SERPUKHOVIAN AND BASHKIRIAN BIOHERM FACIES OF THE KIZIL FORMATION IN THE SOUTHERN URALS

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БИОГЕРМНЫЕ ФАЦИИ СЕРПУХОВСКИХ И БАШКИРСКИХ ОТЛОЖЕНИЙ КИЗИЛЬСКОЙ СВИТЫ НА ЮЖНОМ УРАЛЕ

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Introduction

A thick series of carbonates, widespread on the eastern slope of the Southern Urals in the centre of the Magnitogorsk Megasynclinorium constitute the Kizil Formation established by L.S. Librovitch [1936]. Sedimentation of the Kizil Formation occurred in a shallow-water shelf basin from the Late Viséan, throughout the Serpukhovian and most of the Bashkirian, and was terminated in the Askynbashian because of the raising of a carbonate platform. The Kizil Formation extends along the Ural, Bolshoi Kizil and Khudolaz rivers. It overlies the volcanic rocks of the Berezovskaya Formation and is overlain with an unconformity by conglomerates of the Urtazym Formation of Moscovian age. Due to the considerable thickness of the formation and the abundance of small algal bioherms and biostromes, this sequence of rocks was described as a reefoid formation [Korolyuk et al., 1983]. The largest bioherms are found in the Bashkirian portion of the section [Shchekotova, 1978].

Much research has been done on the biostratigraphy and fossils of the Kizil Formation [Ivanova et al., 1972; Ivanova, 1975; Kochetkova et al., 1977; Kochetkova, 1983; Simonova, 1990; Stepanova, 1997; Stepanova, Kucheva, 2006; Zainakaeva, 2004; Kulagina et al., 2001, 2002; Kulagina, 2007].

The outcrops of the Kizil Formation along the Khudolaz River constitute the stratotype section of the regional stratigraphic subdivisions of the eastern subregion of the Urals, and the hypostratotype of the Averinian (Upper Viséan) [Stepanova, Kucheva, 2006], whereas the outcrops of carbonates along the Bolshoi Kizil River constitute the stratotype of the Kizil Formation. The stratotype section along the Bolshoi Kizil River shows a faunal assemblage of the bioherm facies accumulated in an open shallow marine basin with many brachiopod shoals and banks, and with algal and coral bioherms.

Biostratigraphy and lithology

The Bolshoi Kizil section begins on the right bank of the Ural River 1.2 km south of the village of Proletarka (situated on the opposite bank) and continues along the left bank of the Bolshoi Kizil River (right tributary of the Ural River). The section is located in the west of the Kizil District of the Chelyabinsk Region. It follows the Bolshoi Kizil River upstream for almost 7.5 km. Below the Viséan part of the section is briefly described, and the Serpukhovian and Bashkirian bioherm facies are discussed in greater detail.

The Upper Viséan strata are divided into regional units of substage rank (locally called horizons) including Zhukovian, Kamenskouralian, Averinian and Bogdanovichian. They are exposed in outcrops

separated by covered intervals (Figs. 1, 2). Beds lie monoclinally (dipping at an azimuth 250–260°, at an angle of 25–40°). Different researchers have estimated their thickness differently; the maximum estimate was 1500 m.

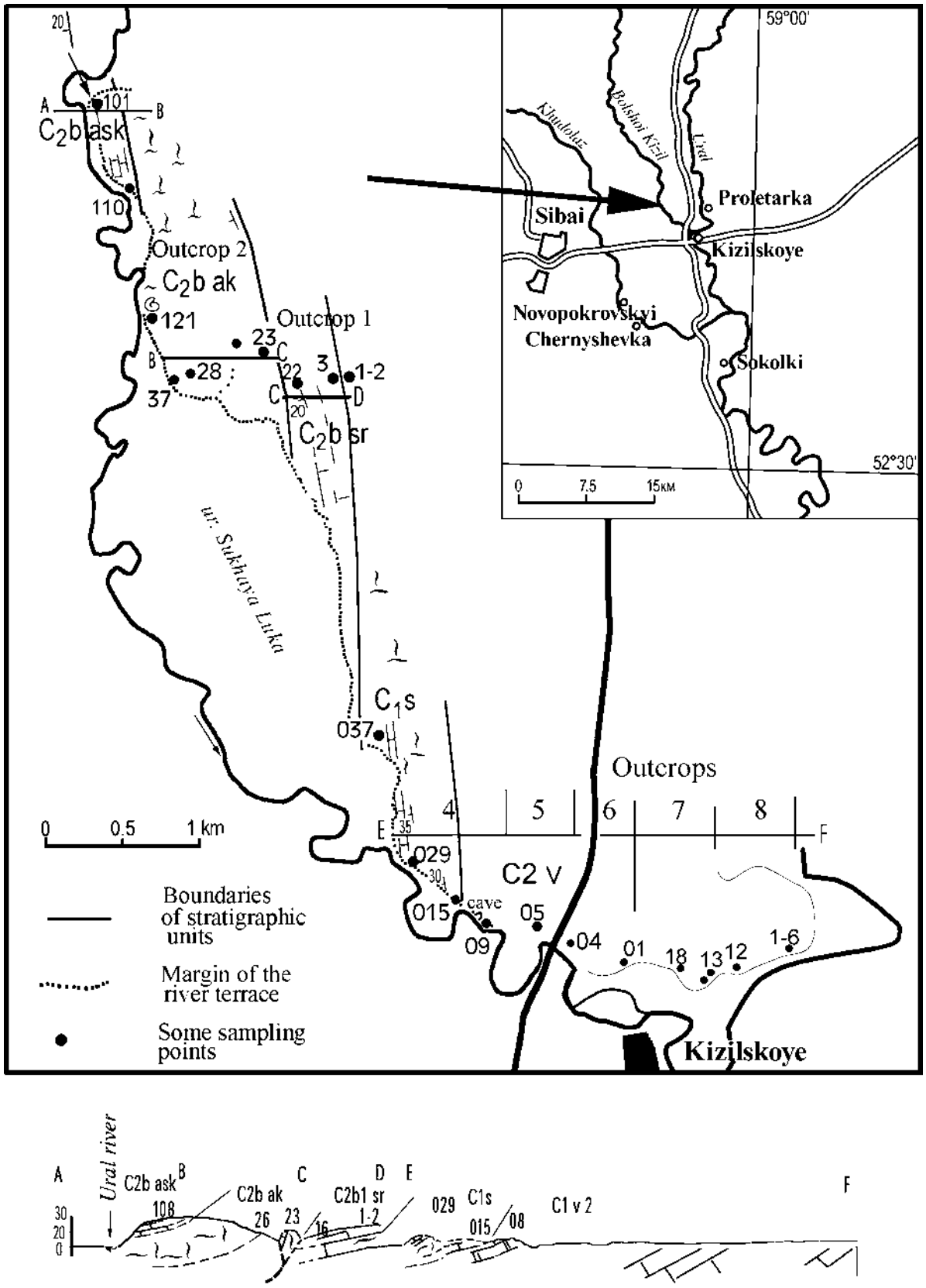


Fig. 1. Geological scheme of the outcrops along the Bolshoi Kizil River

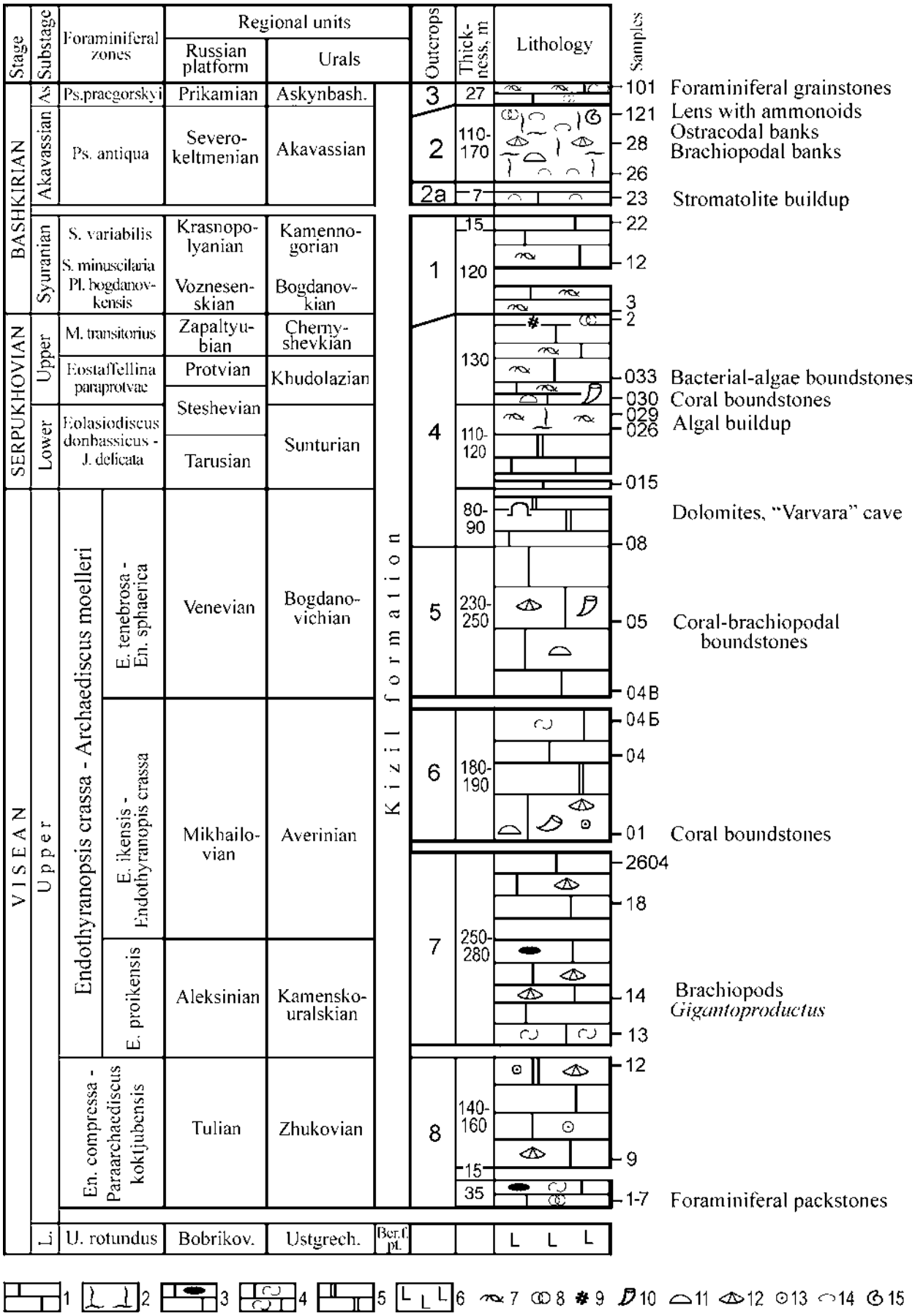


Fig. 2. Generalized section of the Kizil Formation along Bolshoi Kizil River

Upper Viséan Substage

The **Zhukovian** (upper part, Outcrop 8, thickness 190–210 m) correlates with the Tulian of the Russian platform. These strata extend along the right bank of the Ural River. The outcrop begins 1.9 km upstream from the confluence of the Ural and Bolshoi Kizil rivers. The Zhukovian is represented by medium and thickly bedded bioclastic packstones and grainstones with peloids and pellets. Bioclasts include foraminifers, crinoids, corals and brachiopods, they are partly rounded and micritized, sometimes slightly dolomitized. There are occasional nodules of chert at the base of the section. Samples 1–6 contain the fossil alga *Koninckopora* sp. and the foraminifers *Lituotubella glomospiroides* Rauser*, Endothyranopsis compressa* (Rauser et Reitlinger), *Globoendothyra orelica* Vdovenko*, Pojarkovella nibelis* (Durkina), *Paraarchaediscus koktjubensis* (Rauser)*, P. cyrtus* (Conyl et Lys) and numerous other forms. The Zhukovian assemblages of foraminifers characteristically contains large archaeodiscids with a well developed dark layer, numerous pojarkovellids and lituotubellids. The beds correspond to *Paraarchaediscus koktjubensis* Zone and the upper part of Tulian in the Russian Platform.

The **Kamenskouralskian** (Outcrop 7, thickness 150 m) correlates with the Aleksinian of the Russian Platform. It is exposed 1.5 km north of the confluence of the Ural and Bolshoi Kizil rivers, consists of foraminiferal grainstones, foraminiferal-algal-bioclastic grainstones and packstones, sometimes dolomitized, with occasional nodules of light-colored chert in the upper part, with the brachiopods *Gigantoproductus* and numerous foraminifers. Algae *Ungdarella uralica*, syringoporids, colonial tetracorals and foraminifers are found in the upper part.

The Kamenskouralskian corresponds to the *Eostaffella proikensis* Zone based on the presence of *Lituotubella magna* Rauser, *Haplophragmella* sp., *Omphalotis chariessa* Conil et Lys, *Globoendothyra globules* (Eichwald), and *G. ishimica*, *Haplophragmella* sp. *Eostaffella* cf. *parastruvei* (Rauser)*, E.* cf. *proikensis* (Rauser)*, Parastaffella concinna* (Schlykova).

The **Averinian** (Outcrops 7 and 6, thickness over 300 m) is exposed in the land between two rivers in outcrops 7 and 6, and consists of mostly organic limestones with diverse fossils. In Outcrop 7 (thickness 100–130 m), the horizon is composed of thick and indistinctly bedded limestones with accumulations of brachiopods. Algal-foraminiferal packstones and grainstones, algal boundstones, algal-brachiopod wackestones predominate. Algae include *Ungdarella uralica* and *Fasciella kizilia* R. Ivanova (= *Shartymophycus fusus* Kulik). Outcrop 6, along the bend of the B. Kizil River exposes organic limestones, dolomitized in places, with brachiopods. The algal-foraminiferal, foraminiferal and bryozoan-algal packstones prevail. In Stop 01 coral boundstones were observed. Thickness 98 m.

Upward in the section, after a covered interval 22 m thick, we observed medium to thickly bedded bryozoan-crinoidal limestones, in places dolomitized, with colonies of tetracorals and with numerous brachiopods. Thickness 74 m.

The Averinian contains Foraminifers generally continue from the underlying beds while the foraminifers *Bradyina rotula, Janischewskina* sp., *Endothyranopsis crassa* (Brady), *Eostaffella ikensis* Vissarionova, *E. ragushensis* Ganelina, *Cribrostomum eximium regularis* Lipina, *Archaediscus ovoides* Rauser, *A.* cf. *gigas* Rauser, *Asteroarchaediscus baschkiricus* (Krestovnikov et Theodorvich)*, Permodiscus sizranicus* indicative of the *Eostaffella ikensis* Zone.

The **Bogdanovichian** (Outcrops 5, 4; thickness more than 330 m) is exposed along the bend of the left bank of the Bolshoi Kizil River. The Bogdanovichian is composed of boundstone, bioclastic grainstone and dolomite. Crinoidal, foraminiferal, crinoid-brachiopod and oolite limestones are observed on the left bank of the Bolshoi Kizil River near the bridge across the river, on the Sibai – Magnitogorsk highway (Outcrop 5). At Stop 05, on the left of the bridge, in the direction from Sibai to Magnitogorsk thickly bedded wackestones and packstones with brachiopods and crinoids are exposed. Foraminifers were identified in Sample 05 and included *Earlandia vulgaris* (Rauser et Reitlinger), *Forschia mikhailovi* Dain*, Pseudoglomospira*

Legend to Fig. 2: 1–4 — limestones: 1 — bedded, 2 — unbedded, 3 — with chertly nodules, 4 — bioclastic, 5 — dolomites, 6 — volcanic rocks, 7 — algae, 8 — foraminifers, 9 — bryozoans, 10 — solitary corals, 11 — colonial corals, 12 — brachiopods, 13 — crinoids, 14 — ostracodes, 15 — ammonoids

spp., *Endostaffella parva* (Moeller), *Endothyranopsis sphaerica* (Rauser et Reitlinger), *Bradyina rotula* Eichwald, *Biseriella parva* (N. Tchernyscheva), *Palaeotextularia longiseptata crassa* Lipina. Upstream of the river, along the bend of the left bank of the Bolshoi Kizil River there are exposures of younger lithoclastic and bioclastic grainstones with foraminifers of the genera Lituotubella, Globoendothyra endothyranopsis, Bradyina and Janischewskina cf. typica (Mikhailov) (about 140 m; Samples 06, 07). The above species suggest the presence of the *Eostaffella tenebrosa* Zone. The Bogdanovichian correlates with the Venevian of the Russian Platform and corresponds to Cf6 Zone of Belgium.

Outcrop 4 exposing the Viséan-Serpukhovian boundary beds [Kulagina, Gibshman, 2002, 2005; Kulagina et al., 2002] is on the Bolshoi Kizil River, 400 m northeast of the on the Sibai – Magnitogorsk highway. This outcrop shows a continuation of the succession described above. The description begins with the rocky exposures on the left bank of the Bolshoi Kizil River (marker Stop 08a is located 43 m at azimuth 140° from the "Varvara" Cave). The following sequence of thick bedded and indistinctly bedded limestones is observed (bottom to top) (Fig. 3):

1. At Stop 08a we observed bioclastic packstones, with frequent fragments of coral, echinoids, crinoids and bryozoans, containing corals and brachiopods, matrix is dolomitized and re-crystallized.

2. Bioclastic and crinoidal packstones-rudstones with rare algae and foraminifers, in the upper part with corals. Thickness 7 m.

3. Dolomites. Thickness 11 m.

4. Cavernous dolomites. There is a cave at this level. Thickness 9.5 m.

5. Limestones with calcite accumulations, numerous brachiopods *Striatifera*. At the bottom of the gully there is an outcrop of crinoid, algal-bioclastic packstones-rudstones, with rare foraminifers. The algae are mostly *Calcifolium okense* Schwetzov et Birina, there also *Koninckpora* sp. and *Ungdarella* sp. (Sample 011a). Thickness 4.8 m.

Covered interval (bottom of the gully). 12 m.

6. Light limestones are outcropped in the mouth on the right slope of the gully, in thin section — algal packstones-boundstones with many foraminifers (Sample 012): *Pseudoglomospira* spp., *Haplophragmella tetraloculi*, *Endothyranopsis sphaerica* (Rauser et Reitlinger), *Janishewskina typica* Mikhailov and other. Thickness 4 m.

Upstream of the river there is a covered interval 6.7 m thick.

Serpukhovian Stage
Sunturian Horizon

7. Algal boundstones, sometimes grainstones with remains of thin-shelled brachiopods. Algae *Calcifolium okense* Schwetsov et Birina. Foraminifers (Samples 15a, 015) include *Pseudoglomospira* sp., *Haplophragmina* cf. *beschevensis* (Brazhnikova), *Endothyranopsis sphaerica* (Rauser et Reitlinger), *Globoendothyra globula* (Eichwald), *Howchinia bradyana* (Howchin), *Bradyina* cf. *rotula* (Eichwald), *Janishewskina delicata* (Malakhova), Palaeotextulariida, *Rugosoarchaediscus akchimensis* (Grozdilova et Lebedeba), *Asteroarchaediscus baschkiricus* (Krestovnikov et Theodorvich), *Neoarchaediscus postrugosus* (Rauser), *Permodiscus vetustus* Dutkevich, *Eolasiodiscus donbassicus* Reitlinger. Thickness 1 m.

Covered interval 18 m.

8. Massive boundstones formed by *Calcifolium okense* Schwetzov et Birina and *Fasciella kisilia* R. Ivanova, strongly dolomitized, containing brachiopods, crinoids and corals (Sample 016). Thickness 3 m.

9. Fine- and microbioclastic packstones with recrystallized matrix, containing algal, foraminifers, fragments of bryozoans, brachiopods, crinoids, spicules of sponges and chert. Fossils include algae *Calcifolium, Praedonezella*, *Fasciella,* and numerous foraminifers (Samples 017, 019). 5 m.

Covered interval 13 m.

10. Limestones, fissured and dolomite forming small flattened exposures (Sample 020). Thickness 6.5 m.

11. Relict-algal, algal and bioclastic packstones, strongly cavernous and dolomitized. Sometimes caverns are filled with oxidized bitumen; the matrix is represented by homogeneous, very compact, recrystallized micrite. Bioclasts include crinoids, bryozoans, and echinoids. Often areas with numerous

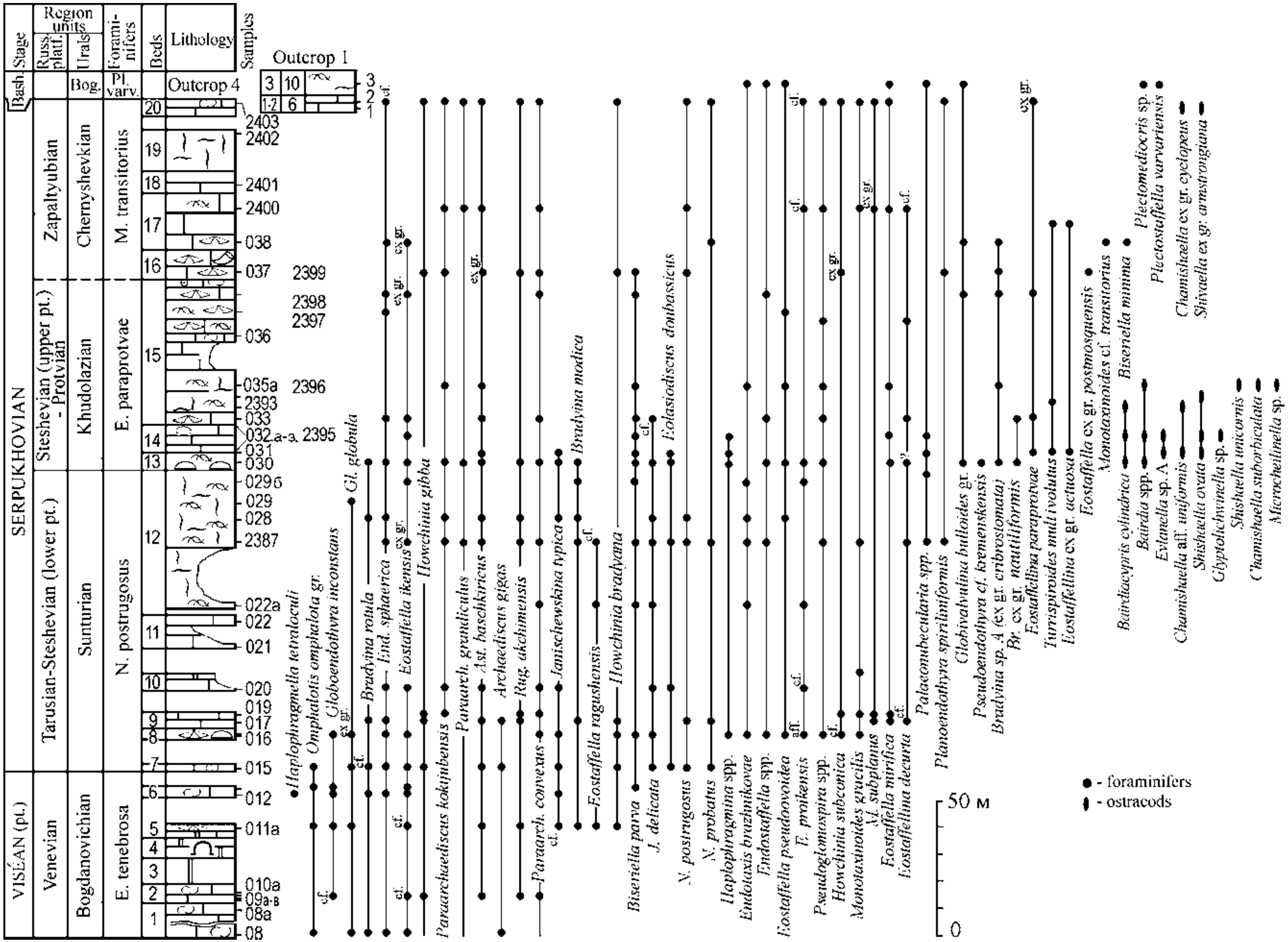


Fig. 3. Distribution of some foraminifers and ostracodes in the Serpukhovian part of the section along the Bolshoi Kizil River. For explanations see Fig. 2

algae may be observed. Presence of single-chambered *Eotuberitina* sp. (cementing the sediments) and bioencrustations (microspongiostromes) is very characteristic (Samples 021, 022). Thickness 13 m.

12. Algal boundstones formed by the algae *Calcifolium okense* Schwetzov et Birina with bioencrustations (Plate 1), with foraminifers, frequent fragments of bryozoans, crinoids, a strong smell of bitumen, brachiopod banks in the lower part, in parts strongly dolomitized (Samples 022a, 2387, 026–029). Thickness 45–52 m.

The thickness of the Sunturian is up to 110 m.

13. At its base, the Khudolazian is composed of boundstone, formed by colonial corals (coral bioherm) and algae (Stop 030, bed 1.3 m) with frequent encrustations, contains bryozoans, spines of echinoids, numerous foraminifers and cysts formed by small *Mediocris* and *Endostaffella*. Algal boundstones and packstones overlays, includes (Samples 031, 031A, 031B): algae of genera *Calcifolium*, *Ungdarella* and *Fasciella*; foraminifers: *Turrispiroides multivolutus* (Reitlinger), *Eostafellina* cf. *paraprotvae* (Rauser), *Pseudoendothyra* cf. *kremenskensis* Rosovskaya, *Globivalvulina eogranulosa* Reitlinger, *Gl. bulloides* (Brady), *Bradyina* ex gr. *cribrostomata* (Rauser and Reitlinger), *Br.* cf. *eonautiliformis* Reitlinger. Thickness 3.4 m.

14. The bed forms a vertical wall composed of distinctly laminar limestones. From bottom to top this bed shows a succession of boundstones formed by *Calcifolium* with bioclasts (Sample 032, Pl. 1, Fig. 2), bioclastic grainstone-packstone (Samples 32a, G26v (в), Pl. 1, Figs. 3, 9), wackestone with unidentified tubular remains (Samples 32b (б) 32v (в), Pl. 2, Figs. 4, 5), bioclastic wackestone-packstone with brachiopods (Sample 32g (г)), boundstones formed by structures produced by cyanobacteria in association with bacterial encrustations, and abundant fibrous cement (Sample 32e) with bacterial inclusions. At the top we observed a bed of "spotty" limestone, microscopically peloid-foraminiferal boundstone with prevailing palaeonubecularias (encrusting foraminifers), spheres and rhodophytes (Sample 2395, Pl. 2, Figs. 1, 2, 6), sometimes with numerous ostracodes (032zh (ж), Pl. 2, Fig. 3). Thickness 11 m.

15. In this interval [small outcrops near the quarry], in the separated outcrops before the quarry there are exposed medium-bedded brachiopods wackestones-packstones (Sample 033), followed by algal wackestones and bafflestones (Sample 2396) and peloid grainstones-packstones (Sample 036). In the wall of the quarry, there are exposed thickly bedded bioclastic wackestones-packstones with numerous brachiopods. Algae: *Praedonezella* sp., *Calcifolium okense* Schwetzov and Birina, *Ungdarella* sp., *Fasciella kizilia* R. Ivanova. Foraminifers: *Earlandia vulgaris* Rauser et Reitlinger, *Endothyranopsis* sp., *Eostaffella* cf. *proikensis* Rauser, *E. ikensis* Vissarionova, *Millerella* cf. *tortula* (Zeller), *Asteroarchaediscus baschkiricus* (Krestovnikov et Theodorvich), *A. parvus* (Rauser), *Biseriella parva* (N. Tchernysheva) (Samples 2397, 2398). 53 m.

The thickness of the Khudolazian is nearly 67 m.

Chernyshevkian Horizon

Beds of the Chernyshevkian Horizon are exposed in a steep river bank excavated in a quarry. The upper part of the Chernyshevkian has been taken off by the quarry, and the description below is cited from N.M. Kotschetkova (unpublished), who studied the outcrop before the quarry was excavated in 1975 (Samples 2387–4003 — collected by N.M. Kotschetkova).

16. Bryozoan-algal packstones and wackestones containing corals, numerous brachiopods and foraminifers (Samples 037, 2399): *Endothyranopsis* sp., *E.* cf. *mirifica* Brazhnikova, *E. postmosquensis* Kireeva, *Neoarchaediscus probatus* (Reitlinger), *N. postrugosus* (Reitlinger), *Monotaxinoides* ex gr. *transitorius* Brazhnikova et Potievskaya. Thickness 11 m.

17. Fine-bioclastic packstones and wackestones with brachiopods in the some beds, with foraminifers (Samples 038, 038b, 038g, 2400): *Pseudoglomospira* spp., *Endothyra* ex gr. *bowmani* (Phillips), *Globivalvulina bulloides* Brady, *Asteroarchaedscus baschkiricus* (Krestovnikov et Theodorvich). Thickness 24 m.

Plate 1. Microfacies of the Serpukhovian (Khudolazian Horizon): 1, 7. Boundstone formed by *Calcifolium okense* Schwetzov et Birina, 1935. 1 — Sample 2387, 7 — Sample 029. **2.** Boundstone formed by *Calcifolium okense* with bioclasts and pelmicrite cement, Sample 032. **3.** Algal boundstone with foraminifers *Palaeotextularia* sp. (upper) and *Eostaffella proikensis* Rauser-Chernousova, 1948, Sample 029. **4.** Algal boundstone with unidentified remains, Sample 029. **5.** *Eostaffella* aff. *pseudostruvei* Rauser-Chernousova, 1948, Sample 029. **6, 9.** Bioclastic grainstone, filling the spaces between the thalluses of *Calcifolium*, Sample G26v (в), level of 32a; in the Fig. 6 bioclastic grainstone includs *Haplphragmina beschevensis* (Brazhnikova, 1967). **8.** *Monotaxinoides subplanus* Brazhnikova et Jarzeva, 1956, ×180, level of the Sample 017 (from [Kulagina, Gibshman, 2005], Fig. 12, photo 29)

Plate 1

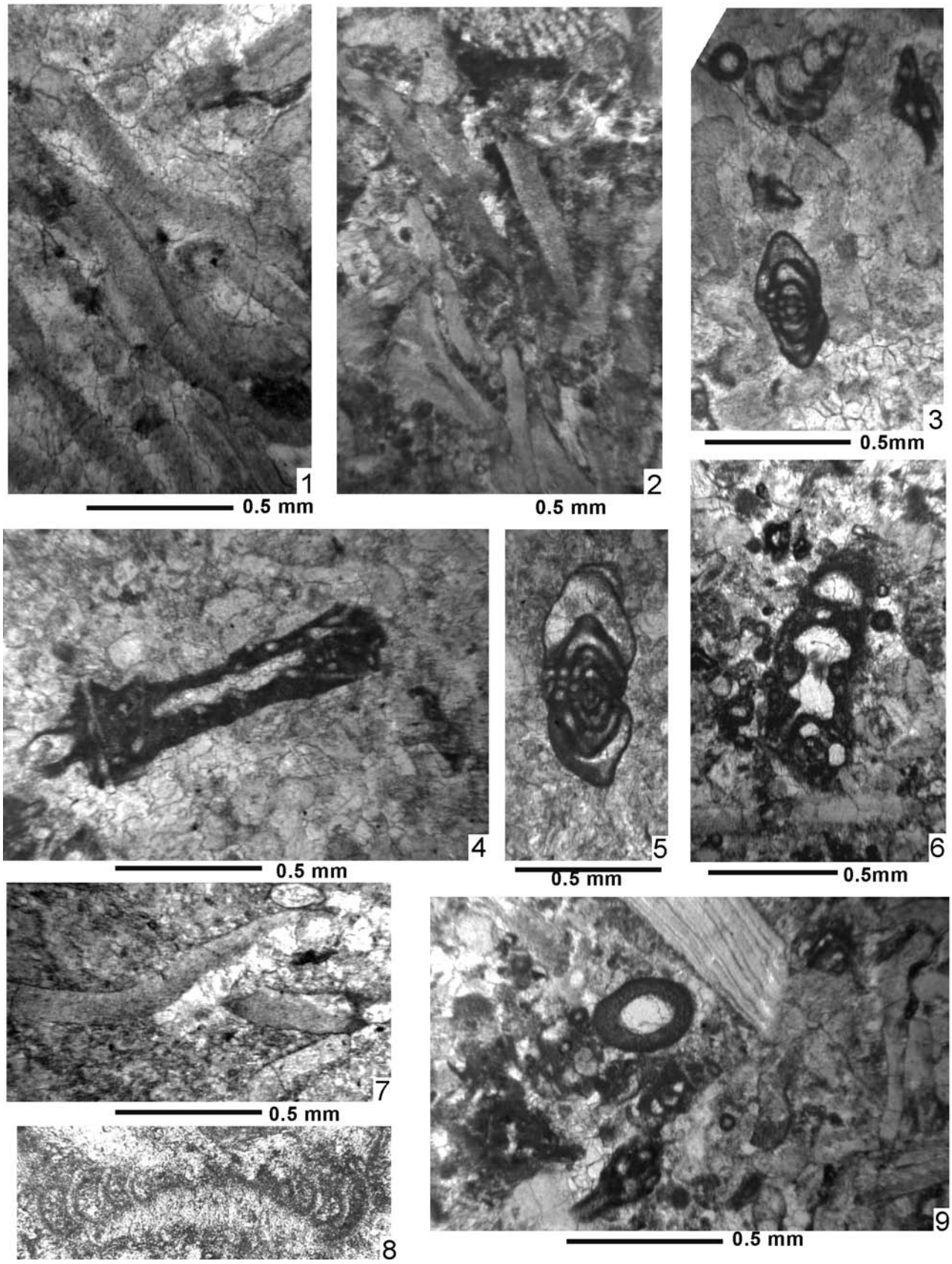
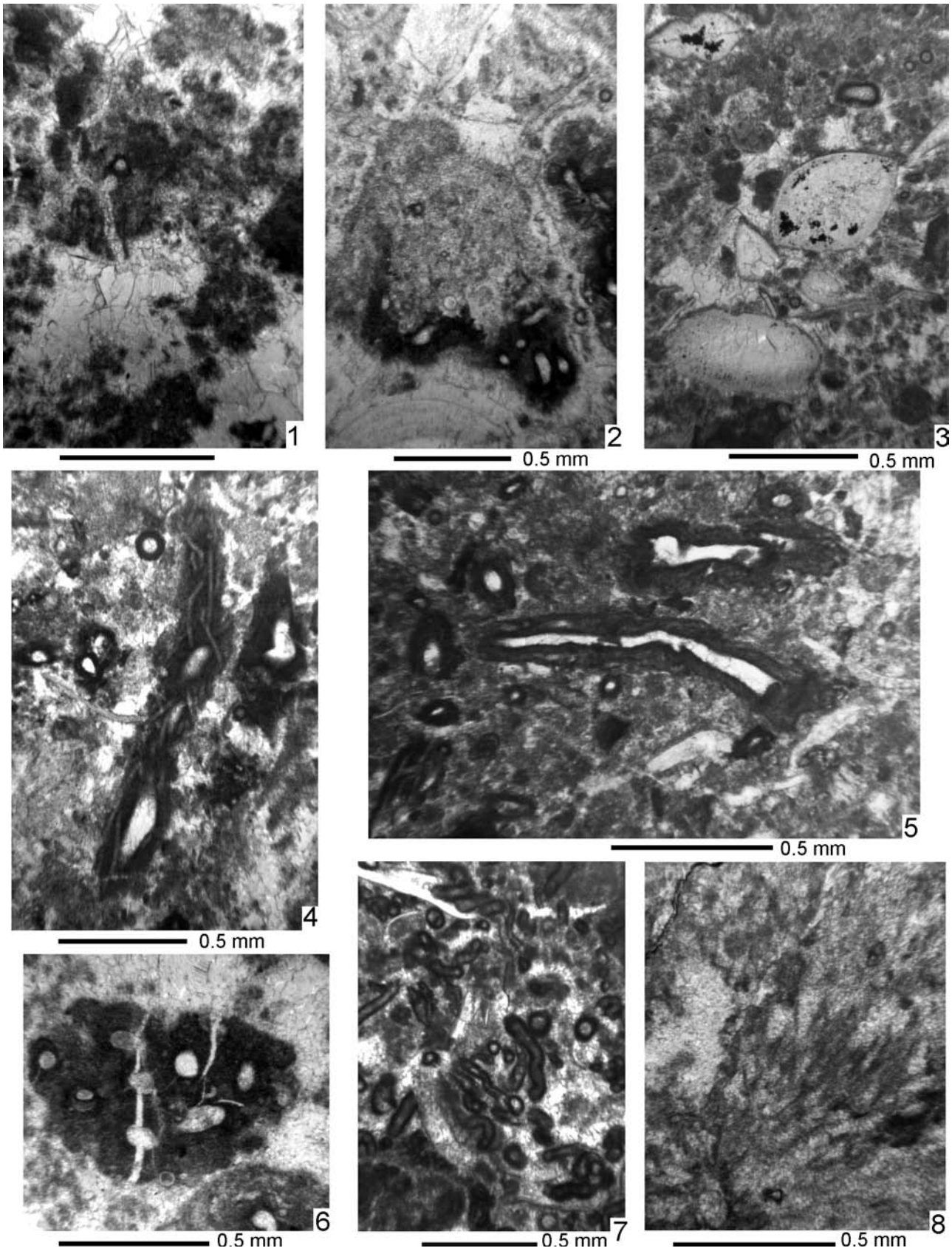


Plate 2



18–19. Mudstones and microbial-lumpy wackestones with numerous thin-walled *Glomospira*-like tubular organisms, possibly playing a role in cementation of the sediment (Samples 2401, 2402). Thickness 24 m.

Covered interval is 5 m.

20. Bryozoan-crinoidal packstones with numerous foraminifers Archaediscidae (Sample 2403). Thickness 2.5 m.

The presumed thickness of the Chernyshevkian is over 66 m, while the thickness of the entire Serpukhovian amounts to 250 m.

Serpukhovian – Bashkirian / Mississippian – Pennsylvanian boundary

The Serpukhovian – Bashkirian boundary beds are exposed in unnamed gullies opening into the flood plain and cutting into the left bank of the Bolshoi Kizil River 4.5 km upstream of the village of Kizilskoe in Outcrop 1 [Kulagina et al., 2001] (Fig. 4).

1. Pachyspheral mudstones and wackestones, thickly bedded, with rare solitary corals, brachiopods, ostracodes and single foraminifers (Sample 1). Thickness 4.5 m.

2. Bioclastic packstones and rudstones, in places with accumulations of small brachiopod shells, with bryozoans, crinoids, foraminifers and algae *Fasciella kizilia* R. Ivanova, *Praedonezella cespeformis* Kulik, *Calcifolium okense* Schwetzov and Birina (Sample 2). This bed includes archaediscid biofacies and contains numerous *Paraarchaediscus*, *Neoarchaediscus*, *Asteroarchaediscus*, *Howchinia*, *Monotaxinoides*, rare *Planoendothyra* and *Eostaffella*. Thickness 1.5 m. This bed corresponds to the Bed 20 of Outcrop 4.

Bashkirian Stage
Syuranian Substage
Bogdanovskvian Horizon

The Bogdanovskian is composed of thick-bedded, indistinctly bedded and massive limestones.

3. Peloidal wackestone with rare brachiopods, pelmatozoan bioclasts, and ostracodes and foraminifers (Sample 3): *Pectostaffella varvariensis* (Brazhnikova et Potievskaya), *Plectomediocris* sp., *Rectoendothyra donbassica* Brazhnikova, conodonts *Declinognathodus noduliferus inaequalis*. Thickness 1.5 m.

This bed is overlain by fine-crystallized dolomite with rare foraminifers and relicts of the micritic grains. Thickness 8.5 m.

4. Algal wackestones, in places recrystallized, with bryozoans, pelmatozoans, and brachiopods. Algae (Sample 5) include numerous *Ungdarella* sp., *Fasciella kisilia* R. Ivanova. The bed contains foraminifers and conodonts. Thickness 13 m.

5–6. Bafflestones formed mainly by *Ungdarella uralica* Maslov (Samples 74, 75). Thickness 15 m.

7–8. Boundstones formed by the algae *Fasciella kisilia* R. Ivanova with *Praedonezella cespeformis* Kulik, *Ungdarella paralella* Kulik, *Calcifolium okense* Schwetzov and Birina. Bioclasts contains bryozoans, crinoids and rare foraminifers (Samples 6–10, 12a, b, v). Thickness 19 m.

Covered interval 5 m.

9. Foraminiferal-bioclastic-peloidal grainstones with fragments of brachiopods, crinoids, and corals (Sample 12). Thickness 6 m.

10. Boundstones intricately recrystallized in places with accumulations of thin-shelled ostracodes, in thin sections with *Spongiostroma* structure and microbial (?) lumps, foraminifers, and brachiopods (Samples 13, 14). Thickness 20 m.

11–12. Bioclastic wackestones and packstones. Thickness 19 m.

Plate 2. All from the Khudolazian: **1.** Microbial boundstone, Sample 2395(4). **2.** Ostracodes rich alga-microbial boundsone, Sample, 32e. **3.** Ostracodes rich peloidal wackestones with cavity encrustations, Sample 032zh (ж). **4, 5.** Wackestone including like-tubular encrusting organisms with micro-grain porous wall. 4 — Sample 032b (б), 5 — Sample 032v (в). **6.** Microbial boundstone with fibrous cementation and encrusting forms, Sample 2395(4). **7.** Boundstone formed by *Pseudoglomospira*-like encrusting unidentified organisms, Sample 032d. **8.** Microbial-algal boundstone formed by *Ortonella* sp., Sample 032z (з)

Fig. 4. Distribution of some foraminifers, conodonts and ostracodes in the Syuranian part of the section along the Bolshoi Kizil River. For explanations see Fig. 2

Covered interval 7 m.

13. Bioclastic and foraminiferal-bioclastic wackestones with numerous calcisphaeras, ostracodes, bryozoans, brachiopods. Thickness 4.5 m.

Thickness of the Bogdanovskian is 62 m.

The range of most characteristic microfauna is shown in Fig. 4.

Kammenogorian Horizon

The Kammenogorian is represented by medium-bedded wackestones and packstones with foraminifers, brachiopods, ostracodes and echinoderms.

14. Foraminiferal-fine-bioclastic grainstones and packstones with numerous encrusting foraminifers *Palaeonubecularia, Tolypammina, Ammovertella*. Thickness 7 m. Then Covered interval follows.

The apparent thickness of the entire Syuranian in this section is about 125 m.

Outcrop 2
Akavassian Substage

The Akavassian is represented by a bioherm massif formed by a series of bioherms, which may be observed along the latitudinal direction of the steep riverbank almost right across the strike and further, after the turn to the north, almost along the strike.

A small bioherm body can be observed in the mouths of the river channels upstream of the unexposed interval, at the right turn of the steep bank from the meridianal to latitudinal direction. Outcrop 2 (marked stops 23–25, Fig. 5).

1. Boundstones built by algae *Donezella lutugini* Maslov, *Berezella* sp., *Maslovoporidium* sp. and stromatolites, often recrystallized with sparite cement and encrustations. Sometimes the rock is represented by carbonate breccia, with angular intraclasts of micrite and serpulid limestone, in places re-crystallized matrix produced by a decaying carbonate buildup. Fossils include crinoids, ostracodes, gastropods, serpulids and assemblage of foraminifers of the *Pseudostaffella antiqua* Zone. Thickness 6–7 m.

Further, the section is interrupted by a covered interval (thickness 40–50 m), probably including a tectonic dislocation.

2. At Stop 26 massive stromatolitic boundstones, in places strongly dolomitized, may be observed. Thin sections show stromatactis structures, in places bitumen. Thickness 4 m.

3. Along the steep bank in the latitudinal direction there are interrupted exposures of a similar massive limestone, in places strongly dolomitized, with accumulations of ostracodes and serpulids. Thickness approximately 65 m.

4. Massive boundstones formed by the algae *Maslovoporidium* sp. and *Donezella lutugini* Maslov in combination with radial-fibrous cement and microbial inclusions recrystallized in a lace-like pattern, with encrustations, contains banks of brachiopods, in places with numerous ostracodes, rare foraminifers and ammonoids (Samples 27, 27a). Thickness about 4 m.

5. A bioherm massif constructed by algal boundstones, ostracode, brachiopod and serpulid banks, and by stromatolite-building algae and structures such as *Spongiostroma*, in places completely recrystallized and dolomitized, with encrustations Samples 28, 28a, 33–36, 121/1–121/3). Boundstones with abundant radial-fibrous cement, embracing bioclasts (Pl. 3, Fig. 5). The foraminiferal wackestones (Sample 37, Pl. 3, Fig. 1, 7) and grainstones are occasionally present (121/4, 121v, Pl. 3, Fig. 4). The bioherm massif contains a limestone lens with numerous ammonoid shells (Fig. 6). Fossils includes: algae *Donezella*, *Ungdarella*, *Beresella*, *Girvanella,* and *Cuneiphycus*; foraminifers: *Pseudostaffella antiqua* (Dutkevich), *Ps.* cf. *paracompressa* Safonova, *Ps. compressa* (Rauser), *Varistaffella korobezikhi* (Rauser et Safonova), V. *varsanofievae* (Rauser); ammonoids: *Bilinguites superbilinguis* (Bisat), *Stenoglaphyrites* sp. nov., *Schartymites barbotanus* (Verneuil), and *Schartymites* sp. nov.; ostracodes by the rich assemblage of the *Kirkbyella aperta* Zone [Kochetkova, 1983]. Brachiopods were determined by Ya.L. Lutfullin and include *Enteletes mesolobus (*Jan.), *Choristites moelleri* (Jan.), *Ch. baschkiricus* (Jan.) and other [Kochetkova et al., 1977]. The thickness is approximately 30 m.

Fig. 5. Distribution of some foraminifers, ammonoids, conodonts and ostracodes in the Akavassian and Askynbashian parts of the section along the Bolshoi Kizil River. For explanations see Fig. 2

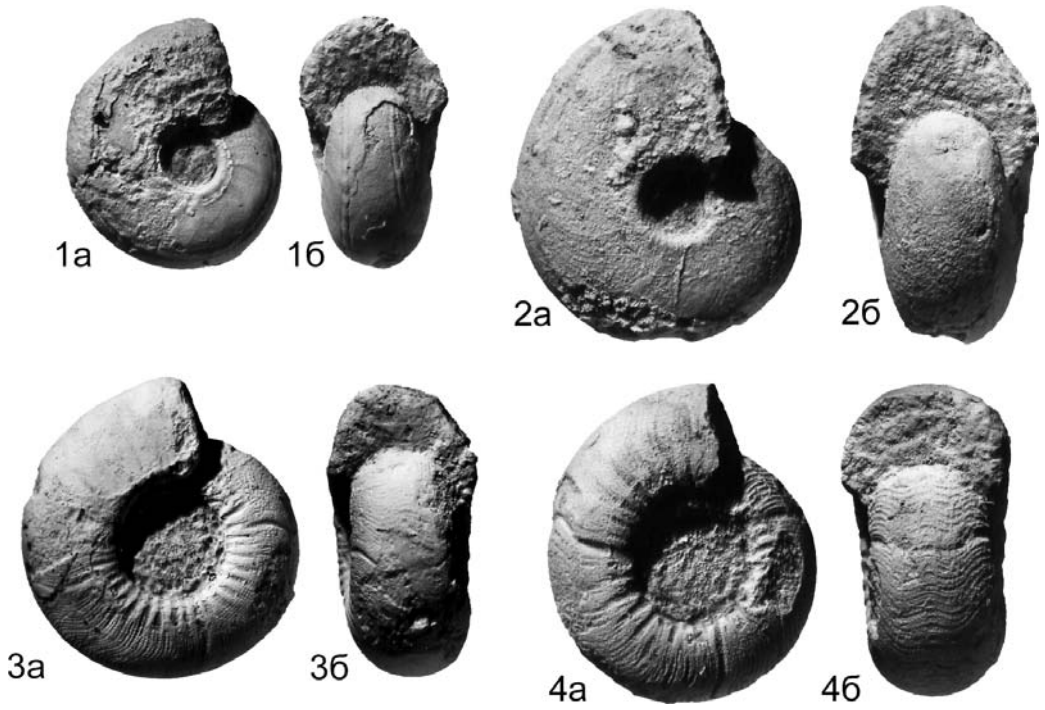


Fig. 6. Ammonoids from Bolshoi Kizil section, Sample 21/2, Bilinguites – Cancelloceras Genozone, Nm2c2 Zone, Akavassian. 1, 2. Bilinguites superbilingues (Bisat, 1924), 1 — Specimen no 4715/40 (×1.5), 2 — Specimen no 4715/39 (×2). 3, 4. Cancelloceras elegans Ruzhencev et Bogoslovskaya, 1978, 3 — Specimen no 4715/30 (×1.5), 4 — Specimen no 4715/31 (×2)

The thickness of the bioherm limestones may only be estimated provisionally because the bedding is not obvious, while the thickness of the bioherm bodies constituting the massif varies. The bioherm massif extends almost along the strike to form rock exposures of the bank for ca. 2 km.

The apparent thickness of the Akavassian is 160–170 m.

Outcrop 3

This outcrop is 7 km upstream of the mouth of the Bolshoi Kizil River. In Outcrop 3 a contact of bioherm massive boundstones and overlying bedded limestones may be observed.

Askynbashian Substage

1. Algal boundstones formed by *Donezella lutugini* Maslov, rare *Berezella* sp. *Cuneiphycus* sp., with rare bioclasts of crinoids, brachiopods, numerous foraminifers (Sample 111): *Pseudoglomospira* sp., *Climacammina* sp., *Globivalvulina* sp., *Asteroarchaediscus rugosus* (Rauser), *Eostaffella* spp., *Pseudostaffella antiqua* (Dutkevich), *Ps.* cf. *conspecta* (Rauser), *Staffellaeformes* sp. Thickness 2 m.

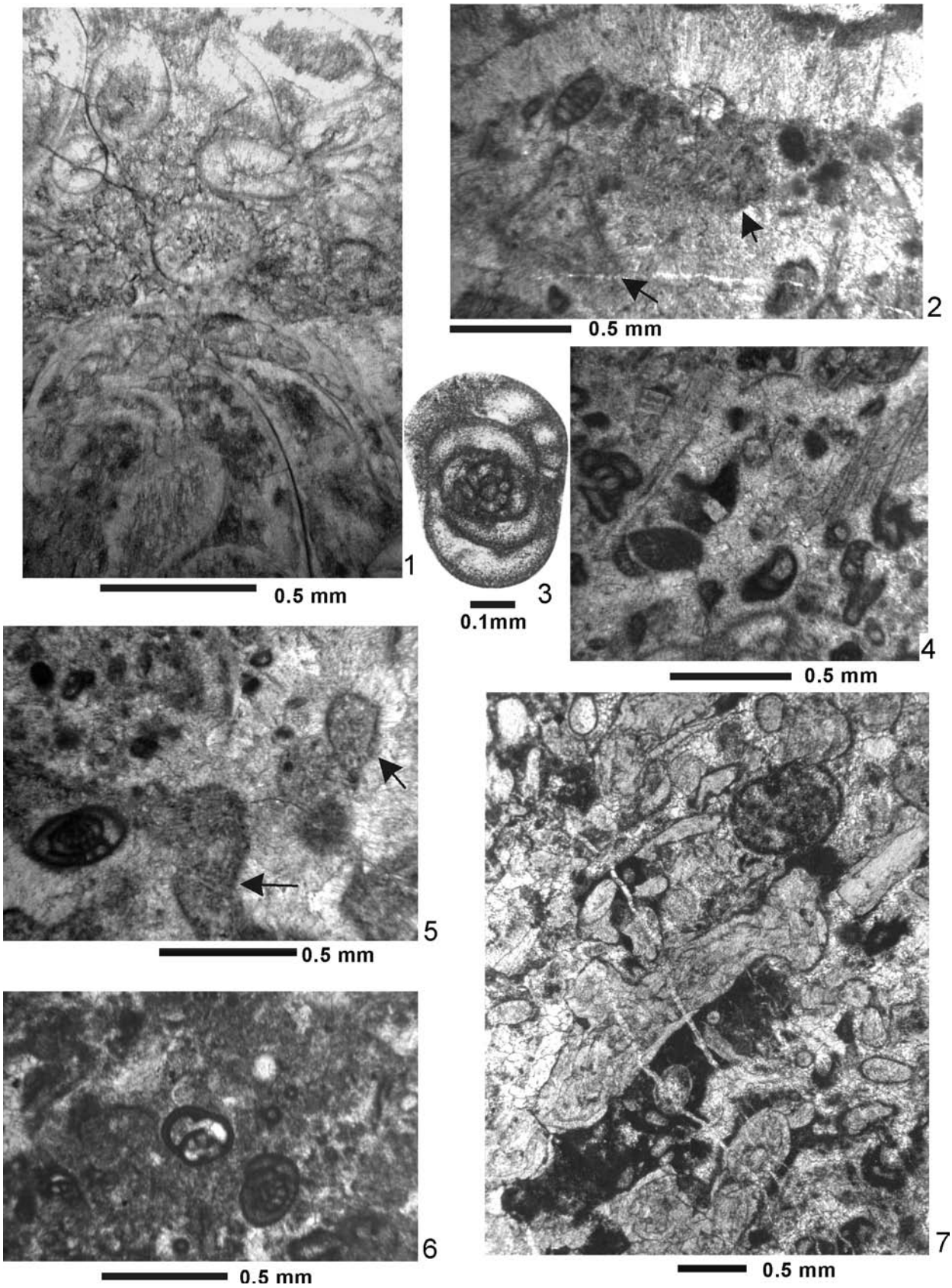
2. Crinoidal rudstones-grainstones with frequent foraminifers, bioclasts of pelmatozoans, bryozoans, brachiopods, and algae *Berezella* sp. Thickness 2 m.

3. Algal-foraminifers boundstones formed by *Donezella lutugini* Maslov, *Maslovoporidium* sp., *Berezella* sp., *Dvinella* sp., *Pseudostacheoides* sp., *Stacheoides* sp., *Epistacheoides* sp. with bioclasts of crinoids, bryozoans, pelmatozoans, brachiopods, numerous foraminifers: *Pseudoglomospira* sp., *Globivalvulina* sp., *Eostaffella* spp., *Ozawainella* spp., *Pseudostaffella* spp., *Asteroarchaediscus* sp., and conodonts of the *Idiognathodus sinuosus* Zone. Thickness 13 m.

4. Foraminiferal bioclastic grainstones containing frequent foraminifers, bioclasts of algae, pelmatozoans, ostracodes, algae *Ungdarella* sp., *Beresella* sp. (Samples 109–101). 10 m.

The thickness of the Askynbashian is 27 m.

Plate 3



Sedimentary settings

The carbonates of the Kizil Formation were deposited during the Late Tulian-Askynbashian. The Viséan beds were deposited on a shallow shelf, in a high wave energy environment. In the Serpukhovian and Bogdanovskian time, sedimentation occurred in the mid-shelf region near bioherm buildups and back-reef lagoons, and was characterized by low energy mudstone accumulation (facial bands 4 and 5 as in J.L. Wilson [1975]). In the Early Serpukhovian (Sunturian), small bioherms formed by the algae *Calcifolium okense*, *Ungdarella uralica* and *Praedonezella cespeformis* and brachiopod banks became widespread. In the Khudolazian time, bacterial-algal buildups with numerous encrusting foraminifers and ostracodes and brachiopod banks were common. In the Late Serpukhovian, among algae, the species *Fasciella kizilia* become dominant, and boundstones produced as a result of metabolism of cyanobacteria and bacterial encrustation, with abundant radial-fibrous cement are formed. Similar algal-microbial buildups were formed in the Serpukhovian in the Peri-Caspian Region [Gibshman et al., 2007].

A similar environment was present at the beginning of the Bashkirian (Bogdanovskian). In the Late Bogdanovskian time, a low energy environment of a deepened lagoon prevailed, where micritic limestones with numerous thin-shelled ostracodes and brachiopods accumulated. In the Kammenogorian, these were replaced by bedded foraminiferal packstones. In the Akavassian, bioherms reached their maximum development, with large bioherm bodies, which were possibly reef buildups formed by algae and hydroid organisms. Based on I.A. Shchekotova's [1978] data, the bioherms in the Bashkirian portion of the Kizil Formation formed dispersed bodies and have a small size of 10–15 mm in diameter and 3–5 m in height, whereas the largest bioherm body is 300 m in diameter and 3–30 m in height. The buildups are composed of various boundstones (stromatolotic, algal, ostracodes, serpulid, or brachiopod). Of bioherm-forming algae, *Beresella*, *Donezella*, *Cuneiphycus*, *Coactilum*, *Ungdarella*, *Maslovoporidium*, and *Ortonella* being widespread. There are also boundstones with an organogenic texture formed by stromatolites and frame-bilding algae *Spongiostroma*-like structures, bacterial inclusions. Limestones of organic origin (boundstones) of all types contain many bacterial inclusions and abundant radial-fibrous cement. Grainstones are subdominant.

In the Akavassian, we observed a limestone lens containing numerous ammonoid shells enclosed in bioherm rocks and connected by radial-fibrous cement. The lens is also in contact with grainstones and boundstones. No other fossils, apart from ostracodes, are present. It is possible that algal bioherms were a suitable ammonoid habitat, while their shells were carried post-mortem by currents toward the base of the buildup and accumulated in local depressions, to subsequently become a substrate for a new buildup.

Biostratigraphy

The Serpukhovian is subdivided into the Sunturian, Khudolazian and Chernyshevkian horizons. The base of the Serpukhovian is defined by the FAD of the foraminifers *Janischewskina delicata*, *Eolasiodiscus donbassicus* and *Neoarchaediscus postrugosus* in Outcrop 4 (Sample 015). The Sunturian is characterized by foraminifers of the *Neoarchaediscus postrugosus* Zone.

The Khudolazian is characterized by foraminifers of the *Eostaffellina paraprotvae* Zone. This zone contains species continuing from the underlying beds and the newly appearing species *Turrispiroides multivolutus*, *Eostafellina* cf. *paraprotvae*, *Bradyina* ex gr. *cribrostomata*, *Pseudoendothyra* cf. *kremenskensis*, *Globivalvulina eogranulosa*. These species are characteristic of the Upper Serpukhovian of the Urals, Donets, and Moscow Basins. The base of the Khudolazian is drawn based on the renovation of the assemblage.

The Chernyshevkian corresponds to the *Monotaxinoides transitorius* Zone. In this section, the Chernyshevkian is represented by mainly brachiopod wackestones and algal boundstones with low diversity

Plate 3. Microfacies of the Bashkirian: **1.** Ostracode boundstone, Outcrop 2, Sample 33 (2). **2, 5.** Algal boundstone formed by red alga *Cuneiphycus* (arrows), surrounded by fibrous cement; algal-microbial wackestone with small foraminifers filled up spaces between algal-fibrous inclusions. Sample 121a (4). **3.** *Pseudostaffella compressa* (Rauser-Chernousova, 1938), ×60, specimen No 121/1133, Sample 21v (в, 11). **4.** Bioclastic-algal packstone-wackestone, partly recrystallized, filling spaces between skeletal remains that form a frame of the bioherm buildup. Sample 121A (5). **6.** Wackestones with *Tenebrozella* sp. and *Pseudostaffella* sp. Outcrop 2, Sample 37 (1). **7.** Algal boundstone formed by *Fasciella kizilia* R. Ivanova, ×25, Sample 7, Bogdanovkian

of foraminifers. The foraminifers *Pseudoglomospira* spp., *Endothyra* ex gr. *bowmani*, *Globivalvulina bulloides*, *Neoarchaediscus probatus*, *N. postrugosus* are relatively common. The base of the zone is drawn based on the considerable decrease in the number of Viséan species and the appearance of *Eostaffella postmosquensis* and *Monotaxinoides* ex gr. *transitorius*. The uppermost Serpukhovian is represented by bryozoan-crinoid packstone to grainstone lithofacies with abundant Archaediscidae and Howchiniidae (Outcrop 1). The upper part of the horizon contains the conodonts *Lochriea nodosa*, *L. ziegleri*, *Gnathodus bilineatus bilineatus*, and *Gn. bilineatus bollandensis*, indicative of the *Gn. bilineatus bollandensis* Zone. The Chernyshevkian corresponds to the Yuldybaevian of the Central-Uralian structural zone of the Southern Urals [Kulagina et al., 2002], Zapaltyubinian of the Donets Basin [Aizenverg et al., 1983], the Arnsbergian of the Franco-Belgian Basin [Laloux, 1987], and the uppermost Mississippian of Arrow Canyon, North America [Brenckle, 1997].

The Bashkirian in this succession includes the Syuranian, Akavassian and Askynbashian substages. The Syuranian is subdivided into the Bogdanovkian and Kamennogorian [Kulagina et al., 2001].

The Bogdanovkian includes the foraminiferal *Plectostaffella varvariensis*, *Pl. bogdanovkensis – Semistaffella minuscularia* and *S. variabilis* zones and the conodont *Declinognathodus noduliferus* Zone with the Early and Late Subzones.

The lower Bashkirian boundary is drawn based on the appearance of conodonts of the Early *Declinognathodus noduliferus* Subzone. The Bolshoi Kizil section is a stratotype of this Subzone (beds 3–8, thickness 57 m). This boundary coincides with changes of foraminiferal assemblages and the appearance of *Plectostaffella varvariensis*, *Plectomediocris* sp. and *Rectoendothyra* sp. The *Plectostaffella varvariensis* Zone corresponds to the Early *Declinognathodus noduliferus* Subzone and correlates with the lower Vosnesenskian of the Donets Basin, Ukraine [Aizenverg et al., 1983; Vachard, Maslo, 1996], Chokerian of the Franco-Belgian Basin [Laloux, 1987] and lowermost Pennsylvanian before the appearance of *Millerella marblensis* Thompson in Arrow Canyon, North America [Brenckle, 1997].

The *Plectostaffella bogdanovkensis – Semistaffella minuscularia* and *S. variabilis* zones represents by the ammodiscid-eostaffellid-archaediscacean biofacies, include representatives of *Palaeonubecularia*, *Pseudoammodiscus*, *Ammovertella*, *Eostaffella*, *Plectostaffella*, *Semistaffella*, *Monotaxinoides* and numerous Archaediscidae. Beds 9–10 (outcrop 1) of the *Pl. bogdanovkensis – S. minuscularia* Zone corresponds to Late *Declinognathodus noduliferus* Subzone. The latter was identified based on the disappearance of the genera *Gnathodus* and *Lochriea* and on the appearance of *Declinognathodus lateralis* (Hig. et Bouck.).

Semistaffella variabilis Zone is indicative of the Kamennogorian.

The Upper Bogdanovkian and Kamennogorian of the Southern Urals correspond to the Krasnopolyanian of the Russian Platform, the Upper Voznesenskian and Feninskian of the Donets Basin, Ukraine [Vachard, Maslo, 1996], the Alportian and Kinderscoutian of the Franco-Belgian Basin [Laloux, 1987], the Tagnana-III Member of the Tagnana Formation of the Bechar Basin, Algeria [Van Ginkel, 2002] and the beds with *Millerella marblensis* Thompson in Arrow Canyon, North America [Brenckle, 1997].

The Akavassian is characterized by foraminifers of the *Pseudostaffella antiqua* Zone, ammonoids of the *Bilinguites – Cancelloceras* Genozone (its upper part — Nm_2c_2 Zone) and assemblage of ostracodes with numerous *Javatius kizilensis* [Kotschekova, 1983].

Ammonoids are found in Outcrop 2 along with the foraminifers (Samples 121/4, 121a), *Pseudostaffella antiqua*, *Ps.* cf. *paracompressa* Safonova, *Ps. compressa*, *Varistaffella korobezikhi*, V. *varsanofievae*, and other characteristic of the *Pseudostaffella antiqua* Zone and the Akavassian. Sample 28 contains numerous ammonoids *Cancelloceras* sp. and *Bilinguites* sp., Samples 121/2–121/4 includes *Cancelloceras* sp. nov., *Cancelloceras elegans*, *Bilinguites superbilinguis*, *Stenoglaphyrites* sp. nov., *Schartymites barbotanus*, and *Schartymites* sp. nov. All these ammonoids indicate the *Bilinguites – Cancelloceras* Genozone (namely its upper part — Nm_2c_2 = *Bilinguites superbilinguis* Zone). Ammonoids of this age are scarcely known in the Southern Urals. Until now only a few outcrops containing ammonoids of this age were recorded in the Orenburg Region (near the villages of Novo-Samarskaya and Utyagulovo). However, ammonoids of this age are widespread in Central Asia (Fergana and Middle Tien-Shan), where the assemblages are dominated by *Cancelloceras* and *Bilinguites*, in China, North America and Western Europe. The presence of *B. superbilinguis* allows a direct correlation with the Upper Namurian G_1 Zone (Yeadonian) in Great Britain and Germany. The *Pseudostaffella antiqua* Zone corresponds to the Severokeltmensky of the Russian platform, the Manuilovsky Horizon of the Donets Basin [Vachard, Maslo, 1996].

Conclusions

Carbonates exposed along the Bolshoi Kizil River display an almost complete, apparently uninterrupted succession of Carboniferous substages from the Tulian to Askynbashian (equivalent to the Upper Viséan to Yeadonian in Western Europe). However, because of the several large intervals covered, it is impossible to observe some stratigraphic boundaries. However, this is one of the best sections in the Southern Urals showing the transition from the Lower to Upper Carboniferous (Mississippian-Pennsylvanian boundary). The base of the Pennsylvanian is fixed by the FAD of the conodont *Declinognathodus noduliferus*.

No contact between the Viséan and Serpukhovian stages has been observed, but the limestones yielding Serpukhovian foraminifers are exposed 6.7 m above the uppermost observed bed of the Viséan limestone. The Serpukhovian age is based on the foraminifers *Janischewskina delicata*, *Eolasiodiscus donbassicus* and *Neoarchaediscus postrugosus*. This section shows a simultaneous appearance of three foraminiferal species marking the base of the Serpukhovian. The Akavassian is represented by massive bioherms dated by foraminifers, ammonoids, and ostracodes. The boundary between the Akavassian and Askynbashian is drawn near the contact of massive and bedded limestones based on foraminifers of the *Staffellaeformes staffellaeformis – Pseudostaffella praegorskyi* Zone and conodonts of the *Idiognathodus sinuosus* Zone.

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