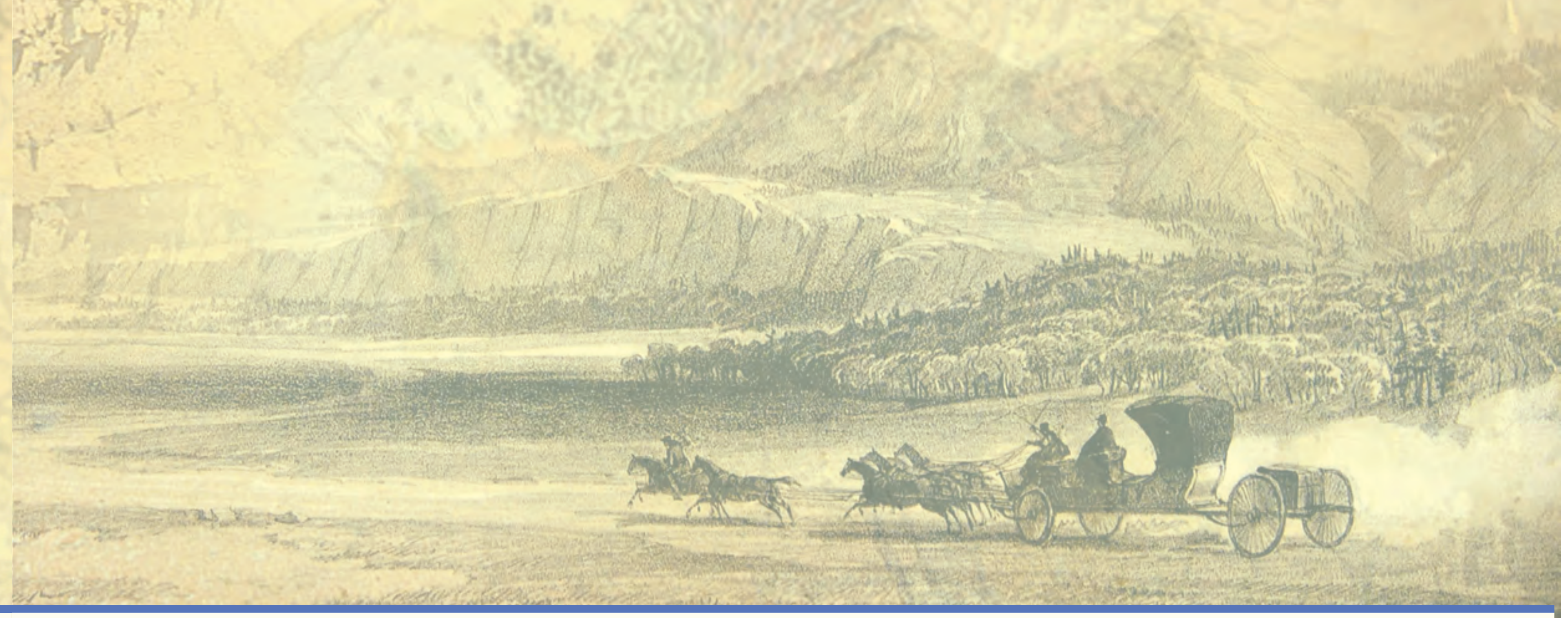
Kazan Federal University
Institute of Geology and Petroleum Technologies

XVIII INTERNATIONAL CONGRESS ON THE CARBONIFEROUS AND PERMIAN

August 11–15, 2015, Kazan, Russia

Southern Urals. Deep water successions of the Carboniferous and Permian



KAZAN FEDERAL UNIVERSITY
THE ZAVARITSKY INSTITUTE OF GEOLOGY AND GEOCHEMISTRY OF THE URAL BRANCH OF THE RUSSIAN ACADEMY OF SCIENCES

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Pre-Congress A3 Trip, 6-10 August, 2015

KAZAN
2015

UDC 551. 73
BBC 26.34
S 75

Editor - in - Chief: Danis K. Nurgaliev

S75 Southern Urals. Deep water successions of the Carboniferous and Permian. A Field Guidebook of XVIII International Congress on Carboniferous and Permian. Pre-Congress A3 Trip, August, 6-10, 2015 / V.V. Chernykh, B.I. Chuvashov, V.I. Davydov, C.M. Henderson, S.Shen, M.D. Schmitz, G.M. Sungatullina, R.Kh. Sungatullin, J.E. Barrick, O.P. Shilovsky – Kazan: Academy of Sciences of the Republic of Tatarstan Press, 2015. - 88 p.

ISBN 978-5-9690-0256-2

This guidebook describes the sections of the Upper Carboniferous and Lower Permian of the Preuralian Foredeep, and gives lithological and paleontological characteristics of the deposits. The guidebook is intended for geologist and paleontologist who study Carboniferous and Permian stratigraphy and paleontology, and for students and teachers of fieldwork techniques.

Co-sponsorship:
Government of the Republic of Tatarstan
Academy of Sciences of the Republic of Tatarstan
JSC “TATNEFT”

We are grateful to Ramil Z. Bukharov, Fuat Z. Kiekbaev, Ruslan Ya. Salavatov (administration of the village Krasnousolsk) and Fayaz Kh. Masitov, Ildar F. Idrisov (the health resort Krasnousolsk administration) for their help in preparing the geological sections for the excursion.

Translated from the Russian by Svetlana V. Nikolaeva and Dinara N. Miftakhutdinova

ISBN 978-5-9690-0256-2

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Introduction

The Guidebook «Southern Urals. Deep water successions of the Carboniferous and Permian» is devoted to the description of the sections of Mechetlino, Dalnyi Tyulkas, Usolka and the Sterlitamak Shikhans. The sections occur in relatively deeper-water portions of the Preuralian Foredeep.

In the Mechetlino section on the right bank of the Yuryuzan River, carbonate- siliciclastic deposits of the Kungurian-Artinskian boundary are exposed. This section contains fusulinids, ammonoids, conodonts and presumably some layers of volcanic tuffs. Numerous fusulinids, ostracods, calcareous algae, conodonts and ammonoids are found here. The Mechetlino section is a candidate for the Global Section Stratotype and Point (GSSP) for the base of the Global Kungurian Stage of the International Stratigraphic Time Scale.

The Usolka and Dal'ny Tulkas sections are located on the right bank of the Usolka River at the northeastern margin of the city of Krasnousolsk, in the Republic of Bashkortostan, Russia. The sections are represented by continuous, thick marine mixed carbonate-siliciclastic deposits of Upper Carboniferous and Lower Permian Age. The Usolka section is proposed as the Global Stratotype Section and Point (GSSP) for the lower boundary of the Gzhelian and Sakmarian Stage. The Dal'ny Tulkas section is proposed as GSSP for the lower boundary of the Artinskian Stage for the International Geochronological Scale.

The Sterlitamak Shikhans are located near the town of Sterlitamak and are mostly composed of carbonate rocks of the Asselian and Sakmarian Stages. Reefs are located on the border of the Russian plate and the Ural trough. During the tour three of these reefs will be shown: Tra-Tau, Shakh-Tau and Yurack-Tau.

MECHETLINO SECTION

On the right bank of the Juryuzan River between the villages Mechetlino and Makhmutova (Southern Preural'ye) (Fig. 1.1), the strata of the upper part of the Artinskian Stage (Sarginian Horizon) are exposed, above which in the section is a thick unit of silty-carbonate deposits of the Saranian and Philippovian Horizons of the Kungurian Stage (Figs. 1.2, 1.3).

This section contains fusulinids, ammonoids, conodonts and presumably some layers of volcanic tuffs. We propose this section as a candidate of the Global Section Stratotype and Point (GSSP) for the base of the Global Kungurian Stage of the International Stratigraphic Time Scale.

The proposed section that we call Mechetlino Quarry (MQ), is located about 600 m east from previously studied and described in the literature Mechetlino section (MS) (Chernykh, 2006; Chuvashov, Chernykh, 2007) that was demonstrated as a potential GSSP at the international field workshop in 2007 (Davydov and Henderson, 2007). Some of the biostratigraphic data from Mechetlino section, particularly conodonts and fusulinids are used in this proposal as Mechetlino and Mechetlino Quarry sections are correlated bed by bed (Fig. 1.3).

The Artinskian-Kungurian interval is exposed in the eastern part of the Mechetlino section in a small quarry and is represented by carbonate, marl, sandstone and sandy carbonate sediments with a total thickness of over 10 meters. The lower part of the section was exposed in a short trench (Fig. 1.1). In the quarry there are thin layers of potential tuff: three of them are in the Artinskian part of the section, and two in the Kungurian. Many layers of the rocks contain considerable admixture of carbonate material and can be processed by standard acid techniques to extract conodonts. The lithology, conodonts and other faunal elements of this section have been preliminary published recently (Chuvashov and Chernykh, 2011).

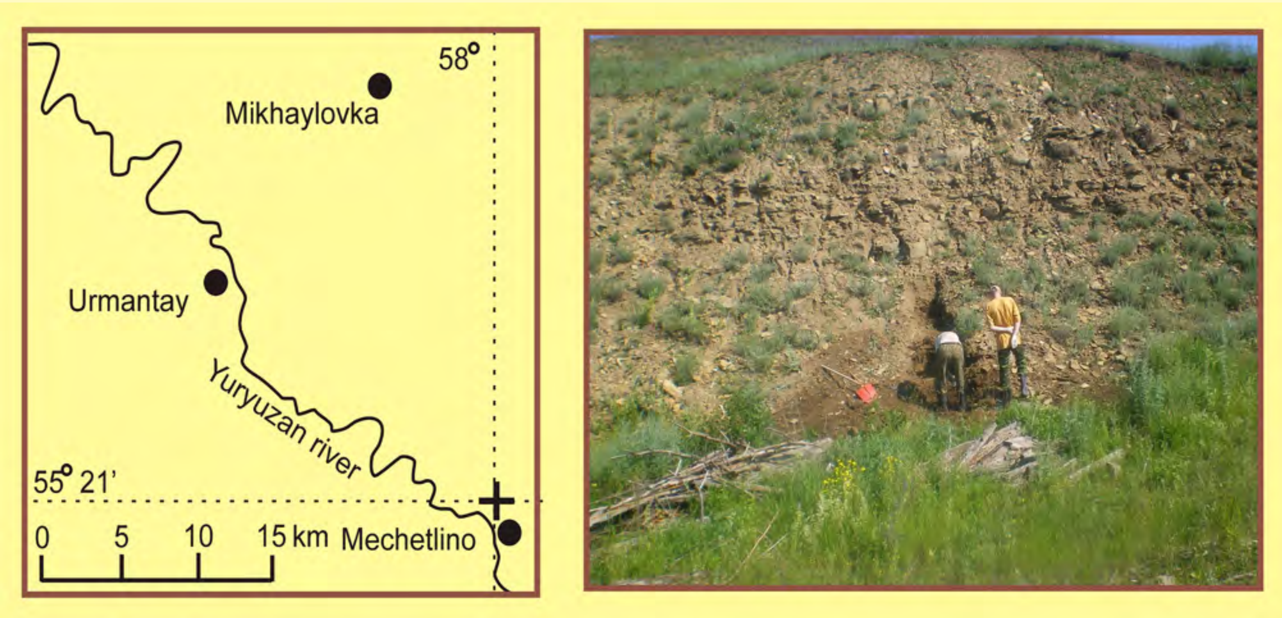


Fig. 1.1. On the left: location of the Mechetlino quarry (+). On the right: view of the Mechetlino quarry (debris opened by trench)

The description of the lithology, distribution of conodonts and other faunal elements of this section have been recently published (Chuvashov and Chernykh, 2011). In 2011, the Artinskian – Kungurian interval in this quarry was excavated (Fg. 1.1) and additional samples for conodonts and ammonoid studies were taken. This collection narrowing of the interval of occurrence of last Artinskian species and first Kungurian species and thus constraining boundary within to less than one meter (Fig. 1.3). The potential volcanic tuff samples were taken from five levels and were sent to Boise State University for searching the datable zircon crystals. However, the recovered zircons from all processed samples turns to be detrital. Devonian age has been obtained from zircons in one and most promising sample.

The description of the studied section is given below. The conodonts (from MQ) and fusulinids (recovered in MS) are illustrated in the paleontological plates (PLATES I-III).

Section description

1. Argillite, dark greenish-gray with lumpy jointing, slightly calcareous with a visible thickness up to 10 cm.

2. Limestone, brownish-gray, fine-grained, bioclastic with an uneven surface and variable thickness from 5 to 8 cm. Fossils present are tiny (2 mm) fragments of crinoids and tubular attached foraminifers. Sample 5919-2 is taken here. Conodonts recovered: *Neostreptognathodus pequopensis* Behnken, *N. ruzhencevi* Kozur ....0.10 m.

3. Gray calcareous argillite passing into the marl. In this layer there are compressed along surface limestone nodules up to 10 cm long and of 3-5 cm in thickness. The nodules possess a distinct Liesegang rings. Small charred fragments of organic remains are present..................... 0.82 m.

4. Bioclastic limestone: dark-brown, gray, thin-bedded (in the lower part 5 cm, upper up to 10 cm) with irregular bedding planes with 3-5 mm interlayers of dark gray marl-argillite. Sample 5919-4 is taken here. Conodonts: *Neostreptognathodus pequopensis* Behnken, *N. ruzhencevi* Kozur, *Sweetognathus somniculosus* Chernykh; ammonoids: *Paragastrioceras verneili* (Ruzhencev), *P. karpinski* (Ruzhencev), *Uraloceras* cf. *U. bogoslovskayae* (Voronov), *U. tchuvashovi* Bogoslovskaya, *U. fedorovi* (Karpinsky).. 0.25 m.

5. Argillite, in the lower part dark gray, thin-plated with a thickness of the plates 0.5 cm. Organic remains are represented by charred plant detritus (1-2 mm). The bottom layer (10 cm) has a series of small (1-5 mm) layers of yellow tuff. In the upper part of this bed there is a 1-cm band of fine-bioclastic limestone. In the upper part of the unit the argillite passes into marl 10-12 cm thick. Tuff sample 5919-5a was taken in this unit ………………….......................……... 0.42 m.

6. Marl, gray to dark gray, thin-bedded. Homogeneous gray layers of 3-4 cm thick replaced by argillite (1-2 cm) interbedded with thin-bedded (up to 3 cm) bioclastic limestone. Sample 5919-6 was taken here. Conodonts: *Sweetognathus somniculosus* Chernykh .... 0.45 m.

7. Greenish-gray sandstone with thin (2-5 cm) interbeds of black argillite with plant detritus... 0.15 m.

8. Sandstone, greenish-gray to black. Platy loose rock with alternating of intercalations of coal like rock with thickness up to 1-1.5 cm. Sandstone layers are denser, coal is loosely com pacted……..…... 0.20 m.

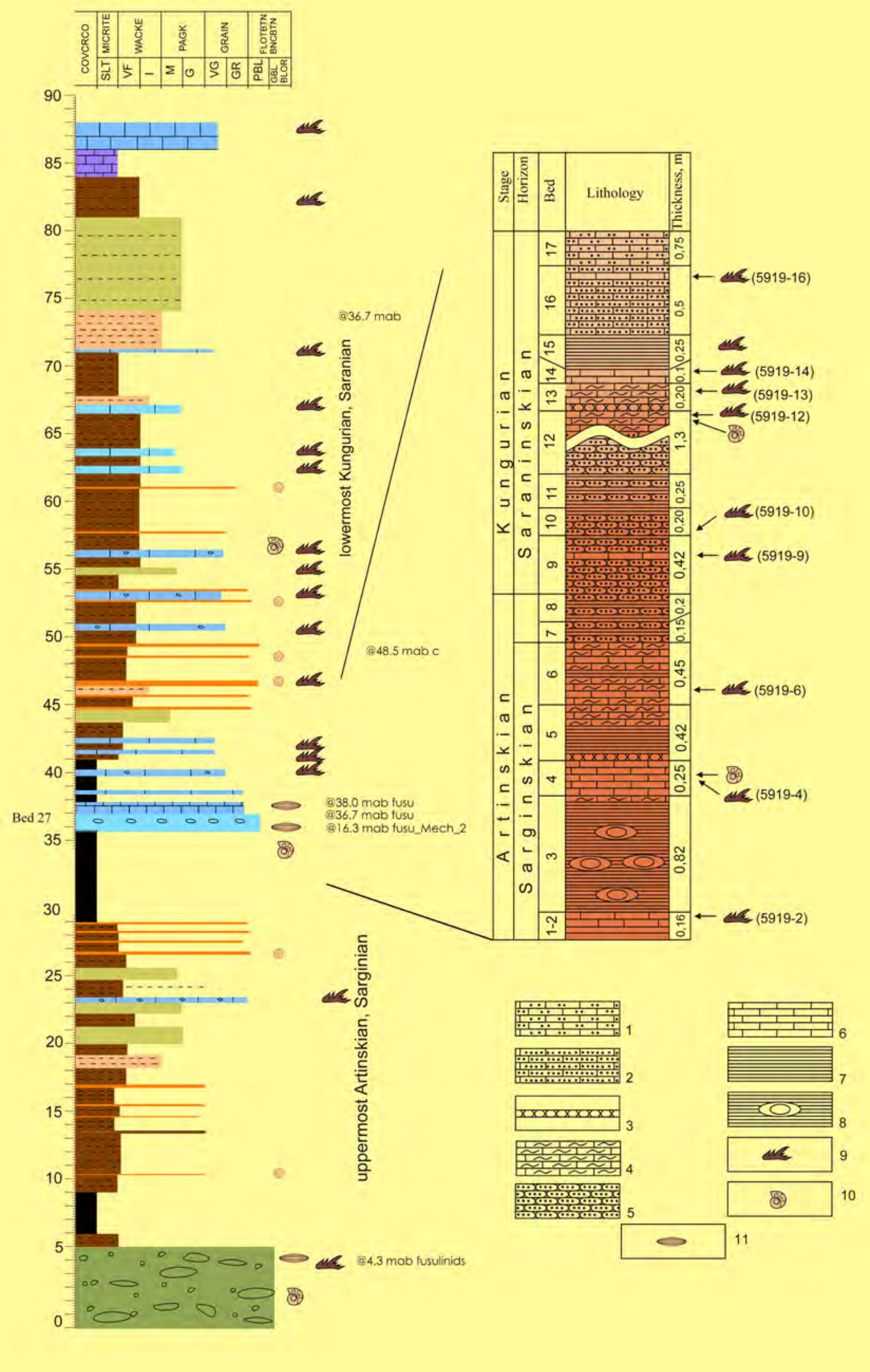


Fig. 1.2. Correlation of the stratigraphic columns of Mechetlino section and Mechetlino quarry.
Legend: 1 – calcareous sandstones; 2 – arenaceous limestones; 3 – tuff; 4 – marl; 5 – sandstones; 6 – limestones; 7 – mudstones; 8 – mudstones whit argillo-calcareous concretions; fossil remains: 9 – conodonts (numbers of informative samples with conodonts are indicated in brackets); 10 – ammonoids; 11- fusulinids

The trenched section ends here and remaining part of the section is in the exposed part of the quarry.

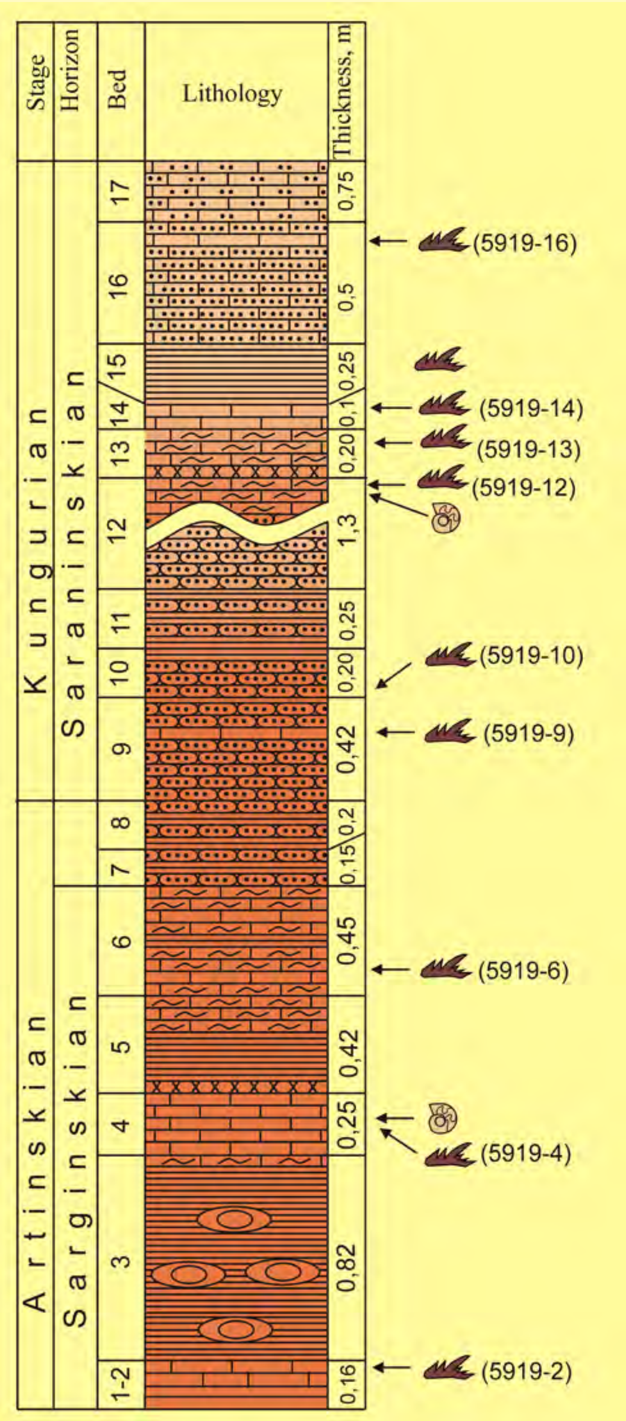


Fig. 1.3. Stratigraphic column with distribution of samples taken for conodonts and ammonoids. Legend in Fig. 1.2

9. Sandstone, gray and greenish-gray, fine-grained to silt-grained (below), massive, highly calcareous matrix. There is frayed plant detritus. The sample 5919-9 is taken here. Conodonts: *Neostreptognathodus pequopensis* Behnken, *N. ruzhencevi* Kozur, *N. lectulus* Chernykh, *N. pnevi* Kozur et Movshovitsch.............. 0.42 m.

10. Sandstone, greenish-gray with a rusty stain on the surface layers. In the lower part of the unit the bed has a thickness of 5-7 cm where there is an alternation of sandstone with interbedded argillite (the thickness of the upper layer is 0.2 m). Above is exposed up to 0.25 m of fine-grained sandstone that splits into irregular plates of thickness of 1-3 cm. Sample 5919-10 is taken here. Conodonts: *Sweetognathus* aff. *S. whitei* (Rhodes), *Neostreptognathodus ruzhencevi* Kozur, *N. labialis* Chernykh, *N. lectulus* Chernykh, *N. cf. N. pnevi* Kozur et Movshovitsch……………….…......................0.45 m.

11. Greenish-gray fine-grained sandstone at the base with an admixture of coarser sandy material. The layer loses its integrity and is divided into the plates of thickness up to 5 cm ……….................................0.25 m.

12. Uniform layer of fine-grained sandstone, in the lower part massive, in the upper part laminated. At the top of the bed is bounded by a tuff bed. Inside of the lower part of the sandstone there is marl with thin (2-3 mm) interlayers of fine-grained gray limestone. To the right from the trench (when facing the face of the quarry), these layers of marl are transformed into compressed nodule of brownish-gray very dense and hard limestone with rare ammonites. The thickness of this nodule is up to 10 cm. Sample 5919-12a is taken from the limestone lens. Sample 5919-12b is taken from a mixture of marl and limestone samples of this unit. Conodonts: *Neostreptognathodus pequopensis* Behnken, *N. ruzhencevi* Kozur, *N. labialis* Chernykh, *N. lectulus* Chernykh, *N. pseudoclinei* Kozur et Movshovitsch, *N. pnevi* Kozur et Movshovitsch………..……….. 1.3m.

13. A small bed of thin-bedded silty limestone with thin stratification in the upper part with a mixture of tuff material. Conodonts: *Neostreptognathodus ruzhencevi* Kozur, *N. labialis* Chernykh, *N. lectulus* Chernykh, *N. pnevi* Kozur et Movshovitsch……………..…………....0.20 m.

14. Lenticular gray - greenish limestone with a mixture of bioclastic material. Conodonts: *Neostreptognathodus pequopensis* Behnken ....0.05 – 0.10m.

15. Argillite, dark greenish-gray strongly calcareous and strongly deformed. Organic materials: small foraminifers, crinoid segments, bryozoans ………..................................…..0.25 m.

16. A massive layer of sandy limestone (base of which is situated 3 m above the bottom of the quarry). Conodonts: *Neostreptognathodus pequopensis* Behnken, *N. ruzhencevi* Kozur, *N. labialis* Chernykh, *N. lectulus* Chernykh, *N. pnevi* Kozur et Movshovitsch ……..………...............……..….... .... 0.50 m.

17. Thick layer of calcareous monolithic sandstone: dark gray fine-grained with thickness up to 10 cm in the lower part. This lower part is situated approximately 75 cm above the tuff layer from unit 13. Sample 5919-17 is taken here …...…0.70 m.

18. Alternation of sandstone with rare interbedded argillite.....………......................…0.50 m.

19. Greenish-gray argillite..................0.27 m.

Above this section there is a packet of alteration of thinly bedded sandstone (thickness of beds 0.5 – 20 cm) with limestone and argillite (thickness up to 10 – 15 cm).

Conodonts

The officially accepted definition the Artinskian-Kungurian boundary proposed to coincide with evolutionary event of the appearance of conodont species *Neostreptognathodus pnevi* within the *N. pequopensis*- *N. pnevi* chronocline (The decisions …, 1998).

All conodonts recovered in both MS and MQ sections belong to two genera: *Sweetognathus* and *Neostreptognathodus*. Several evolutionary trends in both genera were recognized. In MQ section in the Artinskian part *Neostreptognathodus pequopensis* Behnken and *N. ruzhencevi* Kozur were found. The difference between these two species is mainly in the structure of the carinal teeth. In *Neostreptognathodus pequopensis* – the teeth are tuberculate, more or less vertically standing, in *N. ruzhencevi* – the carinal denticles are in the form of slightly inclined short ribs (Pl. I, Figs. 1, 2). This latter type is sometimes marked by a variation in the relative position of the free blade and the carinal parapets. In many cases, the free blade is in a sub-central position, or can be merged with one of the parapets. These variations are considered to be intraspecific (Chernykh, 2006) and not to be included in the taxonomic considaration.

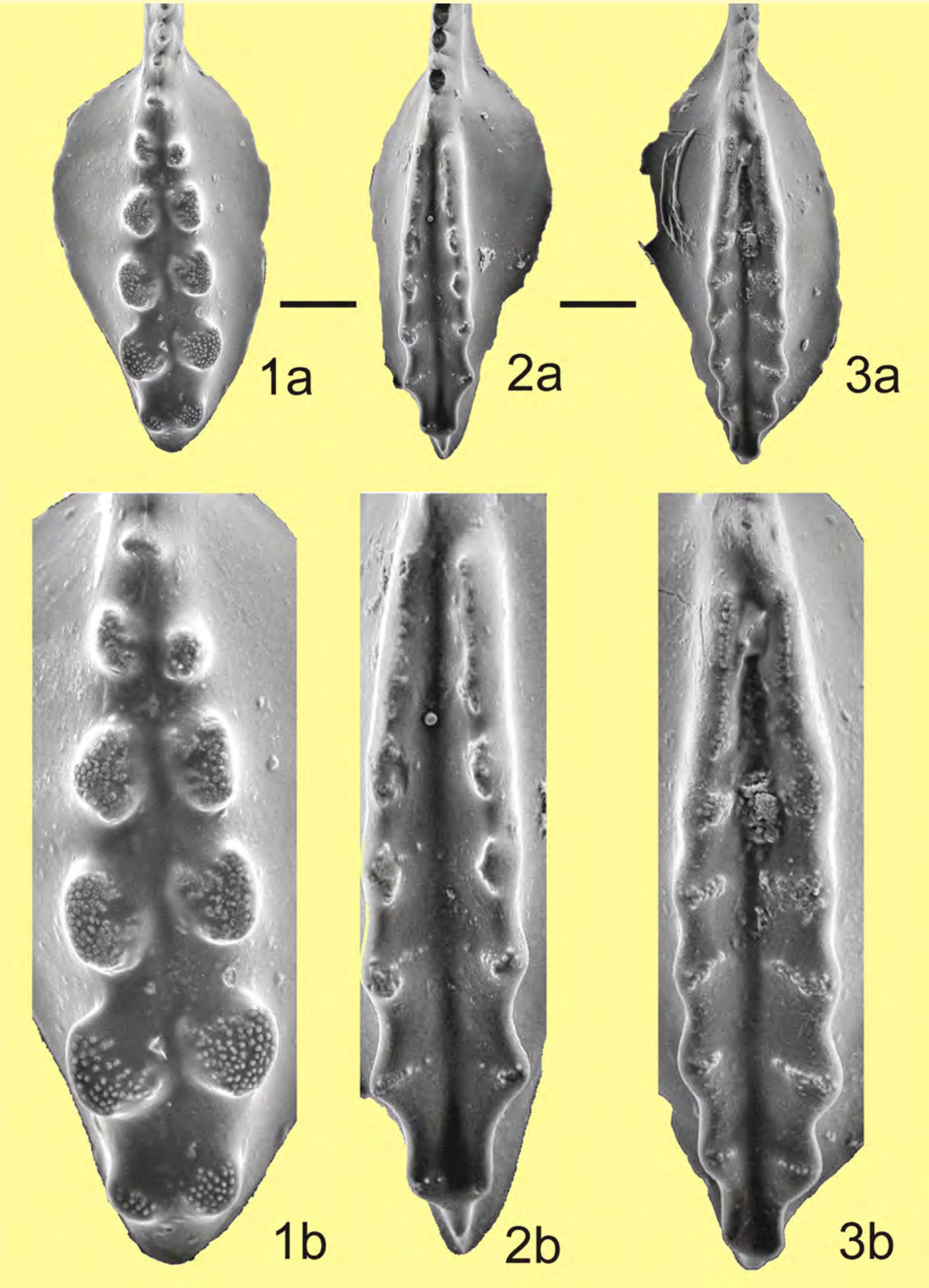


Fig. 1.4. The evolutionary lineage of Neostreptognathodus pequopensis Behnken – N. pnevi Kozur et Movshovitsch Chernykh. 1 – N. pequopensis , from bed 4; 2 - transitional from N. pequopensis to N. pnevi, from bed 9; 3 – N. pnevi, from bed 9

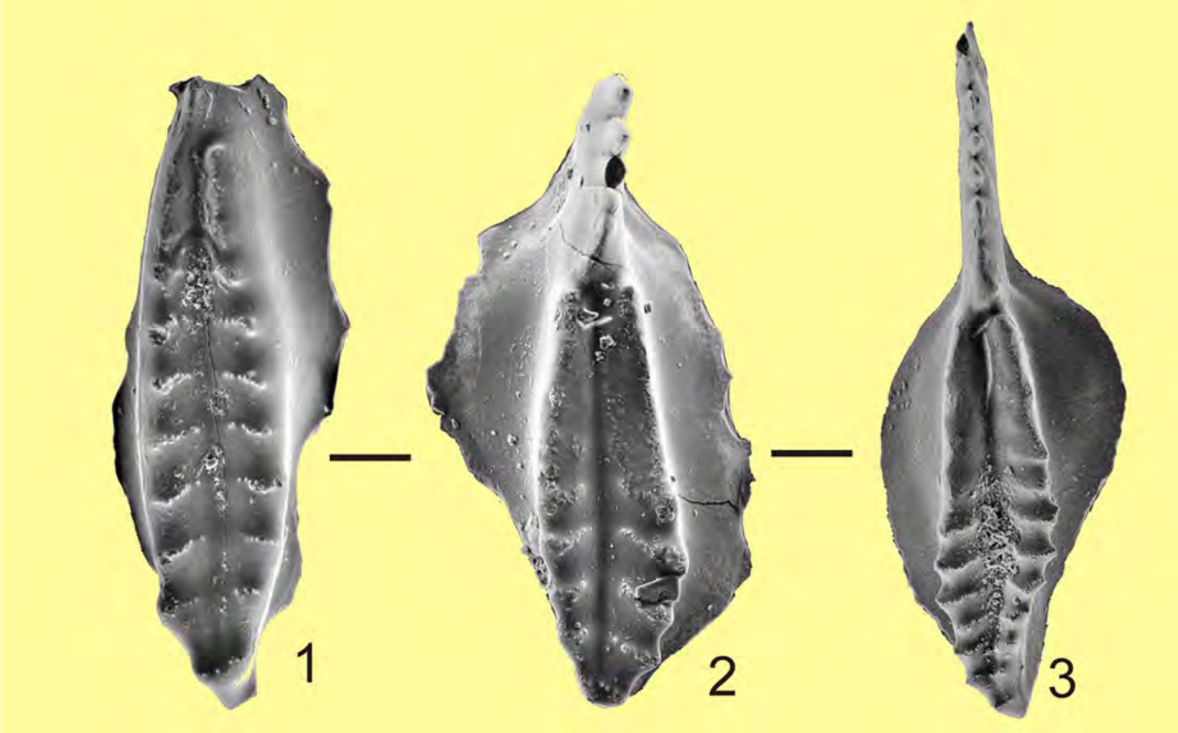


Fig. 1.5. The evolutionary lineage of Neostreptognathodus ruzhencevi Kozur – N. lectulus Chernykh. 1 - Neostreptognathodus ruzhencevi, from bed 2; 2 - N. lectulus, from bed 9; 3 - N. lectulus, from bed 13

Both species appeared in the Artinskian but evolved into the Kungurian, and from that time an increasing number of forms began to lose the anterior carinal teeth. The morphotype of *Neostreptognathodus pequopensis* Behnken evolved by the reduction of teeth into *N. pnevi* Kozur et Movshovitsch (Fig. 1.4), and *N. ruzhencevi* Kozur also by the reduction of teeth evolved into the morphotype of *N. lectulus* Chernykh (Fig. 1.5). The level of the first appearance of this last form is equally able to play the role of markers of the lower boundary of the Kungurian Stage.

Within genus *Sweetognathus* two groups can be distinguished. The first group is made up of forms of the morphotype *Sweetognathus whitei* (Rhodes) but with a greater or lesser reduction of the anterior carinal nodes which remain in the place of a pustular narrow carinal stripe (Pl. II, Fig. 6). Less often, instead of this reduction there is a marked decrease in the size of the carinal teeth, especially in front part of the carina.

Another group of forms based on *Diplognatodus* morphotypes is distinguished by the appearance of numerous pustules on the carinal ridge. Late Artinskian members of this group have often a poorly differentiated carina, due to small lateral swelling in the back area of the pustules (Pl. I, Figs. 11-17). Such forms are designated as *Sweetognathus somniculosus* Chernykh (Chernykh, 2012). In some of these forms the crest is flattened and in its middle part there is a hint of a depression zone – the rudiments of the future median groove. Later, apparently, already in Early Kungurian such forms at first are transformed into those deprived of teeth *Neostreptognathodus pseudoclinei* Kozur et Movshovitsch, and these latter in turn pass in *N. labialis* Chernykh. The development of the line "*Sw. somniculosus-N. pseudoclinei-N. labialis*" is traced in great detail in the MQ (Fig. 1.6).

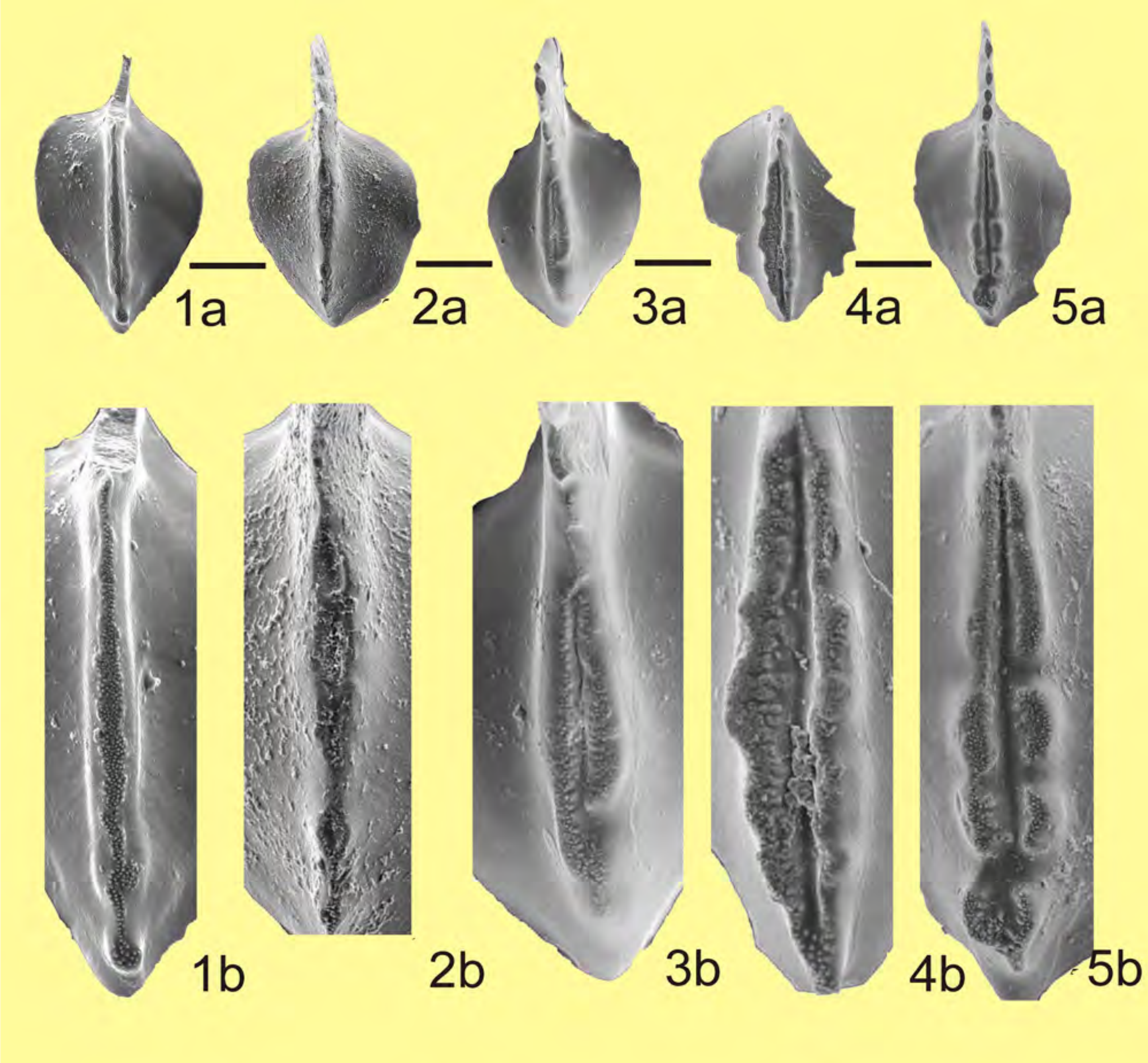


Fig. 1.6. The evolutionary lineage of Sweetognathus somniculosus Chernykh – Neostreptognathodus labialis Chernykh. 1 – Sw. somniculosus, form from the bed 6; 2, 3, 4 – N. pseudoclinei Kozur et Movshovitsch: 2 – transitional from Sw. somniculosus to N. psedoclinei; 3, 4 – transitional from N. pseudoclinei to N. labialis; 5 – N. labialis Chernykh (all forms from the bed 12)

At first from *Sweetognathus somniculosus* appear form *Neostreptognathodus pseudoclinei* with the incompletely developed median groove and only single constriction of the parapets at the back of carina (Pl. II, Fig. 7, 14). Then morphotypes *N. labialis* Chernykh with a fully formed carina consisting of five or six pairs of lip-like opposed teeth separated by a deep median groove joining them (Pl. II, Figs. 15, 16, 19).

The origin of fully developed forms of *Neostreptognathodus labialis* Chernykh is somewhat delayed with respect the time of the appearance of *N. pnevi* Kozur and *N. lectulus* Chernykh. But this delay is negligible and the discovery of *Neostreptognathodus labialis* Chernykh dates the enclosing rocks as Early Saranian.

Table 1

Conodonts distribution on the bed in the Mechetlino quarry

Bed number	2	4	6	9	10	12	13	14	16
m above base	0,16	1,10	1,80	2,75	3,00	4,52	4,70	4,85	5,57
weight in kilograms	5	5	5	8	5	10	5	3	5
Taxon	Number of elements								
Sweetognathus somniculosus		8	3						
Sweetognathus aff. whitei					2	1			
Neostreptognathodus pequopensis	4	3		2	1	6		4	5
Neostreptognathodus ruzhencevi	4	2			2				
Neostreptognathodus pseudoclinei					1	4			
Neostreptognathodus labialis						17	3		7
Neostreptognathodus pnevi				5	1	22	9		
Neostreptognathodus lectulus				10	8	11	8		4
Neostreptognathodus fastigatus						1			
S_c element		2	4	5		1			
P_b element				6		2			5
M element			2	3		2			
Total = 180	8	15	9	31	10	67	20	4	16

Possibly, *Neostreptognathodus pseudoclinei*, whose first appearance is not accurately established in the section but which appears in Kungurian earlier than *N. labialis* Chernykh, will be also useful for determining lower boundary of Kungurian.

Therefore, in the upper part of the Artinskian stage, the following species are present: *Neostreptognathodus pequopensis* Behnken, *N. ruzhencevi* Kozur, *Sweetognathus* aff. *S. whitei* (Rhodes) and *Sw. somniculosus* Chernykh.

All of these species pass into the Kungurian, except for the species *Sweetognathus somniculosus* Chernykh. They are joined by the actual types of Kungurian species as *Neostreptognathodus pseudoclinei* Kozur et Movschovitsch, *N. pnevi* Kozur, *N. lectulus* Chernykh and *N. labialis* Chernykh. This group marks the distribution of conodonts in the transitional Artinskian-Kungurian interval in the Urals, which permits one to quite confidently identify the lower boundary of the Kungurian Stage by the appearance of species such as *N. pnevi* Kozur and *N. lectulus* Chernykh and, possible, N. *pseudoclinei* Kozur et Movschovitsch. The first two species are known in sections of coeval sediments in the USA (Behnken, 1975; Clark et al., 1979; Wardlaw and Collinson, 1986) and Canada (Henderson, 1999).

A special comment should be made about the representation and preservation of conodonts in the described section. The Upper Artinskian-interval is characterized by the low frequency of the occurrence of conodonts (table 1). The total number of specimens of the Artinskian conodonts in the studied collection is from fifteen to twenty. If we add to them the conodonts collected in MS (Chernykh, 2006), that number increase to three dozen. It should be noted that the study of other sections of the Artinskian of the Urals shows the same picture of conodont diversity at this time in the Urals.

In the lowermost part of Kungurian in MQ section the diversity of conodont remains approximately the same as in the Upper Artinskian, i.e.

Table 2

The fusulinids distribution in Mechetlino section

Meters above the base in Mechetlino_1	4.3	36.1	38
Taxon			
Protonodosaria sp.	x	x	x
Hemigordius sp.	x	x	x
Grovesella nevadaensis Davydov, *2011*	x	x	x
Uralofusulinella arkaulensis Tschuvashov, *1980*	x	x	x
Uralofusulinella ajuensis Tschuvashov, *1980*		x	
Pseudofusulina fallax Rauser, *1949*	x	x	
Pseudofusulina paraconcessa Rauser, *1949*	x	x	
Pseudofusulina russiensis Rauser, *1949*	x		
Pseudofusulina paraconcavutas Rauser, *1949*	x		
Pseudofusulina ordinata Kireeva, *1949*	x		
Pseudofusulina alaguvatovi Rauser, *1949*	x		
Pseudofusulina makarovi Rauser, *1949*	x	x	x
Pseudofusulina urushbaevi Rauser, *1949*			x
Pseudofusulina kusjanovi Rauser, *1949*			x
Pseudofusulina curtata Rauser, *1949*			x
Pseudofusulina postsolida Tschuvashov, *1980*	x		
Parafusulina solidissima Rauser, *1949*	x	x	
Parafusulina solida (Schellwien), *1950*		x	

they are rare. However, almost immediately above the boundary the frequency of the occurrence of the conodonts quite significantly increases (tabl. 1). More than 100 specimens were recovered in bed 12 at MQ section and upwards the number of recovered specimens usually exceeds 40 individuals. All together within 5 m of transitional beds more than 200 specimens were found.

The preservation of the conodonts is very good in most samples. Almost all of the Pa elements found are complete, transparent and without any foreign particles, so they can successfully be used to determine Sr isotope ratios. We are convinced that in the proposed MQ section the lower boundary of the Kungurian Stage is nailed down quite precisely. The relatively low representation of conodonts near the Artinskian –Kungurian boundary could be improved by the collection of larger samples.

Fusulinids

Several species fusulinids were reported from upper Artinskian in Mechetlino and Arkaul sections (Chuvashov, 1980; Chuvashov et al., 1990). The latter section is located about 3 km north-west from Mechetlino. Fusulinids in Mechetlino section were recovered from three horizons (Fig. 1.2) and are typical for the upper Artinskian (Plate III, this paper and Chuvashov et al., 1990). Two horizons of fusulinids were recovered in Ismagilov Fm about 40-50 m above the proposed base of the Kungurian near Arkaul village west from Mechetlino section. These samples are still under current study. Preliminary evaluation suggests their taxonomy being close to the Artinskian one. Similar conclusion can be made from the Kungurian record reported from the Nevolian member of Irenian Horizon of Kungurian near Kungur city (Zolotova and Baryshnikov, 1978). Although nine new species were designated the authors considered these fusulinids closely similar to the late Artinskian. In fact all these new species were never recognized elsewhere outside of the topotype. Thus, in the Urals and specifically in Mechetlino section fusulinids cannot be used to designate the proposed boundary as in Tethys and Nevada, North America. The distribution of the forms of fusulinids into Mechetlino section is shown on table 2.

Ammonoids

In MQ section the ammonids were found in bed 4, which is equal to bed 28 in MS. Among the collected forms were identified *Uraloceras tchuvaschovi* Bogoslovskaya, 1976, *U. fedorowi* (Karpinsky, 1889), *U. sp. nov*., *Paragastrioceras verneuili* Ruzhencev, 1956, *P. karpinskii* (Fredericks, 1915). In this assemblage *Uraloceras tchuvaschovi* Bogoslovskaya is the most prominent species. According M. Boiko (2010) it has never been found below the Saranian Horizon in the Urals. Thus, at least in the region this species are a very good index of the Kungurian. *Neostreptognathodus pnevi* Kozur, however in MQ section occurs 1.5 m above the collected *Uraloceras tchuvaschovi* Bogoslovskaya.

In MS section diverse assemblage of ammonoids has been recovered below bed 28. It is includes *Neopronorites permicus* Tchernov, 1907, *Paragastrioceras verneuili* Ruzhencev, *Uraloceras fedorowi* (Karpinsky), *U. aff. fedorowi, U. posterum* Bogoslovskaya et Boiko, 2002, *U. vietum* Ruzhencev, 1956, *U. bogoslovskayae* Voronov, *U. sp.* (identifications of M.F. Bogoslovskaya and M. Boiko). About two meters above bed XX in the lenses of cephalopod's limestone were found *Paragastrioceras cf. karpinskii* (Fredericks, 1915), *Uraloceras bogoslovskayae* Voronov, 1991 and *U. cf. suesi* (Karpinsky, 1889).

Strontium isotope stratigraphy

An apparently rapid, unidirectional decrease in the Sr isotopic composition of seawater beginning near the base of the Permian provides a potential chronostratigraphic proxy. The Sr isotopic compositions of well-preserved (CAI of <2) conodont platform elements were measured for numerous stratigraphic horizons in the Usolka, Dal'ny Tulkas quarry and Dal'ny Tulkas roadcut sections. From one to ten conodont elements were pooled on a generic basis (*Streptognathodus*, *Mesogondolella*, or *Hindeodus*), ultrasonically cleaned in ammonium acetate and ultrapure water and partially dissolved in dilute acetic acid to remove labile Sr. The residual elements were rinsed in ultrapure water and completely dissolved in concentrated nitric acid, dried with hydrogen peroxide to destroy organics and redissolved in dilute nitric acid for separation of Sr via ion chromatography on Sr-spec crown ether resin (Pin and Bassin, 1991). Sr isotope ratios were measured by thermal ionization mass spectrometry with a reproducibility of ± 0.00001 (2 σ).

The strontium measurements were placed within a quantitative age model based upon twenty-four high-precision CA-TIMS U-Pb zircon ash bed ages from the same stratigraphic sections (Schmitz and Davydov, 2012). The resulting chemostratigraphic curve is interpreted to represent the evolving isotopic composition of seawater, based upon the reproducibility of measurements in individual horizons, the stratigraphic consistency of the results, matrix-independent (carbonate, shale, volcanic ash) isotopic compositions, and the comparison with available literature data for brachiopod shells, which fall on or to more radiogenic values compared to the conodont measurements.

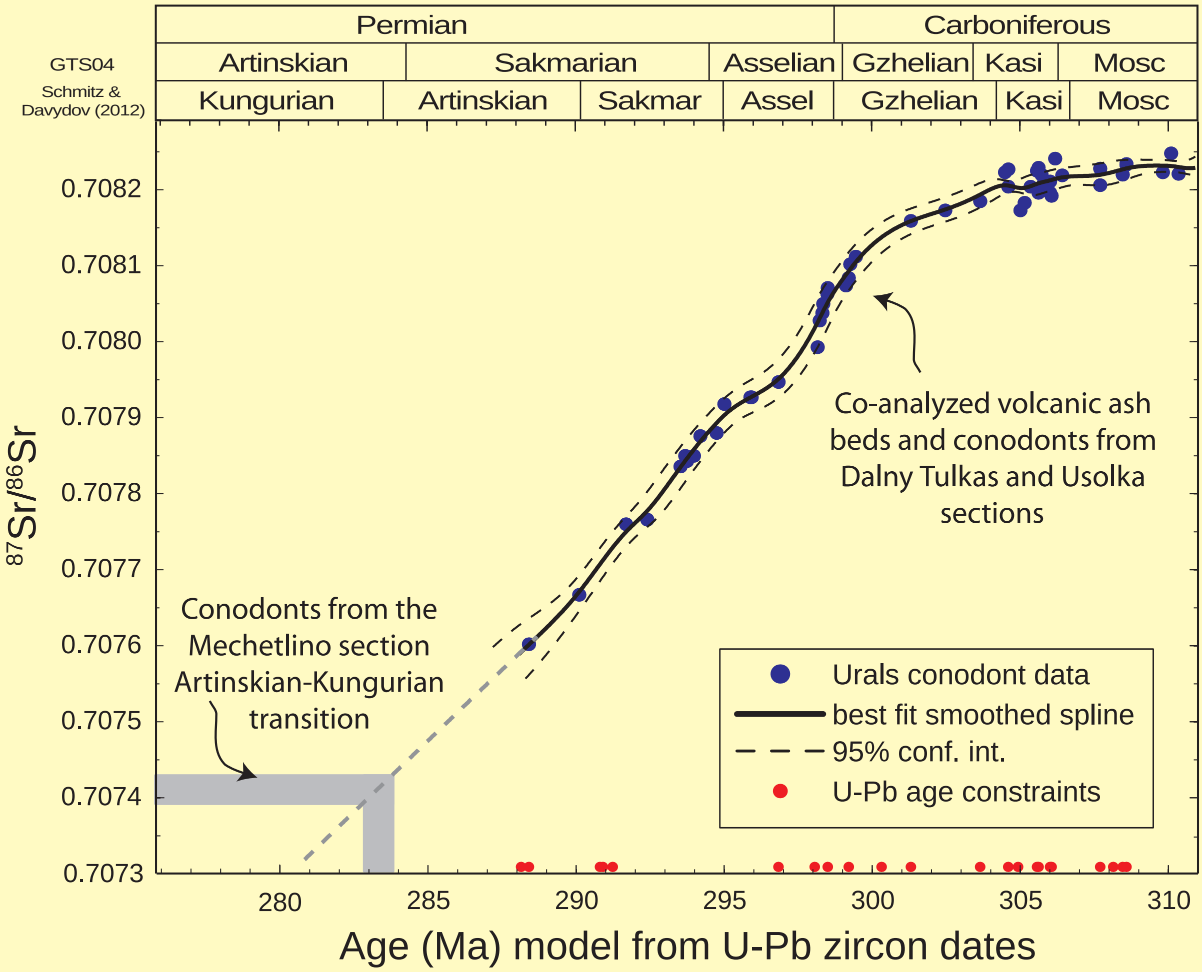


Fig. 1.7. The dating of lower boundary of Kungurian on the relationship of isotopes Sr. Explanation in the text

A smoothed spline fit to these data with 95% confidence interval uncertainties provides a chronostratigraphic proxy with a resolution of approximately 0.5 to 1 Ma from the base of the Asselian through the lower Artinskian Stage (Fig. 1.7). The strontium isotopic composition of seawater at the base of the Artinskian Stage is $^{87}Sr/^{86}Sr = 0.70767$. Unfortunately there are no U-Pb ages for late Artinskian to Kungurian strata of the Urals, however, we may estimate the age of the base Kungurian via extrapolation of the available curve to younger ages; the dashed line in Figure Y illustrates this extrapolation of the decreasing Sr isotopic composition through the lower Permian. To estimate the age of the base of the Kungurian Stage single conodont platforms from strata within the Artinskian-Kungurian transition of the Mechetlino section(s) were subject to the analytical methods outlined above; these conodonts yielded reproducible $^{87}Sr/^{86}Sr = 0.70743$ to 0.70739. Projecting these compositions into the extrapolated seawater curve yields an apparent age for the boundary of 283.5 ± 0.5 Ma (Fig. 1.7).

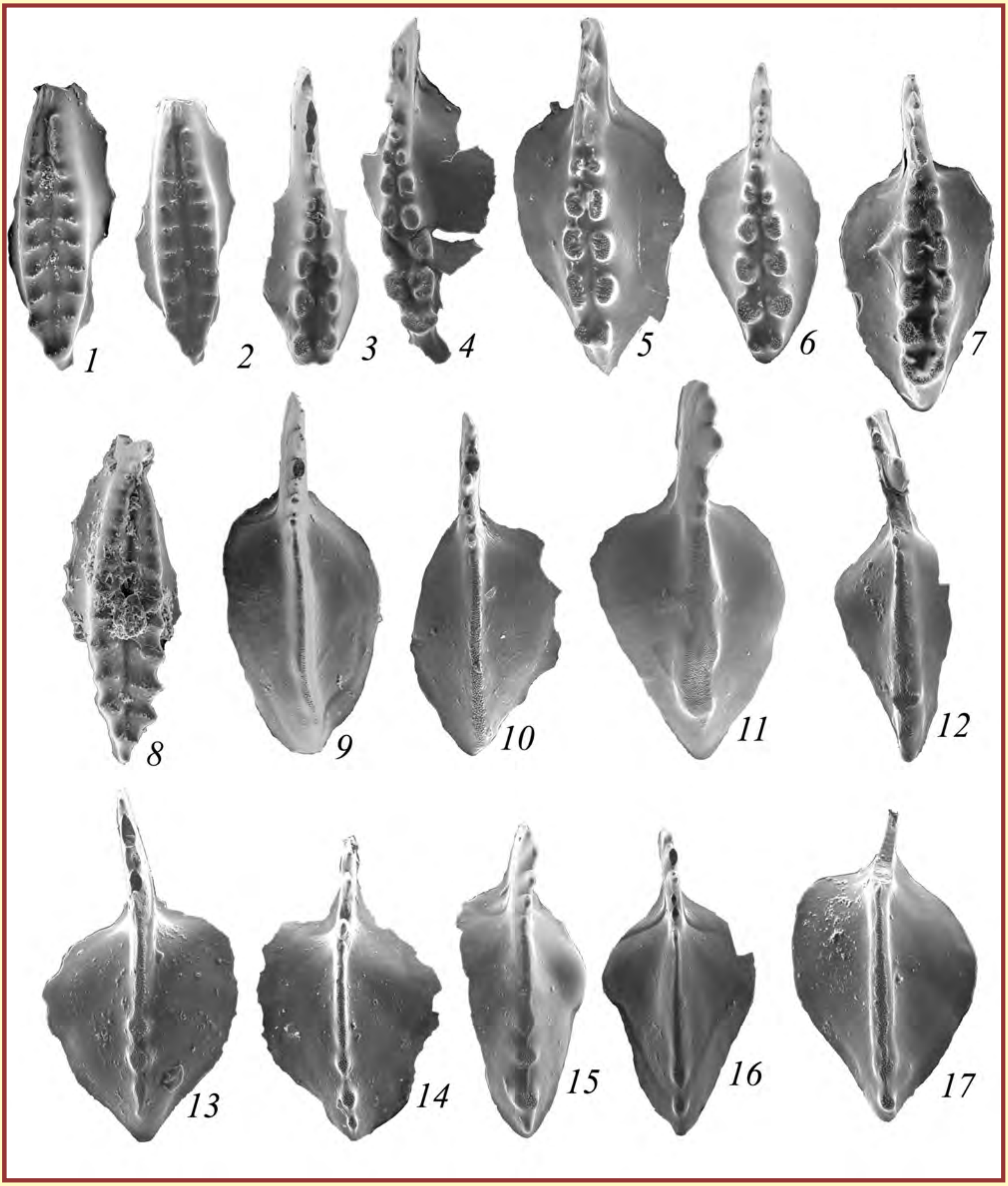


Plate I. The Artinskian conodonts, (x80)

Bed 2: Fig. 1, 2. Neostreptognathodus ruzhencevi Kozur; Fig. 3, 4. Neostreptognathodus pequopensis Behnken. Bed 4: Fig. 5-7. Neostreptognathodus pequopensis Behnken; Fig. 8. Neostreptognathodus ruzhencevi Kozur; Fig. 9-16. Sweetognathus somniculosus Chernykh. Bed 6: Fig. 17. Sweetognathus somniculosus Chernykh

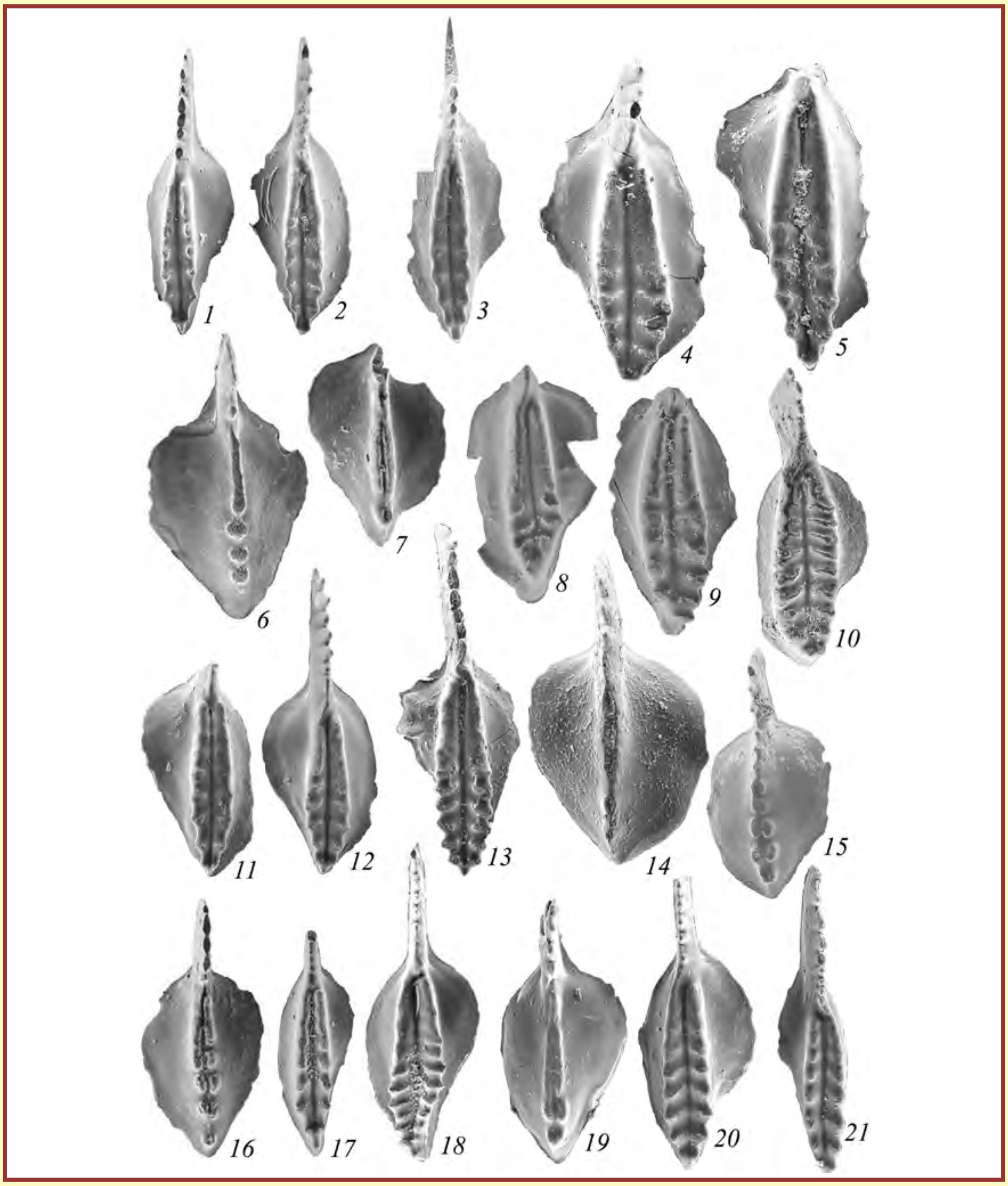


Plate II. The Kungurian conodonts (x80)
Bed 9: Fig. 1. Neostreptognathodus pequopensis Behnken (transitional from N. pequopensis to N. pnevi); Fig. 2, 3. Neostreptognathodus pnevi Kozur et Movshovitsch; Fig. 4, 5. Neostreptognathodus lectulus Chernykh. Bed 10: Fig. 6. Sweetognathus n. sp. 1 (Chernykh, 2006); Fig. 7. Neostreptognathodus pseudoclinei Kozur et Movshovitsch (transitional from N. pseudoclinei to N. labialis); Fig. 8, 9. Neostreptognathodus lectulus Chernykh, 8 – advanced form; Fig. 10. Neostreptognathodus ruzhencevi Kozur.
Bed 12: Fig. 11. Neostreptognathodus pequopensis Behnken (transitional from N. pequopensis to N. pnevi); Fig. 12, 13. Neostreptognathodus lectulus Chernykh, 13 – advanced form; Fig. 14. Neostreptognathodus pseudoclinei Kozur et Movshovitsch (transitional from Sweetognathus somniculosus Chernykh to N. pseudoclinei).
Fig. 15. Neostreptognathodus labialis Chernykh; Bed 13: Fig. 16. Neostreptognathodus labialis Chernykh; Fig. 17. Neostreptognathodus pnevi Kozur et Movshovitsch;
Fig. 18. Neostreptognathodus lectulus Chernykh. Bed 16: Fig. 19. Neostreptognathodus labialis Chernykh (reduction of anterior carinal denticles); Fig. 20. Neostreptognathodus lectulus Chernykh; Fig. 21. Neostreptognathodus pequopensis Behnken

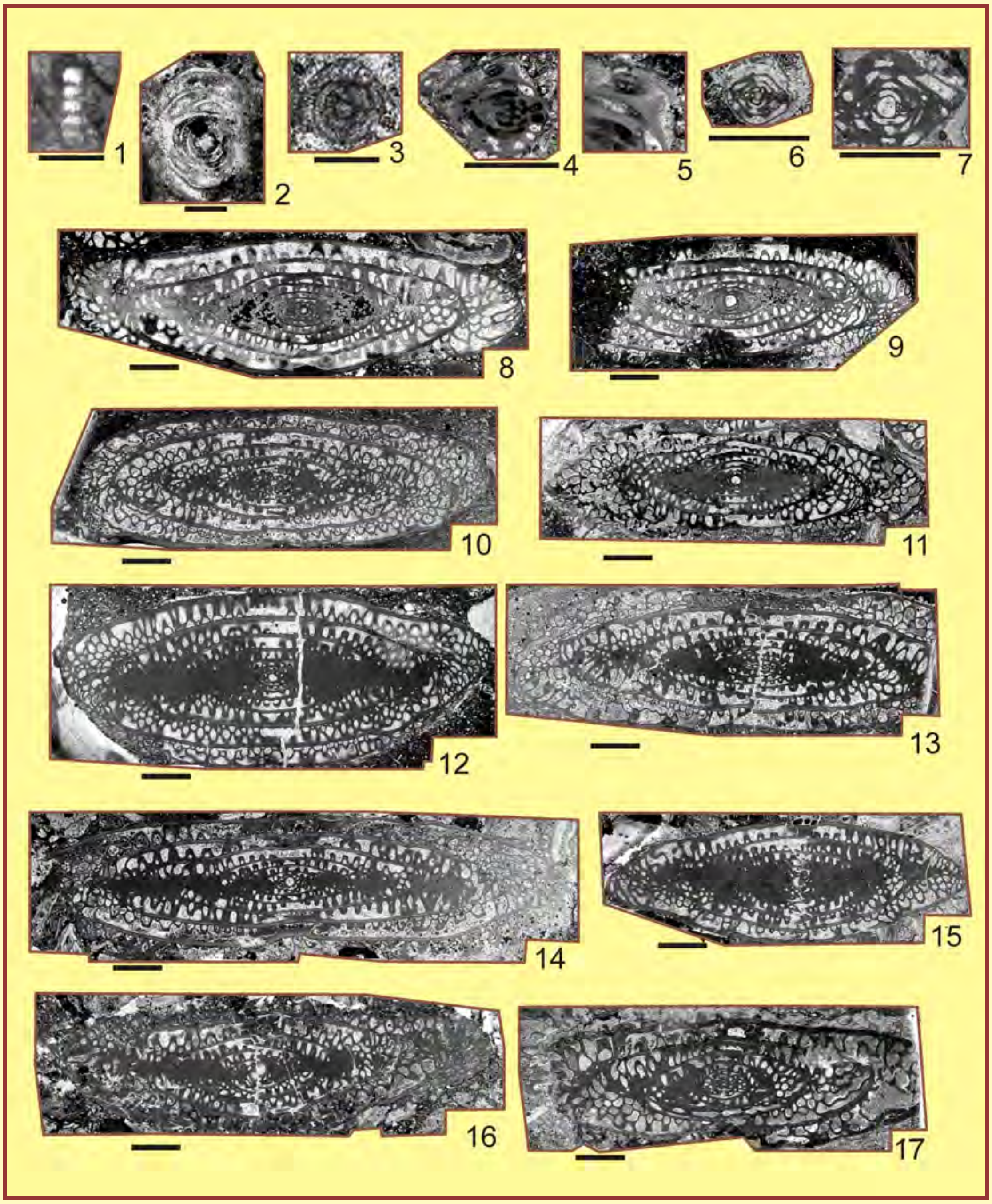


Plate III descriptions of fusulinids from the Mechetlino section
Fig. 1. Protonodosaria sp., bed 1 (4,3 m above the base); Fig. 2. Hemigordius sp., bed 1 (4,3 m above the base); Fig. 3. Grovesella nevadaensis Davydov, bed 1 (4,3 m above the base); Fig. 4. Uralofusulinella arkaulensis Tschuvashov, bed 1 (4,3 m above the base); Fig. 5. Uralofusulinella arkaulensis Tschuvashov, bed 27 (36,3 m above the base); Fig. 6. Uralofusulinella ajuensis Tschuvashov, bed 27 (36,3 m above the base); Fig. 7. Pseudofususlina russiensis Rauser, bed 1 (4,3 m above the base); Fig. 8. Pseudofususlina russiensis Rauser, bed 1 (4,3 m above the base); Fig. 9. Pseudofusulina paraconcavutus Rauser, bed 1 (4,3 m above the base); Fig. 10. Pseudofusulina fallax Rauser, bed 1 (4,3 m above the base); Fig. 11. Pseudofusulina ordinata Kireeva, bed 1 (4,3 m above the base); Fig. 12. Pseudofusulina alaguvatovi Rauser, bed 1 (4,3 m above the base); Fig. 13. Pseudofusulina makarovi Rauser, bed 27 (36,3 m above the base); Fig. 14. Pseudofusulina curtata Rauser, bed 27 (36,3 m above the base); Fig. 15. Parafusulina solidissima Rauser, bed 27 (36,3 m above the base); Fig. 16. Parafusulina solidissima Rauser, bed 27 (36,3 m above the base)

DAL'NY TULKAS SECTION

Introduction

Since the report provided in Permophiles v. 41 (Chuvashov et al., 2002) considerable data have been generated and our understanding has considerably improved regarding a potential GSSP level for the base of the Artinskian. Work has focused on the Dal'ny Tulkas Section in Russia. A field workshop was conducted during June 25-July 4, 2007 in order to determine the reproducibility of the three potential Lower Permian GSSP sections for the base of the Sakmarian, base of the Artinskian and base of the Kungurian. This workshop was reported in Permophiles, v. 49 (Davydov and Henderson, 2007) with Boris Chuvashov, Valeri Chernykh and Viktor Puchkov as hosts and Vladimir Davydov, Emir Gareev, Charles Henderson, Elena Kulagina, Tamra Schiappa, Mark Schmitz, Shuzhong Shen and Michael Stephenson also in attendance. Since this field meeting productive conodont samples have confirmed the FAD position of the conodont *Sweetognathus whitei*. We have also geochronological age, carbon isotopes and Sr isotopic data on conodonts that provide additional constraints on how to correlate the GSSP into other regions. These facts were reported in a series of communications by Galina Kotlyar in *Permophiles*, v. 54 (2009, p. 5). The Russian stratigraphic Commission has voted in favour of the FAD of *Sw. whitei* at Dal'ny Tulkas section for the GSSP level.

The boundary deposits of the Sakmarian and Artinskian are represented most fully in the section on the Dal'ny Tulkas stream, located at the southern end of the Usolka anticline near the eastern outskirts of Krasnousol'sky, Bashkortostan (Fig. 2.1). The deposits of the Kurort Formation of the predominantly Sterlitamak horizon of Sakmarian Stage and the Tulkas suite of the Artinskian Stage are in the Dal'ny Tulkas section boundary interval (Chuvashov et al., 1990).

Along the Dal'ny Tulkas stream, the Kurort Formation includes beds of dark-coloured carbonate mudstone, argillite, sandstone and occasional bioclastic limestone with fusulinaceans, radiolarians, rare ammonoids and bivalves.

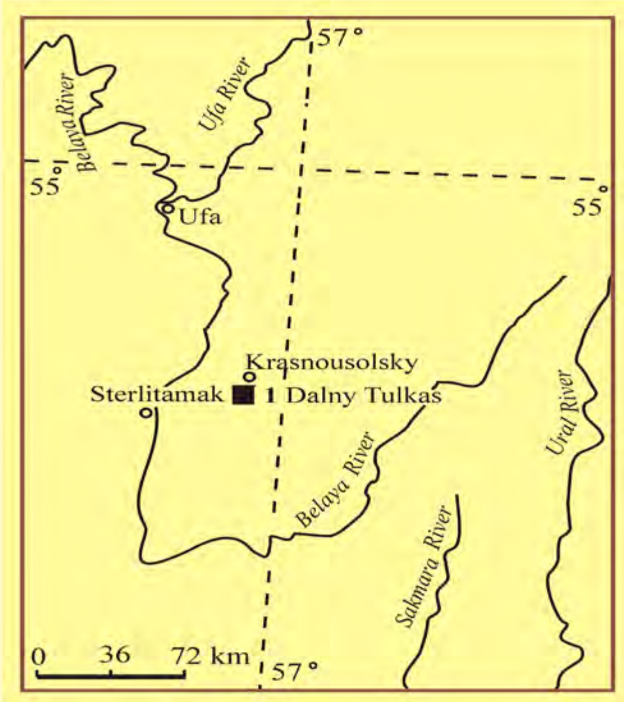


Fig. 2.1. Location of the section Dal'ny Tulkas

The overlying deposits of the Sterlitamak horizon in the interval transitional to the Artinskian Stage are typically poorly exposed. In 2003 a bulldozer clearing this part of the section exposed all beds, which include "striped" sandy-argillaceous limestone with rare interbeds of detrital limestone and carbonate-clay concretions with selected fusulinacean, ammonoid and conodont samples. Practically all conodont samples in the striped interval proved to be productive. In the Artinskian part of the section there are four ash tuff layers.

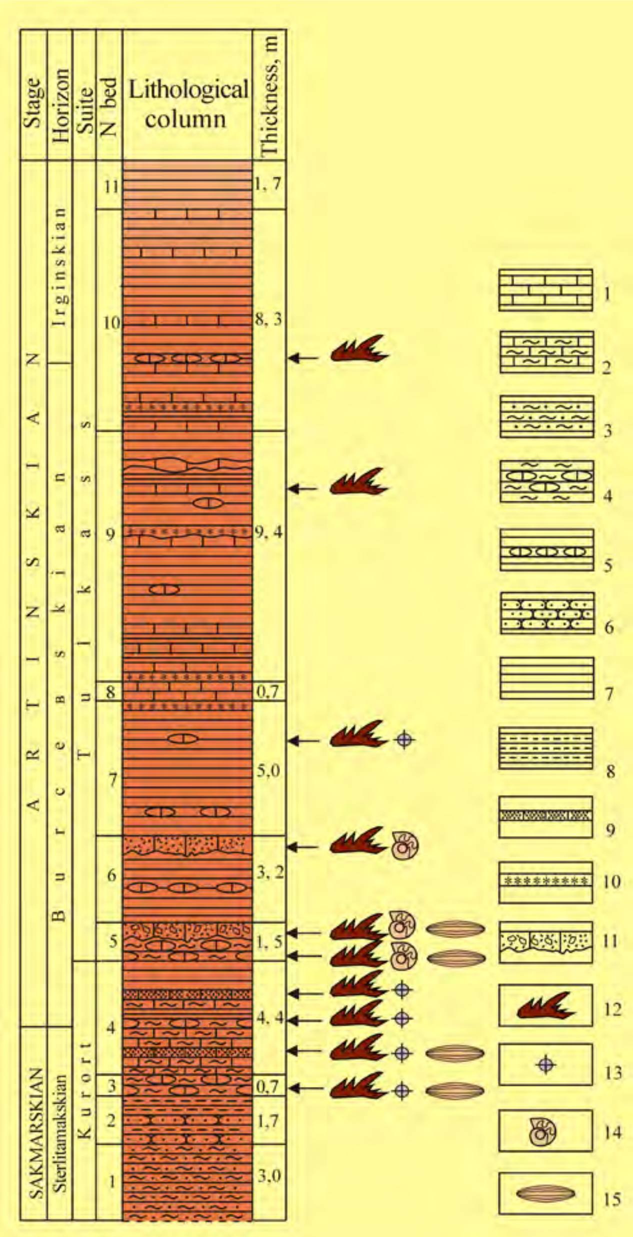


Fig. 2.2. Stratigraphic column with distribution of samples with conodonts, fusulinaceans, radiolarians and ammonoids: 1 - limestone; 2 - carbonate mudstone; 3 - silty mudstone; 4 - mudstone with carbonate concretions; 5 - shale with carbonate concretions; 6 - sandstone; 7 - shale; 8- siltstone; 9 - bioclastic limestone (grainstone and rudstone); 10 - ash tuffs; 11 - limestone with limestone intraclasts; pointers show productive levels: 12 - conodonts, 13 - radiolarians, 14 - ammonoids, 15 - fusulinaceans

The lower boundary of the Artinskian Stage is determined by the level of the appearance in the middle of bed 4 of the cosmopolitan conodont *Sweetognathus whitei* in the phylogenetic lineage – *Sw. merrilli*→*Sw. binodosus*→*Sw. anceps* → *Sw. whitei*→ *Sw. clarki* (Chernykh et al., 2005).

The first Artinskian assemblage of fusulinaceans is noted in the section 2.5 m higher in the base of bed 5, which also includes assemblages of Artinskian ammonoids and conodonts.

A schematic lithological column of the Dal’ny Tulkas section with indications of the paleontological samples is given below (Fig. 2.2) including detailed description and lists of identified ammonoids, fusulinaceans and conodonts.

Section description

Sakmarian Stage

Sterlitamak horizon

Kurort Formation

Bed 1. This unit is ash-grey on the fresh surface and the brownish-grey on the weathered surface and includes silty carbonate mudstone that forms layers from 2 to 5 cm thick. Organic remains include rare shells of ammonoids, fish scales and long stems of noncalcareous algae. In the middle of the bed, in the trench, an argillaceous and calcareous concretion with fusulinaceans was discovered in the original bedding (?), but it was impossible to make oriented thin-secti ons..3 m.

Bed 2. Strongly calcareous and clayey siltstone and fine-grained sandstone forming 15-20 cm thick layers. Organic remains include long thin thalli of non-calcareous algae and thin detritus of terrestrial plants…………………………………...1.7 m.

Bed 3. Limestone is brownish-grey with 10-15 cm thick layers at the base and top of the unit; platy carbonate mudstone with shells of calcitized radiolarians compose the middle part of the layer. In the limestone near the top of the unit there are carbonate concretions with conodonts and rare fusulinaceans. Oriented sections could not be made from of the fusulinaceans. Conodonts include *Sweetognathus cf. obliquidentatus* (Chern.)..0.7 m.

Bed 4a. Monotonous unit of brownish dark grey platy carbonate mudstone with some interbeds of siltstone. The rock texture is platy with thickness of plates of 1-5 cm in one case up to 10 cm. In the lower part of the unit there are recessive (5-7 cm) interbeds of bioclastic (fusulinacean, bryozoans, crinoids) rudstone from which the following fusulinaceans are determined: *Pseudofusulina callosa* Raus., *P. callosa proconcavutas* Raus., *P. jaroslavkensis fraudulenta* Kireeva, *P. cf. parajaroslavkensis* Kireeeva, *P. blochini* Korzh. The given complex of fusulinaceans indicates the upper part of the Sakmarian Stage. The same bed includes Sterlitamakian conodonts: *Mesogondolella bisselli* (Clark and Behnken), *Sweetognathus anceps* Chern., *S. obliquidentatus* (Chern.), transitional forms from *S. anceps* Chern. to *S. whitei* (Rhodes) with a fragmentary mid-carinal connecting ridge.........,........1.8 m.

Artinskian Stage
Burtsevian horizon

Bed 4b. Contains a 0.6 m layer of calcareous concretions in a carbonate mudstone unit, with the conodonts *Mesogondolella bisselli* (Clark and Behnken), *Sweetognathus anceps* Chern., forms transitional from *S. anceps* Chern. to *S. whitei* (Rhodes), and *S. whitei* (Rhodes); the latter indicating the Artinskian. Up 1.2 m the section, a unit of small carbonate concretions contains an Artinskian conodont assemblage including *Mesogondolella bisselli* (Clark et Behnken), *S. obliquidentatus* (Chern.), *S. whitei* (Rhodes). A layer (0.42 m) of resistant, silicified bioclastic (fusulinaceans, bryozoans, crinoids) grainstone-rudstone with graded bedding lies in the upper part of the unit. The fusulinaceans determined from this layer include: *Pseudofusulina aff. longa* Kireeva, *P. fortissima* Kireeva, *P. anostiata* Kireeva, *P. plicatissima* Raus., *P. urdalensis abnormis* Raus. This assemblage is characteristic of the Sterlitamak horizon. Conodonts include: *Mesogondolella bisselli* (Clark and Behnken) and *Sw. obliquidentatus* (Chern.)...................................2.6 m.

Tulkas Formation

Bed 5. The lower part of the bed (60 cm) is brownish grey, unstratified silty carbonate mudstone with numerous scattered calcareous concretions. The numerous fusulinaceans found in the matrix include: *Pseudofusulina callosa* Raus., *P. plicatissima* Raus., *P. plicatissima irregularis* Raus., *P. urdalensis* Raus., *P. fortissima* Kireeva, *P. concavutas* Viss., *P. juresanensis* Raus., *P. consobrina* Raus., *P. paraconcessa* Raus. This fusulinacean assemblage indicates the lower Artinskian Stage.

The upper part of the bed is represented by laminated mudstone with lenses of detrital and breccia-like bioclastic material platy at the top. The lower part of the bed and the breccia limestone contained numerous ammonoids of which M.F. Bogoslovskaya determined: *Popanoceras annae* Ruzh., *P. tschernowi* Max., *P. congregale* Ruzh., *Kargalites sp.*, *Neopronorites skvorzovi* Tschern. This ammonoid assemblage definitely indicates the base of the Artinskian. Rare specimens of *Artinskia sp*. are also found here. The conodont samples were taken from the lower and upper parts of the bed. The sample contained specimens identical to those in the Artinskian conodont assemblage: *Mesogondolella bisselli* (Clark et Behnken), *Sweetognathus whitei* (Rhodes), *S. obliquidentatus* (Chern.) and *S. gravis* Chern.

Fig. 2.3. Dal’ny Tulkas section. Irginian horizon

Bed 6. A major portion of the bed is argillaceous, dark greenish-grey, fissile with isolated carbonate concretions. The unit top includes an interbed (20 cm) of bluish- grey mudstone with an admixture of thin detrital material. In this mudstone and also in the concretions there are rare shells of ammonoids whose taxonomic composition is identical with the assemblage in Bed 5. The conodont assemblage includes: *Mesogondolella bisselli* (Clark and Behnken), *M. bisselli* n. subsp ....3.2 m.

Bed 7. Argillite, dark-brownish-grey in the fresh state and greenish-grey on the weathered surface is platy and occasionally fissile. At the top of the layer are six (thin) interbeds of steel-grey micritic limestone. At 1.1 m below the top, there is a large (0.5 x 20 cm) concretion of mudstone with numerous radiolarians and conodonts including *Mesogondolella bisselli* (Clark et Behnken) ……...5 m.

Bed 8. Limestone, bluish-grey on the fresh surface and whitish on weathered surface, micritic with subordinate layers and lenses of detrital material and ammonoids. Lower 20 cm of the limestone contain interbeds of argillite with thickness up to 4 cm. Both below and above the limestone are interlayers of yellowish-grey silicified ash tuff with thickness up to 10 cm. The thickness of limestone decreases westward .... 0.7-0.5 m.

Bed 9. Above is mostly argillite, in which periodically (through 1-2.5 m) are repeated the interbeds (5-10 cm by thickness) of steel-grey micritic limestone. More frequent there are the horizons of yellowish-light-grey silicified ash tuffs 1-5 cm thick. There are also several lenticular concretions of steel-grey clayey limestone. In the middle of the bed one concretion

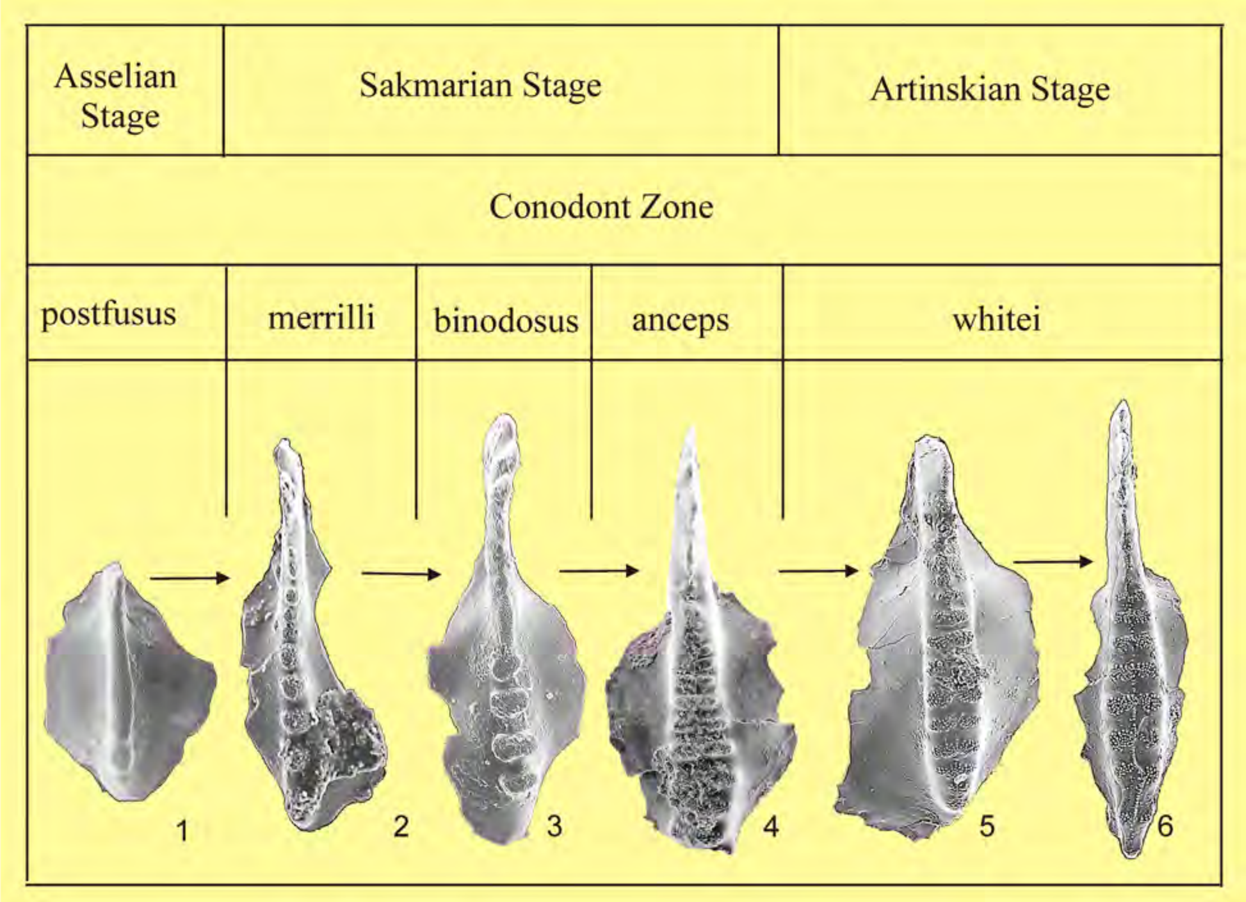


Fig. 2.4. The evolutionary lineage Sweetognathus expansus (Perlmutter) - S. whitei (Rhodes) 1 - Sweetognathus expansus (Perlmutter), Usolka section, bed 21; 2 - S. merrilli Kozur, Usolka section, bed 26/2; 3 - S. binodosus Chern., Usolka section, bed 26/3; 4 - S. anceps Chern., D. Tulkas section, bed 4a; 5 - a form transitional from S. anceps to S. whitei (Rhodes), D. Tulkas section, bed 4b; 6 - S. whitei (Rhodes), D. Tulkas, bed 4b

contained numerous radiolarians and conodonts including *Mesogondolella bisselli* (Clark et Behnken) …...................……….........9.4 m.

Bed 10. Primarily includes argillite as in bed 9, but in contrast, this bed contains more frequent and thicker (15-20 cm) interbeds and concretions of steel-grey micritic and more often detrital limestone, within which there are frequently layers (3-10cm) of yellowish-light-grey silicified ash tuff. In the limestone numerous calcitized radiolarian and conodonts are found in limestone concretions which indicate the Irginian horizon. The conodonts include: *Sweetognathus whitei* (Rhodes), *S. clarki* (Kozur), *S. aff. binodosus* Chern., *Mesogondolella bisselli* (Clark et Behnken), *M. laevigata* Chern ....8.3 m.

Bed 11. Argillite with rare small carbonate concretions without any interbeds of limestone ....1.7 m.

Conodonts

Conodonts were considered the primary biostratigraphic tool, which made it possible to clearly fix the desired boundary and also to correlate it globally correlation on the appearance of the cosmopolitan form – *Sweetognathus whitei*, whose position in the chronomorphocline (Fig. 2.4) *S. binodosus-S. anceps-S. whitei* is confirmed by the study of the Dal'ny Tulkas section which provides some of the most on the conodonts of the genus *Sweetognathus* in the region.

In order to explain the value of these new data, let us recall previously published information about the development of this group of conodonts in the Usolka section (Chernykh and Chuvashov, 2004). The primitive form, *Sweetognathus expansus* (Perlmutter), in which the beginning of the carinal differentiation (Fig. 2.4) occurs, appears in Upper Asselian. In early Tastubian it evolves into *Sweetognathus merrilli* Kozur with carinal development forming rounded nodes in upper view (Fig. 2.4). Further evolution of this group leads to the appearance in the Tastubian Horizon of forms which have few carinal nodes, but that are laterally elongated with a tendency toward the bilobate dumbbell-like structure. These forms are referred to as the species *Sweetognathus binodosus* Chernykh (Fig. 2.4).

The special features of the further evolution of this group during the Sterlitamakian and Artinskian are revealed in the trenched part of the Dal'ny Tulkas section. The development of the carina of the Sterlitamakian representatives of the *Sweetognathus expansus - S. merrilli - S. binodosus* lineage continues in the direction of the differentiation of carinal nodes, that led to the appearance of *S. anceps* Chernykh (Fig. 2.4) that possess dumbbell-like nodes. In addition to these forms, there appear forms that include fragmentary development of the pustulose, mid-carinal connecting ridge, which we consider as transitional to *Sweetognathus whitei* (Rhodes). Specimens of *Sweetognathus anceps* with rudiments of a mid-carinal pustulose ridge continue to be encountered above in the section until finally there appear specimens of *Sweetognathus* with fully developed dumbbell-like nodes and a complete middle pustulose connecting ridge. We assign such forms to the species *Sweetognathus whitei* (Fig. 2.4) whose representatives are widely known in many regions where deposits of Sakmarian-Artinskian age are present. Proposals to use the appearance of *Sweetognathus whitei* for determining the lower boundary of Artinskian Stage were noted previously by a number of authors (Kozur, 1977; Ritter, 1986); however, at the time there was insufficient knowledge about the early members of the evolutionary lineage of this group of conodonts. Those forms, which we isolated into the independent species *Sweetognathus anceps*, also occurred widely but until now they were encountered together with the typical *S. whitei* and the majority of researchers identified their specimens without the fully developed middle connecting ridge in open nomenclature as *S.* aff. *whitei*. We traced the gradual passage from *Sweetognathus anceps* to *S. whitei* for the first time, thus giving a complete picture of the development of these conodonts in the evolutionary lineage *Sweetognathus expansus - S. merrilli - S. binodosus - S. anceps - S. whitei* (Fig. 3.4).

The chronomorphocline *Sweetognathus binodosus-S. whitei* can also be recognized in the lower Great Bear Cape Formation (see the Sakmarian GSSP proposal), southwest Ellesmere Island (Henderson, 1988; Henderson, 1999; Beauchamp and Henderson, 1994; Mei et al., 2002). In China, in the Luodian section (Guizhou) there is a succession *Sweetognathus binodosus - S. whitei* at 316 m above the base of the section (Wang Zhihao, 1994) and also in Korea (Su-In Park, 1989) in the limestone of the Unomasa Formation in a "Stream bed" section, 18 m above the base.

U-Pb geochronology

Schmitz and Davydov (2012) carried out radiometric studies, based on high-precision, isotope dilution-thermal ionization mass spectrometry (ID-TIMS) U- Pb zircon ages for interstratified ash beds in the parastratotype sections of the southern Urals, including in the Dal'ny Tulkas section. Here they selected ash tuffs at three levels - in the upper part of bed 2 (4 m lower than base of Artinskian, in the upper part of bed 7 (10.5 m higher than base of Artinskian) and in the base of bed 9 (2 m higher than the previous sample).

In bed 2, of eight analyzed grains of zircon, six grains yielded a weighted mean $^{206}Pb/^{238}U$ date of 290.81 ± 0.09 Ma. Seven of eight analyzed grains from bed 7 produced a weighted mean $^{206}Pb/^{238}U$ date of 288.36 ± 0.10 Ma. And from the third interlayer of ash tuff (bed 9) all eight investigated grains gave a $^{206}Pb/^{238}U$ date of 288.21 ± 0.06 Ma. “The three dated samples allow the calculation of a relatively constant accumulation rate through the lower portion of the section” (Schmitz and Davydov, 2012, p.561). Volcanic ash beds provide an extrapolated geochronological age of 290.1 Ma (Schmitz and Davydov, 2012) for the base-Artinskian (Henderson et al., 2012).

Strontium Isotopes

M. Schmitz et al. (2009) in a presentation at the International Conodont Symposium indicated a consistent secular trend of $^{87}Sr/^{86}Sr$ isotopic values from conodont elements through the Early Permian. The $^{87}Sr/^{86}Sr$ isotopic value for the base-Artinskian was approximately 0.70765 (Schmitz et al., 2009). Strontium isotopes from individual conodont elements have been integrated with geochronological ages to produce a time

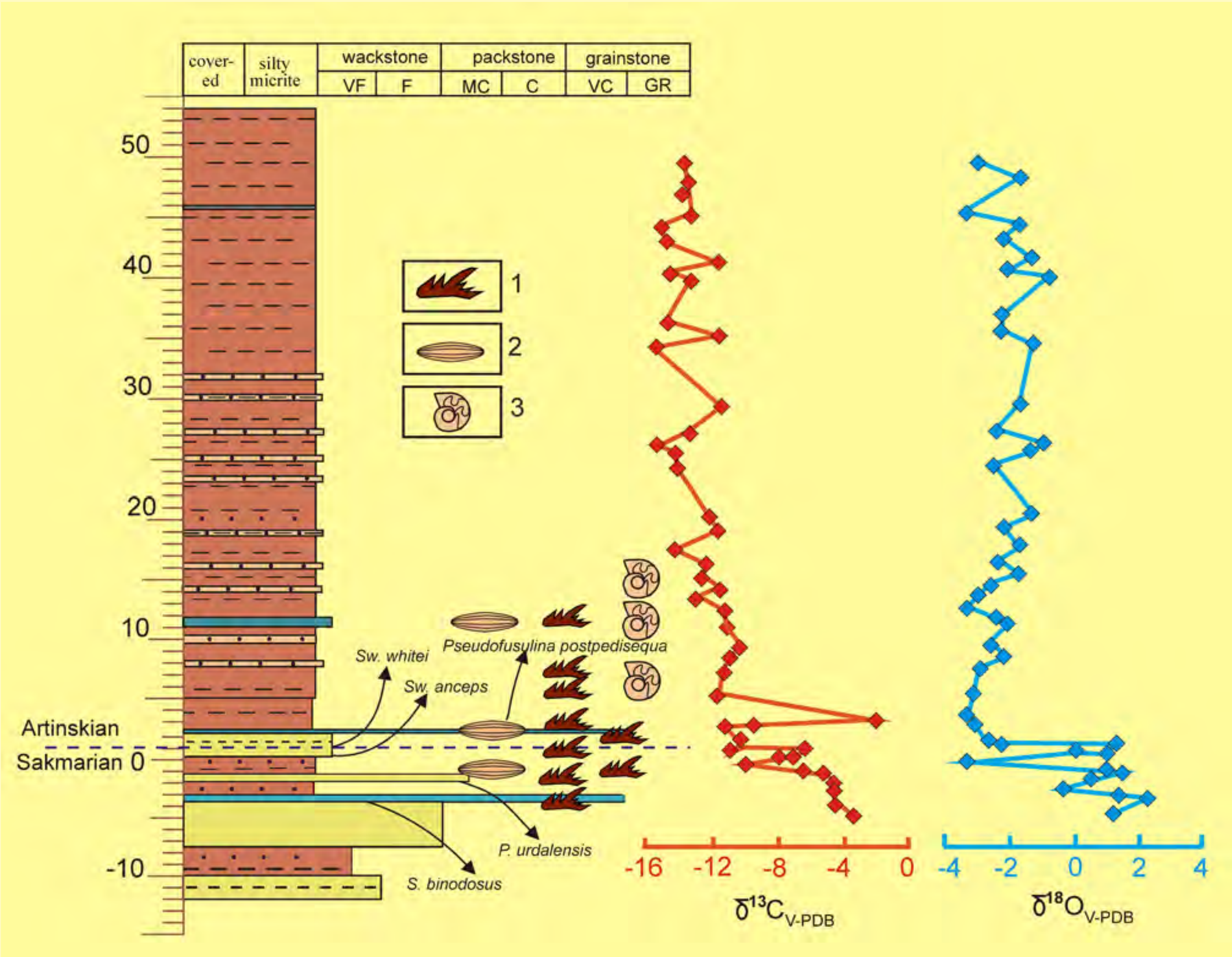


Fig. 2.5. Carbon and oxygen isotopic trends of the Dal’ny Tulkus section (from Zeng et al., 2012). Explanation in the text

model (Schmitz in progress). The strontium isotopic composition of seawater at the base of the Artinskian Stage is now calculated at $^{87}Sr/^{86}Sr$ = 0.70767 (Chernykh et al., 2012).

Carbon isotope chemostratigraphy

A group of Chinese researchers with the participation of V.I. Davydov (USA, Boise State University) conducted a study of carbon and oxygen stable isotopes in the GSSP candidate sections of the South Urals – Usolka, Dal’ny Tulkas and Kondurovsky (Zeng et al., 2012). Basic results obtained from the Dal’ny Tulkas section are given below.

In the Dal’ny Tulkas section the curves of $\delta^{13}C$ and $\delta^{18}O$ display a general concurrent tendency of change and are characterized by a rapid and sharp drop near the Sakmarian-Artinskian boundary and a long-term depletion in the subsequent interval of the Artinskian Stage. The values of $\delta^{13}C$ present a dramatic depletion from −4.7‰ to −11.7‰ near the Sakmarian-Artinskian boundary in the Dal’ny Tulkas section, and for a long time remain at a strongly negative, level higher in the Artinskian Stage with exception of one point with a value of −2.2‰ in the early Artinskian (fig. 2.5). A somewhat similar trend, but with very different values (4‰ to 2‰) is shown by Buggisch et al. (2011) near the Sakmarian-Artinskian boundary in Luodian, China.

These very low values would normally be attributed to diagenesis and Zeng et al. (2012) noted that the sharp drop in $\delta^{13}C$ and its retention for a long time and its associated normal $\delta^{18}O$ values between 1.1‰ to -2.2‰ is difficult to explain. One potential explanation for those anomalous negative values is that the incorporation of ^{12}C derived from oxidized organic matter from organic-rich sediments with low $CaCO_3$ around the Sakmarian/Artinskian boundary at the Dal’ny Tulkas section. A similar excursion is also present around the Wuchiapingian-Changhsingian boundary GSSP at the Meishan section in South China (Shen et al., 2013). Another possible interpretation of such sharp variation in the $\delta^{13}C$ value is due to isotopic re-fractionation of the microbial chemosynthetic processes on the buried organic matter. However, significant $\delta^{13}C$ excursions from Sakmarian to Artinskian at the Luodian section in South China were also revealed (Buggisch et al., 2011) although precise correlation between South China and southern Urals still needs further study. If a similar sharp excursion is confirmed during further study in other regions, and could be very useful for the correlation of distant sections.

Summary

In conclusion, the lower boundary of the Artinskian can be established on conodonts, fusulinaceans and ammonoids in the Dal’ny Tulkas section. The occurrence of the evolutionary lineage *Sweetognathus binodosus - S. anceps - S. whitei* with transitional forms between the named species makes it possible to assume the absence of interruptions in sedimentation for the Sakmarian – Artinskian interval of the Dal’ny Tulkas section. The diversity of the paleontological remains, the presence of ash tuffs, the accessibility of the section for subsequent study and the possibility of the global correlation of the established boundary – all make the FAD of *Sweetognathus whitei* at 1.8 m above the base of bed 4 at the Dal’ny Tulkas section an excellent Global Stratotype Section and Point (GSSP) for the base of the Artinskian Stage. Geochronological age (290.1 Ma), Sr isotopic value (.70767), other fossils and carbon isotopic trends provide additional means for correlation. Finally, Davydov et al. (2007) reported in *Permophiles*, v. 50 that government agreement has been reached to protect all of the defined and proposed Cisuralian GSSP sites.

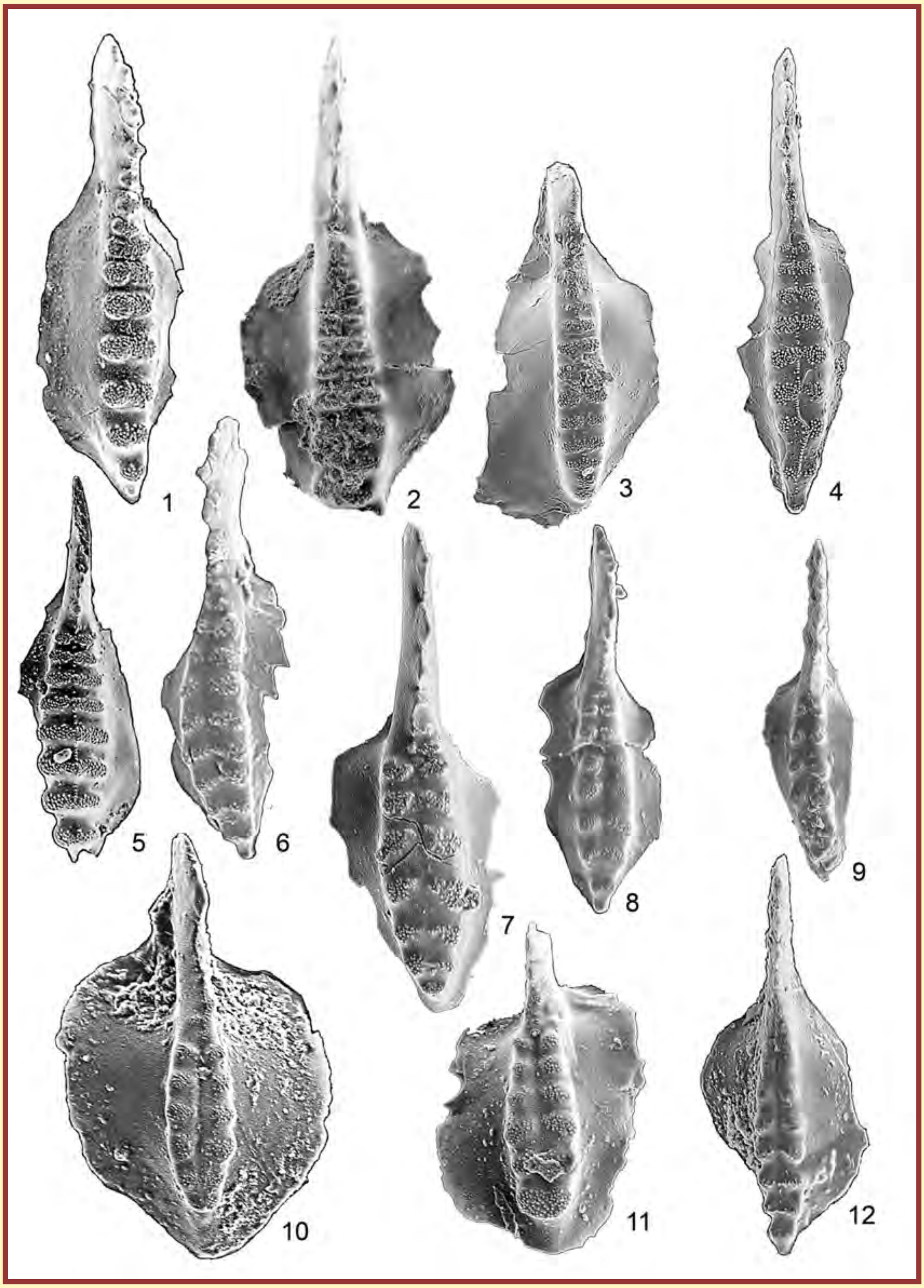


Plate I. Upper Sakmarian-Lower Artinskian conodonts in Dal'ny Tulkas section (x 90)
Fig. 1, 2. Sweetognathus anceps Chernykh, 2005: 1 – holotype DT19-1, bed 5; lower part of Artinskian, whitei zone; 2 – DT24, bed 4a; Upper Sakmarian, zone anceps.
Fig. 3-5. Sweetognathus whitei (Rhodes), 1963: 3 – DT-18a, form transitional from Sw. anceps to Sw. whitei; 4 – DT-18b, typical form with the fully developed middle ridge; bed 4b; 5 – T/19-3; bed 5; lower part of Artinskian, whitei zone. Fig. 6-8. Sweetognathus obliquidentatus (Chernykh), 1990: 6- holotype ZSP-1070/19v; 7 – DT40-3; 8 – T/19-1-5; bed 5; lower part of Artinskian, whitei zone. Fig. 9, 12. Sweetognathus aff. ruzhencevi (Kozur), 1976: 9 – DT40-6; 12 – DT40-13; bed 5; lower part of Artinskian, zone whitei.
Fig. 10, 11. Sweetognathus gravis Chernykh, 2006: 10 – holotype U40-9b; 11 – DT40-10k; bed 5; lower part of Artinskian, whitei zone

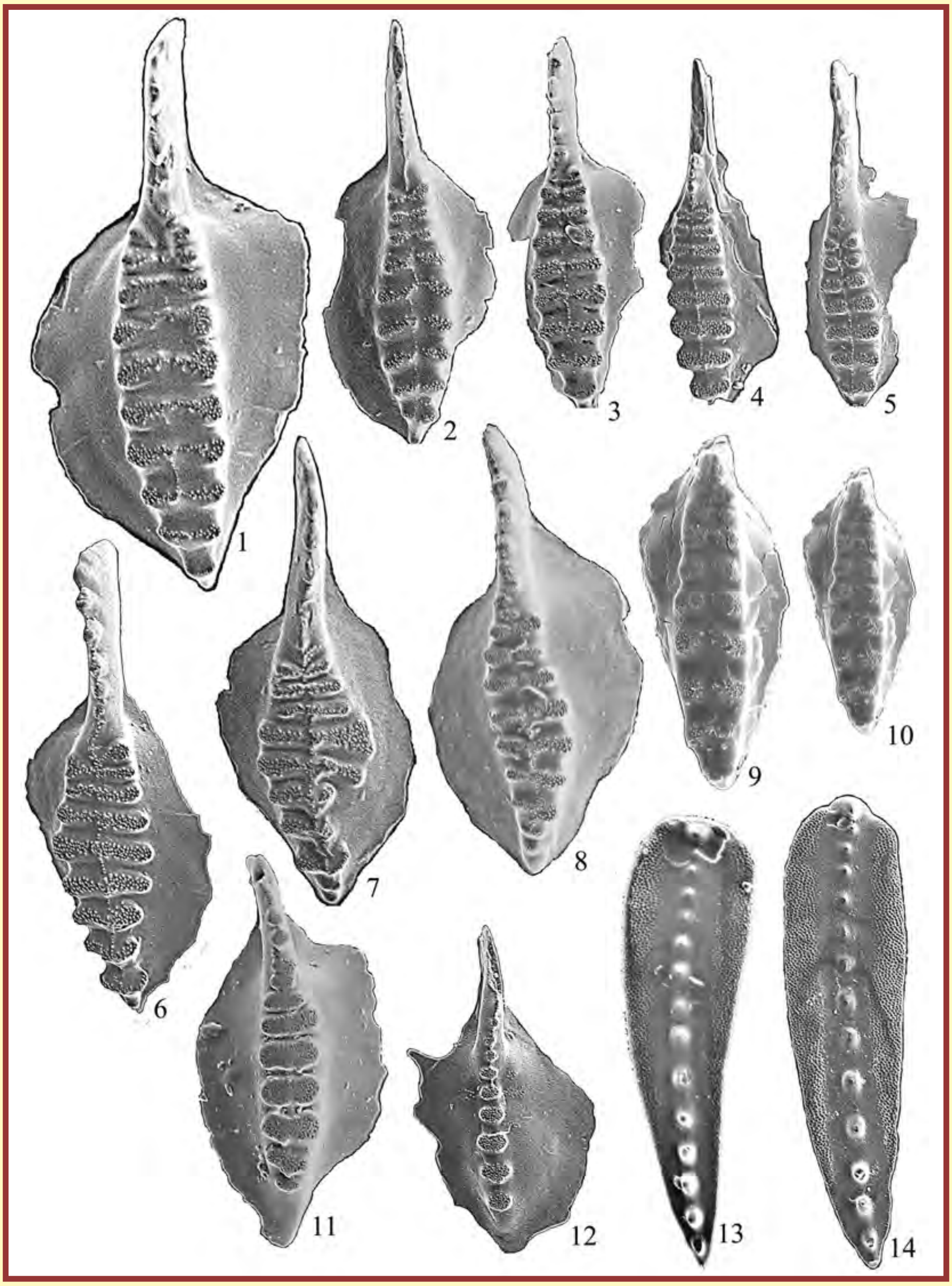


Plate II. Lower Artinskian conodonts in Dal'ny Tulkas section (x 90)
Fig. 1, 7, 8. Sweetognathusaff. whitei (Rhodes), 1963: 1 – DT40-27,the relicts of the longitudinal middle ridge are visible; 7 – DT40-19; 8 – DT-40-21;bed 10,clarki zone. Fig. 2, 3. Sweetognathusaff. clarki (Kozur), 1976: 2– DT40-18; the relicts of the longitudinal middle ridge are visible, the posterior pairs of carinal nodes are separated; 3 – DT40-22;bed 10,clarki zone. Fig. 4-6. Sweetognathus whitei (Rhodes), 1963: 4 – DT40-29, the middle ridge is located above upper surface of carinal nodes; 5 – DT40-17, the middle ridge is located lower upper surface of carinal nodes; 6 – DT40-24; bed 10, clarki zone. Fig. 9, 10. Sweetognathus clarki (Kozur), 1976: 9 – DT40-33; 10 – DT40-32; bed 10,clarki zone. Fig. 11, 12. Sweetognathus binodosus Chernykh, 2005: 11 – DT40-23; 12 – DT40-20; bed 10,clarki zone. Fig. 13, 14 (x 60). Mesogondolella laevigata Chernykh, 2005: 13 – U40-26; 14 – holotype DT40-25; bed 10,clarki zone

STERLITAMAK SHIKHANS - NATURE'S AMAZING GIFT

The Sterlitamak Shikhans are the visible and accessible part of the colossal Late Carboniferous – Early Permian reef system stretching from the Caspian Sea to the Arctic Ocean. They stand out in relief, as high hills with steep slopes: the ancient reefs Tra-Tau, Shakh-Tau, Kush-Tau Yurack-Tau, Malyi Shikhan and Novyi Shikhan (Fig. 3.1). The remainder of the reef bodies are buried in the thick sediment and are inaccessible. Reef buildups were formed by various organisms including bacteria, various unicellular organisms, cnidarians, bryozoans, brachiopods and algae (Fig 3.2).

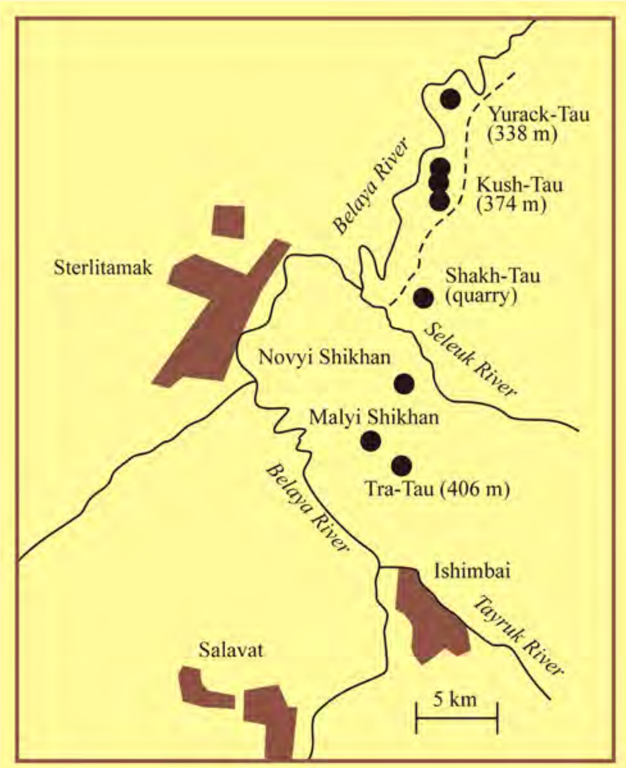


Fig. 3.1. Location of the Reefs

Description of the reefs

Tra-Tau is the most ancient of the reefs (Asselian, Lower Permian) (Fig. 3.3).

Lithology

The reef body of Tra-Tau (Fig. 3.4) is dominated by various types of biogenic versus detrital (clastic) carbonate rocks. The bioclastic limestone massif contains primary voids up to several metres in diameter (Fig. 3.5). The walls of the voids are covered with bitumen crusts or filled with light grey or white micritic carbonate, presumably microbial (bacterial) in origin (Fig.3.5).

Biota

The main reef-builders are calcareous sponges (Fig. 3.6), bryozoans, brachiopods and tubiphytids.

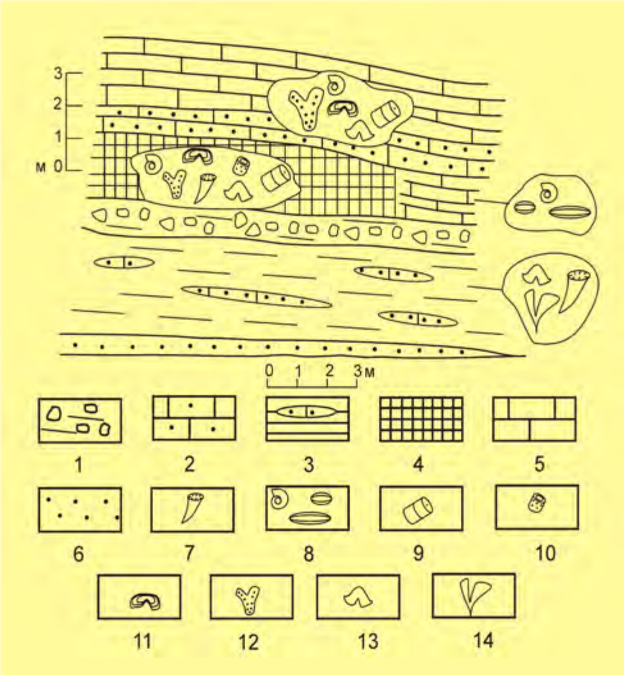


Fig. 3.2. Structures on the eastern side of the Pre-Uralian foredeep. Explanations: 1 - clay rocks with inclusions of pebbles; 2 - sandy limestones; 3 - clay deposits with sandstone lenses; 4 - biogenic building; 5 - limestone; 6 - sandstones; 7 - corals; 8 - foraminifera; 9 - crinoids; 10 - sponges; 11-12 - bryozoans; 13 - brachiopods; 14 - algae

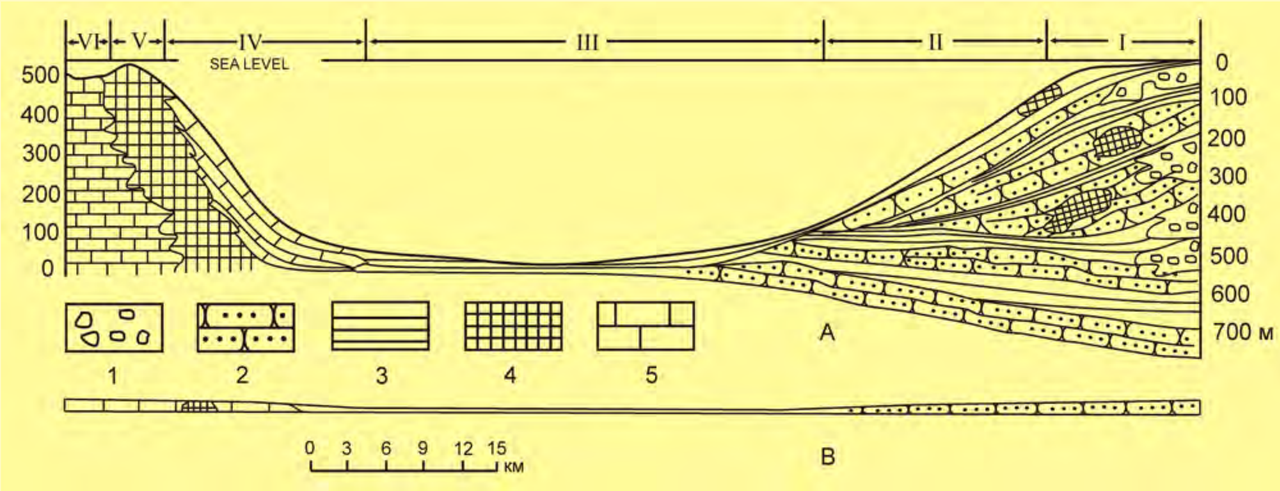


Fig. 3.3. Geological profile through the Pre-Uralian foredeep, Asselian (Rauzer-Chrenousova and Koroljuk, 1991). Explanations: 1 - conglomerate; 2 - sandstone; 3 - argillite; 4 - reef limestone; 5 - limestone. I - coarse-grained deposits; II - sandy - clayey and calcareous sediments; III - clay - calcareous and siliceous deposits; IV - laminated limestone; V - reef limestone; VI - limestone

The exposures contain numerous quite large colonies of calcareous sponges with individual tetracorals. The coarsely-detrital limestone contains fragments of *Palaeoaplysina* plates. A large proportion of the carbonates of Tra-Tau were formed by laminar colonies of encrusting bryozoans.

Fig.3.4.The Tra-Tau Reef

Morphology of the buried reef

Tra-Tau is the most eastern of the reefs and is the shape of a rounded - angular prism with a broad base (Fig. 3.3). The uneven top surface of the Asselian Tra-Tau reef limestone is covered by a thin (up to 1 m) member of brown marls and cherty limestone, remaining in several depressions on the reef surface.

At the base of the Tra-Tau Reef, on its southern side there is a small rise named "Shihanchik" (Gerasimov, 1940), composed of brownish-grey platy, cherty limestone with fusulinids and ammonoids. The ammonoid assemblage includes: *Daraelites elegans* Tschern., *Neopronorites permicus* (Tschern.), *Medlicottia orbignyana* (Vern.), *Paragastrioceras kirgizorum* Voin., *Uraloceras fedorowi* (Karp.), *Eothinites aktas-*

tensis Ruzh., *Popanoceras annae* Ruzh., *Almites permicus* Toum. and *Crimites subkrotowi* Ruzh. The cherty limestone beds contain fusulinids of the *Pseudofusulina juresanensis* zone and Artinskian conodonts (identified by V.V. Chernyh).

The upper part of the reef is split by large fractures filled with various types of younger sediments. One of these fractures (Fig. 8) is a wedge-shaped submeridional crevice filled with dark gray and black argillaceous limestone and marls. Its walls are encrusted by stromatolites up to 10 cm thick.

Fossils include small gastropods, pelecypods, brachiopods and the ammonoid *Agathiceras uralicum* (Karp.). There are numerous large segments of crinoids and fragments of their stems and the conodont *Mesogondolella bisselli* (Clark et Behnken), characteristic of the upper part of the Tastubian and Sterlitamakian horizons (Sakmarian).

The second crevice has a width of about 2.8 m. It is filled with vertical interbeds of limestone 5 - 45 cm thick with numerous various fossils (Neptunian dike). Probably, the original narrow fracture was filled with the loose sediment of a single layer. Later the sides of the crevice were progressively set apart as the reef became part of the tectonic uplift - forebulge [Chuvashov, 2000] and the crevice was gradually filled with the subsequent portions of detrital material.

The sides of the crevice are formed by reef limestone. Conodonts have been recovered from some beds, including *Mesogondolella lata* (Chern.), *M. striata* (Chern.), *Hindeodus sp.* (layer 1); *Mesogondolella lata* (Chern.), *M. bisselli* (Clark et Benken), *Hindeodus sp.* (Layer 2); *Mesogondolella lacerta* Chern., *M. parafoliosa* Chern. (Layer 10), which allows dating the host beds to the Tastubian or the basal Sterlitamakian horizons (Sakmarian).

History and burial of Tra-Tau

1. The reef limestone was formed during the early to middle Asselian (prior to the Sphaeroschwagerina sphaerica - Pseudoschwagerina firma Phase).

2. Subsequently, the reef began to descend and when the forebulge passed beneath it, it split forming a series of fractures. At that time, upper Asselian and Sakmarian clay and detrital sediments were deposited filling the crevices (Fig. 3.5).

3. Eventually the entire reef massif was buried beneath a continuous covering of Artinskian clayey - cherty sediments.

4. The uneven relief of this zone remained until the Early Kungurian and determined the presence of two types of Kungurian sections [Strakhov, 1946]. The depressions between the reef massifs contained a thick (over 1 km) bed of gypsum and anhydrite with bundles of halite and rarer potash salts. The reef massifs were overlain by series of anhydrite and dolomite 500 m thick. These rocks are now exposed in karst sinkholes at the base of Tra-Tau.

5. In the Paleogene the reef zone block from Tra-Tau to Yurak Tau was uplifted and the Kungurian deposits were largely eroded from the surface of the massifs, which was now partly covered by a clay-marl series.

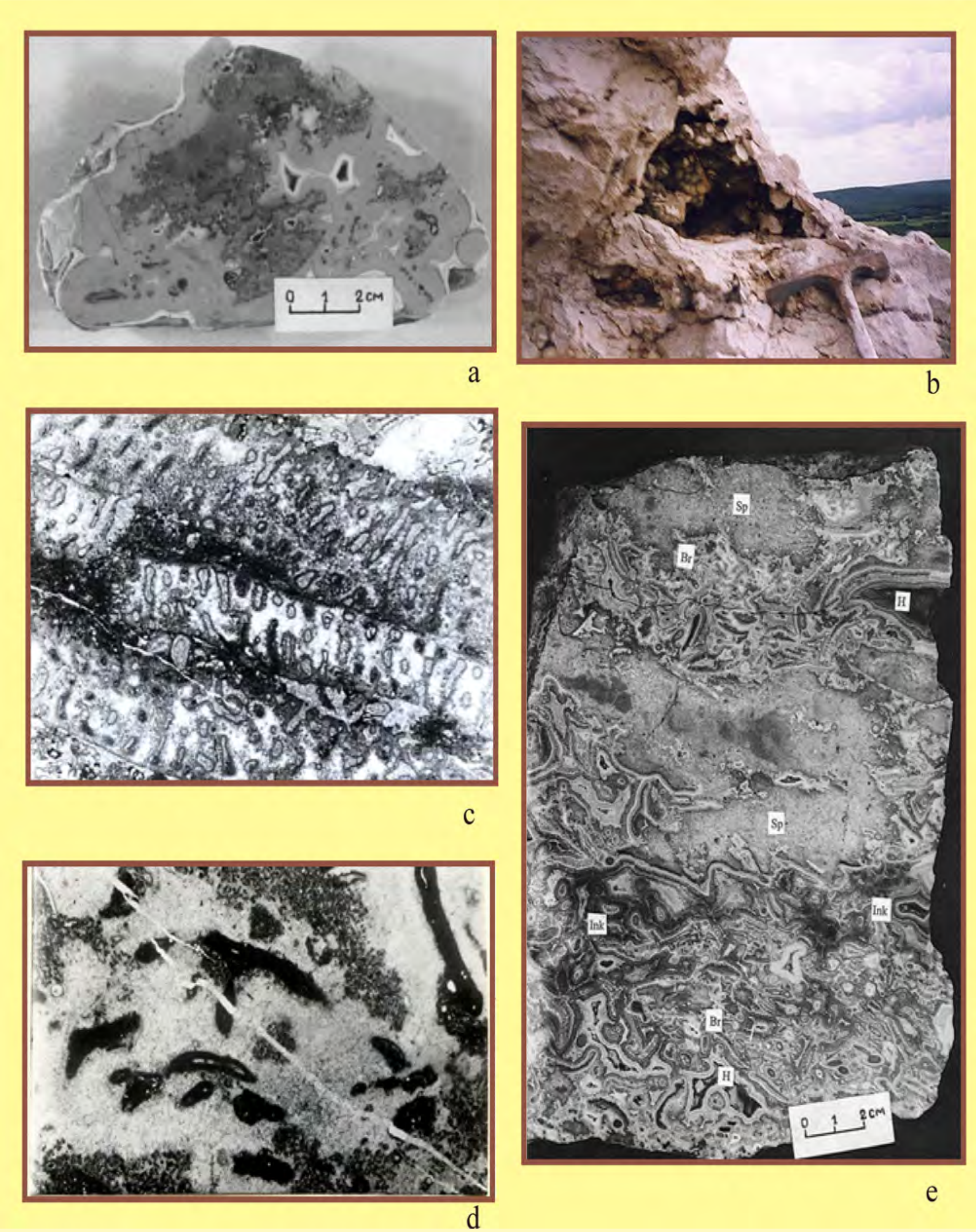


Fig. 3.5. Tra-Tau Reef. a – Cavern, eastern slope of Tra - Tau. Dark spots- oil; b – One of t he largest caverns in the Tra-Tau reef; c, e – sponges; d – tubiphytids

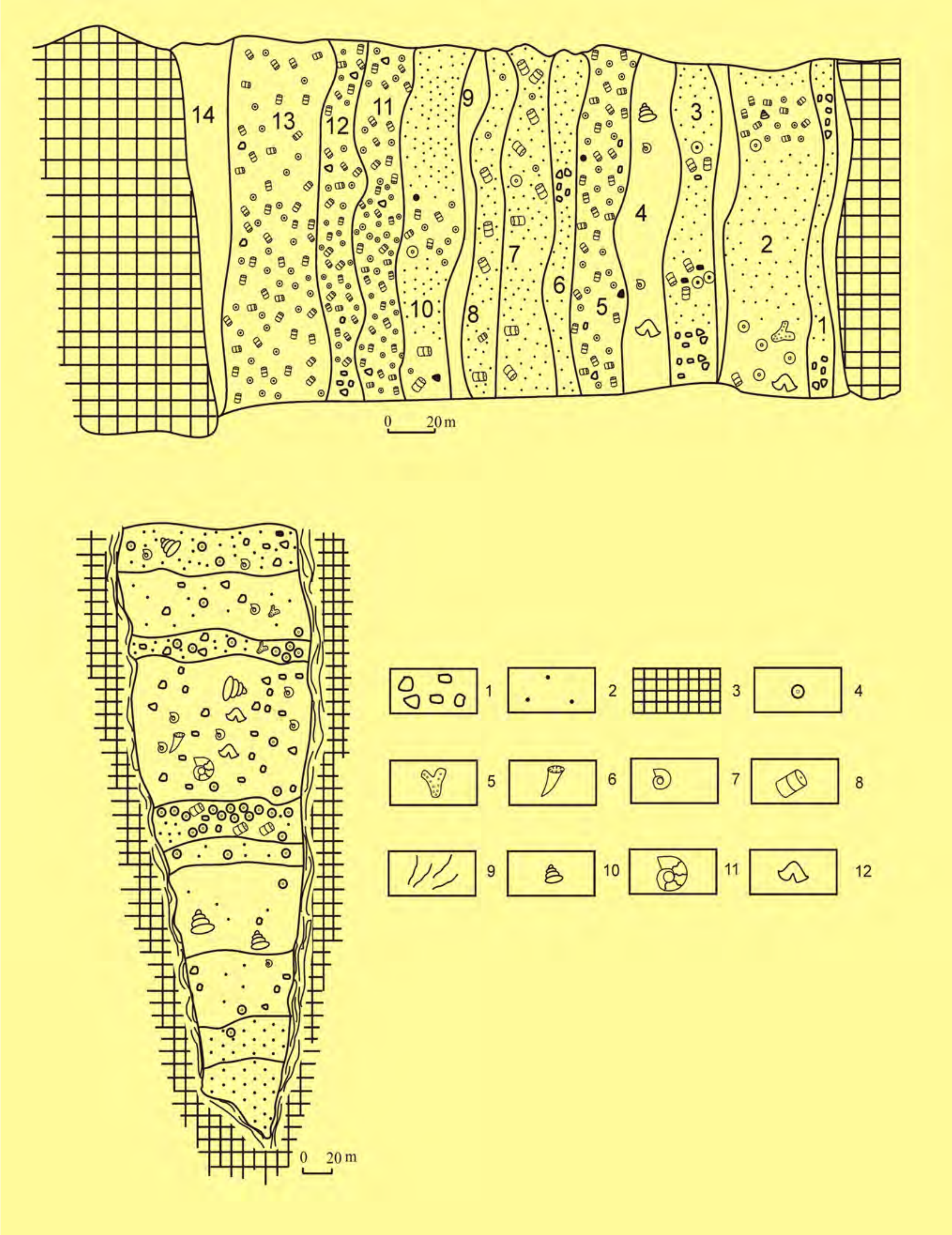


Fig. 3.6. Crevices in the Tra-Tau Reef, filled by detrital sediments. Explanation: 1 - large (1-2 cm) pieces of limestone; 2 - grained limestone; 3 - reef limestones; 4, 8 - crinoids; 5 - bryozoans; 6 - corals; 7, 10 - gastropods; 9 - stromatolites; 11 - ammonoid; 12 - brachiopods

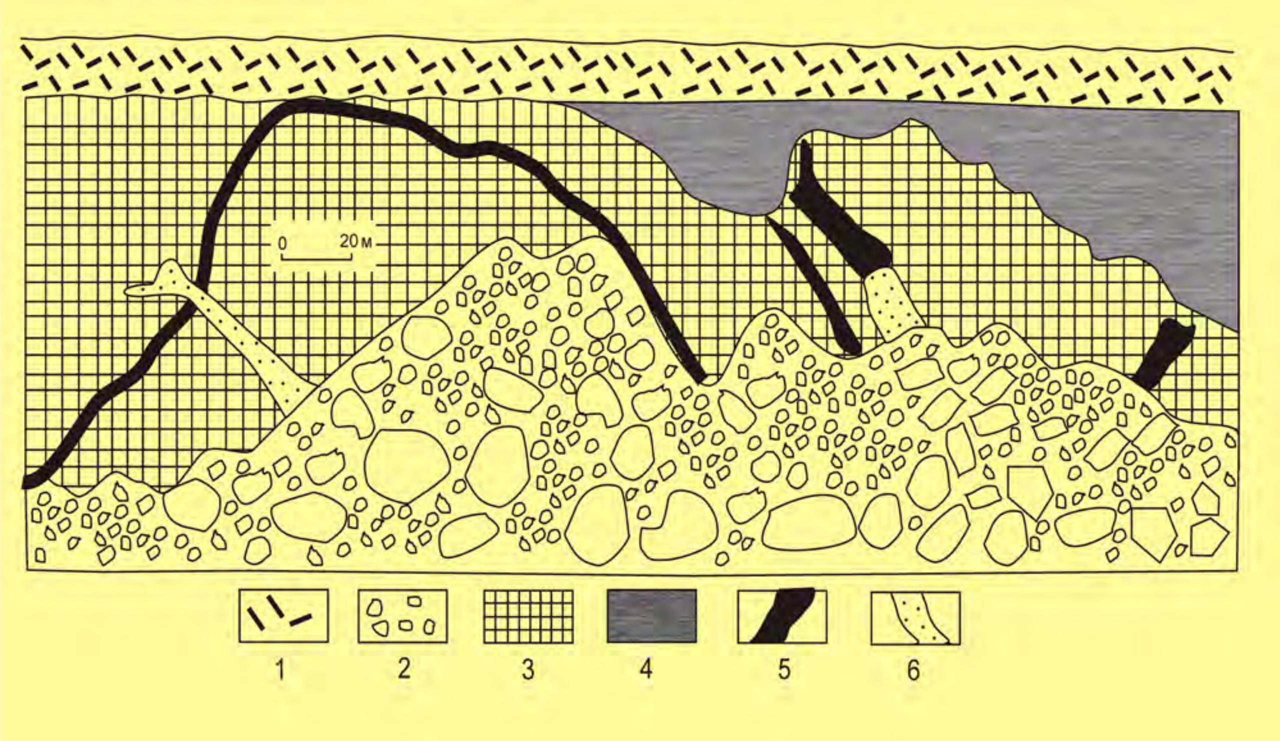


Fig. 3.7. The Shakh Tau Reef. Legend: 1 - Quaternary deposits; 2 - large and small debris; 3 - massive reef deposits; 4 - dark gray limestone and marl. 5 - dark gray cherty mudstone; 6 - clastic limestone

Shakh-Tau

The Shakh-Tau Reef is composed of Permian Asselian, Sakmarian and lower Artinskian rocks. It is split by a system of fractures, filled with sediments of various ages and lithologies. The limestone forming the reef is mined in large quarries for the soda plant in Sterlitamak.

Lithology

The Shakh-Tau reef is formed from the following types of carbonates (Fig. 3.7).

1. Biohermal limestone composed of small foraminifers: calcareous sponges, palaeoaplysinids, bryozoans, brachiopods, Tubiphytes, calcareous algae and stromatolites.

2. Detrital limestone and coquinae: fusulinoid, crinoid, mixed-crinoid-fusulinoid, algal (siphonous and dasycladacean algae), and bryozoans.

3. Micritic limestone, including radiolarian and microbial varieties.

4 Clastic, variously grained limestone, from siltstones to the sandstones, grits, boulders and blocks. Such formations usually fill large fractures in the body of the reef surface.

Biota

The assemblage of organisms that form the Shakh-Tau reef array in general resemble the Tra-Tau fossils. The difference is the presence in the Sakmarian part of the reef of thick (up to 3m) biostromes formed by *Palaeoaplysina*. A spiral shark tooth of a new genus resembling *Helicoprion*, and the species *Shaktauites seiwi* Chuvashov were found in this reef [Chuvashov, 2006].

Depositional History of Shakh-Tau

The surface of the reef, composed of limestone, also has large cracks. They began to fill during the Artinskian with detrital material, products of reef destruction. With further subsidence the surface of the reef and its fractures were covered and filled with dark marl and mudstone often enriched with phosphorus, interbedded with dolomite with radiolarians. Grey and black, strongly bituminous dolomites with crude oil on freshly broken surfaces.

Fig. 3.8. The Yurack-Tau Reef

Yurack-Tau

The Yurack Tau reef (Fig. 3.8) is composed mainly of Asselian carbonates with only a small proportion of Sakmarian limestone (Rauser - Chernousova and Koroljuk, 1991).

On the eastern slope of the reef (Fig. 3.9, The line A-A), the limestones contain fusulinids typical of the Tastubian horizon of Sakmarian age (*Pseudofusulina moelleri* zone). In the upper part of the profile AA met micrite interlayers (10 - 40 cm thick) with radiolaria and embryonic ammonoid shells. The basal beds of the reef contain accumulations of coiled nautilid shells.

The southern slope of the reef Sample 2 (Fig. 3.9) contained the fusulinids *Pseudofusu-*

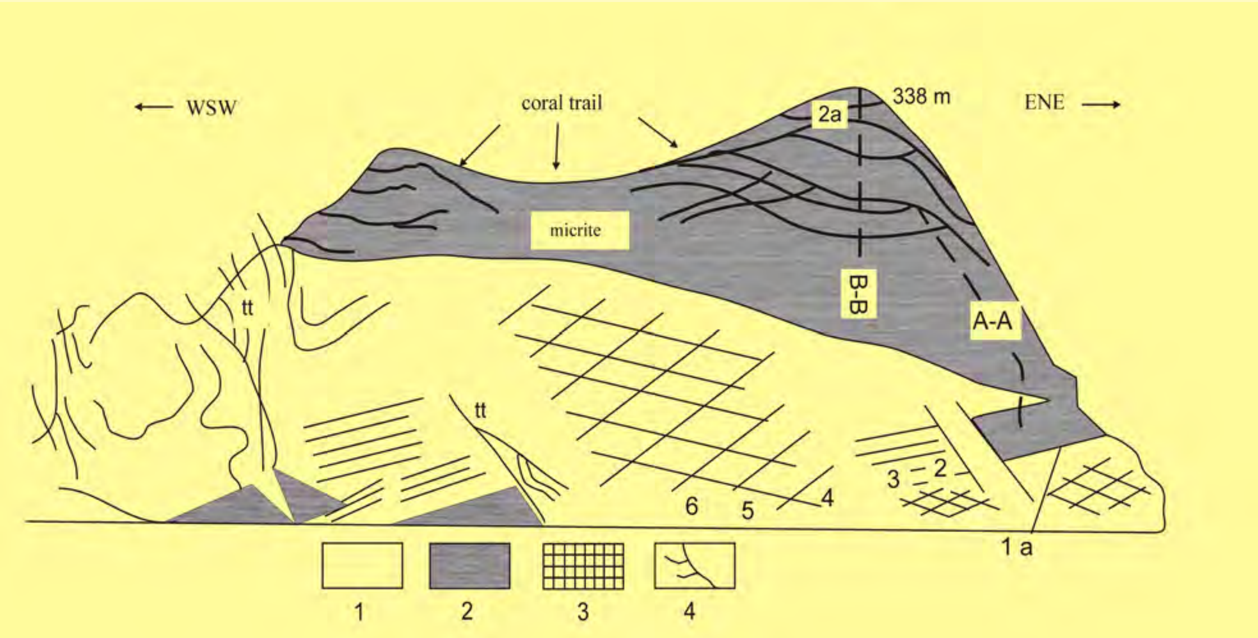


Fig. 3.9. The Yurack Tau Reef. Legend: 1 - carbonate rocks; 2 - organogenic construction; 3 - closed areas; 4 - tt - tectonic cracks; 5 - limestone with fusulinids; A - A - line of sampling (Chuvashov et al., 1996)

lina moelleri (Schellw.), *P. moelleri aequalis* (Schellw.) and others characteristic of the Tastubian horizon (Sakmarian).

Sample 3 contained an assemblage of fusulinids: *Pseudofusulina urdalensis* Raus., *P. concavutas adelpha* Raus., *P. concavutas* Viss., *P. curtata* Raus., typical of the Burtsevo horizon of the Artinskian Stage. In samples 4, 5, 6 (Fig. 3.9), fusulinids of the upper zone of the Tastubian horizon were found: *Pseudofusulina verneuili*: *Pseudofusulina callosa distenta* Kireeva, *P. paraconcavutas* Raus., *P. ex gr. confusa* Raus., *P. fortissima* Kireeva, *P. reticulata* Kireeva, *P. angusta* Kireeva, *P. fixa* Kireeva, *P, karagasensis* Raus., *P. para jaroslavkensis* Kireeva.

The southern slope of the reef, Sample 2 (Fig. 3.9) contained the fusulinids *Pseudofusulina moelleri* (Schellw.), *P. moelleri aequalis* (Schellw.) and others, characteristic of the Tastubian Horizon (Sakmarian). Sample 3 contains the following fusulinids: *Pseudofusulina urdalensis* Raus., *P. concavutas adelpha* Raus., *P. concavutas* Viss., *P. curtata* Raus., typical of the Burtsevo horizon (Artinskian). Samples 4, 5, 6, contain fusulinids of the upper zone of the Tastubian horizon: *Pseudofusulina verneuili*: *Pseudofusulina callosa distenta* Kireeva, *P. paraconcavutas* Raus., *P.* ex gr. *confusa* Raus., *P. fortissima* Kireeva, *P. reticulata* Kireeva, *P. angusta* Kireeva, *P. fixa* Kireeva, *P. karagasensis* Raus., *P. para jaroslavkensis* Kireeva.

The Kush-Tau reef is similar in its age and texture to that of Yurack-Tau. It has been proposed as an alternative source of raw material for the soda plant. To date this reef remains poorly studied and represents an interesting subject for future research.

USOLKA SECTION.
LOWER PERMIAN (ASSELIAN AND SAKMARIAN) DEPOSITS

Introduction

Two sections were used to study the lower boundary of the Sakmarian Stage on the western slope of the South Urals: the section along Usolka River and the historical Russian stratotype for the Sakmarian Stage – the Kondurovsky section (Fig. 4.1). Comparing these sections, it is noteworthy that the Kondurovsky section was formed under conditions of deep shelf or slope whereas the Usolka section is undoubtedly a shallower water succession. The Kondurovsky section represents a thick series of deposits in which local fossils are frequently accompanied by redeposited forms. In spite of the attractiveness of the Kondurovsky section because of the wide variety of fossils (conodonts, ammonoids and fusulinaceans), we nevertheless prefer to use it as the auxiliary stratotype – because the proportion of redeposited fossils is too high.

A section of carbonate mudstone deposits on the right bank of the Usolka River, located near the Krasnousolsky health resort is well known to stratigraphers from the time of the International Congress "Permian System of the World" in 1991. It served as a potential site for defining the conodont-based boundary between the Carboniferous and Permian systems and it can be used as an auxiliary section for defining this boundary.

We propose the Usolka section as the Global Stratotype Section and Point (GSSP) for the lower boundary of the Sakmarian Stage for the International Geochronological Scale.

The detailed description of the Usolka and Kondurovsky sections was previously provided (Chuvashov et al., 1991a; Chuvashov et al., 1991b). We give here the description of the Usolka section and the lithological logs for both sections showing the levels of the first appearance of the most important conodonts (Figs. 4.3, 4.4).

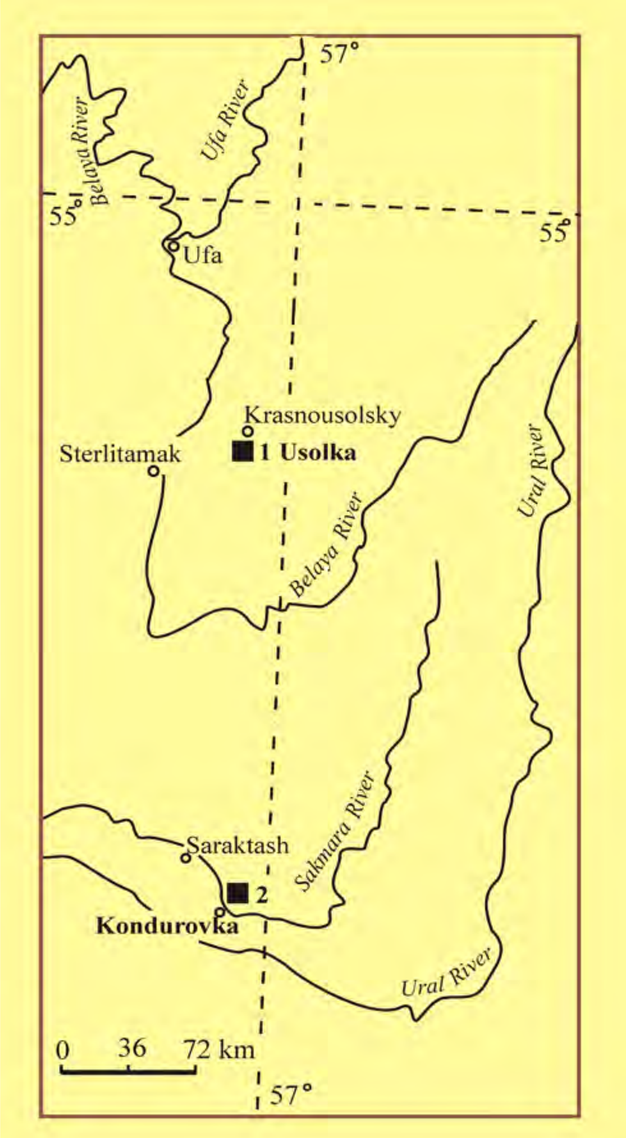


Fig. 4.1. Location of the Usolka (1) and Kondurovsky (2) sections

General characteristic of the Usolka section

The section on the Usolka River largely correlates with the section on Dal'ny Tulkas Creek exhibiting the Upper Carboniferous, Asselian, Sakmarian and Artinskian carbonate mudstone beds. The Gzhelian-Asselian interval at Usolka is condensed and shows uninterrupted deposition

Fig. 4.2. Exposure of Asselian-Sakmarian boundary deposits at the Usolka section

with abundant conodonts. Almost all rocks in this part of the section treatable in acetic or formic acids contain more than 200 conodont specimens per kilogram. In the continuous deposits of the Sakmarian part of the section the quantity and variety of conodonts is reduced (25-50 specimens per kilogram).

The continuity of the Usolka section is demonstrated by the occurrence of all above stratigraphic subdivisions (Stages) with uninterrupted succession of fusulinacean and ammonoid zones. The nature of change of sedimentation cycles and the absence of significant tectonic disruptions and interruptions also testifies to the continuity of sedimentation. In addition to this, the analysis of conodont lineages and morphological trends within the prevailing genera makes it possible to interpret the absence of any post-sedimentary processes like rewashing or redeposition in this section. The most significant shortcoming of the section is the relatively poor characterization of the Asselian beds by fusulinaceans and for ammonoids over the entire interval.

The total thickness of the succession at Usolka is somewhat more than 90 metres. The condensed nature of sedimentation and the corresponding reduced thickness of the stratigraphic subdivisions have positive and negative effects on the construction of the conodont sequence. The possibility of obtaining information about the distribution of conodonts over such a significant stratigraphic range in one section is considered to be of merit. It is also valuable that the slowly accumulated sediments are enriched in fossils, which is probably connected with the abundance of conodonts at Usolka.

This section provides complete information about the stratigraphic sequence and the composition of conodonts. Reducing the spacing of sampling and increasing sample volume as needed, provides information necessary for reconstruction of conodont phylogenies. The study of conodonts in these condensed sediments is performed only for those lithologies where the continuous is possible. In some rocks (claystone, dolostone, silicified limestone, etc.) the extraction of conodonts is nearly impossible and this can lead to errors.

Thus, if even a half-metre interval in this section is missing, it can result in the disappearance of an essential part of a conodont sequence right up to the loss of an entire zone. Therefore we tried to replicate conodont sequence data at the Usolka section by testing other facies types that were deposited more rapidly. The study of such "diluted" sections makes it possible to move away from a narrow time frame, within which is concluded the picture of the historical morphogenesis of conodonts at Usolka for studing more detailed the process of gradual change of conodonts. For this reason, the section of Upper Asselian-Sakmarian flysch deposits on the right bank of the Sakmara River near Kondurovsky settlement (Fig. 4.4) was studied.

The Usolka section made it possible to build the zonal scale on conodonts in the stratigraphic range of Upper Carboniferous to the Irginian Horizon of the Artinskian Stage. To validate this zonal scale we also studied in detail the distribution of conodonts in the Kondurovsky section, where thick flysch deposits crop out.

The boundary deposits between the Asselian and Sakmarian stages at the Usolka section comprise low rock cliff exposure in a roadside groove

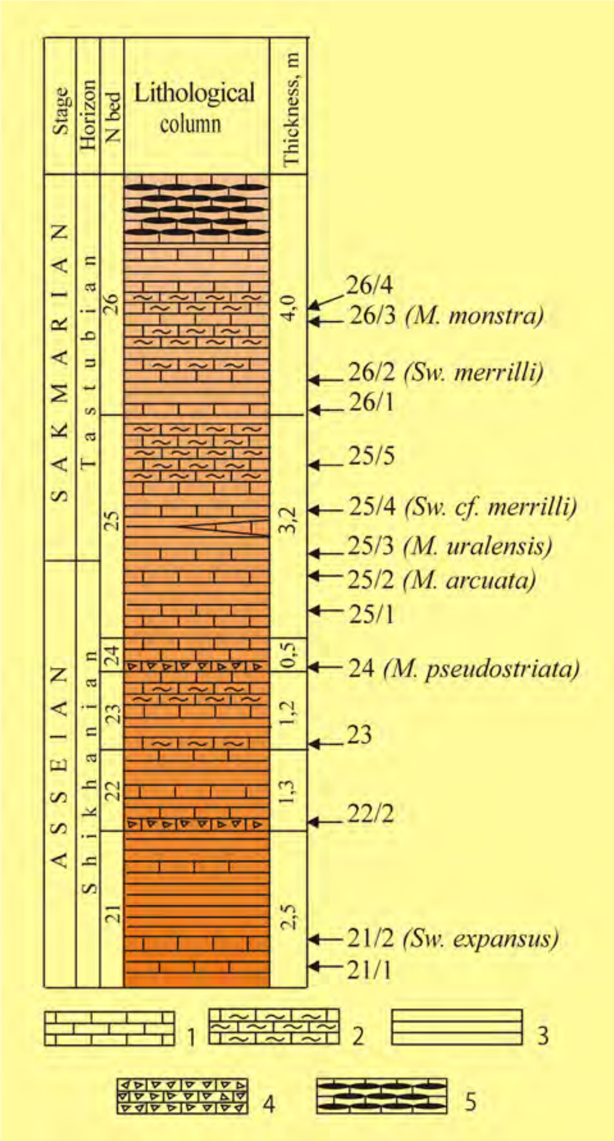


Fig. 4.3. Stratigraphic log showing conodont samples in the Usolka section; 1 - limestone, 2- mudstone, 3- shale, 4 - laminated limestone breccia, 5 - nodules and interbeds of chert; pointers indicate the sampling levels and their number

and are thus completely accessible for study and sampling at any point (Fig. 4.2). The description of the transitional Asselian-Sakmarian deposits of the Usolka section (Fig. 4.3), indication of productive levels and the determinations of fossil remains are given below.

Usolka Section description (in brackets after the conodont sample number is an indication of the distance of the sample from the base of section in metres).

Note: Section metreage levels vary by up to a metre in two versions of the Usolka section (base of bed 26 in Fig 4.9 is at 52 metres; slightly lower than depicted: base of bed 26 in Fig 4.2 and description below is at 53 metres).

Upper Asselian

Shikhanian Horizon

***Mesogondolella striata* Zone**

Bed 21. Alternation of carbonate and clay-rich rocks. The calcareous interbeds with a thickness from 4 to 25 cm have greenish grey or dark-grey colour are fine-grained to aphanitic. The interbeds (4-5 cm) of mudstone frequently have fragmental structure and are divided by dark-grey fissile argillite and marl (from 2.5 to 20 cm). Oval concretions of greenish-grey marl from 1 to 7 cm in size and interbeds of dark-grey chert occur in some argillite levels. The fossil remains include brachiopods, bivalves, fish scales, and conodonts..........……………........................3 m.

Sample 21/1 (45.3 m) is taken 1 m above the base of the bed, and includes the following cono donts: *Streptognathodus anaequalis* Chern., *S.* aff. *anaequalis* Chern., *S. lanceatus* Chern., *Sweetognathus* aff. *expansus* (Perlmutter), *Mesogondolella dentiseparata* (Reshetkova et Chern.).

Sample 21/2 (45.7 m). Conodonts: *Streptognathodus barskovi* Kozur, *S. postfusus* Chern. and Reshetkova, *Mesogondolella dentiseparata* (Reshetkova and Chern.), *M. simulata* (Chern.), and *M. striata* (Chern.).

Bed 22. A 5-7 cm thick breccia occurs at the base of the bed and is composed of angular fragments of green marl, 1 cm limestone frag-

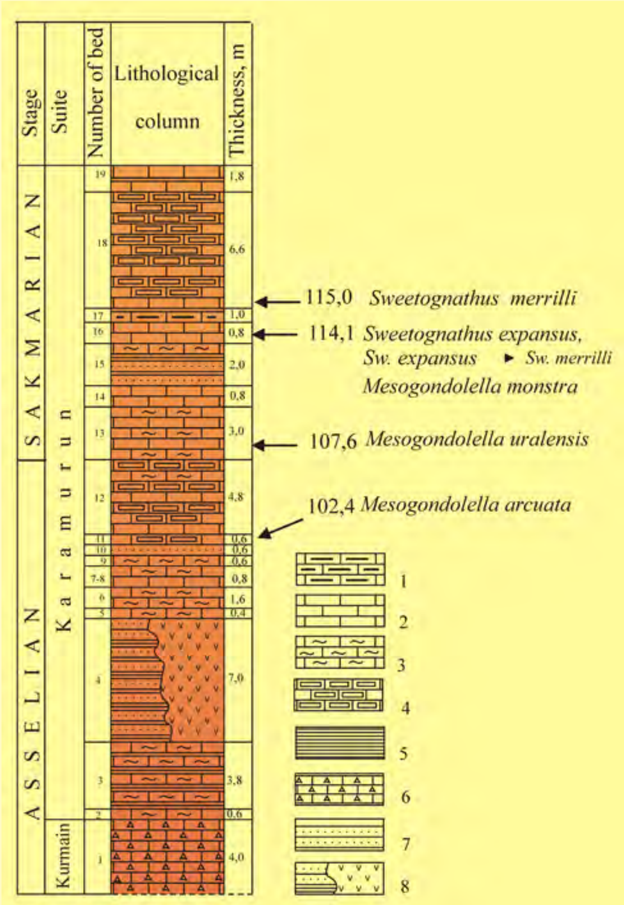


Fig. 4.4. Stratigraphic log showing conodont samples in the Kondurovsky section: 1 – chert, 2 – fine grained limestone, 3 – muddy limestone, 4 – carbonate mudstone, 5 – shale; 6 – calcareous conglomerate-breccia, 7 – siltstone, 8 – covered intervals; pointers indicate the places of occurrences of the most important conodont species and distance (in m) from the beginning of section

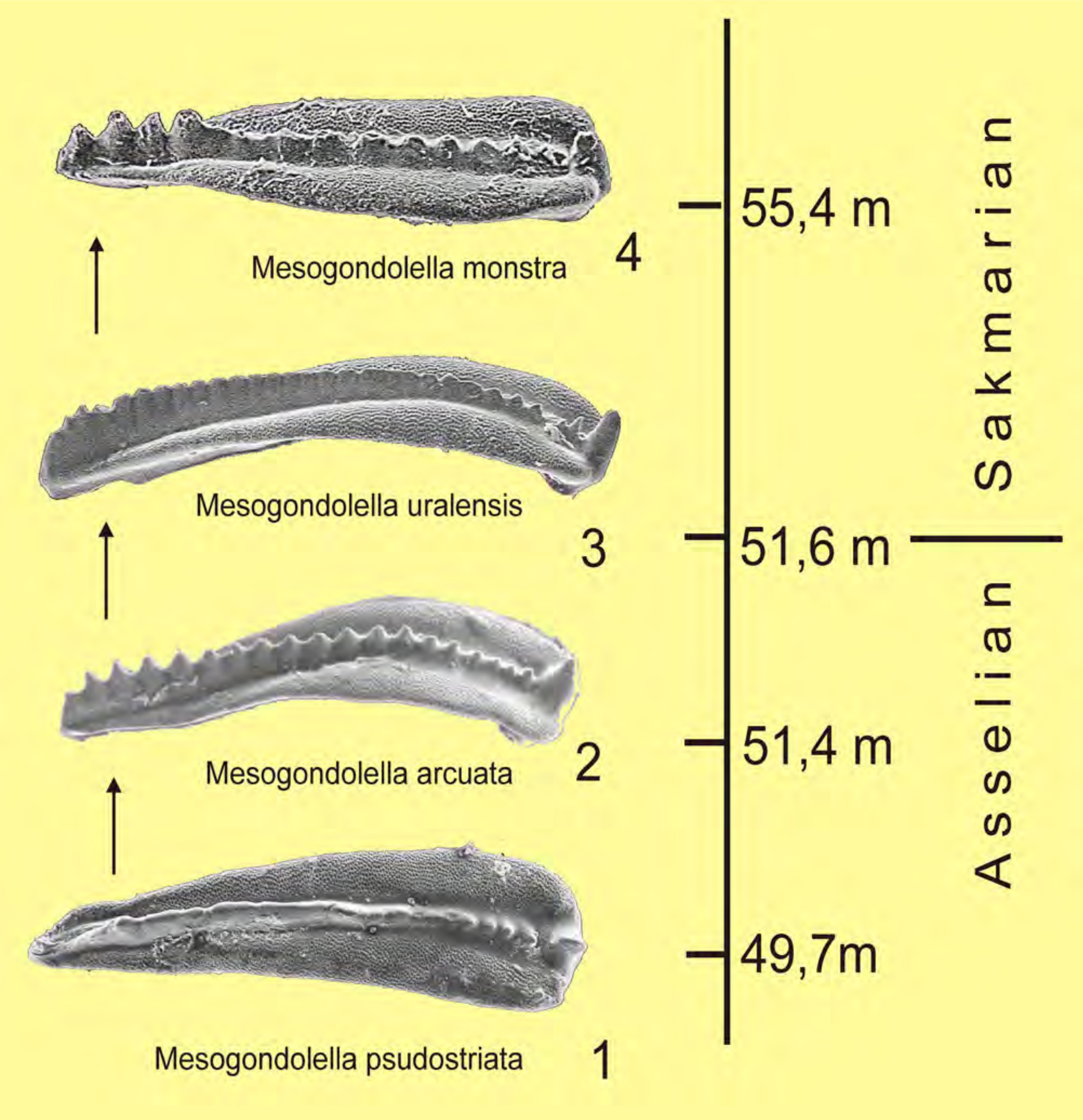


Fig. 4.5. The evolutionary lineage of the Asselian-Sakmarian species of the genus Mesogondolella. Explanations in the text

ments, and also by different organic remains including crinoid ossicles, brachiopods, bryo zoans, and "small" foraminifera. The breccia changes gradually to resistant bioclastic limestone (20 cm) that includes fragments of brachiopod shells, bryozoans and crinoid ossicles. The upper part of the bed is composed of brownish-light-grey aphanitic limestone with platy partings..0.9 m.

Sample 22/2 (47.3 m). The sample comes from the detrital limestone directly above the breccia, and contains *Streptognathodus barskovi* Kozur, *S. postconstrictus* Chern., *S. postfusus* Chern. et Reshetkova, *S. constrictus* Reshetkova et Chern., *Mesogondolella dentiseparata* (Reshetkova et Chern.), *M. striata* (Chern.) and *Adetognathus paralautus* Orchard and Forster.

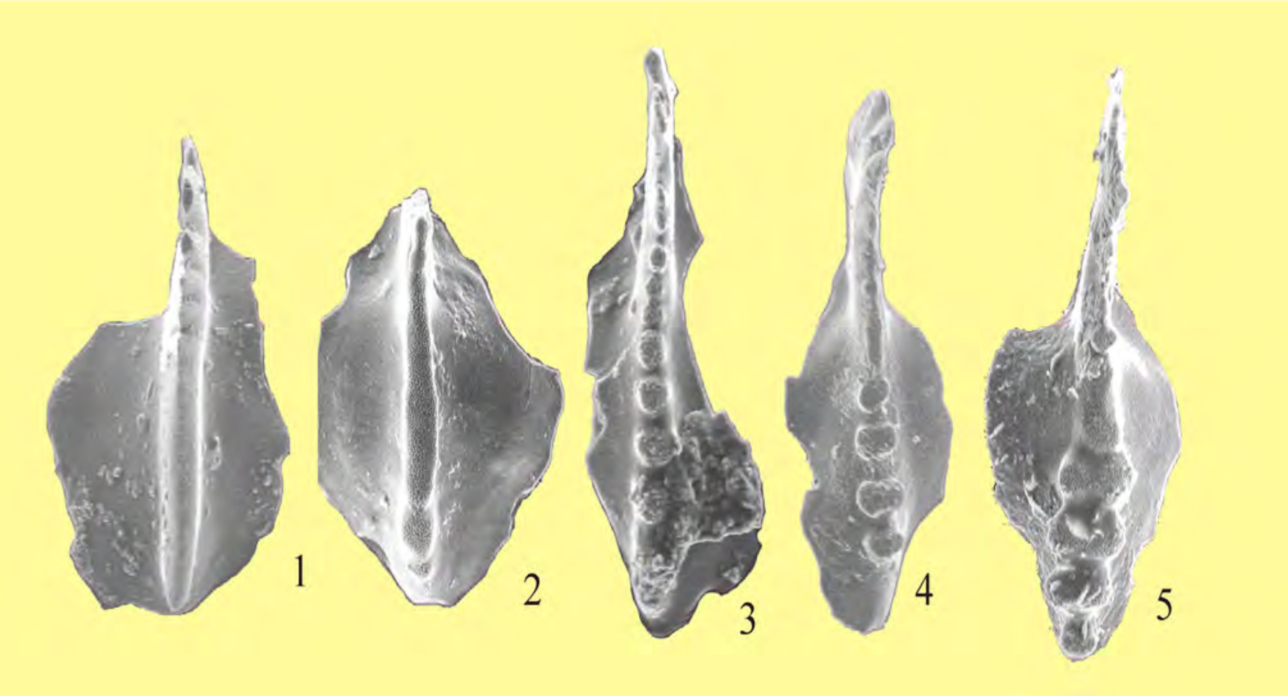


Fig. 4.6. The evolutionary lineage Sweetognathus expansus – Sw. binodosus in the Usolka section. 1 – Sw. expansus (Perlmutter), bed 14; 2 – a form transitional from Sw. expansus to Sw. merrilli, bed 21/2; 3 – Sweetognathus merrilli Kozur, bed 26 (54.3 m from the base of the section); 4, 5 – Sweetognathus binodosus Chern., bed 26 (55.4 m from the base of the section)

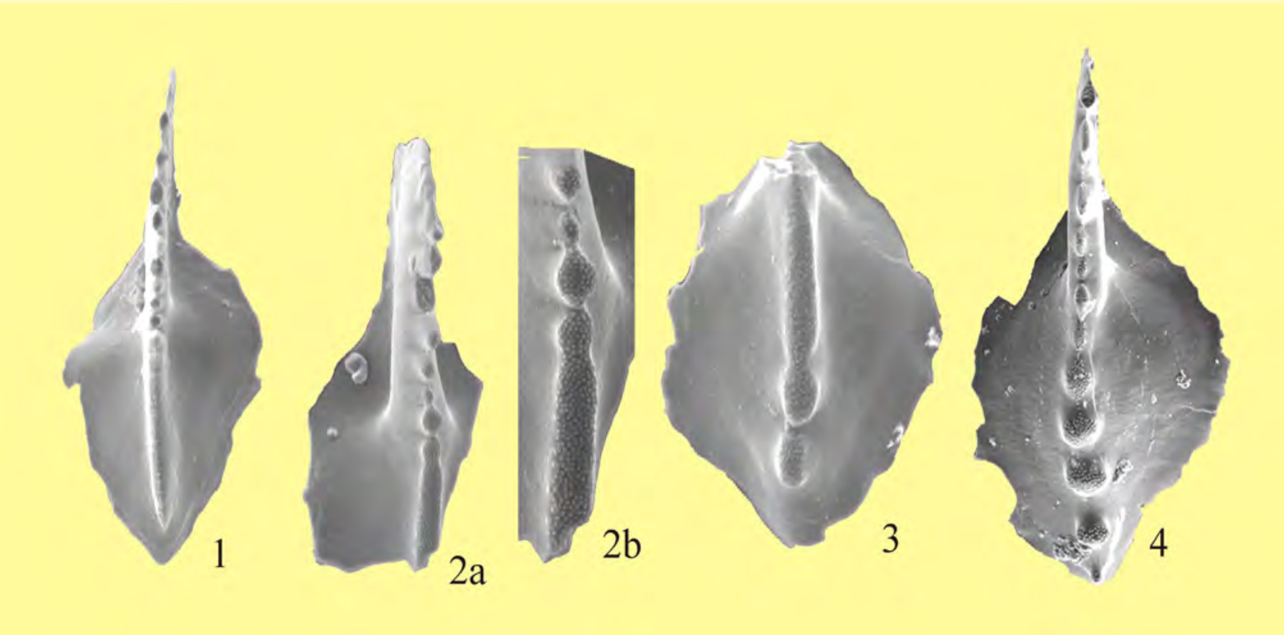


Fig. 4.7. The evolutionary lineage Diplognathodus aff. stevensi – Sweetognathus merrilli, Kondurovsky section. 1 – D. aff. stevensi Clark and Carr, middle part of bed 16; 2, 3 – forms transitional from D. aff. stevensi to D. merrilli Kozur (2b – fragment of the specimen shown in 2a, enlarged), upper part of bed 16; 4 – D. merrilli, bed 18

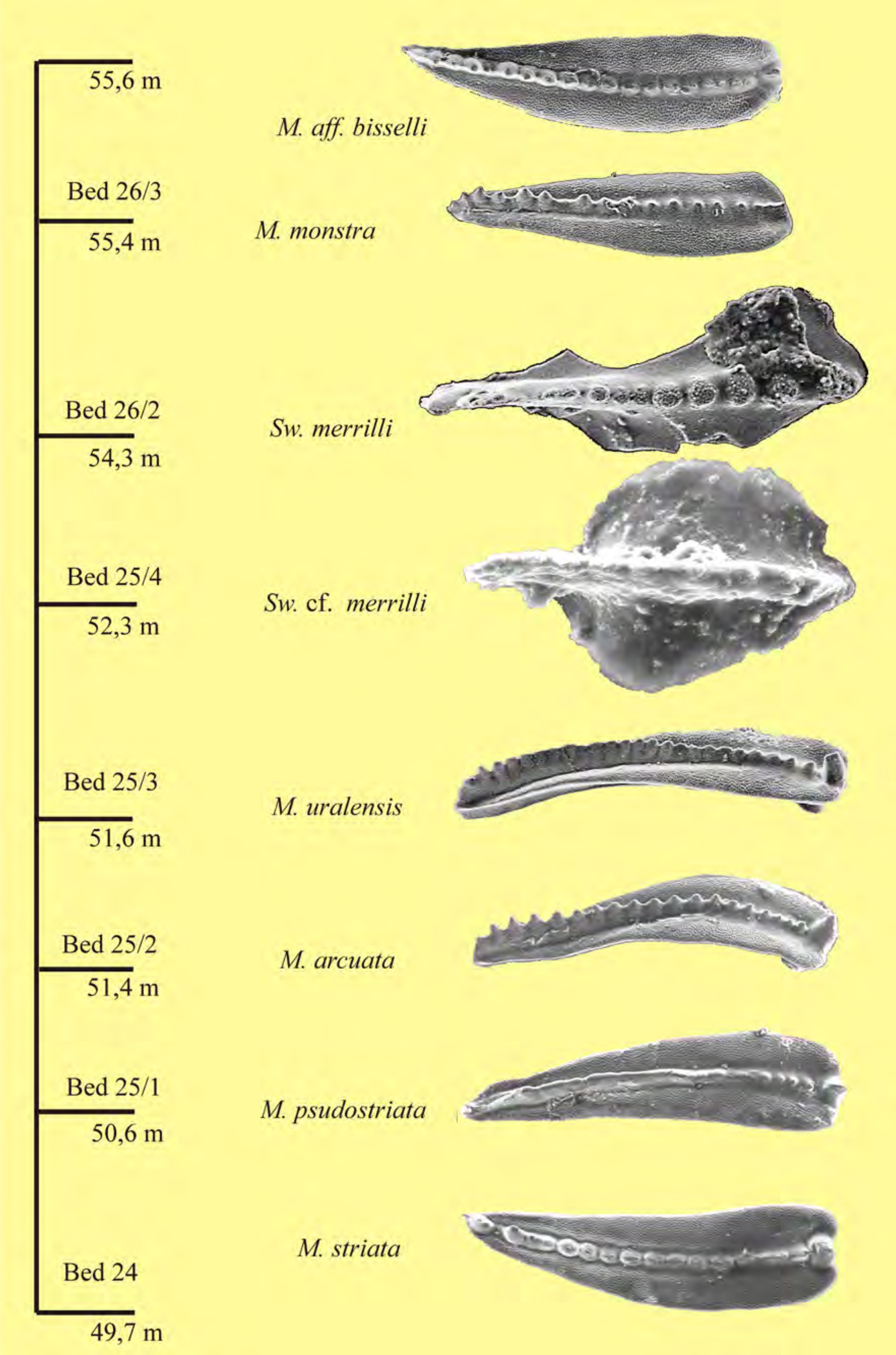


Fig. 4.8. Distribution of conodonts of the Mesogondolella lineage and the level of the first appearance of Sweetognathus merrilli Kozur in the Usolka section (the number of beds and distance in metres from the base of the section are indicated in the left)

Bed 23. Alternation of dark grey marl with grassy-green spots and light-grey aphanitic limestone; layers of argillite are present in the middle part of the bed..1.2 m.

Sample 23/1 (48.8 m). The sample is selected from the middle part of the bed from the brecciated marl interbed (3 cm) containing the conodonts *Mesogondolella dentiseparata* (Reshetkova et Chern.).

***Mesogondolella pseudostriata* Zone**

Bed 24. This greenish-grey breccia changes in thickness (0-20 cm) and includes angular or poorly rounded fragments of light brownish-grey limestone with size from 1 to 2 cm at the base of the bed. These fragments include fossils of fusulinaceans, brachiopods, crinoids ossicles and are surrounded by greyish-green marl. In places the breccia is friable and easily broken by hand. The breccia rapidly changes upward into light grey fine-detrital thick plated limestone .... 0.45 m.

Upper Asselian fusulinaceans are identified in the base of the bed: *Rugosofusulina serratashikhanensis* Suleim., *R. intermedia* Suleim., *Pseudofusulina sulcata* Korzh., *P. decurta* Korzh., *P. idelbajevica* Korzh., *P. ishimbajevi* Korzh., *P. rauserae* Korzh., *P. baschkirica* Korzh., *P. sphaerica* (Bel.), *P. sphaerica timanica* Grozd., *P. exuberata* Sham., *P. exuberata luxuriosa* Sham., *P. firma* Sham., *P. differta* Sham., *P. parva* Bel.

Sample 24 (49.7 m) was taken in the lower part of the bed in the first thick interlayer of limestone above the breccia. Conodonts here included: *Mesogondolella aff. camilla* Chern., *M. simulata* (Chern.), *M. pseudostriata* (Chern.), and *M. striata* (Chern.).

Bed 25. The large part of this bed represents interbedded brownish-grey mudstone (1-3 cm) with characteristic conchoidal fracture and the dark grey fissile or thin-platy argillite, rarely marl.

The thin interlayers of mudstone are frequently silicified. In the layer there are three interbeds (respectively from bottom to top 15, 20 and 12 cm) of the brownish-light- grey bioclastic limestone; it is resistant and partially silicified with “small” foraminifera, fusulinaceans, bryozoans, crinoids and algae *Tubiphytes* sp. The thin interlayers of mudstone sometimes contain radiolarian and sponge spicules. Rare brachiopods, small straight nautiloids and fish bones are encountered in the argillite and marl …..........................3.8 m.

The fusulinaceans, 2 m higher than base of the layer include: *Pseudofusulinella usvae plicata* (Sham. and Scherb.), *Schubertella paramelonica* Suleim., *Rugosofusulina shaktauensis* Suleim., *R. pulchella firma* Suleim., *P. ishimbajevi* Korzh., *Sphaeroschwagerina cf. sphaerica* Scherb. This complex indicates an Upper Asselian age.

Sample 25/1 (50.6 m) is taken from the dark cream-coloured organic-detrital limestone with visible fusulinaceans and there are conodonts including *Mesogondolella cf. pseudostriata*.

Sample 25/2 (51.4 m): *Streptognathodus aff. barskovi* Kozur, *S. constrictus* Reshetkova and Chern., *Mesogondolella arcuata* Chern., *M. pseudostriata* (Chern.), *Mesogondolella arcuata* transitional with *M. uralensis*.

Sakmarian

Tastubian Horizon

***Mesogondolella uralensis* Zone**

Sample 25/3 (51.6 m): *Mesogondolella arcuata* Chern., *M. pseudostriata* (Chern.), *M. uralensis* (Chern.), FAD.

Sample 25/4 (52.3 m): *Sweetognathus cf. merrilli* Kozur, *Diplognathodus* sp.

Sample 25/5 (53.0 m): *Mesogondolella arcuata* Chern., *M. camilla* Chern., *M. pseudostriata* (Chern.), *M. uralensis* (Chern.) and *Diplognathodus* sp.

Bed 26. This bed comprises thin alternations of limestone, marl and argillite. Limestone is brownish-grey and dark grey, aphanitic with thicknesses of 2-5 cm and rarely up to 10 cm.

Limestone interlayers are frequently completely silicified. In the lower part of the bed the brownish-grey and ash-grey thinly platy or fissile interbeds of argillite and marl attain a thickness of 15-20 cm, and above their thickness decreases to 5-7 cm.

A thin (1-2 cm) crust of bioclastic limestone, including segments of crinoids, bryozoan fragments, foraminifers and the alga *Tubiphytes* sp. is encountered in the lower part of the limestone interbeds. Plant microfossils in the argillite include abundant acritarchs of satisfactory and poor preservation..4.4 m.

Sample 26/1 (54.0 m) is undertaken 1 m higher than base of the bed; there are determined the following conodonts: *Streptognathodus postelongatus* Wardlaw, Boardman et Nestell, *Mesogondolella uralensis* (Chern.), *Mesogondolella aff. uralensis* (Chern.).

***Sw. merrilli* Zone**

Sample 26/2 (54.3 m). This bed includes the conodonts *Streptognathodus aff. florensis* Wardlaw, Boardman and Nestell, *Sweetognathus merrilli* Kozur, *Mesogondolella camilla* Chern., *M. aff. uralensis* (Chern.).

***Sw. binodosus (=Mesogondolella monstra)* Zone**

Sample 26/3 (55.4 m). This bed includes the conodonts *Sweetognathus binodosus* Chern., *Mesogondolella obliquimarginata* (Chern.) and *M. monstra* Chern.

Sample 26/4 (55.7 m). This bed contains the conodonts *Streptognathodus postelongatus* Wardlaw, Boardman et Nestell, *Mesogondolella obliquimarginata* Chern. and *M. longifoliosa* (Chern.).

Bed 27. Brownish-grey marl with platy separation at a thickness of 3-5 cm. Upper 4 m of layer includes three interlayers of bioclastic limestone with a bed thickness up to 15 cm, which consist of small foraminifers, bryozoans, crinoids, the algae *Tubiphytes* and other fossil detritus. Tastubian fusulinaceans are determined in the limestone and include *Rugosofusulina shakhtauensis ellipsoidalis* Suleim., *R.* ex gr. *shakhtauensis* Suleim., *Pseudofusulina ischimbajevi* Korzh., *P. baschkirica acuminata* Kir., *P. verneuili* (Moell.), *P. conspiqua* Raus., *P. cf. fixa* Kir. and *P. angusta* Kir. ....10,0 m.

Thin (5-10 cm) interbeds of aphanitic limestone are distributed throughout the unit.

Sample 27 (57.4 m). This bed includes the conodont *Mesogondolella manifesta* Chern.

Thus, the interval between the levels of the lower boundary of Sakmarian Stage, determined by the conodonts (51.6 m) and the first definite Tastubian (Lower Sakmarian) fusulinaceans (57.4 m) is a little less than 6 metres in the Usolka section. The bioclastic limestone in bed 26 lacks fusulinaceans.

Conodonts

The Asselian-Sakmarian conodonts in the Usolka section, which we propose to use as the stratotype of the lower boundary of the Sakmarian Stage are characterized by high frequency of occurrence (75 or more per kilogram of sample) and good preservation. Almost all the obtained P1 elements are complete and transparent with CAI 1.0-1.5, without adhering particles and can be used for determining strontium isotopes.

Conodonts of the genus *Mesogondolella* are most abundant in this interval at both the Usolka and the Kondurovsky sections. Systematic composition and stratigraphic distribution of mesogondolellids in both sections is surprisingly monotonous. The characteristic form *Mesogondolella uralensis* Chern., which we consider as a member of the evolutionary lineage (Fig. 4.5) *M. pseudostriata* - *M. arcuata*- *M. uralensis* - *M. monstra* (Chernykh, 2006), first appears near and somewhat below the traditionally adopted boundary (based on fusulinaceans) of the Sakmarian Stage.

This sequence of conodonts is established in both sections despite differences in facies and supports the evolutionary nature of the revealed chronomorphocline, which we use as the basis for the zonation of the transitional deposits between the Upper Asselian and Sakmarian. We propose to define the position of the lower boundary of the Sakmarian Stage with an evolutionary event - the appearance of the characteristic species *Mesogondolella uralensis* within the chronomorphocline *M. pseudostriata*- *M. monstra* (Fig. 4.5).

As an auxiliary we use data on the evolution of the *Sweetognathus* species, which can also be used to approximate the lower boundary of the Sakmarian. The first representative of this genus in the Uralian succession, *Sweetognathus expansus* (Perlmutter), appears in the Usolka section in bed 21 (Upper Asselian). These forms possess continuous undifferentiated carina with a pustulose surface. Further evolution of this conodont group follows the path of differentiation of the carina and leads to the appearance of *Sweetognathus merrilli* Kozur, which is characterized by a few carinal nodes (Fig. 4.6). The identical evolutionary succession of this species has also been established in the Kondurovsky section (Fig. 4.7).

The level of appearance of *Sw. merrilli* in the Usolka section nearly coincides with the first appearance of *M. uralensis*. We found the typical *Sw. merrilli* in the Usolka section in the upper part of bed 25 and lower part of bed 26. The same example of this form from layer 25/3 was found and demonstrated to us by Bruce Wardlaw at the session of the Permian working group in January 2003 in Boise (USA, Idaho). The first appearance of *Mesogondolella uralensis* at 51.6 metres is only 70 cm lower than the first occurrence of *Sw. merrilli*, so the levels of first appearance of these two species can be considered almost identical (Fig. 4.8). In the Kondurovsky section *M. uralensis* appears somewhat earlier than *Sw. merrilli*, but the 5 m interval between represents a relatively short period of time, taking into account the rapid deposition of flysch sedimentation in this section. The species *Sw. merrilli* may be widespread (Urals, North America, China), but care must be taken before it can be used as an auxiliary indicator of the lower boundary of Sakmarian.

The abundance of conodonts at all levels, noted on the lithological stratigraphic logs for the Usolka and Kondurovsky sections is from 50 to 100 specimens per kilogram. However, the quantity of specimens of the genus *Sweetognathus* is small in comparison.

Fusulinaceans

Fusulinaceans in this section do not form a continuous series, but they are found at several levels, separated by large intervals, making it necessary to use an assemblage of fossil organisms for correlation (fusulinaceans, conodonts, miospores), especially given lithological compositional variations of the deposits. Rare levels with radiolarians only were fixed on the initial stage of study; subsequently they were used, but they did not influence the existing position of boundaries.

Fusulinaceans are found only in two upper beds of the Kholodnolozian Horizon in the thin interbeds of fine bioclastic limestone. This is in essence the species of the genus *Pseudofusulina*, which form the characteristic complex of the upper part of the horizon. The almost complete absence of *Schwagerina* is also noteworthy as it often occurs in shallow carbonate facies. One example of *Sphaeroschwagerina cf. sphaerica* Scherb. is found only in the upper part of bed 25.

The lower boundary of the Tastubian Horizon (thickness of 10 m) is determined according to a change in the species. In the upper four metres of the 10 metre layer there are three interbeds with an impoverished, but significant complex of *Rugosofusulina* and *Pseudofusulina* with the presence of the characteristic Sakmarian form-*Pseudofusulina verneuili* (Moell.).

U-Pb geochronology

Schmitz and Davydov (2012) carried out a radiometric study, based upon high-precision, isotope dilution-thermal ionization mass spectrometer (ID-TIMS) U-Pb zircon ages for interstratified ash beds in the southern Urals sections. Here we provide the results of analysis of two ash-beds from Usolka section, that bracket the Asselian-Sakmarian transition under consideration in this proposal. Zircons of ash-bed from the Kholodnolozhian Horizon (bed 18; 41.25 m above the base were analyzed, nine single grains of zircon yielded a weighted mean 206Pb/238U age of 296.69 ± 0.12 Ma. The second studied ash-bed 25 metres higher in the section (bed 28; 66.2 m above base) relates to Sakmarian, a number of equant zircons from this ash sample gave a weighted mean of 206Pb/238U date of 291.10 ± 0.12 Ma for eight crystals, excluding three antecrysts. The extrapolated age for bed 25.2 at 51.4 metres is 295.5 Ma.

Strontium Isotopes

Schmitz et al. (2009) in a presentation at the International Conodont Symposium indicated a consistent secular trend of 87 Sr/86Sr isotopic values from conodont elements through the Early Permian. The 87Sr/86Sr isotopic value for the base of the Sakmarian was approximately 0.70787 (Schmitz et al., 2009). Strontium isotopes from individual conodont elements have been integrated with geochronological ages to produce a time model (Schmitz in progress). The strontium isotopic composition of seawater at the base of the Sakmarian Stage is now calculated at 87Sr/86Sr = 0.70787.

Carbon isotope chemostratigraphy

A group of Chinese researchers with the participation of V. Davydov (Boise State University, USA) conducted a study of stable carbon and oxygen isotopes in the south Urals sections - Usolka, Dal'ny Tulkas and Kondurovsky (Zeng et al., 2012). The basic results obtained at the Usolka section are of interest to this proposal (Fig. 4.9).

1. A gradually increasing trend in carbonate carbon isotope (δ13C) values has been observed in the interval from the base of Asselian to early Sakmarian, which is generally consistent in timing with the increasing development of Glacial III or P1 from the latest Carboniferous to early Sakmarian (Early Permian) which prevailed in southern Gondwana.

2. An excursion with double negative shifts in δ13Ccarb value is documented immediately above the Asselian/Sakmarian boundary in both the Usolka and Kondurovsky sections, which may have potential to serve as chemostratigraphic markers for intercontinental correlation (Zeng et al., 2012). However, more work in different areas is necessary to confirm this pattern.

3. The following highly positive excursion of δ13C in early Sakmarian indicates the maximum expansion of Glacial III or P1. The negative δ13C shift in the early to middle Sakmarian is possibly related to the quick collapse of Glacial III or P1 on Gondwana; this also accounts for the cyclothemic pattern change (see Fig. 4.9). This negative shift is largely correlative with those documented in other areas of Russia, the North American craton and South China, but further precise biostratigraphic and geochronological constraints are necessary to confirm this global signal.

Summary

We propose that the base of the Sakmarian stage would be defined by the FAD of *Mesogondolella uralensis* in Bed 25 at 51.6 m at the Usolka section. An extrapolated geochronological age of 295.5 Ma, strontium isotope values near 0.70787 and a double negative shift in $\delta^{13}C_{carb}$ value just above the boundary serve as additional methods to correlate the boundary. Furthermore, *Sweetognathus merrilli* appears immediately above the defined boundary and additional fossils including fusulinaceans provide additional data to assist correlation.

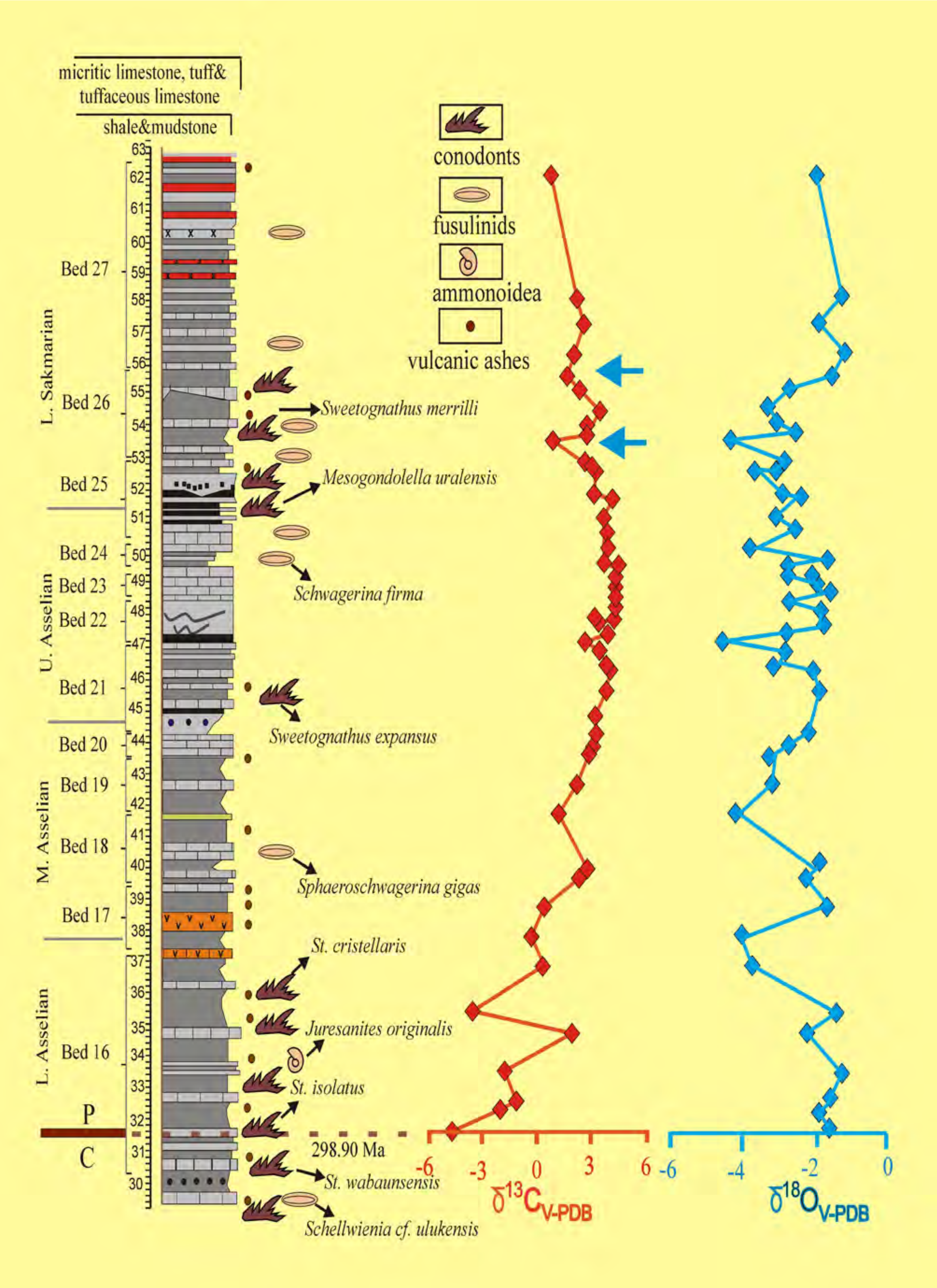


Fig. 4.9. Carbon and oxygen isotope trends of the Usolka section (from Zeng et al., 2012).

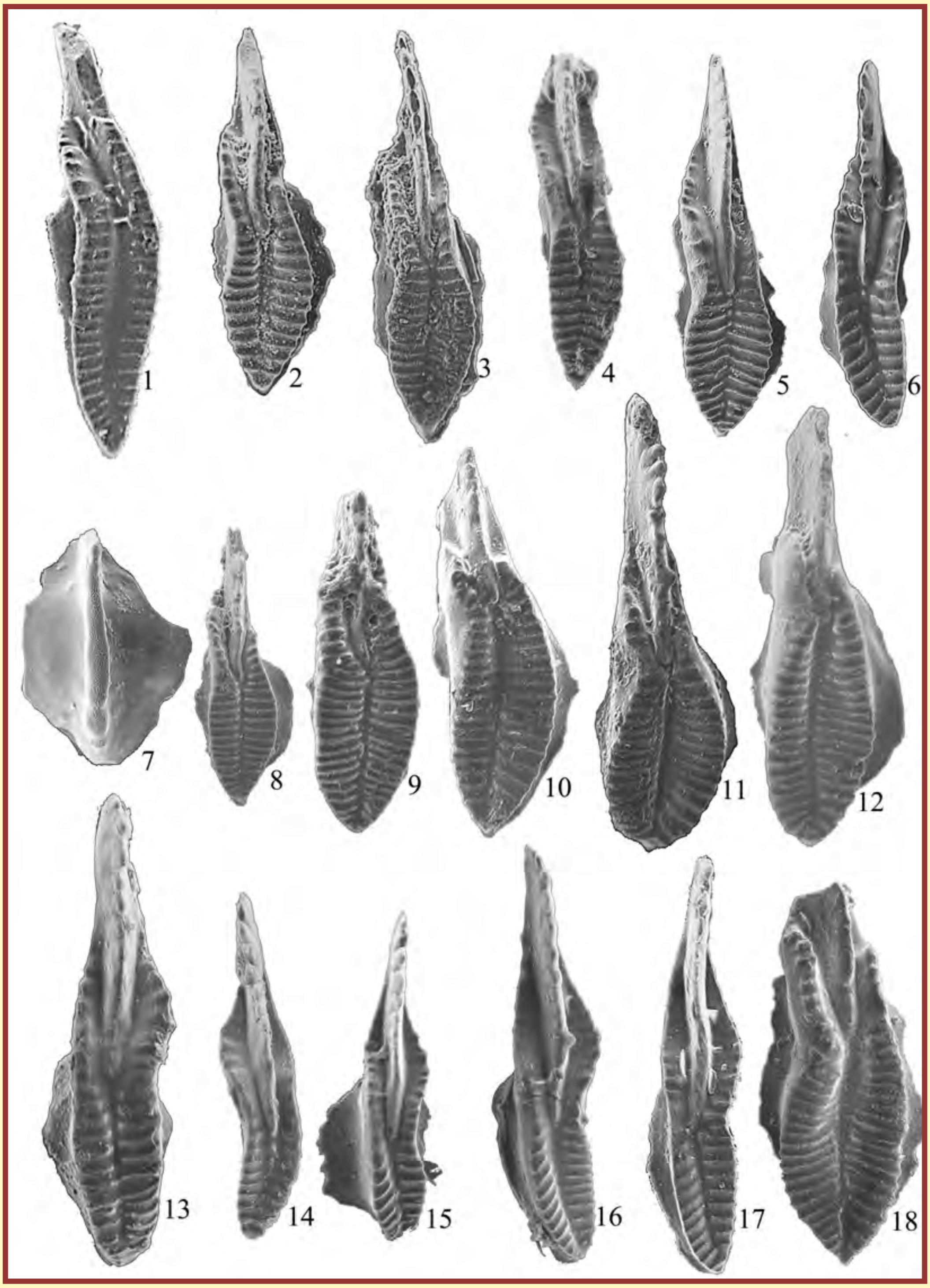


Plate 4.1. Upper Asselian (postfusus zone) conodonts (x 80).
Fig. 1. Adetognathus paralautus Orchard et Forster, 1988, U34-37; Usolka section, bed 22.
Figs. 2-6. Streptognathodus barskovi Kozur: 2 – U34-2; bed 21/2; 3 – U34-38; 4 – U34-41;, bed 22; 5 – T49-47; 6 – T49-33, left forma; Usolka section, bed 22.
Fig. 7. Sweetognathus expansus (Perlmutter), U32A-37-1; Usolka section, bed 21.
Figs. 8-12 (x 60). Streptognathodus postfusus Chernykh et Reshetkova, 1987: 8 – U34-36; 9 – U34-24; 10 – U34-25; 11 – U34-26; 12 – U34-23a; Usolka section, bed 22.
Figs. 13-17. Streptognathodus postconstrictus Chernykh, 2006: 13 – U34-16; 14 – U34-18; Usolka section, bed 22; 15 – U34-48a; bed 25/2; 16 – holotype U34-17; Usolka section, bed 22; 17 – U34-49a; Usolka section, bed 26/1. Fig. 18. Streptognathodus aff. barskovi Kozur, U34-44a; Usolka section, bed 25/2

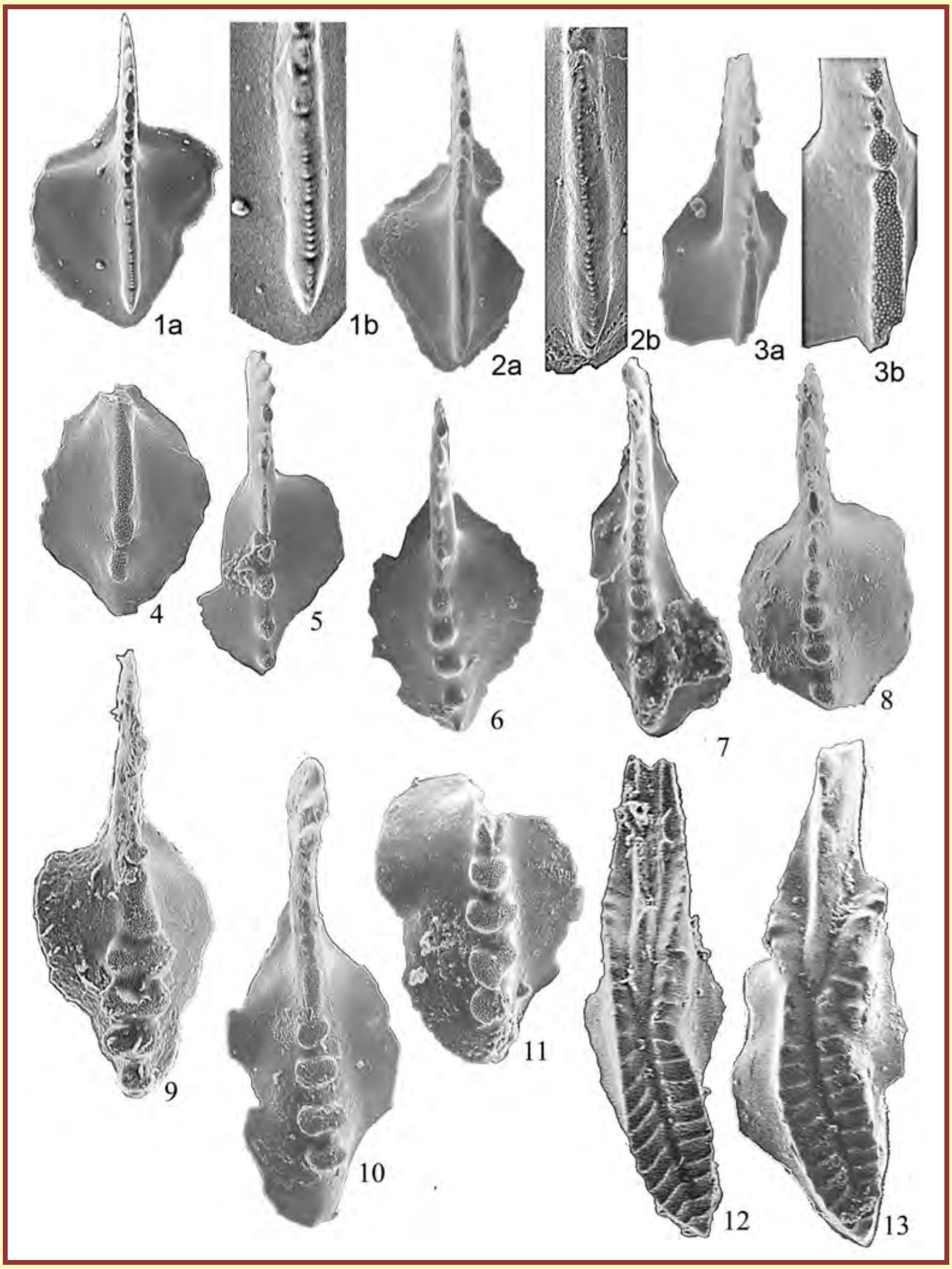


Plate 4.2. Lower Sakmarian conodonts (x 100)
Figs. 1, 2. Diplognathodus stevensi Clark et Carr, 1982: 1 – K36-18 (1b –fragment of the form shown in 1a, x 2); 2 – K36-17 (2b –fragment of the form shown in 2a, x 2); Kondurovsky section, bed 18; lower Sakmarian, merrill zone i. Figs. 3, 4. Sweetognathus expansus (Perlmutter), 1975 transitional form from Sw. expansus to Sw. merrilli Kozur, 1975: 3 – K36-15 (3b - fragment shown in 3a, x 2), development of carinal nodu in the anterior part of the carina; 4 – K16-4, development of carinal nodes in the posterior part of the carina; Kondurovsky section, bed 16; lower Sakmarian, bissilli zone.
Figs. 5-7. Sweetognathus merrilli Kozur, 1975: 5 – K18-2; 6 – K18-3; Kondurovsky section, bed 18; lower Sakmarian, merrilli zone; 7 – U25-3; Usolka section, bed 26/2; lower part of Sakmarian, merrilli zone. Figs. 8-11. Sweetognathus binodosus Chernykh: 8 – U32A-3; 9 – U32A-7; 10 – U32A-5; 11 – U32A-4; Usolka section, bed 26/3; lower part of Sakmarian, binodosus zone. Figs. 12, 13. Streptognathodus aff. lanceatus Chernykh: 12 – U38-37, forma with a prolonged carina; 13 – U38-41; Usolka section, bed 27/2; lower part of Sakmarian, binodosus zone

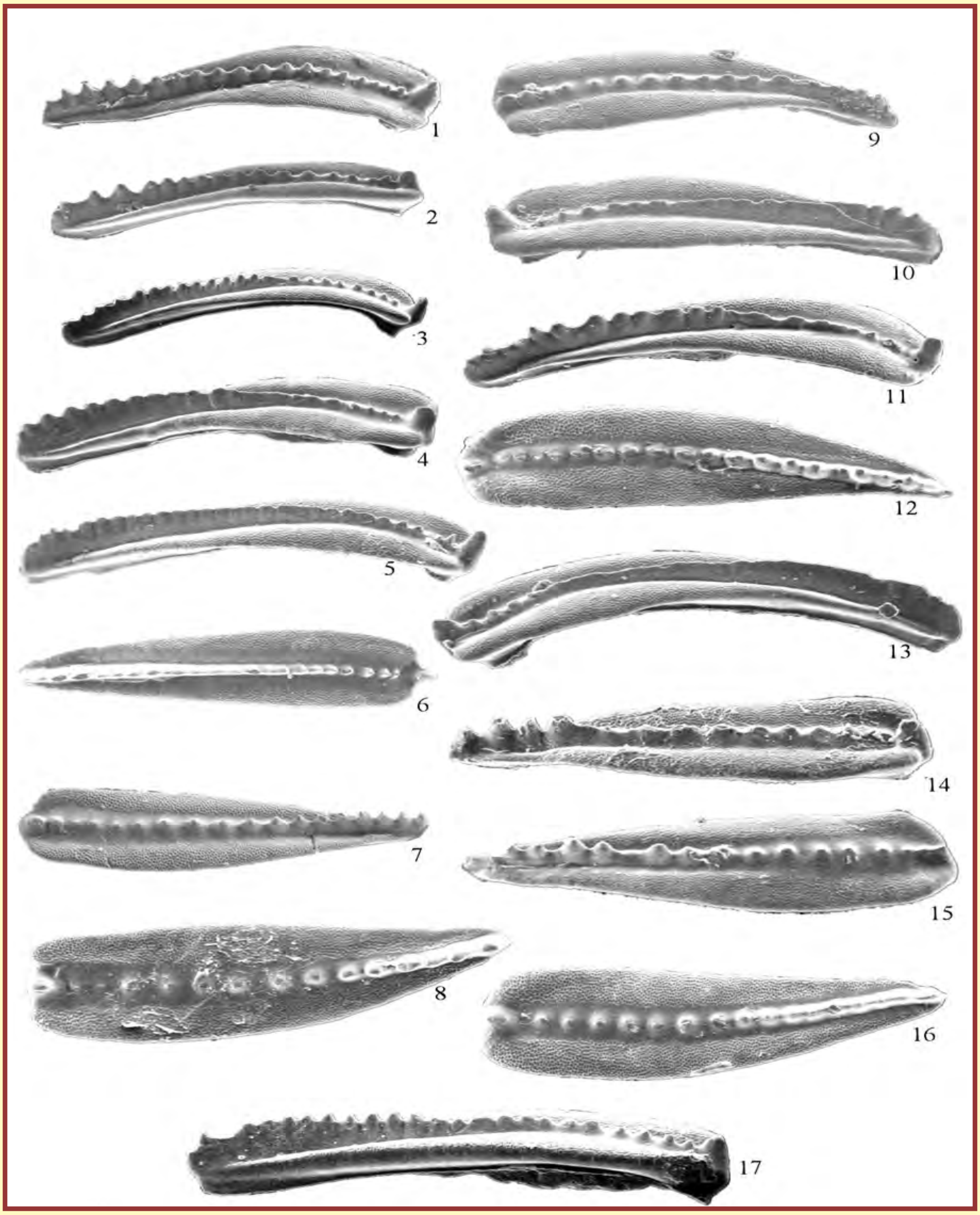


Plate 4.3. Upper Asselian-Lower Sakmarian Mesogondolella (x 50)
Figs. 1, 2, 9, 10. Mesogondolella arcuata Chernykh, 2005: 1 – holotype U34-45; 2 – U34-47; Usolka section, bed 25/2; 9 – K35-2; 10 – K35-1; Kondurovsky section, bed 10 (Kurmainian breccias); Upper Asselian, pseudostriata zone. Figs. 3-6, 11, 13. Mesogondolella uralensis (Chernykh), 1990: 3 – U38-9; 4 – U38-6; 5 – u38-3; 6 – U38-2, upper view; 13 – U38-5; Usolka section, bed 26/1; 11 – K35-14; Kondurovsky section, bed 13; lower part of Sakmarian, uralensis zone. Figs. 7, 8, 12, 14-16. Mesogondolella monstra Chernykh, 2005: 7 – K36-8; Kondurovsky section, bed 16; 8 – U32-14; 12 – U32-11; 14 – holotype U32-19; 15 – U-32-18; 16 – U32-15; Usolka section, bed 26/3; lower part of Sakmarian, binodosus zone. Fig. 17. Mesogondolella aff. uralensis Chernykh, U38-8, transitional from M. uralensis to M. monstra; Usolka section, bed 26/1; lower part of Sakmarian, uralensis zone

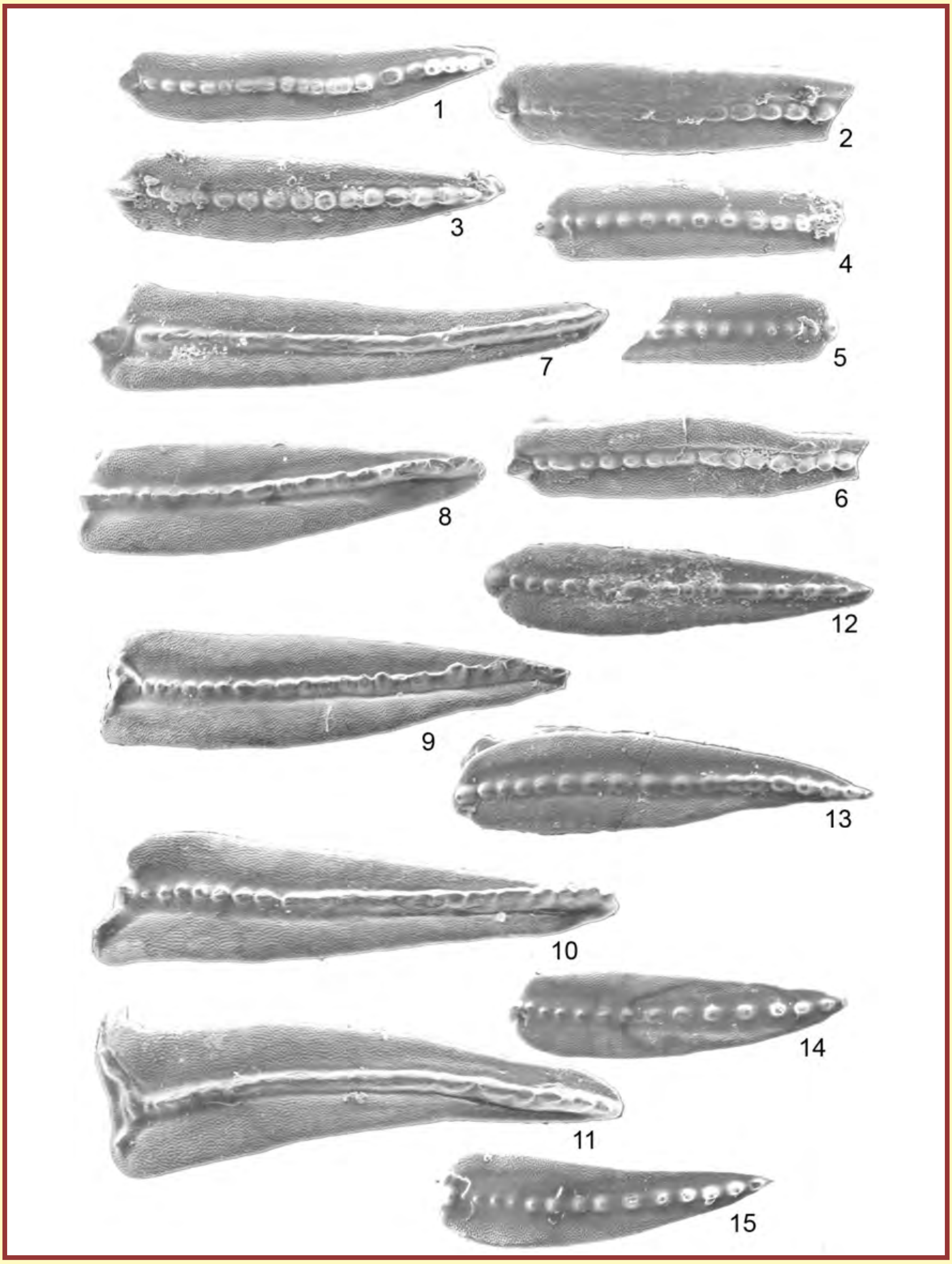


Plate 4.4. Upper Sakmarian and Lower Artinskian Mesogondolella (x 50)
Figs. 1-6. Mesogondolella manifesta Chernykh, 2005: 1 – holotype U38-43; 2 – U38-44; 3 – U38-47; 4 – U38-45; 5 – U38-32; 6 – U38-46; Usolka section, bed 27/1; lower part of Sakmarian, zone merrilli. Figs. 7-11. Mesogondolella camilla Chernykh, 2005: 7 – holotype U37-20; 8 – U37-35; 9 – U37-33; 10 – U38-16; 11 – U38-19; Usolka section, bed 25/5; lower part of Sakmarian, uralensis zone. Figs. 12, 13. Mesogondolella bisselli (Clark et Behnken), 1971: 12 – U40-15; Dal'ny Tulkas, bed 4a; 13 – U40-11; Dal'ny Tulkas, bed 3; upper part of Sakmarian, anceps zone. Figs. 14, 15. Mesogondolella laevigata Chernykh, 2005: 14 – holotype DT40-25; 15 – U40-26; Dal'ny Tulkas section, bed 10; Artinskian, clarki zone

USOLKA SECTION. UPPER CARBONIFEROUS (GZHELIAN) DEPOSITS

The thickness of the Gzhelian Stage at the Usolka River (Fig. 4.1) is more than 25 metres. It is composed of alternating dark thin mudstones, argillaceous marl, marl, argillaceous limestone, bioclastic-detrital, clastic dolomite and chert, of variable thickness. In the mudstones, brown laminated marl and argillaceous marl, phosphorite nodules up to 10-12 cm (along the long axis) are often present in a number of layers. Here there are numerous conodonts, radiolarians, the remains of fish, rare bivalves, cephalopods, inarticulate brachiopods, ostracods, trilobites and abundant fine plant debris. The sediment contains traces of bioturbation. There are bands of yellow clay, which we interpret as modified interlayers of tuffaceous material, typically with small nests of limonitised pyrite.

Less frequently in the section are found marl and grey, greenish-grey argillaceous marl, indistinctly bedded, with rare remains of fish, radiolarians, plant debris, phosphorite and sulphide, along with brachiopods, bivalves, ostracods, fusulinids, bryozoans and gastropods.

Limestones and argillaceous limestones are often more or less silicified and dolomitised, and contain scattered grains of silicates. Most frequently encountered are micritic varieties, slightly less commonly bioclastic and lithoclastic limestones. There are fewer fossils than in the marl, and these are represented by conodonts, radiolarians, spicules of sponges, brachiopods, gastropods, ostracods, crinoids, nautilids, and bivalves.

The bulk of the phosphorite nodules are concentrated in the Gzhelian part of the section, with limited distribution observed in the sediments of the Kasimovian and Asselian stages.

The section is described from the top of the Carboniferous Kasimovian Stage, to more clearly show changes in the conodont assemblage towards the base of the Gzhelian Stage. Several publications (Chuvashov et al., 1983, 1990, 1991, and others) give detailed descriptions of the section, and here we confine ourselves to a brief lithological description of beds with precise sampling levels and a complete list of the conodonts found in them. The distribution of informative samples in the section, the lithology of the rocks, and the bed thicknesses are shown in Fig. 5.1.

Sample numbers (in brackets) indicate the distance at this point from the base of the section, in metres.

Bed 4. Alternation of dark grey, fine-grained argillaceous dolomites, in places becoming dolomitised marl and shale, with nodules of dark grey and black phosphorite. The bed in the upper part is composed of dark grey argillaceous irregularly dolomitised limestone. In the middle part contains a lens (0.7 m) of detrital limestone with a few corals and foraminifers. Conodont samples are taken from this lens at two levels: sample 4/1 is from 0.7 m and sample 4/2 0.9 m above the base of the bed. This 20 cm interval contains the boundary between the Kasimovian (level 4/1) and the Gzhelian (starting at level 4/2) stages.

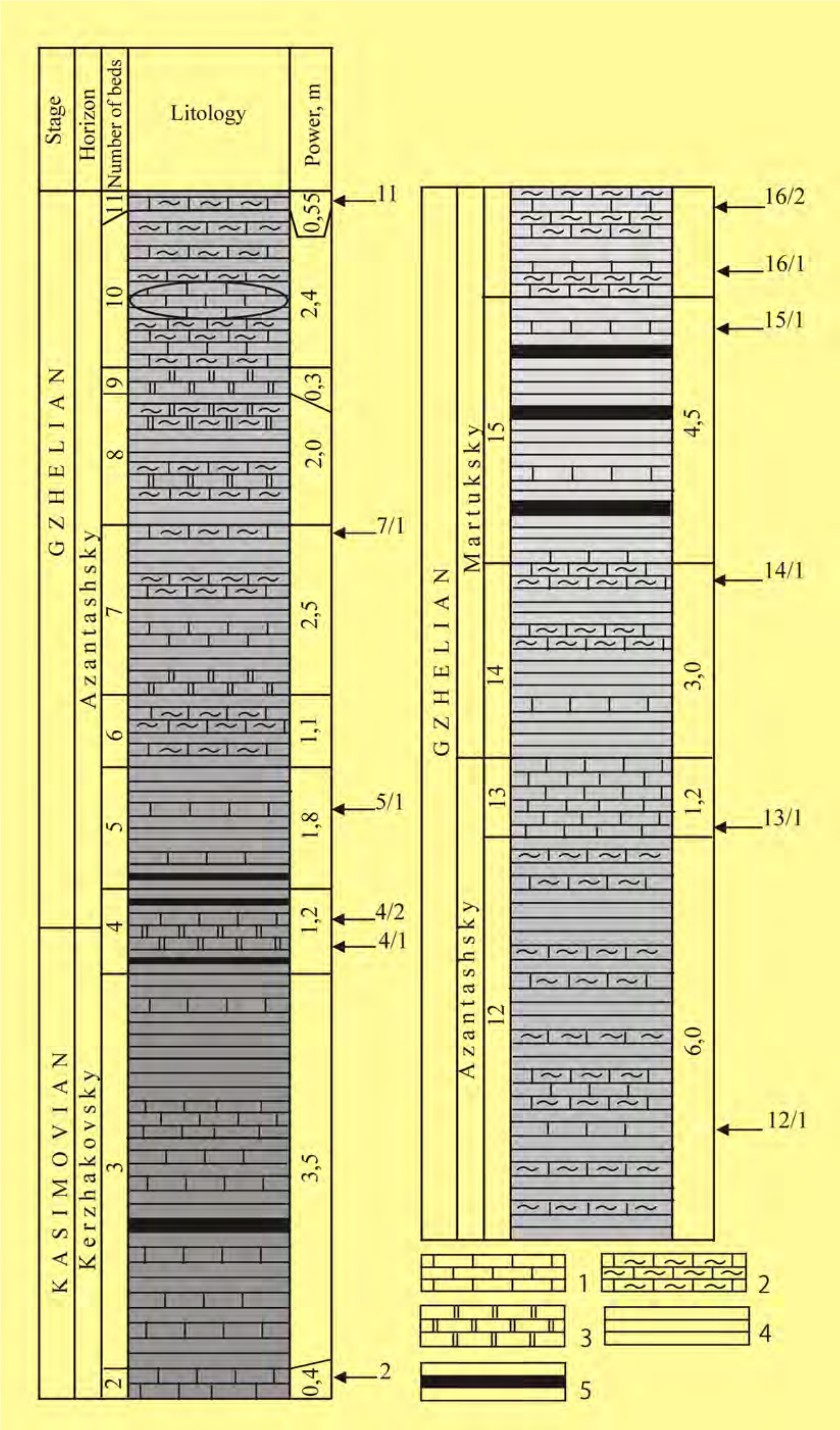


Fig. 5.1. Usolka section

Sample 4/1 (4.7). Includes the following species of conodonts: *Streptognathodus crassus* Chern, *S. dolioliformis* Chern., *S. firmus* Kozits kaya (dominant morphotype) *S. gracilis* Stauffer et Plummer, *S. pawhuskaensis* (Harris et Hollingsworth), *S. pictus* Chern., *S. praenuntius* Chern., *S. zethus* Chern. et Reshetkova, *Idiognathodus excedus* n. sp., *I. magnificus* Stauffer et Plummer, *I. toretzianus* Kozitskaya, *I. undatus* Chern.

Sample 4/2 (4,9): *Streptognathodus auritus* Chern., *S. crassus* Chern., S. *dolioliformis* Chern., *S. elegantulus* Stauffer et Plummer, *S. firmus* Koz., *S. gracilis* Stauffer et Plummer, *S. gravis* Chern., *S. luganicus* Koz., *S. pawhuskaensis* (Harris et Hollingsworth), *S. pictus* Chern., *S. simulator* Ellison (dominant morphotype), *S. sinistrum* Chern., *Idiognathodus excedus* Chern., *I.* cf. *magnificus* Stauffer et Plummer, *I. undatus* Chern.

Bed 5. Alternation of fine-grained argillaceous dolomite with mudstone and chert layers in the lower third of the layer. Dolomites contain lenses and nests of non-dolomitised dark grey clastic limestone, from which was taken an informative sample of conodonts 5/1.

Sample 5/1 (6, 4): *Streptognathodus auritus* Chern., *S. firmus* Kozitskaya, *S. gravis* Chern, *S. luganicus* Koz., *S.* aff. *luganicus* Koz., *S. pawhuskaensis* (Harris et Hollingsworth), *S. pictus* Chern., *S. simulator* Ellison, *S. sinistrum* Chern., *Idiognathodus lobulatus* Koz., *I. toretzianus* Kozitskaya, *Gondolella sublanceolata* Gunnell.

Bed 6. Alternation of thin-plated argillaceous limestones and mudstones with phosphoritic nodules.

Bed 7. At the base of the bed is composed of dark grey thinly-plated dolomites, higher dark grey, almost black, flaky mudstone with oval black phosphorite nodules, overlain in the middle of the bed by grey thickly-plated micritic limestone. In the upper part of the layer are alternating mudstones, argillaceous limestone and marl. Sample 7/1 was collected from micritic limestone.

Sample 7/1 (11.0): *Streptognathodus auritus* Chern., *S. elegantulus* Stauffer et Plummer, *S. firmus* Kozitskaya, *S. luganicus* Koz., *S. pawhuskaensis* (Harris et Hollingsworth), *S. pictus* Chern., *S.* aff. *simulator* Ellison, *Idiognathodus excedus* Chern.

Bed 8. Dolomitic argillaceous marl with small brachiopods on bedding planes.

Bed 9. Dolomite brownish dark grey, slightly bituminous.

Bed 10. Argillite dark grey foliose with interbedded dolomitic marl with small black phosphorite nodules. Lens of dolomitic limestone in the middle of the bed.

Bed 11. Limestone lens with a maximum thickness of 0.5 metres, lying among marl. Sample taken at the top of the lens.

Sample 11 (16.0 m): *Streptognathodus gracilis* Stauffer et Plummer, *S. pawhuskaensis* (Harris et Hollingsworth), S. *aff. simulator* Ellison, *Idiognathodus excedus* Chern., I. tersus Ellison, *Gondolella magna* Stauffer et Plummer.

Bed12. The dark grey thin-bedded mudstones with occasional thin interlayers of dolomitic marl and dolomitic limestone. In the 1.5 metres above the base of layer is the horizon of carbonate nodules (from small to 0.4 metres in diameter). The sample for conodonts was taken from the nodules and the dolomitic marl that substitutes them.

Sample 12 (18.2 m): *Streptognathodus elegantulus* Stauffer et Plummer, *S. gracilis* Stauffer et Plummer, *S. oppletus* Ellison, *S. pawhuskaensis* (Harris et Hollingsworth), *S.* aff. *simulator* Ellison, *S. stigmatis* Chern., *S. vitali* Chern. (dominant morphotype), *S.* aff. *zethus* Chern. et Reshetkova, *Idiognathodus lobulatus* Koz., *I. tersus* Ellison.

Bed 13. The bed includes a series of blocks composed of brownish-grey fine-grained massive dolomitized limestone clay, lying among greenish-grey marl, with abundant shell debris, fusulinids, crinoids and bryozoans. Conodont samples were taken from the top of the bed, represented by a light grey calcareous marl covering a system of blocks.

Sample 13/2 (22.8 m): *Streptognathodus vitali* Chern. (dominant morphotype), *S. postsimulator* Chern., *S. triangularis* Chern., *S. virgilicus* Ritter, *Idiognathodus comprimerus* Chern., *I. insolitus* Chern., I. tersus Ellison, *Gondolelloides* sp. A (Henderson et Orchard).

Bed 14. Dark grey and brownish-grey thin-bedded mudstones with thin (3-4 cm) bands of marl, in places dolomitic. Across the bed with an interval of 0.5-1.0 m repeated bands (1-3 cm) of decomposed bright yellow (ochre) marl, sometimes with remnants of denser clay limestone and marl as large gravel (10 x 12 x 5 cm). Sampled for conodonts at two levels: sample 14/1 is taken 1.2 m above the base layer and sample 14/2 is 1 m higher than the previous.

Sample 14/1 (24.0 m): *Streptognathodus elongatus* Gunnell, *S. simplex* Gunnell.

Sample 14/2 (25.0 m): *Streptognathodus bellus* Chern. et Ritter, *S. elongatus* Gunnell, *S.* aff. *fissus* Chern., *S. simplex* Gunnell (dominant morphotype), *S. tenuialveus* Chern et Ritter, *Sweetognathusus expansus* (Perlmutter), *Gondolella kazakhstanica* Akhmetshina, *Gondolelloides canadensis* Henderson et Orchard, *Solkagnathus velivolus* Chern., *Caenodontus movschovitschi* Kozur et Mostler.

Bed 15. Brownish dark grey platy mudstones with numerous oval phosphorite nodules. Among mudstone with an interval of 0.5-1.0 metres lie interbeds of greenish-grey and dark grey dolomitic marl and clay limestone. Conodonts were sampled from the lower part of the bed.

Sample 15/1 (26.0 m): *Streptognathodus bellus* Chern. et Ritter, *S. fissus* Chern., S. *flexuosus* Chern. et Ritter, *S. insignitus* Akhmet., *S. limulus* Chern., *S. longilatus* Chern. et Ritter, *S. tenuialveus* Chern. et Ritter, *S. variabilis* Chern.

Bed 16. The bulk of the layer is ash dark grey platy marl interbedded with mudstone and dolomitised limestone. A total of seven interbeds of limestone with thickness from 0.05 to 0.3 metres are present.

Sample 16/1 selected from a 10-centimetre-intercalation of limestone occurring in the basal layer. The sample 16/2 taken from 5-centimetre limestone interlayer, located in 8 cm above the previous sample, and sample16/3 from the following limestone intercalation in 1.0 m above the sample 16/2.

Sample 16/1 (31.0 m): *Streptognathodus acuminatus* Gunnel, *S. bellus* Chern. et Ritter, *S. bonus* Chern., *S. insignitus* Akhmet., *S.* aff. *longilatus* Chern. et Ritter, *S. longus* Chern., *S. aff. nodulinearis* Chern. et Resh., *S. wabaunsensis* Gunnel.

Sample 16/2 (31.1 m): *Streptognathodus acuminatus* Gunnel, *S. elongatus* Gunnell, *S. aff. rectangularis* Chern. et Ritter, *S. wabaunsensis* Gunnell.

Sample 16/3 (32.0 m): *Streptognathodus acuminatus* Gunnel, *S. bonus* Chern., *S. aff. bonus* Chern., *S. bipartitus* Chern., *S. russoflangulatus* Chern., *S. invaginatus* Reshetkova et Chern., *S. isolatus* Chern., Ritter et Wardlaw, *S. nodulinearis* Reshetkova et Chern., *S. wabaunsensis* Gunnell, *Diplognathodus sp.*

2. 2. Comments to the stratigraphic distribution of conodonts in the Usolka section.

The Upper Kasimovian-lower Gzhelian interval in the Usolka section presents a uniform series of rock lithology, and the boundary between the stages is fixed only based on the change in the composition of the conodont assemblages encountered in samples of 4/1 and 4/2, sampled at a distance of 20 cm. Almost all taxa transferred from the Upper Kasimovian to the first sample from the Gzhelian part of the section . The exception is actually Kasimovian forms such as *Streptognathodus praenuntius* Chern. The species *Idiognathodus toretzianus* Kozitskaya was found in sample 4/1 and not in the Gzhelian sample 4/2, but was found in bed 5.

1. The biostratigraphic boundary between the Kasimovian and Gzhelian stages in the section is determined based on the first appearance of *Streptognathodus simulator* Ellison, not known in older deposits, underlying the Usolka section. Species of the *simulator* group, e.g., *Streptognathodus auritus* Chern., *S. gravis* Chern., *S. luganicus* Kozitskaya, *S. sinistrum* Chern. appear at the same level. The abundance in the early Gzhelian assemblage of *Streptognatodus* with an eccentric groove on the upper surface of the platform gives it a distinctive, easily recognizable shape.

Beds 5 and 7 contain a similar conodont assemblage, including further streptognatodontids with an eccentric median furrow: *Streptognathodus simulator* Ellison (and similar forms in bed 7), *S. luganicus* Kozitskaya, *S. auritus* Chern., *S. sinistrum* Chern. (Bed 5) and *S. excedus* Chern. There are a number of other species in common with the conodonts from 4/1 sample. All this allows us to consider this part of the section, up to and including bed 11, as a unified biostratigraphic unit and to recognize it as the *simulator* stratozone.

The conodont assemblage from Bed 12 is unusual in that it contains, together with the ancient elements (the name of which have been given in open nomenclature, as they still differ considerably from the typical forms of these species), new forms, the dominant among all present.

This is primarily *Streptognathodus vitali* Chern., which is characteristic in appearance and widely held not only in the Eurasian Gzhelian sections, but in coeval deposits of North America and China. Secondly, we note a slighly belated occurrence in the Urals of *Idiognathodus tersus* Ellison, in comparison with the Moscow region, where this species is recorded with the first *Streptognathodus simulator* Ellison (Alekseev, Goreva, 2007). However, coeval sections in Midcontinent and Texas (USA) with this species, as well as in the Urals, indicate a slightly higher level of the first occurrence of *S. simulator* Ellison (Barrick, Boardman, 1989; Boardman et al., 2006). In the most recent paper, *Idiognathodus tersus* Ellison is included in the conodont assemblage from the Queen Hill Shale (Lecompton) cyclothem, i.e., above Oread (Heebner) tsilotemy, where *Streptognathodus simulator* Ellison occurs. In addition, in the same complex with *Idiognathodus tersus* Ellison American authors noted the presence of *Streptognathodus vitali* Chern.

The conodonts assemblage of Bed 12 suggest that this bed should be assigned to the *vitali* stratozone.

Bed 13 is a large lens of detrital slightly clay limestone. Based on fusulinids found there, it is a high part of the Gzhelian, corresponding, according to B.I. Chuvashov and V.I. Davydov, the *Daixina sokensis* fusulinid zone.

Conodonts obtained from detrital limestone, included species first appeared at this level and not known from older Gzhelian deposits. However, along with them, there are also Early Gzhelian conodonts in the *simulator* zone and species that resemble the typical Kasimovian species *Idiognathodus magnificus* Stauffer et Plummer, *Streptognathodus zethus* Chern. et Reshetkova and others.

The presence in Bed 13 of species of the *tersus* group, such as *Idiognathodus tersus* Ellison, as well as peculiar new morphotypes having features of species of *Idiognathodus* and *Streptognathodus*, is remarkable. Among them *Idiognathodus comprimerus* Chern., *I. insolitus* Chern. In the same bed we found the last members of the simulator group with the eccentrically placed median furrow - *S. postsimulator* Chern. For the first time in the section, the presence of *S*was observed. Bed 13 represents the *virgilicus* stratozone, the lower boundary of which is conventionally placed at the base of Bed 13, and is defined by the first appearance of *S. virgilicus* in the section.

4. Starting from Bed 14, idiognatodontids disappear from the succession. This remarkable event is accompanied by the mass appearance of streptognatodontids with fully developed transversal costae. This is especially true of species such as *Streptognathodus simplex* Gunnell (dominant morphotype) and *S. elongatus* Gunnell.

Streptognathodus tenuialveus Chern. et Ritter and *S. bellus* Chern. et Ritter enter 1 m above. *Gondolelloides canadensis* Henderson et Orchard continues to this level, while a similar morphotype *Solkagnathus velivolus* Chern. enters.

By the appearance in the section, at the sampling level 14/2, the characteristic species *Streptognathodus bellus* Chern. et Ritter fixes the lower boundary of the *Streptognathodus bellus* stratozone. It also includes Bed 15, containing the characteristic species *Streptognathodus variabilis* Chern. and *S. flexuosus* Chern. et Ritter, which are found in all sections of the Gzhelian Stage in the Urals (Nikolsky, Aydaralash etc.).

5. The base of Bed 16 (Sample 16/1, is a limestone 10 cm thick) shows the first appearance in the section of the *wabaunsensis* conodont group: the morphotype *Streptognathodus wabaunsensis* Gunnell, *S. accuminatus* Gunnell, *S. bonus* Chern. and single forms similar to the species of the *S. isolatus* group.

In sample 16/2, from the 5-cm limestone 8 cm higher than the previous sample, *Streptognathodus wabaunsensis* Gunnell became the dominant species.

In general, this (lower) part of the Bed 16, with a thickness of more than 1.2 m, completes the section of Gzhelian Stage and is referred to the *wabaunsensis* stratozone.

The conodont assemblage from sample 16/3, 1 m above sample 16/2, includes numerous Early Asselian forms of the *Streptognathodus isolatus* group, and therefore, the base of layer 16/3 is the upper boundary of the distribution Gzhelian Stage deposits in section Usolka.

The total thickness of the Gzhelian Stage deposits in section is about 25 metres.

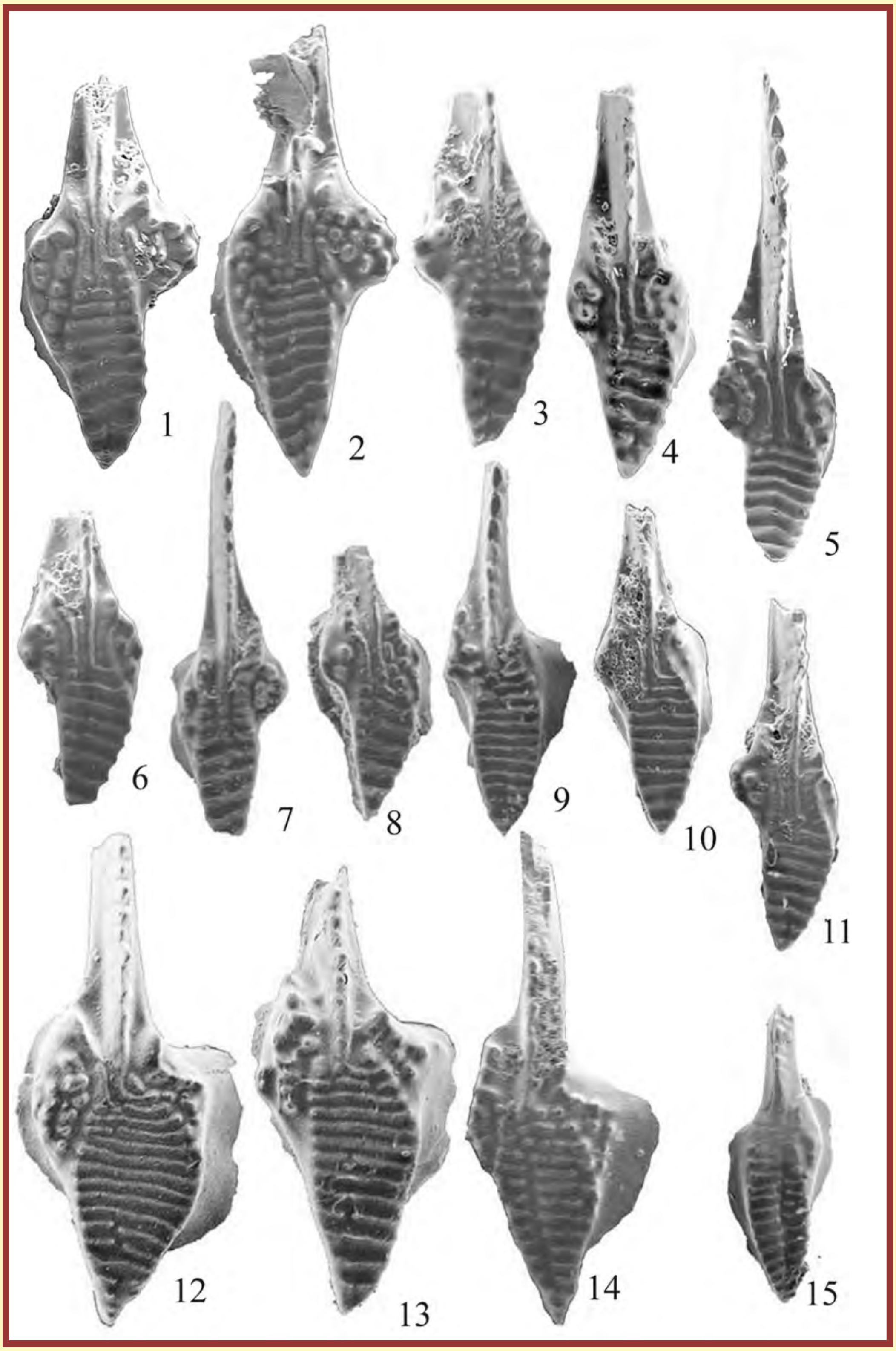


Plate I

Fig. 1-8. Idiognathodus magnificus Stauffer et Plummer: 1 – 6 – bed 4/1, Upper Carboniferous, upper part of Kasimovian, zone firmus; 7 – 8 – bed 4/2, Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 9-11. Idiognathodus excedus Chern.: 9 – bed 4/2, Upper Carboniferous, lower part of Gzhelian, zone simulator; 10 – 11 – bed 4/1, Upper Carboniferous, upper part of Kasimovian, zone firmus. Fig. 12-14. Idiognathodus trianguliferus Chern.: 12 – 13 – bed 4/2, Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 15. Streptognathodus aff. simulator Ellison (x50): bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator

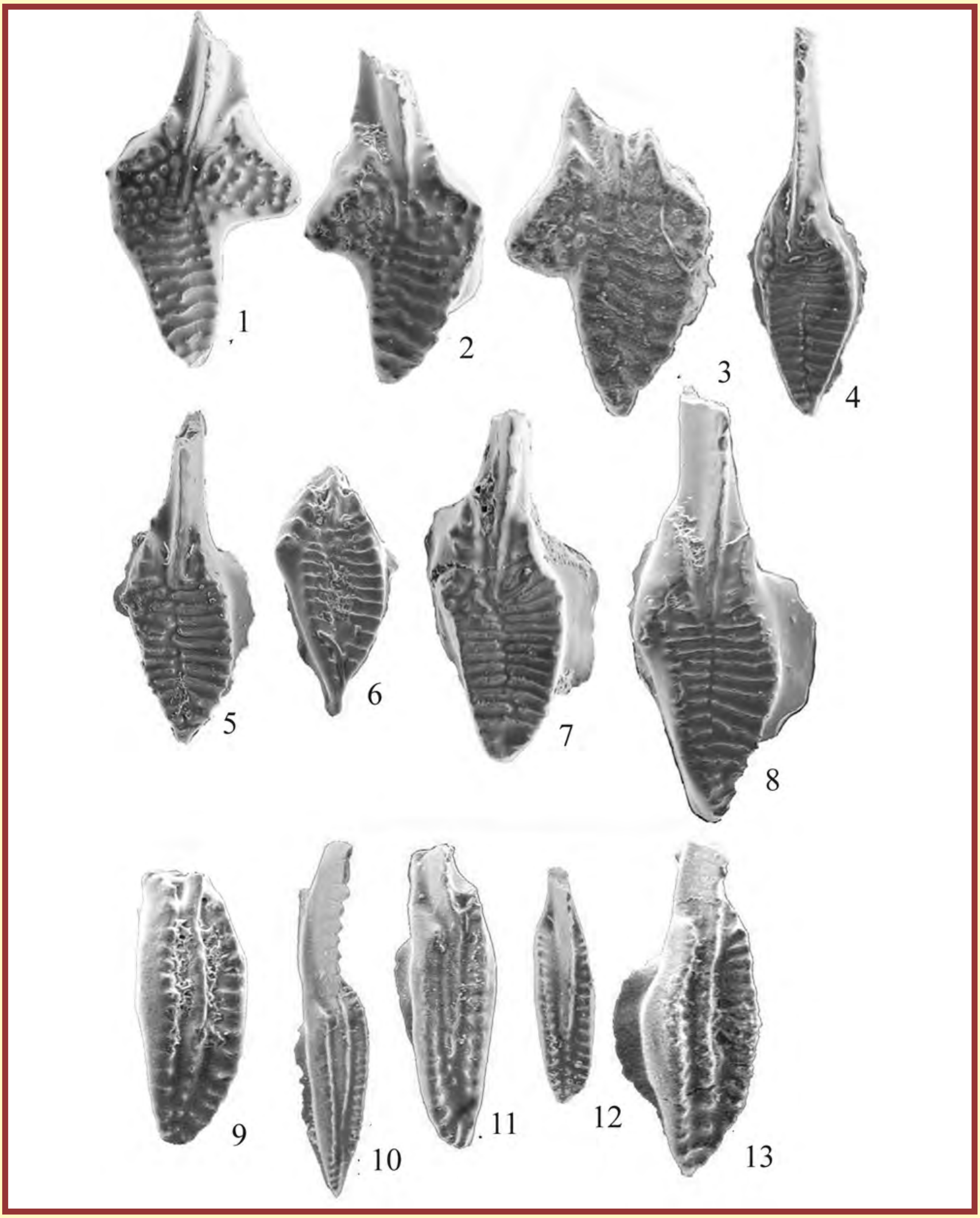


Plate II

Fig. 1-3. Idiognathodus undatus Chern. (x45): 1 – 2 – bed 4/1; Upper Carboniferous, upper part of Kasimovian, zone firmus; 3 – bed 4/2, Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 4-8. Streptognathodus praenuntius Chern. (x50): 4 – 8 – bed 4/1; Upper Carboniferous, upper part of Kasimovian, zone firmus. Fig. 9-13. Streptognathodus firmus Kozitskaya (x60): 9 – bed 4/1, Upper Carboniferous, upper part of Kasimovian, zone firmus; 10 – 13 – bed 4/2, Upper Carboniferous, lower part of Gzhelian, zone simulator

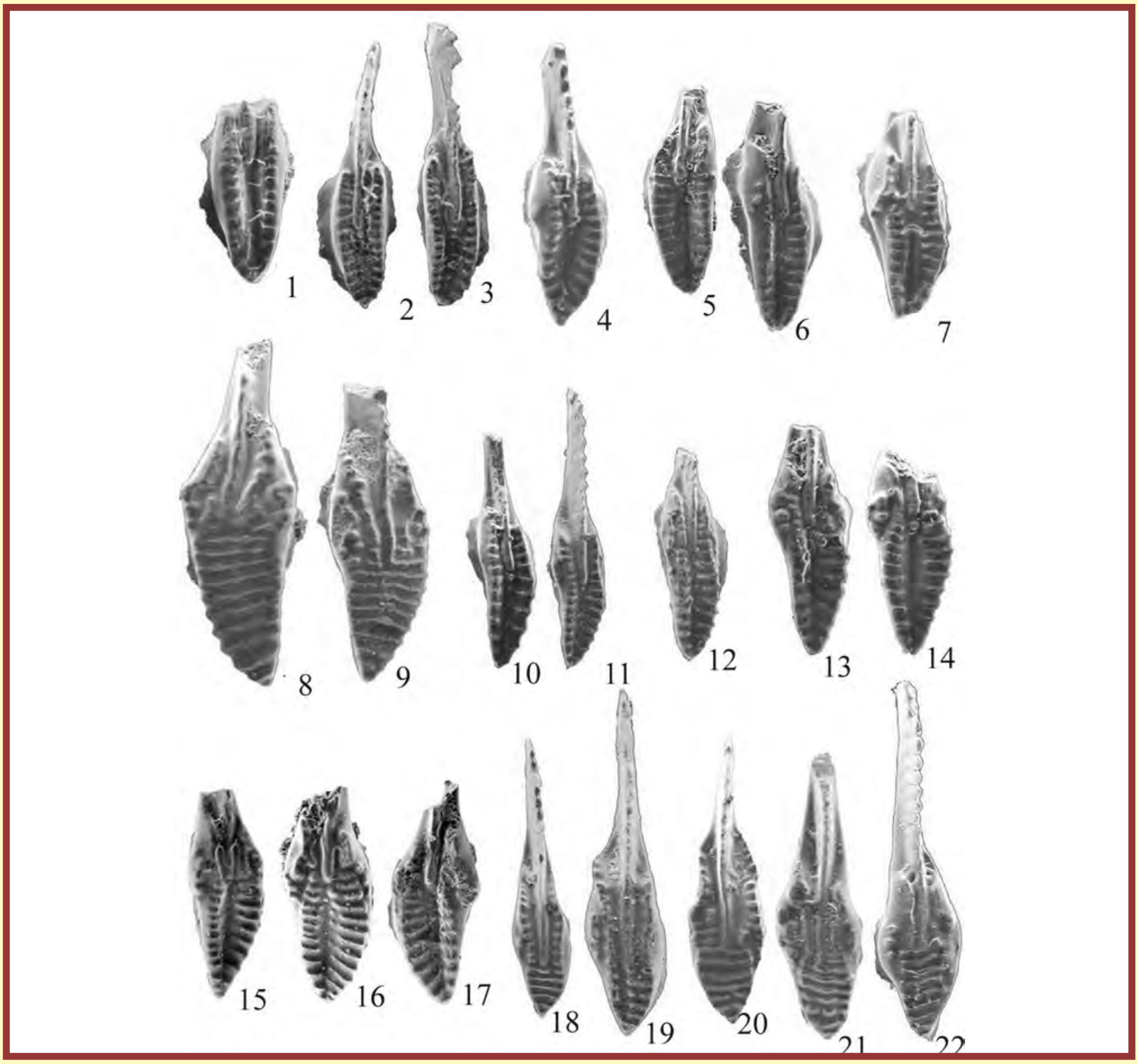


Plate III

Fig. 1-3. Streptognathodus pawhuskaensis (Harris et Hollingsworth): 1 – bed 4/1; Upper Carboniferous, upper part of Kasimovian, zone firmus; 2 – 3, bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 4-7. Streptognathodus crassus n. sp.: 4 – 6 – bed 4/1; Upper Carboniferous, upper part of Kasimovian, zone firmus; 7 – bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 8-9. Idiognathodus toretzianus Kozitskaya: 8 – bed 4/1; Upper Carboniferous, upper part of Kasimovian, zone firmus; 9 – bed 5/1; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 10, 11. (x50). Streptognathodus gracilis Stauffer et Plummer: 10 – bed 4/1; Upper Carboniferous, upper part of Kasimovian, zone firmus; 11 – bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator.
Fig. 12 (x50). Streptognathodus corrugatus Gunnell, bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 13-17. (x50). Streptognathodus zethus Chern. et Reshetkova: bed 4/1; Upper Carboniferous, upper part of Kasimovian, zone firmus. Fig. 18-20. Streptognathodus pictus Chernykh: bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator.
Fig. 21-22. Streptognathodus dolioliformis Chernykh: bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator

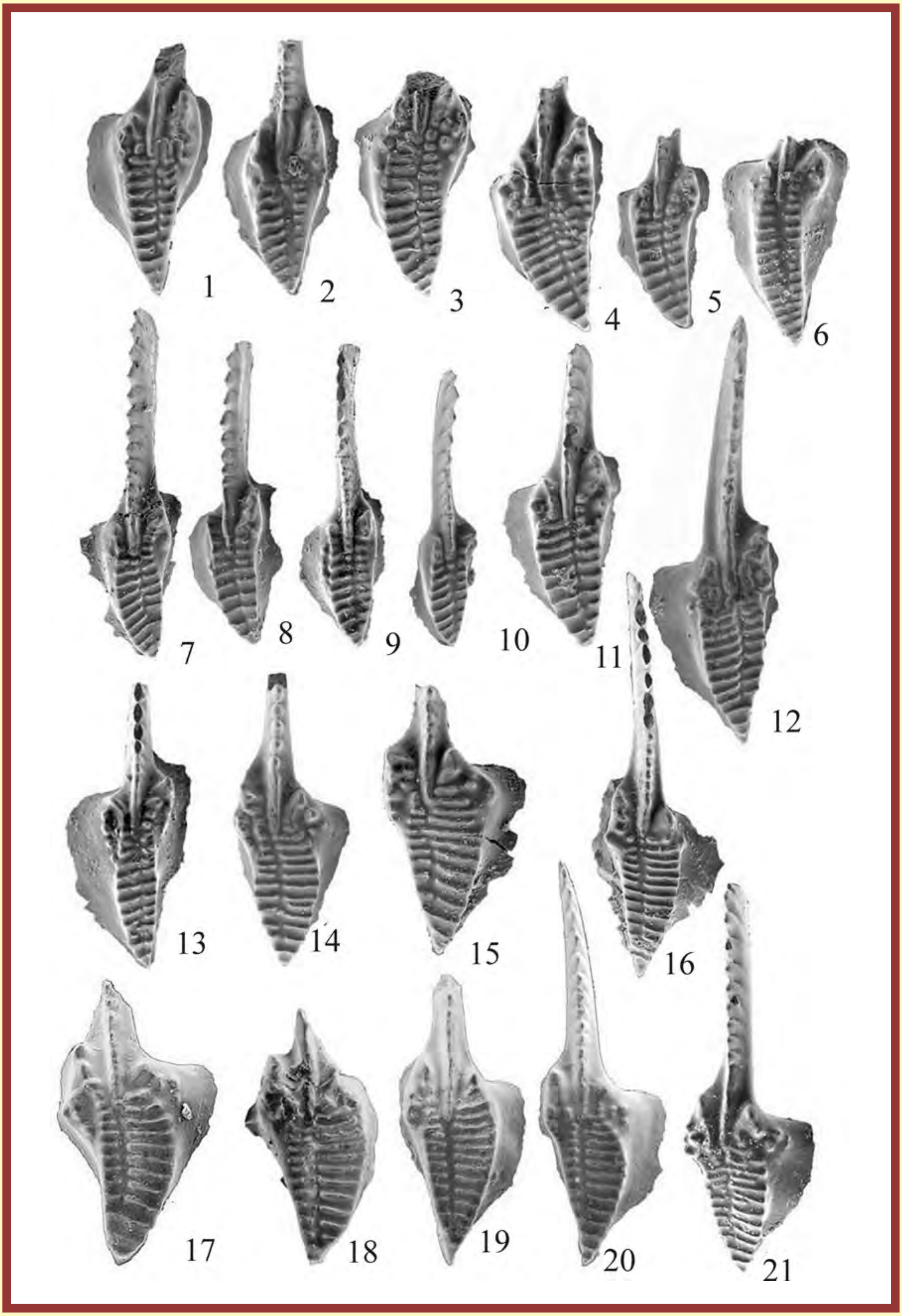


Plate IV

Fig. 1-16, 21. (x50). Streptognathodus simulator Ellison: bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 17-20. Streptognathodus aff. auritus Chernykh: bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator

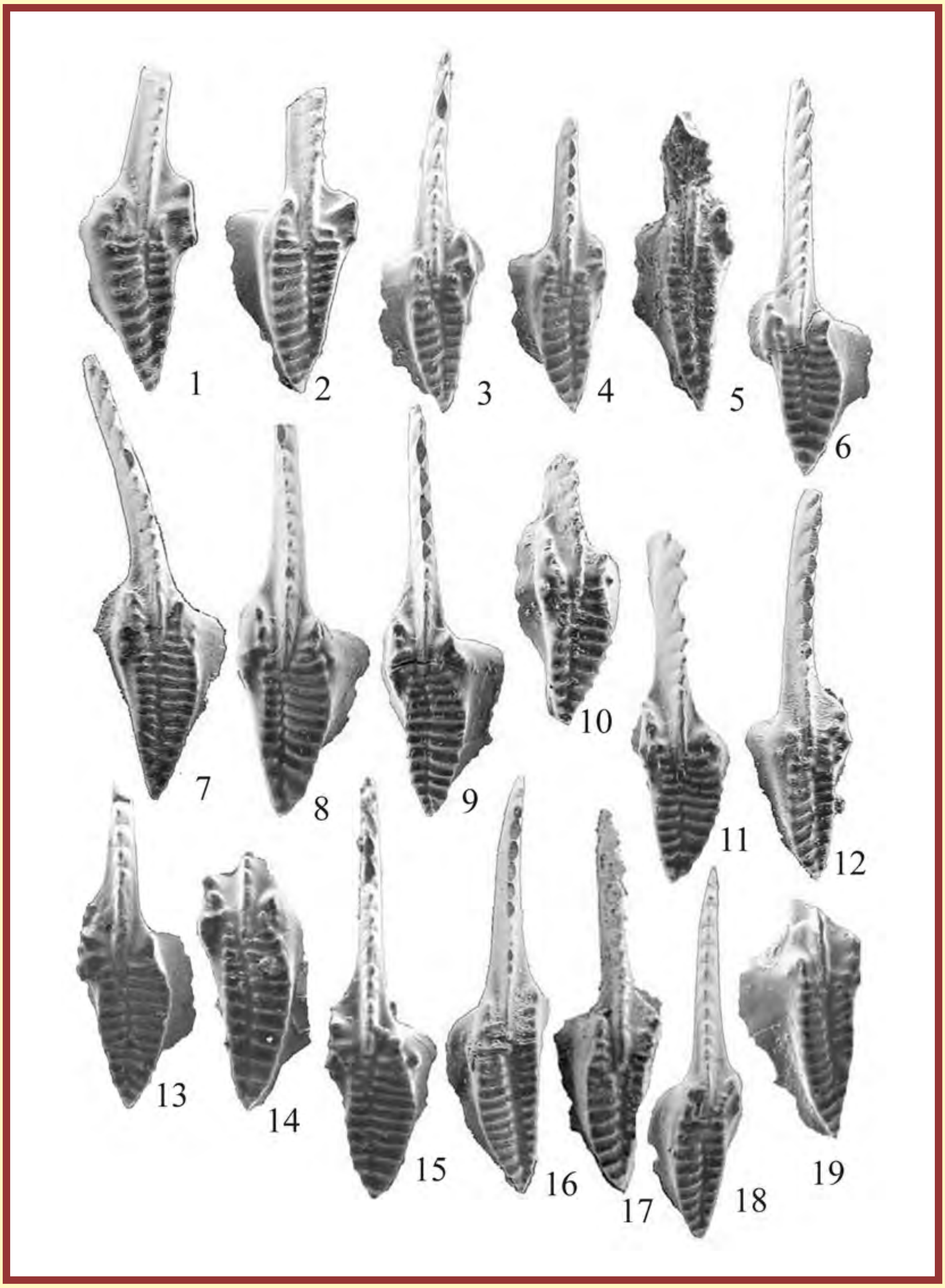


Plate V

Fig. 1-5. Streptognathodus sinistrum Chernykh: 1 – 3 – bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator; 4 – 5 – bed 5/1; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 6-10. Streptognathodus auritus Chernykh: 6 – 9 – bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator; 10 – bed 5/1; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 11-12. Streptognathodus gravis Chernykh: 11 – bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator; 12 – bed 5/1; Upper Carboniferous, lower part of Gzhelian, zone simulator. Fig. 13-15. Streptognathodus aff. gravis n. sp.: bed 13/2; Upper Carboniferous, Gzhelian Stage, zone simulator. Fig. 16-19. Streptognathodus luganicus Kozitskaya: 16 – bed 7/2; 17 – 18 – bed 5/1; 19 – bed 4/2; Upper Carboniferous, lower part of Gzhelian, zone simulator

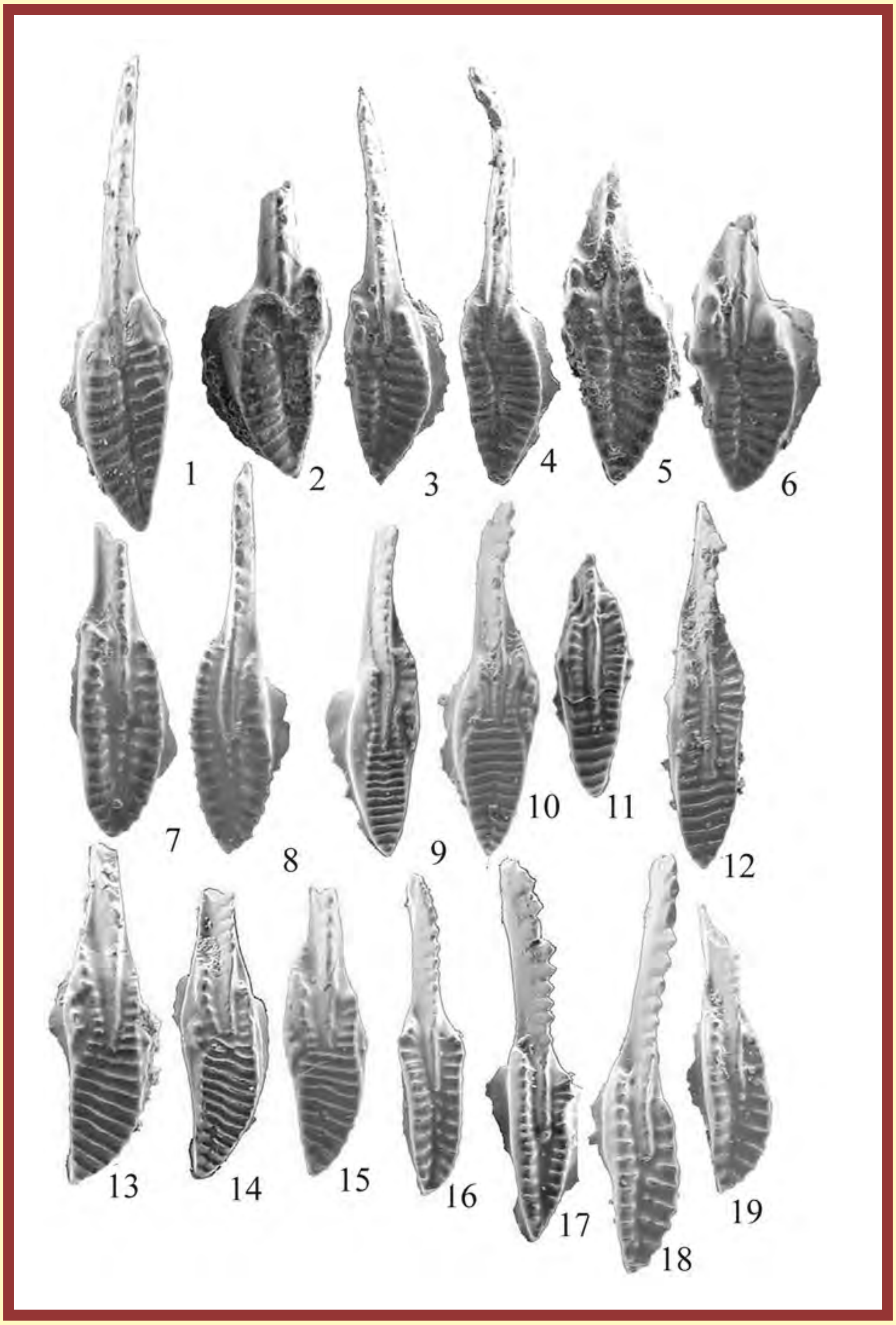


Plate VI

Fig. 1-6. Streptognathodus postsimulator n. sp.: 1 – bed 12; Upper Carboniferous, Gzhelian Stage, zone vitali; 2 – 6 – bed 13/2; Upper Carboniferous, Gzhelian Stage, zone virgilicus. Fig. 7-8. Streptognathodus vitali Chernykh: bed 13; Upper Carboniferous, Gzhelian Stage, zone virgilicus. Fig. 9-10. Idiognathodus comprimerus Chernykh: bed 13; Upper Carboniferous, Gzhelian Stage, zone virgilicus. Fig. 11-12. Idiognathodus tersus Ellison: bed 13; Upper Carboniferous, Gzhelian Stage, zone virgilicus. Fig. 13-15 (x 60). Idiognathodus insolitus Chernykh: bed 13; Upper Carboniferous, Gzhelian Stage, zone virgilicus. Fig. 16-17. Streptognathodus triangularis Chernykh: bed 13/2; Upper Carboniferous, Gzhelian Stage, zone virgilicus. Fig. 18-19. Streptognathodus virgilicus Ritter: bed 13/2; Upper Carboniferous, Gzhelian Stage, zone virgilicus

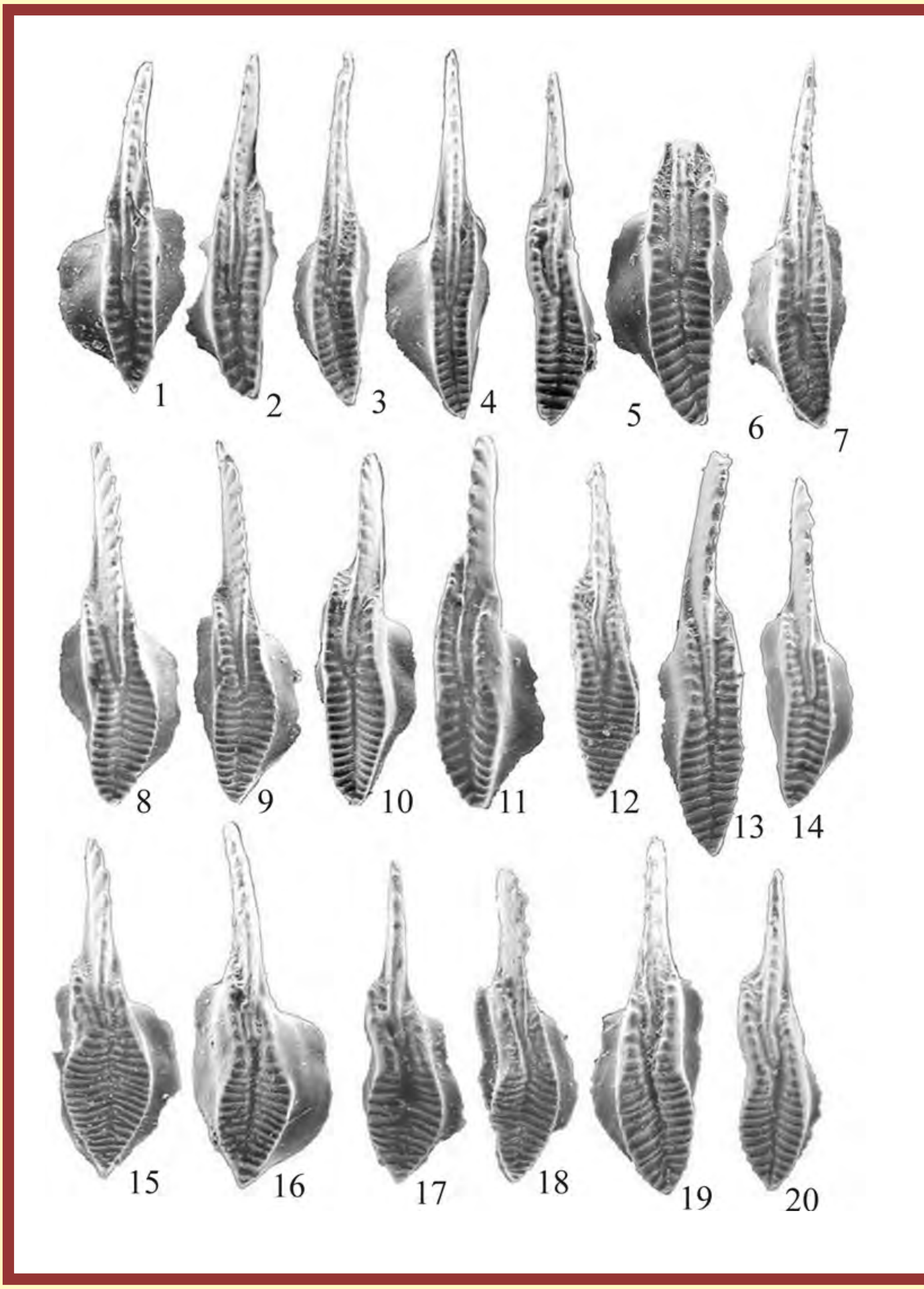


Plate VII

Fig. 1-4. Streptognathodus simplex Gunnell: bed 14/1; Upper Carboniferous, Gzhelian Stage, zone simplex. Fig. 5. Streptognathodus limulus Chernykh: bed 15/1; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 6-7. Streptognathodus tenuialveus Chernykh et Ritter: bed 14/2; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 8-11. Streptognathodus bellus Chernykh et Ritter: bed 14/2; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 12. Streptognathodus longus Chernykh: bed 15/1; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 13-14. Streptognathodus fissus Chernykh: bed 15/1; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 15. Streptognathodus aff. bellusChernykh et Ritter: bed 16/1; Upper Carboniferous, Gzhelian Stage, zone simplex; Fig. 16-20. Streptognathodus wabaunsensis Gunnell: bed 16/1; Upper Carboniferous, Gzhelian Stage, zone wabaunsensis

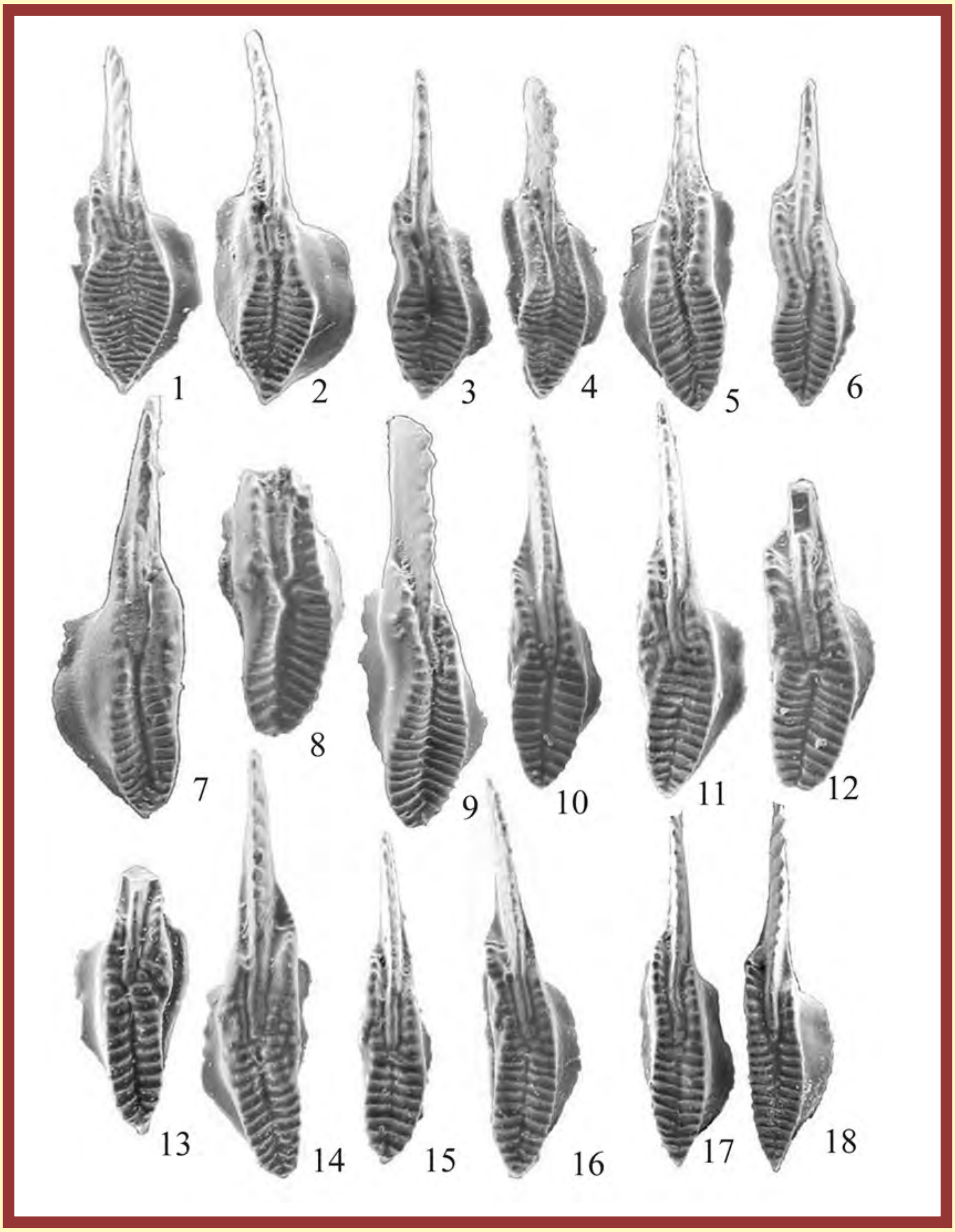


Plate VIII

Fig. 1-6. Streptognathodus variabilis Chernykh: bed 15/1; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 7-8. Streptognathodus ultimus Chernykh: bed 15/1; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 9. Streptognathodus aff. bellus Chern. et Ritter, bed 15/1; Upper Carboniferous, Gzhelian Stage, zone bellus. Fig. 10. Streptognathodus aff. bellus Chernykh et Ritter, bed 16/1; Upper Carboniferous, Gzhelian Stage, zone wabaunsensis. Fig. 11-14. Streptognathodus wabaunsensis Gunnell: bed 16/1; Upper Carboniferous, Gzhelian Stage, zone wabaunsensis. Fig. 15-16. Streptognathodus acuminatus Gunnell: bed 16/1; Upper Carboniferous, Gzhelian Stage, zone wabaunsensis. Fig. 17-18. Streptognathodus longus Chernykh: bed 16/1; Upper Carboniferous, Gzhelian Stage, zone wabaunsensis

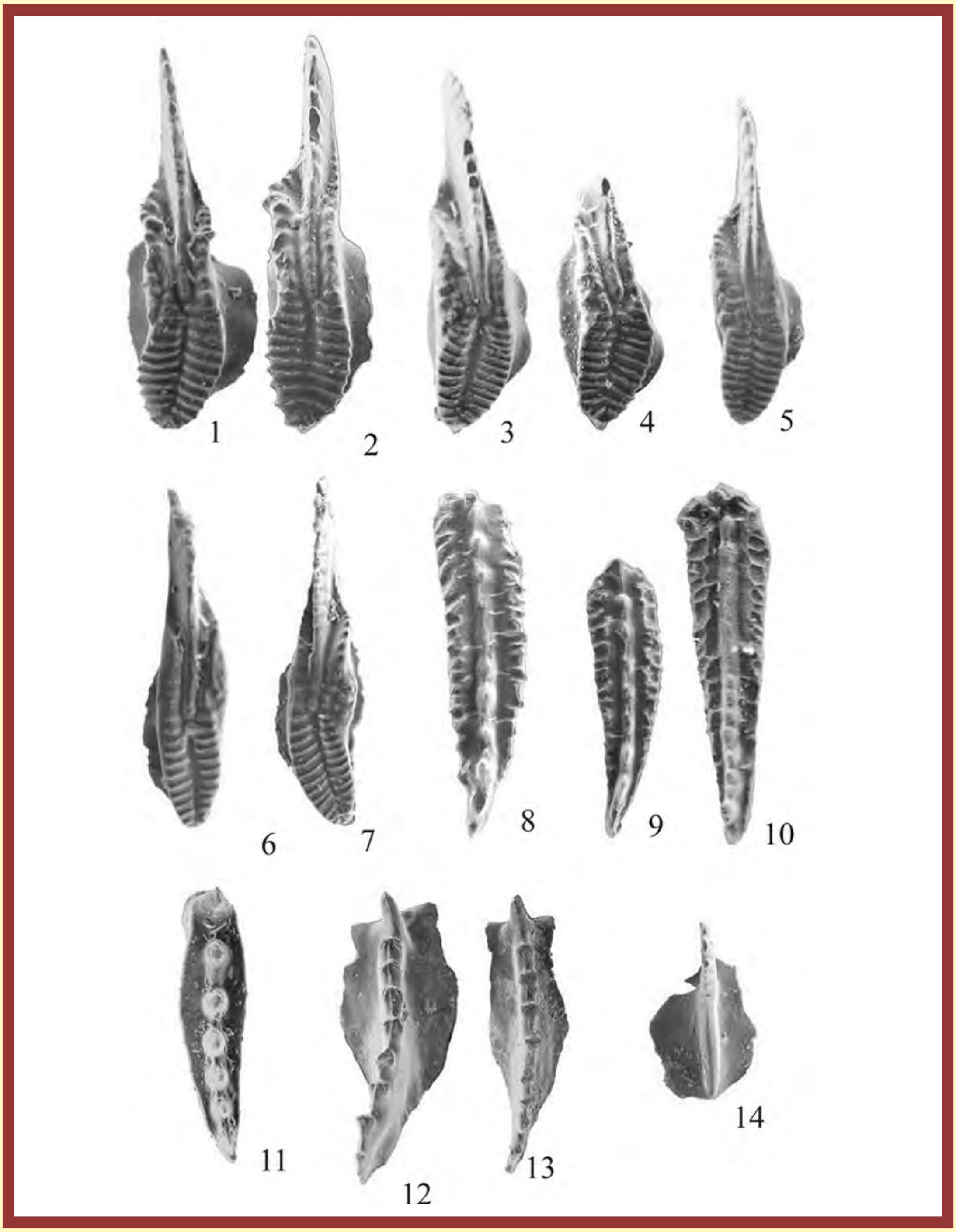


Plate IX

Fig. 1-2. Streptognathodus bonus Chernykh: bed 16/3; Lower Permian, Asselian Stage, zone isolatus. Fig. 3-7. Streptognathodus wabaunsensis Gunnell: bed 16/2; Upper Carboniferous, Gzhelian Stage, zone wabaunsensis. Fig. 8. Gondolella magna Stauffer et Plummer: bed 2; Upper Carboniferous, Kasimovian Stage, zone gracilis-zethus. Fig. 9-10. Gondolella merrilli Gunnell: 9 – bed 2; Upper Carboniferous, Kasimovian Stage, zone gracilis-zethus; 10 – bed 4/1; Upper Carboniferous, Kasimovian Stage, zone firmus. Fig. 11. Gondolella kazakhstanica Akhmetshina (x80), bed 14/1; Upper Carboniferous, Gzhelian Stage, zone simplex. Fig. 12, 13. Solkagnathus velivolus Chernykh (x70): bed 14/1; Upper Carboniferous, Gzhelian Stage, zone simplex. Fig. 14. Diplognathodus expansus (Perlmutter) x100, bed 14/1; Upper Carboniferous, Gzhelian Stage, zone simplex

USOLKA SECTION. MIDDLE PENNSYLVANIAN (MOSCOVIAN-KASIMOVAIN) SUCCESSION

The Usolka section is located on the right bank of the Usolka River at the northeastern margin of the city of Krasnousolsk, the Bashkortostan Republic of Russia (Fig. 6.1). The section occurs in the axial part of the Belsk depression in the relatively deeper-water portion of the Preuralian Foredeep (Chernykh et al., 2006). The section is represented by powerful the continuous marine mixed carbonate-siliciclastic succession. The deposits crowded frequent horizons of with abundant conodonts (Chernykh 2010, 2011, 2012) and numerous volcanic ash layers with zircon crystals. Many volcanic ashes contains an excellent preserved conodonts as well. Radiometric age dates made by Shmitz, Davydov 2012 (Fig. 6.2). The following of the Moscovian-Kasimovian succession is exposed here (Fig. 6.3 – 6.13):

Section description

Moscovian Stage. Neognathodus roundyi Zone

1. Limestone, dark-grey, medium-grained, massive, silicified. Conodonts: *Gondolella laevis* Kossenko et Kozitskaya, *Idiognathodus delicatus* Gunnell, *I. obliquus* Kossenko et Kozitskaya, *I. podolskensis* Goreva, *I. trigonolobatus* Barskov et Alekseev, *I.sp.* 1 ....0.3 m.

2. Limestone, light grey, micritic, massive. Conodonts: Gondolella sp., Idiognathodus obliquus Kossenko et Kozitskaya, I. trigonolobatus Barskov et Alekseev .... 0.25 m.

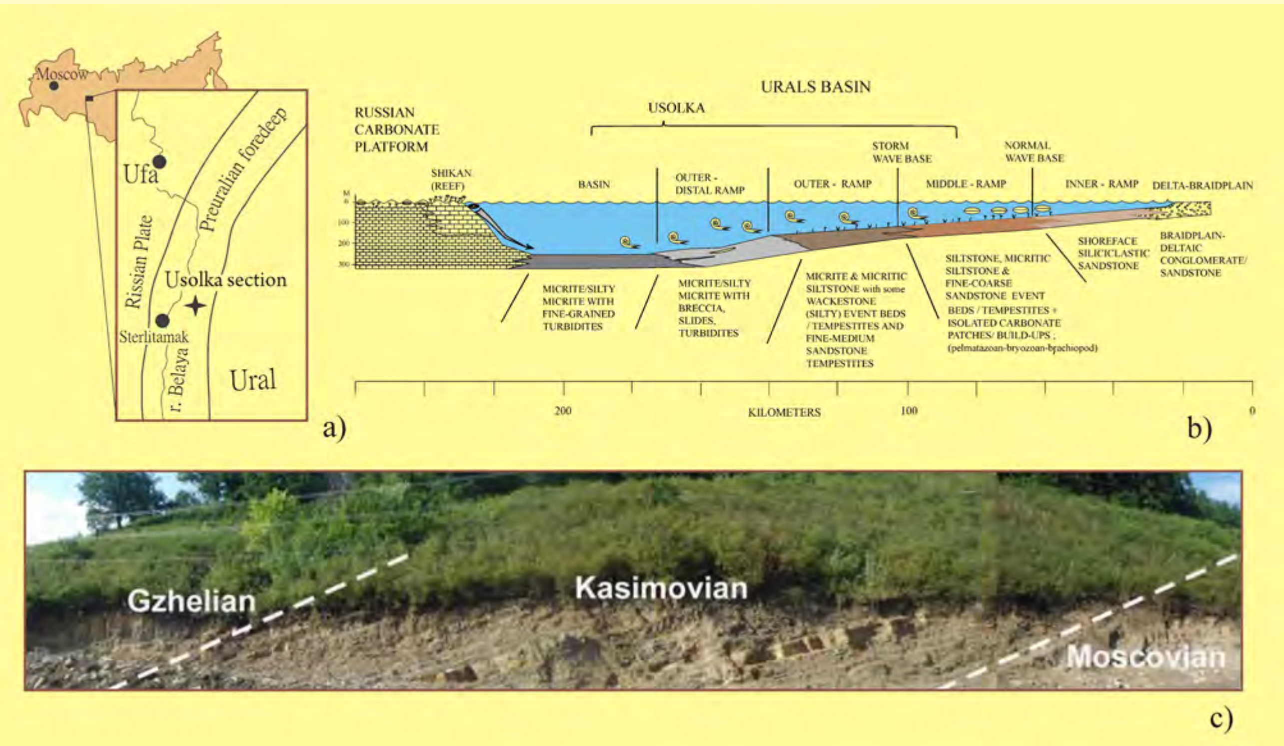


Fig. 6.1. a – location of the Usolka quarry; b – Urals basin. Paleogeographis model (from Davydov et al., 2003); c – Carboniferous deposits of Usolka quarry

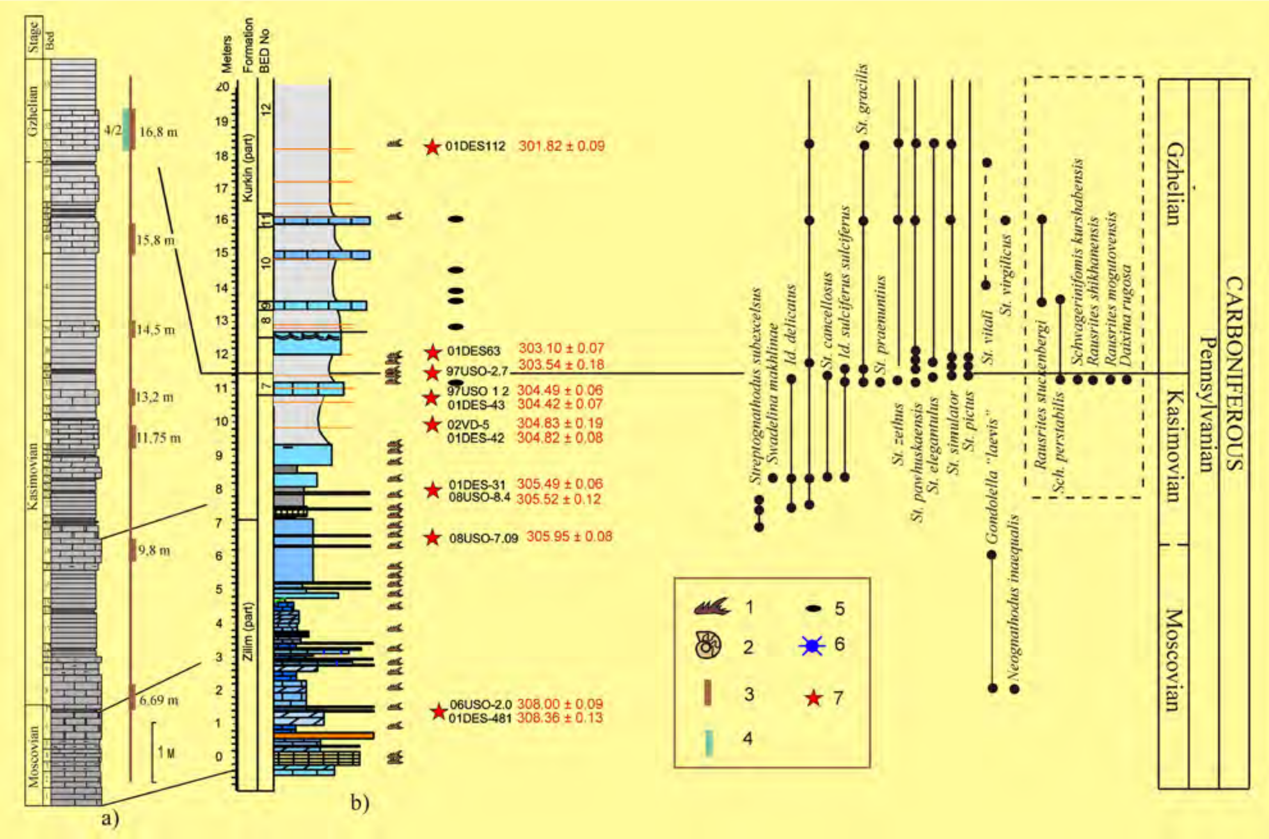


Fig. 6.2. Stratigraphic Log (a – Usolka, 2015, legend is on fig. 6.5; b – Usolka, from Schmitz and Davydov, 2012 taxonomic ranges and radiometric ages from the latter source. Explanations: 1 – conodonts; 2 – ammonoidea; 3 – number of samples, Davydov, 2009; 4 – number of samples, Chernnykh, 2012; 5 – foraminifera; 6 – radiolarian; 7 – dated ash bed

Fig. 6.3. Usolka quarry. Beds 1-6

Fig. 6.4. Usolka quarry. Beds 4-8

a) *b)*

Fig. 6.5. Usolka quarry: a – beds 8-13; b – beds 13 – 18

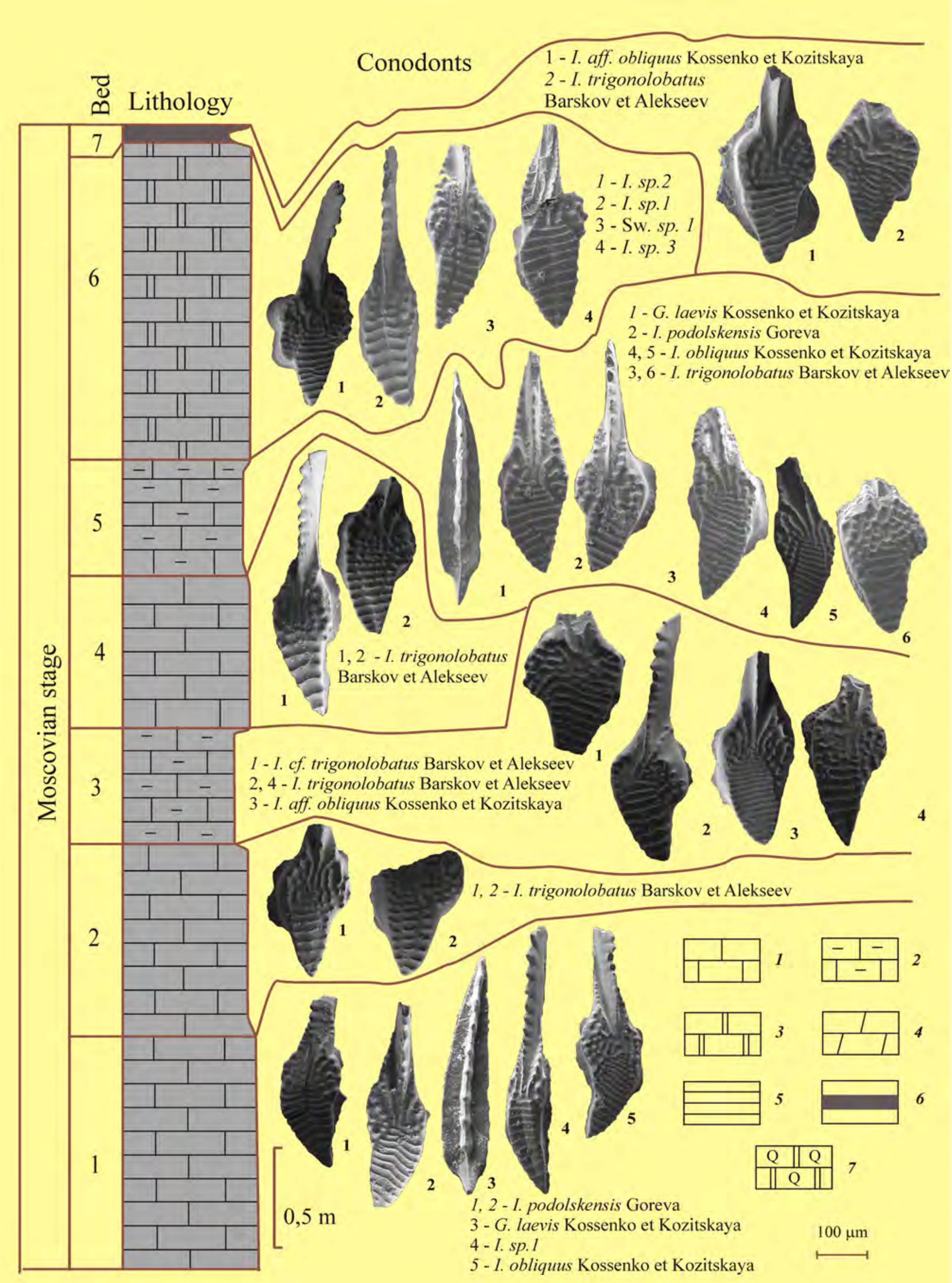


Fig. 6.6. Distribution of significant conodont species in the described succession (beds 1 – 7).
G. – Gondolella, I. – Idiognathodus, S. – Streptognathodus, Sw. – Swadelina.
1 - limistone, 2 - silty limestone, 3 - dolomite, 4 - marl, 5 - mudstone, 6 - volcanik ash, 7 - chert

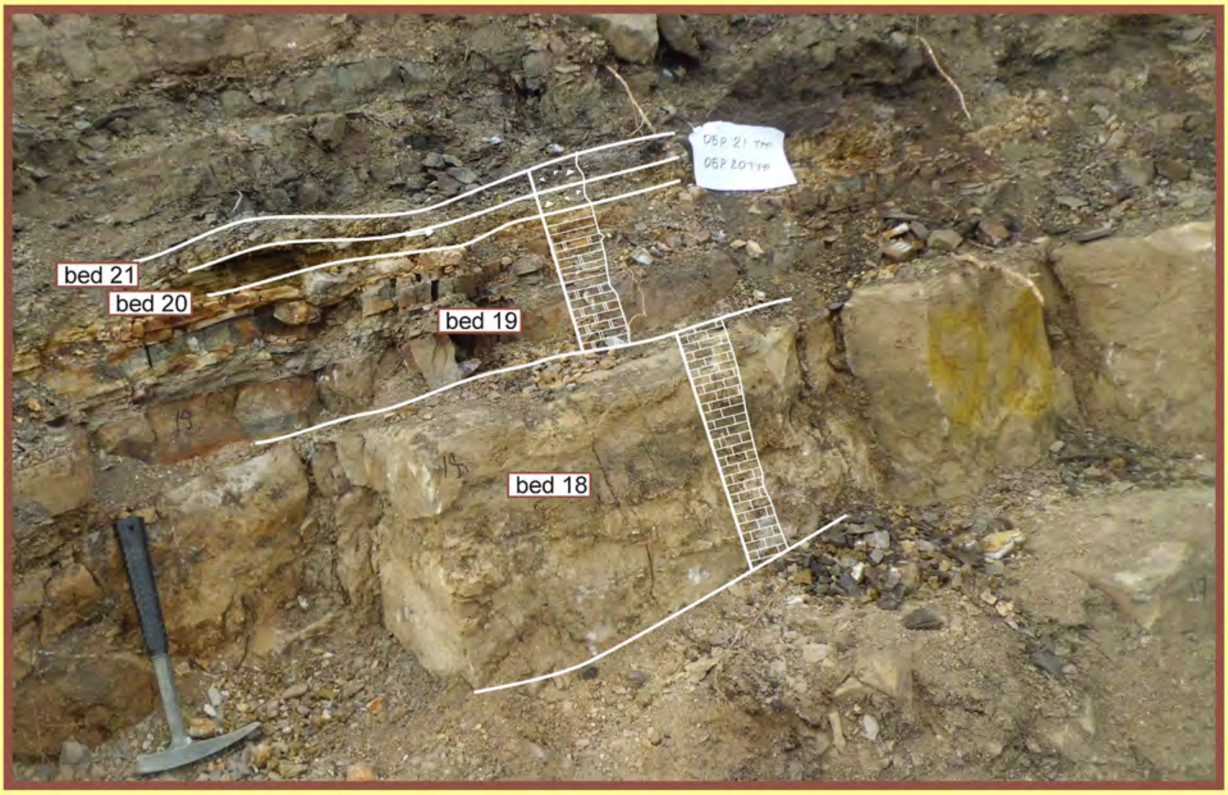


Fig. 6.7. Usolka quarry. Beds 18-21

3. Limestone, silty, gray, cryptocrystalline, massive, with calcite veinlets. Conodonts: *Gondolella laevis* Kossenko et Kozitskaya, *Idiognathodus delicatus* Gunnell, *I. obliquus* Kossenko et Kozitskaya, *I. podolskensis* Goreva, *I. trigonolobatus* Barskov et Alekseev ……..... 0.17 m.

4. Limestone, grey, micritic, with interbeds of dark-grey cherts. Conodonts: *Gondolella laevis* Kossenko et Kozitskaya, *Idiognathodus obliquus* Kossenko et Kozitskaya, *I. podolskensis* Goreva, *I. trigonolobatus* Barskov et Alekseev ……………………………………0.22 m.

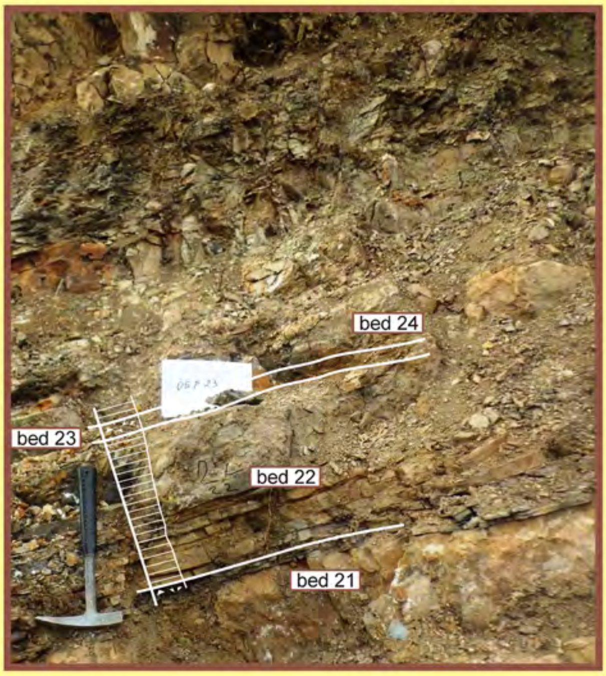
5.Limestone, silty, grey, micritic, massive. Conodonts: *Gondolella laevis* Kossenko et Kozitskaya, *G. magna* Stauffer et Plummer, *Idiognathodus obliquus* Kossenko et Kozitskaya, *I. podolskensis* Goreva, *I. trigonolobatus* Barskov et Alekseev……….............…….... 0.22 m.

6. Dolomite, grey, cryptocrystalline, massive. Conodonts: *Gondolella magna* Stauffer et Plummer, *Idiognathodus obliquus* Kossenko et Kozitskaya, *I. podolskensis* Goreva, *I. trigonolobatus* Barskov et Alekseev, *I.sp.* 1, *I.sp.* 2, *I.sp.* 3, *Swadelina sp.* 1...………………………. 0.42 m.

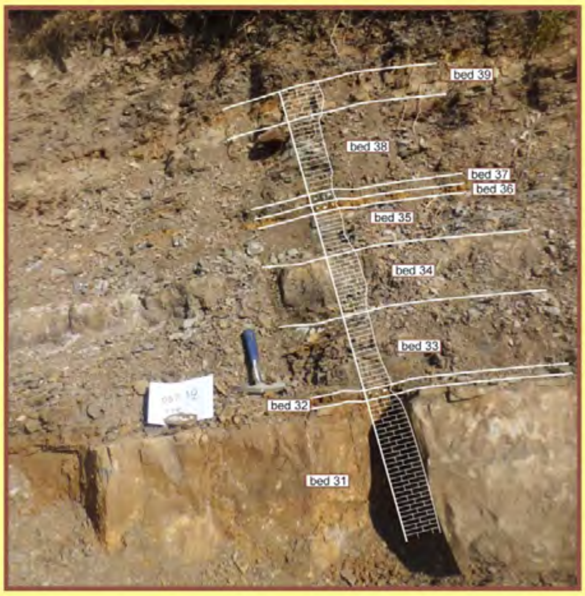
7. Volcanic ash, orange-yellow. Conodonts: *Idiognathodus obliquus* Kossenko et Kozitskaya, *I. trigonolobatus* Kossenko et Kozitskaya ……..................................... 0.03 m.

Kasimovian Stage. *Streptognathodus subexelsus* Zone

8. Limestone, dolomitized, dark-grey, cryptocrystalline, massive. Conodonts: *Idiognathodus trigonolobatus* Barskov et Alekseev, *Streptognathodus subexcelsus* Alekseev et Goreva, *I. sp.* 3, *I. sp.* 4, *Swadelina sp. 1*……….. 0.55 m.



a)



b)

c)

Fig. 6.8. Usolka quarry: a – beds 21 – 24; b – beds 31 – 39; c – beds 26 – 31

Fig. 6.9. Usolka quarry. Beds 39-42

9. Limestone, silty, grey, micritic, massive..…………………………................ 0.22 m.

10. Chert, dark-grey..……………… 0.11 m.

11. Mudstone, grey. Conodonts: *Idiognathodus trigonolobatus* Barskov et Alekseev, *I.sp.* 2, *I.sp.* 4, *Swadelina sp. 1*…......................... 0.11 m.

12. Volcanic ash, orange-yellow. Conodonts: *Idiognathodus trigonolobatus* Barskov et Alekseev……………………....................….. 0.03 m.

13. Alternation of mudstones, grey and limestones, dark-grey, strongly silicified. Conodonts: *Idiognathodus* aff. *trigonolobatus* Barskov et Alekseev, *I. sp.* 2, *Swadelina sp. 1*….........0.58 m.

14. Volcanic ash, orange-yellow. Conodonts: *Streptognathodus sp.*……………........... 0.08 m.

15. Mudstone, dark-grey, thin-bedded. Conodonts: *Streptognathodus makhlinae* Alekseev et Goreva, *I. sp.* 5…...............................….. 0.15 m.

16. Mudstone, dark-grey, silicified, thin-plated, with plates 0.5 cm thick. Conodonts: *Streptognathodus makhlinae* Alekseev et Goreva, *S. sp.* 1…….. 0.48 m.

17. Limestone, silty, grey, micritic, massive. Conodonts: *Idiognathodus sp.* 5, *Streptognathodus makhlinae* Alekseev et Goreva……………………......…………... 0.1 m.

18. Limestone, dolomitized, silty, light grey, micritic, massive. Conodonts: *Idiognathodus arendti* Barskov et Alekseev, *I. sp. 6*……………….......................….. 0.37 m.

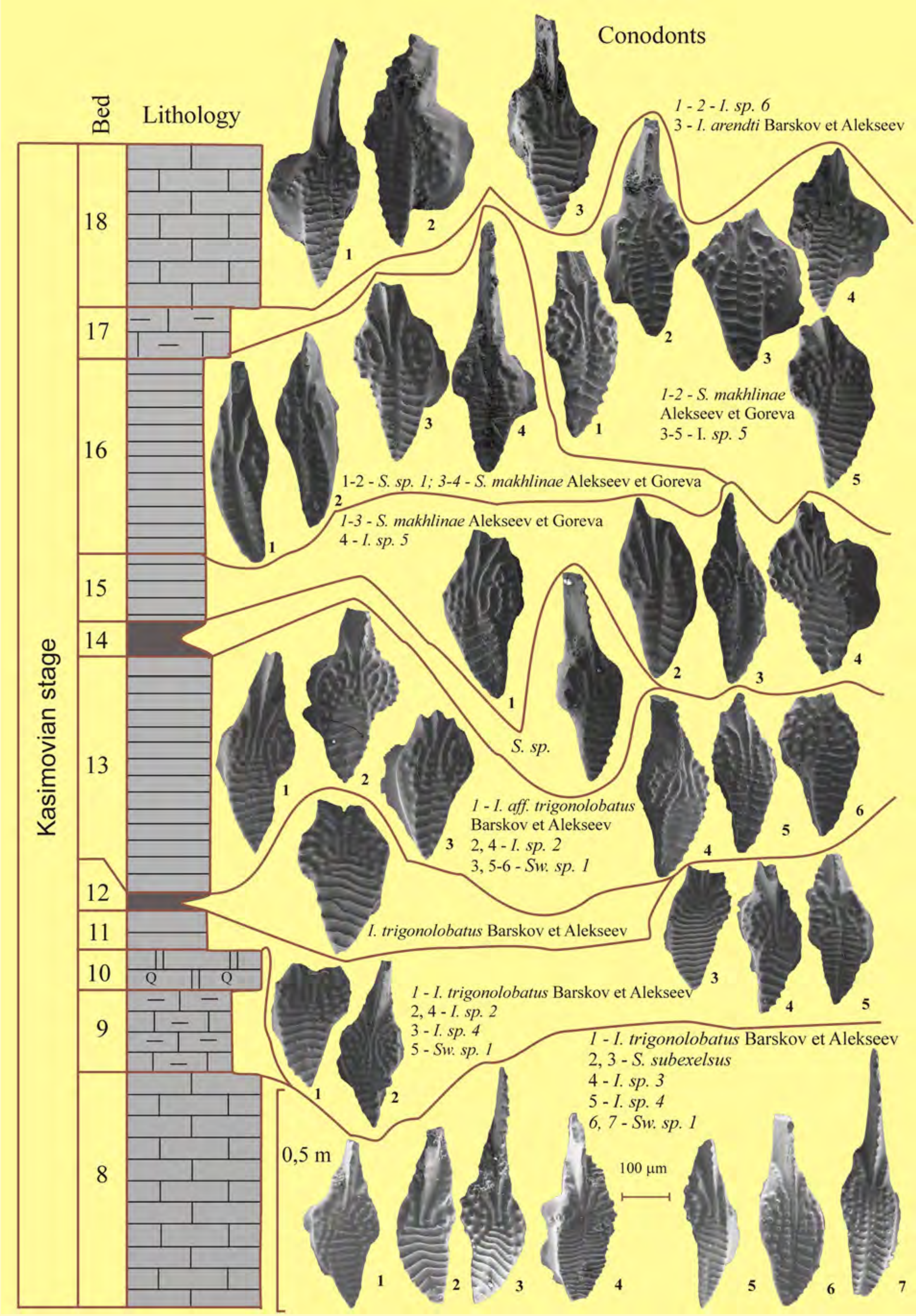


Fig. 6.10. Distribution of significant conodont species in the described succession (beds 8 – 18). Legend is on Fig. 6.6.
I. – Idiognathodus, S. – Streptognathodus, Sw. – Swadelina

19. Dolomite, grey, strongly silicified, micritic, massive, with interlayers of dark gray, thin-bedded mudstone. Conodonts: *Idiognathodus arendti* Barskov et Alekseev, *Streptognathodus makhlinae* Alekseev et Goreva..................................….0.22 m.

20. Volcanic ash, orange-yellow. Conodonts: *Gondolella magna* Stauffer et Plummer ……………………………………..........0.05 m.

Kasimovian Stage.
***Idiognathodus sagittalis* Zone**

21. Volcanic ash, dark-grey. Conodonts: *Idiognathodus* aff. *sagittalis* Kozitskaya ………………………….........…………0.05 m.

22. Mudstone, dark-grey, strongly silicified, with interlayers of cherts.……….......... 0.41 m.

23. Volcanic ash, orange-yellow. Conodonts: *Idiognathodus sp., Streptognathodus cancellosus* Gunnell..............………….........….. 0.03 m.

24. Mudstone, dark-grey, thin-bedded, platy. Conodonts: *Gondolella laevis* Kossenko et Kozitskaya, *Idiognathodus* sp. 7…...…...0.17 m.

25. Volcanic ash, greenish-gray…...... 0.04 m.

26. Limestone, dark-grey, cryptocrystalline, massive, fissured. Conodonts: *Idiognathodus magnificus* Stauffer et Plummer, *Streptognathodus crassus* Chernykh….......................0.16 m.

27. Marl, greenish-gray…........……0.17 m.

28. Volcanic ash, orange-yellow….......0.02 m.

29. Mudstone, grey, micritic, thin-bedded, platy ....0.07 m.

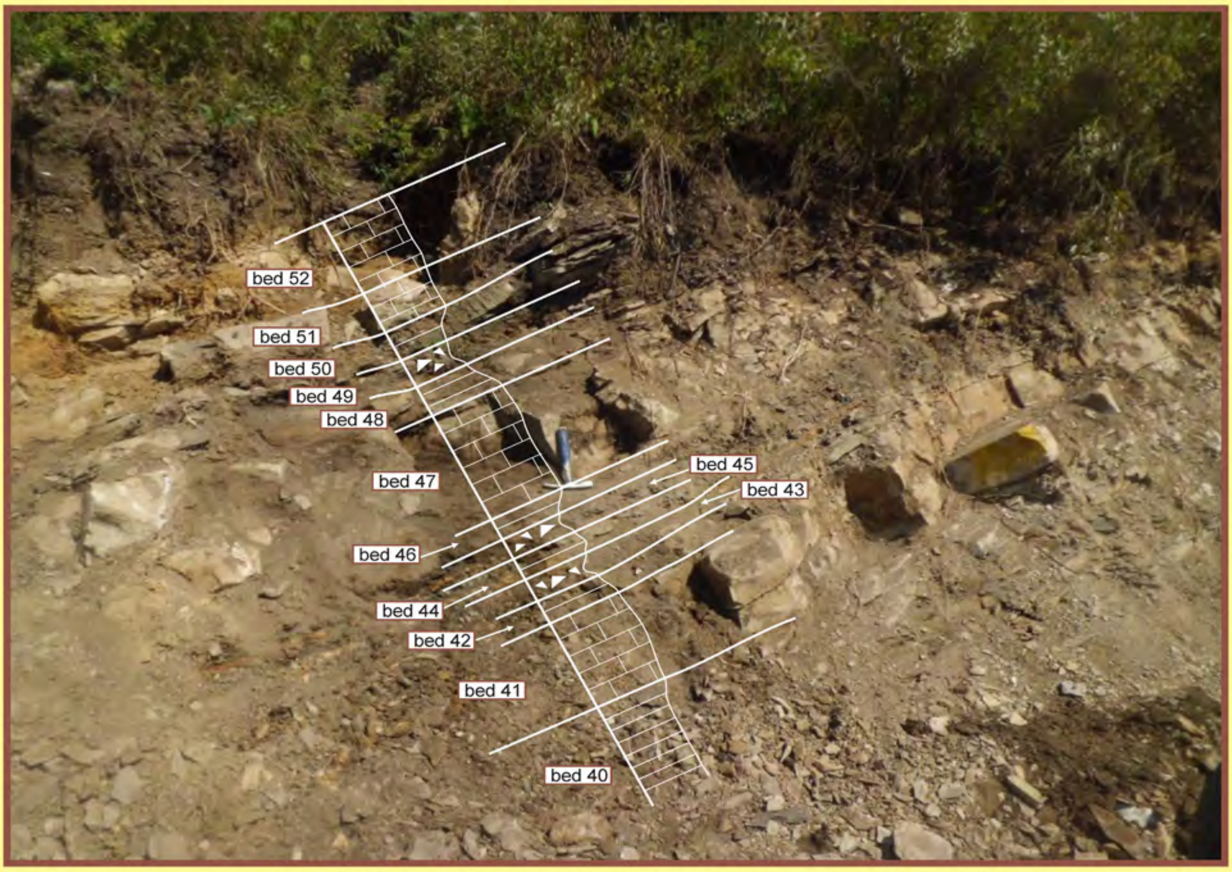


Fig. 6.11. Usolka quarry. Beds 40-52

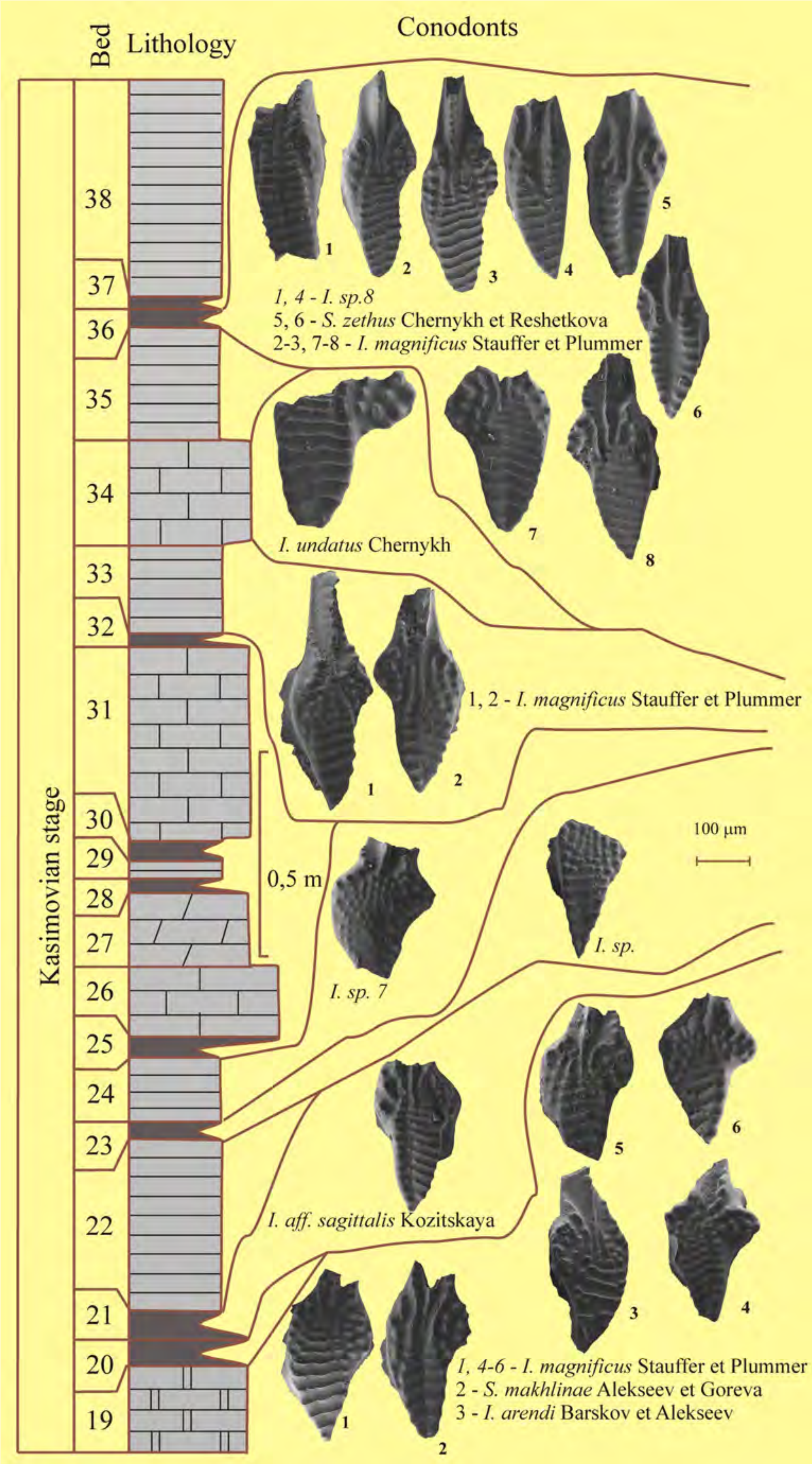


Fig. 6.12. Distribution of significant conodont species in the described succession (beds 19 – 38). Legend is on fig. 6.6.
I. – Idiognathodus, S. – Streptognathodus

30. Volcanic ash, brownish-grey. Conodonts: *Idiognathodus sagittalis* Kozitskaya, *Streptognathodus cancellosus* Gunnell……………………….................……0.03 m.

31. Limestone, grey, micritic, massive, silicified. Conodonts: *Gondolella sp., Streptognathodus sp.*....…….................................. 0.45 m.

32. Volcanic ash, orange-yellow. Conodonts: *Gondolella laevis* Kossenko et Kozitskaya, *G. merrilli* Gunnell, *Idiognathodus sagittalis* Kozitskaya, *Streptognathodus cancellosus* Gunnell ...... 0.05 m.

33. Mudstone, dark-grey, thin-bedded, platy. Conodonts: *Idiognathodus magnificus* Stauffer et Plummer………..................................…… 0.21 m.

34. Limestone, clayey, grey, micritic, massive, silicified. Conodonts: *Idiognathodus undatus* Chernykh...0.24 m.

35. Mudstone, dark-grey, cryptocrystalline, thin-bedded, platy……...........………… 0.26 m.

36. Volcanic ash, orange-yellow. Conodonts: *Idiognathodus sagittalis* Kozitskaya, *I. magnificus* Stauffer et Plummer, I. sp. 8, *Streptognathodus zethus* Chernykh………………....……0.04 m.

37. Volcanic ash, dark-grey……….. 0.03 m.

38. Mudstone brownish-grey, cryptocrystalline, thin-bedded, platy ....……0.52 m.

39. Limestone, silty, grey, micritic, massive. Fossils present are fragments of brachiopods and conodonts: *Idiognathodus toretzianus* Kozitskaya, *Streptognathodus firmus* Kozitskaya, *S. pawhuskaensis* Harris et Hollingsworth …..…........................…0.25 m.

40. Mudstone, dark-grey, thin-bedded, platy……......………………...……………………1.1 m.

Kasimovian Stage.

***Streptognathodus firmus* Zone**

41. Limestone, dolomitized, grey, massive, micritic. Conodonts: *Streptognathodus crassus* Chernykh, *S. praenuntius* Chernykh, *S. zethus* Chernykh et Reshetkova……………….....................…………0.51 m.

42. Mudstone, grey with small phosphatic concretions (2-3 cm in diameter). Conodonts: *Idiognathodus magnificus* Stauffer et Plummer, *Streptognathodus sp. 1., S. pawhuskaensis* Harris et Hollingsworth, *S. praenuntius* Chernykh .... 0.06 m.

43. Volcanic ash, orange-yellow…....0.02 m.

44. Mudstone, grey with numerous small phosphatic concretions (2-3 cm)..........…0.04 m.

45. Volcanic ash, orange-yellow……0.01 m.

46. Mudstone, grey with small phosphatic concretions (3-5 cm)………...........……0.16 m.

47. Limestone, grey, silicified, dolomitized. Conodonts: *Idiognathodus excedus* Chernykh, *I. magnificus* Stauffer et Plummer, *Streptognathodus gracilis* Stauffer et Plummer, *S. pawhuskaensis* Harris et Hollingsworth, *S. praenuntius* Chernykh, *S. zethus* Chernykh et Reshetkova……...…………………......…0.42 m.

48. Mudstone, brownish-grey with small phosphatic concretions (2-3 cm). Conodonts: *Streptognathodus firmus* Kozitskaya .….0.19 m.

49. Volcanic ash, dark-grey. Conodonts: *Idiognathodus toretzianus* Kozitskaya, *Streptognathodus firmus* Kozitskaya, *S. gracilis* Stauffer et Plummer, *S. pawhuskaensis* Harris et Hollingsworth, *S. zethus* Chernykh et Reshetkova. Ammonoids: *Eoasianites* sp.,

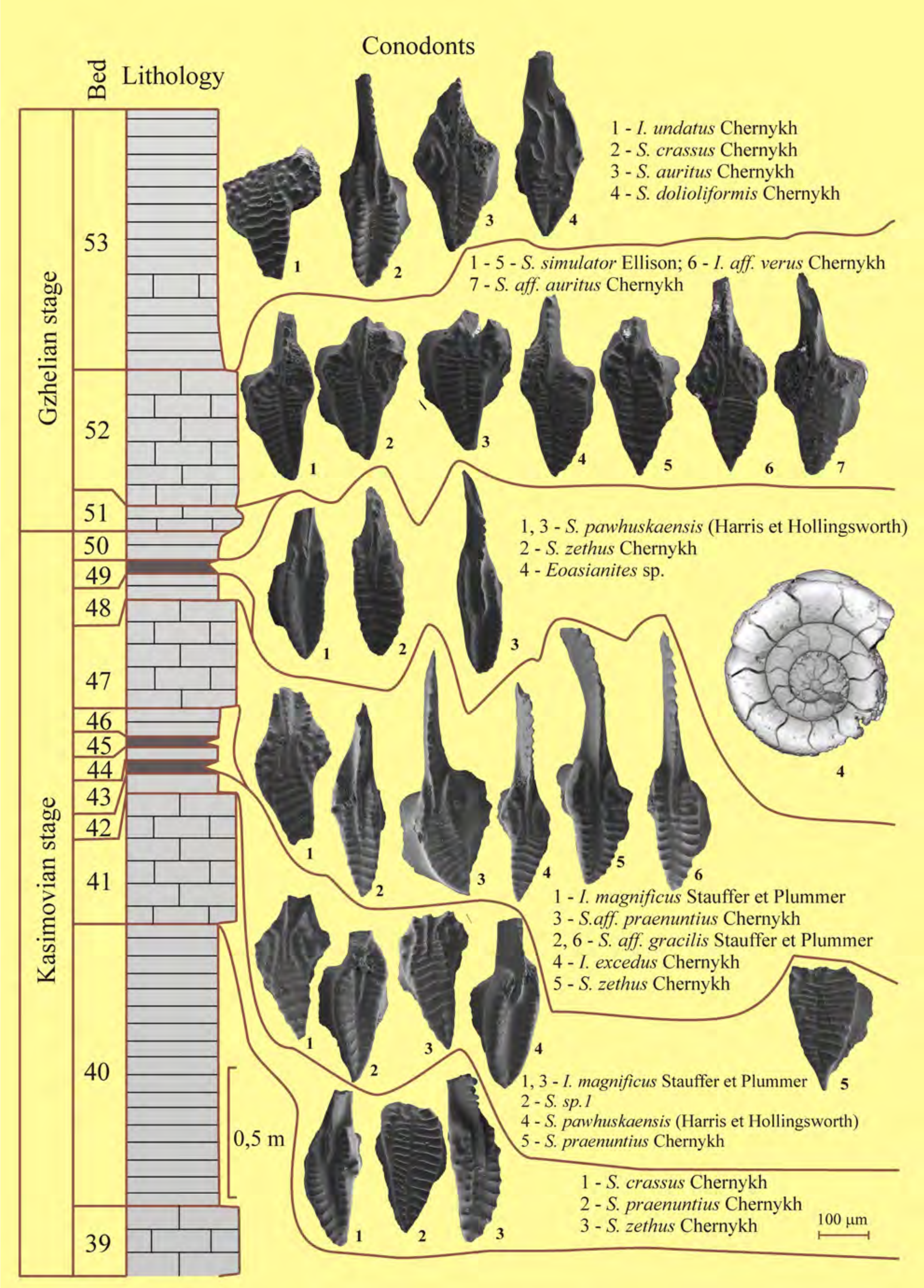


Fig. 6.13. Distribution of significant conodont species in the described succession (beds 39 – 52). Legend is on fig. 6.6. I. – Idiognathodus, S. – Streptognathodus

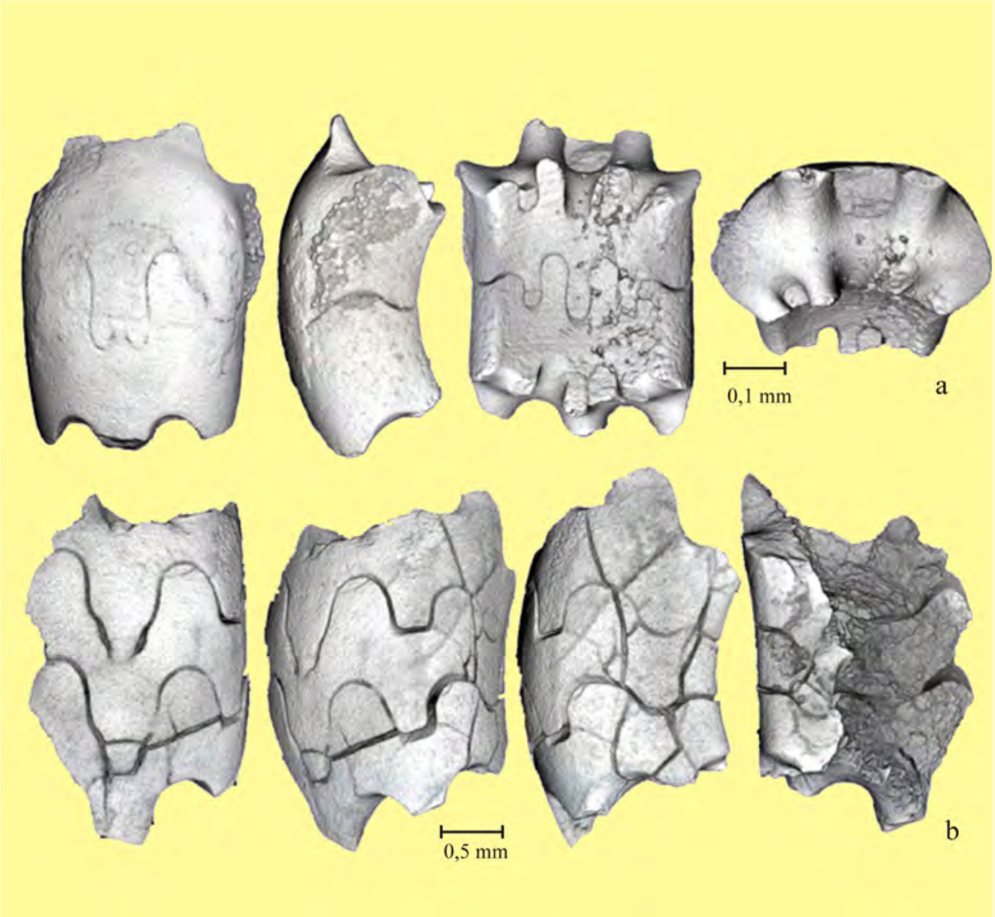


Fig. 6.14. Ammonoidea, Kasimovian Stage, bed 49: a – Eoasianites sp.; b – Daixites sp.

Daixites sp. and ammonitellas (Fig. 6.14 – 6.15)……………………………........….0.05 m.

50. Mudstone, brownish-grey with small phosphatic concretions (2-3 cm)…...........0.16 m.

Gzhelian Stage.
***Streptognathodus simulator* Zone**

51. Limestone, grey, dolomitized. Conodonts: *Idiognathodus toretzianus* Kozitskaya, *Streptognathodus gracilis* Stauffer et Plummer, *S. simulator* Ellison…..........................…0.16 m.

52. Limestone, grey, slightly silty, micritic with bioclastic debris. Conodonts: *Idiognathodus* aff. *verus* Chernykh, *Streptognathodus* aff. *auritus* Chernykh and *S. simulator* Ellison ….0.47 m.

53. Mudstone, grey with layers of micritic limestone. Conodonts: *Idiognathodus undatus* Chernykh, *Streptognathodus* aff. *auritus* Chernykh, *S. crassus* Chernykh, *S. dolioliformis* Chernykh…...................................……..0.85 m.

This work was funded by the subsidy of the Russian Government to support the Program of competitive growth of Kazan Federal University among world class academic centers and universities, and the subsidy allocated to Kazan Federal University for the project part of the state assignment in the sphere of scientific activities.

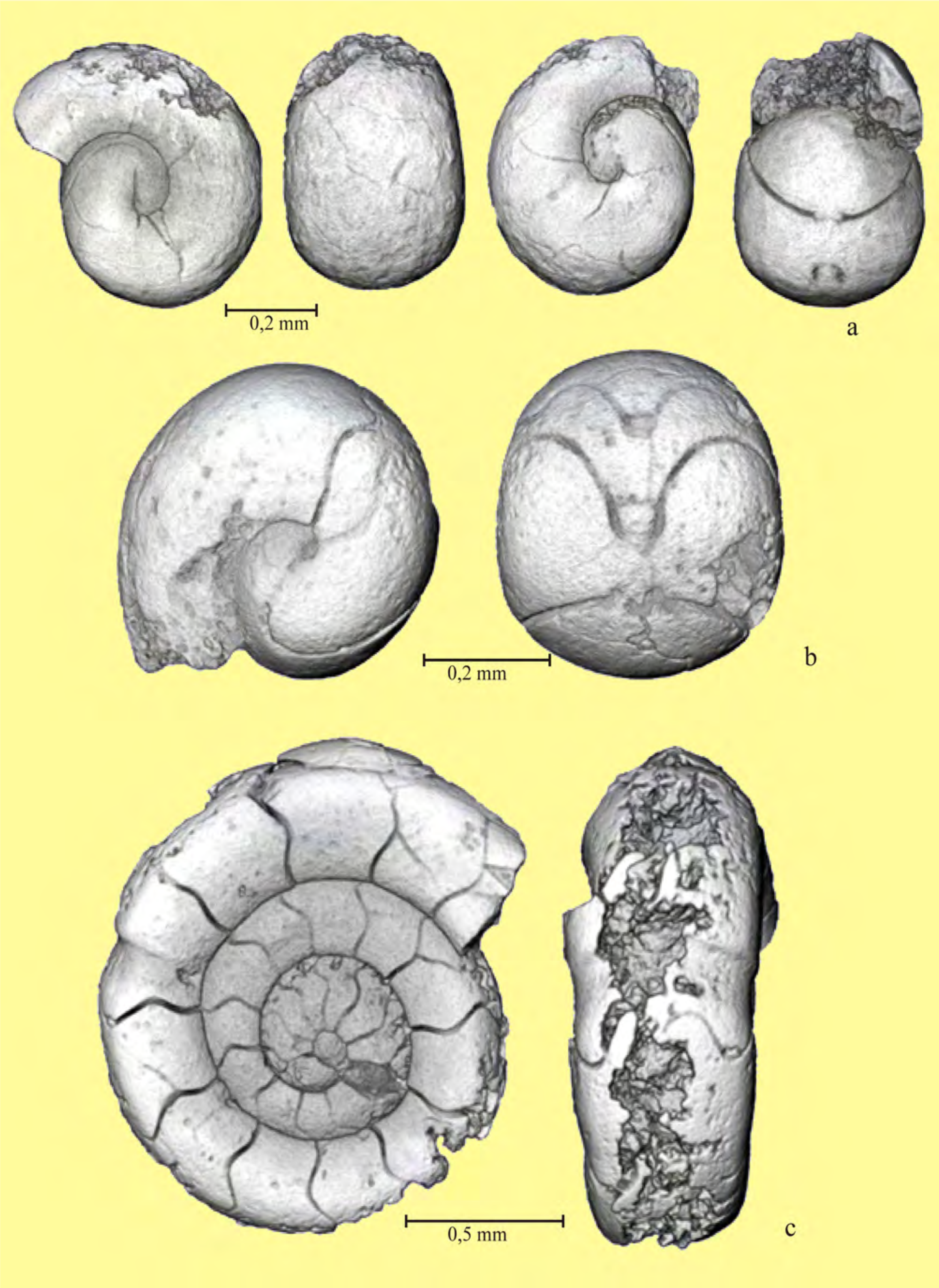


Fig. 6.15. Ammonoidea, Kasimovian Stage, bed 49: a, b – ammonitellas; c – Eoasianites sp

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Pre-Congress A3 Trip: Southern Urals. Deep water successions of the Carboniferous and Permian. Lower Permian GSSPs, 6-9 August, 2015

Date	Event	
06.08	Arrive in Ufa, preferably in the first half of the day. **14.00-18.00.** Depart from Ufa to Yangan-Tau by bus (http://www.yantau.ru/eng/).	 ***Health Resort Yangan-Tau***
07.08	**8.30. Mechetlino quarry,** GSSP candidate for the base of the Kungurian. **8.30 – 13.00.** Right bank of the Yuryuzan River. Artinskian-Kungurian boundary beds with ammonoids, conodonts, and fusulinids. Fossil collecting. **15.00-19.00.** Trip to the Krasnousolsk Health Resort (http://krasnousolsk.ru/3d/).	 ***Mechetlino Section***
08.08	**08.00. Dalnyi Tyulkas quarry,** base of the Artinskian GSSP candidate. **08.30-12.00.** Trip to the Dalnyi Tyulkas section, base of the Artinskian Stage GSSP candidate. Artinskian (Lower Permian) siliciclastics and carbonates with layers of volcanic ash. Fossil collecting.	 ***Dalnyi Tyulkas Section***
	15.00. Usolka quarry, base of the Sakmarian GSSP candidate. **14.00-18.00.** Right bank of the Usolka River. Upper Carboniferous (Kasimovian and Gzhelian) and Lower Permian (Asselian and Sakmarian), composed of a thick series of carbonate-argillaceous rocks with layers of volcanic ash. Fossil collecting.	 ***Usolka Section***
09.08	**07.00.** Departure from Krasnousolsk to Kazan. **08.00-12.00.** A stop at the Shikhany Outcrop. Sterlitamak Shikhany Mounds are isolated mound hills found in the Bashkirian Cisuralia, and are relics of the Early Permian reef complex, composed of limestone with numerous fossils. **12.00.** Trip to Kazan.	 ***Shikhany Mound***

Южный Урал.
Глубоководные разрезы карбона и перми.
Полевая экскурсия А3,
6-10 августа 2015 г.

Главный редактор: *Д. К. Нургалиев*

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ISBN 978-5-9690-0256-2

Подписано в печать 28.07.2015
Бумага мелованная. Формат 60х84 1/8.
Гарнитура «TimesNewRoman».
Печ. л. 11. Печать цифровая.
Тираж 100 экз. Заказ №10/Б.

Издательство Академии наук
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