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MARINE FAUNAS AND LOWER CAMBRIAN STRATIGRAPHY*

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ABSTRACT. This paper summarizes the faunal characteristics and biostratigraphic subdivision of the Lower Cambrian, with special reference to the USSR. Four major faunal and stratigraphic subdivisions are recognized: (1) a pre-trilobite fauna, denoting the lower Aldan and Tommot stages and equivalents, with distinctive archaeocyathean assemblages; (2) the first trilobite assemblages, found in the Upper Aldan and equivalent strata; (3) the acme of Early Cambrian faunas, distinctive of the lower Lena and Botoma stages and equivalents; and (4) the waning of the Archaeocyathi, characterizing the upper Lena and Issafen stages and equivalents. Fossils characteristic of these four early Cambrian faunas are discussed, evaluated, and tabulated, with reference to pertinent Soviet and foreign publications. The base of the Paleozoic is seen as coinciding with the general appearance of skeletal remains, following a late Precambrian episode of soft-bodied evolution recorded in upper Vendian rocks.

Interest in Early Cambrian–Early Paleozoic time has recently been greatly aroused. This interest is not casual. The Early Cambrian gave rise to a new era in the history of our planet, the era of skeletal forms. Its onset may be associated with a radical evolution of geological processes (Cloud, 1968a,b; Cloud and Nelson, 1966; Yasmir, 1965; Missarzhevsky, Meshkova, and Rozanov, 1967; Rozanov, 1967; Rozanov and others, 1969; Rudwick, 1964; Shevyrev, 1962; Sokolov, 1965).

Problems of subdividing the Lower Cambrian and defining the base of the Paleozoic and Phanerozoic are now much discussed, recently being the subject of various symposia and colloquia especially in the last International Geological Congress (Yochelson, 1968; Sokolov, 1968a; Zhuravleva, 1968a). This paper deals with evidence on this problem particularly as it has developed within the USSR.

The Early Cambrian lasted about 30 to 40 m.y.—a duration comparable to that Silurian, Triassic, or Neogene. During Early Cambrian time there appeared numerous groups of skeletal animals such as archaeocyathids, coelenterates, mollusks, brachiopods, arthropods, and others, some of which do not fit easily into any known phylum of living organisms. The appearance of skeletal representatives of different phyla was not synchronous. Several types appeared at the very beginning of the Early Cambrian (Archaeocyathi, Hyolitha, Brachiopoda), but others are not recorded until after a quarter or a third of the epoch had already elapsed (Trilobita, Ostracoda, Stenothecoida). Finally, skeletal remains

* Editorial footnotes in this paper are by Preston Cloud, at whose request it was prepared.

of several phyla did not appear until late in the Early Cambrian (Echinodermata).[1]

Below is given a brief review of the presently known Early Cambrian animal groups that had preservable hard parts.

ARTHROPODA

Trilobita.—Early Cambrian trilobites are represented by more than 25 families belonging to the orders Miomera and Polymera, but only a few are known from the earliest Cambrian (Olenellidae, Pagetidae, Protolenidae, Redlichiidae, and some others). The number of the known Early Cambrian trilobite genera is above 200 by now.

Up to recently (Maksimova and Tchernysheva, 1966; Spizharsky, 1963), it was believed that trilobites were present in the oldest Cambrian strata, with the *"Olenellus"* zone being taken generally as defining the basal Cambrian. But Lermontova (1951), Hupé (1960), Missarzhevsky and Rozanov (1965), Rozanov and Missarzhevsky (1966), Rozanov and others (1969), Sokolov (1965, 1967, 1968a), Zhuravleva (1965, 1968a,b), and others have shown that the general appearance of trilobites was later than that of brachiopods, hyoliths, archaeocyathids, et cetera. Extensive basal Cambrian units devoid of trilobites have been recognized: lower part of the Aldan Stage, or Tommot Stage as defined by Missarzhevsky and Rozanov (1965), Rosanov and Missarshevsky (1966), Rosanov and others (1969), Baltic Stage as defined by Sokolov (1965, 1968a), Assadassien Substage as defined by Hupé (1960), et cetera. The classical zone of *Olenellus* is confined to the later half of the Aldan Stage as defined by the scheme dated from 1956 (Mezhvedomstvenny Komitet, 1959) in the USSR.

A detailed Lower Cambrian zonal sequence based on trilobites was originally suggested for North Africa (Hupé, 1960). As suggested by the present author, the Lower Cambrian there is to be divided into 2 stages, the Sussien and Issafen Stages, also 5 substages. Eight zones are distinguished in the above stages or substages, each having its specific trilobite assemblage. Hupé's scheme is also consistent with the zonation based on Archaeocyathi (Debrenne, 1961, 1964). Meanwhile various North African zonal trilobites have been found at ostensibly the same Lower Cambrian stratigraphical levels in North America (Cloud and Nelson, 1966; Kobayashi, 1962), Europe (Lotze and Sdzuy, 1961), and Siberia (Khomentovsky and Repina, 1965).

A Lower Cambrian sequence showing a trilobite zonation similar to that of North Africa appears to be present in the southeastern part of the Siberian Platform (Yakutia), where 2 to 4 stages as well as corresponding zones have been recognized (Yegorova and Savitsky, 1969; Khomentovsky and Repina, 1965; Meshkova, 1969; Pokrovskaya, 1954; Repina, 1969; Repina and others, 1964; Mezhvedomstvenny Komitet, 1959;

[1] Older echinoderms are known from the Early Cambrian of California, Nevada, and Pennsylvania (Durham, J. W., 1966, 1967, Jour. Paleontology, v. 40, p. 1216-1220; v. 41, p. 97-102.

Rozanov and others, 1969; Suvorova, 1954; Zhuravleva, Korshunov, and Rozanov, 1969).

Biostratigraphical study of the North American and Australian Lower Cambrian trilobites has so far revealed a less detailed zonation (Palmer, 1968), implying that such studies in these areas are far from complete. Of special interest is the Lower Cambrian biostratigraphical sequence of southeastern Asia (Sun Yan Tzhu, 1961; Kobayashi, 1962, 1966, 1967; et cetera), which Kobayashi (1966) divides into 4 stages (with respect to trilobites).

Thus the Lower Cambrian is divided with respect to trilobites into 6 to 8 zones merged into stages and substages. The main goals of the trilobite specialists are to determine the Lower Cambrian boundary, discover the true reasons for the lack of abundant trilobite finds in the basal Cambrian, and to cooperate with specialists studying other groups in order to develop a unified and comprehensive Lower Cambrian stage scale.

The facial study of Lower Cambrian trilobites was first seriously initiated in the USSR during the last 3 to 5 years by Yegorova and Savitsky (1969) and by Repina (1966, 1969), who distinguished the trilobite assemblages of the Siberian Platform for each facial type of the sequence, from brackish-water and intermediate in the west to normal marine in the east. The biofacies study showed that there exist special trilobite assemblages strictly confined not only in time but also by sedimentary facies (for example, the *Bulaiaspis* assemblage).

Of the recent papers on trilobite paleobiogeography, one must mention the paper by Wakhakoo and Shah (1965) in which the authors show that the Middle Cambrian trilobite assemblages of Kashmir are primarily related not to geographical superregions or provinces but to environmental conditions. Thus, the "Pacific" province is actually the cratonic biofacies, whereas the "Atlantic" and "Indo-Australian" ones are extracratonic biofacies. Obviously, this conclusion is to be taken into account in defining biogeographical provinces for the Early Cambrian. Repina (1966, 1968), on the contrary, affirms the probable existence of three biogeographic superregions during Early Cambrian time (Pacific, Atlantic, and Indo-Australian superregions). As concerns the time variation in the relationship between superregions with respect to trilobite assemblages ("migration" of superregions and provinces in time), an article by Sdzuy (1967) is especially important.

Recent monographic reinvestigations (Repina, 1966, 1969; Suvorova, 1964; Tzhan wen Than, 1966; et cetera) aim at revising the families and superfamilies Protolenidae, Olenellidae, Redlichoidea, Corynexochoidea. From such a basis one can make the next step in studying the morphology, taxonomy, and biogeochronology of this extinct arthropodal class.

Ostracoda.—Representatives of this class of the Arthropoda are known from Lower Cambrian deposits of the Siberian Platform (Netzkaya and Ivanova, 1956) but have not been studied in detail.

ARCHAEOCYATHI

Recent studies of the distinctively Early Cambrian Phylum Archaeocyathi have led to the description of a great number of new species, genera, and families. Above 140 archaeocyathean genera and 600 to 700 species are now known. The Archaeocyathi (Euarchaeocyathi) are incorporated into 2 large systematic categories, Regulares and Irregulares, consisting of 5 large orders.

Morphologically, the archaeocyathean skeleton constitutes an exceptionally favorable object of study. Displaying regular mechanical constructions (regular pore alternation in the wall cones, radial intrawall lamellae, bars, et cetera), the calcareous skeleton of the Archaeocyathi is subject not only to qualitative but also to quantitative analyses. The morphological terminology for the Archaeocyathi is so well established that in some instances the diagnoses of perfectly studied species may be reduced to a set of numbers (wall thickness, pore diameter, et cetera) and relationships between numerical values (radial coefficient, pore coefficients, et cetera). Such characteristics are shown by different groups of true Archaeocyathi (Debrenne, 1964; Zhuravleva, 1960; Rozanov and Missarzhevsky, 1966). Numerical methods not only reduce the bulk description and speed up material treatment but also make possible an objective approach to species evaluation and definition, to establishing the boundaries of variability, et cetera. The next step in this direction is to prepare some group for mechanical definition (computer processing) and compilation of tables and card indexes.

Archaeocyathean taxonomy, on the contrary, is, at present, subject to serious revision (Debrenne, 1964; Hill, 1964, 1965). The principles of constructing such categories as the irregular archaeocyathids (subclass Irregulares) and those with pectinate tabulae (suborder Nochoroicyathina of the order Ajacicyathida of the subclass Regulares) need to be modified. Progress in this direction has been made by Rozanov (1966) who used Vavilov's principle of homologous variation as a basis for the classification of the regular archaeocyathids—apparently one of the first successful attempts to apply Vavilov's homological series law to paleontology. Using Rozanov's table it is possible to "predict" the discovery of undescribed systematic categories, as was done successfully by a group of the participants of the 2nd Colloquium on Archaeocyathi held in Novokuznetsk in April, 1967. In the last few years a revision of large taxonomic archaeocyathean categories, such as single-walled (Zhuravleva, 1963), bi-walled (Zhuravleva, Konyushkov, and Rozanov, 1964), Ajacicyathidae, Tercyathidae, and other groups has been carried out. Under preparation for the same revision are the Ethmophyllidae and irregular archaeocyathids. Among the more interesting regional contributions is the monograph by Debrenne (1964) on the North African and West European archaeocyathids and the papers by Hill on the Archaeocyatha of Antarctica and Australia (1965). Debrenne, proceeding from the previously adopted biostratigraphic scheme of the North African Lower Cambrian based on trilobites (Hupé, 1960), not only succeeded in dividing the archaeocyathids into assemblages but also suggested a correlation for the Lower Cambrian of Morocco, West Europe, and Siberia. Hill proved the existence of archaeocyathean assemblages in the Early Cambrian of Antarctica, resembling the Sanashtykgol assemblage of South Siberia.

In the USSR a survey was made of the Lower Cambrian archaeocyathids and trilobites of the Sayan-Altai folded region (Repina and others, 1964). Important results include the discovery and study of the Far East archaeocyathids (Okuneva and Repina, 1967; Shkolnik and others, 1965) and that of a new group of archaeocyathean-like organisms (Radugin, 1966; Yankauskas, 1965a, b).

The stratigraphical value of the Archaeocyathi has now been demonstrated. However, whereas the trilobite zonal assemblages are based on genera, those of the archaeocyathids are based on species. It has also now been clearly established that archaeocyathids appear everywhere earlier in the Lower Cambrian than trilobites and disappear (subtype Euarchaeocyathi) at the Middle Cambrian boundary. Thus the Archaeocyathi are a group uniquely characteristic of the Early Cambrian.

Archaeocyathid biostratigraphy reveals three main stratigraphic boundaries within the Lower Cambrian, which can be traced over great distances. The first boundary coincides with the appearance of abundant trilobites at the contact between the Kenyada horizon and Atdaban horizon of the Siberian Platform. The second boundary is located in the middle part of the Lower Cambrian: It coincides with the base of the Taryn horizon (or lies within the Atdaban horizon) of the southeastern part of the Siberian Platform (Zhuravleva, Repina, and Khomentovsky, 1965) and of the Sanashtykgol horizon of the Sayan-Altai region (Repina and others, 1964). Finally, the third most important boundary divides the Lower Cambrian with respect to archaeocyathid distribution into two subunits: lower and upper. As reported by a number of writers (Repina and others, 1964), it is the upper subunit that corresponds to the Lena stage.

Facial study of archaeocyathids in the last few years has been fruitful (Debrenne, 1964; Yazmir, 1960, 1961; Zhuravleva, 1960, 1966). It was established that archaeocyathids were one of the first bioherm-building marine animals. However, neither the size of these bioherms nor their structural type permit one to identify them with true reefs—complex breakwater constructions of biotic origin in recent seas.[2]

Although biogeographic study of the Archaeocyathi has just been initiated, it has already been established that the outlines of the superregions defined by them do not coincide with those delineated by trilobites (Zhuravleva, 1968a).

Summing up, the recent work of many specialists has made it possible to undertake the numerical description of forms, to prepare for the bulk revision of the group taxonomy, and to build up a detailed archaeocyathid biostratigraphy. Details now becoming available on the ontogeny

[2] The general association of archaeocyathids with the encrusting alga *Epiphyton* (and others), however, implies a very shallow water and possibly wave-breaking habitat.

and phylogeny of this group are full of promise for a detailed reconstruction of its evolution and also for solving such a problematic question (Cloud, 1968b) as what were the original or one of the original multicellular animals in Earth history.

Cribrocyathea.—The class Cribrocyathea Vologdin (1966) incorporates about 3 orders and 30 genera of very small organisms possessing both a carbonaceous skeleton and specific morphological features. Their cups bear no traces of attachment to the substrate (plankton?) and are cylindrical or, rarely, conical. Among the Cribrocyathea are found forms similar to single-walled Archaeocyathi. Cribrocyathean structure, as a whole, is such that they can be assigned to the type Archaeocyathi as an independent class having bilateral symmetry, lacking wall porosity, et cetera (Boyarinov, 1962). Nevertheless, it is not improbable that we deal here with a group of animals(?) typical only of the Early Cambrian and known so far only from Siberia for, in detail, they resemble no other animal or plant. The morphology and taxonomy of the Cribrocyathida proper was developed by Vologdin (1966) and for the Pterocyathida by Radugin (1962, 1966) and Yankauskas (1965a, b; 1969). No cribrocyathean remains are known from the Precambrian or Middle Cambrian deposits. Although their occurrence in the Precambrian is suggested by Radugin (1966) and in the Middle Cambrian by Vologdin (1966), according to the stratigraphical scheme adopted in the USSR they are found only in Lower Cambrian deposits. The small size of cribrocyathean remains (from below a millimeter to rarely several millimeters) is very convenient for stratigraphy, so the future applications of this group are promising.

HYOLITHA AND HYOLITHELMINTHES

After a long break (Holm, 1893), the study of the Early Cambrian Hyolitha is now again in progress (Meshkova, 1965, 1969; Meshkova and Angysheva, 1969; Syssoyev, 1958, 1962; and others). The systematic status of this group is disputable. The problem of affinity between Hyolitha and worms or mollusks (Pteropoda, Cephalopoda) is under discussion. Fisher's standpoint (1962) seems to be most realistic; this author distinguishes them as a special class Calyptoptomatida (= class Hyolitha Marek) of doubtful taxonomic status; most of the Lower Cambrian forms belong to the order Hyolithida.

Possessing a conical shell of variable cross section and shape, the fossil Hyolitha have good preservation, their remains being known from the Early Cambrian up to the Middle Permian; their stratigraphic significance, however, has been established for the Lower Cambrian only.

Because of a range of living habits (nekton, plankton, benthon) the Hyolitha are excellent indicators of facial environment. Thus abundant shell occurrences with broken end parts serve as indicators of a shallow-water environment, whereas individual unbroken shells with opercula imply deeper water (Fisher, 1962).

Reinvestigation of the skeletal morphology of the Middle Cambrian Hyolitha from Matthew's collection by Yochelson (1961) showed that even the main skeletal elements (opercula, supports) were not enough studied. Although the taxonomic description of the Hyolitha as a whole, and of the Early Cambrian ones in particular, is inadequate, more than 20 genera of Early Cambrian Hyolitha are known.

Recent progress includes the transfer of the group *Torellella-Hyolithellus* from this class to a specific new order Hyolithelminthes (Fisher, 1962), also of indefinite status but comparable to a special group of tubular worms.

In spite of a poor knowledge of the morphology and taxonomy of the hyoliths, the study of their biostratigraphical assemblages has progressed. The Lower Cambrian sequence is separated into stages and the Aldan stage into horizons and zones with respect to this group. Hyolithids are also important (together with the Hyolithelmithes) in establishing the basal Cambrian boundary where they are abundant.

It has also been established that whereas skeletal hyoliths are lacking below the adopted Lower Cambrian boundary (base of Sunnagin horizon), the group *Hyolithellus-Torellella* (Order Hyolithelminthes) is found there, as shown by a number of occurrences in the Siberian Platform area and in other regions.

MOLLUSCA

Early Cambrian animals assigned to the Mollusca are rather inhomogeneous. Of them only the Gastropoda obviously belong.

Gastropoda.—At present about 15 gastropod genera are known, which belong to more than 4 families of the order *Archaeogastropoda* Thiele (Vostokova, 1962; Rozanov and Missarzhevsky, 1966). The stages observed in the study of their morphology and taxonomy are roughly the same as for the Class Hyolitha, but their taxonomic status is not disputable. The stratigraphical importance of Archaeogastropods is exceptionally great for the Lower Cambrian, especially for its lower part. The *Oelandiella korobkovi* zone, typical of the lower Lower Cambrian deposits of the Siberian Platform (after the data by Vostokova, 1962), is easily recognized in North America by the occurrence of the genera *Helcionella* Grabau and Shimer and *Aldanella* Vostokova.

Monoplacophora.—Monoplacophores are represented by several genera from the Early Cambrian. Of them *Scenella* Billings is most frequently found (Meshkova, 1969; Rozanov and Missarzhevsky, 1966; Rozanov and others, 1969).

Stenothecoida (= Probivalvia Aksarina, 1968). *Stenothecoides* Resser, *Cambridium* Horny, and *Bagenovia* Radugin are assigned to this recently defined class of mollusks (Yochelson, 1968). All of them are extensively distributed (Siberia, North America) and have rather narrow vertical ranges. They are known so far only from the middle part of the Lower Cambrian (Sanashtykgol horizon of the Sayan-Altai region). None are known from the lower Lower Cambrian or Middle Cambrian.

A new group of ostensible stenothecoids, assigned by Fonin and Smirnova (1967) to a particular family *Tannuolinidae* (genus *Tannuolina*), is known only from the Sanashtykgol horizon of South Siberia

(Tuva). The structure of the inequivalved bivalved shells of these enigmatic animals is so peculiar that the authors who first described *Tannuolina* and compared it with mollusks, brachiopods, and arthropods (cirripedes) concluded that its taxonomic status is uncertain.

Pelecypoda.—True pelecypods are known with confidence only recently from the Early Cambrian deposits (Meshkova, 1969). However, the genus *Palaeoconchiella,* of problematic affinities, was earlier described by Vologdin (1955).

BRACHIOPODA

The remains of inarticulate brachiopods extensively characterize the Lower Cambrian deposits, but unfortunately, their study lags sharply behind the study of the groups discussed above. Beyond the contributions of Lermontova (1940, 1951), we have little new evidence on these exceptionally interesting and stratigraphically important Lower Cambrian fossils (Jaanusson, 1966; Poulsen, 1966; Rowell, 1966; Goryansky, 1969). Although over 20 genera of brachiopods are known from the Early Cambrian, occurring along with the Archaeocyathi and Hyolitha at the very beginning of this epoch, they appear to represent only two Lower Cambrian assemblages (Aksarina, 1962), whereas archaeocyatheans and trilobites delineate some 6 to 8 major biostratigraphical assemblages.

COELENTERATA

No Coelenterata with solid skeletons are known with confidence from the Early Cambrian. However, remains of enigmatic animals are conditionally assigned to different classes and orders of this type, while imprints of jellyfish are known from the late Precambrian of several continents (Glaessner, 1960; Hallam and Swett, 1966; Sokolov, 1967; Sprigg, 1947, 1949).[3]

Tabulata.—Tubular colonies of *Bija* Vologdin (1932) may be primitive Tabulata (Bondarenko, 1966; Sokolov, 1955). Although the age of this fossil is erroneously indicated as Middle Cambrian in the reports of the authors mentioned, it is now known to be Lower Cambrian.

Conulariida.—Representatives of this group (*Palaeoconularia* Tchudinova) were first described from the Lower Cambrian of the West Sayan, Siberia (Tchudinova, 1959). Their rare remains are confined to the Sanashtykgol horizon.

Hydroconozoa.—A new class of Early Cambrian Coelenterata, *Hydroconozoa* (Korde, 1963), incorporating three families and four genera, consists of conical cups with a laminated skeletal structure resembling the Tetracoralla. However, there is no direct evidence favoring assignment of the Hydroconozoa to the Coelenterata.

Scyphozoa.—An important discovery was that of *Velumbrella* Stasinska from the Early Cambrian of Poland, a true *medusoid* (Stasinska, 1966).

Other Coelenterata.—Established representatives of the Rugosa and Stromatoporoidea are not known from the Early Cambrian. Stromato-

[3] The age of the deposits referred to as Precambrian is in dispute.

poroidea, however, may be represented by certain problematical forms. Yavorsky (1940, 1963) has described several species from the Lower Cambrian which he assigns to the stromatoporoid genera *Actinostroma* and *Clathrodictyon*. Moreover, Khalfina (1960) named still another genus of presumed Lower Cambrian stromatoporoids *Korovinella*, and Pospelov (1962), basing his views on the morphological resemblance between the Early Cambrian "Stromatoporoidea" and Archaeocyathi, concluded that there was a direct affinity between these two groups and that the hydroid Coelenterata had evolved directly from the Archaeocyathi (assigning the Archaeocyathi to the Coelenterata as well).

Nestor supported this conclusion (1966), based on comparative morphological and comparative historical data on the two groups that convinced him that the so-called stromatoporoidea of the Cambrian were true archaeocyatheans (for example, *Altaicyathus* Vologdin). Students of the Stromatoporoidea, however, remain critical of these conclusions, so the discussion on the validity of Early Cambrian stromatoporoids continues.

VERMEIDEA

This composite group was extensively represented in the Early Cambrian, for, firstly, remains of vermeidea are rather frequent in Precambrian deposits,[4] and, secondly, for their recognition one frequently has sufficient body imprints and trails of crawls. The study of this group has expanded with the growing application of well-known chemical preparation techniques, especially in the USSR (Meshkova, 1965; Meshkova and Angysheva, 1969; Missarzhevsky, 1965). Chemical preparation makes it possible to examine the finest parts of tubular forms.

The imprints and trails of worm-like forms are common in Lower Cambrian deposits. The biological nature of these forms, however, remains uncertain, and their main importance is for paleoecological reconstructions. Among other things, their finds are correlated with breaks in sedimentation. The imprints found in Lower Cambrian deposits reach lengths of 50 to 60 cm (for example, *Zoophycos* from the Early Cambrian of Yakutia, 40-50 cm long) but are not known to attain dimensions such as those reported by Kravtsov and Lazarenko (1966) for fossil worms from the Middle Cambrian of the northern Siberian Platform (up to 2 m long).

Hyolithelminthes.—As mentioned above (compare Class Hyolitha) one group of the Vermeidea, Hyolithelminthes, is considered as an independent order of indefinite taxonomic status (Hallam and Swett, 1966). Meshkova (1969) also takes them as tubular problematic animals. The remains of Hyolithelminthes most frequently occur in the very lowest (pre-trilobitic) beds from the Lower Cambrian. The genera *Hyolithellus* and *Torellella* are the commonest. Some Hyolithelminthes finds may also be of later Precambrian age.

[4] Although reports of pre-Paleozoic "worms" are common in geological publications, the editor is unaware of any occurrence that he would consider well-authenticated (see Cloud, 1968b).

POGONOPHORA

Early Cambrian and Later Precambrian tubular fossils represented by chitinoid remains (*Sabellidites, Paleolina,* and others) were assigned by Sokolov (1965) to the Phylum Pogonophora (Korkutis, 1966; Sokolov, 1968). There are no direct indications for assigning the Sabelliditida to the Pogonophora. Finds of Pogonophora-like forms from the Early Pliocene (Adegoke, 1967; Heinzelin, 1964), however, show that there is a fossil record, and the phylum is so primitive structurally that it would not be surprising if it were to occur in sediments as old as Early Cambrian.

ARTICULATA

This group, also of indefinite taxonomic status, is represented in the Early Cambrian by *Xenusion auerswaldae* Pompeckj (1927). This metameric animal with paired appendages and bilateral symmetry is similar both to the Arthropoda and the Annelida. *Xenusion* is so far represented by the type specimen only, from a pebble in the glacial drift of northern West Germany once supposed to be of Precambrian age. Jaeger and Martinsson (1967), however, have given convincing evidence that this pebble is actually from the Early Cambrian Kalmersund Sandstone of Sweden.

The imprints of *Pteridinium,* a fossil of uncertain affinities and stratigraphic range, have a specific interest. According to some scientists (Cloud and Nelson, 1966, 1967), *Pteridinium* may denote strata of very early Paleozoic age.

PORIFERA

Spicules of Early Cambrian sponges are abundant and may be defined as belonging to two orders: Heteractinellida (*Chancelloria* and others) and Triaxonida (Family Protospongiidae). Entire sponge skeletons are very rare in Lower Cambrian deposits (Dore and Reid, 1965; Sdzuy, 1969). However, in addition to Walcott's specimens of *Chancelloria* there have been found recently in the Lower Cambrian of Siberia the new sponges *Gonamispongia* Korshunov (1968, Kenyada horizon, Yakutia) and *Girphanovella* Zhuravleva (Sanashtykgol horizon, Tuva, Zhuravleva, and others, 1967).

However, neither spicules (Zhuravleva and Korde, 1956) nor entire sponge specimens are as yet of special significance for Lower Cambrian biostratigraphy, for not only are entire sponges rare, but there are no specialists in the study of Lower Cambrian sponges.

Of special taxonomic-evolutionary interest is the conclusion of Missarzhavsky and Rozanov (1965) on a dual origin of the representatives of the genus *Chancelloria* Walcott; in particular, some forms of this genus are assigned by these authors to the Bryozoa.

PROTOZOA

Foraminifera (?*Obruchivella* Reitlinger, 1948; Vologdin, 1958; Pflug, 1965) as well as *Radiolaria* are reported from the Early Cambrian. However, it appears that most forms assigned to the Foraminifera are of dubious affinity. On further study they are usually considered to be microphytoliths or mineral inclusions.

About 9 families of Radiolaria have been identified from the Cambrian, but they are little studied (Zhamoida, 1968). It is not improbable that the described Early Cambrian "Radiolaria" include a variety of forms, among them being remains of vegetal and mineral origin.

CONODONTS

Conodonts were not known until recently from Early Cambrian deposits. They have now been described, however, by Poulsen (1966) from the Early Cambrian deposits of the island of Bornholm (Denmark), and Meshkova (Meshkova and Angysheva, 1969) has found the genera *Onetodus* Lindström and *Hertzina?* Müller in Lower Cambrian deposits of the Siberian Platform. It must be stressed that not all writers agree that these fossils are true Conodonts (Jaanusson, 1966). To solve this problem is of exceptional interest, particularly if, as some suppose, conodonts are Vertebrata.

MISCELLANEA

All now known animal types of Early Cambrian age have been mentioned above. As yet, however, no proved remains of echinoderms,[5] graptolites, Bryozoa, and Vertebrata are known from the Lower Cambrian.

As mentioned above, however, *Chancelloria*-like forms earlier defined as sponges, together with typical *Chancelloria,* may be Bryozoa (Missarzhevsky and Rozanov, 1965).

Authentic echinoderms are known from the Middle Cambrian, while Lower Cambrian problematic *Helicoplacus* (Durham and Caster, 1963) from eastern California can be regarded as an echinoderm, a fusiform type with spirally coiled plates of calcite.

Graptolites have long been known from Upper Cambrian deposits in North America. New data available on this group permit one to postulate (Kozlowski, 1966) that there may exist common ancestors of graptolites and pterobranchs (invertebrate chordates) of Early Cambrian age.

Besides representatives of different animal groups assigned to presently known or extinct groups of organisms, there also frequently occur remains of undoubted biologic origin but uncertain structure and affinities. These include the vesicular *Anzalia* Termier from the Lower Cambrian of Morocco (Termier, 1963), the rozette-like *Oldhamia* Walcott (Churkin and Brabb, 1965, and many others), and *Dactyloidites* Walcott, regarded as problematic medusoid forms or as radiate-fibrous trails of mud-eaters; also vertical tubes designated as *Scolithos* (Glaessner, 1968, and many others) as well as other problematica as yet undefined.

GENERAL CHARACTERISTICS OF THE EARLY CAMBRIAN BIOTAS

Thus Early Cambrian time, in contrast to the later Precambrian, is characterized by notable increases in number of skeletal forms over a relatively short interval of geological time. Whereas in the Late Precambrian we know only three or four genera of zoogenic origin (referred

[5] See footnote 1.

to the Sabelliditidae, the Hyolithohelminthes, or tubular cores of *Anabarites;* Voronova and Missarzhevsky, 1969), in the succeeding Lower Cambrian deposits we now know about 500 genera and 2800 species (Fonin and Smirnova, 1967).

The marine Early Cambrian fossil fauna is characterized by an abundance of extinct zoogenic groups and types (for example, Archaeocyathi) as well as forms whose nature remains in doubt. Similar groups are known from all parts of the geologic column (Shimansky, 1967), but the Early Cambrian was their heyday. Analysis of the total composition of Early Cambrian animals shows that among representatives of some 30 independent groups of different taxonomic rank only nine are clearly assignable to (five) established Phyla (table 1). The taxonomic status of 10 other groups is conventionally accepted, although unproven, so that

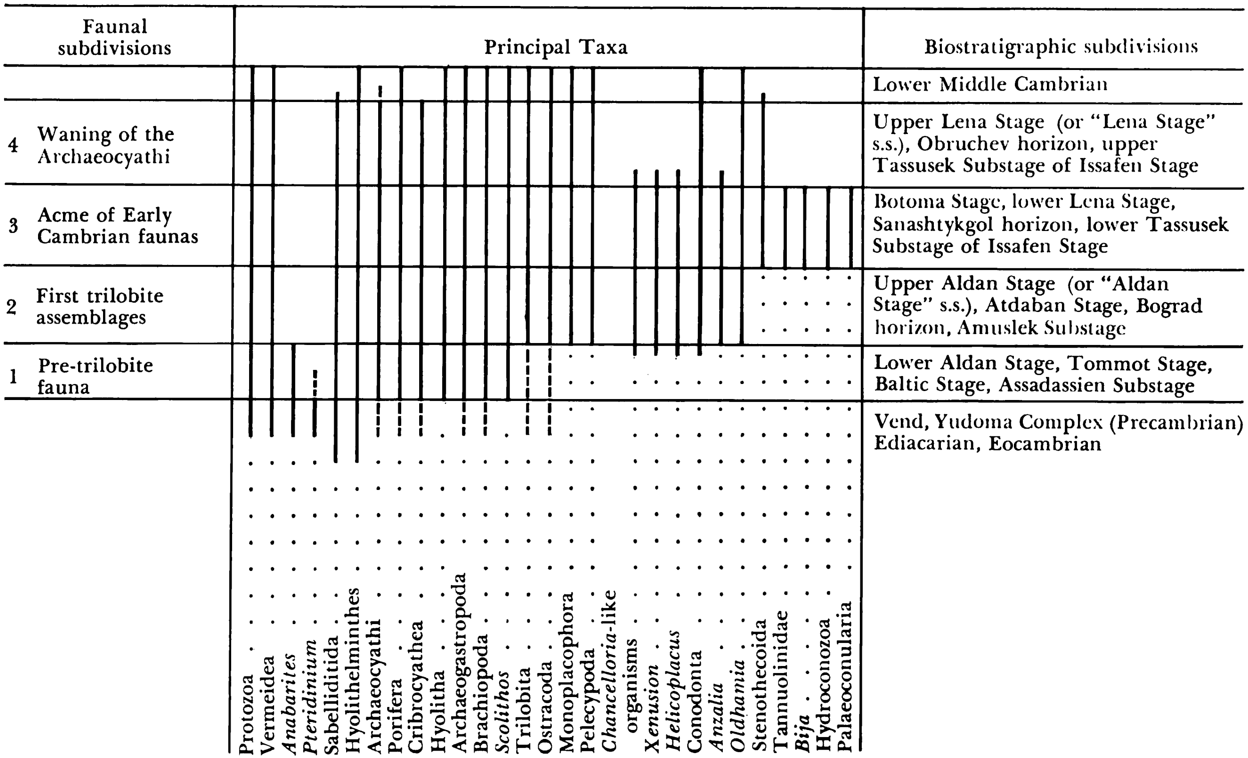
TABLE 1

Principal Early Cambrian Taxa and their affinities

Major Taxon (irrespective of rank)	Biological affinity			
	Established affinity	Conventional affinity	Affinity uncertain	Structure enigmatic
Heteractinellida	Porifera			
Triaxonida	Porifera			
Euarchaeocyathi	Archaeocyathi			
Archaegastropoda	Mollusca			
Monoplacophora	Mollusca			
Bivalvia	Mollusca			
Brachiopoda	Brachiopoda			
Trilobita	Arthropoda			
Ostracoda	Arthropoda			
"Radiolaria"		Protozoa		
Cribrocyathea		Archaeocyathi		
Bija		Coelenterata		
Conulariida		Coelenterata		
Hydroconozoa		Coelenterata		
Stenothecoida		Mollusca		
Tannuolinidae		Mollusca		
Hyolithelminthes		Vermes		
The trails of crawling animals		Vermes		
Sabelliditida		Pogonophora		
Altaicyathus				
Conodonta				
Hyolitha				
Chancelloria-like organisms				
Helicoplacus				
Anabarites				
Xenusion				
Pteridinium				
Anzalia				
Oldhamia and *Dactyloidites*				
Scolithos				
?*Obrutchevella*				

TABLE 2

Ranges in time of principal Early Cambrian Taxa



four other animal Phyla are likely to have been represented in the Early Cambrian deposits. However, we know nothing about the taxonomic affinities of another 12 (or more)[6] groups.

A second result of the analysis of the Early Cambrian faunas is concerned with the role of trilobites. Until very recently this group was regarded as pre-eminent in all aspects of Lower Cambrian history (Maksimova and Tchernysheva, 1966), paleobiogeography, chronostratigraphy, and, naturally, in establishing the limits of the Lower Cambrian. It has now been established, however, that other fossils rival the Trilobita in their importance for Early Cambrian history. Equal are the Archaeocyathi, and there is no doubt that in years to come the same will be the case with the Hyolitha, the Hyolithelminthes, et cetera, as yet still poorly known. Parallel study of the flora will introduce still broader insights.

Of the 31 enumerated groups (table 1) forming in general the marine Early Cambrian fauna (terrestrial and non-marine aquatic biotas are unknown), at least 12 were restricted to this epoch (table 2). Among them we can find such large groups as the Euarchaeocyathi of subphylum rank, the Tannuolinidae and Hydroconozoa of the rank of family or class, et cetera.

LOWER CAMBRIAN FAUNAL SUCCESSION

A succession of faunas of global distribution can be distinguished from the Early Cambrian (table 2).

1. *Pre-trilobite fauna.*—This assemblage includes 13 known major taxa (table 2, pl. 1). Most wide-spread were Archaeocyathi, Hyolitha,

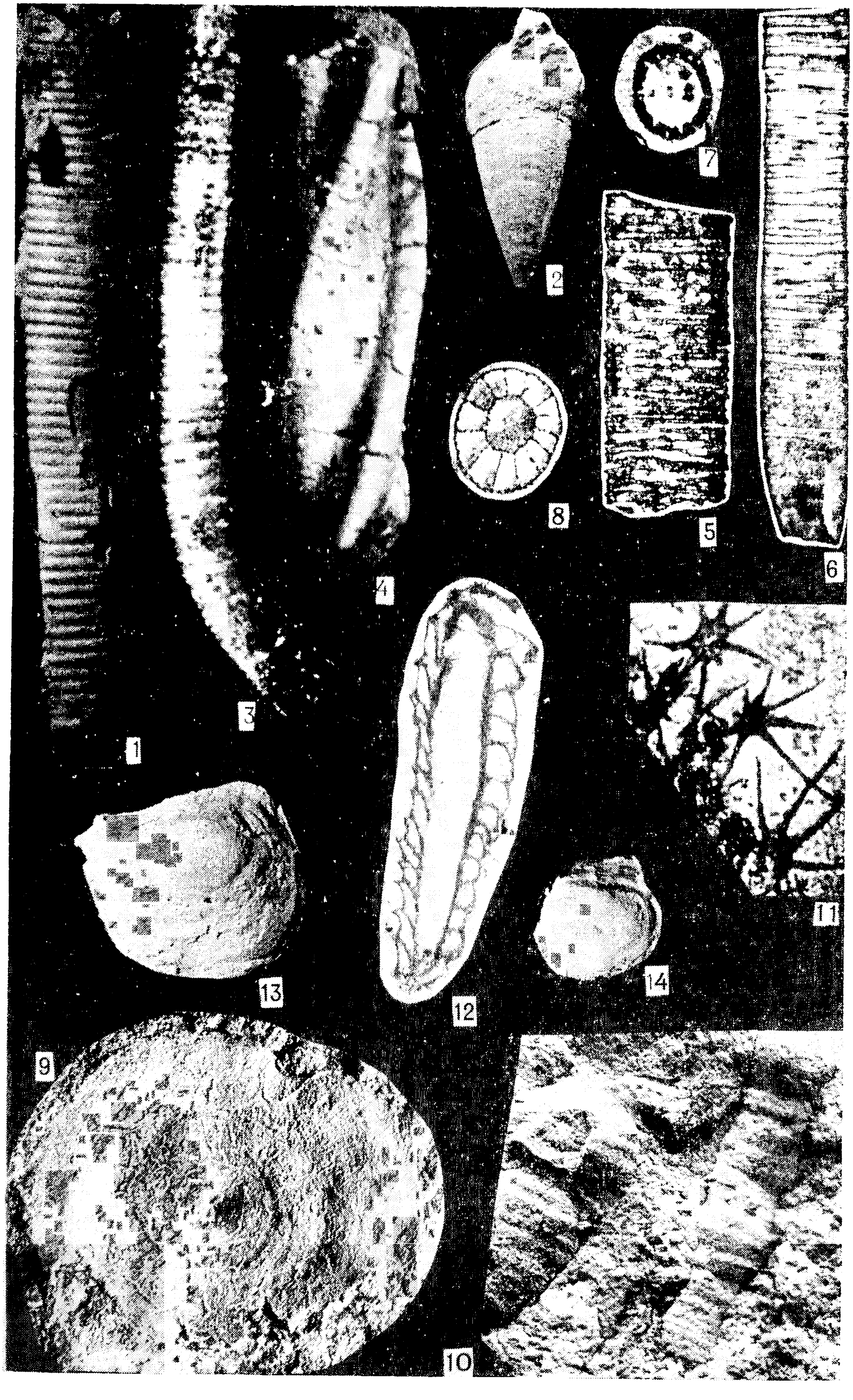
[6] The evidence for the echinodermal affinities of *Helicoplacus* is, nevertheless, impressive, and *Xenusion* is quite possibly an onychophoran.

PLATE 1

Pretrilobite Fauna

Figs. 1 and 2. Hyolitha (from N. P. Meshkova).*
 1. *Circotheca billingsi* (Syssoyev). Lena River, Yakutia, × 20.
 2. *Burithes erum* Missarzhevsky. Lena River, Yakutia, × 20.
Fig. 3. Hyolithelminthes (*Hyolithellus annulatus* Meshkova). Lena River, Yakutia, × 20 (from N. P. Meshkova).
Fig. 4. Vermeidea (*Anabarites ternarius* Missarzhevsky). Fomitch River, Yakutia, × 20 (from N. P. Meshkova).
Figs. 5 and 6. Sabelliditida (from B. S. Sokolov).
 5. *Sabellidites cambriensis* Janishevsky. Luga, Leningrad region, × 10.
 6. *Sabellidites cambriensis* Janishevsky. Luga, Leningrad region, × 4.
Figs. 7 to 10. Archaeocyathi (from I. T. Zhuravleva).
 7. *Archaeolynthus polaris* (Vologdin). Aldan River, Yakutia, × 10.
 8. *Ajacicyathus sunnaginicus* Zhuravleva. Aldan River, Yakutia, × 10.
 9. *Okulitchicyathus disciformis* (Zhuravleva). Lena River, Yakutia, × 2.
 10. *Ajacicyathus anabarensis* (Vologdin). Lena River, Yakutia, × 1.
Fig. 11. Heteractinellida (*Chancelloria grosdilovi* Zhuravleva and Korde). Kotuj River, Yakutia, × 1 (from I. T. Zhuravleva).
Fig. 12. Pterocyathida (*Crispus subdimidiatus* Jankauskas). Mana River, East Sayan, × 20 (from T. V. Jankauskas).
Figs. 13 and 14. Brachiopoda (from Yu. L. Pelman).
 13. Acrotretidae. Aldan River, Yakutia, × 4 (from Yu. L. Pelman).
 14. Acrotretidae. Aldan River, Yakutia, × 4.

* Parentheses enclose the name of the specialists whose material is used on the plates.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Hyolithelminthes, Mollusca (archaeogastropods), Brachiopoda, Porifera. The two latter groups, however, contribute little to the general picture of the Early Cambrian fauna. Global distribution of this fauna has been proved (Hupé, 1960; Missarzhevsky and Rozanov, 1965; Rozanov, 1966; Rozanov and Missarzhesky, 1966; Rozanov and others, 1969; Sokolov, 1965, 1968a; Zhuravleva, 1968b; Zhuraveleva, Korshunov, Rozanov, 1969; et cetera). Biostratigraphically it corresponds to such units as the Tommot Stage (Rozanov, 1966, 1967), the Baltic Stage (Sokolov, 1967, 1968a), or the Assadassien Substage (Hupé, 1960). According to the formal scale accepted by the Stratigraphical Committee of the USSR these divisions are equivalent to the lower part of the Aldan stage (without the Tolba substage).

There is, of course, little doubt that trilobites did exist at this time. Their future discovery is confidently expected.

2. *First trilobite assemblages.*—This faunal assemblage includes not only the first trilobites so far known but also rare ostracods, stellate forms like *Oldhamia* and other taxa indicated in table 2. The fauna of this time becomes richer both in the number of groups (21) and representatives (genera, families) of the earlier known groups (pl. 2). Trilobites are represented by the Family Olenellidae and others, including the widespread and distinctive *Fallotaspis* (Hupé 1960; Repina, 1966, et cetera). The biostratigraphical counterpart of the discussed time is the upper part of the Aldan Stage (or Aldan Stage s.s. Rozanov, 1966), Atdaban Stage or Bograd horizon, or Amuslek Substage (Hupé, 1960; Debrenne, 1964). Because of the lack of fossils in the upper part of the Aldan Stage in the Aldan-river stratotype, it is hardly possible to call this unit the Aldan Stage, however. If in analogy with the pre-trilobite beds it is to be regarded as a stage, then it must be called the Atdaban Stage. The stratotype of this horizon, raised to stage rank, is situated on the Lena-River (Rozanov and others, 1969; Zhuravleva, 1968a,b; Zhuravleva, Korshunov, and Rozanov, 1969).

PLATE 2
First trilobite assemblages

Figs. 1 and 2. Trilobita (from L. N. Repina).*
1. Olenellidae. Khorbusuonka River, Yakutia, × 2.
2. Profallotaspis, jakutensis Repina. Lena River, Yakutia, × 3.

Figs. 3 and 4. Hyolitha (from N. P. Meshkova).
3. *Trapezovitus primus* Meshkova. Lena River, Yakutia, × 1.
4. *Orthotheca tarynica* Meshkova. Lena River, Yakutia, × 2.

Fig. 5. Archaeocyathi—*Thalamocyathus howelli* (Gordon). Kija River, Kuznetsky Alatau, × 6 (from I. T. Zhuravleva).

Fig. 6. Cribrocyathea (*Szecyathus cylindricus* Vologdin). Kija River, Kuznetsky Alatau, × 20 (from T. V. Jankauskas).

Fig. 7. Ostracoda (*Fordilla* sp.). Lena River, Yakutia, × 10 (from N. P. Meshkova).

Fig. 8. *Dactyloidites asteroides* Fitch. Sucharicha River, Krasnojarsky Region, × ½ (from V. A. Lutchinina).

Figs. 9 and 10. Brachiopoda (from Yu. L. Pelman).
9. *Curticia* sp. Lena River, Yakutia, × 4.
10. *Acrothele* sp. Lena River, Yakutia, × 8.

Fig. 11. Sponge spicules. Lena River, Yakutia, × 10 (from N. P. Meshkova).

* Parentheses enclose the name of the specialists whose material is used on the plates.


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3. *Acme of the Early Cambrian faunal groups.*—Almost all the Early Cambrian faunal groups are known from this time. The Archaeocyathi and Trilobita were dominant. Earlier known groups expanded. For the first time there appeared stenothecoids, Hydroconozoa, and numerous small groups (total 26, pl. 3). This faunal division is clearly traced in all the Early Cambrian basins from north Siberia to the Antarctic and over all latitudes. Its biostratigraphic counterpart is the Botoma Stage (Repina and others, 1964), Sanashtykgol horizon (Repina and others, 1964), Timzhit horizon and the lower part of the Tassusek Substage of the Issafen Stage (Hupé, 1960). According to the Stratigraphic Committee of the USSR (Mezhvedomstvenny Komitet, 1959), this corresponds to the lower part of the Lena Stage.

4. *Waning of the archaeocyathean fauna.*—At the very end of Early Cambrian time the trilobites became ascendant, and the number of archaeocyathean genera was reduced. Most other major Early Cambrian groups persisted into Middle Cambrian time (for example, Hyolitha, Brachiopoda), but some (tannuolinids, *Bija*) disappeared. Thus the faunal composition of the youngest Early Cambrian was not as diversified as in the preceding epoch (up to 18 groups, pl. 4). The boundary between this and the preceding third assemblage was abrupt. This was the boundary between subunits (Repina and others, 1964) as reported by several investigations, while others hold the opinion that it should correspond to the Lower-Middle Cambrian boundary (Suvorova, 1961). According to the Stratigraphic Committee of the USSR (Mezhvedomstvenny Komitet, 1959), the upper part of the Lower Cambrian belongs to the upper part of the Lena Stage; it is also known as the Lena Stage s.s.

PLATE 3

Acme of the Early Cambrian faunal groups

Figs. 1 and 2 Trilobita (from L. N. Repina).*
1. *Redlichina furcata* Repina. Suchiye Solontzy, Kuznetsky Alatau, × 1.
2. *Protolenus jakutensis* Lazarenko. Khorbusuonka River, Yakutia, × 2, 5.

Figs. 3 and 4. "Stromatoporoidea" (from V. D. Fonin).
3. *Altaicyathus sp.* Abakan River, West Sayan, × 5.
4. *Altaicyathus* sp. Abakan River, West Sayan, × 5.

Figs. 5 and 6. Archaeocyathi (from I. T. Zhuravleva).
5. *Piamaecyathus altaisajanicus* Zhuravleva. Abakan River, West Sayan, × 6.
6. *Aptocyathus biktashensis* Konjushkov. South Ural, × 4.

Fig. 7. Hyolitha (*Planitheca acreta* Meshkova). Sukharikha River, Krasnoyarsk Region, × 1 (from N. P. Meshkova).

Fig. 8. Tabulata (*Bija sibirica* Vologdin). Sukharikha River, Krasnoyarsk Region, × 10 (from I. T. Zhuravleva).

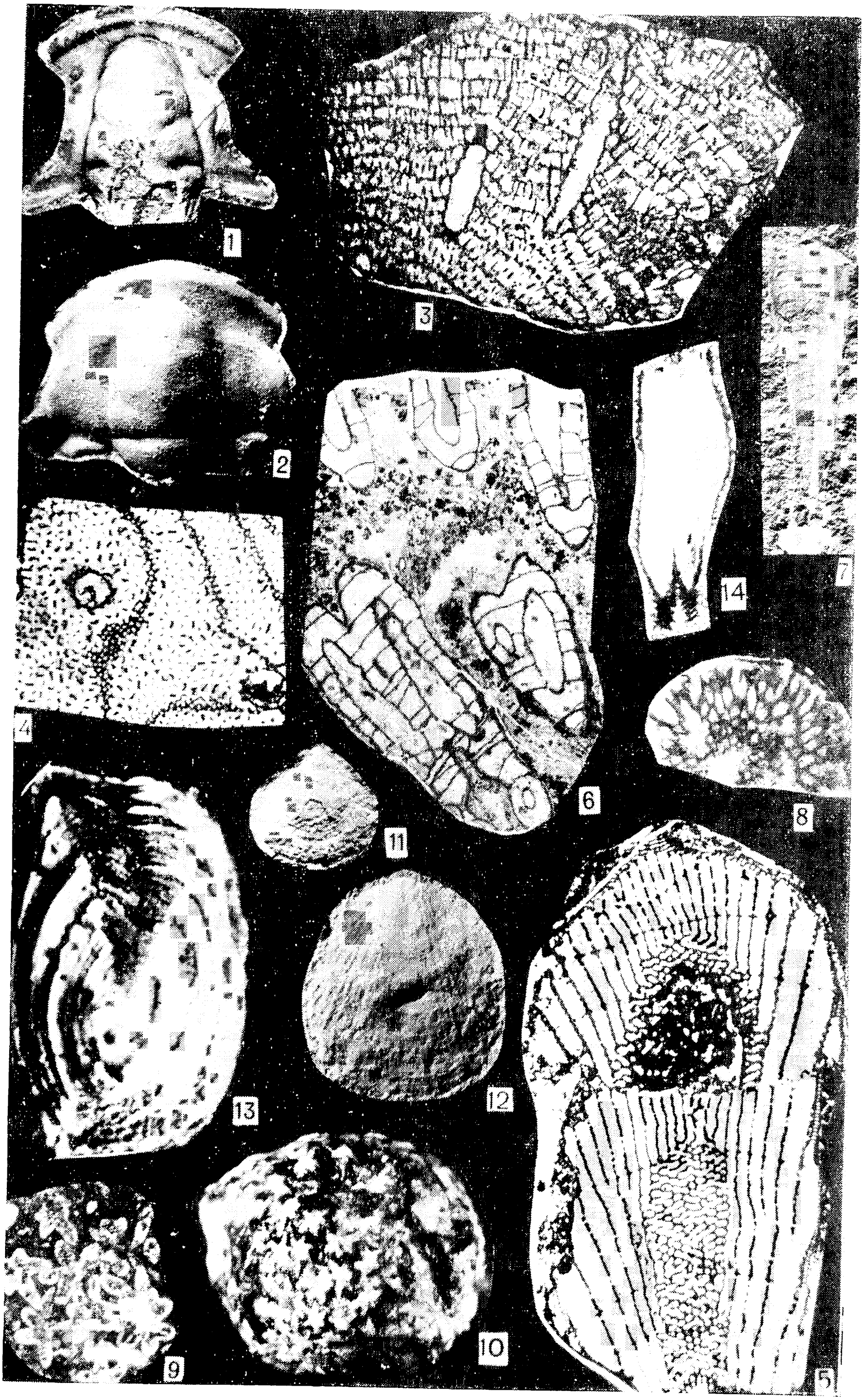
Figs. 9 and 10. Heteractinellida (from E. V. Romanenko).
9. *Curaja sphaerica* Romanenko. Balkhash River, Gorny Altai, × 10.
10. *Curaja sphaerica* Romanenko. Balkhash River, Gorny Altai, × 4.

Figs. 11 and 12. Brachiopoda (from Yu. L. Pelman).
11. *Lingulella* sp. Sinija River, Yakutia, × 8.
12. *Lingulella* sp. Sinija River, Yakutia, × 8.

Fig. 13. Tannuollinidae (*Tannuollina multifora* Fonin and Smirnova). Shivelig-khem River Tuva, × 10 (from V. D. Fonin).

Fig. 14. Cribrocyathea (*Szecyathus* sp.). Abakan River, West Sayan, × 10 (from I. T. Zhuravleva).

* Parentheses enclose the name of the specialists whose material is used on the plates.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(Repina and others, 1964), the Obruchev horizon, or the upper part of the Tassusek Substage (Hupé, 1960).

The above described four Early Cambrian faunas possess all the features inherent to large biostratigraphical assemblages such as are typical of formal stages (Repina and others, 1964; Rozanov, 1966; Rozanov and others, 1969; Sokolov, 1965) and substages (Hupé, 1960; Debrenne, 1964).

However, it is less important to establish their rank than to prove the general distribution and isochrony of their boundaries. And this has almost been achieved. The next step is to work out a single stage scale for the Early Cambrian.

"Skeletization" of most zootypes known from Early Cambrian and later time is confined to latest Precambrian-Early Cambrian time (Cloud, 1968a, b; Glaessner, 1960, 1968; Missarzhevsky and Rozanov, 1965; Rozanov, 1966, 1967; Rozanov and Missarzhevsky, 1966; Shevyrev, 1962; Shimansky, 1967; Sokolov, 1965; Zhuravleva, 1965, et cetera). Only *Anabarites*, Sabelliditidae, and Hyolitheliminthes are represented by solid remains in the Precambrian (upper Vendian). Hence an increasing number of investigators are inclined to regard the Lower Cambrian boundary as that of appearance of abundant skeletal faunas. There are several varieties of this interpretation, however. Several geologists consider this boundary to be geologically instantaneous for all groups of animals. Others, particularly the author of this article (Zhuravleva, 1965) believe the various skeletal groups appeared at different times during the earlier Early Cambrian (Hyolitha, Archaeocyathi) or later (trilobites, et cetera), or even in the upper Vendian (Hyolithelminthes, Sabelliditida). Thus the mass appearance of skeletal forms was not geologically synchronous; it extended from Vendian into late Early Cambrian (echinoderms) or even Upper Cambrian (graptolites) with a maximum in the early part of the Early Cambrian time.

The onset of the upper Early Cambrian (unit 4 of table 2) is associated with an abrupt change in the family composition of the trilobites

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PLATE 4

Waning of the Archaeocyathean fauna

Figs. 1 to 3. Archaeocyathi (from I. T. Zhuraleva).*

1. *Tegerocyathus abakanensis* (Vologdin). Botoma River, Yakutia, × 10.
2. *Claruscyathus solidus* (Vologdin). Siniya River, Yakutia, × 10.
3. *Erbocyathus heterovallum* (Vologdin). Amga River, Yakutia, × 4.

Figs. 4 and 5. Brachiopoda (from L. N. Repina).

4. *Kutorgina* sp. Siniya River, Yakutia, × 4.
5. *Kutorgina* sp. Siniya River, × 4.

Figs. 6 to 11. Trilobita (from L. N. Repina).

6. *Paramicmacca petropavlovskii* Suvorova. Olenek River, Yakutia, × 2.
7. *Lermontovia dzevanovskii* Lermontova. Olenek River, Yakutia, × 3.
8. *Chondragraulos minussensis* Lerm. Erba River, Kuznetsky Alatau, × 2.
9. *Pseudoeteraspis angarensis* N. Tchernysheva. Angara River, Irkutsk Amphitheater, × 4.
10. *Parapoliella obrutchevi* (Lermontova). Angara River, Irkutsk Amphitheater, × 4.
11. *Edelsteinaspis ornata* Lermontova. Uyar River, East Sayan, × 1, 5.

* Parentheses enclose the name of the specialists whose material is used on the plates.

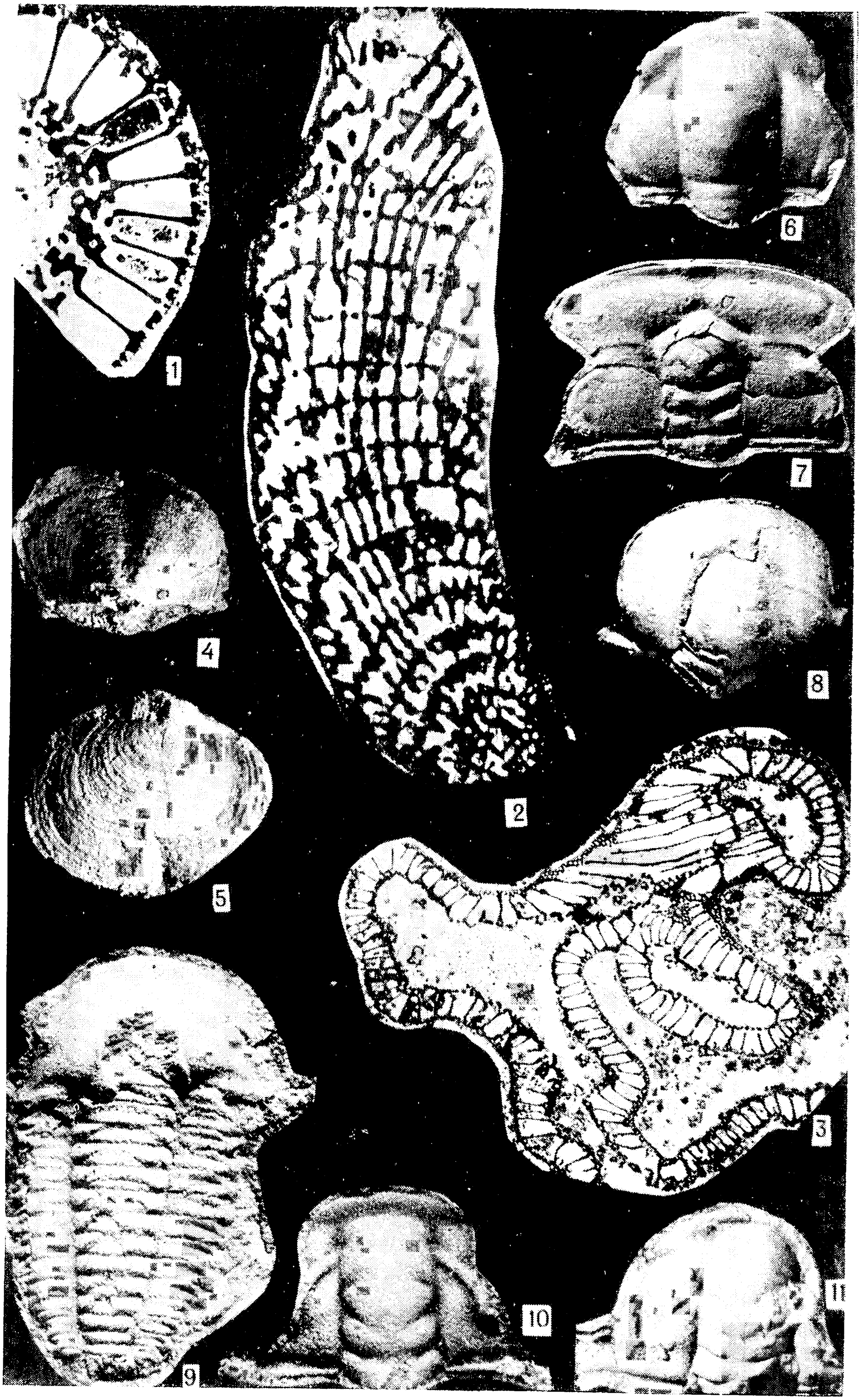
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TABLE 3

Zonal scheme for the Lower Cambrian of the Siberian Platform (middle Lena River)

Mezhvedomstvenny Komitet, 1959: Stages		Horizons	Repina and others, 1964; Khomentovsky and Repina, 1965: Stages	Trilobite zones	Zhuravleva, Korshunov, and Rozanov, 1969: Stages	Horizons	Archaeocyathid zones		Meshkova, 1969: Hyolithid zones	Missarzhevsky, Meshkova, and Rozanov, 1967: Hyolithelminthes zones	Levels
Lena Stage		Elansky	Lena Stage		Lena Stage	Elansky	*Erbocyathus heterovallum*				
Lena Stage		Ketemensky	Lena Stage		Lena Stage	Ketemensky	*Claruscyathus solidus*				
Lena Stage		Kutorginien	Botoma Stage	*Bergeroniaspis ornata-Bergeroniellus asiaticus Bergeroniellus micmacciformis-Erbiellacus Laticephalus*	Botoma Stage	Sinsko-Kutorginien					XVI
Lena Stage		Sinsky	Botoma Stage	*Bergeroniaspis ornata-Bergeroniellus asiaticus Bergeroniellus micmacciformis-Erbiellacus Laticephalus*	Botoma Stage	Sinsko-Kutorginien	*Rozanovicyathus alexi*				XV
Aldan Stage	Zhura Substage		Botoma Stage	*Bergeroniaspis ornata-Bergeroniellus asiaticus Bergeroniellus micmacciformis-Erbiellacus Laticephalus*	Botoma Stage	Tarynsky	*Porocyanthus squamosus*		*Orthotheca cor*		XIV
Aldan Stage	Zhura Substage		Aldan Stage	*Judomia Uktaspis (Prouktaspis)*	Atdaban Stage		*Lenocyathus lenaicus*	*Fansycyathus lermontovae Nochoroicyathus kokoulini*	*Trapezovitus primus*		XII-XIII
Aldan Stage	Zhura Substage		Aldan Stage	*Judomia Uktaspis (Prouktaspis)*	Atdaban Stage		*Lenocyathus lenaicus*	*Fansycyathus lermontovae Nochoroicyathus kokoulini*	*Trapezovitus primus*		XI
Aldan Stage	Zhura Substage		Aldan Stage	*Judomia Uktaspis (Prouktaspis)*	Atdaban Stage		*Lenocyathus lenaicus*	*Fansycyathus lermontovae Nochoroicyathus kokoulini*	*Trapezovitus primus*		X
Aldan Stage	Zhura Substage		Aldan Stage	*Judomia Uktaspis (Prouktaspis)*	Atdaban Stage		*Lenocyathus lenaicus*	*Fansycyathus lermontovae Nochoroicyathus kokoulini*	*Trapezovitus primus*		IX
Aldan Stage	Zhura Substage		Aldan Stage	*Pagetiellus anabarus*	Atdaban Stage		*Lenocyathus lenaicus*	*Porocyathus pinus*	*Quadrotheca clinisepta*		VIII
Aldan Stage	Zhura Substage	Kenyadinsky	Aldan Stage	*Profallotaspis*	Atdaban Stage		*Lenocyathus lenaicus*	*Retecoscinus zegebarti*	*Malykanitheca cuspidata*		V-VII
Aldan Stage	Zhura Substage	Kenyadinsky	Aldan Stage	lower Kenyadinsky	Tommot Stage	Kenyadinsky	*Dokidocyathus lenaicus*		*Lenatheca obrupta*	*Majatheca tumefacta*	IV
Aldan Stage	Zhura Substage	Kenyadinsky	Aldan Stage	lower Kenyadinsky	Tommot Stage	Kenyadinsky	*Dokidocyathus regularis*		*Lenatheca granda*	*Lapworthella bella Lapworthella tortuosa*	II-III
Aldan Stage	Zhura Substage	Sunnaginsky	Aldan Stage	Sunnaginsky	Tommot Stage	Sunnaginsky	*Ajacicyathus sunnaginicus*			*Tiksitheca licis*	I
Aldan Stage	Tolba										

(Protolenidae, Paradoxididae) and the decline of the Archaeocyathi. Little evidence is as yet provided by other groups in establishing this chronostratigraphic boundary.

CONCLUSIONS

The following conclusions emerge from the above review and other studies of the author:

1. The lower boundary of the Lower Cambrian coincides in general with the first appearance of skeletal forms, giving an age for the base of the Paleozoic as 550 to 575 m.y. As for the lower boundary of the Phanerozoic, it was recently suggested (Sokolov, 1968a) that it should be defined at the lower boundary of the Vendian and not that of the Cambrian.

2. Among some thirty principal Early Cambrian animal groups only nine can be assigned confidently to a recognized Phylum. Others are assigned to Phylum with less confidence, and several may be extinct types of animals.

3. Trilobites are not the only group of significance for Early Cambrian history. Equally important are the Archaeocyathi, Hyolitha, possibly the Brachiopoda, and other poorly studied groups.

4. Although skeletal forms first appeared generally only at the beginning of the Early Cambrian time, animal life long preceded this episode. Skeletization was not instantaneous and should not be correlated with instantaneous geological events (Axelrod, 1958; Cloud, 1968a, b; Missarzhevsky and others, 1965; Okulitch, 1960; Poulsen, 1960; Rozanov and others, 1969; Rudwick, 1964; Seilacher, 1956; Shevyrev, 1962; Sokolov, 1968a). It was just a combination of geological and biological consequences that gave rise to such a complicated process as appearance of skeletal forms of various chemical composition and most different animal types.

5. Progress is currently being made toward the goal of a single scheme of Lower Cambrian stage division. As stage schemes proposed for the Lower Cambrian of North Africa (Debrenne, 1965; Hupé, 1960), Europe (Lotze and Sdzuy, 1961), South Siberia and the Siberian Platform (Repina and others, 1964; Rozanov and Missarzhevsky, 1966; Rozanov and others, 1969; Sokolov, 1965; Zhuravleva, Korshunov, Rozanov, 1969), and China and Korea (Kobayashi, 1962; Sun Yan Tzhu, 1961) are increasingly better correlated with each other, one may expect to build up a single scheme.

6. The most highly developed schemes at the present time are those for North Africa and especially that for the Siberian Platform. The latter (table 3) involves the separation of 4 stages and up to 10 to 12 horizons and zones (Meshkova, 1969, et cetera). The lowermost part of the major units, the Tommot or Baltic Stage (corresponding to Assadassian substage in Morocco), is in fact devoid of trilobites.

7. The distinction of stages within the Lower Cambrian differs from that of other units and systems. The Early Cambrian, being the initial epoch of the Paleozoic Era, begins with stages that are characterized more

by previously unknown groups and assemblages of organisms than by the later more usual change of one assemblage to another.

8. The formal characteristics and length of Early Cambrian Time (about 40 m.y.) calls for discussion on the merits of the Lower Cambrian as an independent geological system (Pokrovskaya and Zhuravleva, 1960).

A number of arguable problems arise in studying the Lower Cambrian fauna and biostratigraphy, of which the following are most important:

A. As far as the principle of defining the lower Lower Cambrian boundary by abundant skeletal forms is concerned, can the Sunnagin horizon be regarded as the most ancient? Or will the so-called Nemakit-Daldin horizon defined to the north of the Siberian Platform (Yegorova and Savitzky, 1969) or its analogue in North America, the lower Deep Spring Formation (Cloud and Nelson, 1966, 1967), be incorporated into the Lower Cambrian? The latter are typified by occurrences of Hyolithelmithes, Sabelliditida, and *Pteridinium(?)*.

B. Is it necessary to divide the Lower Cambrian into 4 stages, the Tommot, Atdaban, Botoma, and Lena stages, instead of 2, the Aldan and Lena stages, or to use some other classification?

C. How may the boundaries between stages be defined more accurately?

D. What is to be considered as the upper Lower Cambrian boundary: the top of the existing Lena stage or the Obruchev horizon, or are these to be incorporated into the Middle Cambrian?

E. Finally, is the Cambrian the initial Paleozoic system or was it preceded by Vendian (or Ediacarian) now usually referred to the Proterozoic (Cloud and Nelson, 1966; Sokolov, 1968a)?

To resolve the above problems requires that the study of the Early Cambrian, post-Cambrian, and Precambrian faunas utilize a complex biological-geological approach. More account must be taken of the data on radiometric geochronology and more such data must be obtained. More intensive systematic studies must be made of the Early Cambrian groups to refine the study of faunal zonation and other problems of Early Cambrian time. Naturally, study of the Early Cambrian flora should also be probed as deeply as possible.

A better understanding of Early Cambrian history and its faunas will provide new outlooks on the whole of Earth history and biotal evolution. The study of geological and biological evolution from the very beginning of the Phanerozoic can greatly enhance our understanding of the relationship between these two cardinal types of evolution.

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