Russian Geology and Geophysics © 2019, V.S. Sobolev IGM, Siberian Branch of the RAS
Vol. 60, No. 4, pp. 451–471, 2019 *DOI:10.15372/RGG2019031* *Geologiya i Geofizika*

Silurian Terrigenous-Carbonate Sedimentaion in Gorny Altai: Structure, Facies Variability, Faunal Assemblages, and Stratigraphic Position

N.V. Sennikov[a,b,✉], R.A. Khabibulina[a], O.T. Obut[a,b], N.V. Novozhilova[a,b], D.A. Tokarev[a,b], V.A. Luchinina[a]

[a] *A.A. Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, pr. Akademika Koptyuga 3, Novosibirsk, 630090 Russia*

[b] *Novosibirsk State Universtity, ul. Pirogova 2, Novosibirsk, 630090 Russia*

Received 25 January 2018; received in revised form 19 April 2018; accepted 25 April 2018

Abstract—This paper discusses the structure and facies variability of the Silurian mixed terrigenous-carbonate strata and presents new paleontological and biostratigraphic data. It attempts to refine the stratigraphic position and provide new lithologic evidence (markers) for regional manifestations of global sedimentary events (Mulde transgressive-regressive and Linde regressive events) in the Altai sections. The chronostratigraphic position of the Kuimov Horizon, a regional stratigraphic unit, has been defined based on graptolite and conodont faunas.

Keywords: Silurian, Homerian, Gorstian, Ludfordian, event stratigraphy, Gorny Altai

INTRODUCTION

The Silurian is one of the shortest periods in the Phanerozoic history of Earth spanning 24.6 Myr (Gradstein et al., 2012). At the same time, the General Stratigraphic Scale accepted and used in Russia has currently defined the Upper Silurian as a subsystem (Resolutions..., 2013; Sennikov et al., 2013), spanning a chronostratigraphic interval of only 8.2 or 4.4 Myr of the Ludlow Epoch (1.8 Myr Gorstian Age and 2.6 Myr Ludfordian Age) and 3.8 Myr of the Přídolí Epoch (Gradstein et al., 2012).

Silurian strata are widespread in the Gorny Altai region. Extensive outcrops of Silurian rocks occur in the Charysh–Inya and Anui–Chuya facies zones in the western and central parts of the region (Fig. 1). During the first half of the Silurian, the Altai sections are represented by alternation of terrigenous (Vtorye Utesy, Syrovatyi and Chesnokovka Formations) and carbonate, including reefal (Polati and Chagyrka Formations) complexes. The second half of the Silurian is characterized by a change in the general patterns of sedimentation in favor of mixed terrigenous-carbonate sediments (Kuimov Formation).

SILURIAN GLOBAL SEDIMENTARY AND BIOTIC EVENTS

The Late Silurian stage of the history of sedimentary basins of the world and organisms inhabiting them has a number of specific characteristics. First, a large regressive episode interrupted by recently identified relatively short periods of transgression started after a worldwide and extensive Early Silurian transgression with relative sea-level highstand maxima in the latest Telychian and latest Sheinwoodian (Kaljo et al., 1996; Lehnert et al., 2010; Munnecke et al., 2010; Gradstein et al., 2012). A total of four globally recognized transgressive-regressive sedimentary events have been described during the Late Silurian: Mulde, Linde, Lau, and Klev events (Kaljo et al., 1996; Lehnert et al., 2007, 2010; Calner, 2008; Gradstein et al., 2012; Slavik et al., 2014) (Fig. 2).

Secondly, an overall marine regression punctuated by rapid pulses of transgression resulted in deposition of both laterally and stratigraphically variable rock associations in the Late Silurian basins, which reflect changes in the depositional facies (paleoenvironments). In this regard, the observed changes in benthic communities in a single stratigraphic section can rather be ascribed to evolutionary shifts than changes in paleogeographic conditions. As a result, this involves difficulties in discriminating between typical Gorstian and Ludfordian (Ludlow) benthic groups.

Thirdly, the Late Silurian period also coincided with significant ecological reorganizations and drastic transformations in the structure and composition of the elements of biosphere in the transition from the Lower Paleozoic to Upper Paleozoic biotas. Marine ecosystems became dominated by a variety of pelagic nektonic groups of organisms; the expansion of vertebrates took place during this time interval as well. This time was also characterized by the formation

✉ Corresponding author.
E-mail adress: SennikovNV@ ipgg.sbras.ru (N.V. Sennikov)

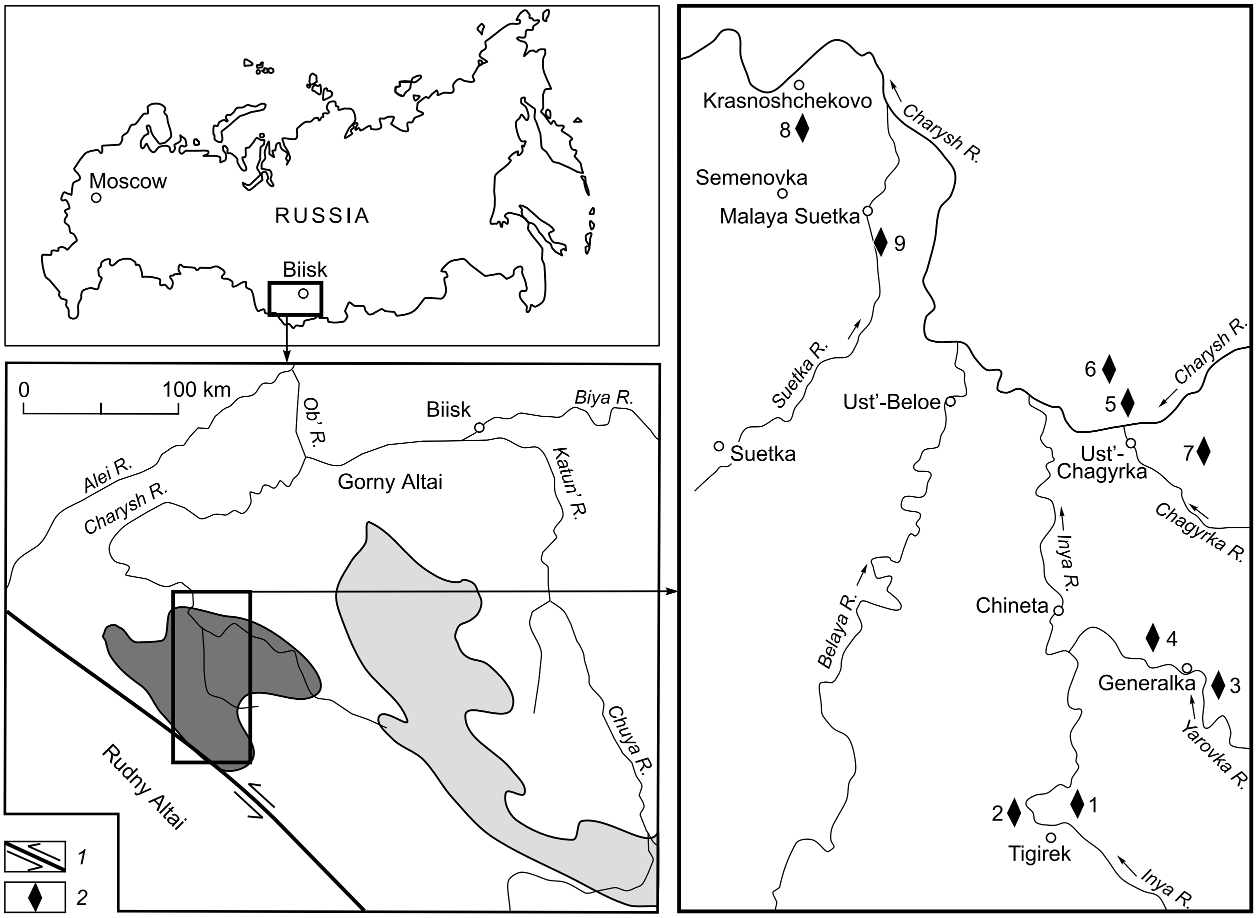

Fig. 1. The occurrence of Silurian rocks of Gorny Altai and location of the studied sections. *1*, zones of displacement of major regional blocks; *2*, sections: 1, Tigirek (incl. Tigirek coastal), 2, Klubnichnyi, 3, Generalka, 4, Generalka slope, 5, Charyshskii Utes, 6, Gornyi Klyuch, 7, Chagyrka right bank, 8, Pautikha, 9, Malaya Suetka. Silurian outcrops in the Charysh–Inya and Anui–Chuya facies zones are shown in black and gray color, respectively.

of continental paleobiotas (both floristic and faunistic components.

The Mulde biotic event (carbon isotope excursion, CIE) near the Homerian/Gorstian boundary (Wenlock/Ludlow) was correlated with the parvus–nassa graptolite Zone and Ozarkodina bohemica longa conodont Zone (Lehnert et al., 2007, 2010; Calner, 2008; Jarochowska et al., 2013; Castagner et al., 2015). The Silurian sections in Western Europe (Thuringia, Sardinia) are characterized by the presence of thin shale interlayers at the top of the Wenlock (Jaeger, 1991). The early part of the Mulde event correlates with a sea-level **lowstand,** while its lower part with a **highstand** with an estimated 16-m rise in sea level (Calner, 2008; Lehnert et al., 2010). The lundgreni extinction event (at the top of the lundgreni graptolite Zone and in the parvus–nassa Zone) also correlates with the Mulde event (Koren' and Urbanek, 1994; Storch, 1995; Koren' et al., 2000, 2006; Sadler et al., 2011).

Sedimentary evidence for the Linde regressive event (Late Gorstian–Early Ludfordian) is recorded at the top of the scanicus graptolite Zone and at the base of the lentwardinensis graptolite Zone (middle part of the A. ploekensis conodont Zone). The Linde event corresponds to a sea-level **lowstand** (Kaljo et al., 1996; Lehnert et al., 2007, 2010; Calner, 2008; Gradstein et al., 2012; Sullivan et al., 2018). As regards the composition of graptolite communities, they became affected by lentwardinensis extinction event at this level (Urbanek, 1993; Storch, 1995; Koren' et al., 2006).

The mid-Ludfordian Lau transgressive Event recorded above the base of the Bohemograptus bohemicus graptolite Zone and below the base of the Ozarkodina snajdri conodont Zone corresponds to a period of sea-level **highstand**. The term Lau event is commonly used only for the biotic extinction (conodonts, graptolites) (Urbanek, 1993), and sometimes the term Kozlowskii Event may be used; it was named for the graptolite zone, at the top of which it is most pronounced (Kozlowskii Event—the formosus Zone or the "fragmentalis" Zone) (Storch, 1995; Koren' et al., 2006; Slavik et al., 2014). Major carbon (CIE) and oxygen isotope excursions were recorded later than the Lau Event (Lehnert et al., 2007, 2010; Calner, 2008; Munnecke et al., 2010; Cramer et al., 2011; Gradstein et al., 2012; Slavik et al.,

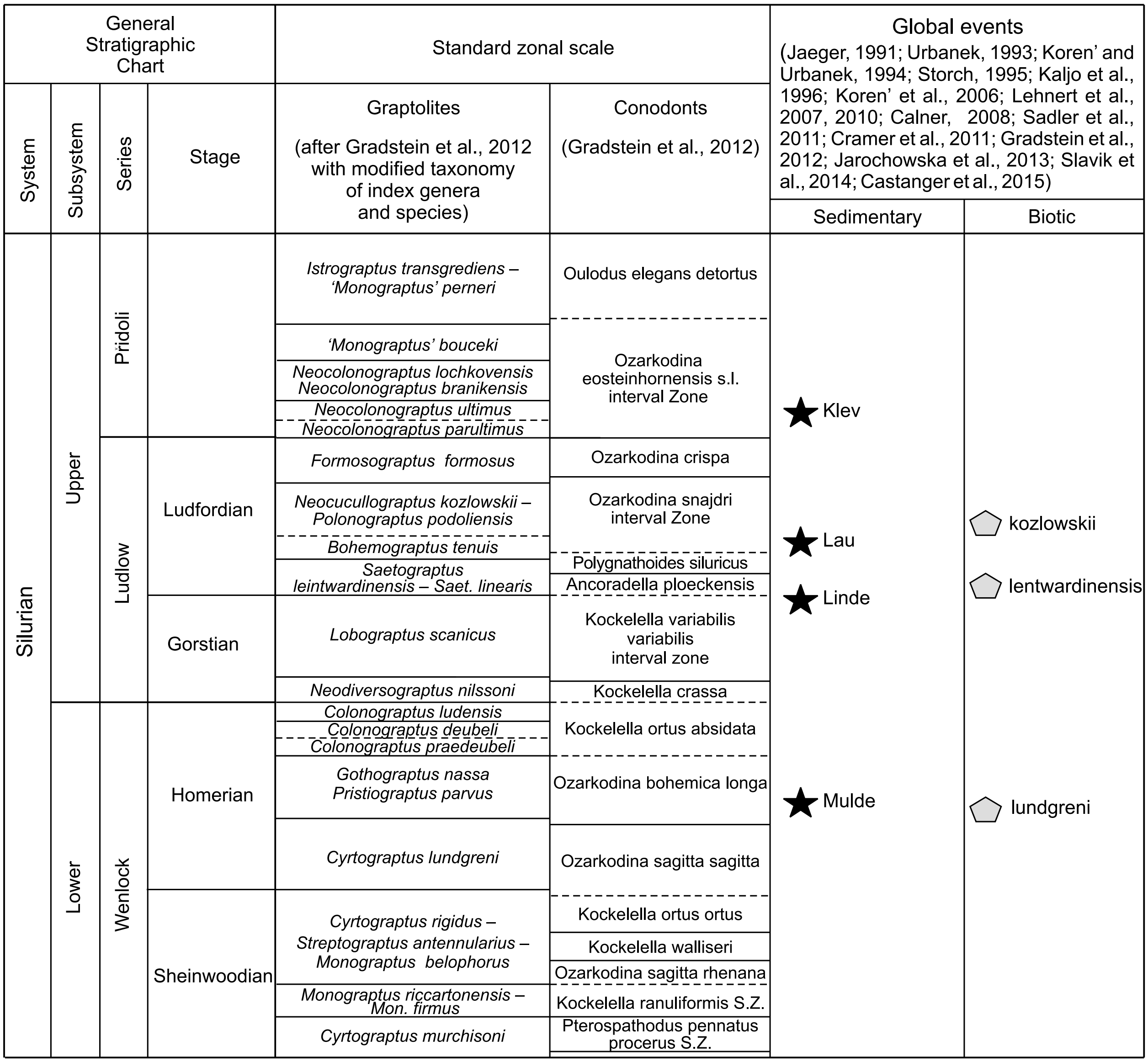

Fig. 2. Stratigraphic position of global sedimentary and biotic events in the Wenlock, Ludlow, and Přídolí Series of the Silurian.

2014). According to various researchers, a 30-m sea-level rise occurred between the Linde and Lau Events (Calner, 2008; Lehnert et al., 2010).

The Klev regressive event is located in the lowermost **Přídolí** at the ultimus graptolite Zone and equates with a sea-level **lowstand** (Kaljo et al., 1996; Lehnert et al., 2007, 2010; Calner, 2008; Gradstein et al., 2012).

LOCAL AND REGIONAL STRATIGRAPHIC UNITS IN THE UPPER PART OF THE SILURIAN OF ALTAI

The upper part of the Silurian sedimentary sequence in the western part of Gorny Altai is composed of terrigenous-carbonate rocks attributed to the Kuimov Formation. This formation is exposed in the Charysh–Inya and Anui–Chuya facies zones of Gorny Altai (Fig. 1). In Salair, this stratigraphic level is occupied by the Potapov Formation. The most representative sections of the Kuimov Formation and its stratotype are located in the Charysh–Inya Zone of western Gorny Altai. In the earlier studies, the entire Silurian section of Gorny Altai was divided into the Chineta (Podchagyrka) terrigenous and Chagyrka carbonate formations, attributable respectively to the Lower and Upper Silurian (Bublychenko, 1936; Stratigraphic..., 1956; Stratigraphy..., 1965; Vladimirskaya and Zheltonogova, 1967). The carbonate sections located on the right bank of the Charysh River directly across the village of Ust'-Chagyrka (stratotype), on the right bank of the Chagyrka River in its lower reaches, on the Inya River (left tributary of the Charysh River) near the villages of Talyi and Tigirek, on the Yarovka River near the Generalka Village (Bartseva and Perfil'ev, 1957; Perfil'ev, 1959; Stratigraphy..., 1965; Stratigraphic..., 1975), as well as some sections in the Anui–Chuya facies zone of Gorny

Altai were attributed to the Chagyrka Formation (Chagyrka limestones) of the Charysh–Inya facies zone of Altai.

The Chagyrka stratigraphic unit is divided into two parts: the lower, composed entirely of limestone, and the upper, represented by limestones and siltstone (Stratigraphic..., 1975). The Chagyrka Horizon previously ascribed to the Ludlow of the Upper Silurian was recognized on the evidence of faunal remains from the Chagyrka Formation (Stratigraphy..., 1965; Vladimirskaya and Zheltonogova, 1967), but it was later correlated with the Wenlock and Ludlow (Stratigraphic..., 1975). In the adopted stratigraphic scheme of the Silurian of Gorny Altai (Decisions..., 1983), the Chagyrka Horizon is correlated with the Wenlock (now Sheinwoodian and Homerian).

The Kuimov stratigraphic unit was proposed by Kul'kov (1966, 1967) as an independent local stratigraphic subdivision to distinguish the upper part of the Chagyrka Formation, which has a specific terrigenous-carbonate lithology and contains a diverse Ludlow (Late Silurian) assemblage of fossils (tabulate and rugose corals, stromatoporoids, brachiopods, and trilobites), differing from the Early Silurian assemblage from the Chagyrka Formation stratotype. Thus, the Chagyrka Formation (and, correspondingly, the Chagyrka Horizon) became assigned to the Wenlock of the Lower Silurian. It has been recently shown (Sennikov et al., 2014) that the Chagyrka Horizon should be equated only with the Scheinwoodian Stage of the Wenlock Series.

The stratotype section of the Kuimov Formation is at the Tigirek Village (Fig. 1), near the Kuimov Creek, the right tributary of the Inya River) and in the vicinity of the former Komsomolets Settlement (Kul'kov, 1966, 1967; Yolkin et al., 1974; Ivanovskii and Kul'kov, 1974).

The Kuimov Horizon was proposed as a regional stratigraphic unit by Ivanovskii and Kul'kov (1974). This horizon was previously correlated (Ivanovskii and Kul'kov, 1974; Stratigraphic..., 1975; Decisions..., 1983; Sennikov et al., 2008) with the entire Ludlow, now regarded as the Ludlow Series (Gorstian and Ludfordian stages). It has been suggested recently (Sennikov et al., 2014) that the Kuimov Horizon spans the Homerian stage (Wenlock) and the Ludlow Series.

Within the Anui–Chuya facies zone of Gorny Altai, the Kuimov Formation is overlain by the Chernyi Anui Formation, correlated with the Přídolí Series of the Silurian. It should be noted that the Maragda Formation was proposed to be recognized in this part of Altai as a local stratigraphic unit separating the Kuimov Formation from the overlying Chernyi Anui Formation (Mironova, 1978; Stratigraphic..., 1991). Since there was no compelling geological evidence (State..., 2001a,b), it can be regarded as a Maragda member of the Kuimov Formation (Sennikov et al., 2014).

NEW LITHOLOGICAL AND BIOSTRATIGRAPHIC DATA

Exposures of the Kuimov Formation in the Charysh–Inya facies zone of Altai were, until recently, limited to the upper reaches of the Inya River near Tigirek (Kul'kov, 1966, 1967; Yolkin et al., 1974; Stratigraphic..., 1975; Deci-

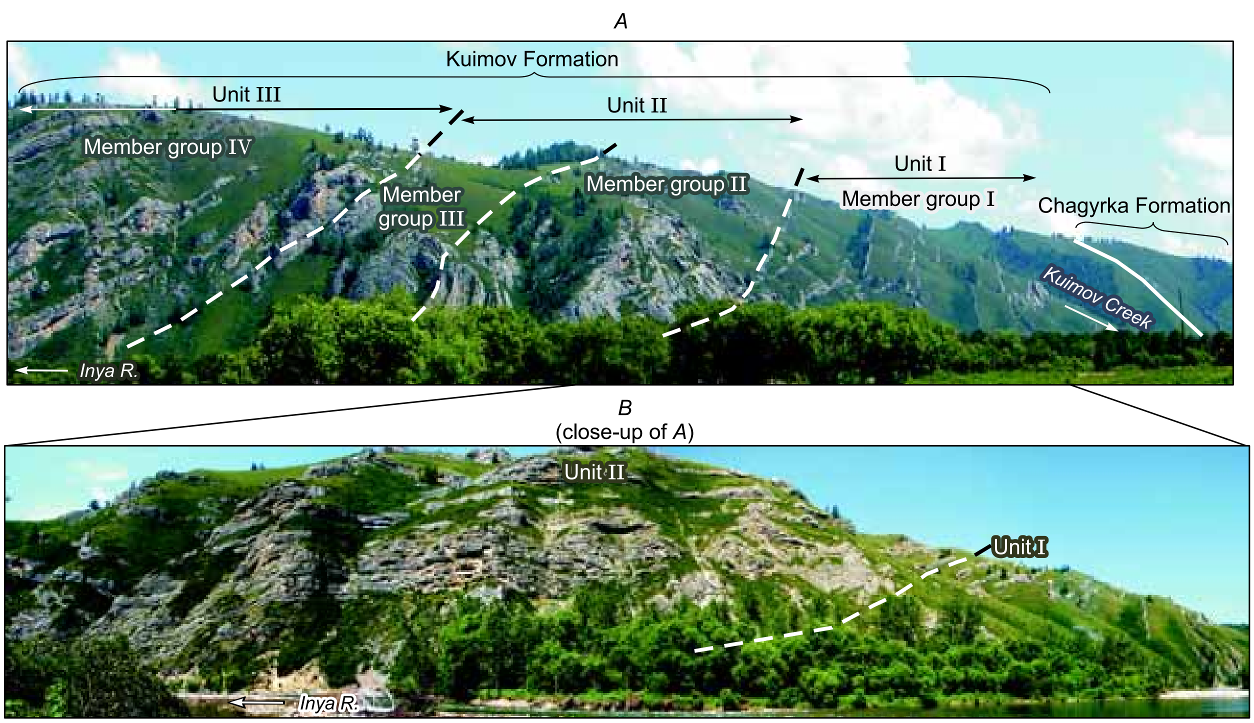

Fig. 3. The panoramic view of the Tigirek section (*A*, general; *B*, Tigirek coastal).

sions..., 1983). Later, several outcrops of the Kuimov Formation were documented to the north of Tigirek Settlement, in the middle course of the Yarovka River (right tributary of the Inya River) (Sennikov et al., 1988) and, subsequently, in the foothills of Altai near the Krasnoshchekovo Village (Sennikov et al., 2001b; Sennikov et al., 2008) (Fig. 1).

In 2012–2017, each of the previously described localities of the Kuimov Formation in the Charysh–Inya facies zone has been examined by the authors of the present study and several new ones have been found. Analysis and synthesis of all data form the basis of this paper.

The **Tigirek (Kuimov) section** is a stratotype section of the Kuimov Formation. It is located on the right bank of the Inya River, upstream of Tigirek, near the Kuimov Creek, as well as on the left and right sides of this creek and along the right side of the Inya River, below the mouth of the creek. The section was studied in different years by various researchers (Kul'kov, 1966, 1967; Yolkin et al., 1974). The best exposed part of the stratotype is in the cliffs on the right bank of the Inya River (Fig. 3).

In the stratotype section of the Kuimov Formation, Kul'kov (1967) identified four groups of members, which constitute three parts of this formation (Fig. 4). The lower part (member group I according to N.P. Kul'kov) is composed of interbedded limestone and calcareous siltstone, the middle part (member groups II and III according to N.P. Kul'kov) consists of thick- to medium-laminated limestone, and the upper part (member group IV according to N.P. Kul'kov) represents the interlayering of thin- and thick-laminated limestone. These parts of the stratotype sufficiently differ from each other and in faunal assemblages. The lower part of the formation in the stratotype section yielded brachiopods, such as *Schelwienella williamsi* Kulk., *Didymothyris didyma* (Dalm.), *Ferganella borealis* (Schloth.), *Lissatrypa operosa* Kulk., *Stegerhynchus nuculus* (Sow.); tabulate corals *Parastriatopora* ex gr. *mutabilis* Tchern.; *Paleofavosites* ex gr. *lichenaroides forbesiformis* Sok., *Favosites* ex gr. *lichenarioides* Sok., *Parastriatopora* ex gr. *mutabilis* Tchern., *Halysites* sp., *Mesofavosites nigeranuensis* Miron.; rugose corals *Lamprophyllum* sp., *Tryplasma flexiosum* (L.), *Cystiphyllum siluriense* Londs.; stromatoporoids *Actinostroma* ex gr. *intertextum* Nich.; the middle part of the formation yielded brachiopods *Conchidium knighti* (Sow.), *Lissatrypa operosa* Kulk., *Leptaena* ex gr. *rhomboidalis* (Wilck.), *Ferganella borealis* (Schloth.); tabulate corals *Squameolites squamiger* Bond., *Favosites* ex gr. *mammilatus* Tchern., *Coenites* sp., *Parastriatopora* ex gr. *mutabilis* Tchern., *Mesofavosites nigeranuensis* Miron.; rugose corals *Tryplasma* ex gr. *hedstroemi* (Wdkd), *Chavsakia* ex gr. *chavsakiensis* Lavr.; stromatoporoids *Actinostrophia* aff. *skalense* Riab., *Actinostrophia* cf. *astroites* Rosen.; the upper part of the formation yielded brachiopods *Conchidium knighti* (Sow.), *Stegerhynchus nuculus* (Sow.), *Ferganella borealis* (Schloth.); tabulate corals *Parastriatopora* ex gr. *mutabilis* Tchern.; rugose corals *Spongophylloides* sp., *Carinophyllum confusum* (Pocta), *Lamprohyllum* ex gr. *degeeri* Wdkd, *Entelophyllum articulatum* (Wahl.); stromatoporoids *Syringostroma (Densastroma) podolicum* Yavor. (Kul'kov, 1967). Note that *Conchidium knighti* (Sow.) of a Ludlow age, the most common taxon of the brachiopod assemblage, which was taken as a basis for distinguishing the Kuimov Formation (Kul'kov, 1966, 1967), appears in the second part of the stratotype section.

The above three parts of the stratotype section of the Kuimov Formation can be considered as three informal units of this formation. However, it should be noted that, as discussed below, a combination of lithologic and paleontological criteria suitable for a strict subdivision of the formation into three units is not easily distinguished in all sections of the Kuimov Formation at a distance from its type locality. However, for subdividing formations into a number of units this can be recommended practice (The Stratigraphic..., 2006). Each unit of the Kuimov Formation is recognized by the following distinct lithological features: the presence of mudstone and siltstone members and layers (Unit I); the presence of massive layers of limestone, sometimes with algal bioherms (Unit II), and a well-defined rhythmic structure of members of thin-, medium- to thick-laminated carbonate rocks.

The study of the boundary interval between units I and II of the Kuimov Formation in the type section on the right bank of the Inya River showed (Fig. 5) the following observations. Unit I of the Kuimov Formation, in the **Tigirek coastal** section, contains terrigenous material in the form of rather thick (3–5 to 7 m) layers of highly calcareous yellowish-gray mudstone with thin flaggy bedding (Fig. 6*h*). Mudstones occur between members of argillaceous limestones. At the base of Unit II of the Kuimov Formation (Fig. 6*d*), the following varieties of limestones are present: (1) massive, to weakly laminated ("pure"), (2) laminated, slightly argillaceous, and (3) lumpy, nonlaminated, argillaceous. The contact between massive and argillaceous limestone is sharp. Algal bioherms, some 0.2–0.5 m thick and up to 3–5 m across, are found at a higher stratigraphic level, growing on top of each other. On a large scale, they have medium-sized convex-upward layered structure, usually characterizing the central zones of reef buildups. Silicified hardground surfaces (hard-ground) with abundant faunal remains (Fig. 6*f*) may develop in places. The presence of hardgrounds indicates short periods of interrupted sedimentation, followed by precipitation of silica (increased concentration).

Klubnichnyi section. This section is located 1–1.5 km away from the Tigirek section, being its western extension, complicated by displacements. The Kuimov Formation in the upper part of this section was first described by Yolkin et al. (1974). The faunal characteristics of the section were later documented in more detail (Bazarova, 1984, 1990; Bakharev and Bazarova, 2004; Sennikov et al., 2008). A detailed description of the individual members of this section was provided in our previous studies (Fig. 7*A*). Several

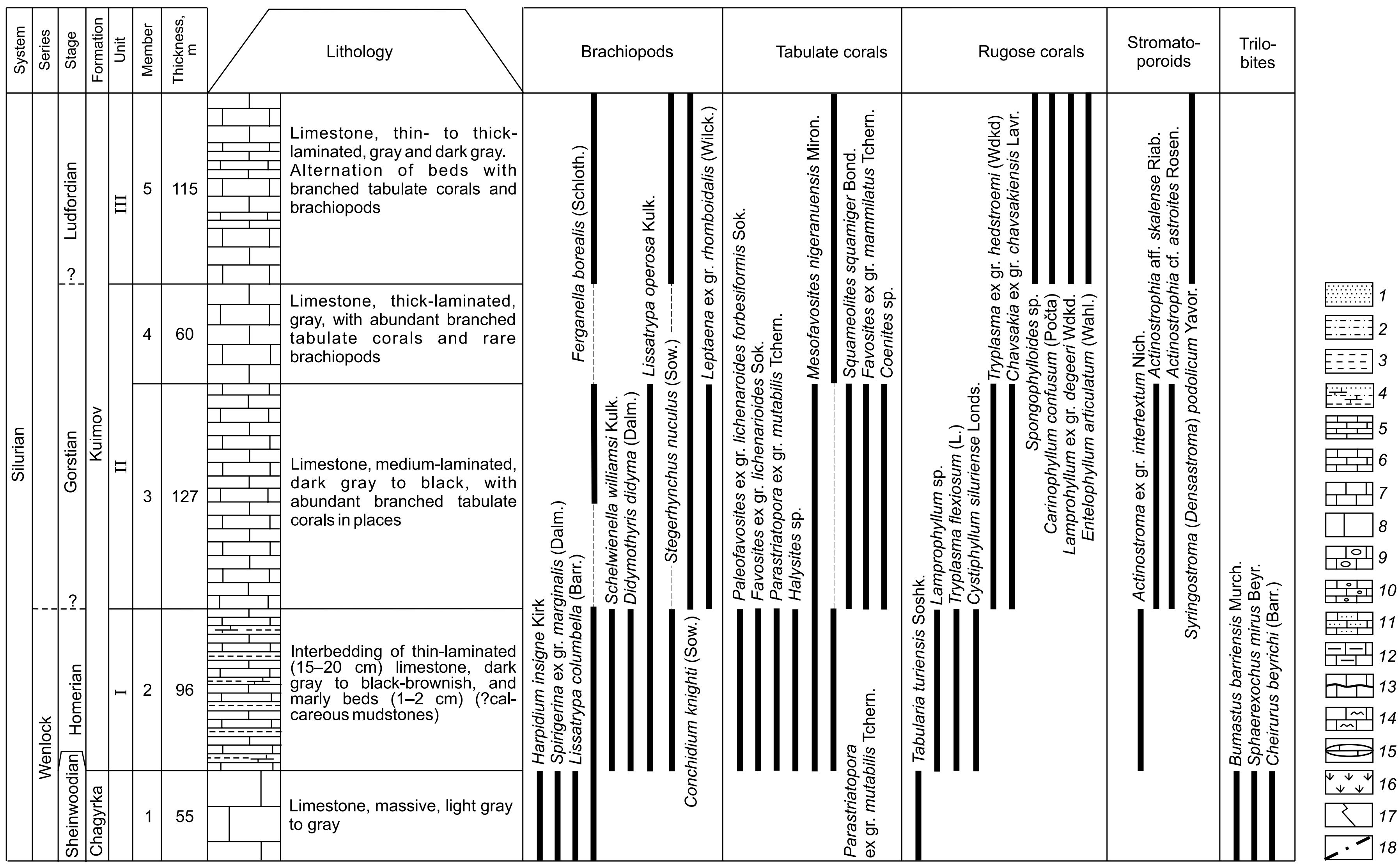

Fig. 4. Lithology and faunal occurrence of the Tigirek section. *1*, sandstone; *2*, siltstone; *3,* mudstone; *4,* calcareous terrigenous rock; *5–14*, limestone: *5*, thin-laminated, *6*, medium-laminated, *7*, thick-laminated, *8*, massive, nonlaminated, *9,* syngenetic breccia and conglomerate/breccia, *10,* with gravel, *11*, with sand, *12*, argillaceous, *13*, wavy-bedded, *14*, bioherm; *15*, limestone lenses; *16,* sodded intervals; *17*, abrupt facies change; *18*, faults.

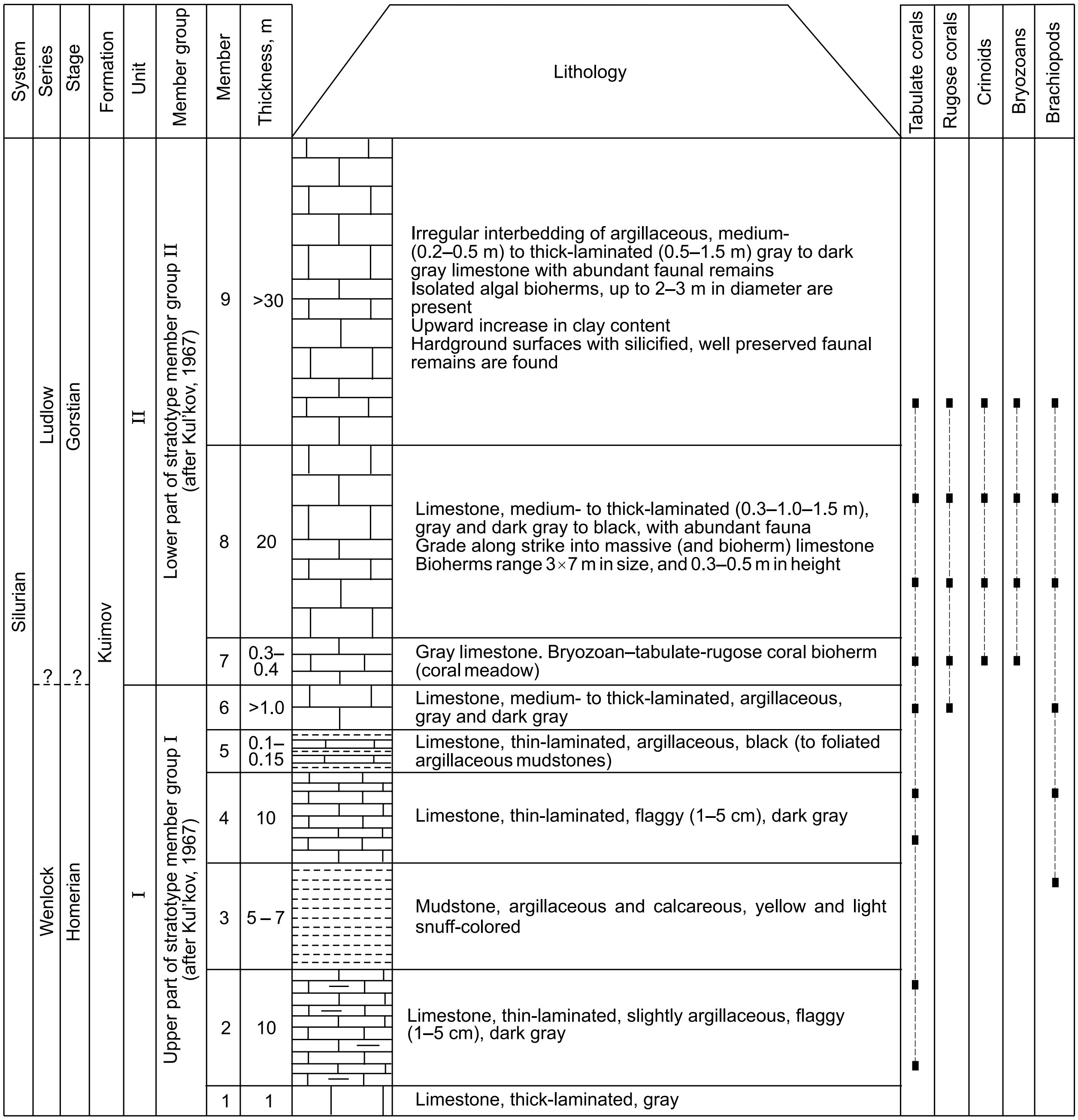

Fig. 5. Lithology and faunal occurrence of the Tigirek coastal section. For legend see Fig. 4.

packages of the rhythmically interbedded (without separate layers with terrigenous material) varieties are a common feature of the Klubnichnyi section (up-section): (a) lumpy, nonlaminated, highly argillaceous limestone, (b) laminated (from 3–5 to 15 cm), slightly argillaceous limestone, (3) massive, "pure" limestone with thick (0.5–1 m) flaggy bedding (Fig. 6*a*, *b*). On some hardgrounds, all organic remains are silicified. It can be stated, on both lithologic (rhythmic structure) and faunal grounds, that this section contains the exposures of Unit III of the Kuimov Formation.

Generalka section. The upper part of the Silurian section composed of terrigenous-carbonate rocks was previously assigned to the Chagyrka Formation near the Generalka Village, on the right bank of the Yarovka River (Bartseva and Perfil'ev, 1957). Later, it was first attributed to the Kuimov Formation based on the occurrences of Ludlow trilobites, brachiopods, tabulate and rugose corals (Sennikov et al., 1988). This upper part of the Silurian section was subsequently described in more detail (Fig. 7*B*). The section can be subdivided into four parts: the lower part composed of

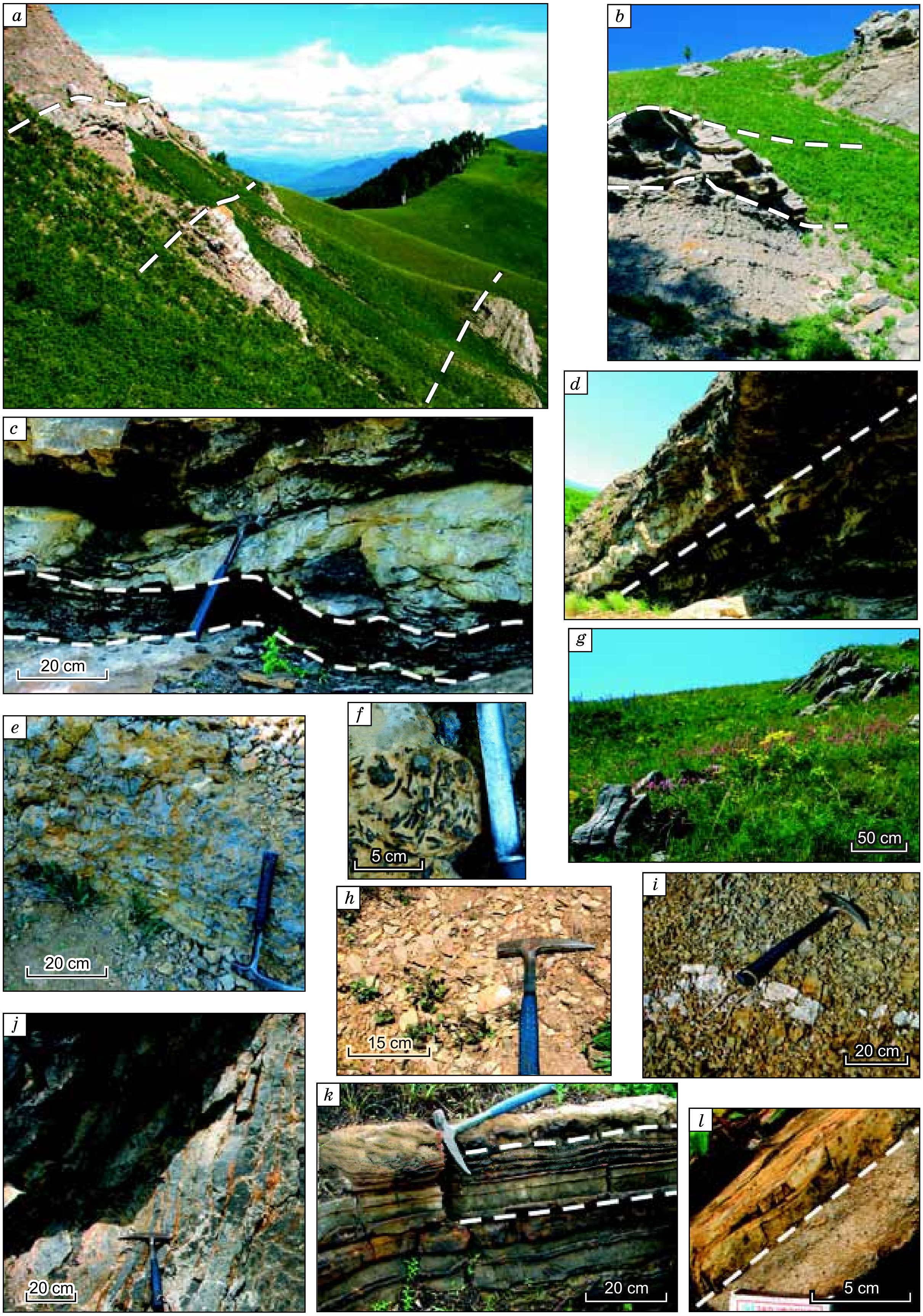
a
b
c
20 cm
d
g
50 cm
e
20 cm
f
5 cm
h
15 cm
i
20 cm
j
20 cm
k
20 cm
l
5 cm

Fig. 6. Structural and textural features of Silurian outcrops of the Kuimov Formation, Gorny Altai. *a*, cyclic structure of unit III; *b*, rhythmic structure of a sedimentary cycle in unit III; *c*, wavy shape of a member consisting of black argillaceous–carbonaceous rocks at the top of unit I; *d*, contact between units I and II (overhanging scarp); *e*, syngenetic carbonate conglomerate/breccia at the base of a rhythm of unit III; *f*, silicified fauna on the hardground surface in unit II; *g*, transition from massive and thick-laminated to medium- and thin-laminated limestones in unit I; *h*, yellow-gray calcareous mudstones of unit I; *i*, limestone lenses enclosed in snuff-gray mudstones of unit I; *j*, wavy, medium-laminated limestones at the base of unit I of the Kuimov Formation; *k*, graded bedding of unit I; *l*, contact between terrigenous (upward) and carbonate (downward) members of distal gravity flow mixtites in unit II. *a*, *b*, *e*, Klubnichnyi section; *c*, *d*, *f*, *h*, Tigirek coastal section; *g*, Chagyrka right bank section; *i*, Slope section; *j*, Charysh coastal section; *k*, *l*, Pautikha section.

alternating sandstone, siltstone, and mudstone with limestone lenses; the succeeding part represented by bioclastic, weakly argillaceous limestone; the overlying part composed of alternating siltstone and mudstone; the upper part composed of weakly argillaceous limestone. The three lower parts of the Kuimov Formation in the Generalka section should be assigned to Unit I of the Kuimov Formation, and the upper part to Unit II of the formation.

Generalka slope section. It was first studied by the authors in 2016 and 2017 (Fig. 7*C*). It is located in a new quarry site, near the road from the Chineta Village, on the right side of a dry ravine down to the Yarovka River near the Generalka Village. Since there is a good correlation between the interbedded siltstone and mudstone members with rare limestone lenses and packages in this section (Fig. 6*i*) and the lower part of the Generalka slope section, the latter can be assign to Unit I of the Kuimov Formation.

Charyshskii Utes section. The carbonate Silurian section along the right bank of the Charysh River directly across Ust'-Chagyrka (Figs. 8 and 9*A*) related to the stratotype of the Chagyrka Formation has been described in detail elsewhere (Bublychenko, 1936; Stratigraphy..., 1965; Kul'kov, 1966, 1967; Yolkin et al., 1974). A detailed study of the topmost part of this section shows that it has marked lithological distinctions from the remaining part of the stratotype represented by massive, nonlaminated bioherm limestone (Figs. 8 and 9*A*). Limestone with indistinct medium to thick bedding (from 10–15 cm to 0.5 m) are observed directly at the water line, in coastal cliffs downstream the Charysh River (Fig. 6*j*). The members have wavy contact surfaces with mud coatings. Interlayers of calcarenite and calcirudite formed within normal wave base are present in places. Small bioherms (0.2–0.5 m in diameter) are found locally in the most massive, nonbedded members. Although this part of the section contains little or no terrigenous material, the above-mentioned thick- to medium-laminated and fine-laminated (5–7 cm) limestones should be attributed to the lowermost part of the overlying Kuimov Formation (the lowermost part of Unit I) rather than to the Chagyrka Formation. Such a phenomenon is observed at the boundary between the Chagyrka and Kuimov stratigraphic units in the Tigirek type section.

Gornyi Klyuch section. The terrigenous-carbonate section at the former village of the same name on the right bank of the Charysh River directly adjoins (<200 m) the stratotype of the Chagyrka Formation (Fig. 8). In 1982–1983, it was assigned to the Kuimov Formation during the Geological Survey-50000. At that time, N.V. Sennikov performed biostratigraphic studies in cooperation with field geologists who conducted geological mapping. Previously, these strata were attributed to the Chagyrka Formation (Stratigraphy..., 1965). This study presents the first detailed bed-by-bed description of this section (Fig. 9*B*). It is located on the eastern side of the former village, on an isolated hill, some 500 m from the Charysh River. Terrigenous members crop out in its lower part, while its upper part represents an alternation of terrigenous and carbonate members. Laterally impersistent limestone form lenticular bodies. Based on field relations (it is aligned parallel to bedding and has conformable contacts through a sodded interval with the basal part of the Kuimov Formation in the Chagyrka Formation stratotype in Charyshskii Utes section) and lithological features, the Gornyi Klyuch section should be attributed to Unit I of the Kuimov Formation.

Chagyrka right bank section. The alternating terrigenous-carbonate and carbonate rocks on the right bank of the Chagyrka River, southeast of the Ust'-Chagyrka Village were first recognized in the previously mapped area of the Chagyrka Formation (Perfil'ev, 1959; Stratigraphy..., 1965) and assigned to the Kuimov Formation during the Geological Survey-50000 in 1982–1983. A detailed description of this section is presented in this study (Fig. 9*C*). It is located southeast of Mt. Poskotnaya, on its slope facing the Chagyrka River. Interbeds of argillaceous limestone and bioclastic limestone with variable proportions of sand- and clay-sized material are exposed in the lower part of the Kuimov Formation. Terrigenous material does not occur in isolated layers. The carbonate interbeds in place grade along strike into pure bioclastic limestone (Fig. 6*g*). The middle part of the Kuimov Formation is represented by massive, pelitomorphic, crinoidal limestone. The upper part of the section is composed of thick-laminated bioclastic limestone with sand and gravel material. Based on the lithological criteria, the lower, middle, and upper parts of the Chagyrka right bank section are attributable to Units I, II, and III of the Kuimov Formation, respectively.

Pautikha section. The sequence of alternating sandstone, siltstone and limestone members on the right bank of in the lower course of the Pautikha River between Krasnoshchekovo and Semenovka Villages was earlier attributed to the Kuimov Formation based on the occurrences of Ludlow brachiopods, trilobites, and conodonts (Sennikov et al., 2001b; Sennikov et al., 2008). The first bed-by-bed description of this section was made by the authors in 2012 (Fig. 9*D*). The

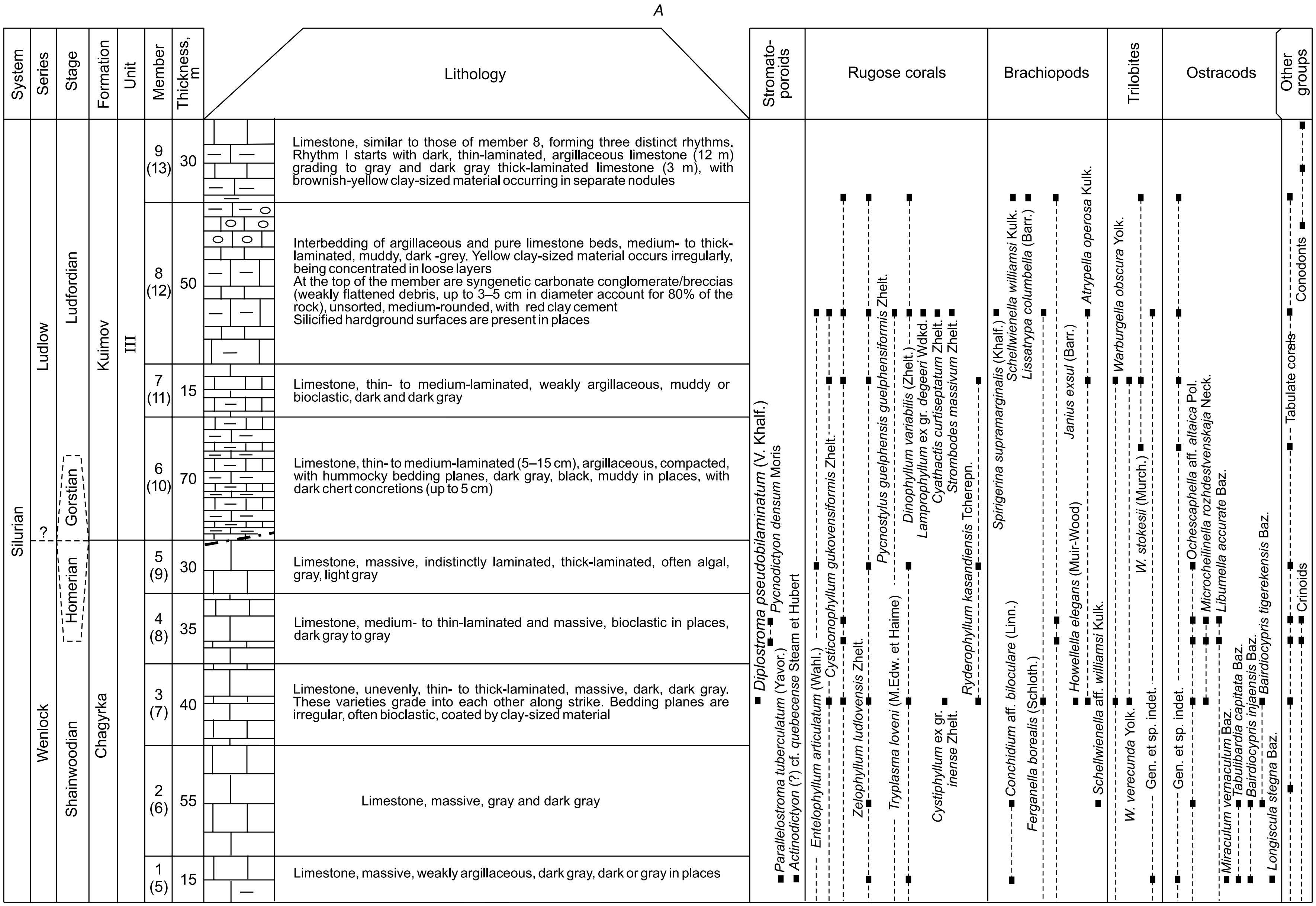

Fig. 7. Lithology and faunal occurrence of the Klubnichnyi section (*A*), the Generalka section (*B*), the Generalka slope section (*C*). For legend see Fig. 4.

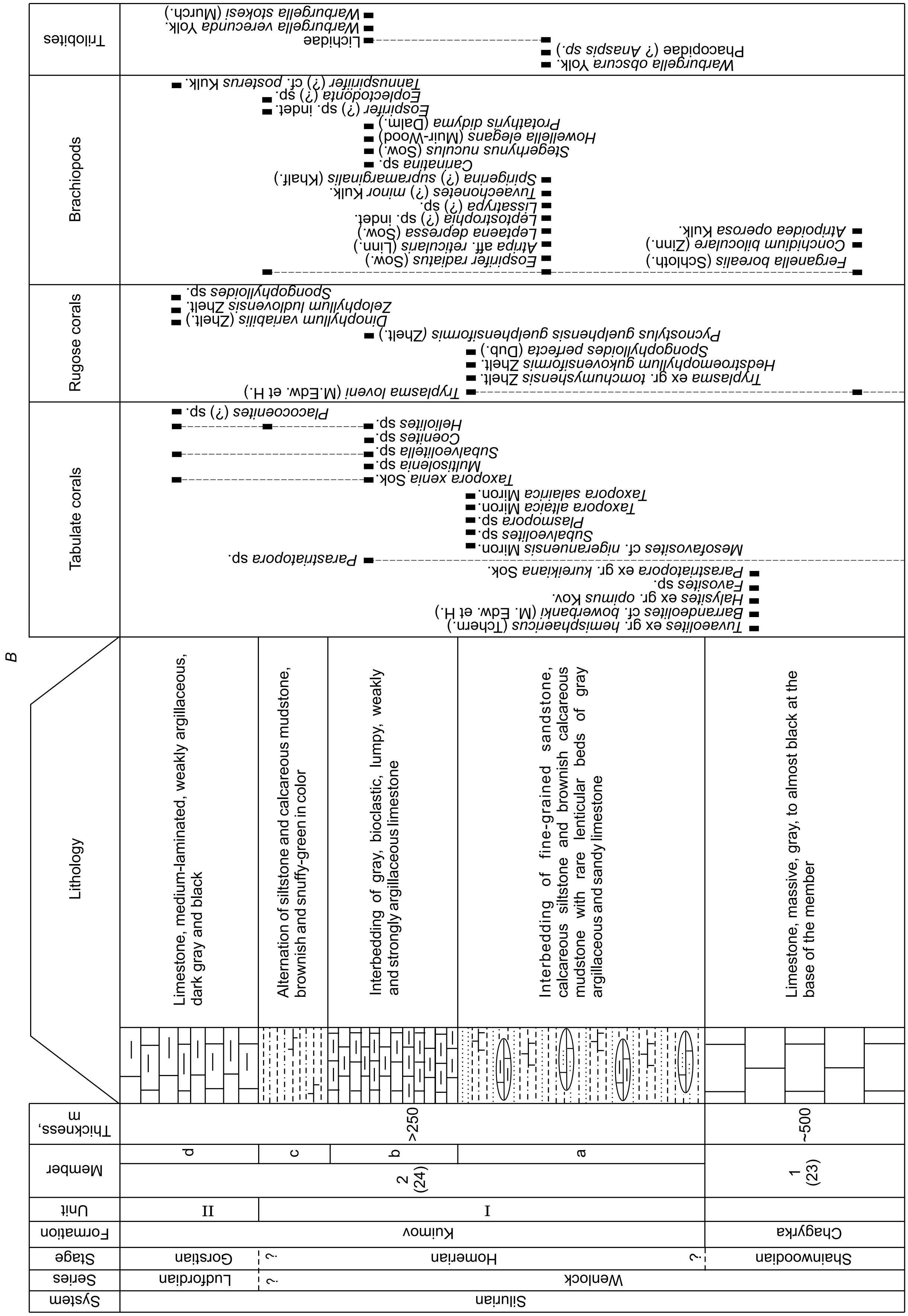

Fig. 7 (*continued*).

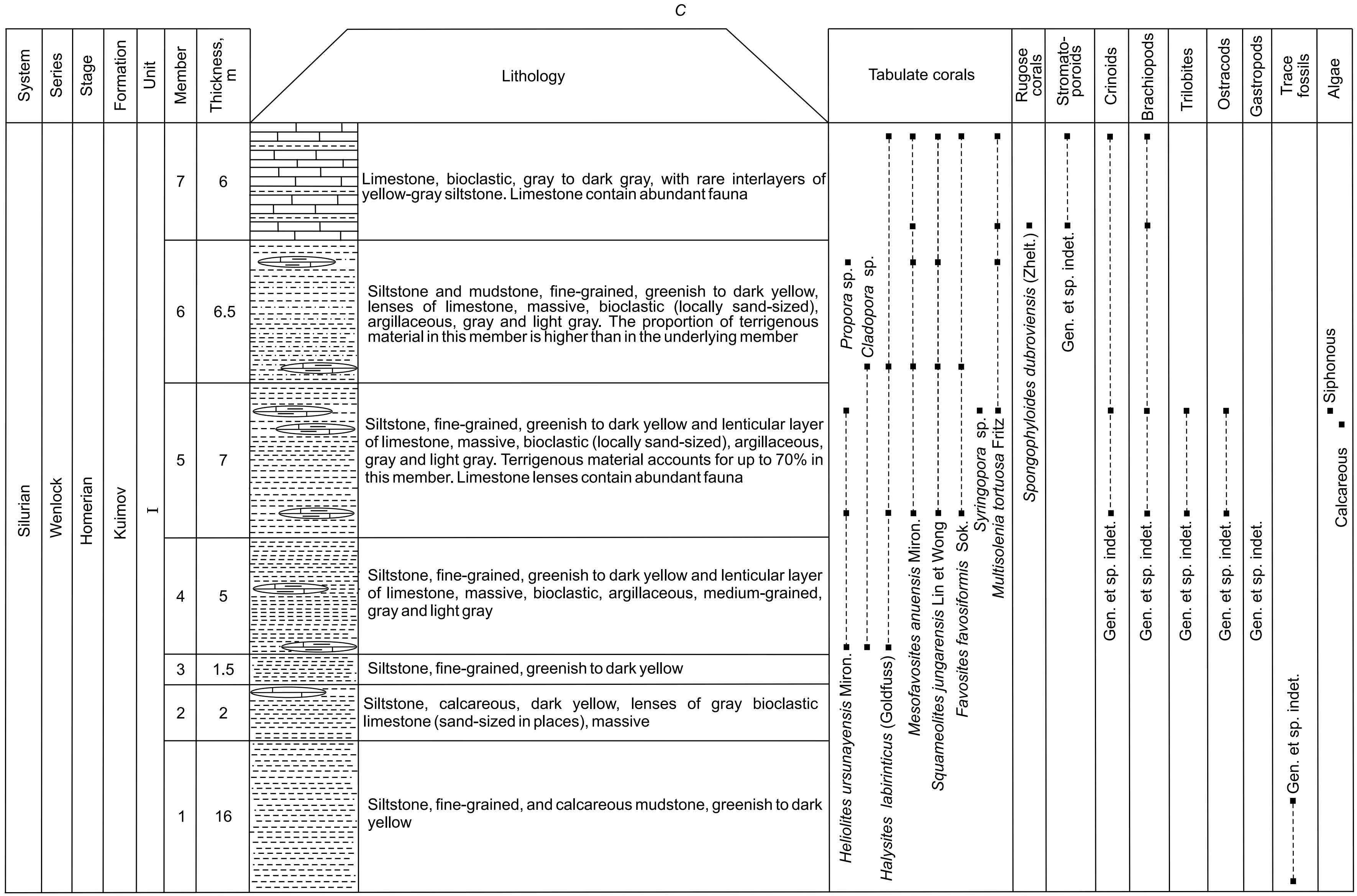

Fig. 7 (*continued*).

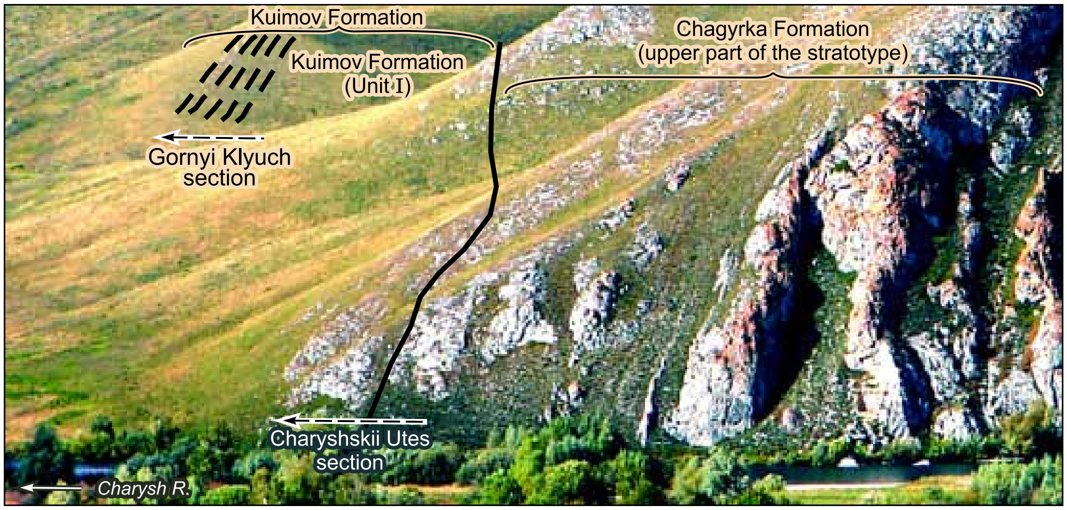

Fig. 8. Panoramic view of the Charyshskii Utes and Gornyi Klyuch sections.

section comprises interbedded members of sandstone, siltstone and bioclastic limestone.

The conodonts yielded from the Pautikha section *Panderodus gracilis* (Branson et Mehl), *Panderodus unicostatus* (Branson et Mehl), *Belodella* cf. *anormalis* Cooper, *Pelekysgnathus dubius* Jeppsson, *Wurmiella excavata* (Branson et Mehl), *Ozarkodina* cf. *cadiaensis* Bischoff, *Ozarkodina* sp. confirm a Gorstian–Ludfordian age (Obut et al., 2013).

The following additional information must be provided. A block of dark gray mudstone with a fauna of poorly preserved graptolites (*Monograptus* cf. *flemingi* (Salter), *Monoclimacis* sp., *Pristiograptus* sp., as well as dendroid graptolites *Callograptus* sp.) is found adjacent to the lowermost part of the Pautikha section. A small outcrop of >30 m thick dark laminated mudstone containing brachiopods and graptolites occurs 7.5 km east of the Pautikha section on the right bank of the Suetka River and 2 km south of the Malaya Suetka River. The graptolites yielded from the **Malaya Suetka section** include *Testograptus testis* (Barrande), *Monograptus* sp., *Callograptus* sp. The first taxon is the index species of the lower Homerian lundgreni/testis Zone. Having examined a small collection of brachiopods from the Malaya Suetka section, Czech paleontologist V. Havlicek (oral communication) has suggested that they are typical transitional Wenlock–Ludlow forms. Based on lithologic and paleontological characteristics, the Malaya Suetka section should be assigned to Unit I of the Kuimov Formation.

The attribution of the entire Silurian interval of the Pautikha section to Unit I of the Kuimov Formation based on the presence of isolated terrigenous members alone is very doubtful. The conodont taxa from this section are indicative of the Gorstian–Ludfordian interval, which should be correlated with Unit II of the Kuimov Formation rather than Unit I. The base of the Pautikha section represented by dark mudstone (including those occurring in an isolated exposure) can be regarded, by analogy with the Malaya Suetka section, as Unit I of the Kuimov Formation. The remaining part of the Pautikha section should be correlated with Units II and III of the Kuimov Formation.

FACIES CHARACTERISTICS AND FAUNAL COMMUNITIES

The following facies trends can be observed in the transition from outcrops of the Kuimov Formation at Tigirek to Generalka, then to Ust'-Chagyrka and further to the north (in present coordinates) in the vicinity of Krasnoshchekovo: (a) a decrease in the overall thickness of the formation; (b) an increase in the thickness of Unit I of the Kuimov Formation; (c) an increase in the proportion of terrigenous material in units I and II; (d) a systematic coarsening trend in terrigenous grain size records—from clay to silt, then to sand and sand-gravel particle size; (e) a decrease in the proportion (to complete disappearance) of bioherm limestones; (f) the appearance of gravity flow mixtites.

We propose the following classification of the Kuimov Formation section based on depositional settings and their location within the paleobasin (Fig. 10). The Tigirek and Klubnichnyi sections belong to the central belt of carbonate sedimentation, most distant from the source of terrigenous material (algal bioherms, coral meadows), corresponding to intense normal wave base range (0–10 m deep), which is represented by limestone conglomerate breccia. The Generalka and Generalka slope sections represent a backreef zone, more proximal to the paleoshore, not more than 30–80 m deep (the euphotic zone with favorable growth conditions for photosynthesizing algae), but deeper than 50 m, below normal and storm wave base and include fine-grained terrigenous material, lenses of limestone, including bioclastic limestone (up to sand-sized). The upper part of the Generalka slope section was deposited around storm wave base (25–50 m), as indicated by dislocated colonies of tabulate corals and carbonate debris with a mud drape.

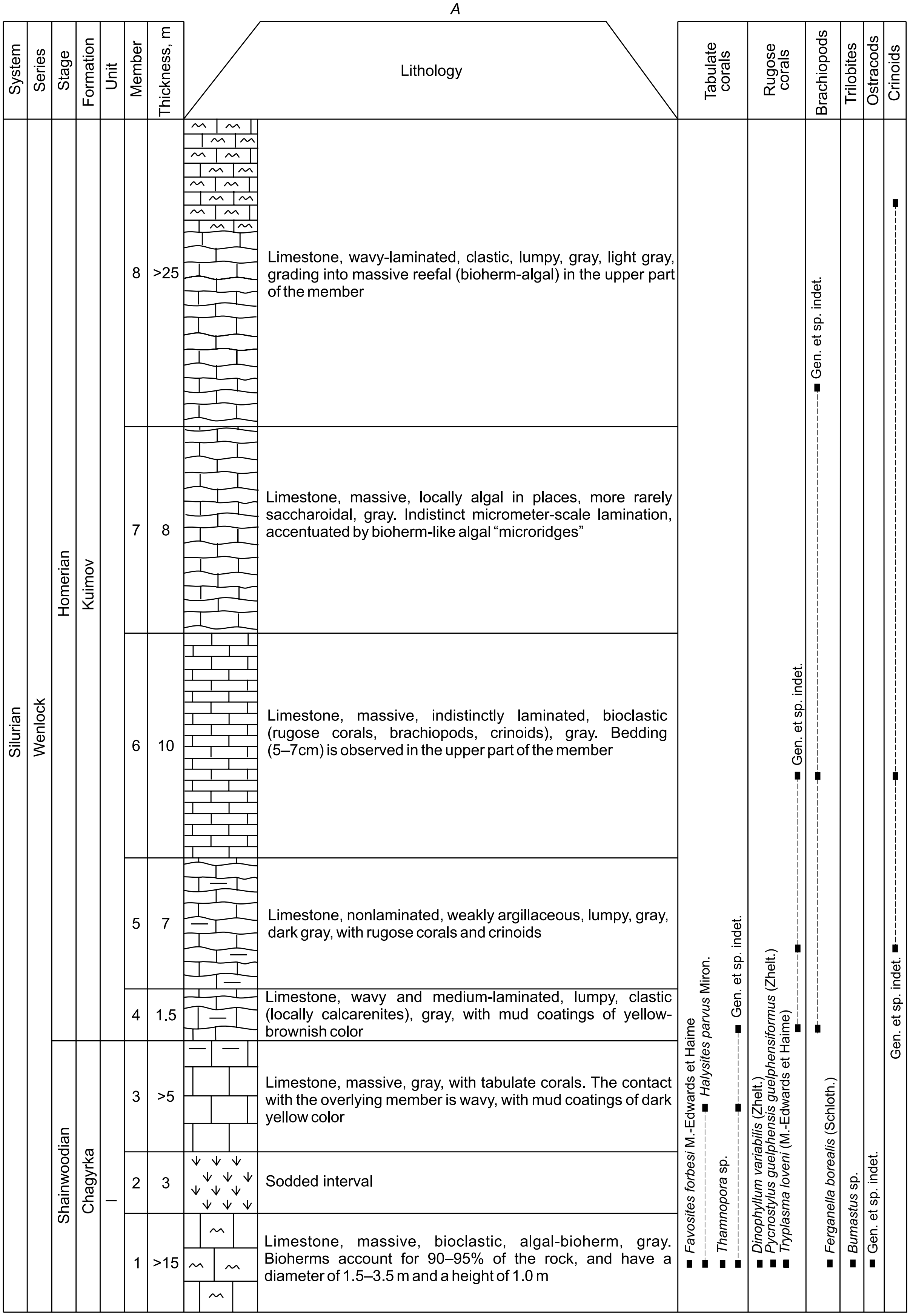

Fig. 9 (*to be continued*).

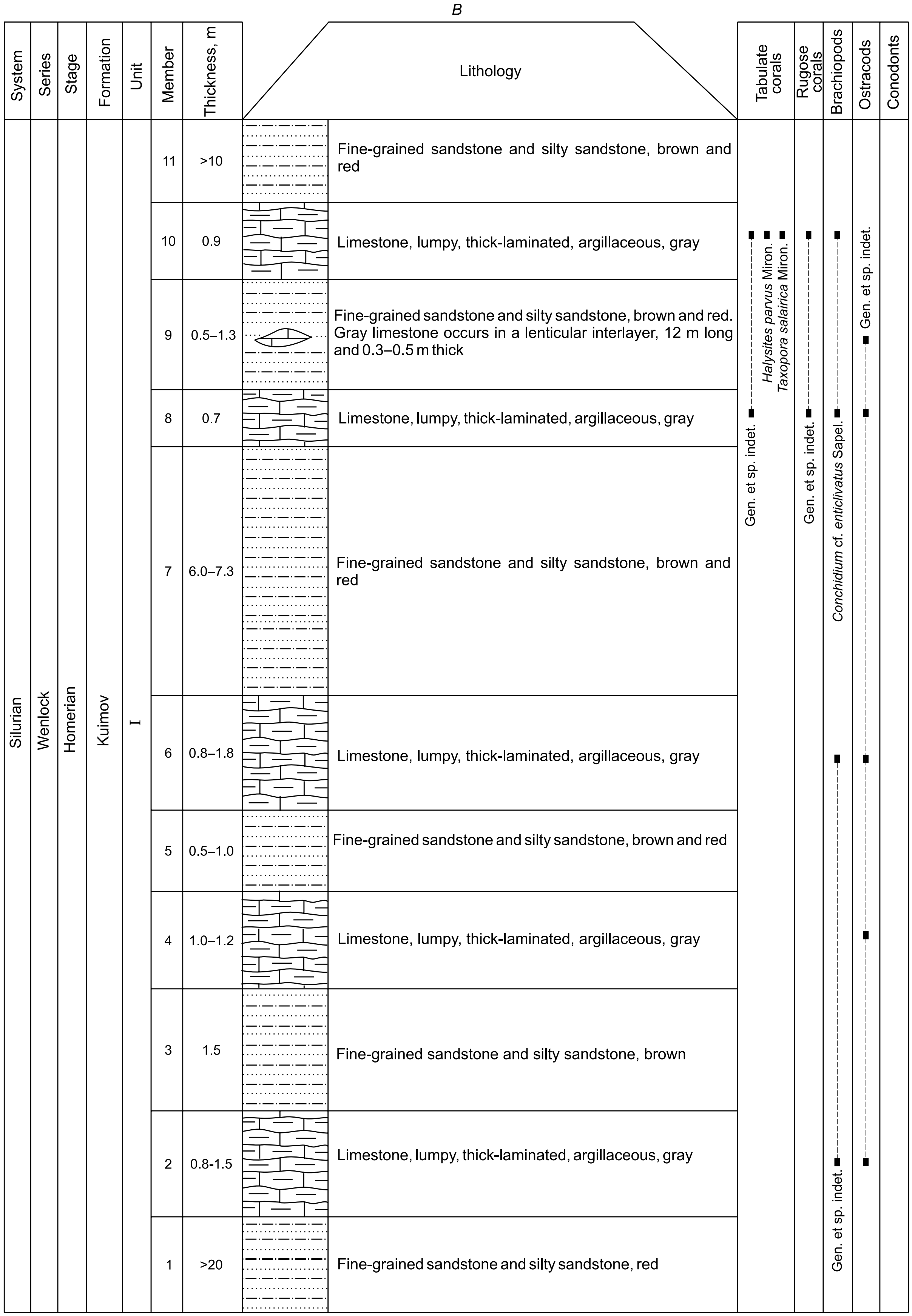

Fig. 9 (*to be continued*).

C

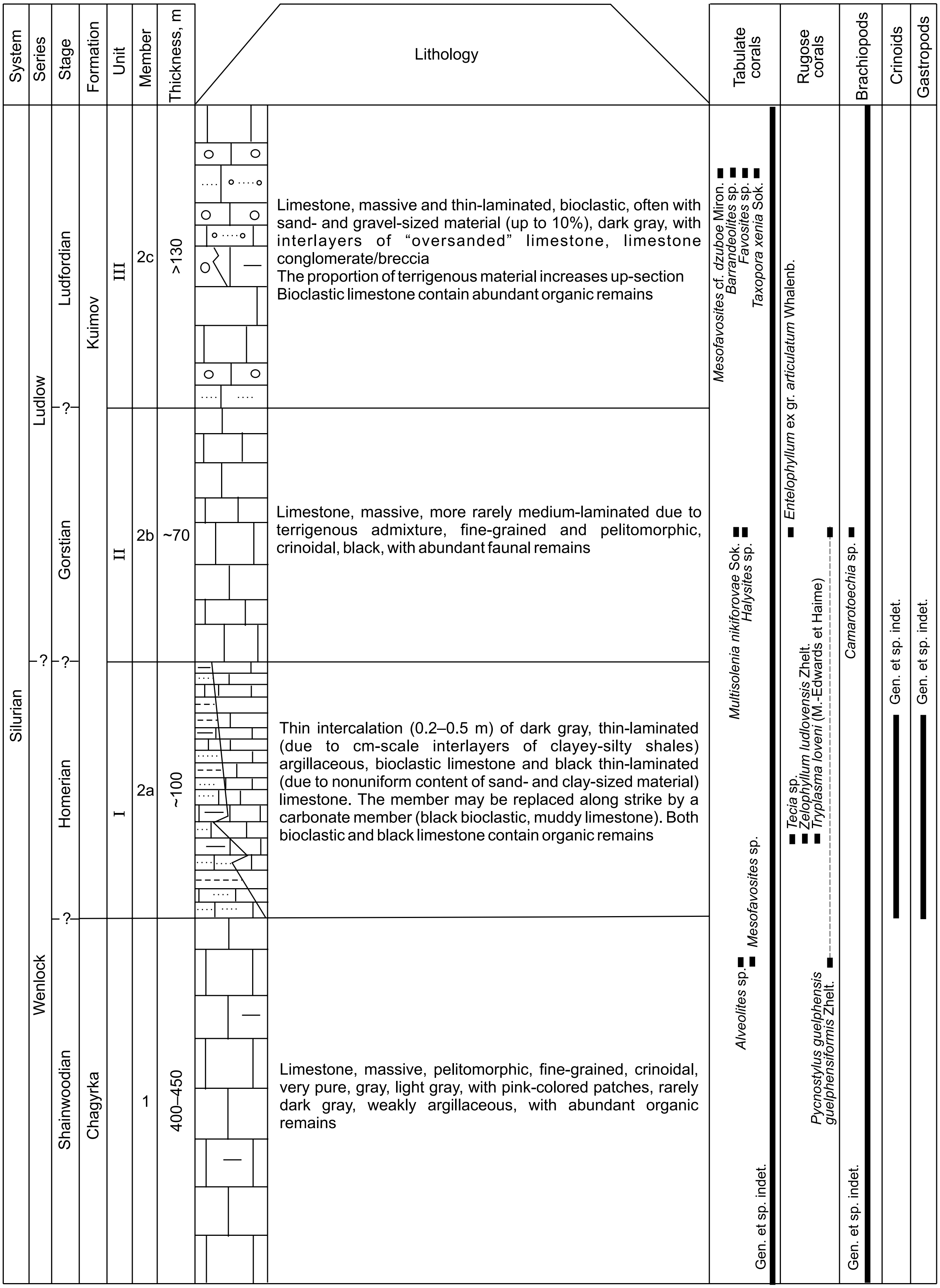

Fig. 9 (*to be continued*).

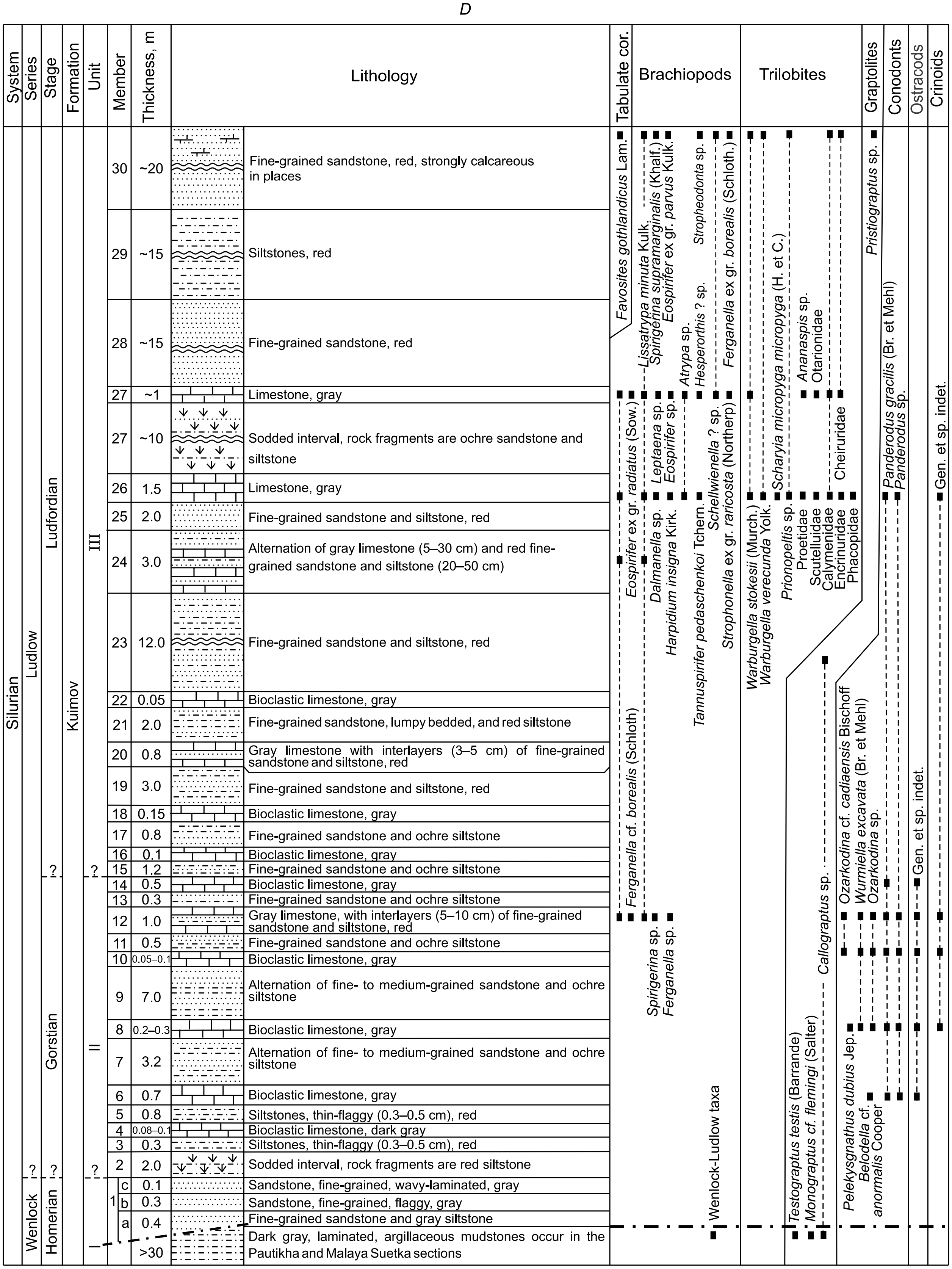

Fig. 9. Lithology and faunal occurrence of the Charyshskii Utes section (*A*), the Gornyi Klyuch section (*B*), the Chagyrka right bank section (*C*), the Pautikha section (*D*). For legend see Fig. 4.

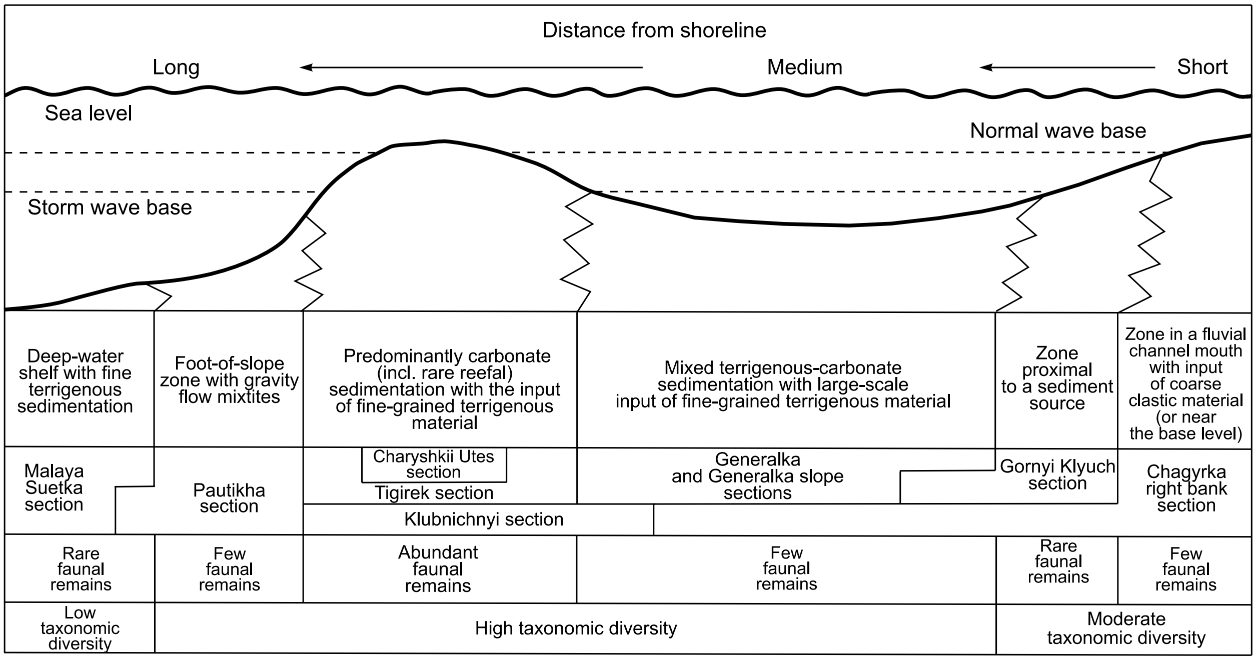

Fig. 10. Model profile of terrigenous-carbonate sedimentation in the Silurian Altai basin.

The Chagyrka right bank section was deposited within normal wave base (0–10 m), in close proximity to a fluvial channel mouth, as indicated by the presence of limestone conglomerate, sand- and gravel-sized material in carbonates. The Charyshskii Utes section deposited within normal wave base (0–10 m), as indicated by the presence of calcarenites, whereas the Gornyi Klyuch section was formed at greater depths, within storm wave base (25–50 m), as suggested by the presence of lumpy, argillaceous limestone and sand-sized material occurring in isolated nonlaminated members. The Pautikha section must have been formed at the foot of the slope (transitional from a shallow to deep shelf setting, from 50–100 m to 100–200 m deep), as indicated by the presence of distal terrigenous and carbonate gravity flow mixtites represented by lenses of detrital limestone, mudstone, sandstone with graded bedding and traces of submarine landslides of a nonlithified sediment (Fig. 6*k*, *l*). The Malaya Suetka section can be classified as belonging to the deep shelf facies (>100–150 m) represented by black thin to parallel laminated mudstone.

Despite significant variations in depositional environment of the Kuimov Formation, the faunal community structure shows relatively little variation between sites: brachiopods are reported from almost all sections and represent the dominant component of paleobiota, based on the population density and taxonomic diversity. The brachiopod occurrences are confined to both carbonate and terrigenous layers. The second most abundant group of organisms represented by tabulate and rugose corals was reported mainly from limestone in most sections of the Kuimov Formation, except for the Malaya Suetka section.

The population density of tabulate and rugose corals, as well as their taxonomic diversity in the rocks of the Kuimov Formation decrease from south to north (in present coordinates). The opposite trend was detected for the taxonomic diversity of the Kuimov trilobites: it increases significantly at the generic level from Tigirek to Pautikha sections. Pelagic groups such as graptolites and conodonts appear in the most seaward sections of the Kuimov Formation (Pautikha and Malaya Suetka).

DISCUSSION

Stratigraphic aspects. The observed changes in the character of sedimentation in the sections of the Kuimov Formation allow it to be subdivided into three units. Each unit exhibits different lithological and faunal characteristics. All three units were identified in the Tigirek (Kuimov Formation stratotype) and Chagyrka right bank sections of the Charysh–Inya facies zone of Altai. The Kuimov Formation exhibits a significant lithological variability between sections in the Anui–Chuya and Charysh–Inya zones. In this regard, the possibility of division of the Kuimov Formation into units in the Anui–Chuya facies zone on the basis of lithology requires further investigation. However, we suppose that the upper member of the Kuimov Formation identified in this region and referred to as the Maragda stratigraphic unit (Mironova, 1978; Stratigraphic..., 1991; Sennikov et al., 2014) can be treated as the upper unit (Unit III or, probably, Unit IV, which is permitted by the Stratigraphic Code of Russia, 2006, Article V.19) of the Kuimov Formation. For consistency, and as per The Stratigraphic Code of Russia (2006), the geographical name Maragda Unit can be equally applied in the area of the previously recognized Maragda stratigraphic unit.

The age of the individual units (parts) of the Kuimov Formation and the chronostratigraphic position of the Kuimov Horizon can be determined using the data on an important orthostratigraphic group, conodonts, from the Kuimov Formation in the Anui–Chuya facies zone of Altai and on two other arthostratigraphic groups such as graptolites and conodonts, from the Potapov Formation of Salair, which is also correlated with the Kuimov Horizon.

The presence of some intermediate forms of graptolites *Monograptus priodon* (Bronn)–*Monograptus flemingi* (Salter) was reported from the middle part of the Potapov Formation (lowermost part of the Kuimov Horizon) in the Gur'evsk–El'tsovka zone of Salair in the upper reaches of the Kamenka River (Sennikov et al., 2001a). The last taxon (*Mon. flemingi* Salter) is indicative of the uppermost Scheinwoodian rigidus graptolite Zone and the lowermost Homerian lundgreni/testis graptolite Zone. The conodonts *Spathognathodus* cf. *inclinatus* (Rhodes), *Ozarkodina typica* Branson et Mehl, *Panderodus* sp., *Trichonodella* sp. were recovered from the middle part of the Kuimov Horizon in the second half of the Potapov Formation of Salair (Gutak et al., 2006, 2007).

The conodonts *Belodella resima* (Philip), *Acodina* cf. *curvata* Stauffer, *Panderodus* sp., *Hindeodella* sp., *Ozarkodina* sp., *Trichnodella* sp. were identified in the topmost part of the Kuimov Horizon in the Maragda unit (member) of the upper part of the Kuimov Formation in the Anui–Chuya facies zone of Altai (Gutak et al., 2000). A richer conodont fauna was recovered by the authors from the Maragda Unit (member) of the Kuimov Formation within the same Anui–Chuya facies zone. This fauna includes *Ozarkodina eosteinhornensis* (Walliser), *Ozarkodina* cf. *remsheidensis* (Ziegler), *Ozarkodina* cf. *multistriola* Mathieson, *Ozarkodina* sp., *Wurmiella excavata* (Branson et Mehl), *Panderodus* sp., *Pelekysgnathus* sp., *Oulodus*? sp. A relatively small number of species and the predominance of representatives of the genus *Ozarkodina* Branson et Mehl are suggestive of an Late Silurian age of this assemblage and a Přídolí age for the beds bearing it. However, it should be noted that recent studies of conodont paleocommunities (Slavik and Carls, 2012; Slavik et al., 2014) show that the terminal Silurian conodont assemblages started to appear in the stratotype area (Barrandian) of the Přídolí Series not at the Ludlow/Přídolí boundary, but slightly lower, in the Upper Ludfordian, after the Lau transgressive Event (post-Lau bio-Event). The same situation is observed in the Ludlow and Přídolí sections of Italy (Corriga et al., 2009; Corradini and Corriga, 2010). In view of the above, the topmost part of the Kuimov Formation (Maragda Unit) in the Anui–Chuya facies zone of Altai can be assigned a post-Middle Ludfordian age.

Lithological features. Lithological variations at the boundary between units I and II of the Kuimov Formation in the Charysh–Inya facies zone of Altai may reflect a response of sedimentation processes in the Altai sea basin to the global Mulde transgressive-regressive Event. These changes were recorded in the Tigirek (including its coastal part), Chagyrka right bank, and Generalka sections by interrupted terrigenous sedimentation and the onset of limestone deposition in the two first sections of the bioherm type (Figs. 3, 4, and 13). In addition, a thin member of black carbonate, argillaceous-carbonaceous rocks having 6.47% C_{org} was identified in the Tigirek coastal section (Fig. 6*c*, *d*).

The boundary interval between units II and III of the Kuimov Formation is characterized by: a) replacement of thick-laminated (and bioherm) limestone by thin- to medium-laminated varieties in the Tigirek section (Figs. 3, 4); (b) replacement of massive limestone by laminated limestone and limestone conglomerate in the Chagyrka right bank section (Fig. 13). Such changes in the depositional setting may reflect a regional response to the Linde regressive Event.

The correlation of the Lau transgressive event interval in the sections of the Kuimov Formation in the Charysh–Inya facies zone of Altai requires further study. The Lau event is probably recorded in sections of the Kuimov Formation in the Anui–Chuya facies zone of Altai, which, as noted above, yielded the conodont species indicative of the post-Lau bio-Event.

The Klev regressive Event led to a termination of Silurian sedimentation over the entire area of the Charysh–Inya facies zone of Gorny Altai.

CONCLUSIONS

1. The Kuimov Formation in the Charysh–Inya facies zone of Gorny Altai comprises a wide variety of terrigenous, terrigenous-carbonate and carbonate rocks. In this facies zone, the formation should be divided into three units (I, II, and III).

2. A separate unit of the Kuimov Formation, formerly referred to as the Maragda Formation, should be recognized in the Anyui–Chuya facies zone based on the evidence from Silurian sections.

3. Overall, facies variations in the Silurian terrigenous-carbonate sediments of Altai occur laterally, from marginal shallow-water to relatively deep-water and distal facies.

4. The early third of the Kuimov Horizon (= Unit I) should be equated with the Homerian (or its longest interval) of the Wenlock Epoch. The second part of the Kuimov Horizon (= Unit II) can be conditionally correlated with the Gorstian of the Ludlow Epoch; the third part of this horizon (= Unit III) can be equated with the Ludfordian (or its part) of the Ludlow Epoch.

5. However, further study is required to establish a precise, zonal correlation between the base of the Kuimov Horizon and the base of the Homerian stage and between its top and the Ludlow/Přídolí boundary of the Upper Silurian.

The authors coordinate their studies with Project 652 of the International Geological Correlation Program (IPGC).

REFERENCES

Bakharev, N.K., Bazarova, L.S., 2004. Silurian and Devonian ostracods of the genus *Miraculum:* new species, phylozones, in: News of Paleontology and Stratigraphy, Issue 6, 7, Suppl. Geology and Geophysics, Vol. 45 [in Russian]. Akad. Izd. Geo, Novosibirsk, pp. 75–87.

Bartseva, M.N., Perfil'ev, Yu.S., 1957. Materials on the Ordovician and Silurian Stratigraphy of the northwestern Altai, in: Materials on Geology and Metallogeny of Rudny Altai (Trans. VAGT, Issue 3) [in Russian], pp. 5–2.

Bazarova, L.S., 1984. New species of the Late Wenlock ostracods of Gorny Altai, in: Paleozoic Paleontology and Biostratigraphy of Siberia [in Russian]. Nauka, Novosibirsk, pp. 66–70.

Bazarova, L.S., 1990. A new genus of the ostracods *Tigerekella* from the Lower Wenlock deposits of the Altai Mountains, in: New in Paleozoic Paleontology and Biostratigraphy of the Asian Part of the USSR [in Russian]. Nauka, Novosibirsk, pp. 72–75.

Bublychenko, N.L., 1936. The main tectonic lines of Rudny Altai, in: The Greater Altai [in Russian]. AN SSSR, Moscow, Vol. 2, pp. 59–111.

Calner, M., 2008. Silurian global events–at the tipping point of climate change, in: Ashraf M.T. (Ed.), Mass Extinctions. Springer-Verlag, Berlin–Heidelberg, pp. 21–58.

Castagner, A., Jarochowska, E., Munnecke, A., Desrochers, A., 2015. Ultrastructures of porostromate microproblematica from a Mulde Event (Homerian, Silurian) bioherm in Podolia, Western Ukraine. Eston. J. Earth Sci. 64 (1), 24–30.

Corradini, C., Corriga, M.G., 2010. Silurian and lowermost Devonian conodonts from the Passo Volaia area (Carnic Alps, Italy). Bollettino della Società Paleontologica Italiana 49 (3), 237–253.

Corriga, M.G., Corradini, C., Ferretti, A., 2009. Silurian conodonts from Sardinia: an overview. Rendiconti della Società Paleontologica Italiana 3 (1), 95–107.

Cramer, B.D., Brett, C.E., Melchin, M.J., Mannik, P., Kleffner, M.A., Mclaughlin, P.I., Loydell, D.K., Munnecke, A., Jeppsson, L., Corradini, C., R. Brunton, F.R., Saltzman, M.R., 2011. Revised correlation of Silurian Provincial Series of North America with global and regional chronostratigraphic units and $\delta^{13}C_{carb}$ chemostratigraphy. Lethaia 44, 185–202.

Decisions of the All-Union Stratigraphic Meeting on the Precambrian, Paleozoic and Quaternary of Central Siberia, 1983. Part I. Upper Proterozoic and Lower Paleozoic [in Russian]. Novosibirsk.

Gradstein, F.M., Ogg, J.G., Smith, A.G., Ogg, G.M., 2012. The Geologic Time Scale 2012. Vol. 1. Elsevier.

Gutak, Ya.M., Abushik, A.F., Savina, N.I., Rodygin, S.A., 2000. The Chernyi Anui Formation and the problem of the Přídolí Series of the Upper Silurian in the Altai Mountains, in: Proc. Region. Conf. Geologists of Siberia, the Far East and Northeast of Russia. Vol. 2, Ch. 3: Paleontology and Stratigraphy [in Russian]. Asinovskaya Tipografiya, Tomsk, pp. 290–294.

Gutak, Ya.M., Antoshkina, A.I., Bagmet, G.N., Savitskii, V.R., 2006. Upper Silurian sediments of the Salair (Potapov Formation, nomenclature issues), in: Problems of Stratigraphy and Regional Geology of Siberia [in Russian]. Nauka, Novosibirsk, pp. 95–99.

Gutak, Ya.M., Savitskii, V.R., Abushik, A.F., Antoshkina, A.I., Rodygin, S.A., Savina, N.I., 2007. The Potapov Formation (Late Silurian) of Salair (paleontological characteristics), in: Nature and Economics of Kuzbass. Regional Collection of Research Articles, Issue 11 [in Russian]. Novokuznetsk, pp. 61–63.

Ivanovskii, A.B., Kul'kov, N.P., 1974. Rugose Corals, Brachiopods and Silurian Stratigraphy of the Altai-Sayan Mountain Region [in Russian]. Nauka, Moscow.

Jaeger, H., 1991. Neue Standart-Graptolithenzonenfolge nach der "Grosen Krise" an der Wenlock/Ludlow-Grense (Silur). Neues. Journ. Geol. Palaontol. Abhandl. 182 (3), 303–354.

Jarochowska, E., Munnecke, A., Kozlowski, W., 2013. The record of the middle Silurian Mulde Event in Podolia, Western Ukraine, in: Proc. 3rd IGCP 591 Annu. Meet. Lund, pp. 144–145.

Kaljo, D., Boucot, A.J., Corfield, R.M., Le Herisse, A., Koren', T.N., Kriz, J., Mannik, P., Marss, T., Nestor, V., Shaver, R.H., Siveter, D.J., Viira, V., 1996. Silurian Bio-Events. Global Events and Event Stratigraphy in the Phanerozoic. Springer-Verlag, Berlin–Heidelberg, pp. 202–224.

Koren', T.N. Urbanek, A., 1994. Adaptive radiation of monograptids after the Late Wenlock crisis. Acta Palaeontologica Polonica. 39 (2), 137–167.

Koren', T.N., Bugrova, E.M., Gavrilova, V.A., Gogin, I.Ya., Zhuravlev, A.V., Kossovaya, O.L., Kotlyar, G.V., Nikolaeva, I.A., Tabachnikova, I.P., Terent'ev, S.S., Tolmacheva, T.Yu., Tur, I.A., Yazykova, E.A., 2000. Using Event-Stratigraphic Levels for Phanerozoic Interregional Correlation in Russia [in Russian]. VSEGEI, St. Petersburg.

Koren', T.N., Modzalevskaya, T.L., Abushik, A.F., Sobolevskaya, R.F., Suyarkova, A.A., Lopushinskaya, T.V., Kurilenko, A.V., Zaika, Yu.V., 2006. Silurian System. Phanerozoic Zonal Stratigraphy of Russia [in Russian]. VSEGEI, St. Petersburg.

Kul'kov, N.P., 1966. Silurian stratigraphy of Gorny Altai: revisited. Bull. MOIP. Geol. Ser. 41 (1), 77–82.

Kul'kov, N.P., 1967. Brachiopods and Silurian Stratigraphy of the Altai Mountains [in Russian]. Nauka, Moscow.

Lehnert, O., Eriksson, M.J., Calner, M., Joachimski, M., Buggisch, W., 2007. Concurrent sedimentary and isotopic indications for global climatic cooling in the Late Silurian. Acta Palaeontologica Sinica 46, 249–255.

Lehnert, O., Männik, P., Joachimski, M.M., Calner, M., Frýda, J., 2010. Palaeoclimate perturbations before the Sheinwoodian glaciation: A trigger for extinctions during the 'Ireviken Event'. Palaeogeogr. Palaeoclimatol. Palaeoecol. 296 (3–4), 320–331.

Mironova, N.V., 1978. Some Přídolí tabulate corals of the Central Altai, in: Upper Ordovician Fauna and Biostratigraphy of the Altai–Sayan Folded Region [in Russian]. Nauka, Moscow, pp. 104–117.

Munnecke, A., Calner, M., Harper, D.T., Servais, T., 2010. Ordovician and Silurian sea-water chemistry, sea level, and climate: A synopsis. Palaeogeogr. Palaeoclimatol. Palaeoecol. 296, 389–413.

Obut, O.T., Izokh, N.G., Sennikov, N.V., 2013. New occurrences of Silurian conodonts in the Kuimov Formation of western Gorny Altai, in: Proc. Interexpo GEO-Siberia-2013. IX Int. Sci. Congr., April 15–26 2013, Novosibirsk "Subsoil Use. Mining. New Directions and Technologies of Prospecting, Exploration and Development of Mineral Deposits. Geoecology" [in Russian]. SGGA, Novosibirsk, Vol. 1, pp. 69–72.

Perfil'ev, Yu.S., 1959. New data on Lower Paleozoic stratigraphy of Gorny Altai, in: News of Higher Educational Institutions. Geology and Exploration, No. 11, pp. 20–30.

Resolutions of the Interdepartmental Stratigraphic Committee and Its Standing Committees, 2013. Issue 42 [in Russian]. VSEGEI, St. Petersburg

Sadler, P.M., Cooper, R.C., Melchin, M., 2011. Sequencing the graptoloid clade: building a global diversity curve from local range charts, regional composites and global time-lines. Proc. Yorkshize Geol. Soc. 58 (4), 329–343.

Sennikov, N.V., Gladkikh, L.A., Mamlin, A.N., Petrunina, Z.E., 1988. Some problematic issues of the Silurian stratigraphy of Altai, in: Paleozoic Fauna and Stratigraphy of Middle Siberia and the Urals [in Russian]. Nauka, Novosibirsk, pp. 100–113.

Sennikov, N.V., Gladkikh, L.A., Butenko, V.A., Petrunina, Z.E., 2001a. New information on Silurian graptolites of Salair, in: The Evolution of Life on Earth [in Russian]. Tomsk, pp. 222–223.

Sennikov, N.V., Izokh, N.G., Yolkin, E.A., Petrunina, Z.E., 2001b. The first data on Ludlow conodonts of Gorny Altai, in: The Evolution of Life on Earth [in Russian]. Tomsk, pp. 223–225.

Sennikov, N.V., Yolkin, E.A., Petrunina, Z.E., Gladkikh, L.A., Obut, O.T., Izokh, N.G., Kipriyanova, T.P., 2008. Ordovician–Silurian Biostratigraphy and Paleogeography of the Gorny Altai. SB RAS, Novosibirsk.

Sennikov, N.V., Tolmacheva, T.Yu., Obut, O.T., 2013. The Silurian system in ISC—current state and problems of correlation within Russia, in: The General Stratigraphic Scale of Russia: Status and Prospects of Revision [in Russian]. Izd. Lema, Moscow, pp. 113–124.

Sennikov, N.V., Obut, O.T., Izokh, N.G., Rodina, O.A., Khabibulina, R.A., 2014. New data and problematic issues of the Silurian stratigraphy of the western Altai-Sayan folded region, in: Proceed. Interexpo GEO-Siberia-2013. IX Int. Sci. Congr., April 15–26, 2013, Novosibirsk "Subsoil Use. Mining. New Directions and Technologies of Prospecting, Exploration and Development of Mineral Deposits. Geoecology" [in Russian]. SGGA, Novosibirsk, Vol. 1, pp. 130–136.

Slavik, L., Carls, P., 2012. Post-Lau Event (Late Ludfordian, Silurian) recovery of conodont faunas of Bohemia. Bull. Geosci. 87 (4), 815–832.

Slavik, L., Storch, P., Manda, S., Fryda, J., 2014. Integrated stratigraphy of the Ludfordian in the Prague Synform. GFF 136 (1), 238–242.

State Geological Map of the Russian Federation, 2010a. Scale 1: 200,000 (second generation), Altai Series, Sheet M-45-VII (Ust'-Kan). Explanatory Note [in Russian]. VSEGEI, St. Petersburg.

State Geological Map of the Russian Federation, 2010b. Scale 1: 200,000 (second generation), Altai Series, Sheet M-45-I (Solonechnoe). Explanatory Note [in Russian]. VSEGEI, St. Petersburg.

Storch, P., 1995. Biotic crises and post-crisis recoveries recorded by Silurian planktonic graptolite faunas of the Barrandian area (Czech Republic). Geolines 3, 59–70.

Stratigraphic Dictionary of the USSR, 1956 [in Russian]. Gosgeoltekhizdat, Moscow.

Stratigraphic Dictionary of the USSR, 1975. Cambrian, Ordovician, Silurian, Devonian [in Russian]. Nedra, Leningrad.

Stratigraphic Dictionary of the USSR, 1991. New Paleozoic Stratigraphic Units of the USSR [in Russian]. Nedra, Leningrad.

Stratigraphy of the USSR, 1965. Silurian System [in Russian]. Nedra, Moscow.

Sullivan, N.B., Loydell, D.K., Montgomer, P., Molyneux, S.G., Zalasiewicz, J., Ratcliffe, K.T., Campbell, E., Griffiths, J.D., Lewis, G., 2018. A record of Late Ordovician to Silurian oceanographic events on the margin of Baltica based on new carbon isotope data, elemental geochemistry, and biostratigraphy from two boreholes in central Poland. Palaeogeogr. Palaeoclimatol. Palaeoecol. 490, 95–106.

The Stratigraphic Code of Russia, 2006 [in Russian]. VSEGEI, St. Petersburg.

Urbanek, A., 1993. Biotic crises in the history of Upper Silurian graptoloids: A Palaeobiological model. Historical Biology. Int. J. Paleobiol. 7 (1), 29–50.

Vladimirskaya, E.V., Zheltonogova, V.A., 1967. Silurian deposits of the Altai-Sayan folded region, in: Paleozoic Stratigraphy of Middle Siberia [in Russian]. Nauka, Novosibirsk, pp. 87–97.

Yolkin, E.A., Zheltonogova, V.A., Sennikov, N.V., Bazarova, L.S., 1974. The Most Ancient Dechenellids (Trilobites) and Silurian Stratigraphy of the Altai Mountains [in Russian]. Nauka, Novosibirsk.

Editorial responsibility: B.N. Shurygin