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Biostratigraphy and lithostratigraphy of the Mid-Carboniferous boundary beds in the Muradymovo section (South Urals, Russia)

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Abstract – The uninterrupted succession of the Mississippian–Pennsylvanian boundary beds in the Muradymovo section in the South Urals contains diverse fossils and has a high correlative potential. The Muradymovo section is located in the Zilair Megasynclinorium (ZM), which belongs to the West Uralian Subregion and displays carbonate-siliciclastic deep-water facies of the Bukharcha Formation, which is partly Serpukhovian (Kosogorian, Protvian and Yuldybaevian) and partly Bashkirian (Syuranian). In the southern ZM, the lower part of the formation contains argillaceous carbonates with beds of shale and siltstone, subordinate clastic limestones and limestone breccia, while the upper part is mostly limestone with cherty interbeds. In the north of the ZM, the formation mainly consists of limestone. The Muradymovo succession contains no identifiable gaps in the Mid-Carboniferous Boundary (MCB) portion and has a succession of foraminiferal, conodont, ammonoid and ostracod zones. The MCB in this section coincides with the base of the Bogdanovkian and is defined by the entry of *Declinognathodus noduliferus.* This level falls within the upper part of the foraminiferal *Monotaxinoides transitorius* Zone, is near the base of the ammonoid *Homoceras–Hudsonoceras* Genozone and can be correlated worldwide.

Keywords: Mid-Carboniferous boundary, biostratigraphy, ammonoids, microfossils, South Urals.

1. Introduction

The Muradymovo section is the best known of the several measured sections spanning the Mid-Carboniferous Boundary (MCB) in the basin of the Bolshoi Ik River, Zilair Megasynclinorium (ZM), western slope of the South Urals, Bashkortostan (Kulagina *et al.* 1992, 2000, 2002). Here we characterize the zonal biostratigraphy in this section, which is important both for regional stratigraphy and for global correlation because of the paucity of sections containing all three biostratigraphically significant groups (conodonts, foraminifers and ammonoids) in a single succession across the MCB. The presence of the above three fossil groups in the Muradymovo section allows the correlation between the first appearance datum (FAD) of *D. noduliferus*, the first appearance of the ammonoid family Homoceratidae and the first Bashkirian foraminifers.

The section was first discovered in 1984 in the course of regional geological research work, and has been visited many times by geologists since then. However, its true value only became apparent when the search for the MCB stratotype revealed a number of sections with similar conodont faunas in the critical interval. This deep-water section was first described bed-by-bed by Kulagina & Pazukhin (1986), who recognized the presence of the MCB beds and sampled the section for conodonts and foraminifers. They recognized the equivalents of the basal (Bogdanovkian) beds of the regional Syuranian Substage, representing the lowermost Bashkirian (MCB beds). Over several consecutive years they resampled the critical MCB portion of the section to increase the stratigraphic resolution and identify zonal boundaries. The base of the Bashkirian was originally placed at the base of the foraminiferal *Plectostaffella bogdanovkensis* Zone and the conodont *Declinognathodus noduliferus-D. lateralis* Zone in Unit 11 (Kulagina *et al.* 1992). After the acceptance of the MCB at the base of the *D. noduliferus* s.l. Zone, the base of the Bashkirian was placed at the base of Unit 9 (Kulagina *et al.* 2002).

The Muradymovo section was not proposed as a Russian candidate section for the Mid-Carboniferous Boundary Global Boundary Stratotype Section and Point (GSSP) for a number of reasons, mainly because of the suspected redeposition of conodonts at some levels and because of the presumed absence of ammonoid occurrences. After ammonoids were discovered in this section in 1997, it was re-excavated and re-sampled during several field seasons. This enabled its comparison with the previously known candidate sections for the MCB GSSP, including the chosen GSSP section in the Arrow Canyon.

Previous search for the MCB stratotype resulted in the choice of a section in Arrow Canyon, Nevada, USA where the Mississippian–Pennsylvanian boundary is marked by the first appearance of the conodont

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Declinognathodus noduliferus (Ellison & Graves, 1941) in Unit G (sample 61b) in the Bird Spring Formation (Lane *et al.* 1985, 1999; Lane & Manger, 1985; Brenckle *et al.* 1997; Richards *et al.* 2002). This boundary closely coincides in time with the first appearance of the ammonoid family Homoceratidae (Bisat, 1924, 1928; Ruzhencev & Bogoslovskaya, 1978; Manger & Saunders, 1982; Pareyn *et al.* 1984; Manger *et al.* 1985; Ramsbottom & Saunders, 1985; Kulagina *et al.* 1992; Nikolaeva, 1994, 1995*a*,*b*; Riley, 1998; Titus *et al.* 1997; Titus & Manger, 2001). Other sections containing the boundary level and proposed as possible candidates included successions in Britain (Riley, 1987; Riley *et al.* 1987), China (Li *et al.* 1987), the Donets Basin, Ukraine (Aizenverg *et al.* 1983; Skipp *et al.* 1989) and Uzbekistan (Nigmadganov & Nemirovskaya, 1992; Nikolaeva & Nigmadganov, 1992; Nikolaeva, 1994, 1995*a*,*b*). Each of the above sections, including the approved GSSP section, had some shortcomings, and the vote was restricted to only three sections (Arrow Canyon in Nevada, Stonehead Beck in England and Aksu in Uzbekistan). The GSSP section in Nevada consists of shallow-water carbonates, with many discontinuities immediately below and above the boundary level and has no ammonoids, although the MCB ammonoids have been found in the Scotty Wash Formation in the Test Site locality in Nevada at a considerable distance from Arrow Canyon (Titus *et al.* 1997; Titus & Manger, 2001). Because of the many disconformities and the absence of ammonoids in the GSSP section, the correlation between the FAD of *Declinognathodus noduliferus* and the first Homoceratidae has remained unclear (Kullmann & Nikolaeva, 2002). In some areas the first homoceratids (*Isohomoceras*) are recorded below the entry of *D. noduliferus* (Stonehead Beck and Aksu; Riley *et al.* 1987; Nigmadganov & Nemirovskaya, 1992; Nikolaeva & Nigmadganov, 1992; Nemirovskaya & Nigmadganov, 1993, 1994), in other places *D. noduliferus* precedes *Isohomoceras* (Test Site).

The Muradymovo section is one of the best MCB sections in the southern Ural Mountains and probably worldwide in terms of the continuity of the strata (lack of unconformities) and the number of biostratigraphically significant fossil groups present. This deep-water succession is very useful for testing the MCB definition (the first evolutionary appearance of the conodont *Declinognathodus noduliferus* s.l.) and evaluating the correlative potential of associated fossil groups.

2. Geological background

According to the modern tectonic interpretation of the geological structures in the Urals (Kondiajn *et al.* 2011), the section is located in the west of the Zilair Megasynclinorium (ZM), which belongs to the southern West Uralian Megazone. The predominant deposition in the Carboniferous in this area was the accumulation of limestones and siliceous-carbonate members. The deposition was influenced by the active growth of the Ural Mountains, which provided an influx of siliciclastics. The limestone turbidites and debris-flow deposits were formed on the slope of a carbonate ramp during phases of intense tectonism followed by increased hinterland erosion, supplying a large amount of siliciclastics (Gorozhanina *et al.* 2001). Siliciclastics and carbonates were deposited in a relatively stable tectonic environment. The sedimentary series of the Zilair Megasynclinorium is thought to be the product of syntectonic sedimentation on the subsiding shelf of Baltica with platform sediments involved in the process of folding in the frontal area of the collision orogen (Alvarez-Marron *et al.* 2000; Puchkov, 2002, 2009). The beds are folded in N–S-trending isoclinal folds, torn by large thrusts in places (Kamaletdinov, 1974). The deposits are subdivided in several formations of similar lithology (Khvorova, 1961; Keller, 1949) in the belt of the Palaeozoic slope formation in the basin of the Sakmara River, traceable throughout the ZM.

The MCB is fixed within the Bukharcha Formation established by Khvorova (1961) and exposed as a narrow N–S-directed belt along the west slope of the ZM. The Bukharcha formation conformably overlies the Verkhneitkulovo Subformation of the Itkulovo Formation, represented by an alternation of siltstone, mudstone, silicite and limestone beds. The Verkhneitkulovo Subformation is *c.* 350–450 m thick and largely unexposed in the area, having been examined mostly in quarries, road-cuts and in a few outcrops. The section of the Verkhneitkulovo Subformation in the road-cut 3 km north of the village of Kugarchi, near the village of Suleimanovo on the Bolshaya Suren River, contains all Upper Viséan foraminiferal zones (Sinitsyna *et al.* 1997). The Bukharcha Formation is overlain by the Unbetovo Formation (Pazukhin & Gorozhanina, 2003).

The Bukharcha formation is composed of limestones with interbeds of spongolite, argillite, argillaceous-chert shale and cherty nodules. The formation is mainly composed of limestone in the northern ZM (Muradymovo and Kurair), whereas in the southern ZM (Kugarchi and Bogdanovka) the basal part of the formation contains beds of argillaceous to cherty shale. The limestones are dominated by argillaceous, micritic and fine-grained varieties. The lower part of the formation contains lithoclast-bioclast-lime grainstone and limestone breccia (Kugarchi, Barangul Creek) and conglomeratic breccia (Azakla River) with semi-rounded fragments (1–3 cm) of fine-grained limestone. Limestones often show fluorite mineralization. The upper part of the formation contains a traceable bed of grainstone, becoming a lime rudstone in places. The Bukharcha Formation has a thickness of 250–320 m. The deposits of the upper portion of the Bukharcha Formation show the deepening trend indicated by spiculite and radiolarite mudstones and wackestones appearing and becoming more abundant in the Yuldybaevian. In other sections in the area (Bogdanovka and Bolshoi Uskalyk) we observed a transition from the deep shelf facies to more basinal depression facies as bioclastic and, in places, gradational-bedded wackestones of the Bukharcha Formation become replaced by laminated siliceous carbonates including spiculite, radiolarite and argillaceous basinal mudstone accumulated in deep-water conditions (Pazukhin & Gorozhanina, 2003).

The Bukharcha Formation contains diverse well-preserved fossils which include crinoids, foraminifers and conodonts and, in the upper part, ammonoids. Bryozoans and sponge spicules are also present. The best sections are in the basins of the Bolshoi Ik River (Muradymovo section) and Bolshaya Suren River (Bogdanovka and Kugarchi sections) (Krestovnikov, 1935; Librovitch, 1947; Einor *et al.* 1973; Ruzhencev & Bogoslovskaya, 1971, 1978; Nikolaeva, 1999; Kulagina *et al.* 2000, 2001, 2002). Stratigraphically, the Bukharcha Formation corresponds to the interval from the Serpukhovian Stage to the Syuranian Substage of the Bashkirian Stage. The Serpukhovian includes the Protvian and Yuldybaevian substages, while the Syuranian Substage includes the Bogdanovkian and Kamennogorian regional substages (Kulagina *et al.* 2001).

3. Geographical location and lithology

The Muradymovo section is located in the Kugarchi District of the Republic of Bashkortostan, 20 km to the SE of the town of Mrakovo, 3 km to the west of the village of Muradymovo (52° 35′ 10″ N, 56° 48′ 02″ E; Fig. 1). The outcrops are observed in the middle part of the steep slope of a hill on the left bank of the Abai–Elga Creek, left tributary of the Bolshoi Ik (Fig. 2). A large portion of the section is exposed in trenches. The beds are overturned, dipping at azimuth 80–120° at an angle of 45–80°. The sampled levels are marked on the section. The Bukharcha Formation in this section is composed mainly of dark-grey medium-bedded limestones, often siliceous, with interbeds, lenses and nodules of black chert. The limestones are dominated by micritic varieties with interbeds of bioclastic, less commonly lithoclastic, lime grainstone. The azimuth of the dip varies over the range 80–120° and the dip angle is 55–45°. The rock units in the section are marked by paint from 55 to 90, and are described in the following sections (Fig. 3).

3.a. Serpukhovian

3.a.1. Kosogorian

The total thickness of the Kosogorian is 34.5 m.

3.a.1.a. Unit 1 (55, 56)

The lowest unit described here is numbered 55 and exposed at the base of the slope of a small gully. It is composed of medium-bedded, in places cherty, mudstone (bed thickness 0.1–0.15 m). This mudstone is overlain by a bed of micrograined grainstone (56), microscopically weakly recrystallized with infrequent foraminifers *Archaesphaera* sp., *Earlandia minima* (Birina), *E. elegans* (Birina), *Pseudoglomospira* spp. and *Mediocris breviscula* Vissarionova. Conodonts from this unit (samples 23, 55, 56) are *Lochriea commutata* (Branson & Mehl), *L. cruciformis* (Clarke) and *L. mononodosa* (Rhodes, Austin & Druce). The thickness is 1 m. This interval is overlain by a covered interval 5 m thick. The overlying beds are measured up the slope along azimuth 270 at a slope angle of 1–20º.

3.a.1.b. Unit 2 (57, 58)

The covered interval terminating Unit 1 is overlain by a member of skeletal crinoid-foraminiferal packstone, with lenses of chert, with a bed of peloid mudstone in the middle that contains only single-chambered spherical foraminifers. The thickness is 4 m. Samples 24, 57, 57a, 58, 58a contain foraminifers and conodonts, the distribution of which is shown in Figure 3. This unit is terminated by a covered interval of thickness 2.5 m.

3.a.1.c. Unit 3 (59)

The covered interval terminating Unit 2 is overlain by a unit composed of fine bioclastic grainstone/packstone and packstone with frequent calcisphaeras, crinoids, bryozoans, algae *Koninckopora*, foraminifers, conodonts *Gnathodus*, *Lochriea*, *Neoprioniodus* and others (samples 59, 59a; see Fig. 3) and also redeposited Famennian taxa *Palmatolepis perlobata schindewolfi* Müller (sample 59). The thickness is 2.5 m. Further on along azimuth 270 there is a covered interval of thickness 2.5 m.

3.a.1.d. Unit 4 (60–64)

The covered interval terminating Unit 3 is overlain by a unit composed of medium- to thin-bedded micritic, in the lower part predominantly fine-grained wackestones/packstone, with peloids and foraminifers *Archaesphaera* and *Eotuberitina* (samples 59b, 25), occasionally recrystallized (sample 61). Limestones contain a small admixture of argillaceous material. In the upper part of the unit, the limestone is argillaceous and microlaminated in places. The rock is weakly dolomitized in places. The limestone contains rare foraminifers and conodonts (Fig. 3). The thickness of the unit is 17 m. The marked bed 60 is 2 m above the base of the interval. Sample 61 was collected 9.5 m away from the marked level of sample 60 along azimuth 240. The bed is traced along-strike up the slope for 10 m, from where the description resumes along azimuth 260.

3.a.2. Protvian

The total thickness of the Protvian is 49.5 m.

3.a.2.a. Unit 5 (65–67)

This unit directly overlies dark-grey mudstone with cherty nodules and is composed of a lighter-coloured bioclastic lime packstone to grainstone consisting of foraminifers, skeletal fragments of crinoids, bryozoans, algae and unidentifiable fine bioclastic grains, frequent conodonts and foraminifers from underlying beds. *Monotaxinoides subplanus* Brazhnikova & Jarzeva and *Gnathodus bollandensis* Higgins & Bouckaert appear

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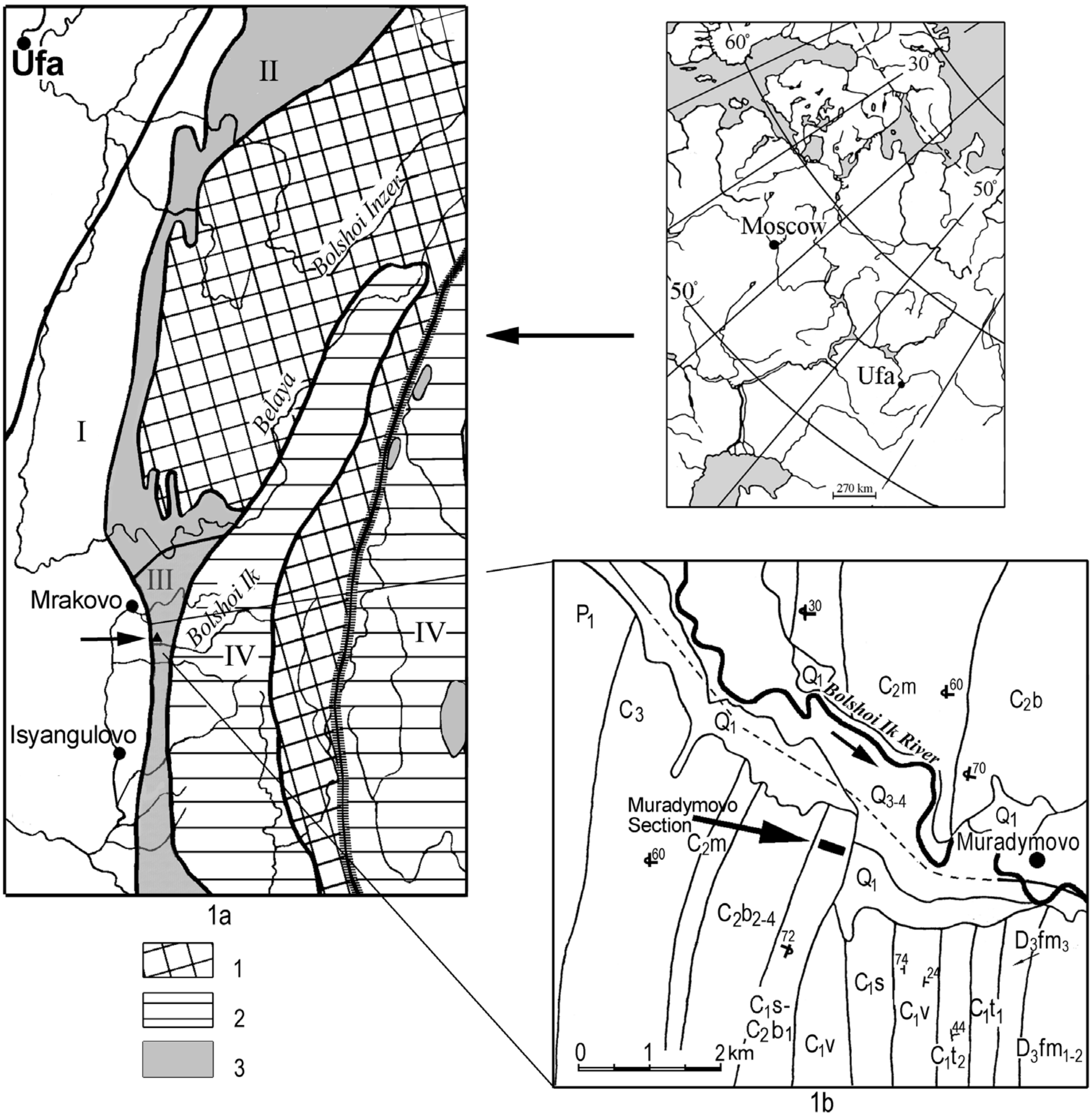

Figure 1. (a) Position of the Muradymovo section. 1 – Pre-Palaeozoic deposits and metamorphic rocks, 2 – Pre-Carboniferous Palaeozoic deposits, 3 – Carboniferous deposits. I–IV – Structural zones of the Urals: I – Cisuralian Foredeep, II – West Uralian, III – Central Uralian, IV – Magnitogorsk. (b) Geological map of the Muradymovo section (modified after Kamaletdinov, 1974). Upper Devonian: D3fm1–2 – Famennian (Zilair Formation): siltstone, sandstone, cherts in the lower part; D3fm$_3$ – Famennian, Kushelgian and Lytvinian substages (Yamashla Formation): limestone, shale. Lower Carboniferous: C1t1 – Lower Tournaisian (Mazitovo Formation): limestone, shale, siltstone, sandstone; C1t2 –Upper Tournaisian (Kuruil Formation): limestone, in places cherty, shale, siltstone; C1v – Viséan (Itkulovo Formation): limestone, shale, siltstone; C1s – Serpukhovian, C2b1– Bashkirian, C1s–C2b1– Serpukhovian and Bashkirian (Syuranian Substage), Bukharcha Formation, limestone; Upper Carboniferous: C2b2–4 – Bashkirian (Akavassian, Askynbashian and Arkhangelskian substages): limestone, lime breccia (Unbetovo Formation) and shale, siltstone, sandstone (lower part of the Kugarchi Formation); C2m – Moscovian (upper part of the Kugarchi and Zolotogorsk formations): shale, siltstone, sandstone, limestone; C3 – Kasimovian and Gzhelian (Abzanovo and Zianchurino Regional substages): sandstone, shale, marl and limestone, clastic in the upper part; Q – Quaternary. Dashed lines indicate faults covered by younger deposits.

here for the first time. The basal part of the bed contains infrequent redeposited Upper Devonian conodonts and foraminifers. The thickness of the bed (sample 65) is 0.5 m. This level is overlain by dark-grey mudstone 5 m thick. A small ridge of dark-grey silicified mudstone can be easily traced upwards in the section. Upwards and along-strike, this mudstone becomes bioclastic grainstone (samples 66 and 66a). This bed is overlain by a bed of dark-grey fine-grained limestone (sample 67). The thickness of Unit 5 is 6.5 m, and it is overlain by a covered interval of 3.5 m.

3.a.2.b. Unit 6 (68, 69, 70)

The base of the unit is composed of a thin interrupted bed of thinly laminated mudstone, overlain by a bed of bioclastic wackestone (sample 68) with *Calcisphaera* and rare fragments of bryozoans and foraminifers. The bed is of thickness 0.5 m and can be easily traced as

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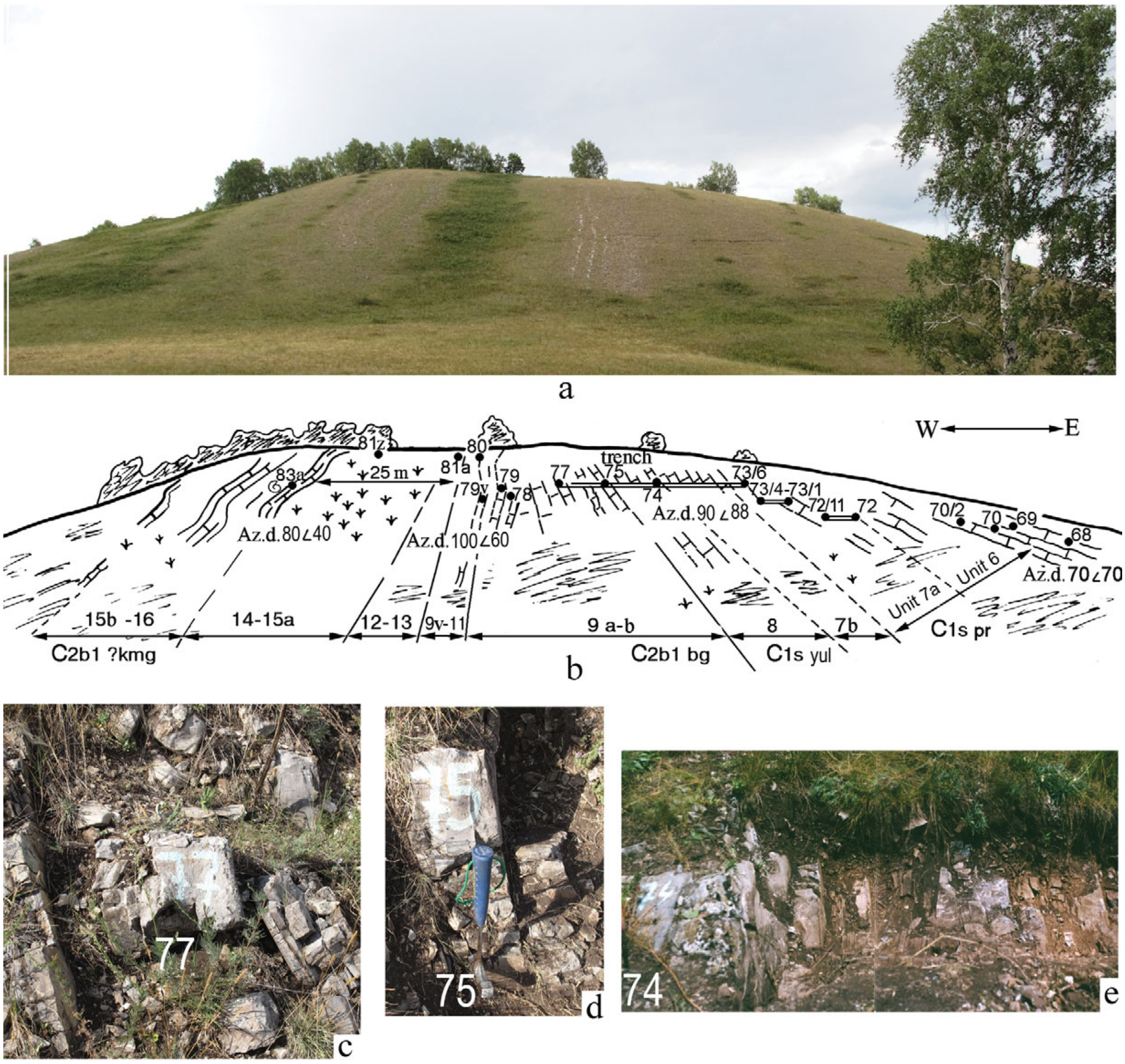

Figure 2. (Colour online) An outcrop of the Serpukhovian and Bashkirian deposits 3 km west of the village of Muradymovo. Drawing (b) from the photograph (a) is modified from Kulagina *et al.* (1992). Marker beds in the trench: (c) sample 77; (d) sample 75; and (e) sample 74. C2b1 ?kmg – ?Kamennogorian Substage of the Bashkirian Stage; C2b1bg – Bogdanovkian Substage of the Bashkirian Stage; C1s jul – Serpukhovian Stage, Yuldybaevian Substage; C1s pr – Serpukhovian Stage, Protvian Substage.

a small ridge up the slope. These beds are overlain by medium-bedded bioclastic packstone (samples 69, 70, 70/1, 70/2) with foraminifers, fragments of algae, crinoids and bryozoans and single oolites. The conodont assemblage contains a redeposited specimen of *Palmatolepis* cf. *glabra lepta* Ziegler & Huddle. Marked bed 70 contains rare imprints of small brachiopods. The entire unit contains lenses and laminae of chert, and is of thickness 5.5 m.

3.a.2.c. Unit 6a (70/2–72)

Unit 6a (thickness 11.9 m) is predominantly composed of medium- and thin-bedded mudstones and wackestones with radiolarians and less-commonly packstones. The assemblage contains ostracods, fish teeth and an impoverished conodont assemblage (see Fig. 3) that includes a redeposited specimen of *Siphonodella* sp. The beds are exposed in discontinuous outcrops which were sampled (samples 70/2, 71, 72). The bed with sample 72 at the top of the unit is 0.2 m thick and contains lenses of chert.

3.a.2.d. Unit 7a (72/1–73/6)

Unit 7a (thickness 8 m) was exposed in trenches 1–3. Trench 1 was described along azimuth 260. A thin bed (0.13 m) of bioclastic and lithoclastic grey loosely cemented limestone with crinoids lies on bed 72. A thin-section of this limestone (sample 72/1) showed clastic limestone containing a rounded fragment of mudstone from the underlying unit. These limestones are likely to represent a debris flow. This bed (thickness 1.7 m) is overlain by a unit of thin- to medium-bedded (predominating thickness 0.10–0.15 m) loosely cemented, crinoid wackestone and dense, interbedded with thin-bedded compact silicified mudstone, wackestones with foraminifers, crinoid remains, rare imprints of small brachiopods and beds of lithoclastic limestones (samples 72/2, 72/4, 72/5, 72/7). The overlying member

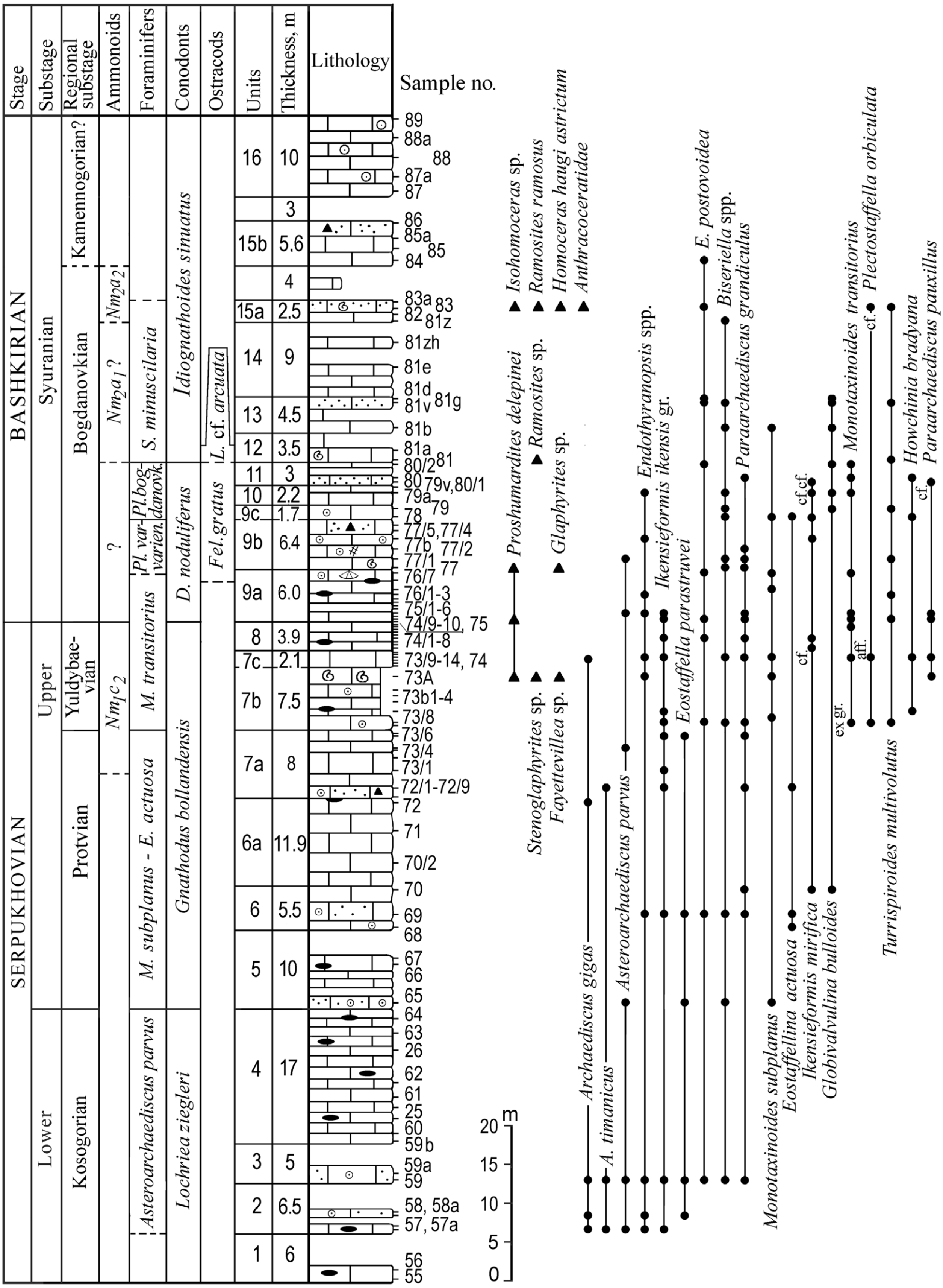

Figure 3. The distribution of fossils (ammonoids by S.V. Nikolaeva, selected foraminifers by E.I. Kulagina, conodonts by V.N. Pazukhin and ostracods by N.N. Kochetova) in the MCB beds of the Muradymovo section. The stratigraphic log was composed by E.I. Kulagina and V.N. Pazukhin. Limestone: 1 – mudstone, packstone; 2 – grainstone; 3 – limestone with lenses of chert. Fossils: 4 – crinoids; 5 – ammonoids; 6 – brachiopods; 7 – bryozoans.

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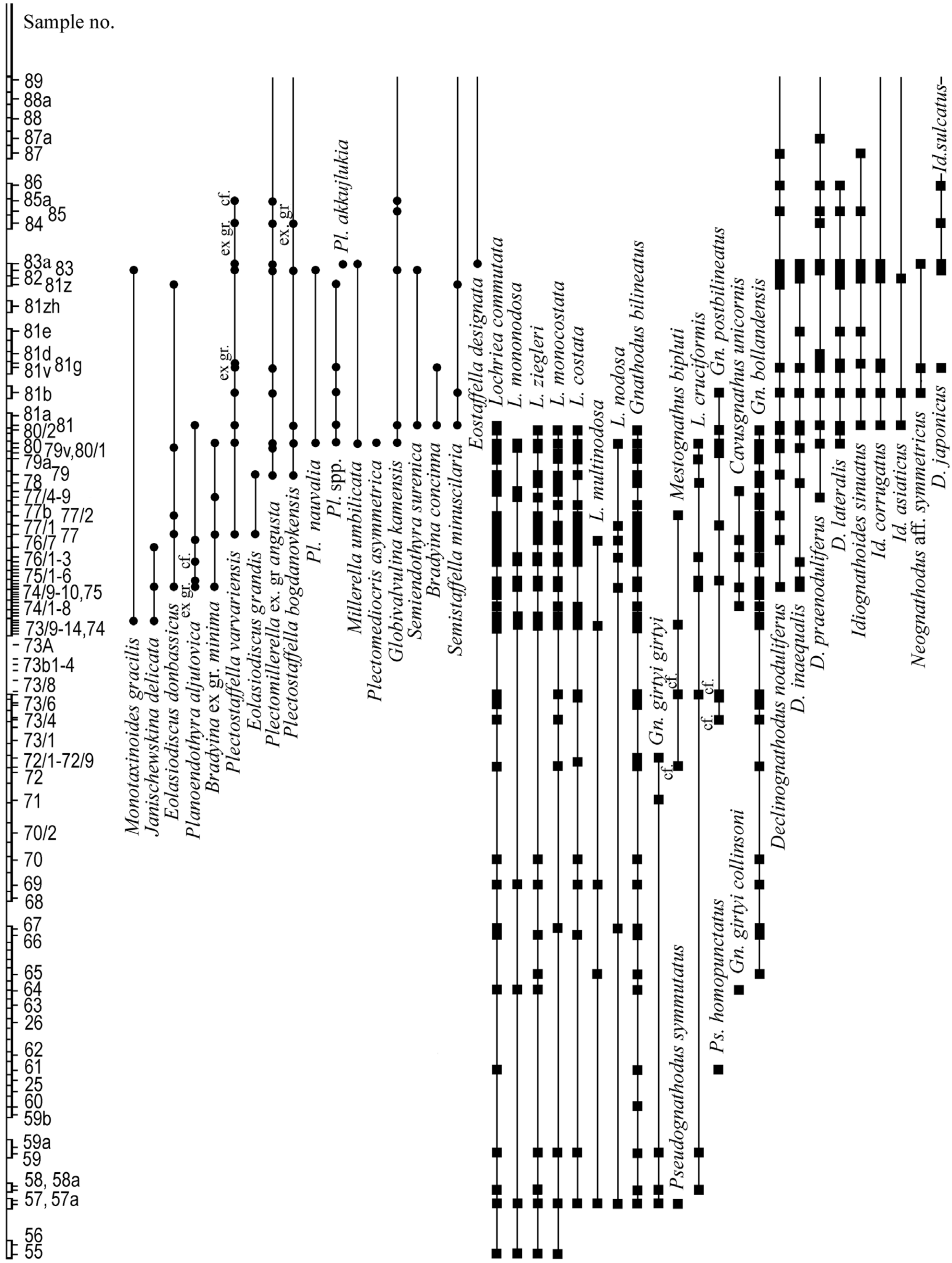

Figure 3. Continued.

consists of dark-grey thinly bedded, compact laminated mudstone with subdominant laminae of chert. In trench 1, from where samples 72/1–72/11 were collected, the visible thickness is 3 m. Trench 2 contains mudstone and packstone with infrequent foraminifers and spongolite in the upper part (samples 73/1–73/4, thickness 3.5 m). Further up the slope, the succession continues in trench 3 exposing bioclastic wackestone/packstone with sponge spicules and foraminifers (samples 73/5–73/6).

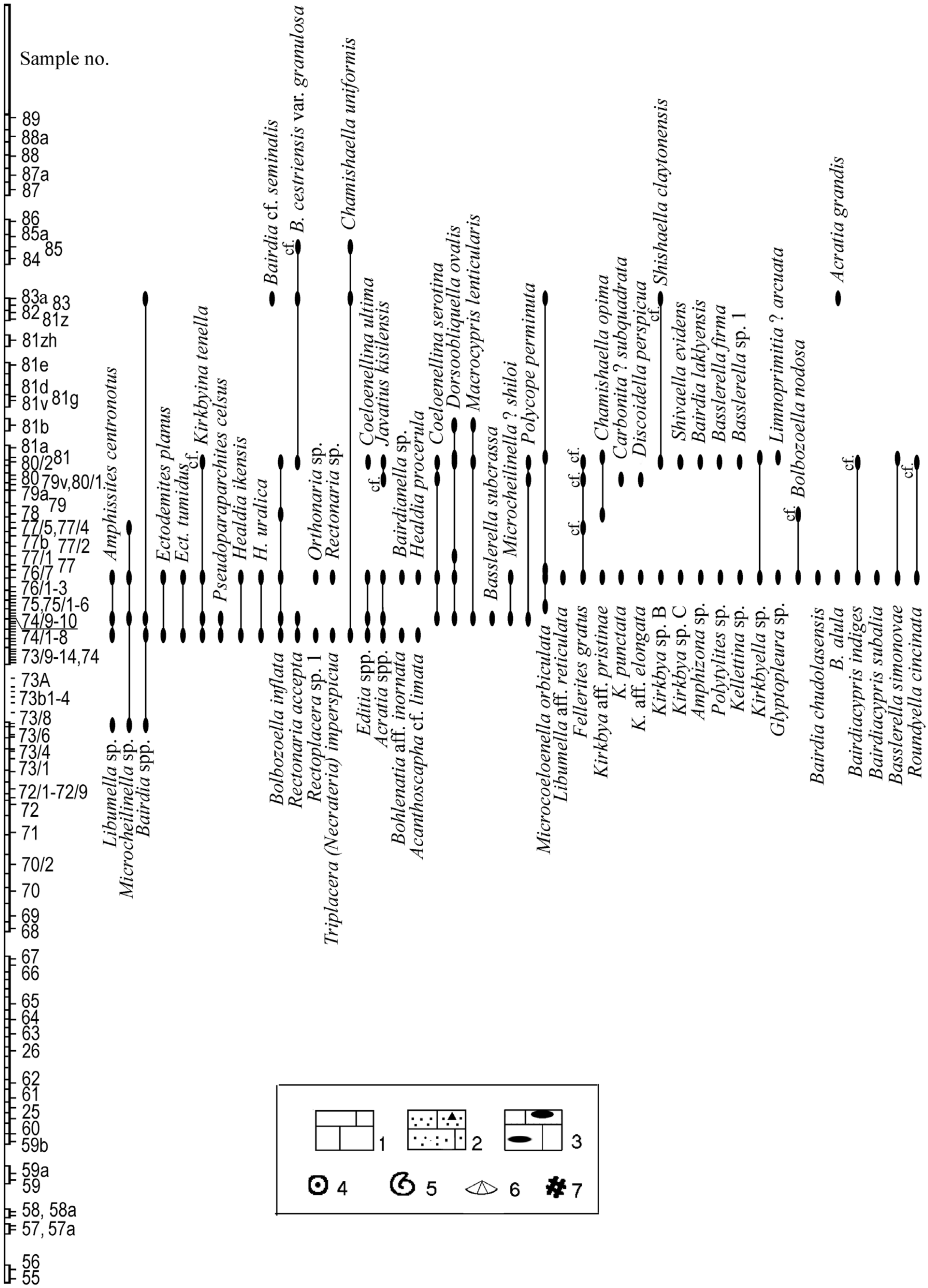

Figure 3. Continued.

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3.a.3. Yuldybaevian

The total thickness of the Yuldybaevian is 13.5 m.

3.a.3.a. Unit 7b (73/7–73A)

The thinly bedded limestone of Unit 7a is overlain by fine-grained foraminiferal packstone, in places silicified, 0.55 m thick (sample 73/7). The packstone is overlain by a bed of thinly laminated limestone (0.1 m), underlying a layer (0.1 m) of bioclastic crinoidal loosely cemented limestone. This interval is overlain by thickly and medium-bedded wackestone and packstone with cherty lenses and cherty limestone, of thickness 1.8 m. This limestone is immediately overlain by a bed of fine-grained, bioclastic, crinoidal, weathered limestone, with rare solitary corals, 0.5 m thick. The overlying bed of thick-bedded fine-grained limestone 4.25 m thick contains bioclastic wackestones and packstones with lenses of cherty limestone, in places strongly weathered, loosely cemented. These are overlain by argillaceous micritic limestone, with a lens of ammonoid shells (sample 73A), 0.45 m thick. The thickness of Unit 7b is 7.5 m.

3.a.3.b. Unit 7c (73/9–73/14, 74)

This unit (thickness 2.1 m) continues the section in trench 3 and consists of thin-bedded micritic argillaceous limestone (beds are 0.10–0.15 m thick) and includes the beds of fine-grained packstone-grainstone with sparite cement, with terrigenous admixture (up to 10 %) with conodonts, foraminifers, ostracods and fragments of algae, bryozoans and brachiopods. Sample 73/14 contains a rich assemblage of conodonts with numerous *Gnathodus bilineatus* (Roundy) (42 specimens), *Gn. bollandensis* (49 specimens) and others (see Fig. 3), and also occasional redeposited Famennian and Tournaisian species *Palmatolepis marginifera marginifera* Helms, *Bispathodus aculeatus aculeatus* (Branson & Mehl) and *Scaliognathus anchoralis* Branson & Mehl (samples 73/9–73/14 and 74).

3.a.3.c. Unit 8 (74/1–8)

The base of the unit immediately above Unit 7c is composed of a bed of packstone 0.4 m thick. The unit is composed of medium- and thinly bedded limestone, micritic, argillaceous, spiculite, microlaminated, in places finely detrital, peloidal, with radiolarians, foraminiferans, bryozoans, algae and conodonts. The thickness is 3.9 m. The conodont assemblage from sample 74/1 contained 50 specimens of *Gnathodus bollandensis* and infrequent redeposited Famennian conodonts *Palmatolepis* cf. *marginifera* Helms and *Polygnathus* spp. (samples 74/1–74/8).

3.b. Bashkirian

The Syuranian, a substage of the Bashkirian, includes the Bogdanovkian and Kamennogorian regional substages. The total thickness of the Syuranian is *c.* 60–63 m.

3.b.1. Bogdanovkian

The total thickness of the Bogdanovkian is *c.* 40 m.

3.b.1.a. Unit 9a (74/9–10, 75–76)

Unit 9a is a continuation of Unit 8 and consists of medium- and thinly-bedded limestone (beds are 0.1–0.2 m thick). The unit is composed of wackestone and packstone, foraminiferal fine-bioclastic, slightly recrystallized, sometimes with carbonate debris, pellets, in places peloidal micritic, spiculite and microlaminated. The foraminiferal assemblage is almost the same as in the underlying beds; however, this unit shows first appearance of the conodonts *Declinognathodus inaequalis* (Higgins) at the base (sample 74/9). There are three specimens along with numerous *Gnathodus bollandensis* (104 specimens). In the next sample (sample 74/10) from the top of the overlying bed of similar lithology (0.55 m thick) we found three specimens of *Declinognathodus inaequalis* and a single *Declinognathodus noduliferus*. The rocks are complicated by syndepositional slump folds; the thickness (*c.* 6 m) is therefore difficult to estimate. Marked bed 75 is 0.2 m thick and is located 0.68 m above the base of the unit. Samples found in this unit are 74/9, 74/10, 75, 75/1–75/4, 76/1–76/7; sample 76/6 contained one redeposited specimen of *Pseudopolygnathus triangulus* (Voges).

3.b.1.b. Unit 9b (77)

Unit 9b begins from marked bed 77. The basal bed of limestone, 0.35 m thick, is overlain by a unit of thick- and medium-bedded limestone. These are bioclastic mudstone and wackestone with layers of biolithoclastic packstone grading to limestone breccia, usually slightly recrystallized, with calcite veins. Biolithoclastic packstones consist of bioclastic and micritic grains of various sizes (0.5–5 mm) and variously rounded, with micritic cement (sample 77b). Samples 77/1, 77 b, 77/2, 77/3 contained several redeposited conodont species ranging in age from Famennian to the Viséan, including *Polygnathus inornatus* Branson & Mehl, *Palmatolepis* sp., *Hindeodella* sp., *Siphonodella* cf. *obsoleta* Hass, *Scaliognathus anchoralis* Branson & Mehl. Lime breccia (sample 77/4) is composed of bioclasts and lithoclasts (micritic, algal, etc.) and contained a redeposited specimen of the early Viséan foraminifer *Eoendothyranopsis* sp. Sample 77/v is represented by micritic finely grained limestone with infrequent quartz grains and clay minerals, with scarce small-sized bioclasts. The bed contains foraminifers, fragments of crinoids, bryozoans and brachiopods and ammonoids. Sample 77 contains *Plectostaffella varvariensis* (Brazhnikova & Potievskaja) and numerous *Gnathodus bilineatus* and *Gn. bollandensis* (more than 50 specimens). The beds are complicated by syndepositional slump folds. Samples 77/1–77/6, 77a, 77b and 77v were collected from this unit, the thickness of which is estimated to be *c.* 6 m.

3.b.1.c. Unit 9c (78, 79)

The basal layers of Unit 9c (thickness 1.7 m) are composed of bioclastic packstone 0.8 m thick. The top

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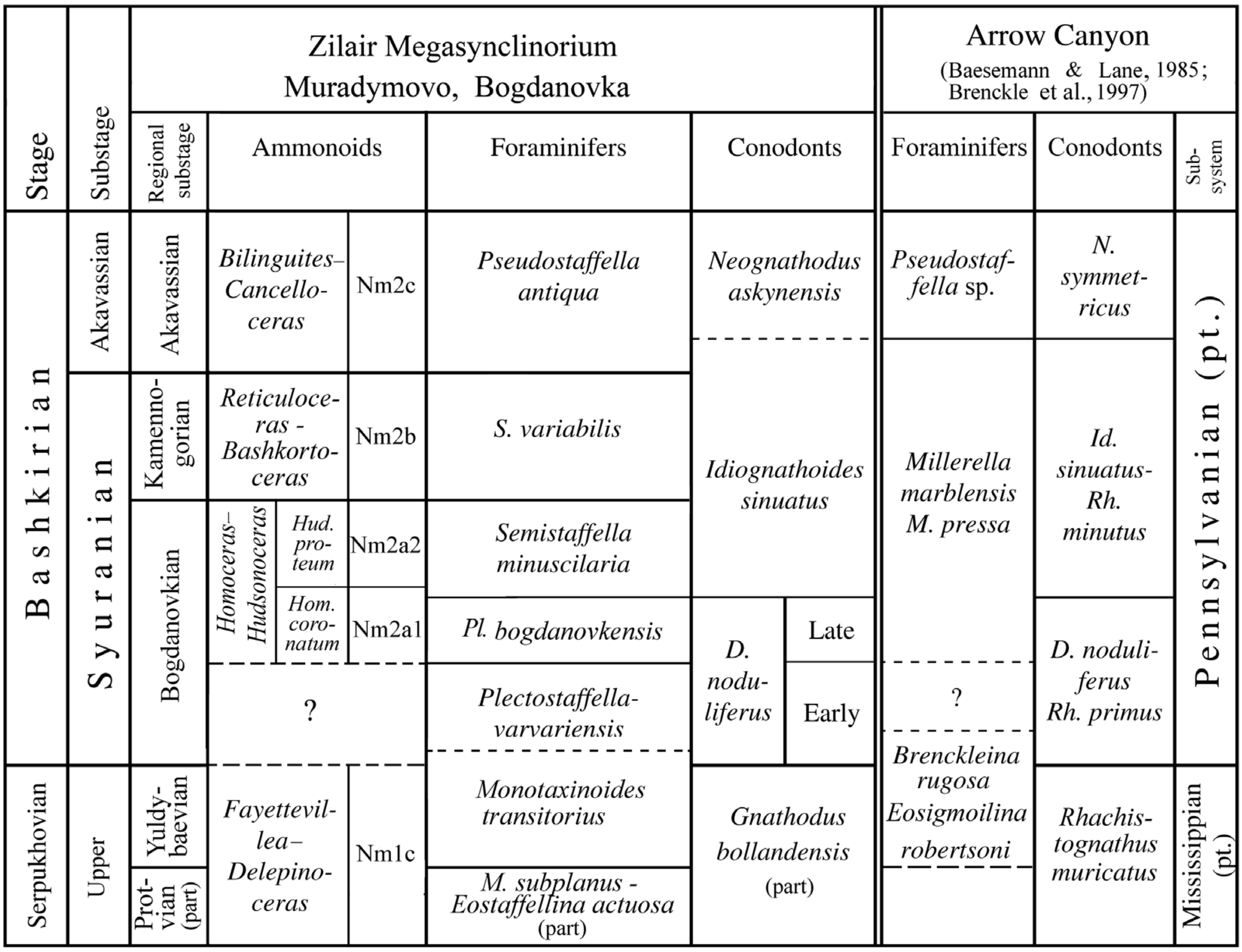

Figure 4. Correlation of the Mid-Carboniferous Boundary beds of the South Urals and the GSSP at Arrow Canyon, Nevada.

of the unit is marked by a layer of limestone 0.7 m thick. The unit consists of bioclastic wackestones and packstone, in places cherty, with foraminifers, crinoids, bryozoans, conodonts and *Calcifolium* algae. This unit shows the first appearance of the zonal species *Plectostaffella bogdanovkensis* Reitlinger (sample 78). The conodont assemblage includes a single specimen of *Declinognathodus noduliferus*, numerous *Gnathodus bollandensis* and *Gn. bilineatus* and redeposited specimens of *Palmatolepis glabra pectinata* Ziegler, *Neopolygnathus communis* (Branson & Mehl) and *Pseudopolygnathus marburgensis* Bischoff & Ziegler (samples 78 and 79).

3.b.1.d. Unit 10 (79a)

Unit 10 includes a covered interval above marked bed 79 (1.5 m thick) and marked bed 79a (0.7 m thick), composed of large-grain bio-lithoclastic grainstone with foraminifers, crinoids, conodonts and the algal species *Fasciella kizilia* Ivanova. The basal portion of the bed is silicified. The unit is 2.2 m thick and is overlain by two beds of limestone of Unit 11, each 0.5 m thick. Upwards in the section, the succession is interrupted by a gully. Bed 79a can be traced towards the top of the hill.

3.b.1.e. Unit 11 (80)

This unit (thickness 3.0 m) is described in the upper portion of the slope. It is exposed 2 m above the covered interval overlying the marked bed 79a and is composed of medium-bedded limestone, mudstone and foraminiferal fine-bioclastic packstone, with terrigenous admixture of infrequent quartz grains, plagioclase, glauconite and fragments of hematized microlaminated rocks (Gorozhanina, pers. comm., 2012). The bed contains abundant conodonts, typical of the Bashkirian and also redeposited late Famennian, Tournaisian, Viséan (rare) and Serpukhovian (frequent) conodonts. Tournaisian conodonts include *Pseudopolygnathus triangulus* (Voges), *Siphonodella duplicata* Branson & Mehl, *Polygnathus inornatus* Branson & Mehl, *Polygnathus symmetricus* Branson, *Siphonodella isosticha* (Cooper) and *S.* aff. *duplicata* Branson & Mehl (samples 79v, 80, 80/1, 80/2).

3.b.1.f. Unit 12 (81a)

The covered interval, which is *c.* 2 m thick, is overlain by a medium-bedded, foraminiferal grainstone with

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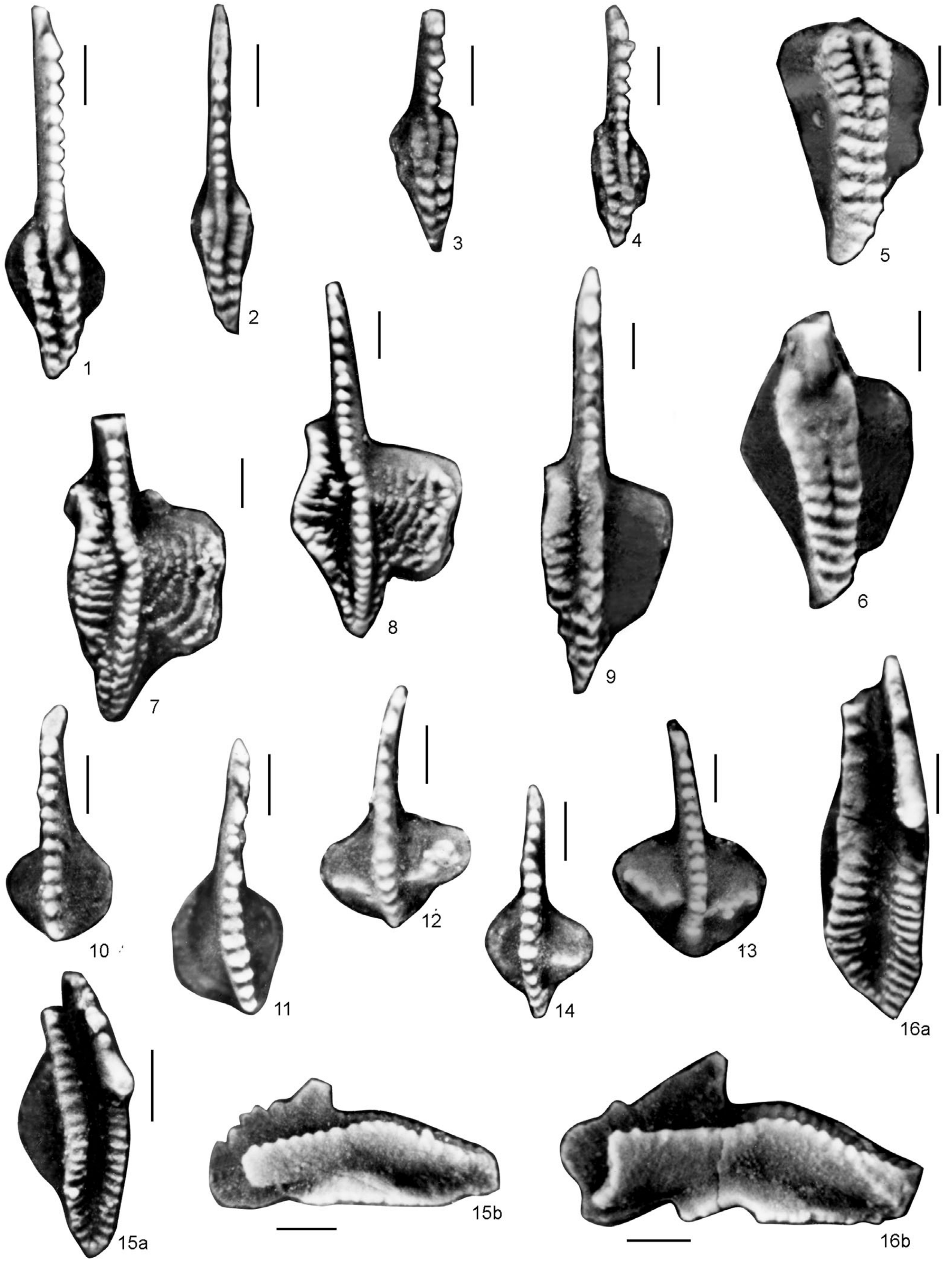

Figure 5. Conodonts from the Muradymovo section. The scale bars are 0.2 mm. **1–4**, *Declinognathodus noduliferus* (Ellison & Graves, 1941). **1**, specimen no. 104/518, Unit 9a, sample no. 74/10. **2**, Specimen no. 104/517, Unit 9a, sample no. 75/1. **3**, Specimen no. 104/523, Unit 9a, sample no. 74/9. **4**. Specimen no. 104/519, Unit 9a, sample no. 74/9. **5**, **6**, *Declinognathodus praenoduliferus* Nigmadganov & Nemirovskaya (1992). **5**, Specimen no. 104/530, Unit 9b, sample no. 77/6. **6**, Specimen no. 104/532, Unit 9b, sample no. 77/6. **7**, **8**, *Gnathodus bilineatus* (Roundy, 1926). **7**, Specimen no. 104/383, Unit 9a, sample no. 75. **8**, Specimen no. 104/493, Unit 9b, sample no. 77. **9**, *Gnathodus bollandensis* Higgins & Bouckaert (1968), specimen no. 104/493, Unit 9a, sample no. 76/3. **10**, **11**, *Lochriea commutata* (Branson & Mehl, 1941). **10**, Specimen no. 104/627, Unit 9c, sample no. 79. **11**, Specimen no. 104/501, Unit 9a, sample no. 74/9. **12**, *Lochriea ziegleri* Nemirovskaya, Perret & Meischner (1994) specimen no. 104/628, Unit 9c, sample no. 79. **13**,

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rare fine-bioclastic materials, small quartz grains and in places micritic. The thickness of the unit is 3.5 m and yielded samples 81 and 81a. It is overlain by 2 m of covered interval.

3.b.1.g. Unit13 (81b, v, g)
The covered interval is overlain by interrupted exposures of grey, micritic and fine-grained, fine-bioclastic limestone with foraminifers, with a layer of foraminiferal grainstone in the upper part (sample 81g) that consists of rounded grains of limestone, bioclasts, oolites and terrigenous grains of quartz and other minerals (up to 15 %). The thickness of this unit is 4.5 m.

3.b.1.h. Unit 14 (81d–81z)
The grainstone bed is followed by outcrops of isolated beds of lime mudstone and lime wackestones, with rare bioclastic grains and foraminifers, from which we collected samples 81g, 81e and 81zh. The isolated outcrops are exposed in a shallow gully. The thickness of the unit is 9 m.

3.b.1.i. Unit 15a (82, 83)
Outcrops of lime mudstone, with rare bioclastic grains, with lime packstone and grainstone in the upper part with microsparite cement, oolites, intraclasts and large bioclasts, grains of plagioclase, are observed on the right bank of a gully. Foraminifers, ammonoids and conodonts are present in samples 82, 83 and 83a. The thickness of this unit is 2.5 m.

3.b.2. Kamennogorian

After the covered interval (4 m) the section continues with units 15b–16 (18.6 m), tentatively assigned to the Kamennogorian.

3.b.2.a. Unit 15b (84–86)
The unit comprises limestone dark-grey medium-bedded fine-grained bioclastic, in places micritic with fine-bioclastic grains. In the upper part, litho-bioclastic packstone-grainstone with foraminifers, algae and other organic remains can be found. The thickness of this unit is 5.6 m, which yielded samples 84–86. Unit 15 is overlain by a covered interval 3 m thick.

3.b.2.b. Unit 16 (87–89)
This unit is dominated by medium-bedded limestone, mudstone and peloid packstone, argillaceous in the lower part, with rare fine-bioclastic grains. Samples 87, 87a, 88, 88a and 89 were collected from this interval and total unit thickness is 10 m.

The slope above the covered interval (*c.* 18–24 m thick) shows exposures of lime grainstone, becoming carbonate breccia with micritic, partly dolomitized cement in places, contains oolites, numerous foraminifers, crinoids and algae (0.2 m). Upwards in the section, these beds are replaced by micritic and lithoclastic bioclastic packstone with foraminifers, bryozoans and conodonts. The total thickness of the outcrop is 7 m. The foraminifers suggest the upper part of the *Pseudostaffella antiqua* and *Pseudostaffella praegorski* zones and conodonts of the *Idiognathodus sinuosus* Zone. The lithology and fossils correspond to those from the overlying Unbetovo Formation. There is no visible contact between the Bukharcha and Unbetovo formations.

4. Zonal subdivision

In the Muradymovo section, the MCB beds contain four major fossil groups. According to the international standard, the base of the Bashkirian is defined by the appearance of the conodont *Declinognathodus noduliferus* in Unit 9a. This level shows changes in other fossil groups (Fig. 4).

4.a. Conodonts

In the Muradymovo section, the Serpukhovian and Bashkirian zonations were first established by Pazukhin in Kulagina *et al.* (1992) and Pazukhin (1995). Since then the zonation has been changed considerably to incorporate changes in the knowledge of the conodont distribution and taxonomy. Conodonts are found here at almost all levels examined in the Serpukhovian and lower and middle Bashkirian (except in the Akavassian). More than 90 samples were processed (the average weight of a sample was 2 kg); 87 samples contained over 4500 conodont elements. The conodont collection is mainly represented by platform elements of the genera *Gnathodus*, *Lochriea*, *Declinognathodus* and *Idiognathoides*. Some samples contained redeposited conodonts, including some Famennian and Tournaisian and more commonly Serpukhovian (in the Syuranian). The section contains an uninterrupted succession of zones from *Lochriea ziegleri* to *Idiognathodus sinuatus* (Fig. 5).

4.a.1. Lochriea ziegleri *Zone (Units 1–4; Serpukhovian)*

The base of the *Lochriea ziegleri* Zone is defined based on the FAD of the index species. The zone shows the first appearance of *Lochriea cruciformis* (Clarke) and *Lochriea multinodosa* (Wirth). The assemblage also contains *Gnathodus bilineatus* (Roundy), *Gn. girtyi girtyi* Hass, *Gn. girtyi collinsoni* Rhodes, Austin & Druce (in the upper horizons), *Lochriea commutata* (Branson & Mehl), *L. costata* (Pazukhin & Nemirovskaya), *L. monocostata* (Pazukhin &

Lochriea costata (Pazukhin & Nemirovskaya in Kulagina *et al.* 1992), specimen no. 104/493, Unit 9b, sample no. 7. **14**, *Lochriea monocostata* (Pazukhin & Nemirovskaya in Kulagina *et al.* 1992), specimen no. 104/505, Unit 9c, sample no. 79. **15**, **16**, *Cavusgnathus unicornis* Youngquist & Miller (1949). **15**, Specimen no. 104/553: **15a**, Upper view and **15b**, Lateral view, Unit 9a, sample no. 74/10. **16**, Specimen no. 104/554: **16a**, upper view and **16b**, lateral view, Unit 9b, sample no. 77/6.

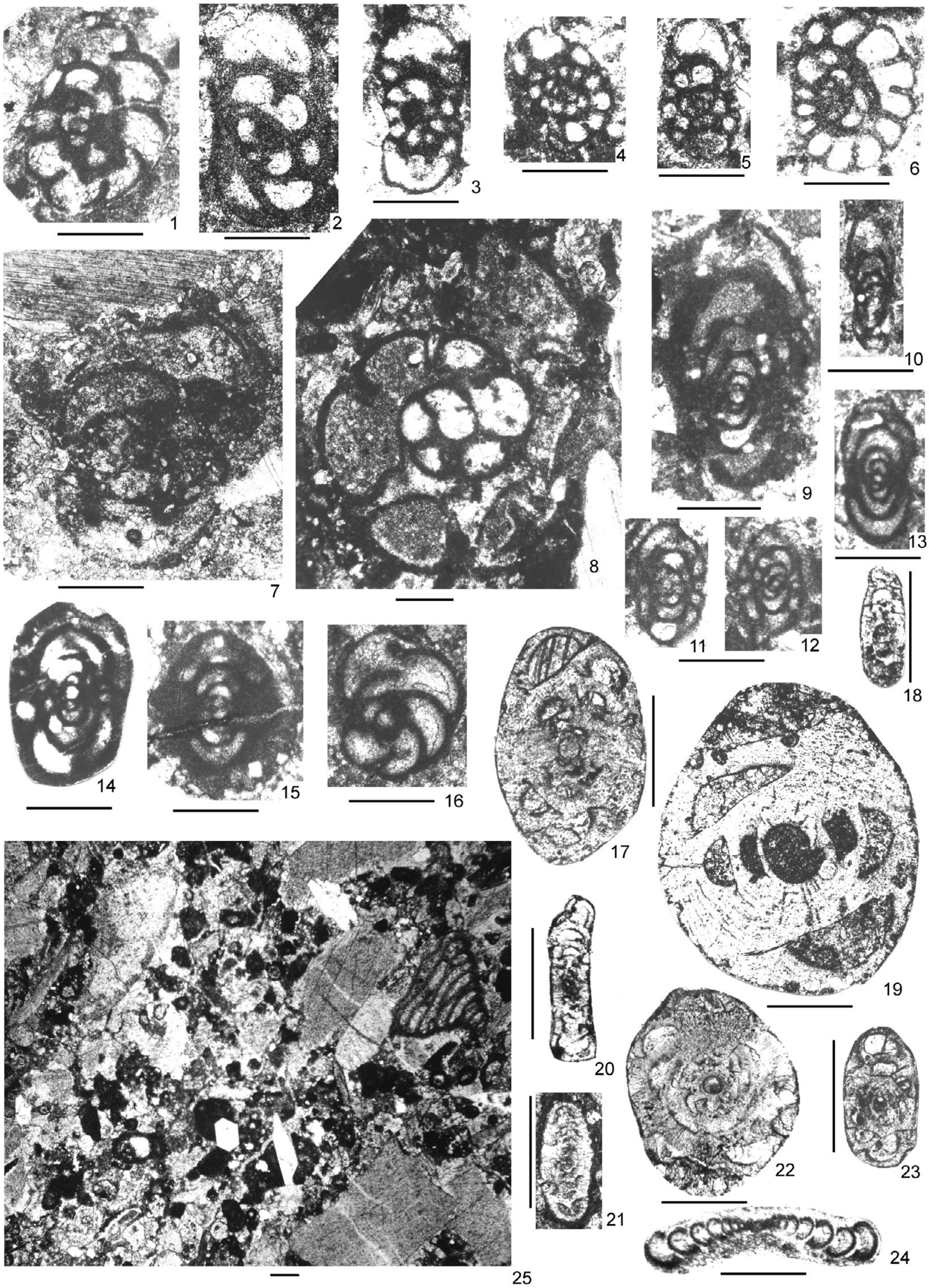

Figure 6. Foraminifers of the Muradymovo section. *Asteroarchaediscus parvus* and *Eostaffellina actuosa* zones. The scale bars are 0.2 mm. **1**, *Endothyra bowmani* Phillips, 1846, specimen no. 121/50, sample 59, Kosogorian. **2**, *Omphalotis* sp., specimen no. 121/260a, sample 69, Protvian. **3–6**, *Pojarkovella nibelis* (Durkina, 1959). **3**, Specimen no. 121/300. **4**, Specimen no. 121/301. **5**, Specimen no. 121/241. **6**, Specimen no. 121/240, all from sample 69, Protvian. **7**, *Endothyranopsis sphaerica* (Rauser-Chernousova & Reitlinger in Rauser-Chernousova *et al*. 1936), specimen no. 121/233, sample 58. **8**, *Janischewskina typica* Mikhailov, 1935, specimen

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Nemirovskaya), *L. mononodosa* (Rhodes, Austin & Druce), *L. nodosa* (Bischoff) and others. The species *Lochriea ziegleri* is widespread in Eurasia and has been considered as a potential marker for the base of the Serpukhovian (Skompski *et al.* 1995; Nemyrovska, 2005; Somerville, 2008) and is currently considered to be the best marker by the Subcommission on the Carboniferous Stratigraphy (Richards, 2011). It appears 3 m above the base of the Venevian in the Moscow Basin (A.S. Alekseev, pers. comm., 2012) and in the P1d Zone of the Brigantian of the British Isles (G. Sevastopulo, pers. comm., 2012).

4.a.2. Gnathodus bollandensis *Zone (Units 5–8; Serpukhovian)*

The base of the *Gnathodus bollandensis* Zone is based on the FAD of the index species. The zone shows the appearance of *Gnathodus postbilineatus* Nigmadganov & Nemirovskaya. The assemblage contains *Gnathodus bilineatus*, *Lochriea commutata*, *L. costata*, *L. cruciformis*, *L. monocostata*, *L. mononodosa*, *L. multinodosa*, *L. nodosa* and infrequent *Cavusgnathus unicornis* Youngquist & Miller. The species *Gnathodus postbilineatus* appearing in the upper part of the zone is used in some sections elsewhere to recognize the *Gnathodus postbilineatus* Zone (Nemyrovska *et al.* 2011), but no such zone has been established so far in the Muradymovo section. The base of the *Gnathodus bollandensis* Zone coincides with the base of the Protvian.

4.a.3. Declinognathodus noduliferus *Zone (Units 9a–11; Bashkirian)*

The *Declinognathodus noduliferus* Zone in the South Urals is subdivided into two subzones: early *Declinognathodus noduliferus* Subzone showing the appearance of the first members of *Declinognathodus* against the background of the Viséan–Serpukhovian fauna and the late *Declinognathodus noduliferus* Subzone recognized based on the predominant occurrence of the *Declinognathodus* species, marked increase in the diversity of the *Declinognathodus* species and almost complete disappearance of *Gnathodus* and *Lochriea* species. In the Muradymovo section the boundary between the subzones is difficult to fix because of the redeposition of the Serpukhovian conodonts recorded up to the top of the *Declinognathodus noduliferus* Zone. The base of the zone is marked by the appearance of the infrequent *Declinognathodus inaequalis*, *D. noduliferus* against the background of the typical Serpukhovian conodont fauna. The middle part of the zone (sample 77/6) contains the first *Declinognathodus praenoduliferus*, closer to the top showing the appearance of *Declinognathodus lateralis* (Higgins & Bouckaert). The species continuing from the Serpukhovian include *Cavusgnathus unicornis* Youngquist & Miller, *Gnathodus bilineatus*, *Gn. bollandensis*, *Gn. postbilineatus*, *Lochriea commutata*, *L. costata*, *L. cruciformis*, *L. monocostata*, *L. mononodosa*, *L. multinodosa*, *L. nodosa*, *L. ziegleri* Nemirovskaya, Perret & Meischner and *Mestognathus bipluti* Higgins.

4.a.4. Idiognathoides sinuatus *Zone (Units 12–16; Bashkirian)*

The *Idiognathoides sinuatus* Zone is recognized in the upper Bogdanovkian and Kamennogorian. The base is drawn based on the appearance of the conodont *Idiognathoides sinuatus* Harris & Hollingsworth. The species *Idiognathoides corrugatus* Harris & Hollingsworth, *Id. asiaticus* Nigmadganov & Nemirovskaya, *Id. sulcatus* Higgins & Bouckaert and *Neognathodus symmetricus* Lane appear in this zone. *D. inaequalis*, *D. lateralis*, *D. japonicus* (Igo & Koike), *D. noduliferus* and *D. praenoduliferus* continue from the underlying beds. The assemblage also contains redeposited Serpukhovian and less commonly Famennian conodonts. This zone and its equivalents are established in many regions of the world, but their positions relative to other fossil groups are not always the same. In the Pennines (British Isles), the boundary between the zones *D. noduliferus* and *Id. corrugatus – Id. sulcatus* is near the base of the R1 Zone (Higgins, 1975). Nemyrovska (1999) reported similar results. In the Gissar Range (South Tien Shan), the base of the *Id. corrugatus* Zone is placed in the upper part of the *Homoceras – Hudsonoceras* Genozone (Nemirovskaya & Nigmadganov, 1994) and approximately coincides with the *Id. sinuatus* Uralian Zone.

4.b. Foraminifers

In the Serpukhovian and Bashkirian stages of the Muradymovo section six foraminiferal assemblages and zonal subdivisions were established (Kulagina

no. 121/245, sample 66a, Protvian. **9**, *Ikensieformis* ex gr. *ikensis* (Vissarionova, 1948), specimen no. 121/261, sample 69, Protvian. **10**, *Paramillerella (Acutella)* aff. *grozdilovae* (Maslo & Vachard, 1997), specimen no. 121/192, sample 69, Protvian. **11**, **12**, *Eostaffella postovoidea* Orlova in Orlova & Bensh, 2004. **11**, Specimen no. 121/256, sample 69. **12**, Specimen no. 121/257, both from sample 69, Protvian. **13**, *Eostaffella ovoidea* Rauser-Chernousova, 1948*a*, specimen no. 121/199, sample 69, Protvian. **14**, **15**, *Eostaffellina actuosa* Reitlinger, 1963. **14**, Specimen no. 121/198, sample 69, Protvian. **15**, specimen no. 121/253, sample 72/3, Protvian. **16**, *Globivalvulina bulloides* (Brady, 1876), specimen no. 121/247, sample 70/1, Protvian. **17**, *Archaediscus karreri* Brady, 1873, specimen no. 121/74, sample 59, Kosogorian. **18**, *Asteroarchaediscus parvus* (Rauser-Chernousova, 1948*b*), specimen no. 121/1190, sample 59, Kosogorian. **19**, *Archaediscus gigas* Rauser-Chernousova, 1948*b*, specimen no. 121/238, sample 58, Kosogorian. **20**, *Planospirodiscus* sp., specimen no. 121/270, sample 70, Protvian. **21**, *Neoarchaediscus probatus* (Reitlinger, 1949), specimen no. 121/237, sample 57a, Kosogorian. **22**, *Neoarchaediscus tumefactus* Ivanova, 1970, specimen no. 121/269, sample 72/3, Protvian. **23**, *Archaediscus timanicus* Reitlinger, 1949, specimen no. 121/236, sample 65, Protvian. **24**, *Monotaxinoides subplanus* (Brazhnikova & Jarzeva, 1956), specimen no. 121/97, sample 65. **25**, Bioclastic grainstone with *Valvulinella* sp., sample 59, Kosogorian.

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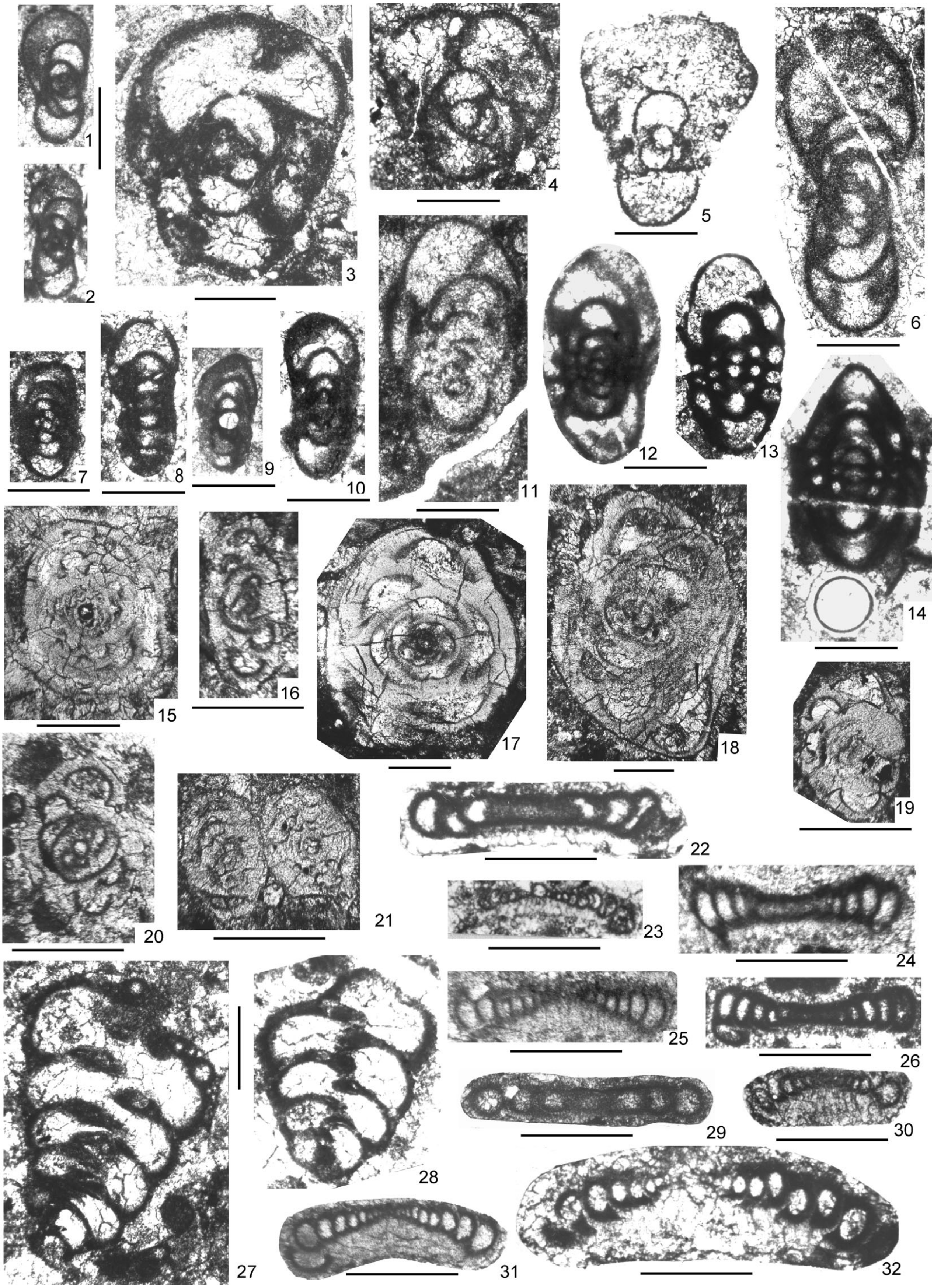

Figure 7. Foraminifers of the Muradymovo section. *Monotaxinoides transitorius* Zone. The scale bars are 0.2 mm. **1**, *Endothyra* sp., specimen no. 121/331, sample 77/1, Yuldybaevian. **2**, *Endostaffella pauperis* (Durkina, 1959), specimen no. 121/281, sample 73/7, Yuldybaevian. **3**, *Endothyranopsis* sp., specimen no. 121/281, sample 73/13, Yuldybaevian. **4**, *Bradyina* ex gr. *minima* Reitlinger, 1950, specimen no. 121/348, sample 75, Bogdanovkian. **5**, *Janischewskina delicata* (Malakhova, 1956), specimen no. 121/278, sample 73/13, Yuldybaevian. **6**, *Planoendothyra* sp. A. Axial section, specimen no. 121/335, sample 74/10, Bogdanovkian. **7**, *Mediocris ovalis*

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& Pazukhin, 1986). After the subsequent study of the previously covered intervals however, the foraminiferal zonation of the section was modified (Kulagina *et al*. 2001, 2002). Some specimens from the Serpukhovian and lower Bashkirian of the Muradymovo section were figured previously (Kulagina, 1988; Kulagina *et al.* 1992, 2001). The foraminiferal taxonomy in this paper is accepted according to the revisions of Rauser-Chernousova *et al.* (1996), Brenckle & Grelecki (1993), Brenckle (2005) and Ginkel (2010). Six general and local zones are recognized from bed 2 of the Muradymovo section. The foraminifers are illustrated in Figures 6–9.

4.b.1. Asteroarchaediscus parvus *Zone (Units 2–4; Serpukhovian)*

This zone correlates with the *N. postrugosus* Zone of the General Stratigraphic Scale of Russia (GSSR). The most diverse assemblages are found in the 2–3 beds of section (samples 57–59, Fig. 6, photographs 1, 7, 17–19, 21, 25). Foraminifers are here represented by diverse archaediscids: *Archaediscus* ex gr. *gigas* Rauser-Chernousova, *A. krestovnikovi* Rauser-Chernousova, *A. grandiculus* Schlykova, *A. angulatus* Sosnina, *A. timanicus* Reitlinger, *Paraarchaediscus koktjubensis* (Rauser-Chernousova), *P. stilus* (Grozdilova & Lebedeva), *Asteroarchaediscus parvus* (Rauser-Chernousova), and *A. baschkiricus* (Krestovnikov & Theodorovich). There are also frequent *Omphalotis omphalota* (Rauser-Chernousova & Reitlinger in Rauser-Chernousova *et al.*), *Endothyranopsis crassa* (Brady), *E. sphaerica* (Rauser-Chernousova & Reitlinger in Rauser-Chernousova *et al.*), *Ikensieformis* ex. gr. *ikensis* (Vissarionova) and species of *Earlandia*, *Endostaffella*, *Palaeotextularia*, *Mediocris* and others. The beds contain rare *Biseriella parva* (N. Tchernysheva). This assemblage corresponds to that of the type Kosogorian of the western slope of the Urals (Ponomareva *et al*. 2002; Ponomareva, 2010), the Sunturian of the Khudolaz section (Stepanova & Kucheva, 2006) and the *Neoarchaediscus regularis – Biseriella parva* Zone of the Central Tien Shan (Orlov-Labkovsky *et al*. 2003).

4.b.2. Monotaxinoides subplanus – Eostaffellina actuosa *Zone (Units 5–6, 7a; Serpukhovian)*

This zone correlates with the *Eostaffellina paraprotvae* Zone of the GSSR and *E. paraprotvae – Ikensieformis mirifica* Zone of the east slope of the Urals (Stepanova & Kucheva, 2006). The base of the *Monotaxinoides subplanus – Eostaffellina actuosa* Zone is defined by the appearance of *Monotaxinoides subplanus* (Brazhnikova & Jarzeva) (Fig. 6, photograph 24). *Eostaffellina actuosa* Reitlinger (Fig. 6, photographs 14, 15), *Ikensieformis mirifica* (Brazhnikova), *Globivalvulina bulloides* (Brady) (Fig. 6, photograph 16) appear upwards in the section (Unit 6). *Monotaxinoides subplanus* is typical of the equivalents of the Protvian in the Donets Basin (Aizenverg *et al*. 1983).

4.b.3. Monotaxinoides transitorius *Zone of the GSSR (Units 7b, 7c, 8, 9a; Serpukhovian and Bashkirian)*

The *Monotaxinoides transitorius* Zone is based on the appearance of the zonal species *Monotaxinoides* ex gr. *transitorius* Brazhnikova & Jarzeva (Fig. 7, photographs 22, 23) and other species of *Monotaxinoides* and *Eolasiodiscus* (Fig. 7, photographs 24–26, 29–31). This zone shows the appearance of *Plectostaffella orbiculata* Ivanova and contains infrequent representatives of species continuing from the underlying beds, including *Endothyranopsis* sp., *Ikensieformis* ex gr. *ikensis*, *I. mirifica*, *Omphalotis* sp., *Howchinia gibba* (Moeller), *H. bradyana* (Howchin) and *Monotaxinoides subplanus*. *Bradyina* ex gr. *minima* Reitlinger enters above the base of the zone (sample 75, Fig. 7, photograph 4).

The foraminiferal assemblage is similar to that of the *Monotaxinoides transitorius* Zone of the Peri-Caspian (Zaitseva & Klenina, 2008). However, based on the data from the Tengiz borehole it is possible to correlate the *M. transitorius* Zone of the Muradymovo section

Vissarionova, 1948, specimen no. 121/334, sample 74/10, Bogdanovkian. **8–10**, *Plectomillerella prisca* (Rauser-Chernousova, 1948*a*). **8**, Specimen no. 121/1196, sample 73/13. **9**, Specimen no. 121/279, sample, 73/7. **10**, specimen no. 121/282, sample 73/7, all from the Yuldybaevian. **11**, *Pseudoendothyra* sp., specimen no. 121/347, sample 74/10, Bogdanovkian. **12**, **13**, *Eostaffella mosquensis* Vissarionova, 1948. **12**, Specimen no. 121/286, sample 73/13. **13**, Specimen no. 121/1191, sample 73/13, Yuldybaevian. **14**, *Ikensieformis* cf. *ikensis* (Vissarionova, 1948), specimen no. 121/292, sample 73/13, Yuldybaevian. **15**, *Neoarchaediscus tumefactus* Ivanova, 1970, specimen no. 121/314, sample 73/7, Yuldybaevian. **16**, *Paraarchaediscus vischerensis* (Grozdilova & Lebedeva, 1954), specimen no. 121/309, sample 73/7, Yuldybaevian. **17**, **18**, *Archaediscus* ex gr. *gigas* Rauser- Chernousova, 1948. **17**, N121/315, sample 73/10. **18**, N121/1192, sample 73/7, Yuldybaevian. **19**, *Archaediscus moelleri* Rauser-Chernousova, 1948*b*, N121/317, sample 73/11, Yuldybaevian. **20**, *Paraarchaediscus grandiculus* (Schlykova, 1951), specimen no. 121/308, sample 73/7, Yuldybaevian. **21**, *Asteroarchaediscus baschkiricus* (Krestovnikov & Theodorovich, 1936), specimen no. 121/311, sample 73/11, Yuldybaevian. **22**, *Monotaxinoides* ex gr. *transitorius* Brazhnikova & Jarzeva, 1956, specimen no. 121/305, sample 73/7, Yuldybaevian. **23**, *Monotaxinoides transitorius* Brazhnikova & Jarzeva, 1956, specimen no. 121/171, sample 75, Bogdanovkian. **24**, **26**, *Monotaxinoides gracilis* (Dain in Reitlinger, 1956): **24**, 121/739, sample 74/10. **26**, Specimen no. 121/365, sample 74/9, Bogdanovkian. **25**, *Monotaxinoides* ex. gr. *subplanus* (Brazhnikova & Jarzeva, 1956), specimen no. 121/302, sample 73/10, Yuldybaevian. **27**, *Palaeotextularia longiseptata* Lipina, 1948, specimen no. 121/312, sample 73/7, Yuldybaevian. **28**, *Palaeotextularia gibbosa minima* Lipina, 1948, specimen no. 121/313, sample 73/13, Yuldybaevian. **29**, *Eolasiodiscus muradymicus* Kulagina in Kulagina *et al.* 1992, specimen no. 121/363, sample 74/10 Bogdanovkian. **30–32**, *Monotaxinoides subplanus* (Brazhnikova & Jarzeva, 1956): **30**, Specimen no. 121/303, sample 73/13, Yuldybaevian. **31**, Specimen no. 121/361, sample 74/10, Bogdanovkian, x 100. **32**, 121/206, sample 73/13, Yuldybaevian.

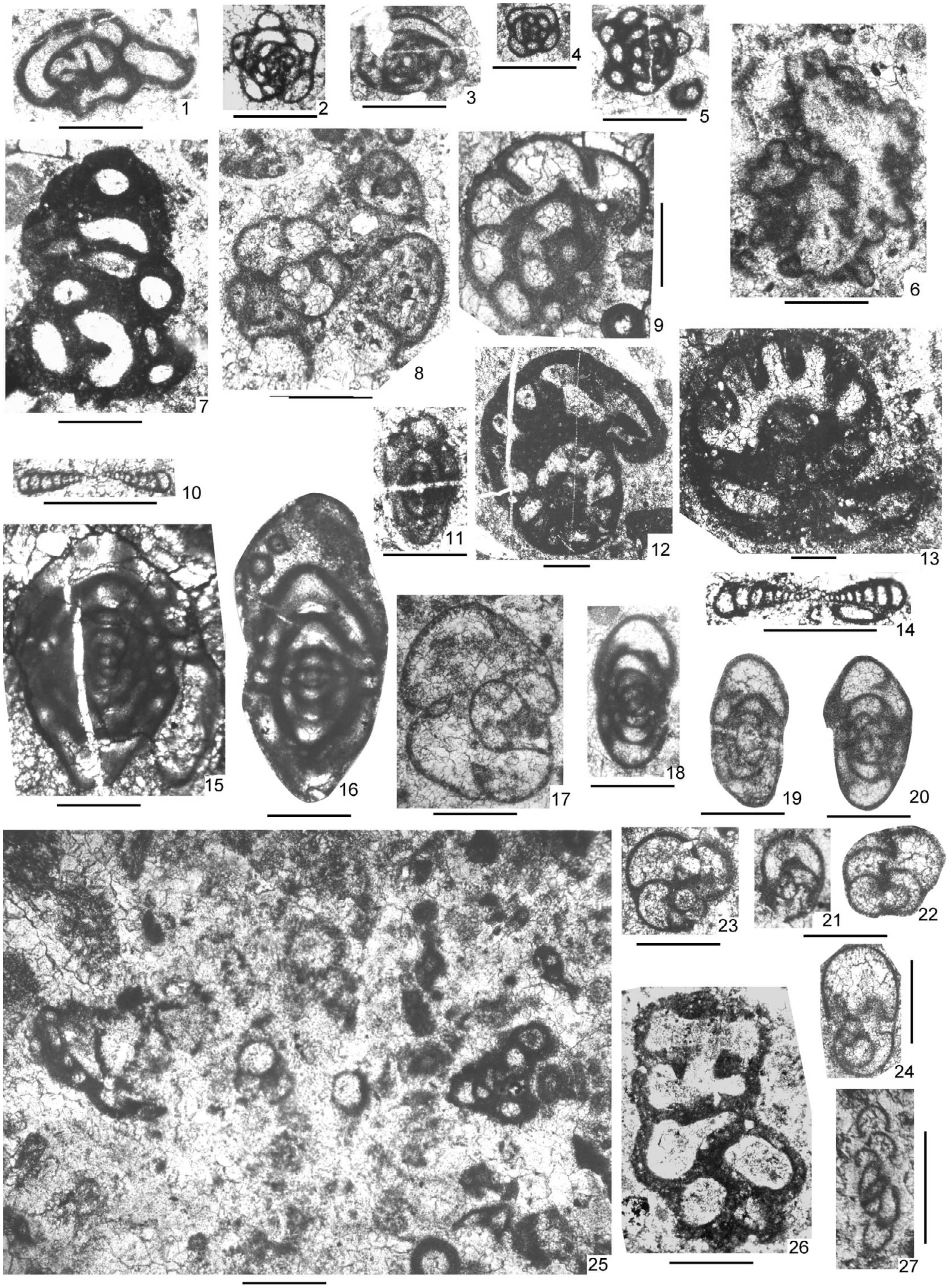

Figure 8. Foraminifers of the Muradymovo section. *Plectostaffella varvariensis* Zone. Bogdanovkian. The scale bar is 0.2 mm. **1**, *Tolypammina* sp., specimen no. 121/327, sample 77. **2–4**, *Pseudoglomospira* spp.: **2**, Specimen no. 121/319, sample 77/1. **3**, specimen no. 121/321, sample 77. **4**, Specimen no. 121/114, sample 77. **5**, *Glomospiroides* sp., specimen no. 121/323, sample 77/6. **6**, Syzygial cysts, specimen no. 121/116, sample 77. **7**, *Tolypammina* sp., specimen no. 121/325, sample 74/10. **8**, *Janischewskina* cf. *delicata* (Malakhova, 1956), 121/119, sample 77. **9**, *Endothyra bowmani* Phillips, 1846, specimen no. 121/313, sample 77. **10**,

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with the lower part of the *M. transitorius* Zone of the Peri-Caspian up to the level of the appearance of *Pl. varvariensis*. Based on the presence of *Monotaxinoides transitorius*, this zone correlates with the *Monotaxinoides transitorius* Zone of the Donets Basin (Vdovenko, 1988). Ponomareva (2004) correlated this zone with the local *Plectostaffella reitlingeri* Zone of the Gostinskyi Section (Vishera Region) of the western slope of the Middle Urals. *Monotaxinoides transitorius* allows correlation with the upper portion of the Arnsbergian Cf7 Zone of the Dinant Basin (Laloux, 1988). In North America, this zone apparently correlates with the interval *Eosigmoilina explicata – Brenckleina rugosa* (Brenckle, 1991).

4.b.4. Plectostaffella varvariensis *Zone (Unit 9b; Bashkirian)*

The *Plectostaffella varvariensis* Zone is defined by the appearance of *Pl. varvariensis* (Brazhnikova & Potievskaja) (samples 77, Fig. 8, photographs 18–20). This zone shows the first appearance of *Bradyina* aff. *pauciseptata* Reitlinger (Fig. 8, photograph 17) and *Eolasiodiscus grandis* Ivanova (Fig. 8, photograph 14). The zone typically contains *Ikensieformis mirifica*, *Eostaffella postovoidea* Orlova, *Eolasiodiscus donbassicus* and *Globivalvulina bulloides* which continue from the Serpukhovian. Of species originating from the Viséan, this zone contains infrequent *Janischewskina* (Fig. 8, photograph 8), *Endothyranopsis* ex gr. *crassa*, *Ikensieformis* ex gr. *ikensis* (Fig. 8, photographs 15, 16), *Howchinia gibba*, *H. bradyana* and long-ranging species *Mediocris breviscula*, acquiring species of *Tolypammina*, diverse *Pseudoglomospira* (Fig. 8, photographs 2–4), some *Eostaffellina*, *Parastaffella* and *Neoarchaediscus*. The base of the zone coincides with the extinction of the large species of *Ikensieformis*, *Omphalotis*, *Globoendothyra* and most Viséan archaediscids. This zone is characterized in the Muradymovo section by the occurrence of large specimens of *Endothyranopsis* and *Howchinia bradyiana*, which are traditionally considered Lower Carboniferous. It could be assumed that these specimens are redeposited since there are occurrences of redeposition in this section, and the foraminifers are found in litho-bioclastic limestone. However, it is worth mentioning that in the algal limestones with no traces of redeposition in the Bolshoi Kizil section, *Endothyranopsis* and *Howchinia bradyiana* are also found along with *D. noduliferus*. In addition, *Endothyranopsis* differs from the Serpukhovian species of this genus in the rapid increase of the height of the last whorl (more than twice) (Fig. 8, photographs 12, 13). A similar assemblage was recognized by Ponomareva (2004) in the Staroutkinsk Regional Substage of the Gostinskii section of the Western Urals. In that section the species *Pl. varvariensis* is recorded in association with the first representatives of *Declinognathodus* below the last brachiopod bank with *Striatifera.* As in Muradymovo, the assemblage of the Gostinskii section is similar to that of the underlying zone and possibly corresponds to the *M. transitorius* of the Peri-Caspian with the earliest *Pl. varvariensis* (Zaitseva & Klenina, 2008). In the Donets Basin the *Plectostaffella varvariensis* Zone correlates with the upper portion of the *Loeblichia minima – Monotaxinoides transitorius – Eosigmoilina explicata* Zone (Vdovenko *et al.* 1989). In the Central Tien Shan Mountains it correlates with the *Plectostaffella posohovae* Zone, recognized by Z.S. Rumjanzeva (Kulagina *et al.* 1992) at the base of the Bashkirian below the *Pl. bogdanovkensis* Zone.

4.b.5. Plectostaffella bogdanovkensis *Zone (Unit 9c–11; Bashkirian)*

The base of this zone is defined by the appearance of *Plectostaffella bogdanovkensis* Reitlinger, *Plectomillerella* ex gr. *angusta* (Kireeva) (Fig. 9, photograph 25) and *Millerella umbilicata* Kireeva (Fig. 9, photograph 5). This zone shows an increase in the species diversity and abundance of representatives of *Plectostaffella* (Fig. 9, photographs 13–15) and the appearance of *Plectostaffella* species with a strongly displaced axis, which are difficult to identify to species (Fig. 9, photograph 12). The assemblage is identical to that described by Reitlinger (1980) from the stratotype of Bogdanovkian (Bogdanovka section) and to that established by us previously in the same section (Kulagina *et al.* 2000). The most significant change in the foraminiferal assemblages of the Muradymovo section is recorded at the base of this zone. The assemblage of this zone is widespread in Eurasia (Gibshman & Akhmetshina, 1991; Ivanova & Chuvashov, 1993; Mizuno & Ueno, 1997; Ponomareva, 2004; Zaitseva & Klenina, 2008). The zone corresponds to the lower portion of the Voznesenskian and the *Plectostaffella bogdanovkensis* Zone of the Donets Basin (Vachard & Maslo, 1996) and Koikebiltau Substage of Central Asia (Rumjanzeva, 1989). In the GSSP section in Arrow Canyon,

Pseudoammodiscus multivolutus Reitlinger, 1949, specimen no. 121/1193, sample 77. **11**, *Eostaffella postovoidea* Orlova in Orlova & Bensh, 2004, specimen no. 121/122, sample 77. **12**, **13**, *Endothyranopsis* sp.: **12**, Specimen no. 121/1194, sample 79a. **13**, Specimen no. 121/329, sample 776. **14**, *Eolasiodiscus grandis* R. Ivanova, 1973, specimen no. 121/134, sample 77. **15**, **16**, *Ikensieformis* ex gr. *ikensis* (Vissarionova, 1948). **15**, Specimen no. 121/342. **16**, Specimen no. 121/341, both from sample 77/3. **17**, *Bradyina* aff. *pauciseptata* Reitlinger, 1950, specimen no. 121/347, sample 77. **18–20**, *Plectostaffella varvariensis* (Brazhnikova & Potievskaja, 1948). **18**, Specimen no. 121/336, sample 77/6. **19**, Specimen no. 121/169, sample 77. **20**, Specimen no. 121/125, sample 77. **21–24**, *Biseriella minima* (Reitlinger, 1950). **21**, Specimen no. 121/354, sample 77. **22**, Specimen no. 121/120, sample 77. **23**, Specimen no. 121/121, sample 77. **24**, Specimen no. 121/355, sample 77. **25**, Wackestone/packstone, recrystallized with encrusting foraminifers, sample 77. **26**, *Climacammina* ex gr. *prisca* Lipina, 1948, specimen no. 121/353, sample 77b. **27**, *Paraarchaediscus koktjubensis* (Rauser-Chernousova, 1948*a*), specimen no. 121/172, sample 77.

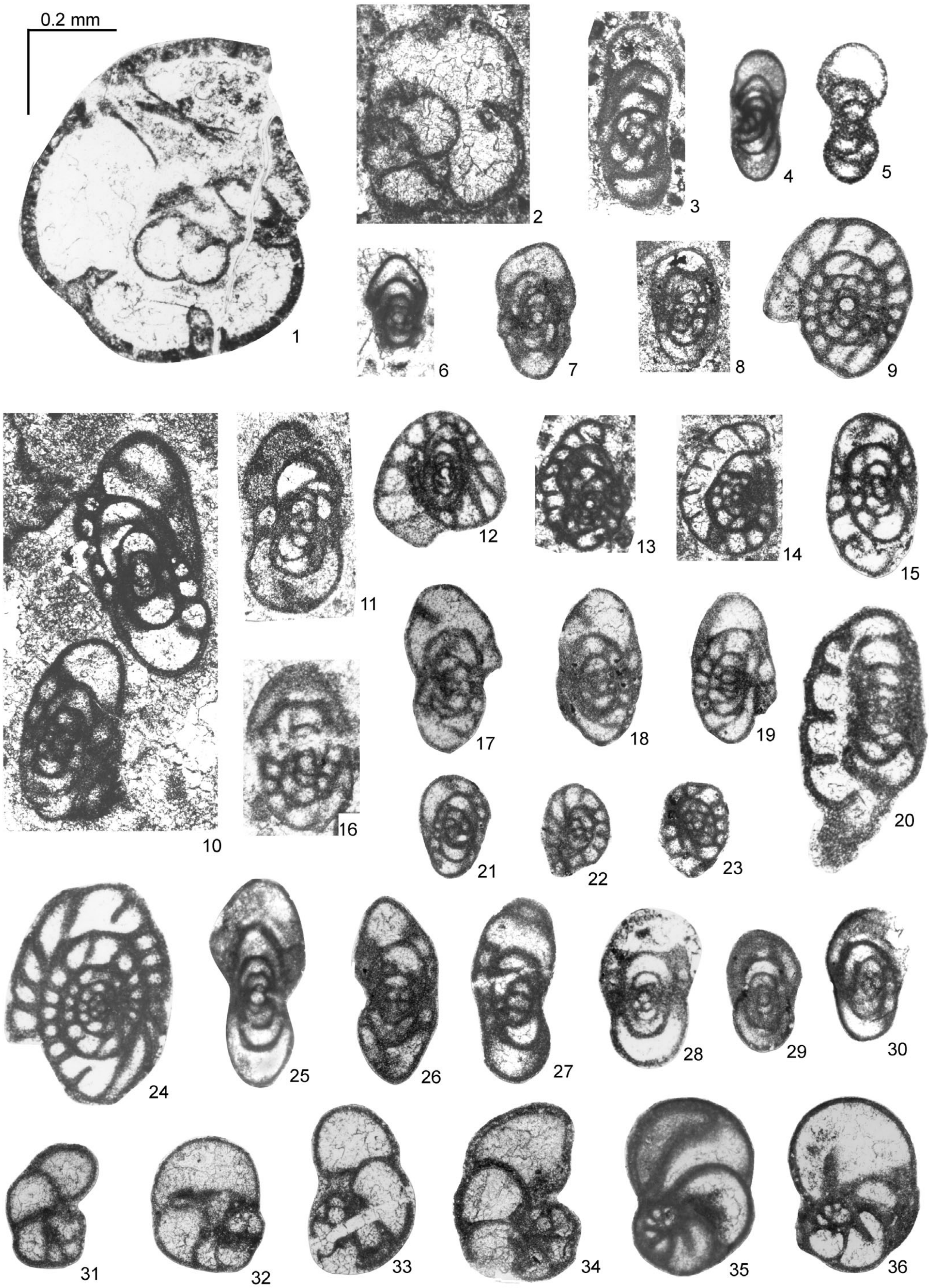

Figure 9. Foraminifers of the Muradymovo section. *Plectostaffella bogdanovkensis* and *Semistaffella minuscilaria* zones, Bogdanovkian. The scale bars are 0.2 mm. **1**, *Bradyina concinna* Reitlinger, 1950, specimen no. 121/384, sample 81. **2**, *Bradyina* ex gr. *minima* Reitlinger, 1950, specimen no. 121/382, sample 81. **3**, *Planoendothyra aljutovica* (Reitlinger, 1950), specimen no. 121/381, sample 81. **4**, *Endostaffella pauperis* (Durkina, 1959), specimen no. 121/388, sample 81. **5**, *Millerella umbilicata* Kireeva in Rauser-Chernousova *et al.* 1951, specimen no. 121/216, sample 80. **6**, *Eostaffella* cf. *paraprisca* Durkina, 1959, specimen no. 121/339, sample 74/9. **7**,

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North America this zone can apparently be correlated with the earliest *Millerella marblensis* (Brenckle *et al.* 1997).

4.b.6. Semistaffella minuscilaria *Zone (Units 12–15a; Bashkirian)*

The assemblage of the zone is dominated by species continuing from the underlying beds. This interval shows the first appearance of *Semiendothyra surenica* Reitlinger, *Bradyina concinna* Reitlinger and *Semistaffella minuscilaria* Reitlinger. The zone correlates with the upper part of the Voznesenskian and the *Millerella marblensis – M. angusta* Zone of the Donets Basin (Vachard & Maslo, 1996) and the Seslavino Substage of the Middle and South Tien Shan Mountains, containing the *Plectostaffella seslavica* (Rumjanzeva, 1989; Kulagina *et al.* 1992) and *Pl. longiscula – Pl. varvariensis* Zone (Orlov-Labkovsky *et al.* 2003).

4.c. Ammonoids

Two ammonoid genozones (*Fayettevillea–Delepinoceras* and *Homoceras–Hudsonoceras*) of the Russian Carboniferous Scale are recognized at Muradymovo (Fig. 10).

4.c.1. Fayettevillea–Delepinoceras *Genozone (Units 7b–9; Serpukhovian)*

The *Fayettevillea-Delepinoceras* Genozone is established beginning from the base of Unit 7b. The lowermost ammonoid-containing sample (73A) contains numerous shells of *Proshumardites delepinei* Schindewolf. These ammonoids are also found in sample 75 (Unit 9a). Sample 77 (Unit 9b) contains the same species in association with *Glaphyrites* sp. These ammonoids indicate the upper part of the *Fayettevillea-Delepinoceras* Genozone (Nm1c2 Zone) of Ruzhencev & Bogoslovskaya (1971, 1978). Both these species appear at this level in many sections of the South Urals, Central Asia and North Africa near the Mid-Carboniferous Boundary (Manger *et al.* 1985). The Nm1c2 Zone corresponds to the upper part of the E2 Zone of Western Europe (Bisat, 1924, 1928; Ramsbottom & Saunders, 1985; Nikolaeva & Kullmann, 1998, etc.).

4.c.2. Homoceras-Hudsonoceras *Genozone (from Unit 12; Bashkirian)*

The ammonoid geochronology of the interval between samples 77 and 81 is difficult to assess. The absence of the association of the index Upper Carboniferous species and *Proshumardites delepinei*, which was recorded in Sholak-Sai (Ruzhencev & Bogoslovskaya, 1971, 1978) and Aksu (Nikolaeva, 1995*a*,*b*) suggests that the basal Pennsylvanian *Homoceras–Hudsonoceras* Genozone begins slightly upwards in the section, approximately at the level of sample 81 (Unit 12) where *Ramosites* sp. enters. This is indirectly supported by the presence of *Ramosites* without accompanying *Isohomoceras* or *Homoceras*, which was recorded in the type Bogdanovkian section by Nikolaeva (1999) and Kulagina *et al.* (2000).

Upward in the section, sample 83 (Unit 15a) contains a typical assemblage of the upper portion of the *Homoceras–Hudsonoceras* Genozone (*(Isohomoceras* sp., *Ramosites ramosus* Ruzhencev & Bogoslovskaya, *Homoceras haugi astrictum* Ruzhencev & Bogoslovskaya and Anthracoceratidae gen. & sp. indet.), indicating the upper part of this genozone: the Nm2a2 Zone. This zone is usually correlated with the H2 Zone of Western Europe (Kullmann & Nikolaeva, 1999).

4.d. Ostracods

Ostracods were obtained from samples collected from the MCB boundary beds in the Muradymovo section and treated with acetic acid to obtain conodonts (Kulagina *et al.* 1992; Figs 11, 12). Ostracods are therefore represented by isolated and fragile valves and less commonly by complete shells with preserved structures and ornamentation. The assemblage

Paramillerella advena (Thompson, 1944), specimen no. 121/144, sample 81. **8**, *Plectostaffella* sp., specimen no. 121/407, sample 83a. **9**, *Eostaffella* sp., specimen no. 121/389, sample 81. **10**, *Plectostaffella akkujlukia* Rumjanzeva in Kulagina *et al.* 1992, specimen no. 121/1195, sample 83a. **11**, *Plectostaffella jachakia* Rumjanzeva in Kulagina *et al.* 1992, specimen no. 121/150, sample 80. **12**, *Plectostaffella* sp. 1, specimen no. 121/209, sample 81. **13**, *Plectostaffella* ex gr. *bogdanovkensis* Reitlinger, 1980, specimen no. 121/208, sample 81. **14**, *Plectostaffella* sp., specimen no. 121/414, sample 81z. **15**, *Plectostaffella* sp., specimen no. 121/211, sample 81. **16**, *Plectostaffella bogdanovkensis* Reitlinger, 1980, specimen no. 121/1175, sample 82/1. **17–19**, *Plectostaffella varvariensis* (Brazhnikova & Potievskaja, 1948). **17**, Specimen no. 121/203. **18**, Specimen no. 121/152. **19**, Specimen no. 121/210, all from sample 81. **20**, *Plectomediocris asymmetrica* Brazhnikova & Vdovenko, 1983, specimen no. 121/222, sample 79v. **21–23**, *Semistaffella minuscilaria* Reitlinger, 1971. **21**, Specimen no. 121/205. **22**, Specimen no. 121/206. **23**, Specimen no. 121/207, all from sample 81. **24**, **25**, *Plectomillerella* ex gr. *angusta* (Kireeva in Rauser-Chernousova *et al.* 1951) (= *Eostaffella pseudostruvei* Rauser-Chernousova and Belyaev, in Rauser-Chernousova *et al.* 1936 in Kulagina *et al.* 1992, pl. 2, fig. 3 and Kulagina *et al.* 2001, pl. 1, fig. 13). **24**, Specimen no. 121/386, sample 81. **25**, Specimen no. 121/370, sample 79. **26**, **27**, *Plectostaffella* cf. *evolutica* (Rumjanzeva, 1970). **26**, Specimen no. 121/147, sample 81b. **27**, Specimen no. 121/221, sample 80. **28**, **29**, *Eostaffellina paraprotvae* (Rauser-Chernousova, 1948*b*). **28**, Specimen no. 121/146. **29**, Specimen no. 121/204, both from sample 81. **30**, *Eostaffella postovoidea* Orlova in Orlova & Bensh, 2004, specimen no. 121/219, sample 81. **31**, *Biseriella minima* (Reitlinger, 1950), specimen no. 121/166, sample 81. **32**, **33**, *Globivalvulina moderata* Reitlinger, 1950. **32**, 121/160. **33**, 121/202, both from sample 81. **34–36**, *Globivalvulina kamensis* Reitlinger, 1950. **34**, 121/162, sample 81. **35**, Specimen no. 121/215, sample 80. **36**, Specimen no. 121/393, sample 81.

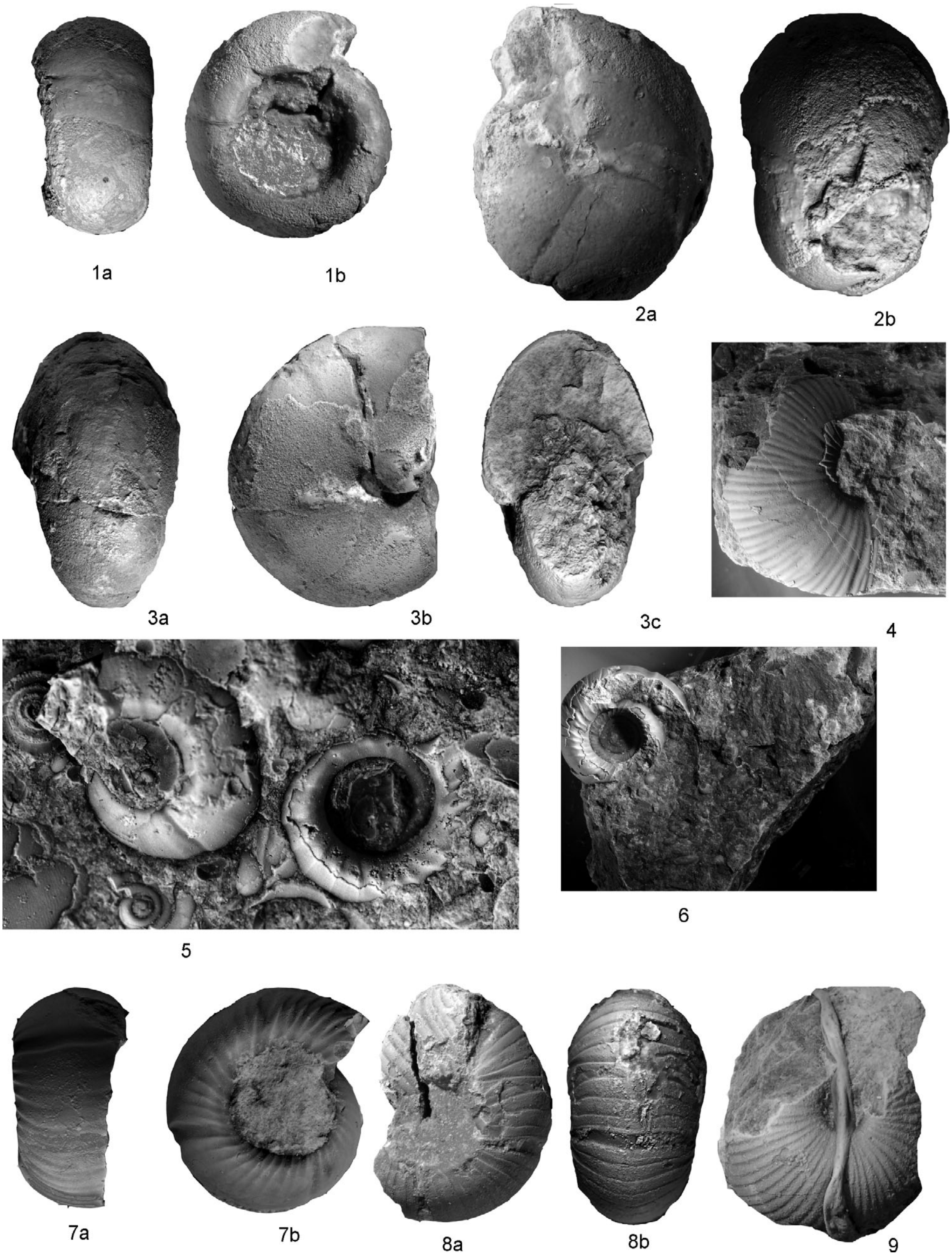

Figure 10. Ammonoids from the Muradymovo section. The scale bars are 2 mm. **1**, *Fayettevillea occidentalis* Ruzhencev & Bogoslovskaya, specimen no. 4715/200, sample 74. **1a**, Lateral view; **1b**, ventral view. **2**, *Proshumardites delepinei* Schindewolf, specimen no. 4715/207, 3 m below sample 74. **2a**, Lateral view; **2b**, ventral view. **3**, *Stenoglaphyrites* sp., specimen no. 4715/208, sample 74. **3a**, Ventral view; **3b**, lateral view; **3c**, apertural view. **4**, *Ramosites* sp., specimen no. 4715/201, sample 73. **5**, Juveniles of *Homoceras haugi astrictum* Ruzhencev & Bogoslovskaya and *Isohomoceras* sp., specimen no. 4715/210, sample 83. **6**, Juvenile of *Homoceras* sp. Ruzhencev & Bogoslovskaya, specimen no. 4715/201, sample 83. **7**, **8**, *Homoceras haugi astrictum* Ruzhencev & Bogoslovskaya, sample 83. **7**, Specimen no. 4715/203. **7a**, Ventral view; **7b**, lateral view. **8**, Specimen no. 4715/205. **8a**, Lateral view; **8b**, ventral view. **9**, *Isohomoceras* sp., specimen no. 4715/206, sample 83.

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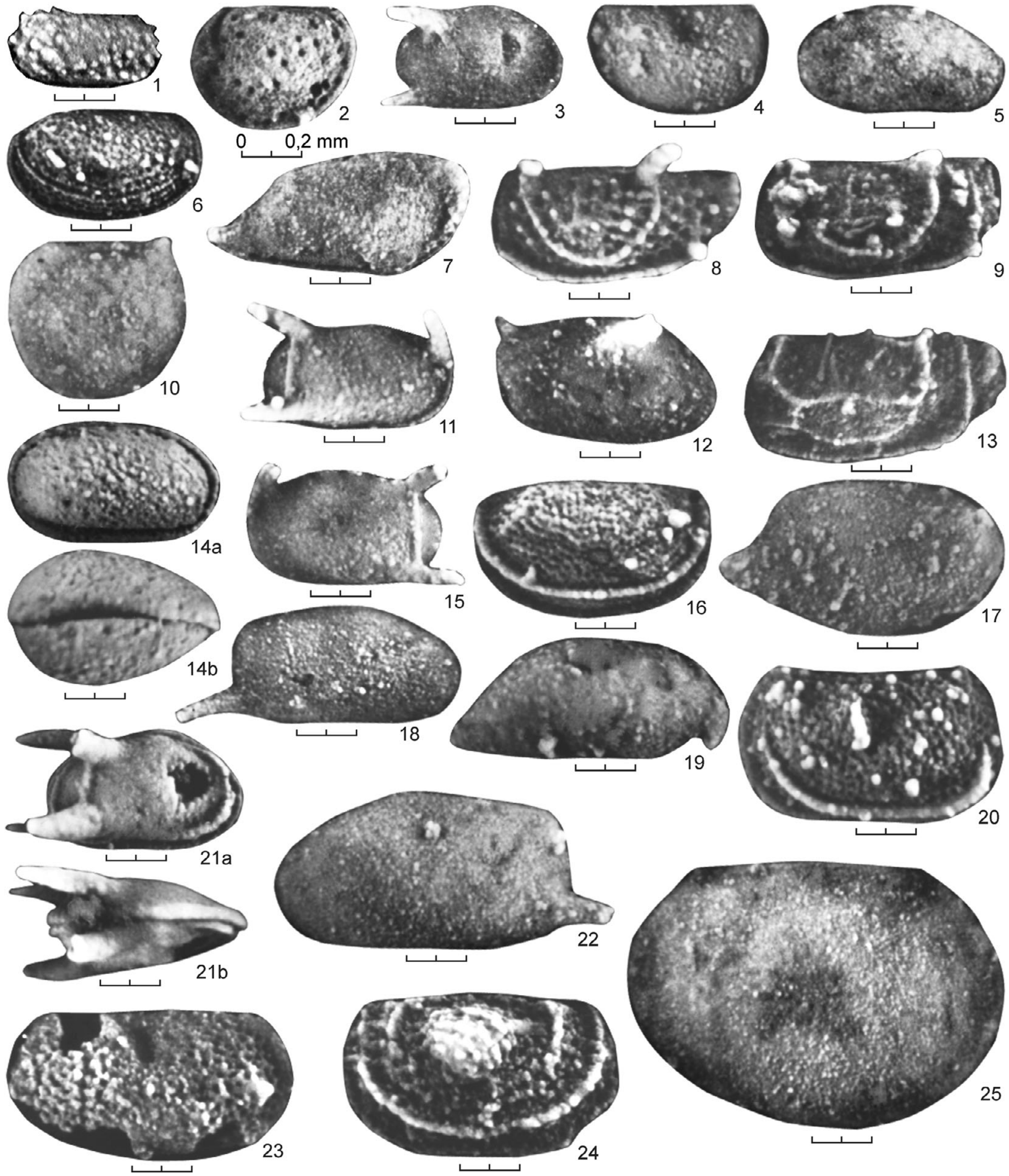

Figure 11. Ostracods from the Muradymovo section. The scale bars are 0.2 mm. **1**, *Microcheilinella* ? *shiloi* Bless in Simakov *et al*. 1984, specimen no. 66–325, sample 76/3, right valve view, Bogdanovkian. **2**, *Libumella* sp., specimen no. 66–12, sample 73/7, left valve view, Yuldybaevian. **3**, *Healdia* sp. 1, specimen no. 66–316, sample 74/3, right valve view, Yuldybaevian. **4**, *Kirkbyina tenella* N. Kotchetova in Kulagina *et al*. 1992, specimen no. 66–311, sample 74/3, right valve view, Yuldybaevian. **5**, *Bolbozoella inflata* Gründel, 1975, specimen no. 66–320, sample 74/3, right valve view, Yuldybaevian. **6**, *Ectodemites tumidus* Cooper, 1941, specimen no. 66–207, sample 74/3, left valve view, Yuldybaevian. **7**, *Bohlenatia* aff. *inornata* (Cordell, 1952), specimen no. 66–203, sample 74/3, right valve view, Yuldybaevian. **8**, *Editia* sp. 2, specimen no. 66–150, sample 76/3, left valve view, Bogdanovkian. **9**, *Editia* sp. 2, specimen no. 66–309, sample 74/9, left valve view, Yuldybaevian. **10**, *Pseudoparaparchites celsus* N. Kotchetova, 1991, sample 74/3, left valve view, Yuldybaevian. **11**, *Healdia ikensis* N. Kotchetova in Kulagina *et al*. 1992, holotype no. 66–66, sample 74/3, right valve view, Yuldybaevian. **12**, *Rectonaria* aff. *accepta* N. Kotchetova in Kulagina *et al*. 1992, specimen no. 66–321, sample 74/3, left valve view, Yuldybaevian. **13**, *Editia* sp. 3, specimen no. 66–310, sample 74/9, left valve view, Yuldybaevian. **14a**, **14b**, *Microcheilinella extuberata*, specimen no. 66–326, sample 76/3, right valve view and dorsal view, Bogdanovkian. **15**, *Healdia ikensis* N. Kotchetova in Kulagina *et al*. 1992, specimen no. 66–68, sample 76/3, left valve view, Bogdanovkian. **16**, *Kirkbya* aff. *punctata* Kellett, 1933, specimen no. 66–238, sample 76/3, right valve view, Bogdanovkian. **17**, *Rectoplacera* sp. 1, specimen no. 66–99, sample 74/3, right

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contains mainly benthic taxa, including paraparchitids (*Javatius*, *Coeloenellina*, *Libumella*, *Fellerites*), kirkbyellids (*Kirkbyella*), kirkbyoids (*Kirkbya*, *Amphissites*, *Ectodemites*, *Polytylites*, *Amphizona*, *Editia*, *Kelletina*), kloedenelloids (*Limnoprimitia*, *Kirkbyina*), glyptopleurids (*Glyptopleura*), paraparchitoids (*Shishaella*, *Shivaella*, *Chamishaella*, *Microcoeloenella*, *Dorsoobliquella*), healdiids (*Healdia*, *Bolbozoella*, *Carbonita*), bairdioids (*Bairdia*, *Bairdiocypris*, *Bairdianella*, *Basslerella*, *Acratia*, *Bohlenatia*, *Bairdiocypris*, *Acanthoscapha*, *Macrocypris*), roundyellids (*Roundyella*), microcheilinids (*Microcheilinella*) and polycopids (*Polycope*) from the orders Palaeocopida, Platycopida, Metacopida, Podocopida and Cladocopida. The assemblage characteristically contains rectonarids (*Rectoplacera*, *Rectonaria*, *Triplacera*). The ostracods were studied mainly by Nataliya Kochetova (= N. Kotchetova). Three successive assemblages are recognized in the MCB portion of the Muradymovo section, described in the following.

4.d.1. Ostracod assemblage I

This assemblage is found in limestones of the upper part of the Yuldybaevian in Unit 8 (Fig. 3). This assemblage includes species characteristic of the *Pseudoparaparchites celsus* regional zone, which are usually associated with the Protvian and lower part of the Yuldybaevian (Kulagina *et al.* 1992) and *Pseudoparaparchites celsus* N. Kotchetova in association with kirkbyids, *Healdia ikensis* N. Kotchetova, *H. uralica* N. Kotchetova, *Bolbozoella inflata* Grundel, *Bohlenatia* aff. *inornata* (Green), *Acanthoscapha* cf. *limata* N. Kotchetova, *Microcheilinella* ? *shiloi* Bless, singular rectonarids and *Editia* spp., *Acratia* sp. However, in this section we observe the occurrence of *Pseudoparaparchites celsus* unusually high in the section of several valves, which could possibly be redeposited.

4.d.2. Ostracod assemblage II

The second ostracod assemblage (II) is found in the limestone of the upper part of Unit 9a and in Units 10 and 11 (Fig. 3), typical of the lower Bogdanovkian containing the transitional assemblage with surviving Serpukhovian species. This association is characteristic of the *Fellerites gratus* Zone, the base of which is based on the appearance of the index species alongside *Javatius kisilensis* (Kotschetkova). The assemblage contains species continuing from the underlying beds, diverse kirkbyaceans, *Kirkbyella* sp. and *Chamishaella opima* Kotschetkova, *Discoidella perspicua* Kotschetkova, *Bairdia chudolasensis* Kotschetkova, *Bairdiocypris indiges* Kotschetkova and other taxa commonly found in the Bashkirian of the South Urals (Kotschetkova, 1983).

4.d.3. Ostracod assemblage III

The basal portion of Unit 12 (sample 81) contains several taxa of Assemblage III, which is typical of the middle and upper Bogdanovkian. This assemblage includes *Limnoprimitia* cf. *arcuata* (Bean), allowing the tentative recognition of the *Limnoprimitia arcuata* Zone (Kulagina *et al.* 2001; Kochetova, 2008). The assemblage also contains *Dorsoobliquella ovalis* Kotschetkova, *Microcoeloenella orbiculata* Kotschetkova, *Bairdia cestriensis* var. *granulosa* Girty, *Bairdia* cf. *seminalis* (Knight) and *Acratia grandis* Kotschetkova.

5. Correlation of the zones

In the Muradymovo section, there are successions of conodont, foraminiferal, ammonoid and ostracod zones (Fig. 4). The succession of the conodont zones is the most complete and representative and allows the reliable correlation with zones based on other fossil groups. The lower Serpukhovian Substage contains the assemblage of the conodont *Lochriea ziegleri* Zone, while its foraminiferal assemblage contains species continuing from the upper Viséan in association with the species *Archaediscus timanicus* Reitlinger (1950) that was originally described from the Bashkirian.

The upper Serpukhovian Substage (Protvian and Yuldybaevian) includes the conodont *Gn. bollandensis* Zone. This zone correlates with foraminiferal *Monotaxinoides subplanus* – *Eostaffellina actuosa* Zone and the lower, largest portion of the *Monotaxinoides transitorius* Zone that corresponds to the beds with the ammonoids assemblage of the *Fayettevillea–Delepinoceras* Zone. The association of the foraminifers, conodonts and ammonoids is recorded in the interval *c.* 4 m thick (upper part of Unit 7b to Unit 7c).

The *Declinognathodus noduliferus* Zone identified by the first appearance of the conodont *Declinognathodus inaequalis* and *D. noduliferus* at the base of Unit 9a (samples 74/9, 74/10, 75) corresponds to the upper part of the foraminiferal *Monotaxinoides transitorius*

valve view, Yuldybaevian. **18**, *Healdia* sp. 2, specimen no. 66–318, sample 76/3, right valve view, Bogdanovkian. **19**, *Acratia* sp., specimen no. 66–323, sample 74/3, right valve view, Yuldybaevian. **20**, *Ectodemites* sp., specimen no. 66–208, sample 74/3, right valve view, Yuldybaevian. **21a**, **21b**, *Healdia uralica* N. Kotchetova in Kulagina *et al*. 1992, specimen no. 66–60, holotype, sample 76/3, right valve view and dorsal view, Bogdanovkian. **22**, *Healdia* sp. 2, specimen no. 66–319, sample 74/3, left valve view, Yuldybaevian. **23**, *Kirkbyella* sp., specimen no. 66–239, sample 76/3, left valve view, Bogdanovkian. **24**, *Amphissites* aff. *centronotus* (Ulrich & Bassler, 1906), specimen no. 66–24, sample 76/3, left valve view, Bogdanovkian. **25**, *Chamishaella uniformis* Kotschetkova, 1983, specimen no. 66–312, sample 74/3, right valve view, Yuldybaevian.

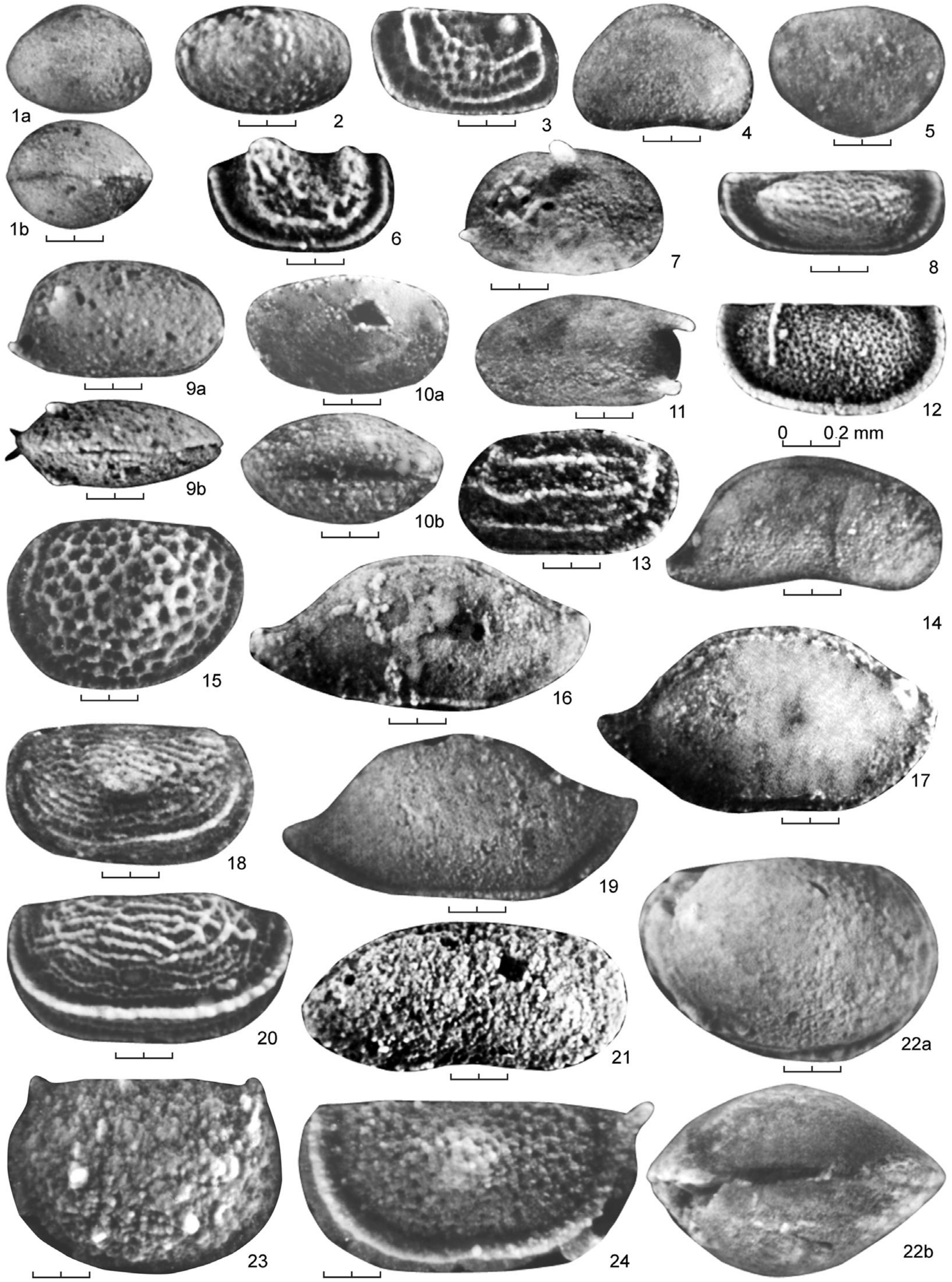

Figure 12. Ostracods from the Muradymovo section. The scale bars are 0.2 mm. All except photographs 22a,b from sample 76/3. Bogdanovkian: **1a**, **1b**, *Basslerella simonovae* Kotschetkova, 1983, specimen no. 66–141, right valve view and dorsal view. **2**, *Dorsoobliquella* cf. *ovalis* Kotschetkova, 1983, specimen no. 66–314, right valve view. **3**, *Editia* sp. 1, specimen no. 66–152, right valve view. **4**, *Bairdiocypris subalia* N. Kotchetova in Kulagina *et al*. 1992, specimen no. 66–79, right valve view. **5**, *Microcoeloenella orbiculata* Kotschetkova, 1983, specimen no. 66–313, right valve view. **6**, *Kellettina* sp., specimen no. 66–32, right valve view. **7**, *Rectonaria* sp. 1, specimen no. 66–104, right valve view. **8**, *Kirkbya* aff. *elongata* Cooper, 1941, specimen no. 66–213, right valve

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Zone, *Pl. varvariensis* and *Pl. bogdanovkensis* Zones. The deposits at 5 m above the base of the conodont *D. noduliferus* Zone and up to its top contain the ostracod assemblage II with *Fellerites gratus*.

The *Declinognathodus noduliferus* Zone in all studied sections of this interval lies near the boundary between the *Fayettevillea–Delepinoceras* and *Homoceras–Hudsonoceras* genozones and their equivalents (zones E and H in Western Europe and North America). The association of *Proshumardites delepinei* and *Isohomoceras* established in the lower part of the *Homoceras–Hudsonoceras* Genozone in Sholak-Sai (South Urals; Ruzhencev & Bogoslovskaya, 1978) and in the Aksu section (Tien Shan Mountains; Nikolaeva, 1994), containing the first occurrence of *D. noduliferus* (Nikolaeva & Nigmadganov, 1992), is not recorded at Muradymovo. The base of the *Homoceras–Hudsonoceras* Genozone should possibly be around the base of the *Pl. varvariensis* foraminiferal Zone (as in other sections in the area; Kulagina *et al.* 2000), but the lowest ammonoid occurrences of the *Homoceras–Hudsonoceras* Genozone is in sample 81 (Unit 12), containing *Ramosites* sp. Sample 83 (Unit 15a) contains a typical assemblage of the *Homoceras–Hudsonoceras* Genozone of the Uralian scale usually correlating with the Alportian. This level corresponds to the base of the foraminiferal *Semistaffella minuscilaria* Zone and conodont *Idiognathoides sinuatus* Zone.

The boundary level defined by conodonts in different regions may occur both above and below the first appearance of the ammonoid genus *Isohomoceras*, which indicates the base of the *Homoceras–Hudsonoceras* Genozone. In the Muradymovo section, the boundary between the genozones can be at any level between samples 73 and 83 because this interval contains ammonoids that, in other regions, occur both in the *Fayettevillea–Delepinoceras* and *Homoceras–Hudsonoceras* genozones. However, it is most likely that the base of the *Homoceras–Hudsonoceras* Genozone lies between samples 77 and 81 because the genus *Ramosites* was not found below this interval, whereas no characteristic Mississippian ammonoid species is found above it.

The middle part of the conodont *Idiognathoides sinuatus* Zone, 18 m above the base, contains an ammonoid assemblage of the upper part of the *Homoceras–Hudsonoceras* genozone. In this part of the zone, *Id. sulcatus* has been recorded. Ostracod assemblage III is found in association with foraminifers of the *Semistaffella minuscilaria* Zone and conodonts of the lower part of the *Idiognathoides sinuatus* Zone.

6. Summary

In the Muradymovo section the position of the MCB is presently identified by the first appearance of the conodonts *Declinognathodus inaequalis* and *D. noduliferus.* It is placed within the foraminiferal *Monotaxinoides transitorius* Zone. The base of the *Pl. varvariensis* Zone is a foraminiferal level nearest to the base of the Pennsylvanian (6 m above the base of *D. noduliferus* Zone), but the most significant change in the foraminiferal assemblages of the Muradymovo section is recorded higher, at the base of *Plectostaffella bogdanovkensis* Zone, which is widespread in Eurasia. Notably, the assemblage of the boundary beds in Muradymovo does not contain *Rhachistognathus primus* Dunn, so the *Rhachistognathus primus – D. noduliferus* conodont zone fixed near the MCB at Arrow Canyon (Lane *et al.* 1999; Richards *et al.* 2002) cannot be recognized. Instead, the assemblage contains *D. praenoduliferus* and *D. postbilineatus*; the situation is somewhat similar to that of the Aksu Section, Tien Shan Mountains and La Lastra section in Spain (Nemirovskaya & Nigmadganov, 1994; Nemyrovska *et al.* 2011). Ammonoids indicate the presence of the *Fayettevillea–Delepinoceras* and *Homoceras–Hudsonoceras* zones (E2 to H), facilitating broad correlations across the South Urals, Western Europe, Central Asia and Nevada in the USA. In summary, the Muradymovo section is a very good auxiliary section for the MCB interval allowing reliable correlations with many other successions worldwide.

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view. **9a**, **9b**, *Rectonaria* sp. 2, specimen no. 66–95, right valve view and dorsal view. **10a**, **10b**, *Coeloenellina serotina* Kotschetkova, 1983, specimen no. 66–4, right valve view and dorsal view. **11**, *Healdia* sp. 1, specimen no. 66–317, left valve view. **12**, *Kirkbya* sp. C, specimen no. 66–23, right valve view. **13**, *Amphisona* sp., specimen no. 66–30, left valve view. **14**, *Bairdianella* sp., specimen no. 66–136, right valve view. **15**, *Libumella* aff. *reticulata* Robinson, 1978, specimen no. 66–13, left valve view. **16**, *Bairdia alula* Kotschetkova, 1983, specimen no. 66–322, right valve view. **17**, *Bairdia chudolasensis* Kotschetkova, 1983, specimen no. 66–129, right valve view. **18**. *Ectodemites tumidus* Cooper, 1941, specimen no. 66–206, left valve view. **19**, *Acanthoscapha* aff. *limata* N. Kotchetova in Kulagina *et al*. 1992, specimen no. 66–324, right valve view. **20**, *Kirkbya* sp. B, specimen no. 66- 214, right valve view. **21**, *Bairdiocypris indiges* Kotschetkova, 1983, specimen no. 66–215, right valve view. **22a**, **22b**, *Chamishaella opima* Kotschetkova, 1983, specimen no. 66–223, right valve view and dorsal view, sample 80a. **23**, *Fellerites gratus* N. Kotchetova & Vakula in Kulagina *et al*. 1992, specimen no. 66–21, left valve view. **24**, *Kirkbya* sp. A, specimen no. 66–308, right valve view.

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