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## COLUMNAR STROMATOLITES AND LATE PRECAMBRIAN STRATIGRAPHY

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**ABSTRACT.** Although many stromatolites may express the physical environment of deposition more than the biology of the algae that produced them, the columnar stromatolites changed contemporaneously and in a regular manner with decreasing age during the Late Precambrian or Riphean in many parts of the USSR (1500 to 600 m.y.), as checked by K-Ar dates on glauconite.

Using such characters as shape and size of column, manner of ramification, and form and texture of microstrata, columnar stromatolites can be divided into four supergroups—Conophytonida, Kussiellida, Tungussida, and Gymnosolenida—and these into form-genera and form-species. Using these taxa, the Riphean floras can be divided into three assemblages, and the last of these into three subassemblages, each recognizable in its proper stratigraphic position in widely separated parts of the USSR (the three subassemblages are also found in Spitzbergen). The first assemblage contains only Conophytonida and Kussiellida (except locally at the top); the second is rich in Tungussida; in the third the Gymnosolenida appear and proliferate. The three subassemblages of the third assemblage are characterized by the gymnosolenid form-genera *Inseria*, *Gymnosolen*, and *Boxonia*, respectively. Form-species (but not form-genera) of microphytolites (microproblematica, catagraphs) can be used in conjunction with the columnar stromatolites to separate the assemblages, and especially the youngest subassemblages (Vendian), where Gymnosolenida are rare.

Problematic organic remains—stromatolites and microproblematica—were found to be of use for the stratigraphy of the Late Precambrian or Riphean. The Riphean of the USSR is nowadays subdivided into three major units according to stromatolite assemblages (Garris and others, 1964; Keller and others, 1960; Komar and others, 1964; Koroyluk, 1963; Krylov, 1963).

Stromatolites (Stromatolithi Pia) are laminated carbonate macrostructures, stratiform, nodular or columnar. They are usually considered to be formed by blue-green algae. Doubt persists as to whether the form of the structures "is biologically controlled or a function of the physical environment" (Hoffman, 1967). Two main factors nevertheless allow the use of stromatolites for stratigraphical purposes, in Late Precambrian stratigraphy of the USSR at least: the stability of the sequence of changing columnar stromatolite assemblages in the Late Precambrian of different regions of the USSR, and the similarity of the assemblages in series ranging in the same absolute age intervals (determined by K-argon dates on glauconite) (Garris and others, 1964; Keller, 1966; Keller and others, 1960; Nuzhnov, 1967; Raaben, 1964; et cetera).

Columnar stromatolites are preferable to stratiform and nodular ones, since more morphological characteristics are discernible in their structures: shape and size of single columns, mode of ramification and shape of complicated "bushes", form of microstrata, et cetera. The texture of microstrata is another kind of characteristic that is also important.

## MORPHOLOGICAL FEATURES

*Shape of individual columns.*—Three main types of columns can be noted: (A) cylindroid (subcylindroid), the base of the cylinder being circular, ellipsoidal, or irregular; (B) cup-shaped, that is, narrow at the base and widening upward, individual variations being numerous; (C) pseudocylindroid, with a well developed cylindrical part, but narrow at the very base and widened at the very top.

*Size of columns.*—Diameters of the columns are in general exceedingly varied; the variation interval is larger in some stromatolites and more restricted in others. Diameters of some *Conophyton* vary from 0.12 to 2.0 m. Diameters of pseudocylindric columns of some *Gymnosolen* or *Inseria* rarely exceed 3 to 5 cm and of others — 4 to 10 cm. Biostatistics is to be applied to establish intervals of the variation of diameters for most of the columnar stromatolites.

*Ramification.*—A great many columnar stromatolites ramify; a single column gives rise to several others, producing a brush-like structure with parallel or divergent branches. The mode of ramification of stromatolites is rather stable. Certain stromatolites ramify “passively” that is, the structures does not widen upward; axes of the columns remain roughly parallel through the structure. The “passive” mode of ramification is well represented by *Kussiella* Kryl. Other stromatolites: *Tungussia* Semikh., *Parmites* Raab., *Gymnosolen* Steinm., et cetera, branch “actively”; ramification is accompanied by a general widening of the structure (see figs). Axes of the newly-formed columns diverge at the base and then either remain inclined to each other at different angles (*Tungussia*, et cetera) or run parallel and grow upright again (*Gymnosolen*, *Inseria*, et cetera).

The shape of the columns and the mode of ramification are closely related; stromatolites with cylindrical columns ramify “passively” or do not ramify at all. Columns of non-ramifying stromatolites are cylindroidal with transversal section mostly circular or oval. Stromatolites with cup-like and pseudocylindrical columns branch “actively”, the former making “bushes” with strongly divergent branches, the latter with subparallel ones.

*Form of stromatolitic microstrata.*—Microstrata of columnar stromatolites are thin lenses arching upward. The shape of the arch varies strongly, a definite form, conic, being characteristic of *Conophyton* only. A thickened zone, forming a prominence, is present in the middle part of each stratum in *Conophyton*. Prominences being superposed, an upright central zone arises that runs through the column (Kirichenko, 1961; Komar, Raaben, and Semikhatov, 1965).

No central zone is observed by other stromatolites, or it may appear accidentally in isolated strata (Komar, Raaben, and Semikhatov, 1965; Krylov, 1965).

Most columnar stromatolites have dome-shaped microstrata thinned slightly at the margins. A sharp thinning out accompanied by a well

pronounced curving of the marginal part is observed in some cases. This is especially characteristic of *Boxonia*, *Gymnosolen*, and others; hence they are sometimes named "walled" stromatolites. The margins of a stratum descend along the column to meet the margins of the subjacent strata. Together they envelop the peripheral part of the column forming a "wall" (Korolyuk, 1960, 1963; Semikhatov, 1962). The surface of the columns in this case is even and smooth.

The surface of stromatolite columns without a wall is uneven. Fringes are obviously formed by marginal parts of the strata protruding into the surrounding rock (Korolyuk, 1960; Krylov, 1963). The length, evenness, and arrangement of fringes are characteristic of some groups of columnar stromatolites—*Kussiella*, *Jurusania*, *Baicalia*, et cetera).

Some stromatolites, such as *Tungussia*, *Inseria*, *Poludia*, have columns that are partly enveloped (Raaben, 1964; Semikhatov, 1962).

#### TEXTURE OF MICROSTRATA

If not obliterated by recrystallization, fine textures are observed in stromatolitic strata. Algal structures were even described, a natural classification proposed, and attempts made for using the structures for correlation of Precambrian (Vologdin, 1963), but these attempts were not successful (Raaben and Komar, 1964).

True algal structures are in fact rare, if present, in stromatolitic microstrata (Komar, 1966; Korolyuk, 1963; Krylov, 1963; Semikhatov, 1962); one should give simply a formal review of the textures observed.

Thin banded "membrane-like" textures, globular or lumpy textures, lenticular and filamentous textures, et cetera, are distinguished according to the shape of patches of crystalline carbonate ("dark patches") that alternate with or are included in phanero-crystalline carbonate ("pale bands"). The size, quantity, and disposition of the "dark" patches characterize a definite texture (Komar, 1966; Komar, Raaben, and Semikhatov, 1965). They vary considerably in different columnar stromatolites. The textures, however, as a rule, are rather stable if identified in the same column structure, bioherm, or well traced stromatolitic bed (Komar, 1966; Komar, Raaben, and Semikhatov, 1962; Several textures were identified in localities lying far apart (Komar, 1966; Komar, Raaben, and Semikhatov, 1965; Semikhatov, 1962; Semikhatov and Komar, 1965). The types of textures—banded, globular, filamentous, et cetera—are not directly connected with one or another morphology of the stromatolitic structure, similar types having been observed even in stratiform and columnar stromatolites (Komar, 1966). Textures that are strictly analogous are observed, as a rule, among columnar stromatolites with similar morphological features. At the same time, among stromatolites with similar morphological characteristics several different textures are frequently present. Accordingly, the texture of microstrata is considered to be a specific characteristic in the form-classification adopted.

## PLATE I

A.



B.



C.



D.

*Conophyton* Maslov, different form-species; thin sections, axial: A. *C.garganicus* Kor., B. *C.miloradovići* Raab., C. *C.lituis* Masl., D. *C.cylindricus* (Grab.), E. *C.metula* Kirich. (after Komar, Raaben, Semikhatov, 1965).

## PLATE 1 (Continued)

E.



## CLASSIFICATION

As columnar stromatolites proved to be most suitable for biostratigraphical correlation in the Late Precambrian, a great number of them have recently been described from the Riphean of the USSR (Golovanov, 1966; Kirichenko, 1961; Komar, 1966; Komar, Raaben, and Semikhatov, 1965; Korolyuk, 1960, 1963; Krylov, 1963, 1967; Raaben, 1964; Semikhatov, 1962), binary nomenclature being applied. Several classifications were proposed based on morphological characteristics only (Krylov, 1963, 1967) or on both morphology and texture of microstrata (Komar, 1966; Korolyuk, 1960; Raaben, 1964; Komar, 1964). These are form-taxa, as the biological value of the characteristics is unknown. Many genera were distinguished within the large genus *Collenia* (Korolyuk, 1960; Krylov, 1963; Semikhatov, 1962).

The author suggests subdividing columnar stromatolites into four main supergroups based on the mode of ramification and shape of the columns (Raaben, 1964):

1. Conophytonida (non-ramified, with cylindroidal columns)
2. Kussiellida (ramifying passively, cylindroidal columns)
3. Tungussida (ramifying actively, columns widening upward, cup-like, with axes divergent)
4. Gymnosolenida (ramifying actively, pseudocylindroidal columns, axes running roughly parallel).

Conophytonida are non-ramified stromatolites. The structures are cylindroidal in shape with a circular or oval transverse section. They form lens-like or stratiform bioherms, 50 m and more thick, consisting of parallel stems of varied size. Two groups or form-genera are distinguished: *Conophyton* Masl. and *Collonella* Kom. They differ in that *Conophyton* cylindroids are formed by a series of conic microstrata 1

## PLATE 2

A.



B.



C.

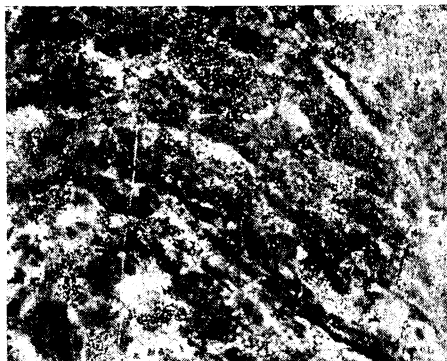
D.

Textures of microstrata in different form-species A. to D., *Conophyton* Masl., A. *C. cylindricus* (Grab.), B. *C. garganicus* Kor., C. *C. circulus* Kor., D. *C. miloradovici* Raab. (after Komar, Raaben, Semikhatov, 1965).

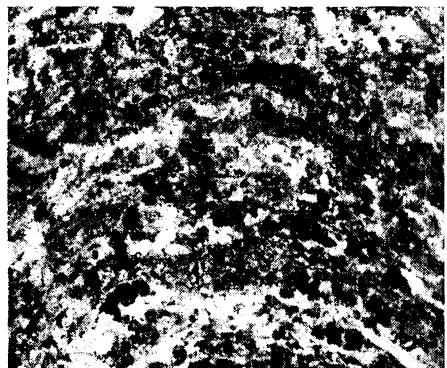
to 3 mm thick, and a well pronounced central zone is present where the thickness increases from 2 to 11 times (Komar, Raaben, and Semikhatov, 1965), whereas *Colonella* structures are formed by series of dome-shaped microstrata, thickening slightly in the central part (Komar, 1966). Seven formal species of *Conophyton* are nowadays distinguished in the Riphean of the USSR based on the fine texture of microstrata (Komar, Raaben, and Semikhatov, 1965). Three of them are represented in the Lower and Middle Riphean: *C. cylindricus* (Grab.), *C. garganicus* Kor., and *C. lituus* Masl. One species—*C. metula* Kirich.— is known only in the Middle Riphean. *C. miloradovici* Raab., *C. circulus* Kor., and *C. baculus* Kirich. are Upper Riphean forms. The first is widely developed in the Urals, Timan Ridge, and Spitzbergen; *C. circulus* and *C. baculus* are reported from two different localities of Siberia (Golovanov and Raaben, 1967; Kirichenko, 1961; Raaben, 1964; Zhuravlev and others, 1966).

## PLATE 2 (Continued)

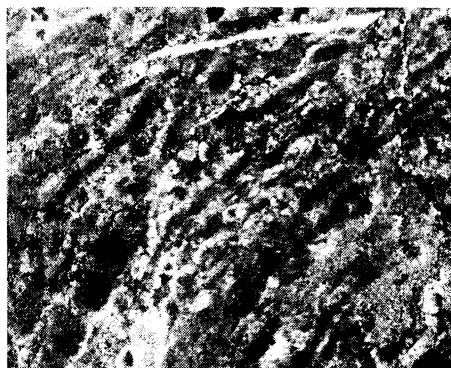
E.



F.



G.



H.

E. *F. Inzeria* Kryl., F. *I.tjomusi* Kryl., E. *I.djejimi* Raaben; G. *H. Gymnosolen* Steinm., H. *G.ramsayi* Steinm., G. *G.furcatus* Kom.

Several species of *Colonella* are reported from the Lower and Middle Riphean of Central and Northern Siberia; they are also differentiated by textural characteristics. No *Colonella* is known in the Upper Riphean. *Colonella* and *Conophyton* are frequently closely related (Komar, 1966).

The supergroup Kussiellida is characterized by subcylindroidal columns, frequently elongated and irregular in transverse sections. They are usually subdivided upward into several minor columns of the same form, parallel to one another. Microstrata are dome-shaped, varying in shape and in height. Marginal parts protrude in the surrounding rock, the surface of the columns being fringed. Fringes are symmetrical, annular, and more or less equidistant in *Kussiella* Kryl.; *Jurusania* Kryl. is characterized by irregularly disposed fringes, sometimes uneven, and very long. *Kussiella* is mostly characteristic of the Lower Riphean and is represented by the widespread species *K.kussiensis* (Kryl.) and some others. Some years ago no *Kussiella* were known from the Middle and

Upper Riphean. Nowadays *Kussiella* sp. has been reported from the Middle Riphean of the Uchuro-Mayo region (Nuzhnov, 1967), *K.enigmatica* Raab. and some others from the Upper Riphean of the Urals (Raaben, 1964) and Spitzbergen (Golovanov and Raaben, 1967). *Jurusania* seems to be spread in the Upper Riphean only. *J.cylindrica* Raab. and *J.nisvensis* Raab. occur in its lower horizons in the Urals (Krylov, 1963; Raaben, 1964) and *J.judormica*, *J.allachjunica* Kom. et Semikh., and *J.sibirica* (Yak.)—in the uppermost levels (Vendian) (Semikhatov, 1962) of Siberia.

The supergroup Tungussida is characterized by cup-like columns, mostly irregular, the diameter rapidly increasing upward. Structures are actively ramifying, that is, the ramified bush expands upward, unlike the structure of the Kussiellida. Axes of the columns are divergent. The formal genera *Baicalia* Kryl., *Tungussia* Semikh., *Parmites* Raab., *Poludia* Raab., et cetera are distinguished by differences in inclination of the columns, in the character of the surface, et cetera.

The Tungussida form the main mass of the Middle Riphean assemblage. Numbers of species of *Baicalia*, *Tungussia*, and *Anabaria* Kom. are reported (Golovanov, 1966; Komar, 1966; Korolyuk, 1963; Nuzhnov, 1967; Semikhatov, 1962). Tungussida are widespread in the Upper Riphean as well. *Parmites* and *Poludia* appear in Upper Riphean only (Raaben, 1964; Semikhatov, 1962).

Gymnosolenida are stromatolites ramifying actively with columns roughly parallel, pseudocylindric, that is, a well pronounced cylindrical part is developed narrowing at the very base and widening at the very top only. Several form-genera are distinguished: *Gymnosolen* Steinm., *Minjaria* Kryl., *Inseria* Kryl., *Boxonia* Kor., on the basis of characteristics of the marginal parts of the microstrata. Each group is represented by form-species, identified by texture of microstrata.

Gymnosolenida are index stromatolites of the Upper Riphean. Several *Inseria* and *G.furcatus* Kom. appear in the lowermost beds, aged 950 to 900 m.y.; numerous species are typical for the middle part (760 to 680 m.y.) Rare Gymnosolenida are present in the uppermost levels of the Riphean (Vendian).

#### SUBDIVISION OF THE RIPHEAN BASED ON STROMATOLITES

As established by the investigations of many geologists (Keller and others, 1960; Komar, 1966; Komar and others, 1964; Korolyuk, 1963; Krylov, 1963; Nuzhnov, 1967; Raaben, 1960, 1964; Semikhatov, 1962), the following assemblages of columnar stromatolites are present in the Riphean.

*Assemblage I* characterizes the most ancient series of Riphean; the Burzyan series of the stratotypic section in the Urals, as well as the basal part of the Billiakh formation (Kotuykan series) of the Anabar shield, the Kyuyutingdin series of the Olenek uplift, and the Uchur formation of the eastern part of the Aldan shield. The absolute age of these series ranges from 1500 to 1400 m.y. (Garris and others, 1964;

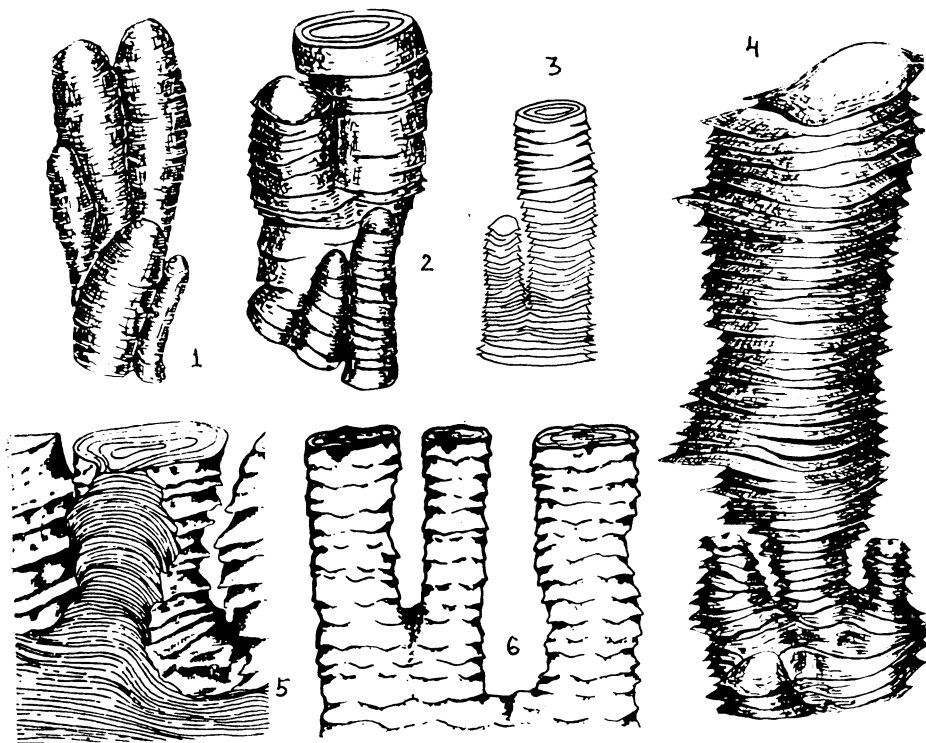


Fig. 1. Lower Riphean assemblage: 1. *Omachtenia givunensis* Nuzhn.; 2, 4. *Omachtenia omachtensis* Nuzhn.; 3, 5. *Kussiella kussiensis* (Masl.) (after Nuzhnov, 1967; Krylov, 1963; Komar, 1966).

Kazakov and Tugarinov, 1963; Kazakov and others, 1966; Keller, 1966; Keller and others, 1960; Komar, 1966; Komar and others, 1964). The assemblage is represented by Conophytonida and Kussiellida: *Conophyton cylindricus* (Grab.), *C.garganicus* Kor., *C.lituus* Masl., *Colonella laminata* Kom., *C.discreta* Kom., *Kussiella kussiensis* (Masl.) *Kussiella vittata* Kom., *Omachtenia omachtensis* Nuzhn. (Komar, 1966; Komar, Raaben, and Semikhatov, 1965; Krylov, 1963; Nuzhnov, 1967).

*Conophyton garganicus*, *C.cylindricus*, as well as *Kussiella kussiensis* are widespread, being reported both in the Urals and in different localities of Siberia. The other members of the assemblage are known in the Siberian sections only. The Burzyan and Uchur series do not include columnar stromatolites other than Conophytonida and Kussiellida; the Kotuikan series, however, in its upper part is characterized by a mixed assemblage, *Kussiella* beds alternating with *Baicalia* beds (Golovanov, 1966; Komar, 1966).

*Assemblage II*—Middle Riphean—is known as the *Baicalia* assemblage. It is widespread, being represented in the Uralian stratotype (Yurmatin series) and in most Siberian sections; for example, the lower

part of the Yumastakh series of the Anabar shield, the Arymass, Debengdin, and lower Khaypakh series of the Olenek uplift, the lower part of the Late Precambrian of Kharaulakh, the Maya series of the eastern slope of the Aldan shield, in the Sukhopit series, and the lower part of the Tungussic series of the Yenisey Ridge, the Sukhotungussic and Derevnin series of the Turukhan uplift (Golovanov, 1966; Komar, 1966; Komar, Raaben, and Semikhatov, 1965; Krylov, 1963; Nuzhnov, 1967; Semikhatov, 1962). Absolute ages of the series mentioned range from 1300 to 980 m.y. (Garris and others, 1964; Kazakov and Tugarinov, 1963; Kazakov and others, 1966; Keller and others, 1960; Keller, Semikhatov, and Chumakov, 1967); Komar, 1966; Komar and others, 1964). *Baicalia baicalica* (Masl.) is the sole form reported in the Yourmatin series of the Urals, the series representing the lowermost part of Middle Riphean according to the absolute age data (top 1290 m.y.) (Garris and others, 1964; Keller and others, 1960; Komar and others, 1964). The Middle Riphean of Siberia is rich in various Tungussida: *Baicalia baicalica* (Masl.), *Baicalia prima* Semikh., *Baicalia minuta* Kom., *Baicalia maica* Nuzhn., *Tungussia nodosa* Semikh., *T.confusa* Semikh., *T.laquensa* Golov., *Anabaria radialis* Kom., *A.divergens* Kom., et cetera; *Baicalia baicalica*, *B.prima*, and *T.nodosa* are the most common species (Golovanov, 1966; Komar, 1966; Nuzhnov, 1967; Semikhatov, 1962). *Anabaria* Komar is to be especially noted, as it is reported only from the Middle Riphean of Northern Siberia (Komar, 1966). It offers some similarity with Upper Riphean stromatolites. Conophytonida are represented in the Middle Riphean of Siberia by *Conophyton metula* Kirich., as well as by *C.cylindricus*, *C.garganicus*, and *C.lituus* (Komar, Raaben, and Semikhatov, 1965). New species of *Colonella* appear: *C.lineata* Kom. and *C.cormosa* Kom. Kussiellida are present; *Kussiella* sp. was reported from the Enin series of the eastern slope of Aldan shield (Nuzhnov, 1967).

*Assemblage III*, especially rich and various, is established in the upper series of Riphean (Komar, 1966; Komar and others, 1964; Komar, Raaben, and Semikhatov, 1965; Krylov, 1963, 1967; Raaben, 1964; Raaben and Komar, 1964; Semikhatov, 1962). Several new genera appear and develop widely here, representing the supergroup Gymnosolenida: *Gymnosolen* Steinm., *Inseria* Kryl., *Boxonia* Kor., and others, each being represented by several species. Tungussida are common, such as *Tungussia* Semikh., *Parmites* Raaben, *Poludia* Raab., as well as Kussiellida, *Jurusania* Kryl. *Conophyton* Masl. is represented by three new forms. The assemblage is present in the Karatau series of the Urals, and analogues in the Timan Ridge and the Kanin Peninsula (Zhuravlev and others, 1966), as well as in the upper members of the Yumastakh series of the Anabar shield, the upper Khaipakh and Kharbusuon series of the Olenek uplift, upper members of the Tungussic series and the Oslyan series of the Yenisey Ridge and analogues in the Turukhan Uplift, as well as in the Tyan-Shan. This assemblage is especially well developed in the Middle and in the lowermost parts of the Upper Hecla Hoek

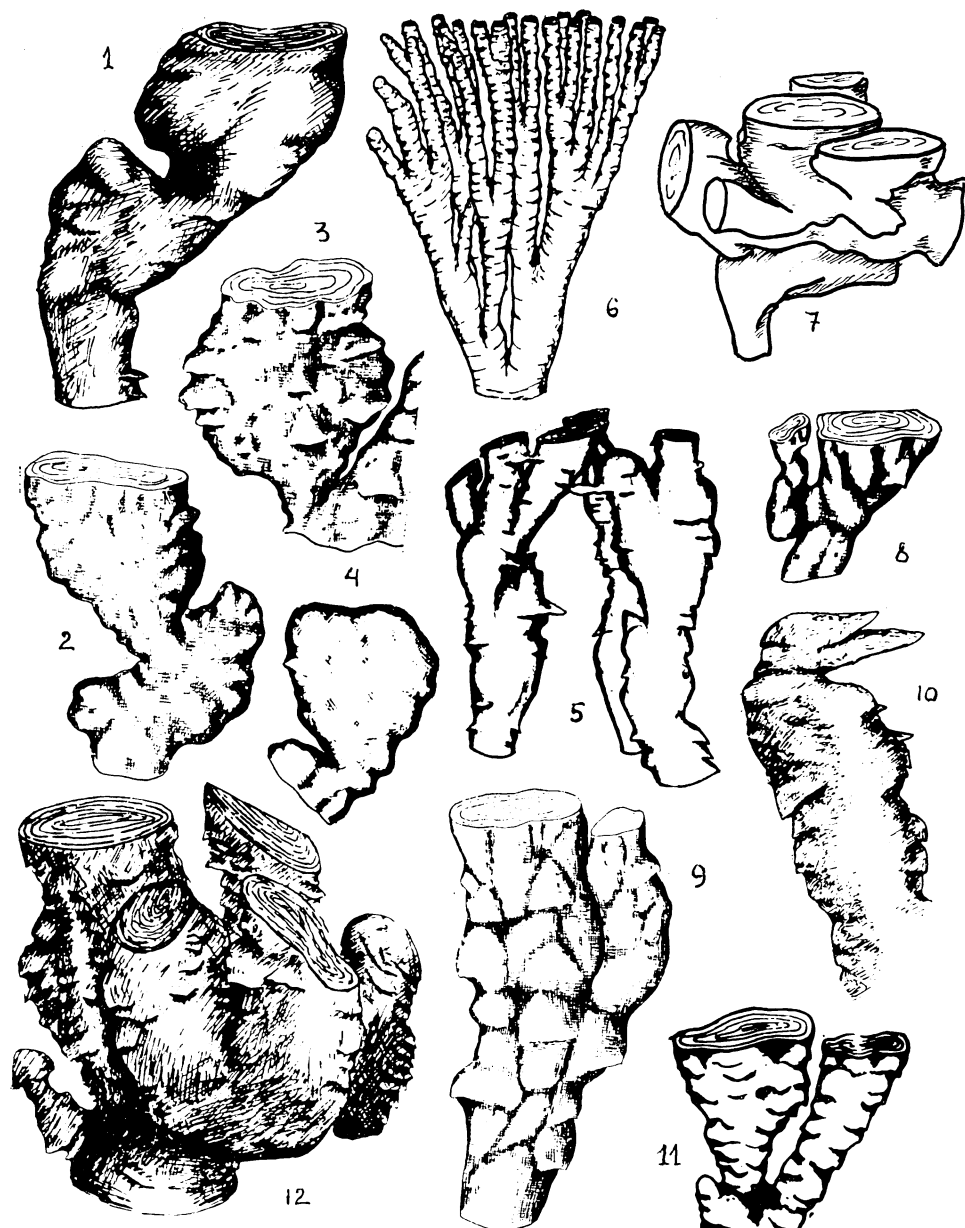


Fig. 2. Middle Riphean assemblage: 1. *Baicalia prima* Semikh.; 2, 3. *Baicalia baicalica* Kryl.; 4. *Baicalia kirghisica* Kryl.; 5, 12. *Baicalia prima* Semikh.; 6. *Anabaria radialis* Kom.; 7. *Tungussia nodosa* Semikh.; 8, 9. *Baicalia baicalica* Kryl.; 10. *Baicalia maica* Nuzhn.; 11. *Baicalia minuta* Kom. (after Semikhatov, 1962; Krylov, 1963, 1967; Komar, 1966; Nuzhnov, 1967).

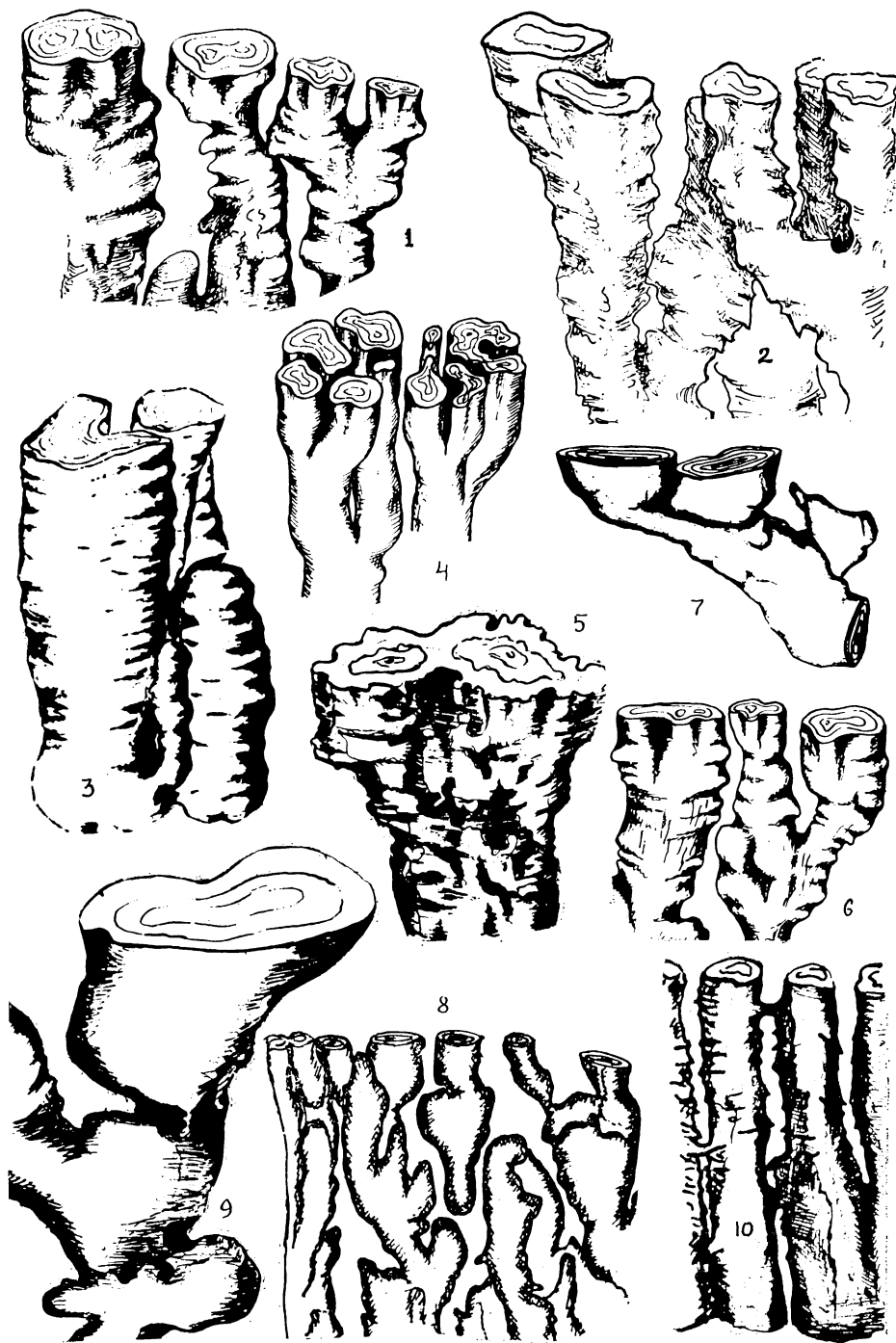


Fig. 3. Upper Riphean assemblage: lowermost subassemblage Biryanian): 1, 3, 5, 6. *Inseria ijomusi* Kryl. (1, 6. Central Siberia, collector, M. A. Semikhatov; 3. South Ural, after Krylov, 1963; 5. Polud Ridge); 2, 8. Some other representatives of *Inseria* Kryl. 2. Central Siberia, collector, M. A. Semikhatov; 8. North Siberia, after N. P. Golovanov); *Gymnosolen furcatus* Kom. (North Siberia, collector V. I. A. Komar); 7. *Tungussia nodosa* Semikh. (Polud Ridge); 9. *Tungussia colcimi* Raab.; 10. *Jurussia nisivensis* Raab. (Polud Ridge).

of Spitzbergen (Golovanov and Raaben, 1967; Komar, 1966; Krylov, 1963; Raaben, 1964; Raaben and Komar, 1964; Semikhatov, 1962; Zhuravlev and others, 1966).

The Upper Riphean assemblage proves not to be monotonous when traced from bottom to top in the sequences. Three subassemblages are established characterizing the basal, middle, and upper members of the Upper Riphean. The first subassemblage, the Biryanian, appears in the lower part of the Karatau series of the Urals, in the uppermost part of the Maya series of the Aldan as well as in the Shorikh and Turukhan uplift of Central Siberia. The absolute age of the series ranges from 960 to 900 m.y. (Garris and others, 1964; Keller, 1966; Komar, 1966; Raaben, 1964; Semikhatov, 1962), dates established for the lower parts of the series. The *Inseria* group is especially characteristic for the subassemblage, the most common form being *I.tjomusi* Kryl.; this form is associated with *Jurusania* spp. in the Urals and several other species of *Inseria* in Siberia. *G.furcatus* Kom. was reported from North Siberia in the series giving almost the same absolute age data (Komar, 1966). *Tungussia* Semikh. is common in all levels. Rare *Baicalia* (*B.lacera* Semikh., and others) were reported from the Turukhan uplift and the Uchuro-Maya region (Nuzhnov, 1967; Semikhatov, 1962).

The middle subassemblage, the Minyarian, is established in series ranging from 760 to 680 m.y. by the K-argon method, in the Minyar series of the South Urals, the upper member of the Nisva series of Polud Ridge, the Bystrin series of the Timan Ridge and the Kanin Peninsula. The upper part of the Lom Fiord supergroup (Middle Hecla Hoek) of Spitzbergen includes the same very well pronounced assemblage (Golovanov and Raaben, 1967; Raaben, 1967).

Several *Gymnosolen*, namely *G.ramsayi* Steinm., as well as *Inseria djejimi* Raab., *Minjaria uralica* Kryl. are representatives of the *Gymnosolenida* and are index-fossils of the subassemblage as well as *Conophyton miloradovici* Raab., *Parmites concreescens* Raab., and *Poludia polymorpha* Raab.

The subassemblage is unknown in Siberia; no limestone or dolomitic series ranging approximately from 750 to 700 m.y. have been established in Siberian sequences.

The upper subassemblage is relatively poor, *Gymnosolenida* being represented by *Boxonia* Kor. only; *B. grumulosa* Kom. was reported in several localities in Siberia and is also present in the Rysso dolomite of the Hecla Hoek of Spitzbergen. Numerous *Tungussia*, whose species characteristics are still to be examined, rare *Conophyton*, namely *C.circulus*, *Jurusania sibirica* (Yak.) and *Jurusania allakhjunica* Kom. et Semikh., are other columnar stromatolites identified in the uppermost (Vendian) series of Riphean, ranging from 675 to 600 m.y. (Garris and others, 1964; Keller, 1966a, b; Komar, 1966). The Ukian series of the Urals (620-612 m.y.), the Yudomian series of East Siberia, the Khatyspyt, Turkutian, and Starorechin series of North Siberia, the upper part of the Boxon series of the Irkutsk amphitheatre represent the very uppermost

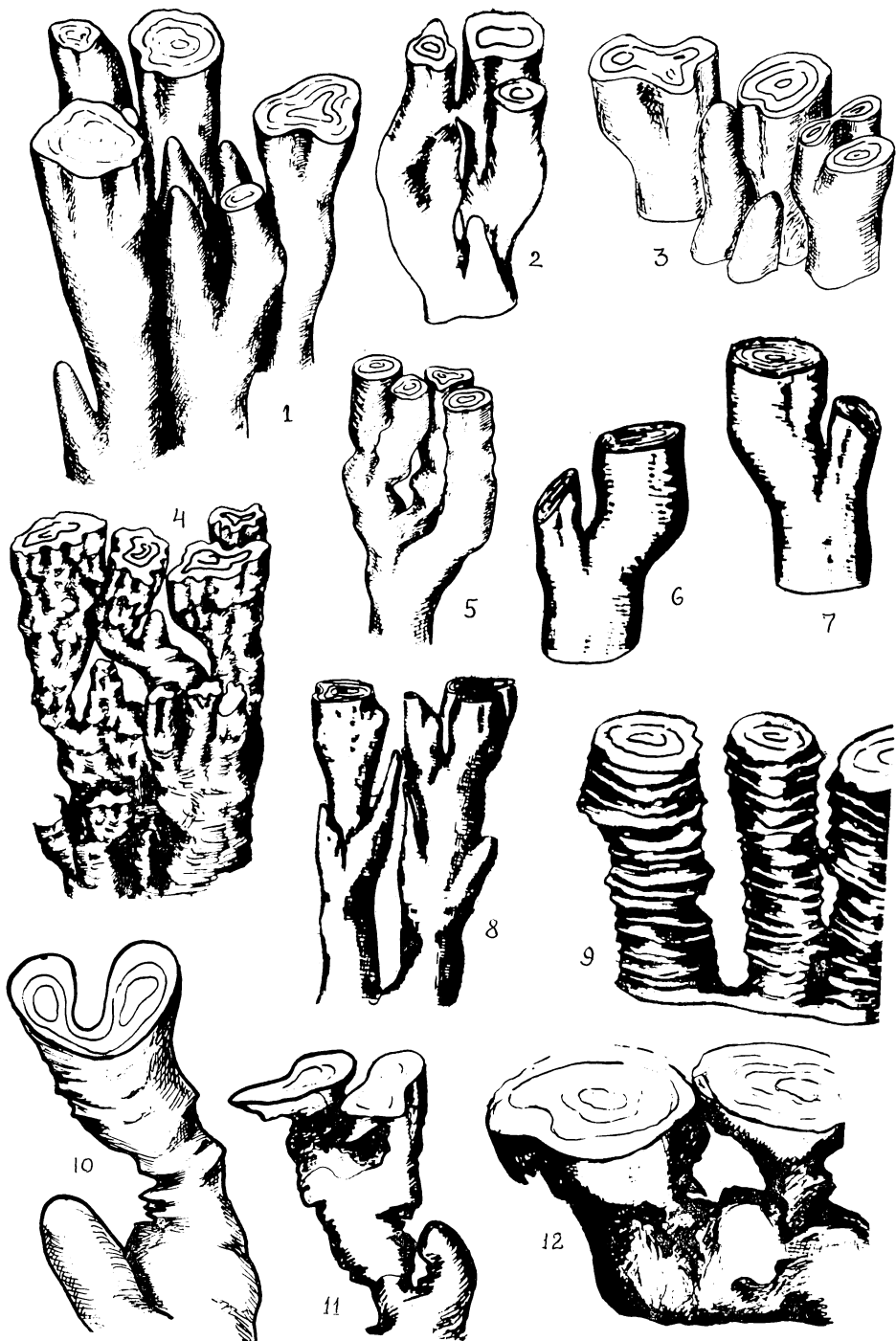


Fig. 4. Upper Riphean assemblage; middle subassemblage (Minyarian): 1, 2, 3, 5, 8. *Gymnosolen ramsayi* Steinm. (1, 3. Polud Ridge; 2, 5. Kana Peninsula; 8. South Ural, after I. N. Krylov 1963); 4. *Inseria dzejimi* Raab S.Timan; 6, 7. *Minjaria uralica* Kryl. (South Ural, after I. N. Krylov); 9. *Kussiella enigmatica* Raab. (S.Timan); 10. *Poludia polymorpha* Raab. (Polud Ridge); 11, 12. *Tungussia* Semikh. Polud Ridge).

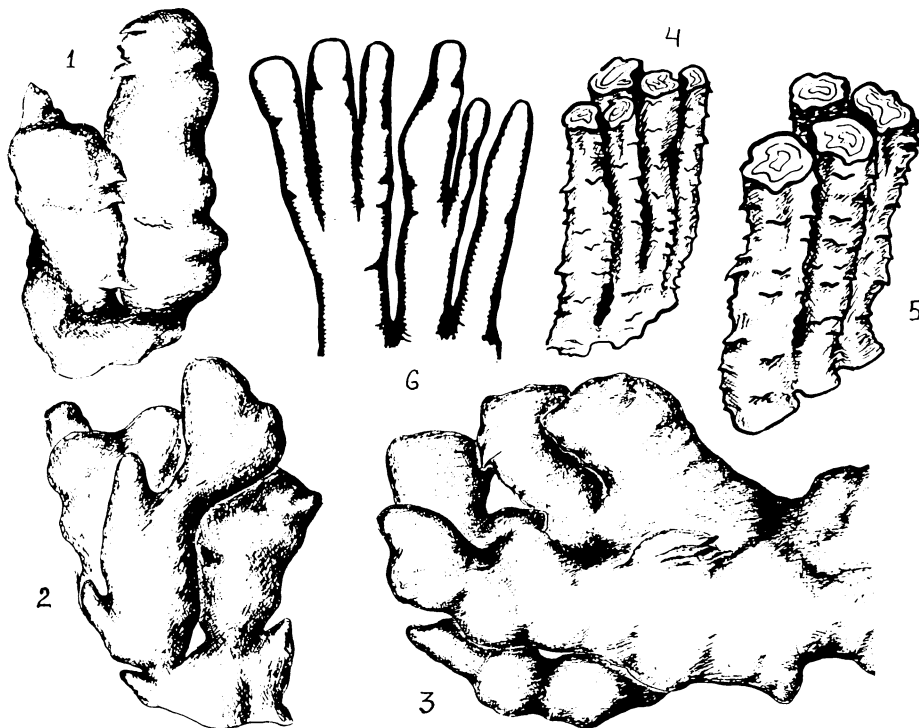


Fig. 5. Upper Riphean assemblage: uppermost subassemblage (Vendian): 1, 2. *Linella* Kryl. (South Ural, after I. N. Krylov, 1967); 3. *Tungussia bassa* Kryl. (South Ural, after I. N. Krylov, 1967); 4, 5. *Jurusania sibirica* (Yak.) (E. Siberia); 6. *Boxonia* Kor. (after Komar, 1966).

sub-division of Upper Riphean, often called Vendian (Garris and others, 1964; Keller, 1966a, b; Keller, Semikhatov, and Chumakov, 1967). Vendian is frequently considered as an independent subdivision of the Precambrian or of the Riphean, notwithstanding its short duration (Keller, 1966a, b; Keller, Semikhatov, and Chumakov, 1967; and others).

#### NONCOLUMNAR STROMATOLITES

Stratiform and nodular stromatolites have been explored systematically in North Siberia only (Komar, 1966). Several form-genera and form-species were established from Lower, Middle, and Upper Riphean that could be used for correlation of sequences some hundred kilometers apart, if belonging to the same geotectonic area. Possibilities of using noncolumnar stromatolites for a general correlation are still to be examined.

#### ASSEMBLAGES OF MICROPHYTOLITES

Assemblages of microphytolites (microproblematica) are established in the Riphean associated with the columnar stromatolite assemblages (Keller, 1966a; Zabrodin, 1968; Zhuravleva, 1964). The majority of form-

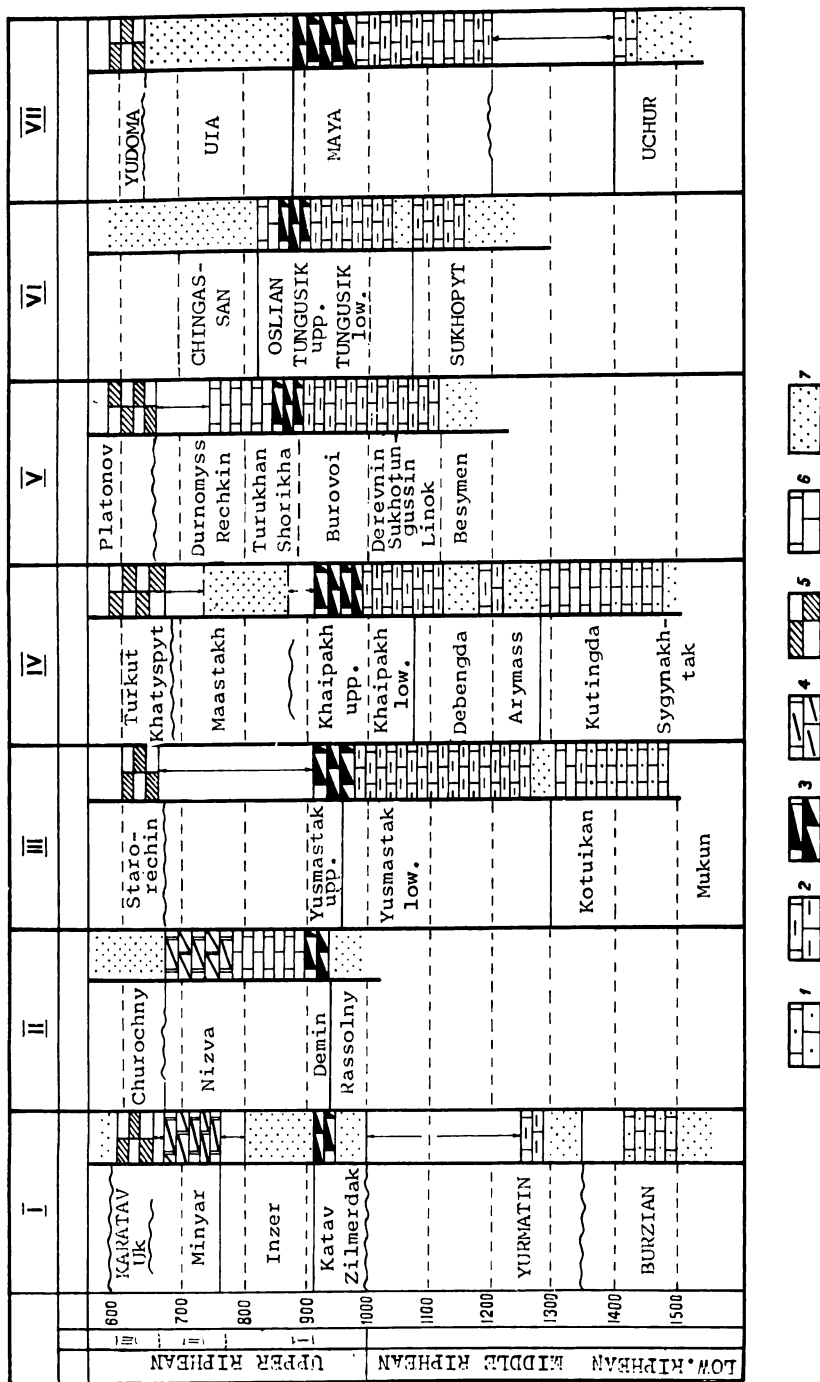


Fig. 6. Distribution of columnar stromatolites in the Riphean sections of USSR.  
 1 to 6. Series or formations mostly carbonatic with assemblages of stromatolites: 1. Lower Riphean; 2. Middle Riphean; 3 to 5. Upper Riphean, 3. lowermost subassemblage (Biryaman), 4. middle subassemblage (Manyarian), 5. uppermost subassemblage (Vendian); 6. subassemblage uncertain; 7. series or formations mostly terrigenous.  
 I. S. Urals; II. Polud Ridge; III. Anabar shield; IV. Olenek uplift; V. Turukhan uplift; VI. Yenisey Ridge; VII. Uchuro-Maya Region.

genera—*Osagia* Twenh., *Vesicularites* Reitl., *Radiosus* Z. Zhur., *Asterosphaeroides* Reitl.—pass through the Riphean. A number of form-species of these genera proved useful for correlation (Zabrodin, 1968; Zhuravlev and others, 1966; Zhuravleva, 1964). Series bearing a Lower Riphean assemblage of stromatolites or belonging to the same time interval are characterized by *Osagia libidinosa* Z.Zhur., *Vesicularites rotundus* Z.Zhur., *Radiosus tenebricus* Z.Zhur., *R. ovale* Z.Zhur., and some other forms (Zhuravleva, 1964). A middle Riphean assemblage includes *Osagia tenuilamellata*, Reitl., *Vesicularites flexuosus* Z.Zhur., *V. compositus* Z.Zhur., et cetera (Zhuravleva, 1964). *Radiosus aculeatus* Z.Zhur., *R. elongatus* Z.Zhur., et cetera, *Vesicularites elongatus* Zabr., *V. enigmatus* Zabr., *V. raabena* Zabr., et cetera (Zhuravleva, 1964; Zabrodin, 1968) are established in the Upper Riphean series, as well as several *Osagia*; some of them are associated with the Biryanian subassemblage of stromatolites, and others with the Minyarian subassemblage. New species of *Vesicularites* appear in the uppermost series of the Upper Riphean (Vendian), *V. bothridioformis* (Krasnop.) and *V. lobatus* Reitl. being especially characteristic; they are widespread in the series aged 650 to 600 m.y. (Zhuravleva, 1964). The same assemblage occurs in carbonate members of the Polarisbren series of Spitzbergen which underlies and overlies the tillites (Golovanov and Raaben, 1967; Raaben, 1967).

#### CONCLUSIONS

Columnar stromatolites are useful for correlation of Late Precambrian strata of vast areas. Stratigraphical unities established on the basis of an analysis of stromatolitic assemblages prove to be nearly isochronous when controlled by absolute age data.

Definite assemblages of columnar stromatolites are associated with definite assemblages of algal problematica of another kind—that is, microphytolites.

Some of the subdivisions of the Riphean are recognizable not only in the USSR; the Upper Riphean is identified in Spitzbergen, well characterized by assemblages of columnar stromatolites and microproblematica, and its subordinate units are identified as well, on the basis of corresponding subassemblages. The Vendian is especially well established, tillites occurring in its middle part.

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