuliphores of *Peltaspermopsis* cf. *buevichae* Gomankov et Meyen, PIN Nos. 5339/197–198,

7–9 – a leaf of *Tatarina conspicua* Gomankov et Meyen, PIN Nos. 5339/170, 8, 7.

Conifers:

4 –pollen strobili of *Dvinostrobus sagittalis* Gomankov et Meyen, PIN No. 5339/185,

5, 6 – a branch of *Quadrocladus schweitzeri* Meyen, PIN Nos. 5339/9–11, 195a.

Scale bars: 2–4, 7–9 – 5 mm, 1, 5, 6 – 10 mm.

Photos by Eugeny V. Karasev.


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by leaves of the lycopsid *Lepidophylloides delicata* (Gomankov) Gomankov and associated dispersed megaspores. Other fossil plants include leaves with venation of the *Taeniopteris* type (Fig. 51, 1) produced by ferns or seed ferns, and the moss *Protosphagnum nervatum* Neuburg.

Gomankov (2002) assigned the flora of the Mutovino Locality to the Aleksandrovka paleofloristic assemblage, indicating that it differed from the preceding Kotel'nich assemblage by the almost total disappearance of Cordaitales and the absence of sphenophytes of the genus *Sphenophyllum* Brongniart, 1822, and the lower diversity of peltasperms as its difference from the succeeding Vokhma assemblage. According to palynological data (Gomankov, 2002), the stratigraphic range of the Aleksandrovka assemblage is limited to the Kovrovo Beds of the Severodvinian Stage.

Klimovo and Bolshoe Kalikino Localities

In 1993, M.P. Arefiev collected horsetail stems of *Paracalamites* sp. and *Phyllopytis* sp. from red beds of the Klimovo Locality underlying paleosols (Figs. 21, 52, 2-5). In 2014, we found fragments of pinnae of *Pecopteris* sp. (Fig. 52, 1). At approximately this stratigraphic level from the Bolshoe Kalikino section, Gomankov (2001) listed horsetail stems of *Neocalamites*, leaves of the peltasperms *Pursongia angustifoli*a Zalessky and leaves of the gymnosperm *Rhipidopsis* cf. *ginkgoides* Schmalhausen.

Aristovo Locality

The Aristovo Channel is the richest and best-studied locality for plant remains in the basin of the Severnaya Dvina and Sukhona rivers (Figs. 29, 30). Plant remains from this locality are preserved as compressions and impressions. Gomankov and Meyen (1986) were the first to study the floristic assemblage of the Aristovo section. Seed ferns of the families Peltaspermaceae and Angaropeltaceae are dominant. Peltasperms are represented by leaves of *Tatarina conspicua* Meyen (plate Flora 5, Fig. 8), *Ustyugia pinnata* (Meyen et Gomankov) Gomankov, *Pursongia beloussovae* (Radcz.) Gomankov et Meyen, ovuliferous discs of *Peltaspermopsis buevichiae* (Gomankov et Meyen) Gomankov and associated ovules of *Salpingocarpus bicornutus* Meyen, *S. variabilis* Meyen and *Salpingocarpus* sp. The family *Angaropeltaceae* is represented by leaves of *Phylladoderma (Aequistomia) aequalis* Meyen and *P. (A) annulata* Meyen. Synangia of seed ferns affiliated to three species: *Permotheca striatifera* Meyen et Gomankov, *P. vesicasporoides* S. Meryen, Esaul. et Gomankov and *P. vittatinifera* Meyen et Gomankov. Conifers are represented by shoots of *Quadrocladus dvinensis* Meyen and *Geinitzia* sp., ovuliferous dwarf-shoots of *Sashinia aristovensis* Meyen and strobili of *Dvinostrobus sagittalis* Gomankov et Meyen. Leaves of the lycopsid *Fasciostomia delicata* Gomankov are less abundant. There are occasional pinnae of *Pecopteris sp.* Some plants were defined as incertae sedis: *Enigmodiscus multistriatus* Meyen, *Hastipellis dvinensis* Meyen, *Estomia* sp. SVM-1, *Arisadia densa* Meyen, *Allicospermum* SVM-1. Perfectly preserved bryophyte leaves have been restudied by Ignatov (1990) and assigned to *Pelliothallites tataricus* Meyen, *Thallites* sp., *Arvildia elenea* Ignatov, *Gomankovia latifolia* Ignatov, *Aristovia subcordata* Ignatov, *A. microcellulata* Ignatov, *Protochyraea polymorpha* Ignatov, *Ignatievia papillosa* Ignatov, *Rhizinigerites neuburgae* Meyen, *Protosphagnum nervatum* Neuburg, *Palaeosphagnum meyenii* Ignatov, *Vorcutannularia minima* Ignatov, *Servicktia acuta* Ignatov, and *S. vorcutannularoides* Ignatov.

Zavrazhie Locality

The Zavrazhie Channel is at the same stratigraphic level as the Aristovo Channel (Fig. 23). Plant remains are represented by well-preserved impressions and occasionally small fragments of poorly preserved cuticles. Here you can find peltasperms, represented by leaves of *Pursongia amalitzkii* Zallesky and ovuliferous discs of *Peltaspermopsis polyspermis* (Naugolnykh, 2001).

Eleonora Locality (Figs. 23, 29)

The plant mesofossils include dispersed megaspores and numerous fragmentary cuticles of gymnosperm and bryophyte leaves. The megaspore assemblage contains megaspores of *Erlansonisporites*? sp.; only one specimen of *Maiturisporites* sp. was found (Fig. 53, 1-2). Earlier, more or less representative transitional Permian/Triassic megaspore assemblages were obtained from the Nedubrovo Member of the Vokhma Formation at the Nedubrovo locality where megaspores were represented by species of the genera *Otynisporites* and *Maexisporites*. Megaspores from older Vyatkian deposits in the Moscow Basin are represented by megaspores, which were found only in association with leaves of the lycopsid genus *Fasciostomia* (Gomankov, Mey-

Fig. 52. Plant remains from Salaryovo Formation, Vyatkian (Wuchiapingian – Changhsingian).

1–5 – Klimovo Locality, Rovdino Member, Lower Vyatkian (Wuchiapingian): 1 – the apical part of pinnae Pecopteris sp.,

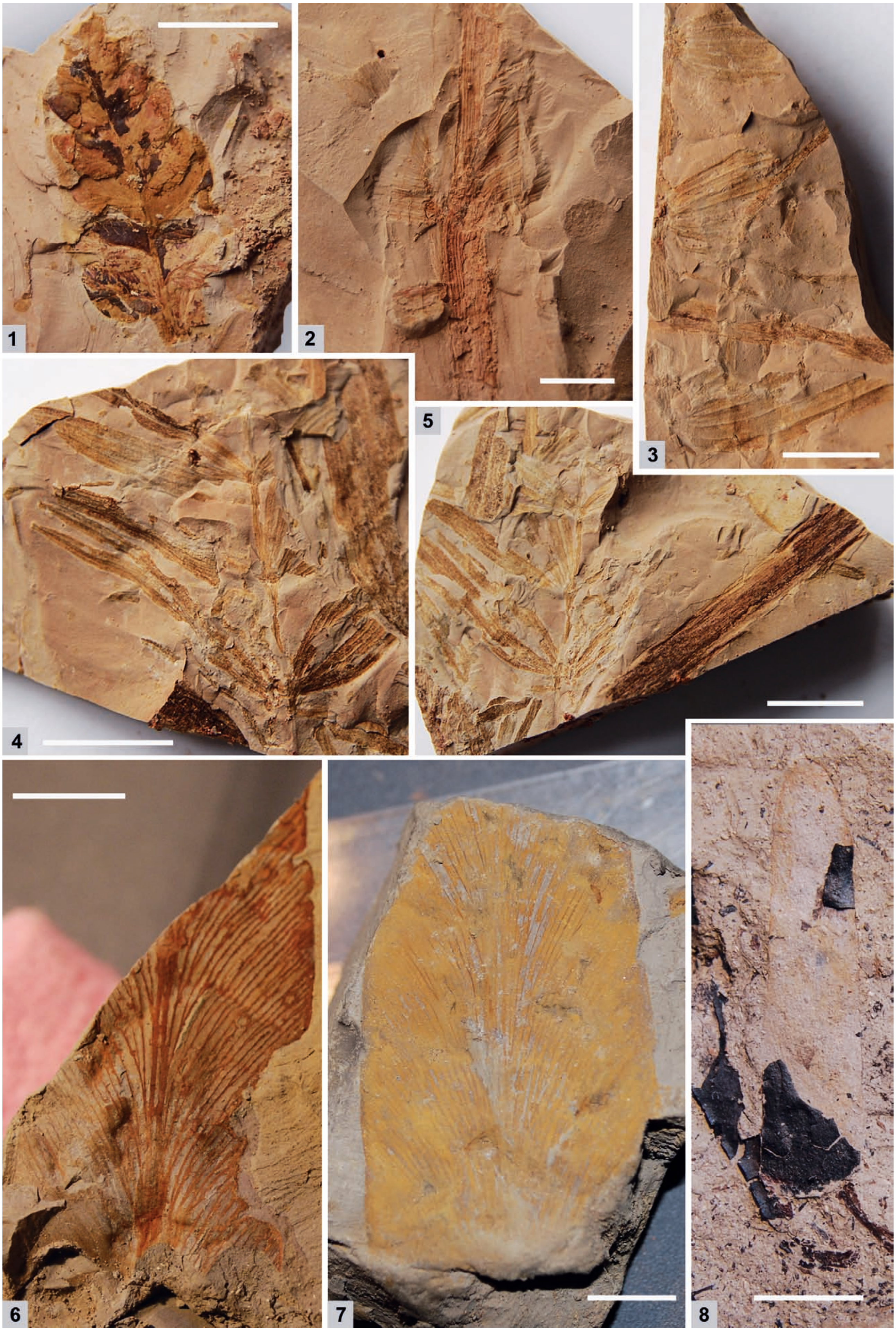
2–5 – equisetophyte stems with leaves of *Phyllopitys* sp.

6, 7 – leaf of peltaspermalean pteridosperms *Pursongia amalitzkii* Zalessky, Zavrazhie Locality, Komaritsa Member, Upper Vyatkian (Changhsingian).

8 – leaf of peltaspermalean pteridosperms of *Tatarina conspicua* Gomankov et Meyen, PIN No. 5426/1, Aristovo Channel, Salaryovo Formation, Komaritsa Member, Upper Vyatkian (Changhsingian).

Scale bars 10 mm.

Photos by Eugeny V. Karasev.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en, 1986). Thus, the assemblage of megaspores from the Eleonora Locality has no taxa in common with megaspore assemblages known in the Late Permian and Early Triassic localities of the Moscow Basin. The fragments of bryophyte leaves belong to the order *Protosphagnales* (Ignatov, 2015, pers. comm.). Most fragments of dispersed leaf cuticles of gymnosperms belong to pteridosperms of the family *Angaropeltaceae* of the genus *Aquestomia* Meyen. Less numerous are cuticles of peltasperm pteridosperms *Interpeltacutis conformis* (Karasev, 2013). The presence of dispersed cuticles of the *Angaropeltaceae* and peltasperms are typical of both Late Permian and Early Triassic (Induan) deposits. Unlike frequently occurring cuticles, a large number of dispersed megaspores is not typical of Vyatkian deposits. The recognized assemblages of megaspores at the top of the Vyatkian Stage may indicate an increased diversity of lycopsids during that time; this trend probably continued during the terminal Permian and Early Triassic in the Moscow Basin.

Tais Locality

In 1891, L.I. Lutugin was the first to find *Glossopteris*-like leaves near the mouth of the Luza River (Gomankov, Meyen, 1986). This locality was subsequently neglected for several decades, until 2012, when M.P. Arefiev visited it and made a sufficiently representative collection of fossil leaves and plant generative structures.

The plant remains of the Tais Locality are represented by well-preserved impressions and occasionally by small fragments of poorly preserved cuticles. The plant macrofossils include the shoots of mosses *Muscites* sp., numerous shoots of the horsetail *Neocalamites* sp. and fragmentary sterile pinnae of ferns *Sphenopteris* sp. and *Pecopteris* sp. Conifers are represented by shoots of *Quadrocladus dvinensis* Meyen (Fig. 53, 3). The linear-lanceolate leaves of peltasperms *Tatarina conspicua* are sub-dominant (Fig. 53, 4). Rare fragments of large leaves were preliminarily identified as *Rhaphidopteris* (?) sp.

Of particular interest are two impressions of peltoids of *Vetlugaspermum* sp. (Fig. 53, 5). The genus *Vetlugospermum* was described from the Vokhma formation of the Spasskoe locality on the Vetluga River as a member of the family Vetlugospermaceae (Naugolnykh, 2012). Karasev (2009) described bilaterally symmetric peltoids of *Navipelta* from the Nedurovo locality, which are very similar to peltoids of *Vetlugospermum*. According to recent data, the Nedubrovo locality has a terminal Permian age (Lozovsky, 2013; Arefiev et al., 2015). Thus, the Tais locality has elements that are typical of the Upper Permian and Lower Triassic sediments of the Moscow Basin.

Nedubrovo Locality (Figs. 53, 6-13, 54)

The Nedubrovo section is exposed in a series of large outcrops on the left bank of the Kichmenga River (Fig. 32). The plant remains are fragmentary but with well-preserved cuticles. In 1999, Krasilov, Afonin and Lozovsky published the first data on the assemblage of plant remains from the Nedubrovo section (Krassilov et al., 1999). They showed that the floristic assemblage from the Nedubrovo Locality includes elements typical of both the Tatarian flora of the East European platform (*Tatarina conspicua* Meyen and *Phylladoderma (Aequistomia) annulata* Meyen) and typical of Zechstein elements (*Ullmannia* cf. *bronnii* Goepert (Fig. 53, 11) and *Quadrocladus* cf. *solmsii* (Gothan et Nagathard) Schweitzer et al. (Fig. 53, 12)). Mesofossils are represented by megaspores of *Otynisporites eotriassicus* Fuglewicz and *O. tuberculatus* Fuglewicz (Fig. 53, 9-10), characteristic of the Induan of Central Europe and Northern China (Krassilov et al., 1999).

Karasev (2009) described a new genus of female generative structures of *Navipelta* Karasev (Fig. 53, 6-8). Ovuliferous organs (peltoids) of *Navipelta* in their peltate organization are similar to the ovuliferous organs of peltasperms. However, ovuliferous organs of *Navipelta* are bilaterally symmetrical, with rhomboidal outlines and of greater thickness; the tissues of the peltoids contain abundant secretory canals and cavities. Fragmentary leaves of *Permophyllocladus* sp. are also found in the Nedubrovo Locality (Fig. 53, 13). Leaves of *Permophyllocladus* are well known from the top of the Vyatkian and the beds with the Vyaznikian biota and are very simi-

Fig. 53. The plant remains from the beds with Vyaznikian and Nedubrovian biota (Eleonora, Tais and Nedubrovo localities).

1, 2 – megaspores of lycopsids of *Erlansonisporites*? sp., Eleonora Locality, Salaryovo Formation, Komaritsa Member, the lowermost part of the beds with the Vyaznikian biota, Upper Vyatkian (Changhsingian).

3–5 – remains from the Tais Locality, Salaryovo Formation, Komaritsa Member, the beds with the Vyaznikian biota, Upper Vyatkian (Changhsingian): 3 – a branch of *Quadrocladus dvinensis* Meyen, NHM St.AOBM No. 3894/21, 4 – cuticle of peltasperms leaf of *Tatarina conspicua* mod. sinuosa Gomankov et Meyen, PIN No. 5539/7, 5 – peltate ovuliphores *Vetlugaspermum* sp., NHM St.AOBM No. 3894/21.

6–13 – remains from the Nedubrovo Locality, Vokhma Formation, Nedubrovo Member, uppermost Upper Vyatkian (upper part of the Changhsingian): 6–8 – peltate ovuliphores *Navipelta resinifera* (Karasev), PIN No. 4820–46. 9, 10 – megaspores *Otynisporites eotriassicus* Fuglewicz, PIN No. 4820/800. 11 – the stomata of leaf *Ullmannia* cf. *bronnii* Goeppert, PIN No. 4820/790, 12 – stomata of leaf *Quadrocladus solmsii* (Gothan et Nagalhard) Schweitzer PIN No. 4820/118. 13 – segmented leaf of peltasperm of *Tatarina rinatata* Karasev, PIN No. 4820–26.

Scale bars: 1 – 200 μm, 2 – 30 μm, 3 – 5 mm, 4 – 200 μm, 5–8 – 2 mm, 9 – 100 μm, 10 – 30 μm, 12 – 50 μm, 13 – 1 mm.

Photos by Eugeny V. Karasev.

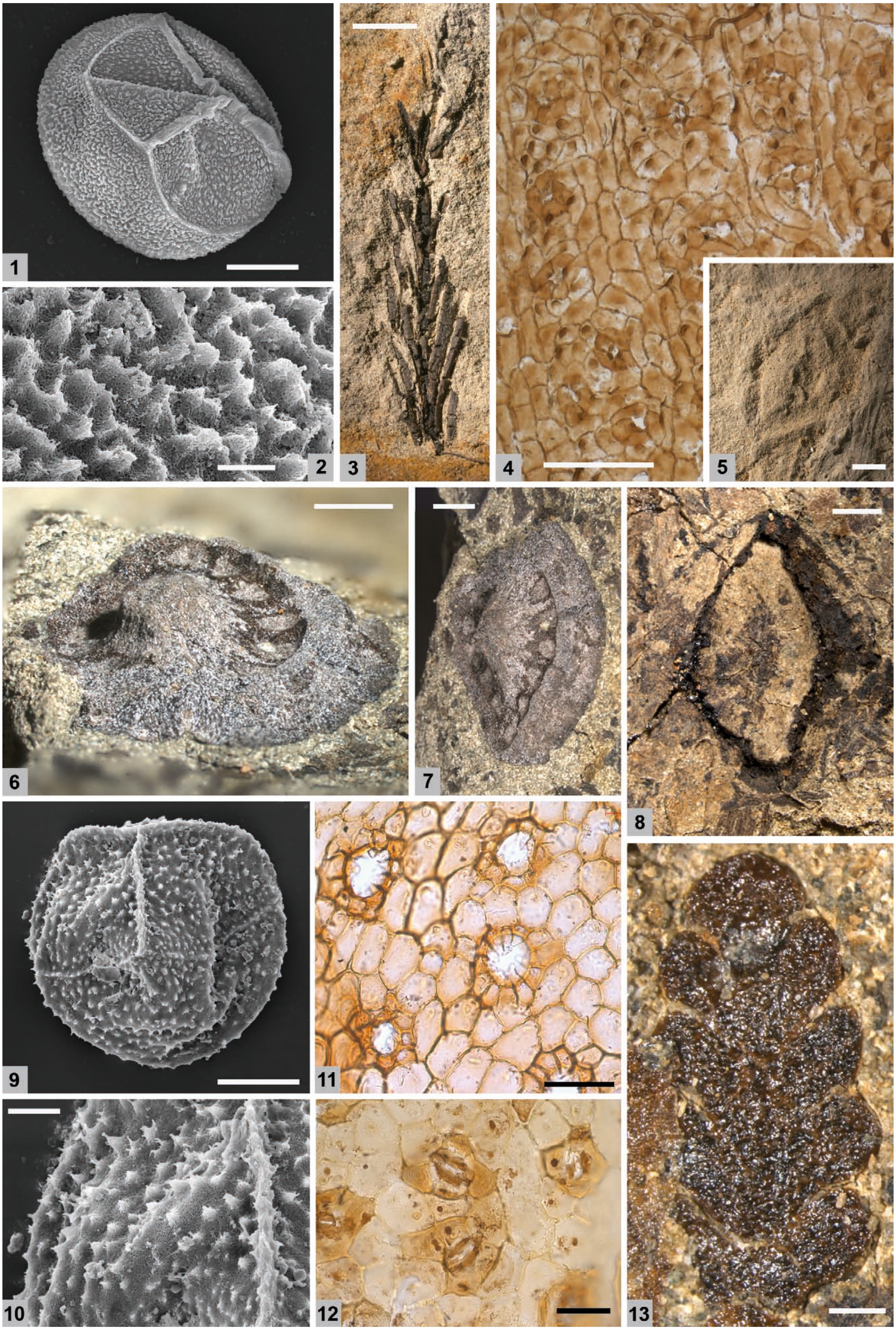
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Fig. 54. Vegetative cells of *Reduviasporonites chalastus* Balme from the Nedubrovo Locality, Vokhma Formation, Nedubrovo Member, uppermost Upper Vyatkian (upper part of the Changhsingian). Scale bars 10 µm. All photos from Afonin et al., 2001.

lar to leaves of *Germaropteris* which are common in the latest Permian deposits of Western Europe (Kustatscher et al., 2014).

In 2001 Afonin, Barinova and Krassilov (Afonin et al., 2001) published data about *Tympanicysta* Balme from the Nedubrovo Member. *Reduviasporonites chalastus* (Fig. 54) (as senior synonym of *Tympanicysta stoschiana*) was found in various abundances at different stratigraphic levels of the Salaryovo and Vokhma Formations, either in the latest Permian or in the earliest Triassic. The proliferation of *Reduviasporonites chalastus* recorded from the Permian–Triassic deposits in various localities (e.g. China, Israel, Southern Alps, Australia, South Africa) has been closely associated with the Permian–Triassic mass extinction event (Visscher et al., 2011). The origin of the species has been largely debated in the literature (Afonin et al., 2001; C.B. Foster et al. 2002; Spina et al., 2014). Visscher et al. (2011) interpreted *Reduviasporonites* as fungal remains, representing hyphae and conidia of ascomycetes similar to those of the modern *Rhizoctonia*. Afonin et al. (2001) proposed an algal affinity and demonstrated that the spores assigned to *Reduviasporonites* are more closely allied to Zygnematalean algae. Spina et al. (2014) showed close morphological similarities to some algae belonging to the order Trentepohliales, and suggested that the presence of sporopollenin-like substances in the cell walls, as well as special structures of carbohydrates and alcohols, were probably adaptations against desiccation in a subaerial habitat.

Sholga Locality

The megaspore assemblage comprises at least nine species of megaspores, among them two new species, one of the genus *Maexisporites* and the other *Otynisporites.* Additionally, megaspores referable to *O. tuberculatus* Fuglewicz, *Hughesisporites* sp. cf. *H. simplex* Fuglewicz, *Maexisporites pyramidalis* Fuglewicz, *Trileites* sp. cf. *T. vulgaris* Fuglewicz, and *Verrutriletes* sp were identified. The taxa identified are known from the Lower Triassic deposits of Eastern Europe, Central India, East China and Southern Australia. The assemblage from Sholga contains species typical of the *Otynisporites eotriassicus* Zone including *O. tuberculatus, H. simplex* and *Trileites vulgaris*. Thus, the megaspore assemblage from the upper part of the Astashikha Member and from the Ryabi Member of the Vokhma Formation can be confidently compared with that of the lower Buntsandstein of Eastern Europe (Karasev, Turnau, 2014).

In the Sukhona and Malaya Severnaya Dvina valleys the oldest Permian palynoassemblages were found in the Urzhumian (Vostroe and Kopylovo sections) and are described by A.V. Gomankov (Tatarian beds..., 2001) (Fig. 35). The Severodvinian spores and pollen were studied in the Babie outcrop (Arefiev et al., 2012) and the Mutovino Channel, while the Vyatkian taxa were studied in the Bolshoe Kalikino section and the Aristovo Channel (Tatarian beds…, 2001). As a rule, these palynospectra are dominated by ribbed saccate and non-saccate pollen.

Younger spores and pollen come from the beds with the Vyaznikian and Nedubrovian biotas and are dated as the terminal Permian. S.A. Afonin (2005) was the first to study palynology of the Vyazniki deposits in the Sokovka Locality near the town of Vyazniki, Vladimir Region. Additional material was later obtained from the Eleonora (Malaya Severnaya Dvina River) (Figs. 23, 29), Tais and Pashina Gora Channel (Yug River) localities.

The spectrum of the Eleonora Locality (46/14-2 Sample, Fig. 55, 1-4) is represented by dominating spores of lycopsids *Kraeuselisporites* and pteridophyta *Reticuloidosporites* sp. cf., *R. warchianus*, constituting 80% of the spectrum with participation of *Punctatisporites, Calamospora* and *Osmundacidites. Protohaploxypinus* sp., P. *latissimus, P. perfectus, Lueckisporites, Scutasporites* (single – 3%), *Ventralvittatina* and *Weylandites tataricus* (single – 2%) are presented in few percent.

Kraeuselisporites, which supposedly belong to lycopsids *Suchonodendron* or *Takhtajanodoxa*, were earlier found in the Vyatkian of Aristovo Channel (Gomankov, 2002). The absolute majority of *Kraeuselisporites* and *Reticuloidosporites* suggests a heavily inundated environment.

Another type of palynoassociations distinguished by diverse miospore content is characteristic of the spectra from the Tais (160/2-2 Sample) and Pashina Gora (136/10 and 136/11 Samples, Fig. 55, 5-16) localities. All these samples contain abundant monosaccate *Cordaitina* (40–60% of each spectrum) represented by *C. rotata, C. vulgaris, C. uralensis, C. abutiloida, Luberisaccites stipticus, Divarisaccus spongiosus* together with single *Florinites* and *Remysporites*. Also recorded is *Subsacculifera retroflexus* (4-12%) with insignificant content of *Protohaploxypinus, Lunatisporites, Lueckisporites* and *Vittatina*-like *Ventralvittatina* and *Weylandites*. *Calamospora, Apiculatisporis* and *Brevitriletes* are represented by sparse specimens. The spectrum (136/10 Sample) is distinguished by the presence of *Protopodocarpus alatus* of large size.

The spectra containing numerous *Cordaitina* along with *Ventralvittatina, Weylandites*, and *Protopodocarpus* may be considered as "archaic" because these forms are characteristic of older deposits. A sharp difference in dominating taxa between the spectra from the different parts of the Moscow syncline draws attention to data of Gomankov et al. (1986) who noted that some Vyatkian samples are characterized by increased amount of *Cordaitina,* other samples – by *Protopodocarpus* and *Vittatina* and others – by lycopsids and pteridophyte spores.

S.V. Meyen related the floral changes to some paleogeographic and paleoclimatic episodes. He wrote that "…many stratigraphic boundaries have a climatogenous background… Episodes of coolings and warmings are recorded at the boundaries of the Permian and Mesozoic units" (Meyen, 2002, pp. 106–110). The results of the studies indicate a possible cooling in the terminal Permian. This agrees with sedimentological and isotopic ($\delta^{18}O$) data. In the Yug and Malaya Severnaya Dvina rivers basin, the Upper Vyatkian deposits indicate a considerable river activation in the Uralian distributive province as well as a progressing cooling recorded by lighter oxygen isotopic values in pedogenic carbonates.

A spectrum from the Nedubrovo Member of the Vokhma Formation, which was earlier studied by S.A. Afonin (Nedubrovo Locality) (Afonin, 2000; Lozovskyi et al., 2001), has been supplemented by new material (133/6-3 Sample). The palynospectrum is characterized by diverse composition dominated by *Cycadopites, Klausipollenites schaubergeri*, which constitute more than a half of the spectrum. In addition, bisaccate *Alisporites* sp., *Klausipollenites decipiens, Falcisporites zapfei, Platysaccus* are present. A significant role belongs to *Ephedripites, E. permasensis*, as well as *Lunatisporites noviaulensis, L. pellucidus, L. transversundatus, L. hexagonalis, Striatoabieites richteri,* with participation of *Lueckisporites* and *Scutasporites*. There are single specimens of *Cordaitina, Crustaesporites* and *Striomonosaccites*. No representatives of *Vittatina*-like pollen have been found. Spores are not numerous but diverse and represented by *Apiculatisporis, Limatulasporites fossulatus, Leptolepidites jonkeri, Rewanispora foveolata, Punctatisporites triassicus, Proprisporites pocockii, Kraeuselisporites, Lundbladispora, Densoisporites playfordi.* Planktonic organisms *Reduviasporonites chalastus, Pilasporites* and *Inaperturopollenites nebulosus* are also present. The co-occurrence of the typical Late Permian and Early Triassic elements does not contradict the opinion of the Nedubrovo palynoflora being the youngest Permian flora.

A younger palynoflora, the *Densoisporites comlitatus – Ephedripites* sp. assemblage, is known from the Sholga Section, Yug River basin (Yaroshenko and Lozovsky, 2004). It corresponds to upper Astashikha Member and Ryabi Member of the Vokhma Formation, Lower Triassic.

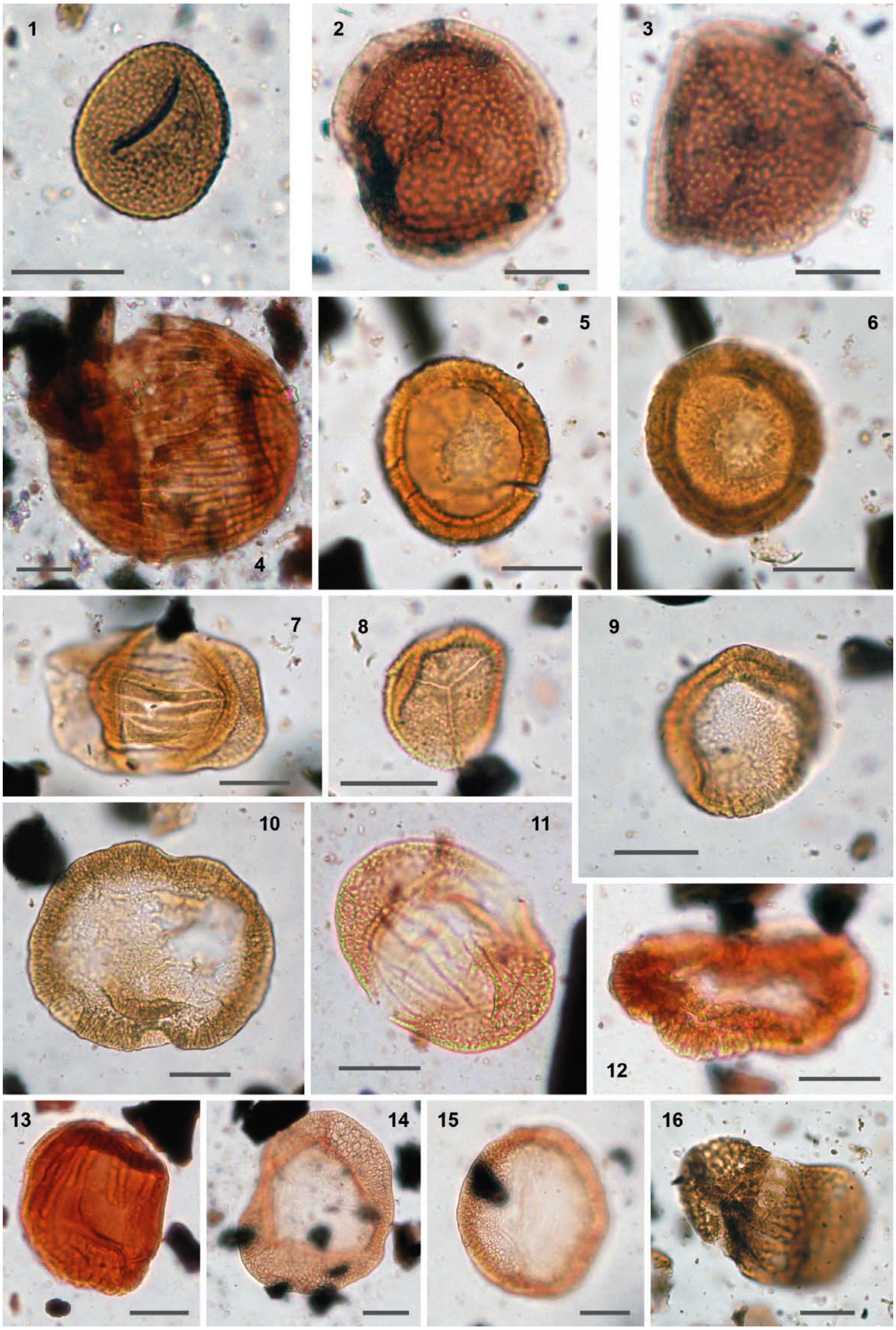

Fig. 55. Spores and pollen from the beds with Vyaznikian biota, Upper Vyatkian (Changhsingian).

1–4 – Eleonora Locality, Savvatiy section, Malaya Severnaya Dvina River: 1 – *Reticuloidosporites* sp. cf. *R. warchianus* Balme, 1970, 2, 3 – *Kraeuselisporites* sp., 4 – *Weylandites tataricus* Gomankov, 1996.

5–16 – Tais Locality, Pashina Gora section, Yug River: 5, 6 – *Cordaitina vulgaris* (Zauer) Varyukhina, 1971 ex Utting, 1994, 7 – *Protohaploxypinus perfectus* (Naumova) Samoilovich, 1953, 8 – *Apiculatisporis* sp. cf. *A. melvillensis* Utting, 1994, 9 – *Luberisaccites stipticus* (Luber) Dibner, 1970, 10 – *Cordaitina uralensis* (Luber) Samoilovich, 1953, 11 – *Protohaploxypinus latissimus* (Luber) Samoilovich, 1953, 12 – *Cordaitina abutiloida* (Andrejva) Dibner, 1970, 13 – *Ventralvittatina* sp., 14 – *Divarisaccus spongiosus* (Luber) Dibner, 1970, 15 – *Cordaitina punctata* (Luber) Hart, 1965, 16 – *Striatopodocarpites* sp. Scale bars 20 µm.

Synthesis of the data

The isotope, sedimentological and biotic data obtained allow reconstruction of paleogeographical history of the Moscow Basin in the terminal Permian–beginning of Triassic. In the Severodvinian Age, a great regional cooling occurred in this region. The first features of this event are probably already manifested in the Lower Severodvinian, when the biota of the East European Platform underwent extinction of the main members of the aquatic block of Dinocephalian tetrapod community, and terrigenous sedimentation slightly intensified and the first paleosols appeared in the Sukhona River Basin.

At the Early–Late Severodvinian boundary, progressing cooling resulted in further intensification of the river flow, which is reflected in a significant lightening of the isotope composition of oxygen in sedimentary carbonates. An increase in the rate of terrigenous sedimentation caused closure or regression of the Early Severodvinian Basin. In the area of the Sukhona River, the most hydrophytic members of the *Tatarina* Flora, which expanded along with alluvial conditions, appeared. Relict marine ostracods, such as *Bairdia*, which probably showed a short revival occurred in the lakes, when the mineralized Sukhona Basin approached normal marine conditions because of intensification of the river flow.

Further cooling during the Late Severodvinian resulted in activation of river systems of the Ural and Fennoscandia source regions, the final basin of which was situated in the northeastern Moscow Basin. In the western regions of the East Russian Depression, lacustrine–alluvial landscapes expanded at that time. As a result of increased terrigenous sedimentation, aerial and subaerial conditions became widespread. The peak of the Severodvinian cooling is recorded by the lightest isotope composition of oxygen in sedimentary and pedogenic carbonates of the Strelna Member of the Poldarsa Formation. It coincides in time with complete disappearance of the Dinocephalian tetrapod fauna, appearance of reptiles of Gondwanan origin and development of monodomonant hydrophytic sphenophyte community. Perhaps, a fall in temperature was the main factor of the Severodvinian crisis in tetrapod community, which resulted in complete disruption and extinction of the Dinocephalian fauna. However, periodic warming gave rise to lakes with a heavy isotope oxygen composition of their water, which is evidence of warming episodes and renewal of active evaporitization.

At the end of the Severodvinian Age, a significant warming is reconstructed, which is supported by a weighting of the isotope oxygen composition and widespread deposits of inland playas and sebkhas represented by silty–clayey breccias. A fall in temperature was probably connected with the disappearance of Angarida elements from the East European fauna of bivalves and appearance of the taxa known in Gondwana and China. In plant community, a xerophytic element, *Acantopteridium*, is recorded at that time. During a new short cooling at the Severodvinian–Vyatkian boundary, rich communities of aquatic invertebrates, fishes, tetrapods and plants already occurred and persisted almost throughout the Vyatkian Age.

After the warming episode, the Early Vyatkian Time at the level of Kalikino and Erga Members is characterized by a new significant cooling. At that time, intensified terrigenous sedimentation from the Fennoscandia and Ural resulted in regional expansion of red silty–clayey beds of the Salaryovo Formation. The effect of the Ural River system is particularly strongly pronounced at the level of the Rovdino Member. In the Sukhona River Basin, many river channels appeared, with sands dominated by an epidote–zoisite mineral association, which is indicative of the Ural source region. The Late Vyatkian was also characterized by further cooling, which caused humidification and an increased hydromorphy of landscapes. The next fall in temperature at the level of the lower part of the Komaritsa Member correlates with a rich fauna of terrestrial and aquatic tetrapods from the Sokolki, Zavrazhie, Savvatiy and Aristovo localities. A succeeding cooling dated to the Vyaznikian Time caused sharp activation of the Ural River system, development of deep erosive cuts, the base of which was filled with gravelstones with Ural flints. In the vegetative cover of that time, important changes are recorded, including the presence of cordaitaceous pollen and appearance of new elements, such as *Vetlugaspermum* sp., which continued in the Triassic.

The peak of the Late Vyatkian cooling falls on the Nedubrovo member. The temperature minimum correlates with negative excursion of $\delta^{13}C$, indicating the global event horizon of the Permian–Triassic extinction. At the same time, a new general regional intensification of the effect of the Ural alluvial system occurs. Finally, in the Vyaznikian and Nedubrovian time a large part of the Moscow Syncline underwent the influence of the Ural source region.

Succeeding warming, which in the Moscow Basin is only weakly pronounced compared to the Permian Time, correlates with expansion of the Triassic biota. Thus, transition from the Permian to Triassic marks the end of a long paleogeographical reorganization, which lasted from the Severodvinian to the end of the Vyatkian.

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The Sukhona River Natural, Historical, and Cultural Park

The Valley of the Sukhona and Malaya Severnaya Dvina rivers is a real jewel of the Russian North. It can rightly be on a par with such UNESCO World Heritage Site as the Solovetsky Monastery on the White Sea, or the paintings of Dionysius in the Ferapontov Monastery.

Amazingly, the Sukhona River banks have turned out to be the place where the geological history, reflecting the sequence of events of the Late Permian ecological crisis, is unified with rich historical and cultural heritage of human civilization.

In the 17-th century, Velikiy Ustyug became one of the most attractive trading centers in the Russian Tsardom. Most of the eastern-bound Russian expeditions started from the banks of the Sukhona in the same century, while many others in the 18-th century.

A handful of brave men set off for the Pacific Ocean to discover the Bering Strait, Kamchatka Peninsula, the Aleutian Islands, Russian Far East, as well as Alaska.

A host of prominent personalities originally came from the places situated along the banks of the Sukhona and Severnaya Dvina. Among them are such renown trail-blazers as Semyon Dezhnev, whose name was given to the easternmost part of the Eurasian land, Cape of Dezhnev; Erofey Khabarov, Ivan Kuskov, the first Commandant of Fort Ross in California; Admiral Nikolay Kuznetsov, a long-time Commander-in-Chief of the Soviet Russian Navy in the Second World War.

Their names are forever imprinted on the memory of mankind and could be easily found on geographical maps. However, what is more important is the greatness of human spirit manifested by their lives!

Nowadays, it is Feodor Konyukhov, a world famous traveller, painter and writer, as well as a holder of many world records, who is closely connected with the activities carried out on the banks of Sukhona and Severnaya Dvina.

The spirit of these people is still felt here today as at any time before. The ancient history of the region in question should be preferably learned from the sources covering the times of the Late Permian epoch.

The best sites of the Sukhona and Malaya Severnaya Dvina Rivers.

Page 100, Opoki Outcrope, left bank of the Sukhona River.

Page 101, from left to right and top to bottom:
the mouth of the Strelna River;
Sokolki Outcrope;
Klimovo Outcrope;
Opoki Outcrope, left bank of the Sukhona River;
skull of a Dicynodon trautscholdi lies on the bank the Malaya Severnaya Dvina River.
Photo published by M. Arefiev in National Geographic Russia, 2004, no. 10. Skull was brought to the bank of the River from the museum for the photoshoot.

Pages 102-103, the mouth of the Strelna River.

Photos by Michael P. Arefiev, Dmitryi S. Kopylov, Valeriy V. Bulanov.

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Type and reference sections of the Permian–Triassic continental sequences
of the East European Platform: main isotope, magnetic, and biotic events

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Sukhona and Severnaya Dvina Rivers field trip

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На английском языке

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