13th International Symposium on the Ordovician System

ORDOVICIAN SEDIMENTARY BASINS AND PALEOBIOTAS OF THE GORNY ALTAI

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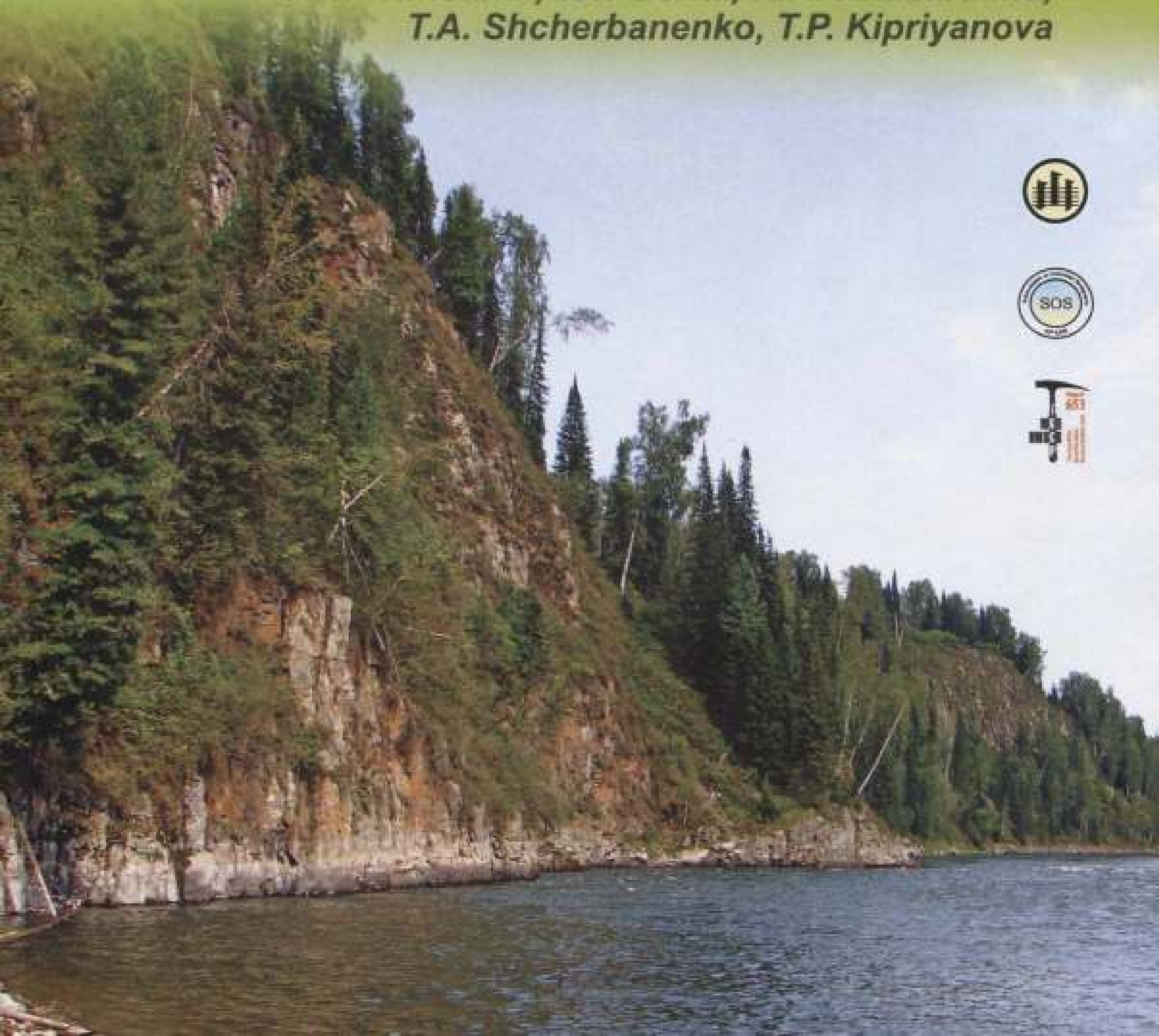

TROFIMUK INSTITUTE OF PETROLEUM GEOLOGY AND GEOPHYSICS
RUSSIAN ACADEMY OF SCIENCES
SIBERIAN BRANCH
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Сенников Н.В. Ордовикские седиментационные бассейны и палеобиоты Горного Алтая / **Н.В. Сенников, О.Т. Обут, Е.В. Лыкова, А.В. Тимохин, Т.В. Гонта, Р.А. Хабибулина, Т.А. Щербаненко, Т.П Киприянова** ; Ред. Н.В. Сенников, А.В. Каныгин ; [Перевод Н.Н. Мжельской, О.Т. Обут, Н.В. Сенникова]; Институт нефтегазовой геологии и геофизики им. А.А. Трофимука СО РАН; Новосибирский национальный исследовательский университет. Новосибирск : Изд-во СО РАН, 2019. – 184 с.

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This book is an expanded guidebook for a field excursion to the Ordovician sections of the Gorny Altai being shown to participants in the 13th International Symposium on the Ordovician System, Novosibirsk, 2019. The present guidebook concerns Ordovician stratigraphy, palaeogeography, lithology, and facies in key sections in the Gorny Altai, described bed-by-bed.

These data were previously published in part, mainly in syntheses scattered through various books and papers. This book is a synthesis of present-day knowledge with revisions of the paleontology and age implications. Updating has become possible due to discoveries of graptolite and conodont assemblages of zonal significance. The book is based on abundant biostratigraphic and geological data accumulated over the past 15 years about Ordovician deposition in the Gorny Altai. Publication of these data is a necessary step toward broad public discussion of new ideas, a prerequisite for updating the Gorny Altai Ordovician stratigraphic charts.

CONTENTS

INTRODUCTION

Ordovician strata are widespread in four major tectonic units of Siberia: in the Altai-Sayan Folded Area, upon the Siberian Craton, in the Taimyr Peninsula, and in the basement of the West Siberian Plate (Fig. 1).

The Gorny Altai lies in the western Altai-Sayan Folded Area (ASFA), a collage of terranes within the Central Asian orogen. The ASFA comprises several large geologic structures composed of Paleozoic (including Ordovician) formations of differing origins. Additional to the Gorny Altai are the Salair, Kuznetsky Alatau and Gornaya Shoriya in the west, and the West Sayan, and Tuva in the east (Fig. 2). The present tectonic framework of the ASFA (Dobretsov, 2003) has resulted from successive accretion of orogens of different ages to the Siberian craton.

In the Ordovician sediments of the Gorny Altai, all the stages (or substages or their parts) of the new Ordovician stage standard of the GSSP – Tremadocian, Floian, Dapingian, Darriwilian, Sandbian, Katian, and Hirnantian (Sennikov, Tolmacheva, 2013; Sennikov et al., 2014, 2015a, 2018a,b) are well-defined and identifiable in certain stratigraphic intervals of specific terrigenous and terrigenous carbonate sections. The application of the Ordovician stages with clear-cut lower boundaries, marked by the first appearance of the index species of the graptolite and conodont zones, and the application of the proposed "informal" substages (time slices) (Bergström et al., 2009) stimulated a major revision of the Ordovician regional subdivisions of the ASFA with the subsequent considerable specification of the chronostratigraphic extent of the previously used horizons and recognition of new ones. Also, the chronostratigraphic position of most of the Ordovician local stratigraphic units (formations) of the western ASFA has been determined more precisely. This dramatic revision has revealed many disputable problems of the Ordovician biostratigraphy of the ASFA, and the new, mainly zonal, biostratigraphic data have made it possible to propose their substantiated modern solutions. The Ordovician sections of the western ASFA are key to the resolution of the disputable questions related to the positioning of the boundaries of stratigraphic units in European Russia, not only in Asian geologic regions such as the Siberian Platform, Tuva, Kolyma, and Chukchi Peninsula, where both sedimentary and volcanosedimentary rocks occur in abundance.

The Altaian regional graptolite and conodont pelagic zonal successions can be used for precise correlations of the boundaries of local and regional units (or their parts) with the Ordovician stage boundaries of the ISC – the so-called "direct" correlations with stage boundaries based on the FAD (First Appearance Data) of the same-named index species. This shows the high efficiency of application of pelagic zonal successions in chronostratigraphy. The stratigraphic position of the ISC stage boundaries is easy to determine in the folded areas of Siberia (Gorny Altai), in which graptolites occur in terrigenous sediments and deepwater conodont assemblages are observed in carbonates.

The Ordovician sedimentary patterns of the Gorny Altai (Fig. 3) consist mainly of rhythmic alternation of terrigenous and carbonate rocks with rare volcanic intercalations. The terrigenous sections occasionally contain limestone lenses. Biohermal carbonates are frequent, mostly as algal buildups. Various facies occur dispersed through the palaeo-basin; thicknesses vary greatly.

The Gorny Altai territory is completely covered by 1:200 000 geological surveys and much of it by 1:50 000 surveys undertaken during the past 60 to 70 years. Most of the surveys were carried out by people from the West Siberian Geological Surveys (currently the Zapsibgeolsyomka Prospecting Company). Large-scale (1:25 000, 1:10 000, 1:5 000) geological surveys for the reference localities of the Ordovician rocks in the Gorny Atlai were carried out as special stratigraphic investigations by Ermikov V.D., Gladkikh L.A., Khlebnikova T.V., Krivchikov A.V., Kuznetsov S.A., Mamlin A.N., Petrunina Z.E., Podryadchikov S.S., Puzyrev A.A., Sennikov N.V., Shokalsky S.P., Yolkin E.A., Zeifert L.L., and Zybin V.A.

Paleontological and stratigraphical data, analyzed in this monograph were collected during field studies over many years by Alekseenko A.A., Andreeva O.N., Bogashchenko E.I., Buyanova E.V., Ermikov V.D., Gabova M.F., Gladkikh L.A., Gonta T.V., Iwata K., Izokh N.G., Kalinin E.A., Khabibulina R.A., Khlebnikova T.V., Krivchikov A.V., Kul'kov N.P., Lykova E.V., Mamlina M.I., Mannik P., Mel'nikova L.M., Obut O.T., Perfil'ev E.E., Petrunina Z.E., Savitsky V.R., Sennikov N.V., Severgina L.G., Sharudo E.A., Timokhin A.V., Tokarev D.A., Tolmacheva T.Yu., Yakovleva E.V., and Yolkin E.A.

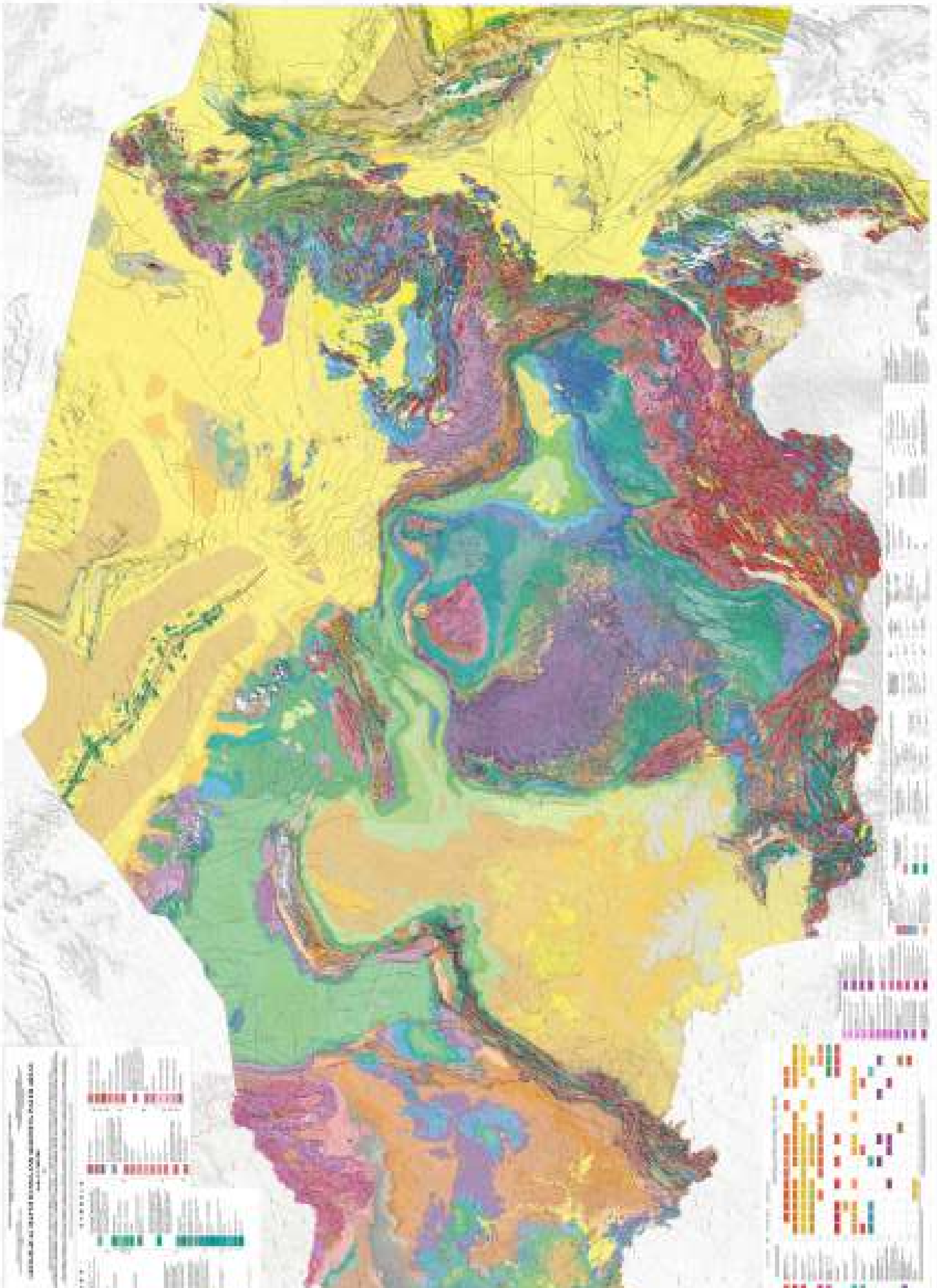


Fig. 1. Geolological map of Russia and adjoining water areas.

Fig. 2. Russia with location of the Altai-Sayan Folded Area (ASFA) including Rudny Altai, Gorny Altai, Salair, Kuznetsky Alatau, Kuznetsk basin, Minusa, West Sayan and Tuva.

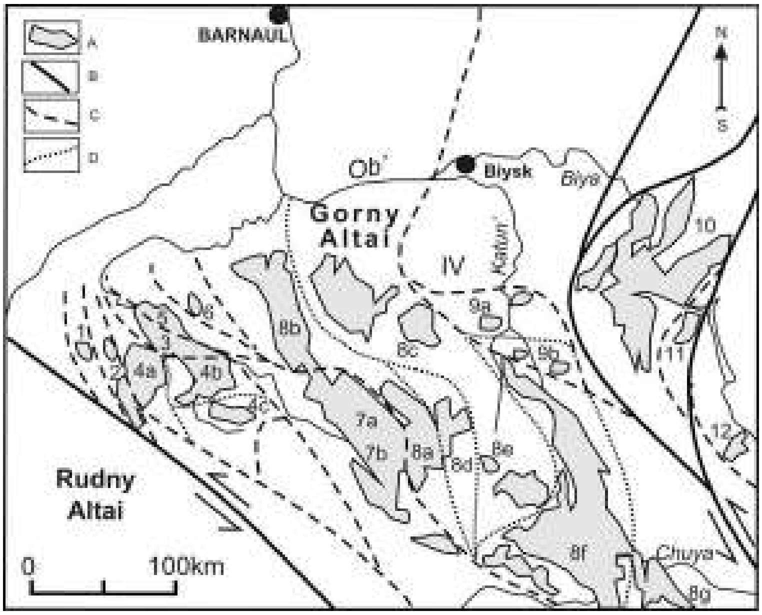


Fig. 3. Sketch map of locations of the Altai Ordovician deposits with main structural-tectonic elements.

A – areas with the wide-spread occurrence of the Ordovician strata; B – deep faults, constraint regional blocks; C-D – boundaries: C – structural-facies zones, D – subzones (areas). 1-12 – structural-facies zones: 1 – Milovanovka; 2 – Loktevka-Batun; 3 – Suetka-Kuibyshevo; 4 – Charysh-Inya; 5 – Kharlovo; 6 – Vydrikha; 7 – Talitsa; 8 – Anui-Chuya; 9 – Biya-Katun’; 10 – Uymen’-Lebed’; 11 – Teletskoe Lakeside; 12 – Ulagan.

Faunal remains included in the present monograph were identified as follows: trilobites – Petrunina Z.E., Andreeva O.N., Yolkin E.A., Timokhin A.V.; graptolites – Obut A.M., Sennikov N.V., Lykova E.V.; conodonts – Moskalenko T.A., Izokh N.G., Obut O.T., Tolmacheva T.Yu.; ostracods – Mel’nikova L.M., Gonta T.V.; brachiopods – Severgina L.G., Andreeva O.N., Kul’kov N.P., Savitsky V.R., Modzalevskaya T.L., Shcherbanenko T.A.; stromatoporoids – Khromykh V.G.; tabulate corals – Dzyubo P.S., Galenko L.V., Khabibulina R.A.; rugose corals – Zheltonogova V.A.; bryozoans – Volkova K.N., Koromyslova A.V.; crinoids – Stukalina G.A., Dubatolova Yu.A.; gastropods – Byalyi V.I.; radiolarians – Obut O.T., Iwata K.; chitinozoans – Obut A.M., Zaslavskaya N.M., Obut O.T.

Photographs illustrated sections and outcrops have been taken by Sennikov N.V., Obut O.T., Lykova E.V., and Mannik P.

1. ORDOVICIAN STRATIGRAPHY OF THE GORNY ALTAI

The Ordovician stratigraphic charts of the Gorny Altai have been compiled through the past seven decades by joint efforts of prospecting, academic, and educational institutions, namely, All-Russian Geological Institute (VSEGEI, St. Petersburg), Siberian Research Institute of Geology, Geophysics & Mineral Resources (SNIIGGiMS, Novosibirsk), Institute of Geology & Geophysics (currently Trofimuk Institute of Petroleum Geology and Geophysics, Novosibirsk), Zapsibgeologiya (Novokuznetsk), Zapsibgeolsyomka (Elan' Village), Tomsk and Novosibirsk State Universities, Tomsk Technological Institute (currently Tomsk Technological University), Kuzbass Pedagogical Academy (Novokuznetsk), and others.

Among researchers who played important role in the investigation of the Ordovician stratigraphy of the Gorny Altai should be noted the following persons (in the alphabetic order): Andreeva O.N., Avrov D.P., Bartseva N.M., Bublichenko N.L., Cherepnina S.V., Dubatolova Yu.A., Dzyubo P.S., Ermikov V.D., Fedyanov V.V., Galenko L.V., Gintsinger A.B., Gladkikh L.A., Gutak Ya.M., Isaev G.D., Izokh N.G., Khalfina V.K., Khlebnikova T.V., Khromykh V.G., Kononov A.N., Krivchikov A.V., Krivchikov V.A., Kuznetsov V.A., Kul'kov N.P., Levitsky E.S., Lyakhnitsky V.N., Lykova E.V., Mamlin A.N., Modzalevskaya E.A., Modzalevskaya T.L., Moskalenko T.A., Nekhoroshev V.P., Nikonov A.A., Obut A.M., Obut O.T., Perfil'ev Yu.S., Petrunina Z.E., Podryadchikov S.S., Potapova M.S., Puzyrev A.A., Romanenko M.F., Savitsky V.P., Sennikov N.V., Sennikov V.M., Severgina L.G., Stukalina G.A., Tikhonov V.I., Usov M.A., Vyltsan I.A., Vinkman M.K., Volkov V.V., Volkova K.N., Yaroshinskaya A.M., Yolkin E.A., Zaslavskaya N.M., Zeifert L.L., Zheltonogova V.A.

1.1. ORDOVICIAN REGIONAL STRATIGRAPHIC UNITS

According to the usual practice in Russia, regional correlation follows chronostratigraphic subdivision into regional stages (called *horizons* in the Russian stratigraphic code). Regional stages comprise regionally spread coeval formations (or their parts) and correspond to stages of regional geological history, and especially to stages in the evolution of marine faunal groups. Regional stages are discussed and approved collectively for further use at special Russian Stratigraphic Workshops held every ten to fifteen years, or sometimes every five or seven years. The succession of regional stages, together with the respective subdivision of the International Stratigraphic Chart (Scale), make basis for correlation of local units (formations and groups) as part of regional charts and for inter-regional correlations.

There are three main steps in synthesis of stratigraphic and biostratigraphic data: (1) subdivision of local sections, (2) correlation of the sections (intra- and partly inter-regional correlations of composite sections from nearby regions), (3) age assignment (correlation among sections from geographically dispersed regions and global correlation, including correlation with the units in the International Stratigraphic Chart). The three objectives are performed with reference to different Ordovician faunal groups.

The greatest part of local Ordovician sections in the Gorny Altai are correlated mainly according to trilobites and brachiopods. These two groups of benthic organisms occur in diverse complexes of terrigenous, terrigenous-carbonate and purely carbonate compositions and, for this reason, are used in subdivision of local sections and in intra-regional correlation. Trilobites and brachiopods are also of broad use in correlation among sections from the nearby areas of Gorny Altai, Salair, Kuznetsky Alatau, Siberian Platform, Taimyr, Kazakhstan, and Urals.

Other communities besides trilobites and brachiopods used in subdivision of local sections are abundant tabulate and rugose corals, ostracods, fishes, bryozoans, crinoids, nautiloids, gastropods, stromatoporoids, radiolarians, and chitinozoans. In some cases, they may be useful for intra- or, more rarely, inter-regional correlations.

Besides the local subdivision, the succession of trilobite and brachiopod assemblages is the key to Gorny Altai regional Ordovician stages, and these, in turn, most often serve as ties in correlation among sections from proximal regions.

Succession of trilobite and graptolie assemblages is regarded as the base for the Altai Ordovician regional stages (horizons) as well as a reliable key for the intra-regional correlation. Inter-regional correlation is usually fulfilled on the bases of regional stages (horizons).

Global correlation and dating of the deposits with respect to the International Stratigraphic Chart are made proceeding from pelagic faunas of graptolites and conodonts. Although these faunal groups are less abundant in the Ordovician sections of the Gorny Altai than others.

The current Paleozoic stratigraphic charts for Central Siberia were approved at the USSR Workshops on Ordovician-Silurian Stratigraphy of 1956, 1964, 1979 and 2012 in Novosibirsk which were four milestones in the history of stratigraphic studies in the Gorny Altai and in the Altai-Sayan Folded Area as a whole (Decisions…, 1959; Documents…, 1964; Correlative…, 1964; Stratigraphy…, 1967; Decisions…, 1983; Sennikov et al., 2018a,b). The workshops concerned with unification of regional stratigraphic charts as an outcome of years-long work; the charts were then considered by the USSR Interdepartmental Stratigraphic Committee and ratified to become official guidelines for further use in geological surveys.

The Ordovician regional stages of the Gorny Altai are correlated to the units of the International Stratigraphic Chart (Scale) on the basis of the respective graptolite, conodont and chitinozoans zones (Fig. 4).

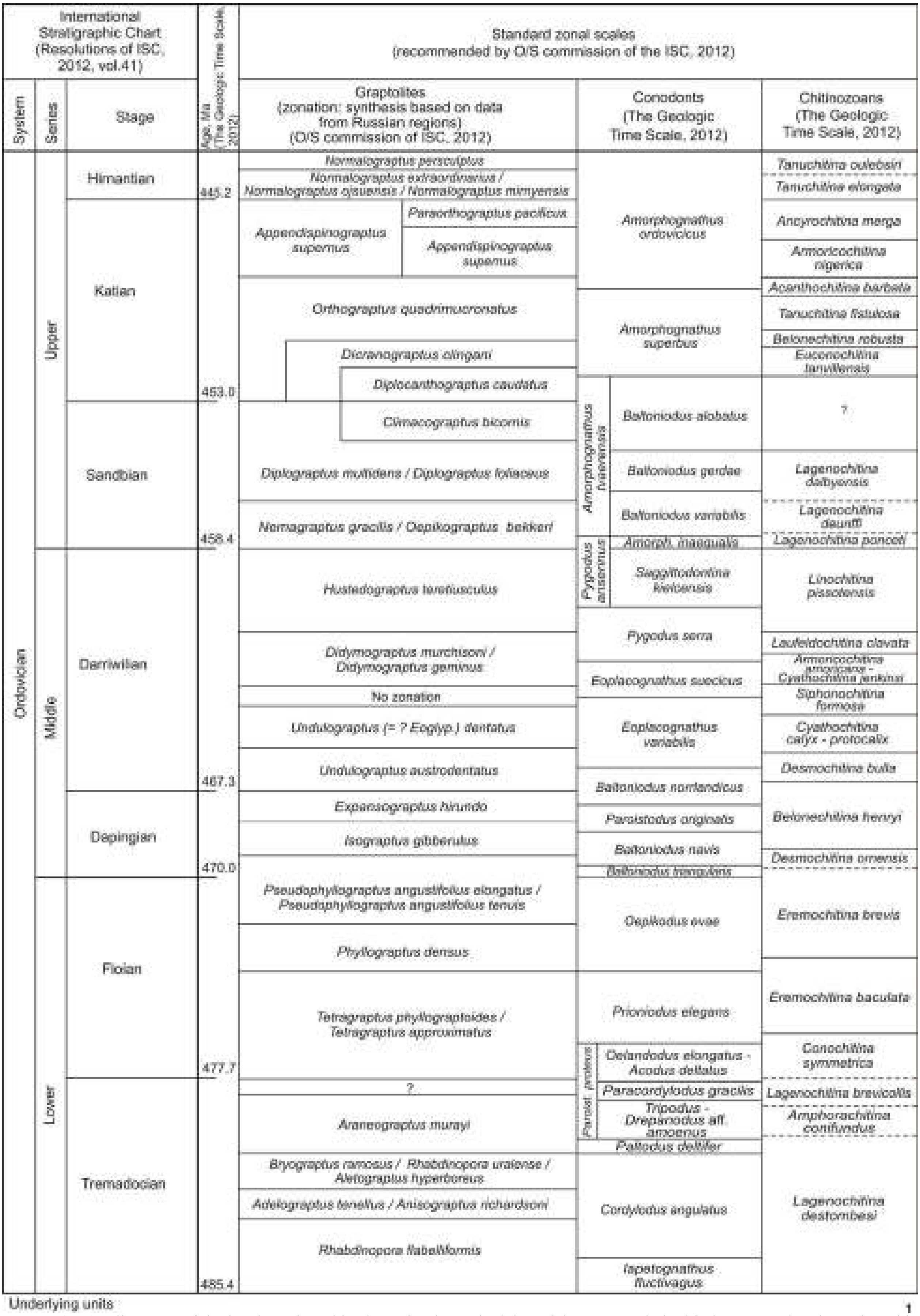
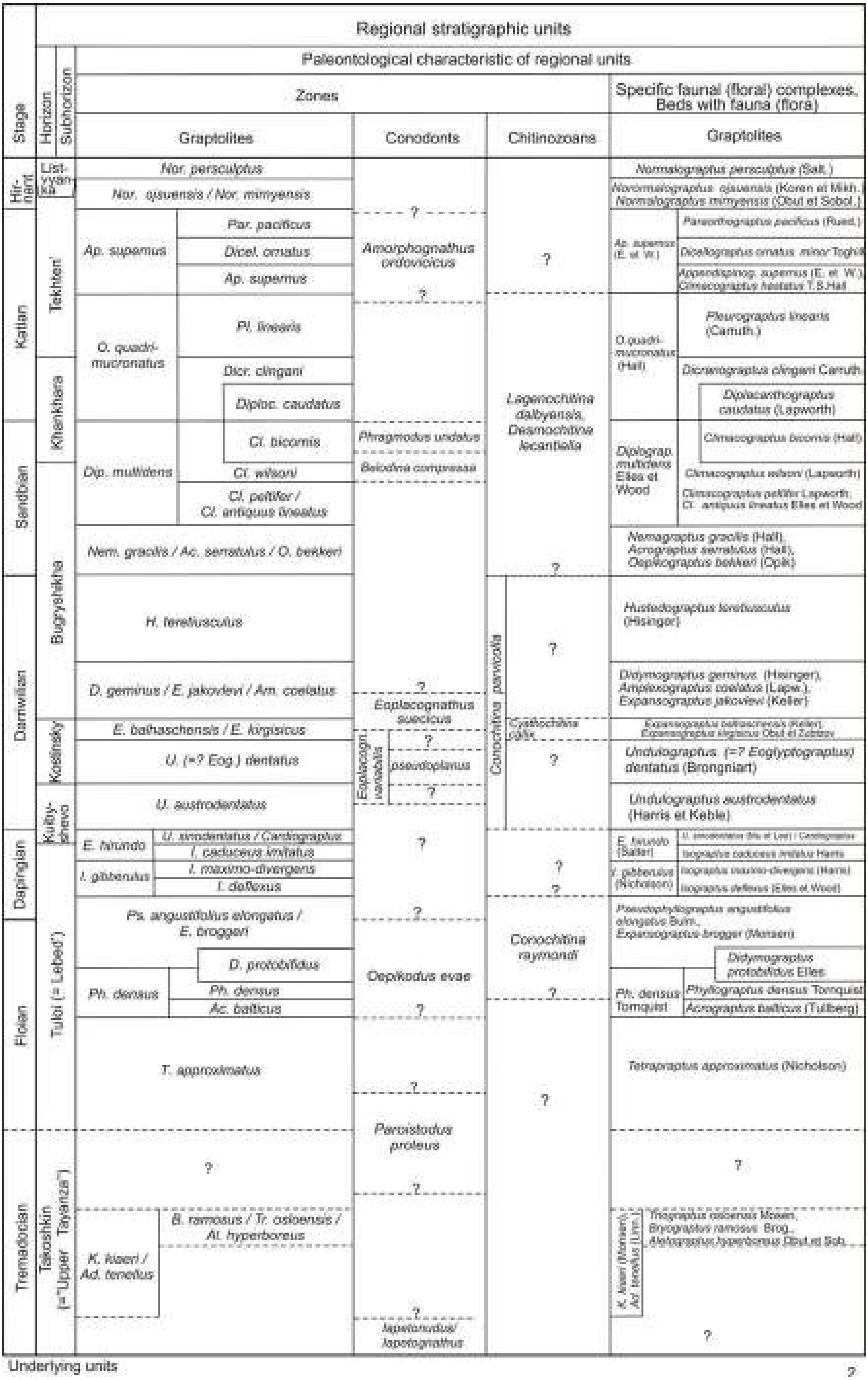


Fig. 4. Alignment of the local stratigraphic charts for the Ordovician of the Gorny Altai with the International Stratigraphic Chart based on regional stages (horizons), graptolite and conodont zones.



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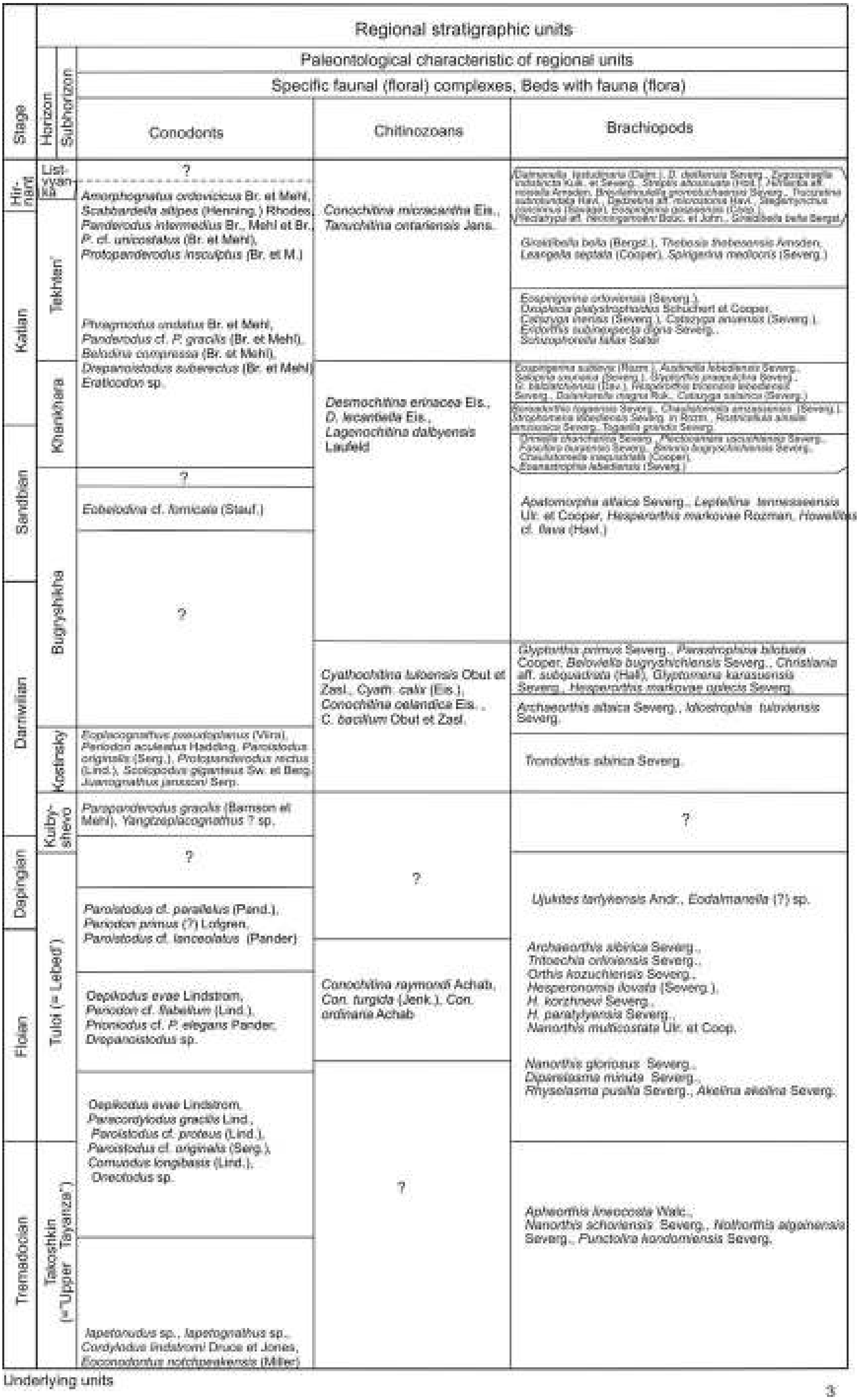

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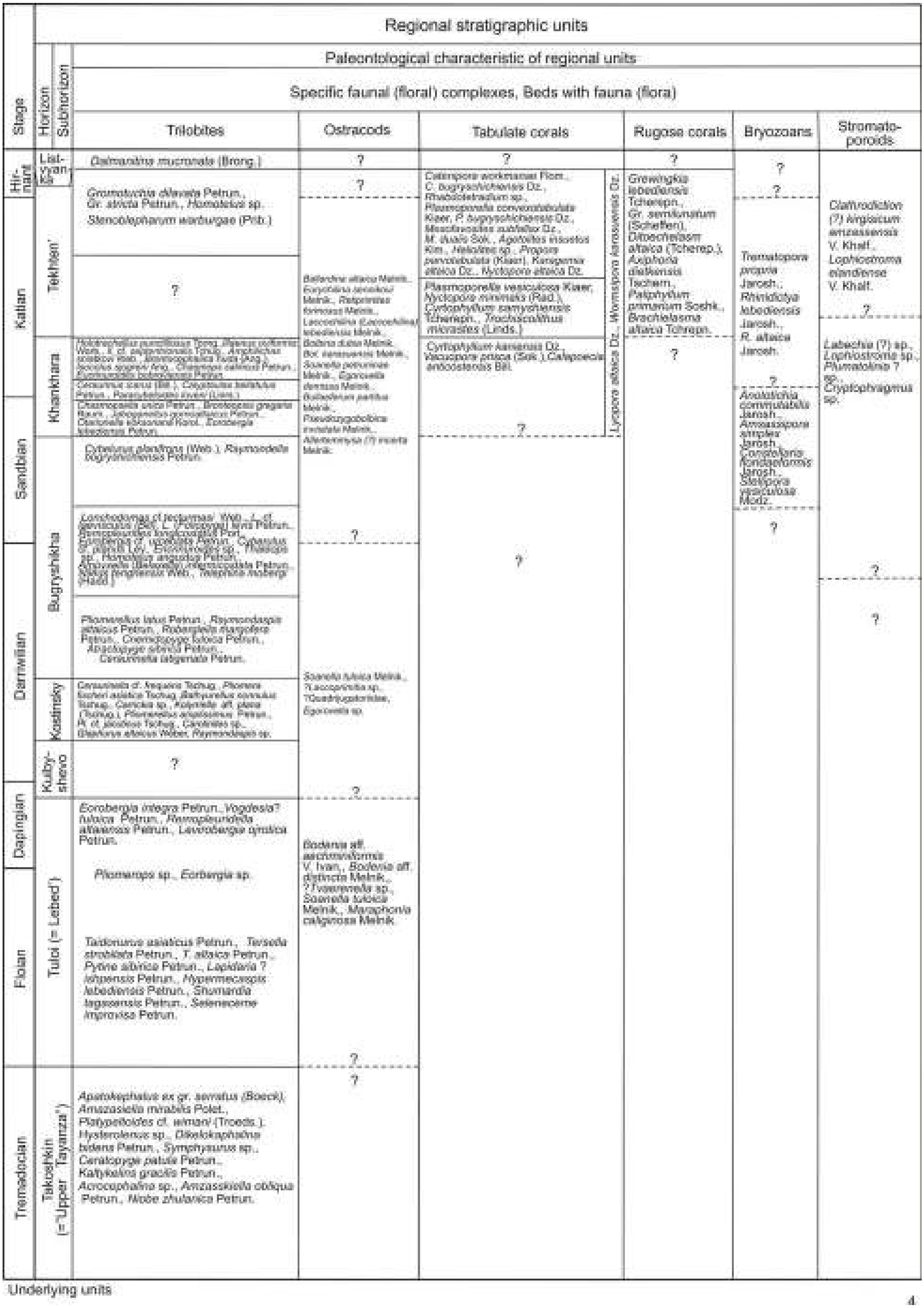

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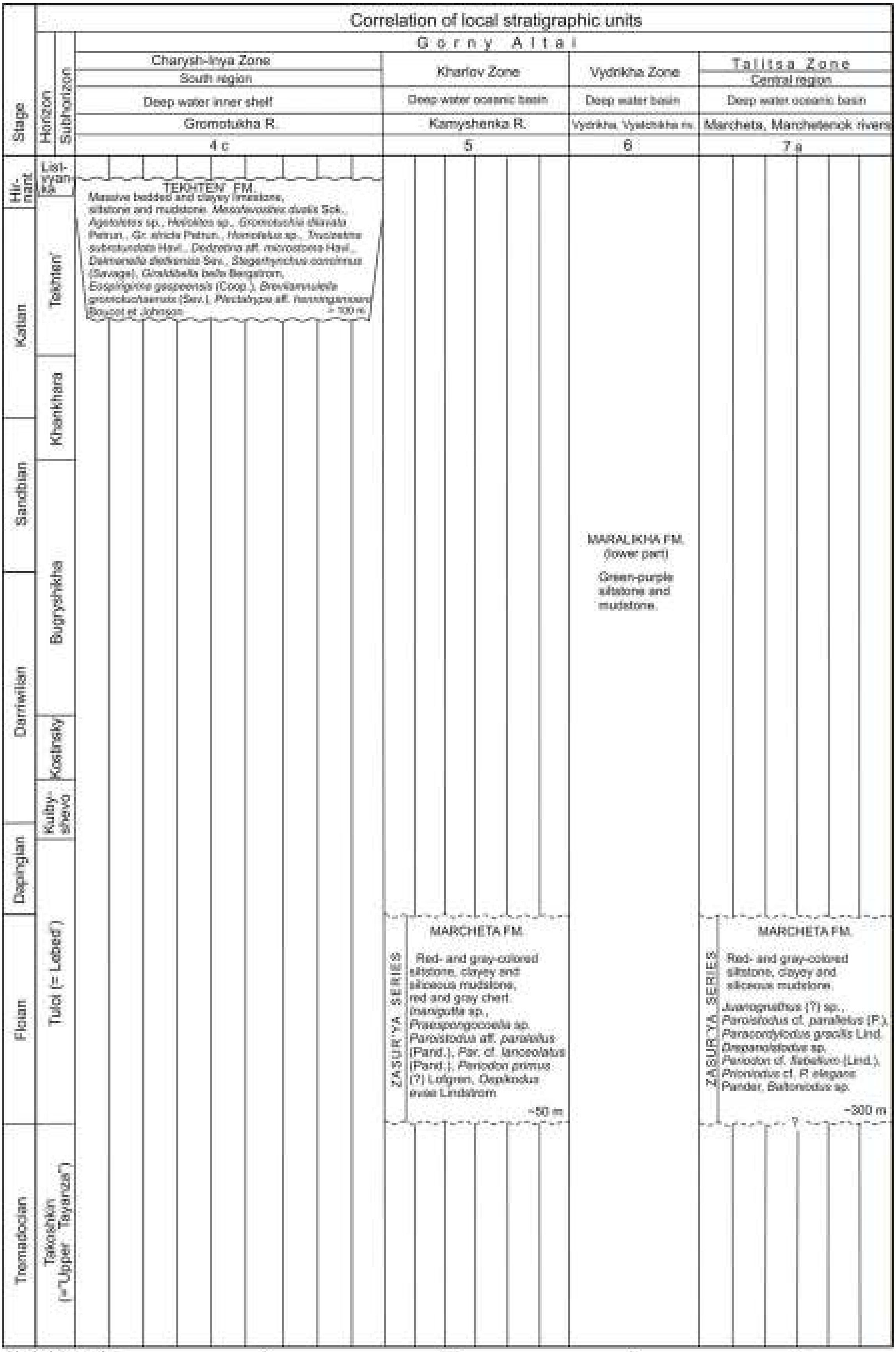

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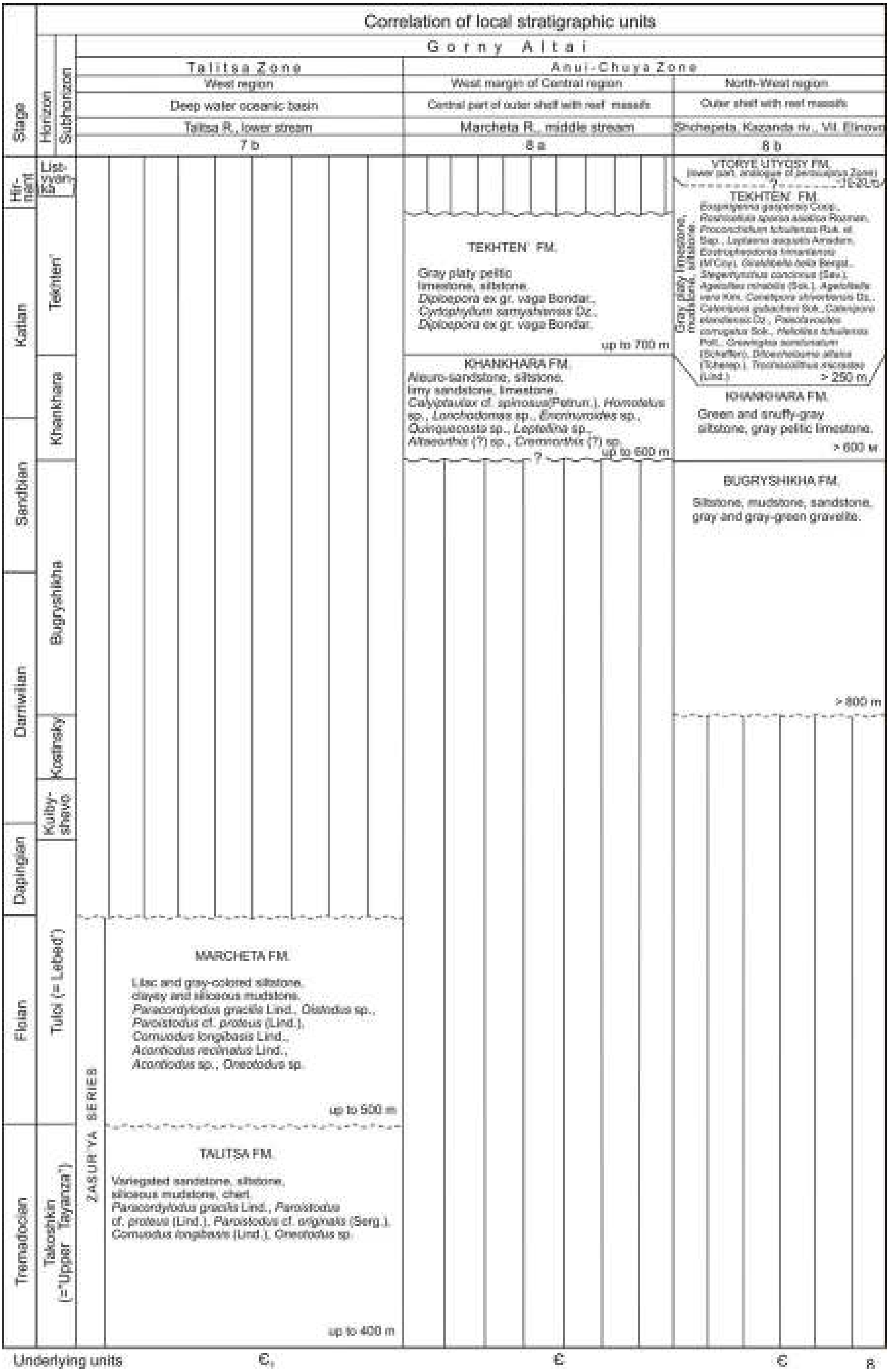

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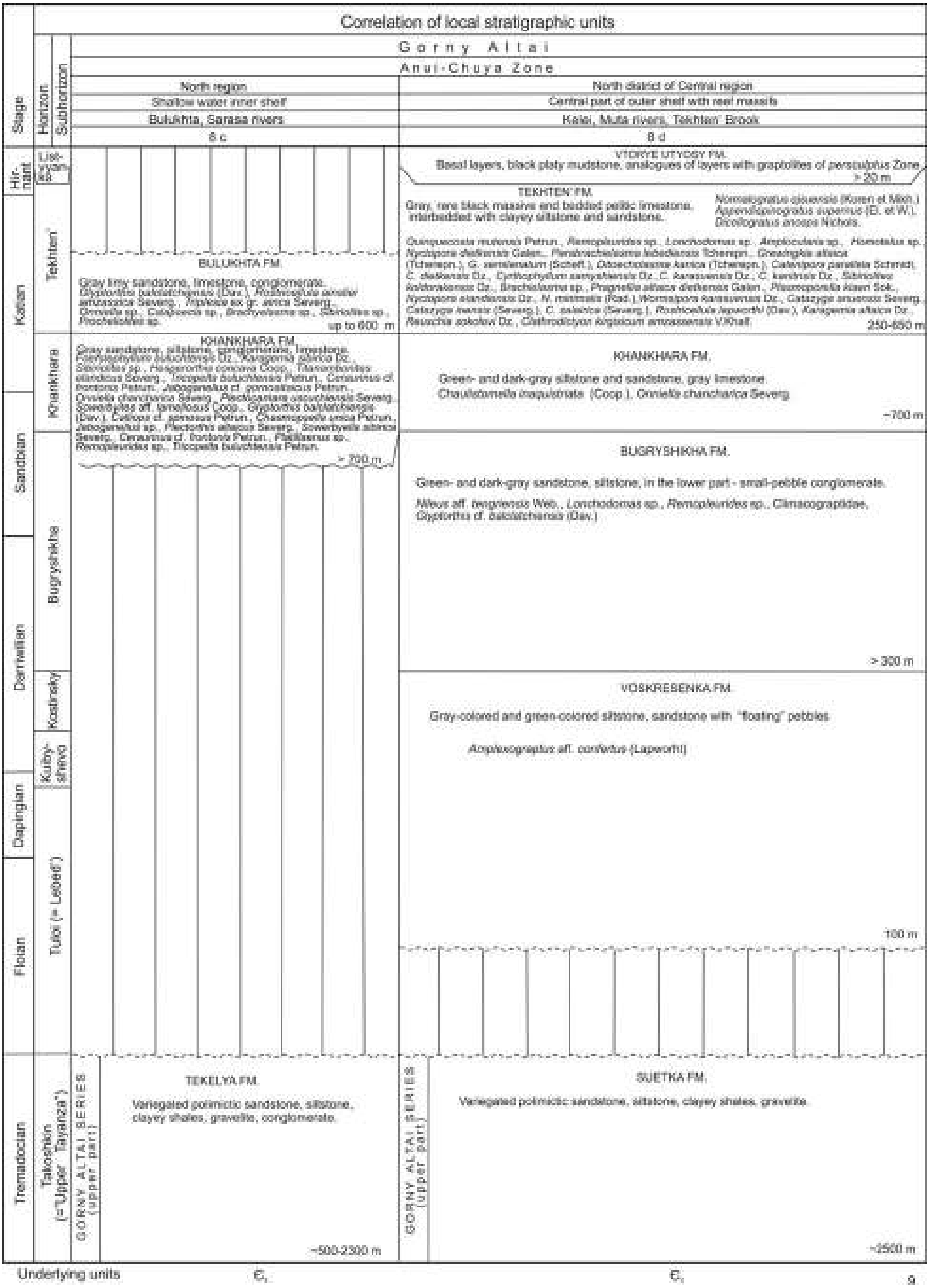

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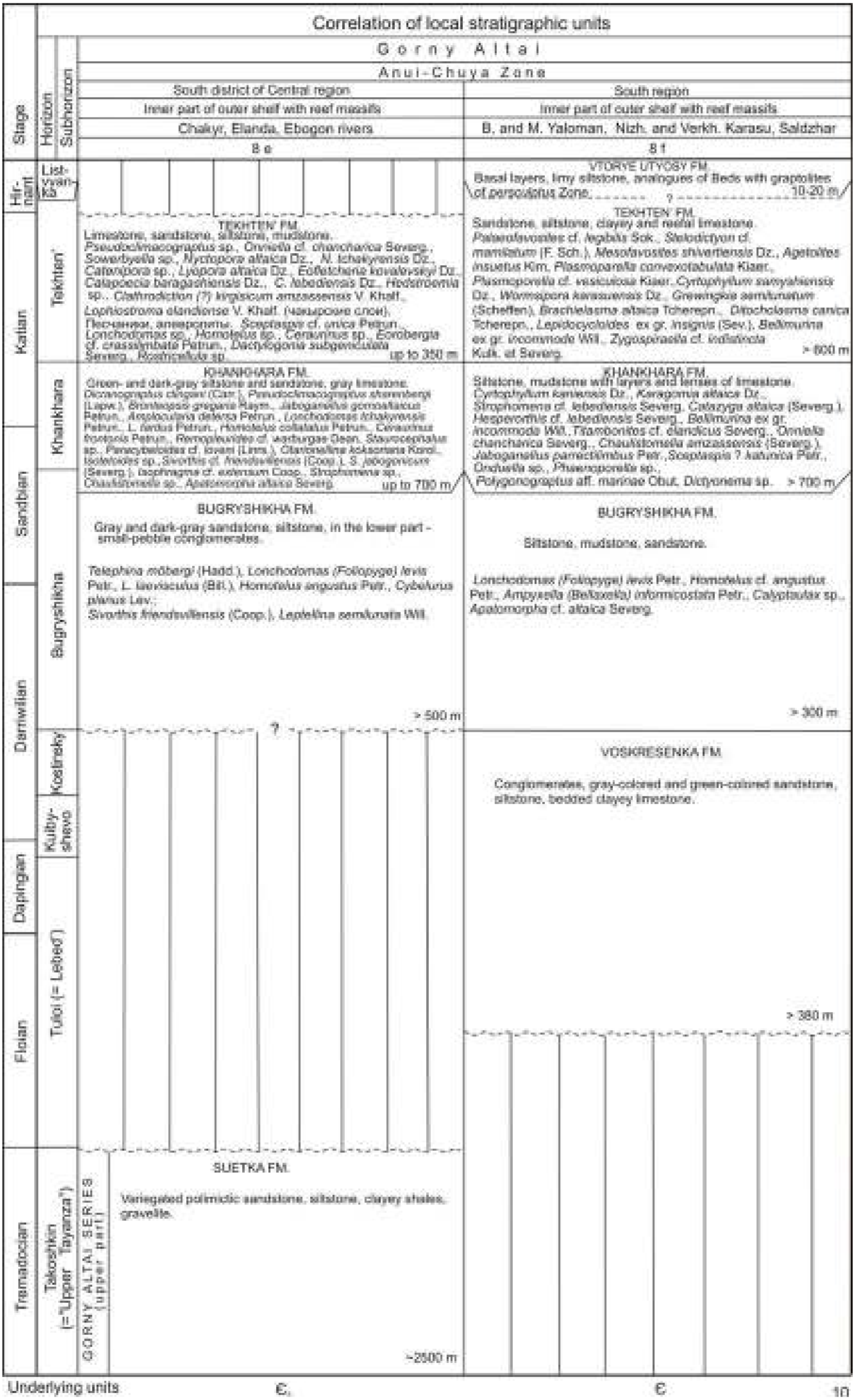

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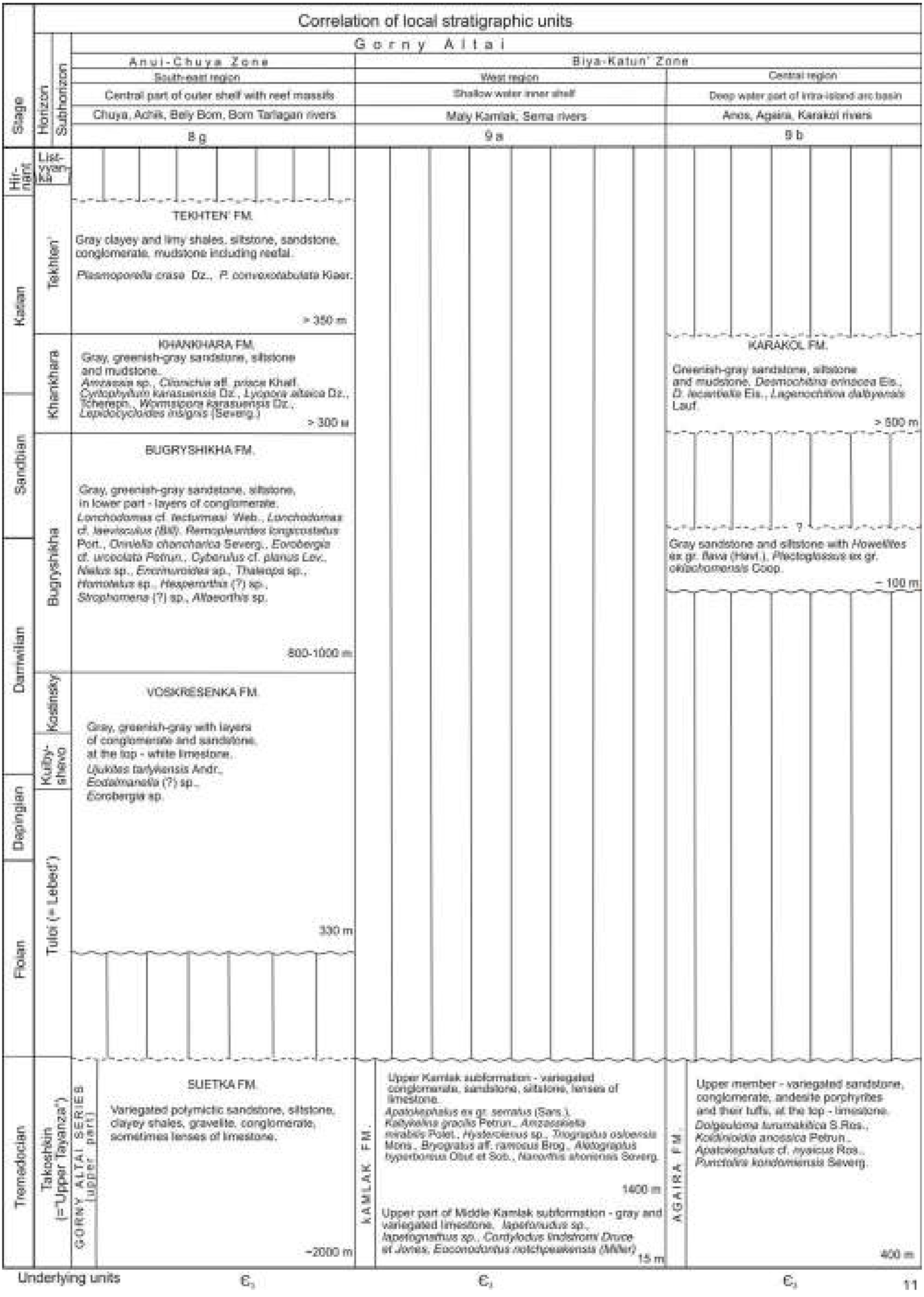

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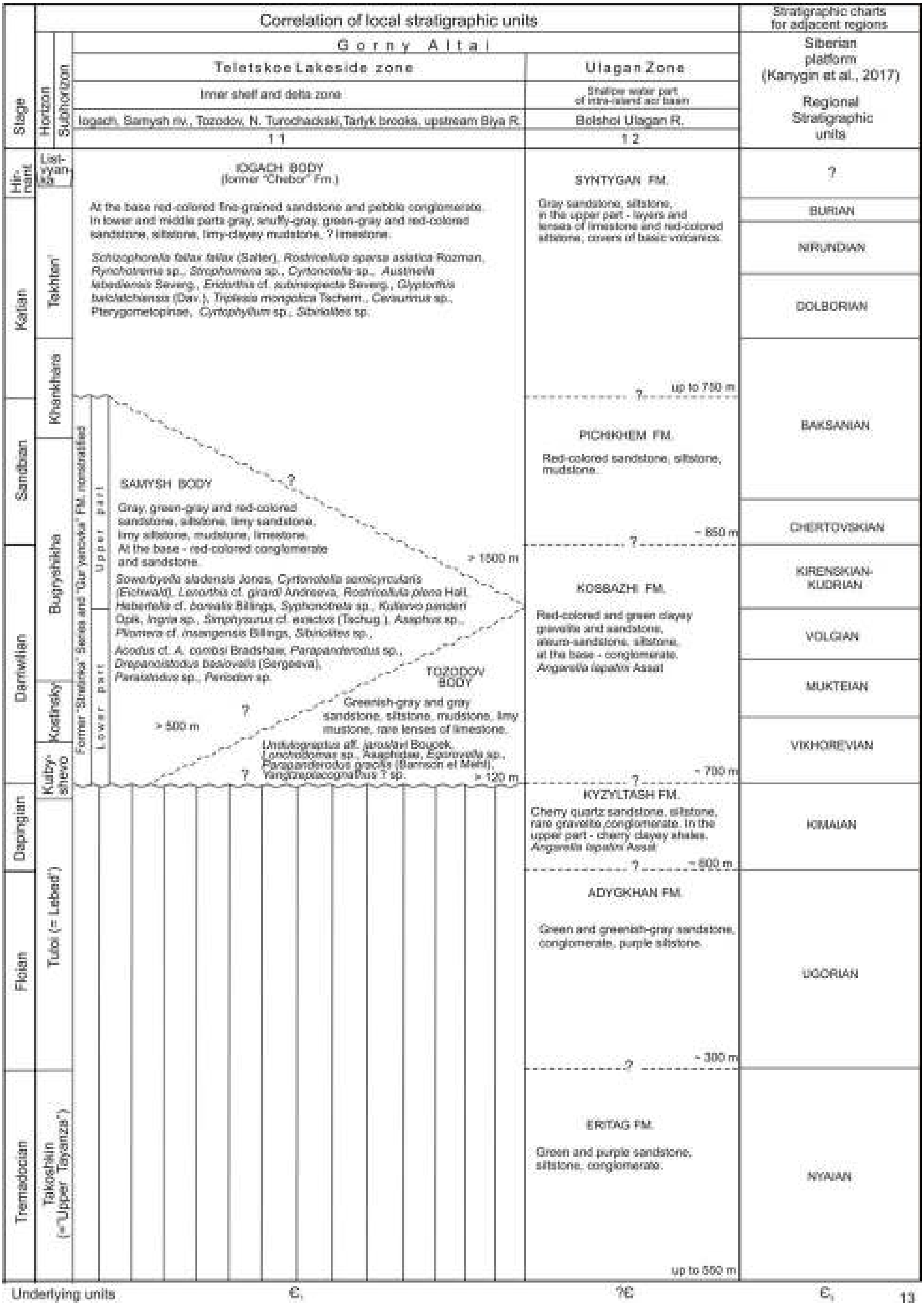

Stage
Horizon
Subhorizon
Correlation of local stratigraphic units
Gorny Altai
Teletskoe Lakeside zone
Inner shelf and delta zone
Iogach, Samysh riv., Tozodov, N. Turochackski, Tarlyk brooks, upstream Biya R.
11
Ulagan Zone
Shallow water part of intra-island acr basin
Bolshoi Ulagan R.
12
Stratigraphic charts for adjacent regions
Siberian platform (Kanygin et al., 2017)
Regional Stratigraphic units
Hirnant
Listvyanka
Katian
Tekhten'
Khankhara
Sandbian
Darriwilian
Bugryshikha
Kostinsky
Kubyshevo
Dapingian
Floian
Tuloi (= Lebed')
Tremadocian
Takoshkin (="Upper Tayanza")
Former "Strelnoka" Series and "Gur'yanovka" Fm. nonstratified
Upper part
Lower part
IOGACH BODY (former "Chebor" Fm.)
At the base red-colored fine-grained sandstone and pebble conglomerate. In lower and middle parts gray, snuffy-gray, green-gray and red-colored sandstone, siltstone, limy-clayey mudstone, ? limestone.
Schizophorella fallax fallax (Salter), Rostricellula sparsa asiatica Rozman, Rynchotrema sp., Strophomena sp., Cyrtonotella sp., Austinella lebedensis Severg., Eridorthis cf. subinexpecta Severg., Glyptorthis balclatchiensis (Dav.), Triplesia mongolica Tschern., Ceraurinus sp., Pterygometopinae, Cyrtophyllum sp., Sibiriolites sp.
SAMYSH BODY
Gray, green-gray and red-colored sandstone, siltstone, limy sandstone, limy siltstone, mudstone, limestone. At the base - red-colored conglomerate and sandstone.
Sowerbyella sladensis Jones, Cyrtonotella semicyrcularis (Eichwald), Lenorthis cf. girardi Andreeva, Rostricellula plena Hall, Hebertella cf. borealis Billings, Syphonotreta sp., Kullervo panderi Opik, Ingria sp., Simphysurus cf. exactus (Tschug.), Asaphus sp., Pliomera cf. insangensis Billings, Sibiriolites sp.,
Acodus cf. A. combsi Bradshaw, Parapanderodus sp., Drepanoistodus basiovalis (Sergeeva), Paroistodus sp., Periodon sp.
> 1500 m
> 500 m
TOZODOV BODY
Greenish-gray and gray sandstone, siltstone, mudstone, limy mustone, rare lenses of limestone.
Undulograptus aff. jaroslavi Boucek, Lonchodomas sp., Asaphidae, Egorovella sp., Parapanderodus gracilis (Barnson et Mehl), Yangtzeplacognathus ? sp.
> 120 m
SYNTYGAN FM.
Gray sandstone, siltstone, in the upper part - layers and lenses of limestone and red-colored siltstone, covers of basic volcanics.
up to 750 m
PICHIKHEM FM.
Red-colored sandstone, siltstone, mudstone.
~ 850 m
KOSBAZHI FM.
Red-colored and green clayey gravelite and sandstone, aleuro-sandstone, siltstone, at the base - conglomerate.
Angarella lapatini Assat
~ 700 m
KYZYLTASH FM.
Cherry quartz sandstone, siltstone, rare gravelite, conglomerate. In the upper part - cherry clayey shales.
Angarella lapatini Assat
~ 600 m
ADYGKHAN FM.
Green and greenish-gray sandstone, conglomerate, purple siltstone.
~ 300 m
ERITAG FM.
Green and purple sandstone, siltstone, conglomerate.
up to 550 m
?
BURIAN
NIRUNDIAN
DOLBORIAN
BAKSANIAN
CHERTOVSKIAN
KIRENSKIAN-KUDRIAN
VOLGIAN
MUKTEIAN
VIKHOREVIAN
KIMAIAN
UGORIAN
NYAIAN
Underlying units
?Є
13

Fig. 4. The end.

1.1.1. REGIONAL STRATIGRAPHIC UNITS OF THE WESTERN PART OF ASFA

Takoshkin (=Verkhne-Tayanza) Regional stage (Horizon) was defined by collective authors (Sennikov et al., 2014, 2018a,b).

The position of the lower boundary of the Ordovician System and, correspondingly, the position of the Tremadocian Stage (Lower Ordovician) were fixed in the Green Point type section on Newfoundland, Canada (Cooper et al., 2001), with the zonal conodont species *Iapetognathus fluctivagus*. The lower boundary of the Tremadocian is now correlated with the lower boundaries of the fossil-bearing Marcheta Formation (the Zasur'ya Group, Gorny Altai). With a low degree of certainty, the lower boundary of the Tremadocian is correlated with the lower boundaries of the nonfossiliferous Suetka and Tekelyu Formations (the Gorny Altai Group, Altai). Hereafter, for younger Ordovician chronostratigraphic intervals, no data are presented on the succession of formations in the Ulagan zone of Gorny Altai: Eritag, Adygkhan, Kyzyltash, Kosbazhi, Pichikhem, and Syntygan (Naumenko and Gutak, 1982). This is explained by the fact that the boundaries of these six formations are tentatively correlated with the lower boundaries of six Ordovician stages of the ISS because of the extremely poor paleontological knowledge of the entire Ordovician section of this part of Altai. According to the old official chart (Decisions…, 1983), the Dobry Horizon was the oldest one in the succession of Ordovician regional stratigraphic units in the western ASFA. This horizon was detected from trilobite assemblages and correlated with the Lower Tremadocian. The Upper Tremadocian included the next horizon - the Tayanza Horizon, substantiated (Decisions…, 1983) by a succession of trilobite assemblages (Petrunina, 1966, 1968, 1973). In recent years, in the Biya–Katun' zone (Gorny Altai), the Middle Kamlak Subformation, correlated on trilobites with the Tayanza Horizon, conodont assemblages (including the Upper Cambrian *Proconodontus* Zone and the lowermost Ordovician *Iapetognathus/Iapetonudus* Zone), which mark the position of the Cambrian/Ordovician boundary in the upper Tayanza Horizon (Sennikov et al., 2014) were found. The Tayanza Horizon on trilobites in the key sections of Gornaya Shoriya was divided into three zones: (1) *Ap. sibiricus/N. oriens*, (2) *Am. mirabilis/Sh. pusillina*, and (3) T*er. strobilata/Niobe zhulanica* (Petrunina, 1966, 1968). On the other hand, in the Middle and Upper Kamlak subformations of the Biya–Katun' zone (Gorny Altai) and in the Middle and Upper Ishpa subformations of the Uymen'-Lebed' zone, the Tayanza Horizon contains two trilobite assemblages clearly different in stratigraphic position. The first one corresponds to above-mentioned two lower trilobite zones, whereas the upper one corresponds to the third zone. Therefore, the Tayanza regional stratigraphic unit could be accepted in horizon rank and divided into two subhorizons, formally named "Lower–Middle Tayanza" and "Upper Tayanza". The lower unit must correspond to the upper Cambrian (the *Proconodontus* conodont Zone), whereas the "Upper Tayanza" unit must belong to the Tremadocian: the *Iapetognathus/Iapetonudus* conodont Zone and the *B. ramosus/Tr. osloensis/Al. hyperboreus graptolite* Zone (Sennikov et al., 2008, 2014; 2018a,b).

The trilobite species *Harpidoides eximius* Petrun., *Acrocephalina lata* Petrun., *A. contracta* Petrun., *Lusampa cupoides* Petrun., *L. tenuis* Petrun., *Bilacunaspis repentis* Petrun., *B. angusta* Petrun., *Niobella altaiensis* Petrun., *Proapatokephalops altaicus* Petrun., *Plethopeltides* (*Maximovella*) *improvisus* Petrun., and *Ishpella repentina* Petrun., which coexist in the Lower Kamlak Subformation with the conodonts of the Upper Cambrian *Proconodontus* Zone, were previously assigned to the Dobry Horizon, correlated with the Lower Tremadocian. According to the presented conodont data, the Dobry Horizon in the western ASFA should be correlated with the Upper Cambrian. Trilobites *Kaufmannella (Butyrinia) robustispina* Petrun. and *Kaltykelina altaica* Petrun., typical of the upper Dobry Horizon and the Lower–Middle Tayanza Subhorizon, are observed in the upper part of the Lower Kamlak Subformation and in the Middle Kamlak Subformation, lower in the section than conodonts *Iapetonudus* sp. These Dobry-Tayanza "transitional" taxa should be assigned to the Late Cambrian. Trilobites *Niobides* cf. *armatus* Harr. et Leanza, *Platypeltoides* cf. *anderssoni* (Troeds.), *Platypeltoides* cf. *wimani* (Troeds.), *Macropyge urceolata* Petrun., *Apatokephalus kamlakensis* Petrun., and *Harpidoides assiensis* Petrun. in the upper part of the Middle Kamlak Subformation were previously assigned to the lower Tayanza Horizon (= "Lower–Middle Tayanza" Subhorizon) and correlated with the lower part of the Upper Tremadocian. As the considered trilobite taxa were found lower in the Kamlak Section than conodonts *Iapetonudus* sp. and *Iapetognathus* sp., the lower part (two-thirds?) of the Tayanza Horizon ("Lower–Middle Tayanza" Subhorizon) should be viewed as the uppermost Upper Cambrian interval in the western ASFA. The trilobite species *Ishpella platycephala* Petrun., observed in all three Kamlak subformations, and the trilobite species *Amzasskiella mirabilis* Polet. in the lower part of the upper Middle Kamlak Subformation and in the Upper Kamlak Subformation within a lower interval than the graptolites of the Upper Tremadocian *ramosus/osloensis/hyperboreus* Zonal Level, previously assigned to the Dobry–Tayanza and Lower– Upper Tayanza "transitional" forms, respectively, should be considered Cambrian–Ordovician "transitional" taxa. In the light of the foregoing, the *Ap. sibiricus/N. oriens* trilobite Zone should be correlated with the Upper Cambrian, whereas the *Am. mirabilis/Sh. pusillina* Zone should occupy a transitional position between Cambrian and Ordovician. The elements of the assemblage of the third trilobite zone of the Tayanza Horizon – the species *Bijaspis katuniana* Petrun., *Parapliomera sibirica* Petrun., *Deltacare sibirica* Petrun., *Euloma shorica* Petrun., *Apatokephalus* ex gr. *serratus* (Sars), *Hysterolenus verus* Petrun., and *Borogothus* *altaicus* Petrun., observed in the upper part of the Upper Kamlak Subformation, lower than the graptolites of the Upper Tremadocian *B. ramosus/Tr. osloensis/Al. hyperboreus* Zonal Level, which are assigned to the "Upper Tayanza" Subhorizon and previously correlated with the Upper Tremadocian should be correlated with the chronostratigraphic extent of the entire Tremadocian.

Tuloi (=Lebed') Regional stage (Horizon) was proposed by collective authors (Decisions…, 1983; Sennikov et al., 2014, 2018a,b).

The GSSP of the Lower Ordovician Floian Stage of the ISS was detected in the Diabasbrottet Section, Sweden, and marked by the first appearance of the graptolite marker species *Tetragraptus approximatus* (Bergström et al., 2004). The marker species of the lower boundary of the Floian Stage *T. approximatus* is observed in the Tuloi Formation of the Uymen'–Lebed' zone of Gorny Altai. Correspondingly, the lower boundary of the Tuloi Formation (Tuloi stratotype section) and the lower boundary of the regional stratigraphic unit based on biostratigraphic data on this formation – the Lebed' Horizon, are correlated with the base of the Floian Stage of the GSSR. The lower boundary of the Talitsa Formation (Zasur'ya Group) in northwestern Gorny Altai is correlated by conodont assemblages with the lower boundary of the Floian Stage less reliably than the lower boundary of the Tuloi Formation. The *Lagenochitina esthonica chitinozoan* Zone is recognized in the interval corresponding to the Floian Stage, in the GSSP of the younger Dapingian Huanghuachang Stage, China (Wang et al., 2005). The species *Conochitina raymondii* Achab (Achab, 1989) was recognized in this zone on Newfoundland, Canada, and, later, on the Yangtze Plate, China (Wang and Chen, 2003). This species was found in the Tuloi Formation of the Uymen'–Lebed' zone, Gorny Altai, in the *densus* graptolite Zone in a section near the Tandoshka River (Sennikov and Obut, 2002). It is more complicated to determine the chronostratigraphic position of the upper boundary of the previously used stratigraphic units: the Lebed' Horizon and Tuloi Formation. Finds of a diverse graptolite assemblage in the new Pridorozhny Section of Altai (Bukolova, 2011), in the uppermost Tuloi Formation of the Uymen'–Lebed' zone, Gorny Altai, immediately beneath the basal member of the Karasa Formation, require that the upper boundary of the Tuloi Formation (and, correspondingly, the lower boundary of the overlying Karasa Formation) be placed lower, at the boundary between *I. caduceus imitatus* and *U. sinodentatus/Cardiograptus* subzones of the *E. hirundo* graptolite Zone. Previously (Decisions…, 1983), the upper Tuloi Formation was correlated with the Kostinsky and lower part of Bugryshikha horizons. This contradicted brachiopod data (Kul'kov and Severgina, 1989) on the presence of the species *Trondorthis sibirica* Severg. in the type section of the Kostinsky beds near former Batun Village, in the lower Karasa Formation, which overlay the Tuloi Formation. With accepting an older age for the upper boundary of the Tuloi Formation (and, correspondingly, the lower boundary of the Karasa Formation), the brachiopod assemblage with *Trondorthis sibirica* Severg. occupies the same stratigraphic position both in the Kostinsky beds of the Voskresenka Formation (the Charysh–Inya zone of Gorny Altai) and the lower part Karasa Formation (the Uymen'–Lebed' zone of Gorny Altai). When the Lebed' Horizon was recognized, it encompassed (including the Lebed' stratotype section near Stretinka Village) the Tuloi Formation of the Uymen'–Lebed' zone, Gorny Altai, without its uppermost part (Decisions…, 1983). To prevent uncertainty in understanding the phrase "without its uppermost part," the stratigraphic extent of the Lebed' stratotype Section should be increased (by less than one-third) to that of the entire Tuloi Formation. Previously (Decisions…, 1983), the Lebed' Horizon was correlated with the Arenigian (a Stage of the British scale) and did not extend beyond the Lower Ordovician. In the proposed new version, the Lebed' Horizon in its stratotype coincides with the Tuloi Formation. In the new stage division of the GSSP, the Tuloi (=Lebed') Horizon will correspond to the Lower Ordovician Floian Stage and three-quarters of the Middle Ordovician Dapingian Stage.

Tuloi (=Lebed') Horizon is characterised by graptolites zones: *approximatus, densus* (*balticus* and *densus subzones*), *protobifidus, angustifolius elongatus – broggeri, gibberulus* (*deflexus and maximo-divergens* subzones*), hirundo* (*caduceus imitatus* Subzone).

Kuibyshevo Regional stage (Horizon) was proposed by collective authors (Sennikov et al., 2014, 2018a,b). The Dapingian GSSP is the Huanghuachang section, China, which is marked by the first appearance of the conodont species *Baltoniodus triangularis* (Wang et al., 2005). The Huangnitang Section, China, marked by the first appearance of the graptolite species *Undulograptus austrodentatus* (Mitchell et al., 1997), was selected as the Darriwilian GSSP. These two boundaries do not coincide with any of the boundaries of the fossil-bearing Ordovician local stratigraphic units of the western ASFA. With accepting an older age for the upper boundary of the Tuloi Formation, Gorny Altai (see above), a large stratigraphic gap has been detected from graptolite zonal stratigraphy between the upper boundary of the Tuloi (=Lebed') Horizon and the lower boundary of the overlying Kostinsky Horizon, according to the official Ordovician stratigraphic chart of the ASFA (Decisions…, 1983). The convergence of these two neighboring horizons, required by the stratigraphic chart of 1979 (Decisions…, 1983), was not confirmed in individual sections. In the zonal scale of graptolites from the stratotypes of the considered horizons, the Tuloi (=Lebed') Horizon has "terminated" (zonal dating of the upper boundary of the horizon), whereas the Kostinsky Horizon has not "begun" (zonal record of the lower boundary of the horizon). No actual relationships between the horizons (more precisely, neighbouring peculiar faunal assemblages) were observed in the Altai or Salair sections: The stratotype of the Tuloi (=Lebed') Horizon with the Tuloi (=Lebed') assemblage of benthic fauna is localized in the Uymen'–Lebed' zone of Gorny Altai (Lebed' Section), whereas the type sections of the Kostinsky Horizon with a peculiar assemblage of benthic fauna are localized in the Charysh–Inya zone of this region (the Barany Section in the upper Voskresenka Formation near Ust'-Chagyrka Village and the Batun Section near former Batun Village). In the Uymen'–Lebed' Zone of Gorny Altai, the Tuloi Formation (including the stratotype of the Lebed' Horizon near the Lebed' River) is overlain by the basal sandstone member of the Karasa Formation, which does not contain any fossils. Also, they are very few in higher members of the lower Karasa Formation. The Kostinsky beds of the upper Voskresenka Formation (including the formation stratotype near the Barany Creek) in the Charysh–Inya zone of Gorny Altai are underlain by nonfossiliferous sandstone and siltstone members. In connection with these two facts, note that no sections with a continuous succession of benthic faunal assemblages are known from upper Tuloi (=Lebed') Horizon to lower part of Kostinsky Horizon in Gorny Altai or Salair Ridge. The data on the pelagic graptolite assemblages in their synthesized Altai zonal succession, compared with the data from the stratotypes of the Tuloi (=Lebed') and Kostinsky horizons, clearly indicate the presence of a chronostratigraphic interval between the termination of the former and the beginning of the latter. A new horizon is required for a continuous chronostratigraphic succession of regional units; e.g., the Kuibyshevo Horizon, after Kuibyshevo Village, Gorny Altai, with a stratotype in the Maralikha-1 Section, in the Charysh–Inya zone of the region, which contains graptolite assemblages showing a continuous zonal succession (Sennikov et al., 2008). The new horizon includes the *U. sinodentatus/Cardiograptus* Subzone of the *E. hirundo graptolite* Zone and the *U. austrodentatus graptolite* Zone. The stratotype section of the Kuibyshevo Horizon contains the graptolite assemblage of the *I. caduceus imitatus* Subzone of the *E. hirundo graptolite* Zone (Sennikov et al., 2008), which corresponds to the uppermost Tuloi (=Lebed') Horizon. Also, the Maralikha-1 Section contains some specimens from benthic groups: trilobites, brachiopods, nautiloids, and crinoids, which might permit determining the possible benthic faunal assemblage for the Kuibyshevo Horizon. In the new stage division of the GSSP, the Kuibyshevo Horizon will correspond to the upper quarter of the Dapingian and the lower quarter of the Darriwilian.

Kostinsky Regional stage (Horizon) was defined by E.S. Levitsky (Levitsky, 1963; Severgina, 1973; Sennikov et al., 1982; Decisions…, 1983; Sennikov et al., 2014, 2018a,b). It is aligned with the upper half of the lower Darriwilian (Da1) and middle Darriwilian (Da2).

In connection with new finds of graptolite assemblages in the type locality of the Kostinsky Horizon (the Batun Section near former Batun Village) near the Kostinsky mine in the Charysh–Inya zone of Gorny Altai, the stratigraphic extent of the Kostinsky Horizon should be increased (by less than one-third) to include two graptolite zones: *U*. (= *?Eogl.*) *dentatus* and *E. balhaschensis/E. kirgisicus.* Previously, the Kostinsky Horizon included the Lower Llanvirnian and corresponded to the interval of the now-invalid *D. bifidus* graptolite Zone (Decisions…, 1983); later, it was correlated (Sennikov, 1996) with its chronostratigraphic analog – the *E. balhaschensis/E. kirgisicus* graptolite Zone. In the new stage division of the GSSP, the Kostinsky Horizon will correspond to the second quarter of the Dapingian. Analysis of available biostratigraphic data permits more precise positioning of the lower boundary of the Zaichikha Formation in the Berd'–Khmelevka zone of the Salair Ridge. Its base was previously correlated with the lower boundary of the *H. teretiusculus* graptolite Zone (Decisions…, 1983) and, later (Petrunina and Sennikov, 1986), with the upper boundary of the Arenig (top of the *E. hirundo* graptolite Zone). In the Izyrak Section, which is the stratotype for the Izyrak Formation, underlying the Zaichikha Formation, and the parastratotype for the latter, graptolites of the *E. balhaschensis* Zone were detected in the uppermost Izyrak and the lowermost Zaichikha formations. Graptolites of the *E. jakovlevi* Zone were detected 20 m higher in the section than the base of the Zaichikha Formation. The lower boundary of the Zaichikha Formation should be placed in the upper one-third (?upper quarter) of the *E. balhaschensis* Zone, i.e., below the upper boundary of the Kostinsky Horizon in the middle Darriwilian Stage. Similar new data on the distribution of graptolites permit more precise positioning of the base of the Karastun Formation in the Gur'evsk–El'tsovka zone of the Salair Ridge. Its lower boundary was correlated with the lower boundary of the *H. teretiusculus* graptolite Zone (Decisions…, 1983). Graptolites of the *E. balhaschensis/E. kirgisicus* Zone were detected in the Korovy Prud Section in this part of the Salair Ridge, in the lowermost Karastun Formation. By analogy with the lower boundary of the Zaichikha Formation (see above), this suggests a correlation between the base of the Karastun Formation and the upper part of the *E. balhaschensis/E. kirgisicus* graptolite Zone.

The Kostinsky Horizon is characterized by trilobite fauna *Megalaspides sibirica* Petrun., *Eorobergia compacta* Petrun., *Kolymella* cf. *plana* (Tchug.), *Eccoptochile tchagyrica* Petrun., *Ceraurinella* cf. *frequens* Tchug., and brachiopods *Idiostrophia costata* Ulrich and Cooper, *Chaganella* sp., *Hesperonomia tylyensis* Severg., *Hesperonomiella kuznetskiana* Severg., *Beloviella salairica* Severg., *Trondorthis sibirica* Severg., *Tr. talovkiensis* Severg.

Graptolites of the dentatus-kirgisicus Zone are known from the Kostinsky Horizon. Regional *dentatus-kirgisicus* Zone is treated as analogue of the *artus* Zone of the British zonal scale and the *dentatus* Zone of the North-American zonal scale of the International Stratigraphic Scale, that coincides with lower 4b (=Da2) and transitional 4a/4b (Da1/ Da2) of the middle part of the Darriwilian Stage (Webby et al., 2004).

Conodonts of the *E. pseudoplanus* Zone aligned with upper subzone of the variabilis zone from the North-Atlantic zonal scale of the International Stratigraphic Scale, that coincides with the upper part of 4a (=Da1) and lower one third of 4b (=Da2) of the middle part of the Darriwilian Stage (Viira et al., 2001; Webby et al., 2004) are recovered from this horison.

Bugryshikha Regional stage (Horizon) was proposed by (Levitsky, 1963; Severgina, 1965, 1968, 1972, 1973; Gintsinger, V.Sennikov, 1967; Stratigraphic…, 1975; Decisions…, 1983; Sennikov et al., 2018a,b). This horizon is aligned with upper Darriwilian (Da3), lower Sandbian (Sa1) and lower half of upper Sandbian (Sa2).

The Sandbian GSSP, localized in the Fågelsång Section, Sweden, is marked by the first appearance of the graptolite species *Nemagraptus gracilis* (Bergström et al., 2000). This boundary is correlated with the lower boundary of the fossiliferous Gur'yanovka Formation of the Uymen'– Lebed' zone, Gorny Altai. The Sandbian Stage is divided into two time slices (Bergström et al., 2009), proposed as "informal" substages: lower and upper. The lower boundary of the upper one is marked by the base of the *Cl. bicornis* graptolite Zone. Reliable data have been obtained that the lower boundary of the Khankhara Horizon, detected (Sennikov et al., 2008) within the Khankhara Formation of the Charysh–Inya zone of Gorny Altai (and the lower boundary of this formation) corresponds to the middle part of the *Cl. wilsoni* graptolite Zone (Sennikov et al., 2011a). A basal member of oolitic limestones is localized within the Malaya Uskuchevka Section (doublet section of the formation parastratotype near the Bol'shaya Uskuchevka River) and the Khankhara Section (formation stratotype) at the base of the Khankhara Formation. In the Malaya Uskuchevka Section (Sennikov et al., 2008), the boundary between the graptolite assemblages of the *Cl. peltifer/Cl. antiquus lineatus* Zone (which underlies the *Cl. wilsoni* Zone) and the *Cl. wilsoni* Zone is much lower than the base of the oolitic limestones in the middle Bugryshikha Formation. This is to emphasize that the lower boundary of the Khankhara Formation must be localized higher in the section than the lower part of the *Cl. wilsoni* graptolite Zone. In the Ebogon Section, in the Anui–Chuya zone of Altai, the first (lowest) finds of the graptolite assemblage of the *Dicr. clingani* Zone (which overlies the *Cl. wilsoni* Zone) are localized considerably higher that the basal member of oolitic limestones, in the upper Khankhara Formation. This indicates that the lower boundary of the Khankhara Formation must be localized lower than the lower boundary of the *Dicr. clingani* graptolite Zone. The lower boundary of the Khankhara Horizon (and, correspondingly, the base of the Khankhara Formation) should be correlated with the lower boundary of the *Cl. bicornis* graptolite Zone (Teilzone including the upper part of the *Cl. wilsoni* Complexes Zone), which will correspond to the base of the "informal" Upper Sandbian Substage in the new stage subdivision of the GSSP. Conodonts from two interbeds of lumpy and clayey limestones with abundant shell fragments are observed at the lower boundary of the Khankhara Horizon from the section of the middle Gur'yanovka Formation, which is localized on the right bank of the Biya River, near the Chechenek Creek (the Biya Section in the Uymen'–Lebed' zone of Gorny Altai. The conodonts are of medium preservation, and their assemblage includes the species *Panderodus gracilis* (Branson and Mehl), *Phragmodus undatus* Branson and Mehl, and *Erraticodon* sp., typical of the Upper Sandbian *Belodina compressa* and *Phragmodus undatus* zones. Analysis of the biostratigraphic data makes it possible to revise the chronostratigraphic position of the lower boundary of the Veber Formation of the Gur'evsk–El'tsovka zone, Salair Ridge. In the official stratigraphic chart (Decisions…, 1983), the base of the Veber Formation, according to the data from regional correlations of benthic communities, was placed at the base of the *Pl. linearis* graptolite Zone (correlated with the base of the Ashgillian). A brachiopod assemblage with *Boreadorthis togaensis* Severg. was detected in the lower Veber Formation, near El'tsovka Village (Bobrovka limestones). This species is typical of the lower part of the Upper Gur'yanovka Subformation in the Lebed' River Section in the Uymen'–Lebed' zone of Gorny Altai (Kul'kov, Severgina, 1989). The boundary between Lower and Upper Gur'yanovka subformations, based on finds of conodonts (Lebed' and Biya sections) *Scandodus* sp., *Phragmodus undatus* Br. et M., *Panderodus* cf. *P. gracilis* (Br. et M.), *Belodina compressa* (Br. et Mehl), and *Aphelognathus* sp., is now correlated with the lower boundary of the Khankhara Horizon. Thus, with the present state of knowledge, the lower boundary of the Veber Formation of the Gur'evsk–El'tsovka zone of the Salair Ridge should be correlated with the base of the Khankhara Horizon, i.e., with the base of the *Cl. bicornis* graptolite Zone. In the new stage division of the GSSR, the base of the Veber Formation will correspond to the base of the "informal" Upper Sandbian Substage. On the other hand, note that trilobites *Tretaspis* sp. were found in the upper Karastun Formation, which underlies the Veber Formation, in the Karastun stratotype Section, on Mt. Orlinaya, near Gur'evsk, in the Gur'evsk–El'tsovka zone of the Salair Ridge. Trinucleid trilobites, which this species belongs to, are found in Great Britain in the lower Pushgillian Subdivision of the Ashgillian Stage, correlated with the *Pl. linearis* graptolite Zone (Koren', 2002). In the Charysh–Inya zone of Gorny Altai, in the Chineta Section, *Tretaspis* sp. were found in the lowermost Khankhara Formation (Sennikov et al., 2008). This suggests that the base of the Veber Formation (= top of the Karastun Formation) must be localized above the base of the Khankhara Horizon. In the Gur'evsk–El'tsovka zone of the Salair Ridge, the Karastun Formation is localized below the Veber Formation. It is now the most natural to correlate the upper boundary of the Karastun Formation, which is exclusively terrigenous, with the base of the Khankhara Horizon, i.e., with the base of the *Cl. bicornis* graptolite Zone, by analogy with the upper boundary of the Bugryshikha Formation of terrigenous rocks in the Charysh–Inya zone of Gorny Altai. The Salair Veber Formation, observed (including its stratotype) in the outskirts of Gur'evsk, is underlain by sediments with basal conglomerates (like the previously recognized Gorny Formation, which is now included in the Veber Formation) and, sometimes, unconformity (Gintsinger, 1969). Some researchers (Gintsinger, 1969; Stratigraphic…, 1975; and others) were right in saying that the sedimentation of the Veber Formation might have been preceded by a gap. This gap might have been included the lower Khankhara Horizon – the interval of the *Cl. bicornis* graptolite Zone, i.e., the Upper Sandbian of the GSSP.

The Bugryshikha Horizon is subdivided into two subhorizons. The Lower Bugryshikha Subhorizon is characterized by trilobite fauna *Eorobergia integra* Petrun., *Vogdesia*? *tuloica* Petrun., *Remopleuridiella altaiensis* Petrun., *Levirobergia oirotica* Petrun., and brachiopods *Archaeorthis altaica* Severg., I*diostrophia tuloviensis* Severg., and Upper Bugryshikha Subhorizon by trilobites *Pliomerellus latus* Petrun., *Raymondaspis altaicus* Petrun., *Robergiella margofera* Petrun., *Cnemidopyge tuloica* Petrun., *Atractopyge sibirica* Petrun., *Ceraurinella latigenata* Petrun., and brachiopods *Glyptorthis primus* Severg., *Parastrophina bilobata* Cooper, *Beloviella bugryshichaensis* Severg., *Christiania* aff. *subquadrata* (Hall), *Glyptomena karasuensis* Severg.

The lower half of the Upper Bugryshikha Subhorizon is dominated by trilobites *Homotelus angustus* Petrun., *Lonchodomas* (*Foliopyge*) *levis* Petrun., *Ampyxella* (*Belaxella*) *infermicostata* Petrun., *Nileus tengriensis* Web., *Telephina mobergi* (Hadd.), and the upper half of the Upper Bugryshikha Subhorizon – by trilobites *Cybelurus planifrons* Weber, *Raymondella bugryshichiensis* Petrun. On a whole brachiopods *Apatomorpha altaica* Severg., *Leptellina tennesseensis* Cooper, *Hesperorthis markovae* Rozman are distributed in the Upper Bugryshikha Subhorizon.

Graptolites of the *jakovlevi-coelatus*, *teretiusculus*, *gracilis-serratulus*, *multidens* (Subzone of *antiquus lineatus-peltifer* and lower part of Subzone *wilsoni*) zones are typical for the Bugryshikha Horizon.

Khankhara Regional stage (Horizon) was proposed by (Sennikov et al., 2008). It could be aligned with upper half of upper Sandbian (Sa2) and lower Katian (Ka1) (Sennikov et al., 2018a,b).

The Katian GSSP, observed in the Black Knob Ridge section, United States, is marked by the first appearance of the graptolite species *Diplacanthograptus caudatus* (Goldman et al., 2007). This boundary does not coincide with any of the boundaries of the fossil-bearing Ordovician local stratigraphic units in the western ASFA. The Katian Stage is divided into four time slices (Bergström et al., 2009), proposed as "informal" substages: lower, first middle, second middle, and upper. The lower boundary of the second substage (first middle) is marked by the base of the *Pl. linearis* graptolite Zone. The Tekhten' Horizon, detected in the Upper Ordovician of the western ASFA (Sennikov et al., 2008), and, correspondingly, the Tekhten' Formation (with a stratotype in the Anui–Chuya zone of Gorny Altai) (Sennikov et al., 2001) were correlated with the Ashgillian Stage of the British scale, whose base corresponded to the lower boundary of the *Pl. linearis* Zone. However, there is no conclusive evidence that the lower boundary of the Tekhten' Horizon corresponds to the base of the *Pl. linearis* Subzone of the *O. quadrimucronatus* graptolite Zone. In the Ebogon Section (the Anui–Chuya zone, Gorny Altai), the latest (uppermost) finds (Sennikov et al., 2001) of graptolites of the *Dicr. clingani* Subzone (the lower of two subzones of the *O. quadrimucronatus* Zone) are observed 300 m lower than the base of the Tekhten' Formation, which overlies the Khankhara Formation. This only shows that the lower boundary of the Tekhten' Formation is localized above the upper part of the *Dicr*. *clingani* Zone. In the Khankhara Section (the Charysh–Inya zone, Gorny Altai), graptolites of the *Pl. linearis* Zone were found in the lower Tekhten' Formation (previously, the upper Khankhara Formation (Sennikov et al., 1984)). The lower boundary of the Tekhten' Horizon is tentatively correlated with the base of the *Pl. linearis* Subzone, i.e., the base of the second "informal" Katian substage in the GSSP.

The Khankhara Horizon is subdivided into three subhorizons. Trilobites *Chasmopsella unica* Petrun., *Bronteopsis gregaria* Raum., *Jaboganellus gornoaltaicus* Petrun., *Otarionelliana koksoriana* Korol., *Eorobergia lebediensis* Petrun., and brachiopods *Onniella chancharica (*Severg.), *Plectocamara uscuchiensis* Severg., *Fascifera buraensis* Severg., *Bimuria bugryshichaensis* Severg., *Chaulistomella inaquistriata* (Cooper), *Eoanastrophia lebediensis* (Severg.) are typical for the Lower Khankhara Subhorizon.

Trilobites *Ceraurinus icarus* (Bill.), *Calyptaulax bellatulus* Petrun., *Paracybeloides loveni* (Linrs.), and brachiopods *Boreadorthis togaensis* Severg., *Chaulistomella amzassensis* (Severg.), *Strophomena lebediensis* Severg., *Rostricellula ainsliei amzassica* Severg., *Togaella grandis* Severg. are typical for the Middle Khankhara Subhorizon.

Trilobites *Holotrachellus punctillosus* Torng., *Illaenus oviformis* Warb., *Illaenus* cf. *septentrigonalis* Tchug., *Amphilichas sniatkovi* Weber, *Brontocephalina nuda* (Ang.), *Isocolus sjogreni* Ang., *Chasmops saliricus* Petrun., *Eucrinuroides bobroviensis* Petrun., and brachiopods *Eospirigerina sublevis* Severg., *Austinella lebediensis* Severg., *Salopina uxunaica* (Severg.), *Glyptorthis praepulchra* Severg., *Gl. balclatchiensis* (Dav.), *Hesperorthis lebediensis* Severg., *Dulankarella magna* Ruk., *Catazyga salairica* (Severg.) are typical for the Upper Khankhara Subhorizon.

The following graptolite zones are distinguished for the Khankhara Horizon: upper part of *multidens-wilsoni*, *bicornis*, *clingani-caudatus* and *linearis*.

Tekhten' Regional stage (Horizon) was proposed by N.V. Sennikov, Z.E. Petrunina and L.A. Gladkikh (Sennikov et al., 2001). It is aligned with middle (Ka2, Ka3) and upper (Ka4) Katian, as well as with lower Hirnantian (Hi1).

The Tekhten' Horizon is subdivided into three subhorizons. The Lower Tekhten' Subhorison is characterized by brachiopods *Eospirigerina orloviensis* (Severg.), *Oxoplecia platystrophoides* Schubert et Cooper, *Catazyga inensis* (Severg.), *Catazyga anuensis* Severg., *Eridorthis subinexpecta digna* Severg., *Schizophorella fallax* Salter.

Trilobites *Stenoblepharum warburgae* (Prib.) and brachiopods *Giraldibella bella* (Bergst.), *Thebesia thebesensis* Amsden, *Leangella septata* (Cooper) are typical for the Middle Tekhten' Subhorison. The Upper Tekhten' Subhorison is characterized by trilobites *Mucronaspis mucronata* (Brongniart) and brachiopods *Dalmanella testudinaria* (Dalm.), *Zygospiraella indistincta* Kulk. et Severg., *Streptis altosinuata* (Holt.), *Hirnantia* aff. *noixella* Amsden, *Brevilamnulella gromotuchaensis* Severg.

The Hirnantian GSSP, observed in the Wangjiawan North section, China, is marked by the first appearance of the graptolite species *Normalograptus extraordinarius* (Chen et al., 2006). The lower boundary of the Hirnantian Stage is correlated with the lower boundary of the Chebor Formation of the Uymen'–Lebed' zone, Gorny Altai. The Hirnantian Stage is divided into two time slices (Bergström et al., 2009). Note that the lower boundary of the upper "informal" substage is marked by the end of the Hirnantian Isotopic Carbon Excursion (HICE), observed worldwide (Bergström et al., 2006, 2009; Chen et al., 2006; Kaljo and Martma, 2011; Mitchell et al., 2011; Underwood et al., 1997), rather than by the marker species of a graptolite or conodont zone. For the Ordovician sediments of the western ASFA, a new horizon – the Listvyanka Horizon (Sennikov et al., 2008) was proposed within the Upper Hirnantian. It includes the mudstones of the lower Vtorye Utyosy Formation (with a stratotype in the Charysh–Inya Zone of Gorny Altai) with graptolites of the *Nor. persculptus* Zone. It is now proposed that the stratigraphic extent of the Listvyanka Horizon should be increased (by less than one-third), so that it includes the dalmanitinae carbonate member of the upper Tekhten' Formation with trilobites *Mucronaspis mucronata* (Brongniart), which underlies the Vtorye Utyosy Formation. According to the latest data, this member (Sennikov and Ainsaar, 2012), correlated with the lowermost *Nor. persculptus* graptolite Zone, has a considerably increased content of heavy carbon isotopes, which corresponds to the HICE. Thus, the Ordovician Listvyanka Horizon of the ASFA will include the uppermost Tekhten' Formation (its peculiar dalmanitinae terminal member) and the lower Vtorye Utyosy Formation. The Listvyanka Horizon will be correlated with the *Nor. persculptus* graptolite Zone in its full extent. In the ISS, it will correspond to the "informal" Upper Hirnantian Substage. Previously, the dalmanitinae carbonate member belonged to the Tekhten' Horizon. The Tekhten' Horizon will correspond to the Tekhten' Formation without its uppermost part – the dalmanitinae member. Note that the Tekhten' Formation in the Tekhten' Section of the Anui–Chuya zone of Altai does not contain this characteristic dalmanitinae member in the upper part of its stratotype (Sennikov et al., 2001, 2008).

Tekhten' Horizon is characterised by graptolites of the *linearis*, *supernus*, *ornatus*, *pacificus*, *ojsuensis/mimyensis* zones and by conodonts of *ordovicicus* Zone.

Listvyanka Regional stage (Horizon) was proposed by (Sennikov et al., 2008, 2014, 2018a,b). It is aligned with uppermost upper Hirnantian (Hi1).

Graptolites of the *persculptus* Zone are common for the Listvyanka Horizon. Along with graptolites chitinozoans *Conochitina microcantha* Eisenack have been recovered. The other fauna at this stratigraphic level on the Gorny Altai are represented trilobites *Dalmaniotina mucronata* (Brong.) and brachiopods.

Fig. 4 presents intra-regional correlation charts of local Ordovician stratigraphic units of the Gorny Altai based mainly on synthetic modern paleontological data.

1.2. ORDOVICIAN GRAPTOLITE ZONES OF THE GORNY ALTAI

The Ordovician sediments of the Gorny Altai contain the following succession of graptolite biostratigraphic units (Fig. 5) (Obut, Sennikov, 1984, Bukolova, 2011; Sennikov et al., 2015a, 2018a,b): Tremadocian, the *kiaeri/tenellus* Zone (the upper half of the zone is regarded as the *ramosus/osloensis* Subzone) (Takoshkin = Upper Tayanza Horizon, Kamlak and Ishpa formations); Floian, the *approximatus* (Tuloi Horizon, Tuloi Formation), *densus* (the lower half is regarded as the *balticus* Subzone) (Tuloi Horizon, Tuloi Formation), and *angustifolius elongatus/broggeri* (without the uppermost part) (Tuloi Horizon, Tuloi Formation) zones; Dapingian, the *angustifolius elongatus/broggeri* (uppermost part) (Tuloi Horizon, Tuloi Formation), *gibberulus* (with the *deflexus* lower Subzone and the *maximo-divergens* upper Subzone) (Tuloi Horizon, Tuloi Formation), and *hirundo* (with the *caduceus imitatus*

Fig. 5. Graptolite zonation and correlation levels for the Ordovician of the Gorny Altai and Salair.

lower Subzone and the *sinodentatus/Cardiograptus* upper Subzone) (upper Tuloi–lower Kuibyshevo horizons, Tuloi and Karasa formations) zones; Darriwilian, the *austrodentatus* (Kuibyshevo Horizon, Voskresenka Formation), *dentatus* (Kostinsky Horizon, Voskresenka and Karasa Formations), *balhaschensis/kirgisicus* (Kostinsky Horizon, Voskresenka Formation), *jakovlevi/coelatus* (Bugryshikha Horizon, Bugryshikha and Karasa formations), and *teretiusculus* (Bugryshikha Horizon, Bugryshikha and Karasa formations) zones; Sandbian, the *gracilis/serratulus/bekkeri* (Bugryshikha Horizon, Bugryshikha Formation), and *foliaceus* (= former *multidens* Zone) (with the *peltifer/antiquus lineatus* lower Subzone and the *wilsoni* upper Subzone) (upper Bugryshikha–lower Khankhara horizons, upper Bugryshikha and lower Khankhara formations) zones; Katian, the *quadrimucronatus* (with the *clingani* lower Subzone and the *linearis* upper Subzone) (upper Khankhara–lower Tekhten' horizons, upper Khankhara and lower Tekhten' formations), *supernus*, *ornatus*, and *pacificus* (Tekhten' Horizon, Tekhten' Formation) zones; Hirnantian, the *ojsuensis/mirnyensis* (Tekhten' Horizon, Tekhten' Formation), *persculptus* (Listvyanka Horizon, lower Vtorye Utyosy Formation) (Bukolova, 2011; Obut and Sennikov, 1984; Sennikov, 1976, 1996, 2012, 2013; Sennikov et al., 2008, 2011a, b). Besides, the *protobifidus* Teilzone (Sennikov, 2013; Sennikov et al., 2008), which marks the Upper Floian of the ISC (Section Salair), is distinguished in the Ordovician of Gorny Altai, in the upper part of the *densus* Zone and the lower part of the *angustifolius elongatus/broggeri* Zone. The *bicornis* Teilzone, which marks the Upper Sandbian of the ISC (Section The Taimyr Peninsula), is recognized in the Ordovician of Altai, in the upper part of the *wilsoni* Subzone of the *multidens* Zone. The *caudatus* Teilzone is distinguished in Ordovician sections of Gorny Altai, in the lower part of the *clingani* Subzone of the *quadrimucronatus* Zone. The index species of this zone, *Diplocanthograptus caudatus* (Lap.), marks the Katian Stage of the ISC in the GSSP (Black Knob Ridge Section, United States) (Goldman et al., 2007). The *caudatus* Zone is distinguished in the Ordovician of Scotland (as a subzone of the *clingani* Zone) (Zalasiewicz et al., 2009) and North America (Loydell, 2012). In northeastern Russia (Kolyma River), finds of the species *Dip. caudatus* (Lap.) (Obut and Sobolevskaya, 1968) in the lower part of the *ingens wellingtonensis* Zone (lower zone of the Katian Stage) allow to define beds with *Dip. caudatus.* The overwhelming majority of the graptolite zones (their assemblages and index species) and beds defined in the Ordovician of Gorny Altai are used worldwide (Cooper et al., 2004; Gradstein et al., 2012; Loydell, 2012; Webby et al., 2004; Zalasiewicz et al., 2009). The exceptions are the *balhaschensis/kirgisicus* Zone, which is described above (Section Salair), and the *jakovlevi/coelatus* Zone. Data on the species *Expansograptus jakovlevi* (Kel.), found in Salair together with *Didymograptus geminus* (His.), are considered above (Section Salair). The species *Amplexograptus coelatus* (Lap.) occurs in the Ordovician sediments of Great Britain (Elles and Wood, 1901–1918; Strachan, 1996, 1997; Zalasiewicz et al., 2009), in the *murchisoni* Zone (probably, also in the uppermost part of the *underlain artus* Zone (former *bifidus* Zone), and spreads to the overlain zones. In Altai the species *Am. coelatus* (Lap.) and the corresponding assemblage are observed in numerous sections below the assemblage of the *teretiusculus* Zone (Sennikov et al., 2008).

1.3. ORDOVICIAN CONODONT ZONES OF THE GORNY ALTAI

The first data on conodonts from the Ordovician sediments of Gorny Altai were obtained not long ago (Moskalenko, 1977), but the present state of knowledge of this group (Iwata et al., 1997; Izokh et al., 2003, 2005) is similar to that of conodonts in folded regions such as the Urals and Kazakhstan. As there are not enough monographic studies of the Ordovician conodonts of Altai (Sennikov et al. 2015) and the rare and low-abundance species are not clearly identified, the biostratigraphic units are based on species with a wide geographic range and cosmopolitan taxa, yet allow direct correlations between the proposed zonation and the zones of the ISC/GSS (Fig. 6). Gorny Altai is the only Russian region with detected elements of the zonal taxon *Iapetognathus* and the associated genus *Iapetonudus* (Sennikov et al., 2014) characterize the base of Ordovician in the type sections of North America (Cooper et al., 2001). The appearance of elements of *Cordylodus angulatus* in the Upper Kamlak Subformation marks the lower boundary of the overlain zone. Beds with *Paroistodus proteus* were defined in the cherts of the upper Talitsa Formation (Zasur'ya Group) of the Takoshkin Horizon and in the cherts of the Marcheta Formation (Zasur'ya Group) of the Tuloi Horizon in its stratotype. The assemblage of the beds includes *Paroistodus* cf. *proteus* (Lind.), *Paracordylodus gracilis*, *Cornuodus longibasis*, *Drepanodus reclinatus*, *Oneotodus* sp., and some other species defined in open nomenclature. The conodont assemblage allows dating this interval as Late Tremadocian – Early Floian. Beds with *Oepikodus evae* were established in the cherts of the upper Marcheta Formation (Zasur'ya Group), Tuloi Horizon. The conodont assemblage in the beds includes *O. evae*, *Periodon* cf. *flabellum*, *Prioniodus* cf. *P. elegans*, *Baltoniodus* sp., and *Drepanoistodus* sp. The beds are correlated with the same-named zone in the upper Floian. The upper Voskresenka Formation (Kuibyshevo Horizon) in its type section contains beds with *Periodon flabellum – Parapanderodus striatus*, whose assemblage includes *Semiacontiodus*? *mufushanensis*, *Acodus eletsus*, J*uanognathus jaanussoni*, *Protoprioniodus* sp., *Cooperignathus* sp., ?*Tangshanodus tangshanensis*, *Dr. suberectus* s.l., *Triangulodus larapintinensis*, *Anodontus longus*, *Naimanodus degtiarevi*, *Panderodus*? *nogami*, and others. These taxa permit assigning the considered beds and the Kuibyshevo Horizon to the Upper Dapingian – lowermost Darriwilian. The upper Voskresenka Formation (Kostinsky Horizon) contains beds with *Eoplacognathus pseudoplanus*, whose assemblage includes *Periodon aculeatus*, *Scolopodus* sp., *Drepanodus arcuatus*, *Ansella* sp., and *Paroistodus* sp. (Izokh et al., 2005). The beds are

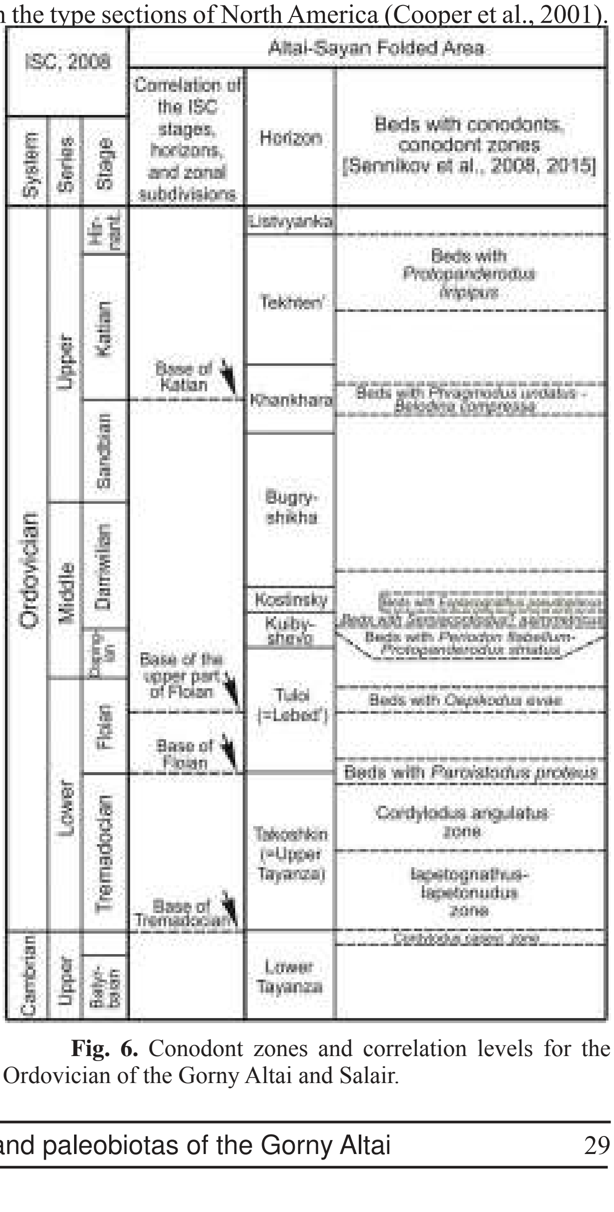


Fig. 6. Conodont zones and correlation levels for the Ordovician of the Gorny Altai and Salair.

correlated with the same-named zone in the lower Darriwilian (Middle Ordovician) of the northwestern East European Platform. Beds with *Ph. undatus* and *Belodina compressa* were defined in the lower and middle Gur'yanovka Formation (Khankhara Horizon). Along with the nominal species, the assemblage includes *Panderodus* cf. *P. gracilis*, *Aphelognathus* sp., *B. compressa* and *Drepanoistodus suberectus*. The coexistence of *Ph. undatus* and *B. compressa* is typical of the upper Sandbian–lower Katian on many continents, including North America and Eurasia (East European Platform); it permits a reliable correlation of the beds defined in the Gur'yanovka Formation with this stratigraphic interval. Beds with *Protopanderodus liripipus* were established in a cherty terrigenous series (Tekhten' Horizon) in the western part of the region. Thin limestone layers contain a conodont assemblage, in which along with the nominal species *Periodon grandis*, *Panderodus* sp., *Decoriconus* sp., *Paroistodus ?mutatus* and *B. compressa* were identified; it allows a correlation of the distinguished beds with the upper Katian.

1.4. LOCAL ORDOVICIAN STRATIGRAPHIC UNITS OF THE GORNY ALTAI

Ordovician strata in the Gorny Altai occur in two genetically different types of sections that record oceanic and shelf deposition.

1.4.1. OCEANIC DEPOSITION

Oceanic Ordovician sections are known in the western and northwestern Gorny Altai (Anui-Chuya and Charysh-Inya facies zones) and consist of the following units.

Zasur'ya Group

The Zasur'ya stratigraphic unit was first distinguished as a formation by O.P. Goryainova in 1956 (unpublished evidence). Tikhonov (1956) in his publication referred to Goryainova's definition but applied the name Zasur'ya to the lower subformation of a variegated formation in the western Gorny Altai. The Zasur'ya unit has no stratotype section and its typical locality is in the area northwest of Krasnoshchekovo Village on the right side of the Charysh River, in the catchments of the Zasur'ya, Molchanikha, and Berezovy brooks. Sennikov et al. (2001, 2003) suggested to distinguish the Zasur'ya unit as a group divided into three formations.

According to the present knowledge, the lithology of the Zasur'ya Group consists of clayey-siliceous schists, jade, chert, mudstone, siltstone, sandstone, tuffaceous sandstone, tuff breccias, and gabbro, gabbro-diabase and diabase dikes, and mafic volcanics. According to the chemistry of basalts, the group was deposited in an ocean (Iwata et al., 1997; Buslov et al., 1999, 2000; Sennikov et al., 2003; Safonova et al., 2011). Variolite pillow lavas, aphyre or less often plagioclase-pyroxene and pyroxene-plagioclase porphyry basalts and scarce andesites are of low-K oceanic tholeiite affinity and can be classified as mid-ocean ridge (MORB) or ocean-island (OIB) basalts (Figs 7-11). Basalts are quite rare in the sections of the Zasur'ya Group and exist as 1 to 10 m thick or thicker layers.

Conodont assemblages in the Zasur'ya Group are localized at two intervals: of (1) Late Cambrian (Aksai Stage – Early Batyrbai Substage) and (2) Early Ordovician (Late Tremadocian Substage – Floian Stage). No transitional Batyrbai-Tremadocian conodont zones in the group have been found so far. All conodonts were extracted by hydrofluoric acid dissolution from chert, siliceous mudstone, and other siliceous rocks. The absence of conodont finds from the Cambrian-Ordovician boundary strata in the Zasur'ya Group is implicit evidence that a large part of the sections lack siliceous rocks. This hypothesis is supported by the stacking pattern of the Zasur'ya sections along the Talitsa River where the group shows distinct division into three units, with a purely terrigenous middle unit (the Talitsa Formation) that is almost void of siliceous sediments.

Listvenny Formation

The Listvenny Formation, 200 to 300 m thick, is the lowermost unit in the Zasur'ya Group (Sennikov et al., 2001, 2003). Its stratotype section occurs in the Listvenny Brook – Talitsa River divide in the western Gorny Altai. The Listvenny Formation contains, in all its sections, red or more rarely gray siliceous rocks, often with volcanic intercalations, among red and gray terrigenous members. The formation bears conodonts, radiolarians, and siliceous sponge spicules. The conodont age of the Listvenny Formation is defined at five stratigraphic intervals corresponding to the conodont zones: (1) Aksai age, W. *matsushitai* Zone, (2) Aksai age, *M. erectus* Zone, (3) earliest Batyrbai age, *P. muelleri* Zone, (4) Batyrbai age, *E. notchpeakensis* Zone, (5) middle Batyrbai age, *C. minutus* Zone. Relationships of the Listvenny Formation with the underlying rocks remain unknown. The formation is conformably overlain by the Talitsa Formation.

Fig. 7. Original/sedimentary field contacts of oceanic light gray to brown chert and basalt in the Lower Ordovician of the Gorny Altai (Marcheta Formation, Charysh River).

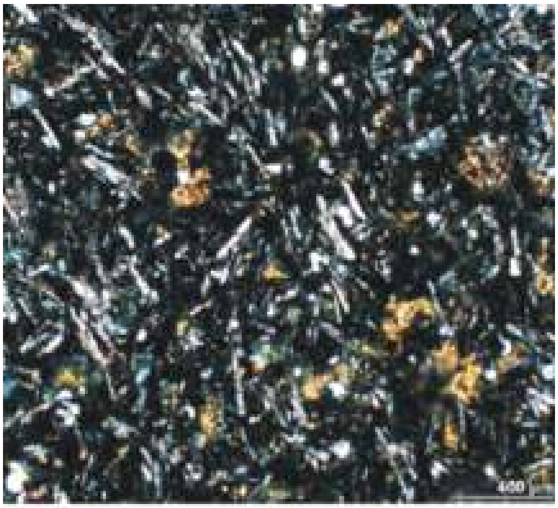


Fig. 8. The typical aphyric basalt (thin-section) in the Lower Ordovician of the Gorny Altai (from Safonova et al., 2011).

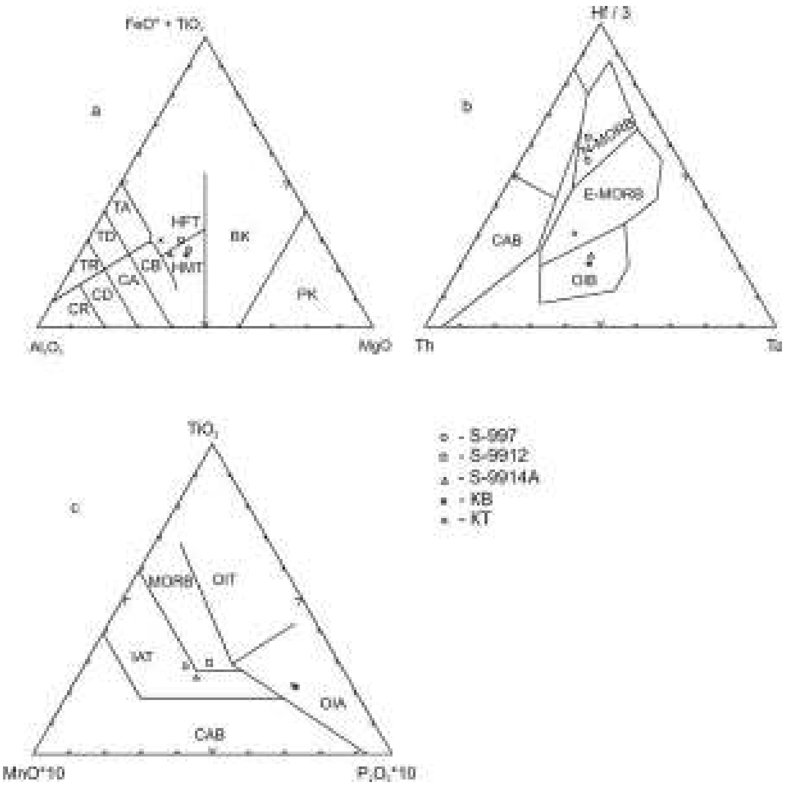
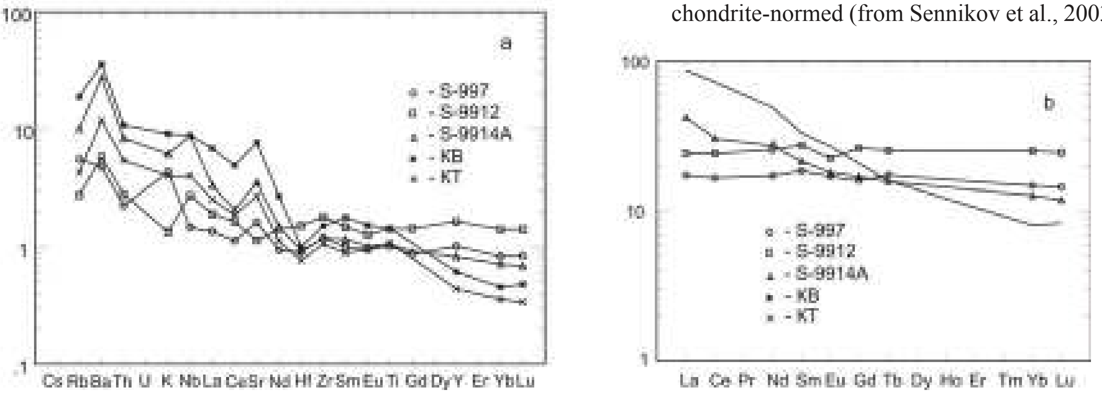


Fig. 9. Chemical composition of basaltoids of the Zasur'ya Group (Gorny Altai). a – classification diagram; b, c – discrimination diagrams. Tholeiitic series: TR – rhyolite; TD – dacite; TA – tholeiite andesites; HFT – high-ferrous tholeiite. Calc-alkalic series: CR – rhyolite; CD – dacite; CA – calc-alkali andesites; HMT – high-magnesium tholeiite; BK – komatiite basalt; PK – komatiite; IAT – island-arc tholeiites; MORB – mid-ocean ridge basalts; OIT – ocean-island tholeiites; OIA – ocean-island alkalic basalts; CAB – calc-alkalic basalts; OIB – ocean-island basalts (from Sennikov et al., 2003).

Fig. 10. Rare-earth element distribution curves of basaltoids of the Zasur'ya Group. *a* – MORB-normed, *b* – chondrite-normed (from Sennikov et al., 2003).



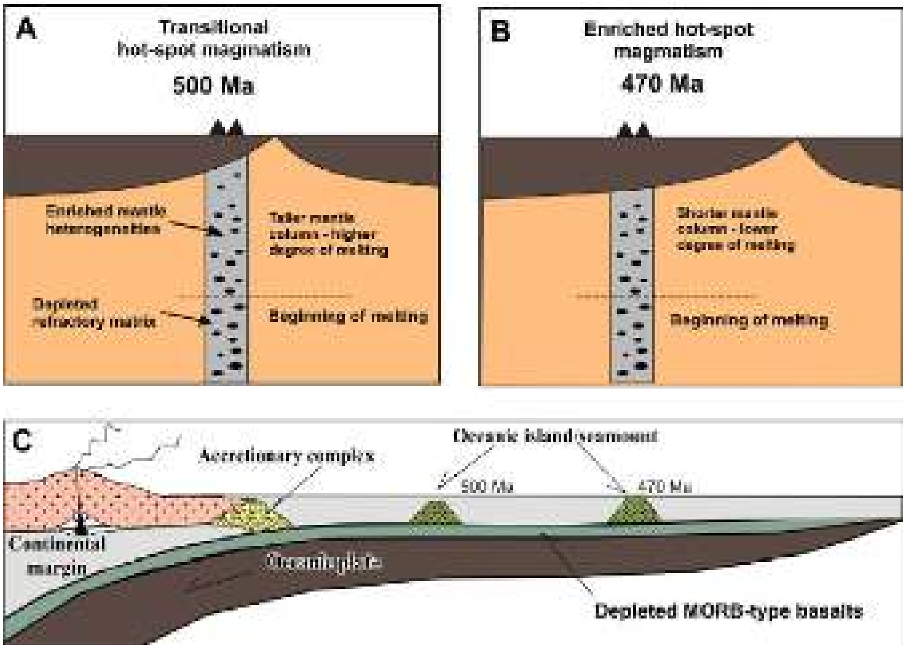


Fig. 11. Scheme for the 500 Ma transitional (A) and 470 Ma enriched (B) hot-spot oceanic basalts (Groups 2 and 3) of the Zasur'ya Group in respect to the thickness of the oceanic lithosphere. At 500 Ma the lavas probably erupted closer to MOR, i.e., under a thinner/younger oceanic lithosphere. This resulted in the relatively high degrees of melting and therefore in a larger portion of incompatible element depleted refractory material in the melt. At 470 Ma, when the plume is located under a thicker but older oceanic lithosphere, the melting column was shorter, the average degree of melting was lower and the melt was more contributed by incompatible element enriched less refractory material of mantle heterogeneities.

C – in the Ordovician the crust of the Paleo-Asian Ocean subducted beneath the SW active margin of the Siberian continent (from Safonova et al., 2011).

Talitsa Formation

The 400–450 m thick Talitsa Formation, the middle unit of the Zasur'ya Group, consists of gray (or less often variegated) terrigenous rocks. Its stratotype is located in the middle reaches of the Talitsa River (right tributary of the Charysh River) in the western Gorny Altai (Sennikov et al., 2001, 2003). The faunal groups found in the formation are radiolarians and siliceous sponge spicules. The Talitsa Formation conformably oversteps the Listvenny Formation and is conformably (?) overlain by the Marcheta Formation.

Marcheta Formation

The Marcheta Formation, the upper unit of the Zasur'ya Group, varying in thickness from 600 to 950 m, is composed of alternating red and gray terrigenous and siliceous rocks (Figs 12, 13). The stratotype of the formation was distinguished as two composite sections along the Marcheta River, the left tributary of the Muta River in the northwestern Gorny Altai (Sennikov et al., 2001, 2003). No reliably proven basalts have been found so far in the paleontologically constrained sections of the Marcheta Formation. The Marcheta rocks include scarce layers of tuff and tuffaceous sandstone. The formation contains conodonts, radiolarians, and siliceous sponge spicules. The conodont age of the Marcheta Formation of the Zasur'ya Group is defined at three stratigraphic intervals corresponding to the conodont zones: (1) Tremadocian-Floian boundary strata, *P. proteus* Zone, (2) upper part of the Floian, *P. elegans* Zone, and (3) middle Floian, *O. evae* Zone. The Marcheta Formation conformably (?) overlies the Talitsa Formation. The relationship of the formation with the overlying strata remains uncertain.

Fig. 12. Massive red chert yielded radiolarians in the Lower Ordovician of the Gorny Altai (Marcheta Formation, Charysh Section).

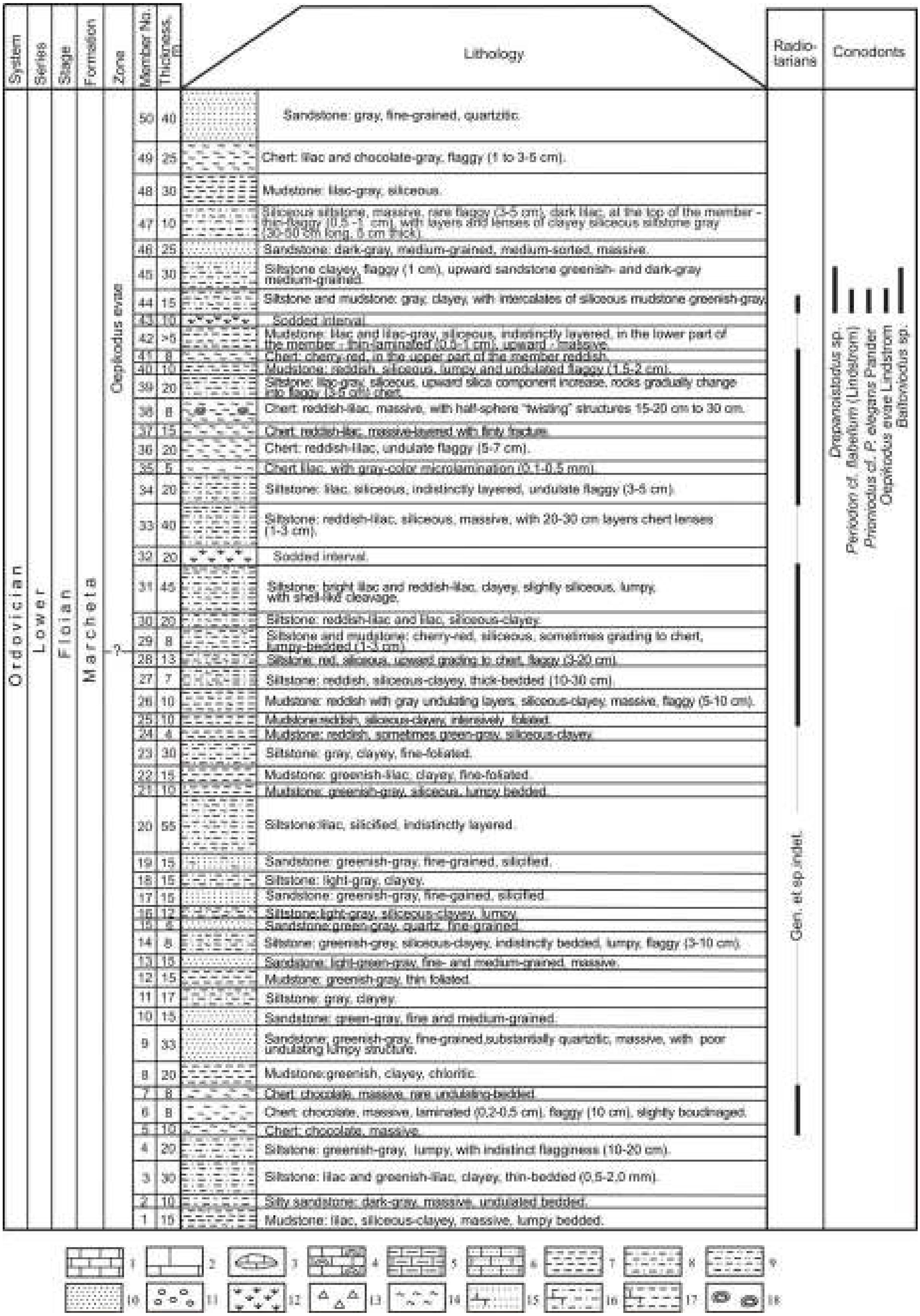


Fig. 13. Lithology and ranges of fossil taxa from Charysh Section.

The legend (for this and other logs) : 1 – limestone, 2 – massive limestone, 3 – lenses, 4 – algal limestone, 5 – clayey limestone, 6 – sandy limestone, 7 – mudstone, 8 – siltstone, 9 – aleuro-sandstone, 10 – sandstone, 11 – conglomerate, 12 – sodded interval, 13 – breccia, 14 – cherts, 15 – limy sandstone, 16 – limy siltstone, 17 – limy mudstone, 18 – "twisting" structures.

1.4.2. SHELF DEPOSITION

Ordovician shelf deposition in the Gorny Altai is known in the western, northwestern, central, northern, northeastern, and eastern parts of the area. There are three main local Ordovician successions that were deposited in different environments of a single basin.

1.4.2.1. THE FIRST FACIES TYPE OF SHELF DEPOSITION

SUCCESSION 1 (Uymen'-Lebed' facies zone) of Ordovician shelf facies comprises the Ishpa, Tuloi, Karasa, Gur'yanovka, and Chebor formations which occur in the northeastern and eastern Gorny Altai and were deposited on a relatively shallow inner shelf proximal to the shore.

Ishpa Formation

The Ishpa Formation in the northeastern Gorny Altai (Krivchikov et al., 1976; Decisions..., 1983; Stratigraphic…, 1991) reaches a thickness of 1000 m. Its stratotype section is located along the Ishpa River (left tributary of the Biya River) near Verkh-Biysk Village (Petrunina et al., 1984). The basal member of the formation is conglomerate of pebbles and cobbles of sedimentary, volcanic, and intrusive rocks. The Ishpa Formation is generally composed of mudstone, siltstone, and sandstone, with limestone and conglomerate interbeds. The faunas include algae, trilobites, brachiopods, and graptolites. Graptolite assemblages correspond to the *tenellus – kiaeri* Zone. The formation rests upon the Middle-Late Cambrian Tandoshka Formation and under the Tuloi Formation with unconformities along both contacts. Its lower section correlates with the upper Upper Cambrian, the middle part is the Lower Tremadocian, and the upper section is the Upper Tremadocian.

Tuloi Formation

The Tuloi Formation, up to 2600 m thick, occurs in the northeastern Gorny Altai. It was originally distinguished (Krivchikov et al., 1976; Decisions..., 1983; Petrunina et al., 1984; Stratigraphic…, 1991) as the lower unit of the Stretinka Formation (Group). The formation is represented by its stratotype section on the right side of the Biya River 2.4 km downstream of the Tuloi inflow and then on the right side of the lower Tuloi River. The formation consists of interbedded mudstone, siltstone, silty sandstone, and sandstone. Its basal member is composed of coarse conglomerate and sandstone with floating lenses of intrusive, volcanic, and terrigenous pebbles. The Tuloi strata contain trilobites, brachiopods, graptolites, and chitinozoans. According to graptolite zonation, the formation spans the *appoximatus*, *densus*, *angustifolius elongatus*, *gibberulus* and *hirundo* zones. The formation conformably oversteps the Tremadocian Ishpa Formation and is conformably overlain by the Middle Ordovician Karasa Formation. The Tuloi Formation correlates with the Floian and the Dapingian (without terminal part).

Karasa Formation

The Karasa Formation, 450 m thick, is known in the northeastern Gorny Altai. It was originally recognized (Krivchikov et al., 1976; Decisions..., 1983; Stratigraphic…, 1991) as the upper unit of the Stretinka Formation (Group). Its stratotype section crops out on the right side of the Tuloi River downstream of the Karasa River mouth. The formation basal member consists of light gray and yellowish-gray quartz sandstone and the full section comprises interbedded mudstone, siltstone, silty sandstone, and sandstone. It contains trilobites, brachiopods, ostracods, crinoids, hyoliths, orthoceratites, gastropods, graptolites, and chitinozoans. There are two graptolite zones: *dentatus* and *teretiusculus*. The formation lies concordantly over the Tuloi Formation and is erosively overlain by the Gur'yanovka Formation. The Karasa Formation correlates with upper part Dapingian and the Darriwilian.

Gur'yanovka Formation

The Gur'yanovka Formation reaching a thickness of 1000 m occurs in the northeastern Gorny Altai. The formation was recognized by V.M. Sennikov (Sennikov, 1962; Stratigraphic…, 1975; Decisions..., 1983) and is represented by a stratotype section on the right side of the Lebed' River upstream of the Bura River mouth, near former Gur'yanovka Village. The formation is composed of siltstone, sandstone, limy-clayey mudstone, and limestone, with the basal member of gravelstone and coarse to medium sandstone, or less often of fine conglomerate. The faunas include tabulate and rugose corals, stromatoporoids, trilobites, brachiopods, ostracods, bryozoans, pelecypods, gastropods, orthoceratites, conodonts, and graptolites. The Gur'yanovka Formation rests on the weakly eroded surface of the Middle Ordovician Karasa Formation and is conformably overlain by the Chebor Formation. The formation conventionally correlates with the Sandbian and the Katian.

Chebor Formation

The Chebor Formation, up to 1100 m thick, is known in the northeastern Gorny Altai in the Lebed', Baigol, Biya, and Samysh catchments (northeastern and central Uymen'-Lebed' Synclinorium. The formation was distinguished by V.M. Sennikov (Sennikov, 1962; Stratigraphic…, 1975; Decisions..., 1983) and has its stratotype section on the right side of the Lebed' River upstream of the Ayugozha mouth, the left Lebed' tributary, near Chebor Mountain.

The Chebor section consists of mudstone and siltstone, less abundant sandstone, with thin layers and lenses of gray limestone. The basal member is composed of fine conglomerate and gravelstone with quartz pebble. The fauna finds are brachiopods and tabulate corals. The formation concordantly overlies the Middle Ordovician Gur'yanovka Formation and is discordantly overlain by the Silurian Tochilny Formation (?). The Chebor Formation conventionally correlates with the Hirnantian.

1.4.2.2. THE SECOND FACIES TYPE OF SHELF DEPOSITION

SUCCESSION 2 (Biya-Katun' facies zone) of shelf facies includes the Kamlak, Khankhara, and Bulukhta formations found in the northern Gorny Altai. They were deposited at the outer-to-inner shelf transition. Some sections of the local stratigraphic units in succession 2 formed in estuaries of large rivers that most likely flew from mountains.

Kamlak Formation

The Kamlak Formation up to 2000 m thick is cropped out in the northern Gorny Altai. It was recognized as a separate stratigraphic unit by (Ermikov et al., 1979; Decisions…, 1983; Petrunina et al., 1984; Petrunina, 1990; Stratigraphic …, 1991; Contributions…, 2001; Sennikov et al., 2008). The formation's composite stratotype section occurs on the left bank of the Maly Kamlak River and along the Tokoshkin Brook, its left tributary. The Kamlak Formation consists of interbedded sandstone, siltstone, limestone, conglomerate, gravelstone, and mudstone and contains trilobites, brachiopods, graptolites, and conodonts. The conodonts correspond to *Cordylodus lindströmi – Iapetognathus fluctivagus* zones and graptolites – to the *osloensis – ramosus* zone. Contact with underlain and overlain formations is uncomformable. The Kamlak Formation is subdivided into three subformations. The Lower Kamlak Subformation (about 120 m thick) is aligned with the upper Cambrian, the most part of the Middle Kamlak Subformation (~440 m) with the uppermost Cambrian; terminal part of the Middle Kamlak Subformation (~15 m) with the lowermost part Tremadocian, and the Upper Kamlak Subformation (up to 1400 m) with the Tremadocian.

Khankhara Formation

For data on the Khankhara Formation see below (Succession 3).

Bulukhta Formation

The Bulukhta Formation, about 500 m thick, is known on the northeastern periphery of the Anui-Chuya area of the Gorny Altai (Bulukhta and Sarasa rivers). A.B. Gintsinger (Gintsinger, 1958, 1964; Vinkman, Gintsinger, 1967; Stratigraphic…, 1975; Decisions…, 1983; Sennikov et al., 1995) distinguished it as a separate stratigraphic unit. The formation's stratotype section occurs in the middle reaches of the Bulukhta River (left tributary of the Ulus-Cherga River). It is composed of sandstone, siltstone, mudstone, limestone, and conglomerate and contains tabulate and rugose corals and brachiopods. The formation concordantly oversteps the Khankhara Formation and is discordantly (?) overlain by the Vtorye Utyosy Formation. The Bulukhta Formation correlates with the second half of the Katian.

1.4.2.3. THE THIRD FACIES TYPE OF SHELF DEPOSITION

SUCCESSION 3 (Anui-Chuya and Charysh-Inya facies zones) includes the Voskresenka, Bugryshikha, Khankhara, and Tekhten' formations, and the basal layers of the lower Vtorye Utyosy Formation found in the western, northwestern, and central Gorny Altai. The deposition occurred far offshore, on a relatively deep outer shelf and on a shallow-marine carbonate platform along the shelf edge at the foot of the continental slope.

Voskresenka Formation

The Voskresenka Formation occupies the western and central parts of the Gorny Altai (Sennikov et al., 1979, 1982; Ermikov et al., 1979; Decisions…, 1983; Stratigraphic…, 1991, Contributions…, 2001). Its stratotype section, about 300 m thick, has been documented in the western Gorny Altai at the Barany – Voskresenka brooks divide (left tributaries of the Charysh River) near Ust'-Chagyrka Village. The Voskresenka Formation, 285 m to 900 m thick, consists of sandstone, siltstone, mudstone, less often conglomerate and limestone. The rocks contain trilobites, brachiopods, crinoids, gastropods, graptolites, and conodonts. Graptolites include zonal assemblages of the *approximatus*, *densus*, *gibberulus*, *austrodentatus-hirundo*, and *dentatus-kirgisicus* zones (Petrunina et al., 1984; Sennikov, 1996). The *E. pseudoplanus* conodont zone in the upper part of the Voskresenka Formation (Kostinsky Beds) correlates with the upper subzone of the *variabilis* Zone in the North Atlantic standard of the International Stratigraphic scale: upper part 4a (=Da1) and lower one third 4b (=Da2) of the lower and middle Darriwilian (Webby et al., 2004). The formation lies discordantly over different Cambrian units and is conformably overlain by the Bugryshikha Formation. The Voskresenka Formation correlates with the Floian, Dapingian, and lower and middle Darriwilian of the international scale.

Bugryshikha Formation

The Bugryshikha Formation varies in thickness from 140 m to 1600 m and occurs in the Charysh-Inya and Anui-Chuya areas of the Gorny Altai near Bugryshikha Village. The formation was first distinguished as an unnamed unit by A.A. Nikonov (Nikonov, 1931; Usov, 1936; Stratigraphic…, 1956, 1975; Perfil'ev, 1959; Sennikov et al., 1959; Decisions…, 1959, 1983; Petrunina, Severgina, 1962; Contributions…, 2001); V.A. Kuznetsov (1948) coined the name Bugryshikha Formation. The stratotype of the formation is a composite section near Bugryshikha Village along the Bolshaya and Malaya Uskuchevka rivers, the right tributaries of the Belaya River. The lower part of the formation crops out along the Bugryshikha River (the Belaya left tributary) where it is exposed lying discordantly upon variegated terrigenous rocks of the Suetka Formation of the Gorny Altai Group. The Bugryshikha Formation is composed of sandstone, siltstone, or more rarely mudstone and conglomerate. The Bugryshikha strata bear trilobites, brachiopods, and graptolites. The section spans the graptolite zones: *jakovlevi-coelatus*, *teretiusculus*, *gracilis-serratulus*, and *multidens* (*antiquus lineatus-peltifer* and lower *wilsoni* subzones). The Bugryshikha Formation conformably lies over the Voskresenka Formation and under the Khankhara Formation. It correlates with the upper half of the Darriwilian and the lower half of the Sandbian.

Khankhara Formation

The Khankhara Formation, with a variable thickness of 60 to 800 m, is found in the western, northwestern, northern and central Gorny Altai. It was distinguished in 1929 by A.A. Nikonov (Usov, 1936; Stratigraphic…, 1956, 1975; Tikhonov, 1956; Sennikov et al., 1959; Decisions..., 1959, 1983; Contributions…, 2001). Its stratotype section has been designated on the left side of the Malaya Khankhara River near Chineta Village, and a section on the right side of the Malaya Uskuchevka River near Bugryshikha Village is its hypostratotype. The Khankhara Formation consists of sandstone, calcareous-argillaceous siltstone, and mudstone with limestone and marl interbeds. The base of the formation is a prominent lithological marker being composed of gray sandy and clayey limestone or often oolitic limestone occasionally grading into limestone conglomerate. The fauna found in the Khankhara section includes tabulate corals, gastropods, crinoids, trilobites, brachiopods, and graptolites.

The graptolite zonation includes the upper *multidens-wilsoni* Zone and *bicornis*, *clingani-caudatus* and *linearis* zones.

The formation rests conformably upon the Middle Ordovician Bugryshikha Formation and is gradually overlain by the upper Upper Ordovician Tekhten' Formation. The Khankhara Formation correlates with the upper half of the Sandbian and the lower half of the Katian.

Tekhten' Formation

The Tekhten' Formation, from 115 m to 700 m thick, occurs in the western, northwestern, and central Gorny Altai. It was distinguished (Sennikov et al., 2001; Contributions…, 2001) in upper Ordovician strata which make up a single complex of carbonate-terrigenous rocks standing out against the strata above and below. The carbonates are most often of reef origin. Terrigenous rocks are found on the periphery of reefal carbonates, where they replace the flanks of the latter along the strike, as well as inside the carbonate bodies. Reef frameworks are present in different strata but most often are found in the lower and upper parts of the section. Limestone locally predominate throughout the formation thickness (invalid Orlov Formation) or are restricted mainly to the lower layers (invalid Chakyr Formation) while the upper section consists of terrigenous sediments with thin limestone layers (invalid Dietken Formation). In many sections the carbonate-terrigenous proportions are intermediate between the two extremes. The stratotype section of the Tekhten' Formation is located on the right side of the Tekhten' River (right tributary of the Muta River). The formation is composed of limestone with algal bioherms alternating with calcareous siltstone, sandstone, or less often mudstone. The Tekhten' strata contain tabulate and rugose corals, stromatoporoids, trilobites, brachiopods, ostracods, gastropods, crinoids, graptolites, conodonts, scolecodonts, radiolarians, siliceous sponge spicules, and chitinozoans. The graptolite assemblages in the formation correspond to the *supernus* Zone with the *supernus* and *ornatus* subzones. The Tekhten' Formation concordantly lies over the Khankhara Formation and under the Vtorye Utyosy Formation. It correlates with the upper half of the Katian and with the lower half of the Hirnantian.

Vtorye Utyosy Formation

The greatest part of the Vtorye Utyosy Formation consist of black and dark gray mudstone and is aligned with the Llandovery Series of the Silurian. The basal beds Vtorye Utyosy Formation marked by the *persculptus* graptolite Zone of the terminal Ordovician (upper half).

2. TRACES OF GLOBAL SEDIMENTARY EVENTS IN THE ORDOVICIAN SECTIONS OF THE GORNY ALTAI

Many global sedimentary events are related to the Cambrian / Ordovician boundary and the lowermost Ordovician. The uniqueness of the Cambrian-Ordovician boundary interval has been inferred from the following evidence:

a) The concentration of numerous global abiotic (sedimentary) events, whereas biotic extinction events were extremely rare. The Late Devonian – Early Carboniferous proves to be another "geo-critical" interval in the Phanerozoic where global sedimentation events sided with global extinction events (Waliser, 1996).

b) The considered boundary is characterized by a revolutionary restructuring of marine communities, which resulted in the formation of complicated pelagic biota structure.

c) The Paleo-Tethys and large-scale displacements of the continental blocks (Dobretsov, 2003, 2011) gave rise to the Caledonian Salair orogeny represented by the Salair and Gorny Altai terranes. The Early Caledonian endo –- and exogenous events were manifest as large-scale collision-accretional events, i.e. accretion of the Gondwanian back-arc and island-arc structures and terranes (Altai-Mongolian, Chulyshman etc.) onto the margin of Siberia, which was accompanied by the basins deformation, orogeny, formation of a coarse-clastic (conglomerate, brecciated, olistostromes, produced by submarine landslide, etc.) bodies.

A new active volcanism event (following the large-scale Early-Middle Cambrian) began in the western part of the region (Kuznetsky Alatau, Salair, Altai), with subsequent "closure" of the Altai segment of the Paleoasian ocean and the onset of the Altai-Salair margin of the Siberian craton transition from active to amagmatic passive margin. The onset of typical shelf sedimentation was characteristic of most of the Gorny Altai area (western, northwestern, central and northern parts) (Sennikov et al., 2008; Sennikov et al., 2018a,b).

d) The existence of the Khadar magnetochronostratigraphic superchron in the studied interval (Dobretsov, 2011). Superchron is a polarity interval when the orientation of a planet's geomagnetic field does not change which suggests the absence of geomagnetic reversals (changes in the Earth's magnetic polarity). The three superchrons identified in the Earth's history correspond to the periods of: 490–460, 300–260 and 124–86 Ma.

1. Terminal Late Cambrian sedimentation regressive event Lange Ranch Eustatic Event (LREE).

The LREE was designated on the basis on the basis of material from North America and China (Miller, 1984) and is currently understood as coinciding with the base of *Cordylous proavus* conodont Zone.

In the Gorny Altai, terminal Cambrian conodonts of *C. proavus* Zone (end of Batyrbaian) were recovered at the base of the Lower Kamlak Subformation of shelf genesis. However, a lithological marker for the LREE has not been found yet.

2. Global Early Ordovician Acerocare regressive event (ARE).

The ARE event was defined in carbonate shelf sequences of North American, Siberian and Chinese platforms and is aligned with the base of the *iapetognathus fluctivagus* conodont Zone and the base of the *Rhabdinopora flabelliformis parabola* graptolite Zone. Previously, the ARE event was believed to correspond to LREE eustatic event (Erdtmann, Miller, 1981).

The ARE event is designated within the Kamlak Formation (lower part of the upper subformation), in the northern part of the Altai shelf basin (Petrunina et al., 1984; Sennikov et al., 2008). A 35 m-thick member of conglomerate identified within the Kamlak Section grades into sandstone along strike. Limestone from the uppermost part of Middle Kamlak Subformation in the Kamlak Section yielded conodonts of the *Iapetognathus fluctivagus* Zone. The ARE event is designated within the Kamlak Formation (Anui-Chuya facies zone) in the northern part of Altai shelf basin, where it coincides with the Lower/Middle Kamlak subformation boundary. At the base of the Middle Kamlak Subformation there are three consecutive 30 m thick conglomerate beds. These conglomerate is represented by middle-sized, poorly sorted, well-rounded pebbles, which occupy 50 % of the rock and include diorite, quartzite, gneiss, and crystalline schist.

3. Black Mountain transgressive event (BME).

The event is linked to the base of the *Cordylodus angulatus conodont* Zone and defined in Australia (Miller, 1984). In the sections at Salair region (near Gorny Altai), the BME event was not manifest in the shelf basin. The conodonts found there indicate that the event should have proceeded inside an unified member of reefal limestone of the Tolstochikha Formation.

The transgressive event, BME, in the Gorny Altai was not proved by paleontological data, since conodonts of the *C. angulatus* Zone are absent. However, noteworthy is that within the relatively shallow-water Upper Kamlak

Fig. 14. Tremadocian black mudstone in the Kamlak Formation (Kamlak Section).

Fig. 15. Terrigenous rock overlain limestone (Ishpa Formation, Ishpa Section).

Subformation (Anui-Chuya facies zone) of the Altai paleobasin a “sudden” appearance of deep-water black shales is observed, that could be regarded as BME traces (Fig. 14).

4. Global sedimentary regressive «Peltocare» event (PRE).

Peltocare Regressive event (Erdman, 1986) was established in the Baltic paleobasin and correlated with the lower boundary of the *Adelograptus tenellus graptolite* Zone. The regressive event PRE is defined in the Ishpa Formation (Uimen’-Lebed’ facies zone), the Altai shelf basin. It could be recognized by the appearance of sandstone and mudstone in the upper part of formation overlying mainly organogenic limestone from the middle part of formation (Fig. 15) (Krivchikov et al., 1976; Petrunina et al., 1984; Sennikov et al., 2008). Graptolites of the *Ad. tenellus* Zone were identified at the Pereval Section, in the basal layers of the upper Ishpa Formation.

5. Global sedimentary regressive «Kelly Creek» event (KCE).

Kelly Creek Regressive event (Nicoll et al., 1992) was designated in Australia below the base of the *Par. proteus* conodont Zone. In the Gorny Altai, the KCE regressive event was defined in the upper Kamlak Subformation based on the presence of three members of basal conglomerate up to 170 m thick (Petrunina et al., 1984; Sennikov et al., 2008; Noskov, 2007). Conglomerate have large- and medium-size, poorly sorted, well-rounded, pebbles include granite, granodiorite, syenite, diorite, felsite, basalt, quartzite, chert, sandstone, siltstone, limestone. Graptolites of the *T. osloensis/Al. hyperboreus* Zone, stratigraphically fully aligned with the *Kiaerograptus* Zone, were recovered from the sandstone that overlies the Kamlak conglomerate. The Baltoscandian standard *Kiaerograptus* Zone is below the base of the *Par. proteus* conodont Zone, which will make it possible to identify the KCE when graptolites of this zone are found.

6. Global sedimentary regressive «Ceratopyge» event (CRE).

Ceratopyge Regressive event (Erdtmann, 1986) was established in North America and positioned in the upper Tremadocian, middle parts of the *Araneograptus murrayi* graptolite and *Paroistodus proteus* conodont zones, respectively. The CRE regressive event in the Gorny Altai is identified in the marine sediments (fragments of the Paleoasian ocean) at the base of the Marcheta Formation (Anui-Chuya facies zone) by the appearing red-color terrigenous rocks and red chert (Sennikov et al., 2001, 2003; Sennikov et al., 2008). Terrigenous rocks from the underlying Talitsa Formation are mainly grey-colored, rarely lilac, and chert are mainly violet and red-brown. In the Marcheta-2 Section, conodonts of the middle part of *Par. proteus* Zone were recorded.

7. Global sedimentary regressive «Basal Arenig BioEvent» (BAgB) (= «Late Tremadoc - Early Arenig Lowstand»).

A global biotic Basal Arenig Bio-Event (BAgB) is defined at the Tremadocian/Floian (Arenigian) boundary (Walliser, 1986), with the biota responding by a dramatic change in the structure of benthic-pelagic communities. The event was assumingly triggered by a global transgression. The BAgB biotic event is aligned with the base of the *T. approximatus* graptolite Zone. In the Altai shelf basin, the biotic BAgB event and, thus, the global transgressive event, is identified in the lower part of the Tuloi Formation (Uimen’-Lebed’ facies zone) (Krivchikov et al., 1976; Petrunina et al., 1984; Sennikov et al., 2008; Noskov, 2007). This formation overlies, with dip and azimuthal unconformity and thick (up to 130 m) basal conglomerate, different Cambrian horizons: the Lower Cambrian in the Lebed’ Section, the Middle Cambrian in the Tagaza section, and the Upper Cambrian in the Tandoshka Section. It also overlies the Lower Ordovician (Tremadocian in the Ishpa and Tuloi sections). Basal conglomerate of the Ishpa Formation have large-, occasionally medium-size, poorly sorted, well-rounded pebbles, which include granite, granodiorite, syenite, diorite, gabbro, tuffs, quartzite, sandstone, hornfel (Figs 16, 17). Graptolites of the *T. approximatus* Zone were recovered at the lower parts of the formation overlying the conglomerates in the Tuloi, Lebed' and Tagaza sections.

Fig. 16. Conglomerate of basal member of the Tuloi Formation (Tuloi Section) (General view).

Fig. 17. The pebbles in the conglomerate of basal member of the Tuloi Formation (Tuloi Section).

8. Global sedimentary transgressive «Mid Arenig Highstand» event (=? «Helskjer Drowning Event»).

The identification of the considered transgression event in the Gorny Altai has thus far been disputable. The end of sedimentary hiatus in the Suetka-Kuibyshev, Charysh-Inya and Anui-Chuya facies zones (Gorny Altai Group) and the onset of Ordovician-Silurian deposition of a coarse clastic basal unit of the Voskresenka Formation lying with angular and azimuthal unconformity over Cambrian-Tremadocian sediments could be in a way interpreted as its traces (Sennikov et al., 2008; Sennikov et al., 2018a,b). In some areas, in western parts (in modern coordinates) of the Altai basin (Charysh-Inya facies zone), the middle Floian Stage was marked by inception of sedimentary strata exhibiting characteristic features of shelf deposition (the Voskresenka Formation). Their formation was substantially contributed by the degrading subducted oceanic pelagic sediments (Zasur'ya Group). The oceanic deposition (Marcheta Formation) also continued. Middle Floian oceanic sediments (upper part of the Marcheta Formation) are found in two regions, to the north and east (in modern coordinates) relative to Floian shelf sediments, specifically, the continental slope position is reconstructed from the shelf Floian deposits (northerly direction), suggesting that younger oceanic fragments were consistently attaching to the edge of accretionary complex. A global regression with the sea level dropped by 80–100 m was established within the latest Dapingian – earliest Darriwilian stratigraphic interval.

9. Global sedimentary regressive «Stein Lowstand Event» or «Late Arenig – Early Llanvirn Lowstand».

Large-scale global regression occurred at the end of Dapingian- beginning of Darriwilian, markeed by 80–100 m sea level fall (Nielsen, 2003, 2004, 2011; Munnecke et al., 2010; Gradstein et al., 2012). This event is broadly registered within the Middle Ordovician sections across the Siberian Platform (Kanygin et al., 2010).

The "Stein Lowstand Event" global regression is proposed as the major cause of "unexpected" occurrence of the offshore bar quartz sandstone within the studied medium-to-great depth sections of Gorny Altai. Yellow-gray sandstone well sorted and rounded of the Karasa Formation overlay deep-water black mudstone of the Tuloi Formation (Fig. 18).

Traces of regressive Stein Lowstand Event were recorded in the Uimen'-Lebed' paleobasin (Pridorozhny, Tuloi sections) with stratigraphic position within the boundary between graptolite subzones: *caduceus imitatus* and *sinodentatus/Cardiograptus* subzones of the *E. hirundo* graptolite Zone. Well-sorted and well-rounded yellow-grey sandstone of bar origin (Karasa Formation) overlie black deep-water mudstone of the Tuloi Formation.

The lowermost Karasa Formation within the Lebed' (25 m), Pridorozhny (25 m) and Tuloi (80 m) sections is comprised by the basal bed of the medium-well sorted, well-rounded medium-to-coarse-grained quartz sandstone (90 %) and quartzite (10 %) (Noskov, 2007). It is interpreted either as an offshore bar (Sennikov, 1962; Bukolova,

Fig. 18. Massive beds of the bar sandstone of the basal member of the Karasa Formation (Tuloi Section).

2011), or beach deposits (Noskov, 2007). Therefore, the mid upper Dapingian strata of these sections were accumulated within the lower shoreface (< 10 m) and upper shoreface (0–10 m).

10. Global sedimentary transgressive «Furudal Highstand» event or «Late Llanvirn – Caradoc Highstand».

The estimated amplitude of water level rise between transgressive Furudal Highstand (Nielsen, 2003, 2004, 2011) and regressive Stein Lowstand Event events is 100–150 m (Gradstein et al., 2012). A specific basal member of "bar" quartz sandstone at the base of the Karasa Formation is absent from the Yurok Section, which implies that the latter bears no evidence of Late Arenig – Early Llanvirn Lowstand global regression Event recorded in other sections of this part of Altai.

There are no offshore-bar quartz sandstone documented at the base of the Karasa Formation in the Yurok Section. Hence, it carries no records of the "Late Arenig–Early Llanvirn Lowstand" global event, fixed at the base of the Karasa Formation in the other studied section of northeastern Gorny Altai, possibly due to a comparatively greater depth and distal remoteness of the Yurok Section area from the shore in the Late Arenig–Early Llanvirn time. At the maximum of the sea-level fall, the upper part of the "Yurok uplift" was proposedly still situated below the fair-weather wave base and was not affected by erosional processes. Considering the total sea-level fall estimation at 80–100 m, the top of the uplift was located deeper than 25–50 m even during the maximum of the regression. Consequently, prior to initiation of the "Stein L.E." (upper third of the Dapingian, the uplift had been localized as deep as 100–150 m. The maximum of the "Furudal Highstand" (upper third of the Darriwilian) placed the top of the uplift 150–200 m below the sea base. A comparatively low thickness (at least 45 m) and specific lithological composition (fine, homogenous, well-sorted terrigenous material) of the lower Karasa Formation within the Yurok Section reveal its offshore remoteness, and depth at 150–200 m, same as for the uppermost Tuloi Formation.

It is of special notification, the Dapingian–Darriwilian stage in the evolution of graptolites, juxtaposed between the "Basal Llanvirn" event (extinction of isograptids and anisograptids in the *gibberulus* graptolite Zone) and "Basal Caradoc" event (didymograptids went extinct at the base of the *peltifer* graptolite Zone), displays no ecological crises (Barnes et al., 1996; Cooper et al., 2004; Webby et al., 2004; and others). Such periods of ecological stability are usually marked by equalization of specimens within the genera both, in the certain locality and within the whole paleobasin. It is the pattern identified in the Yurok Section, where the quantity dominating taxa can not be established within the paleocommunity during the Dapingian–Darriwilian interval. However, the pre-crisis period (*teretiusculus* graptolite Zone) in the Yurok and Lebed' sections reveals minimum of the equalization, with *Hustedograptus teretiusculus* (His.) being drastically dominant (several dozen of the specimens, where the other taxa being rare and scarce).

The Yurok Section demonstrates, that after the global regression and "Basal Llanvirn" biotic event, accompanied by rapid depletion of taxonomical abundance and decrease of the population densities of the graptolites, the Upper Dapingian – Lower Darriwilian stage was characterized by a comparatively rapid revival of the population densities and taxonomical abundance of the graptolites inhabiting the offshore-remote zones with depths at 150–200 m. At the same time, the comparatively proximal and less-deep (< 100–150 m) zones of the paleobasin (Lebed', Pridorozhny, and Tuloi sections) demonstrate a considerably decreased rate of the revival.

The overlaying siltstone and mudstone of the Karasa Formation in the Lebed' (400 m) and Tuloi (370 m) sections, corresponding the *austrodentatus*, *dentatus*, *balhaschensis*, *jakovlevi*, and *teretiusculus* graptolite zones, mirror a gradual transition to the medium-depth zone (100–150 m). The "Late Arenig–Early Llanvirn Lowstand" was followed by a rapid sea level rise, culminated in the global "Furudal Highstand" (Nielsen, 2003, 2004, 2011), also known as the "Late Llanvirn–Caradoc Highstand" (Gradstein et al., 2012), within the *teretiusculus* graptolite Zone. Total sea level rise during the transgression is estimated at 100–150 m (Gradstein et al., 2012).

11. Global sedimentary regressive «Vollen Lowstand» event.

The high stand climax (Late Llanvirn-Caradoc Highstand transgressive sedimentation event) was followed by a regression event with a large-scale sea level drop by 100–130 m (Nielsen, 2004, 2011; Munnecke et al., 2010; Gradstein et al., 2012). The basal coarse-grained (conglomerate, gravelite, sandstone with floating gravel and coarse sand) member that belongs to the Gur'yanovka Formation (Uimen'-Lebed' facies zone), dated to the earliest Sandbian, bears evidence of the global early Sandbian regression Vollen Lowstand in the Late Ordovician Altai sections, rather than of local break in sedimentation. The basal member of the Gur'yanovka Formation is composed of pebbles and gravel which include jasperoid, granite, porphyrite, diabase, sandstone, and siltstone (Noskov, 2007). While talus composed of a variety of Ordovician, as well as older sediments could be supplied from the areas, which became exposed during the previous regression.

12. Global sewdimentary regressive «Frognerkilen Lowstand Event» or «Solvang Lowstand Event».

The described below phenomena manifest in the Gur'yanovka Formation sections (Uimen'-Lebed' facies zone) could be regarded as signatures left by the two global early Katian regressions in the Gorny Altai: (i) the appearance of carbonate gravelite layer (calcirudite with unsorted medium-rounded fragments) in the Bura Section (8th member); (ii) a layer of conglomerate with pebbles of limestone in the Tuloi Section (8th member); and (iii) solitary grains of coarse-grained sand (medium-rounded and -sorted) in fine- and medium-grained sandstones of the Biya section (9th member). The early Katian regressions are most likely to have been caused by the first multi-stage Late Ordovician episodes of global glaciation. The chronostratigraphic position of the two events is recorded at the lowest portion of the *Dicranograptus clingani* graptolite Zone for the former and at the topmost part of this zone for the latter. Estimations of the extent of such regressions yielded a 100 m drop in sea level (Nielsen, 2004, 2011; Munnecke et al., 2010; Gradstein et al., 2012). The Ebogon Section (Anui-Chuya facies zone) is composed of black to dark gray shale with graptolites (*Dicranograptus clingani* Zone) and trilobites. These beds formed at depths of 100 m and below are abruptly overstepped by limestone containing oolitic intercalations, which is interpreted as the result of the wave action, being the signatures left by the "Solvang Lowstand Event".

13. Global sedimentary maximum regressive event connected with the Late Ordovician Glacial – «Ashgill Lowstand Interval» (= «Hirnantian Lowstand Event»).

A global sea level drop from 80 to 150 m was reported for the latest Ordovician (Late Katian and Hirnantian stages), i.e. during the period of most extensive Late Ordovician Glacial there was, which prompted the appearance of shallow-water sedimentary formations and breaks in sedimentation. In the Gorny Altai, this is evidenced by the gray-colored carbonate and thin clastic sediments of the Gur'yanovka Formation (Uimen'-Lebed' facies zone) sharply replaced by the overlying red-colored, clastic (sandstone and gravelite), extremely shallow-water sediments of the Chebor Formation. The Lebed' Section (Chebor Formation) is featured by: gravel-pebble diamictites; tempestites; oblique and cross-lamination; multidirectional and multi-scale wave and current ripples; traces of high-amplitude wave action (Fig. 19, a-e). The desiccation cracks, ichnofossils and other signatures of tidal zone and coastal plain are characteristic of the Gur'yanovka Glade Section (Chebor Formation) (Fig. 19,f).

14. Global Hirnantian sedimentary event (HICE).

A positive carbon isotope excursion pronouncedly distinguished at the latest Ordovician (Hirnantian Stage) with a maximum recorded in the middle part of a specific member with the so-called Hirnantian-Dalmanitian assemblages of benthic fauna which corresponded to either transitional layers between *Nor. extraordinarius* and *Nor. persculptus* graptolite zones, or the lower half of the latter. This excursion reflecting a sharp increase in carbon isotope content developing to

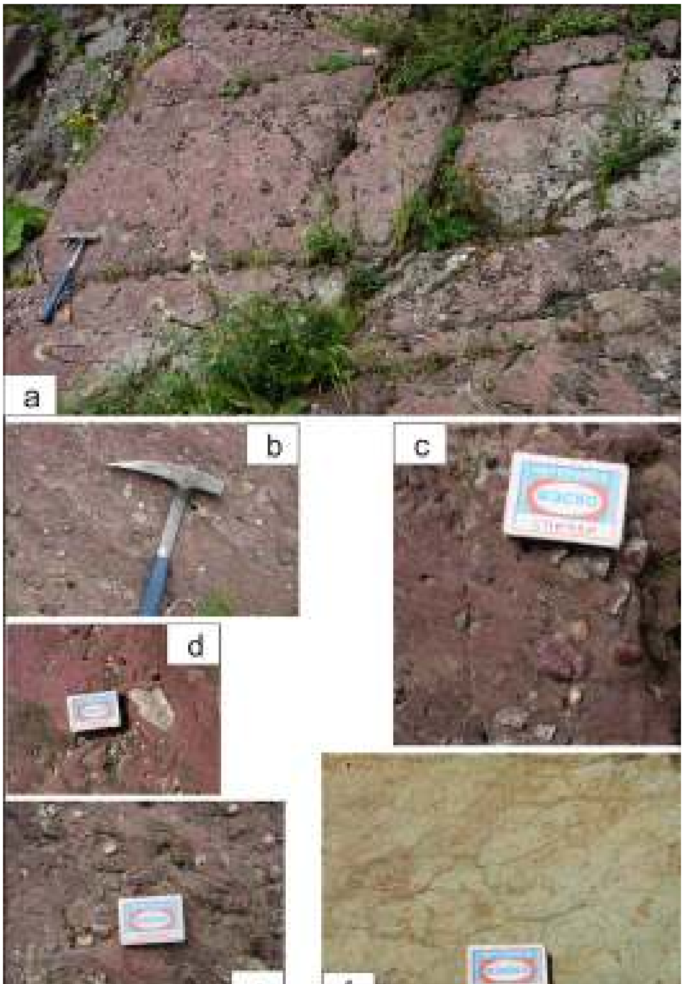


Fig. 19. Lithologic manifestation of the Hirnantian Lowstand Event (Ashgill Lowstand Interval) in the Gorny Altai (Lebed' River).

Fig. 20. The 3 m thick Dalmanitina Limestone Member in the Burovlyanka Section with the light gray lower unit and the dark gray (beige) upper unit. The ruler is 2.8 m long.

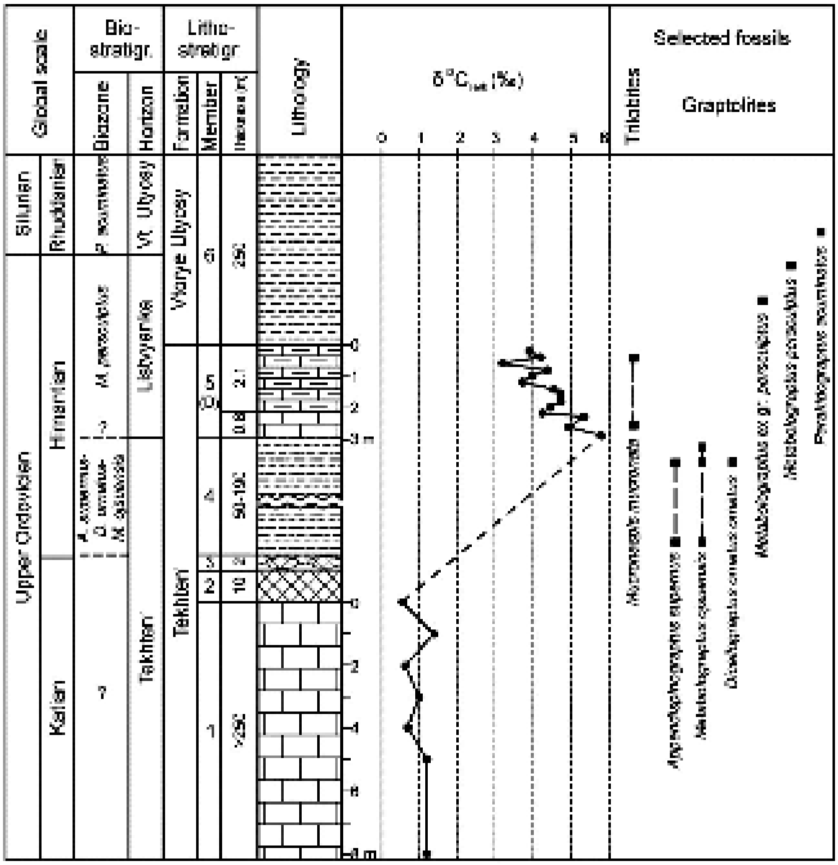


Fig. 21. Stratigraphy, selected fossils (after Sennikov et al., 2014) and carbon isotope data of the Burovlyanka section. Note that thicknesses of the stratigraphic units are not to scale, except for the sampled intervals (members 1 and 5). D – Dalmanitina Member (Member 5) (from Sennikov et al., 2015b).

peaks and indicating maximum absolute values for carbon isotopes throughout the Ordovician, was termed "Hirnantian isotope carbon excursion" (HICE).

The HICE abiotic event has thus far been recorded in almost all Late Ordovician sections, including: a) the Global boundary Stratotype Section and Point (GSSP) for the base of the Hirnantian Stage (the Ordovician System), (Wangjiawan North Section in China) (Chen et al., 2006); b) GSSP for the Rhuddanian (the Silurian System) (Dob's Linn Section in Scotland) (Underwood et al., 1997); c) in the Mirny Section in the Kolyma region in NE Siberia (Russian regional standard of the Hirnantian) (Kaljo, Martma, 2011) and in the key sections of the Ordovician-Silurian boundary stratigraphic interval of numerous geological regions across the continents (Bergström et al., 2006; Kaljo, Martma, 2011; Meidla et al., 2011; Mitchell et al., 2011; Schonlaub et al., 2011 et al.). Continuous Ordovician-Silurian sections with finds of both pelagic assemblages, including graptolites, conodonts and radiolarians, and benthic Dalmanitian fauna were recorded in the Gorny Altai (Charysh-Inya facies zone) (Sennikov, 1998, 2012; Sennikov et al., 2008; Obut, Semenova, 2011; Sennikov et al., 2011b). In the Gorny Altai sections, these complexes allowed a distinct differentiation of the Hirnantian Stage, which corresponds to *Nor. ojsuensis* and *Nor. persculptus* graptolite zones. While studying the Burovlyanka Section (Charysh-Inya facies zone), a key section for the Gorny Altai, carbon isotopes enabled the records of the HICE sedimentation event in the lowermost part of the Dalmanitian member, corresponding to the lowermost part of *Nor. persculptus* Zone (Sennikov, Ainsaar, 2012; Sennikov et al., 2015b) (Figs 20, 21).

3. PALEOGEOGRAPHY OF THE WESTERN ALTAI-SAYAN FOLDED AREA (ORDOVICIAN ALTAI-SALAIR BASIN)

3.1. SEDIMENTARY TYPIES AND BIOTAS OF THE ALTAI-SALAIR ORDOVICIAN BASIN

The Altai-Salair Ordovician basin represented shelf continental-margin basin of the Siberian Craton. The so-called Paleo-Asian Ocean was directly linked with the Altai-Salair shelf basin. Its separate fragments could be observed as tectonic blocks in the Gorny Altai area.

Local lithostratigraphic subdivisions (formations) in the Altai-Salair Ordovician basin characterize wide range of sedimentary facies: from shelf to oceanic genesis. Formations could be subdivided into two groups. First is represented by only one rocks association, for example, sandstone and siltstone, confined to a single specific facies. The second group includes formations represented by the diverse rock associations, for example, limestone, mudstone, siltstone and sandstone. Such rocks in the various sections characterize relatively same facies that on the other hand could be assigned to the different paleogeographic environments.

3.1.1. OCEANIC GENESIS

1. Volcanic-siliceous-terrigenous sedimentary type (massive, coarse-laminated tuff, tuff sandstone, chert, siliceous mudstone, siltstone, sandstone yielded numerous siliceous sponge spicules, radiolarians and rare conodonts). As an example: Marcheta Formation (Marcheta-2 and Talitsa sections) – Late Tremadocian – Floian.

2. Siliceous-terrigenous sedimentary type (massive, coarse-laminated chert, siliceous mudstone, siltstone, sandstone with numerous siliceous sponge spicules, radiolarians and rare conodonts). As an example: Marcheta Formation (Kamyshenka and Charysh sections) – Late Tremadocian – Floian.

3.1.2. CONTINENTAL SLOPE GENESIS

1. Terrigenous flysch sedimentary type (coarse-laminated rhythmic sandstone, siltstone, mudstone, with rare but taxonomically diverse trilobites, brachiopods, single poor graptolites). As an example: Bugryshikha Formation (Malaya Uskuchevka and Pichuzhikha-2 sections) – Late Darriwilian – Early Sandbian.

2. Terrigenous underwater-sliding (gravitation-mixtite) sedimentary type (non-bedded, often lense with landslide traces and small isolated sphere jointing in terrigeneous rocks ("twisting"), chert, siliceous mudstone, siltstone, with rare unvaried radiolarians and rare siliceous sponge spicules). As an example: siliceous-terrigenous sequence (Suetka Section) – Early Hirnantian.

3. Siliceous-terrigenous (gravitational-mixtitic) sedimentary type (fine-laminated, often lenses with traces of sliding and isolated sphere jointing in terrigeneous rocks ("twisting"), chert, siliceous mudstone, siltstone with few and taxonomically monotonous radiolarians and rare siliceous sponge spicules). As an example: siliceous-terrigenous sequence (Suetka Section) – Early Hirnantian.

3.1.3. SHELF GENESIS

The outer shelf, which is quite far from the shore, must have had depths of 150–250 m, that is, greater than those in the inner shelf. It supported a carbonate platform, which occupied at least 70 % of the studied strip. The platform, in its turn, developed reefs, whose tops reached the sea surface (so-called level reefs). About 20–25 % of the outer shelf was occupied by the inner edge of the carbonate platform, with terrigenous-carbonate and carbonate-terrigenous sedimentation; 5–10 %, by the outer edge and bottom of the carbonate platform, with carbonate–terrigenous or, less often, siliceous-terrigenous sedimentation.

1. Volcanic-terrigenous sedimentary type (volcanic islands and arcs).

A. Volcanoes slope facies (porphyrite, tuff, sandstone lenses and rare limestone lenses with single trilobites and brachiopods). As an example: Salair, Krasnoe Formation (Section Krasnoe), El'tsovka Formation (El'tsovka Section) – Tremadocian.

B. Facies distant from the volcanic arc (porphyrite, tuff, beds and lenses of sandstone, siltstone and limestone with few taxonomically diverse trilobites and brachiopods). As an example: Gorny Altai, Agayra Formation (Anos Section) – Tremadocian.

2. Siliceous-terrigenous sedimentary type.

A. Facies of the distant from shore deep shelf (chert, siliceous mudstone, siltstone with taxonomically diverse radiolarians and rare taxonomically diverse conodonts siliceous sponge spicules). As an example: Tekhten' Formation (sections Tachalov and Barany), siliceous-terrigenous sequence (Suetka Section) – Early Hirnantian.

B. Facies of the shelf foreland, near continental slope edge (sandstone, siltstone, siliceous mudstone with few poor graptolites). As an example: Tekhten' Formation (Rudovozy Section) – Early Hirnantian.

3. Terrigenous sedimentary type.

A. Avandelta front of the mountain river (varicolored conglomerate and sandstone). As an example: Upper Subformation of the Kamlak Formation (Section Takoshkin) – Late Tremadocian; Bulukhta Formation (Boriskin Log Section) – Early Hirnantian.

B. Riverside facies:

a) location close to cliffy (iron-bound) desiccated river bank (beds and lenses of the well-rounded and well-sorted conglometare, gravelstone, sandstone). As an example: lower basal bed of the Tuloi Formation (Mingalevsky, Ishpa sections) – Early Floian;

b) location close to relatively plane bank (massive, well-sorted and well-rounded sandstone). As an example: lower basal bed of the Karasa Formation (Tuloi Section) – Middle Darriwilian.

C. Facies distant from the bank (siltstone, mudstone, rarely sandstone with taxonomically diverse graptolites, trilobites and brachiopods). As an example: middle and upper parts of the Tuloi Formation (Stretenka, Tagaza, Tandoshka sections) – Floian; Bugryshikha Formation (Maralikha Section) – Late Darriwilian – Early Sandbian; Khankhara Formation (Ebogon Section) – Late Sandbian – Early Katian; Ilovaty Formation (Ilovaty, Cheremshanka sections) (Salair) – Floian – Early Darriwilian; Karastun Formation (Korovy Section) (Salair) – Middle Darriwilian – Sandbian; Izyrak Formation (Izyrak Section) (Salair) – Floian – Early Darriwilian.

D. Facies of the underwater highs tops (fine-platy and cross-laminating mudstone with traces of maceration and yielded abundant taxonomically diverse graptolites). As an example: Voskresenka Formation (Pichuzhikha Section) – Floian.

E. Facies of the underwater highs bottoms (gravitation-mixtite) (coarse-laminated sandstone and siltstones with the middle size isolated sphere jointing in terrigeneous rocks (“twisting”), up to 0.2–0.3 m in diameter, with rare taxonomically monotonous graptolites). As an example: Voskresenka Formation (Maralikha Section) – Lower Darriwilian.

4. Carbonate-terrigenous sedimentary type.

A. Facies slightly distant from the shore (carbonate mudstone, marl, clayey limestone with rare taxonomically poor corals and brachiopods). As an example: Diskovaya Formation (Algain Section) – Early Katian (Gornaya Shoriya).

B. Facies distant from the shore (intercalation of prevailed carbonate mudstone and siltstone, with the secondary in amount middle-laminated clayey limestone yielded few taxonomically diverse brachiopods and trilobites, rare taxonomically poor corals and graptolites). As an example: Khankhara Formation (Verkhnyaya Karasu, Nizhnyaya Karasu, Marcheta-4 sections) – Early Katian.

5. Terrigenous-carbonate sedimentary type.

A. Facies distant from the shore (intercalation of prevailed fine-laminated carbonate clayey limestone with the secondary in amount of carbonate mudstone and siltstone yielded abundant taxonomically diverse brachiopods and trilobites, rare taxonomically monotonous corals). As an example: Khankhara Formation (Marinikha, Kholmogorikha sections) – Early Katian.

B. Facies adjacent to distant parts of the reefs (middle and fine-laminated clayey limestone with intercalates of carbonaceous mudstone with abundant diverse corals, trilobites, brachiopods). As an example: Tekhten’ Formation (Elanda Section) – Late Katian.

C. Facies of bays on the reef edges (lenses of the algae bioherms small in size, to 1-2 m in diameter, in the siltstone-mudstone matrix with rare taxonomically monotonous brachiopods and graptolites). As an example: Tekhten’ Formation (Burovlyanka Section) – Early Hirnantian.

6. Carbonate (reef) sedimentary type

A. Facies of the groups of large reefs (up to 2-3 km in diameter) on the carbonate platform at shelf edge:

a) the central parts of separate reefs (massive, un-laminated limestone, with large algae bioherms up 20-30 m, with rare taxonomically monotonous corals). As an example: Tekhten’ Formation (Orlov, Burovlyanka, Marcheta-4, Tekhten’, Chakyr, Muta, Bely Bom sections) – Late Katian – Early Hirnantian;

b) the marginal part of the separate reefs (coarse- and middle laminated limestone, with large taxonomically diverse corals). As an example: Tekhten’ Formation (Tekhten’, Muta sections) – Late Katian;

B. Facies of middle-sized reefs (0.5–1 km in diameter) on the slopes of fade volcanoes (massive, un-laminated limestone, with abundant taxonomically diverse trilobites, as well as rare taxonomically poor brachiopods and conodonts). As an example: Tolstochikha Formation (Orlinaya Section) – Tremadocian (Salair).

C. Facies of separate, small (0.05–0.1 km in diameter), isolated reefs (patch-reef). As an example: Tekhten’ Formation (sections Tachalov, Burovlyanka) – Early Hirnantian; Veber Formation (Spornaya Sopka Section) – Early Hirnantian (Salair).

D. Shallow-water distant from shore facies (middle-laminated oolitic limestone, with rare brachiopod and trilobite fragments). As an example: basal bed of the Khankhara Formation (Malaya Uskuchevka, Ebogon, Belaya sections) – Late Sandbian.

3.2. SEDIMENTARY MODEL PROFILES FOR THE ORDOVICIAN OF THE ALTAI BASIN

Regularities in lithofacies succession in the different facies area of the Gorny Altai was found out during alignment of the Ordovician local lithostratigraphic subdivisions based on graptolite and conodont zonation (Figs 22–24).

Analysis of fauna paleo-assemblages obtained from the local stratigraphic subdivisions (formations) turned out variations in composition and population density within different fauna groups (Fig. 25).

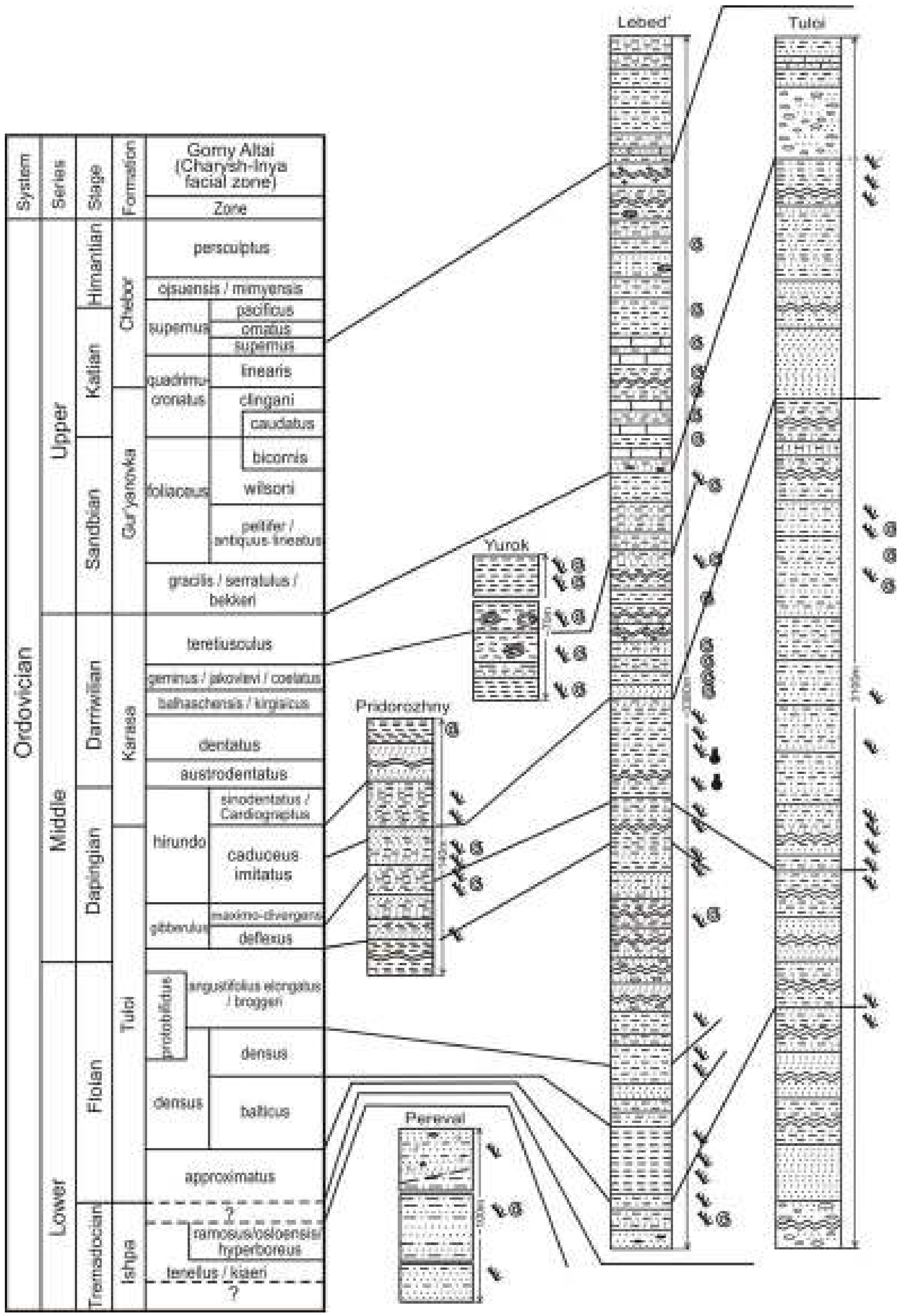


Fig. 22. Correlation of the Ordovician key sections of the Uymen'-Lebed' facies zone.

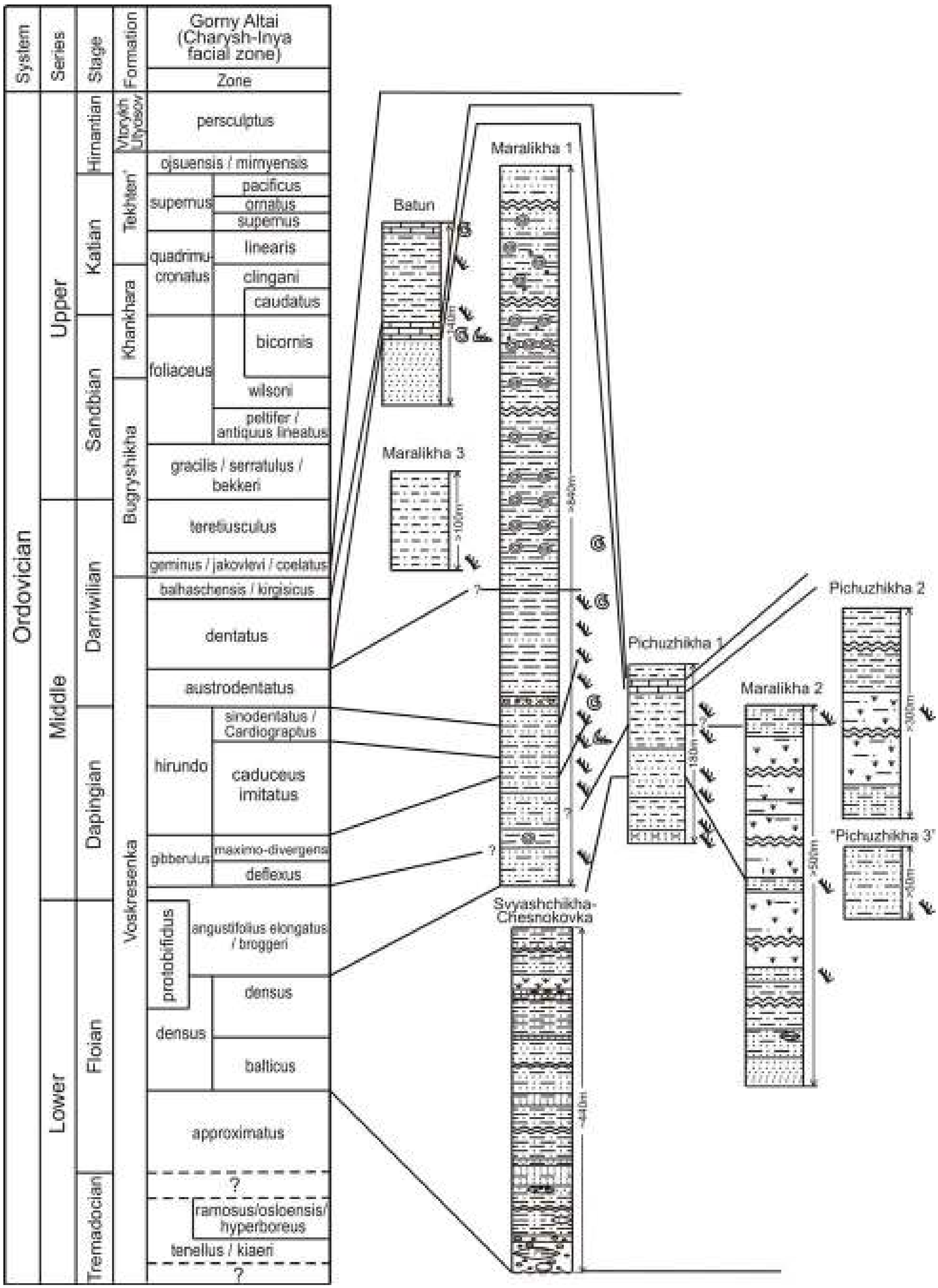


Fig. 23. Correlation of the Ordovician key sections of the Charysh-Inya facies zone.

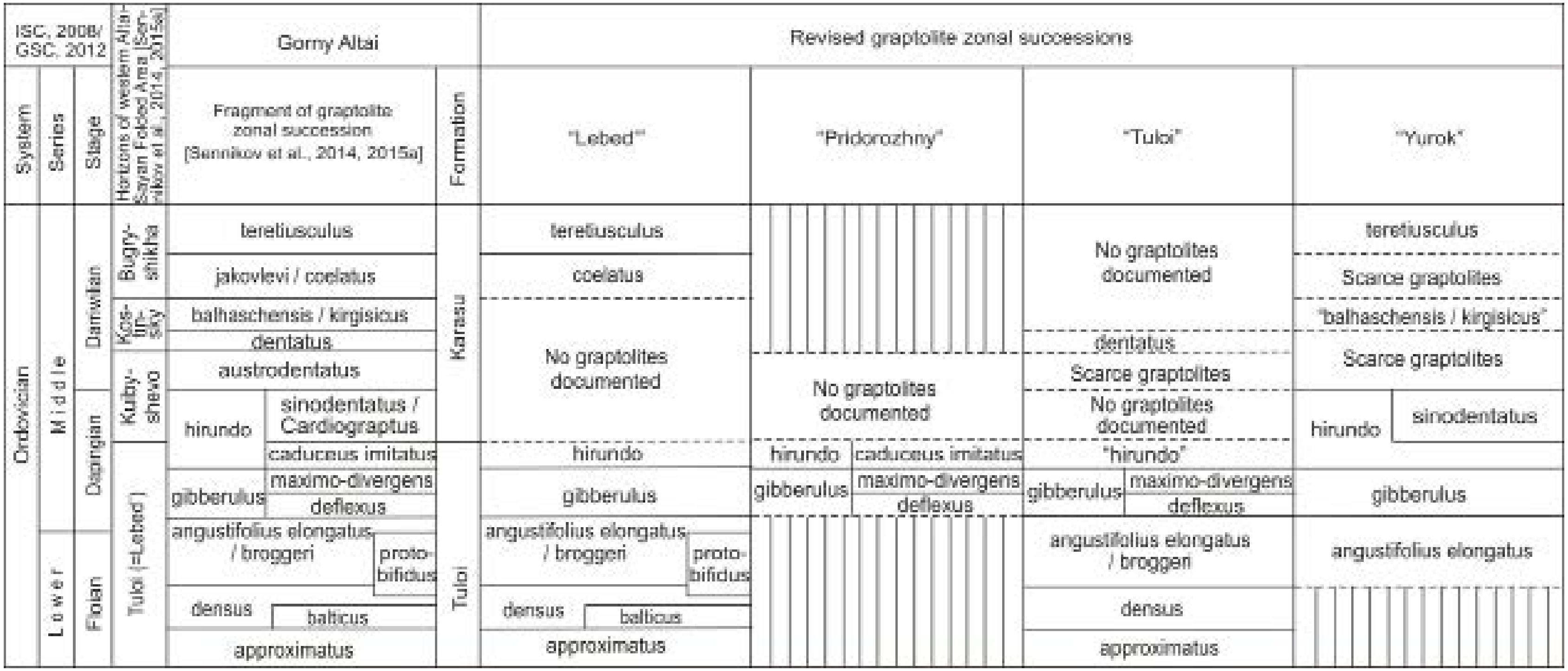


Fig. 24. Correlation of identified zonal successions in the studied sections of the Uymen'-Lebed' facies zone, and regional graptolite zonation for the Lower (excluding Tremadocian) and Middle Ordovician of the Gorny Altai.

Sections	Lebed'	Bura	Gyr'yanovka Medow	Tuloi-Karasa	Chechenek	Biya
Distribution of lithological types of rocks						
Sandstone (including gravelstone and conglomerate)	~20%	~3%	15%	~40%	47%	~40%
Mudstone and siltstone	~30%	~9%	30%	~40%	43%	~42%
Limestone (including clayey and sandy)	~50%	~88%	55%	~20%	10%	~18%
Frequency of faunal groups occurence in separate layers and beds						
High (> 100 specimen)	Brachiopods, tabulate corals /heliolithids	Tabulate corals /heliolithids, brachiopods		Brachiopods	Brachiopods	Brachiopods
Middle (100-10 specimen)	Ostracods, nautiloids	Ostracods, trilobites	Brachiopods, ostracods, tabulate corals	Ostracods		Conodonts, ostracods
Low (< 10 specimen)	Conodonts, trilobites	Conodonts, rugose corals, stromatoporoids		Trilobites, nautiloids		
Rare findings	Rugose corals		Rugose corals, bryozoans, trilobites, ichnofossils	Tabulate corals	Trilobites, crinoids	Corals, bryozoans, trilobites, nautiloids
Taxonomic variety of faunal groups entirely throughout the section						
High (> 10 specimen)		Brachiopods		Brachiopods, ostracods		
Middle (10-5 specimen)	Brachiopods, conodonts	Tabulate corals/ heliolithids, trilobites	Brachiopods	Trilobites		Brachiopods
Low (< 5 specimen) and weakly studied	Tabulate/ heliolithids, ostracods, trilobites, rugose corals, nautiloids	Bryozoans, rugose corals, conodonts, stromatoporoids	Rugose corals, bryozoans, tabulate corals, ostracods, ichnofossils	Tabulate corals, nautiloids	Brachiopods, trilobites, crinoids	Conodonts, trilobites, bryozoans, corals, ostracods, nautiloids

Fig. 25. Correlation of identified zonal successions in the studied sections of the Uymen'-Lebed' structure-facies zone, and regional graptolite zonation for the Lower (excluding Tremadocian) and Middle Ordovician of the Gorny Altai.

In recent years, the event stratigraphy has been increasingly corroborated by numerous data on the world ocean level fall (during regressions) and rise (during transgressions) in absolute ages (Nielsen, 2003, 2004, 2011; Munnecke et al., 2010; Gradstein et al., 2012). The granulometric composition of terrigenous sediments, their sedimentation behavior and fauna characteristics enable first-approximation estimates of absolute paleodepths of the sedimentation (Fig. 26). A comparative study of abrupt changes in the lithological composition within a series of Ordovician sections of the Gorny Altai allowed marking some of the abrupt large-scale changes in the Ordovician Altai basin depths (Fig. 27).

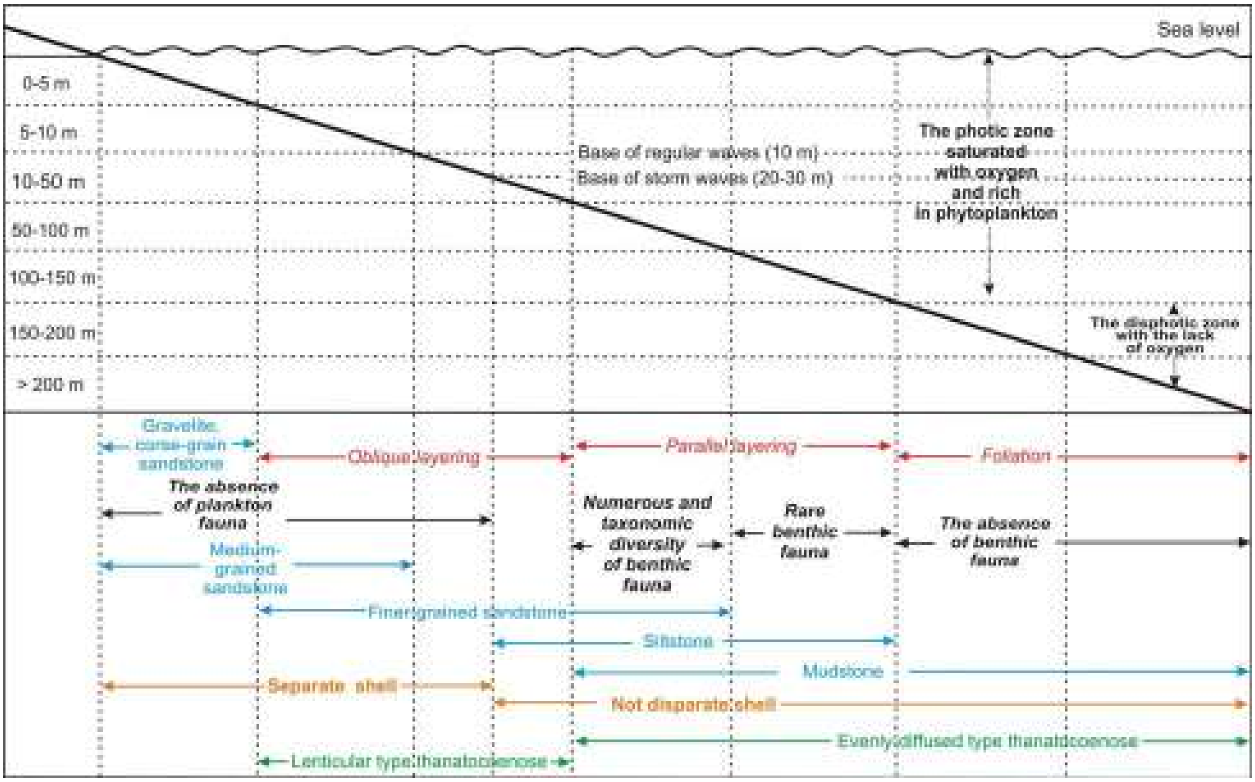


Fig. 26. Standard profile for depths of marine basin.

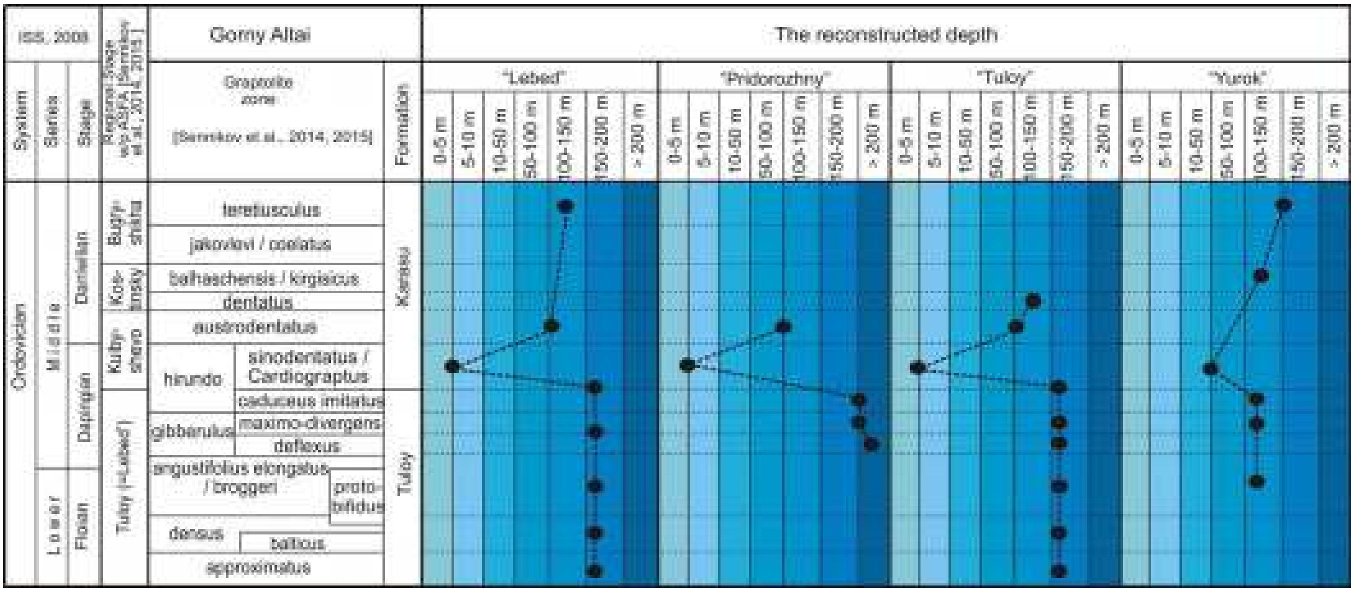


Fig. 27. Reconstructed depth variations within the studied areas of the Gorny Altai paleobasin in the Early–Middle Ordovician.

Integrated analysis of sedimentary features and composition of fauna groups (paleo-communities) revealed the patterns of their relationships based on : a) the distance from the provenance area of terrigenous material supplied to the paleobasin; b) the paleobasin's depth; c) the paleo-seafloor topography (micro-lows, large slope angles, etc.), d) sediment composition, e) grain-size of clastic sediments, f) thickness of forming beds (Fig. 28). The patterns variability is most prominent for the succeeding stratigraphic intervals.

Reconstruction of spatial facies substitution of lithological types of Ordovician sedimentary rocks in the Gorny Altai area throughout the sections revealed different patterns of facies relationships between clastic and carbonate rock associations and, accordingly, changes of fauna groups in paleocommunities (Figs 29, 30).

While analysis and generalization of the revealed patterns allowed to construct the so-called model profiles of Ordovician sedimentation in the paleobasins of the Gorny Altai (Figs 31–33). Each of these profiles has its own prototype (see above Figs 29, 30), represented by a group of real sections of a certain chronostratigraphical interval (straddling usually 1–2, rarely 3 stages) for specific areas corresponding to any offshore part of the Ordovician Altai paleobasin. Comparison of the model profiles allows to reveal specific evolution of individual parts of the paleo-offshore areas and to identify the trends in sedimentation processes within the paleobasin, which serves as the basis for a comparative analysis of the Ordovician Altai basin development and evolutionary stages of other known Ordovician

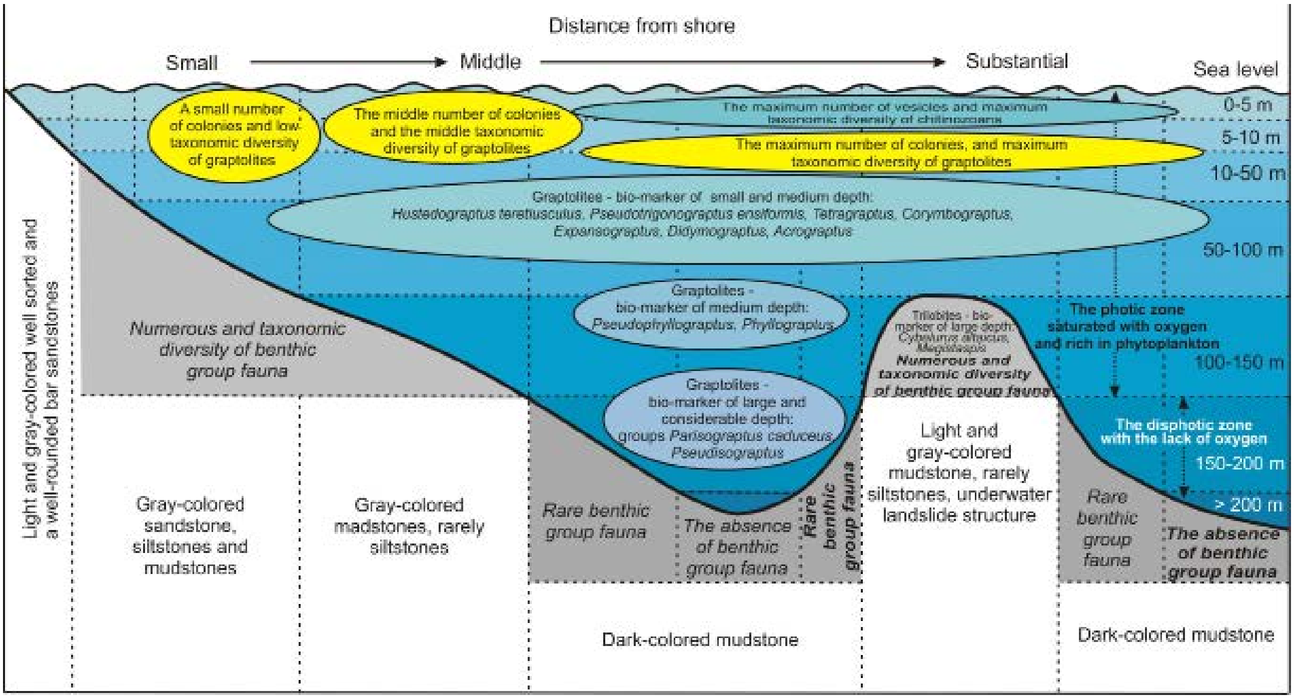


Fig. 28. Model profile of the Altai paleobasin (Uymen'-Lebed' facies zone / Tuloi and Karasa formations / Dapingian Stage – Darriwilian Stage).

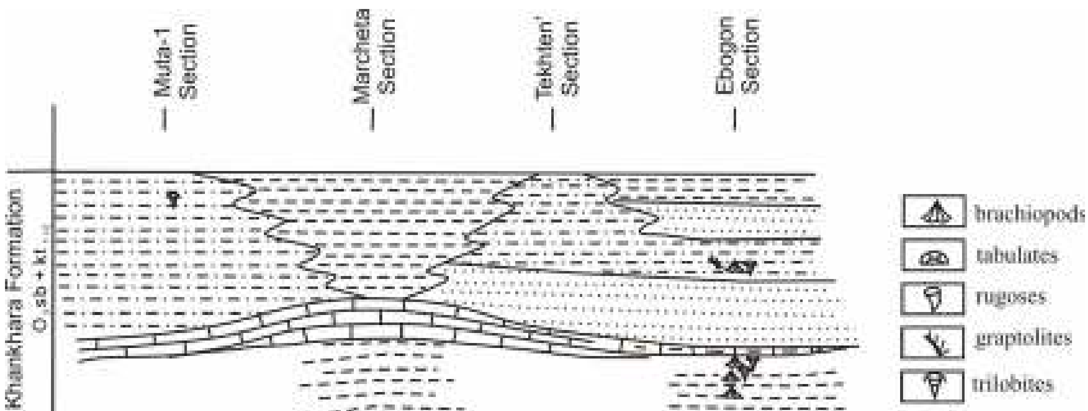


Fig. 29. Lihtological profile of the Altai paleobasin (Anui-Chuya facies zone / Khankhara Formation / Upper part Sandbian Stage – Lower part Katian Stage).

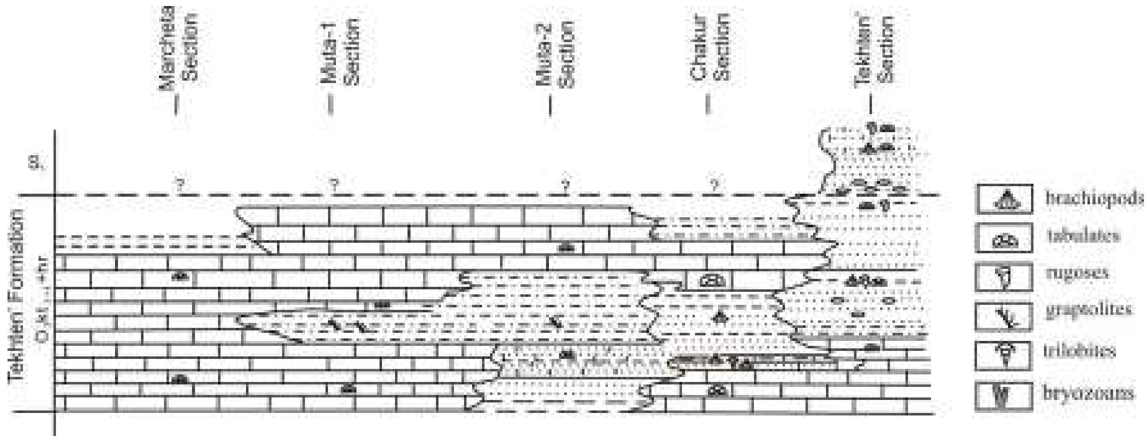


Fig. 30. Lihtological profile of the Altai paleobasin (Anui-Chuya facies zone / Tekhten' Formation / upper part Katian Stage – Hirnantian Stage).

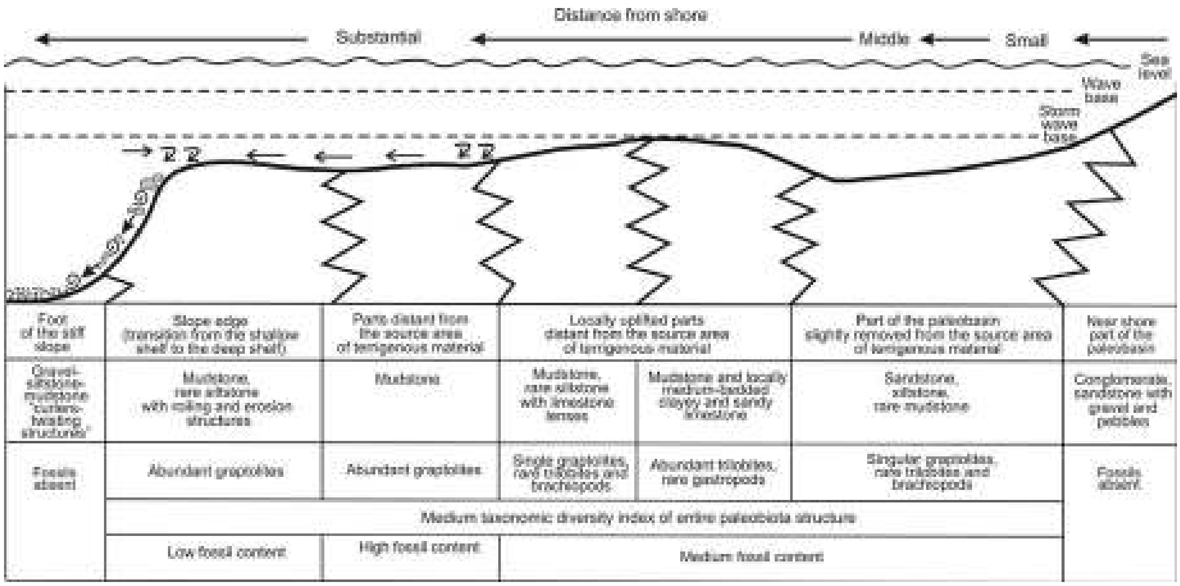


Fig. 31. Model profile of the Altai paleobasin (Charysh-Inya facies zone / Voskresenka Formation / upper part Floian Stage – lower part Darriwilian Stage).

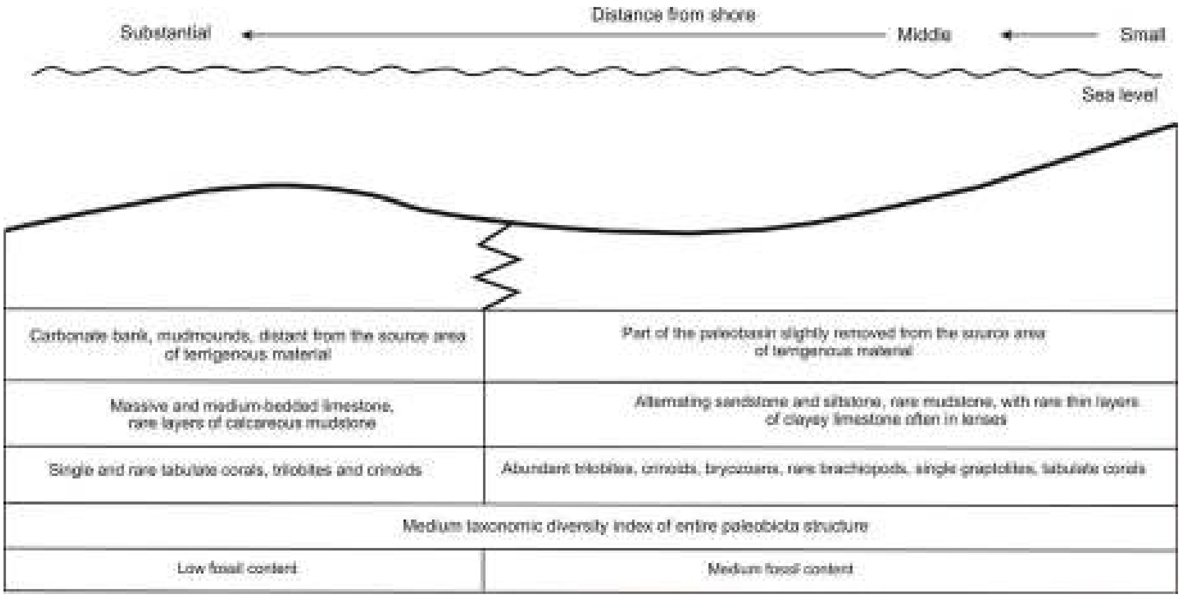


Fig. 32. Model profile of the Altai paleobasin (Anui-Chuya facies zone / Khankhara Formation / upper part Sandbian Stage – lower part Katian Stage).

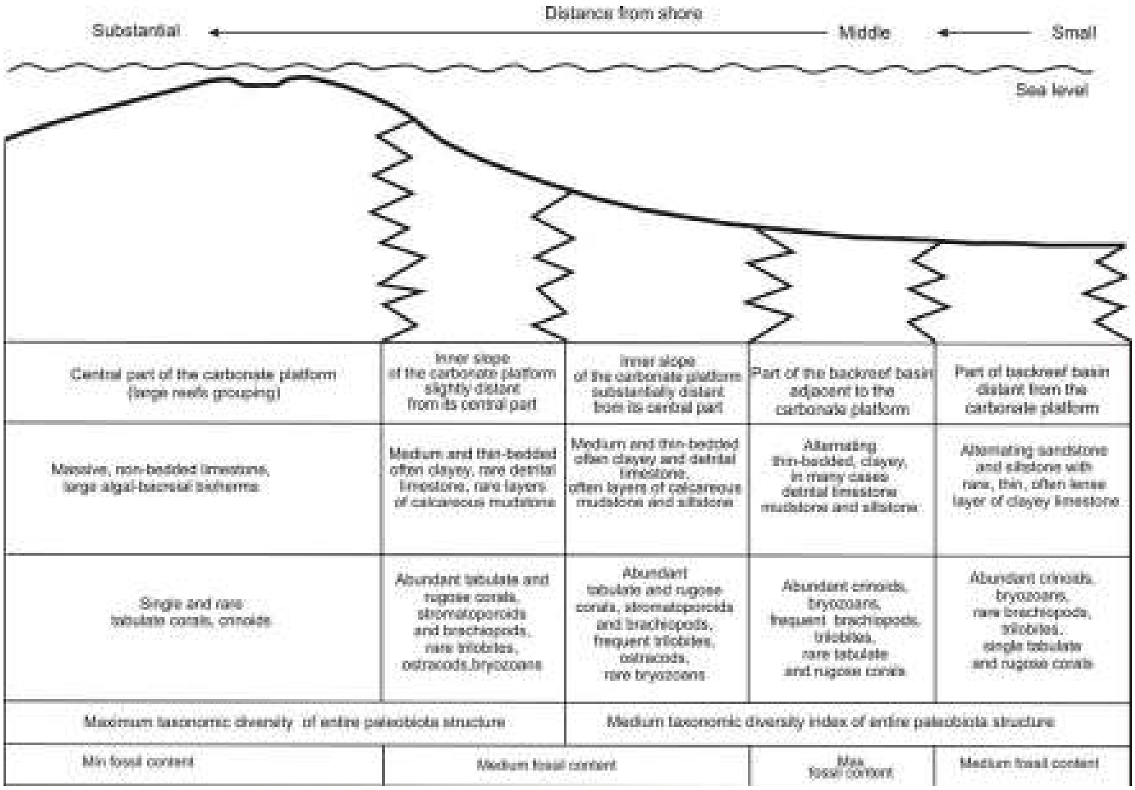


Fig. 33. Model profile of the Altai paleobasin (Anui-Chuya facies zone / Tekhten' Formation / Upper part Katian Stage – Hirnantian Stage).

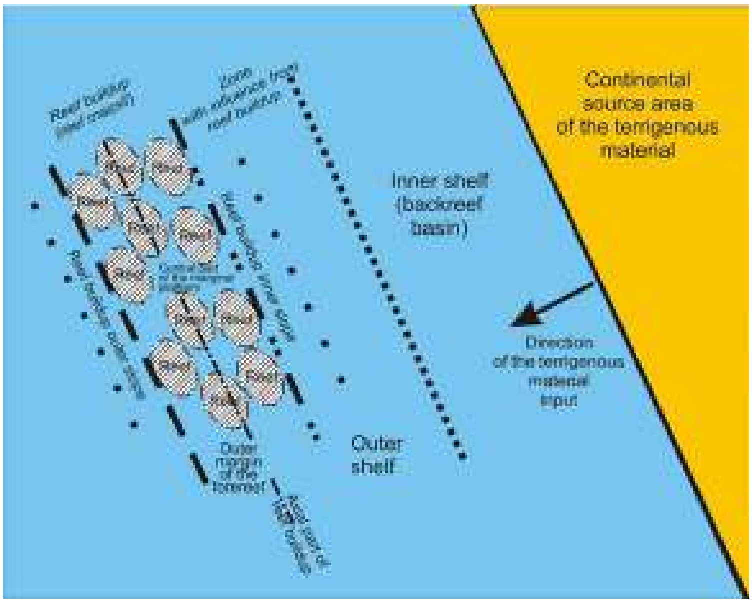


Fig. 34. General structural scheme of the Late Ordovician Altai basin.

basins in Siberia, the Urals, Taimyr, the Baltic region and across the world.

Generalization of the series of facies profiles across the outcrops of Ordovician shelf sediments in the Gorny Altai area allowed an inference about the predominant sedimentation types in the Late Ordovician basin described as: (i) reefogenic type in the carbonate-platform zone and (ii) terrigenous-carbonate and terrigenous type in the inner-shelf zone (Yolkin et al., 1994; Sennikov et al., 2008) (Fig. 34).

3.3. PALEOGEOGRAPHIC RECONSTRUCTION OF THE ORDOVICIAN ALTAI BASIN

This study is the systematic synthesis of successive changes in paleogeography and contours of the Ordovician Altai basin. The synthesis is based on a series of stage- (and substage) scale paleogeographic charts for the whole Ordovician-Silurian basin history which have been compiled and partly published by today (Yolkin et al., 1994; Sennikov, 2006a, b; Sennikov et al., 2008).

4. ORDOVICIAN KEY SECTIONS IN THE GORNY ALTAI

The described sections are grouped geographically into areas of the western, northwestern, central, northern and northeastern Gorny Altai. The member subdivision and bed-by-bed description of the sections have been the responsibility of N.V. Sennikov, Z.E. Petrunina, L.A. Gladkikh, A.V. Krivchikov, O.T. Obut, E.V. Bukolova (Lykova). The section symbols are keyed as follows. The letters stand for author's name (e.g., Yo for Yolkin, S for Sennikov, P for Puzyrev, R for Russkikh, B for Bukolova in Yo-7039, S-78115, P-78032-1/12, R-7812 and B-097) or for location (LSS for location from succession of sections, F for faunal location, H for shallow hole). Two first numerals after hyphen denote the year when the description was made (70 for 1970, 78 for 1978, etc.) and the following digits before hyphen are section or locality numbers (39, 115, 032); numerals after second hyphen are member numbers (-1 for first member), and numerals after slash mark the sampling depth in meters above the member base (/12 means that the sample was collected at 12 m above the base of the member).

4.1. NORTH-EASTERN GORNY ALTAI (Uymen'–Lebed' facies Zone)

Ordovician sedimentary sequences cropped out in the north-east of the Gorny Altai form a large-scale anticline, accompanied by synclines and tectonic dislocations and belong to the Uymen'–Lebed' facies zone (Fig. 35).

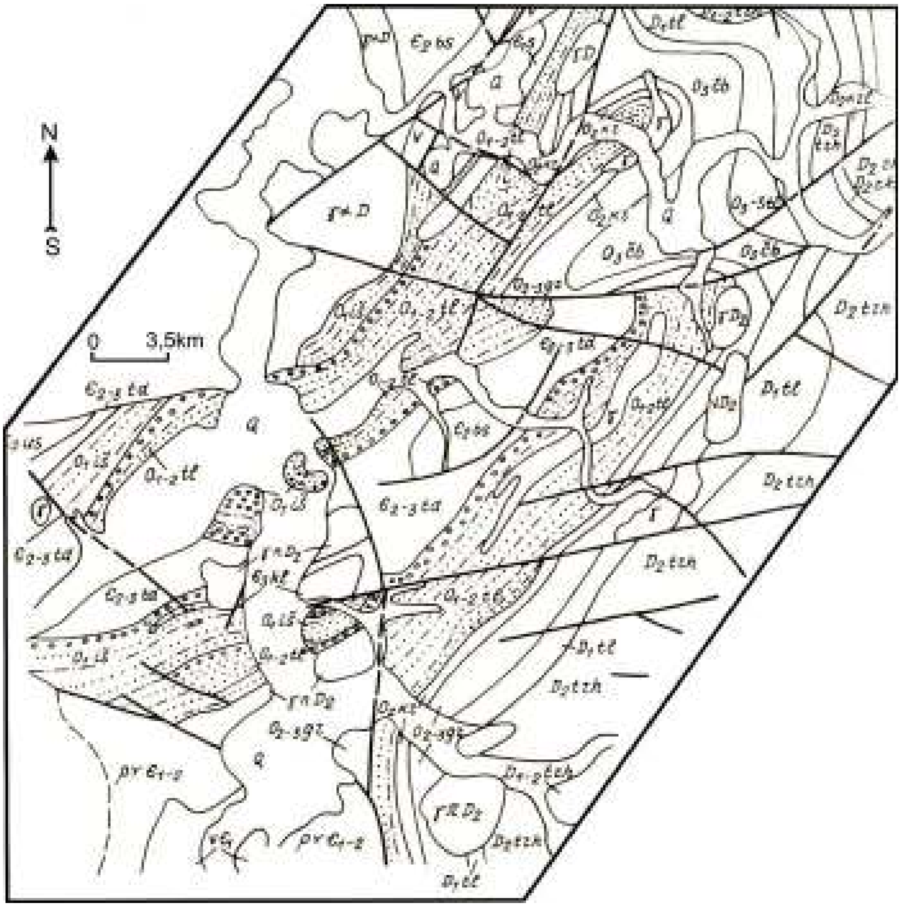


Fig. 35. Sketch map of the lower and middle stream of the Biya River (Sennikov et al., 2008).

4.1.1. AREA OF VERKH-BIYSK VILLAGE

Pereval Section
Chronostratigraphic subdivisions of the International Stratigraphic Scale: Tremadocian.
Regional stratigraphic subdivisions: Takoshkin Regional stage (Horizon).
Local lithostratigraphic subdivisions: Ishpa Formation.
Zones: *tenellus – kiaeri* graptolite zones.
Fauna: trilobites, graptolites.

A small fragment of the Ishpa Formation (S-0726) is exposed in a quarry on a pass along the left side of the roadway from Gorno-Altaisk to Verkh-Biysk Village (distance mark 105/9) (Figs 36, 37).

Fig. 36. General view of the Pereval Section (upper part of Ishpa Formation).

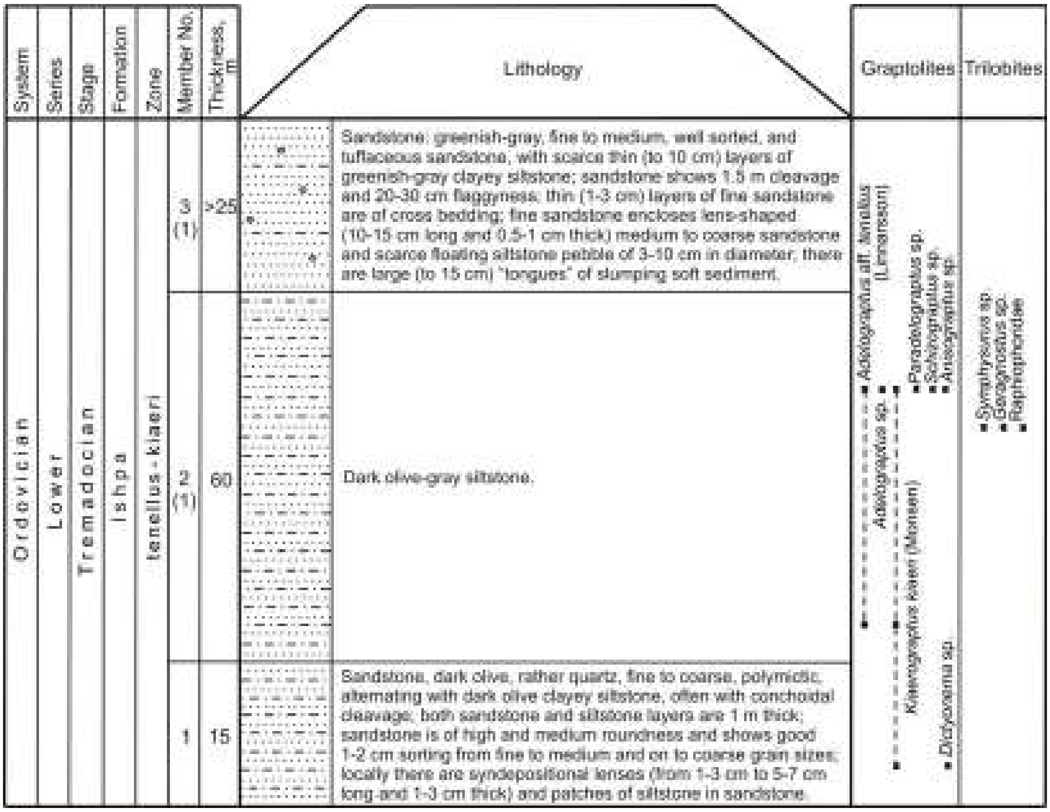


Fig. 37. Lithology and ranges of fossil taxa from the Pereval Section.

Dark olive-gray siltstone in bedrock exposures along the right side of the roadway between the two quarries (S-0726 and S-0727) contains graptolites (loc. S-0726) *Dictyonema* sp., *Kiaerograptus kiaeri* (Monsen), (loc. S-78146) *Adelograptus* aff. *tenellus* (Linnnarsson), *Kiaerograptus kiaeri* (Monsen), and sandstone (loc 205) contains trilobites *Symphysurus* sp., *Geragnostus* sp., Raphiophoridae; graptolites *Anisograptus* sp. are found at loc. 4062a/1668 in the same area; (loc. B-097-099) graptolites *Adelograptus* aff. *tenellus* (Linnnarsson), *Adelograptus* sp., *Paradelograptus* sp., *Kiaerograptus kiaeri* (Monsen), *Schizograptus* sp. According to rock lithology and faunas (trilobite and graptolite assemblages), the section fragment belongs to the Ishpa Formation. Graptolites correspond to the Tremadocian *Adelograptus tenellus* and *Kiaerograptus kiaeri* zones.

The total thickness of the Ishpa composite section (S-0726, S-0727, S-78146) may reach no less than 100 m.

Peculiarities in facies, faunal assemblages and sedimentary environments.

The siltstone topping the studied section comprise layers with traces of washouts formed in the extremely shallow intertidal zone (Fig. 38). Alternatively, rare graptolites were found in the lower and middle parts of the Pereval Section, which may indicate average depths (50–100 m) of the enclosing rocks deposition.

Fig. 38. Lithology of the Pereval Section (upper part of the Ishpa Formation).

Ishpa Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Cambrian (Furongian), Ordovician (Tremadocian).

Regional stratigraphic subdivisions: Takoshkin Regional stage (Horizon).

Local lithostratigraphic subdivisions: Ishpa Formation.

Fauna: trilobites, brachiopods, algae, siliceous sponges.

Lower parts of the Ishpa Formation cropped out on the left bank of Biya River, near Village Danilkino: conglomerate greenish-gray polimictic, more than 200 m thick. In the carbonate pebbles trilobites known from the uppermost Cambrian were found.

The two sections accepted as composite stratotype of the Ishpa Formation are located: (1) 350 m upstream of the river's mouth on the left bank of the Ishpa Rv. (Figs 39, 40); (2) one km upstream of the former, on the right bank of the Ishpa river. The latter section reveals the upper horizons of the Ishpa Formation with the concordantly overlying Tuloi Formation (Floian, Dapingian), with conglomerate and siltstone. The total thickness of the Ishpa Formation including the 200 m member of conglomerate in the vicinity of Danilkino Village measures 1085 m. The left-bank part of the stratotype defined from trilobites is dated as Late Cambrian, while the right-bank part is dated as Tremadocian.

Facies and depositional settings.

In the studied section, one of the conglomerate members of the Ishpa

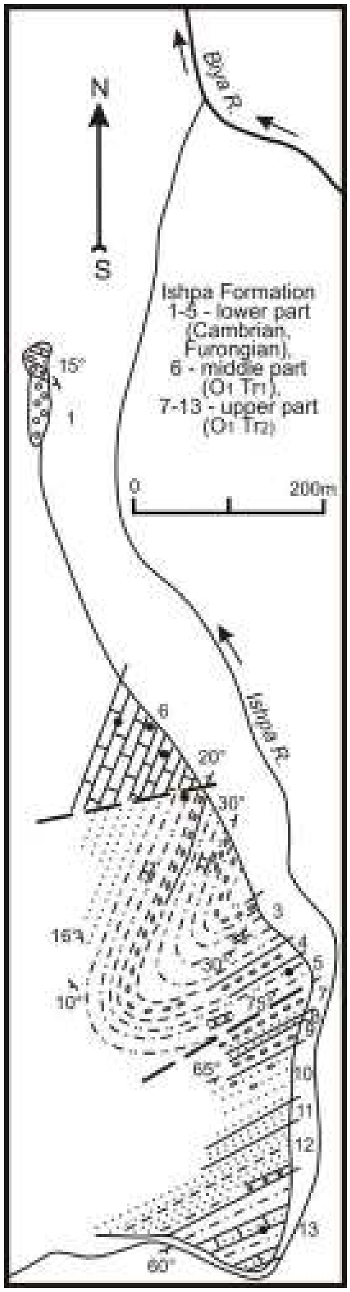


Fig. 39. Sketch map of the Ishpa area.

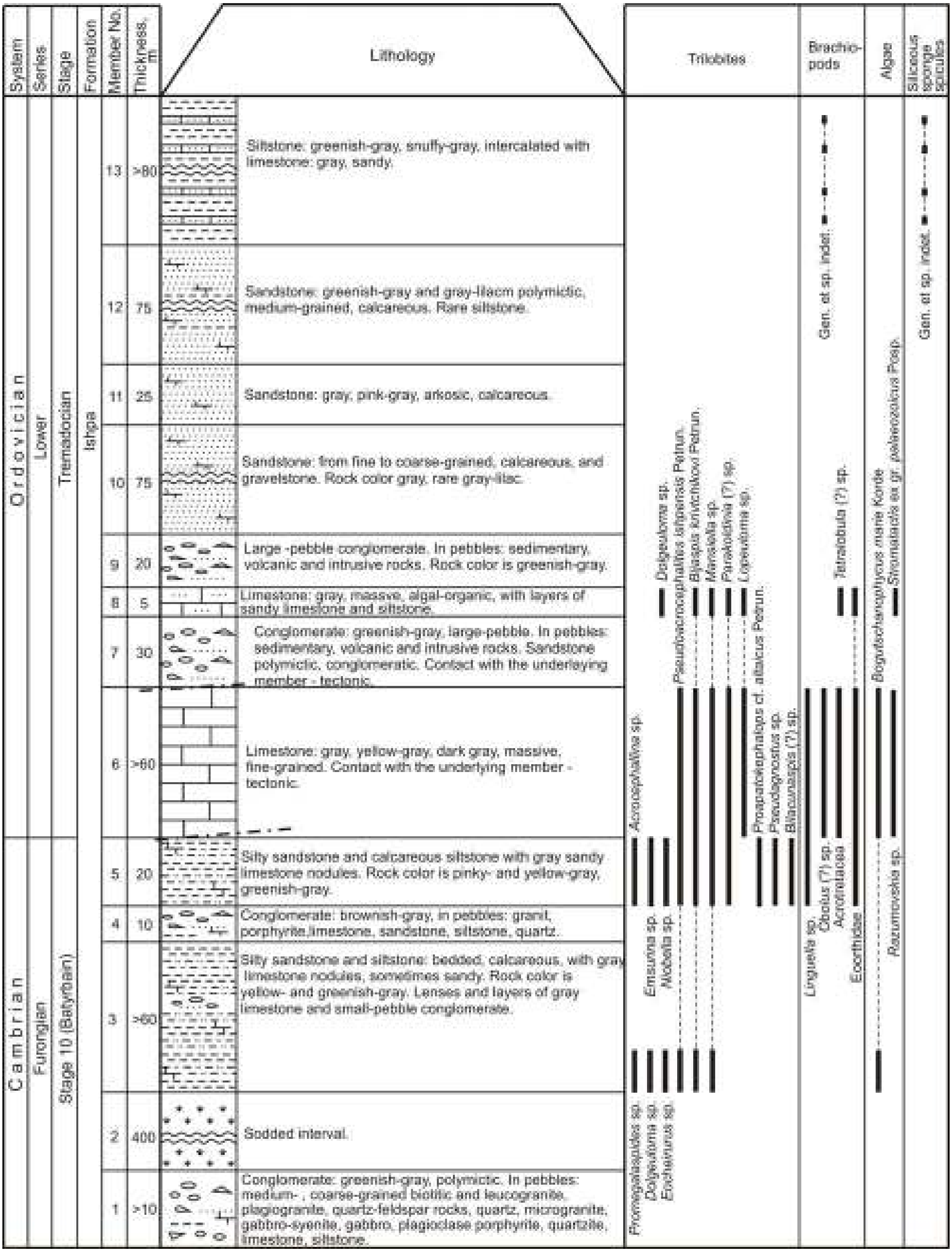


Fig. 40. Lithology and ranges of fossil taxa from the Ishpa Section.

Formation consists of the group of conglomerate-breccia layers with the characteristically almost unrounded fragments of tabular sandstone stratification-oriented layers. The deposition of such rocks is largely influenced by coastal erosion (persistent wave action) affecting a steep cliff composed by horizontally lying, weakly cemented sedimentary rocks, with rapid burial of such buildups in wave-cut notches. In some cases, even sandy cement is absent from large fragments (Fig. 41e, f).

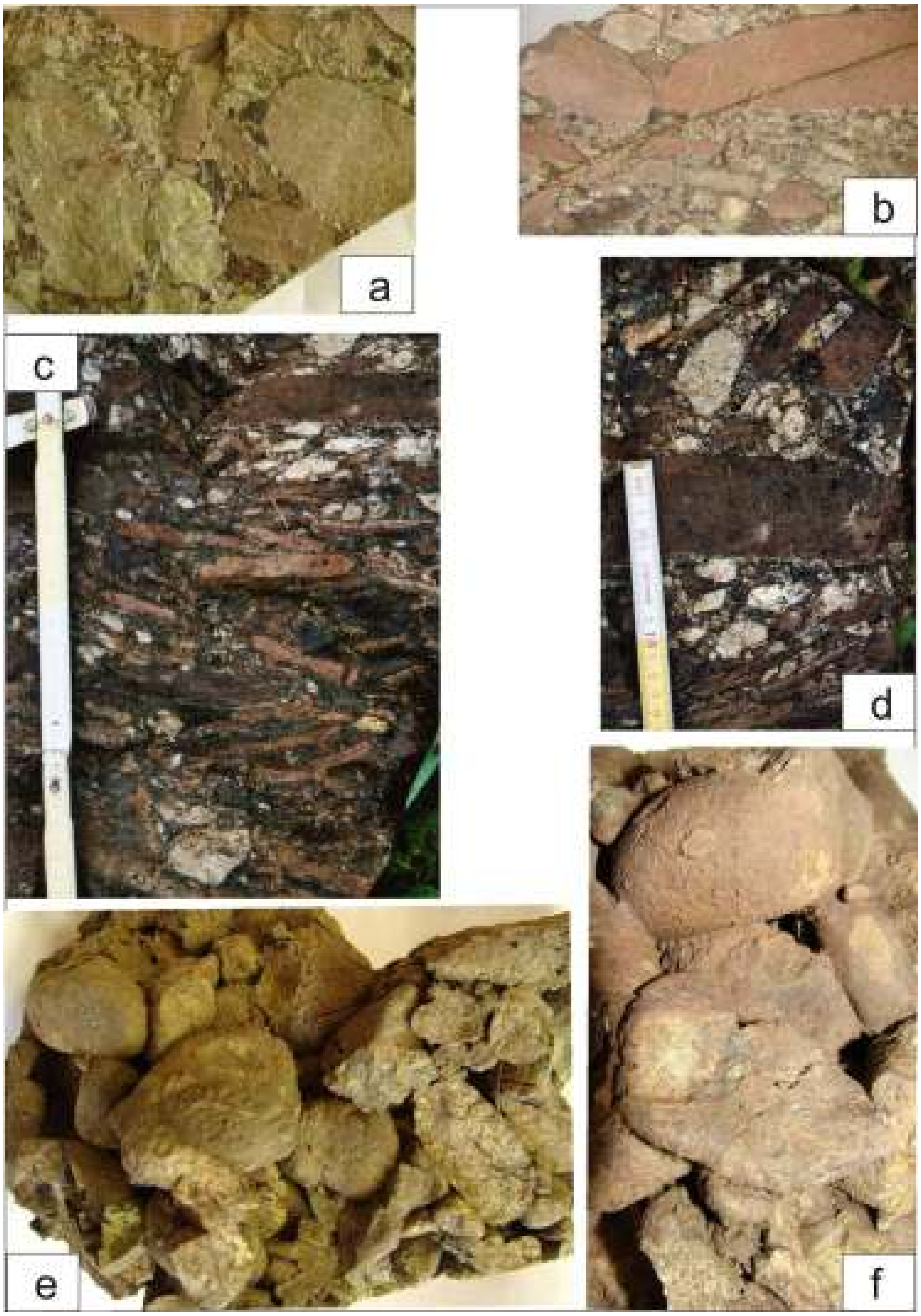


Fig. 41. Conglomerate in the Ishpa Section (lower part of the Ishpa Formation).

a and b – mixed unrounded blocks and rounded pebbles; c – packages of the fallen down layers near coastal cliff; d – poorly rounded pebble layers: wave-cut notches; e and f – pebbles almost without matrix: regular wave activity.

4.1.2. AREA OF TUROCHAK VILLAGE (LEBED' RIVER)

Lebed' Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Floian, Dapingian, Darriwilian, Sandbian, Katian, Hirnantian.

Regional stratigraphic subdivisions: Tuloi, Kuibyshevo, Kostinsky, Bugryshikha, Khankhara, Tekhten' and Lystvyanka regional stages (horizons).

Local lithostratigraphic subdivisions: Tuloi, Karasa, Gur'yanovka and Chebor formations.

Zones: "*approximatus*", *densus*, *protobifidus*, *angustifolius elongatus*, *gibberulus*, "*hirundo – jakovlevi/ coelatus*", "*teretiusculus*" graptolite zones.

Fauna: graptolites, brachiopods, trilobites, ostracods, orthoceratids, crinoids, gastropods, bryozoans, tabulates, heliolitids, chitinozoans.

The Lebed' Section – is one of the most well studied Ordovician section in Altai (Figs 42–46).

The Gur'yanovka Formation parastratotype is exposed in the right side of the Lebed' River, upstream of former Stretinka Village, with visible contacts with the underlying Karasa Formation and the overlying Chebor Formation. A large part of the Gur'yanovka Formation in the middle of the Bura strtatotype section in the Lebed' River right side near former Gur'yanovka Village is hidden under vegetation and encloses dike layers. The Lebed' and Bura sections, with fossils therein, were extensively studied in previous years (Dzyubo, 1960; Sennikov, 1962; Krivchikov et al., 1976; Severgina, 1978, 1984; Petrunina et al., 1984; Kul'kov and Severgina, 1989; Sennikov et al., 2008, 2018a,b; Melnikova, 2010). In the Lebed' Section, the Gur'yanovka Formation basal member composed of greenish and dark gray medium to coarse (up to gravel) polymictic sandstone lies over greenish-gray siltstone of the Karasa Formation top containing graptolites of the terminal Darriwilian *teretiusculus* Zone, in the right side of the Lebed' River, 300 m upstream of the third river shallow from former Stretinka Village (Fig. 42). The basal member is overlain by organic limestone intercalated with limy siltstone and mudstone.

The Gur'yanovka Formation is overlain by purple clayey mudstone of the Chebor Formation with gradual 1 m thick transition. The boundary between the two formations in this section may follow the base of the purple and lilac mudstone or rather the top of uppermost limestone or limy mudstone. The latter interpretation is consistent with red coloration appearing in the Gur'yanovka Formation limestone at the top of the Gur'yanovka Glade and Biya sections (see below). Therefore, the Gur'yanovka Formation – Chebor Formation boundary may correspond to the member 17 base instead of the member 18 top. The thickness of the Gur'yanovka Formation in the Lebed' Section is within 200 m, though it was previously overestimated to >500 m (Krivchikov et al., 1976), possibly, because some riverside outcrops became hardly accessible and the strike of some members aligns with the river stream direction.

Peculiarities in facies, faunal assemblages and sedimentary environments (notably for the Gur'yanovka Formation).

According to previous data (Dzyubo, 1960; Krivchikov et al., 1976; Kul'kov and Severgina, 1989; Sennikov, 1962; Melnikova, 2010), the Gur'yanovka Formation (stratotype) in the Lebed'-Stretinka Section contains the fauna assemblages of *Severginella altaica* (Sev.), *Salopia uxunaica* (Sev.), *Glyptomena subgirvanensis* Sev., *Schizophorella altaica* (Sev.), *Severginella shorica* (Sev.), *Chaulistomella lebanonensis* (Cooper), *Austinella lebediensis* Sev., *Boreadorthis togaensis* Sev. brachiopods; *Ceraurinus* cf. *icarus* (Bill.) trilobites; *Grammolomatella* sp., Eurychilina? sp. *ostracods*; *Nyctopora elandiensis* Dz. tabulates; and *Cyrtophyllum* ex gr. *jaconurensis* Dz., *Sibiriolites lebediensis* Dz. heliolitids. We have additionally identified *Chaetetes tchakerensis* Dz. heliolitids (member 6); *Nyctopora denticulate* Sok. et Tes., *Nyct. nicholsoni* (Rad.), *Calapoecia baragashiensis* Dz. tabulates (members 7, 9, and 13); and *Scandodus* sp., P*hragmodus undatus* Br. et M., *Panderodus* cf. *P. gracilis* (Br. et M.), *Aphelognathus* sp., *Belodina compressa* (Br. et M.) and *Drepanoistodus suberectus* (Br. et M.) conodonts (member 13).

Limestone occupies a half of Gur'yanovka Formation in the total Lebed' Section volume. It is commonly dark gray, with low clay contents, and enclose 0.5–1.0 cm pure algal nodules, as well as larger and purer nodules of 1-3 cm.

Clay material often produces nodular textures on eroded surfaces or forms separate 5–7 cm layers. The sediments contain locally numerous round or oval algal nodules, 0.5 to 1.0–1.5 cm in diameter, and abundant (70-80 % of the rock volume) 2–3 cm algal calyptrae with knobby surfaces. There appear large (15–20 cm) and small (3–5 cm) colonies of tabulates turned upside down relative to their lifetime position. Large colonies are coated with clayey limestone, which indicates their transport on the sea bottom. Sandstone occupies about 20 % of the section volume (Fig. 47).

The sand material is well sorted and rounded, like siltstone (20 % of the section). Clay most often occurs as a minor component of limestone or less often as separate layers (no more than 10 % of the section volume).

The Gur'yanovka Formation oryctocenoses in the Lebed' Section comprise abundant brachiopods, tabulates, and heliolitids, less abundant ostracods and nautiloids, few trilobites and conodonts, and sporadic rugoses. The taxonomic diversity is the greatest among brachiopods, medium in conodonts, and low in tabulates, heliolitids, ostracods and trilobites. Lithological features, such as: clayey limestone with nodular textures, limestone with lumpy beds, nodular mudstone, fine-grained well sorted and rounded sand in limestone, algal nodules and calyptrae, colonies of tabulates turned upside down relative to their lifetime position, including those coated with clayey limestone (Fig. 47), etc., indicate shallow marine deposition environments, within 10 m above fair-weather wave base (FWB) for the most of the Gur'yanovka Formation units and subunits in the Lebed' Section. On the other hand, 1–2 mm lamination in mudstone produced by clay laminas indicates deposition at >10 m below FWB. The sea apparently had a rough bottom topography, with rises and depressions of different magnitudes (the laminated mudstones are indicators of shallow depressions). Some carbonate layers in the section also may have deposited >10 m below FWB, judging by brachiopod shelly banks with preserved intact double-valved shells. Note, however, the presence of algal calyptrae that were produced by limy blue-green algae (Cyanobacteria) which bloom only within the euphotic zone, within depths of 30–80 m (Chuvashov et al., 1987; Luchinina, 1973).

In the Lebed' Section, the Chebor Formation is represented by variegated, mostly red sandstone, siltstone, and mudstone. The rocks exhibit different-scale ripple structures, traces of multidirectional ripples, cross-bedding, traces of storm activity (tempestites), desiccation cracks on the mudstone bed surface filled with sandy material of the overlying layer, traces of bioturbation, chaotic (mainly quartz) unrounded to poorly rounded fragments of pebble and gravel particle size in a poorly sorted sandy matrix (Figs 48, 49).

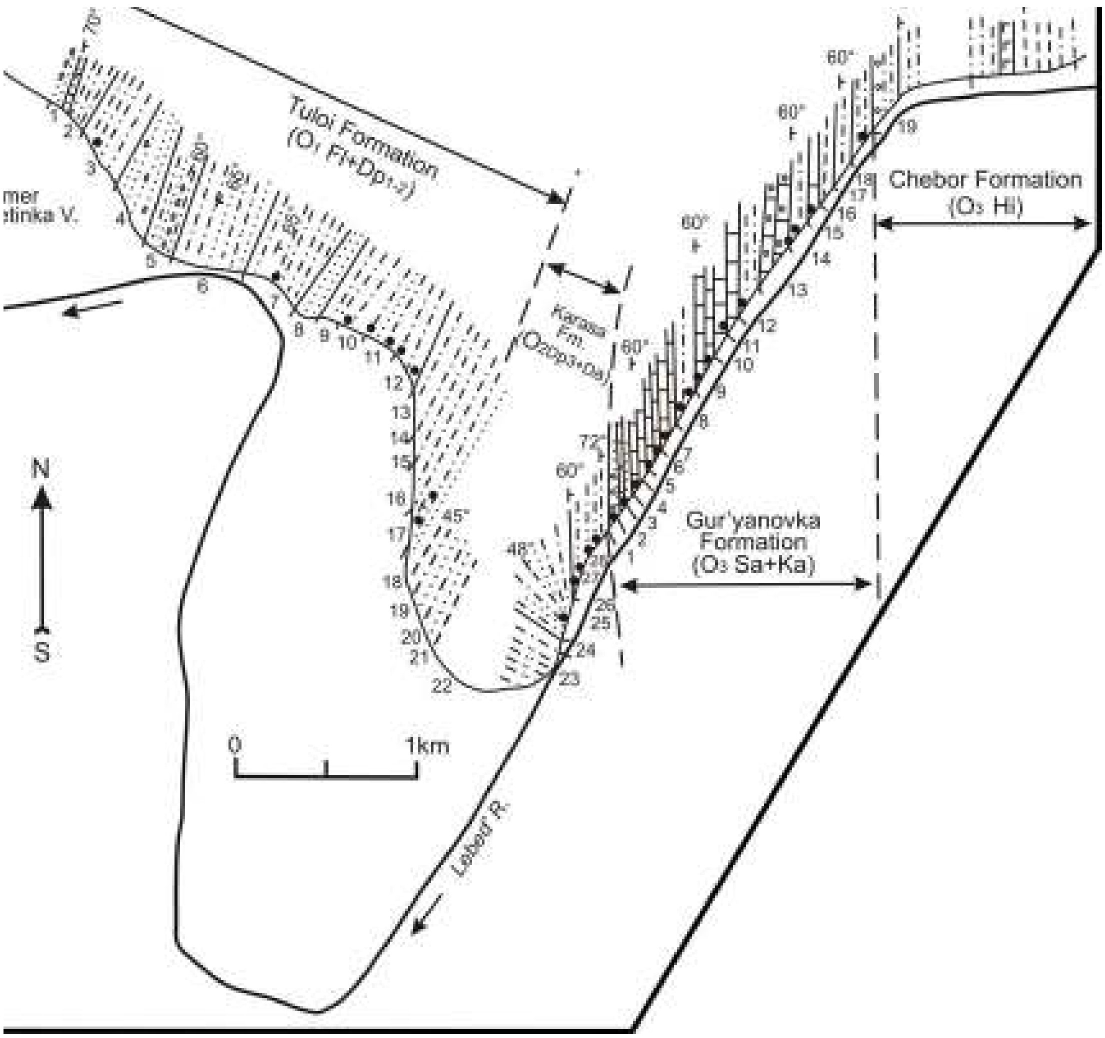


Fig. 42. Sketch map of the Lebed' River area.

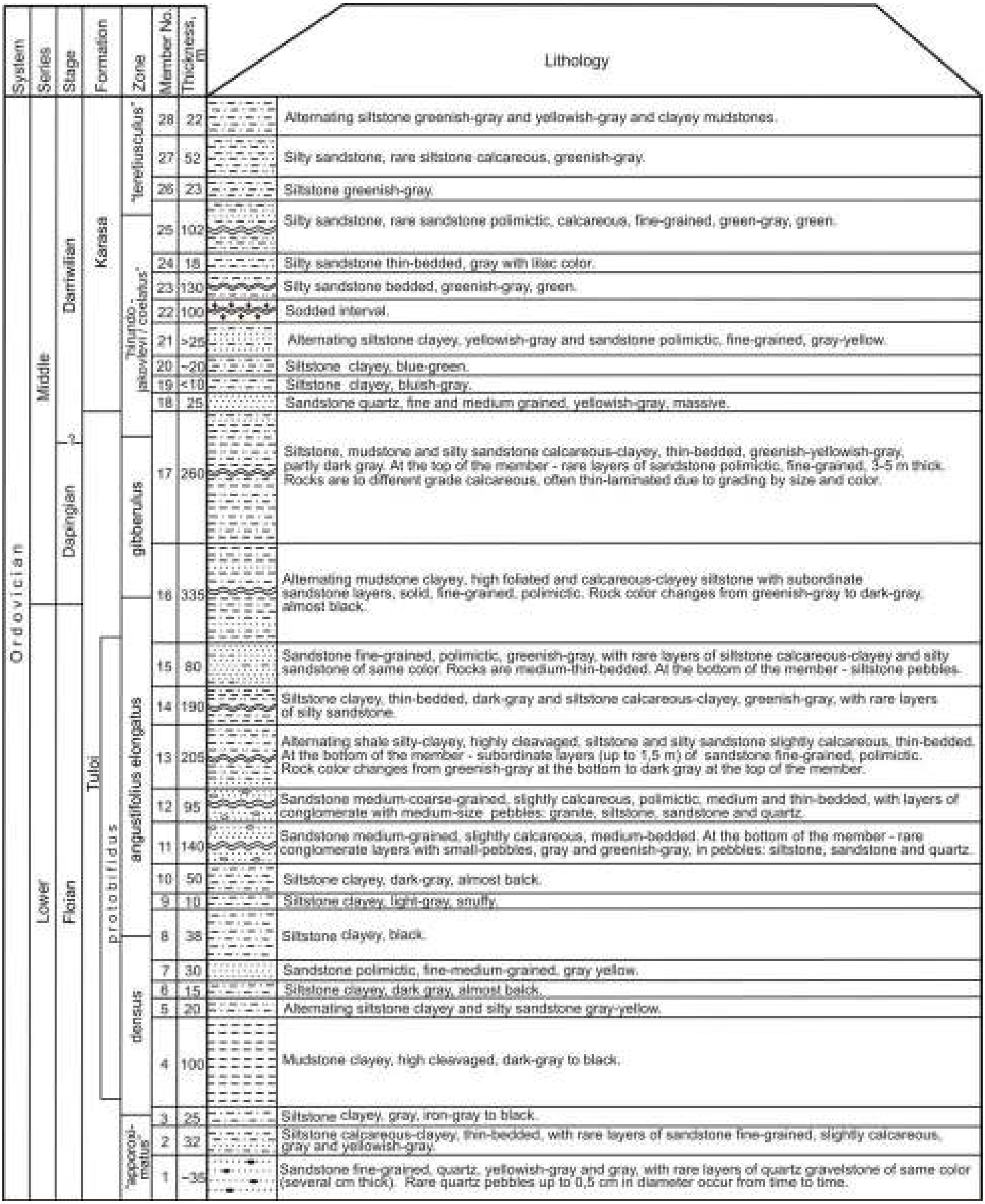


Fig. 43. Lithology and ranges of fossil taxa from the Lebed' Section (Tuloi and Karasa formations).

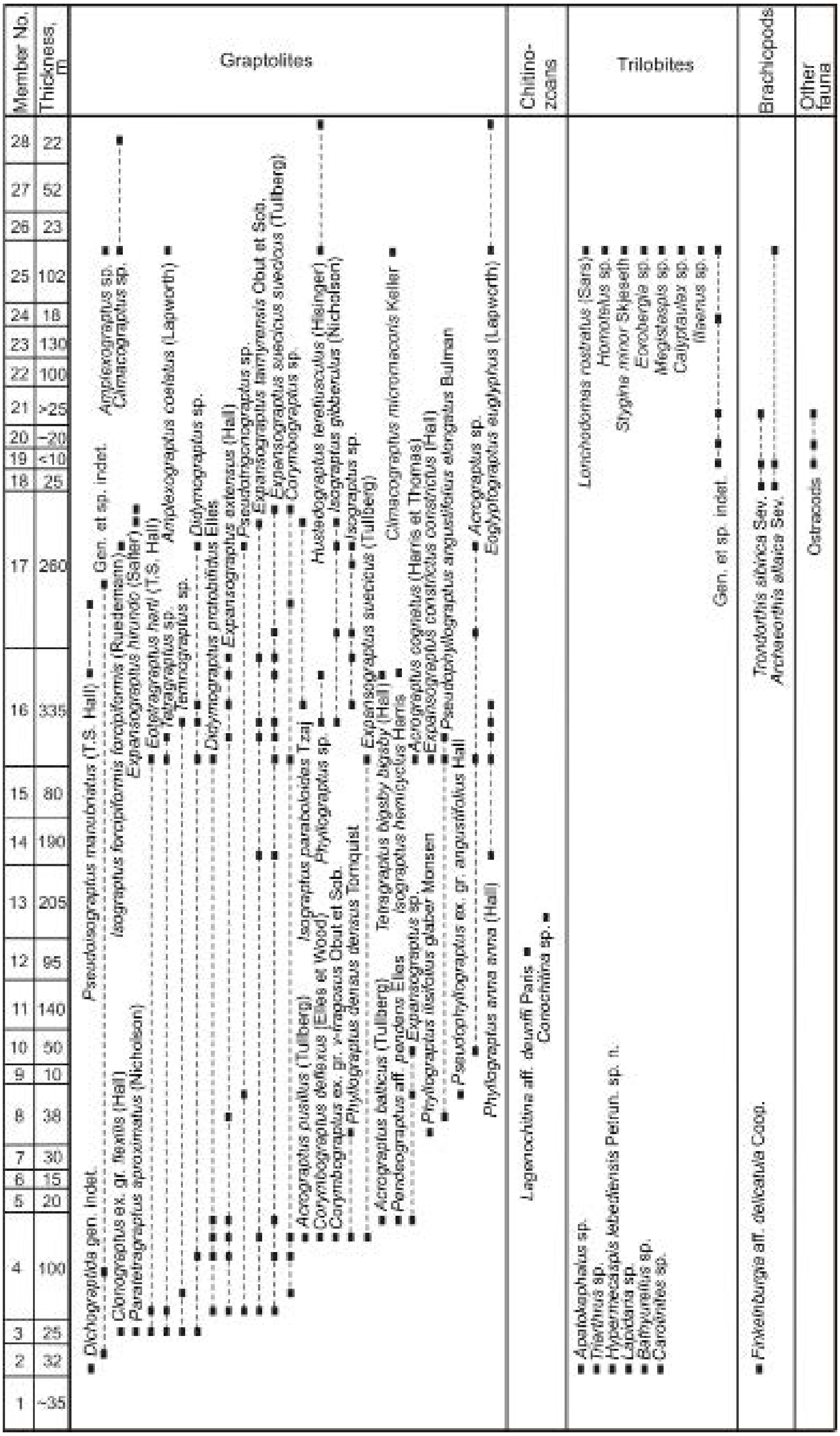


Fig. 43. The end.

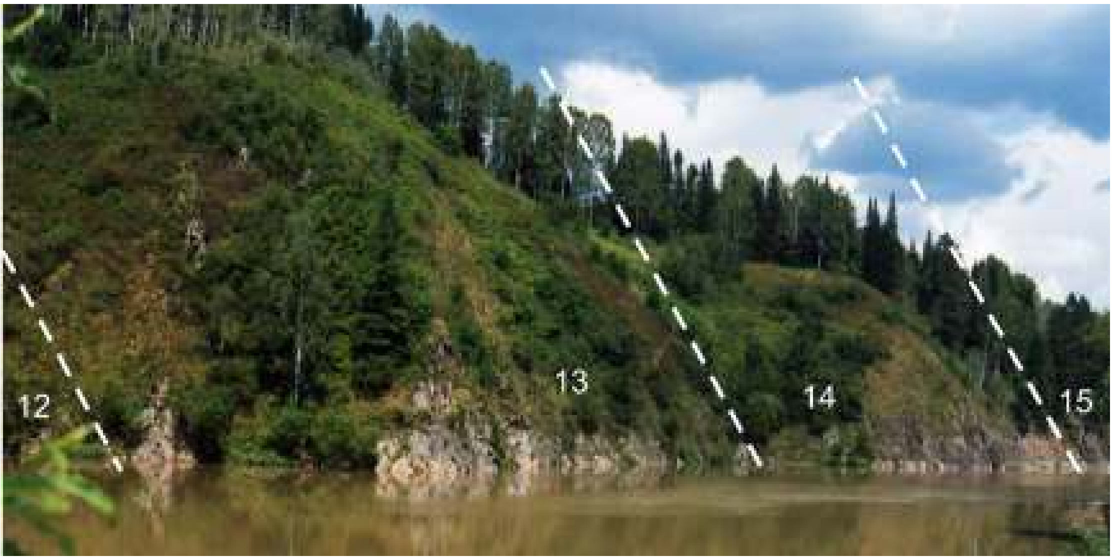


Fig. 44. General view of the Lebed' Section (lower part, Tuloi Formation).

Fig. 45. General view of the Lebed' Section (middle part, Karasa Formation).

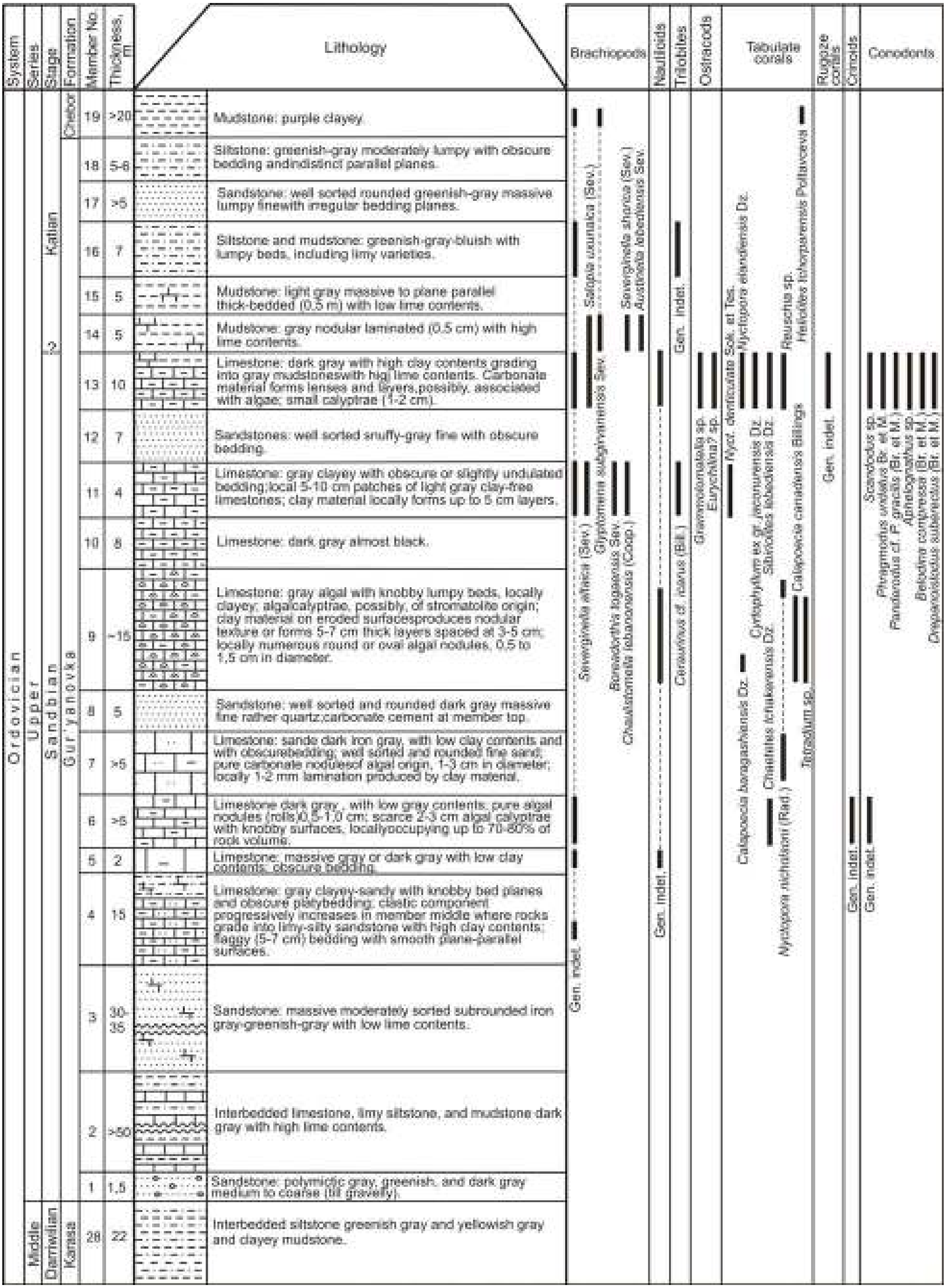


Fig. 46. Lithology and ranges of fossil taxa from the Lebed' Section (Gur'yanovka and Chebor formations).

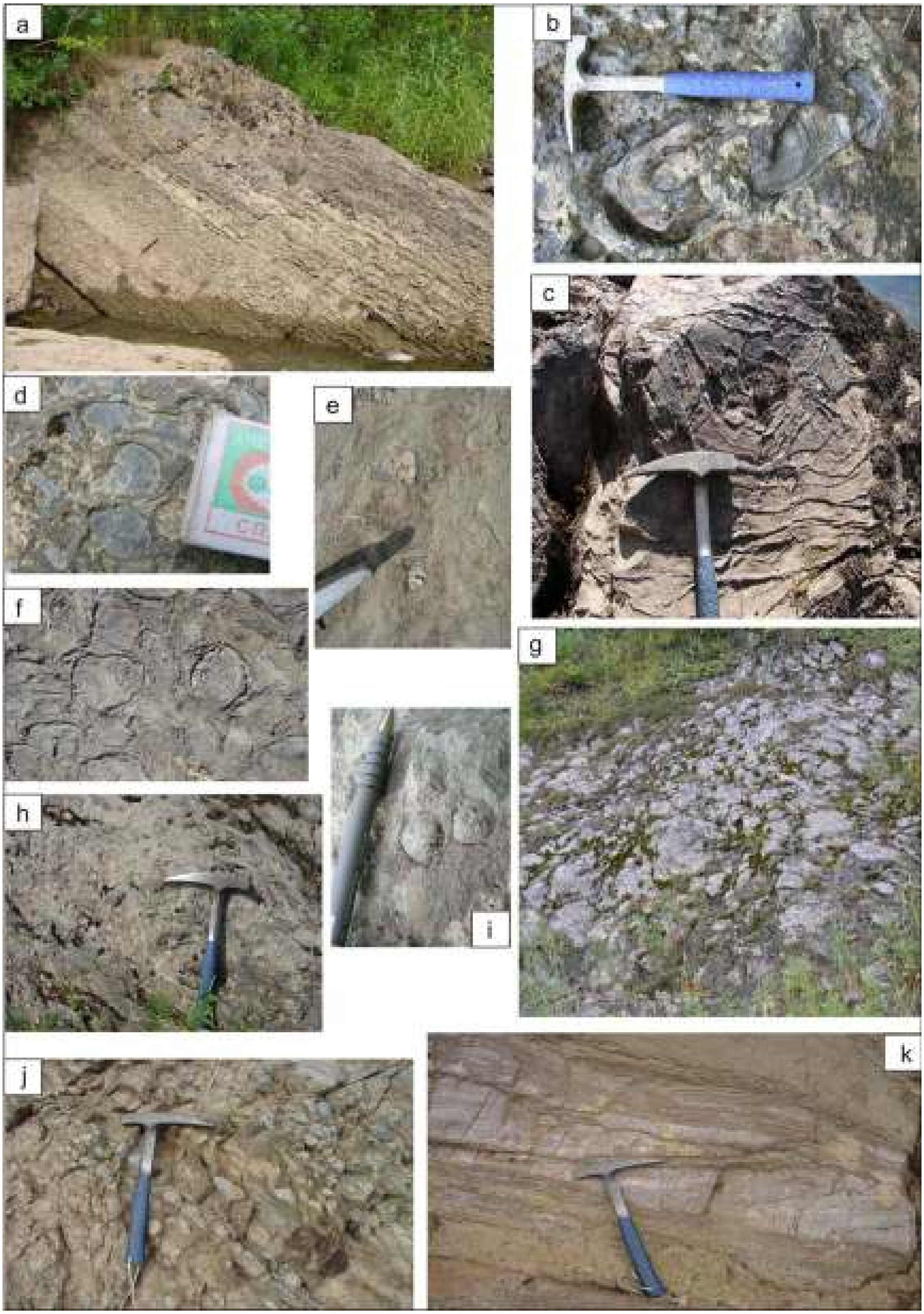


Fig. 47. Lithological peculiarities of limestone in the Gu’yanovka Formation sections.

The Gur’yanovka Formation – Lebed’ Section (b, d, f-i), the Bura Section (a, e, j, k), the Biya Section (c): a – river terrace outcrop (2 × 2 m) that exposes a sequence of medium-bedded nodular clayey limestone; b – upside down and clay-coated isolated colonies of tabulate corals; c – filled erosion channels in submarine sand bars; d – algal calyptrae in lifetime position; e – nodular mudstone (upper layer on the left) upon clayey limestone surface with wave ripple marks; f – whole brachiopod shells in a coquina bank; g – outcrop (3 × 5 m) of knobby-lumpy-laminated clayey limestone; h – separated dorsal shells of brachiopods, convex upward, on bed surface; i – lumpy clayey limestone; j – low-angle crossbeds of sandy limestone; k – algal nodules (rolls).

Fig. 48. General view of the Lebed' Section (upper part).

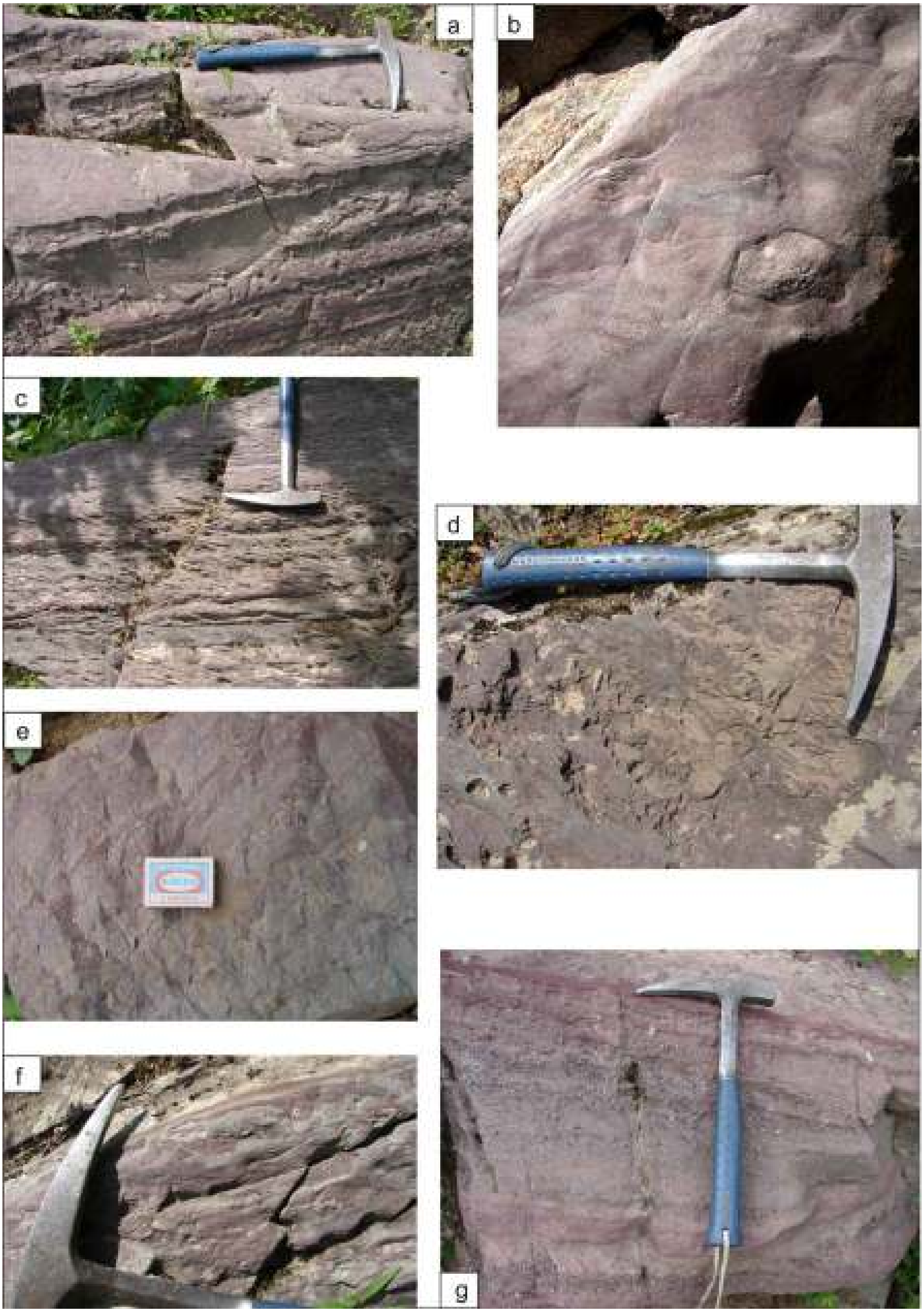


Fig. 49. Lithological peculiarities of sandstone and siltstone in the Chebor Formation – Lebed' Section.
a and g – ditches and washouts in the near-shore zone; b and f – tempestites: storm activity; c – sigmoidal micro-layers: tidal markers; d – traces of intensive bioturbation; e – doubled layers: tidal traces.

Pridorozhny Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Floian, Dapingian, Darriwilian.

Regional stratigraphic subdivisions: Tuloi and Kuibyshevo regional stages (horizons).

Local lithostratigraphic subdivisions: Tuloi and Karasa formations.

Zones: *gibberulus* (*deflexus* and *maximo-divergens* subzones), *hirundo* (*caduceus imitatus* Subzone) graptolite zones.

Fauna: graptolites, brachiopods.

The Pridorozhny Section is composed of the Tuloi and Karasa formations (Figs 50, 51).

Peculiarities in facies, faunal assemblages and sedimentary environments.

The mentioned above specific aspects of graptolite paleocommunities and indicating taxa allow the paleobasin reconstruction as follows. Since the Floian–Dapingian–Darriwilian graptolites are documented in more than 100 localities in the studied sections, the embedding strata within the Uymen'–Lebed' structure-facies zone (northeastern Gorny Altai) were proposedly accumulated in relatively distal shelf environments of the paleobasin. An average amount of the graptolite colonies within each the locality counts 5–10, rarely 20–30 rhabdosomes. The occurrences containing hundreds of the colonies are extremely rare. The graptolite assemblages are taxonomically dominated by species and subspecies of *Isograptus* Moberg, *Pseudisograptus* Beavis, *Parisograptus* Chen et Zhang, *Corymbograptus* Obut et Sob., and *Acrograptus* Tzaj genera, which are also specific for distal parts of paleobasins.

The studied graptolite assemblages contain specific depth indicating taxa. The shallow-water and medium-depth bioindicators are represented by numerous *Hustedograptus teretiusculus* (Hus.) (>40 specimens from 7 localities within the Lebed' and Yurok sections), *Pseudotrigonograptus ensiformis* (Hall) (~20 specimens from 5 localities within the Lebed', Pridorozhny and Tuloi sections), species of *Pseudophyllograptus* Cooper et Fortey (>10 specimens from 3 localities within the Lebed', Tuloi, and Yurok sections), species of *Phyllograptus* Hall (>30 specimens from more than 10 localities within the Lebed' and Yurok sections), and numerous didymograptins species of *Corymbograptus* Obut et Sob. and *Expansograptus* (Boucek et Pribyl) (>200 specimens from several dozen localities within the Lebed', Pridorozhny and Tuloi sections).

Besides that, the Lebed', Pridorozhny and Tuloi sections reveal numerous bioindicators of deep-water environments – species of *Pseudisograptus* Beavis, *Parisograptus* Chen et Zhang, and *Isograptus* Moberg. Rhabdosoms of *Pseudisograptus* Beavis are abundant in the Pridorozhny Section, whereas the Tuloi Section is characterized only by scarce occurrences. Various species of *Parisograptus* Chen et Zhang and *Isograptus* Moberg demonstrate considerable population densities in the Lebed', Pridorozhny and Tuloi sections. There are only occasional occurrences of deep-water bioindicators (*Pseudisograptus* Bevais and *Parisograptus* Chen et Zhang) documented in the Yurok section.

Fig. 50. General view of the Pridorozhny Section.

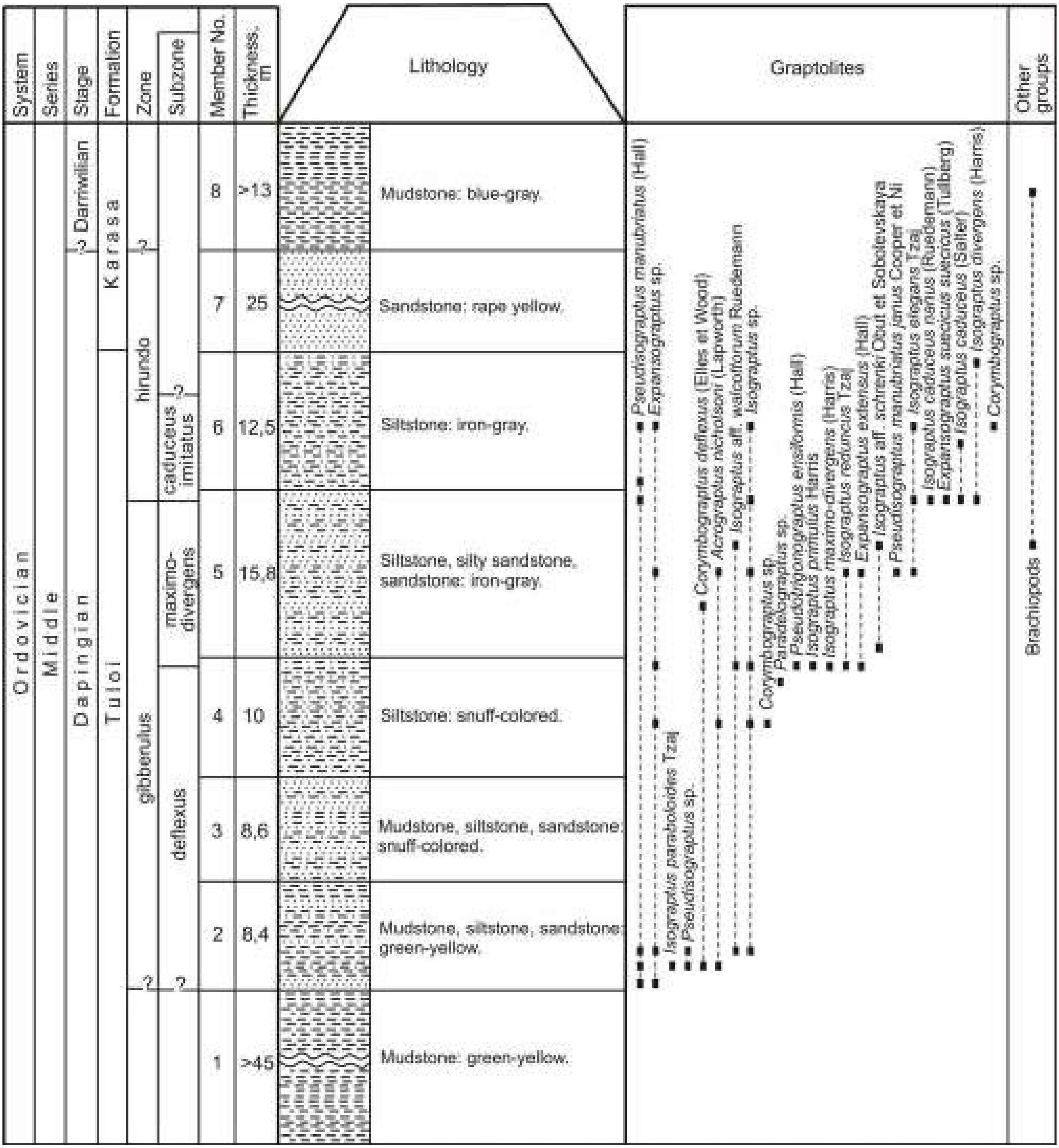


Fig. 51. Lithology and ranges of fossil taxa from the Pridorozhny Section.

All these parameters provide a basis for the bioindicator estimate of the studied sections of the Altai Ordovician paeobasin. Accordingly the dominating graptolite bioindicators, the Pridorozhny Section is reconstructed within the deepened outer shelf zone (>200 m), the Tuloi and Lebed' sections correspond the lower outer shelf environments (150–200 m), whereas the Yurok Section is situated in the upper outer shelf zone (100–150 m) of the paleobasin.

Upstream from the Lebed' Section on the right bank of Lebed' River near mouth of its right tributary Bura River, in the vicinity of the former Gur'yanovka Village, the upper part of the Gur'yanovka Formation and stratotype of the Cheborka Formation are situated (Bura and Gur'yanovka Glade sections) (Fig. 52).

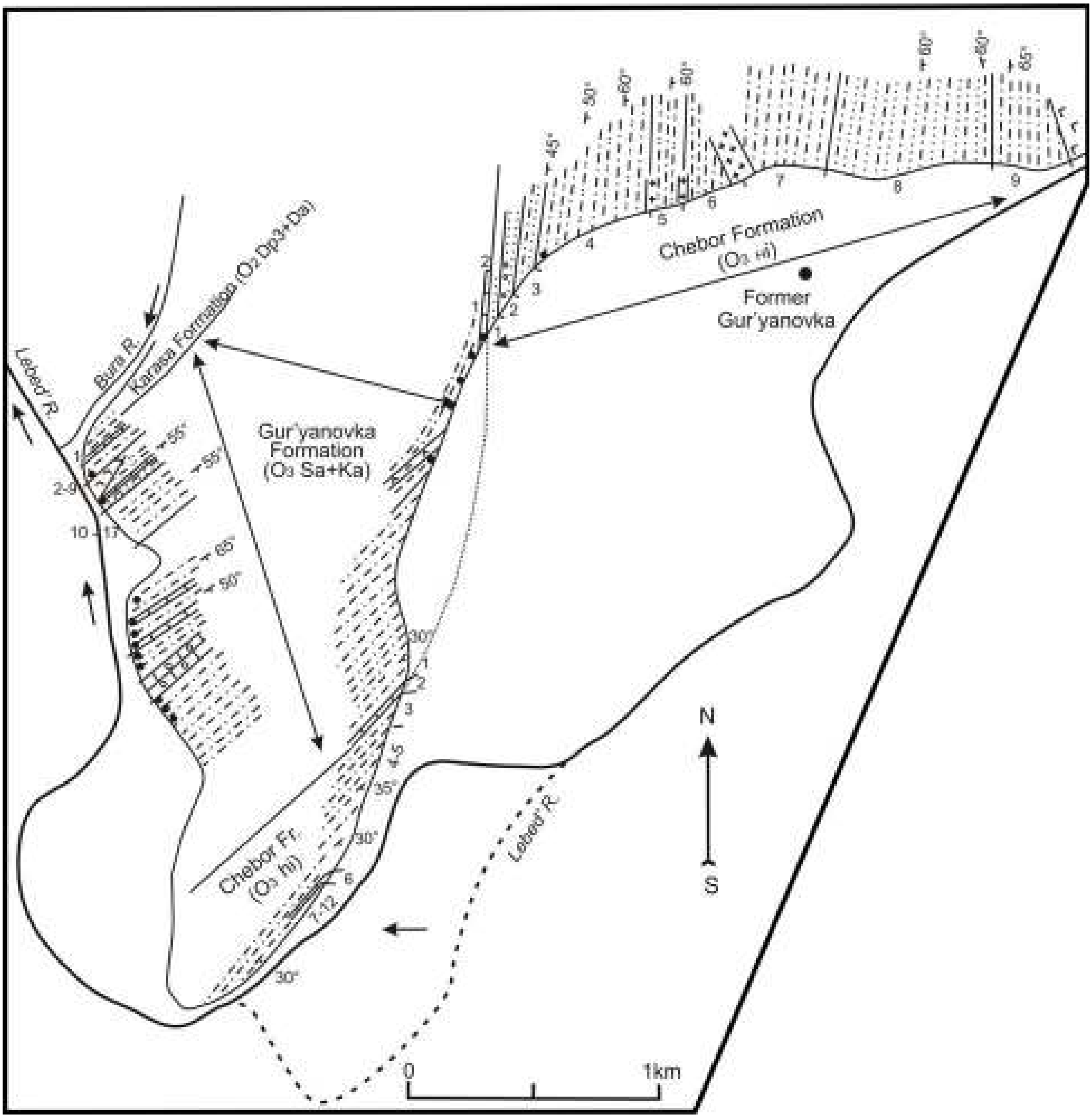


Fig. 52. Sketch map of the Gur'yanovka area.

Fig. 53. General view of the Bura Section (lower part).

Bura Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Sandbian.

Regional stratigraphic subdivisions: Khankhara and Tekhten' regional stages (horizons).

Local lithostratigraphic subdivisions: Gur'yanovka Formation.

Fauna: conodonts, trilobites, ostracods, brachiopods, stramatoporoids, tabulates, heliolitids, rugoses, bryozoans.

The Bura Section crops out in the right side of the Lebed' River, upstream of the Bura mouth (Figs 52–54). It was first documented by V.M. Sennikov (1962) and then by other researchers (Krivchikov et al., 1976; Kul'kov and Severgina, 1989). The river has changed its course for the past fifty years, the formerly exposed terraces became overgrown with trees and shrubs, and most of the Gur'yanovka Formation stratotype section became almost inaccessible. According to our observations upstream of the Bura mouth, limy gray mudstone lies over the 5 m thick top member of the Karasa Formation composed of dirty yellow or snuffy fine- to medium-grained massive sandstone with low lime contents and under limestone layers with different clay contents intercalated with scarce sandstone and mudstone layers and sets of layers. The total currently exposed thickness of the lower Gur'yanovka Formation in the Bura Section is at least 170 m, which is much less than 500 m reported by Sennikov (1962), without the 150 m thick vegetated interval. Kul'kov and Severgina (1989) estimated the thickness of the middle Gur'yanovka Formation as 400 m.

Peculiarities in facies, faunal assemblages and sedimentary environments.

Earlier studies (Cherepnina, 1960; Dzyubo, 1960; Krivchikov et al., 1976; Kul'kov and Severgina, 1989; Melnikova, 2010; Yaroshinskaya, 1960) revealed the following fauna assemblages: (1) *Onniella* cf. *flava* (Havl.), *Apatamorpha altaica* Sev., *Fascifera buraensis* Sev., *Eoanostrophia lebediensis* Sev., *Eridorthis subinexpecta* Sev. brachiopods and *Homotelus* sp., *Eorobergia* sp., *Bumastus* sp. trilobites in the lower part of Gur'yanovka Section; (2) *Eridorthis subinexpecta* Sev., *Catazyga salairica* (Sev.), *Boreadorthis togaensis* Sev., *Strophomena lebediensis* Sev. in Rozm., *Dactylogonia subgeniculata* Sev., *Chaulistomella amzassensis* (Sev.), *Severginella altaica* (Sev.), *Parastrophinella salairica* Sev. brachiopods; *Ceraurinus icarus* (Bill.), *Illaenus* sp. trilobites; *Stallipora vesiculosa* Modz., *Phenopora multifera* Nekh. bryozoans; *Grewingkia altaica* Tcherepn. rugoses; *Eofletcheria mironovae* Dz., *Nyctopora elandiensis* Dz. tabulates; and *Cyrtophyllum baragashensis* Dz., *Sibiriolites lebediensis* Dz. heliolitids in the middle part of section part; (3) *Glyptorthis praerulchra S*ev., *Hesperorthis lebediensis* Sev., *Austinella lebediensis* Sev., *Salopina uxunaica* (Sev.), *Strophomena lebediensis* Sev., *Glyptomena subgirvanensis* Sev., *Fardenia* cf. *scalena* Will., *Parastrophinella salairica* Sev., *Anoptambonites grayae sibirica* Sev., *Catazyga salairica* (Sev.), *Severginella schorica* (Sev.), *Triplesia ainca* Sev., *Rhynchotretoides aincus* Sev., *Spirigerina sublevis* Rozm.

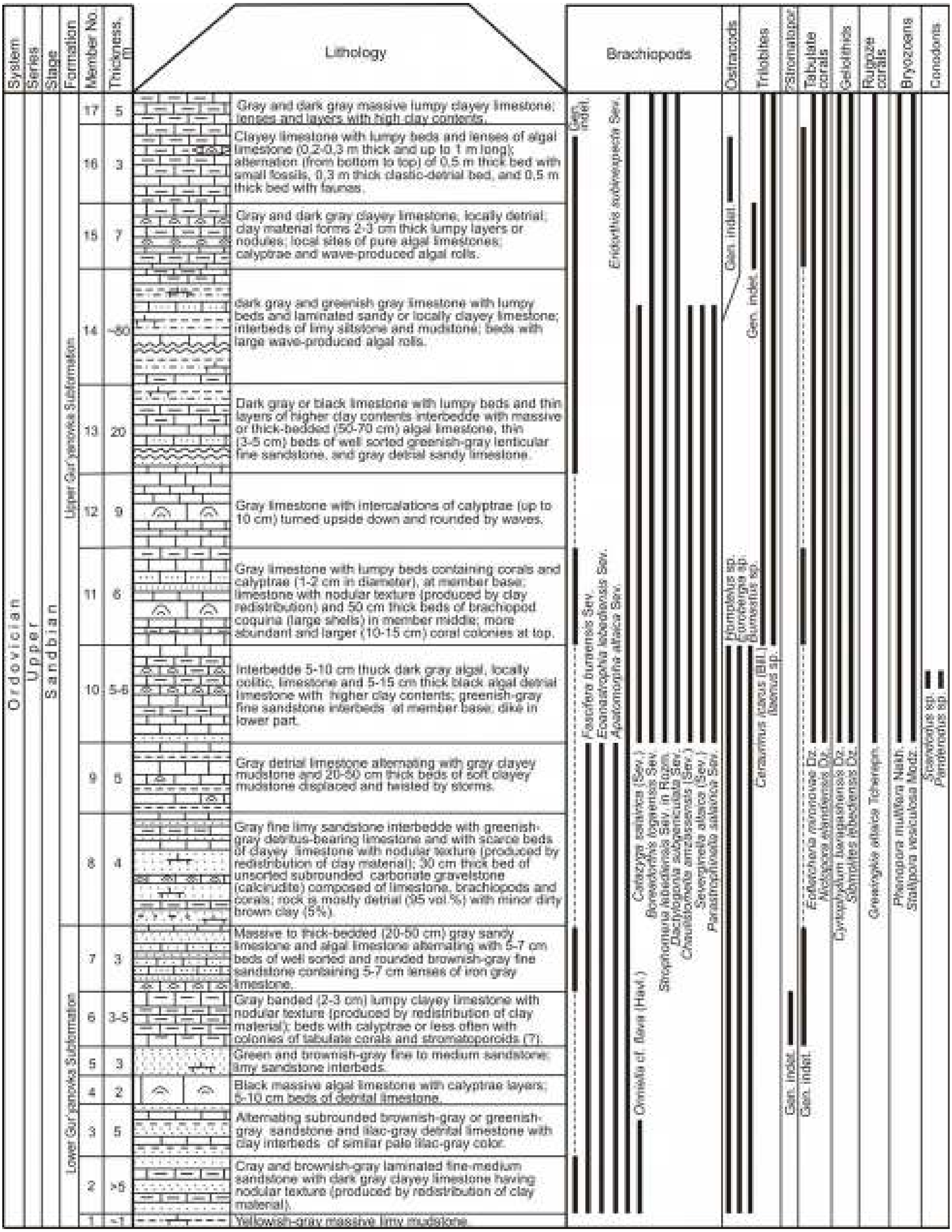


Fig. 54. Lithology and ranges of fossil taxa from the Bura Section.

brachiopods in the upper section part, along with *Egorovella demissa* Melnik ostracods; *Nictopora minimalis* (Rad.), *Nic. tschakerenensis* Dz., *Calapoecia baragashensis* Dz., *Cal. anticostensis* (Bill.), *Paleofavosites inkensis* Tscherep. tabulates; *Sibiriolites lebediensis* Dz. heliolitids; *Clathrodictyon kirgizicum amzassensis* V. Khalf. stromatoporoids; *Constellaria floridaformis* Jarosh. bryozoans; *Anclotichia commutatilis* Jarosh., *Stellopora vesiculosa* Modz. We have found also *Scandodus* sp. and *Panderodus* sp. conodonts in member 10 of the Bura Section.

Most of the Bura Section (88 %) is occupied by limestone of massive algal, detrital, nodular clayey (clay nodules), gravelly carbonate (calcirudite), and oolitic varieties and brachiopod coquina, with frequent algal calyptrae and sporadic graded bedding (according to the sizes of benthic clasts). Sandstone in the Bura Section makes 3 % of the section volume. It is well rounded and sorted.

Siltstone and mudstone constitute 9 % of the total thickness and are often poorly consolidated, with signatures of transport and rolling by storms. Low-angle crossbeds delineate small depressions of the sea bottom.

The Gur'yanovka Formation oryctocenoses in the Bura Section comprise predominant brachiopods, tabulates, and heliolitids, less frequent ostracods and trilobites, and few conodonts, stromatoporoids and rugoses. The taxonomic diversity is the greatest in brachiopods, intermediate in trilobites, tabulates and heliolitids, and low in bryozoans, rugoses, and conodonts. Lithology features, such as: 1) limestone with knobby lumpy beds; 2) nodular clayey limestone; 3) twisted lumpy mudstone layers; 4) carbonate gravelstone (calcirudites); 5) algal nodules and calyptrae; 6) sorting into layers according to sizes of benthic fauna; and 7) brachiopod coquina, suggest shallow-water deposition (3–5 to 10 m above fair-weather wave base) of most units and subunits in the Bura Section. The presence of calyptrae and hermatypic corals records deposition in the euphotic zone, to depths of 30–80 m. It is possible to make up a composite section (of three segments) of the Gur'yanovka Formation/Chebor Formation transition in the immediate vicinity of the Bura Section, near former Gur'yanovka Village; for the Chebor Formation this corresponds to the lower one third of its stratotype. The lower part of the Gur'yanovka Glade Section correlates with the second half of the upper Gur'yanovka Formation stratotype (Krivchikov et al., 1976; Kul'kov and Severgina, 1989; Sennikov, 1962) and continues the Bura Section, judging by the strike of rocks (Krivchikov et al., 1976; Sennikov, 1962). At present, the section part corresponding to the Gur'yanovka Formation top is hidden under thick vegetation while that correlated with the overlying Chebor Formation became better exposed as a result of the Lebed' River course change. Thus, we observed (Figs 55, 56) two terminal units of the composite Gur'yanovka Formation stratotype: (i) intercalated gray mudstone, siltstone and fine sandstone with sporadic lenses of reddish limestone and (ii) intercalated gray and greenish-gray clayey limestone and limy sandstone.

Gur'yanovka Glade Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Katian, Hirnantian.
Regional stratigraphic subdivisions: Khankhara and Tekhten' regional stages (horizons).
Local lithostratigraphic subdivisions: Gur'yanovka Formation.
Fauna: trilobites, ostracods, tabulate and rugose corals, bryozoans, ichnofossils.

Fig. 55. General view of the Gur'yanovka Glade Section (middle part).

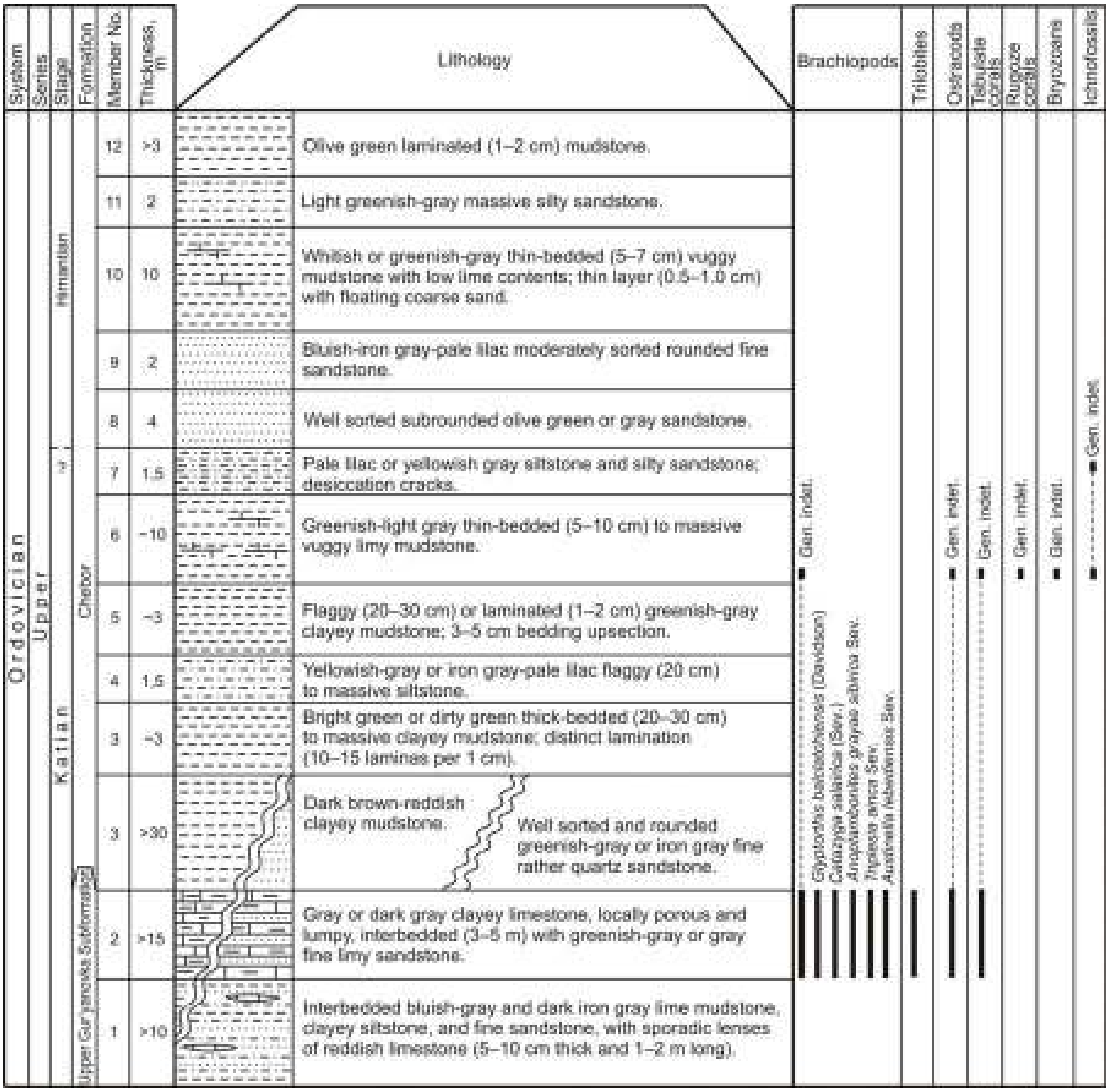


Fig. 56. Lithology and ranges of fossil taxa from the Gur'yanovka Glade Section.

4.1.3. AREA OF TULOI VILLAGE

Tuloi Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Floian, Dapingian, Darriwilian, Sandbian.

Regional stratigraphic subdivisions: Tuloi (Lebed'), Kuibyshevo, Kostinsky and Bugryshikha regional stages (horizons).

Local lithostratigraphic subdivisions: Tuloi, Karasa and Gur'yanovka formations.

Zones: *apporoximatus*, *densus*, *angustifolius elongatus*, *gibberulus*, *hirundo*, *dentatus* graptolite zones; *Cyathochitina parvicolla*, *Cyath. calix* chitinozoan zones.

Fauna: graptolites, brachiopods, trilobites, ostracods, orthoceratids, crinoids, gastropods, bryozoans, hyolithes, chitinozoans.

The stratotype section of the Tuloi Formation extends along the right side of the Biya River downstream of the Tuloi inflow and then upstream the Tuloi on its right side (Figs 57–62). According to graptolites, trilobites, and brachiopods, the Tuloi Formation spans the Floian, Dapingian, and lower Darriwilian. The formation overlaid conformably over the Ishpa Formation and is underlain by the Karasa Formation.

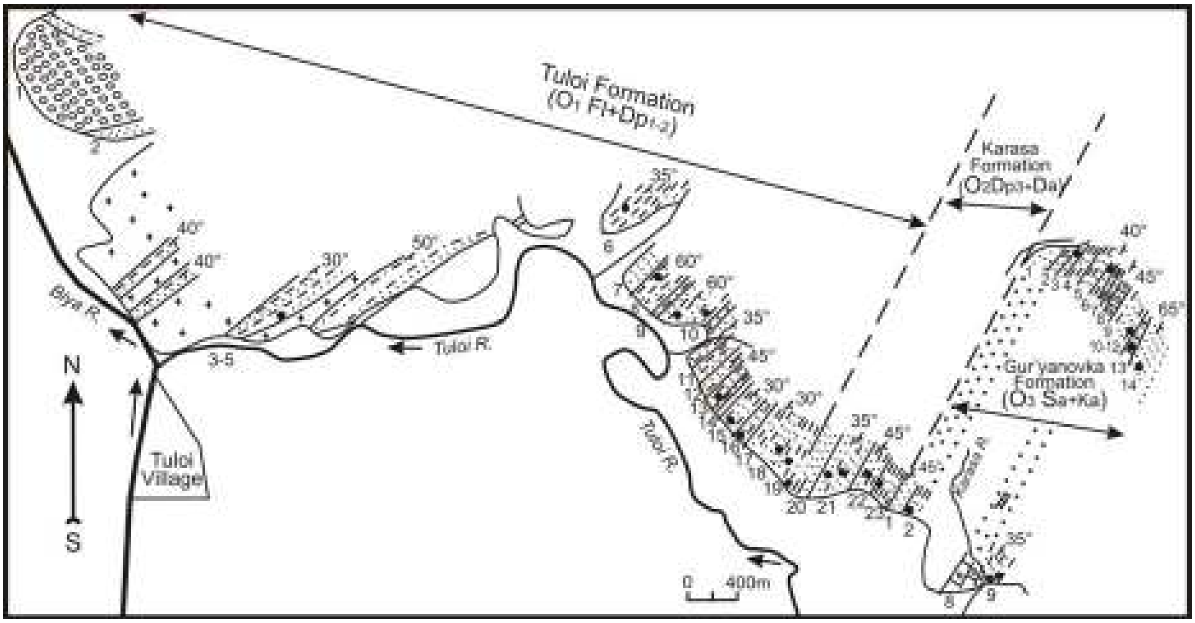


Fig. 57. Sketch map of the Tuloi Village area.

Fig. 58. Upper part of the Tuloi Formation in the Tuloi Section.

Fig. 59. Upper part of the Tuloi Formation in the Tuloi Section.

Members 1 through 19 belong to the Tuloi Formation, members 20 through 23 belong to the Karasa Formation, and members 24 and 25 belong to the Gur'yanovka Formation. The total thickness of the Tuloi Formation in the section exceeds 2500 m, the Karasa Formation is 450 m thick, and the Gur'yanovka Formation is more than 150 m thick.

The graptolite zonation of the section is as follows: members 1 through 5 belong to the *apporoximatus* Zone (loc. LSS-401a, S-75141); member 6 may conventionally correspond to the *densus* and *angustifolius elongatus* zones (loc. H-81), and members 7 and 8 are conventionally aligned with the *gibberulis* Zone (loc. 282, H-79); the base of member 9 correlates with the *gibberulus* – *hirundo* boundary, and members 9 through 16 belong to the *hirundo* Zone (loc. H-78, H-75, H-73, LSS-422a, LSS-423, H-91, H-84, H-85, H-87, LSS-418, H-88); members 17 through 22 contain no graptolites; members 18 through 22 correlate with the Darriwilian according to trilobites and brachiopods (loc. H-95, LSS-415, H-92, H-102, H-103); graptolites from member 23 (loc. H-104, LSS-409) correspond to the *dentatus* Zone.

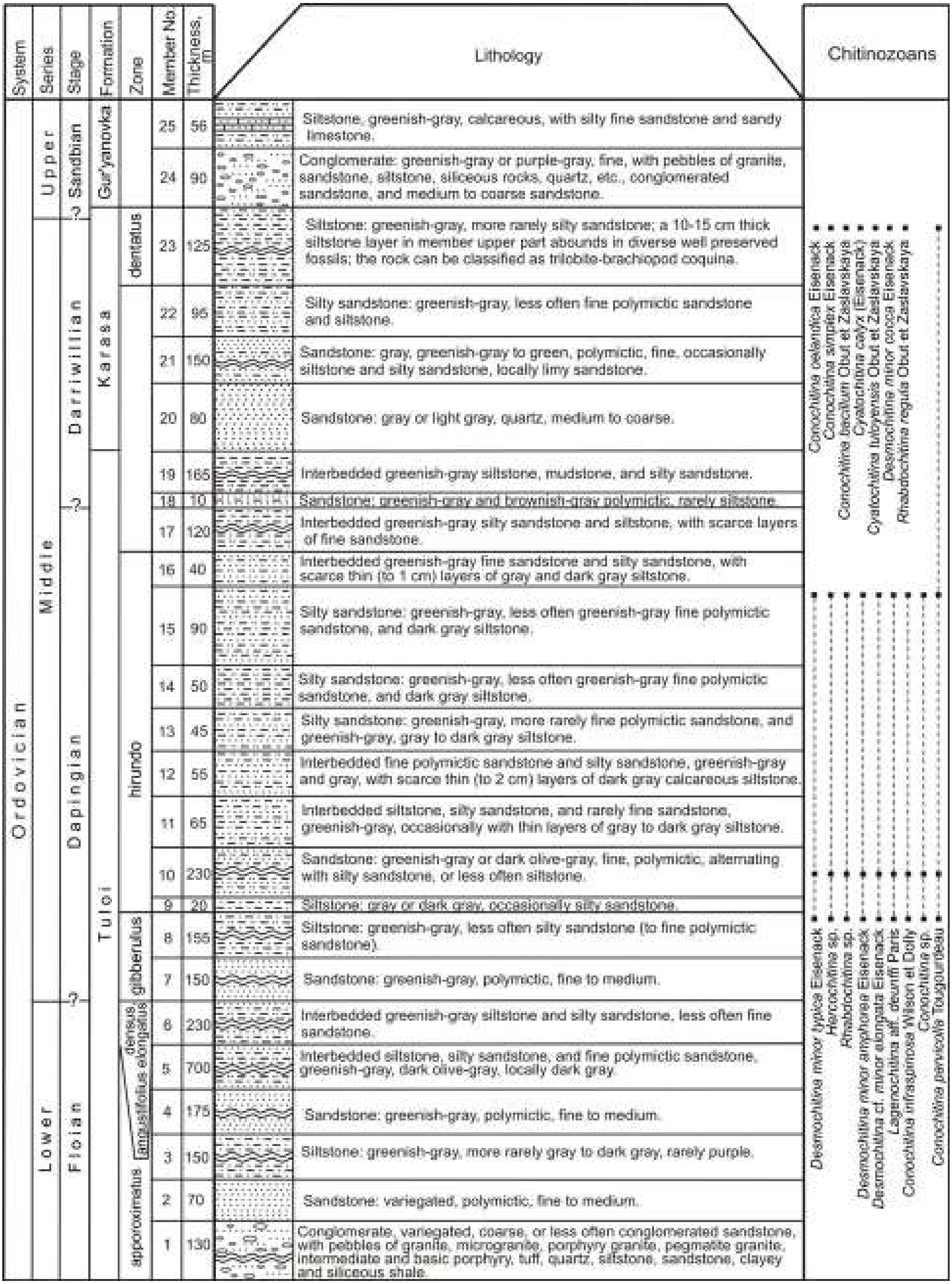


Fig. 60. Lithology and ranges of fossil taxa from the Tuloi Section.

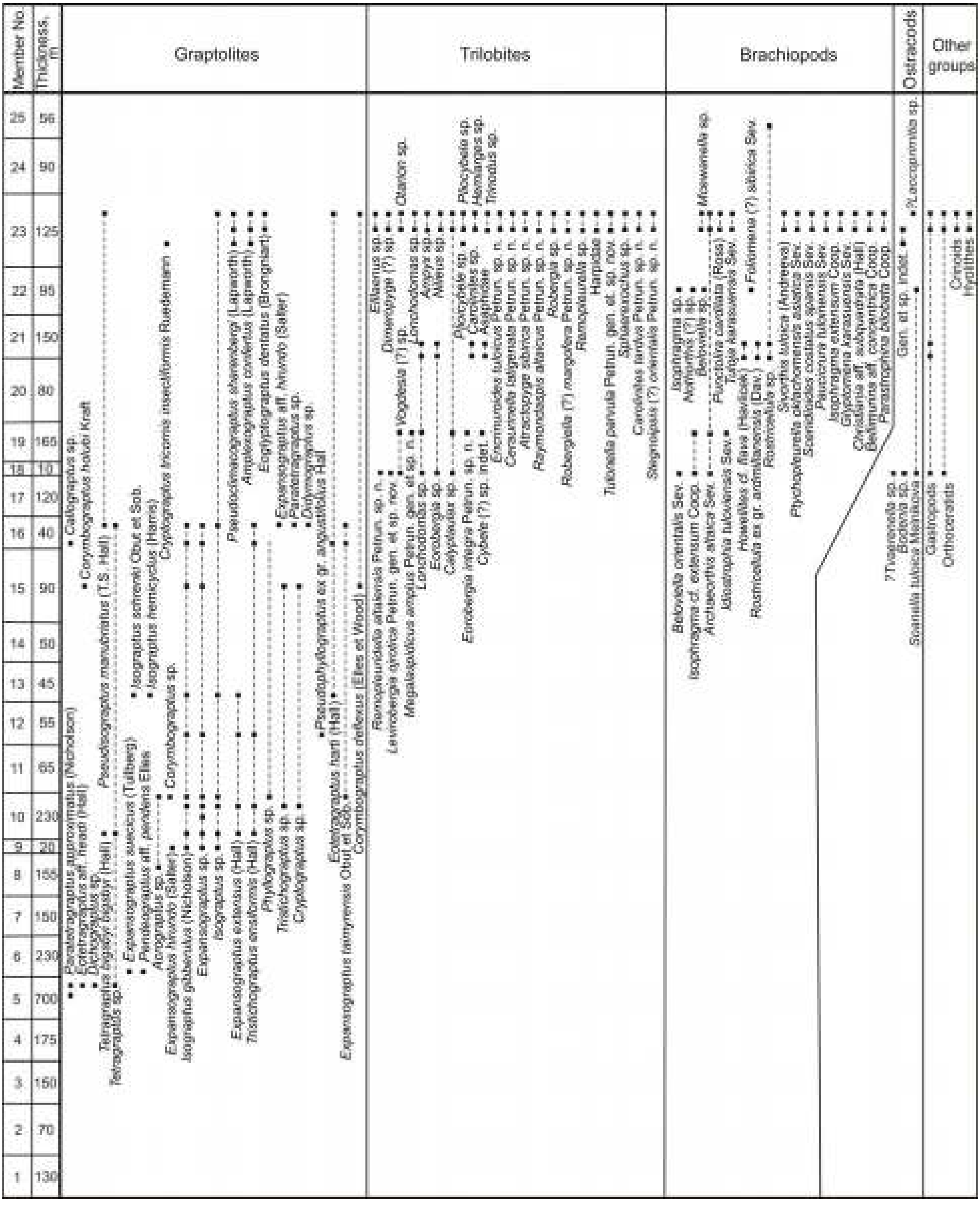


Fig. 60. The end.

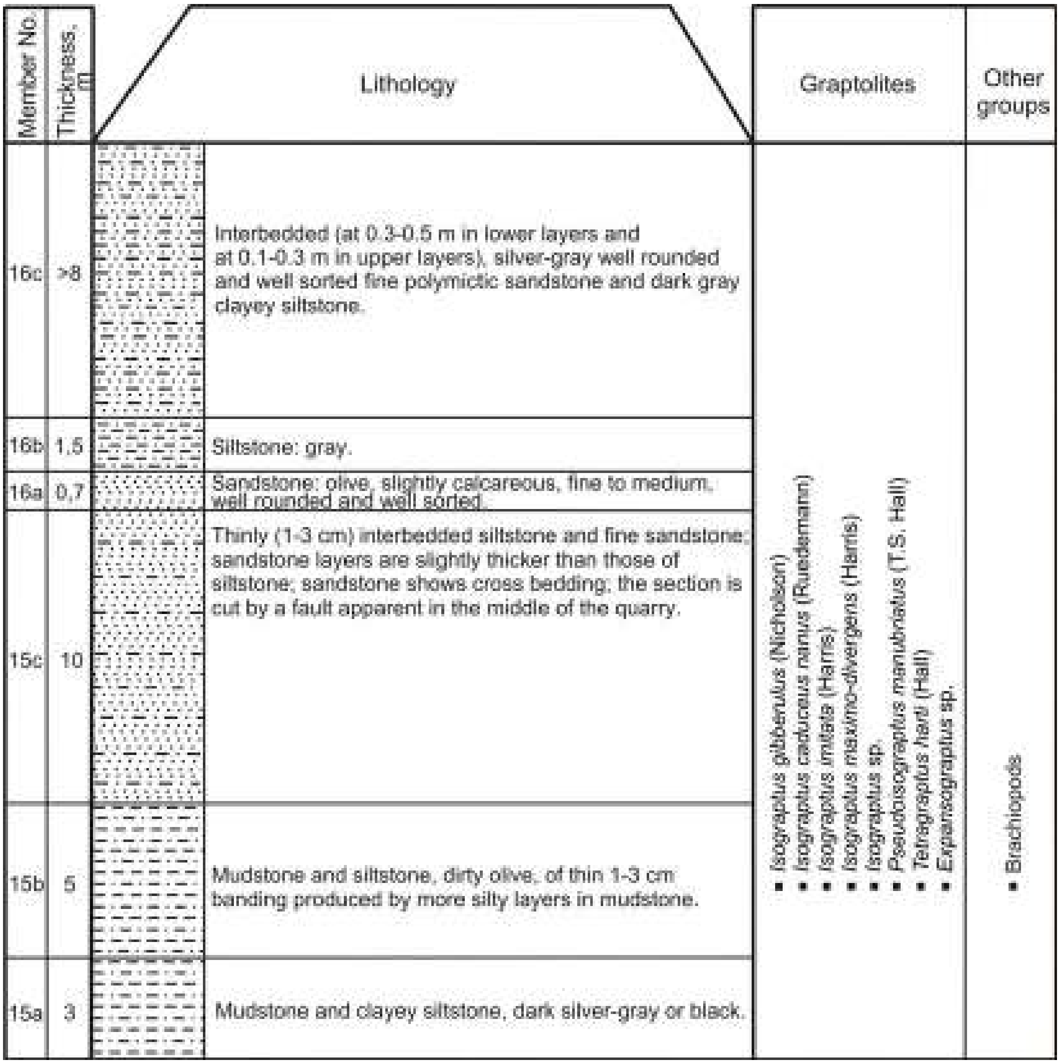


Fig. 61. Lithology and ranges of fossil taxa from the middle part of the Tuloi Section.

Fig. 62. Upper part of the Karasa Formation in the Tuloi Section.

Yurok Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Dapingian, Darriwilian.

Regional stratigraphic subdivisions: Tuloi, Kuibyshevo, Kostinsky and Bugryshikha regional stages (horizons).

Local lithostratigraphic subdivisions: Tuloi and Karasa formations.

Zone: "*angustifolius elongatus*", "*gibberulus*", "*hirundo*", *sinodentatus*, "*austrodentatus*", "*dentatus*", "*balhaschensis/kirgisicus*", "*jakovlevi/coelatus*", *teretiusculus* graptolites zones.

Fauna: graptolites, trilobites, brachiopods, gastropods, echinoderms, nautiloides, bryozoans, bivalves, phyllocarids.

The Yurok Section was studied during 2011–2015 (Sennikov et al., 2018a,b). It is localized on a side of the road, connecting Artybash and Turochak villages, 240 m northward from a bridge across the Yurok Creek (right tributary of the Biya River). The section comprises subvertical beds of the Upper Tuloi and Karasa formations, which are stratigraphically arranged towards the Teletskoe Lake, with a total thickness along the road exceeding 50 m. The section is paleontologically characterized by graptolites, trilobites, phyllocarids, gastropods, brachiopods, ostracods, bryozoans, bivalves, echinoderms, and nautiloids. The Yurok Section is logged as follows (Figs 63–65):

Peculiarities in facies, faunal assemblages and sedimentary environments.

In the Yurok Section, the upper Tuloi Formation (20-m thick interval corresponding the Upper Floian and Lower–Middle Dapingian angustifolius elongatus, gibberulus and hirundo graptolite zones) and lower Karasa Formation (up to 45 m of the Darriwilian austrodentatus – teretiusculus graptolite zones) are composed of monotonous clayey mudstone with scarce interbeds of siltstone and yellow-brownish-gray (snuffy-gray) fine-grained sandstone. The basal quartz sandstone member of the Karasa Formation is not represented in the Yurok Section. It could be caused by a hidden tectonic fault, since there is a low-amplitude fault zone documented within the lower Karasa Formation, between the first and second members of the section. Specific lithological composition (very scarce sandstone interbeds, dramatically reduced thickness) of the Upper Floian – Lower–Middle Dapingian upper Tuloi Formation interpret the sedimentary record comprised in the Pridorozhny and Yurok sections as the distal parts of the shelf paleobasin. Black and dark color of the rocks and lack of the benthic fauna in the Pridorozhny Section substantiate an interpretation of this section as the most distal one. However, the light (snuffy) color of the strata, as well as both abundant and diverse fossils of the benthic fauna (trilobites, ostracods, phyllocarids, gastropods, brachiopods, bryozoans, echinoderms) in the Yurok Section contradict its interpretation within the deepened outer shelf, or even within the comparatively deep-water environments. At the same time, there are numerous specimens of full

Fig. 63. General view of the Yurok Section.

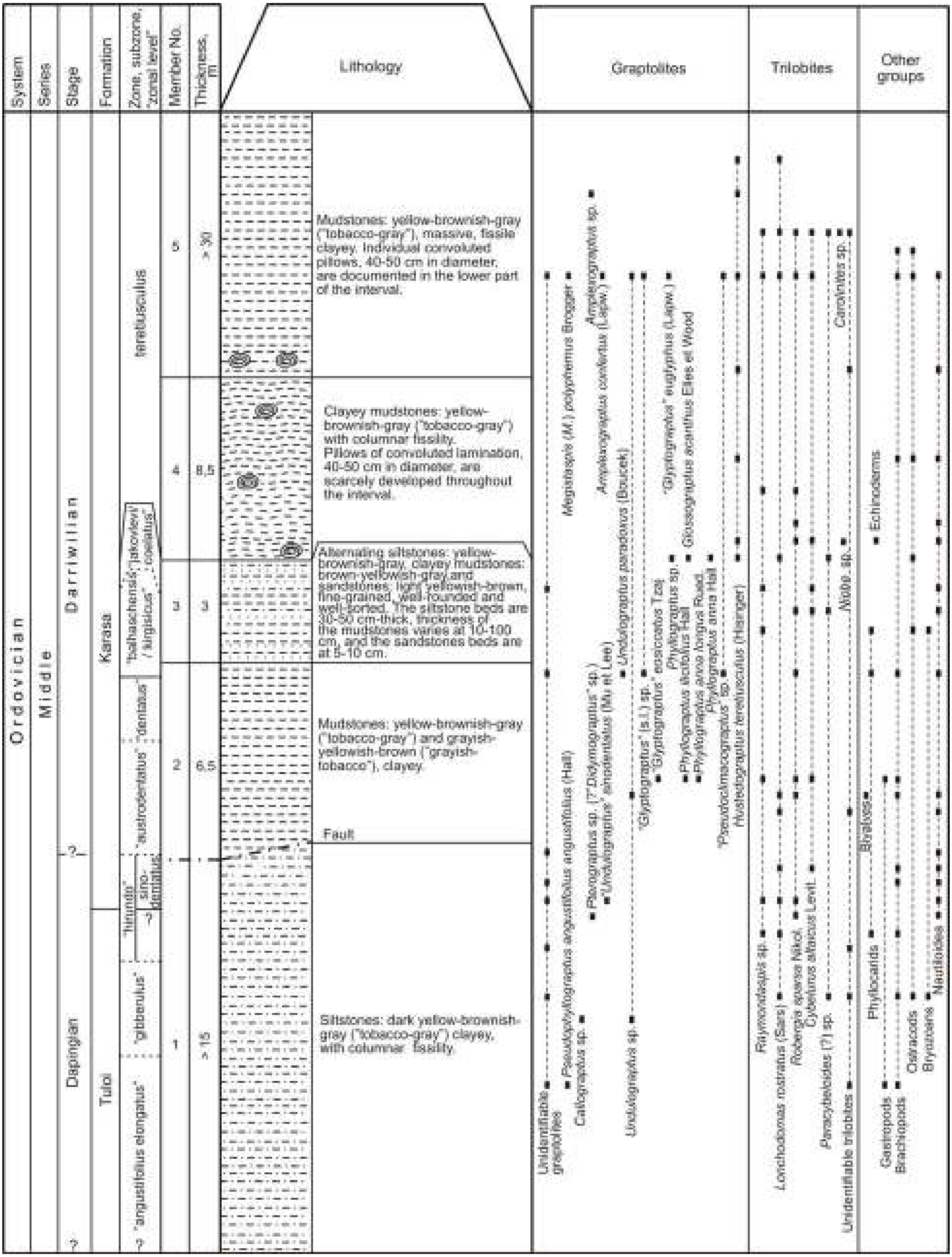


Fig. 64. Lithology and ranges of fossil taxa from the Yurok Section.

Fig. 65. Subaqueous slumping "twistings and rolls" in mudstone found in the Yurok Section (Karasa Formation).

trilobite skeletons found in the Yurok Section, which preservation conditions postulate a lack of wave influence on the benthic communities. Therefore, the upper Floian and lower-to-middle Dapingian strata of the Yurok Section must be accumulated not only below the fair-weather wave base, but even below the base of storm wave agitation – within the upper outer shelf and medium-depth inner shelf (50–100–150 m). Considering both remoteness of the Yurok Section from the shoreline and relatively shallow depth, we interpret the upper Floian and lower–middle Dapingian strata within the section to be accumulated on a top or slope of a local submarine uplift. This assumption is further supported by the gravity slump structures (convoluted pillows) found in the Yurok Section.

Amongst the trilobite taxa from the Yurok Section above enlisted, *Cybelurus altaicus* Levit. has the biggest potential for appliance as an age-constraint and correlative marker. This taxon was originally defined on a material obtained from the Bugryshikha and Gora Altai sections (stratotypes of Bugryshikha Formation and Bugryshikha Horizon), localized near the Bugryshikha Village in the northwestern Gorny Altai (Charysh–Inya facies zone). The type material originates from the stratigraphic level, characterized by the upper Darriwilian graptolites of *teretiusculus* Zone (Levitsky, 1963; Sennikov et al., 2008). Within the Loktevka–Batun structure-facies zone of the Gorny Altai, this trilobite species was found in the Batun Section (named after the Batun Village, nearby located), within the Voskresenka Formation which comprises there a stratotype of the Kostinsky Horizon (Levitsky, 1962, 1963; Perfil'ev and Levitsky, 1963; Sennikov, 1977; Sennikov et al., 1982, 2014, 2015a). Trilobites *Cybelurus altaicus* Levit. are found there in association with middle–upper Darriwilian graptolites of *dentatus* and *balhaschensis* zones. Composite trilobite complex of the Bugryshikha and Batun areas, associated with *Cybelurus altaicus* Levit., comprise *Cybelurus planus* Levit., *Cybelurus batunensis* Levit., *Aksanatella altaica* Petrun., *Aksanatella bugryshichica* Petrun., *Eorobergia ojrotica* Levit., *Raymondaspis communis* Levit., *Ceraurinus abnormalis* Levit., *Ceraurinella* cf. *frequens* Tschug., *Bijacybele* cf. *strigosa* Petrun., *Lonchodomas communis* Levit., *Bathyurellus nonnulus* Tschug., *Pliomera fischeri asiatica* Tschug., *Pliomerellus amplissimus* Petrun., *Pliomerellus* cf. *jacuticus* Tschug., *Kolymella* aff. *plana* (Tschug.), *Glaphurus altaicus* Weber, *Homotelus* sp., *Carrickia* sp., *Carolinites* sp., *Nileus* sp. Within the northeastern Gorny Altai (Uymen'–Lebed' structure-facies zone), trilobites *Cybelurus altaicus* Levit. were identified in the Tuloi Section, in the Karasa Formation (Andreeva, 1985). This stratigraphic level was lately constrained as the upper Darriwilian *dentatus* graptolite Zone. *Cybelurus altaicus* Levit. is also known from Tuva Region. These trilobites were revealed in the stratotype section of the Tarlyk Formation of the Malinovka Group, localized near the Tarlyk Village. Trilobite complex, including *Cybelurus altaicus* Levit., was found in the lower Tarlyk Member, which

Fig. 66. General view of the Biya Section.

section represents a stratotype of the Lower Tarlyk Horizon (Andreeva, 1985; Levitsky, 1962; Sennikov et al., 2006a, b, 2015a), in association with the Darriwilian graptolites and lower Darriwilian conodonts (*Eoplacognathus variabilis – E. suecicus* Zone) (Sennikov et al., 2000, 2015a). This trilobite complex contains *Cybelurus altaicus* Levit., *Cybelurus planifrons* (Weber), *Carolinites spinosus* And., *Carolinites marophtalma* (Harr. et Leanz), *Carolinites* aff. *genacinaca* Ross, *Bulbaspis* cf. *ovulum* (Weber), *Plesiomegalaspis* aff. *estonica* Tjernv., *Plesiomegalaspis* sp., *Cybele* cf. *bellatula* Dalm., *Symphysurus* cf. *exactus* Tschug., *Symphysurus* cf. *kujandensis* Tschug., *Ampyx* aff. *politus* Raymond, *Ampixella clavata* And., *Ogigites* aff. *almatyensis* Tschug., *Robergia deckeri* Coop., *Lonchodomas eximius* And., *Malinaspis tuvaensis* And., etc. Until recently, the upper member of the Tuloi Section has been characterized by trilobite taxa, identified by Z.E. Petrunina (Sennikov et al., 2008), and along with new species including *Encrinuroides* sp., *Ceraurinella* sp., *Atractopyge* sp., *Pliocybele* sp., *Raymondaspis* sp., *Robergia* sp., *Robergiella* (?) sp., *Remopleurella* sp., *Sphaerexochus* sp., *Carolinites* sp., *Hemiarges* sp., *Trinodus* sp., *Calyptaulax* sp., *Stegnoipsis* (?) sp., *Illaenus* sp., *Dimeropyge* (?) sp., *Otarion* sp., *Lonchodomas* sp., *Ampyx* sp., *Nilieus* sp. Our recent discoveries demonstrate the trilobite complex of the upper member of the Karasa Formation within the Tuloi Section sits inside the middle Darriwilian *dentatus* graptolite Zone, and contains certain trilobites taxa, not registered within the Yurok Section. The Tuloi trilobite complex is comprised by *Megistaspis* (*M.*) *polyphemus* Brogger, *Lonchodomas rostratus* (Sars), *Robergia sparsa* Nikol., *Ampyx* sp., *Paracybeloides* (?) sp., *Carolinites* sp., *Raymondaspis* sp., *Agerina* sp., *Niellus* sp. In Baltoscandia, trilobites *Megistapis* Jaanusson gave a name for “*Megistapis* limestones” (type area Bornholm Island), localized in the upper Volkhov Horizon and allegedly accumulated on a relatively distal shelf (Bergström et al., 2013; Pärnaste and Bergström, 2013), adjacent to deep-water facies of graptolite mud (Männil, 1966).

Biya Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: upper Sandbian, Katian.

Regional stratigraphic subdivisions: Khankhara and Tekhten’ regional stages (horizons).

Local lithostratigraphic subdivisions: Gur’yanovka and Chebor formations.

Fauna: crinoids, trilobites, ostracods, briozoans, nautiloids, corals, conodonts.

The Biya section, which was mentioned in geological survey reports and in some early publications (Kul’kov and Severgina, 1989; Sennikov et al., 1959; etc.) and documented in detail by our team for the first time, is located in the right side of the Biya River upstream of the Chechenek Creek mouth. The base of the Gur’yanovka Formation does not crop out in this section (see above). River terrace outcrops expose alternating sandstone, mudstone, and clayey limestone

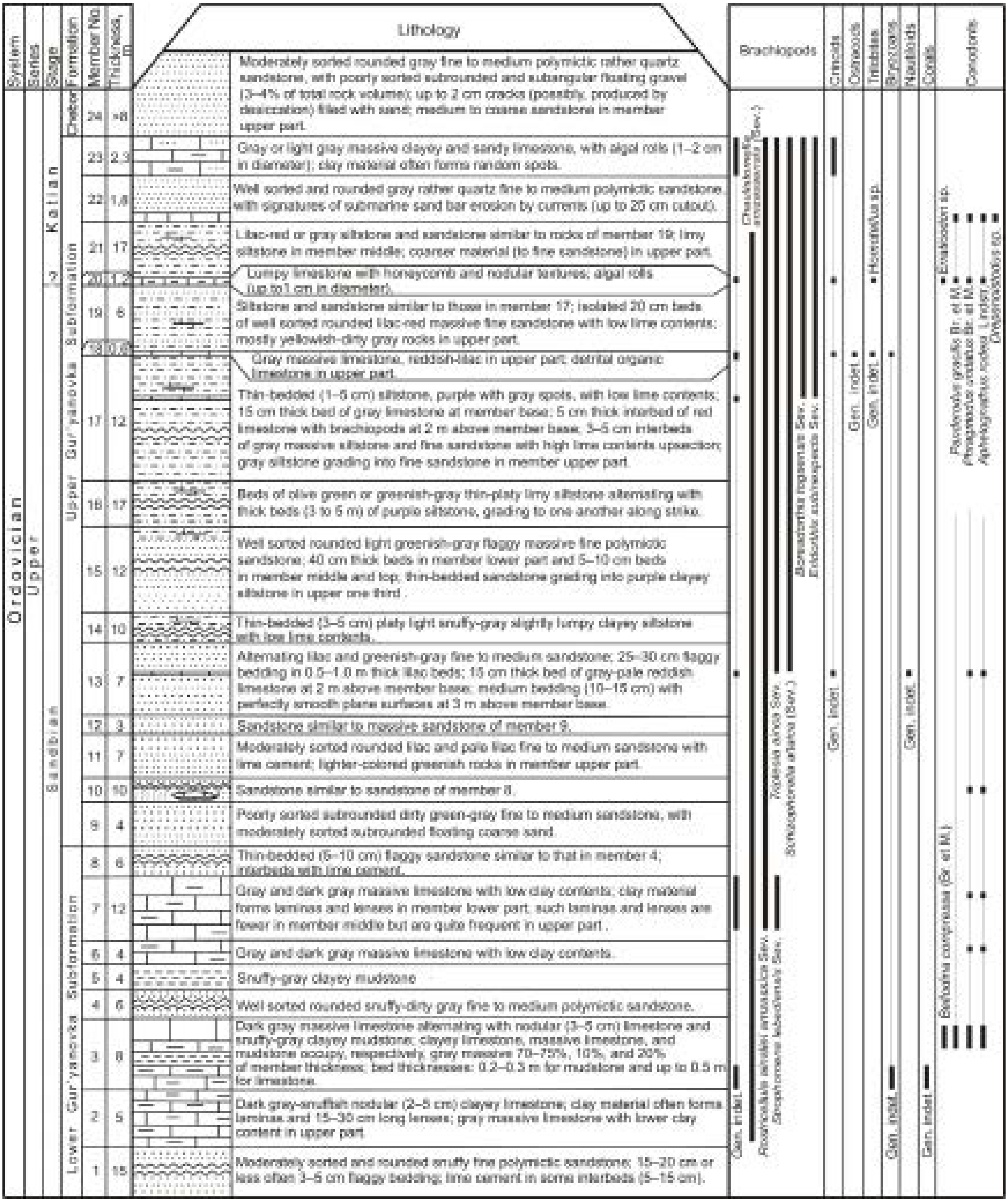


Fig. 67. Lithology and ranges of fossil taxa from the Biya Section.

(Figs 66, 67). The Gur'yanovka Formation has a total thickness of 170 m in the section (without the buried basal part). Its boundary with the overlying Chebor Formation corresponds to the top of the terminal limestone bed, and the uppermost member (N 24) should belong to the Chebor Formation rather than to the Gur'yanovka Formation. Note that the presence of floating pebbles and gravel among sandstone and siltstone was mentioned earlier (Krivchikov et al., 1976; Sennikov, 1962) in the terminal Biya section member, as well as in the basal members of different Chebor Formation sections. Note also that we observed a fragment of the Chebor Formation composed of alternating lilac and gray sandstone, siltstone, and mudstone 100-150 m south of the Biya section end, in an isolate fault-bounded block on the right side of the Biya River.

Peculiarities in facies, faunal assemblages and sedimentary environments.

The previously reported fauna found in the section on the right side of Biya River, near the Chechenek Creek mouth, and assigned to the Karasa Formation (Kul'kov and Severgina, 1989) was restricted to *Glyptorthis primus* Sev. brachiopods. L. Severgina also found *Strophomena lebediensis* Sev. in Rozm., *Chaustimella amzassensis* (Sev.), *Rostricellula ainsliei amzassica* Sev., *Schizophorella altaica* (Sev.), *Triplesia ainca* Sev., *Boreadorthis togaensis* Sev., and *Eridorthis subinexpecta* Sev. brachiopods typical of the Gur'yanovka Formation fauna during geological surveys, between 510 and 615 m downstream of the Yurok River inlet into the Biya. We discovered *Belodina compressa* (Br. et M.), *Panderodus gracilis* (Br. et M.), *Phragmodus undatus* Br. et M., and *Erraticodon* sp. conodonts in members 3 and 20.

Both clastic and carbonate Gur'yanovka Formation rocks have red and lilac colors in the middle of the Biya Section. The appearance of this bright coloration (purple, brown, lilac, and red) in the northern and eastern parts of the Uymen'–Lebed' facies zone was previously interpreted (Krivchikov et al., 1976; Sennikov, 1962) as the principal or at least significant criterion to separate the Gur'yanovka Formation from the overlying Chebor Formation. Note, however, that lilac rock coloration appears also at the base of the Gur'yanovka Formation stratotype described above, near the Bura mouth, and red rocks occur at the top of the Gur'yanovka Formation in the Gur'yanovka Glade section (see above). Almost all limestones in the Biya section are clayey or less often sandy. Some are detrital organic varieties (coquina), with detritus of various fauna groups, as well as limestone with algal rolls, 1–2 cm in diameter. Siltstone are fine- or medium-grained, rounded, well or moderately sorted, with either clay or lime cement. The cross sections of some sandstone members display signatures of submarine sandbars eroded by currents, with channels incised to 25 cm depths. Such channels were apparently formed below storm wave base (SWB), at sea depths more than 30 m. The presence of sandstone layers with perfectly smooth surfaces in the Biya Section indicates deposition in relatively deep water, below SWB (deeper than 30 m).

The Gur'yanovka Formation fauna assemblages in the Biya Section include predominant brachiopods, less frequent or few ostracods and conodonts, and sporadic trilobites, nautiloids, tabulates, and bryozoans. Brachiopods show the highest taxonomic diversity in the Gur'yanovka Formation oryctocenoses, while conodonts and trilobites are represented by few taxa. Limestones in the section almost lack corals and are free from algal calyptrae, which is evidence of sunlight shortage on the sea floor; together with the lack of clay lithologies, this indicates clear water and medium shelf depths exceeding 30–80 m in the disphotic zone. Facies of other Gur'yanovka Formation rocks in the section suggest deposition environments below fair-weather wave base but within SWB (10–30 m) or greater sea depths (50–100 m) for different section parts.

4.2. EASTERN GORNY ALTAI
(Teletskoe Lakeside facies zone)

4.2.1. AREA OF IOGACH VILLAGE

Tozodov Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale:

Regional stratigraphic subdivisions: Kuibyshevo, Kostinsky, Bugryshikha regional stages (horizons).

Local lithostratigraphic subdivisions: Tozodov Body.

Fauna: trilobites, ostracods, brachiopods, orthoceratids, bryozoans.

The Tozodov Section is located on the right side of the eponymous brook (right tributary of the Iogach Rv.) in two road quarries, one km from the creek's mouth (Figs 68–70). The total thickness of the exposed part of the section is more than 150 m. The thickness of the non-red part of the Tozodov Section as a possible lithological analogue of the often green-gray Karasa Formation (upper half of the Stretinka Group), is at least 120 m. This interval should be considered as a stand-alone gray terrigenous Tozodov Body. The thickness of red-colored part of the Tozodov Section, which was previously correlated with the Chebor Formation (Uimen'-Lebed' facies zone), is at least 30 m.

Peculiarities in facies, faunal assemblages and sedimentary environments.

The ichnofossils Gordia Emmons established in the seventh member are interpreted as biomarkers of relatively deep-water facies (Mangano, Droser, 2004). The ostracods *Egorovella* sp. were found in the third member of the Tozodov Section, while the eighth member contained diverse trilobites, namely *Asaphus knyrkoi* F. Schmidt, *Asaphus striatus* Brogger, *Lonchodomas rostratus* (Sars), *Pliomera fischeri* (Eichwald), characteristic of the middle and lower parts of the Upper Ordovician of Baltoscandia (Ivantsov, 2003). The faunas reported from this member also include the bryozoans *Dianulites ramosoformis* Jaroshinskaja.

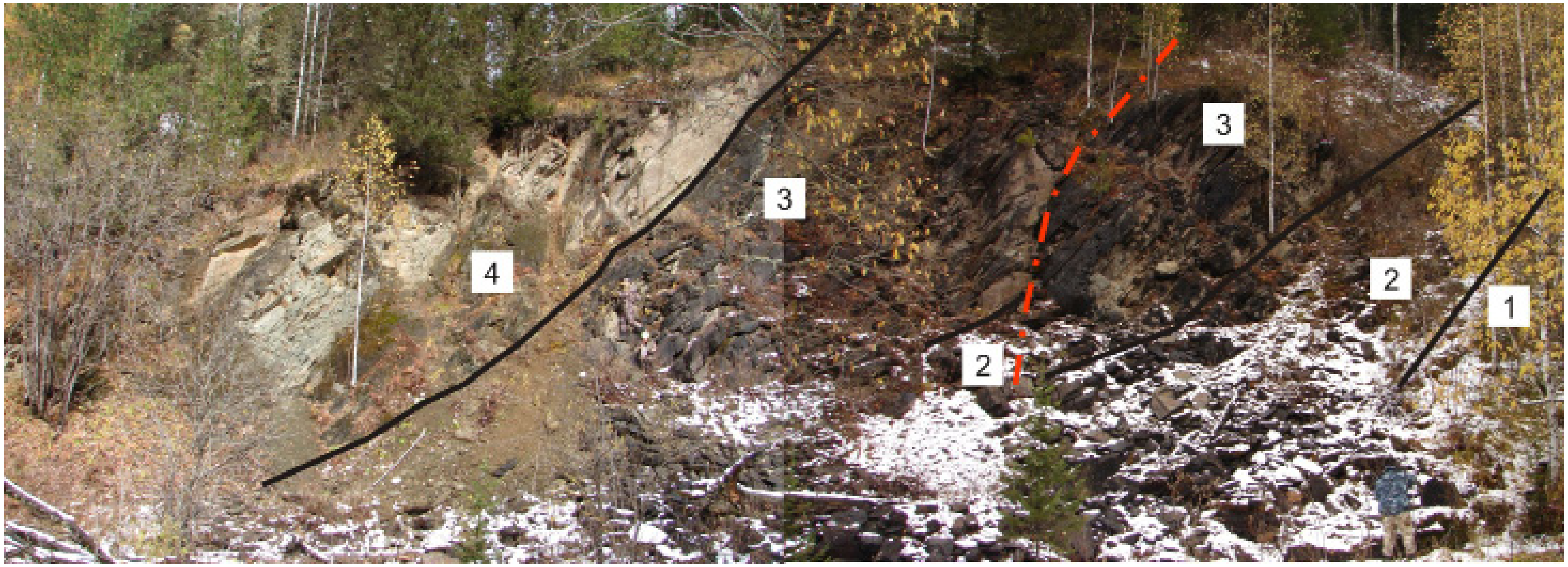


Fig. 68. General view of the Tozodov Section (lower part).

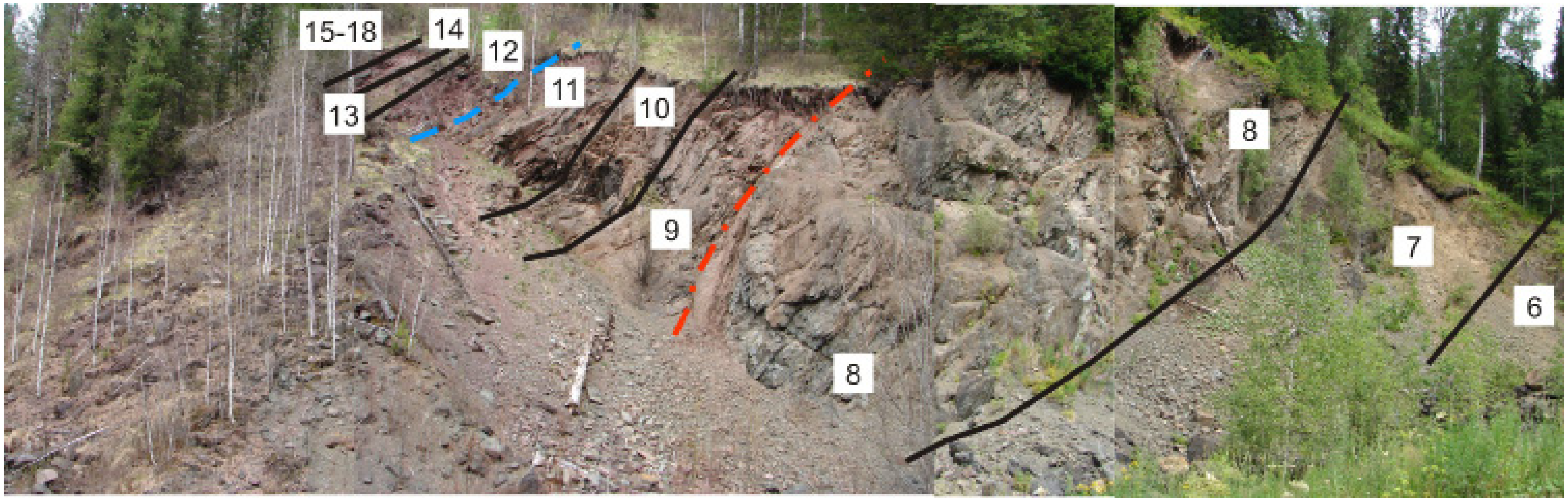


Fig. 69. General view of the Tozodov Section (middle and upper parts).

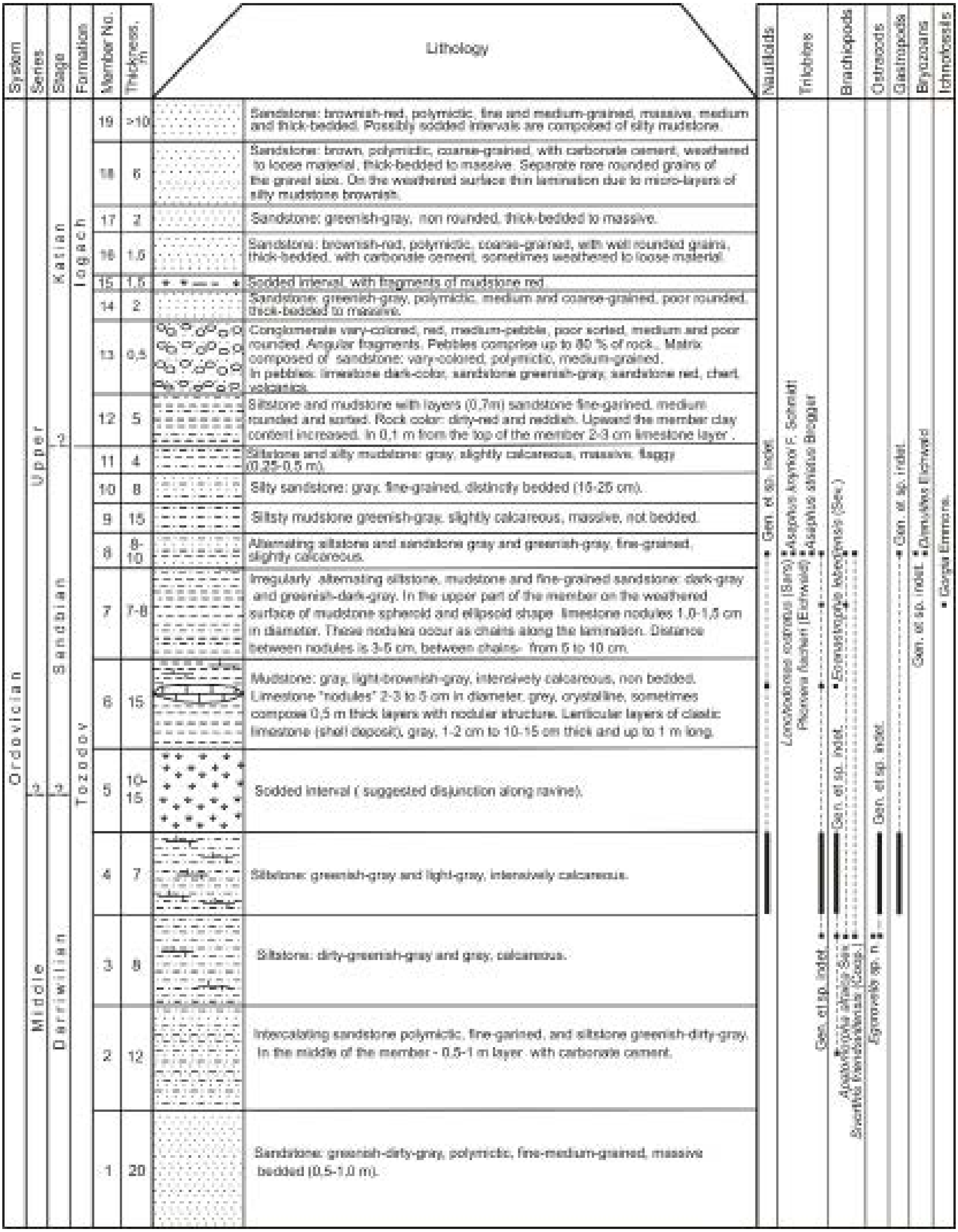


Fig. 70. Lithology and ranges of fossil taxa from the Tozodov Section.

4.3. NORTHERN GORNY ALTAI
(Biya-Katun' facies zone)

4.3.1. AREA OF KAMLAK VILLAGE

Kamlak Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Upper Cambrian (Furongian) and Lower Ordovician (Tremadocian).

Regional stratigraphic subdivisions: Ordovician – Takoshkin Regional stage (Horizon).

Local lithostratigraphic subdivisions: Kamlak Formation.

Zone: *Iapetognathus* conodont Zone, *osloensis-hyperboreus* graptolite Zone.

Fauna: conodonts, graptolites, trilobites, brachiopods, chitinozoans, problematics.

Tremadocian strata are most completely represented and best constrained by faunas near Kamlak Village thus making a tie for Tremadocian correlations throughout the Gorny Altai. A small (6 × 7 km) Kamlak graben is filled with terrigenous-carbonate sediments folded in an asymmetric fold cut by faults. According to lithology and fauna patterns, the stratotype section includes three units of unequal thicknesses: The Lower, Middle, and Upper Kamlak subformations (Figs 71–73). The subdivision of the Kamlak Section into subformations is based on lithology and faunal control, mainly from trilobites. Members are aligned according to lithology and trilobite, graptolite, and brachiopod assemblages.

The Lower Kamlak Subformation crops out in the middle reaches of the Maly Kamlak River where the base of the Kamlak Formation contacts, along a fault, with the volcanic rocks of the Middle Cambrian Ust'-Sema Formation. The total thickness of the Lower Kamlak Subformation is about 120 m. The Lower and Middle Kamlak subformations are divided by a fault. The total thickness of the Middle Kamlak Subformation is about 440 m. The Middle and Upper Kamlak subformations are

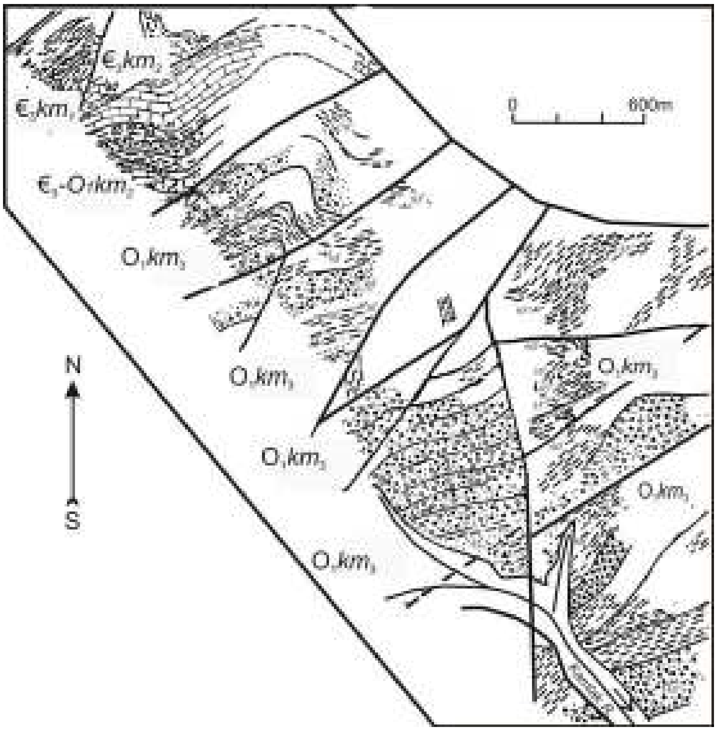


Fig. 71. Sketch map of the Kamlak area.

Fig. 72. Limestone of the Member 10 of the Middle Kamlak Subformation (Kamlak Section).

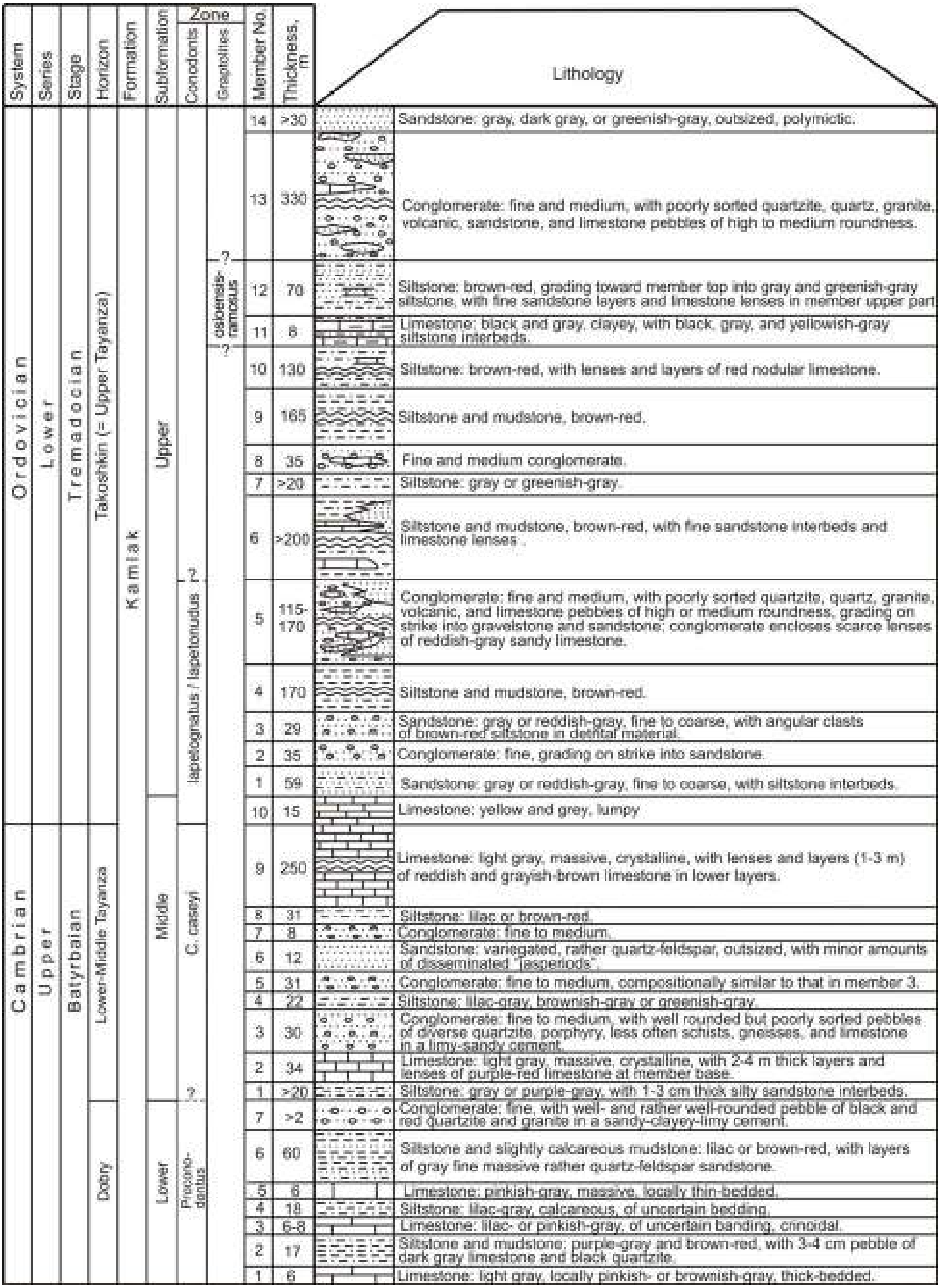


Fig. 73. Lithology and ranges of fossil taxa from the Kamlak Section.

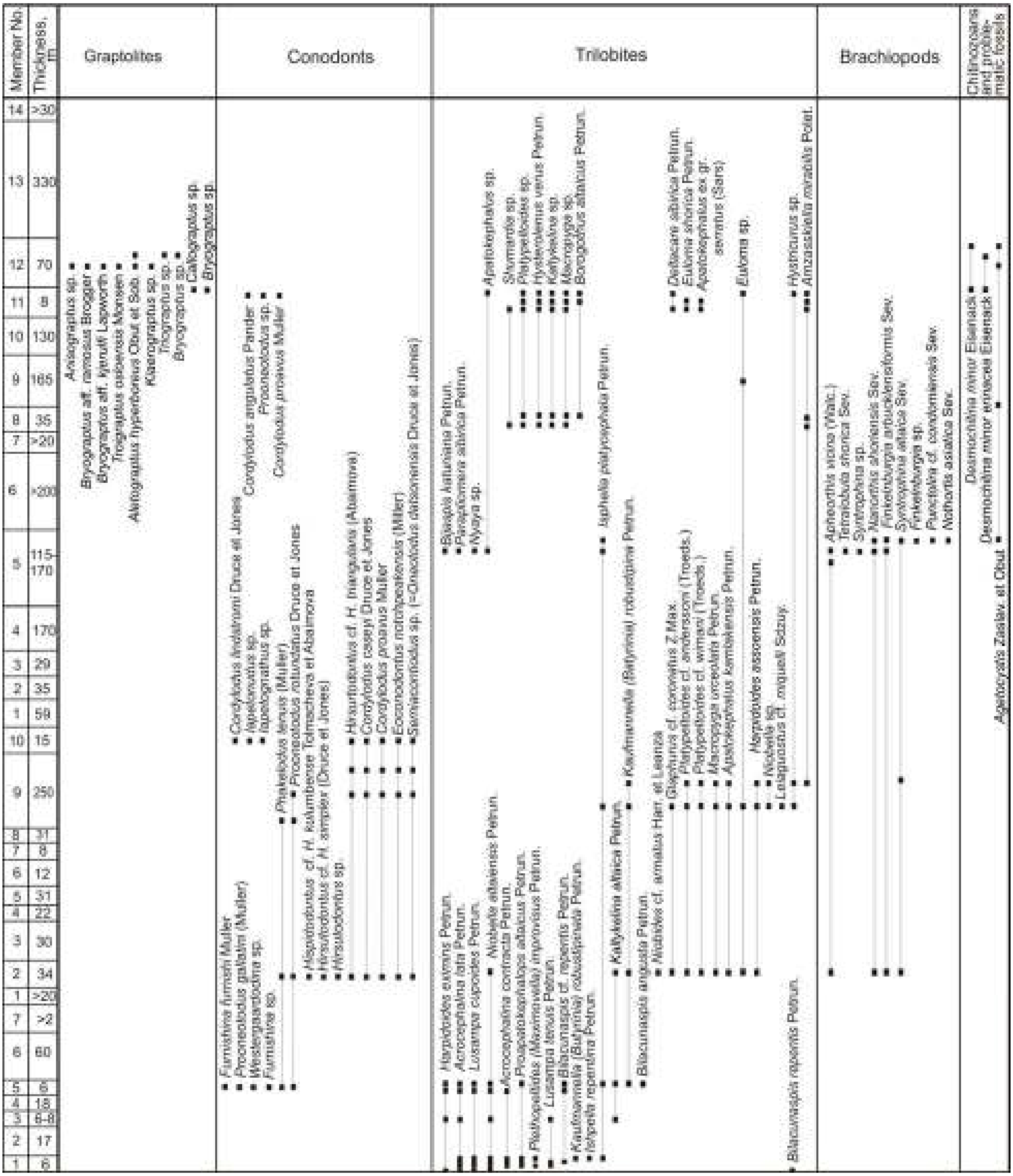


Fig. 73. The end.

divided by a fault. The Upper Kamlak Subformation has a total thickness of about 1400 m and is of a Late Tremadocian age according to the faunas.

According to B.D. Erdtmann who looked through the data, some graptolite forms found in member 12 uper Kamlak Subformation and identified as *Triograptus osloensis* Monsen and *Aletograptus hyperboreus* Obut et Sob. may belong to genus *Psigraptus* Jackson. These forms are rhabdosomes buried in sandstone, and their preservation leaves unknown the intravital direction (upward or horizontal?) of branches off the sicula. On the other hand, the Altai morphs lack occluded autothecas typical of Psigraptus and thus may be transitional from the Triograptus Monsen and *Aletograptus* genera to *Psigraptus* Jackson. The graptolite assemblage from locs S-7662, S-7664, and S-7661 generally corresponds to the *osloensis - ramosus* Zone.

In the year 2007 P. Mannik collected limestone samples from the Kamlak Section. Chemical proceeding revealed conodonts (provisional identification): from the lower part of the Middle Kamlak Formation, member 9, sample N 10 and from the upper part of the Middle Kamlak Formation, member 16, sample N 9 – *Variobiliconus* sp.

The composite section of the Kamlak Formation can be correlated with the International Stratigraphic Chart on the basis of few species of conodonts and graptolites. The conodont species *Oneotodus datsonensis* Druce et Jones found in members 9 and 10 in the lower half of the Middle Kamlak Subformation is known in the Datsonian and lowermost Warendian groups of Australia that span a stratigraphic interval of the *Cordylodus proavus*, *Hirsutodontus simplex*, *Cordylodus prolindstromi* and *Cordylodus lindstromi* zones (Dubinina, 2000). One may expect to find a transitional assemblage between the *Cordylodus lindstromi* and *lapetognathus fluctivagus* zones in the Lower Middle Kamlak Subformation. The graptolite assemblage found in member 12 of the Upper Kamlak Subformation corresponds to the *osloensis-ramosus* Zone. Earlier data on trilobites from the Lower Kamlak Subformation defined its Early Tremadocian age (Ermikov et al., 1979; Petrunina et al., 1984). The present view is that the Lower Kamlak Subformation must rather correlate with the uppermost Cambrian, proceeding from the revised conodont-based age and stratigraphy of the Ordovician-Silurian boundary strata (Webby et al., 2004) and from the correlation of the Mansian and Loparian regional stages of the Siberian Platform with the Late Cambrian (Kanygin et al., 2007). The trilobite and graptolite data suggest a Late Tremadocian age of the Upper Kamlak Subformation. Thus, the Middle Kamlak Subformation may correlate with the Lower Tremadocian. The trilobite assemblage from the Middle Kamlak Subformation differs from those in both the Lower and Upper Kamlak subformations.

4.4. NORTH-WESTERN GORNY ALTAI (Anui-Chuya facies zone)

4.4.1. AREA OF UST'-KAN VILLAGE

Chakyr-Azratkan (Chakyr-Elanda) Section
Chronostratigraphic subdivisions of the International Stratigraphic Scale: Katian.
Regional stratigraphic subdivisions: Tekhten' Regional stage (Horizone).
Local lithostratigraphic subdivisions: Tekhten' Formation.
Fauna: alge, tabulate corals, stromatoporoids, trilobites, brachiopods, graptolites.

One of the studied sections crops out on the watershed ridge between the Chakyr and Elanda rivers 4.8 km (azimuth 185) from the Elanda mountain (elevation: 1663.7 m). The massive gray limestone with rare poorly preserved corals are overlain by terrigenous strata (Figs 74, 75). Two uppermost carbonate members in this section can be attributed to typical outcrops of the Chakyr beds with characteristically abundant corals.

The tabulate corals established on the Chakyr-Azratkan watershed in the upper member of platy limestone (being part of the stratotype section of the local stratigraphic unit) include: *Nyctopora altaica* Dz., *N. tchakyrensis* Dz., *Lyopora altaica* Dz., *Eofletcheria kovalevskyi* Dz., *Calapoecia baragashiensis* Dz. and *C. lebediensis* Dz.

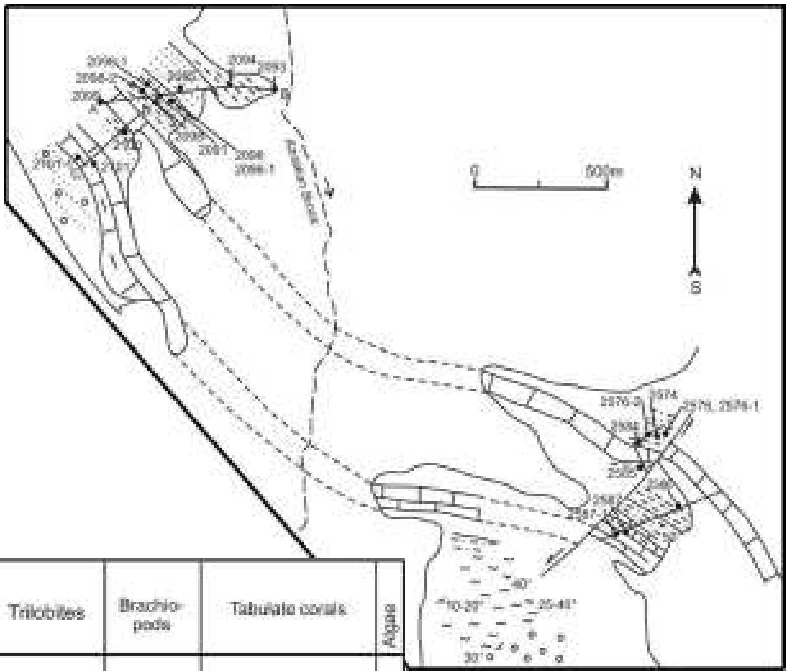
The brachiopod assemblages *Onniella* cf. *chancharica* Severg., *Sowerbyella* sp. were encountered along with corals in carbonates, while graptolites *Pseudoclimacograptus* sp., *Lincograptus* sp. and *Desmograptus* sp., tilobites *Sceptaspis* cf. *unica* Petrun., *Lonchodomas* sp., *Homotelus* sp., *Ceraurinus* sp., *Eorobergia* cf. *crassilimbata* Petrun., and the brachiopods *Dactylogonia subgeniculata* Severg., *Rostricellula* sp. are reported from the under- and overlying calcareous-terrigenous rocks.

The youngest carbonate member (thickness: 80 m) is featured as a solitary ridge descending into the Azratkan valley, where at the foot of its left side limestone become massive and bear many algal structures forming separate calyptraes and their grouping both in intravitam and displaced positions (Sennikov et al., 2001; Sennikov et al., 2017).

The fauna found in the upper two members of the laminated limestone which constitute the second integral part of the stratotype of the Chakyr Beds section along the strike of the right bank of Azratkan (Elanda) Section (Fig. 76) included tabulate corals *Calapoecia lebediensis* Dz., *C. altaica* Dz., *C. anticostensis* Bill., *Eofletcheria kovalevskyi* Dz., *Billingsaria* sp., *Fletcheriella altaica* Dz., *Nyctopora asratkanensis* Dz., *N. altaica* Dz., *Nyctopora* sp., *Catenipora elandiensis* Dz. and *Eofletcheria sokolovi* Dz., heliolitids *Chaetetes tchakyrensis* Dz. (Sennikov et al., 2001). In addition to these, formerly from this composite section on the Chakyr Rv. (Dzyubo, 1960a,b, 1966; Dzyubo, Mironova, 1960; Cherepnina, 1960; Stratigraphic..., 1975) reported the tabulate *Nictoporas minimaluis* (Radugin),

Fig. 74. Sketch map of the Chakyr-Azratkan area.

Grewingkia semilunatum (Scheffen), *Catenipora kuruensis* Sok., *Paliphyllum primarium* Soshk. and rugose corals *Brachielasma altaica* Tcherepn. The listed tabulate genera from the Chakyr beds included (besides the above mentioned) those identified earlier *Saffordophyllum* Bass., *Foerstephyllum* Bass., *Reuschia* Kiaer, *Fletcheriella* Sok., and also heliolitids – *Wormsipora* Sok., *Stelliporella* Went., *Proheliolites* Kiaer (Dzyubo, 1966). In the past, this taxonomic diversity and representativeness in corals in the section once served as the basis for identification of the Chakyr Formation as a new local straton (Chakyr limestone, Chakyr beds) (Stratigraphic..., 1975; V. Sennikov, Sennikov, 1982; Sennikov et al., 2001, 2017).



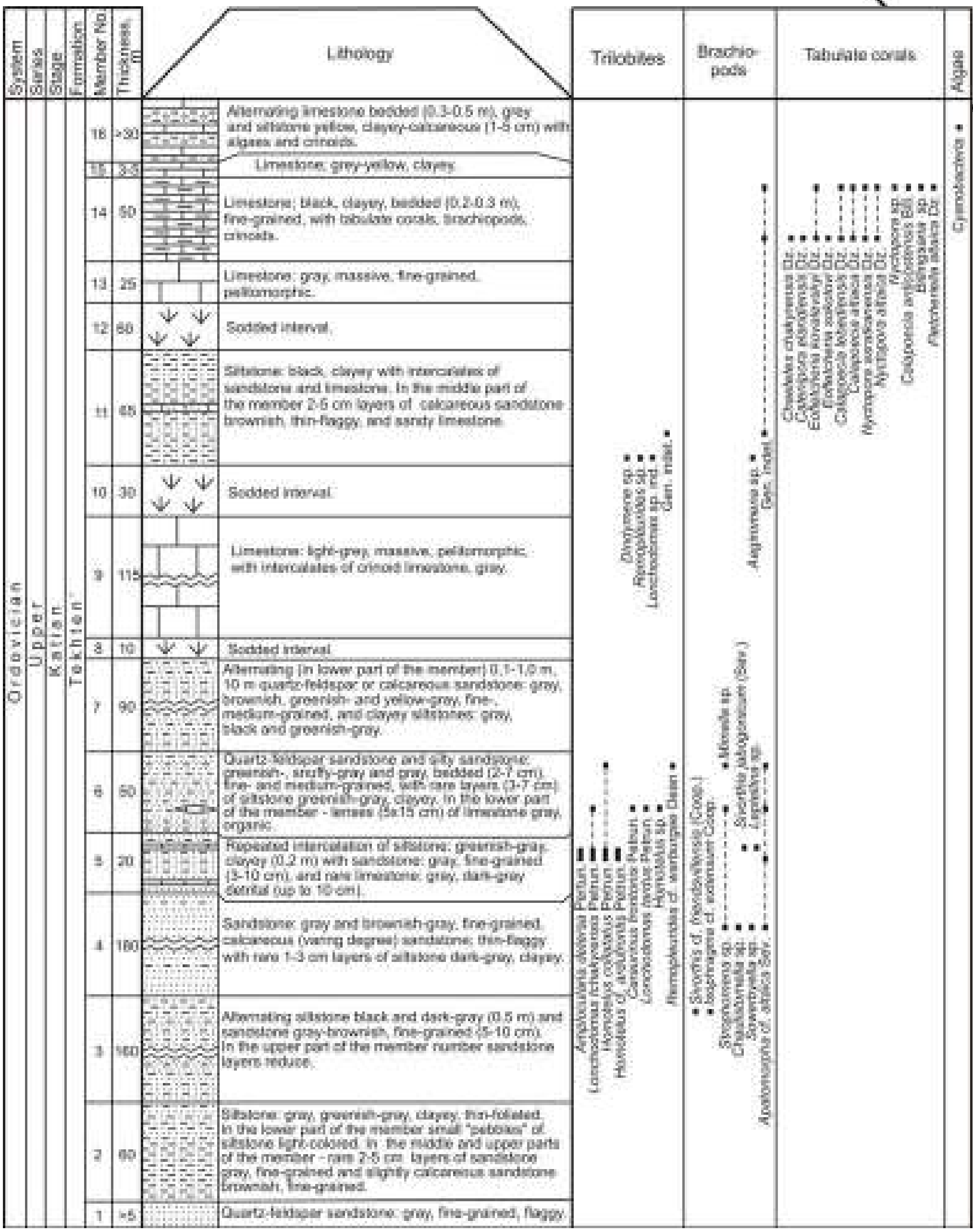


Fig. 75. Lithology and ranges of fossil taxa from the Chakyr-Azratkan (Chakyr-Elanda) Section.

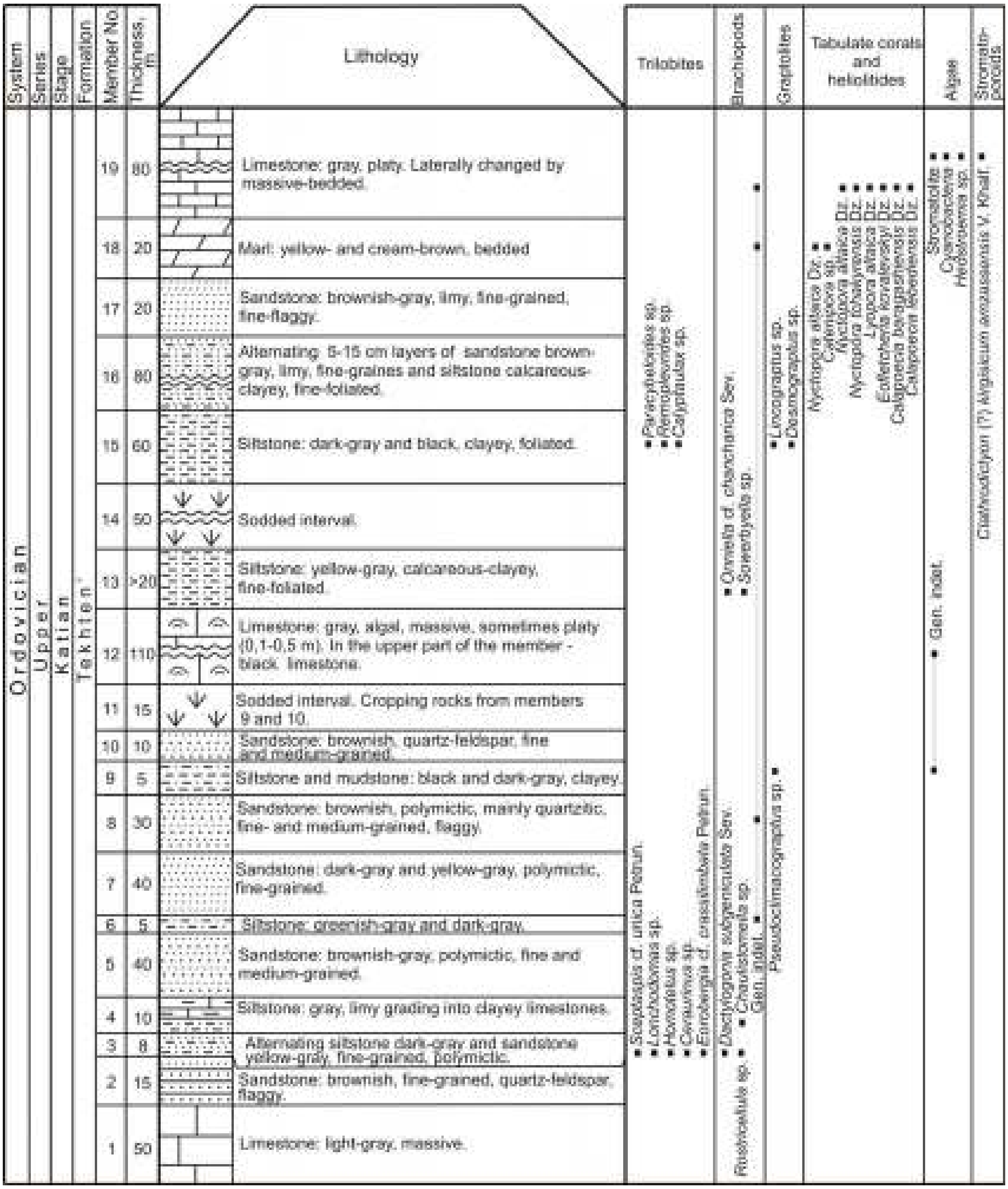


Fig. 76. Lithology and ranges of fossil taxa from the Azratkan (Elanda) Section.

Peculiarities in facies, faunal assemblages and sedimentary environments.

Members in the Chakyr-Azratkan (Chakyr-Elanda) Section with abundant corals should be termed "coral meadows". The organogenic structures found on the left bank of the Azratkan (Elanda) Rriver are composed of calcareous blue-green algae (Cyanobacteria), which, being enveloped (wrapped) in the bacterial film, formed organic micro-structures in the form of algal crusts, irregular hemispheres (1-2 cm), isolated from each other calyptrae (micro-domes) of 3–5, rarely up to 7 cm in diameter and 1–2 cm in height composed successively layered bacterial mats covers (Fig. 77).

Cyanobacteria (calyptraes) together with corals formed coral-algae meadows, covering large areas of the bottom. Localities occupied by extensively developed cyanobacterial micro-structures are characterized by significantly lower corals density, than the areas with sparse calyptraes.

Not only cyanae "build" calyptraes on the basis of their own colonies (Luchinina, 1973), rather their activity co-existing (symbiosis) with bacteria provides the basis for the formation of organomineral structures (stromatolites). In theses structures the "capture" of sediment particles and the biomineralization of the colony mats of calcareous blue-green filamentous algae take place along with the minerals precipitation on the surface of such tissue. Stromatolite

Fig. 77. Microbial-algae structures in limestone of the Tekhten' Formation (Chakyr-Azratkan Section).
a - g – calyptraes, h – stromatolite's structure, i – calcareous algae *Hedstroemia* sp.

structures were also recorded in the studied section. Besides cyanobacteria, calcareous red algae (Rhodophyta) devoid of a bacterial membrane were found in the sections. Red algae are a characteristic element of organogenic builups (Brooke, Riding, 1998; Luchinina, Terleev, 2004). The red algae *Hedstroemia* sp. revealed among the latter was close to *Hedstroemia aequalis* Hoeg were identified in the Kozhim Rv. Section in the Urals (Chuvashov et al., 1993).

Ebogon Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Sandbian, Katian.
Regional stratigraphic subdivisions: Bugryshikha, Khankhara, Tekhten' regional stages (horizons).
Local lithostratigraphic subdivisions: Bugryshikha, Khankhara, Tekhten' formations.
Zone: *clingani* graptolite Zone.
Fauna: graptolites, trilobites, brachiopods, ostracods, bryozoans, gastropods.

The section on the Ebogon and Elanda watershed was studied by several researchers (Sennikov, Vinkman, Kononov, 1959; Kononov, 1964). The area is bounded by the Ebogon and Elanda watershed and complicated by a series of small ridges.

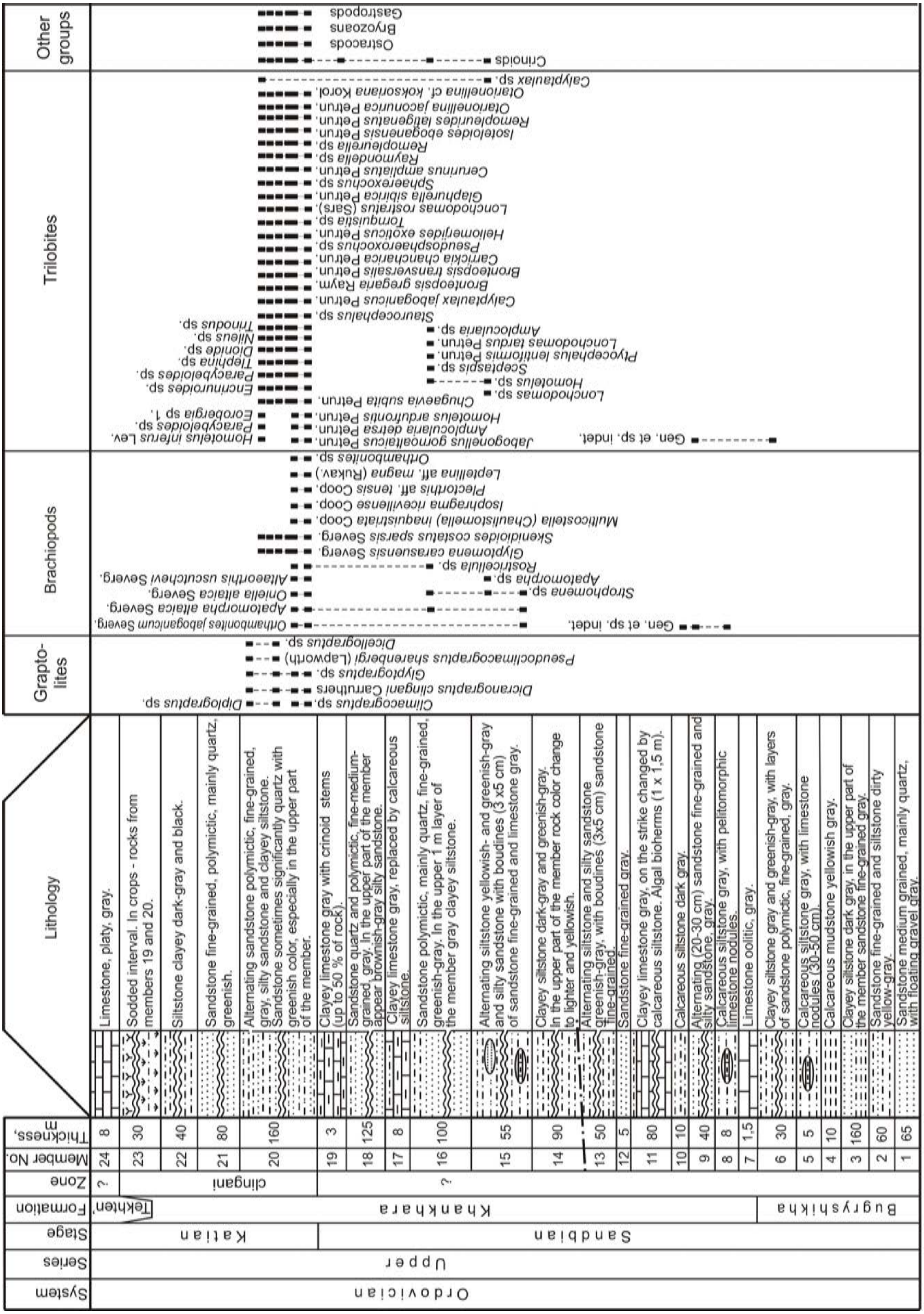


Fig. 78. Lithology and ranges of fossil taxa from the Ebogon Section.

The initial point of the section is located on one of these ridges, descending from the spurs (1663.7 m), 4.2 km from the elevation mark (azimuth 270°). A bed-by-bed description provided below concerns with only the topmost part of the section. The thickness of the lower part of the section totaling 525 m thick is characterized by alternation of sandstone and siltstone with rare thin (up to 1.5 m) intercalations of limestone. Given that the faulting affected the saddle on the crest, the upper part of the section is stratigraphically directed upsection and down the crest along the azimuth 250° (Fig. 78).

The section established along the ridge axis. The Katian trilobites were found 100-150 m north of the section line in the localites U-1671 и U-1672, in the deposits corresponding to the lower half of the 7th member. In addition to the above mentioned taxa these fauna finds included trilobites *Jabogonellus* sp., *Ceraurinella* sp., *Raymondella* sp., *Isoteloides* sp., *Pharostoma* sp., and *Calyptaulax* sp., brachiopods *Chaulistomella inaquistriata* (Coop.), *Isophragma zicevillense* Coop., *Apatomorpha altaica* Severgina, *Rostricellula* sp., *Plectorthis* aff. *tensis* Coop., *Leptellina* aff. *magna* (Rukav.), *Oniella altaica* Severgina, *Altaeorthis uscutchevi* Severgina, *Sivorthis jaboganicum* (Severg.) and Katian graptolites (clingani Subzone, *quadrimucronatus* Zone) *Dicranograprus clingani* Carruthers, *Climacograptus* sp., *Glyptograptus* sp., as well as ostracods, bryozoan, gastropods and crinoids.

4.4.2. AREA OF UST'-MUTA VILLAGE

Marchetyonok Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: ? Tremadocian.

Regional stratigraphic subdivisions: Takoshkin and Tuloi regional stages (horizons).

Local lithostratigraphic subdivisions: Marcheta Formation.

Ordovician sections of the marine genesis in the vicinity of Ust'-Muta Village occur in separate fault blocks on the left bank of the lower Marcheta River (Figs 79, 80). The section (S-012) of the Marcheta Formation (Zasur'ya Group) is located on the left bank of the Marchetyonok Brook (Marcheta left tributary), 1350 m far from its mouth, and comprises.

The section of the Marcheta Formation (S-002) crops out on the left bank of the Marcheta River (left tributary of the Muta River), 900 m far from the Marchetyonok Brook inflow. The section begins at the floodplane terrace, then follows the second ridge from the Marchetyonok value, reaches the Marcheta/Marchetyonok divide, and ends at the top of 1201.0 m mountain. It comprises siltstone, mudstone, chert (Fig. 80).

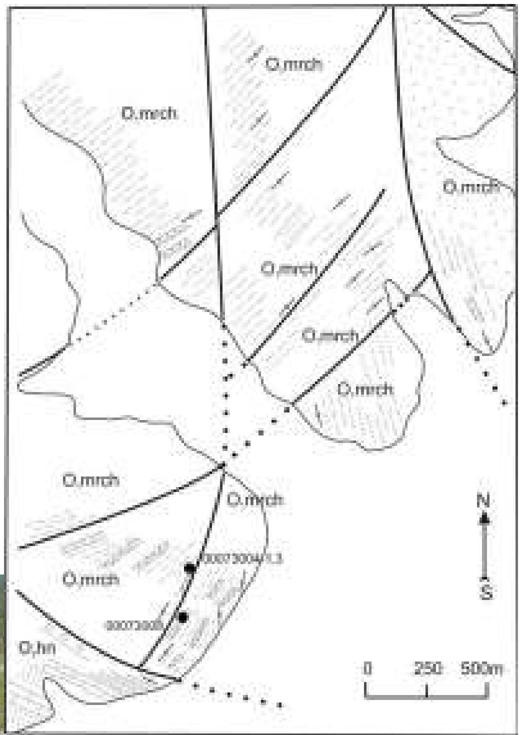


Fig. 79. Sketch map of the Marcheta area.

Fig. 80. Violet-reddish mudstone from the Marchetyonok Section.

Marcheta-1 Section
Chronostratigraphic subdivisions of the International Stratigraphic Scale: Tremadocian, Floian.
Regional stratigraphic subdivisions: Tuloi and Lebed' regional stages (horizons).
Local lithostratigraphic subdivisions: Marcheta Formation.
Zone: *proteus* conodont Zone.
Fauna: conodonts, radiolarians, demosponges.

Peculiarities in facies and sedimentary environments.
Member 6 of the Marcheta-1 Section composed of massive chert was formed on the mounds in the zone with underwater hydrotherms activity (?hydrothermal quartzites, ?jasperoids) (Figs 81, 82).

Fig. 81. Massive chert (?hydrothermal quartzites, ?jasperoids) from the Marcheta-1 Section (Member 6).

Marcheta-2 Section
Chronostratigraphic subdivisions of the International Stratigraphic Scale: Floian.
Regional stratigraphic subdivisions: Tuloi Regional stage (Horizon).
Local lithostratigraphic subdivisions: Marcheta Formation.
Zone: *elegans* conodont Zone.
Fauna: conodonts, radiolarians, demosponges.

Another section of the Marcheta Formation (S-013) (Fig. 83) crops out 300 m westward of the Marcheta-1 Section, opposite a spring on the left bank of the Marcheta River. The section begins 100 m far from the hill toe. It exposes upper strata of the Marcheta-1 Section but with slightly different lithologies and different member thicknesses.

All members, about 360 m of total thickness, belong to the Marcheta Formation.

Lithologies, especially in siliceous members, grade rapidly into one another along the strike in the three Marcheta sections: 6 m of red chert pass into red low-silica mudstone and siltstone within a distance of 30-50 m and then into gray mudstone and siltstone 50-70 m away. Color changes still more rapidly from red or lilac to sea-green, gray, darc olive, ets. Loaf-shaped concretions and traces of clay flowage found in the Marchetyonok Section and syndepositional breccia in the Marcheta-2 Section are typical of slope facies. Taking into account the marine origin of the Zasur'ya sediments, one may assume that the Marchetyonok Section formed on a seamount slope and the Marcheta-1 and Marcheta-2 sections were deposited on the sea floor in a vicinity of such a slope.

Peculiarities in facies, faunal assemblages and sedimentary environments.
The lithofacies characteristics and low formation rate of the Zasur'ya Group (including the Marcheta Formation) (Sennikov et al., 2002, 2003, 2004; 2011b) suggest that these rocks formed in an oceanic environment (below the CCCD – Calcium Carbonate Compensation Depth) at depths corresponding to 4000–5000 m in the present-day oceans.

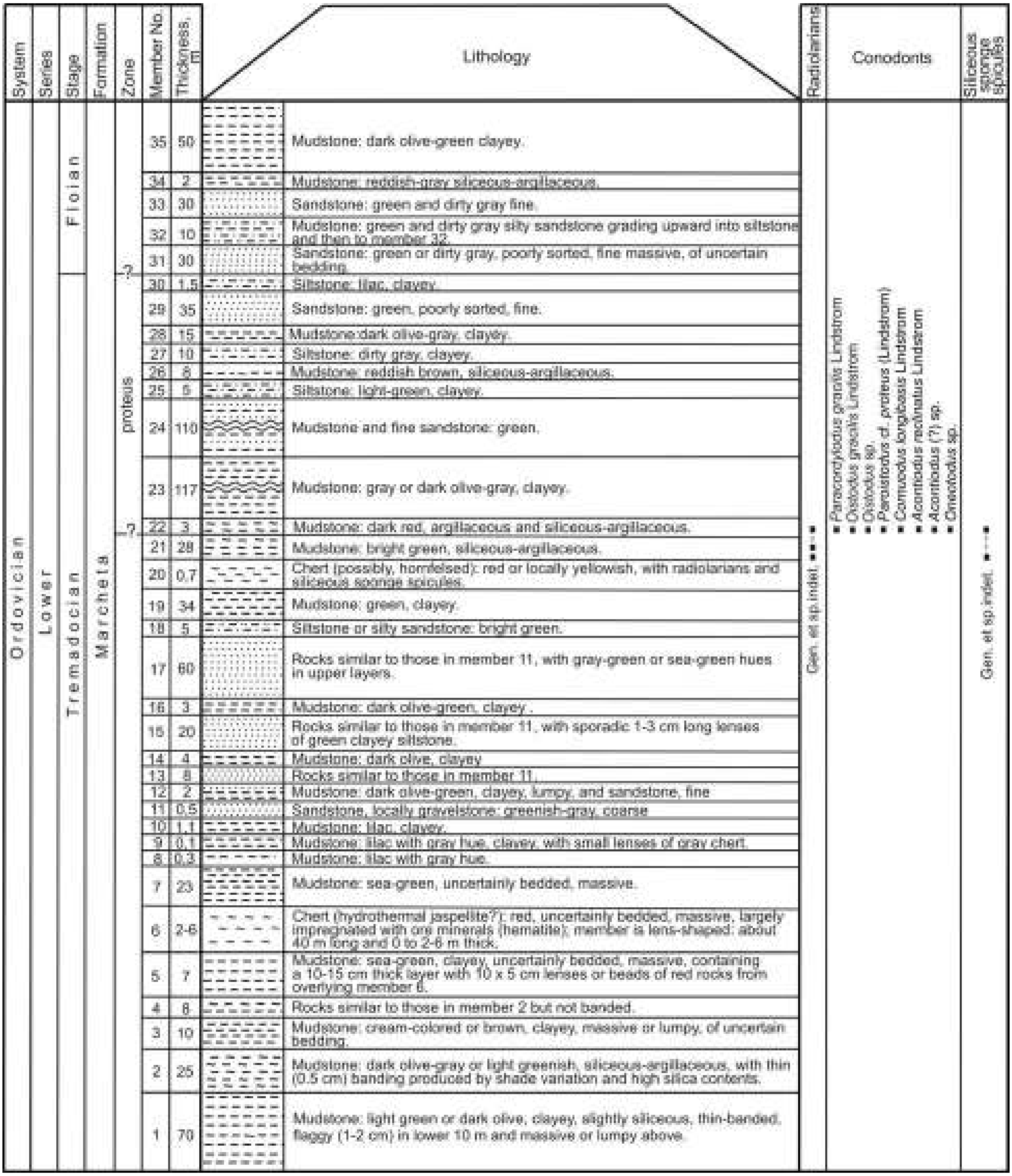


Fig. 82. Lithology and ranges of fossil taxa from the Marcheta-1 Section.

Considering the possibly great CCCD in the Paleozoic, the first estimate of the paleobasin depth in the Altai segment of the Paleoasian Ocean equals 1500–2000 m. Such depths, shallow on the ocean scale, are indirectly confirmed by the dominance of volcanic rock samples with the characteristics of paleoceanic uplift basalts. For bioindicator control of this value, let us analyze the taxonomic diversity of the faunal fossil assemblages in the Zasur'ya Group, the density of taphocoenosis, their morphologic complexity and skeleton preservation. Apart from the above-mentioned conodonts, the Zasur'ya Group chert contains radiolarians and sponge spicules. Microfossils have not been found in the white, gray, or green chert. Siliceous sponges spicules are relatively rare in the Zasur'ya Group chert and do not form large accumulations; therefore, most of these chert is radiolarite, not spongolite radiolarite. Most of the faunal fossils are associated with the red chert; a smaller proportion, with the brown-red and lilac ones. The terrigenous rocks

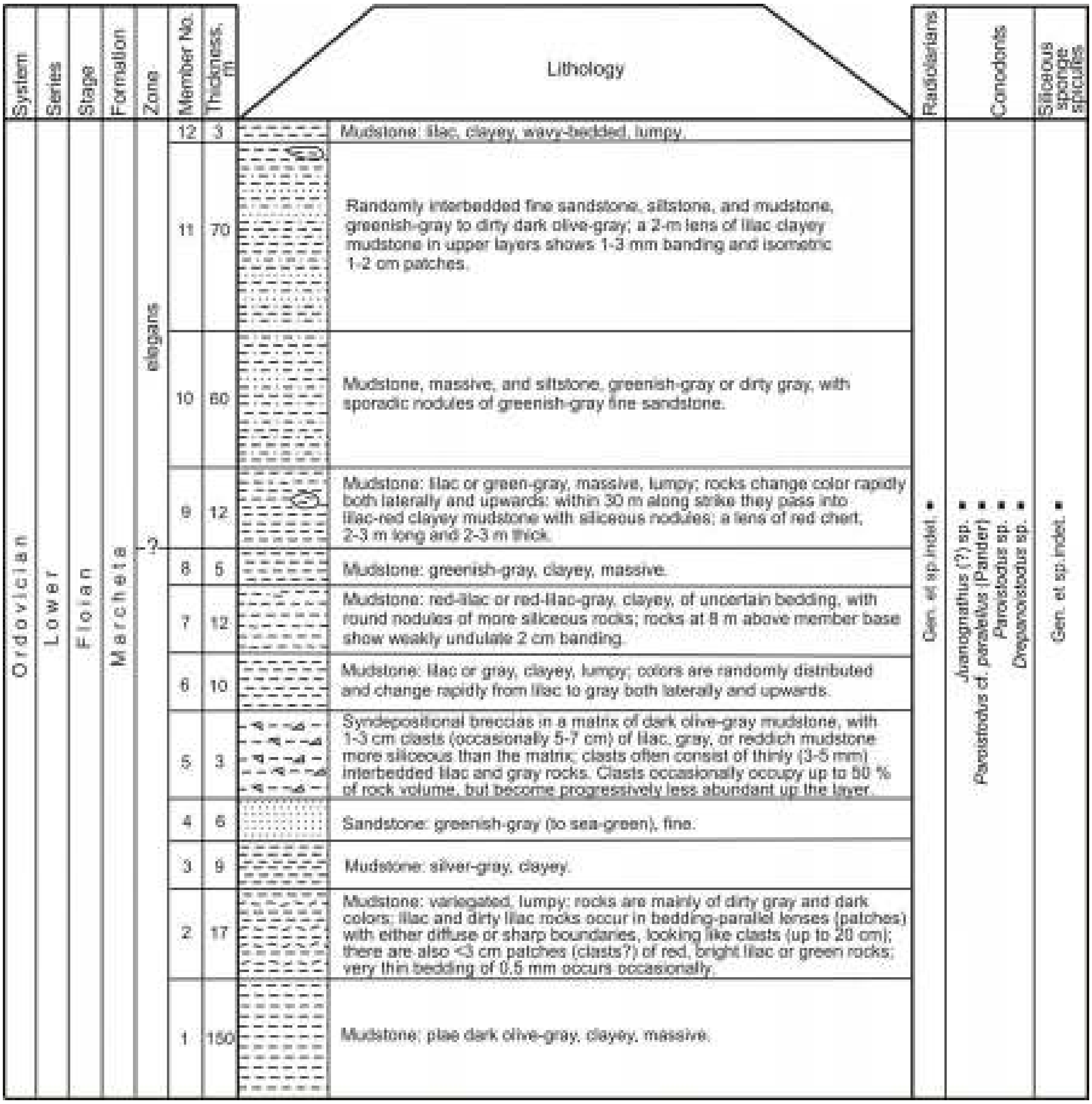


Fig. 83. Lithology and ranges of fossil taxa from the Marcheta-2 Section.

of the studied stratigraphic unit contain neither benthic nor pelagic fossils. The absence of benthos (except siliceous sponges) or widespread planktonic organisms such as graptolites and chitinozoans suggests that the paleobasin was fairly deep during the formation of the siliceous sediments of the Zasur'ya Group. The radiolarian taxonomic diversity in the Zasur'ya Group is low (several species within two genera in the open nomenclature); the morphology is simple; taphocoenosis density is low to medium (>10 to 10–100 specimens/cm2 of the rock thin section or chip); the skeleton preservation is >10 % to 10-25%. The conodont fragments in the Zasur'ya Group show medium preservation; their taxonomic diversity in various zonal time-stratigraphic units is estimated as medium (3–5 species within 2–3 genera); the taphocoenosis density, as high (up to 10 specimens/locality). Considering the data on present-day basins, the high taxonomic diversity of radiolarians in the Zasur'ya Group may suggest that their communities lived in the lower part of the cool-water zone (200–500 m) and in the cold-water zone (500–5000 m). In the Charysh succession, their taphocoenosis are of medium density; in the other successions, a low density. This suggests that the upper distribution limit of the radiolarians is 200–300 m in the Charysh succession and over 300–500 m in the other successions. The poor and very poor skeleton preservation of the studied radiolarian assemblage suggests that the dead radiolarians covered considerable distances (300–700 m and more) before reaching the paleobasin bottom. Although the calculations are arbitrary, it is estimated on the basis of bioindicators that the Zasur'ya Group formed at depths of 500-1000 m in the Charysh area and at depths of 700–1200 m in the other areas. This is shallower than the first estimated depth of the paleoceanic rises in the Altai segment of the Paleoasian Ocean (1500–2000 m).

Tekhten' Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Katian, Hirnantian, Rhuddanian, Aeronian.

Regional stratigraphic subdivisions: Tekhten', Listvyanka, Vtorye Utyosy and Syrovaty regional stages (horizons).

Local lithostratigraphic subdivisions: Tekhten', Vtorye Utyosy, Syrovaty formations.

Fauna: tabulate corals, rugose corals, trilobites, brachiopods, crinoids, graptolites.

The stratotype section of the Upper Ordovician Tekhten' Formation (Tekhten' Regional Stage) and the overlying Lower Silurian Vtorye Utyosy Formation is located on the right bank of the Tekhten' Brook, the right tributary of the Muta River, near Ust'-Muta Village (Fig. 84). The formation, in a much smaller stratigraphic volume, was formerly named the Dietken Formation according to Dietken, wrong respelling of an Altai name used in topographic maps. The documented section begins on the right side of a small ravine, 400 m from point 1181.0 m at azimuth 210°. The main section rises from the hill toe to point 1181.0 m and continues to the top at 1451.0 m. Members 1 and 2 and lower Member 3 crop out 200 m to the north of the section origin where the section begins with Member 3 (Figs 85, 86).

The section continues as far as the Muta/Anui river divide and then along the left side of the Surta Ravine (left bank of the Anui River near Bely Anui Village) as exposed alternating sandy-silty rocks with rare limestone layers containing rather representative Llandoverian corals and brachiopods.

Some members of the section are clearly traceable

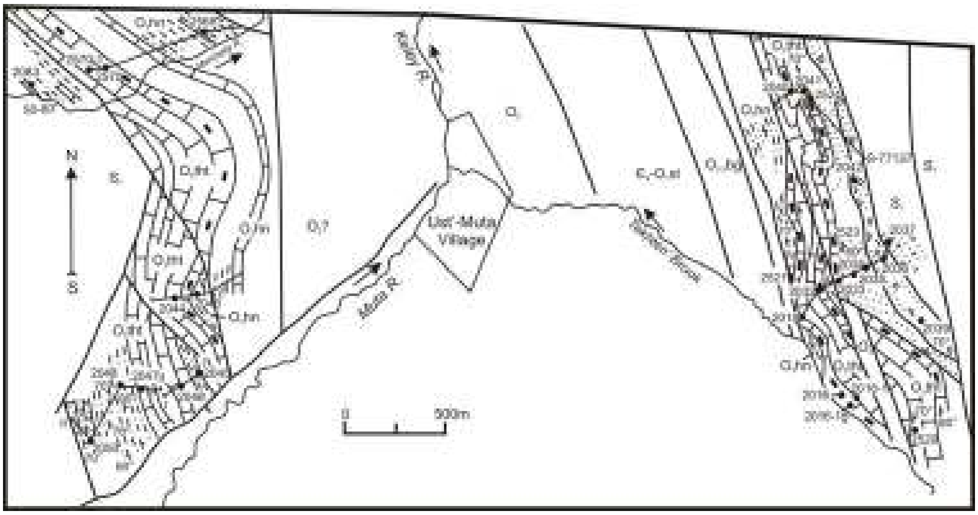


Fig. 84. Sketch map of the Ust'-Muta Village area.

Fig. 85. General view of the Tekhten' Section (middle part).

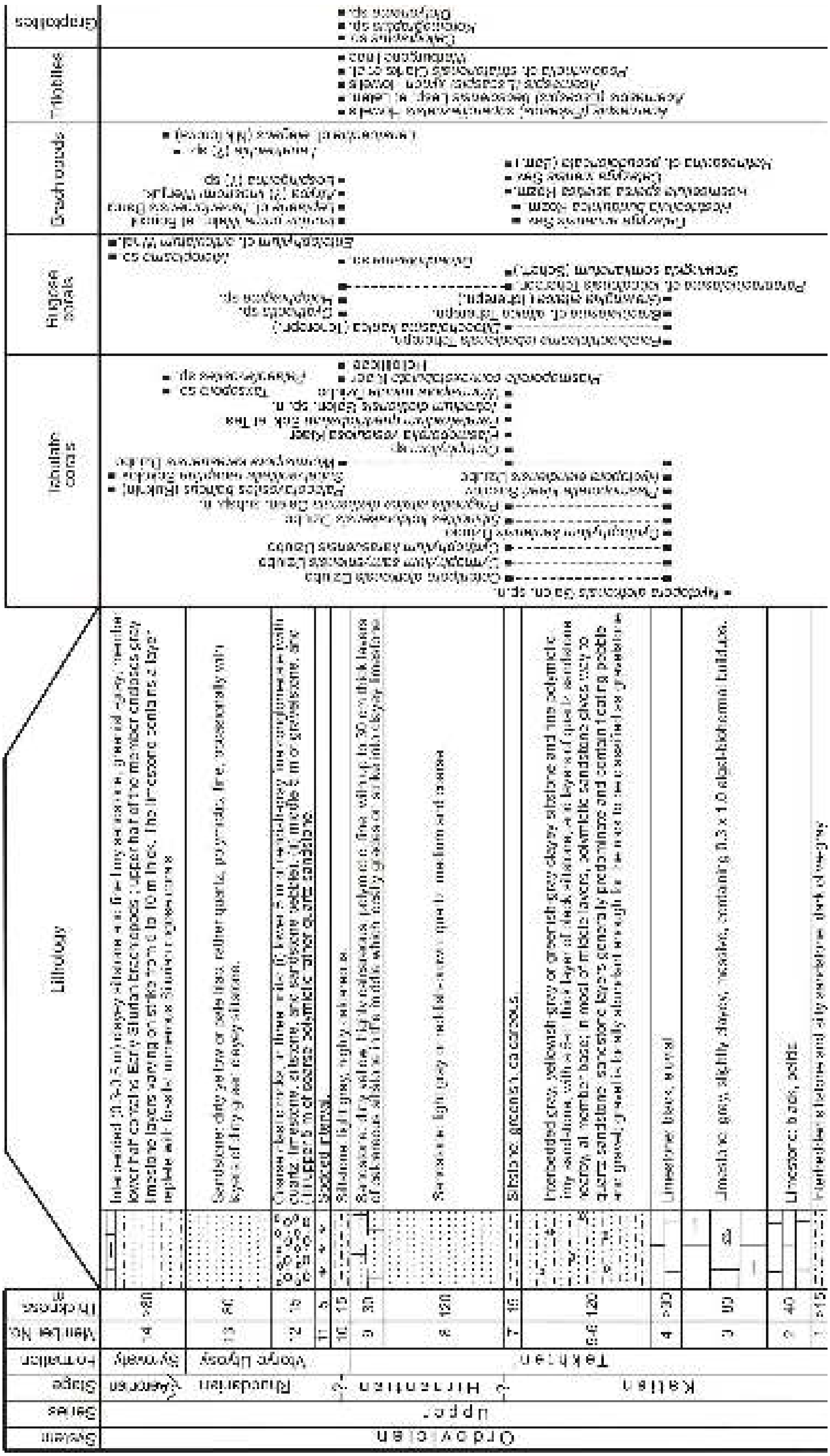


Fig. 86. Lithology and ranges of fossil taxa from the Tekhten' Section.

southeastwards and northwestwards providing additional faunal evidence. For instance, black flaggy limestone, an equivalent of Member 2 on the right side of the upper Shiroky Ravine (a small ravine across the right Tekhten' watershed), 470 m far from point 1251.0 m at azimuth 35° (loc. 2040, 2041) contains Late Ordovician rugose corals *Grewingkia altaica* (Tcherepn.), *Parabrachielasma lebediensis* Tcherepn., *Ditoecholasma kanica* (Tcherepn.), tabulate corals *Cyrtophyllum kaninensis* Dziubo, *C. samyshiensis* Dziubo. Equivalent of Member 10 on the southern slope of point 1402.0 m, (loc. 142) trilobites *Acernaspis* (*Eskaspis*) *superciliexcelsis* Howells, *Acer*. (*Escaspis*) *becsciensis* Lesp. et Leten., *Podowrinella* cf. *striatonensis* Clarks et al., Warburgenellinae, (loc. 2039) trilobites *Acernaspis* (*Eskaspis*) *superciliexcelsis* Howells, *Acer*. (*Escaspis*) *xynon* Howells, Warburgenellinae, brachiopods *Isorthis prima* Walm. et Boucot, *Leptaena* cf. *haverfordensis* Bancr., *Atrypa* (?) *lindstromi* Wenjuk., *Eospirigerina* (?) sp., rugose corals *Cyathactis* sp., *Holophragma* sp., as well as dendroid graptolites were collected.

Members 1 through 9 belong to the Tekhten' Formation, Members 10 through 13 belong to the Vtorye Utyosy Formation, and Member 14 belongs to the Syrovaty Formation. The thickness of the Tekhten' Formation in the section is about 470 m, the Vtorye Utyosy Formation is 115 m thick, and the incomplete thickness of the Syrovaty Formation is over 80 m.

Muta Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Katian, Hirnantian.
Regional stratigraphic subdivisions: Tekhten' Regional stage (Horizon).
Local lithostratigraphic subdivisions: Tekhten' Formation.
Zone: *supernus* graptolite Zone.
Fauna: stromatoporoids, tabulate corals, rugose corals, trilobites, crinoids, graptolites.

A sequence of lithologies different from the Tekhten'-type Section of the same Upper Ordovician age occurs 3 km to the west of the Tekhten' Brook. The section esposed at the Muta site orginates 2.5 km uphill from Ust'-Muta Village on the side of a ravine that crosses the Muta left watershed (Figs 87, 88).

Peculiarities in facies, faunal assemblages and sedimentary environments.

Carbonate members in the Marcheta Section are interpreted as uplifted reef structures. They belong to the central parts of reef uplifts.

Fig. 87. General view of the Muta Section (upper part).

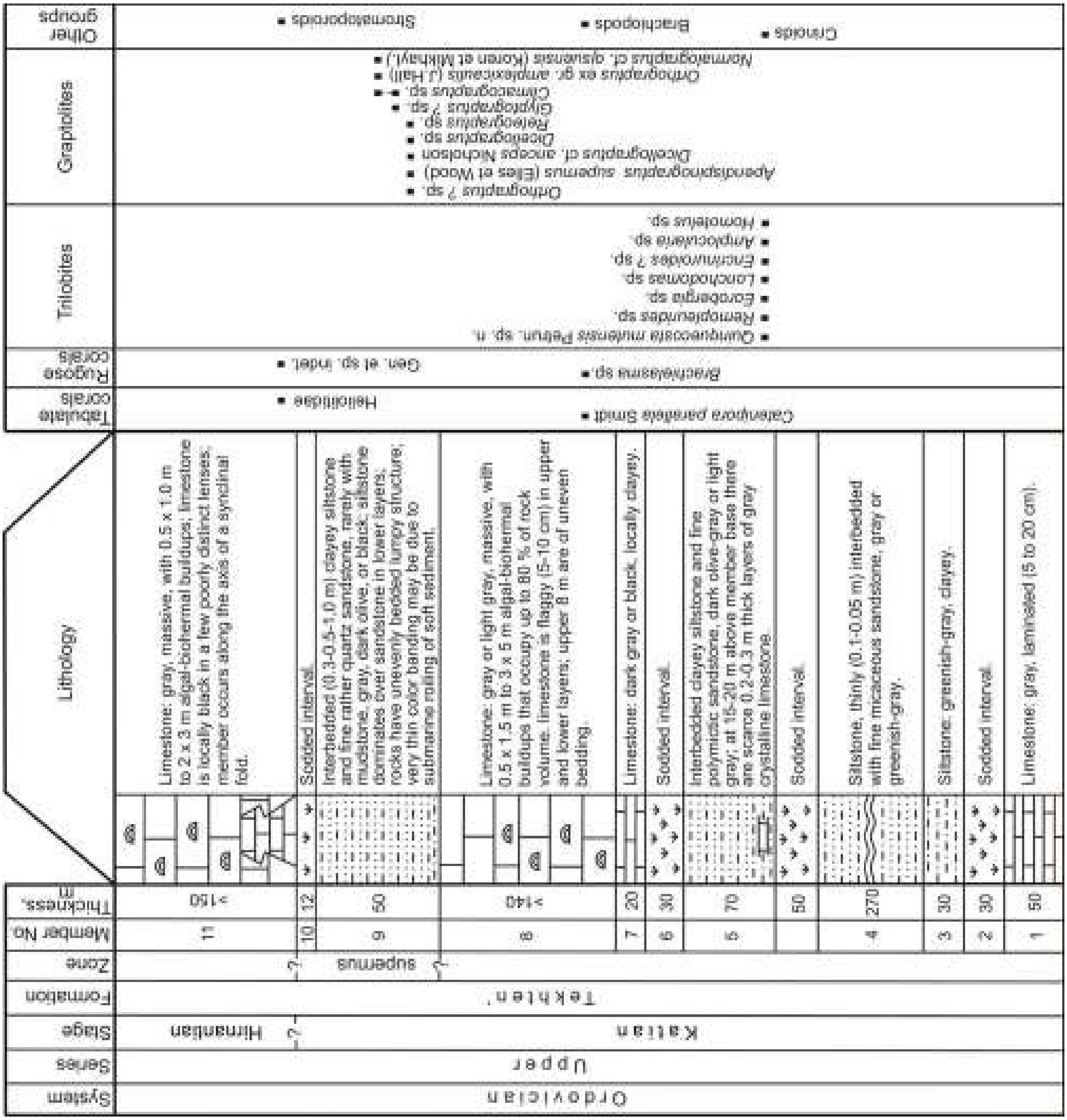


Fig. 88. Lithology and ranges of fossil taxa from the Muta Section.

4.5. WESTERN GORNY ALTAI
(Charysh–Inya facies zone)

4.5.1. AREA OF UST'-CHAGYRKA VILLAGE

Barany-1 Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: ? Tremadocian, Floian, Dapingian, Lower Darriwilian.

Regional stratigraphic subdivisions: Takoshkin, Tuloi (=Lebed'), Kuibyshevo and Kostinsky regional stages (horizons).

Local lithostratigraphic subdivisions: Suetka, Voskresenka and Bugryshikha formations.

Fauna: conodonts, trilobites, brachiopods, gastropods, chitinozoans.

The Voskresenka Formation in the vicinity of Ust'-Chagyrka Village crops out along the Barany, Voskresenka, and Tachalov brooks, the left tributaries of the Chagyrka River (Figs 89, 90). An outcrop on the right side of the Barany Brook, 300 m from 500.3 m mountain at azimuth 235° exposes lilac to red siltstone and sandstone of the Suetka Formation (Gorny Altai Group) overstepped, with a sharp angular unconformity, by (stratotype section of Voskresenka Formation, P-78032) (Figs 90–92).

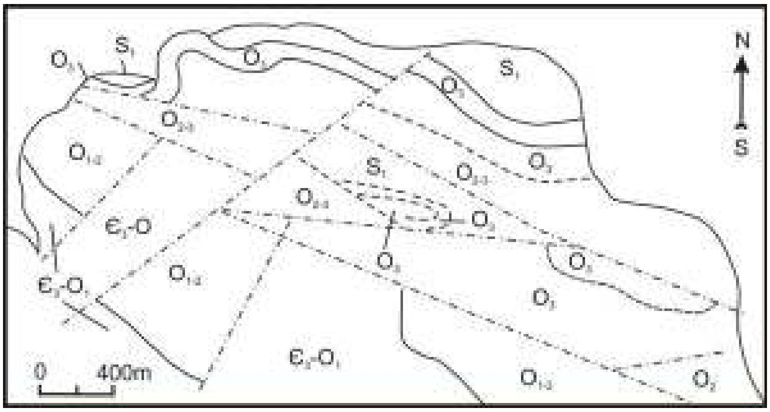


Fig. 89. Sketch map of the Ust'-Chagyrka area.

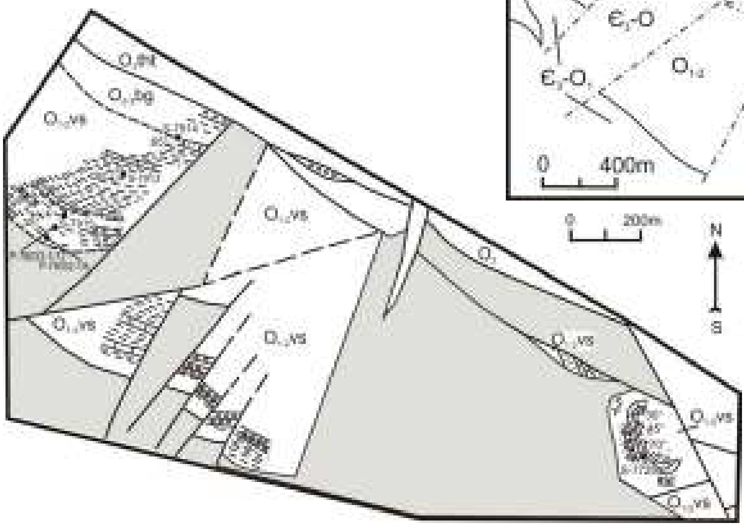


Fig. 90. Sketch map of the Barany area.

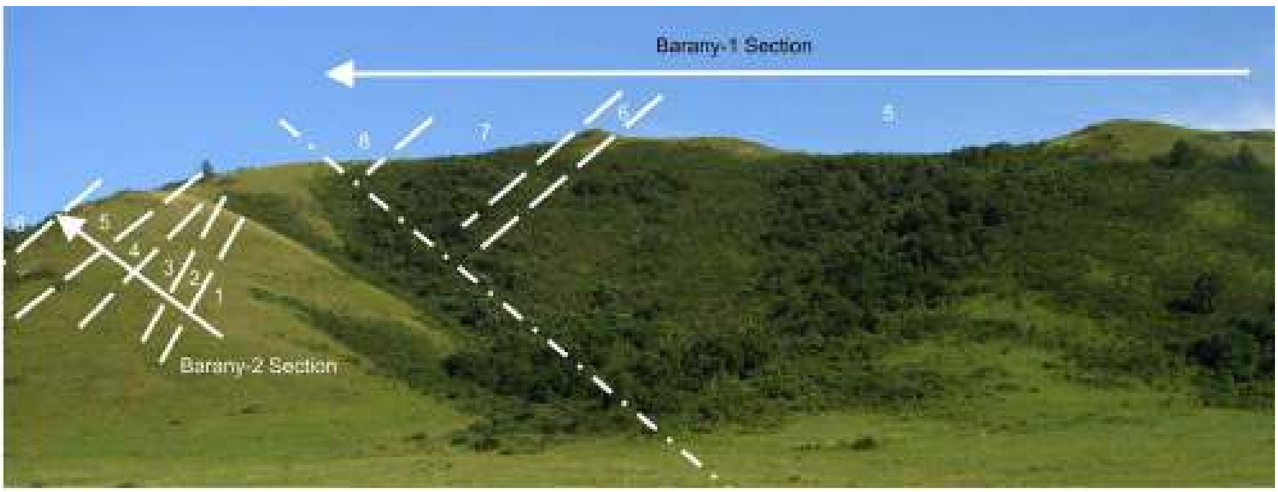


Fig. 91. General view of the exposure of the Barany-1 and Barany-2 sections.

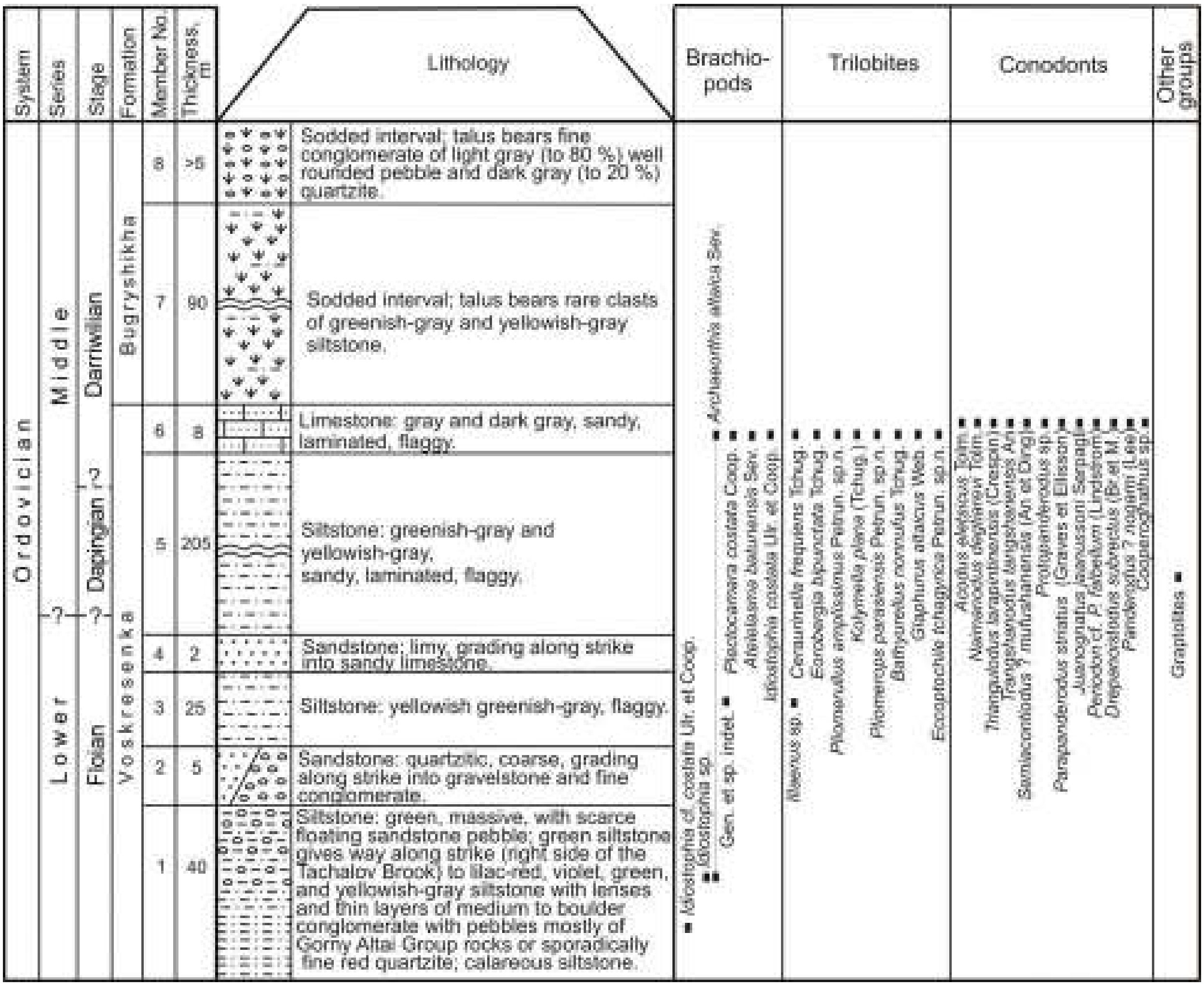


Fig. 92. Lithology and ranges of fossil taxa from the Barany-1 Section.

The member top is truncated by a fault. The total thickness of the section is about 380 m.

Members 1 through 6 belong to the Voskresenka Formation and members 7 and 8 belong to the overlying Bugryshikha Formation. The Voskresenka Formation in the Barany Section is 285 m thick and the Bugryshikha Formation is 95 m (incomplete thickness).

Gastropods and crinoids were collected from sandy limestone equivalent to member 4 on the right side of the Tachalov Brook (loc. S-7736) and gastropods were found on the right side of the Voskresenka Brook (loc. S-7726). Chitinozoans extracted by acid dissolution of rocks were identified as *Desmochitina minor* Eisenack and *Desmochitina* sp. at loc. S-7726 and *Desmochitina rhenana* Eisenack and *Conochitina* sp. at loc. S-7736. These species indicate an Ordovician age of the host sediment (most likely Tremadocian-Darriwilian, judging by their distribution in the Gorny Altai). Gastropods from S-7726 identified as *Temnodicus* sp. are similar, according to V.I. Byaly, to the *Temnodiscus* sp. known from the variegated member of the Lugovoi Formation in the Biryusa River catchment (Siberian craton) correlated with the Nyaya regional stage (Early Tremadocian). Thus, the fauna-bearing sandy limestone can be conventionally assigned a Tremadocian age.

Voskresenka-1 Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Darriwilian, Sandbian, Katian, Hirnantian.

Regional stratigraphic subdivisions: Bugryshikha, Khankhara and Tekhten' regional stages (horizons).

Local lithostratigraphic subdivisions: Bugryshikha, Khankhara and Tekhten' formations.

Zones: *coelatus*, *teretiusculus*, *serratulus*, *multidens* graptolite zones.

Fauna: tabulate corals, trilobites, brachiopods, ostracods, crinoids, bryozoans, gastropods, graptolites, polychaets, siliceous sponges, conodonts.

The most complete and stratigraphically continuous Ordovician section crops out of near Ust'-Chagyrka Village, in the Tachalov/Voskresenka brook divide (Fig. 93), 200 m from 530.3 m mountain at azimuth 15° and on northeastward down the divide. The rocks show monoclinal bedding to a dip of 75–80°. The section (S-78115) consists of (Fig. 94):

Members 1 through 10 in S-78115 belong to the Bugryshikha Formation, members 11 through 14 belong to the Khankhara Formation, and members 15 through 17 belong to the Tekhten' Formation. Thus, the Bugryshikha Formation in the Voskresenka-1 Section totals a thickness of about 140 m, the Khankhara Formation is more than 60 m thick, and the Tekhten' Formation is over 115 m.

The S-78115 section includes the graptolite zones: *coelatus* (lower half of member 6), *teretiusculus* (upper half of member 6 and lower half of member 7), *serratulus* (upper half of member 7), and *multidens* (member 8).

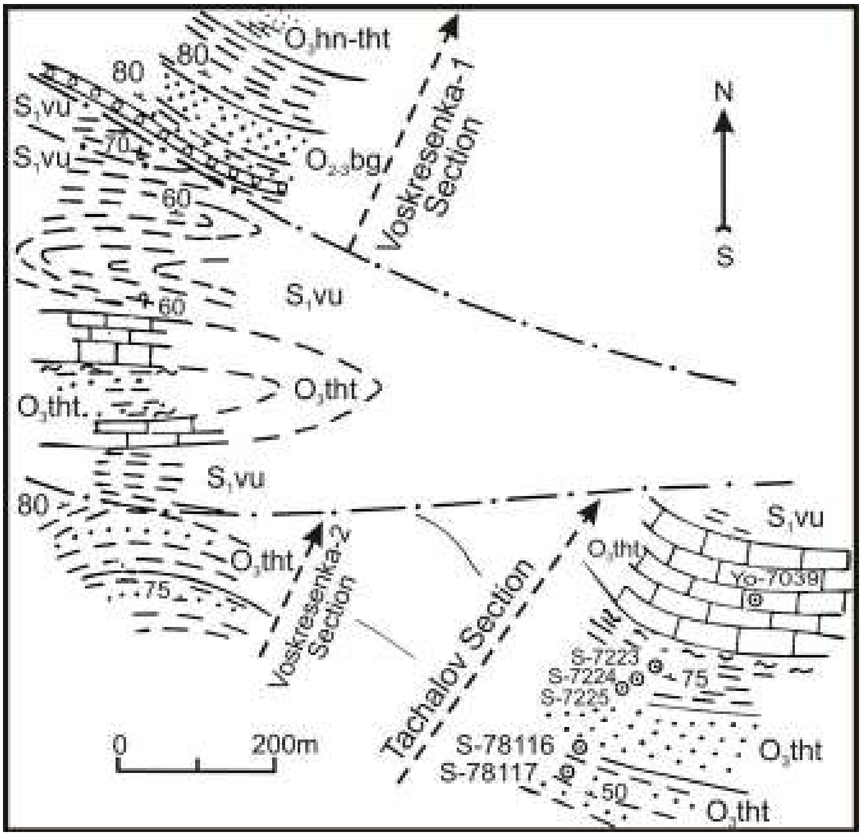


Fig. 93. Sketch map of the Voskresenka-Thachalov area.

Fig. 94. Lithology and ranges of fossil taxa from the Voskresenka-1 Section.

Tachalov Section

Chronostratigraphic subdivisions of the International Stratigraphic Scale: Katian, Hirnantian.

Regional stratigraphic subdivisions: Khankhara and Tekhten' regional stages (horizons).

Local lithostratigraphic subdivisions: Khankhara and Tekhten' formations.

Zones: *bicornis* and *supernus* (lower *supernus*, middle *ornatus* and upper *pacificus* subzones) graptolite zones and *A. ordovicicus* conodont Zone.

Fauna: tabulate corals, brachiopods, graptolites, polychaetes, conodonts, radiolarians, and chitinozoans.

The section occurs on the left side of the Tachalov Brook, left tributary of the Chagyrka River, near Ust'-Chagyrka Village where equivalents of the upper Voskresenka-1 Section (members 15 through 17) are exposed, namely (Figs 95–97):

Basal member 1a of the section belongs to the Khankhara Formation and members 1b through 3 belong to the Tekhten' Formation. The latter has an incomplete thickness of 130 m in the section.

The section includes *bicornis* and *supernus* (with lower *supernus*, middle *ornatus* and upper *pacificus* subzones) graptolite zones and *A. ordovicicus* conodont Zone.

Peculiarities in facies, faunal assemblages and sedimentary environments.

The chert in the Tachalov Section and especially Voskresenka and Barany-2 sections is often banded and variously colored (owing to the codeposition of silica with metal hydroxides); this may suggest absent agitation of near-bottom water, which is enriched in silica, including biogenic silica. Consequently, such chert formed in basin bottom depressions in relative isolation not only from wave action (depths over 50–100 m) but also from near-bottom currents. In the Tachalov Section, the siliceous rocks (radiolarites) are underlain by wellsorted fine-grained sandstone interbedded with siltstone unaffected by wave action. Lenses of fine detrital limestone reflect the transport of bioclastic matter by near-bottom currents and its accumulation in microdepressions at the basin bottom. The sandstone and siltstone contain only pelagic fauna (graptolites,

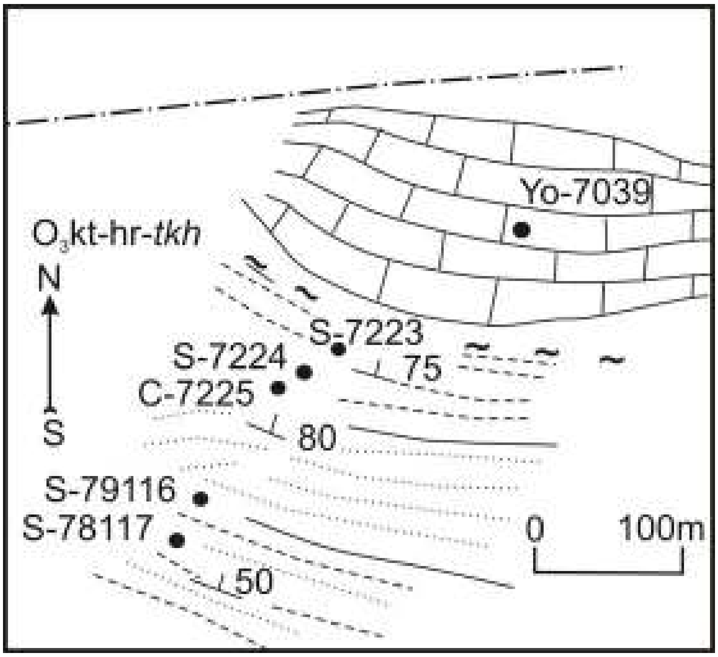


Fig. 95. Sketch map of the Tachalov area.

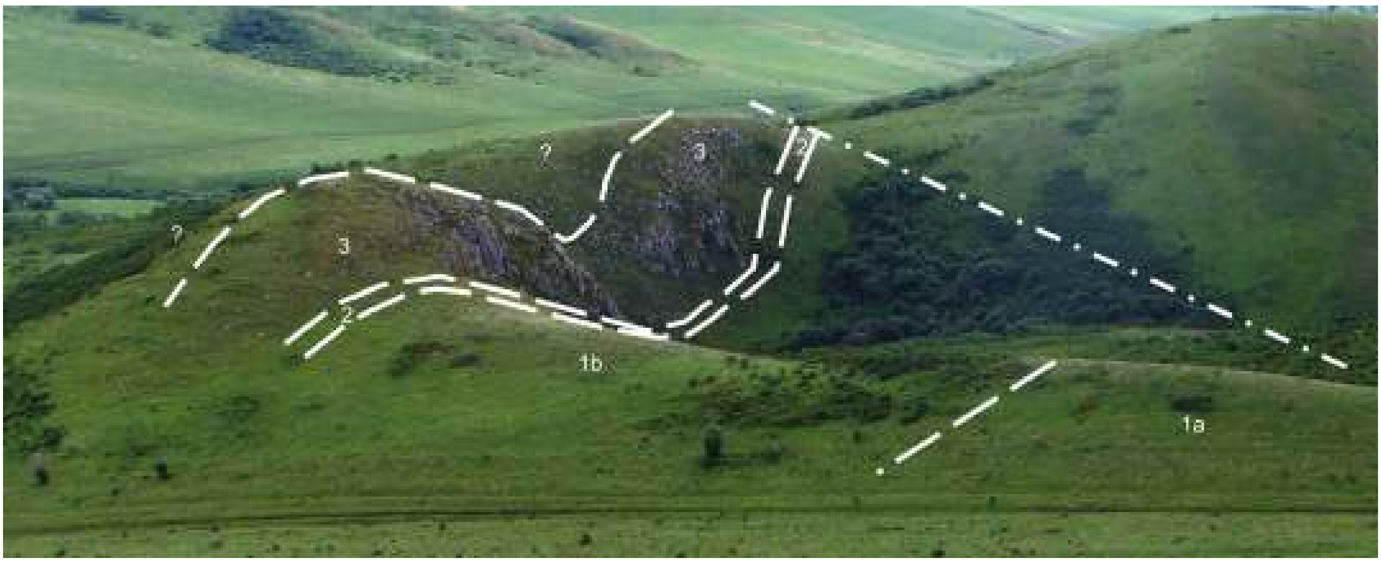


Fig. 96. General view of the Tachalov Section.

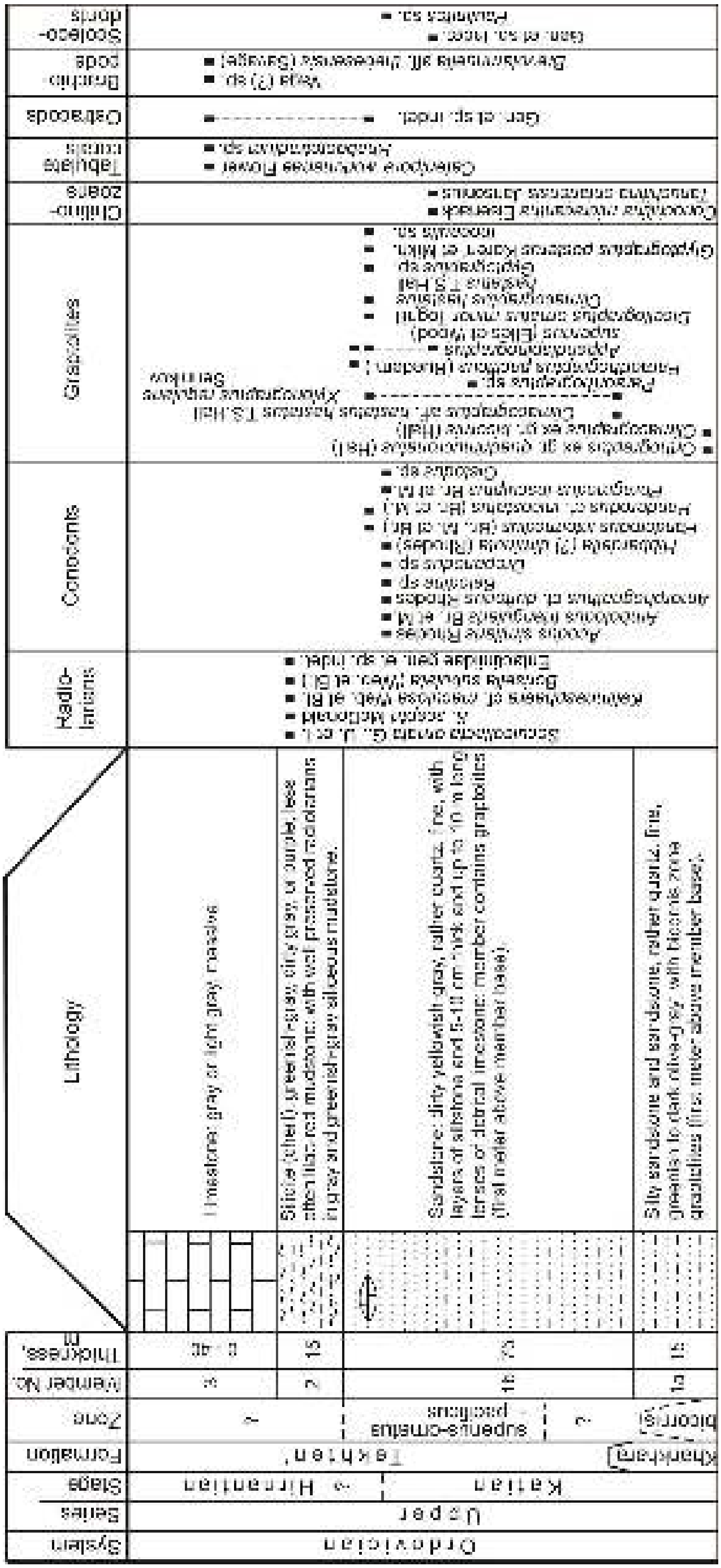


Fig. 97. Lithology and ranges of fossil taxa from the Tachalov Section.

chitinozoans), and the limestone lenses contain pelagic conodonts (*A. ordovicicus* Zone), benthic ostracods, and polychaetes. Conodont assemblages from the chert and limestone are very close in their taxonomic composition. The conodont fragments in the Tachalov Section show medium preservation, high taxonomic diversity, and medium taphocoenosis density (10–100 specimens/locality). In the studied successions of the upper Tekhten' Formation in the Tachalov–Voskresenka area, the siliceous rocks (radiolarites) are immediately overlain by unstratified gray limestone. Outcrops of such carbonates are rounded in plan and lenticular in section; the lenticular shape is traced for a distance of 10–20 m (Barany-2 Section) to 100–150 m (Voskresenka and Tachalov sections). The massive outcrops of these carbonate units suggest that such limestone may be of extremely shallow-water algal-bioherm origin. Such proximity between the chert and limestone poses a question: either the chert with radiolarians (radiolarites) are not of deep-water origin or the limestone are not of shallow-water origin (200 meters and more) and do not have an allochthonous-bioherm character. The uncertain genesis of the chert and carbonate rock units suggested that a 200-250 m rapid regression (a local uplift of the basin bottom or a general sea level fall) had occurred before the chert stopped accumulating and the carbonates started to form. According to the global data and numerous reconstructions of T–R cycles, the World Ocean level fell abruptly by 80-100 m in the late Ordovician owing to the global glaciation (Brenchley, 2004; Haq and Schutter, 2008; Nielsen, 2004). No local orogeny which could have led to a large-scale bottom uplift in the Late Ordovician Altai basin was observed (Sennikov, 2006a, b). All this casts doubt upon the shallow-water origin of the carbonate sediments in the upper Tekhten' Formation in the Tachalov – Voskresenka area. Such massive gray organic-clastic limestone in the upper units of the Tachalov and Voskresenka sections, where poorly sorted bioclasts are embedded in a micritic groundmass and 30–80 % of the volume is accounted for by crinoidal and stromatoporoid(?) fragments as well as ostracod and brachiopod fragments and shells, should be assigned to bioclastic wackestone-packstones (Varaksina and Sennikov, 2006). The above allochthonous wackestone-packstones with a large amount of micritic groundmass might have formed in large depressions at a considerable distance from shallow-water areas with autochthonous carbonate accumulation. In general, the carbonates crowning the Tachalov, Voskresenka, and Barany-2 sections might have formed in local closed depressions with respect to the relatively deepwater parts of the shelf (150–300 m). The chert in the Tachalov – Voskresenka and Barany-2 sections contain rich radiolarian assemblages (5–6 species within four genera), forming medium- and high-density taphocoenosis (10–100 and over 100 specimens/cm^2 of the rock thin section or chip). With the modern parameters for estimating the depths of warm-water radiolarian communities and their maximum population density, all this yields an average depth of 150–250 m. The good radiolarian preservation in the chert of the Tachalov Section (75–100 %) and the good radiolarian preservation in the Barany-2 Section (50–75 %) suggest that the radiolarian skeletons almost immediately reached the paleobasin bottom, without intense dissolution, and only in the sediment they dissolved very slightly. The above data suggest that the cherts (radiolarites) in the Tachalov and Barany-2 sections accumulated at depths of ~250–300 m.

Voskresenka-2 Section
Chronostratigraphic subdivisions of the International stratigraphic scale: Katian.
Regional stratigraphic subdivisions: Khankhara Regional stage (Horizon).
Local lithostratigraphic subdivisions: Khankhara Formation.
Zones: *caudatus* graptolite Zone.
Fauna: graptolites.

Dirty yellow-gray fine sandstone of member 1 in the Tachalov Section extend along strike to the right side of the Voskresenka Brook where the Voskresenka-2 Section, stratigraphically higher than S-78117 and lower than S-7225.

The Voskresenka-2 Section belongs to the Khankhara Formation and spans the caudatus graptolite Zone.

Barany-2 Section
Chronostratigraphic subdivisions of the International stratigraphic scale: Katian, Hirnantian.
Regional stratigraphic subdivisions: Tekhten', Listvyanka and Vtorye Utyosy regional stages (horizons).
Local lithostratigraphic subdivisions: Tekhten', Listvyanka and Vtorye Utyosy formations.
Zones: *persculptus* graptolite Zone.
Fauna: trilobites, graptolites, radiolarians, siliceous sponges.

The Barany-2 Section (S-832 = S-0525) is located near Ust'-Chagyrka Village, on the right side of the lower Barany Brook where it enters the Charysh River valley. The section includes (Figs 98, 99):

Members 1 through 5 belong to the Tekhten' Formation and Member 6 belongs to the Vtorye Utyosy Formation. The incomplete thickness of the Tekhten' Formation in the section is about 20 m.

Peculiarities in facies, faunal assemblages and sedimentary environments.
See above description for the Tachalov Section.

Fig. 98. Massive chert in the Tekhten' Formation, Barany-2 Section.

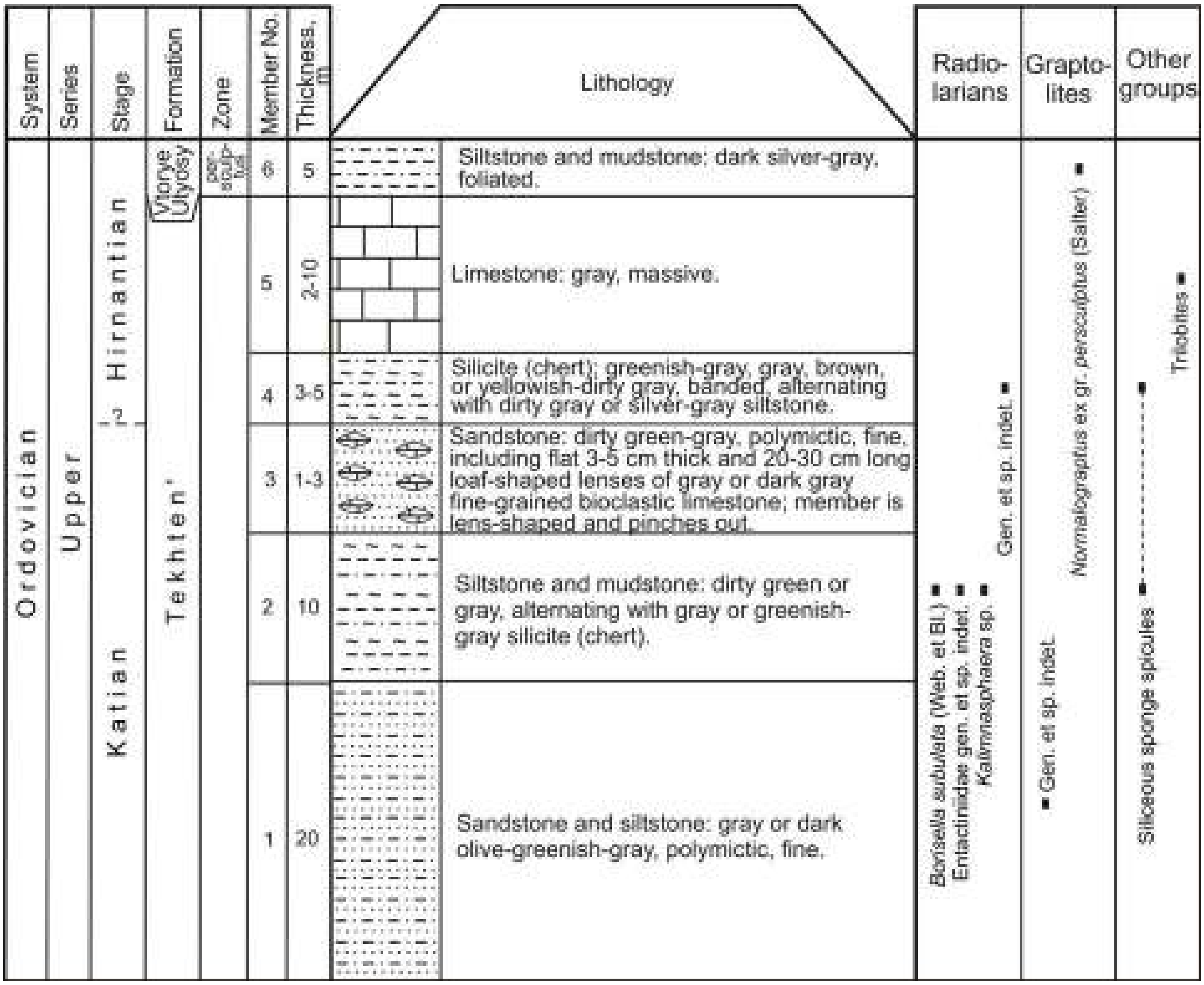


Fig. 99. Lithology and ranges of fossil taxa from the Barany-2 Section.

4.5.2. AREA OF MARALIKHA VILLAGE

Pichuzhikha Section
Chronostratigraphic subdivisions of the International stratigraphic scale: Floian, Dapingian, Dariwillian.
Regional stratigraphic subdivisions: Tuloi, Kuibyshevo, Kostinsky and Bugryshikha regional stages (horizons).
Local lithostratigraphic subdivisions: Voskresenka Formation.
Zones: *densus*, *gibberulus* graptolite zones.
Fauna: graptolites.

Stratigraphically higher strata of the Voskresenka Formation crop out on the right side of the Pichuzhikha Brook, 200 m far from the place where it enters the Charysh River terrace. The section from the water surface upwards includes (Figs 100–102):

The top of the section is truncated by a fault. Member 1 is conventionally equated to the *approximatus* Zone; Member 2 and lower 20 m, Member 3 correlate with the balticus Subzone of the *densus* Zone; upper 45 m, Member 3 make up the *densus* Subzone of the *densus* Zone; lower 30 m, Member 4 are conventionally correlated to the *angustifolius elongatus* Zone and its upper 40 m form the *gibberulus* Zone; Member 5 may correspond to the top of the Voskresenka Formation and may be assigned a middle Darriwilian age by analogy with the stratotype section of the Voskresenka Formation near Ust'-Chagyrka Village. Members 1 through 5 belong to the Voskresenka Formation and Member 6 may belong to the Bugryshikha Formation. The total thickness of the Voskresenka Formation in the Pichuzhikha Section is 180 m.

Peculiarities in facies, faunal assemblages and sedimentary environments.

Rocks composing the Pichuzhikha Section deposited on a large seamount, which is proved by the extremely thin Voskresenka Formation as compared to other sections of this formation. Given that the seamount was significantly removed from the provenance area of terrigenous material supplied from land, therefore only thin terrigenous sediments (dark-colored mudstone and siltstone) deposited on its top. The seamount was quite steep giving way to underwater landslide down the slope. The top of this seamount located at depths not exceeding the depth of storm waves action (below 50 m) was eroding due to landslide activity and affiliated water motion. Gravelite formed at the foot of the studied seamount in the form of thick beds with "curlers" and "twists" (Maralikha Section see below), created by underwater landslides, regularly descending from the slope of such seamount.

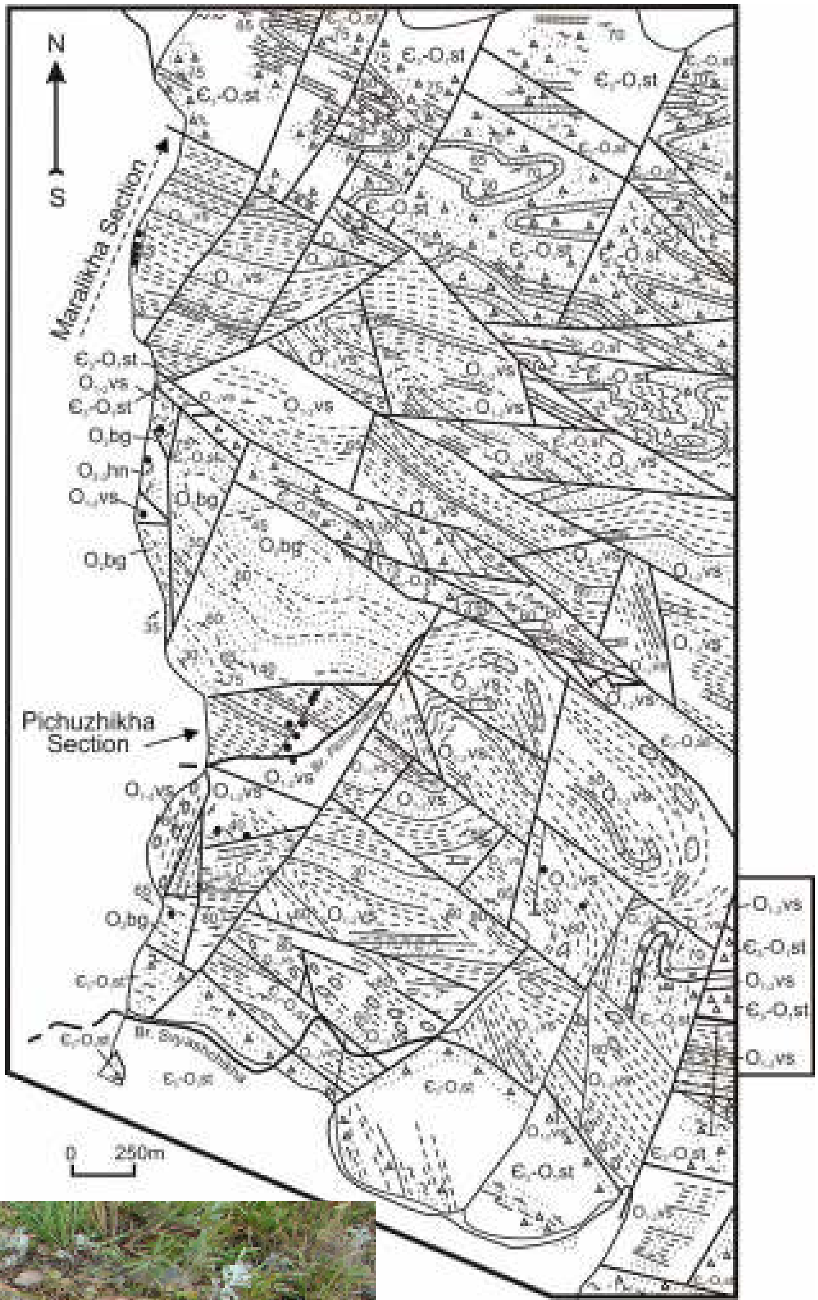


Fig. 100. Sketch map of the Maralikha area.

Fig. 101. Sitstone in the Voskresenka Formation, Pichuzhikha Section.

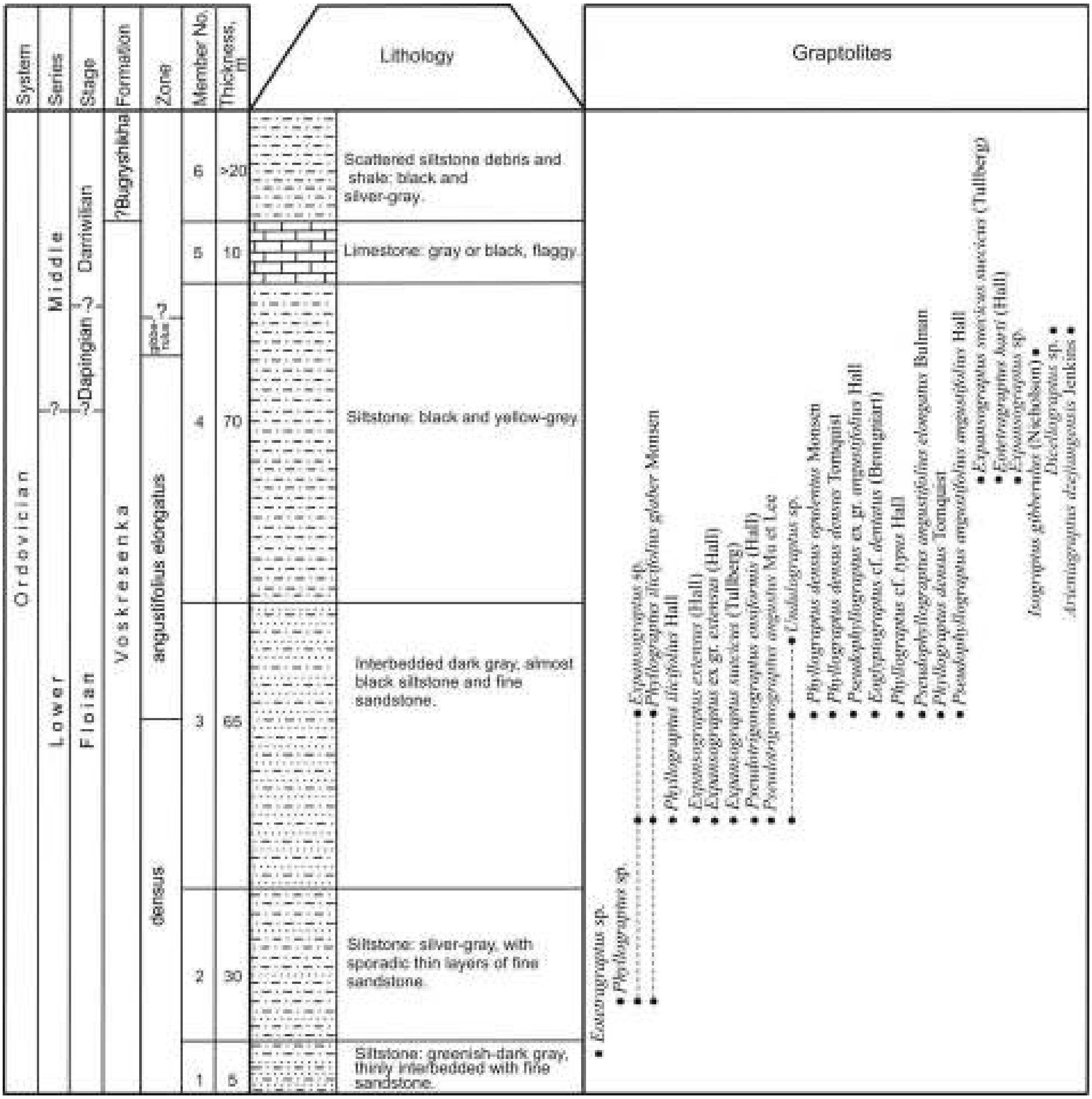


Fig. 102. Lithology and ranges of fossil taxa from the Pichuzhikha Section.

Maralikha Section

Chronostratigraphic subdivisions of the International stratigraphic scale: Dapingian, Darriwilian.
Regional stratigraphic subdivisions: Tuloi (=Lebed') and Kuybushevo regional stages (horizons).
Local lithostratigraphic subdivisions: Voskresenka Formation.
Zones: *caduceus imitatus*, *hirundo*, *Cardiograptus*, *sinodentatus*, *austrodentatus* graptolite zones.
Fauna: graptolites, nautiloids, crinoids, trilobites and brachiopods.

Section representing upper part of the Voskresenka Formation is cropped out on the right bank of the Charysh River Valley, near alt 352, 1 m. It is represented by specific rocks formed as a result of the under-water sliding. Stratigraphically upward are observed (section S-8212 – Maralikha) (Figs 100, 103–106):

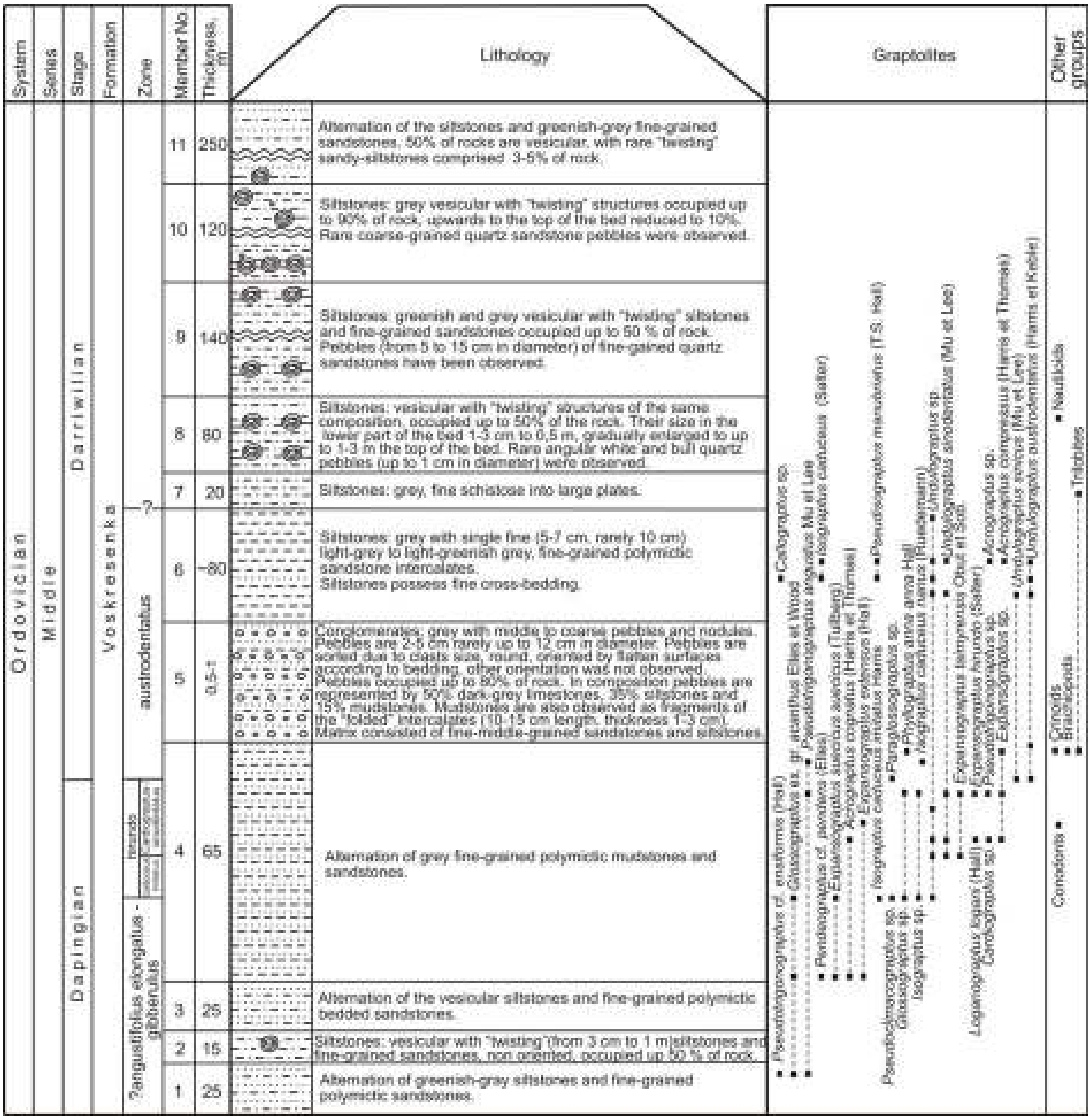
A tectonic dislocation binds the top of the section.

Members 1–3, as well as lower 20 m of the Member 4 of the Maralikha Section could be aligned with *angustifolius elongatus* and *gibberulus* zones according to the collected graptolites. Interval from the 20 to 29 m of the Member 4 coincides with *I. caduceus imitatus* Zone. Interval from the 30 m up to the top of the Member 4 and provisionally Member 5 of the section were aligned with *hirundo*, *Cardiograptus*, *sinodentatus* zones. Base of the Member 6 is aligned with lower Darriwilian boundary, overlain by *austrodentatus* Zone.

All members of the Maralikha section are assigned to Voskresenka Formation. Total thickness of the Voskresenka Formation within this section is more than 800 m.

Fig. 103. General view of the middle part of the Maralikha Section.

Fig. 104. Lithology and ranges of fossil taxa from the Maralikha Section.



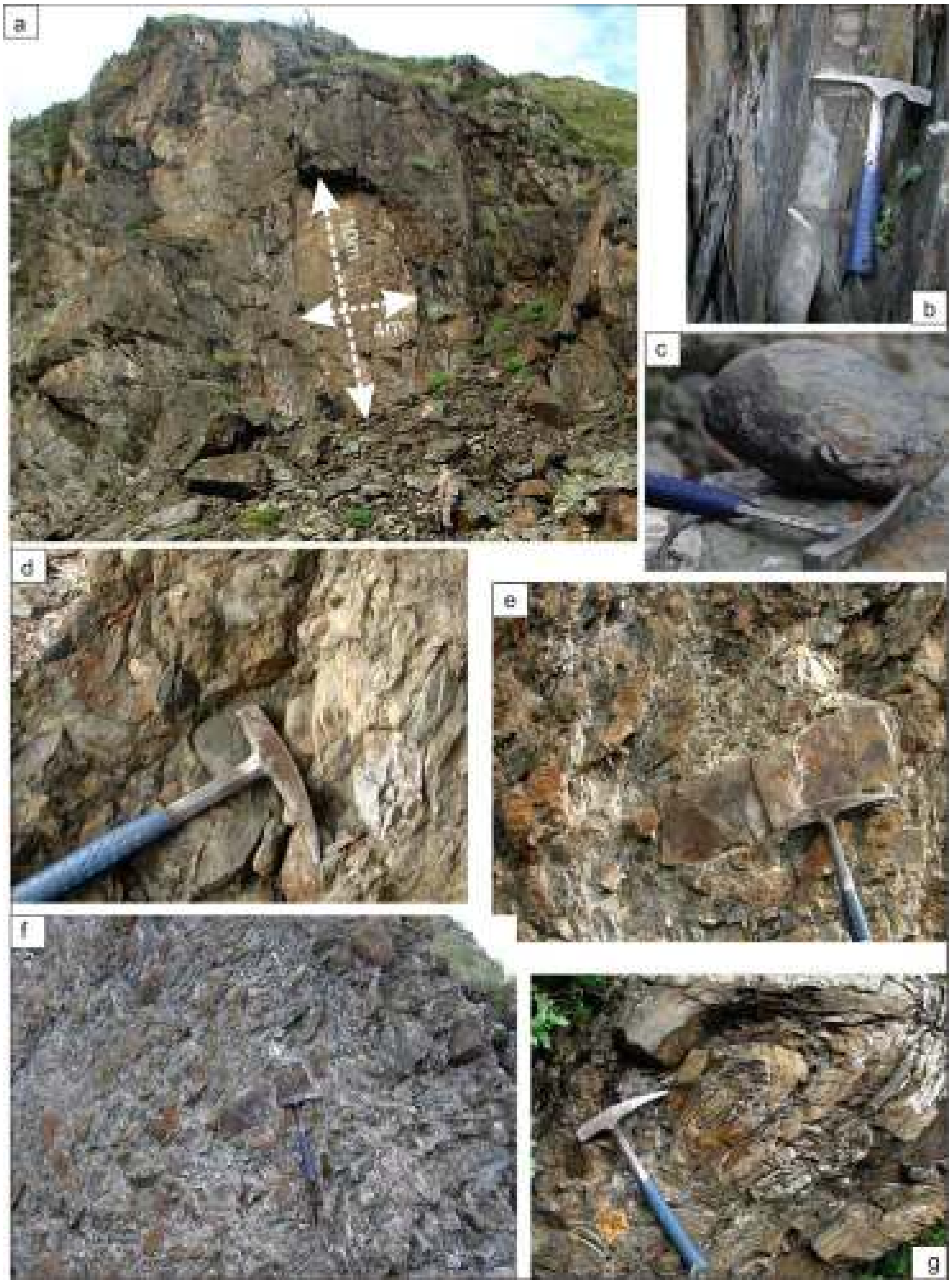


Fig. 105. Lithological peculiarities in the terrigenous rocks of the Maralikha Section (a-f) and in similar Silurian rocks (g).

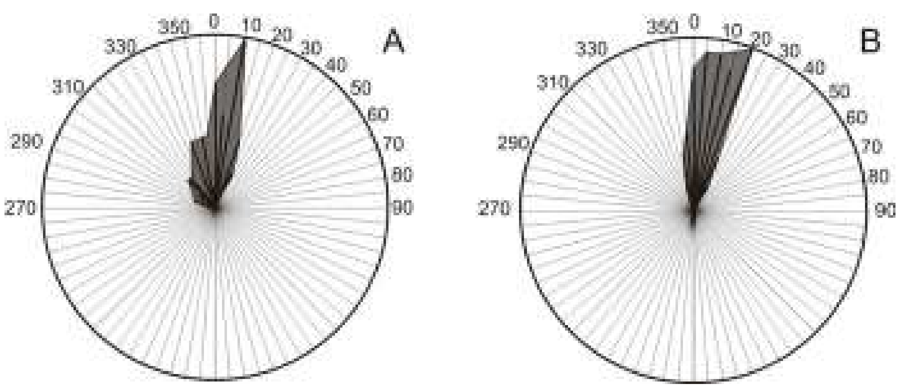


Fig. 106. Diagram (in modern coordinates) for directions of non-lithified movement during underwater sliding in the Maralikha Section (A – member 6, B – memder 8)

Peculiarities in facies, faunal assemblages and sedimentary environments.

The second half of the Maralikha Section is composed of rocks related to gravelite representing a specific lithological type – clastic sandy-aleuritic and argillite (siltstone) sediments. Such deposits formed on the slope of the seamount and slide down the slope as underwater landslides before the layers formed became lithified. As a result, some parts of the disrupted layer began to roll down the slope, acquiring gradually rounded shape with a more elongated axis across the direction of the movement. Some "curlers" and "twists" have internal structure in the form "spheres" insert into each other. The sediments formation at the slope foot followed by their compaction such "curlers" and "twists" became flattened. Such landslides may have been triggered by be giant storms, or evolved in places of abrupt terrain changes in the offshore parts inherent in transition areas (from shallow to deeper or redeepened shelf). One shouldn't rule out another most likely cause of underwater landslides as earthquakes. Regular appearance of units with "curlers" and "twists" in the Maralikha Section allows a most plausible assumption of a sharply defined crest on the shelf. Alternatively, this may be the presence of huge (up to 10 m in diameter) "curlers" and "twists" which can be attributed to olistostromes.

4.5.3. AREA OF BUGRYSHIKHA VILLAGE

Gora Altai Section

Chronostratigraphic subdivisions of the International stratigraphic scale: Darriwilian.

Regional stratigraphic subdivisions: Bugryshikha Regional stage (Horizon).

Local lithostratigraphic subdivisions: Bugryshikha Formation.

Fauna: trilobites, brachiopods.

Middle Ordovician strata in the lower part of the composite stratotype section of the Bugryshikha Formation crop out near Bugryshikha Village, on the left side of the Belaya River and along the right and left sides of the lower Bugryshikha River (left tributary of the Belaya River). The lowermost member of the Bugryshikha Formation is exposed on Gora Altai (Fig. 107) that descends in a bluff into the Belaya River on its left side below the Bugryshikha inflow. The documented section (S-071) includes the following members, listed downstream (Fig. 108):

From the first and third members of the Gora Altai Section directly in the coastal cliff of Belaya River (locs 216 and 216a) trilobites *Lonchodomas sagittatus* Levit., *Nileus tengriensis* Web., *Homotelus angustus* Petrun., brachiopods *Archaeorthis altaica* Severg., *Glyptorthis primus* Severg., *Atelelasma subdorsoconvexum* Severg., *Ujukites tarlykensis* Andreeva have been found. From the rocks analogue to the third bed of the described section, on the flatten top of the Gora Altai (loc. 803) brachiopods *Ujukites tarlykensis* Andreeva were collected, and at the western slope of the Gora Altai, near Bugryshikha Village (loc. 178) brachiopods *Glyptorthis primus* Severg. Possibly, at the same stratigraphic level on the right bank of the Bugryshikha River, near Bugryshikha Village (loc. F-10) brachiopods *Atelelasma subdorsoconvexum* Severg. in Rozman. have been recovered.

Fig. 107. General view of the exposure along left bank of Belaya River, the Gora Altai Section.

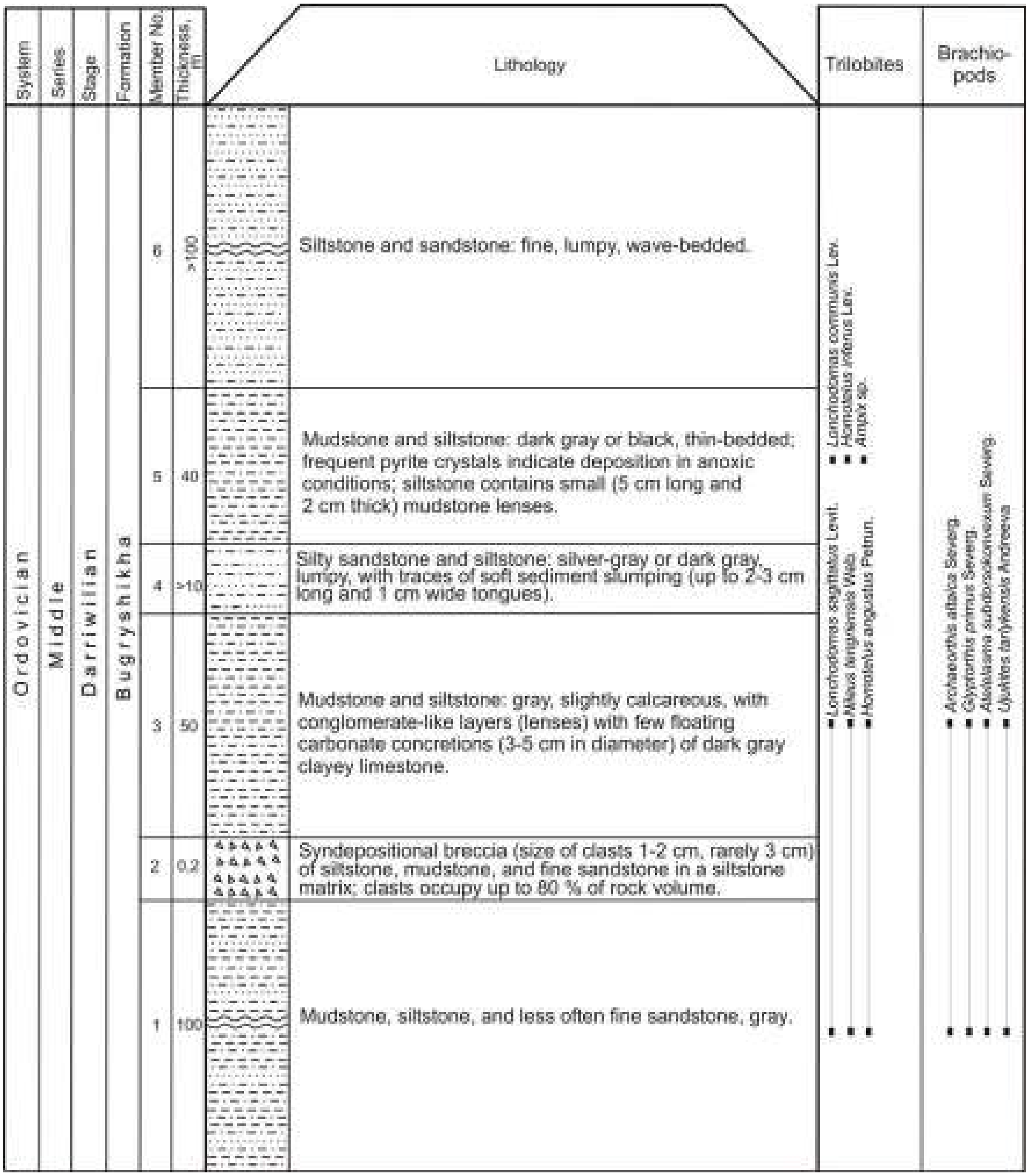


Fig. 108. Lithology and ranges of fossil taxa from the Gora Altai Section.

All members, of a total thickness of 300 m, belong to the lower Bugryshikha Formation.

The Gora Altai Section is extended upwards with the Bugryshikha Section, 1.5 km far to the northwest, on the other side of the same synclinal fold.

Bugryshikha Section

Chronostratigraphic subdivisions of the International stratigraphic scale: Darriwilian.

Regional stratigraphic subdivisions: Bugryshikha Regional stage (Horizon).

Local lithostratigraphic subdivisions: Bugryshikha Formation.

Zones: *teretiusculus* graptolite Zone.

Fauna: trilobites, brachiopods, graptolites.

The Bugryshikha Section occurs northwest of the Gora Altai Section, 150 m from 580.8 m mountain at azimuth 190°. The documented section includes the following members, listed downhill toward Bugryshikha Village (Fig. 109):

All members belong to the lower half of the Bugryshikha Formation. The section is 850 m thick, and the total thickness of the composite stratotype section of the Bugryshikha Formation is 1000 m (without the lowermost and

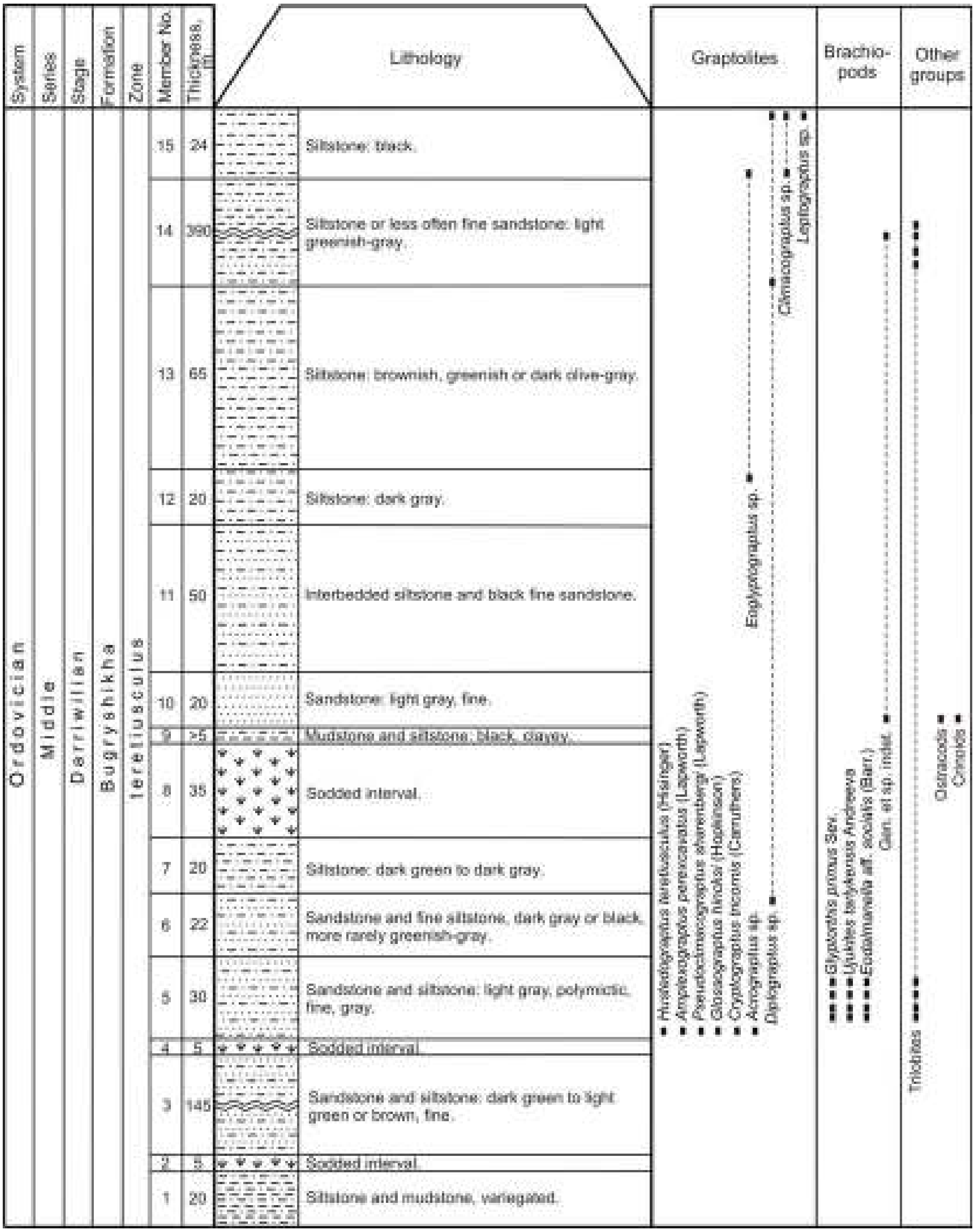


Fig. 109. Lithology and ranges of fossil taxa from the Bugryshikha Section.

uppermost strata). Findings of graptolites in member 5 correspond to the *teretiusculus* Zone. According to graptolite, trilobite, and brachiopod assemblages, the Bugryshikha Formation in its stratotype section correlates with the Upper Darriwilian – Lower Sandbian.

The Gora Altai Section is extended upwards by the Malaya Uskuchevka Section located 1 km far to the southeast on the other side of the same anticlinal fold, on the right side of the Belaya River.

Malaya Uskuchevka Section

Chronostratigraphic subdivisions of the International stratigraphic scale: Darriwilian, Sandbian.
Regional stratigraphic subdivisions: Bugryshikha and Khankhara regional stages (horizons).
Local lithostratigraphic subdivisions: Bugryshikha and Khankhara formations.
Zones: *multidens* graptolite Zone (*antiquus lineatus, wilsoni* subzones).
Fauna: trilobites, brachiopods, graptolites.

A large part of the Bugryshikha and Khankhara formations crops out on the right side of the Malaya Uskuchevka River (right tributary of the Belaya River), uphill from the roadway. The section (S-8351) may be considered a parastratotype of the Khankhara Formation as its members exactly match those in the parastratotype section along the Bolshaya Uskuchevka River (Fig. 110):

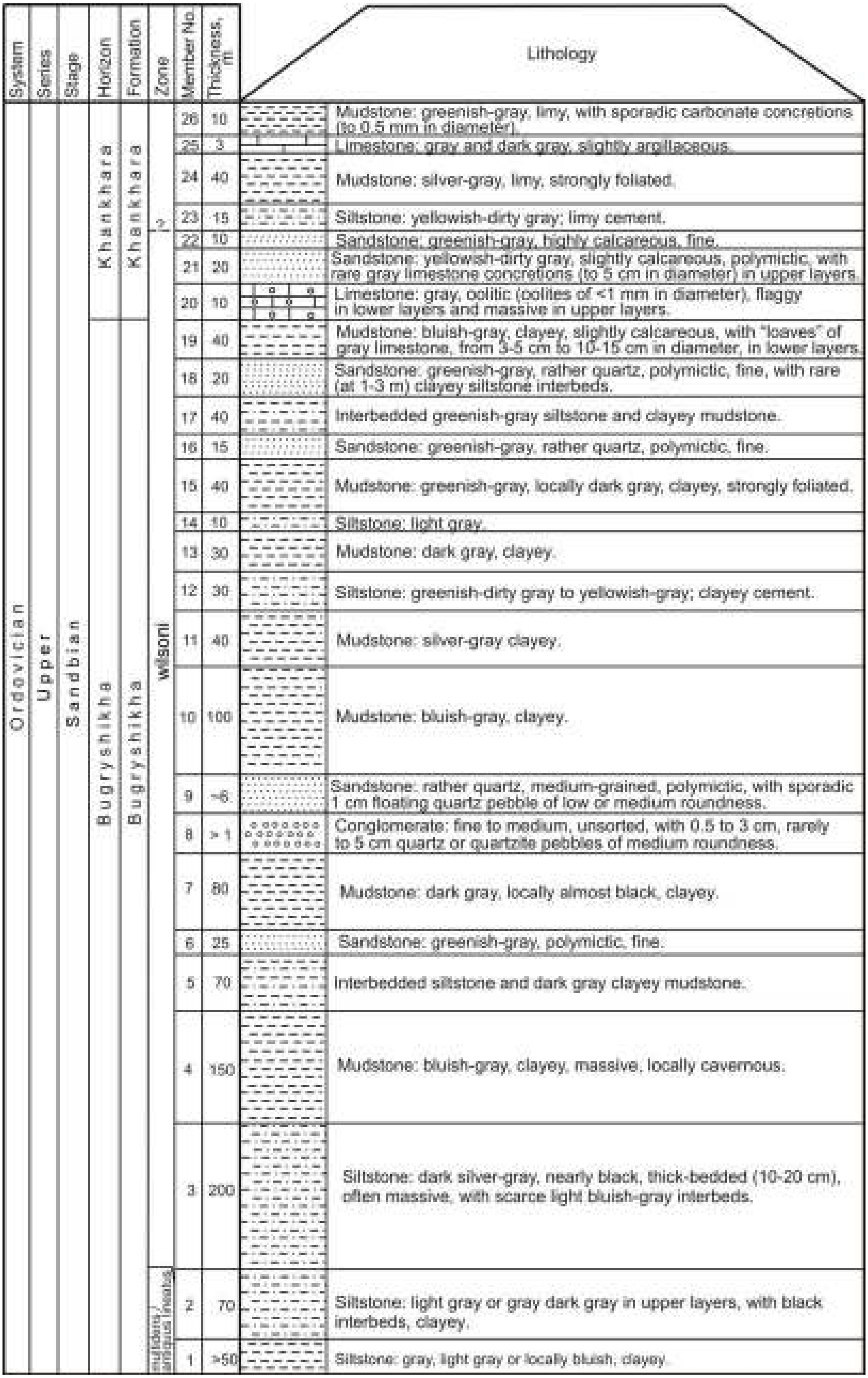


Fig. 110. Lithology and ranges of fossil taxa from the Malaya Uskuchevka Section.

Members 1 through 19 belong to the Bugryshikha Formation; members 20 through 26 belong to the Khankhara Formation. The incomplete thickness of the Bugryshikha Formation in the section is 980 m (without basal layers) and that of the Khankhara Formation exceeds 110 m. Trilobite and brachiopod assemblages indicate a Late Darriwilian and Early Sandbian age of the section. Graptolites correspond to the *multidens* Zone, including the *antiquus lineatus* Subzone at loc. S-7645 and the *wilsoni* Subzone at other localities.

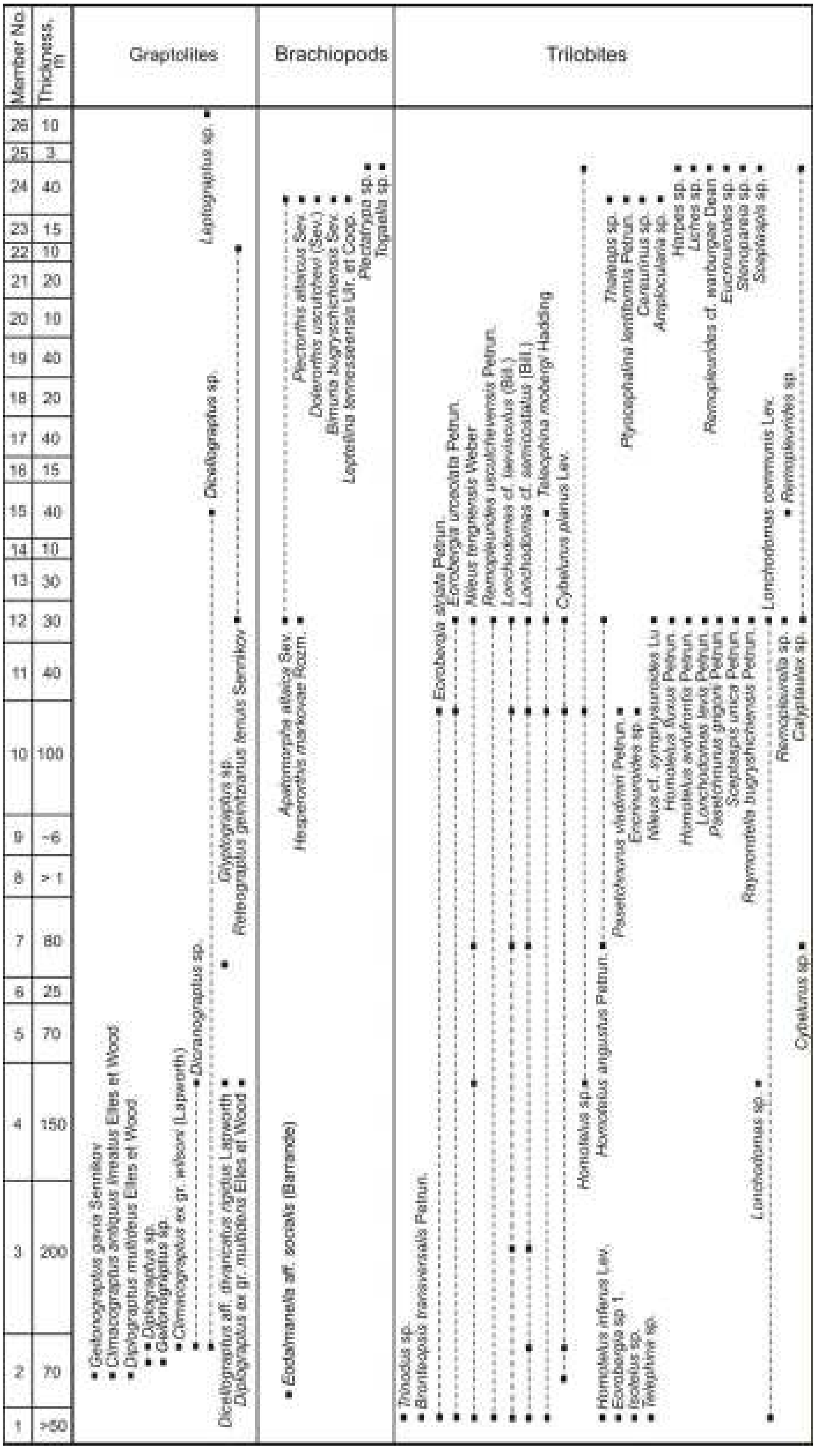


Fig. 110. The end.

4.5.4. AREA OF KRASNOSHCHEKOVO VILLAGE

Batun Section
Chronostratigraphic subdivisions of the International stratigraphic scale: Darriwilian.
Regional stratigraphic subdivisions: Kostinsky Regional stage (Horizon).
Local lithostratigraphic subdivisions: Voskresenka Formation.
Zones: *dentatus*, *balhaschensis* graptolite zones.
Fauna: graptolites, conodonts, trilobites, brachiopods.

Fig. 111. Lithology and ranges of fossil taxa from the Batun Section.

The Batun Section occurs on the west of Krasnoshekovo Village, near former Kostinsky mine. Despite the poorly exposed section, it produce relatively diverce fossil groups. The Batun Section is the stratotype for the Kostinsky Horizon (Fig. 111).

Suetka Section
Chronostratigraphic subdivisions of the International stratigraphic scale: Katian.
Regional stratigraphic subdivisions: Tekhten' Regional stage (Horizon).
Local lithostratigraphic subdivisions: Siliceous-terrigenous Body.
Zones: *supernus* graptolite Zone.
Fauna: graptolites, conodonts, radiolarians.

The Suetka Section (loc. S-8223=S-0515-0518) occurs on the right side of the Suetka River, 2 km upstream of Suetka Village, on the southern slope of 323.6 m mountain (Fig. 112). The section consists of (Figs 113, 114):

The whole section, with a total thickness of about 70 m, belongs to the siliceous-terrigenous sequence and spans the *supernus* graptolite Zone.

Peculiarities in facies, faunal assemblages and sedimentary environments.
The chert beds in the Suetka Section (Maralikha – Suetka area) are up to 3 m thick. The chert is massive, gray, dark gray, and black, usually banded owing to lighter strips (0.1-1.0 cm) against a darker background. Also, light brown-yellow chert is observed, which show banding owing to color tints (1-3 cm). Conodonts (*A. ordovicicus* Zone) in the Suetka succession were found in lenticular beds of olistostrome limestone in the lower part of the succession, where graptolites (s*upernus – ojsuensis* zones) were also found in siliceous mudstone. The conodont assemblage from the carbonate lenses is dominated by *Periodon grandis* (Ethington),

who are usually numerous only in the relatively deep-water sediments of the slope foot and paleobasin bottom. A similar conodont assemblage the same age was found in the Tachalov Section, which contains almost the same species except *Periodon grandis* (Ethington), replaced by the genus *Amorphognathus* (Moskalenko, 1977). This is a more shallow-water conodont assemblage as compared with that in the succession, whose fragments are well-preserved, show medium taxonomic diversity, and form high-density taphocoenosis (30–40 elements/kg rock), which is typical of warm-water assemblages developing above the continental slope. The gray and black chert in the lower and upper parts of the Suetka succession yielded radiolarians. The radiolarian taxonomic diversity is high (over five species within five genera); their morphology is moderately complex; they form medium-density taphocoenosis (10–100 specimens/cm^2 of the rock thin section or chip); their preservation is 75–100 % in the lower part of the succession and 50–75 % in its upper part. Many of the chert interbeds in the Suetka Section can be called radiolarites. The high taxonomic diversity of the radiolarian assemblages with shells of complex morphology my indicate dwelling depths of 75–500 m. The high-density taphocoenosis propose dwelling depths of 150–250 m. The excellent preservation of the radiolarian skeletons in the lower part of the succession (like in

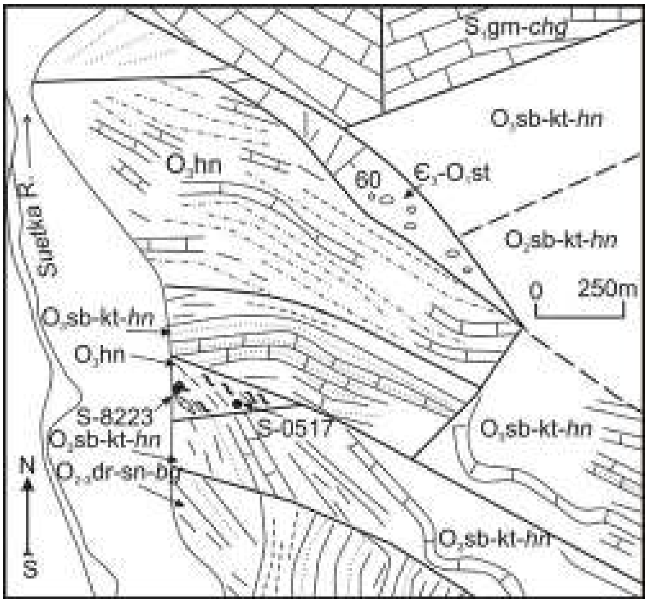


Fig. 112. Sketch map of the Suetka area.

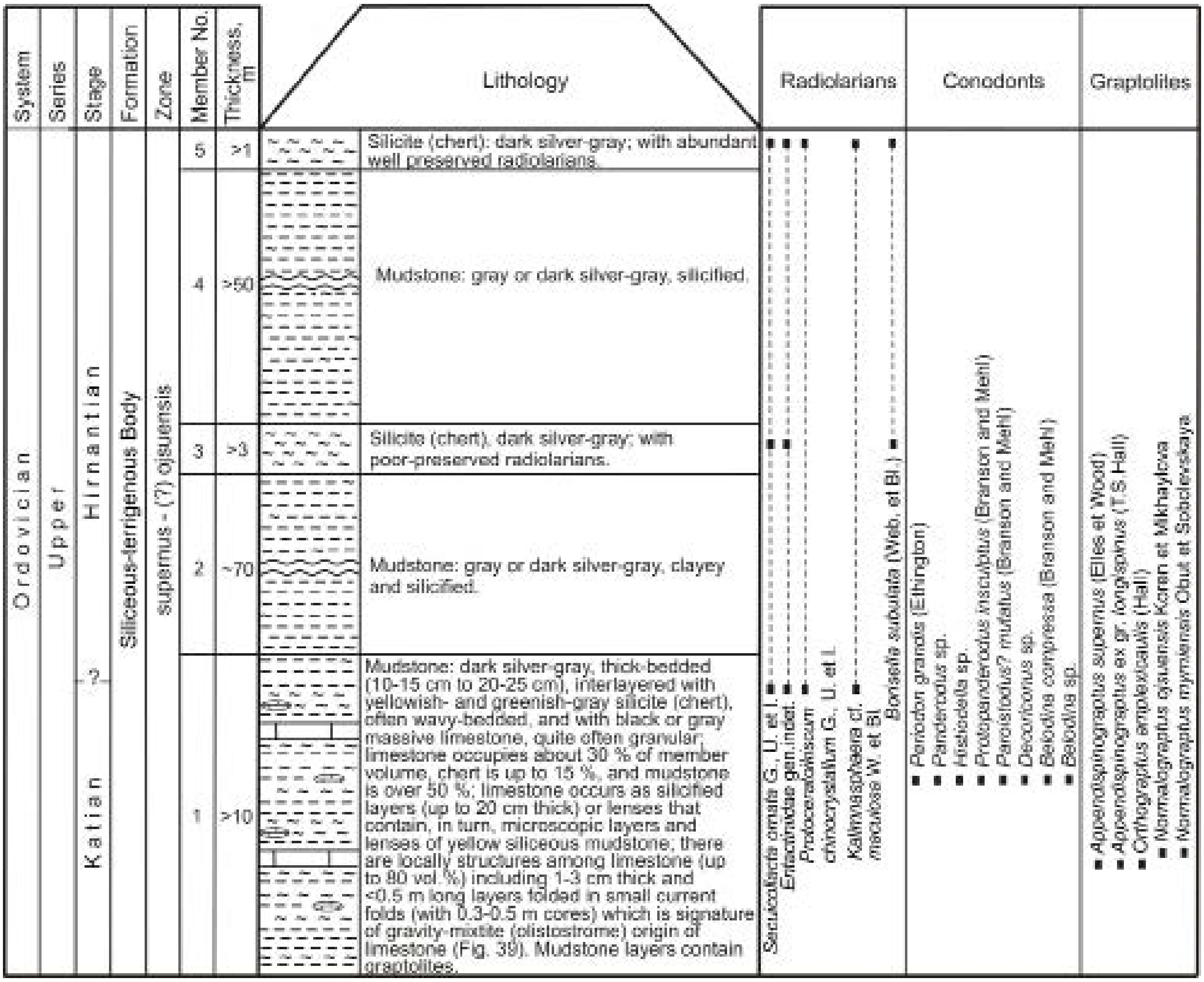


Fig. 113. Lithology and ranges of fossil taxa from the Suetka Section.

Fig. 114. Lithological peculiarities of the the chert and limestone of the Suetka Section.
a – c, e – chert; d – massive sitstone; f – lens of limestine.

the Tachalov one) proved that they did not dissolve and the lower distribution limit of the radiolarian communities was located near the basin bottom. The well-preserved radiolarian skeletons in the upper part of Suetka Section may suggest that the shells dissolved for a short time before reaching the paleobasin bottom, 100–150 m below their dwelling place. According to the bioindicator analysis, the chert from the lower part of Suetka Section might has formed at depths of 150–250 m, but the conodonts from the Suetka and Tachalov sections suggest depths of 300–350 m, which is more probable. Therefore, the paleobasin depths for the upper Suetka successsion might have been 350–500 m. Note that graptolites were found only in the lower part of the succession. The absence of graptolites in the Altai successions with deep-water oceanic rocks indirectly confirms the relatively deep-water origin of the upper Suetka Section.

4.5.5. AREA OF CHINETA VILLAGE

Chineta Section

***Chronostratigraphic subdivisions of the International stratigraphic scal**e*: Sandbian, Katian.

Regional stratigraphic subdivisions: Bugryshikha, Khankhara, Tekhten' and Listvyanka regional stages (horizons).

Local lithostratigraphic subdivisions: Bugryshikha, Khankhara, Tekhten' and Vtorye Utyosy formations.

Zones: *teretiusculus*, *wilsoni* and *clingani* graptolite zones.

Fauna: trilobites, brachiopods, graptolites, conodonts.

A section that spans the Middle-Upper Ordovician Bugryshikha, Khankhara, and Tekhten' formations and the Lower Silurian Vtorye Utyosy Formation crops out at the northeastern end of Chineta Village, on the right side of the Inya River (Fig. 115). The documented section includes the following members, listed down the southern slope of 609.3 m mountain (Fig. 116):

On the southern slope of 609.3 m mountain, the section is extended with a repetition of Member 4 (see above), at least 100 m thick, composed of interbedded siltstone and fine sandstone, quite often slightly calcareous; in upper part there is an interbed of light gray fine to medium limy sandstone grading into sandy limestone; limestone contains trilobites and brachiopods (loc. S-812, 90 m far from point 609.3 m at azimuth 145°).

Equivalents of Member 2 on the other side of the fold north of point 609.3 m contain graptolites *Diplograptus* sp., *Dicellograptus* sp. (loc. 2302/1).

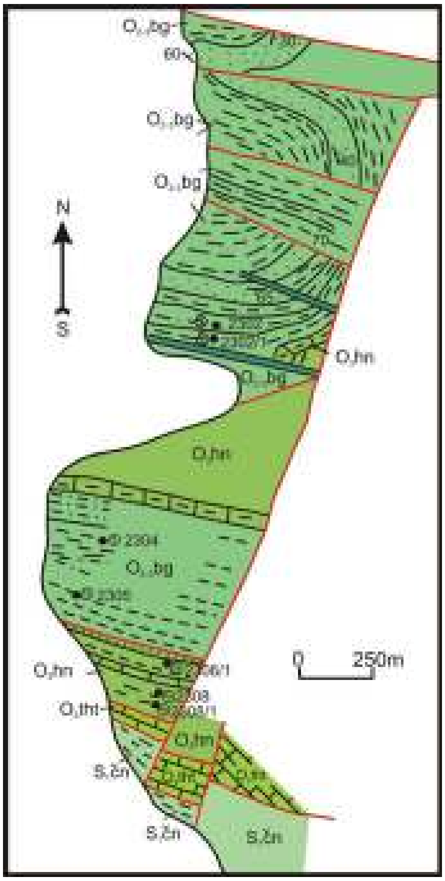


Fig. 115. Sketch map of the Chineta area.

Members 1 and 2 belong to the Bugryshikha Formation, members 3 through 4 belong to the Khankhara Formation, Member 5 marks the base of the Tekhten' Formation, and Member 6 correlates with the Vtorye Utyosy Formation.

Loc. S-795 in Member 2 may correspond to the *teretiusculus* graptolite Zone and loc. 2308 and 2308/1 in Member 4 apparently belongs to the *wilsoni* and *clingani* zones.

The incomplete thickness of the Bugryshikha Formation in the section is at least 220 m, the Khankhara Formation is more than 120 m thick, the incomplete thickness of the Tekhten' Formation is at least 40 m, and that of the Vtorye Utyosy Formation exceeds 30 m.

Burovlyanka Section

Chronostratigraphic subdivisions of the International stratigraphic scale: Katian, Hirnantian, Rhuddanian, Aeronian stages.

Regional stratigraphic subdivisions: Tekhten', Listvyanka and Vtorrye Utyosy regional stages (horizons).

Local lithostratigraphic subdivisions: Tekhten' and Vtorye Utyosy formations.

Zones: *supernus-ornatus-ojsuensis*, *persculptus*, *acuminatus*, *sibiricus*, *cyphus* graptolite zones.

Fauna: trilobites, brachiopods, graptolites, conodonts, crinoids, algae.

Upper Ordovician and Lower Silurian strata crop out on the left bank of the Inya River opposite Chineta Village, on the divide of the Burovlyanka and Listvyanka brooks (Inya left tributaries) and along the left side of the Listvyanka Brook (Fig. 117). The fragment of section S-882 exposed on the southern slope of 591 m mountain, right upward from the Burovlyanka floodplain includes (Figs 118, 119).

Section S-833 runs parallel to S-822 on the southwestern slope of 635.4 m mountain, from the Burovlyanka Brook floodplain toward the Burovlyanka/Listvyanka divide and consists of:

On the left bank of the Listvyanka Brook, in 700 m upstream from its mouth from the equivalent of the upper part of Member 4 from S-833 section represented by siltstone (loc. S-824-2/10). Middle Llandoverian *triangulatus*, *gregarius* zones graptolites were identified. Among them: *Demirastrites triangulatus* (Harkness), *Hedrograptus rectangularis* (McCoy). *Hedrograptus* sp., *Rastrites longispinus* Pemer and *Monograptus* sp.

Siltstone in equivalents of Member 6 of S-833 on the left bank of the Listvyanka Brook, 500 m upstream of its mouth, contains Upper Llandoverian graptolites of the *halli* Zone (loc. S-824-1/1), 120 m stratigraphically

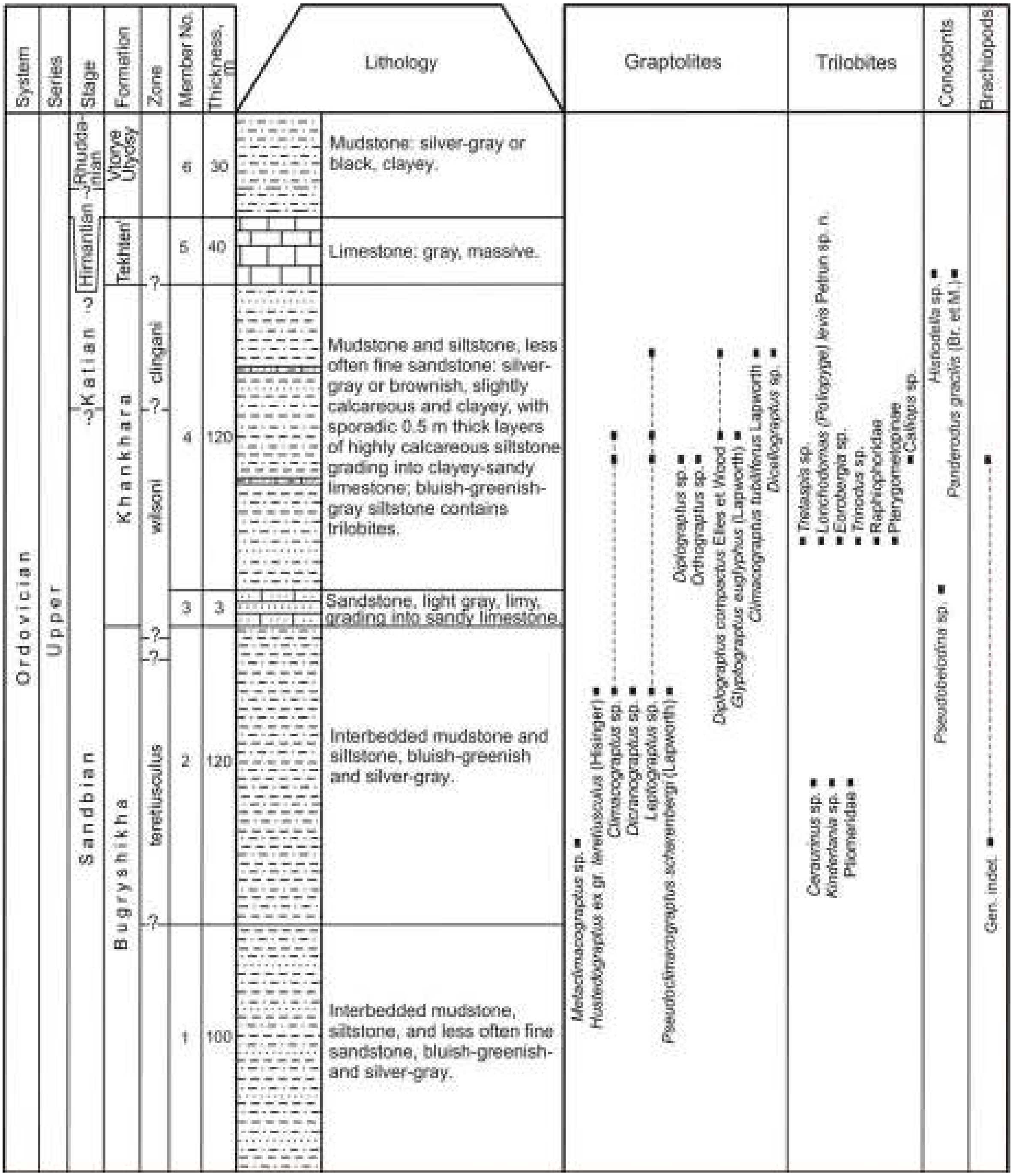


Fig. 116. Lithology and ranges of fossil taxa from the Chineta Section.

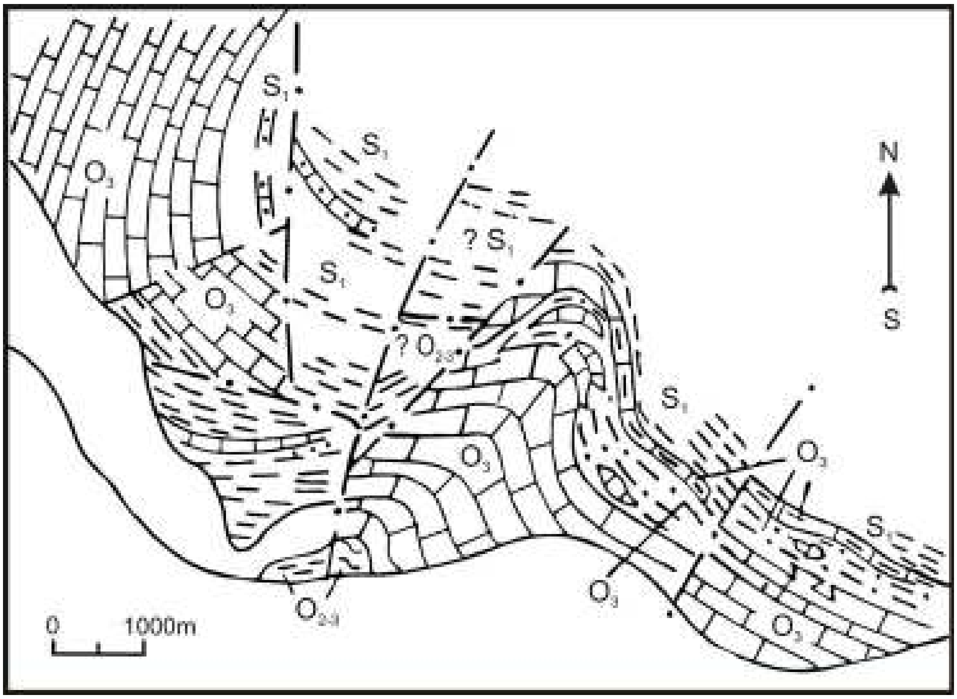


Fig. 117. Sketch map of the Burovlyanka area.

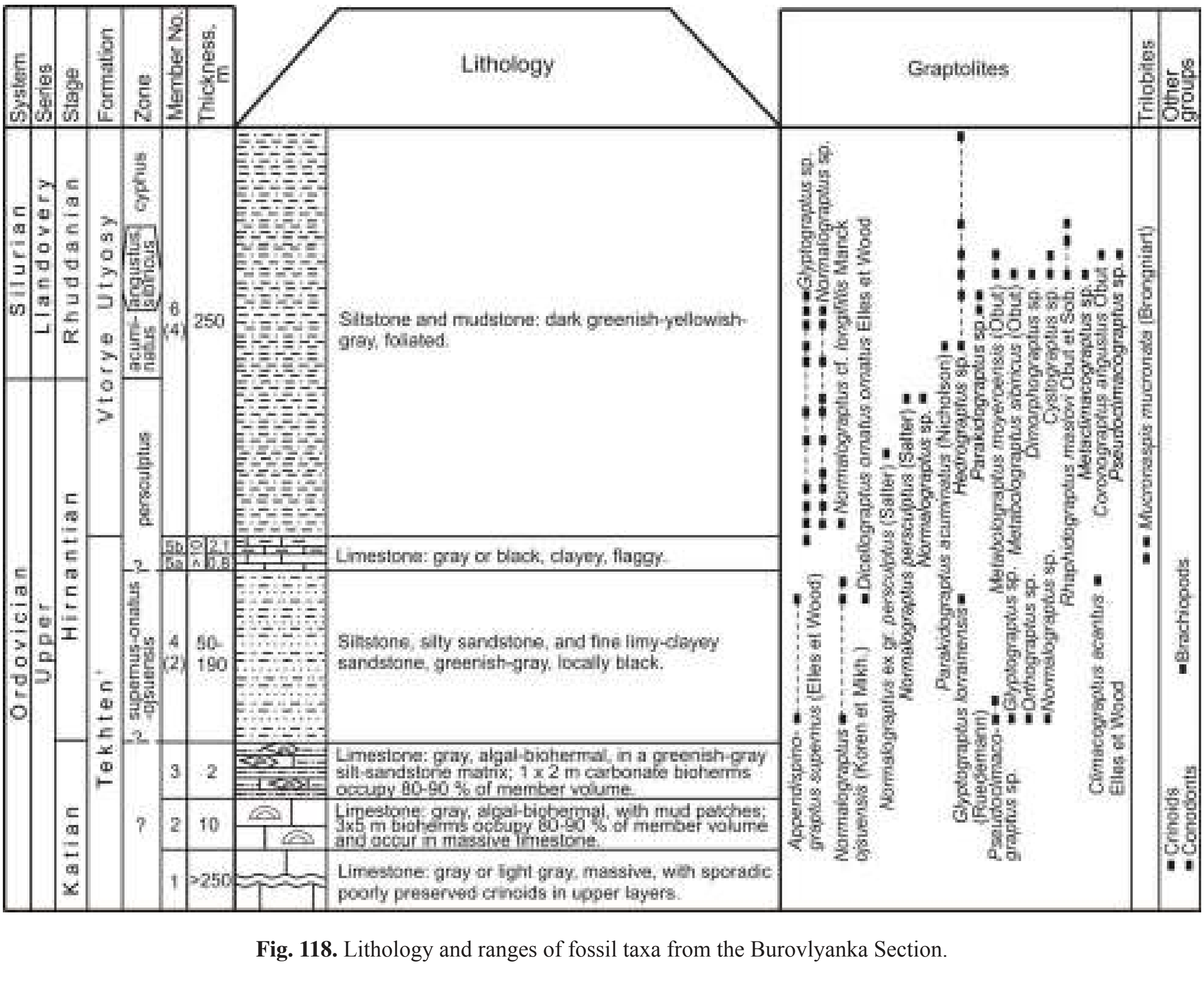


Fig. 118. Lithology and ranges of fossil taxa from the Burovlyanka Section.

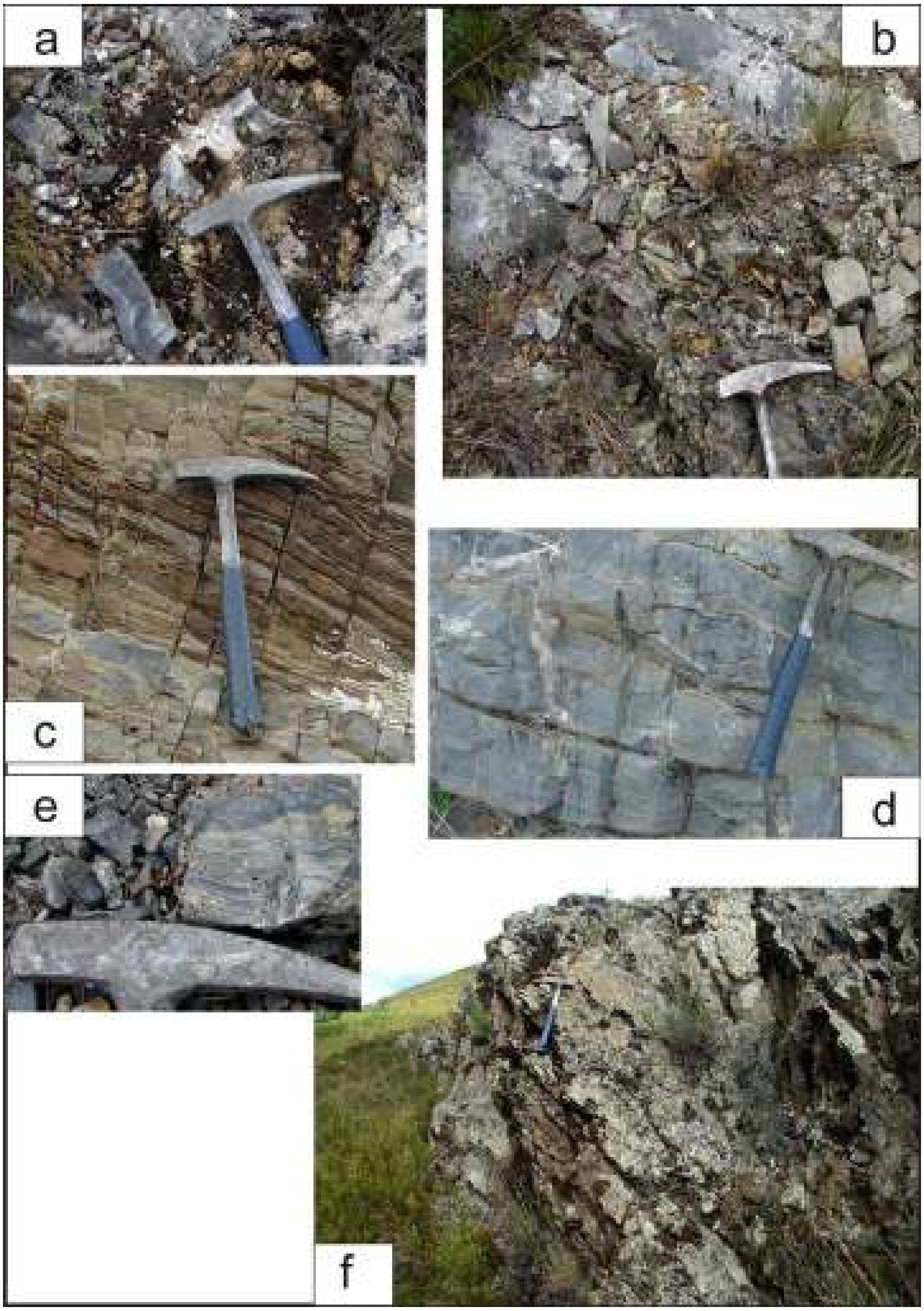


Fig. 119. Lithological peculiarities of limestone of the Burovlyanka Section.
a - b – algaes bioherms in the terrigenous matrix (siltstone); c – Dalmanitina member clayey thin-bedded limestone; d - e – Dalmanitina member massive limestone; f – siltstone and sandstone.

higher than loc. S-824-2/10 with graptolites of the *triangulatus* and *gregarius* zones: *Stimulograptus halli* (Barrande), *Monograptus* sp., *Paradiversograptus capillaris* (Carruthers) and *Glyptograptus tamariscus* (Niholson).

Siltstone in equivalents of Member 6 of S-833 on the left bank of the Inya River, 100 m upstream of an island near the Listvyanka Brook inflow (loc. S-8341) contains graptolites of the Upper Llandoverian *guerichi* Zone: *Spirograptus guerichi* Loydell, Storch et Melchin, *Rastrites* sp., *Stimulograptus halli* (Barrande), *Oktavites planus* (Barrande), *Paradiversograptus runcinatus* (Lapworth), *Paradiversograptus capillaris* (Carruthers), *Agetograptus tenuissimus* Sennikov, *Hedrograptus* sp., *Petalograptus* sp.

All six members of S-822 section and members 1–3 of S-833 section belong to Tekhten' Formation, and members 4 and 5 of S-833 section – to Vtorye Utyosy Formation, Member 6 of S-833 section to the Syrovaty Formation. Thickness of the Tekhten' Formation in the composite Burovlyanka Section (incomplete) is more than 330 m, Vtorye Utyosy Formation – about 420 m, Syrovaty Formation – more than 100 m.

CONCLUSIONS

This book contains the paleontological, biostratigraphic, lithologic and biofacies data on the key Ordovician sections from five large parts of the Gorny Altai - Uymen'-Lebed', Teletskoe Lakeside, Biya-Katun', Anui-Chuya and Charysh-Inya facies zones. In addition to the above mentioned facies zones, the Ordovician sedimentary sections with a specific set of formations could be distinguished. These are interpreted either as separate paleo-offshore area of the unique Altai shelf paleobasin (Milovanoka and Vydrikha facies zones) or as fragments of another paleobasin (Ulagan facies zone). We carried out detailed studies and bed-by-bed descriptions of the reference sections from the Milovanoka, Vydrikha and Ulagan facies zones. Some of the paleontological-stratigraphic data obtained from them could be correctly aligned with those from the five main structural facies zone. However, most sequences from the Milovanoka, Vydrikha and Ulagan zones still require further study of litho- and biostratigraphy in order to generate paleogeographic and geodynamics reconstructions.

Authors hope that readers can get an overview of the structure of the Altai Ordovician sedimentary basins and the paleobiota inhabiting them. Geological materials from the Gorny Altai (South of West Siberia) could be a good example of the successive evolutionary development of sedimentary basins and the entire biosphere during the Ordovician period of the Earth's history.

Acknowledgements

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PALEONTOLOGICAL PLATES

Tabulate corals

Plate 1

Tabulate corals from the localities in the northeastern part of Gorny Altai, the right bank of the Lebed' River, Lebed' Section.

Collection of Raliya A. Khabibulina.

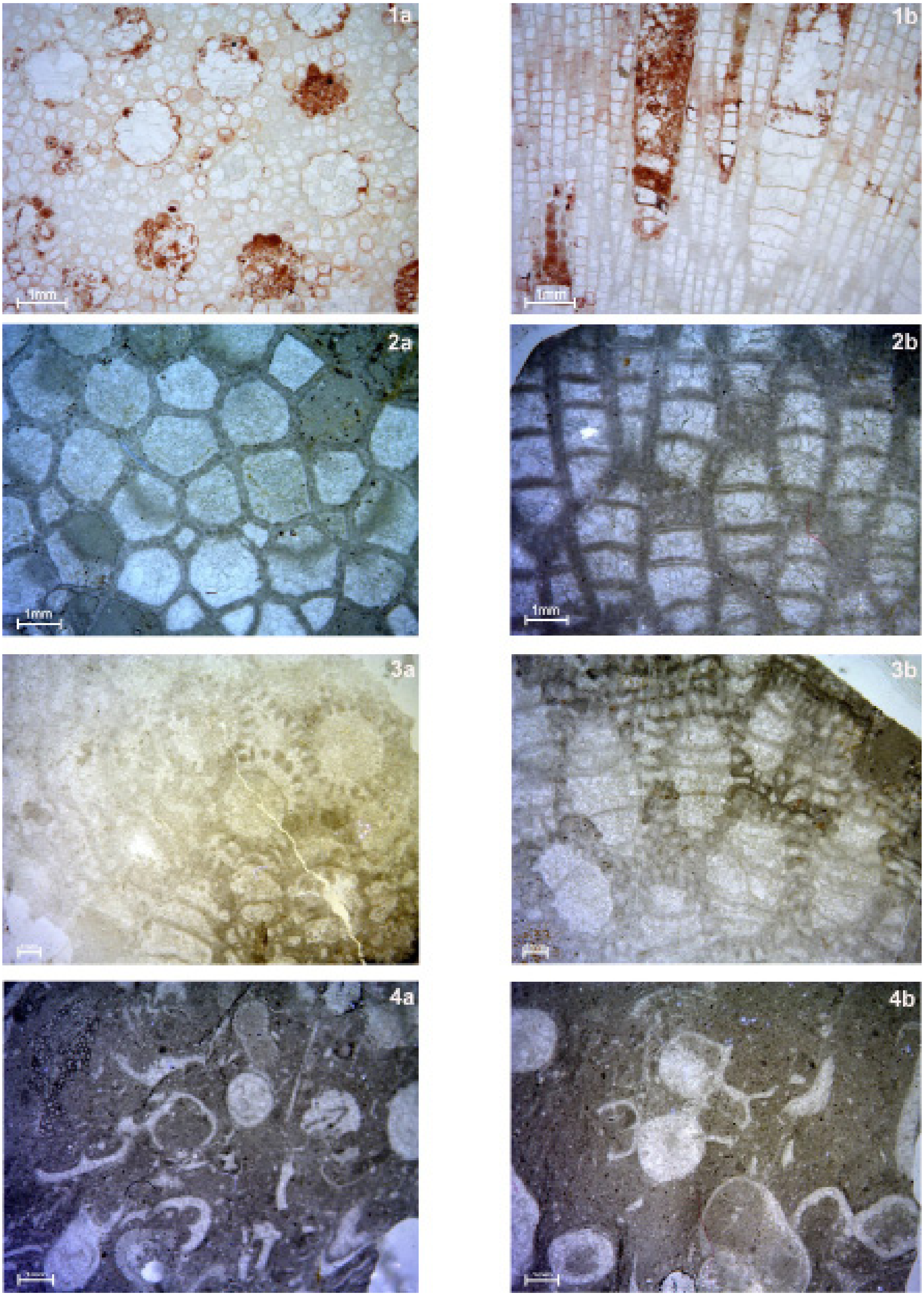
Fig. 1. *Heliolites tchorparensis* Poltavceva:
The Lebed' section, Member 19, loc. Kh1013-2. Upper Ordovician, Chebor Formation.
1a – transverse thin section, 1b – longitudinal thin section.

Fig. 2. *Nyctopora nicholsoni* (Raduguin):
The Lebed' section, Member 7, loc. Kh1014-2. Upper Ordovician, Gur'yanovka Formation.
2a – transverse thin section, 2b – longitudinal thin section.

Fig. 3. *Calapoecia canadensis* Billings:
The Lebed' section, Member 9, loc. Kh1014-4. Upper Ordovician, Gur'yanovka Formation.
3a – transverse thin section, 3b – longitudinal thin section.

Fig. 4. *Tetradium* sp.:
The Lebed' section, Member 9, loc. Kh1214-9. Upper Ordovician. Gur'yanovka Formation.
4a – transverse thin section, 4b – longitudinal thin section.

Plate 1



Tabulate corals

Plate 2

Tabulate corals from the localities in the eastern part of Gorny Altai, Teletskoye Lakeside, the right bank of the Verkhniy Turochak River, left tributary of Iogach River.

Collection of Raliya A. Khabibulina.

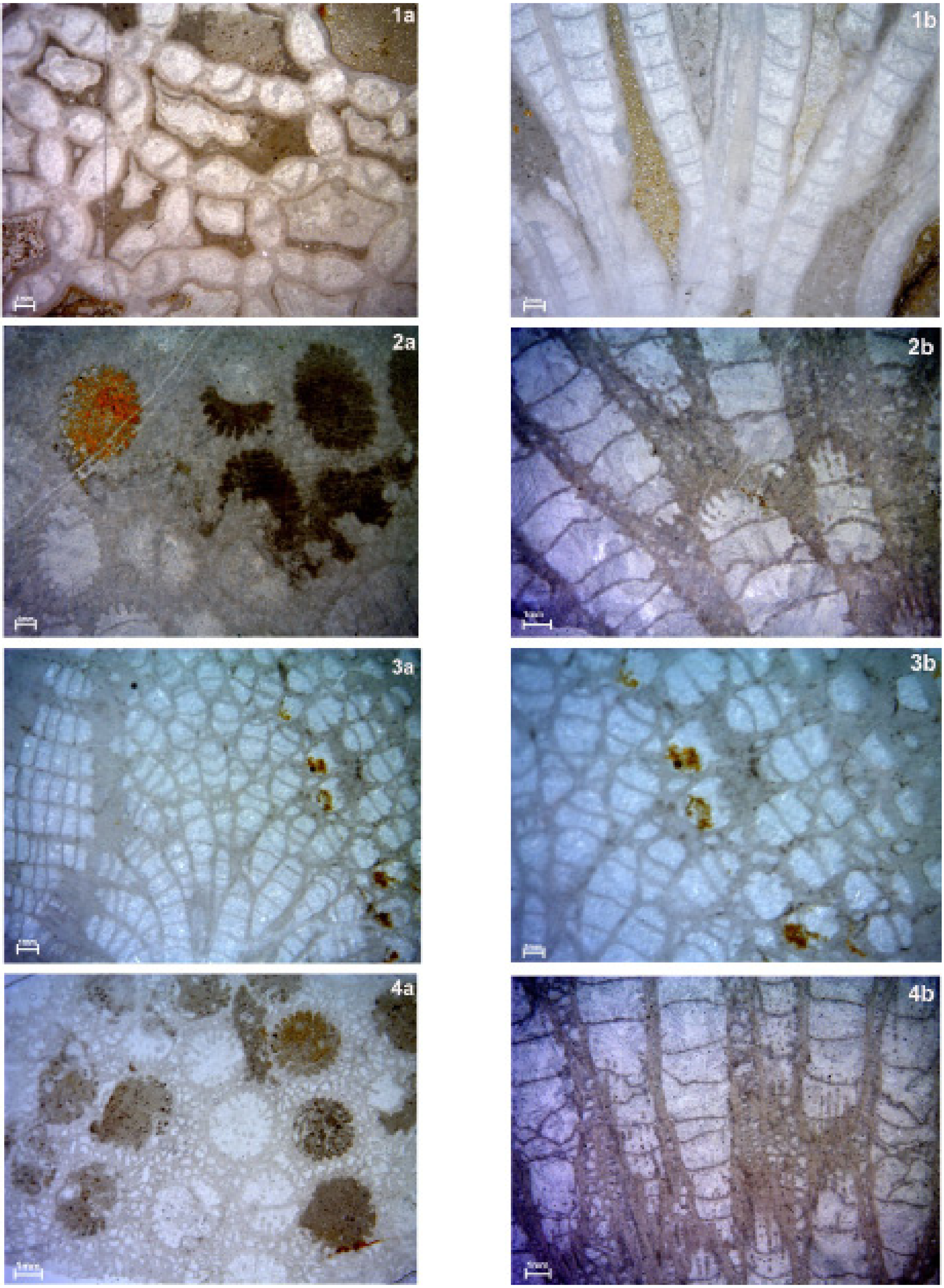
Fig. 1. *Catenipora* sp.:
The Verkhniy Turochak Section, Member 4, loc. S-183. Upper Ordovician, Samysh Body.
1a – transverse thin section, 1b – longitudinal thin section.

Fig. 2. *Rhaphidophyllum ellipsoidalis* Preobrazhensky:
The Verkhniy Turochak Section, loc. 6116. Upper Ordovician, Samysh Body.
2a – transverse thin section, 2b – longitudinal thin section.

Fig. 3. *Nyctopora denticulate* Sokolov et Tesakov:
The Verkhniy Turochak Section, Member 4, loc. S-1754. Upper Ordovician, Samysh Body.
3a – transverse thin section, 3b – longitudinal thin section.

Fig. 4. *Cyrtophyllum bargastensis* Dziubo:
The Verkhniy Turochak Section, Member 4, loc. S-183. Upper Ordovician, Samysh Body.
4a – transverse thin section, 4b – longitudinal thin section

Plate 2



Tabulate corals

Plate 3

Tabulate corals from the localities in the eastern part of Gorny Altai, Teletskoye Lakeside (Verkhniy Turochak River), Biya and Lebed' rivers and nothwestern part of Gorny Altai (Charysh River).

Collection of Raliya A. Khabibulina.

Fig. 1. *Reuschia aperta* Kiaer:

The right bank of Verkhniy Turochak River (left tributary of Iogach River). The Verkhniy Turochak Section, loc. 6116. Upper Ordovician, Samysh Body.

1a – transverse thin section, 1b – longitudinal thin section

Fig. 2. *Tetradium borealis* Tchernychev:

The right bank of the Biya River, loc. 7134. Upper Ordovician.

2a – transverse thin section, 2b – transverse thin section.

Fig. 3. *Mesofavosites* sp.:

The right bank of the Charysh River (near Ust'-Kan Village), loc. S-1615. Upper Ordovician- Lower Silurian.

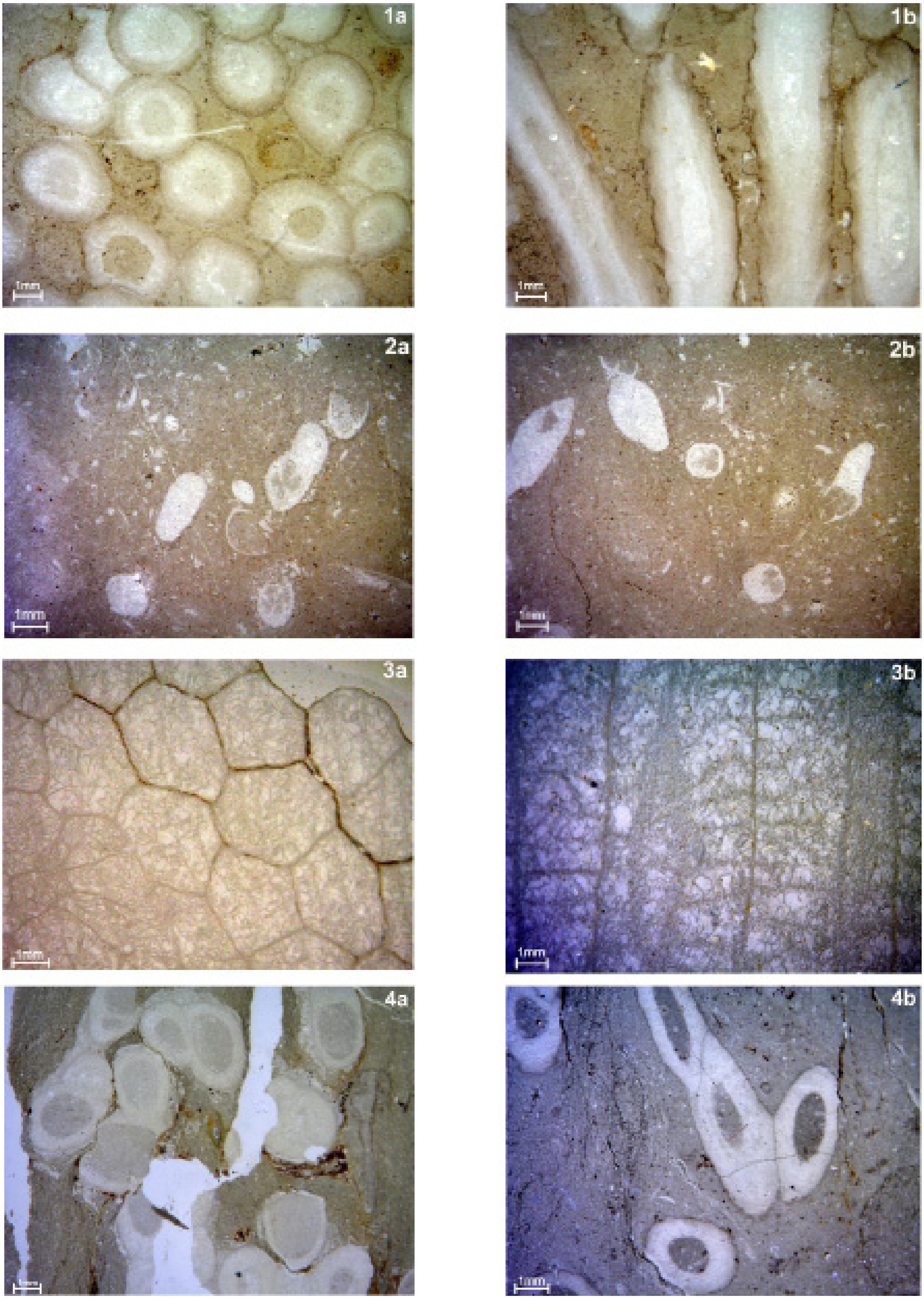
3a – transverse thin section, 3b –longitudinal thin section.

Fig. 4. *Reuschia* sp.:

The right bank of the Lebed' River. Lebed' Section, Member 9, loc. Kh1214-13.Upper Ordovician, Gur'yanovka Formation.

4a – transverse thin section, 4b – longitudinal thin section.

Plate 3



Brachiopods

Plate 4

Brachiopods from the eastern part of Gorny Altai, Teletskoye Lakeside, the Tozodov Section. Tozodov Formation, Upper Ordovician, Sandbian Stage.

Collection of Tatyana A. Shcherbanenko.

Fig. 1. *Eoanastrophia lebediensis* (Severgina):

1 – specimen Tozodov-6/1, ventral exterior, natural-sized; 1a – ventral exterior; 1b – dorsal exterior; 1c – lateral view; 1d – anterior view; 1e – posterior view; all ×3. The Tozodov Section, Member 6.

Figs 2-6. *Apatomorpha altaica* Severgina:

2 – specimen C-1440/2, ventral exterior, natural-sized. 2a – ventral exterior; 2b – dorsal exterior; 2c –lateral view; 2d – posterior view; all ×3. The Tozodov Section, Member 3.

3 – specimen C-1440/3, ventral exterior, natural-sized. 3a – ventral exterior; 3b – dorsal exterior; 3c – lateral view; 3d – posterior view; all ×2. The Tozodov Section, Member 3.

4 – specimen C-1441/4, internal mold of ventral valve, ×3. The Tozodov Section, Member 7.

5 – specimen C-1442/5, internal mold of dorsal valve, ×3. The Tozodov Section, Member 8.

6 – specimen C-1442/6, cardinal process, ×3. The Tozodov Section, Member 8.

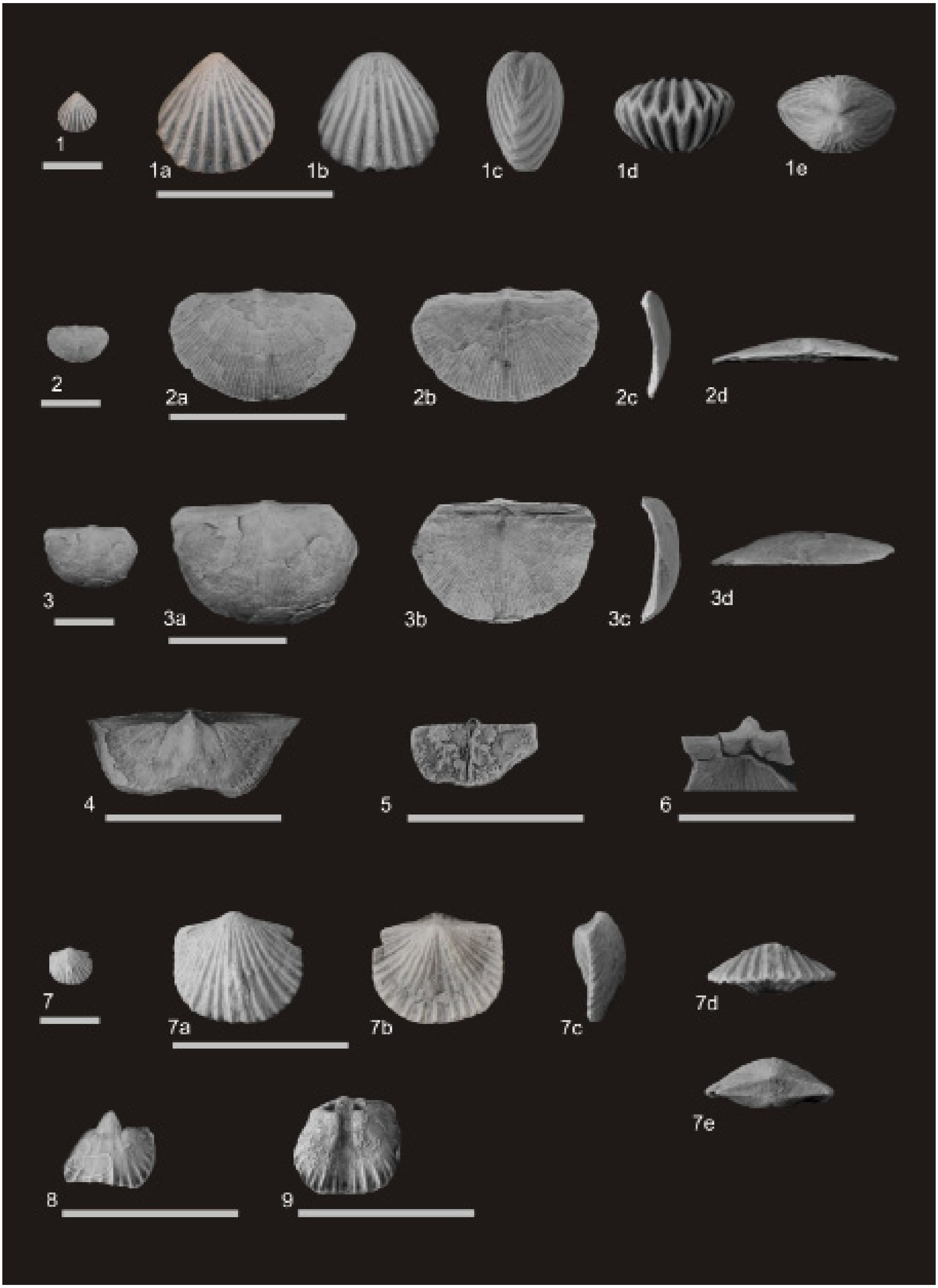
Figs 7-9. *Sivorthis friendsvillensis* (Cooper):

7 – specimen C-1440/7, ventral exterior, natural-sized. 7a – ventral exterior; 7b – dorsal exterior; 7c – lateral view; 7d – anterior view; 7e – posterior view; all ×3. Tozodov Section, Member 3.

8 – specimen C-1442/8, internal mold of ventral valve ×3. Tozodov Section, Member 8.

9 – specimen C-1442/9, internal mold of dorsal valve, ×3. Tozodov Section, Member 8.

Plate 4



Trilobites

Plate 5

Trilobites from the localities in the northwestern Gorny Altai, Bugryshikha Formation, the Gora Altai Section. Specimens 1–6 are from Member 5, in 1 m from the bottom; specimens 7–11 are from Member 14, in 2 m from the bottom.

Collection of Aleksander V. Timokhin.

Figs 1, 4, 8 – *Homotelus inferus* Levitsky.

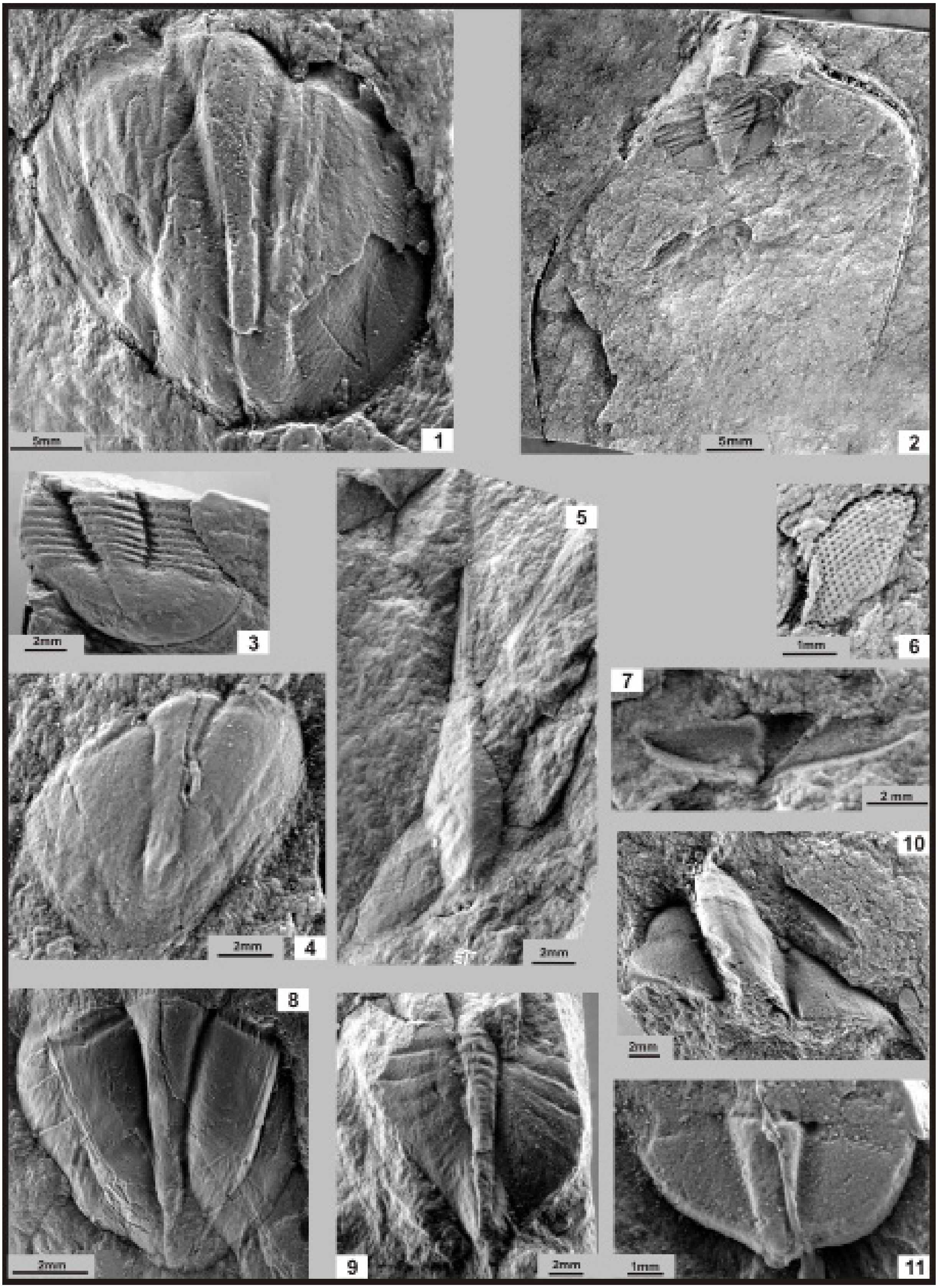
Figs 2, 5, 7, 10, 11 – *Lonchodomas rostratus* (Sars).

Fig. 3 – *Niellus* sp.

Fig. 6 – *Telephina* sp.

Fig. 9 – *Megistaspis* sp.

Plate 5



Trilobites

Plate 6

Trilobites from the localities in the northwestern Gorny Altai, Bugryshikha Formation, the Gora Altai Section. All specimens are from Member 5, in 3m from the bottom.
Collection of Aleksander V. Timokhin.

Figs 1, 3 – *Lonchodomas communis* Levitsky.

Figs 2, 9, 14 – *Lonchodomas rostratus* (Sars).

Fig. 4 – *Eorobergia insignis* Petrunina.

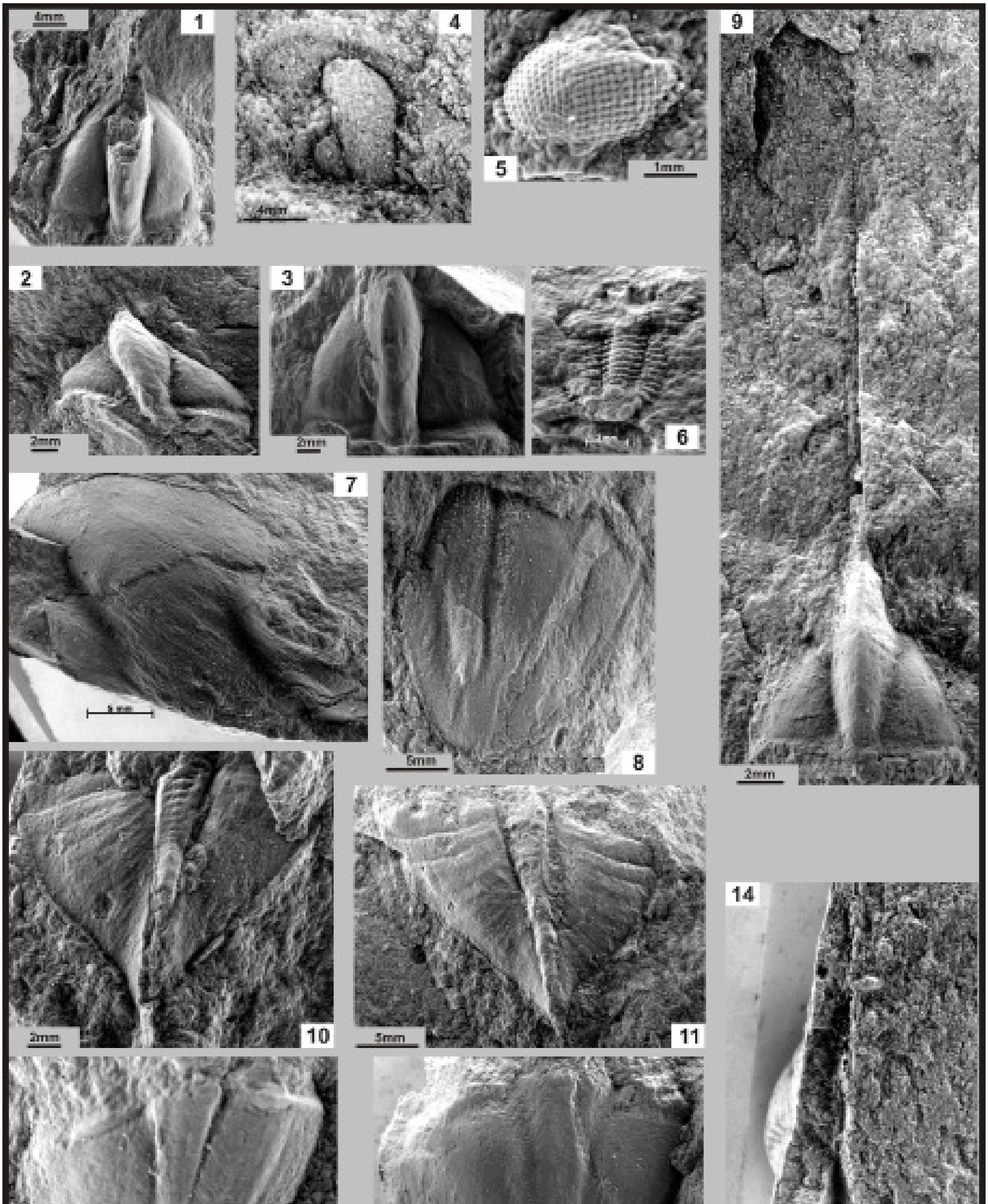
Fig. 5 – *Telephina* ex gr. *mobergi* Hadding.

Fig. 6 – Gen. nov. sp.indet.

Figs 7, 8, 12, 13 – *Homotelus inferus* Levitsky.

Figs 10, 11 – *Megistaspis* sp.

Plate 6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Trilobites

Plate 7

Trilobites from the localities in the northwestern Gorny Altai, Bugryshikha Formation, the Malaya Uskuchevka Section. All specimens are from Member 1.

Collection of Aleksander V. Timokhin.

Figs 1, 2, 11 – *Niellus* sp.

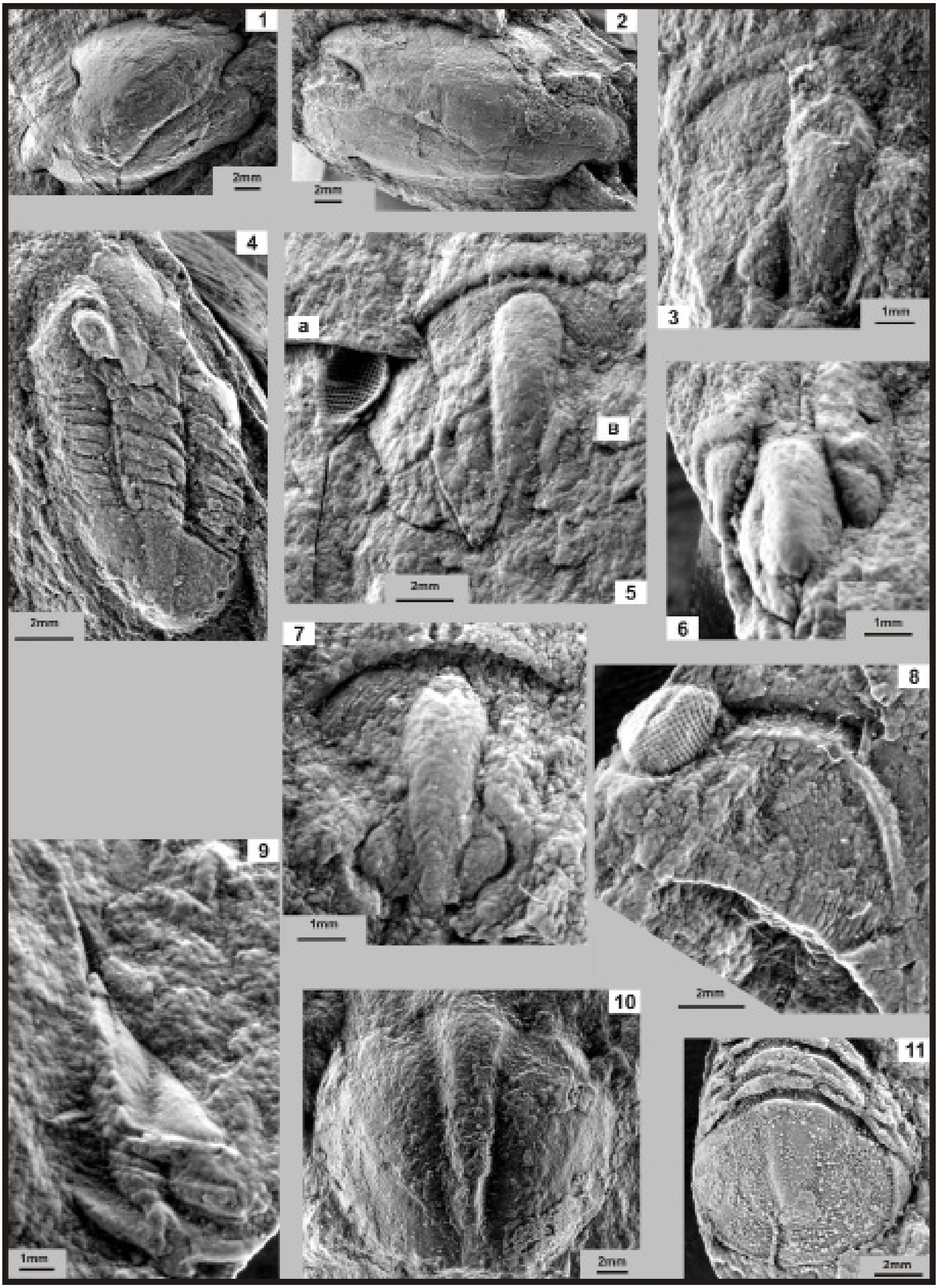
Figs 3, 5b, 7 – *Eorobergia* sp.

Figs 4, 10 – *Homotelus inferus* Levitsky.

Figs 5a, 6, 8 – *Telephina* sp.

Fig. 9 – *Lonchodomas rostratus* (Sars)

Plate 7



Trilobites

Plate 8

Trilobites from the localities in the northwestern Gorny Altai, Khankhara Formation, the Ebogon Section. All specimens are from Member 20.

Collection of Aleksander V. Timokhin.

Fig. 1 – *Bronteopsis transversal* Petrunina.

Figs 2, 6, 9, 10 – *Erratecrinuru brutoni* Owen.

Fig. 3 – *Bronteopsis gregaria* Raymond.

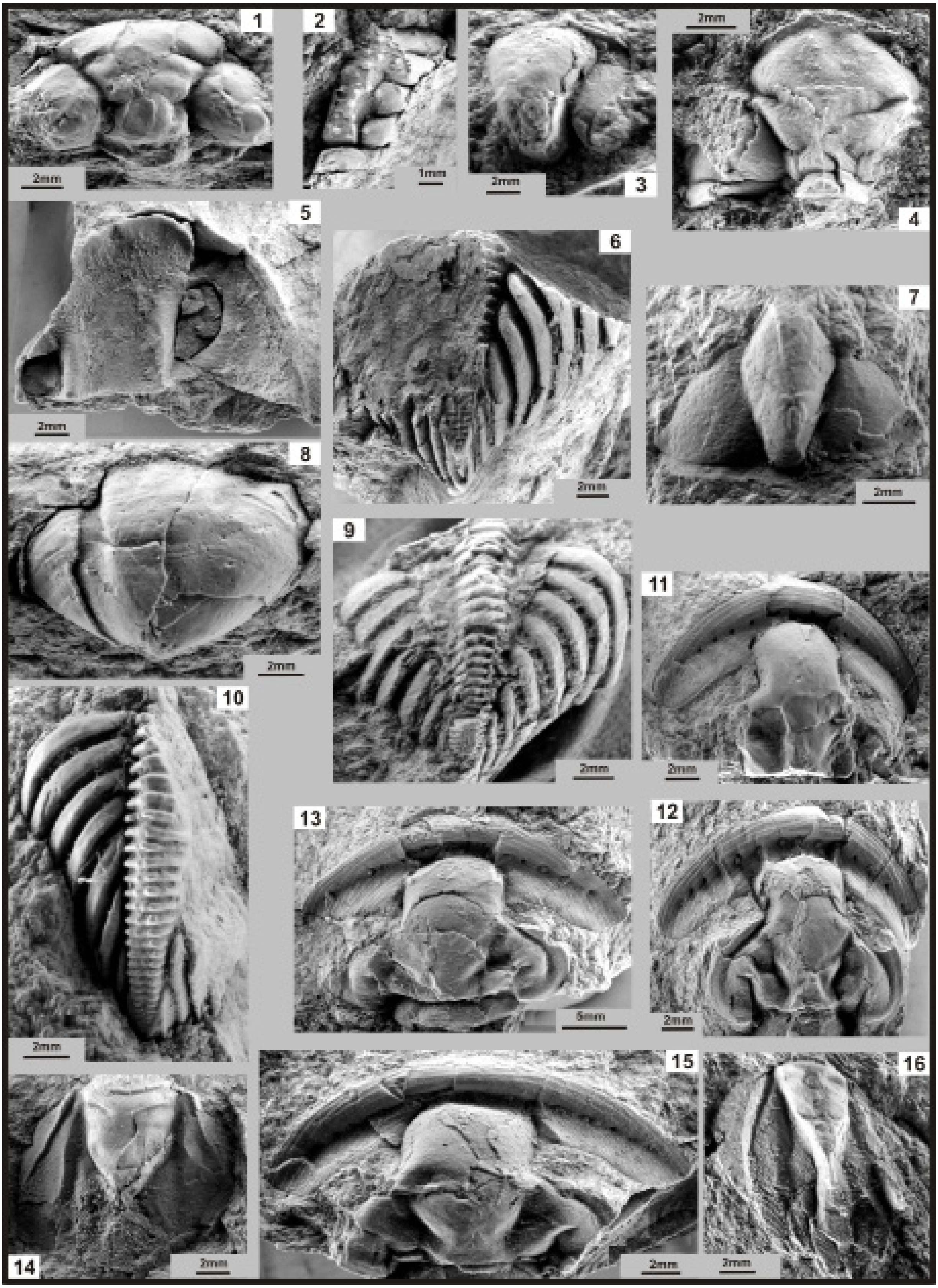
Fig. 4 – *Calyptaulax* sp.

Figs 5, 8 – *Niellus* sp.

Fig. 7 – *Lonchodomas rostratus* (Sars).

Figs 11, 12, 13, 14, 15, 16 – *Eorobergia* sp.

Plate 8



Trilobites

Plate 9

Trilobites from the localities in the northwestern Gorny Altai, Khankhara Formation, the Ebogon Section. All specimens are from Member 20.

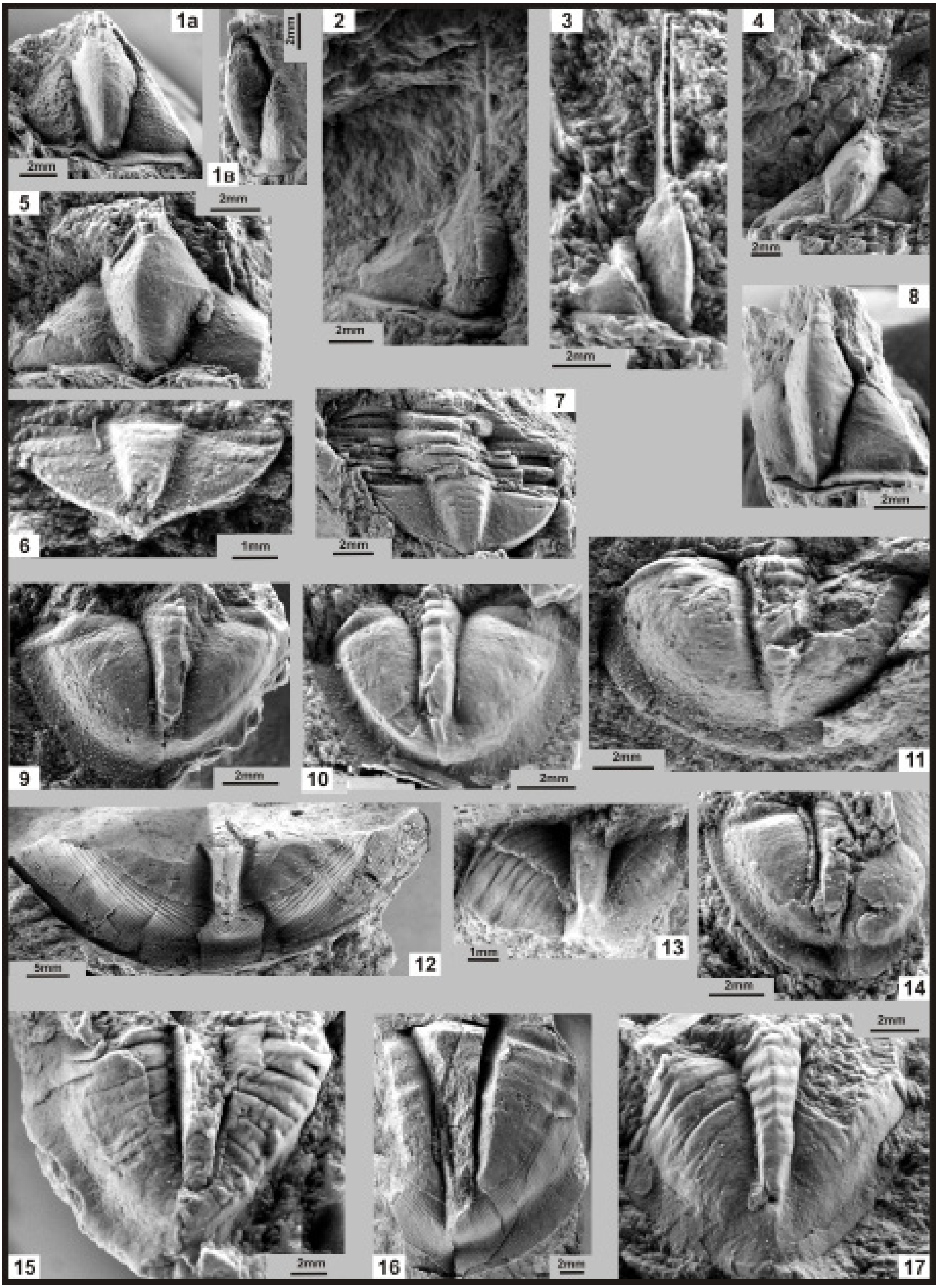
Collection of Aleksander V. Timokhin.

Figs 1a, 1b, 2, 3, 4, 5, 6, 7, 8 – *Lonchodomas rostratus* (Sars).

Figs 9, 10, 11, 12, 14 – *Stygina minor* Skjeseth.

Figs 13, 15, 16, 17 – *Megistaspis* sp.

Plate 9



Trilobites

Plate 10

Trilobites from the localities in the northeastern Gorny Altai. Figs 1-6: Lebed' River, the Lebed' Section, Karasa Formation, Member 25; figs 8–12: Biya River, Samysh Body, loc. S-1618.

Collection of Aleksander V. Timokhin.

Figs 1, 3, 7, 12 – *Homotelus* sp.

Figs 2, 10 – *Lonchodomas rostratus* (Sars).

Fig. 4 – *Calyptaulax* sp.

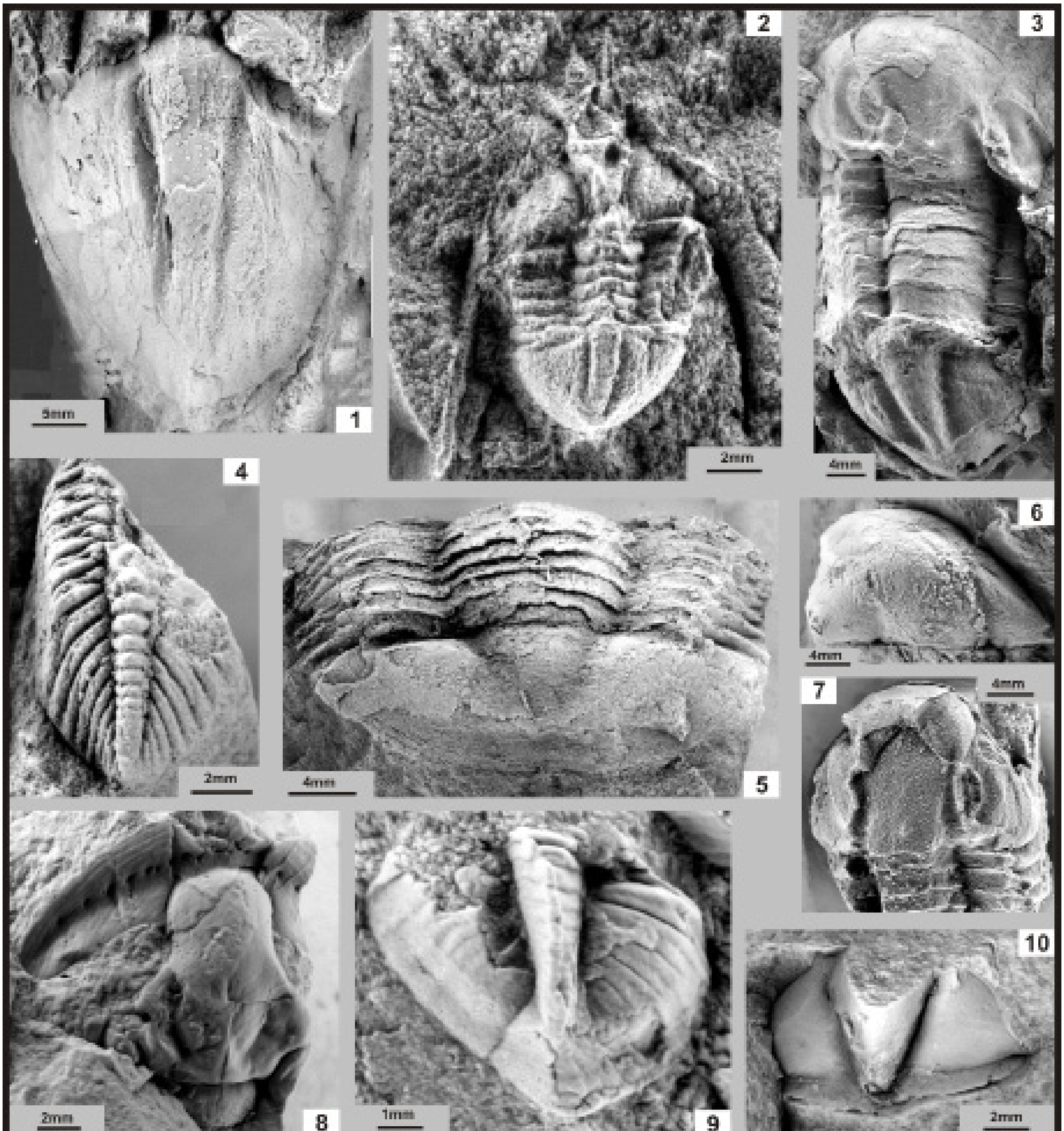
Figs 5, 6 – *Illaenus* sp.

Fig. 8 – *Eorobergia* sp.

Fig. 9 – *Megistaspis* sp.

Fig. 11 – *Stygina minor* Skjeseth

Plate 10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Trilobites

Plate 11

Trilobites from the localities in the northeastern Gorny Altai, Karasa Formation, the Yurok Section.
Collection of Aleksander V. Timokhin.

Figs 1, 2 – *Cybelurus altaicus* Levitsky:
Member 1, in 3 m from the bottom, loc. C-1118-1.

Figs 3, 4, – *Paracybeloides(?)* sp.:
specimen 3 - Member 2, in 8 m from the bottom, loc. C-1118-2; specimen 4 – Member 3, loc. C-1116-c.

Fig. 5 – *Carolinites* sp.:
Member 3, loc. C-1116-c.

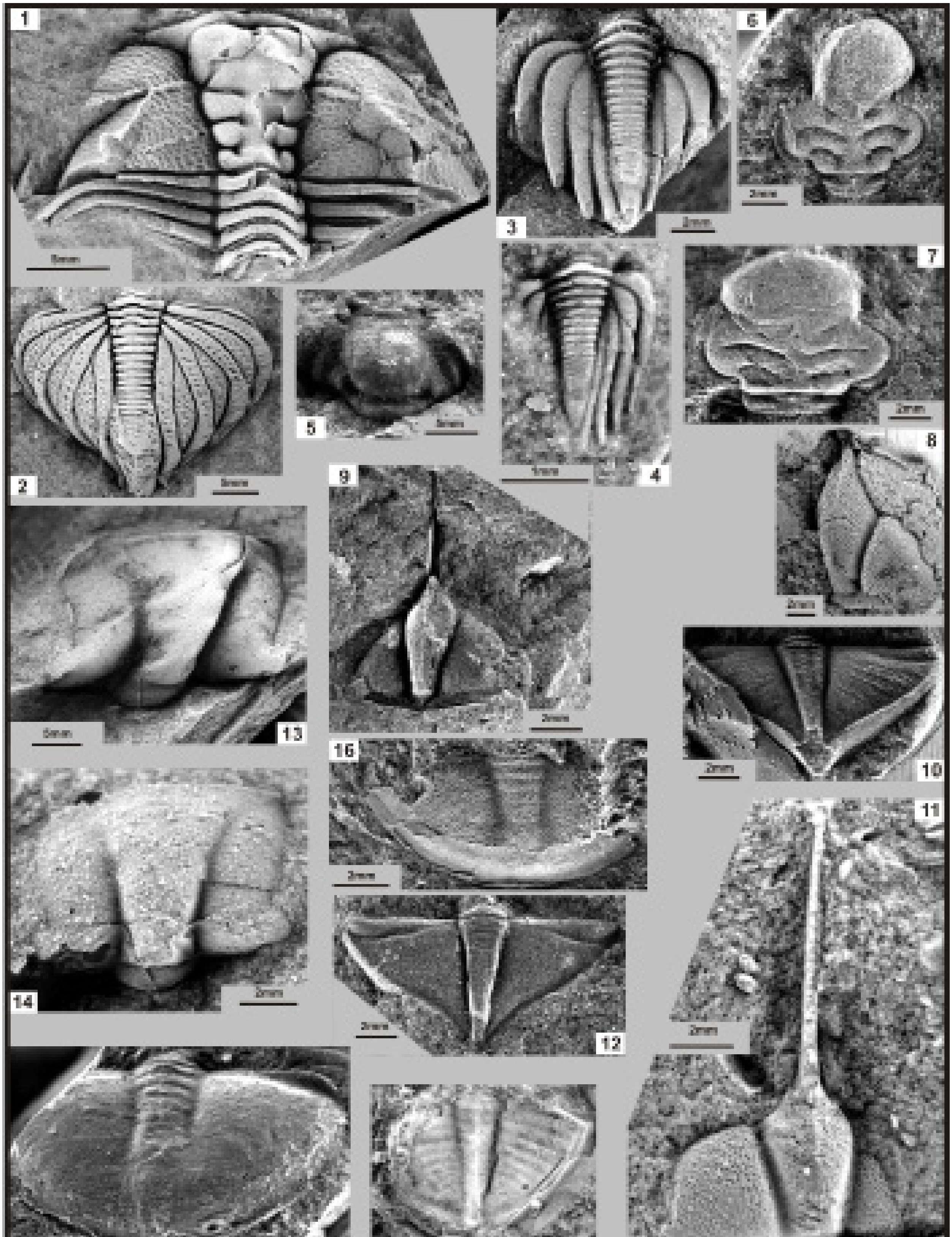
Figs 6, 7 – *Robergia sparsa* Nikolaisen:
specimen 6 – Member 3, loc. C-1116-c; specimen 7 - Member 2, in 5 m from the bottom, loc. C-1118-2,.

Figs 8, 9, 10, 11, 12 – *Lonchodomas rostratus* (Sars):
specimen 8 - Member 3, loc. C-1116-c; specimens 9, 12 - Member 2, in 8 m from the bottom, loc. C-1118-2; specimen 10 - Member 3, loc. C-1116-a; specimen 11 – Member 3 , loc. C-1116-c.

Figs 13 – 16, *Raymondaspis* sp.
specimen 14 - Member 2, loc. C-1118-2, 5 m from the bottom; specimen 15 – Member 4, in 5 m from the bottom, loc. C-1118-4; specimen 16 – Member 3 , loc. C-1116-c.

Fig. 17 – *Megistaspis (M.) polyphemus* Brogger:
Member 1, in 3 m from the bottom, loc. C-1118-1.

Plate 11



Trilobites

Plate 12

Trilobites from the localities in the northeastern Gorny Altai. Figs 1-6, 8-16: upper part of the Karasa Formation, upper part of the Tuloi Section, loc. R-409b; fig 7: lower part of the Karasa Formation, the Yurok Section, Member 2, in 7,5 m from the bottom, loc. C-1118-2.

Collection of Aleksander V. Timokhin.

Figs 1, 2 – *Megistaspis (M.) polyphemus* Brogger.

Fig. 3 – *Paracybeloides* (?) sp.

Figs 4, 5 - *Robergia sparsa* Nikolaisen.

Fig. 6 – *Carolinites* sp.

Fig. 7 – *Niobe* sp.

Figs 8, 9, 10 - *Lonchodomas rostratus* (Sars).

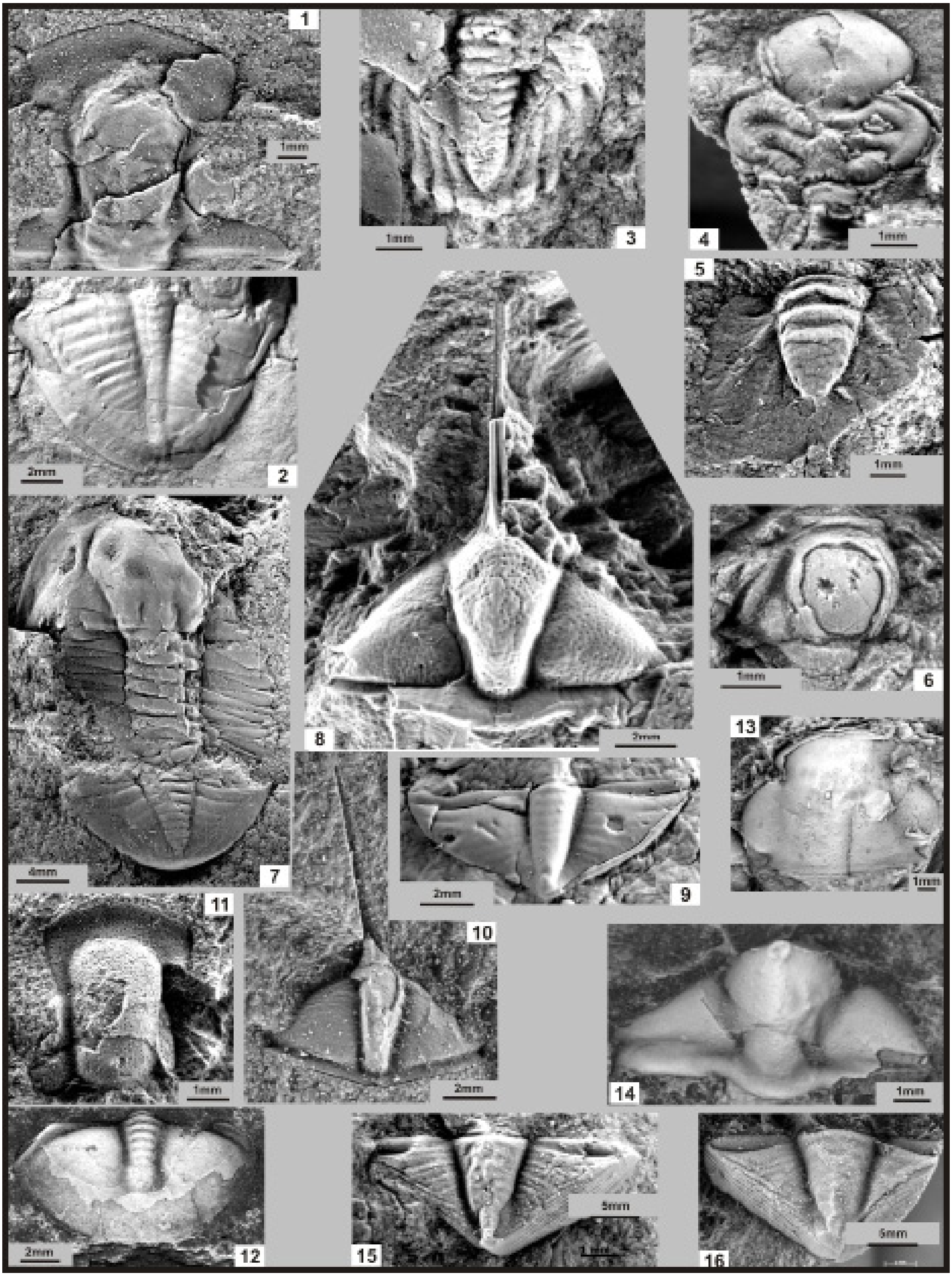
Fig. 11 – *Agerina* sp.

Fig. 12 – *Raymondaspis* sp.

Fig. 13 – *Niellus* sp.

Figs 14 –16 - *Ampyx* sp.

Plate 12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Trilobites

Plate 13

Trilobites from the localities in the eastern Gorny Altai, Tozodov Formation, the Tozodov Section, members 7–8.

Collection of Aleksander V. Timokhin.

Figs 1, 4 – *Asaphus knyrkoi* F. Schmidt.

Figs 2, 3, 6, 17 – *Asaphus striatus* Brogger.

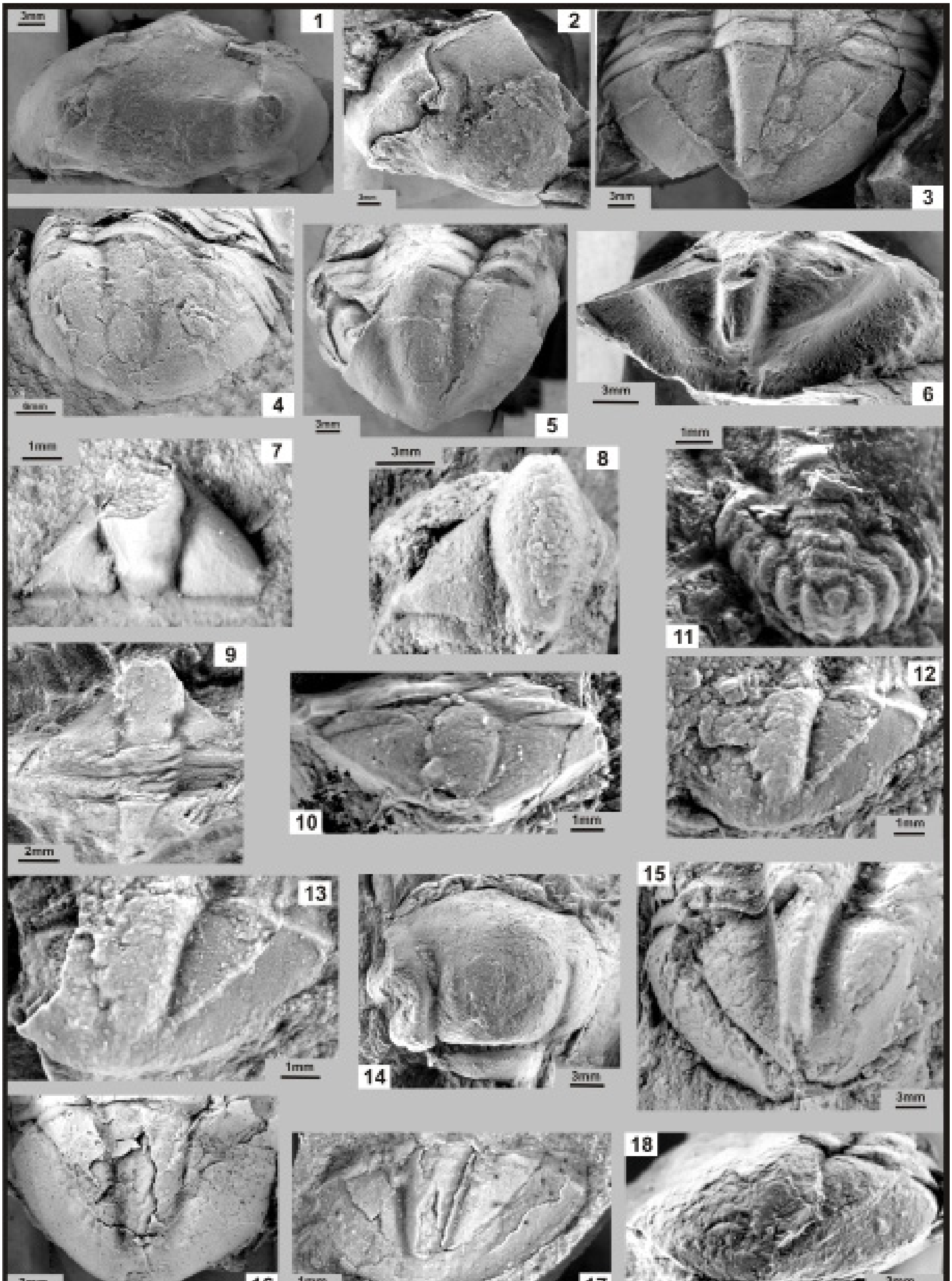
Figs 7, 8, 9, 10 – *Lonchodomas rostratus* (Sars).

Fig. 11 – *Pliomera fischeri* (Eichwald).

Figs 5, 14, 16, 18 – *Illaenus* sp.

Figs 12, 13 – *Homotelus* sp.

Plate 13



Ostracods

Plate 14

Ostracods from the localities of the Teletskoe Lakeside area, northeastern part of Gorny Altai.
Collections of Taras V. Gonta.

Figs 1–3. *Primitia* sp.: Samysh River, loc. S-1630, specimen 1 – left valve, lateral view; specimen 2 – left valve, lateral view; specimen 3– right valve, lateral view.

Figs 4, 5. *Laccochilina (Laccochilina)* aff. *torosa* Kanygin: Tarlyk River, loc. S-1631, specimen 4 – male right valve, lateral view; specimen 5 – male left valve, lateral view.

Figs 6, 7. *Bolbina* sp.: Verkhniy Turochak River, loc. S-1754, specimen 6 – male left valve, lateral view, specimen 7 – female left valve, lateral view.

Figs 8, 9. *Rigidella* sp. 1: Tarlyk River, loc. S-1631, specimen 8 – left valve, lateral view; specimen 9 – right valve, lateral view.

Figs 10, 11. *Rigidella* sp. 2: Tarlyk River, loc. S-1631, specimens 10, 11 - left valves, lateral view.

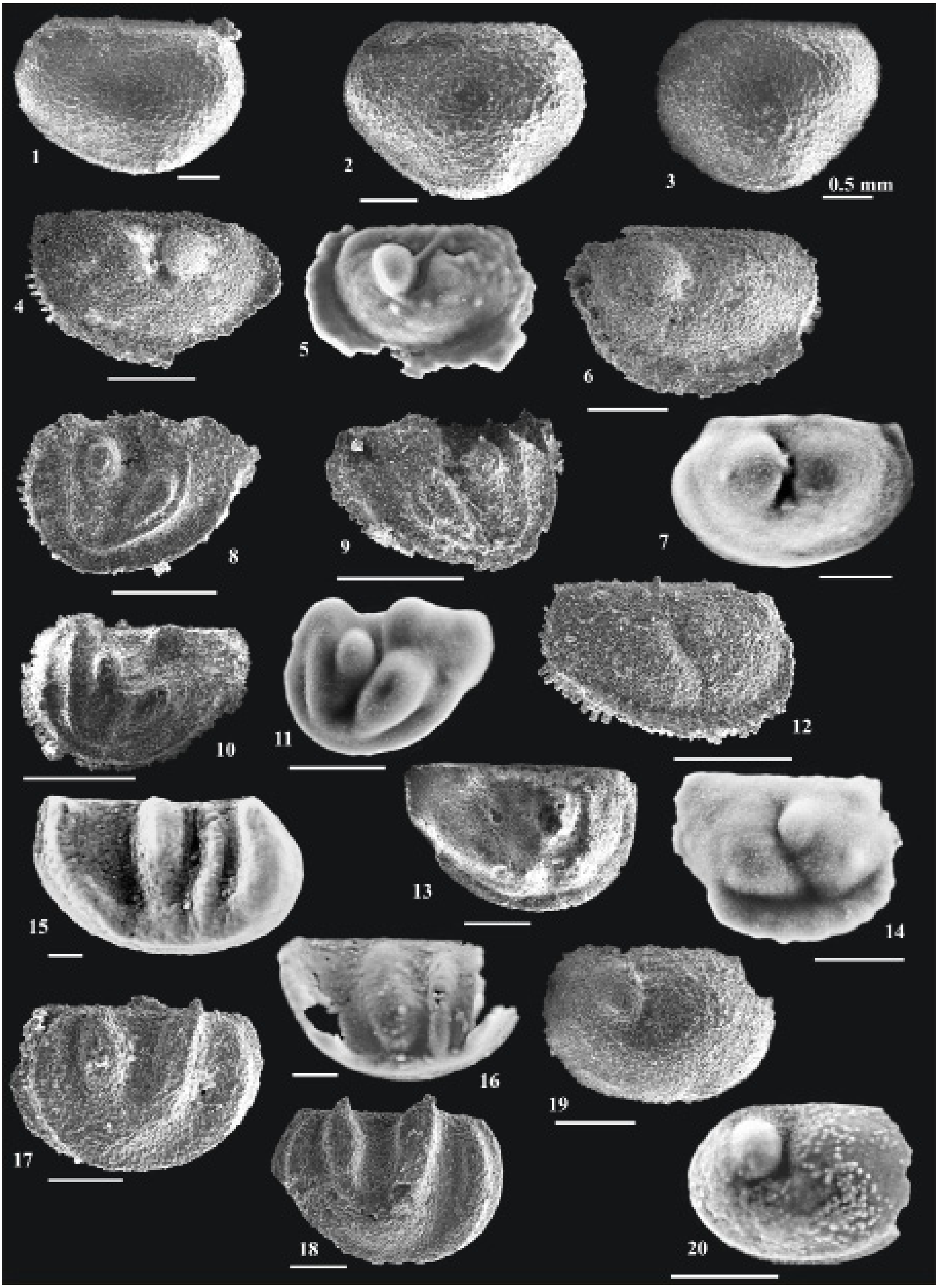
Figs 12–14. *Steuslofia* sp.: Tarlyk River, loc. S-1631, specimens 12, 13, 14 - right valves, lateral view.

Figs 15, 16. *Egorovella* sp.: specimen 15 – Tozodov Brook, loc. S-1442, right valve, lateral view; specimen 16 – Tarlyk River, loc.S-1631, right valve, lateral view.

Figs 17, 18. *Pseudozygobolbina invisitata* Melnikova: Samysh River, loc. S-1630, specimens 17, 18 – left valves, lateral view.

Figs 19, 20. *Hallatina* aff *orlovi* V. Ivanova: Tarlyk River, loc. S-1631, specimens 19, 20 – left valves, lateral view.

Plate 14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Graptolites

Plate 15

Graptolites from the localities in the northeastern part of Gorny Altai. Scale bar 1 mm.
Collections of Elena V. Lykova, Nikolay V. Sennikov.

Fig. 1. *Eotetragraptus quadribrachiatus* (Hall):
The left bank of the Lebed' River, Pridorozhny Section, loc. B-1011a. Tuloi Formation, Dapingian, *E. hirundo* Zone, *I. caduceus-imitatus* Subzone.

Fig. 2. *Eotetragraptus harti* (T.S. Hall):
The right bank of the Tuloi River, Tuloi Section, loc. S-0724. Tuloi Formation, Dapingian, *E. hirundo* Zone.

Figs 3, 10. *Pseudoisograptus manubriatus* (T.S.Hall):
3 – the right bank of the Tuloi River, Tuloi Section, loc. B-1111. Tuloi Formation, Dapingian, E. *hirundo* Zone; 10 – right bank of the Tuloi River, Tuloi Section, loc. B-117. Tuloi Formation, Dapingian, *E. hirundo* Zone.

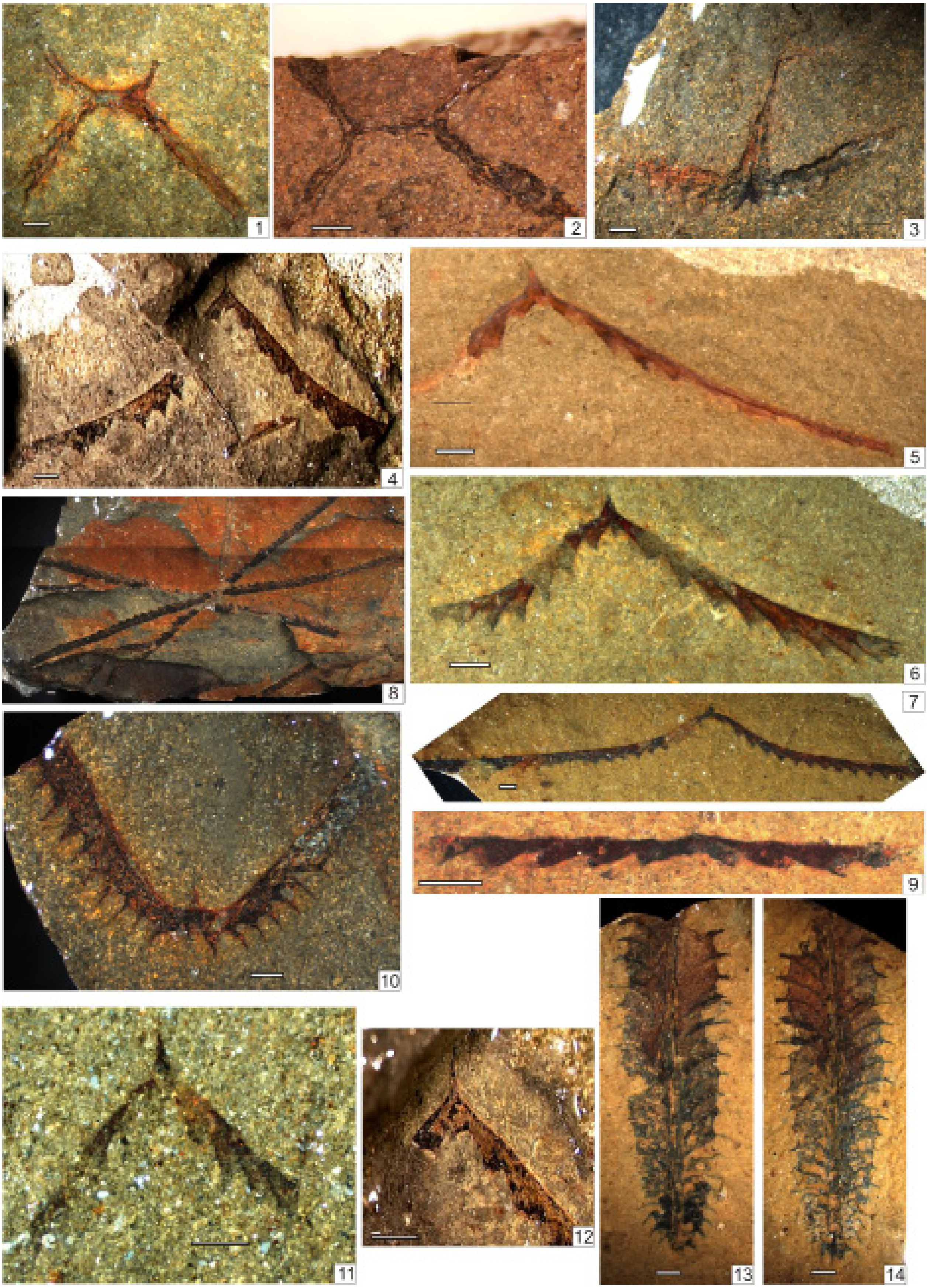
Figs 4, 5, 11, 12. *Corymbograptus deflexus* (Elles et Wood):
4, 12 – the right bank of the Tuloi River, Tuloi Section, loc. S-0724. Tuloi Formation, Dapingian, *E. hirundo* Zone; 5, 11 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-107. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 6, 7. *Corymbograptus inflexus* (Chen et Xia):
6, 7 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-106. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *C. deflexus* subzone.

Figs 8, 9. *Expansograptus extensus* (Hall):
8 – the right bank of the Tuloi River, Tuloi Section, loc. B-118. Tuloi Formation, Dapingian, *E. hirundo* Zone; 9 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-096. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 13, 14. *Pseudophyllograptus angustifolius angustifolius* Hall:
13, 14 – the right bank of the Biya River, Yurok Section, loc. S-1118-4/18. Tuloi Formation, Floian, *Ps. angustifolius elongatus* Zone.

Plate 15



Graptolites

Plate 16

Graptolites from the localities in the northeastern part of Gorny Altai. Scale bar 1 mm.
Collections of Elena V. Lykova, Nikolay V. Sennikov.

Figs 1, 2, 6. *Pseudoisograptus manubriatus* (T.S.Hall):
1 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-096. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone; 2 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-109. Tuloi Formation, Dapingian, *E. hirundo* Zone, *I. caduceus-imitatus* Subzone; 6 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-106 a. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *C. deflexus* Subzone.

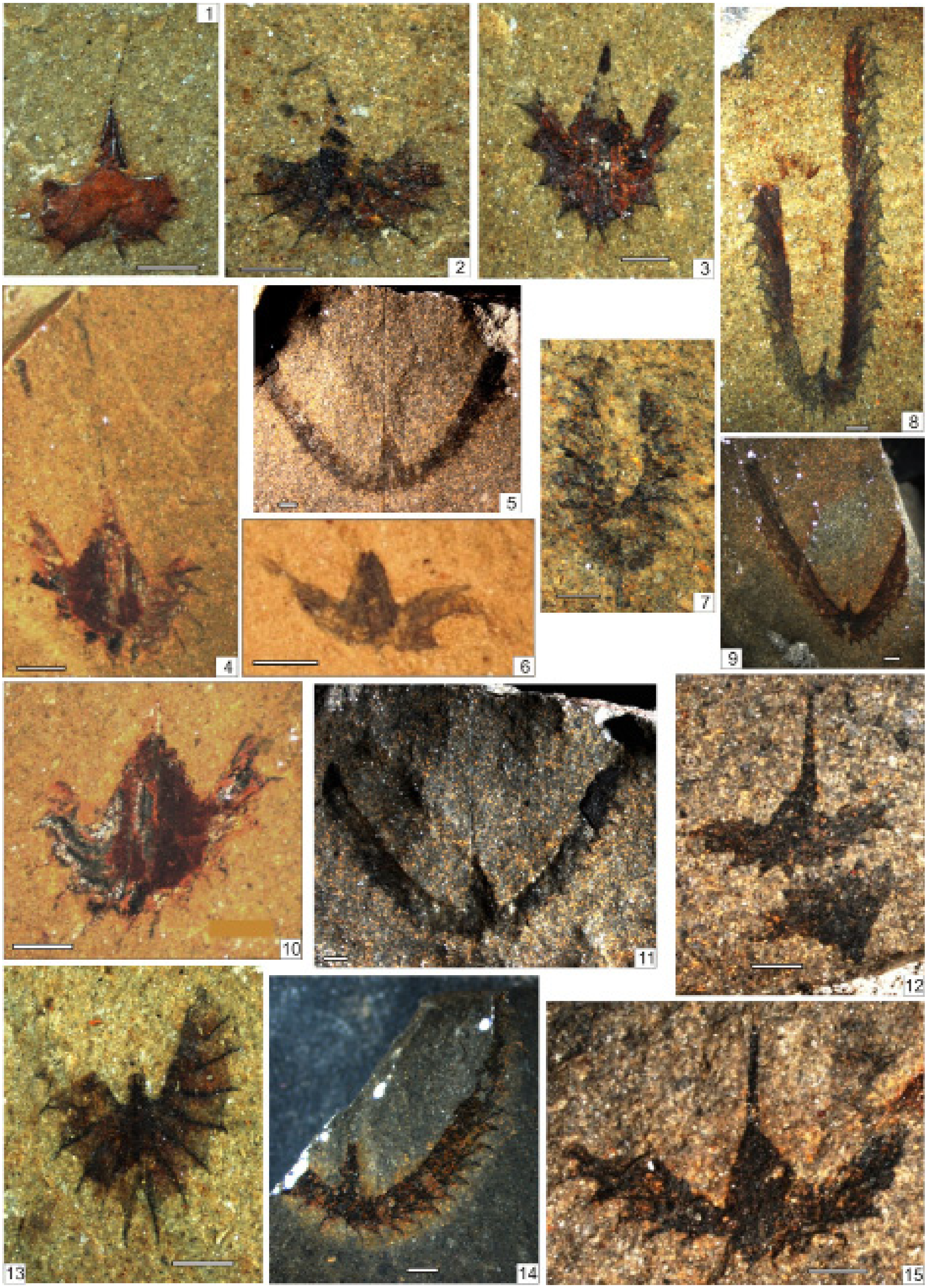
Figs 3, 4, 10. *Pseudisograptus manubriatus janus* Cooper et Ni :
3 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-093. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone; 4, 10 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -096. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 7, 8, 9. *Isograptus gibberulus* (Nicholson):
7, 8 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-108. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone; 9 – the right bank of the Tuloi River, Tuloi Section, loc. B –117. Tuloi Formation, Dapingian, *E. hirundo* Zone.

Figs 5, 11, 12, 14, 15. *Pseudoisograptus manubriatus* (T.S.Hall):
5, 11, 12, 15 – the right bank of the Tuloi River, Tuloi Section, loc. S-0724. Tuloi Formation, Dapingian, *E. hirundo* Zone; 14 – the right bank of the Tuloi River, Tuloi Section, loc. B-117. Tuloi Formation, Dapingian, *E. hirundo* Zone.

Figs 13. *Isograptus divergens* (Harris)
13 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-107a. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Plate 16



Graptolites

Plate 17

Graptolites from the localities in the northeastern part of Gorny Altai. Scale bar 1 mm.
Collections of Elena V. Lykova, Nikolay V. Sennikov.

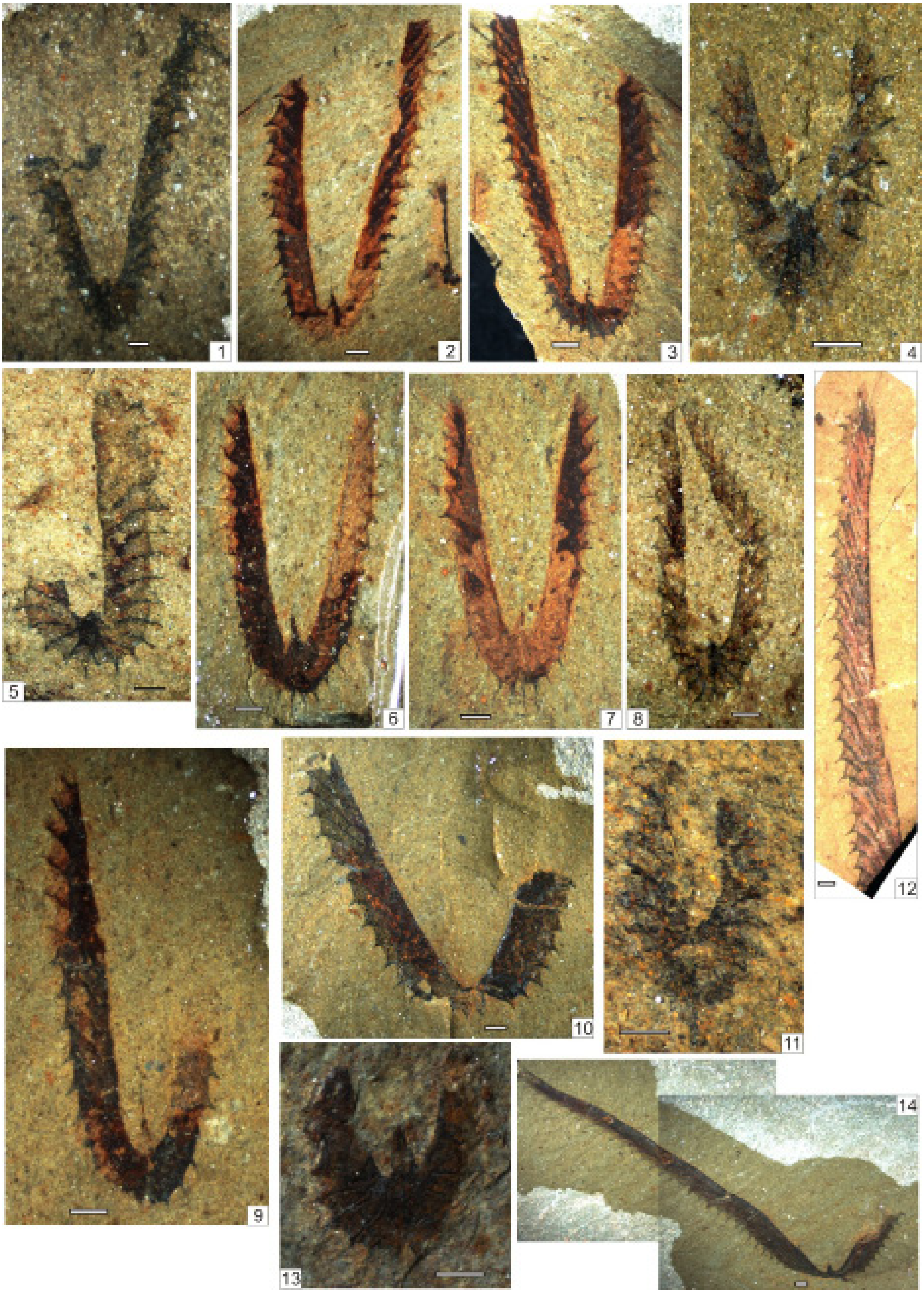
Figs 1, 2, 3, 11. *Isograptus gibberulus* (Nicholson):
1 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-096. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone; 2, 3 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -107a. Tuloi Formation, Dapingian, *I. gibberulus* Zone, I. *maximo-divergens* Subzone; 11 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -108. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 4, 6-9, 13. *Isograptus divergens* (Harris):
4 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-109. Tuloi Formation, Dapingian, *E. hirundo* Zone, *I. caduceus-imitatus* Subzone; 6, 7, 9, 13 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -107a. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone; 8 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -093. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 5. *Isograptus forcipiformis* (Ruedemann):
5 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-093. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 10, 12, 14. *Isograptus maximo-divergens* (Harris):
10, 14 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-109. Tuloi Formation, Dapingian, *E. hirundo* Zone, *I. caduceus-imitatus* Subzone; 12 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -093. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Plate 17



Graptolites

Plate 18

Graptolites from the localities in the northeastern part of Gorny Altai. Scale bar 1 mm.
Collections of Elena V. Lykova, Nikolay V. Sennikov.

Figs 1, 3. *Isograptus divergens* (Harris):
1 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-109. Tuloi Formation, Dapingian, *E. hirundo* Zone, *I. caduceus-imitatus* Subzone; 3 – the left bank of the Lebed' River, Pridorozhny Section, loc. B –107a. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 2, 4. *Isograptus walcottorum* Ruedemann:
2 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-096. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone; 4 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -093. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 5, 13. *Isograptus paraboloides* Tzaj :
5, 13 – the right bank of the Tuloi River, Tuloi Section, loc. B-118. Tuloi Formation, Dapingian, *E. hirundo* Zone.

Figs 6, 12. *Isograptus elegans* Tzaj:
6 – the right bank of the Tuloi River, Tuloi Section, loc. S-0724. Tuloi Formation, Dapingian, *E. hirundo* Zone; 12 – the left bank of the Lebed' River, Pridorozhny Section, loc. B -096. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Fig. 7. *Isograptus maximo-divergens* (Harris):
7 – the left bank of the Lebed' River, Pridorozhny Section, loc. B-108. Tuloi Formation, Dapingian, *I. gibberulus* Zone, *I. maximo-divergens* Subzone.

Figs 8, 9, 11. *Phyllograptus ilicifolius* Hall:
8, 9, 11 – the right bank of the Biya River, Yurok Section, loc. S-1118-4/5. Tuloi Formation, Floian, *Ps. angustifolius elongatus* Zone.

Fig. 10. *Phyllograptus anna longus* Ruedemann:
10 – the right bank of the Biya River, Yurok Section, loc. S-1118-4/5. Tuloi Formation, Floian, *Ps. angustifolius elongatus* Zone.

Plate 18

Graptolites

Plate 19

Graptolites from the localities in the western (Krasnoshchekovo and Maralikha villages, Charysh River) and northeastern (Tuloi, Lebed'and Biya rivers) parts of Gorny Altai. Scale bar 1 mm.

Collections of Elena V. Lykova, Nikolay V. Sennikov.

Figs 1, 2, 3, 4, 13. *Eoglyptograptus dentatus* (Brongniart):
1, 2, 3 – West of Krasnoshekovo Village, Batun Section, loc. S-813a. Voskresenka Formation, Darriwilian, *E. dentatus* Zone.

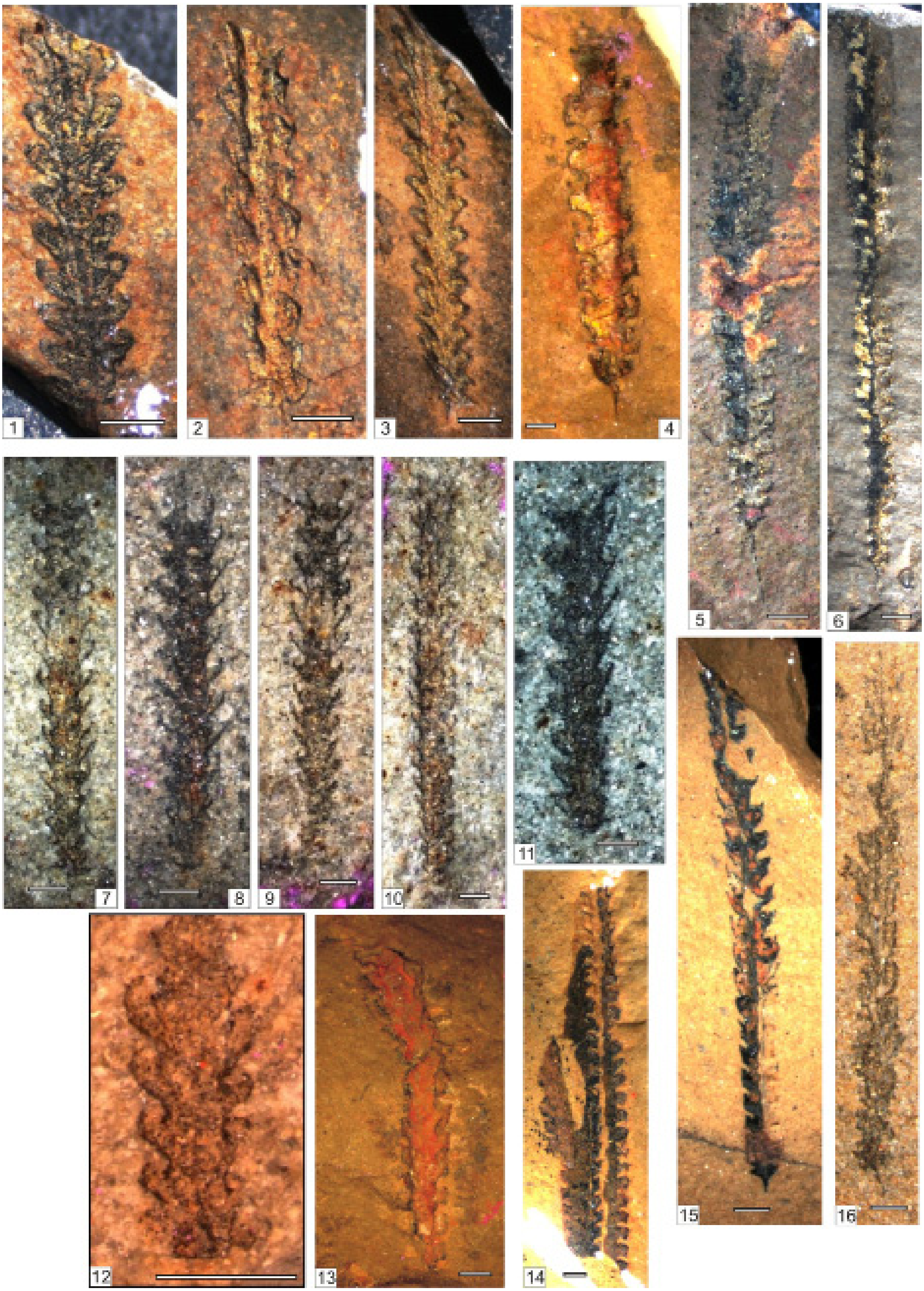
Figs 4, 13. *Amplexograptus confertus* (Lapworth):
4, 13 – the right bank of the Tuloi River, Tuloi Section, loc. LSS-409. Karasa Formation, Darriwilian, *E. dentatus* Zone.

Figs 5, 6, 14–16. *Hustedograptus teretiusculus* (Hisinger):
5, 6 – Former Stretinka Village, Lebed' River, Lebed' Section, loc. S-7546 (=R-254). Karasa Formation, Darriwilian, *H. teretiusculus* Zone; 14 - the right bank of the Biya River, Yurok Section, loc. S-1118-1/3. Tuloi Formation, Floian, *Ps. angustifolius elongatus* Zone; 15 - the right bank of the Biya River, Yurok Section, loc. S-1118-2/8. Tuloi Formation, Floian, *Ps. angustifolius elongatus* Zone; 16 – left bank of the Charysh River, Charysh Section, loc. S-804-6. Bugryshikha Formation, Darriwilian - Sandbian, *H. teretiusculus – C. peltifer, A. antiquus lineatus* zones.

Figs 7-11. *Undulograptus austrodentatus* (Harris et Keble):
7–10 – vicinity of Maralikha Village, Maralikha Section, loc. S-072. Voskresenka Formation, Darriwilian, *U. austrodentatus* Zone; 11 – vicinity of Maralikha Village, Maralikha Section, loc. S-0523. Voskresenka Formation, Darriwilian, *U. austrodentatus* Zone.

Fig. 12. *Undulograptus sinicus* (Mu et Lee):
12 – vicinity of Maralikha Village, Maralikha section, loc. S-072. Voskresenka Formation, Darriwilian, *U. austrodentatus* Zone.

Plate 19



Conodonts

Plate 20

Late Cambrian - Early Ordovician conodonts from the localities in the northern part of Gorny Altai, Kamlak Village, Kamlak Formation.

Collection of Tatyana Yu. Tolmacheva.

Figs 1, 2. *Iapetonudus* sp.:
The Kamlak Section, Member 10, Middle Kamlak Subformation, Lower Tremadocian.

Fig. 3. *Cordylodus lindstromi* Druce et Jones:
The Kamlak Section, Member 10, Middle Kamlak Subformation, Lower Tremadocian.

Figs 4, 5. *Cordylodus caseyi* Druce et Jones, emend. Landing:
The Kamlak Section, Members 9-10, Middle Kamlak Subformation, Upper Cambrian.

Figs. 6, 7. *Iapetognathus* sp.:
The Kamlak Section, Member 10, Middle Kamlak Subformation, Lower Tremadocian.

Fig. 8. *Hispidodontus* cf. *H. kulumbense* Tolmacheva et Abaimova:
The Kamlak Section, Members 2, Middle Kamlak Subformation, Upper Cambrian.

Figs 9, 13, 14. *Cordylodus proavus* Müller:
The Kamlak Section, Members 11, Upper Kamlak Subformation, Lower Ordovician.

Fig. 10. *Hirsutudontus simplex* (Druce et Jones, 1971):
The Kamlak Section, Members 2, Middle Kamlak Subformation, Upper Cambrian.

Fig. 11. *Hirsutudontus* sp.:
The Kamlak Section, Members 2, Middle Kamlak Subformation, Upper Cambrian.

Fig. 12. *Phakelodus tenuis* (Müller):
The Kamlak Section, Members 9, Lower Kamlak Subformation, Upper Cambrian.

Figs 15, 16. *Westergaardodina* sp.:
The Kamlak Section, Members 5, Lower Kamlak Subformation, Upper Cambrian.

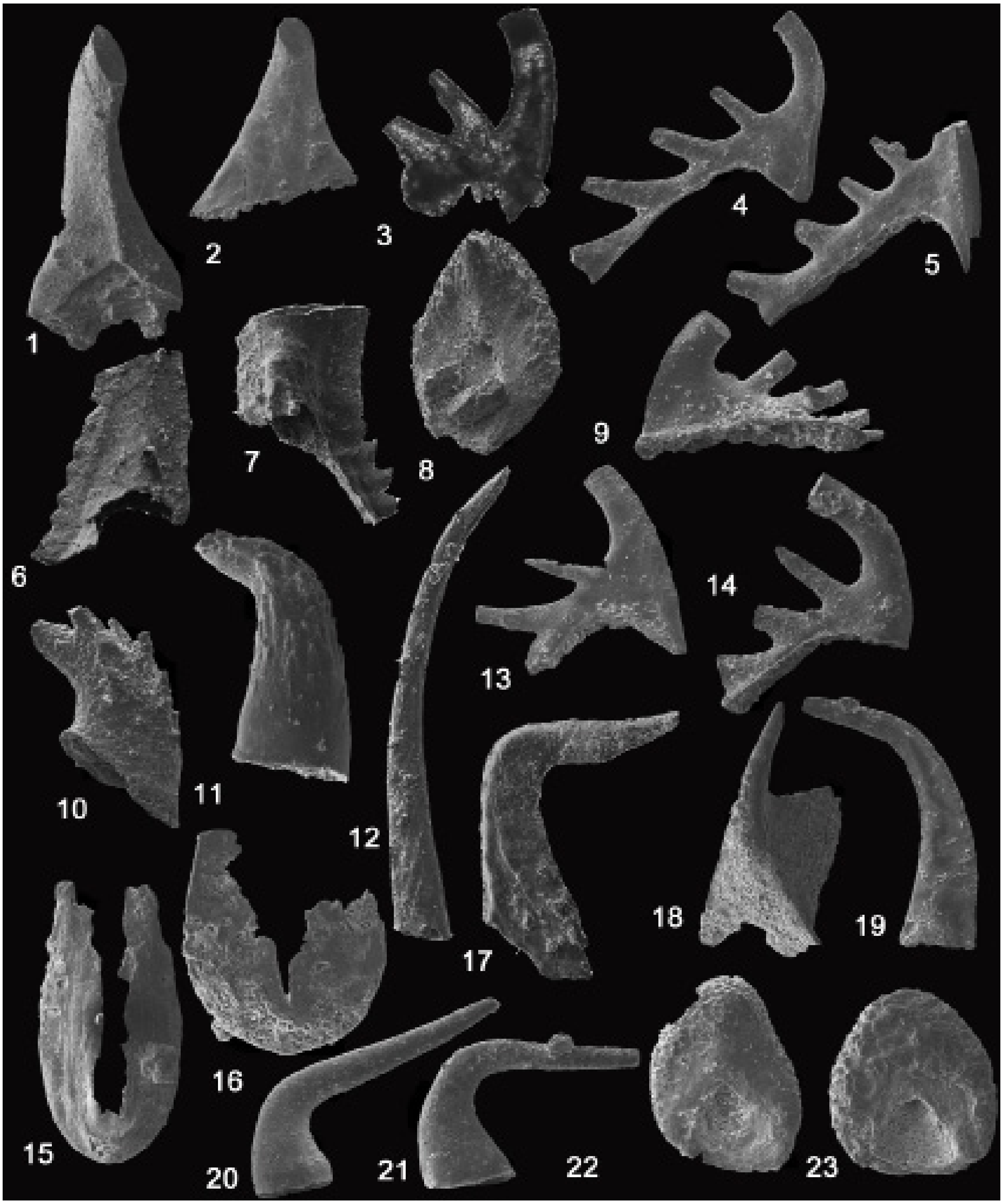
Figs 17, 19. *Eoconodontus notchpeakensis* (Miller):
The Kamlak Section, Members 9-10, Middle Kamlak Subformation, Upper Cambrian.

Fig. 18. *Furnishina furnishi* Müller:
The Kamlak Section, Members 5, Lower Kamlak Subformation, Upper Cambrian.

Figs 20, 21. *Semiacontiodus* sp.:
The Kamlak Section, Members 9-10, Middle Kamlak Subformation, Upper Cambrian.

Figs 22, 23. *Hispidodontus* cf. *triangularis* (Abaimova, 1975):
The Kamlak Section, Members 9-10, Middle Kamlak Subformation, Upper Cambrian.

Plate 20



Conodonts

Plate 21

Late Ordovician conodonts from the localities in the northeastern part of Gorny Altai, Lebed', Biya and Bura rivers, Gur'yanovka Formation.

Collections of Tatyana Yu. Tolmacheva and Olga T. Obut

Figs 1–4, 9. *Phragmodus undatus* Branson et Mehl:
1–3, 9 – the Lebed' Section, Member 13, Gur'yanovka Formation, Sandbian; 4 – the Biya Section, Member 20, Gur'yanovka Formation, Sandbian.

Figs 5-8. *Belodina compressa* (Branson et Mehl):
5, 7, 8 - the Lebed' Section, Member 13, Gur'yanovka Formation, Sandbian; 6 – the Biya Section, Member 3, Gur'yanovka Formation, Sandbian.

Figs 10-16. *Scandodus* sp.:
10–14 – the Lebed' Section, Member 13, Gur'yanovka Formation, Sandbian, 15–16 – the Bura Section, Member 10, Gur'yanovka Formation, Sandbian.

Figs 17-19. *Drepanodus* sp.:
the Bura Section, Member 10, Gur'yanovka Formation, Sandbian.

Fig. 20. *Erraticodon* sp.:
the Biya Section, Member 20, Gur'yanovka Formation, Sandbian.

Fig. 21. *Aphelognathus* sp.:
the Lebed' Section, Member 13, Gur'yanovka Formation, Sandbian.

Fig. 22. *Drepanoistodus suberectus* (Branson et Mehl):
the Lebed' Section, Member 13, Gur'yanovka Formation, Sandbian.

Fig. 23. *Panderodus* cf. *P. gracilis* (Branson et Mehl):
the Lebed' Section, Member 13, Gur'yanovka Formation, Sandbian.

Plate 21

Conodonts

Plate 22

Late Ordovician conodonts from the locality in the northwestern part of Gorny Altai, Siliceous-terrigenous Body, Katian, the Suetka Section, Member 1. Scale =100 µm.

Collections of Tatyana Yu. Tolmacheva and Olga T. Obut.

Figs 1–3, 6. *Periodon grandis* (Ethington):
1 – Sc element, 2 – Sc element, 3 – Sd element, 4 – M element.

Figs 4, 5. *Histiodella* sp.:
8 – P element, 9 – S element.

Figs 7, 8. *Panderodus* sp.

Figs 9, 13, 14. *Paroistodus*? *mutatus* (Branson et Mehl):
7 – M element, 11, 12 – S elements.

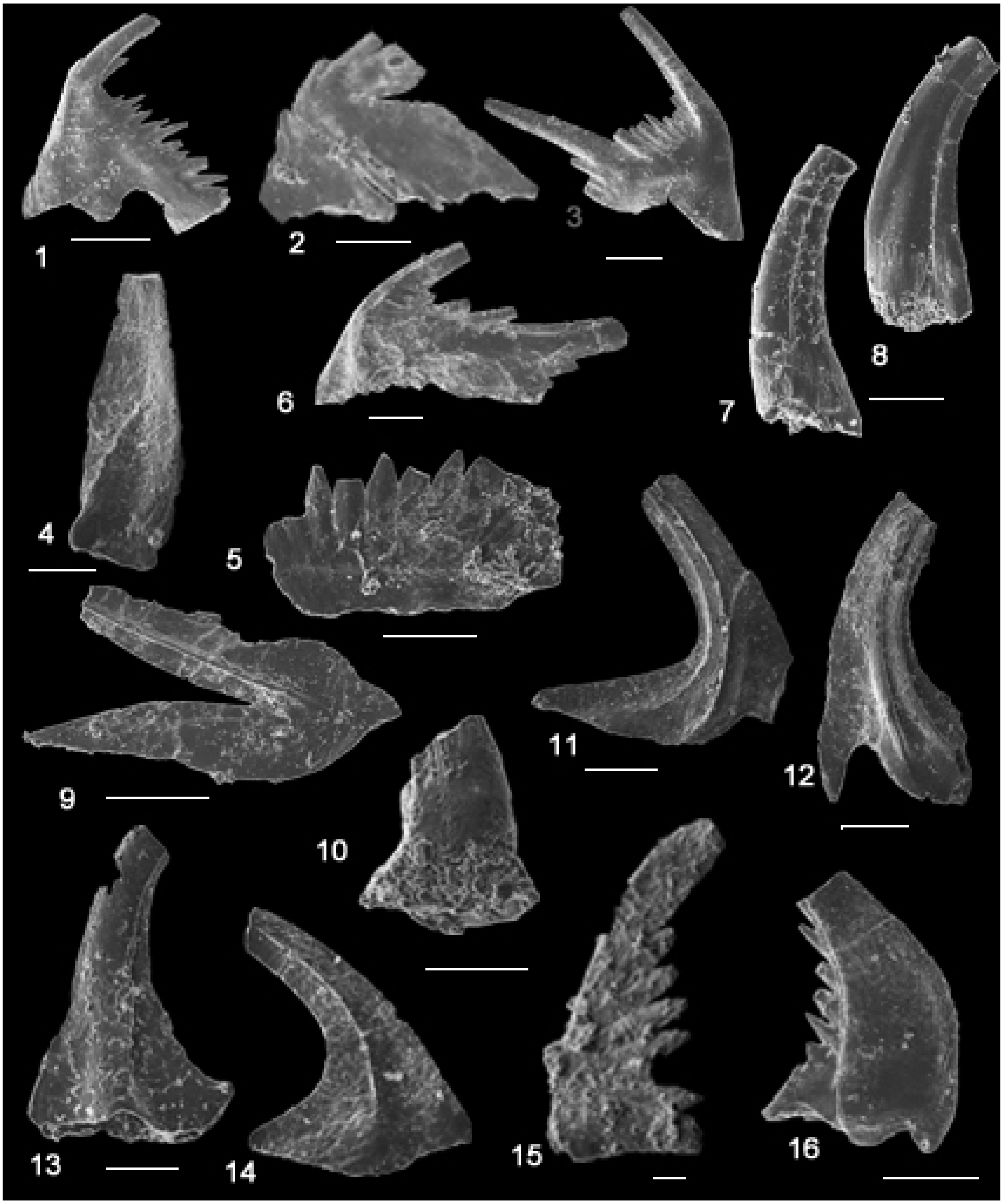
Fig. 10. *Decoriconus* sp.

Figs 11, 12. *Protopanderodus insculptus* (Branson et Mehl).

Fig. 15. *Belodina compressa* (Branson et Mehl).

Fig. 16. *Belodina* sp.

Plate 22



Conodonts

Plate 23

Middle Ordovician conodonts from the Teletskoe Lakeside area, eastern Gorny Altai, Samysh Body, Darriwilian. Specimens illustrated on figs 1, 2, 4–10, 12, 15, 16, 18 - from locality on the right bank of Samysh River. Specimens illustrated on figs 3, 11, 13, 14, 17, 19, 20 – from locality on Nizhniy Turochak Brook, right tributary of the Iogach River. Scale = 200 µm.

Collections of Olga T. Obut.

Figs 1–4. *Acodus* sp.
1, 2 – Sd elements, 3, 4 – M elements.

Figs 5, 9, 10. *Drepanoistodus* cf. *arcuatus* Pander:
5, 9 – S elements, 10 – P element.

Figs 6–8, 13 – *Periodon* sp.:
6, 7 – S elements, 8, 13 – M elements.

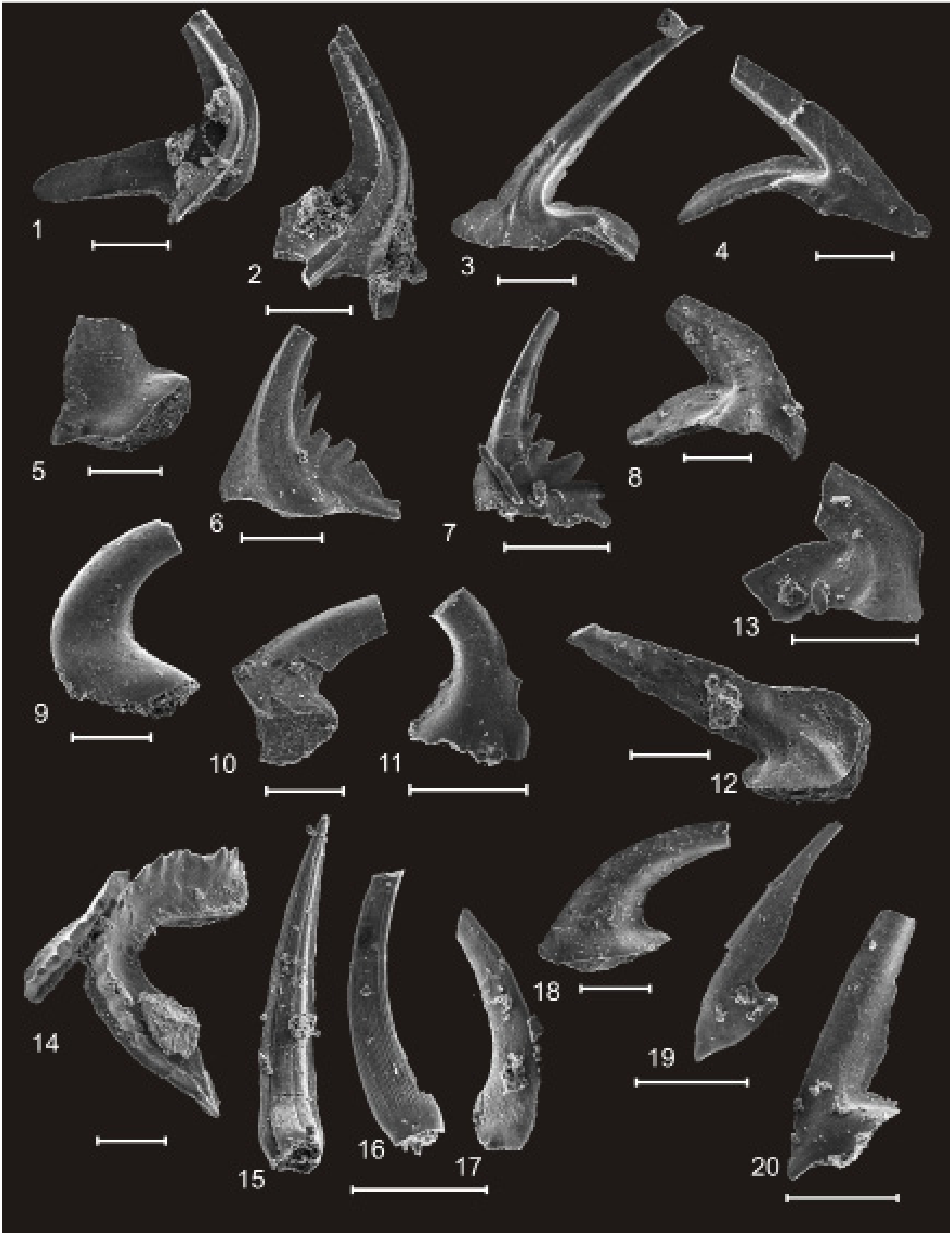
Fig. 11. ? *Drepanodus* sp.

Figs 12, 18–20. *Drepanoistodus* sp.:
12 – M element, 18–20 – S elements.

Fig. 14. *Eoplacognathus* sp.:
Pa element.

Figs. 15–-17. *Parapanderodus striatus* (Graves et Ellison).

Plate 23



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