Russian Geology and Geophysics
Vol. 43, No. 6, pp. 493-511, 2002

Geologiya i Geofizika
UDC 551.732(571.5)

MAJOR CAMBRIAN BIOTIC BOUNDARIES IN THE NORTHERN SIBERIAN PLATFORM

I.V. Korovnikov, A.V. Fedoseev, and D.P. Sipin

Institute of Petroleum Geology, Siberian Branch of the RAS, 3 prosp. Akad. Koptyuga, Novosibirsk, 630090, Russia

We have characterized the complexes of guide faunal groups (small shelly fossils, archaeocyathids, trilobites, and brachiopods), and traced their stratigraphic and lateral distribution in the Cambrian deposits of the northern Siberian Platform. Eleven boundaries have been established where the most significant biotic changes of the major faunal group complexes occur. We have compared these boundaries with the boundaries described in the literature, and with data on carbon isotope analysis from selected sections of the Siberian Platform. Some of the established boundaries correspond well to global biotic events and to the peaks or valleys of carbon isotope ratio plots. The examples include Boundary 1, marking the lower boundary of the Tommotian Stage; Boundary 3, the lower boundary of the Atdabanian Stage; Boundary 5, the lower boundary of the Botomian Stage; and Boundaries 7 and 8, marking the transition from Lower to Middle Cambrian in the Siberian Platform. In addition, Boundary 9 marks the lower boundary of the *Triplagnostus gibbus* Zone of the Amgan Stage, which occurs almost universally.

Cambrian, trilobites, brachiopods, archaecyathids, small shelly fossils, biotic boundaries, northern Siberian Platform

INTRODUCTION

Present days witness an intense search for global stratotypes for stages of the Cambrian and boundaries between them and between different Cambrian epochs. Despite high endemicity of Cambrian faunas, attempts to find world-wide biomarkers still continue. For example, several "biotic events", more or less evident throughout the world, may be distinguished in the Cambrian history [1]. Chemostratigraphic methods also gain popularity. The most promising of these relies on analysis of $^{12}C/^{13}C$ carbon isotope ratio [2–4]. The peaks of this ratio can be robustly correlated with the defined horizons and usually correspond to global biotic events [1]. In addition, studies continue on trilobites as the major faunal group of the Cambrian. These determine the horizons of global appearance of certain trilobite species and establish their isochronism [5].

The Siberian Platform with its Cambrian sections of outstanding quality has long been one of the world's best test grounds for development of global stratigraphic standards and for studies of the biosphere evolution at early stages of the formation of marine ecosystems. Abundant paleontological, stratigraphic, and paleogeographic data for this region have been accumulated over the past decades.

To establish major breakpoints in the dynamics of taxonomic diversity, we have investigated lateral and stratigraphic distribution of the guide Cambrian faunal groups: small shelly fossils, archaeocyathids, trilobites and brachiopods. As a study region, we selected the northern Siberian Platform, which includes the western part of the platform (Igarka region), Western and Eastern Anabar, Olenek uplift, and Kharaulakh Mountains (lower Lena River) (Figs. 1 and 2). Cambrian sections there reveal several types of sediments, originated in lagoonal, open shallow-shelf and relatively deepwater parts of the paleobasin, as well as the full range of transition-type sediments.

We have characterized a number of complexes of guide faunal groups. Such complexes may correspond to associations of different taxonomic ranks (species, genera, families, superfamilies, and so on); their index forms

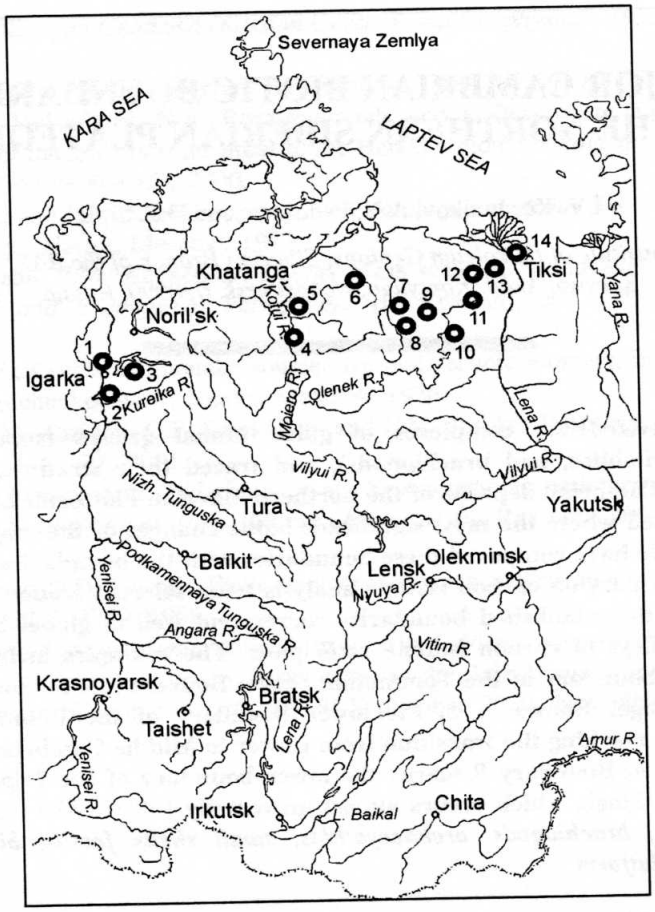

Fig. 1. Locations of sections in the territory under study. 1, Yenisei River, near Plakhinsky Island; 2, Sukharikha River [6, 7]; 3, Kulyumbe River [8]; 4, Kotui River [8, 9]; 5, Kotuikan River [9]; 6, Fomich River [9]; 7, Yulegir-Yuryakh River [10]; 8, Malaya Kuonamka River [8]; 9, Nekekit River [9]; 10, Amydai River [11]; 11, Boroulakh River [10]; 12, Olenek River (Mt. Salankan) [8, 10]; 13, Khorbosuonka River [12]; 14, Lena River (Bulkur anticline) [13].

are the taxa most characteristic for a given region in a given environment and dominating over other Cambrian species.

The materials analyzed in this work were collected by us during field trips to the northwestern Siberian Platform. The data on other Cambrian sections of the northern Siberian Platform were taken from the literature (Fig. 1).

MAJOR FAUNAL GROUPS AND FEATURES OF CAMBRIAN ECOSYSTEMS

The main feature of Cambrian ecosystems is the benthic lifestyle of most of the species forming the major faunal groups. The most abundant and widespread taxa at that time were small shelly organisms (hyoliths, etc.), archaeocyathids, brachiopods and trilobites. They inhabited nearly every zone of epicontinental seas from very shallow (10–30 m) to rather deep (200–300 m) parts of the basin. The only exceptions were lagoonal environments where the extreme shallowness governed the formation of sediments produced mostly by phytoplankton, which are represented by dolomite in today's sections.

These major Cambrian faunal groups may be divided in two classes according to their lifestyles and ways of feeding. A number of small shelly organisms (mollusks, hyoliths, coeloscleritophores, tommotiids) [14] and all trilobites were mobile benthic forms that freely moved on the sea bottom; a few of these could be burrowing animals. Some authors believe that several trilobite forms could move in the bottom water layer (vagile benthos) [15–17]. All these forms were detritophages, i.e., they fed on organic debris in the upper layer of bottom sediments.

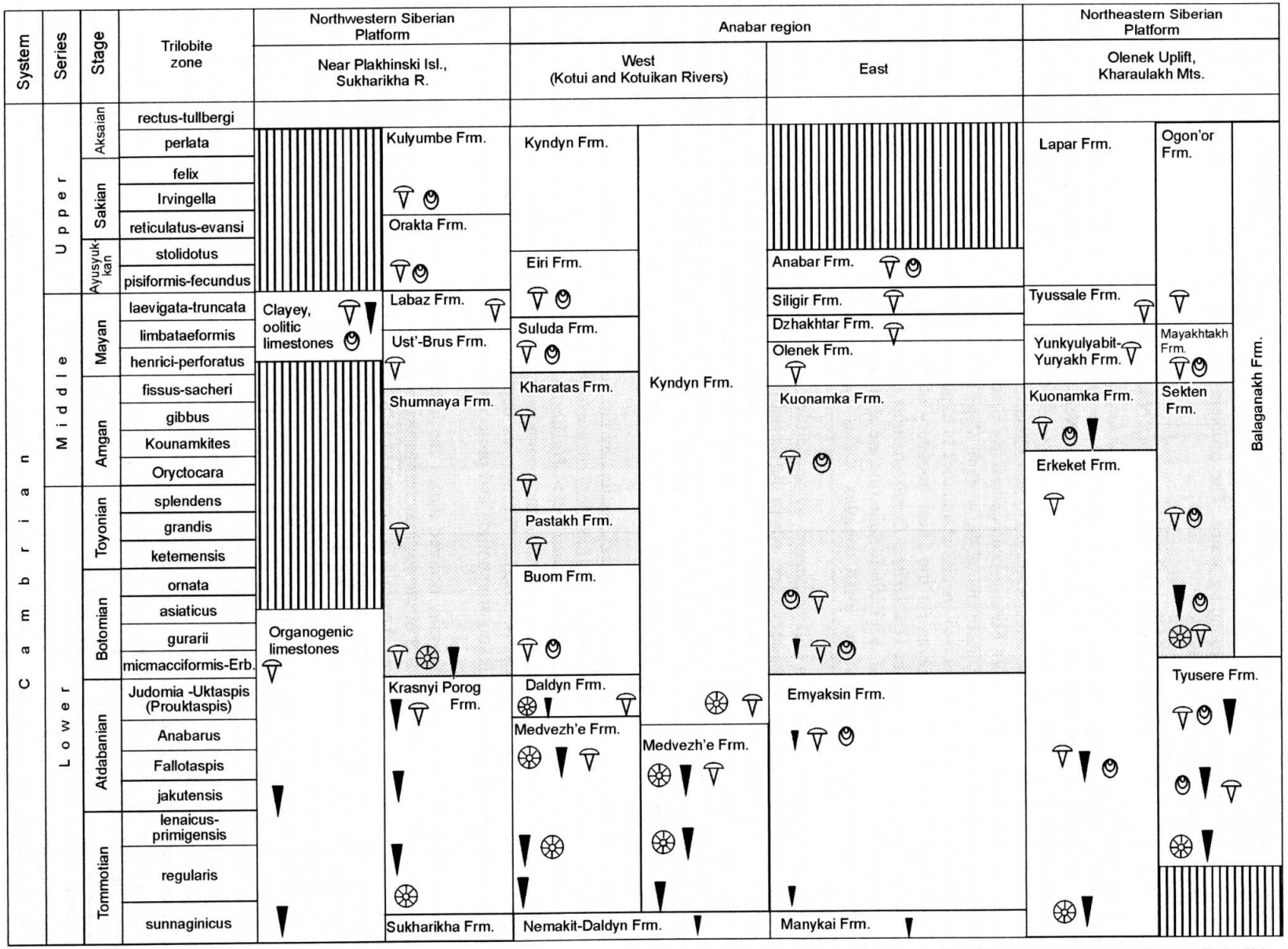

Fig. 2. Correlation scheme for Cambrian deposits in the northern Siberian Platform and distribution of guide faunal groups. *1*, small shelly organisms; *2*, archaeocyathids; *3*, brachiopods; *4*, trilobites; *5*, suites consisting of or containing black bituminous schists and limestone; *6*, gaps in sedimentation.

Another group of organisms included archaeocyatids, brachiopods, and problematic forms such as anabaritids and hyolithellminths. Archaeocyathids and the mentioned problematica inhabited shallow waters (10–30 m) in the environments with mostly regular seawater salinity. Brachiopods settled all zones from extremely shallow to deep waters; isolated specimens of *Kutorgina* could be found even in lagoonal environments with high salinity. The deepest zones were inhabited by brachiopods with phosphate-containing shells (subtype Linguliformea). According to the way of feeding, archaeocyathids and brachiopods are classified as sestenophages, or suspension feeders, which filtered their food from the surrounding water. The problematica probably also fall into this category, although it has not been definitely proven.

COMPLEXES OF MAJOR FAUNAL GROUPS

Small shelly fossils (Fig. 3). Following the dynamics of diversification of small shelly fossils, two chronological divisions of low rank can be recognized in the Nemakit-Daldyn age, one corresponding to the *Anabarites trisulcatus* Zone, and the other, to the *Purella antiqua* Zone [18]. These fossil complexes are known from the sections along the Kotui, Kotuikan, Kuonamka, and Olenek Rivers. Of these complexes, the oldest one is dominated by *Anabarites trisulcatus* Miss., accompanied by protoconodonts *Protohertzinia* and anabaritids *Cambrotubulus*. A complex of this age discovered at the western slope of the Anabar anteclise (Kotui and Kotuikan Rivers) is very rich in species. The revealed species abundance is explained, most likely, by the fact that this area was explored very thoroughly in searching for the lower boundary of the Cambrian. Anabaritids are represented there by several species of the genera *Anabarites*, *Cambrotubulus*, and *Aculeochrea*, and protoconodonts, by Protohertzinia and Hertzinia; remains of sabelliditids *Paleolina* are also known [14, 19–23]. It is hard to confidently determine the area-specific features of the fossil complex at this stage of the ecosystem evolution because of species scarcity.

The younger complex *antiqua* is still dominated by anabaritids, with their diversity markedly increased in the Anabar sections, especially on the eastern slope, where the persisting forms are supplemented by five anabaritid genera, while on the western slope three new genera are found. In addition, a significant part of the paleontological complex from the Kotui sections is formed by hyoliths *Spinulitheca*, *Loculitheca*, *Ladatheca*, *Conotheca*, and *Circotheca*, mollusks *Purella*, *Anabarella* and *Seccuriconus*, hyolithellminths, and coeloscleritophores. In this respect the faunal complex of this area is similar to the complex of the Olenek Plateau of the same age, which is poorer in anabaritids but enriched in monoplacophorans *Purella* and *Anabarella*, and hyoliths *Crossbitheca* and *Loculitheca* [14, 19–25].

The highest diversity of faunal communities was reached by the Tommotian. Anabaritids, monoplacophorans, gastropods, hyolithellminths, orthothecimorph hyoliths, and coeloscleritophores are highly abundant at this level (*Ladatheca—Aldanella—Oelandiella—Igorella—Watsonella—Halkieria—Tiksitheca* complex). In the sections along the Olenek River they are joined by tommotiids, protoconodonts, and hyolithimorphic hyoliths [14, 19–22, 24–26]. The sections from the northwestern Siberian Platform are depleted in anabaritids *Tiksitheca*, whereas the rest of small shelly faunal groups, including tommotiids and protoconodonts, are well represented there [6, 7, 14, 22].

A notable drop in the complex diversity occured during the later Tommotian and Early Atdabanian both in the northwestern part of the platform and in the sections on the Anabar and Olenek Rivers. During this interval, the number of taxa decreased more than threefold as compared to the Early Tommotian. The Kuonamka section is represented only by several hyolith genera (*Allatheca*, *Dorsojugatus*, *Obliquatheca*, *Eonovitatus*) and hyolithellminths [20, 23]. The faunal complex from Olenek mostly inherited the features of the earlier complex there but was depleted in anabaritids and mollusks. The same holds true for the sections from the northwestern Siberian Platform, where the genera that appeared earlier gradually went extinct during the post-Sunnagin part of the Tommotian. In the Kotui sections the deposits of the Upper Tommotian stage are represented by dolomite mostly free of fossils. This complex, however, is the oldest and most diverse for the lower Lena River [13, 14]. It is quite similar to the complexes of Olenek Plateau sections of the same age, but differs from them in having additional hyoliths, *Conotheca* and *Turcutheca*, as well as abundant *Chancelloriidae*, which, in turn, compares it to the sections from the northwestern Siberian Platform.

Up the section the role of mollusks and problematica decreases while the influence of hyoliths increases. The Atdabanian-Botomian fauna of Eastern Anabar is represented exclusively by hyoliths [14, 20, 23]. The genera *Burithes*, *Gracilitheca*, *Doliutus*, *Tetratheca*, *Trapezovitus*, *Lenatheca*, *Novitatus*, etc., which dominate this complex, are also found in the sections on the Olenek and lower Lena Rivers, where they are joined by chancelloriids, gastropods *Pelagiella*, and conodontomorphic problematica. A characteristic feature of the Lena sections is the presence of tommotiids *Lapworthella* and endemic hyolithids *Nelegerocornus*. In the sections along the Sukharikha

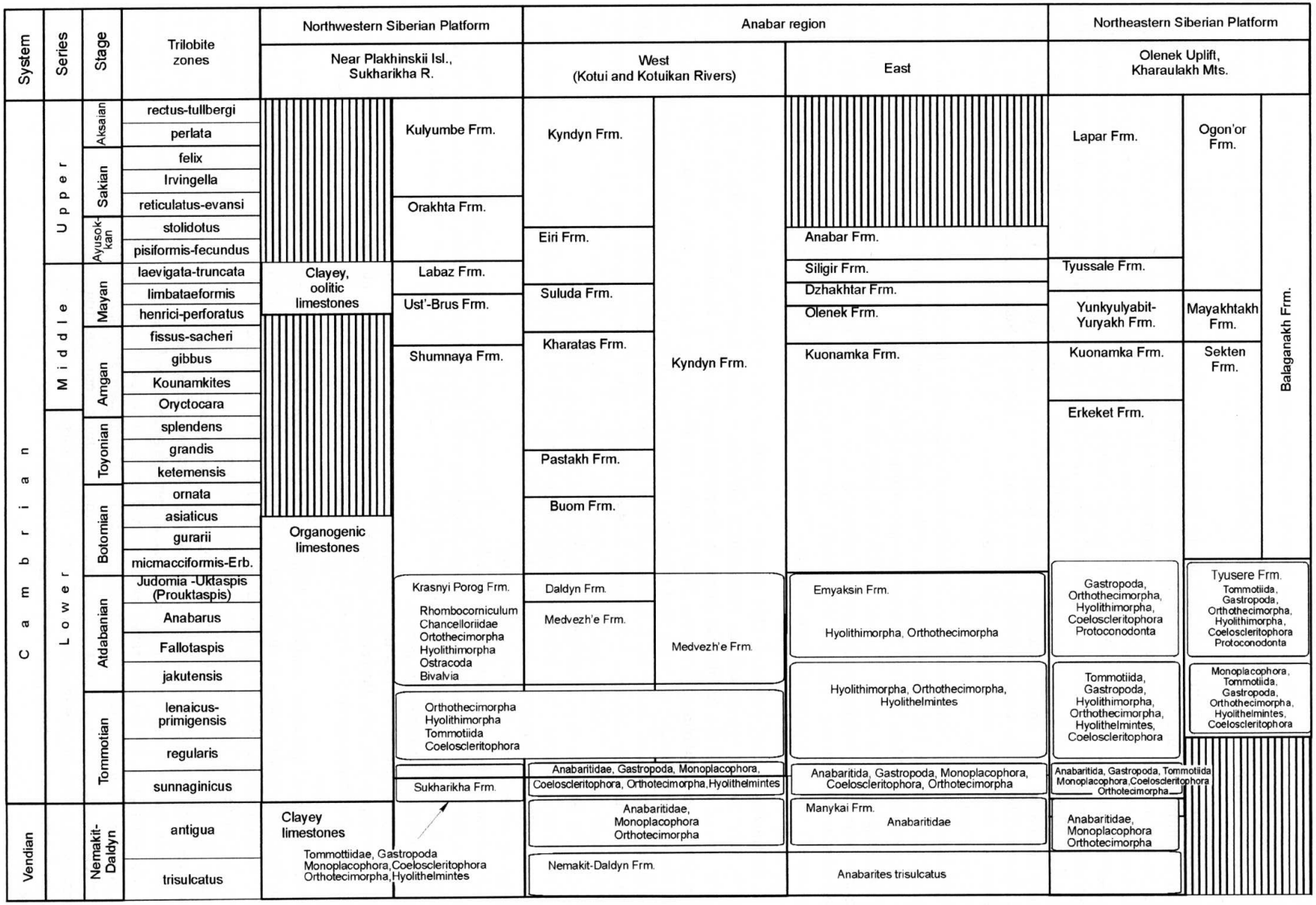

Fig. 3. Distribution of small shelly fauna complexes in the Lower Cambrian of the northern Siberian Platform.

River (northwestern Siberian Platform) this interval is represented by hyolith genera *Obliquatheca*, *Tetratheca*, *Lenatheca*, and *Burithes*, problematic phosphate forms *Rhombocorniculum*, *Nikolarithes*, *Hadimopanella*, and *Markuelia*, chancelloriids *Arhiasterella*; it is also worthly of note that bivalves (*Fordilla*) and ostracodes (*Cambria*) appeared.

Our analysis of the dynamics of small shelly faunal complexes in the interval from the Nemakit-Daldyn to the Early Botomian age suggests that the evolution of these complexes may be divided in five stages. The established boundaries are not ranked uniformly: the most pronounced change occurred in the Early Tommotian age, and this boundary seems well suited to define a geologic age boundary; in other cases the transitions are smooth and many predecessors' features are inherited. Analysis of lateral changes of the complexes reveals characteristic features of the sections from the eastern Anabar region and lower reaches of the Lena River (Kharaulakh Mountains); the sections from Olenek River are intermediate. To explain these differences, we suggest that the bottom depths gradually decreased from middle Kuonamka River through lower Olenek River to Kharaulakh Mountains. West of the Anabar Plateau the bottom profile shallowed out from Kotui to Sukharikha River; note that the faunal complexes of the Kotui sections are most similar to those from the Olenek sections, and the complexes of Sukharikha sections, to the Kharaulakh sections.

Trilobites (Fig. 4). Scarce remains of trilobites are found on the territory under study starting from the bottom of the Atdabanian Stage. The Cambrian deposits of the northern Siberian Platform are rich in diverse representatives of the class Trilobita. More than 50 families are described in the literature.

"Fallotaspididae" complex. The first reliable findings of trilobites in the area under study come from the *Fallotaspis* lone. They belong to the genus *Fallotaspis* [12]. However, findings of trilobite problematica were reported from the *Profallotaspis* lone of the Yerkeket Formation on the Olenek Plateau [18]. This trilobite complex is ubiquitous in the northeastern Siberian Platform (Eastern Anabar, Olenek Plateau, Kharaulakh Mountains) within the *Profallotaspis* and *Fallotaspis* lones.

"Judomia-*Pagetiidae*" *complex.* This complex is found in the northwestern Siberian Platform (Sukharikha River), western Anabar region and the northeastern Siberian Platform (Olenek Plateau, Kharaulakh Mountains) within the second half of the Atdabanian Stage. In the northwestern Siberian Platform the first findings of trilobites occur in the Upper Atdabanian horizons. They include rare *Pagetiellus lenaica*, *Judomia* sp., *Tirangulaspis* sp. [27]. In the western Anabar region the first trilobites are also found in the Upper Atdabanian (*Judomia* lone) and include several species of *Judomia*, *Tirangulaspis annio*, *Hebediscus vagus*, *Chorbusulina bella*, etc. [9]. This complex is dominated by *Judomia*, with pagetiids also abundant. The Olenek Plateau and Kharaulakh Mountains harbor *Pagetiellus* in the Yerketek and Tyuser Formations, as well as members of the family Nevadiidae (*Nevadella* genus) [12, 13]. Specimens of *Judomia* are found somewhat higher in the section.

"Pagetiidae" complex. This complex occurs in the upper half of the Atdabanian Stage on the eastern slope of the Anabar Plateau. *Pagetiella* are found ubiquitously but are comparatively rare in clayey greenish-gray and red sandstone of the lower Emyaksin Formation.

"Calodiscus-Erbiella" complex is established at the very bottom of the Botomian Stage (lower Shumnaya Formation) in the northwestern Siberian Platform. *Erbiella pjankovskia*, *Rondocephallus*, *Bergeroniellus*, *Poliellina*, *Calodiscus*, etc. are found here [27]. The complex is indicative of lower Botomian age. The most abundant species belong to *Erbiella* and *Calodiscus* genera.

*"Protolenidae (*Bergeroniellus *and* Bergeroniaspis*)" complex.* Abundant and diverse remains of protolenid trilobites *Protolenus borealis*, *Bergeroniellus asiaticus*, *Bergeroniaspis dualis*, etc. are found in section intervals that date from the Botomian in the western Anabar region [9]. Pagetiids also occur here. The complex falls within the Buom Formation.

"Protolenidae-Pagetiidae" complex. Trilobite complexes of the eastern Anabar region and the northeastern Siberian Platform sharply change at the beginning of the Botomian. The dominant Pagetiidae and olenillid trilobites give way to abundant and diverse protolenids. They, however, still coexisted with Pagetiids, which were represented by a new set of genera and species. The "Protolenidae-Pagetiidae" trilobite complexes from the eastern slopes of the Anabar Plateau and the northeastern Siberian Platform significantly diverged in terms of genera and species. For instance, on the eastern slopes of the Anabar Plateau, protolenids were most widely represented by *Bergeroniellus expansus* and *Bergeroniellus spinosus*, and pagetiids, by *Pagetiellus ultimus*, *Neocobboldia dentata*, and *Neopagetina* [10]. Within the same time interval on the Olenek Plateau and in the Kharaulakh Mountains, protolenids were more abundant and diverse, including the genera *Protolenus*, *Nelegeria*, *Bergeroniaspis*, and *Bergeroniellus* [12, 13]. In addition to protolenids and pagetiids, representatives of other families (Dorypygidae, Edelsteinaspidae, Ptychopariidae) appeared there during this time. These complexes existed throughout the Botomian. In the northernmost parts of this area the section consists of dolomites of the Balagan Formation, free of trilobites.

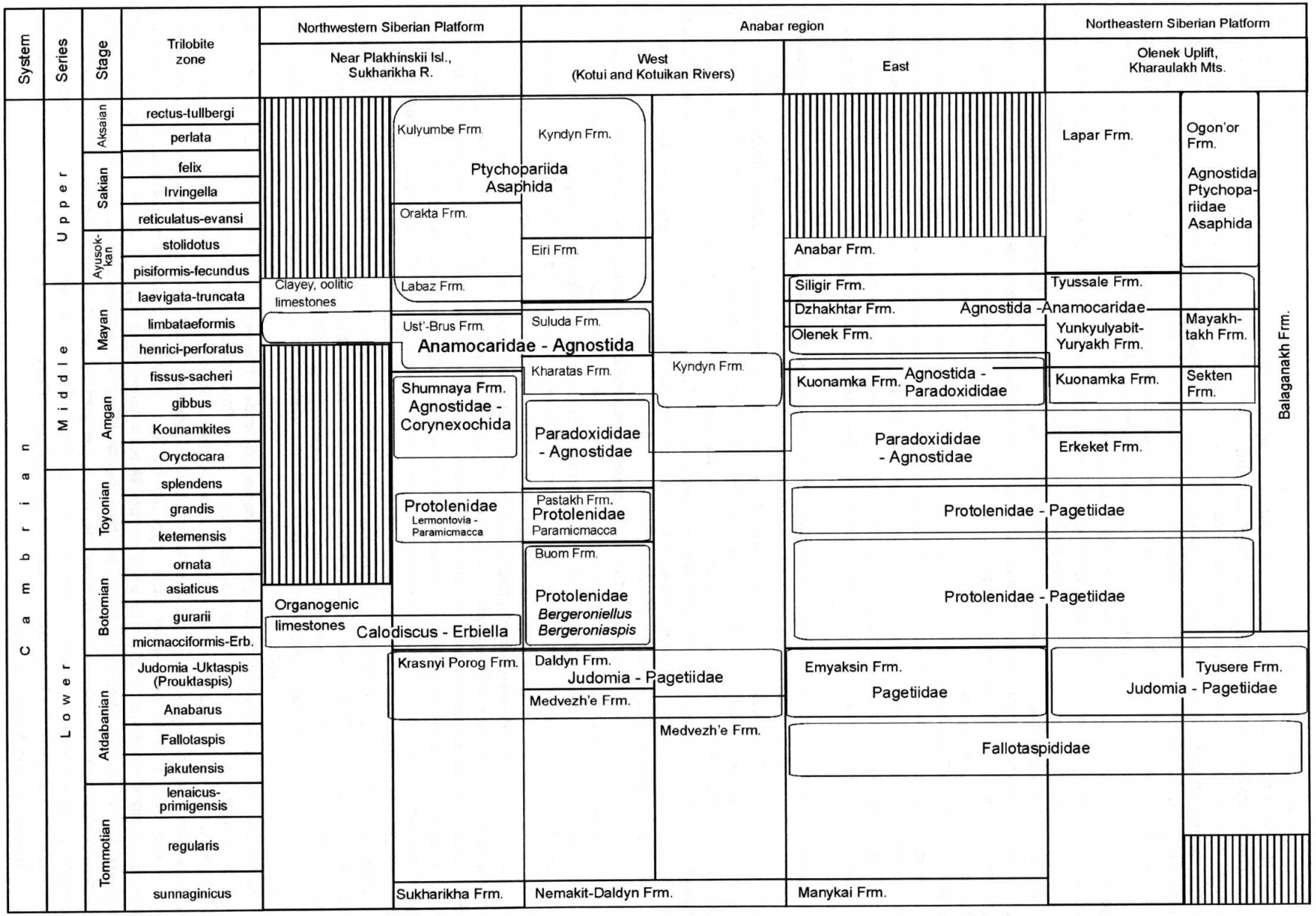

Fig. 4. Distribution of trilobite complexes in the Cambrian of the northern Siberian Platform.

In the later deposits (Toyonian Stage) the most representative members of the complexes are still protolenid trilobites. However, Toyonian "Protolenidae-Pagetiidae" complex remarkably differs from the earlier Botomian complex. The Toyonian deposits of Kuonamka, Yerkeket, and Sekten Formations are most confidently characterized by findings of *Lermontovia* and *Paramicmacca*, with sporadic occurrence of members of the families Pagetiidae, Dorypygidae, and Ptychopariidae. First representatives of Agraulidae, Solenopleuridae, and Leostracidae appear at this time [13]. The complexes of the northeastern Siberian Platform differ laterally. For example, dolomitic organoclastic limestone of the Sekten Formation of the Kharaulakh Mountains contain about 30 trilobite species, of which the most abundant are protolenids *Paramicmacca submissa*, *P. modesta*, and *P. convexa*, with findings of *Kootenia magnaformis*, *Menneraspis delicata*, *Binodaspis convexa*, etc. [13]. At the same time, Toyonian deposits of the eastern Anabar region and Olenek Plateau are characterized by the presence of *Lermontovia dzevanovskii*, *L. grandis*, *Paramicmacca petropavlovskii*, *Kootenia*, *Cheiruroides gracilis*, *Pagetia horrida*, etc. [10].

"Protolenidae (Lermontovia-Paramicmacca)*" complex.* For the Toyonian Stage of the northwestern Siberian Platform and western Anabar region, *Kootenia anabarensis*, *Paramicmacca pecularis*, *Binodaspis prima*, *Lermontovia lenaica*, and *L. grandis* are most characteristic. These horizons are dominated by protolenids *Paramicmacca* and *Lermontovia*.

"Paradoxididae-Agnostidae" complex. The terminal layers of Lower Cambrian in the western and eastern Anabar regions and in the northeastern Siberian Platform contain remains of the earliest paradoxidids (*Anabaraspis*), which, together with agnostids, dominate the trilobite complex of the lower half of the Amgan Formation. In the eastern Anabar region and northeastern Siberian Platform this complex occurs until the end of the *Kounamkites* lone, whereas in the western Anabar region it continues slightly higher into the middle of the *Triplagnostus gibbus* lone.

Starting in the Upper Toyonian age, protolenids in the eastern Anabar region are replaced with species of the family Paradoxididae (*Anabaraspis*), and the earliest species of the order Agnostida are found (*Peronopsis* and *Condylopyge*); in the Kharaulakh sections, deposits of the same age harbour endemic paradoxidids *Anabaraceps*. Through the *Anabaraspis* time, a mixed trilobite complex, transitional between Lower and Middle Cambrian, is found both in the Kharaulakh and eastern Anabar regions. The newly appeared middle Cambrian paradoxidids and agnostids were still accompanied by last protolenids (*Lermontovia*, *Paramicmacca*), continuing ptychopariid forms (*Eoptychoparia*, *Solenopleura*, *Chondragaulos*, *Alokistocare*, *Menneraspis*, *Erbia*), corynexochides (*Kootenia*, *Olenoides*), and pagetiids (*Neopagetina*, *Pagetia*).

Starting in the *Oryctocara* time, agnostids and typical paradoxidids (*Paradoxides*) are joined in the Eastern Anabar by oryctocephalids *Oryctocara*, *Oryctocephalos*, *Cheiruroides*, *Tonkinella*, and *Oryctocepalus*. *Dolichometopus* corynexochids appear in the northeastern part of the region, whereas the first oryctocephalids start to appear only in the *Kounamkites* lone. This lone is characterized throughout the region by abundant findings of Ptychagnostidae agnostids (*Pentagnostus*, *Ptychagnostus*, *Triplagnostus*), and *Kounamkites* ptychopariids. The earliest anomocarids (*Chondranomocare*) emerge in the eastern Anabar region.

"Agnostidae-Corynexochida" complex. Trilobites of the lower Middle Cambrian from the northwestern Siberian Platform differ somewhat from the complexes of its northeastern parts. The genera continuing from the Lower Cambrian, such as *Pagetia*, *Erbia*, *Kootenia* and *Chondragraulos*, are joined with new genera typical of Middle Cambrian: *Olenoides*, *Chondranomocare*, *Bathynothus*, *Kounamkites*, *Peronopsis*, *Ptarmigania*, and *Oryctocara*. The following trilobite complex is characteristic for the lower Amgan Stage in the northwestern Siberian Platform: *Pagetia ferox* Lerm., *Chondranomocare bidjensis* Polet., *Kounamkites rotundatus* N. Tchern., *K. frequens* N. Tchern., *Erbia granulosa* Lerm., *Peronopsis fallax* Linnr., *Granularia* sp., *Olenoides* sp., *Bathynothus anabarensis* Laz., *Antagmopleura* sp., *Chondragraulos* sp., *Ptamigania* sp., *Oryctocara* sp.

The same deposits with rare occurrences of *Triplagnostus gibbus* Linnr. correspond to the next *Triplagnostus gibbus* lone.

The "Agnostidae-Corynexochida" complex distinguished here corresponds to the *Oryctocara* and *Kounamkites* lones of the Amgan Stage, and the lower *Tomagnostus fissus - Paradoxides sacheri* lone.

"Anomocaridae-Agnostida" complex. The conditions of facies formation in the northwestern Siberian Platform changed drastically in the upper half of the Amgan Stage. Dark gray and black siliceous limestone of the Shumnaya Formation gave way to shallower-water facies typified by light gray and clayey greenish-gray limestone with massive algal blanket bioherms. This boundary is marked in the sections by the appearance of *Eodiscus*, *Peronopsis*, *Phalacroma*, *Cotalagnostus*, *Bailiaspis*, *Holocephalina*, *Kooteniella*, *Solenopleura*, *Pseudanomocarina*, *Corynexochus*, *Paradoxides*, and *Agraulos*. They charaterize the upper part of the Amgan Stage and correspond to the *Tomagnostus fissus—Paradoxides sacheri* lone. *Peronopsis*, *Kootenia*, and *Olenoides* occur throughout the Amgan Stage sections; *Peronopsis*, *Phalacroma*, *Olenoides*, *Solenopleura*, *Corynexochus*, and *Agraulos* penetrate into the overlying deposits of the Mayan Stage.

At the next boundary, a rich trilobite complex of the *Anopolenus henrichi—Corynexochus perforatus* lone appears. The advent of *Linguagnostus*, *Anopolenus*, *Koptura*, *Liostracus*, *Anomocarioides*, *Metanomocare*, *Dasometopus*, *Centropleura*, *Basocephalus*, *Dorypyge*, *Elyx*, and *Ctenocephalus* was at the beginning of the Mayan Stage.

Trilobite genera passing into the next *Anomocarioides limbataeformis* lone are *Phalacroma*, *Linguagnostus*, *Solenopleura*, *Agralos*, *Centropleura*, and *Dasometopus*; in addition, the trilobite complex from these deposits includes newly appeared *Phoidagnostus*, *Bellagnostus*, *Anomocarina*, *Buitella*, *Schorella*, *Onchonotellus*, *Suludella*, *Hatangia*, *Proasaphiscus*, *Irinia*, *Harataspis*, and *Semicyclocephalus*.

Thus, the "Anomocaridae-Agnostida" complex may be distinguished in the deposits of the upper half of the Amgan Stage and the lower half of the Mayan Stage of the western Anabar region and northwestern Siberian Platform.

"Agnostida-Paradoxididae" complex. The *Kounamkites* lone from the eastern Anabar region is characterized by mass findings of the Ptychagnostidae agnostids (*Pentagnostus*, *Ptychagnostus*, *Triplagnostus*), and ptychopariid trilobites (*Kounamkites*). The first anomocarids (*Chondranomocare*) appear in the eastern Anabar region. Paradoxidids are also quite abundant.

"Agnostida-Anomocaridae" complex. In the Cambrian deposits of the Kharaulakh Mountains, the earliest anomocarids appear somewhat later, starting from the *Triplagnostus gibbus* lone, which is also marked by early disappearance of paradoxidids. As a result, the "Agnostida-Anomocaridae" complex dominated by agnostids can be distinguished. Interestingly, some pychagnostid species were distributed world-wide starting with the upper *Kounamkites* lone and the *Tomagnostus fissus—Paradoxides sacheri* lone. Middle Cambrian seas likely communicated during this interval through oceanic currents which might spread larvae of agnostid trilobites at the early stages of development. During the Amgan Age, the dominant forms of trilobites coexisted with still evolving Conocoryphidae, Utiidae, Dinesidae, Dorypygidae, Oryctocephalidae, Dolichometopidae, and other families.

At the base of the Mayan Stage paradoxidids disappear from the eastern Anabar region, while anomocarids (*Anomocarioides*, *Forchhammeria*, *Anomocarina*, and *Metanomocare*) and agnostids (Peronopsidae, Ptychagnostidae, Spinagnostidae, Diplagnostidae, Phalacromidae, and Clavagnostidae) become dominating. Thus, the "Agnostida-Anomocaridae" trilobite complex may be distinguished in the Eastern Anabar throughout the Mayan age.

"Ptychopariida-Asaphida" complex. The boundary of the Upper Cambrian is marked by the appearance of *Pseudagnostus*, *Baltagnostus*, *Clavagnostus*, *Palaeadotus*, *Toxotis*, *Aplexura*, *Damesella*, *Menomonia*, *Paracoldinia*, *Maiaspis*, *Theodenisia*, *Pauciella*, *Brassicicephalus*, *Acidaspidella*, and *Nganasanella*, typical of the Ayusokkan Stage of the Upper Cambrian.

With the appearance of *Gliptagnostus reticulatus* agnostids, a base of the respective lone and the Saki Stage can be traced, both characterized by the complex of *Agnostus*, *Gliptagnostus*, *Olenaspella*, *Iwayaspis*, *Schoriella*, *Maspakites*, *Idahoia*, *Raashelinna*, and *Maduiya*.

The next stage is marked by the appearance of a widespread genus *Irvingella* associated with *Eoacidaspis*, *Tagenarella*, and *Catuniella* in the Noril'sk region, and with a more endemic complex of the Igarka region (*Faciura*, *Gabriella*, *Enstyna*, *Aplexura*, *Kuljumbina*, *Plethopeltoides*, *Sigmocheilus*, *Menomonia*, *Agnostus*, and *Koldinia*). They are replaced, in turn, by the Aksai Stage complex, represented by *Amorphella*, *Yurakia*, *Polyariella*, *Graciella*, *Monosulcatina*, *Tukalandaspis*, *Kaninia*, *Kujandaspis*, and *Dolgeuloma*.

Thus, trilobite complexes of the northwestern Siberian platform differ significantly from those of the northeastern part. As a rule, the northwestern complexes were dominated by endemic trilobite species of the inner shelf and the transition zone, whereas the northeastern open-sea slope facies were largely inhabited by widely distributed genera and species.

"Agnostida-Ptychopariidae-Asaphida" complex. The overlying deposits of the Upper Cambrian from the eastern Anabar region are devoid of faunal remains; in the northeastern Siberian Platform, agnostids continue to dominate together with species of the orders Ptichopariida and Asaphida. Anomocarids gradually disappear from the sections, and the "Agnostida-Ptychopariidae-Asaphida" complex may be distinguished in this region. An excellent correlative boundary is visible at the base of the *Gliptagnostus reticulatus—Olenaspella evansi* lone. Global appearance of abundant remains of *Gliptagnostus reticulatus* in open sea facies allows exact interregional correlation of the Upper Cambrian.

Archaeocyathids (Fig. 5). *Northwestern Siberian Platform.* The earliest findings of archaeocyathids occur at the very top of the Sukharikha Formation. Found here are species from the most ancient complex of the Siberian Platform, one comprising the *Nochoroicyathus sunnaginicus* lone: *Nochoroicyathus sunnaginicus*, *Archaeolynthus polaris*, *Cryptoporocyathus junicanensis*, etc. [22]

Up the section, in the lower Krasnyi Porog Formation, archaeocyathids of the *Dokidocyathus regularis* lone

of the Tommotian stage occur: *Nochoroicyathus anabarensis*, *Tumulocyathus* sp., *Dokidocyathus* sp., and *Retecoscinus sakhaensis* [22].

The next findings of archaeocyathids occur at the Atdabanian stage. *Lenocyathus lenaicus*, *Baikalocyathus* sp., *Coscinocyathus isointevallum*, etc. are found here [8].

The last occurrences of archaeocyathids in this region come from the lower Botomian stage. They belong to the *Botomocyathus zelenovi* lone: *Botomocyathus zelenovi*, *Stapicyathus stapiporus*, *Ajaciathus* sp., etc. [8].

Western Anabar. The earliest findings of archaeocyathids in this region occur at the Upper Tommotian Stage: *Archaeolynthus polaris*, *Nochoroicyathus turbidus*, *Tumulocyathus kotuyikensis*, *Sakhacyathus subartus*, etc. This complex corresponds to the *lenaicus-primigensis* lone.

The next complex of archaeocyathids from this section comes from the lower Atdabanian stage: *Korshunovicyathus melnikovi*, *Dokidocyathella incognita*, *Baikalocyathus* sp.

Finally, *Nochoroicyathus arteintervallum* is found at the uppermost Atdabanian Stage.

Northeastern Siberian Platform. Archaeocyathids, which were widespread on the Siberian Platform in the Early Cambrian, are scarce here and confined to two stratigraphic horizons only. The findings are concentrated on the Olenek Plateau and in Kharaulakh. The earliest findings, of the Late Tommotian—Early Atdabanian age, come from the Tuser, Kessyusin, and Erkeket Formations. *Nochoroicyathus* sp., *Dictyocyathus translucidus*, *Archeolynthus*, *Cryptoporocyathus*, etc. are found here.

The next interval of the sections where archaeocyathids are found corresponds to the Late Atdabanian—Early Botomian. Arhcaeocyathids of the order Ajacicyathida also existed in the northeastern part of the region under study and included *Robustocyathelus legitimus*, *Carinacyathus minaevae*, *C. squamosus*, etc. [8].

Brachiopods (Fig. 6) are found in the Cambrian deposits of the Northern Siberian platform almost ubiquitously. In species diversity, they are second only to trilobites, and sometimes even surpass them in abundance. This makes brachiopods important for the stratigraphy of the region.

"Cryptotreta neguertchenensis" complex is common in the eastern Anabar region and the northeastern Siberian Platform and includes *Cryptotreta neguertchenensis* and *Lingulella lingulata* [28, 29]. The age interval of its existence corresponds to the lower half of the Atdabanian Stage (*Profallotaspis* and *Fallotaspis* lones).

"Obolellidae" complex. Species from this complex are found in almost all regions of the northern Siberian Platform. In the northwest it is scarce *Obolella* sp. [6, 7]. In the western Anabar region *Obolella crassa*, *Kotujella calva*, and *Kutorginia* sp. are known from the upper Medvezh'ya Formation [9]. In the northeast and in the eastern Anabar region, abundant *Obolella*, *Alisina*, and *Sibiria*, as well as rare *Lingulella*, are found in the upper Tumer and Emyaksin and middle Erkeket Formations [8, 13]. This complex is distinguished in the upper half of the Atdabanian Stage and corresponds to the *Pagetiellus anabarus* and *Judomia-Uktaspis* (*Prouktaspis*) lones. In the western Anabar region, obolellids continue to exist in the lower Botomian Stage.

"Lingulella, Botsfordia, Obolellidae" complex is distinguished in the northwestern Siberian Platform within the Botomian and lower half of the Toyonian Stage. Here, in the lower Shumnaya Formation *Lingulella* and *Botsfordia caelata* appear along with the persistent obolellids and become dominating [6].

"Botsfordia caelata, Linnarssonia" *complex.* In the Lower Botomian, brachiopods with carbonate-containing shells were completely replaced by phosphate-containing shelly forms in the eastern Anabar region. Abundant *Botsfordia caelata*, *Linnarssonia anabarica*, and *Pegmatreta* sp. are found here in the Kuonamka Formation [8, 29]. The complex is common at the lower Botomian Stage.

"Obolellidae-Kutorgina" complex. Clayey carbonate sediments continue to accumulate in the northeastern Siberian Platform during the Botomian. As a result, the Obolellidae complex was still dominating here, with *Kutorgina* also appearing. The interval of the complex corresponds to the Botomian Stage.

"Acrotretidae-Nisusia" complex. Brachiopods with phosphate shells continued to dominate in the eastern Anabar region during the Toyonian, but their species composition changed. New species from the genera *Lingulella* and *Linnarssonia* appear in the complex, as does the genus *Acrotreta*. Brachiopods of the class Calciata (*Nisusia*), absent during the Botomian, also make their appearance.

"Tremalobulus-Matutella" complex. Obolellidae still dominated in the northeast of the region. However, the dominance shifted to the newly appeared genera *Trematolobus* and *Matutella*. Their interval of occurrence corresponds to the Toyonian Stage.

Lingulella sp. Findings of the Middle Cambrian brachiopods in the northwestern Siberian Platform are confined to the upper Amgan Stage. Singular *Lingulella* sp. are found here [8].

"Acrotretidae (Pegmatreta, Homotreta)" complex. Bituminous sediments rich in organic matter of the Kuonamka Formation continue to accumulate in the eastern Anabar region during the early Middle Cambrian. In the northeast of the region (Olenek plateau and Kharaulakh), clayey carbonate sediments accumulated. Brachiopods are represented by acrotretids in both regions, dominated by *Pegmatreta*, *Homotreta*, and *Linnarssonia* [29]. Also

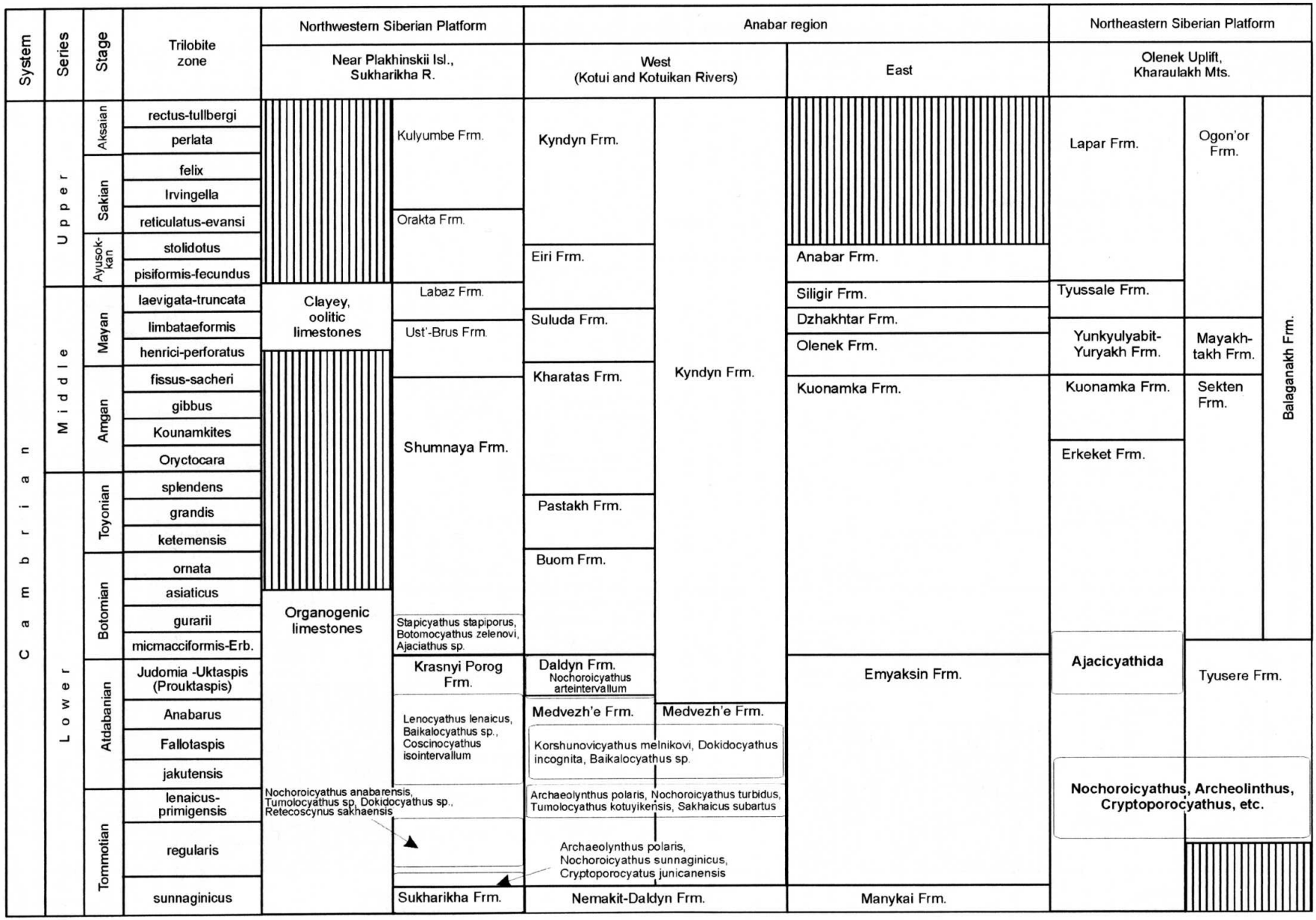

Fig. 5. Distribution of archaeocyathid complexes in the Cambrian of the northern Siberian Platform.

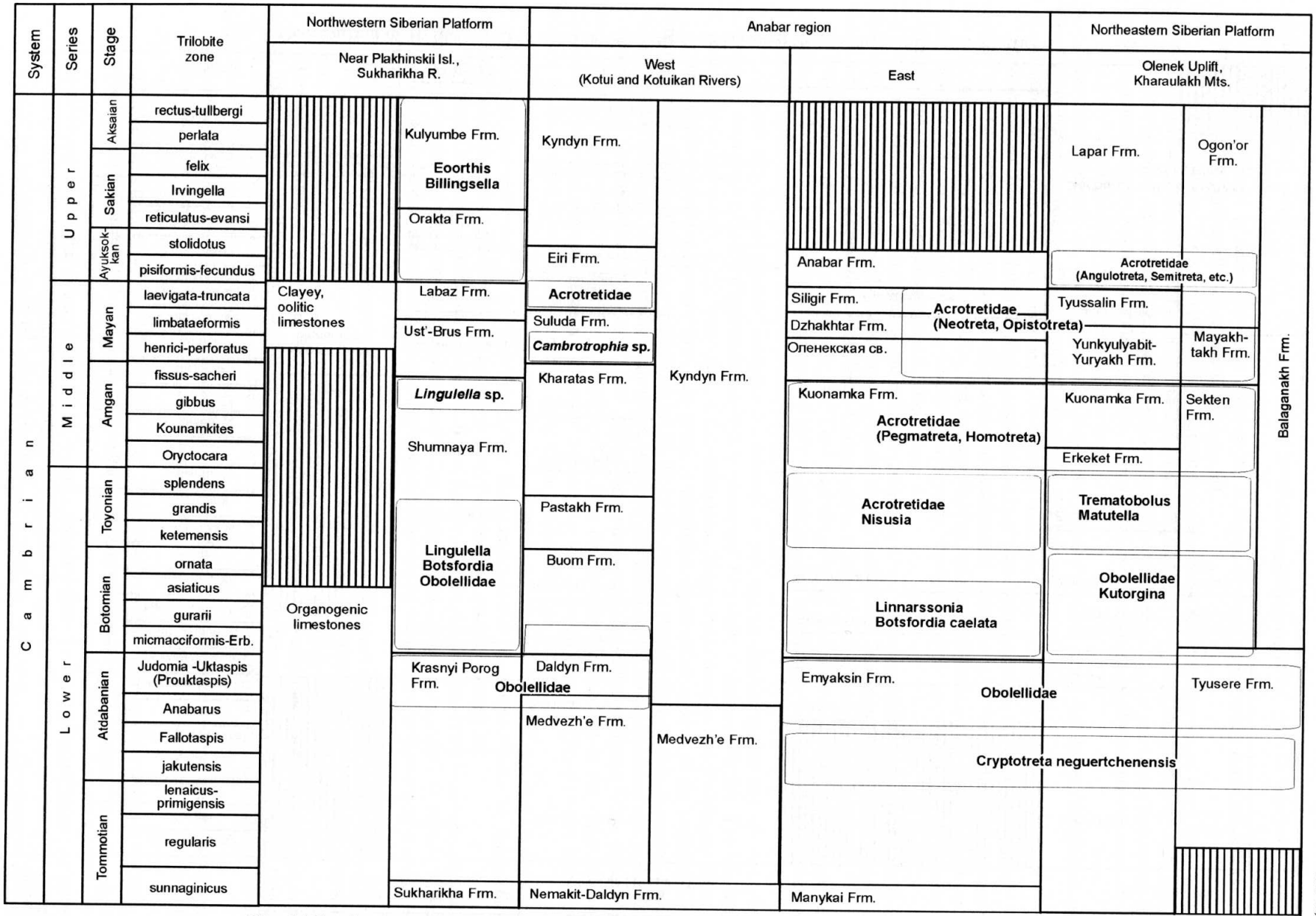

Fig. 6. Distribution of brachiopod complexes in the Cambrian of the northern Siberian Platform.

present in this complex were acrothelids (*Acrothele*, *Eothele*) [29], botsfordiids, lingulids, etc. The difference between these two complexes was that brachiopod species diversity was higher in the northeast. The complex occurs in the interval corresponding to a large part of the Amgan Stage of the Middle Cambrian, except for the *Tomagnostus fissus—Paradoxides sacheri* lone.

Cambrotrothia sp. These brachiopods are known from the lower Mayan Stage in the western Anabar region.

"Acrotretidae" complex. Acrotretid brachiopods *Lingulella* sp., *Acrothele* sp., and *Acrothreta* sp. are reported from the upper Mayan Stage in the western Anabar region [8].

"Acrotretidae (Neotreta, Opistotreta)" complex. The Mayan horizons of Cambrian sections of the eastern Anabar region and northeastern Siberian Platform are still dominated by acrotretids. Their composition, however, markedly changes. This brachiopod complex now includes *Neotreta*, *Opistotreta*, *Anabolotreta*, etc. It occurs from the upper Amgan Stage (*Tomagnostus fissus—Paradoxides sacheri* lone) through the late Mayan Stage of the Middle Cambrian.

"Eoorthis, Billingsella" complex. The Upper Cambrian sections of the northwestern Siberian Platform are characterized by the presence of articulate brachiopods. *Billingsella* are known from Ayussokan and lower Sakian Stages, whereas *Eoorthis* dominates up the section [8, 30].

"Acrotretidae (Angulotreta, Semitreta)" complex. In the Upper Cambrian of the northeastern Siberian Platform, brachiopods are found only in Kharaulakh. They are still represented by acrotretids; *Angulotreta*, *Semitreta*, etc. appear and dominate. This complex occurs in the Ogon'er Formation of the Ayussokan Stage of the Upper Cambrian [29].

These distribution schemes of the major Cambrian faunal groups are by no means complete, especially in the part regarding brachiopods and small shelly fossils. The available data allow distinguishing the complexes of small shelly fossils only down to the lower Botomian Stage, although quite abundant remains of these forms are found throughout the Lower and Middle Cambrian. Phosphate-shelled brachiopods (subtype Linguliformea) from the Middle and Upper Cambrian of the northwestern Siberian Platform and the western Anabar region, as well as brachiopods of the Upper Cambrian of the northeastern part, also are poorly investigated.

Further studies of these faunal groups from the indicated regions and age intervals will permit refining and better substantiating of the most important boundaries of changes of the Cambrian ecosystems of the Siberian Platform.

Major biotic boundaries of ecosystem evolution (Fig. 7). A taxonomic analysis of the Cambrian faunal complexes of the northern Siberian Platform shows that all significant changes in the composition of the major guide groups here coincide with the established boundaries of the regional stratigraphic subdivisions [31], and often with the boundaries of formations. This is not surprising given the benthic character of this fauna, which makes its evolution strongly dependent on the physical and chemical conditions of the bottom of the paleobasin.

We found eleven most pronounced boundaries of changes of the complexes of major faunal groups of the northern Siberian Platform. These boundaries are correlated with the established Cambrian biotic events and carbon isotope analysis data.

Boundaries 1 and 2. The Late Precambrian and Early Cambrian on the territory under study is characterized by abundant findings of small shelly fossils. At the level that we consider as a lower boundary of the Cambrian, communities of anabaritids and monoplacophorans are replaced with abundant and diverse hyolithellminths, gastropods, tommotiids, etc. However, different groups of small shelly organisms still dominated the Early Cambrian ecosystems in the northeastern Siberian Platform. The northwestern part also harbors the most ancient archaeocyathids of the Siberian Platform.

Within this interval, the CR3 global biotic event (Fig. 8) is distinguished by Brasier [1], who also analyzed isotope contents in this age interval from the stratotype sections of the Siberian Platform and found positive peaks I and II ([2], Fig. 8). Our Boundaries 1 and 2 correspond to peak I and the valley between peaks I and II, respectively. Isotope analysis also gives a similar picture for the northern Siberian Platform [4].

Boundary 3. The late Tommotian-early Atdabanian ages are marked by pronounced changes in the complexes. Brachiopods and trilobites appeared. Archaeocyathids were scarce and few in species, as are the brachiopods and trilobites, but the last two groups soon underwent a burst of speciation in the northern Siberian Platform.

Thus, the boundary between the Tommotian and Atdabanian Stages of the Lower Cambrian is the first of the most important boundaries in reshaping of ecosystems in the region under study. This horizon is confidently traced not only in the Siberian Platform, but also world-wide. It corresponds to the appearance of the first trilobites. Many investigators regard it as a global event: CR4 [1], FT [5] (Fig. 8).

Boundary 4. The next significant change in the composition of the complexes occurred in the middle Atdabanian. The first myomeric trilobites of Pagetiidae family mark the beginning of the *Pagetiellus anabarus* time. *Judomia* is abundant between polymeric trilobites; ellipsocephalids *Chorbusulina* and *Charaulaspis*

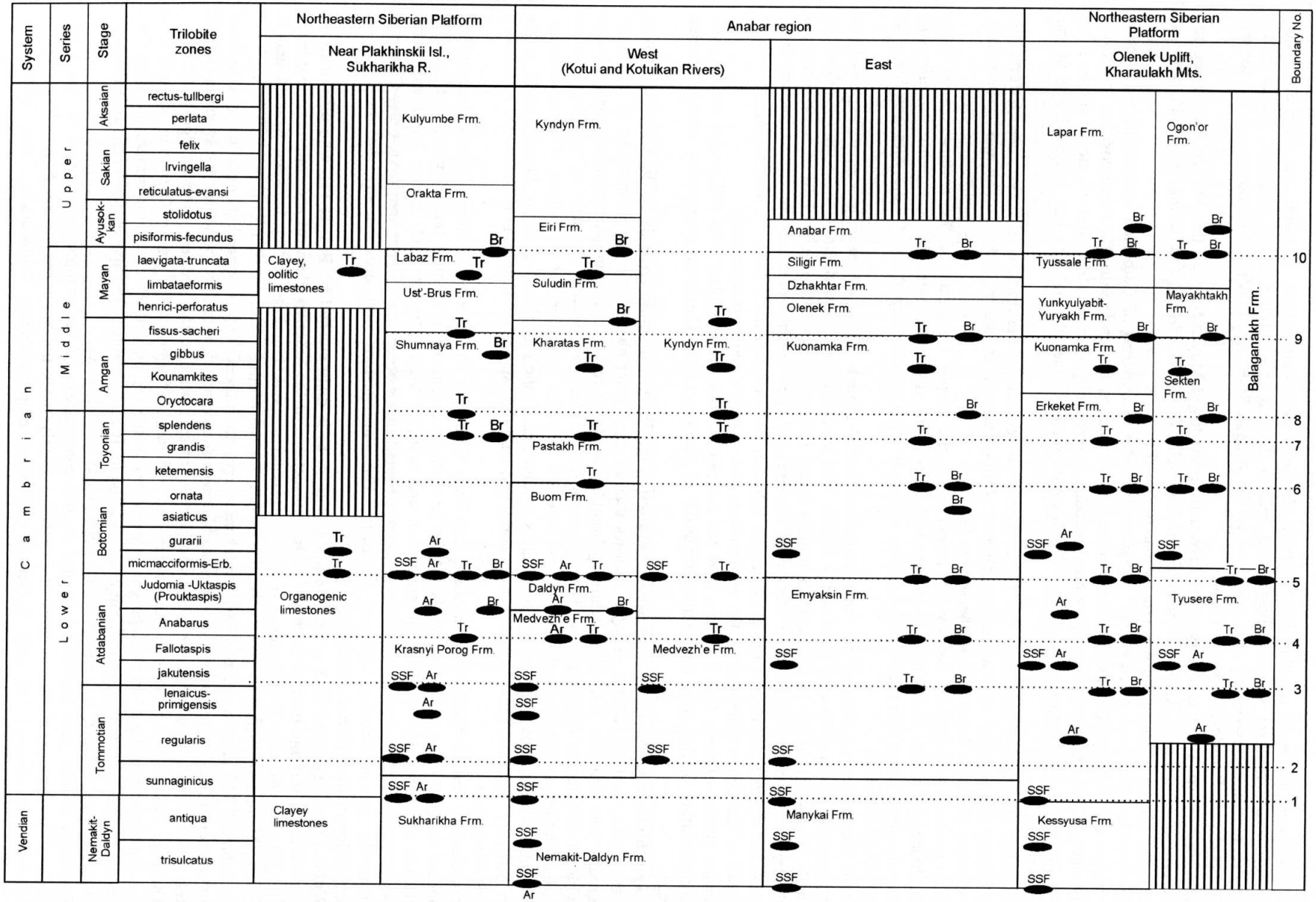

Fig. 7. Major biotic boundaries of evolution of the guide faunal groups in the Cambrian of the norhern Siberian Platform. Shown are boundaries of the complexes: SSF, small shelly fossils; Ar, archaeocyathids; Tr, trilobites; Br, brachiopods.

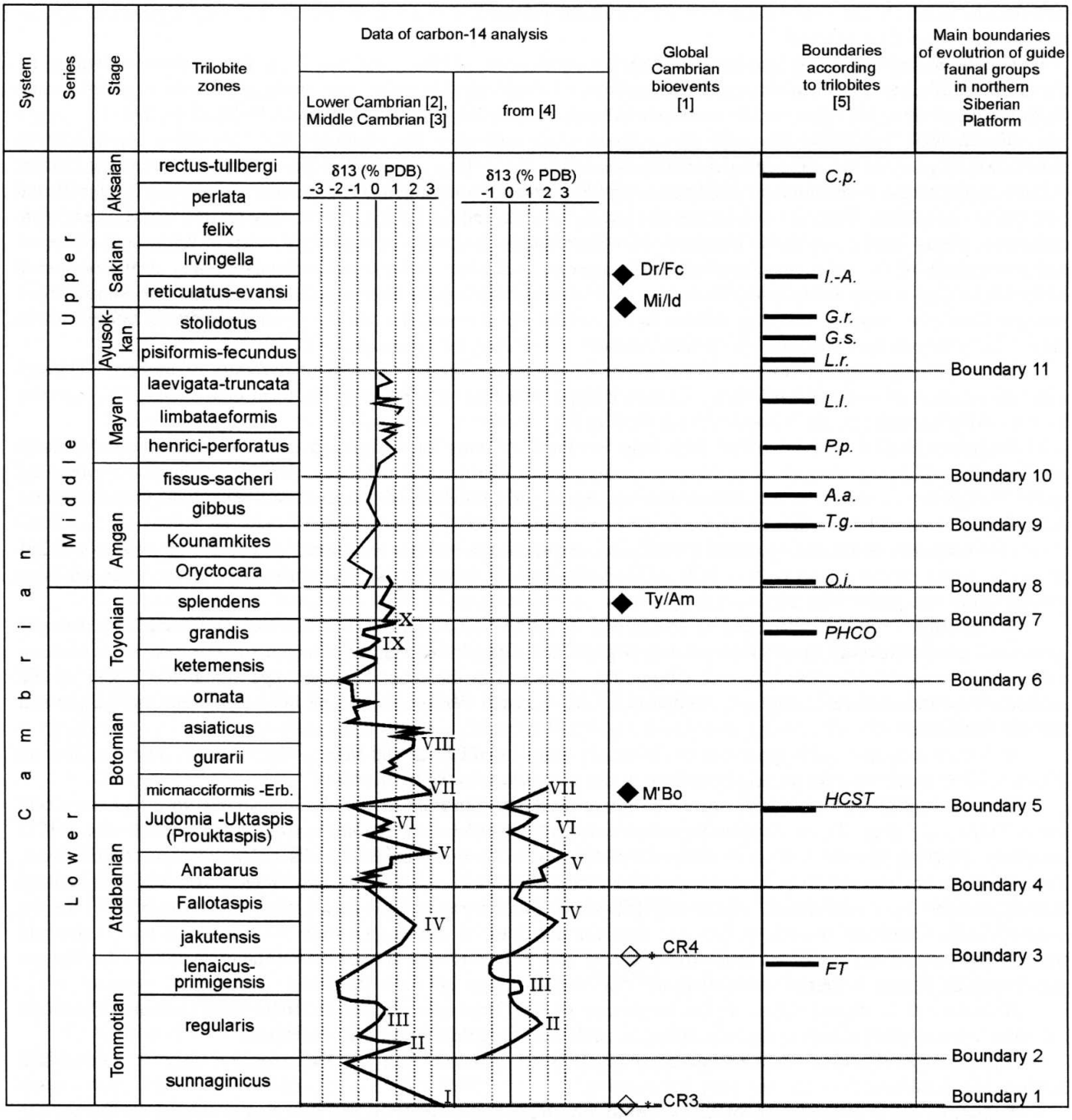

Fig. 8. Correlation of the major biotic boundaries of evolution of the guide faunal groups of the norhern Siberian Platform with global biotic events, trilobite boundaries, and carbon isotopic analysis data. Roman numerals, the peaks of the carbon isotopic data plot defined by Brasier et al. [2]. Diamonds, boundaries of global biotic events distinguished by Brasier [1]: CR3, *Sunnaginia imbricata* complex; CR4, appearance of first trilobites; M'Bo, Botomian crisis, drop in biodiversity; Ty/Am, Toyonian/Amgan extinction; Mi/Id and Dr/Fc, mass extinctions of trilobites in the Upper Cambrian. Letter indices, horizons of appearance of trilobite groups suggested by Geyer and Shergold [5], from bottom to top: FT, appearance of first trilobites; HCST, *Hebediscus attleborensis—Calodiscus—Serrodiscus—Triangulaspis*; PHCO, *Protolenus—Hamatolenus—Cobboldites—Orytocara*; O.i., *Oryctocephalus indicus*; T.g., *Ptychagnostus (Triplagnostus) gibbus*; A.a., *Acidicus atavus*; P.p., *Ptychagnostus punctuosus*; L.l., *Lejopyge laevigata*; L.r., *Linguagnostus reconditus*; G.s., *Gliptagnostus stolidotus*; G.r., *Gliptagnostus reticulatus*; I.-A., *Irvingella* in association with *Agnostotes*; C.p., *Cordylodus proavus*.

codominate with it in the late Atdabanian. Brachiopods of the class Calciata (*Obolella, Alisina*) appear and spread wide in the same time interval.

This boundary can be regarded a boundary between lones, although, judging from the qualitative changes of the northern Siberian Platform complexes it is obviously more significant. It does not appear to be a global event. Carbon isotope analysis show that it corresponds to the valley between peaks IV and V [4] (Fig. 8).

Boundary 5. Significant lithologic changes take place at the boundary between the Atdabanian and Botomian Stages. Many parts of the Siberian paleobasin were brought to large depths by transgression. Clayey silt rich in organic matter began to accumulate (Kuonamka and Shumnaya Formations). This boundary is marked by significant changes in complexes. Trilobite complexes are totally restructured. In the eastern Anabar region, brachiopods with carbonate shells are completely replaced by brachiopods with phosphate shells (class Lingulata). Scarce archaeocyathids of the order Ajacicyathida that appeared in the late Atdabanian and existed only in the northeast of the region, go extinct in the early Botomian and never appear again. Some small shelly fossils are known from younger Cambrian deposits but they remain to be studied. As a result, a leading role in the younger complexes is played by trilobites and brachiopods, which continue their rapid evolution in the Cambrian.

This boundary corresponds to a global event. It is characterized by a peak of diversity of bioherms [1] and wide distribution of eodiscoid trilobites. Carbon isotope data from the Siberian Platform characterize this horizon by the valley between peaks VI and VII [2, 4] (Fig. 8).

Boundary 6. The next boundary falls between the Botomian and Toyonian. For the trilobite complexes it manifested itself in the change of taxonomic composition of protolenid trilobites; for the brachiopod complexes, in the change of acrotretids in the eastern Anabar region and obolellids on the Olenek Plateau and in Kharaulakh. Afterwards, changes of trilobite and brachiopod communities occur much less synchronously.

This boundary is not distinguished globally. However, here we note a more drastic decrease in acrchaeocyathid diversity, which began in the middle Botomian (Botomian-Toyonian crisis). Carbon isotope analysis reveals here a valley between peaks VIII and IX [2] (Fig. 8).

Boundaries 7 and 8. Pronounced changes in trilobite communities occur in the Toyonian (*Anabaraspis splendens* time). Several families appeared (Agnostidae, Paradoxididae, Oryctocephalidae) that later became widespread in the Middle Cambrian. Brachiopod complexes, on the other hand, change somewhat higher up the section where the modern stratigraphic schemes of the Siberian Platform draw the border between the Lower and Middle Cambrian.

This transition interval is typical of the boundary deposits of Lower and Middle Cambrian all over the Siberian Platform. The faunal change at this boundary is not abrupt but extended in time.

This interval of the Cambrian section of the northern Siberian Platform likely corresponds to the global biotic event Ty/Am [1] (Fig. 8), or Amgan-Toyonian extinction. Boundary 7 probably also corresponds to the PHCO boundary [5] (Fig. 8), which is characterized by changes in the complexes of eodiscoid and polymeric trilobites. Near the same horizon the $^{12}C/^{13}C$ isotopic ratio reaches its maximum for the Amgan Stage (peak X) [2]. Boundary 8 most probably falls near the *O. i.* boundary [5], which has been suggested as a global stratotype (GSSP) for the Lower/Middle Cambrian boundary. Isotopic data for this interval are known only from a report by Brasier and Sukhov [3] concerning the cores from the northern Siberian Platform. There the boundary between the Amgan and Toyonian Stages is marked by a peak of $^{12}C/^{13}C$ ratio (Fig. 8).

Boundary 9 is distinguished at the beginning of the *Triplagnostus gibbus* time. The earliest anomocarid trilobites appear, domination of agnostids begins and their taxonomic diversity increases.

This horizon is well recognized globally [5] (Fig. 8). Isotopic data are also reported only by Brasier and Sukhov [3]; however, they are not very informative.

Boundary 10. Accumulation of clayey bituminous sediments ends in the Siberian Platform by the middle *Tomagnostus fissus—Paradoxides sacheri* time. The Lower Cambrian transgression of the paleobasin gave way to a regression, and carbonate and clayey carbonate sediments again started to accumulate in the late Amgan. These pronounced lithologic changes were followed by the restructuring of trilobite and brachiopod complexes.

This horizon lies slightly above the *A. a.* (*Aciducus atavus*) boundary [5] (Fig. 8) which is confidently recognized in many regions of the world.

Boundary 11. The Middle/Late Cambrian boundary is also marked by significant lithologic changes, which brought on changes in complexes of trilobites and brachiopods; the latter dominate during the whole Upper Cambrian.

This horizon lies below the global *L. r.* (*Linguagnostus reconditus*) boundary [5] (Fig. 8).

RESULTS

The study of the major Cambrian guide faunal groups of the northern Siberian Platform revealed many complexes separated stratigraphically and laterally. We distinguished eleven major boundaries at which the most significant changes of faunal communities occur. These boundaries can be correlated with the currently established global biotic events and with available carbon isotope data. Thus, some of our boundaries coincide both with boundaries of the regional stratigraphic subdivisions as well as with global Cambrian biotic events. They include: Boundary 1, marking the lower boundary of the Tommotian Stage; Boundary 3, the lower boundary of the Atdabanian Stage; Boundary 5, the lower boundary of the Botomian Stage; and Boundaries 7 and 8, marking the transition from the Lower to Middle Cambrian in the Siberian Platform. In addition, Boundary 9 marks the lower boundary of the *Triplagnostus gibbus* zone of the Amgan Stage, which occurs almost universally.

This work was supported by grant 01-05-65057 from the Russian Foundation for Basic Research, and by SB RAS UIGGM Cambrian Project 1760).

REFERENCES

1. Brasier, M.D., The basal Cambrian transition and Cambrian bio-events (from terminal Proterozoic extinctions to Cambrian biomeres), in *Global events and events stratigraphy in the Phanerozoic*, pp. 113–138, Springer, 1996.

2. Brasier, M.D., A.Yu. Rozanov, A.Yu. Zhuravlev, et al. A carbon isotope reference scale for the Lower Cambrian succession in Siberia: report of IGCP Project 303, *Geol. Mag.*, **131**, 6, 767–783, 1994.

3. Brasier, M.D., and S.S. Sukhov, The falling amplitude of carbon isotopic oscillation through the Lower to Middle Cambrian: northern Siberia data, *Can. J. Sci.*, **35**, 353–373, 1998.

4. Kouchinsky, A., S. Bengtson, V.V. Missarzhevsky, et al., Carbonic isotopic excursions and the problem of pre-Tommotian Stage in Siberia, *Geol. Mag.*, Cambridge Univ. Press, 4, 387–396, 2001.

5. Geyer, G., and J. Shergold, The guest for internationally recognized divisions of Cambrian time, *Episodes*, **23**, 3, 188–195, 2000.

6. Luchinina, V.A., I.V. Korovnikov, D.P. Sipin, and A.V. Fedoseev, Upper Vendian–Lower Cambrian biostratigraphy of the Sukharikha River section (Siberian Platform), *Geologiya i Geofizika* (*Russian Geology and Geophysics*), **38**, 8, 1346–1358 (1385–1397), 1997.

7. Rowland, S.M., V.A. Luchinina, I.V. Korovnikov, et al., Biostratigraphy of the Vendian-Cambrian Sukharikha River section, northwestern Siberian Platform, *Can. J. Earth Sci.*, **35**, 339–352, 1998.

8. *The Cambrian in Siberia* [in Russian], 133 pp., Nauka, Novosibirsk, 1992.

9. Egorova, L.I., and V.E. Savitskii, *Stratigraphy and biofacies of the Cambrian on the Siberian Platform (western Anabar region)* [in Russian], 408 pp., Nedra, Moscow, 1969.

10. The Cambrian of the Siberian Platform (Trudy SNIIGGiMS, issue 130) [in Russian], 200 pp., Nedra, Moscow, 1972.

11. Fedoseev, A.V., Characteristics of the distribution of the Ptychagnostidae (trilobites) in the Amydai section of the Amgaian Stage (northeastern Siberian Platform), *Geologiya i Geofizika* (*Russian Geology and Geophysics*), **40**, 10, 1411–1424 (1389–1402), 1999.

12. Korovnikov, I.V., The trilobite assemblages and biostratigraphy of the Lower Cambrian section on the Khorbosuonka River (Olenek Uplift, northeastern Siberian Platform), *Geologiya i Geofizika* (*Russian Geology and Geophysics*), **39**, 10, 1377–1391(1378–1392), 1998.

13. *Biostratigraphy and fauna of the Lower Cambrian in Kharaulakh* [in Russian], 299 pp., Nauka, Moscow, 1974.

14. Missarzhevskii, V.V., *Ancient skeletal fossils and stratigraphy of Precambrian and Cambrian boundary units (Trudy GIN AN SSSR, issue 443)* [in Russian], 238 pp., Nauka, Moscow, 1989.

15. Robinson, R.A., Mode of life of Agnostid trilobites, in *24th Int. Geol. Congr.*, Sect. 7, 33–40, 1972.

16. Robinson, R.A., Some Middle Cambrian agnostoid trilobites from western North America, *J. Paleontol.*, **56**, 1, 132–160, 1982.

17. Rowell, A.J., R.A. Robinson, and D.K. Strickland, Aspects of Cambrian agnostoid phylogeny and chronocorrelation, *J. Paleontol.*, **56**, 1, 161–182, 1982.

18. Khomentovsky, V.V., and G.A. Karlova, Specific ecology of Vendian-Cambrian biotas of small shelly fossils on the Siberian Platform, *Stratigrafiya. Geologicheskaya Korrelyatsiya*, **2**, 3, 8–17, 1994.

19. *The Vendian. Historico-geological and paleontological grounds. Vol. 2. Stratigraphy and geological processes* [in Russian], pp. 83–161, Nauka, Moscow, 1985.

20. Vasil'eva, N.I., *Small shelly fossils and Lower Cambrian biostratigraphy of the Siberian Platform* [in Russian], 139 pp., VNIGRI, St. Petersburg, 1998.

21. Khomentovsky, V.V., and G.A. Karlova, Biostratigraphy of the Vendian-Cambrian beds and Lower Cambrian boundary in Siberia, *Geol. Mag.*, **130**, 29–45, 1993.

22. *The Tommotian Stage and problem of the lower boundary of the Cambrian* [in Russian], 380 pp., Nauka, Moscow, 1969.

23. Val'kov, A.K., *Biostratigraphy and hyoliths of the northeastern Siberian Platform* [in Russian], 139 pp., Nauka, Novosibirsk, 1975.

24. Meshkova, N.P., I.T. Zhuravleva, and V.A. Luchinina, Lower Cambrian and lower part of the Middle Cambrian of the Olenek Uplift, in *Problems of paleontology and biostratigraphy of the Lower Cambrian in Siberia and Far East* [in Russian], pp. 194–216, Nauka, Novosibirsk, 1973.

25. Val'kov, A.K., P.N. Kolosov, and Yu.V. Davydov, Reference section of boundary Vendian-Cambrian deposits of the Olenek Uplift in the northeastern Siberian Platform, *Otechestv. Geologiya*, 8, 5–8, 1997.

26. Val'kov, A.K., *Biostratigraphy of the Lower Cambrian in the eastern Siberian Platform. Yudoma-Olenek region* [in Russian], 136 pp., Nauka, Moscow, 1987.

27. Repina, L.N., Trilobites of the Taryn horizon of the Lower Cambrian sections on the Sukharikha River (Igarka region), in *Problems of biostratigraphy and paleontology of the Lower Cambrian in Siberia* [in Russian], pp. 184–216, Nauka, Moscow, 1972.

28. Pel'man, Yu.L., *Early- and Middle-Cambrian inarticulate brachiopods of the Siberian Platform* [in Russian], 168 pp., Nauka, Novosibirsk, 1977.

29. Korovnikov, I.V., Improved brachiopod-based biostratigraphy of the Lower and Middle Cambrian sediments in the north of the Siberian Platform, *Geologiya i Geofizika* (*Russian Geology and Geophysics*), **37**, 4, 52–59(47–54), 1996.

30. Yadrenkina, A.G., *The Upper Cambrian and Ordovician brachiopods from the northwestern Siberian Platform* [in Russian], 164 pp., Zapadno-Sibirskoe Izd., Novosibirsk, 1974.

31. *Resolutions of the All-Union stratigraphic conference of Precambrian, Paleozoic, and Quaternary of Central Siberia. Part I* [in Russian], 216 pp., Novosibirsk, 1983.

Editorial responsibility: A.V. Kanygin

28 April 2001