Correlation of Uppermost Carboniferous and Lower Permian Rugose Coral Zones from the Urals to Western North America

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Correlation of Uppermost Carboniferous and Lower Permian Rugose Coral Zones from the Urals to Western North America

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More than 40 species of uppermost Carboniferous and Lower Permian rugose corals collected from 5 areas on the Russian Platform and the Ural Mountains permit eight coral zones to be erected. They are the (1) Timania dobroljubovae *zone, (2)* Arctophyllum minimum *zone, (3)* Ferganophyllum *sp. nov. 1 zone and its analogue in Timan, the* Timania *sp. 1-* Heritschioides *aff.* H. carneyi *zone, (4)* Kleopatrina *(*K.*)* pseudoelegans-Tschussovskenia captiosa *zone and its partial analogue in Timan, the* Lophbillidium *zone, (5)* Timania schmidti-Kleopatrina *(*K.*)* magnifica *zone, (6)* Protolonsdaleiastraea biseptata *zone, (7)* Protolonsdaleiastraea longiseptata *zone, and (8)* Protolonsdaleiastraea juresanensis *zone. Several of these zones can be extended to Spitsbergen and North America. Especially important for international correlation are four levels at which major changes in the assemblages of rugose corals occur. These are (1) at the base of the* Timania dobrolubjovae *zone, (2) at the base of the* Kleopatrina *(*K.*)* pseudoelegans-Tschussovskenia captiosa *zone, (3) at the base of the* Protolonsdaleiastraea biseptata *zone, and (4) at the top of the* Protolonsdaleiastraea juresanensis *zone.*

INTRODUCTION

Considerable data on Upper Carboniferous-Lower Permian coral assemblages of the Urals, Russian Platform, and north Timan have been generated by previous workers, including Stuckenberg (1895) revised by Ivanovsky (1987), Dobrolyubova (1936a,b), Soshkina et al. (1941), and Simakova (*in* Gorsky and Kalmykova, 1986). New collections of uppermost Carboniferous and Lower Permian rugose corals, made bed by bed during 1980, 1981, 1983, 1984, 1986, and 1987 in the Ural Mountains and Russian platform, have resulted in development of a new coral zonation that is considerably more refined than earlier ones and has allowed speculation on intercontinental correlations. Corals from five regions, stretching about 1200 km from southern Russia almost to the Arctic Ocean, have been collected and studied (Fig. 1). Detailed location maps are shown on Figures 2–6. The coral zones proposed are here referred to as the: (1) *Timania dobroljubovae* zone, (2) *Arctophyllum minimum* zone, (3) *Ferganophyllum* sp. nov. 1 zone (to be named *F. uralicum* by

FIGURE 1—Area from which corals were collected for this study. I, Moscow region; II, Samarskaya Luka; III, middle Urals; IV, north Timan; V, south Urals.

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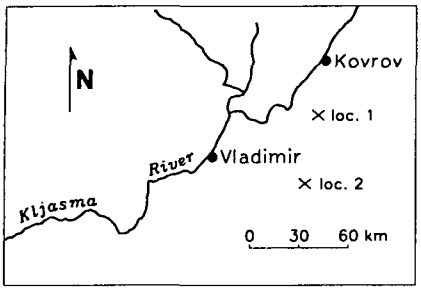


FIGURE 2—Location of Upper Carboniferous sections in the Moscow region: Melekhovo quarry (loc. 1); Dukino quarry (loc. 2).

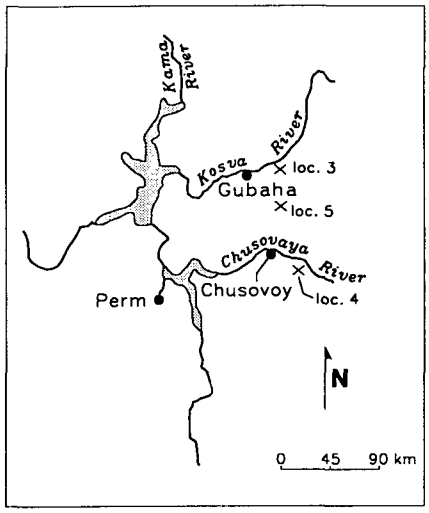


FIGURE 3—Location of sections in the middle Urals: Most (loc. 3), Plakun Stone (loc. 4), Filinok (loc. 5).

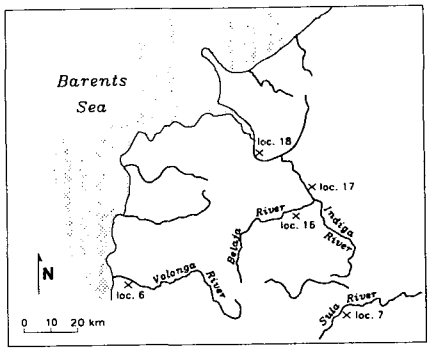


FIGURE 4—Location of north Timan sections: Malaja Pokajama (loc. 6), Sula River (loc. 7), Belaja River (loc. 16), Indiga River (locs. 17, 18).

Kossovaya, in press), (4) *Kleopatrina (K.) pseudoelegans-Tschussovskenia captiosa* zone, (5) *Timania schmidti-Kleopatrina (K.) magnifica* zone, (6) *Protolonsdaleiastraea biseptata* zone, (7) *Protolonsdaleiastraea longiseptata* zone, and (8) *Protolonsdaleiastraea juresanensis* zone. Fusulinids collected with the corals show that zones 1 and 2 are Gzhelian (Late Carboniferous), zones 3 and 4 are Asselian, zones 5–7 are Sakmarian, and zone 8 is Artinskian in age.

Coral thin sections were made in the All-Russian Scientific Geological Institute (VSEGEI) and are now kept in the Central Scientific Research Geological Museum in St. Petersburg. All specimens were identified by the author who made comparisons with holotypes in the Dobrolyubova, Soshkina, and Stuckenberg collections in St. Petersburg, Moscow, and Kazan. The taxonomy of the Cyathopsidae and Bothrophyllidae are based upon the taxonomic work of Kossovaya (1989).

CORAL ZONATION

Timania dobroljubovae zone

This zone is characterized by cyathopsid corals including *Timania* and *Arctophyllum*. The base of this zone is placed at the stratigraphically lowest occurrence of *Arctophyllum* and *Timania*. Corals identified from this zone are: *Timania dobroljubovae* Kossovaya, 1986; *Arctophyllum intermedium* (Toula, 1875); *Geyeronaotia multicystata* Kossovaya, 1986; *Pseudowannerophyllum solidum* (Ross and Ross, 1963); *Allotropiochisma (Alligia) flabella* Fedorowski, 1987; and *Falsiamplexus delicatus* (Ross and Ross, 1963).

In the Plakun Stone section (Fig. 3, loc. 4) the coral fauna consists of *Allotropiochisma (Alligia) flabella, Falsiamplexus delicatus,* and *Pseudowannerophyllum solidum,* which occur with the following fusulinids identified by Vladimir Davydov (oral commun., 1993): *Schellweinia parairregularis, S. delicata, Daixina baitugensis, D. timanensis atypica, D.* cf. *D. symmetrica,* and *D. uralica compacta.* This coral zone also has been observed in beds 8–14 in the Sula River Section (Fig. 7). The fusulinid *Triticites pergratus* and the corals *Arctophyllum intermedium, Timania* cf. *T. dobroljubovae, Geyeronaotia multicystata, Lophophyllidium (L.) wewokanum* Jeffords, 1947 are present. This zone also is represented in bed 9 (work in progress) of Melekhovo quarry (Fig. 2, loc. 1) where *Timania dobroljubovae* is present.

In the Yablonevy Ovrag carbonate section (Fig. 6, loc. 22) *Geyeronaotia multicystata* and *"Caninophyllum" grekae* Kossovaya, 1986 are present, as well as the fusulinids *Daixina sokensis sokensis, D. sokensis symmetrica,* and *D. baitugensis* (Isakova, *in* Muravyev and Grigoryeva, 1986). Fusulinids show that this zone is equivalent to the *Daixina sokensis* fusulinid zone.

Arctophyllum minimum zone

This zone is distinguished by *Arctophyllum minimum* but it also includes *Caninostrotion compositum* (Dobrolyubova and Kabakovich, 1948); *Lophocarinophyllum* sp., *Gshelia rouilleri* Stuckenberg, 1895; and *Bothrophyllum samaraense* Kossovaya (*in* Muravyeva and Grigoryeva, 1986). The base of this zone is placed at the lowest occurrence of *A. minimum.*

In both the Melekhovo (loc. 1) and Dykino (loc. 2) quarries (Fig. 2) the coral assemblage consists of *A. minimum, Caninostrotion compositum, Lophocarinophyllum* sp., and *Gshelia rouilleri.* Bed 36 of the Yablonevy Ovrag section (Fig. 6, loc. 22) (Muravyev, Grigoryeva, and others, 1984) has yielded *Arctophyllum minimum* and *Bothrophyllum samaraense* and the fusulinids *Ultradaixina* aff. *U. vozhgalensis, D. insignus, Rugosofusulina stabilis longa, R. uralensis, Pseudofusulina kljasmica,* and others (Isakova, *in* Muravyev and Grigoryeva, 1986). Equivalents of this zone also have been distinguished in the section along the Sula River (Fig. 7, bed 17) where alternating dolomite and *Palaeoaplysina*-bearing limestone have yielded *Arctophyllum* aff. *A. minimum, Ferganophyllum or-*

dinatum (Ross and Ross, 1962), and fusulinids identified by S. Remizova (oral commun., 1993) as *Rugosofusulina prisca, R.* cf. *R. aktjubensis,* and *Daixina* sp.

The fusulinids from the equivalent *F. ordinatum* zone show that this zone corresponds to the *Daixina robusta-Ultradaixina bosbytauensis* fusulinid zone (Fig. 7).

Ferganophyllum sp. nov. 1 zone

This coral assemblage zone occurs in the section at Most (Fig. 3, loc. 3; Fig. 8) and is characterized by *"Thysanophyllum" major* Dobrolyubova, 1936a; *Ferganophyllum* sp. nov. 1; and *Tschussovskenia minor* Fedorowski, 1965. *Ferganophyllum* sp. aff. *F. ruprechti* also is present. The fusulinids from these beds (Zolotova, 1972) include *Triticites pseudoarcticus, Pseudofusulina paragregaria, P. accurata, P. angulata,* and *Sphaeroschwagerina* sp.

A coral assemblage equivalent in age to the *Ferganophyllum* sp. nov. 1 zone occurs in the Sula River section in beds 18–21 (Fig. 7). The corals here include *Timania* sp. 1, *Heritschioides* aff. *H. carneyi* Wilson, 1982, *Ferganophyllum* sp. nov. 1, and *Fomichevella southeri* Stevens and Rycerski, 1989. This zone is here referred to as the *Timania* sp. 1-*Heritschioides* aff. *H. carneyi* zone. The base of this zone is placed below the lowest occurrence of *Heritschioides* at the base of bed 18 in the Sula River section (Fig. 7). Slightly above the lower boundary of this zone, the following fusulinids were identified by S. Remizova (oral commun., 1993): *Pseudofusulina paragregaria, P. gregaria, P. paramoelleri, Sphaeroschwagerina belojaensis, S.* cf. *S. vulgaris,* and *S.* cf. *S. fusiformis.*

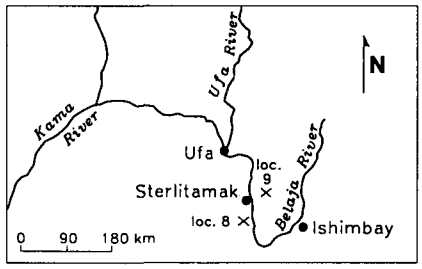


FIGURE 5—Location of south Urals (Bashkirian) sections: Shakh-Tau (loc. 8), Tra-Tau (loc. 9).

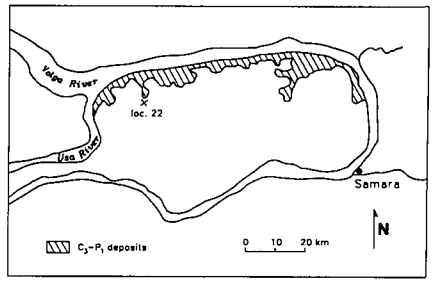


FIGURE 6—Location of Yablonevy Ovrag section (Samarskaja Luka, loc. 22) (Geology from Muravyev et al., 1983). C3-P1 indicate distribution of Late Carboniferous and Early Permian rocks.

The range of the *Timania* sp. 1-*Heritschioides* aff. *H. carneyi* zone is equivalent to that of the *Ferganophyllum* sp. nov. 1 zone and is correlated with the *Sphaeroschwagerina vulgaris-S. fusiformis* and the lower part of the *S. moelleri-Pseudofusulinia fecunda* fusulinid zones (Fig. 8).

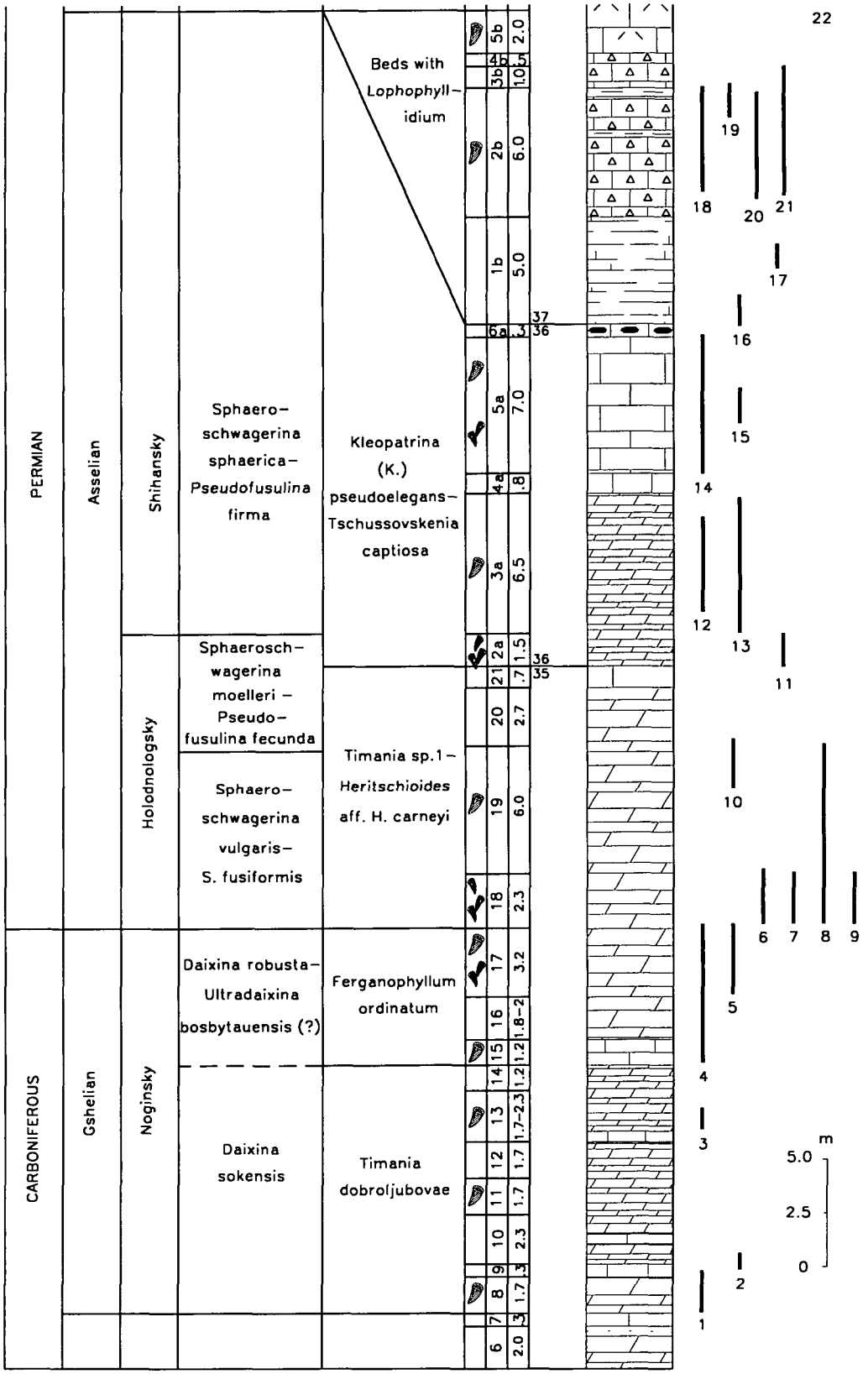
Kleopatrina (K.) pseudoelegans-Tschussovskenia captiosa zone

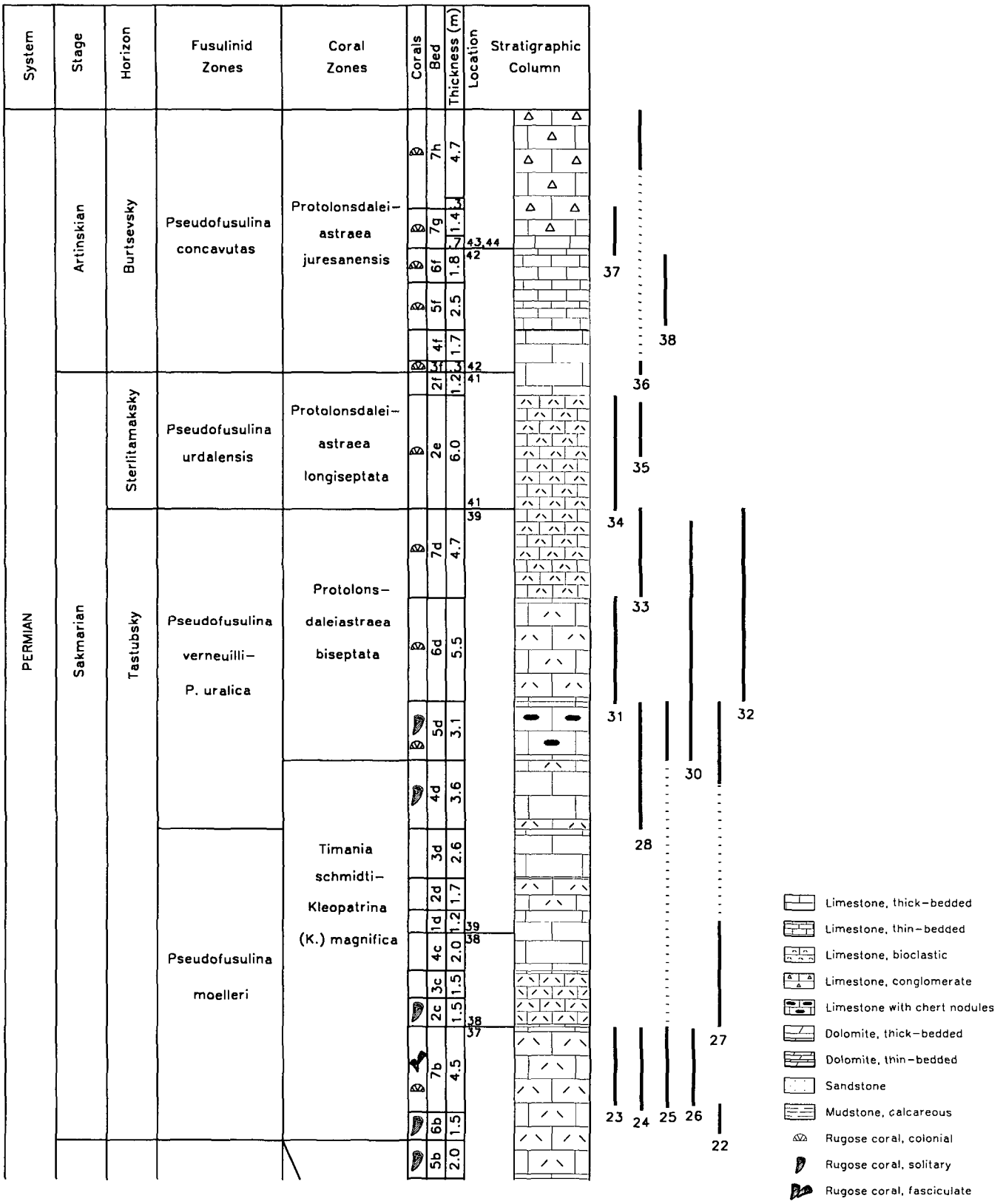
This zone is characterized by *Kleopatrina (K.) pseudoelegans* (Dobrolyubova, 1936b) and *Tschussovskenia captiosa* Dobrolyubova, 1936a, but also includes *"Thysanophyllum" aseptatum* Dobrolyubova, 1936a, *Timania* sp. 2 (a small form), *Actinophrentis columnare* Fedorowski, 1987, *Lophotichium simulatum* Fedorowski, 1987, and *Lophophyllidium (Lophbillidium)* sp. The lower boundary of this zone at the Shakh-Tau (Fig. 5, loc. 8) and Filinok sections (Fig. 3, loc. 5), the latter based on data of M. Simakova (oral commun., 1993), is placed below the lowest occurrence of *Kleopatrina pseudoelegans. Kleopatrina* appears in the middle of the *Sphaeroschwagerina moelleri-Pseudofusulina fecunda* fusulinid zone and gradually replaces the Bothrophyllidae and Cyathopsidae in these sections. In the Sula River section (Fig. 7), beds 2a–5b that comprise this zone are represented by carbonates with dome-shaped *Palaeoaplysina*-bearing bioherms. Here and in the Most section (Fig. 8), the lower boundary is drawn below the lowest occurrence of *Tschussovskenia captiosa.*

In bed 10 in the Most section (Fig. 8) the following fusulinids occur with the corals: *Paraschwagerina mukhamediarovica, P. akhunovi,* and *Sphaeroschwagerina sphaerica* (Zolotova, 1972). In the Sula River section (Fig. 7), S. Remizova (oral commun., 1993) has identified *Sphaeroschwagerina* sp., *S. fusiformis,* and *Pseudofusulina paragregaria simplex* in bed 2a. An assemblage of small, primitive rugose corals including *Lophbillidium* sp. occur in the upper part of this zone in beds 1b–5b (Fig. 7). This part of the section also is characterized by a small species of *Triticites.* The appearance of this peculiar assemblage of rugose corals and fusulinids probably is due to changes in environmental and sed-

→

FIGURE 7—Distribution of corals in the Sula River section (loc. 7). 1, *Arctophyllum intermedium*; 2, *Timania* sp. cf. *T. dobroljubovae*; 3, *Geyeronaotia multicystata*; 4, *Ferganophyllum ordinatum*; 5, *Arctophyllum* sp. aff. *A. minimum*; 6, *Timania* sp. 1; 7, *Lophophyllidium (Lophbillidium)* sp. 1; 8, *Ferganophyllum* sp. 2; 9, *Heritschioides* aff. *H. carneyi*; 10, *Fomichevella southeri*; 11, *Tschussovskenia captiosa*; 12, *Lophotichium simulatum*; 13, *Timania* sp. 1; 14, *T.* sp. 2; 15, *Amplexocarinia* sp.; 16, *Actinophrentis columnare*; 17, Gen. et sp. 1 nov.; 18, *Lophophyllidium (Lophbillidium)* sp. 2; 19, *Lophotichium* sp. aff. *L. simulatum*; 20, *Lophophyllidium (Lophbillidium)* sp. 3; 21, *Asserculinia* sp.; 22, Gen. et sp. nov. 2; 23, *Protowentzelella simplex*; 24, *Heritschioides densicolumella*; 25, *Kleopatrina (K.) uralensis*; 26, *K. (K.) magnifica*; 27, *Timania schmidti*; 28, Gen. et sp. 3 nov.; 30, *Protolonsdaleiastraea biseptata*; 31, *P. dobroljubovae*; 32, *P. complexa*; 33, *P. cargalensis*; 34, *P. longiseptata*; 35, *P. gerthi*; 36, *P. pseudowischeriana*; 37, *P. juresanensis*; 38, *P. gerthi* subsp. 1. Same legend is used for Figures 7, 8, and 9.


PERMIAN
CARBONIFEROUS
Asselian
Gshelian
Shihansky
Holodnologsky
Noginsky
Sphaero-schwagerina sphaerica-Pseudofusulina firma
Sphaerosch-wagerina moelleri - Pseudo-fusulina fecunda
Sphaero-schwagerina vulgaris-S. fusiformis
Daixina robusta-Ultradaixina bosbytauensis (?)
Daixina sokensis
Beds with Lophophyll-idium
Kleopatrina (K.) pseudoelegans-Tschussovskenia captiosa
Timania sp.1-Heritschioides aff. H. carneyi
Ferganophyllum ordinatum
Timania dobroljubovae
m
5.0
2.5
0


System
Stage
Horizon
Fusulinid Zones
Coral Zones
Corals
Bed
Thickness (m)
Location
Stratigraphic Column
PERMIAN
Artinskian
Sakmarian
Burtsevsky
Sterlitamaksky
Tastubsky
Pseudofusulina concavutas
Pseudofusulina urdalensis
Pseudofusulina verneuilli–P. uralica
Pseudofusulina moelleri
Protolonsdalei–astraea juresanensis
Protolonsdalei–astraea longiseptata
Protolons–daleiastraea biseptata
Timania schmidti–Kleopatrina (K.) magnifica
7h 4.7
7g 1.4
6f 1.8
5f 2.5
4f 1.7
3f .3
2f 1.2
2e 6.0
7d 4.7
6d 5.5
5d 3.1
4d 3.6
3d 2.6
2d 1.7
1d 1.2
4c 2.0
3c 1.5
2c 1.5
7b 4.5
6b 1.5
5b 2.0
43,44
42
41
39
38
37
22
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24
25
26
27
28
30
31
32
33
34
35
36
37
38
Limestone, thick-bedded
Limestone, thin-bedded
Limestone, bioclastic
Limestone, conglomerate
Limestone with chert nodules
Dolomite, thick-bedded
Dolomite, thin-bedded
Sandstone
Mudstone, calcareous
Rugose coral, colonial
Rugose coral, solitary
Rugose coral, fasciculate

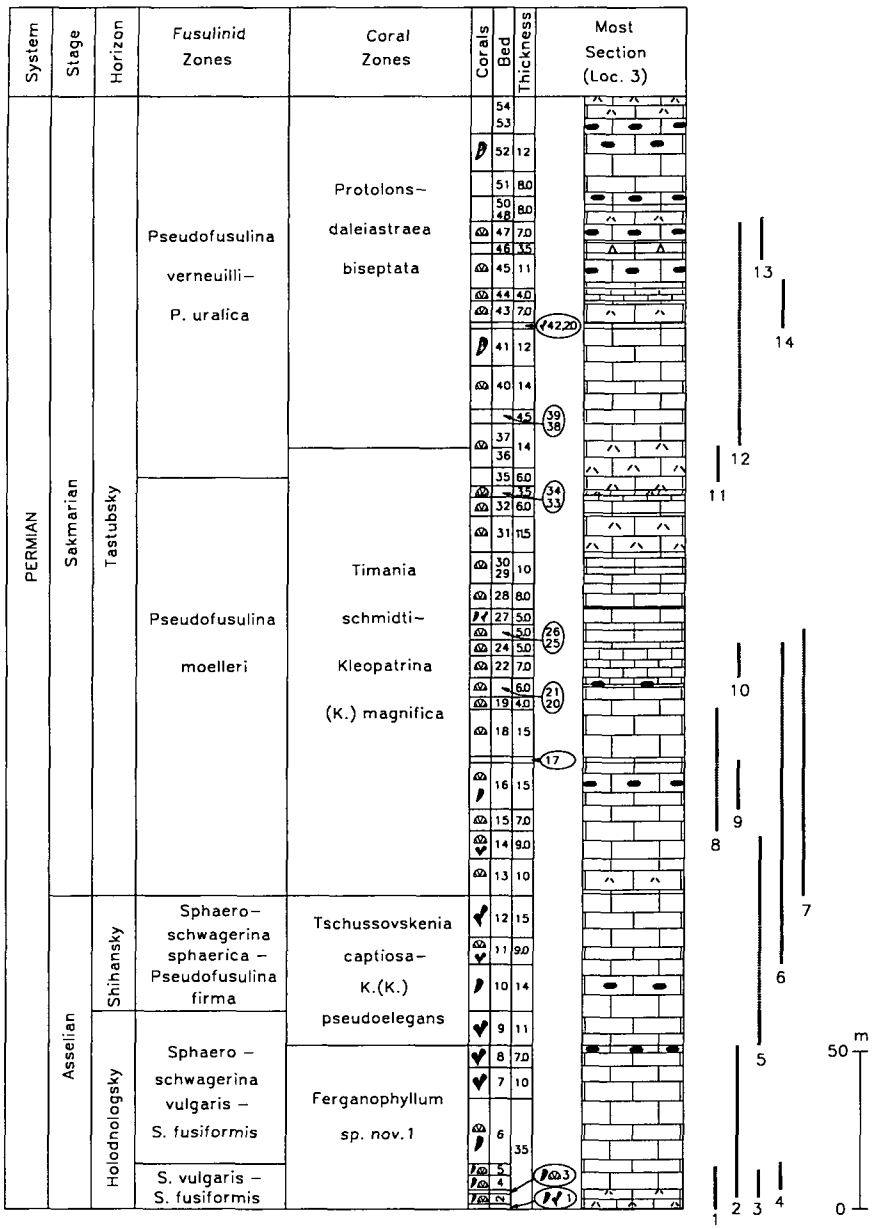

FIGURE 8—Distribution of corals in the Most section (loc. 3). 1, *Ferganophyllum* sp. aff. *F. ruprechti*; 2, *F.* sp. nov. 1; 3, *Tschussovskenia minor*; 4, *"Thysanophyllum" major*; 5, *Tschussovskenia captiosa*; 6, *"Thysanophyllum" aseptatum*; 7, *Kleopatrina* (*Porfirievella*) *stylidophylloides radiata*; 8, *"Thysanophyllum" arcticum*; 9, *Kleopatrina* (*K.*) *magnifica*; 10, *K.* (*K.*) *uralensis*; 11, *Timania schmidti*; 12, *"Orionastraea" solida*; 13, *"Orionastraea" campophylloides*; 14, *Protolonsdaleiastraea biseptata*. *Protolonsdaleiastraea pseudowischeriana* occurs in bed 56, 16.3 m above the top of bed 54.

imentary factors associated with the onset of a major transgressive cycle. This coral zone corresponds to the upper part of the *Sphaeroschwagerina moelleri-Pseudofusulina fecunda* and the *S. sphaerica-P. firma* fusulinid zones.

Timania schmidti-Kleopatrina (*K.*) *magnifica* zone

This zone is characterized by *Timania schmidti* Stuckenberg, 1895 and *Kleopatrina* (*K.*) *magnifica* (Porfiriev, in Soshkina et al., 1941), but it also contains *Kleopatrina* (*K.*) *uralensis* (McCutcheon and Wilson, 1961), *K.* (*Porfirievella*) *whitneyi* (Wilson, 1982), *K.* (*P.*) *stylidophylloides radiata* (Porfiriev, in Soshkina et al., 1941), *Protowentzelella simplex* Porfiriev, in Soshkina et al., 1941, *"Thysanophyllum" arcticum* Fedorowski, 1967, and *"T." aseptatum*. In the bioclastic limestones in the Most section (Fig. 8), along the Sula River (Fig. 7) and in the Malaja Pokajama section (Fig. 9), the base of this zone is placed below the lowest occurrence of *Kleopatrina magnifica* and species of *K.* (*Porfirievella*).

In the Most section (Fig. 8), this coral assemblage is associated with the fusulinids *Pseudofusulina sulcata* and *P. moelleri*. In the Sula River section (Fig. 7, bed 7b), the fusulinids include *Pseudofusulina paragregaria, P. sphaerica sphaerica, P. sphaerica poljarica*, and *P. timanica*. In the lower part of the 1d–7d sequence on the Sula River (Fig. 7), a small species of *Triticites* and *Pseudofusulina* aff. *P. perplexa* were reported by Remizova (1987, 1990). In the Malaja Pokajama section (Fig. 9), in beds 162–166 (Fig. 9), the fusulinids include *Occidentoschwagerina aijuvensis, Kanmeraea indigena, Pseudofusulina recondita*, and small species of *Triticites*.

This coral zone corresponds to the *Pseudofusulina moelleri* and lower *P. verneuilli-P. uralica* fusulinid zones.

Protolonsdaleiastraea biseptata zone

The corals of this zone are *Timania schmidti, Kleopatrina* (*K.*) *uralensis, K.* (*K.*) *magnifica, Protolonsdaleiastraea biseptata* (Dobrolyubova, 1936a), *P. dobroljubovae* (Minato and Kato, 1965), *P. complexa* (Dobrolyubova, 1936a), *P. cargalensis* (Dobrolyubova, in Soshkina et al., 1941), *"Orionastraea" solida* (Stuckenberg, 1895), and *"O." campophylloides* (Dobrolyubova, 1936a). The base of this zone is placed at the lowest occurrence of corals with incomplete

intercorallite walls (i.e., *Protolonsdaleiastraea* and *"Orionastraea"*). This is at the base of bed 37 in the Most section (Fig. 8), bed 5d in the Sula River section (Fig. 7), and bed 167 in the Malaja Pokajama section (Fig. 9). At the Sula River locality (Fig. 7), *Kleopatrina* (*K.*) *uralensis, Protolonsdaleiastraea biseptata, P. dobroljubovae, P. complexa, P. cargalensis,* and *Timania schmidti* are present in beds 5d–7d. The upper part of this zone contains the fusulinids *Waeringella sulaensis, Pseudofusulina indigaensis,* and *P. p[illegible]lexa.* The Malaja Pokajama section (Fig. 4, loc. 6) has yielded the corals *Timania schmidti, Kleopatrina* (*K.*) *magnifica,* and *Protolonsdaleiastraea complexa.* These corals are associated with the fusulinids *Pseudofusulina uralensis rhombiformis, P. marina,* and *P. tschernyschewi acuta.* Some difference in the coral assemblage is recorded in bioclastic limestones in beds 37–54 of the Most section (Fig. 8) where *"Orionastraea" solida, "O". campophylloides,* and *Protolonsdaleiastraea biseptata* occur with the fusulinids identified by Zolotova (1972) as *Pseudofusulina rhombiformis, P.* aff. *P. uralica,* and *P. paraverneuilli.* This coral zone corresponds in age to the upper part of the *Pseudofusulina verneuilli-P. uralica* fusulinid zone.

Protolonsdaleiastraea longiseptata zone

The corals of this zone comprise only a few colonies of *Protolonsdaleiastraea longiseptata* (Dobrolyubova, 1936b), *P. pseudowischeriana* (Porfiriev, in Soshkina et al., 1941), and *P. gerthi* (Dobrolyubova, *in* Soshkina et al., 1941). In the Most section (Fig. 8), Belaja River section (Fig. 4, loc. 16), Sula River section (Fig. 7), and Malaja Pokajama section (Fig. 9), this zone is marked by the appearance of species of *Protolonsdaleiastraea* with complicated axial structures, multitrabeculation of fine septal structures, carination of septa, and a thamnasteroid condition. In bed 2e at the Sula River section (Fig. 7), *Protolonsdaleiastraea longiseptata* and *P. gerthi* are present. In the upper part of that bed, the fusulinid *Pseudofusulina urdalensis* occurs. In the Malaja Pokajama section (Fig. 9, loc. 6) *Protolonsdaleiastraea longiseptata* and *P.* sp. are present.

In the Most section (Fig. 8), bed 56, 16.3 m above the top of bed 54, contains *Protolonsdaleiastraea pseudowischeriana* with the fusulinids *Pseudofusulina* aff. *P. plicatissima* and *P. callosa.* This shows that the *Protolonsdaleiastraea longiseptata* coral zone corresponds to the *Pseudofusulina urdalensis* fusulinid zone.

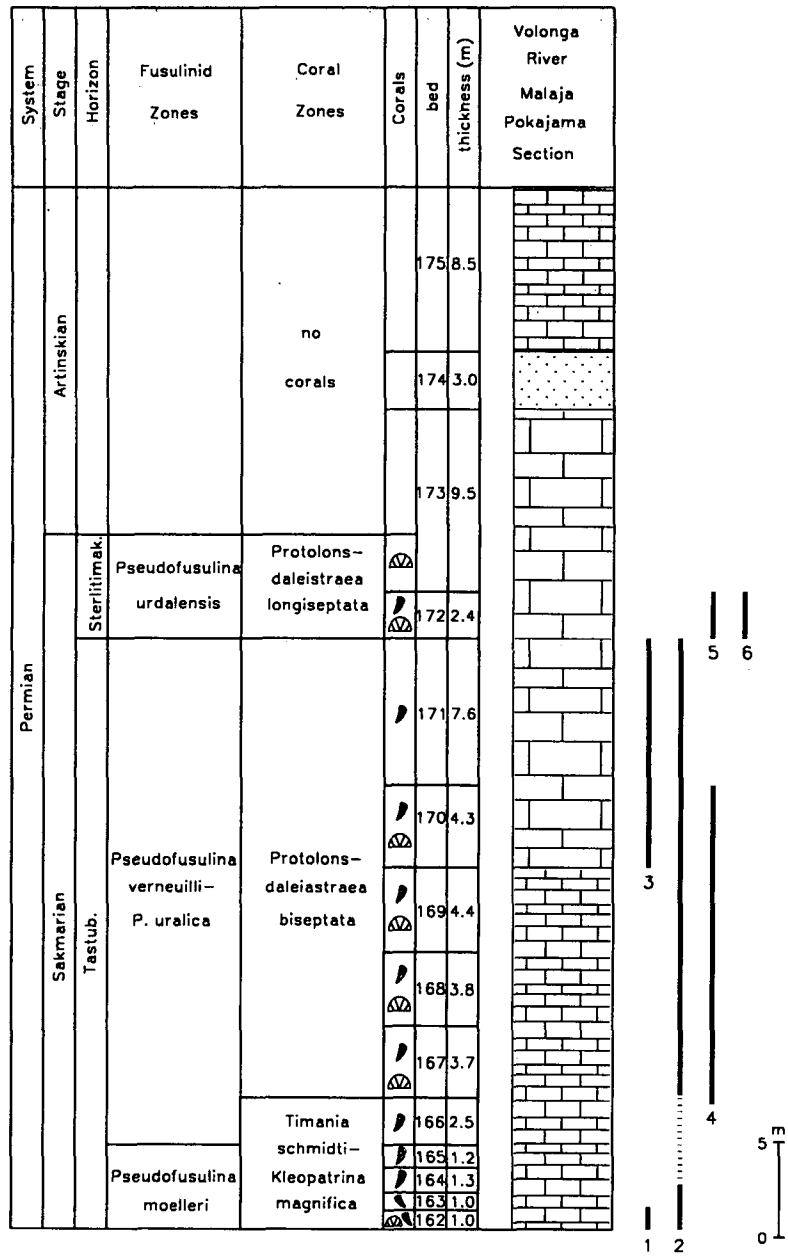

FIGURE 9—Distribution of corals in the Malaja Pokajama section (loc. 6). 1, *Kleopatrina* (*Porfirievella*) *whitneyi*; 2, *Timania schmidti*; 3, *Kleopatrina* (*K.*) *magnifica*; 4, *Protolonsdaleiastraea complexa*; 5, *P. longiseptata*; 6, *P.* sp. nov.

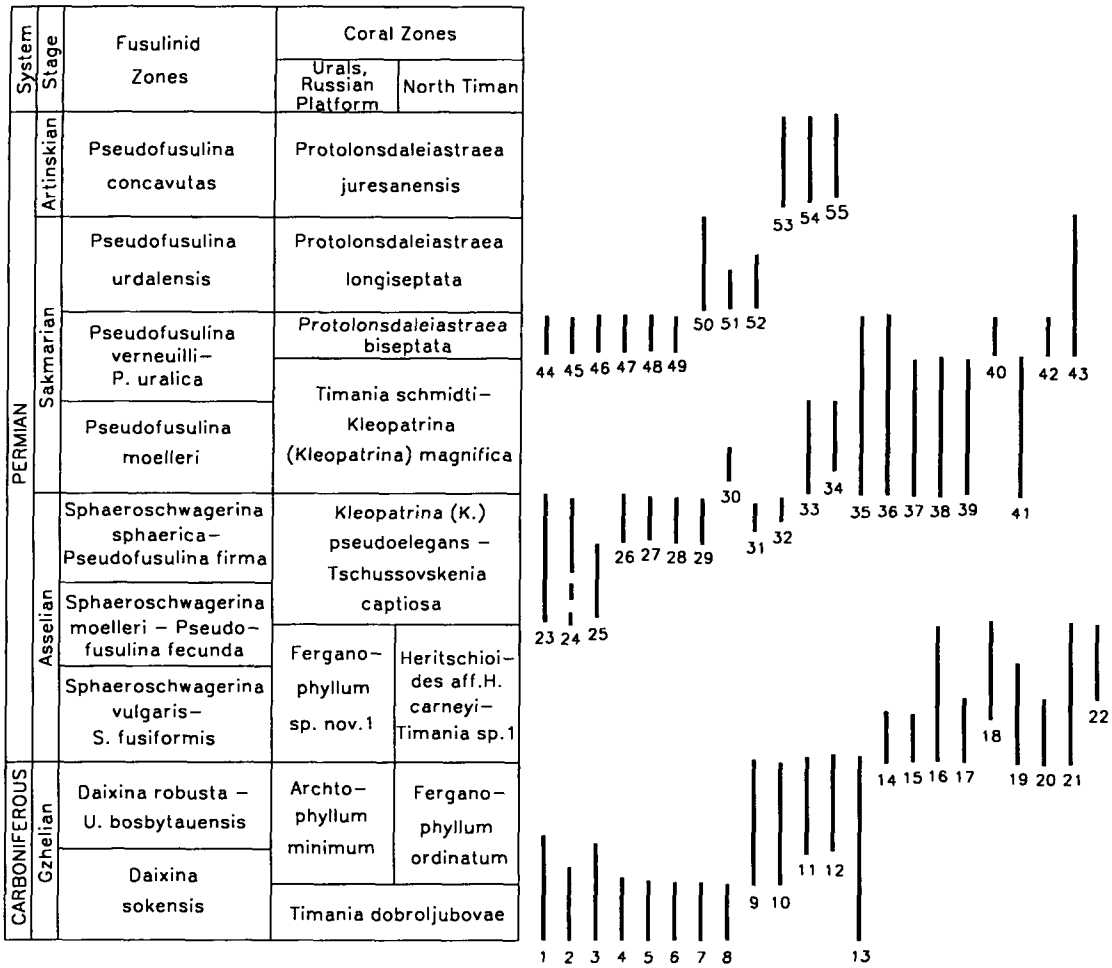

FIGURE 10—Summary of distribution of coral species in the Upper Carboniferous-Lower Permian of the Urals, Russian Platform, and north Timan. 1, *"Caninophyllum" grekae*; 2, *Arctophyllum intermedium*; 3, *Timania dobroljubovae*; 4, *Geyeronaotia multicystata*; 5, *Allotropichisma* (*Alligia*) *flabella*; 6, *Falsiamplexus delicatus*; 7, *Lophophyllidium* (*Lophophyllidium*) *wewokanum*; 8, *Pseudowannerophyllum solidum*; 9, *Arctophyllum minimum*; 10, *Ferganophyllum ordinatum*; 11, *Bothrophyllum samaraense*; 12, *Lophocarinophyllum* sp.; 13, *Gshelia rouilleri*; 14, *Tschussovskenia minor*; 15, *Ferganophyllum* sp. 2; 16, *F.* sp. nov. 1; 17, *F.* sp. aff. *F. ruprechti*; 18, *Timania* sp. 1; 19, *"Thysanophyllum" major*; 20, *Lophophyllidium* (*Lophbillidium*) sp. 1; 21, *Heritschioides* aff. *H. carneyi*; 22, *Fomichevella southeri*; 23, *Tschussovskenia captiosa*; 24, *Kleopatrina* (*K.*) *pseudoelegans*; 25, *Timania* sp. 2; 26, *Asserculinia* sp.; 27, Gen. et sp. 1 nov.; 28, *Lophophyllidium* (*Lophbillidium*) sp. 2; 29, *Lophotiochium simulatum*; 30, Gen. et sp. 2 nov.; 31, *Amplexocarinia* sp.; 32, *Actinophrentis columnare*; 33, *"Thysanophyllum" aseptatum*; 34, *"T." arcticum*; 35, *Kleopatrina* (*K.*) *magnifica*; 36, *Kleopatrina* (*K.*) *uralensis*; 37, *K.* (*Porfirievella*) *stylidophylloides radiata*; 38, *K.* (*P.*) *whitneyi*; 39, *Timania schmidti*; 40, *Protolonsdaleiastraea biseptata*; 41, *Protowentzelella simplex*; 42, *Protolonsdaleiastraea complexa*; 43, *P. densireticulata*; 44, *P. dobroljubovae*; 45, *P. cargalensis*; 46, *"Orionastraea" solida*; 47, *"O." campophylloides*; 48, *"O." breviseptata*; 49, Gen. et sp. 3 nov.; 50, *Protolonsdaleiastraea longiseptata*; 51, *P.* sp.; 52, *P. gerthi*; 53, *P. pseudowischeriana*; 54, *P. juresanensis*; 55, *P. gerthi* subsp. 1.

Protolonsdaleiastraea juresanensis zone

This zone has been recognized in the *Palaeoaplysina*-bearing limestones in the Sula River section (Fig. 7, beds 3f–7h) and on the Indiga River (Fig. 4, loc. 17). The corals are mostly integrated and the septa are carinate and multitrabecular. The assemblage comprises *Protolonsdaleiastraea juresanensis* (Dobrolyubova, *in* Soshkina et al., 1941), *P. pseudowischeriana, P. longiseptata, P.* sp. 1, and a species similar to *Stikineastraea fergusoni* (Wilson, 1982). According to Barkhatova (1970), the fusulinid *Pseudofusulina concavutas* is abundant in this zone. Thus, this coral zone is within the *P. concavutas* fusulinid zone of early Artinskian age.

Higher coral zones

Corals are rare in the upper part of the Lower Permian, occurring mainly in the lower part of the Artinskian. Species represented include *Amplexocarinia irginae* Soshkina,

		Urals & Russian platform		N. Timan	Spitsbergen	Eastern Nevada		Klamath Mts., Calif.		Glass Mts., Texas		
System	Stage	Fusulinid Zones	Coral Zones		Coral assemblages (Fedorowski, 1965, 1967; Birkenmajer & Fedorowski, 1980; Ezaki & Kawamura, 1992)	Formation	Coral Zones (Easton, 1960; Wilson & Langenheim, 1962; Stevens, 1967)	Zones of McCloud Ls.	Corals (Wilson, 1982, 1985)	Stages	Formation	Coral assemblages (Fedorowski, 1987; Ross & Ross, 1962, 1963)
PERMIAN	Art.	Pseudofusulina concavutus	Protolonsdaleiastraea juresanenis			Arcturus		H & G		Leonardian	Skinner Ranch	Lophotichium dugoutensis, Assimulia tergida, Assimulia obscessa
	Sakmarian	Pseudofusulina urdalensis	Protolonsdaleiastraea longiseptata									
		Pseudofusulina verneuilli– P. uralica	Protolonsdaleiastraea biseptata		Coral horizon 6. Protolonsdaleiastraea complexa		"Orionastraea" hudsoni					
			Timania schmidti – K. (Kleopatrina) magnifica		Coral horizons 4 – 5 K. (Kleopatrina) magnifica, K. (Porfirievella) stylidophylloides		K. (Porfirievella) arcturusensis			Wolfcampian	Lennox Hills	Lophotichium sp., Pseudowannerophyllum solidum, Lophotichium simulatum, Assimulia flexibilis
							Durhamina cordillerensis					
						Rib Hill		F	Langenheimia, K. (Kleopatrina), K. (Porfirievella)			
								E & D	Stikineastraea, K. (Porfirievella)			
		Pseudofusulina moelleri				Riepe Spring	"Thysanophyllum" princeps	C	Heritschioides, K. (Porfirievella), peggyae			
	Asselian	Sphaeroschwagerina sphaerica–Pseudofusulina firma		Lophbillidium					Heritschioides		Neal Ranch	Actinophrentis columnare, Lophotichium rotundiseptatum
		Sphaeroschwagerina moelleri – Pseudofusulina fecunda	K. (Kleopatrina) pseudoelegans–Tschussovskenia captiosa									
		S. vulgaris – S. fusiformis	Fergano-phyllum sp. nov.1	Heritschioides aff.H.carneyi-Timania sp.1	"Pseudotimania" sp.							
CARBONIFEROUS	Gzhelian	Daixina robusta – U. bosbytauensis	Arctophyllum minimum	Fergano-phyllum ordinatum				B	Gshelia, Heritschioides skinneri	Virgilian	Gaptauk w/ Uddenites	Ferganophyllum ordinatum
		Daixina sokensis	Timania dobroljubovae					A	Heritschioides aff. H. carneyi			Allotropiochisma flabella, Pseudowannerophyllum wewokanum

FIGURE 11—Correlation of Carboniferous-Permian deposits in the Cordilleran-Arctic-Uralian Realm based on coral faunas.

1932, *A. heimoi* Heritsch, 1936, *A. muralis* Soshkina, 1925, and *Ufimia rhizoides* (Soshkina, 1925). In the Upper Permian (Kazanian) of the Urals and Volga regions, corals continue to be rare. Ivanovsky (1989) reported *Paralleynia permiana* Soshkina, 1936, *Calophyllum profundum* German *in* Geinitz, 1842, *Groenlandophyllum teicherti* Flugel, 1973, *G. variabile* Soshkina, in Soshkina et al., 1941, *Sassendalia bashkirica* Ivanovsky, 1989, *Pentaphyllum hexaseptatum* (Soshkina, 1928,) and *Euriphyllum minor* Fontaine, 1961 from these beds.

Stratigraphic ranges of species

The stratigraphic ranges of all species from the base of the *Timania dobroljubovae* zone to the top of the *Protolonsdaleiastraea juresanensis* zone, based on the occurrences of corals in all the stratigraphic sections studied, are given in Figure 10. These data are the basis for intercontinental rugose coral correlations.

AGE AND CORRELATION

Numerous latest Carboniferous and Early Permian rugose corals in the Ural Mountains and Russian Platform are either present or are represented by closely related forms in Spitsbergen and North America. Therefore, it seems possible to make relatively accurate correlations between Lower Permian Stages established in Russia and those of West Texas by comparing the faunas in intermediate areas such as North Timan, Spitsbergen, eastern Nevada, and the Klamath Mountains in California (Fig. 11).

Four major changes have occurred in the general character of the coral faunas during latest Carboniferous

and Early Permian time that can be correlated intercontinentally. These changes occur at the base of the *Timania dobroljubovae* zone, the base of the *Kleopatrina pseudoelegans-Tschussovskenia captiosa* zone, the base of the *Protolonsdaleiastraea biseptata* zone, and the top of the *Protolonsdaleiastraea juresanensis* zone.

Three coral zones belong to the lowest assemblage of zones: the *Timania dobroljubovae* zone, and the *Arctophyllum minimum* and *Ferganophyllum* sp. nov. 1 zones with their analogs in Timan. These coral faunas, which embrace the upper Gzhelian and lower Asselian Stages, are characterized by an abundance of relatively simple corals including *Arctophyllum, Ferganophyllum,* and *Timania.* The two lowest coral zones differ on a specific level and the appearance of fasciculate colonies of the "cyathopside" type in the *Arctophyllum minimum* zone. The *Ferganophyllum* sp. nov. 1 zone, which also contains an abundance of small specimens of *Timania,* is marked by the appearance of massive colonies of "*Thysanophyllum*".

Corals of the *Timania dobroljubovae* zone (*Allotropiochisma* (*Alligia*) *flabella, Pseudowannerophyllum solidum, Falsiamplexus delicatus,* and *Lophophyllidium* (*Lophophyllidium*) *wewokanum*) in Russia, also are present in the *Uddenites*-bearing beds in Texas (Ross and Ross, 1962, 1963; Fedorowski, 1987). Thus, the *Uddenities*-bearing member of the Gaptank Formation is correlated with this zone. The *Arctophyllum minimum* zone is correlated with greater difficulty. The presence of *Ferganophyllum ordinatum* in Timan and in the *Uddenities*-bearing beds in Texas is the basis for the correlation of this zone with beds in North America. The cyathopsid coral in the Nordenskioldbreen Formation of West Spitsbergen, described as *Pseudotimania* sp. by Ezaki and Kawamura (1992), is similar to a small species of *Timania* in the *Heritschioides* aff. *H. carneyi-Timania* sp. 1 zone of North Timan (Kossovaya, in prep.) and is the basis for this correlation.

The second important change in the character of the coral faunas is at the base of the *Kleopatrina pseudoelegans-Tschussovskenia captiosa* zone. Above this level, coral assemblages are characterized by the predominance of the massive coral *Kleopatrina* (*Kleopatrina*), fasciculate colonies of *Tschussovskenia,* the continuation of "*Thysanophyllum*", and later, the appearance of *Kleopatrina* (*Porfirievella*). This assemblage of corals extends from the middle Asselian through much of the Sakmarian. Two coral zones are recognized in this assemblage: the *Kleopatrina pseudoelegans-Tschussovskenia captiosa* zone with the partially equivalent *Lophbillidium* zone in Timan, and the *Timania schmidti-Kleopatrina magnifica* zone.

Species similar to those in the *Lophbillidium* zone occur in the Neal Ranch and Hess Formations of Texas thereby providing a basis for correlation. The common occurrence of *Kleopatrina* (*Kleopatrina*) and "*Thysanophyllum*" in Nevada suggest that the upper part of the "*Thysanophyllum*" *princeps* zone in eastern Nevada (Easton, 1960; Stevens, 1967; Wilson and Langenheim, 1962) correlates with the *Kleopatrina pseudoelegans-Tschussovskenia captiosa* zone and the lower part of the *Timania schmidti-Kleopatrina magnifica* zone.

The base of the *Timania schmidti-Kleopatrina* (*Kleopatrina*) *magnifica* zone is marked by the first appearance of *Kleopatrina* (*Porfirievella*). In the Klamath Mountains the first occurrence of this subgenus, represented by *K.* (*P.*) *peggyae,* is in the middle part of the zone C of the McCloud Limestone (Wilson, 1982). At Hornsund, Spitsbergen, the base of coral beds 4–5 of the Treskelodden Formation is correlated with the lower boundary of the *Timania schmidti-Kleopatrina* (*Kleopatrina*) *magnifica* zone on the basis of the first appearance of *K.* (*K.*) *magnifica* and *Kleopatrina* (*Porfirievella*) *stylidophylloides* (Fedorowski, 1965, 1967; Birkenmajer and Fedorowski, 1980).

The third level at which a major change in the character of the coral assemblages occurs is at the base of the *Protolonsdaleiastraea biseptata* zone. Here, the predominant corals comprise asteroid and cerioid-asteroid colonies of the genera "*Orionastraea*" and *Protolonsdaleiastraea.* These genera, which represent the *Protolonsdaleiastraea biseptata* zone, are less complex than *Stikineastraea* and *Langenheimia* which occur below this zone in the Klamath Mountains. This would seem to demand a different phylogeny for *Langenheimia* and *Stikineastreaea.*

The *Protolonsdaleiastraea biseptata* zone is characterized by the first appearance of cerioid-asteroid and asteroid colonies of "*Orionastraea*". The diversity of *Kleopatrina* species decreases and *Tschussovskenia* and "*Thysanophyllum*" disappear. *Protolonsdaleiastraea dobroljubovae* is present in this zone and also in the Asitka Group (Stikine assemblage) in Canada (Wu and others, 1985). *Protolonsdaleiastraea complexa* is present both in Russia and coral bed 6 of the Treskelodden Formation in Spitsbergen (Birkenmajer and Fedorowski, 1980).

Asteroid colonies of the *Protolonsdaleiastraea longiseptata* zone are frequently represented by morphologically more complex forms than in the underlying zone. Walls generally are lacking, axial structures are complex, and septa are thickened and carinated (e.g., *Protolonsdaleiastraea gerthi*).

An analogue of the *Protolonsdaleiastraea juresanensis* zone may be present in the Asitka Group of Canada. The basis of this supposition is the presence of a species of *Protolonsdaleiastraea* in Canada referred to as *P.*? sp. by Wu and others (1985) with corallites having close to a thamnasteroid condition and characterized by a complex axial structure similar to that in *P. juresanensis.* The Canadian species occurs with the fusulinid *Schwagerina sustutensis.*

CONCLUSIONS

New data on the age ranges of uppermost Carboniferous and Lower Permian rugose corals show that eight zones can be recognized in Russia and that several of them can be recognized

in Spitsbergen and North America. Four very important rugose coral levels can be determined on an international scale: (1) the base of the *Timania dobroljubovae* zone, (2) the base of the *Kleopatrina* (*K.*) *pseudoelegans-Tschussovskenia* zone, (3) the base of the *Protolonsdaleiastraea biseptata* zone, and (4) the top of the *Protolonsdaleiastraea juresanensis* zone. At the end of the *P. juresanensis* zone, a major regressive cycle led to isolation and restriction of basins throughout this realm and extermination of all but the most simple rugose corals.

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