Conodont stratigraphy and correlation of the Ordovician volcanogenic and volcanogenic sedimentary sequences in the South Urals

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[1] Conodont studies of three types of the South Uralian Ordovician sections related to various tectonic zones and, accordingly, to different elements of the Uralian paleoocean active margin, have provided a significant advancement of the Ordovician stratigraphy in the region. The siliceous basaltic type of section (Polyakovka Formation) in the Western Magnitogorsk zone was formed at different stages of the ocean basin evolution. The stratigraphic range of the formation is extended to the Upper Tremadocian–Ashgillian owing to a finding of redeposited Late Tremadocian *Loxodus* cf. *latibasis* Ji et Barnes. The other section types are recorded in structures of the Sakmara and Sakmara–Voznesenka zones. Sediments of the siliceous tuffaceous type (Kuragan Formation) were accumulated from the Arenigian to Ashgillian inclusive. The basal, Arenigian–Llanvirnian part of the Kuragan Formation, was deposited in a distal area of the marginal basin and its top (Novokursk sequence) was associated with foot environments of the Ordovician Guberlya ensimatic island arc. The island arc complex corresponding to a third, volcanogenic type of section, is represented by the successive Guberlya and Baulus formations. The Llanvirnian-earliest Caradocian age of the Guberlya Formation is estimated from the conodont evidence; its status as the Ordovician formation is regained; and its conformable contact with the Upper Caradocian–Ashgillian Baulus Formation is revealed. A set of massive sulfide ore deposits is associated with the Baulus Formation sediments. Similar in composition, Late Caradocian–Ashgillian conodont associations are recorded in supraore cherts of the Blyava and Komsomol'skoe deposits, and in many of the deposits located along the supraore cherts strike. Conodont "faunal beds" are first distinguished in sections of the reported formations. The Ordovician interval of the Polyakovka Formation is characterized by eleven successive faunal beds. Five faunal beds are recorded in the Ordovician of the Kuragan Formation. The section of the Guberlya Formation includes the succession of six faunal beds embracing the upper Middle to lower Upper Ordovician. Two faunal beds are recognized in the Upper Ordovician Baulus Formation. The proposed South Urals Ordovician conodont scale that includes eleven stratigraphic units, is based on the successive alteration of conodont associations with the use of species of the *Periodon, Pygodus, Ansella*, and *Protopanderodus* lineages. The scale represents one of still few variants of conodont scales developed for the Tropical Domain of the Open-Sea or Open-Ocean Paleobiogeographic Realm. Eight deep-water and/or relatively deep-water biofacies are identified and analyzed. *INDEX TERMS:* 0410 Biogeosciences: Biodiversity; 0459 Biogeosciences: Macro- and micropaleontology; 3030 Marine Geology and Geophysics: Micropaleontology; 4950 Paleoceanography: Paleoecology; *KEYWORDS:* Stratigraphy, Ordovician, conodonts, formations, "faunal beds", biofacies, volcanogenic sedimentary deposits, South Urals.

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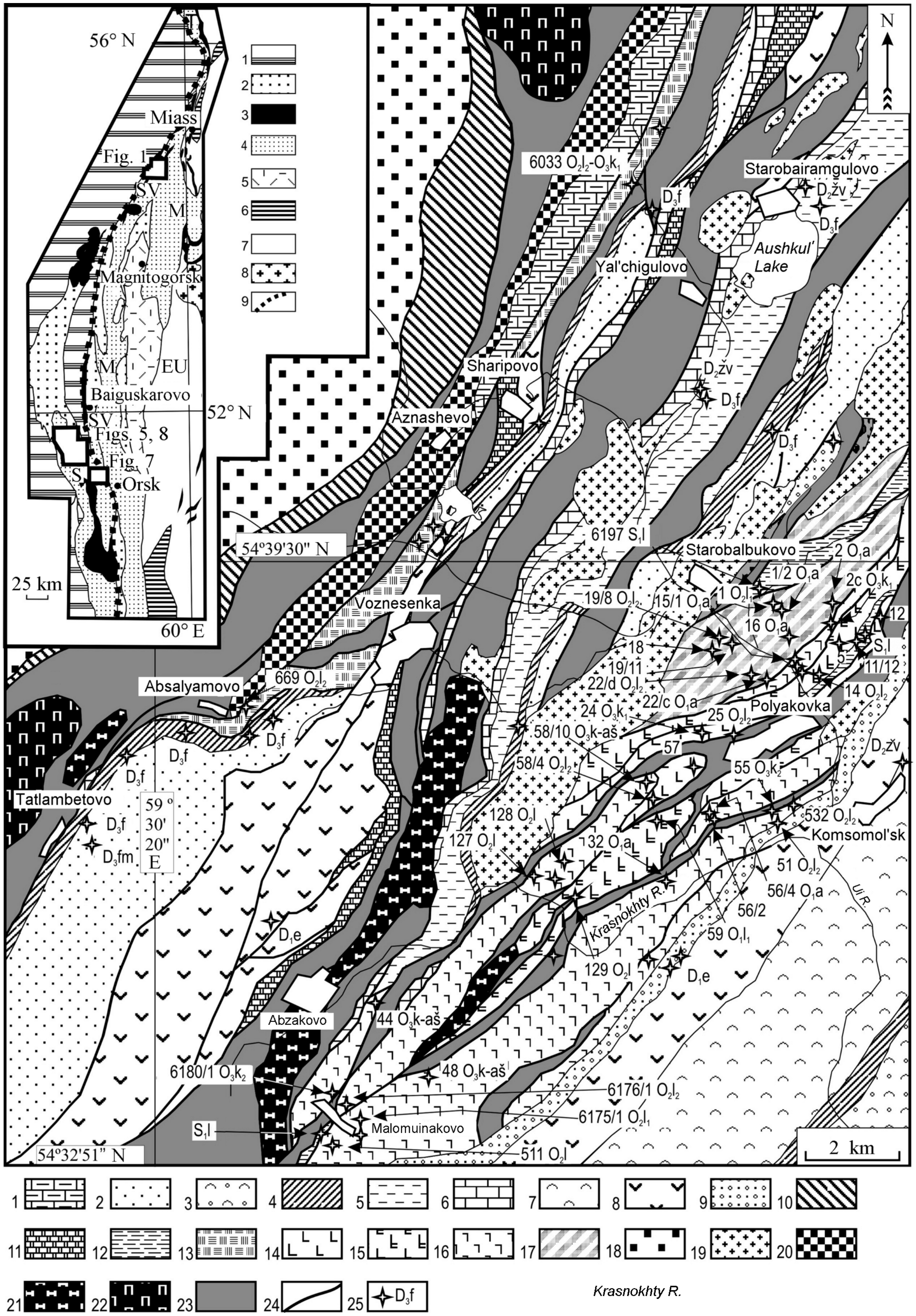
Introduction

[2] In the South Urals the Paleozoic complexes of various structural-and-formational paleozones are tectonically juxtaposed. They make up a system of nappes with facially dif-


56° N
Miass
Fig. 1
SV
M
Magnitogorsk
M
EU
Baiguskarovo
52° N
SV
Figs. 5, 8
Fig. 7
S
Orsk
25 km
60° E
N
6033 O2l2-O3k1
Starobairamgulovo
D3f
D2žv
Aushkul' Lake
Yal'chigulovo
Sharipovo
D2žv
D3f
Aznashevo
54°39'30" N
6197 S1l
Starobalbukovo
2 O1a
1/2 O1a
2c O3k1
1 O2l1
19/8 O2l2
15/1 O1a
16 O1a
12
18
S1l
19/11
11/12
22/d O2l
14 O2l2
22/c O1a
Polyakovka
24 O3k1
25 O2l2
58/10 O3k-aš
57
D2žv
58/4 O2l2
55 O3k2
532 O2l2
Komsomol'sk
128 O2l
127 O2l
32 O1a
51 O2l2
56/4 O1a
Krasnokhty R.
56/2
59 O1l1
Ui R.
129 O2l
D1e
Voznesenka
Absalyamovo
669 O2l2
D3f
Tatlambetovo
59° 30' 20" E
D3fm
D1e
Abzakovo
44 O3k-aš
48 O3k-aš
6180/1 O3k2
6176/1 O2l2
6175/1 O2l1
S1l
Malomuinakovo
511 O2l
54°32'51" N
2 km
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
D3f
Krasnokhty R.

ferent sections. It is evident that in this case geodynamic and paleogeographical reconstructions are possible only on the basis of detailed stratigraphy of different-sized allochthons. This is particularly true for the Ordovician volcanogenic and volcanogenic sedimentary sequences that are widespread in the South Urals. The stratigraphic subdivision of sequences using conodonts and correlation of the recognized units were performed on the fine-resolution mapping. We studied 204 Ordovician to Devonian localities, 95 of which are Ordovician sites. Conodont elements were found in cherts, phthanites, siliceous siltstones, tuffites, tephroids, and in other rocks at bedding surfaces or inside the sediments. In the latter case they are visible in translucent chips. At times, to reveal a complete association the rock was sawn up to thinnest plates. The Ordovician conodont associations are generally abundant, taxonomically diverse, and are mainly represented by North Atlantic and, rarer, by Midcontinent species. Several thousands of conodont elements are included in the conodont collection no. 4876 deposited in the Geological Institute, Russian Academy of Sciences.

[3] In this work we took into account the revision of Ordovician units [*Fortey,* 1995; *Fortey et al.,* 1995] in the historically type area, Anglo-Wales. It primarily concerns the expanded range of the Llanvirnian and the reduced Llandeilian which now is not a separate stage but is considered as the Llanvirnian upper substage. The Llandeilian is defined by the single graptolite *teretiusculus* Zone. The range of Caradocian is widened at the expense of decreased Llandeilian. The Arenigian and Tremadocian ranges have also changed, namely, a part of Arenigian is referred to the latter stage. This became possible owing to the evidence for corresponding of the Arenigian base, i.e. of the graptolite *Tetragraptus approximatus* Zone lower boundary, to the level within the conodont *proteus* Zone as demonstrated in the sections from the Hunneberg Mountains, southwestern Sweden [*Maletz et al.,* 1996]. Only the lesser part, upper third of the proteus Zone, is now referred to the Arenigian. The rest two thirds of the zone extended the Tremadocian range.

[4] Consequently, the traditional British Ordovician presently includes five units, namely, Tremadocian, Arenigian, Llanvirnian, Caradocian, and Ashgillian with the lower boundaries: at the base of the *approximatus* Zone for the Arenigian, at the base of the *artus* (= '*bifidus*') Zone for the Llanvirnian, at the base of the *gracilis* Zone for the Caradocian, and only the Ashgillian lower boundary corresponds not to the base but to the middle of the *linearis* Zone [*Fortey,* 1995].

[5] The lower series of the Ordovician includes the Tremadocian and lower half of the Arenigian; the Middle Ordovician embraces the Arenigian upper half and the Llanvirnian; Caradocian and Ashgillian are referred to the Upper Ordovician [*Mitchell et al.,* 1997; Figure 1].

[6] The first occurrence of conodont *Iapetognathus fluctivagus* Nicoll et al. defines the base of the Lower Ordovician. The following GSSP suggestions as to the Middle Ordovician base are now considered: (1) first occurrence of conodont *Baltoniodus? triangularis* (Lindström) in the Huanghuachang section in China and (2) first occurrence of conodont *Cooperignathus aranda* (Cooper) in the Niquivil section in Argentine. Finally, the Upper Ordovician base corresponds to the lower boundary of the graptolite *Nemagraptus gracilis* Zone (Ordovician News no. 23, 2006; no. 24, 2007).

[7] In this paper we do not discuss stages of the general scale, which development has yet to be completed. However, the correlation between the unit boundaries of the traditional British scale and the general zonation is already out-

Figure 1. Scheme of the geological structure in the north of the Western Magnitogorsk and Sakmara–Voznesenka zones (compiled using records by V. I. Kozlov, I. S. Anisimov, V. V. Babkin, A. V. Zhdanov and others). 1 – terrigenous carbonate sediments (C_1); 2 – Zilair Formation (D_3–C_1) – flyschoid clayey terrigenous sediments with tuffaceous admixture; 3 – Bugodak Formation (D_3fm) – tuffs, tuffites, andesites, basaltic andesites; 4–5 – Mukasovo Formation (D_3f) and its analogs: 4 – cherts, siliceous siltstones, 5 – grey- and red-colored sandstones and siltstones; 6 – limestones (D_2žv); 7 – Ulutau Formation and analogs of the Yarlykapovo Horizon, nonsubdivided (D_2žv) – basalts, rhyolite tuffs, cherts, jaspers, manganese ores; 8 – Irendyk and Karamalytash formations, pooled and their analogs (D_{1-2}) – intermediate and basic volcanites; 9 – Mansurovo sequence (D_1e) – tuffaceous terrigenous sediments bearing mixtite and chert beds; 10 – terrigenous siliceous and basaltic siliceous sequences (S–D_1); 11 – limestones (S_2–D_1); 12 – Sakmara Formation (S_{1-2}) – carbonaceous siliceous shales and siltstones; 13 – Guberlya Formation (O_{2-3}) – basalts, tuffites, cherts, tuffs of mixed composition; 14–17 – Polyakovka Formation (O_{1-3}) in the nappes' section: 14 – first (lower) nappe – basalts, cherts (O_2l–O_3k$_1$), 15 – second nappe – basalts and cherts (O_2l–O_3k$_1$), 16 – third nappe – basalts and cherts (O_1a–O_3k-aš), 17 – fourth nappe – basalts, red cherts, specular schists (O_1a–O_2l$_2$); 18 – meta-arkoses R_3?; 19 – Balbukovka complex of alkalic granitoids (PZ_3); 20 – gabbro-diorites (D_1); 21 – dunite-wehrlite-clinopyroxenite complexes; 22 – peridotites (lherzolites) of the Nurali (on the north) and Tatlambet (on the south) massifs; 23 – serpentinite melange; 24 – fault deformations; 25 – findings of paleontological remains, their numbers and age.
The inset map shows rock complexes in the South Urals (after *Savel'ev et al.* [1998], simplified) and location of the studied areas (Figures 1, 5, 7, and 8, Baiguskarovo area): 1 – East European platform margin; 2 – Late Devonian–Early Carboniferous graywackes (Zilair series): 3 – ophiolitic massifs and serpentinite melanges; 4 – Ordovician and Devonian complexes of accretionary prisms and island arcs (SV – Sakmara–Voznesenka, M – Magnitogorsk, S – Sakmara, T – Tagil zones); 5 – Late Devonian and Carboniferous suprasubduction and riftogenic volcanogenic and carbonate complexes; 6–7 – East Uralian zone: 6 – pre-Paleozoic and Early Paleozoic metamorphic complexes, 7 – terrigenous covers, riftogenic volcanic complexes; 8 – Late Paleozoic granitoids of the Dzhabyk massif; 9 – Major Uralian Fault.

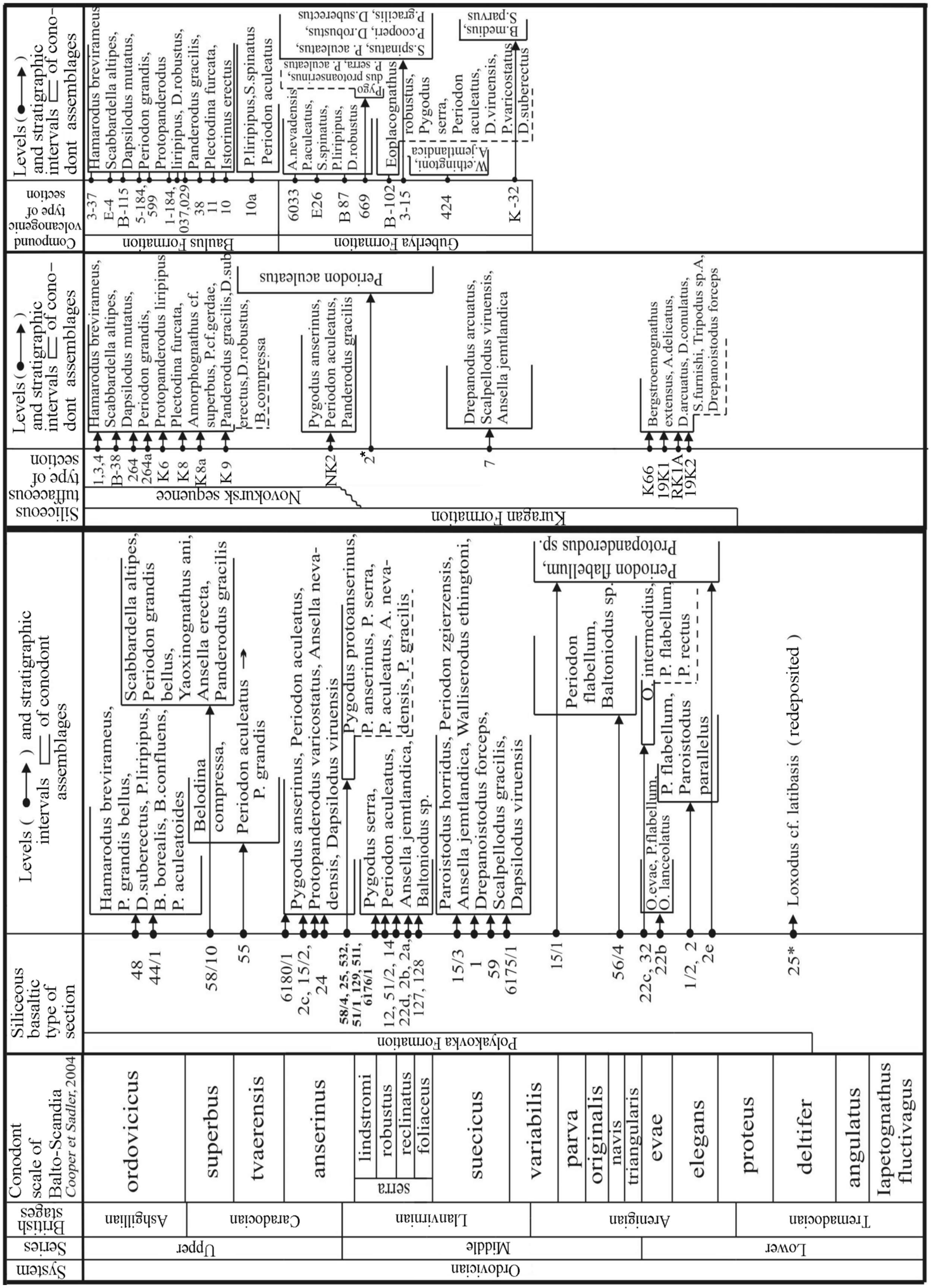


Figure 2. Successions of Ordovician conodont assemblages with the indicated stratigraphic ranges in sections of the Polyakovka, Kuragan, Guberlya, and Baulus formations of the South Urals.

lined (International Subcommission..., 2006 (http://www.ordovician.cn)).

[8] The following three types of sections are recorded among the Ordovician volcanogenic and volcanogenic sedimentary sequences: siliceous basaltic, siliceous tuffaceous, and compound volcanogenic; they vary in stratigraphic completeness and are related to different elements of the Uralian paleoocean active margin (see below). In relation to tectonic zonality of the South Urals these types of Ordovician sections are distributed as follows (see inset map in Figure 1): the siliceous basaltic type is recorded in the Western Magnitogorsk zone; the other types, in the Sakmara and Sakmara–Voznesenka zones.

[9] Taken as the basis the previously published description of the sections [*Ryazantsev et al.,* 1999, 2000, 2005] is supplemented with new conodont localities and supported by fresh records. Among these are the data on composition and successive alteration of conodont associations in certain sections; recognition of stratigraphic range of every association in a section (Figure 2); on these grounds the distinction of additional biostratigraphic units, namely, "faunal beds"; the use of overlapped ranges of conodont assemblages for establishing the boundaries of faunal beds (see below); correlation of certain sections in order to compile a composite section of a formation, where the recognized faunal beds hold their places; elucidation, where possible, of major conodont morphophylogenetic lineages; and correlation of faunal-bed successions in three types of the South Uralian sections with the conodont zonation of Balto-Scandia and traditional British stages (Figure 3).

[10] On the same basis we refined correlations and analyzed the conodont biofacies in the region. We illustrated some diagnostic species of Arenigian (see Appendix, Plate 1), Llanvirnian (see Appendix, Plate 2), Uppermost Llanvirnian (see Appendix, Plate 3), Uppermost Llanvirnian – Caradocian (see Appendix, Plate 4), and Upper Caradocian – Ashgillian (see Appendix, Plate 5) conodont associations of the South Urals.

[11] Conodonts were photographed in reflected light using stereomicroscope Leica MZ 8 (with binocular tube assembly) in the Geological Institute, Russian Academy of Sciences. Prior to imaging, the rocks were moistened with water, whether it be cherts bearing conodonts visible in translucent chips or bedding surfaces of tuffaceous siltstones with conodonts.

[12] In this work we took into account both the most detailed conodont zonation of Balto-Scandia [*Cooper and Sadler,* 2004] and the record on siliceous sequences of Central Kazakhstan [*Dubinina,* 1991, 1998, 2000; *Tolmacheva et al.,* 2001, 2004]. The latter is especially important for comparison with the South Uralian conodont scale presented in this paper. Unlike paleoenvironments of Balto-Scandia, the deep-water Central Kazakhstan and South Urals' environments belong to a part of the North Atlantic Realm that was recently considered [*Zhen and Percival,* 2003] as a separate paleobiogeographic Open-Ocean Realm of the Tropical Domain. Stratigraphic range of certain species is there wider than in the Ordovician sections of Balto-Scandia. In addition, we considered the records on Western Newfoundland [*Johnston,* 1987; *Pohler,* 1994] and northwestern China (Kuruktag) [*Wang and Qi,* 2001] that are also referred to that realm.

Siliceous Basaltic Type of Section

[13] **Polyakovka Formation.** The siliceous basaltic complex in the northern Magnitogorsk zone is recognized as the Polyakovka Formation and is dated as the Ordovician from conodont evidence [*Borisenok et al.,* 1998; *Ivanov et al.,* 1989; *Ryazantsev et al.,* 1999; *Zonenshain et al.,* 1984]. Previously the Polyakovka Formation distinguished within the Uchaly region [*Koptev-Dvornikov et al.,* 1940], was subdivided into two sequences, volcanogenic and volcanogenic sedimentary one. Its age was estimated as Silurian based on graptolite findings from the overlying siliceous clayey shales.

[14] In the stratotype area, the Polyakovka Village region (Figure 1), the siliceous basaltic complex forms a stripe of exposures up to 5 km wide and over 30 km long. Here, on the flanks of antiform complicated by strike-slip faults and reversed faults, in the set of four nappes, the sections of siliceous basaltic complex differing in composition and thickness of synchronous units, are juxtaposed (Figure 4). This structure steeply dips northwestward (at 60° to 80°), i.e. the antiform southern flank is overturned.

[15] **The first nappe.** On the western flank of the pericline, near the western margin of the Polyakovka Village, the serpentinite melange is overlain by a complex of parallel doleritic dikes ranging in thickness from 5 cm to 1 m. Among them the sets of the dike-into-dike type with chilled contacts, are recorded. In the basal part the screens are represented by serpentinites and pyroxenites; at the top, by aphyric pillow basalts. The overlying 30-m-thick basalt member yields single sills. The basalts are overlain by a 60-m-thick member of red-brown, grey-green, dark grey, and black chert beds. The red-brown bed nearby the base, at Point 25 (Figures 1–4), contains numerous *Pygodus protoanserinus* Zhang, *P. anserinus* Lamont et Lindström, scarce *P. serra* (Hadding), a full range of numerous elements of *Periodon aculeatus* Hadding, as well as *Ansella nevadensis* (Ethington et Schumacher), *Panderodus* sp., *Protopanderodus* sp., and the redeposited Late Tremadocian *Loxodus* cf. *latibasis* Ji et Barnes (see Appendix, Plate 3, fig. 14). This association is characteristic of the *Pygodus protoanserinus* and *P. anserinus* Beds of the Polyakovka Formation (Figure 3), which correspond to the lowermost *anserinus* Zone of Balto-Scandia [*Cooper and Sadler,* 2004], i.e. to the uppermost Llanvirnian of Britain [*Fortey,* 1995].

[16] Upward from the base a 20-m-thick member of clayey siliceous shales bearing pale-yellow chert lenses and rare beds of carbonaceous siliceous shales, is recorded. In this member, recovered by a small quarry, at Point 24 (Figure 4) *Pygodus anserinus* Lamont et Lindström, *Periodon aculeatus* Hadding, and *Protopanderodus varicostatus* (Sweet et Bergstrom) were encountered. Stratigraphic range of the assemblage corresponds to the uppermost Llanvirnian–Lower Caradocian (Figure 2). It is characteristic of the *Pygodus anserinus, Periodon aculeatus*, and *Ansella nevadensis* Beds

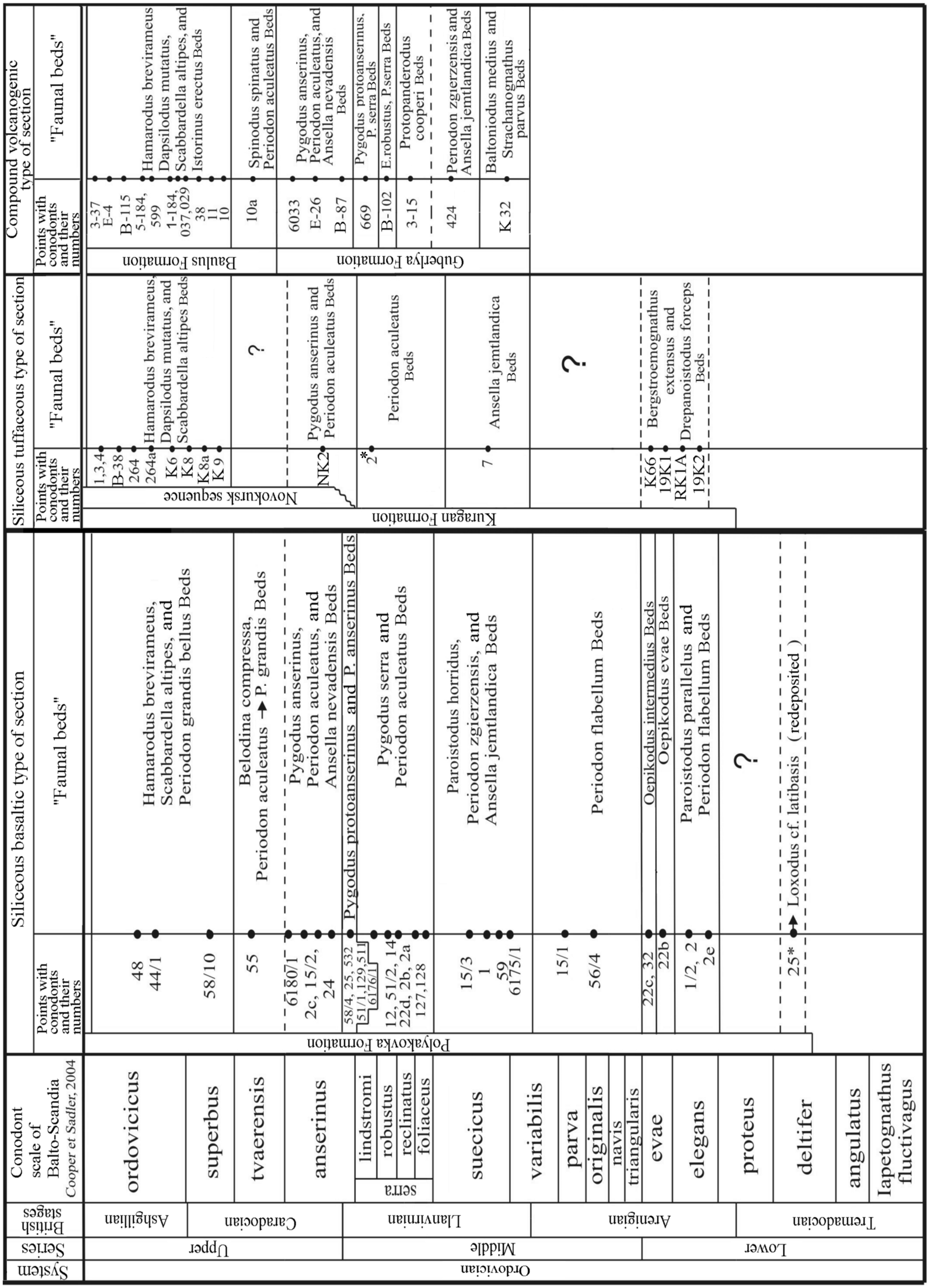


Figure 3. Correlation of the Ordovician faunal beds' successions in the sections of the Polyakovka, Kuragan, Guberlya, and Baulus formations in the South Urals with the Balto-Scandia conodont scale and British Ordovician stages.

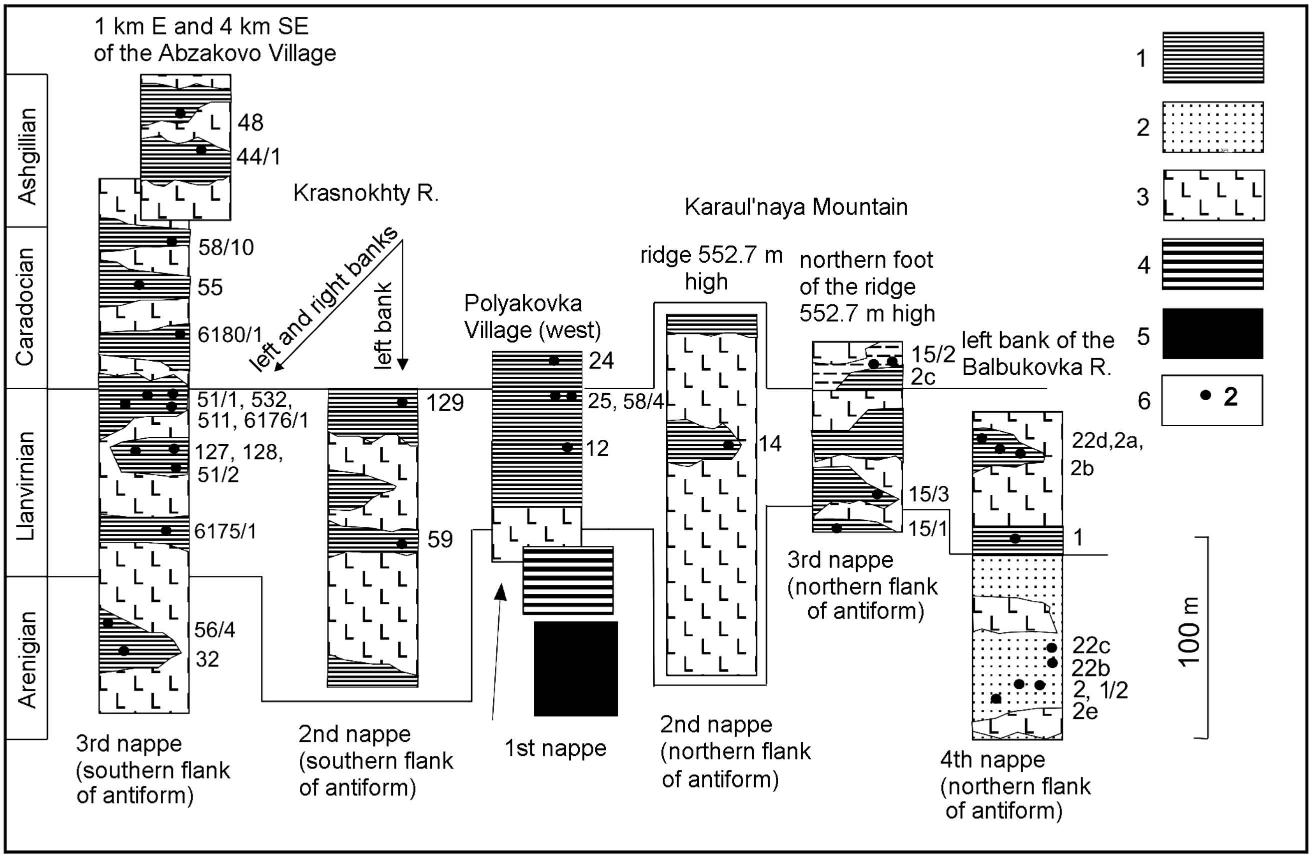


Figure 4. Correlation of sections of the Polyakovka siliceous basaltic complex (Western Magnitogorsk zone): 1 – grey-green, rarely red-brown cherts and siliceous siltstones, phthanites, clayey siliceous shales; 2 – red-brown and red cherts, siltstones, specular schists; 3 – grey-green aphyric basalts, hyaloclastites; 4 – dolerites of the parallel dike (sills) complex; 5 – serpentinite melange; 6 – points of conodont localities and their numbers.

of the Polyakovka Formation (Figure 3), corresponding to the upper part of the *anserinus* Zone of Balto-Scandia, i.e. to the lower part of the Caradocian Stage (Upper Ordovician).

[17] This example shows that the stratigraphic range of the conodont association does not coincide with the range of the recognized faunal beds. As noted in the Introduction, we use a method of overlapped ranges of conodont assemblages (Figure 2) to establish the boundaries of faunal beds (Figure 3). In this instance, owing to overlapping of adjacent intervals of conodont assemblage ranges, the base of faunal beds is shifted upwards (Figures 2 and 3). Thus the recognized *Pygodus anserinus, Periodon aculeatus*, and *Ansella nevadensis* Beds do not include the uppermost Llanvirnian analogs but are referred only to those of the lower part of the Caradocian.

[18] At 2 km southwards a member of grey-green coarsely flaggy cherts (Point 58/4) (Figures 1 and 4) overlies the 15-m-thick bed of pyroxene-plagioclase porphyrites. The cherts contain abundant *Pygodus protoanserinus* Zhang (see Appendix, Plate 3, figs. 7–9, 11), few *P. anserinus* Lamont et Lindström, *P. serra* (Hadding), a full range of numerous elements of *Periodon aculeatus* Hadding, along with *Ansella* sp. and *Baltoniodus* sp. The association is characteristic of the *Pygodus protoanserinus* and *P. anserinus* Beds of the Polyakovka Formation (Figure 3), which correspond to the lowermost *anserinus* Zone of Balto-Scandia, i.e. to the uppermost Llanvirnian. We can say about a part of the *anserinus* Zone or, more precisely, about its lowermost portion based on the studies of the *Pygodus* morphophylogeny. The succession *P. serra* → *P. protoanserinus* → *P. anserinus* was traced in Sweden [*Zhang,* 1998] and in the South Urals (this paper). These records permit the distinction of narrow stratigraphic units in the uppermost Llanvirnian and its analogs. For instance, the *Pygodus protoanserinus* and *P. serra* Beds in the South Uralian sections correspond to the upper part of the *serra* Zone of Balto-Scandia, whereas the Uralian *Pygodus protoanserinus* and *P. anserinus* Beds, to the lower part of the *anserinus* Zone of Balto-Scandia (Figure 3).

[19] At the northern extension of the nappe, west of the serpentinite stripe recovered by the quarry, a sequence of homogeneous, massive, grey-green aphyric basalts bearing rare grey chert lenses and crowned by a 10- to 13-m-thick horizon of massive grey-green and red-brown bedded cherts, is recorded. The horizon extends for a distance of 1 km, from

Point 11/9 to Point 12 (Figures 1 and 4). At the latter point *Pygodus serra* (Hadding) and *Periodon aculeatus* Hadding, typical for the Upper Llanvirnian beds of the same name, were gathered (Figure 3).

[20] As a whole the interval from the Upper Llanvirnian analogs to Lower Caradocian, i.e. from the upper Middle to lower Upper Ordovician inclusive, is estimated in the first nappe.

[21] **The second nappe** (Figures 1 and 4). The faults separating the second nappe are associated with serpentinite stripes and lenses. The nappe is composed of a 150- to 250-m-thick sequence of aphyric and, rarer, porphyritic basalts with grey chert lenses and members bearing Llanvirnian conodonts.

[22] On the northern flank of the antiform at Point 14 (Figure 4) the rocks contain *Pygodus* cf. *serra* (Hadding) and *Periodon aculeatus* Hadding characteristic of the *Pygodus serra* and *Periodon aculeatus* Beds (Figure 3) corresponding to the Upper Llanvirnian.

[23] On the southern flank of the antiform at Point 59 (Figure 4) *Periodon zgierzensis* Dzik, *Ansella jemtlandica* (Löfgren), *Drepanoistodus forceps* (Lindström), and *Protopanderodus* sp. were encountered. They are peculiar to the *Paroistodus horridus, Periodon zgierzensis*, and *Ansella jemtlandica* Beds corresponding to the Lower Llanvirnian analogs (Figure 3).

[24] The chert beds at the southwestern extension of the nappe are referred to the *Pygodus protoanserinus* and *P. anserinus* Beds (Figure 3) that correspond to the uppermost Llanvirnian. At Point 129 located 2.3 km southwest of Point 59 (Figures 1 and 4) the cherts yield *Pygodus* cf. *protoanserinus* Zhang, *Periodon aculeatus* Hadding, *Drepanoistodus suberectus* (Branson et Mehl), and *Drepanodus* sp.

[25] **The third nappe** (Figures 1 and 4). The section embraces the interval from the “Middle” Arenigian to Lower Caradocian on the northern flank, and to the Ashgillian, on the southern one (Figure 4).

[26] On the northern flank of the antiform the 100-m-thick section is exposed on the left bank of the Ui River, along the road connecting the Komsomolskii and Starobairamgulovo villages, nearby the northwestern foot of the Karaul’naya Mountain. The following units are traced from the north to the south (Figure 4):

[27] 1. Grey-green aphyric basalts. Thickness 15 m.

[28] 2. Grey-green, compact cherts, at Point 15/1 bearing *Periodon flabellum* (Lindström) (see Appendix, Plate 1, figs. 1, 4) and *Protopanderodus* sp., corresponding to the *Periodon flabellum* Beds (Figure 3), i.e. to the “Middle”–Upper Arenigian analogs. Thickness 10 m.

[29] 3. Grey-green aphyric basalts. Thickness 25 m.

[30] 4. Yellow-green, siliceous flaggy siltstones, at Point 15/3 bearing *Periodon zgierzensis* Dzik, *Ansella* cf. *jemtlandica* (Löfgren), *Paroistodus* cf. *horridus* (Barnes et Poplawski), and *Pygodus* sp., and representing the *Paroistodus horridus, Periodon zgierzensis*, and *Ansella jemtlandica* Beds (Figure 3) referred to the Lower Llanvirnian analogs. Thickness 12 m.

[31] 5. Grey-green aphyric basalts. Thickness 15 m.

[32] 6. Pale-yellow, flaggy siltstones, at Point 15/2 yielding *Pygodus anserinus* Lamont et Lindström, *Periodon aculeatus* Hadding, *Protopanderodus* sp., and *Baltoniodus* sp., corresponding to the *Pygodus anserinus, Periodon aculeatus*, and *Ansella nevadensis* Beds (Figure 3), i.e. to the Lower Caradocian analogs. Thickness 6 m.

[33] At 1.2 km northeast of Point 15/2, at Point 2c (Figures 1 and 4) the similar rocks bearing *Pygodus* cf. *anserinus* Lamont et Lindström, *Ansella nevadensis* (Ethington et Schumacher), *Periodon aculeatus* Hadding, *Dapsilodus viruensis* (Fahraeus), *Protopanderodus varicostatus* (Sweet et Bergstrom), and *Drepanodus robustus* Hadding are correlative to the same faunal beds of the Lower Caradocian (Figure 3).

[34] On the southern flank of the antiform the Ordovician rocks make up a wider stripe of exposures in the form of a ridge along the Krasnokhty River left bank (Figures 1 and 4). They are represented by grey-green and black chert members alternating with aphyric basalts and hyaloclastites. The second and third nappes are separated by the fault, south of which the 50-m-thick member of grey-green aphyric basalts interbedded with grey-green, dark grey, and, rarely, white cherts, is recorded. The latter, at Point 56/4 (Figure 1) yield *Periodon flabellum* (Lindström) and *Baltoniodus* sp. characteristic of the *Periodon flabellum* Beds that correspond to the Upper Arenigian (Figure 3). Further southward, at the extension of this horizon, at Point 32 (Figure 1) the rocks bear *Periodon flabellum* (Lindström) and *Oepikodus intermedius* Serpagli attributed to the *Oepikodus intermedius* Beds, i.e. to the “Middle” Arenigian analogs (Figure 3). The term “Middle” Arenigian is informal and so is used in quotation marks.

[35] The younger stratigraphic units are recovered at Points 51 and 55. Nearby the southeastern foot of the ridge, in bedrock outcrops, grey cherts are exposed. At Point 51/2 (Figures 1 and 4) they contain *Pygodus serra* (Hadding) and *Periodon aculeatus* Hadding, specific for the *Pygodus serra* and *Periodon aculeatus* Beds that correspond to the Upper Llanvirnian (Figure 3). Upward along the slope the grey cherts are replaced by hard-rock outcrops of clotted, grey- and white-colored cherts bearing at Point 51/1 (Figures 1 and 4) numerous *Pygodus anserinus* Lamont et Lindström (see Appendix, Plate 4, figs. 1, 5), *Periodon aculeatus* Hadding and scarce *Pygodus serra* (Hadding), *Plectodina* sp., and *Panderodus* sp. Despite the absence of *Pygodus protoanserinus* Zhang, the combined occurrence of the two other species, namely, *P. anserinus* Lamont et Lindström and *P. serra* (Hadding), which occur concurrently only in the lower part of the *anserinus* Zone of Balto-Scandia [*Zhang,* 1998], makes it possible to consider the association as a faunal characteristics of the *Pygodus protoanserinus* and *P. anserinus* Beds (Figure 3) corresponding to the uppermost Llanvirnian analogs. The member is about 50 m thick. In the westward direction it grades into the 200-m-thick sequence of monotonously alternated grey hornfels cherts and grey-green aphyric basalts.

[36] In the middle part of the ridge the section is terminated by the 3- to 8-m-thick chert bed. At Point 55 (Figures 1 and 4) the massive, grey-green cherts yield *Periodon aculeatus* Hadding, the advanced, transitional to *P. gran-*

dis (Ethington) form (see Appendix, Plate 4, figs. 6, 7, 9–12), *Belodina compressa* (Branson et Mehl), and *Baltoniodus* sp., i.e. the association characteristic of the *Belodina compressa, Periodon aculeatus* → *P. grandis* Beds (Figure 3) corresponding to the analogs of the mid-Caradocian.

[37] At 200 m northeast of Point 55 the massive, grey-green cherts at Point 532 (Figures 1 and 4) bearing *Pygodus protoanserinus* Zhang, *P. anserinus* Lamont et Lindström, *P. serra* (Hadding), *Periodon* cf. *aculeatus* Hadding, *Walliserodus ethingtoni* (Fahraeus), *Drepanodus* cf. *arcuatus* Pander, and *Panderodus* sp. are referred to the *Pygodus protoanserinus* and *P. anserinus* Beds (Figure 3) that are correlative to the lowermost *anserinus* Zone of Balto-Scandia, i.e. to the uppermost Llanvirnian.

[38] The grey cherts occurring among basalts at the southwestern extension of the nappe on the left bank of the Krasnokhty River (Points 127 and 128) (Figures 1 and 4) correspond to the Upper Llanvirnian *Pygodus serra* and *Periodon aculeatus* Beds (Figure 3). At Point 127 the cherts contain *Pygodus* cf. *serra* (Hadding), *Periodon* cf. *aculeatus* Hadding, and *Ansella* sp. and in Point 128, *Pygodus serra* (Hadding), *Periodon* cf. *aculeatus* Hadding, and *Panderodus* sp.

[39] The repeated alternation of aphyric basalts and grey-green cherts is observed 2.3 km northeast of Point 128. Here, at Point 58/10 (Figures 1 and 4) the yellow-brown foliated cherts yield *Periodon grandis bellus* (Moskalenko), *Ansella erecta* (Rhodes et Dineley), *Scabbardella altipes* (Henningsmoen), *Yaoxinognathus ani* Zhen, Webby et Barnes, and *Panderodus gracilis* (Branson et Mehl) (Figure 2). The assemblage is characteristic of the *Hamarodus brevirameus, Scabbardella altipes*, and *Periodon grandis bellus* Beds of the Polyakovka Formation (Figure 3) and ranges from the Upper Caradocian analogs to the Ashgillian.

[40] Some facies changes are recorded at the southwestern extension of the Polyakovka assemblage distribution area referred to the third nappe, on the right bank of the Krasnokhty River. The 200-m-thick lenslike sequence including aphyric basalts, hyaloclastites, lava breccias, yellow and dark red cherts in places substituted by red jaspers, is exposed north of the Malomuinakovo Village (Figure 1). In the upper part of the section, in red cherts at Point 6175/1 *Paroistodus horridus* (Barnnes et Poplawski), *Periodon zgierzensis* Dzik, and *Ansella* sp. were collected. They are characteristic of the *Paroistodus horridus, Periodon zgierzensis*, and *Ansella jemtlandica* Beds (Figure 3) assigned to the Lower Llanvirnian analogs. Further westwards they are replaced by the 100-m-thick sequence mainly composed of carbonaceous siliceous shales and basalt lenses. At Point 6176/1 (Figures 1 and 4) the rocks contain the predominant *Periodon aculeatus* Hadding, along with *Pygodus protoanserinus* Zhang, *P. anserinus* Lamont et Lindström, *Drepanoistodus suberectus* (Branson et Mehl), and *Panderodus gracilis* (Branson et Mehl) that are peculiar for the *Pygodus protoanserinus* and *P. anserinus* Beds (Figure 3) referred to the uppermost Llanvirnian analogs. These faunal beds are also correlative to the chert strata at Point 511 located 1 km southwest of the previous point (Figures 1 and 4). They bear *Pygodus* cf. *anserinus* Lamont et Lindström, *P. serra* (Hadding), *Periodon aculeatus* Hadding, *Protopanderodus* cf. *cooperi* Sweet et Bergstrom, *Drepanoistodus suberectus* (Branson et Mehl), *Spinodus* cf. *spinatus* (Hadding), and *Panderodus* sp. At 440 m northwest of Point 511 the pillow basalts with hyaloclastites and lenses of carbonaceous siliceous rocks bearing Early Silurian graptolites, are recorded [*Maslov and Artyushkova,* 2000].

[41] West of Point 6176/1, in a 70-m-wide stripe, the serpentinite melange with lenses of basalts decoupled by grey-green cherts is exposed. The conodont association derived at Point 6180/1 (Figures 1 and 4) includes the predominant in the assemblage, transitional from *Periodon aculeatus* Hadding to *P. grandis* (Ethington) forms, as well as *Pygodus* cf. *anserinus* Lamont et Lindström, transitional forms from *Protopanderodus varicostatus* (Sweet et Bergstrom) to *P. liripipus* Kennedy et al., *Drepanodus robustus* Hadding, *Drepanoistodus suberectus* (Branson et Mehl), *Panderodus gracilis* (Branson et Mehl), and *Yaoxianognathus* sp. The association is characteristic of the uppermost *Pygodus anserinus, Periodon aculeatus*, and *Ansella nevadensis* Beds that are referred to the Middle Caradocian analogs, i.e. to the *anserinus–tvaerensis* zonal boundary of Balto-Scandia (Figure 3).

[42] The uppermost Ordovician rocks are also recorded at the southwestern extension of the Polyakovka assemblage distribution area. At Point 44/1 located 1 km east of the Abzakovo Village (Figures 1–4), in a small roadside quarry the aphyric basalts are interbedded with grey, grey-blue, and black cherts bearing *Hamarodus brevirameus* (Walliser) (see Appendix, Plate 5, figs. 2, 8), *Scabbardella altipes* (Henningsmoen), *Protopanderodus liripipus* Kennedy et al., *Periodon grandis bellus* (Moskalenko), *Plectodina aculeatoides* Sweet, *Besselodus borealis* Nowlan et McCracken, *Belodina* cf. *confluens* Sweet, *Drepanoistodus suberectus* (Branson et Mehl), and *Ozarkodina* sp. At 4 km southeast of the Abzakovo Village, at Point 48 (Figures 1–4) *Hamarodus brevirameus* (Walliser), *Periodon* cf. *grandis* (Ethington), and *Belodina* sp. were encountered. The conodont assemblages at both points are peculiar to the *Hamarodus brevirameus, Scabbardella altipes*, and *Periodon grandis bellus* Beds (Figure 3) that are attributed to the Upper Caradocian–Ashgillian analogs.

[43] Consequently, the rocks of the third nappe embrace an interval from the "Middle" Arenigian to Ashgillian inclusive, i.e. from the uppermost Lower to Upper Ordovician.

[44] **The fourth nappe** is represented on the northern flank of the antiform (Figure 1) and includes the Arenigian to Llanvirnian interval (Figure 4). The Arenigian complex, 80 m to 100 m thick, unlike that of the third nappe, is composed of red-colored cherts, siltstones, specular schists, and grey-green aphyric basalts. Scarce grey-green chert lenses are recorded as well.

[45] At Point 2 (Figures 1–4) the middle part of the red siltstone member yields *Periodon flabellum* (Lindström) and *Paroistodus parallelus* (Pander) characteristic of the *Paroistodus parallelus* and *Periodon flabellum* Beds that correspond to the Lower Arenigian (Figure 3). At Point 2a, 60 m to the west, the red with grey-green spots siltstones contain rare *Pygodus serra* (Hadding) and *Ansella jemtlandica* (Löfgren) along with numerous *Periodon aculeatus* Hadding; and 10 m

upward from the base, at Point 2b, the green siliceous siltstones bear *Pygodus* cf. *serra* (Hadding). Both points are referred to the *Pygodus serra* and *Periodon aculeatus* Beds corresponding to the Upper Llanvirnian (Figure 3). Further westwards, behind the fault, the grey and red specular schists bearing the Arenigian *Periodon flabellum* (Lindström), are exposed at Point 2e (Figure 4).

[46] At Point 1/2 (Figures 1, 3, 4) the red-colored member recovered on the hill, on the Balbukovka River left bank and referred to the *Paroistodus parallelus* and *Periodon flabellum* Beds corresponding to the Lower Arenigian, yields *P.* cf. *parallelus* (Pander) and *P.* cf. *flabellum* (Lindström). In a northwestward direction the red-colored member is replaced by the 10-m-thick phthanite bed that contains at Point 1 (Figures 1–4) *Walliserodus ethingtoni* (Fahraeus), *Scalpellodus gracilis* (Sergeeva), *Dapsilodus viruensis* (Fahraeus), and *Panderodus* cf. *gracilis* (Branson et Mehl). This association is peculiar to the *Paroistodus horridus, Periodon zgierzensis*, and *Ansella jemtlandica* Beds corresponding to the Lower Llanvirnian analogs (Figures 2 and 3). Upward from the base grey-green aphyric basalts are exposed.

[47] South of the Polyakovka–Voznesenka road, 1.5 km south-southeast of the Starobalbukovo Village, on the hillock (Point 22, Figure 1) the following units are recorded upward from the base (Figure 4):

[48] 1. Siliceous, red with hematite crystals siltstones, at Point 22b bearing *Oepikodus evae* Lindström (see Appendix, Plate 1, figs. 2, 3, 5), *Periodon flabellum* (Lindström), *Oistodus lanceolatus* Pander, and *Drepanoistodus forceps* (Lindström), referred to the *Oepikodus evae* Beds (Figure 3) correlative with the "Middle" Arenigian. Thickness 30 m.

[49] 2. Grey siliceous siltstones, at Point 22c yielding *Periodon flabellum* (Lindström), *Oepikodus* cf. *intermedius* Serpagli, and *Protopanderodus* cf. *rectus* (Lindström), assigned to the *O. intermedius* Beds (Figure 3) that correspond to the "Middle" Arenigian. Thickness 10 m.

[50] 3. Grey aphyric basalts with grey-green chert beds, at Point 22d (Figure 4) containing *Pygodus serra* (Hadding) (see Appendix, Plate 2, figs. 6–8), *Periodon aculeatus* Hadding, *Spinodus spinatus* (Hadding), and *Drepanoistodus suberectus* (Branson et Mehl), referred to the *Pygodus serra* and *Periodon aculeatus* Beds (Figure 3) correlative with the Upper Llanvirnian. Thickness 20 m.

[51] Thus the fourth nappe is composed of rocks ranging in age from the Lower Arenigian to Upper Llanvirnian except for the uppermost Llanvirnian.

[52] The available conodont records indicate that the Polyakovka siliceous basaltic complex embraces the interval from Arenigian to Ashgillian inclusive. The stratigraphic range of the Polyakovka Formation can be extended owing to a finding of redeposited Late Tremadocian *Loxodus* cf. *latibasis* Ji et Barnes (see above). The state of preservation and color index, common to all conodont elements in the assemblage, suggest that the Late Tremadocian *Loxodus* cf. *latibasis* Ji et Barnes was redeposited just from the Polyakovka Formation.

[53] The Polyakovka complex grades into the sequence of interbedded basalts and carbonaceous siliceous shales that can be correlated with the Dergaish Formation of the Orenburg region [*Tishchenko and Cherkasov,* 1985]. It is in turn conformably overlain by the carbonaceous shale sequence bearing Middle Llandoverian–Wenlockian conodonts and graptolites, which is the analog of the Sakmara Formation of the stratotype region.

[54] The recognition of the Polyakovka Formation only in the range of the Middle Ordovician [*Maslov and Artyushkova,* 2000] seems improper.

[55] **The composite section of the Polyakovka Formation,** which combines the sections of the four nappes, includes the succession of eleven faunal beds (Figure 3) correlated with the conodont zones of Balto-Scandia [*Cooper and Sadler,* 2004] and traditional stages of the British Ordovician, and referred to the Upper Tremadocian–Ashgillian stratigraphic interval.

[56] The stratigraphic succession of the *Pygodus, Periodon, Protopanderodus*, and *Ansella* species recognized in the Polyakovka Formation, does not contradict the present notion of morphophylogeny of these genera.

[57] The following peculiarities of the discussed section should be noted: (1) the successive chronological alteration of the species *Periodon flabellum* → *P. zgierzensis* → *P. aculeatus* → *P. grandis bellus* (Figure 2); (2) the distinct succession in evolution of *Protopanderodus rectus* → *P. varicostatus* → *P. liripipus* → *P. insculptus*; (3) the lineage *Ansella jemtlandica* → *A. nevadensis* → *A. erecta*; and finally (4) the succession *Pygodus serra* → *P. protoanserinus* → *P. anserinus*, in which *P. protoanserinus* is the most important link that permitted the distinction of the *Pygodus protoanserinus* and *P. anserinus* Beds of a narrow stratigraphic range (Figure 3). Apparently, it will be possible in the future to recognize the *Pygodus protoanserinus* and *P. serra* Beds within the Polyakovka rocks, as is done in the Guberlya Formation (see below).

[58] **Paleoenvironments during the formation of the siliceous basaltic complex.** The Ordovician Polyakovka siliceous basaltic complex of the Western Magnitogorsk zone represents an upper unit of the ophiolitic suite [*Ruzhentsev,* 1976; *Ryazantsev et al.,* 1999]. The fragment of the ophiolitic section we observed (Figure 4) within the first nappe (see above). According to A. V. Ryazantsev, the siliceous basaltic complex was formed at different stages of evolution of the oceanic basin located east of the Ordovician Guberlya ensimatic island arc [*Ryazantsev et al.,* 2005]. To date, the complex is studied in the set of deformed nappes which represent a fragment of the accretionary prism formed in front of the Devonian Magnitogorsk arc. The nappes are characterized by close occurrence of the fragments of sections from different paleooceanic zones, which vary, as shown above, in stratigraphic completeness and in composition of its certain parts.

[59] The siliceous tuffaceous and compound volcanogenic section types of the Kuragan, Guberlya, and Baulus formations are connected by gradual facies changes and, partly, by stratigraphic transitions and are widespread in the Sakmara and southern Sakmara–Voznesenka zones. They are represented in the nappes separated by serpentinite melange and olistostromes.

Siliceous Tuffaceous Type of Section

[60] The Kuragan Formation characterized by the siliceous tuffaceous type of section is widespread on the flanks of the Utyagulovo and Blyava synforms (Figure 5). The formation was distinguished in the 1930s [*Lermontova and Razumovskii,* 1933]. Its section was described in the range of all Ordovician series [*Ruzhentsev,* 1976] and dated by means of conodonts [*Artyushkova et al.,* 1991; *Maslov et al.,* 1993; *Ryazantsev et al.,* 2000, 2005], (K. S. Ivanov and V. N. Puchkov, preprint, 1984).

[61] The **Kuragan Formation** is represented in the lower part by red or grey-green tuffaceous siltstones decoupled by basalt flows and sills. The grey and, rarer, red siliceous tephroids (Novokursk sequence) dominate in the upper part of the section. The close spatial association of the Kuragan Formation with the Tremadocian terrigenous Kidryasovo series is recorded (Figures 5 and 6). In places the formation is conformably overlain by carbonaceous shales of the Silurian Sakmara Formation (Figures 5 and 6).

[62] Nearby the Blyava station (Figure 5a), on the slopes of the Kolnabuk gully, almost vertical occurrence of rocks is observed. The following units are recorded in westward direction upward from the base (Figure 6):

[63] 1. Aphyric basalts decoupled by 0.5-1-m-thick lenses of red tuffaceous siltstones, at Point 19K2 bearing *Tripodus* sp. A Tolmach. and *Drepanodus arcuatus* Pander; and 30 m westwards at Point PK1A with *Acodus delicatus* Branson et Mehl. and *D. arcuatus* Pander, referred to the *Bergstroemognathus extensus* and *Drepanoistodus forceps* Beds corresponding to the upper Lower–“Middle” Arenigian (Figures 2 and 3). Thickness 100 m.

[64] 2. Red tuffaceous siltstones and siliceous tuffites decoupled by 2–10-m-thick beds and lenses of aphyric basalts and at Point 19K1 yielding *Bergstroemognathus extensus* (Graves et Ellison), *Acodus delicatus* Branson et Mehl, *Drepanodus arcuatus* Pander, and *Drepanoistodus forceps* (Lind.); at Point K66 bearing *A. delicatus* Branson et Mehl, *Drepanodus conulatus* Lindström, *Scandodus furnishi* Lindström, and numerous molds of inarticulate brachiopods and ostracodes. They are assigned to the same *Bergstroemognathus extensus* and *Drepanoistodus forceps* Beds, i.e. to the upper Lower–“Middle” Arenigian analogs (Figure 3). Thickness 150 m.

[65] 3. Red tuffaceous siltstones with rare lenses of grey-green tuffaceous siltstones. Thickness 300 m.

[66] 4. Back of the fault, red siltstones similar to that of Bed 3, bearing gabbroid sills. Thickness 150 m.

[67] 5. Massive alternated pink, violet, and pistachio-colored tuffites. Thickness 50 m.

[68] In the stratotype area, 1.4 km northeast of the Kidryasovo Village (Figure 5), on the right bank of the Pis’menka River, the cherry-colored tuffaceous argillites of the Kuragan Formation yield Arenigian–Llanvirnian conodonts identified by S. V. Dubinina [*Korinevskii,* 1988].

[69] The younger units of the section were studied in the Shaitantau Mountains northwest of the Novokurskii Village (Figure 5b). The Shaitantau Mountains are mainly composed of the Silurian Sakmara Formation making up the core of the synform, on which flanks the Ordovician Kuragan rocks are exposed. The Ordovician and Silurian sediments are tectonically overlain by the Ordovician Guberlya Formation and by the Devonian siliceous basaltic complex.

[70] The basal part of the section on the western synform flank is represented by poorly exposed red-colored tuffaceous siltstones bearing grey lenses. The rock is enriched with inarticulate brachiopod and ostracode detritus. The red siltstones at Point 7 (Figure 6) contain *Drepanodus arcuatus* Pander, *Scalpellodus* cf. *S. viruensis* (Löfgren), and *Ansella jemtlandica* (Löfgren) and are referred to the *Ansella jemtlandica* Beds that correspond to the Lower Llanvirnian (Figure 3).

[71] On the eastern flank of the synform (Figures 5b and 6) the red tuffaceous siltstone sequence is overlain by the 50- to 150-m thick member of red and grey-green siliceous tephroids bearing scarce lenses of variegated tuffaceous sandstones. The tephroids at Point 1 yield *Hamarodus brevirameus* (Walliser), *Protopanderodus liripipus* Kennedy et al., *Panderodus gracilis* (Branson et Mehl), *Scabbardella altipes* (Henningsmoen), and redeposited *Periodon aculeatus* Hadding and are referred to the *Hamarodus brevirameus, Dapsilodus mutatus*, and *Scabbardella altipes* Beds corresponding to the Upper Caradocian–Ashgillian (Figure 3).

[72] Crowns of the eastern ridges in the Shaitantau Mountains are made up of the thrust sheet, in the lower part of which grey siliceous tephroids at Point 2* (Figures 5b and 6) contain redeposited conodont elements of *Periodon aculeatus* Hadding that serve as a marker of the *Periodon aculeatus* Beds of the Kuragan Formation, corresponding to the Upper Llanvirnian analogs (Figure 3). Further upwards the grey siliceous tephroids at Point 3 (Figures 5b and 6) yield *Hamarodus brevirameus* (Walliser), *Scabbardella altipes* (Henningsmoen), *Dapsilodus mutatus* (Branson et Mehl), *Periodon grandis* (Ethington), *Protopanderodus liripipus* Kennedy et al., *Panderodus* sp., *Ansella* sp., and *Plectodina furcata* (Hinde); at Point 4, *Hamarodus brevirameus* (Walliser), *Protopanderodus liripipus* Kennedy et al., *Periodon grandis* (Ethington), and *Spinodus spinatus* (Hadding) (see Appendix, Plate 5, fig. 18), and are assigned to the *Hamarodus brevirameus, Dapsilodus mutatus*, and *Scabbardella altipes* Beds corresponding to the Upper Caradocian-Ashgillian (Figure 3). The grey-colored member is 50- to 150-m-thick.

[73] It is conformably overlain by carbonaceous, clayey siliceous and dolomitic shales of the Sakmara Formation, 250–300 m thick (Figures 5b and 6). At Point 5 they contain Llandoverian conodonts *Ozarkodina aldridgei* Uyeno et Barnes and *Dapsilodus obliquicostatus* (Branson et Mehl) and at Point 6, Llandoverian graptolites *Lagarograptus acinaces* (Tornquist).

[74] According to composition, the red-colored tuffaceous siltstone sequence at the base of the Shaitantau section is correlated with the Kuragan sediments from the Blyava Station area (Figure 6). The overlying siliceous tephroids are recognized as the Novokursk [*Khvorova et al.,* 1978] or Pis’menka [*Puchkov,* 2000; *Puchkov et al.,* 1990] sequence in the upper part of the Kuragan Formation. In this paper we accept the first variant.

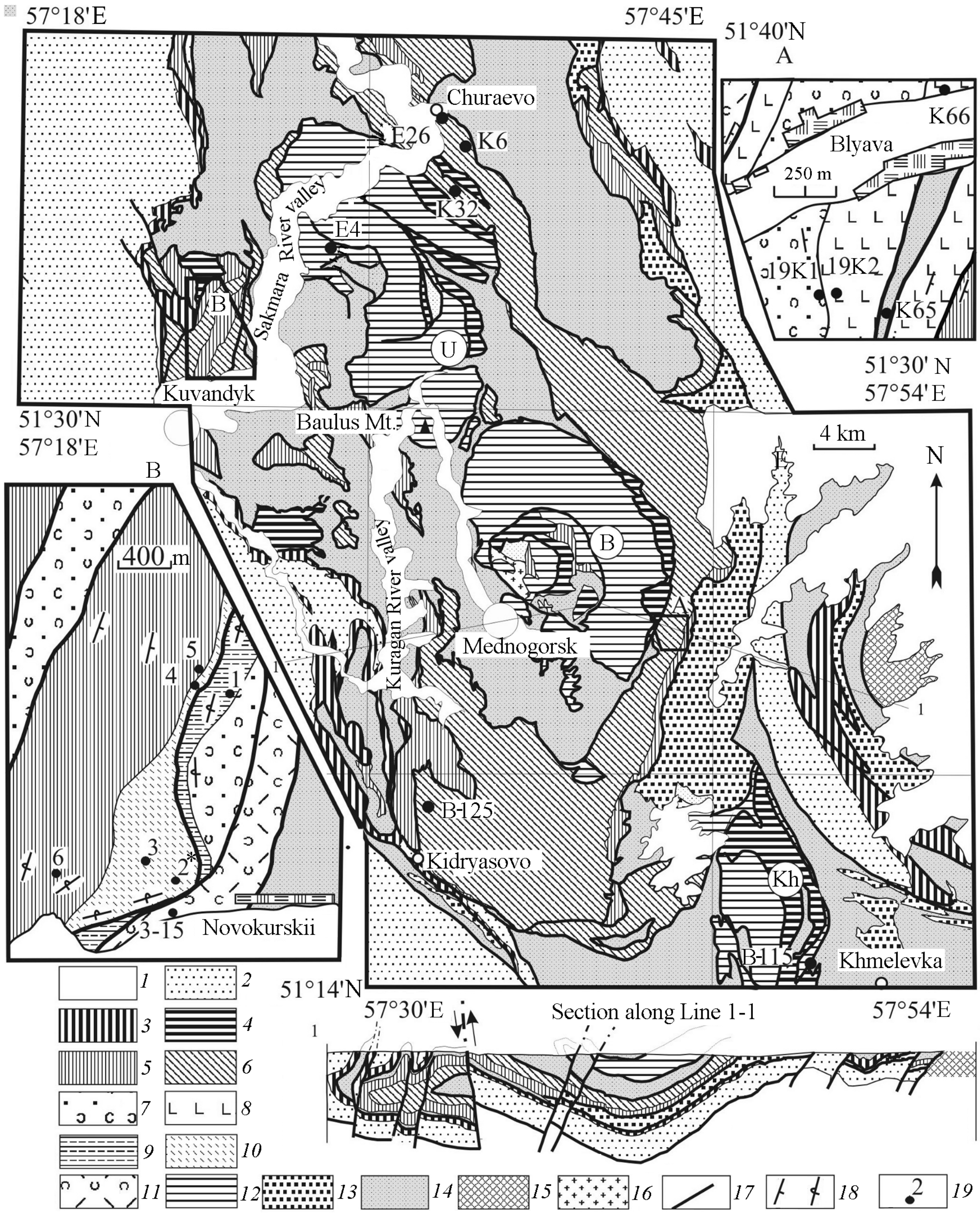


Figure 5. Scheme of the geological structure of the Sakmara zone in the Mednogorsk massive sulphide ore deposit area (compiled using record of geological survey by B. F. Khromykh, V. T. Tishchenko, N. T. Vidyukov and the authors' data): 1 – soft Mesozoic–Cenozoic sediments; 2 – flyschoid terrigenous and terrigenous carbonate sediments (D_3–C_1); 3 – siliceous condensed section (D_{1-3}); 4 – Devonian basaltoid sequences with mixtite beds (D_{1-2}); 5 – siliceous–black-shale sediments of the Silurian Sakmara Formation (S_{1-2}); 6 – siliceous tuffaceous sediments of the Kuragan Formation (O_{1-3}) and volcanogenic tuffaceous deposits of the Guberlya Formation (O_{2-3}); 7–10 – elements of the section of the Kuragan Formation (in insets): 7 – tuffaceous sandstones and siltstones with basalt lenses and sills, 8 – basalts with siliceous tuffite lenses, 9 – grey siliceous tephroids, 10 – red siliceous tephroids; 11 – Guberlya Formation (O_{2-3}), tuffs and tuffites of mixed composition (in insets); 12 – compound volcanogenic complex, Baulus (O_3) and Blyava (S_1) formations; 13 – terrigenous arkosic sediments of the Kidryasovo Formation (O_1t);

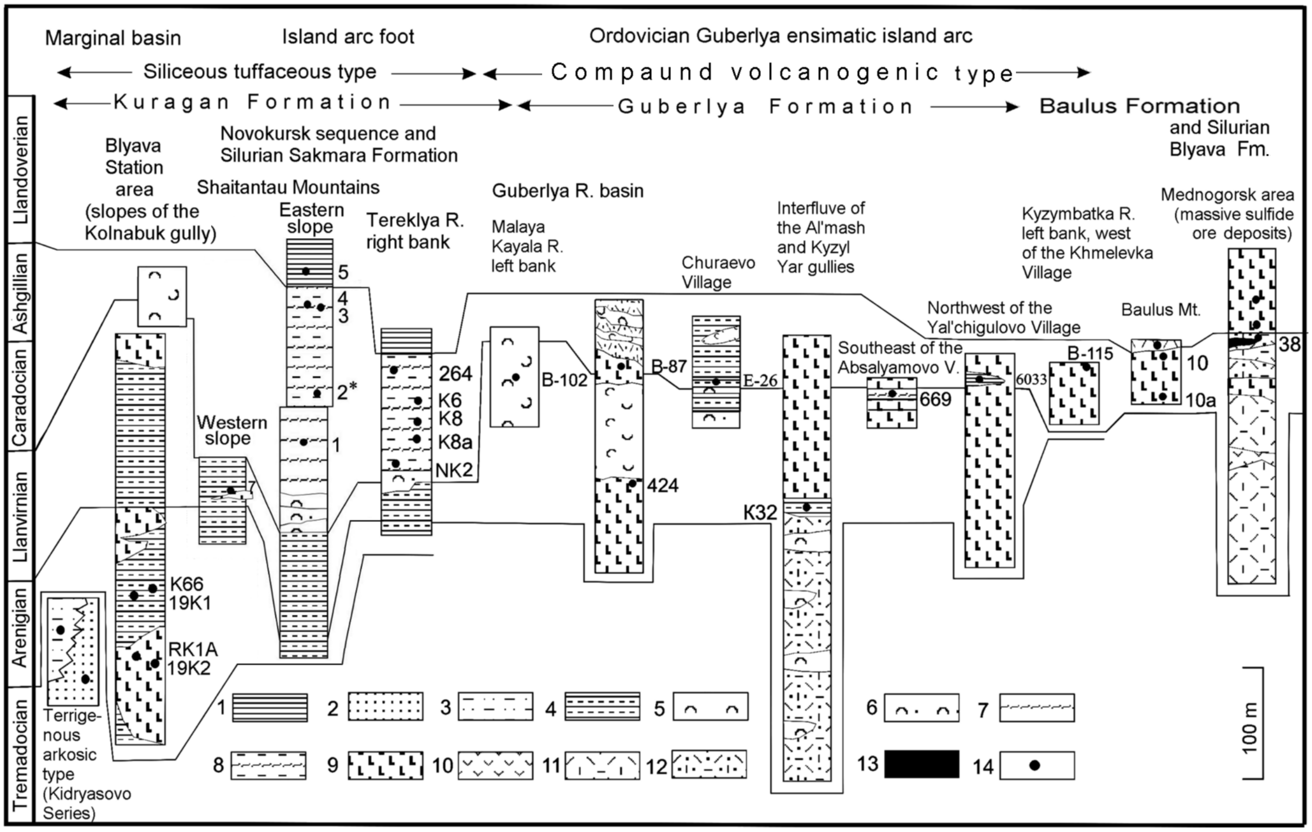


Figure 6. Correlation of sections of the Kuragan, Guberlya, and Baulus formations in the Sakmara and eastern Sakmara–Voznesenka zones: 1 – carbonaceous shales and cherts; 2 – arkoses; 3 – siltstones, argillites, and arkoses; 4 – tuffaceous sandstones and siltstones; 5 – tuffites of mixed composition; 6 – tuffaceous sandstones and gravelstones; 7 – variegated siliceous tephroids; 8 – grey siliceous tephroids; 9 – basalts; 10 – andesites; 11 – rhyolites and dacites; 12 – rhyolite and dacite tuffs; 13 – massive sulfide ores; 14 – points of conodont and other organic remains localities and their numbers. Redeposited conodonts are recorded at Point 2*.

[75] Both sequences of the Kuragan Formation, i.e. the lower (red-colored tuffaceous siltstone with basalt flows) and the upper (siliceous tephroid) Novokursk sequence, make up the northeastern flank of the Utyagulovo synform on the left bank of the Sakmara River, east of the Churaevo and Yumaguzino 1 Villages (Figure 5).

[76] Nearby the Yumaguzino 1 Village, on the right bank of the Tereklya River (left tributary of the Sakmara River) (Figure 6), the red tuffaceous sandstones and siltstones are exposed at the ridge foot. The slope and top of the ridge are composed of mainly grey and grey-green siliceous tephroids. The siliceous rocks are decoupled by variegated tuffaceous sandstones and gravelstones. The beds steeply (60°–70°) dip westward (overturned occurrence).

[77] The grey tephroids (enriched in sand-sized tephra) at Point K8a (Figure 6), 40 m above the top of the red sequence, yield *Hamarodus brevirameus* (Walliser), *Scabbardella* cf. *altipes* (Henningsmoen), *Periodon grandis* (Ethington), *Protopanderodus* cf. *liripipus* Kennedy et al., *Amorphognathus* cf. *superbus* (Rhodes), *Prioniodus* cf. *gerdae* Bergstrom, and *Panderodus gracilis* (Branson et Mehl), and are referred to the *Hamarodus brevirameus, Dapsilodus mutatus*, and *Scabbardella altipes* Beds (Figure 3) corresponding to the Upper Caradocian–Ashgillian. The similar rocks exposed 50 m upward from the top, at Point K8 (Figures 2 and 6), and bearing *H. brevirameus* (Walliser), *P. liripipus* Kennedy et al., *P. grandis* (Ethington), *Drepanodus robustus* (Hadding), *Istorinus* sp., *Baltoniodus* sp., *Amorphognathus* sp., and *Pan-*

⇐ 14 – serpentinite melanges, ophiolitoclastic mixtites, olistostromes; 15 – metamorphic complexes of the Uraltau zone; 16 – diorites (O_3); 17 – faults; 18 – normal and overturned elements of occurrence; 19 – conodont localities, their numbers and age. Letters indicate synforms: B – Blyava, U – Utyagulovo, Kh – Khmelevka. The insets demonstrate structure of the Blyava Station area (A) and Shaitantau Mountains (B).

derodus sp., are assigned to the same faunal beds. The similar conodont assemblage was recorded 70 m above, in the member of manganese-bearing siliceous rocks. This association at Point K6 (Figures 2, 5, 6) includes *H. brevirameus* (Walliser), *Dapsilodus mutatus* (Branson et Mehl), *P. liripipus* Kennedy et al., *P. grandis* (Ethington), *Drepanoistodus suberectus* (Branson et Mehl), *Panderodus gracilis* (Branson et Mehl), and *Spinodus* sp. and is peculiar to the same faunal beds corresponding to the Upper Caradocian–Ashgillian analogs (Figure 3). The siliceous tephroid (i.e. Novokursk) sequence is overlain there by the carbonaceous shales of the Sakmara Formation (Figure 6).

[78] North of the Yumaguzino 1 Village and 1.3 km northwest of Point K8a, the Novokursk sequence becomes up to 230 m thick [*Ruzhentsev,* 2005]. The thickness of the overlying carbonaceous shales of the Sakmara Formation increases as well.

[79] Twenty meters above the top of the red-colored sequence, at Point NK-2 (Figure 6), the grey siliceous tephroids of the Novokursk unit contain *Pygodus anserinus* (Lamont et Lindström), *Periodon aculeatus* Hadding, *Panderodus gracilis* (Branson et Mehl), and *Protopanderodus* sp. and are referred to the *Pygodus anserinus* and *Periodon aculeatus* Beds correlative with the uppermost Llanvirnian–Lower Caradocian (Figure 3).

[80] The light grey tuffosilicites 100 m above the top of the red-colored sequence, at Points 264 and 264a (Figures 2 and 6) bear *Hamarodus brevirameus* (Walliser), *Protopanderodus liripipus* Kennedy et al., *Scabbardella altipes* (Henningsmoen), *Periodon* cf. *grandis* (Ethington), *Belodina compressa* (Branson et Mehl), *Panderodus gracilis* (Branson et Mehl), and *Drepanoistodus suberectus* (Branson et Mehl) and are assigned to the *Hamarodus brevirameus, Dapsilodus mutatus*, and *Scabbardella altipes* Beds (Figure 3) corresponding to the Upper Caradocian–Ashgillian.

[81] The fragment of the section that includes the contact between the red-colored siltstone and siliceous tephroid Novokursk sequences is recorded further southward, nearby the crossing of the roads to Churaevo and Kuvandyk [*Ryazantsev et al.,* 2005, Fig. 9]. The grey siliceous tephroids at Point B-38 yield *Protopanderodus liripipus* Kennedy et al., *Periodon grandis* (Ethington), *Panderodus gracilis* (Branson et Mehl), and *Plectodina* sp. The association is characteristic of the *Hamarodus brevirameus, Dapsilodus mutatus*, and *Scabbardella altipes* Beds (Figure 3) corresponding to the Upper Caradocian–Ashgillian analogs.

[82] Thus the siliceous tuffaceous type of section (Kuragan Formation) was accumulated from the upper Lower Arenigian to Ashgillian inclusive.

[83] **The composite section of the Kuragan Formation** includes the succession of five faunal beds (Figure 3) that are correlated with the conodont zones of Balto-Scandia [*Cooper and Sadler,* 2004] and traditional Ordovician stages of Britain, and embrace the interval from the upper Lower Arenigian to Ashgillian. In two points of the Kuragan section the continuity of faunal beds is broken (Figure 3).

[84] The stratigraphic succession of the species *Periodon aculeatus* → *P. grandis* does not contradict the present notion of morphophylogeny of the genus.

[85] **Paleoenvironments during the formation of the siliceous tuffaceous complex.** As shown above, in the Ordovician siliceous tuffaceous complex (Kuragan Formation) the lower and upper parts are clearly distinguished. The lower part represented by red-colored tuffaceous sandstones and siltstones with basalt flows, was likely formed in a distal part of the marginal basin (Figure 6) that was located west of the Ordovician Guberlya ensimatic island arc [*Ryazantsev et al.,* 2005]. Formation of the upper part of the complex, which is composed of red- and grey-colored siliceous tephroids (Novokursk sequence of the Kuragan Formation), was associated with environments of an island arc foot (Figure 6).

Compound Volcanogenic Type of Section

[86] Sections of this type are characteristic of the island arc Guberlya and Baulus formations; they are succeeding and are connected by gradual facies changes.

[87] **The Guberlya Formation** was distinguished on the eastern slope of the South Urals by K. E. Razumovskaya in 1941 and is recorded in the discussed region as well [*Ruzhentsev,* 1976]. According to the above authors, the Guberlya Formation overlies with a gradual transition the Kuragan Formation. Other geologists [*Kheraskov and Milanovskii,* 1953; *Sidorenko et al.,* 1964] considered them as synchronous units.

[88] The Guberlya Formation is mainly composed of tuffites, acidic and intermediate tuffs, and basalt and rhyolite flows. It is located in the stratotype area in the Guberlya, Malaya and Bol'shaya Kayala River basins (Figure 7), and on the flanks of the Blyava and Utyagulovo synforms (Figure 5). The analogs of the Guberlya Formation are first recorded in the eastern Sakmara–Voznesenka zone (Figures 1 and 6) (see below).

[89] In the stratotype area (Figure 7) the Ordovician Kidryasovo and Guberlya formations were distinguished [*Sharfman and Tsetlin,* 1968]. The Tremadocian age of the Kidryasovo Formation was defined from the trilobite and brachiopod evidence, whereas the Guberlya Formation was estimated as Middle or Early-Middle Ordovician based on its correlation with the fauna-bearing Kuragan Formation.

[90] Subsequently, in the distribution area of the Guberlya Formation the Devonian organic remains were found in limestones [*Sharfman and Tsetlin,* 1968] and cherts [*Puchkov and Ivanov,* 1985]. As a result of finding in cherts of Early–Middle Devonian conodonts made by K. S. Ivanov and V. N. Puchkov, the Guberlya Formation was considered invalid and was eliminated from stratigraphic scales [*Antsygin et al.,* 1993]. The volcanogenic sedimentary, mixtite-bearing rocks distributed in the area were suggested to consider the analogs of the Devonian Kosistek Formation.

[91] Our research revealed that the discussed area is mainly occupied by the Ordovician volcanogenic sedimentary rocks (Guberlya Formation) and by the olistostrome yielding cherty olistoliths with conodonts ranging in age from the Lochkovian to Lower Famennian inclusive [*Borisenok and Ryazant-*

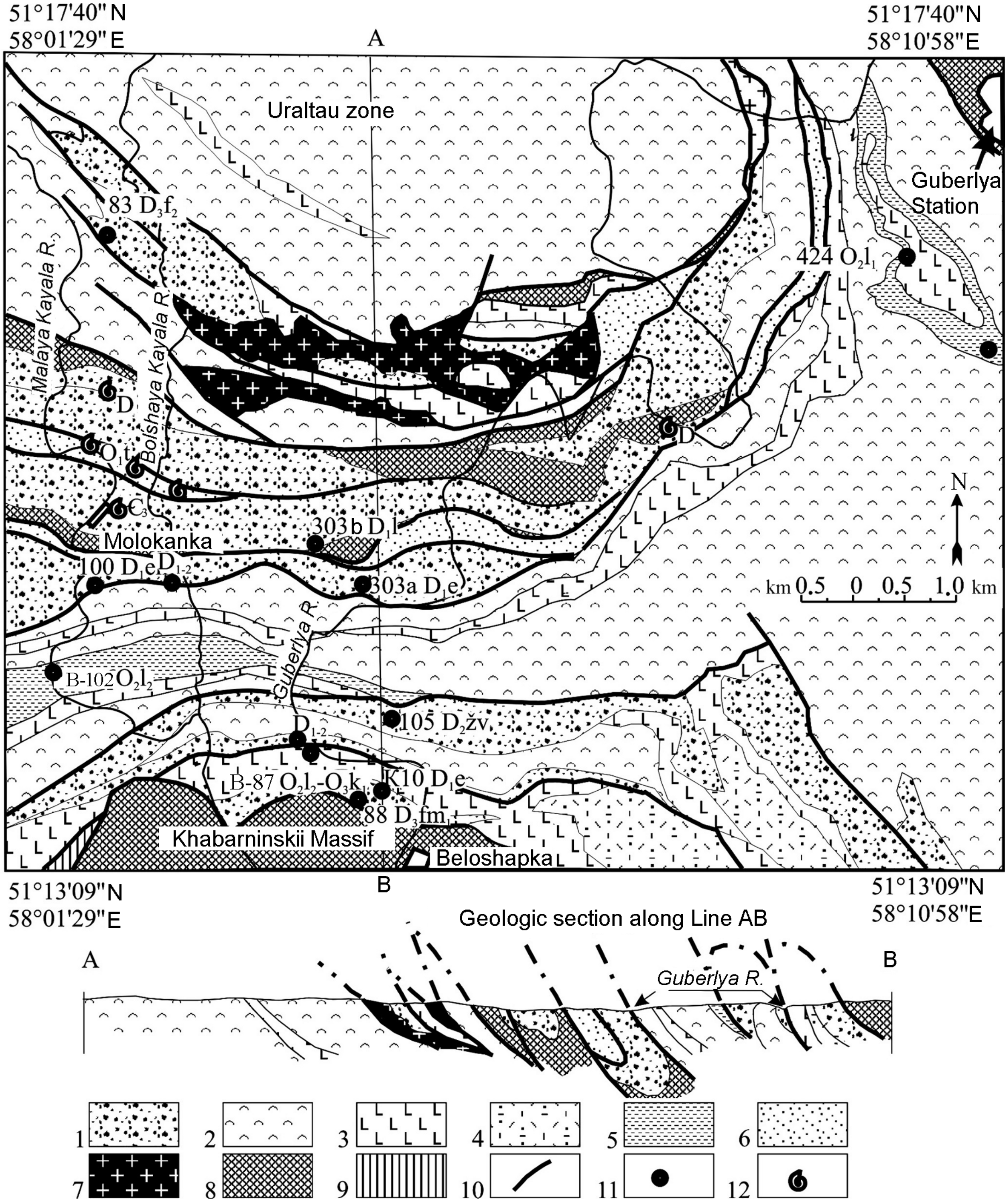


Figure 7. Scheme of the geological structure of the Guberlya, Bol'shaya and Malaya Kayala Rivers' interfluve: 1 – polymictic olistostrome (C_1?); 2–5 – Guberlya Formation: 2 – tuffs, tuffites, siltstones, 3 – basalts, 4 – quartz rhyolites, 5 – red tuffaceous siltstones; 6 – Kidryasovo Formation (O_1t) – sandstones and siltstones; 7 – granitoids (PZ_1); 8 – ophiolites and serpentinite melanges; 9 – metabasalts – amphibolites and green schists; 10 – faults; 11–12 – findings of organic remains, their numbers and age: 11 – shelly fauna, 12 – conodonts.

sev, 2005; *Ryazantsev et al.,* 2005]. The Tremadocian terrigenous sediments of the Kidryasovo Formation are locally distributed there.

[92] The Guberlya Formation is variable in composition. It is largely made up of tuffites and pillow basalts with lesser participation of rhyolites. The basalts contain limestone lenslike beds, small lenses, and interpillow bodies and are decoupled by horizons, members, and lenses of siliceous tuffites that commonly look like smears on pillow surface.

[93] The relatively undisturbed section occurs on the left bank of the Guberlya River, west of the Guberlya station (Figures 6 and 7). It begins with the pillow basalt member, less than 100 m thick, decoupled by 0.5–2-m-thick horizons of red tuffites, and is further built up by the 180-m-thick red tuffite member. The overlying sequence of over 500 m thick is represented by alternated lenslike light pistachio, rarer red, tuffites bearing beds of quartz rhyolite and basalt tuffs. The tuffites of the lower member at Point 424 (Figures 6 and 7) yield *Periodon zgierzensis* Dzik, *Walliserodus ethingtoni* (Fahraeus), *Ansella jemtlandica* (Löfgren), *Oistodus? tablepointensis* Stouge, *Dapsilodus* cf. *mutatus* (Branson et Mehl), *Drepanodus robustus* Hadding, and *Protopanderodus* cf. *liripipus* Kennedy et al. sensu *Stouge* [1984]. The association is characteristic of the *Periodon zgierzensis* and *Ansella jemtlandica* Beds corresponding to the mid-Llanvirnian (Figure 3).

[94] On the right bank of the Guberlya River, at Point B-87 (Figures 6 and 7), the 10-cm-thick red tuffite bed among basalts contains *Ansella nevadensis* (Ethington et Schumacher), *Periodon aculeatus* Hadding, *Dapsilodus similaris* (Rhodes), and *Walliserodus* sp. This assemblage is specific for the *Pygodus anserinus, Periodon aculeatus*, and *Ansella nevadensis* Beds (Figure 3) correlative with the uppermost Llanvirnian–Lower Caradocian analogs.

[95] Further northward the section is mainly composed of monotonous, red and pistachio-colored tuffites bearing rare members of basalts and basalt tuffs with carbonate cement. The following conodonts were found on the left bank of the Malaya Kayala River, in the 10–20-m-thick red tuffite bed, at Point B-102 (Figures 6 and 7): *Pygodus serra* (Hadding), *Periodon aculeatus* Hadding, *Eoplacognathus* cf. *robustus* Bergstrom, *Dapsilodus viruensis* (Fahraeus), *Protopanderodus varicostatus* (Sweet et Bergstrom), *Drepanoistodus suberectus* (Branson et Mehl), *Plectodina* sp., and *Ansella* sp. (Figure 2). The association is characteristic of the *Eoplacognathus robustus* and *Pygodus serra* Beds (Figure 3) and provides their correlation with the *robustus* Subzone of the serra Zone in Balto-Scandia, i.e. with the uppermost Llanvirnian.

[96] Sections of the Guberlya Formation were studied beyond the stratotype area as well.

[97] On the northeastern flank of the Utyagulovo synform (Figure 5) tuffs, tuffites, and basalts are more common in the section. The following units are recorded on the left bank of the Sakmara River, on the watershed of the Almash and Kyzyl Yar gullies, nearby their junction (Figure 6):

[98] 1. Frequently alternating fine-clastic tuffs of quartz and basic rhyolites and grey-green, turquoise-colored and, rarer, red ashstones and tuffites. Aphyric basalt lenses occur in the upper part. Total thickness is 300 m.

[99] 2. Red siltstones and tuffaceous siltstones, bearing grey-green tuffite lenses, numerous molds of ostracodes and inarticulate brachiopods, and at Point K-32 including *Baltoniodus medius* (Dzik), *Strachanognathus parvus* Rhodes, *Periodon aculeatus* Hadding, *Drepanodus arcuatus* Pander, and *Protopanderodus* sp. referred to the *Baltoniodus medius* and *Strachanognathus parvus* Beds (Figure 3), i.e. to the Lower Llanvirnian analogs. Thickness 20 m.

[100] 3. Grey-green, tinged with violet, coarse-bladed aphyric basalts. Thickness 200 m.

[101] Nearby the base of the section this structure is complicated with fault wedges composed of ultrabasites and siliciclastic rocks bearing Early Devonian (Emsian) conodonts. North of the structure the section is represented by tuffaceous rocks of the Kuragan Formation.

[102] The section of the Guberlya Formation was also studied at the eastern margin of the Churaevo Village (Figure 5). Here, at the northern foot of the mountain with a fire-prevention post at the top, above the poorly exposed red tuffaceous siltstones of the lowermost Kuragan Formation, the following units are recorded in the westward direction (Figure 6):

[103] 1. Grey-yellow tuffaceous sandstones and gravelstones with a peculiar pseudopillow shelly parting. Thickness 15 m.

[104] 2. Interbedded red and pink tuffaceous sandstones and siltstones, yellowish and greenish tuffites, and red radiolarites. The red-brown tuffaceous siltstones with 0.5-cm-thick tephra layers of mixed composition at Point E-26 (Figures 5 and 6) contain numerous large *Spinodus spinatus* (Hadding), *Walliserodus ethingtoni* (Fahraeus), *Protopanderodus liripipus* Kennedy et al., and *Drepanodus robustus* Hadding (Figure 2) and are referred to the upper part of the *Pygodus anserinus, Periodon aculeatus*, and *Ansella nevadensis* Beds (Figure 3) corresponding to the uppermost Llanvirnian–Lower Caradocian. Thickness 30 m.

[105] 3. Tuffaceous siltstones and sandstones decoupled by tuffaceous conglomerate lenses. Thickness 60 m.

[106] In the Shaitantau Mountains sections of the Guberlya and Kuragan formations are tectonically juxtaposed. The Guberlya Formation fringes the Shaitantau Mountains with a narrow stripe marking the common antiform structure (Figure 5b).

[107] South and east of the mountains the section is composed of rhythmically alternated, variegated, sand- and silt-sized tuffites. The rhythms commonly begin with a gravel-sized sediments. Southeast of the Shaitantau Mountains, 500 m southwest of the western margin of the Novokurskii Village, the tuffites terminate with a 5-mm-thick layer of grey cherts yielding at Point 3-15 (Figure 5b) *Spinodus spinatus* (Hadding), *Periodon aculeatus* Hadding, *Protopanderodus cooperi* (Sweet et Bergstrom), *Drepanodus* cf. *robustus* Hadding, *Panderodus gracilis* (Branson et Mehl), *Drepanoistodus suberectus* (Branson et Mehl), and *Ansella* sp. (Figure 2). These sediments correspond to the *Protopanderodus cooperi* Beds, i.e. to the Upper Llanvirnian analogs (Figure 3).

[108] On the flanks of the Blyava synform (Figure 5) the tuffaceous sediments typical for the Guberlya Formation are associated with tuffaceous sandstones and siltstones bearing

basalt flows, which are characteristic of the lower part of the Kuragan Formation, and occupy a higher structural and, most likely, stratigraphic position.

[109] **Eastern part of the Sakmara–Voznesenka zone.** The volcanogenic and tuffaceous rocks recorded in the area represent the analogs of the Guberlya Formation. They make up small-sized tectonic lenses in the structure of serpentinite melange between the Nurali and Tatlambet ophiolitic massifs (Figure 1).

[110] At 250 m southeast of the Absalyamovo Village (Figure 1) the 40-m-thick block of grey-green aphyric basalts bears the 15-m-thick, greenish, siliceous tuffite bed. The tuffites at Point 669 (Figures 1 and 6) contain *Pygodus protoanserinus* Zhang, *P. serra* (Hadding), *Periodon aculeatus* Hadding, *Protopanderodus varicostatus* (Sweet et Bergstrom), *Drepanodus arcuatus* Pander, *Panderodus* sp., and *Ansella* sp. (Figure 2) and are assigned to the *Pygodus protoanserinus* and *P. serra* Beds (Figure 3) correlative with the uppermost Llanvirnian.

[111] The serpentinite melange located 2.2 km northwest of the Yal'chigulovo Village (Figure 1) is overlain by the 20-m-thick mixtite horizon bearing ophiolite rock fragments. The mixtites are replaced upwards by the 200-m-thick grey-green aphyric basalts and basaltic andesites. In the upper part of the section, at Point 6033 (Figures 1 and 6), the 6–10-m-thick lenses of grey-green, brown and dark grey cherts yield *Periodon aculeatus* Hadding, *Pygodus* cf. *anserinus* Lamont et Lindström, *Drepanodus robustus* Hadding, and *Ansella* sp., referred to the *Pygodus anserinus, Periodon aculeatus*, and *Ansella nevadensis* Beds (Figure 3), i.e. to the analogs of the uppermost Llanvirnian–Lower Caradocian.

[112] Thus, the research of sections of the Guberlya Formation located within and beyond the stratotype area provided reason enough to re-establish the formation in the Ordovician stratigraphic scheme, with more refined composition and age. According to composition, the Guberlya Formation is intermediate between the Ordovician volcanogenic Baulus Formation (see below) and the siliceous tuffaceous Kuragan Formation. The Guberlya Formation is of Llanvirnian–Early Caradocian age.

[113] **The composite section of the Guberlya Formation** includes the succession of six faunal beds (Figure 3) that are correlated with the conodont zones of Balto-Scandia [*Cooper and Sadler,* 2004] and traditional Ordovician stages of Britain, and are referred to the Lower Llanvirnian–Lower Caradocian interval.

[114] The stratigraphic successions of the *Periodon, Ansella*, and *Pygodus* species revealed in the section of the formation does not contradict the present notion on morphophylogeny of these genera. In the composite section one can record the chronological successions *Periodon zgierzensis* → *P. aculeatus* (Figure 2); *Ansella jemtlandica* → *A. nevadensis*; and *Pygodus serra* → *P. protoanserinus* → *P. anserinus*. The concurrent occurrence of *P. protoanserinus* Zhang and *P. serra* (Hadding) permitted the distinction of the *Pygodus protoanserinus* and *P. serra* Beds of a narrow stratigraphic range for the Upper Llanvirnian analogs (Figure 3), which is of fundamental importance for development of high-resolution Ordovician conodont scale in the South Urals.

[115] The **Baulus Formation** distinguished by V.T. Tishchenko in 1988 is represented by acidic, basic, and, to a lesser degree, intermediate extrusive rocks. Its sediments make up cores of the large Blyava and Utyagulovo synforms (Figure 5), between which the stratotype section was described in a small synform at the Blyava and Kuragan Rivers confluence [*Artyushkova et al.,* 1991; *Maslov et al.,* 1993].

[116] In the Blyavtamak Village area, on the southern slope of the Baulus Mountain (Figures 5 and 6) upward from the foot, the basalts and basaltic tuffs grade into rhyolites and rhyolite tuffs. The beds dip gently at $\leq 20°$. Nearby the contact between acidic and basic rocks, in the 20-m-thick member, extrusive rocks are decoupled by beds of fine-clastic tuffs, tuffites, and red cherts. The lower chert stratum, at Point 10a (Figures 2 and 6) bearing *Spinodus spinatus* (Hadding), *Periodon aculeatus* Hadding, *Protopanderodus liripipus* Kennedy et al., and *Ansella* sp. identified by Dubinina [*Artyushkova et al.,* 1991], is referred to the *Spinodus spinatus* and *Periodon aculeatus* Beds (Figure 3) corresponding to the mid-Caradocian. The upper chert bed with burrow molds yields at Point 10 (Figure 6) *Protopanderodus insculptus* (Branson et Mehl) (see Appendix, Plate 5, fig. 19), *Scabbardella altipes* (Henningsmoen), *Dapsilodus mutatus* (Branson et Mehl), *Walliserodus* cf. *nakholmensis* (Hamar), *Panderodus gracilis* (Branson et Mehl), *Cornuodus longibasis* (Lindström), *Icriodella* sp., and *Istorinus erectus* Knupfer (Figure 2) and is assigned to the *Hamarodus brevirameus, Dapsilodus mutatus, Scabbardella altipes*, and *Istorinus erectus* Beds correlative with the Upper Caradocian–Ashgillian (Figure 3).

[117] On the left bank of the Blyava River, southwest of the Blyavtamak Village, an aphyric basalt block with grey chert beds is recorded. It is likely a fragment of section of the Baulus Formation. At Point 11 (Figure 2) the cherts contain *Hamarodus brevirameus* (Walliser), *Periodon grandis* (Ethington), *Dapsilodus mutatus* (Branson et Mehl), *Plectodina furcata* (Hinde), *Panderodus gracilis* (Branson et Mehl), and *Belodina* sp. and are also referred to the *Hamarodus brevirameus, Dapsilodus mutatus, Scabbardella altipes*, and *Istorinus erectus* Beds that correspond to the Upper Caradocian–Ashgillian (Figure 3).

[118] **The Blyava synform** (Figures 5 and 8) is characterized by the most complete sections of the formation. In the Mednogorsk region the section of the Baulus Formation is associated with a set of massive sulfide ore deposits among which the Yamankasy deposit (Figure 8) is recognized as typical, associated with black smokers [*Herrington et al.,* 2002; *Maslennikov,* 1999; *Zaikov et al.,* 2001]. The ores yield vestimentifers, brachiopods, and pelecypods of wide stratigraphic range and occur in transitional part of the section from the rhyolite-dacite (with andesites) to basaltic sequence. The transition between the sequences is gradual in the Blyava and Komsomol'skoe deposits.

[119] In the western wall of the Blyava quarry (Figure 8), above the ore stratum, the member of interbedded rhyolites, their tuffs, and basalts is crowned by the 0.5–2-m-thick bed of red siliceous siltstones and hematite-siliceous shales. At

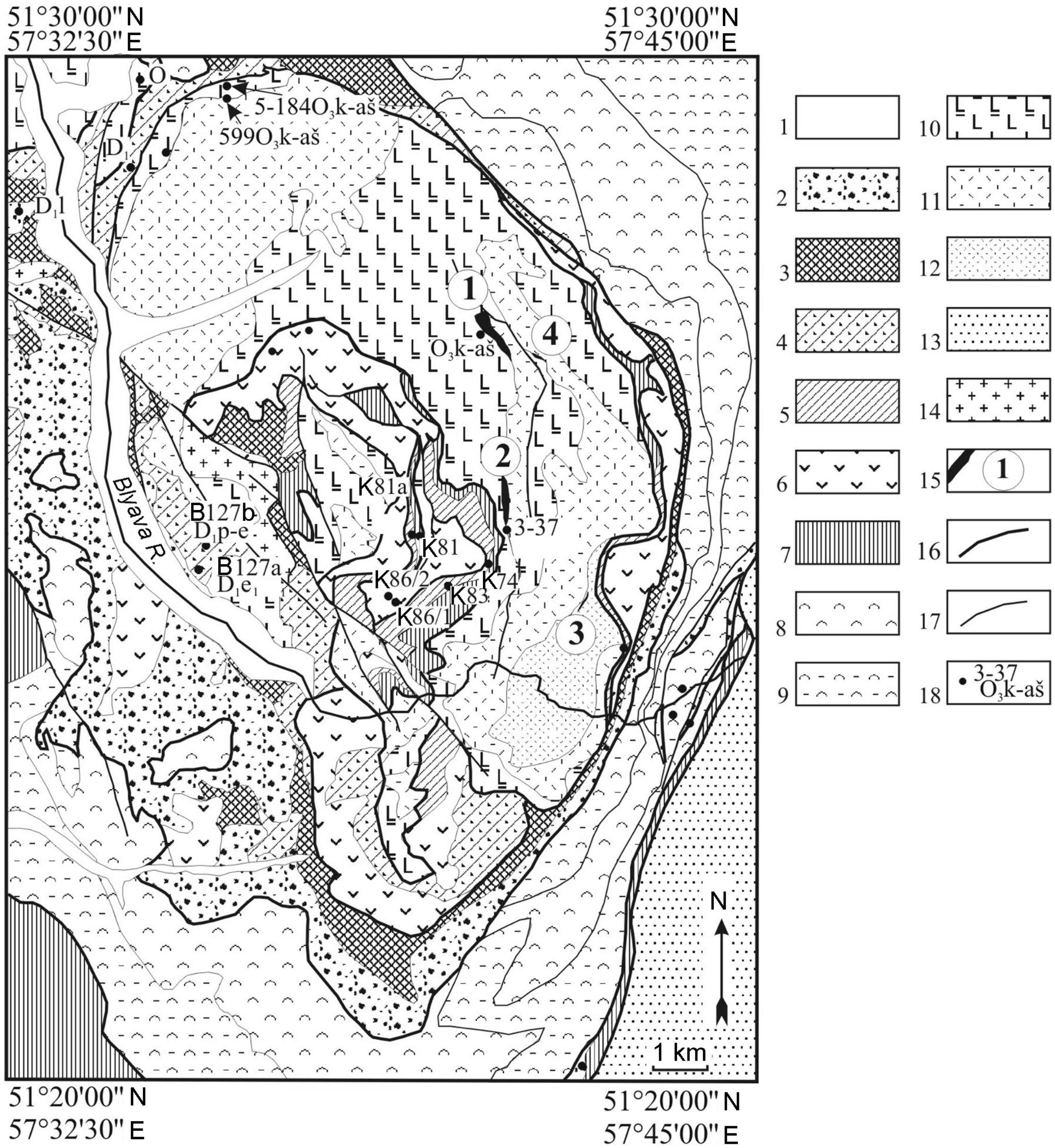


Figure 8. Structural elements of the Blyava synform: 1 – soft Cenozoic sediments; 2 – polymictic olistostromes; 3 – ophiolitoclastic mixtites; 4 – siliciclastic olistostromes; 5 – siliceous sediments (D_{1-2}); 6 – basalts with chert and siliciclastic rock lenses – Ishmuratovo Formation (D_{1-2}); 7 – siliceous black-shale Sakmara Formation (S_{1-2}); 8 – tuffaceous sediments of the upper part of the Kuragan Formation (Guberlya Formation analogs O_{2-3}); 9 – tuffaceous sediments and basalts of the lower part of the Kuragan Formation (O_{1-2}); 10–12 – extrusive complex of mixed composition (Baulus (O_3) and Blyava (S_1) formations): 10 – nonsubdivided basaltoids of the Blyava and upper Baulus formations, 11 – acidic extrusions of the upper Baulus Formation, 12 – acidic and basic extrusions of the lower Baulus Formation; 13 – arkosic sandstones and siltstones of the Kidryasovo Series (O_1t); 14 – diorites (O_3); 15 – massive sulfide ores; 16 – nappe boundaries; 17 – other faults; 18 – points of conodont localities, their numbers and age. Figures indicate massive sulfide ore deposits: 1 – Blyava, 2 – Komsomol'skoe, 3 – Yamankasy, 4 – Razumovskoe.

Point 38 (Figure 6) the red siliceous siltstones bearing *Dapsilodus mutatus* (Branson et Mehl), the form transitional from *Periodon* cf. *aculeatus* Hadding to *P.* cf. *grandis* (Ethington), *Drepanodus robustus* Hadding, *Protopanderodus* cf. *liripipus* Kennedy et al., and *Panderodus* sp. (Figure 2), are referred to the *Hamarodus brevirameus, Dapsilodus mutatus, Scabbardella altipes*, and *Istorinus erectus* Beds of the Baulus Formation section (Figure 3), which are correlative with the Upper Caradocian–Ashgillian. Previously the findings in this horizon of inarticulate brachiopods [*Korinevskii,* 1992] and, evidently in the same bed, of Ordovician conodonts [*Ivanov et al.,* 1989; *Maslov et al.,* 1993] were reported. The siliceous rocks terminating the Baulus Formation are overlain by the 0.5-m-thick bed that represents the base of the Blyava Formation. It is composed (upward from the base) of siliciclastic sandstones, basaltic tuffites, and carbonaceous siliceous shales. The latter are recorded above, among the pillow basalts as well. The Llandoverian, including Late Llandoverian, graptolites were encountered in the shales at different levels [*Borodaev et al.,* 1963].

[120] At the Komsomol'skoe deposit (Figure 8), on the left bank of the Khersonka River, the member overlying the ore-bearing sequence is composed of interbedded basalts, quartz rhyolite tuffs and tuffites, red flaggy siltstones, cherts, jaspers, and hematite shales. This level is analogous to the supraore bed recovered in the Blyava quarry. The Middle and Lower–Middle Ordovician conodonts were found there previously [*Ivanov et al.,* 1989]. At Point 3-37 (Figure 8) we collected in red jaspers the Late Caradocian–Ashgillian *Hamarodus brevirameus* (Walliser), *Panderodus* sp., and *Protopanderodus* sp., characteristic of the above-mentioned beds of the Baulus Formation (Figure 3). This confirms the validity of correlation of the supraore horizons in the Blyava and Komsomol'skoe deposits.

[121] At the northern closure of the Blyava synform (Figure 8) the section of the Baulus Formation is overturned. With the normal succession of rocks of the formation the quartz and basic rhyolites are overlain by basalts (100-m-wide outcrop). In the mid-section the basalt member is decoupled by a 2–10-m-thick, red, brown, and grey siliceous tuffaceous siltstone bed. At Point 599 (Figures 2 and 8) the siltstones contain *Hamarodus* cf. *brevirameus* (Walliser), *Scabbardella* cf. *altipes* (Henningsmoen), and *Periodon* sp. of the Late Caradocian–Ashgillian age. The basalts are further replaced by siliceous and siliciclastic rocks of the Lower–Middle Devonian Akchura Formation. The same siliceous tuffaceous siltstone bed, 200 m to the northeast, at Point 5-184 (Figures 2 and 8) yields *H.* cf. *brevirameus* (Walliser), *Protopanderodus* cf. *liripipus* Kennedy et al., *Drepanodus robustus* (Hadding), and *Panderodus* sp. In both points the conodont associations are characteristic of the *Hamarodus brevirameus, Dapsilodus mutatus, Scabbardella altipes*, and *Istorinus erectus* Beds of the Baulus Formation (Figure 3), which correspond to the Upper Caradocian–Ashgillian. The overturned occurrence previously resulted in the mistaken inference that the volcanites belong to the Devonian section, and they were distinguished as the Utyagulovo Formation [*Maslov et al.,* 1993].

[122] The question of the age of ore-bearing sequences and the massive sulfide ore deposits, was debated over a long period [*Artyushkova et al.,* 1991; *Ivanov,* 1996; *Ivanov et al.,* 1989; *Korinevskii,* 1992]. From the available records we infer the Ordovician and Silurian age of the ore-bearing volcanogenic complex and the Late Ordovician age of the massive sulfide ore deposits (Figure 6). The schematic section of the ore-bearing volcanogenic complex is described in the other paper [*Ryazantsev et al.,* 2005].

[123] The data on composition and age of the ore-bearing volcanogenic complex of the Sakmara zone permit its comparison with that of the Tagil zone [*Karetin,* 2000] (see inset map Figure 1). Their similarity is in association of the ore deposits with the Ordovician–Silurian boundary and in the occurrence of siliceous rocks at this level.

[124] **Utyagulovo synform.** The Baulus Formation is there of similar composition and along with the Silurian and Devonian siliceous basaltic sequences makes up the synform core (Figure 5). The sequence of interbedded aphyric and amygdaloidal basalts, quartz rhyolites and tuffs, is recorded from the western flank to the core of the synform. The sequence is replaced by the 40-m-thick member of red siliceous tuffaceous siltstones bearing lenses of grey cherts and turquoise-colored tuffites. At Point E-4 (Figure 5) the red tuffaceous siltstones yield *Hamarodus* cf. *brevirameus* (Walliser), *Protopanderodus liripipus* Kennedy et al., *Scabbardella altipes* (Henningsmoen), *Periodon* cf. *grandis* (Ethington), *Belodina confluens* Sweet, *Drepanodus* cf. *robustus* Hadding, and *Istorinus* sp. (Figure 2) and are referred to the *Hamarodus brevirameus, Dapsilodus mutatus, Scabbardella altipes*, and *Istorinus erectus* Beds (Figure 3) correlative with the Upper Caradocian–Ashgillian. The member is further built up by the aphyric and vesicular basalt sequence with lenses of acidic extrusive rocks.

[125] **Khmelevka synform.** The similar in composition sediments located nearby the Khmelevka Village (Figure 5) are assigned to the Baulus Formation as well. Here, the extrusive sequences of different age occur on the synform flanks structurally above the serpentinite melange. Three kilometers west of the Khmelevka Village, on the left bank of the Kyzymbadka River (18 m west of the felsitic stack), the up to 0.2-m-thick red chert lenses among the basalts contain conodonts. The previous data available from this point are contradictory (K. S. Ivanov and V. N. Puchkov, preprint, 1984), [*Korinevskii,* 1988]. Subsequent to Korinevskii, we collected at Point B-115 (Figure 6) *H. brevirameus* (Walliser), *P. liripipus* Kennedey et al. (see Appendix, Plate 5, fig. 15), *S. altipes* (Henningsmoen), *Istorinus* cf. *erectus* Knupfer, *Periodon* sp., *Histiodella* sp., and *Plectodina* sp. (Figure 2). This assemblage is typical for the *Hamarodus brevirameus, Dapsilodus mutatus, Scabbardella altipes*, and *Istorinus erectus* Beds that correspond to the Upper Caradocian–Ashgillian (Figure 3). Thickness of the basalts bearing lenses of cherts of the Baulus Formation does not exceed 100 m.

[126] **Southern part of the Sakmara–Voznesenka zone.** In this area the Baulus Formation analogs are recorded. In the Baiguskarovo Village region (see inset map in Figure 1), on the left bank of the Dergamysh River, the section is dominated by pillow basalts with rare chert, phthanite, and jasper lenses. The Caradocian conodonts were encountered in the jasper beds [*Artyushkova and Maslov,* 1998]. The faunal characteristic of the section was supplemented by Borisenok [*Borisenok and Ryazantsev,* 2005].

[127] In the 2–4-m-thick and about 200-m-long bed of jaspers and red siliceous siltstones, at 600 m from the Bai-

guskarovo Village at Point 037 (Figure 2) we collected *Periodon grandis* (Ethington), *Panderodus* sp. A Dzik, and *Dapsilodus* sp. The phthanite lens among basalts, at 1.5 km from the Baiguskarovo Village margin, at Point 1-184 (Figure 2), yields *Scabbardalla altipes* subsp. B Orchard, *Panderodus gracilis* (Branson et Mehl), and *Plectodina* sp. Five meters upward from the base the bluish-green cherts alternating with phthanites, at Point 029 (Figure 2) bear *S. altipes* (Henningsmoen) and *D. mutatus* (Branson et Mehl).

[128] According to composition and age, these sediments are correlative with the Baulus Formation of the Sakmara zone, namely, with the *Hamarodus brevirameus, Dapsilodus mutatus, Scabbardella altipes*, and *Istorinus erectus* Beds (Figure 3) corresponding to the Upper Caradocian–Ashgillian.

[129] **The composite section of the Baulus Formation** includes the succession of two faunal beds (Figure 3) that are correlated with the conodont zones of Balto-Scandia [*Cooper and Sadler,* 2004] and traditional Ordovician stages of Britain, and are referred to the Upper Caradocian–Ashgillian interval.

[130] The stratigraphic succession *Periodon aculeatus* → *P. grandis* established in the section of the Baulus Formation does not contradict the present notion on evolution of this genus.

[131] **Paleoenvironments during the formation of the compound volcanogenic complex.** As shown above, the Guberlya Formation rocks are dominated by tuffites, acidic and intermediate tuffs, and basalt and rhyolite flows. The Baulus Formation is represented by acidic, basic, and, to a lesser extent, intermediate extrusive rocks. The Guberlya and Baulus formations are successive in time (Figures 2, 3, 6). They form an island arc complex. Its formation and, correspondingly, the generation of the volcanic (Guberlya) arc occurred from the mid-Ordovician (Early Llanvirnian) to the terminal Ordovician (Late Ashgillian). The sediments of the Guberlya Formation (Llanvirnian–Lower Caradocian) record the initiation and development of the Guberlya ensimatic island arc. Subsequently, in the Late Caradocian–Ashgillian the Guberlya arc likely experienced splitting (riftogenesis). During this period the sediments of the Baulus Formation were accumulated. Black smokers that were associated with the ore formation in the Baulus (Late Caradocian–Ashgillian) time, were formed in the island-arc structure, under its splitting.

[132] Volcanites of both formations are strongly heterogeneous in chemical composition. Basalts of the Guberlya Formation are correlative with intraplate oceanic and island-arc tholeiites [*Borisenok and Ryazantsev,* 2005]; basaltoids of the Baulus Formation, with island-arc tholeiites, MORB, and intraplate oceanic basalts. All the available data indicate that the volcanogenic complex reflects the evolution of the ensimatic island arc which experienced splitting, riftogenesis, and died off by the beginning of the Silurian.

Conodont Biofacies

[133] The analysis of composition of the South Uralian conodont associations and of their predominant and attendant species provided the recognition of the *Oepikodus, Periodon*, and HDS biofacies.

[134] **The *Oepikodus* biofacies of the Middle Arenigian (= *Oepikodus evae* biofacies).** The *Oepikodus evae* biofacies is named for the predominant species *Oepikodus evae* Lindström and is considered as the equivalent of the Middle Arenigian *Oepikodus* biofacies.

[135] The fauna of this biofacies includes dominating *Oepikodus evae* Lindström and *Periodon flabellum* (Lindström) and less common *Protopanderodus rectus* (Lindström) and *Oistodus lanceolatus* Pander. It is characteristic of the North Atlantic Realm. In the South Urals the fauna is recorded in the lower part of the Polyakovka Formation (Figure 2) and is associated with environments of an open oceanic basin.

[136] The similar in composition and relationships of faunal components Middle Arenigian *Oepikodus* biofacies was described in the lower part of Bed 11, Green Point Formation [*Johnston,* 1987; *Pohler,* 1994], that was formed *in situ* in the lower part of the Western Newfoundland continental slope. This fauna is also dominated by *O. evae* Lindström and *P. flabellum* (Lindström) constituting about 80% of the total assemblage. Less numerous are *Drepanodus arcuatus* Pander, *P. rectus* (Lindström), and *Paroistodus parallelus* (Pander). The assemblage also includes rare *Reutterodus andinus* Serpagli and *Bergstroemognathus extensus* (Graves et Ellison) referred to the *Juanognathus* faunal component.

[137] The absence of the *Juanognathus* component in the fauna of the *Oepikodus* biofacies in the South Urals (lower part of the Polyakovka Formation) and its low ratio in the same biofacies in the Western Newfoundland indicate the occurrence of different paleoenvironments in the discussed regions. In the former case it was a pelagic environment of the open ocean, far from land and relatively deep-water, probably below the thermocline. In the latter case the environment was restricted to the lower part of continental slope. Furthermore, the presence of the *Juanognathus* component in the fauna suggests the occurrence of conodonts above the constant thermocline level, since its species could not overcome this barrier [*Dubinina,* 1991, 2000]. However, both environments existed in open ocean conditions.

[138] In the South Urals the synchronous conodont association was recorded in the lower part of the Kuragan Formation as well. It includes *Bergstroemognathus extensus* (Graves et Ellison) referred to the *Juanognathus* component (Figure 2) though the diagnostic species was not found there. The presence of the *Juanognathus* component indicates a more shallow, above the thermocline, and likely less remote from the shore marginal-marine environment. As in the Arenigian the Guberlya arc did not exist yet, the lower parts of the Kuragan and Polyakovka formations were accumulated in a single oceanic basin but, as shown above, in its different parts that varied in depth and distance from the shore.

[139] **The *Periodon* biofacies.** Six corresponding biofacies differing in composition and ratio of faunal components are recorded in the Upper Arenigian–Middle Caradocian interval. It is apparent that the distinction of six *Periodon* biofacies from the Upper Arenigian to mid-Caradocian presents difficulties in their interpretation, as for each biofacies a certain stratigraphic interval should be pointed out. In this paper we suggest to give them names for predominant species.

[140] **1. *Periodon* biofacies of the Upper Arenigian (= *Periodon flabellum* biofacies).** The corresponding fauna includes the predominant *Periodon flabellum* (Lindström) and scarcer *Protopanderodus rectus* (Lindström) and *Baltoniodus* sp. It was encountered in the lower part of the Polyakovka Formation (Figure 2) and is associated with the open ocean environment.

[141] **2. *Periodon* biofacies of the Lower Llanvirnian (= *Periodon zgierzensis* biofacies).** The predominant component of this fauna includes *Periodon zgierzensis* Dzik, *Ansella jemtlandica* (Löfgren), *Paroistodus horridus* (Barnes et Poplawski), and *Walliserodus ethingtoni* (Fahraeus). The attendant species are *Drepanoistodus forceps* (Lindström), *Drepanodus arcuatus* Pander, *Strachanognathus parvus* Rhodes, *Protopanderodus* sp. *Scalpellodus viruensis* (Löfgren), *Dapsilodus viruensis* (Fahraeus), and *Baltoniodus medius* (Dzik). The fauna (Figure 2) was studied in the mid-parts of the Polyakovka and Kuragan formations and in the lower portion of the Guberlya Formation, which correspond to an ocean basin, distal part of a marginal basin, and to the incipient Guberlya ensimatic island arc environments, respectively.

[142] **3. *Periodon* biofacies of the Upper Llanvirnian (= *Periodon aculeatus*–*Pygodus serra* biofacies).** This fauna is dominated by *Periodon aculeatus* Hadding and *Pygodus serra* (Hadding). Significantly numerous faunal component is represented by *Protopanderodus varicostatus* (Sweet et Bergstrom) and *Drepanoistodus suberectus* (Branson et Mehl). Among attendant species are *Ansella jemtlandica* (Löfgren), *Eoplacognathus robustus* Bergstrom, and *Dapsilodus viruensis* (Fahraeus). The association was recorded in middle parts of the Polyakovka and Guberlya formations (Figure 2) and corresponds to an open ocean and Guberlya ensimatic island arc environments, respectively.

[143] **4. *Periodon* biofacies of the uppermost Llanvirnian (= *Periodon aculeatus*–*Pygodus protoanserinus* biofacies).** The predominant component of the fauna involves *Periodon aculeatus* Hadding and *Pygodus protoanserinus* Zhang. Relatively numerous are *Pygodus serra* (Hadding), *Pygodus anserinus* Lamont et Lindström, *Drepanoistodus suberectus* (Branson et Mehl), and *Spinodus spinatus* (Hadding), whereas *Ansella nevadensis* (Ethington et Schumacher), and *Protopanderodus cooperi* Sweet et Bergstrom are attendant taxa (Figure 2). This fauna inhabited oceanic basin (mid-part of the Polyakovka Formation) and the ensimatic island arc area (mid-part of the Guberlya Formation).

[144] **5. *Periodon* biofacies of the Lower Caradocian (= *Periodon aculeatus*–*Pygodus anserinus* biofacies).** The assemblage is dominated by *Periodon aculeatus* Hadding and *Pygodus anserinus* Lamont et Lindström. Common occurrence is characteristic of *Protopanderodus varicostatus* (Sweet et Bergstrom), *Ansella nevadensis* (Ethington et Schumacher), *Panderodus gracilis* (Branson et Mehl), and *Spinodus spinatus* (Hadding). The group of attendant species includes *Drepanoistodus suberectus* (Branson et Mehl), *Drepanodus robustus* Hadding, *Protopanderodus cooperi* (Sweet et Bergstrom), *Dapsilodus similaris* (Rhodes), and *Walliserodus* sp. (Figure 2). The fauna inhabited oceanic basin (middle–upper parts of the Polyakovka Formation), the ensimatic island arc area (upper part of the Guberlya Formation), and the island-arc foot area from the side of the marginal basin (Novokursk sequence of the Kuragan Formation) (Figure 6).

[145] According to the relationship between faunal components, the third, fourth, and fifth *Periodon* biofacies of the South Urals are similar to the *Pygodus*–*Periodon* biofacies from northwestern China (Tarim, Kuruktag). This fauna that inhabited an open shelf (Tarim) and slope (Kuruktag) was referred [*Wang and Qi,* 2001] to relatively deep and cold-water environments of the North Atlantic Realm.

[146] **6. *Periodon* biofacies of the "Middle" Caradocian (= *Periodon aculeatus* → *Periodon grandis* biofacies).** The predominant component of this fauna includes the form transitional from *Periodon aculeatus* Hadding to *Periodon grandis* (Ethington). The following species are less common: *Belodina compressa* (Branson et Mehl), *Spinodus spinatus* (Hadding), *Protopanderodus liripipus* Kennedy et al., *Ansella* sp., and *Baltoniodus* sp. (Figure 2). The fauna inhabited oceanic basin (upper part of the Polyakovka Formation) and environment associated with the splitting of the island arc during riftogenesis (lower part of the Baulus Formation).

[147] The *Periodon* biofacies of the South Urals belongs to that of the North Atlantic Realm, or more precisely to a part of this realm, still imperfectly studied [*Zhen and Percival,* 2003]. A similar in composition and relationship of faunal components Upper Arenigian *Periodon* biofacies is known from relatively deep-water environments around the North American continent and was described in many localities, for instance, from the lower part of the Western Newfoundland continental slope [*Johnston,* 1987; *Pohler,* 1994]. The Lower Llanvirnian *Periodon* biofacies was studied along the western margin of Baltica [*Rasmussen,* 1998] and in other open-ocean environments. The species characteristic of this biofacies are known in both open ocean environments of the Iapetus Ocean and on continental slopes of Laurentia, Baltica and other continents (South America, southern China). Rasmussen believes that this fauna does not indicate its attribution to a separate faunal province. However, the *Periodon* biofacies was suggested to be referred to a distinct subprovince of the North Atlantic Realm [*Pohler,* 1994]. We hold the former viewpoint.

[148] **The *Hamarodus brevirameus*–*Dapsilodus mutatus*–*Scabbardella altipes* or HDS biofacies of the Upper Caradocian–Ashgillian.** The fauna of the

HDS biofacies includes (Figure 2): (1) the predominant species *Hamarodus brevirameus* (Walliser), *Periodon grandis* (Ethington), *Protopanderodus liripipus* Kennedey et al., *Drepanodus robustus* Hadding, and *Drepanoistodus suberectus* (Branson et Mehl) that are widespread in the North Atlantic Realm; (2) significant in number of specimens faunal component represented by *Dapsilodus mutatus* (Branson et Mehl), *Scabbardella altipes* (Henningsmoen), and *Istorinus erectus* Knupfer that are characteristic of the cold-water Mediterranean province of the North Atlantic Realm; (3) important though low in number component including *Belodina confluens* Sweet, *Panderodus gracilis* (Branson et Mehl), and *Plectodina furcata* (Hinde), i.e. species typical for the North American Midcontinent Realm; (4) few *Yaoxianognathus ani* Zhen et al. known from Australia and China.

[149] The conodont fauna derived from the Upper Ordovician cherts and siliceous and tuffaceous shales in the South Urals, namely, from the uppermost Polyakovka, Kuragan, and Baulus formations (Figures 2 and 6), undoubtedly refers to the relatively deep-water and/or relatively cool-water HDS biofacies of the North Atlantic Realm [*Sweet and Bergstrom,* 1984] and bears rare, as a rule, synchronously redeposited, shallow, and likely more thermophilic elements of the North American Midcontinent type.

[150] To date, it is found that the HDS biofacies was widely distributed in all three provinces, i.e. British, Baltic, and Mediterranean, of the North Atlantic Realm [*Ferretti and Serpagli,* 1999]. Moreover, the temperate (boreal) water masses are considered to be the most favorable for the HDS biofacies fauna [*Stouge and Rasmussen,* 1996]. The biofacies is known from a strongly diverse set of paleoenvironments [*Armstrong and Owen,* 2002; *Ferretti and Barnes,* 1997; *Ferretty and Schonlaub,* 2001; *Ferretti and Serpagli,* 1999; *Stouge and Rasmussen,* 1996; *Sweet and Bergstrom,* 1984; *Zhen et al.,* 1999]. The depth of a basin evidently did not influence this fauna which is known from the deep shelf to marginal marine and open-ocean environments [*Stouge and Rasmussen,* 1996]. The HDS biofacies fauna of the South Urals is associated with the latter, namely, with an oceanic basin environment (upper part of the Polyakovka Formation), Guberlya ensimatic island-arc foot area from the side of a marginal basin (Novokursk sequence of the Kuragan Formation), and with environments associated with island arc splitting during riftogenesis (upper part of the Baulus Formation), which, as shown above, were also favorable for the black smokers formation.

[151] Consequently, eight deep-water and/or relatively deep-water Lower–Middle–Upper Ordovician conodont biofacies of the South Urals are related to those of the North Atlantic Realm or, according to the new concept [*Zhen and Percival,* 2003], to biofacies of the biogeographic Open-Ocean (= Open-Sea) Realm of the Tropical Domain. We emphasize that the authors of the new concept on Ordovician conodont biogeography [*Zhen and Percival,* 2003] eliminated from consideration such terms as North Atlantic and North American Midcontinent realms, provinces, and faunal components. However, we retain in this paper these terms that were long used in the Ordovician conodont biogeography. Nevertheless, this is in no way to say that we ignore or disregard the new scheme [*Zhen and Percival,* 2003] of biogeographic units.

Conclusions

[152] The findings of Ordovician conodonts in volcanogenic and volcanogenic sedimentary sequences of different tectonic zones in the South Urals first provided a significant advancement of stratigraphy in the region. To do this, we studied three types of Ordovician sections, namely, siliceous basaltic, siliceous tuffaceous, and volcanogenic differing in stratigraphic completeness and being associated with various elements of the Uralian paleoocean active margin.

[153] The siliceous basaltic type of section (Polyakovka Formation) in the Western Magnitogorsk zone was formed at different stages of the ocean basin evolution. It makes up a system of nappes which represent a fragment of the accretionary prism in front of the Devonian Magnitogorsk arc. The formation embraces the Upper Tremadocian–Ashgillian stratigraphic interval. The other types of section are connected by gradual facies changes and, partly, by stratigraphic transitions and are recorded in structures of the Sakmara and Sakmara–Voznesenka zones.

[154] The siliceous tuffaceous type of section (Kuragan Formation) has been formed from the Arenigian to Ashgillian inclusive. The Arenigian-Llanvirnian interval, i.e. the lower part of the Kuragan Formation, is mainly composed of tuffaceous sandstones and siltstones, which in the Caradocian–Ashgillian were replaced by siliceous tephroids of the Novokursk sequence (upper part of the Kuragan Formation). The former were accumulated in the distal part of a marginal basin; the latter were associated with environments of the Ordovician Guberlya ensimatic island-arc foot area.

[155] The island-arc complex corresponding to the volcanogenic type of section is represented by the successive Guberlya and Baulus formations.

[156] The conodont studies provided the age estimate of the Guberlya Formation as Llanvirnian–lowermost Caradocian; its status as the Ordovician formation is regained; and its conformable contact with the Upper Caradocian–Ashgillian Baulus Formation is recognized.

[157] The section of the Baulus Formation includes a set of massive sulfide ore deposits associated with the black smokers activity. Directly in the supraore cherts of the Blyava and Komsomol'skoe deposits and in many localities along the supraore cherts strike the similar in composition Late Caradocian–Ashgillian conodont associations are recorded.

[158] From the conodont evidence we distinguished additional biostratigraphic units or faunal beds in the sections of the studied formations. The Ordovician sections of the Polyakovka and Kuragan formations include successions of eleven and five faunal beds, respectively. The section of the Guberlya Formation is characterized by six successive faunal beds embracing the upper Middle to lower Upper Ordovician. The Upper Ordovician Baulus Formation includes two faunal beds.

[159] The Ordovician conodont scale of the South Urals comprises eleven (11) units and is based on successive alteration of conodont associations with the use of stratigraphic successions of the *Periodon, Pygodus, Ansella*, and *Protopanderodus* species, which does not contradict the present notion of morphophylogeny of these genera.

[160] The stratigraphic succession of the *Pygodus* species is of particular importance; its middle member *P. protoanserinus* provided the distinction of fine-resolution units. In the uppermost Llanvirnian analogs the *P. protoanserinus* and *P. anserinus* Beds replace the *P. protoanserinus* and *P. serra* Beds (Figure 3). The former are distinguished in the Polyakovka Formation; the latter, in the Guberlya Formation. There are strong grounds to believe that both units will be recognized in the single siliceous basaltic (oceanic) type of section. Then the Ordovician stratigraphic scale of the South Urals will include twelve (12) conodont units.

[161] The Ordovician conodont scale of the South Urals represents one of still few variants of scales related to the biogeographic Open-Ocean (= Open-Sea) Realm (OSR) of the Tropical Domain [*Zhen and Percival,* 2003]. The realm was dominated by cosmopolitan and widespread taxa, whereas endemics were of minor importance. This fact prevents from distinction of a province, i.e. smaller biogeographic unit within the Realm. Recall that among the scales of this Realm are the Upper Cambrian–Lower Ordovician Sarykum scale [*Dubinina,* 1991, 1998, 2000] and the Upper Cambrian-Middle Ordovician Burubaital scale [*Tolmacheva et al.,* 2001, 2004] of Central Kazakhstan.

[162] We identified eight deep-water and/or relatively deep-water biofacies, i.e. (1) "Middle" Arenigian *Oepikodus evae*; (2) Upper Arenigian *Periodon flabellum*; (3) Lower Llanvirnian *Periodon zgierzensis*; (4) Upper Llanvirnian *Periodon aculeatus–Pygodus serra*; (5) uppermost Llanvirnian *Periodon aculeatus–Pygodus protoanserinus*; (6) Lower Caradocian *Periodon aculeatus–Pygodus anserinus*; (7) "Middle" Caradocian *Periodon aculeatus* → *Periodon grandis*; and (8) Upper Caradocian–Ashgillian *Hamarodus brevirameus–Dapsilodus mutatus–Scabbardella altipes* or HDS biofacies. The listed Ordovician conodont biofacies of the South Urals refer to those of still imperfectly studied part of the North Atlantic Realm that was recently considered [*Zhen and Percival,* 2003] as a distinct paleobiogeographic Open-Ocean Realm of the Tropical Domain.

[163] The South Uralian conodont biofacies were compared within the studied region to an extent that the fossil material permitted. For the most part, they were compared with biofacies of the North Atlantic Realm or of the Open-Ocean Realm of the Tropical Domain using the literature records.

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Appendix: Diagnostic species of various Ordovician conodont associations of the South Urals

Plate 1. Arenigian conodonts from the Polyakovka Formation.

1, 4, 6, 7, 9, 11–13 – *Periodon flabellum* (Lindström, 1954). 1 – Sc element, specimen no. 4876/4, × 53.4,[1] lateral view, Sample 15/1; 4 – Sd element, specimen no. 4876/5, × 46, postero-lateral view, Sample 15/1; 6 – Pa element, specimen no. 4876/6, × 62.7, posterior view, Sample 2; 7 – Sc element, specimen no. 4876/7, × 47, lateral view, Sample 2; 9 – Pb element, specimen no. 4876/8, × 91, posterior view, Sample 2; 11 – Sd element, specimen no. 4876/9, × 108, lateral view, Sample 22c; 12 – Pa element, specimen no. 4876/11, × 36.3, anterior view, Sample 22c; 13 – Pa element, specimen no. 4876/10, × 74.5, anterior view, Sample 22c; 2, 3, 5 – *Oepikodus* cf. *O. evae* (Lindström, 1954). 2 – Pa element (mold), specimen no. 4876/3, × 50, lateral view, Sample 22b; 3 – Pa element (mold), specimen no. 4876/2, × 44, lateral view, Sample 22b; 5 – Sd element, specimen no. 4876/1, × 85, lateral view, Sample 22b; 8 – *Paroistodus parallelus* (Pander, 1856). M element, specimen no. 4876/12, × 73.5, lateral view, Sample 2; 10 – *Drepanoistodus forceps* (Lindström, 1954). M element, specimen no. 4876/13, × 56, lateral view, Sample 22b.

Plate 2. Llanvirnian conodonts from the Polyakovka and Kuragan formations.

1 – *Drepanodus arcuatus* Pander, 1856. Sd element, specimen no. 4876/24, × 48, lateral view, Sample 7, Kuragan Formation; 2, 3 – *Scalpellodus* cf. *S. viruensis* (Löfgren, 1978). 2 – specimen no. 4876/25, × 119.6, lateral view, Sample 7, Kuragan Formation; 3 – specimen no. 4876/26, × 82.3, lateral view, Sample 7, Kuragan Formation; 4 – *Drepanoistodus suberectus* (Branson et Mehl, 1933). Sc element, specimen no. 4876/23, × 108.8, lateral view, Sample 22d, Polyakovka Formation; 5, 9, 11–13 – *Periodon aculeatus* Hadding, 1913. 5 – Pa element, specimen no. 4876/20, × 75.5, posterior view, Sample 22d, Polyakovka Formation; 9 – Pa element, specimen no. 4876/21, × 55, posterior view, Sample 2, Kuragan Formation; 11 – M element, specimen no. 4876/18, × 72.5, lateral view, Sample 22d, Polyakovka Formation; 12 – Pb element, specimen no. 4876/22, × 104, posterior view, Sample 2, Kuragan Formation; 13 – Sd element, specimen no. 4876/19, × 81.3, lateral view, Sample 22d, Polyakovka Formation; 6–8 – *Pygodus serra* (Hadding, 1913). 6 – Pa element, specimen no. 4876/14, × 100, upper view, Sample 22d, Polyakovka Formation; 7 – Pb element, specimen no. 4876/16, × 130, lateral view, Sample 22d, Polyakovka Formation; 8 – Pa element, specimen no. 4876/15, × 117.6, upper view, Sample 22d, Polyakovka Formation; 10 – *Spinodus spinatus* (Hadding, 1913). Sb element, specimen no. 4876/17, × 112, lateral view, Sample 22d, Polyakovka Formation.

[1]Here and below scale coefficients are set for the plate images (pages 29–33) printed without magnification (41pc width).

Plate 3. Uppermost Llanvirnian conodonts (*Pygodus protoanserinus* and *P. anserinus* Beds) from the Polyakovka Formation.

1–4, 6, 10, 13, 17 – *Periodon aculeatus* Hadding, 1913. 1 – Sc element, specimen no. 4876/27, × 64.7, lateral view, Sample 58/4; 2 – Sd element, specimen no. 4876/28, × 48.6, lateral view, Sample 58/4; 3 – Sc element, specimen no. 4876/29, × 60.8, lateral view, Sample 58/4; 4 – M element, specimen no. 4876/31, × 56.8, lateral view, Sample 58/4; 6 – M element, specimen no. 4876/30, × 57.8, lateral view, Sample 58/4; 10 – Pa element, specimen no. 4876/32, × 39.2, posterior view, Sample 58/4; 13 – Sc element, specimen no. 4876/33, × 70.6, lateral view, Sample 58/4; 17 – Sc element, specimen no. 4876/34, × 47, lateral view, Sample 25; 5, 12, 16 – *Pygodus anserinus* Lamont et Lindström, 1957. 5 – Pa element, specimen no. 4876/35, × 51, upper view, Sample 58/4; 12 – Pa element, specimen no. 4876/36, × 56, upper view, Sample 58/4; 16 – Pa element, specimen no. 4876/37, × 62.7, upper view, Sample 25; 7–9, 11, 15 – *Pygodus protoanserinus* Zhang, 1998. 7 – Pa element, specimen no. 4876/40, × 49, upper view, Sample 58/4; 8 – Pa element, specimen no. 4876/41, × 82.3, upper view, Sample 58/4; 9 – Pa element, specimen no. 4876/38, × 71.5, upper view, Sample 58/4; 11 – Pa element, specimen no. 4876/39, × 86.2, upper view, Sample 58/4; 15 – Pa element, specimen no. 4876/42, × 68.6, upper view, Sample 25; 14 – *Loxodus* cf. *latibasis* Ji et Barnes, 1994. Specimen no. 4876/43 (redeposited), × 110, inner lateral view, Sample 25; 18 – *Pygodus* cf. *P. serra* (Hadding, 1913). Pa element, specimen no. 4876/44, × 71.5, upper view, Sample 25.

Plate 4. Uppermost Llanvirnian–Caradocian conodonts from the Polyakovka Formation.

1, 5 – *Pygodus anserinus* Lamont et Lindström, 1957. 1 – Pb element, specimen no. 4876/46, × 74.5, lateral view, Sample 51/1; 5 – Pa element, specimen no. 4876/45, × 102, upper view, Sample 51/1; 4 – *Plectodina* sp. Specimen no. 4876/47, × 117.6, anterior view, Sample 51/1; 2, 3 – *Periodon aculeatus* Hadding, 1913. 2 – Sd element, specimen no. 4876/48, × 98, inner lateral view, Sample 51/1; 3 – M element, specimen no. 4876/49, × 78.4, lateral view, Sample 51/1; 8 – *Drepanodus robustus* Hadding, 1913. Sd element, specimen no. 4876/50, × 47, lateral view, Sample 2c; 6, 7, 9–12 – *Periodon aculeatus* Hadding, 1913, transitional to *Periodon grandis* (Ethington, 1959). 6 – M element, specimen no. 4876/51, × 74.3, lateral view, Sample 55; 7 – Pb element, specimen no. 4876/52, × 79.4, postero-lateral view, Sample 55; 9 – Pa element, specimen no. 4876/53, × 100, antero-lateral view, Sample 55; 10 – Sa element, specimen no. 4876/10, × 81.3, lateral view, Sample 55; 11 – Pb element, specimen no. 4876/55, × 66.6, anterior view, Sample

55; 12 – Sc element, specimen no. 4876/56, × 110.3, lateral view, Sample 55.

Plate 5. Upper Caradocian-Ashgillian conodonts from the Polyakovka, Kuragan (Novokursk sequence), and Baulus formations.

1 – *Panderodus* sp. Specimen no. 4876/57, × 69.6, lateral view, Sample 3, Kuragan Formation (Novokursk sequence); 2–4, 8 – *Hamarodus brevirameus* (Walliser, 1964). 2 – Pb element, specimen no. 4876/58, × 137.2, posterior view, Sample 44/1, Polyakovka Formation; 3 – Pb element, specimen no. 4876/59, × 71.5, posterior view, Sample B-115, Baulus Formation; 4 – Sc element, specimen no. 4876/60, × 62.7, lateral view, Sample 3, Kuragan Formation (Novokursk sequence); 8 – M element, specimen no. 4876/61, × 50, lateral view, Sample 44/1, Polyakovka Formation; 5 – *Panderodus gracilis* (Branson et Mehl, 1933). S element, specimen no. 4876/62, × 71.5, antero-lateral view, Sample 58/10, Polyakovka Formation; 6, 9 – *Scabbardella altipes* (Henningsmoen, 1947). 6 – specimen no. 4876/63 (redeposited), × 72.5, lateral view, Sample 134, Blyava Formation; 9 – specimen no. 4876/64, × 78.4, lateral view, Sample 44/1, Polyakovka Formation; 7, 14 – *Dapsilodus mutatus* (Branson et Mehl, 1933). 7 – specimen no. 4876/65 (redeposited), × 67.6, lateral view, Sample 134, Blyava Formation; 14 – specimen no. 4876/66 (redeposited), × 70.5, lateral view, Sample 134, Blyava Formation; 10, 11 – *Periodon grandis* (Ethington, 1959). 10 – Sd element, specimen no. 4876/67, × 61.3, lateral view, Sample 4, Kuragan Formation (Novokursk sequence); 11 – Pb element, specimen no. 4876/68, × 62.7, postero-lateral view, Sample 3, Kuragan Formation (Novokursk sequence); 12, 13 – *Periodon grandis bellus* (Moskalenko, 1988). 12 – Sc element, specimen no. 4876/70, × 80.4, lateral view, Sample 44/1, Polyakovka Formation; 13 – M element, specimen no. 4876/69, × 44, lateral view, Sample 58/10, Polyakovka Formation; 15 – *Protopanderodus liripipus* Kennedy, Barnes et Uyeno, 1979. Specimen no. 4876/71, × 55, lateral view, Sample B-115, Baulus Formation; 16 – *Walliserodus* cf. *W. nakholmensis* (Hamar, 1966). Specimen no. 4876/72 (mold), × 32.3, lateral view, Sample 10, Baulus Formation; 17 – *Ansella* sp. Specimen no. 4876/74, × 34.3, outer lateral view, Sample 3, Kuragan Formation (Novokursk sequence); 18 – *Spinodus spinatus* (Hadding, 1913). Sc element, specimen no. 4876/75, × 46, lateral view, Sample 4, Kuragan Formation (Novokursk sequence); 19 – *Protopanderodus insculptus* (Branson et Mehl, 1933). Specimen no. 4876/73, × 56, lateral view, Sample 10, Baulus Formation.

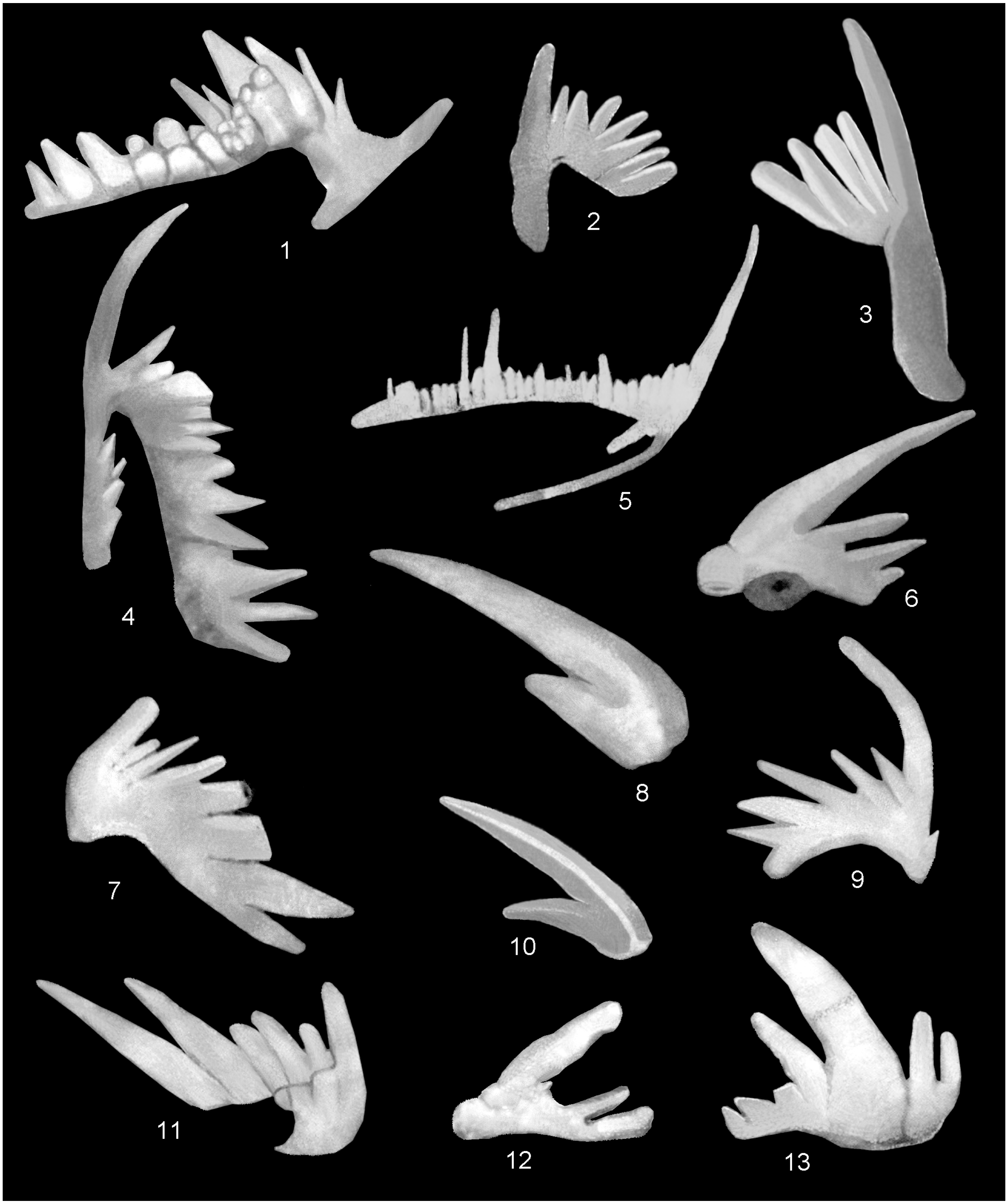

Plate 1. Arenigian conodonts from the Polyakovka Formation.

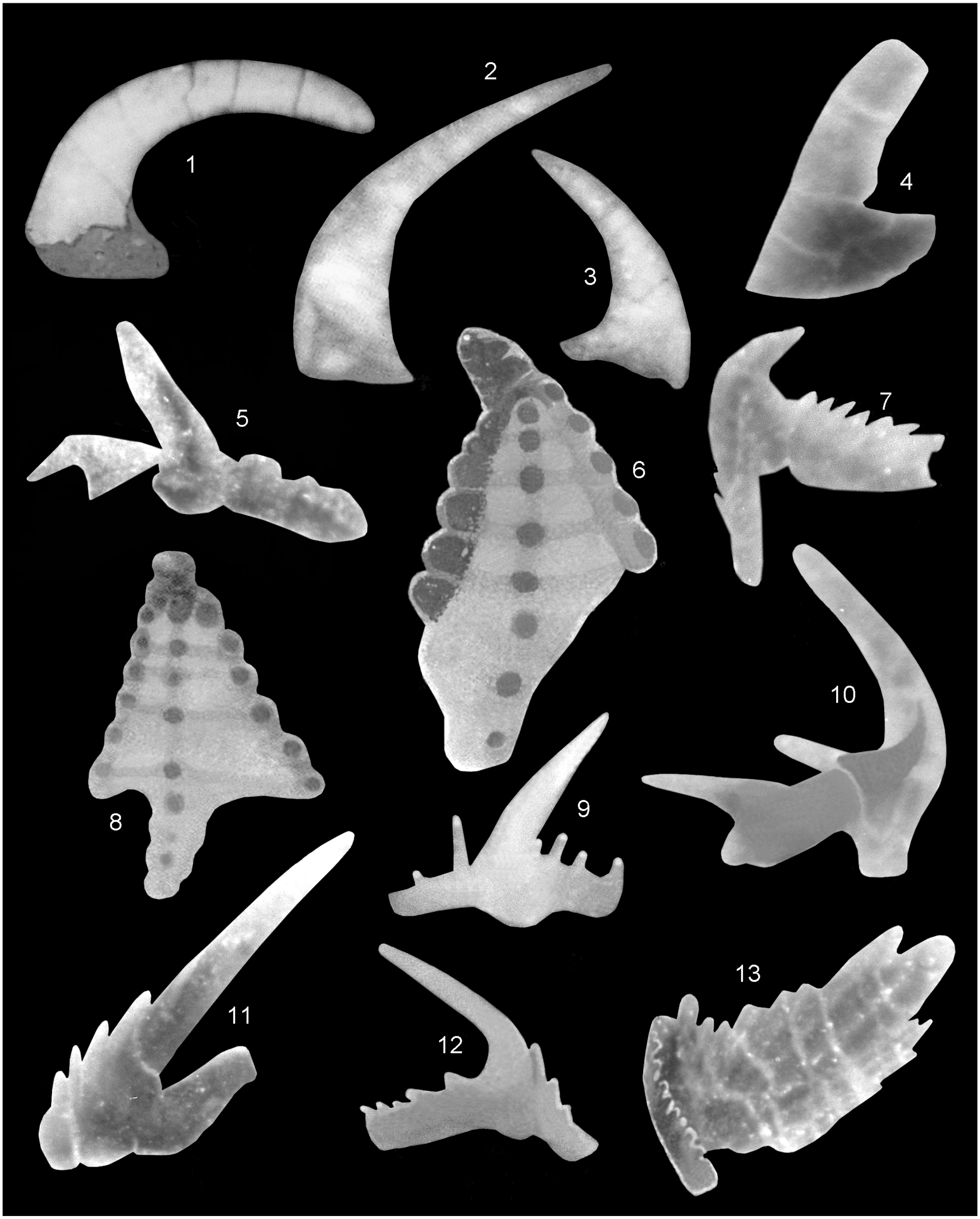

Plate 2. Llanvirnian conodonts from the Polyakovka and Kuragan formations.

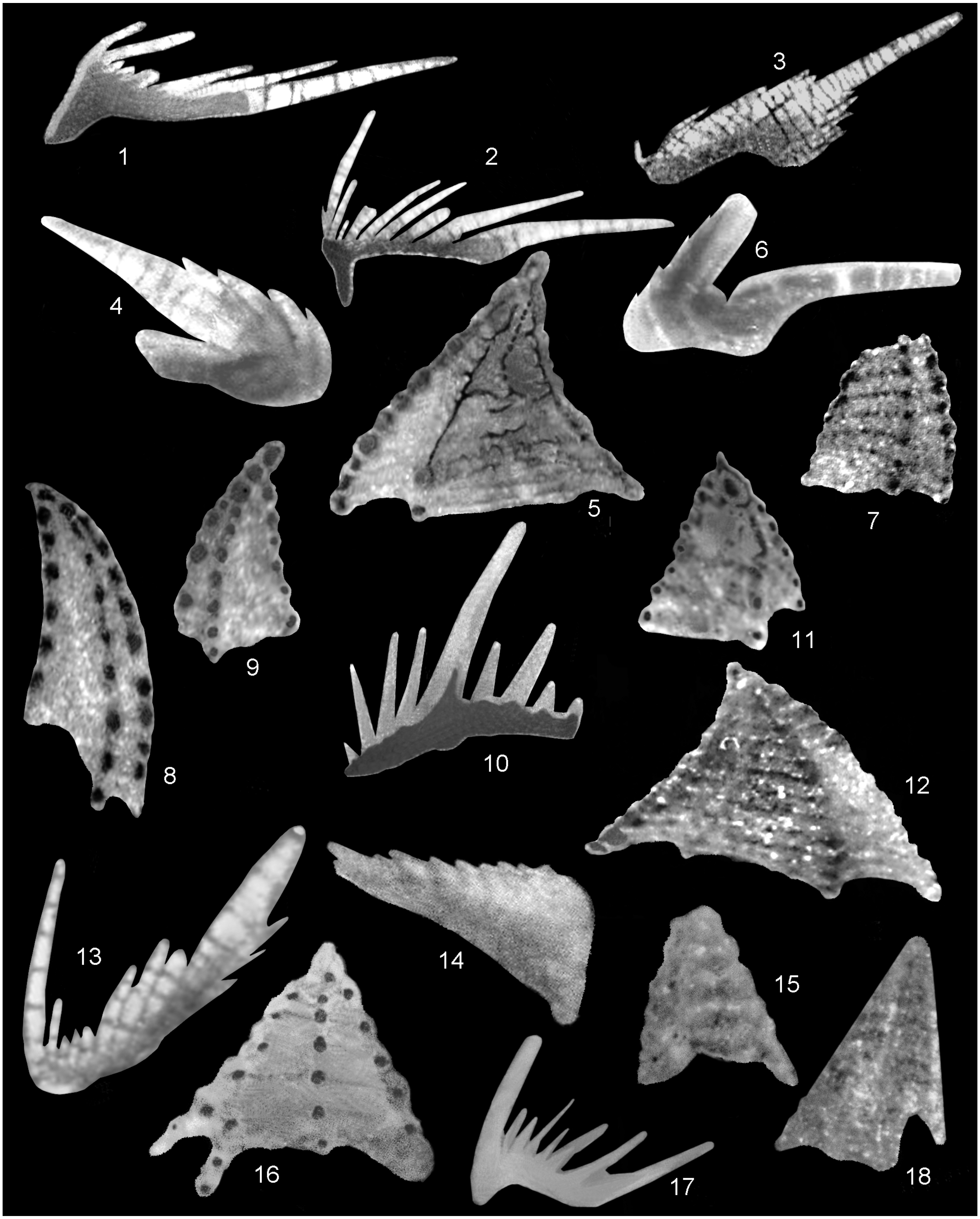

Plate 3. Uppermost Llanvirnian conodonts (*Pygodus protoanserinus* and *P. anserinus* Beds) from the Polyakovka Formation.

Plate 4. Uppermost Llanvirnian–Caradocian conodonts from the Polyakovka Formation.

Plate 5. Upper Caradocian-Ashgillian conodonts from the Polyakovka, Kuragan (Novokursk sequence), and Baulus formations.