

## New data on the Serpukhovian (Carboniferous) coral assemblages from the northwestern part of the Moscow Basin (Russia)

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**ABSTRACT** - Research in two quarries of the Borovichi area near the Uglovka town (northwestern Moscow Basin) has provided several rugose and tabulate corals that improve the knowledge on the palaeontology of that area. The Zarech'e quarry yielded rare specimens of *Syringopora reticulata* and *Dibunophyllum bipartitum*, as well as common specimens of *Actinocyathus floriformis*, *A. borealis* and *A. crassiconus*. The Uglovka quarry provided also *Syringopora reticulata*, *Dibunophyllum bipartitum* but different species of colonial rugosans: *Actinocyathus* sp., *Lonsdaleia multiseptata* and *Schoenophyllum* sp. The palaeogeographical distribution of the recorded species indicates a good communication of the Eastern European Basin with western and eastern Palaeotethys during the Serpukhovian. The presence of the genus *Schoenophyllum* suggests also connection with North America, probably along the northern coast of Laurussia.

### INTRODUCTION

Mississippian rocks are well exposed in the northwestern part of the Moscow Basin. During the first half of the 20<sup>th</sup> century, many geologists worked on those rocks and described local sections (Yanishevsky, 1936; Hecker, 1938b; Sokolov, 1944) or undertook regional works (Forsch, 1935; Yanishevsky, 1937; Hecker, 1938a; Sokolov, 1941). The stratigraphy and sedimentology of the Mississippian from that area was simultaneously studied and the facies and cyclicity of the deposits were identified (Bruns, 1939).

The Serpukhovian Stage is widely represented in that region and is documented by three lithostratigraphic units: the Rovnoe Formation (Tarusian Regional Stage), the Poneretka Formation (Steshevian Regional Stage) and the Uglovka Formation (Protvian Regional Stage). Palaeontological studies allowed the identification of the fossil assemblages of that age (Mikhailov, 1939; Sokolov, 1939b; Ganelina, 1951, 1956; Pozner, 1951; Shlykova, 1951; Yanishevsky, 1954, 1960; Vostokova, 1955). Coral assemblages from those units have been largely known since that time (Stuckenbergh, 1904; Karaeva, 1935; Sokolov, 1939a; Dobrolyubova, 1958), but their knowledge was improved with the more recent taxonomic works of Hecker (1997, 2001, 2002, 2010), Poty & Hecker (2003) and Savitsky et al. (2007).

New research in two quarries in the Borovichi area, whose coral record has not been previously studied in detail, has provided several rugose and tabulate corals, as well as chaetetids, that improve the knowledge on the regional palaeontology. Chaetetids from Uglovka quarry were figured by Sokolov (1950, pl. XVIII, figs 3-4).

The Zarech'e quarry is located 7.8 km south-west from Uglovka town (Fig. 1) and contains marly limestones belonging to the upper part of the Poneretka Formation. The coral assemblage from that quarry shows

a low diversity. It is composed of rare specimens of the tabulate genus *Syringopora* and the solitary rugosan *Dibunophyllum bipartitum* (McCoy, 1849) and common specimens of the colonial rugosan genus *Actinocyathus*. Within the last genus, there are representatives of two different species groups, *A. floriformis* (Martin, 1809) and *A. crassiconus* (McCoy, 1849).

The Uglovka quarry is located 4 km south-east of Uglovka town (Fig. 1) and contains limestones and dolostones belonging to the Uglovka Formation that provided corals from two different beds (Fig. 2, units 2 and 6). Previous sampling in that quarry (Savitsky et al., 2007, 2015) yielded *Corwenia densivesiculosa* Dobrolyubova, 1958 in the lower beds. The Uglovka assemblage recorded herein is composed of common tabulate corals belonging to the genus *Syringopora*, rare solitary rugosans of the genus *Dibunophyllum* and frequent colonial rugosans of the genera *Actinocyathus*, *Lonsdaleia* and *Schoenophyllum* in the lower beds and *Syringopora* in the upper beds. Chaetetids are common in both units.

The Zarech'e quarry contains a rich foraminiferal assemblage, with the remarkable occurrence of *Brenckleina rugosa* (Brazhnikova, 1964) and the narrow form of *Eostaffellina paraprotvae* (Rauser-Chernousova, 1948), both suggesting a Serpukhovian age. Samples of the Uglovka quarry contain more evolved assemblages, with common large and rounded forms of *Eostaffellina*, including *E. actuosa* Reitlinger, 1963 and *E. protvaeensis* Gibshman, 2019 which allow to assign the succession to the late Serpukhovian.

### CORAL ASSEMBLAGES

All specimens mentioned below are housed in the All-Russian Geological Survey Institute VSEGEI.

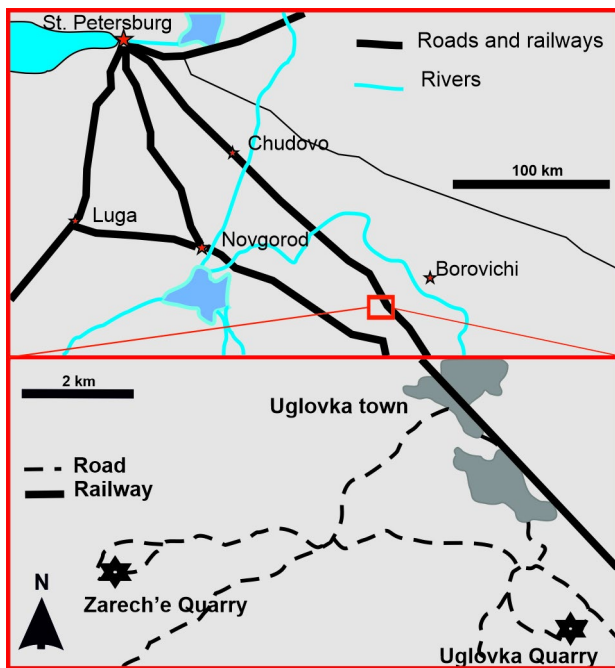


Fig. 1 - (color online) Location map of the studied quarries.

#### Zarech'e quarry

The assemblage in the Zarech'e quarry is quite impoverished, mainly due to difficult conditions of sampling because of limited accessibility, but also to taphonomic processes. Corals are commonly fragmented and eroded, but large pieces of colonies are preserved.

One single specimen of a solitary coral has been collected (ZAR-14). It is eroded and lacks the apex and part of the calice. Most part of the dissepimentarium is absent by abrasion and the specimen is partly silicified. It belongs to *Dibunophyllum bipartitum* and shows all characteristic features of the species (Fig. 3a).

Three specimens of syringoporoids have been recorded in Zarech'e, from which only one has been sectioned (ZAR-3) because the other two are not well preserved. It is a fragment of a colony and belongs to *Syringopora reticulata* Goldfuss, 1826. The specimen from the Zarech'e quarry, as well as several specimens from that species recorded in the Uglovka quarry (Fig. 3b) have most typical features of the species (axial syrinx, common septal spines, common connecting tubuli and thick lamellar wall, about 0.2-0.25 mm). The diameter of the studied specimens is larger than the typically described (2-2.5 mm against 1.5-2 mm), but no other *Syringopora* species fits with the features of our specimens (Chudinova, 1986; Coronado & Rodríguez, 2014).

Six fragments of colonies belonging to the genus *Actinocyathus* have been recorded in the Zarech'e quarry. Two groups of species of *Actinocyathus* have been distinguished in the Moscow Basin, the *A. crassiconus* group having long minor septa, and the *A. floriformis* group having short or absent minor septa (Hecker, 1997). Both groups are present in Zarech'e. Four specimens have short septa (*A. floriformis* group, ZAR-5, 9, 10, 15). Two of them, ZAR-5 and ZAR-15 bear all diagnostic features of the nominal species (Fig. 3c), but ZAR-9 and ZAR-10 show lower number of septa, smaller tabularium and a

smaller and simpler axial structure (Fig. 3d) and belong to *A. borealis* of the same species group (Poty & Hecker, 2003).

Two specimens of massive lonsdaleiinae with long minor septa have been recorded in the Zarech'e quarry. Both can be assigned to *Actinocyathus crassiconus*, based on the long minor septa, 25-27 major septa, tabularium diameter 6-7 mm, 15-20 radial lamellae in the axial structure.

#### Uglovka quarry

Corals are by far more abundant and slightly more diverse in the Uglovka quarry than in the Zarech'e quarry. Both quarries have some species in common; *Syringopora reticulata* is common, both in units 2 and 6 and *Dibunophyllum bipartitum* which in Uglovka quarry occurs only in unit 2. Seven specimens have been recorded there (UGL2-4, 2-7, 2-12, 2-20, 2-21, 2-22, 2-32B) (Fig. 3a).

In contrast, most colonial lonsdaleiinae are different from the Zarech'e quarry. Four fragments of fasciculate lonsdaleiinae recorded in the Uglovka quarry (UGL2-20, 2-28, 2-31, 2-33) have been identified as *Lonsdaleia multiseptata* Dobrolyubova, 1958 (Fig. 3f). They fit well with all features of the species (about 25-28 septa, well developed minor septa and regular axial structure), but they are slightly smaller than the types described by Dobrolyubova (1958), 9-14 mm against 13-17 mm in tabularium diameter.

Massive lonsdaleiinae are more common, but show poor preservation. Thirteen small fragments of colonies have been recorded (UGL2-8, 2-9, 2-10, 2-13, 2-14, 2-16, 2-18, 2-23, 2-25, UGL9-7, 9-8, 9-10, 9-11) but only four have been sectioned (UGL2-8, 2-10, 2-18, 2-23) (Fig. 3g). Unluckily, all of them show common features that do not fit with any described species. They have short minor septa, which implies that they belong to the species group of *Actinocyathus floriformis*. The axial structure is large and has few radial lamellae (five to ten), and it is similar to *A. lativesiculosus* (of the *A. crassiconus* group), but neither the minor septa nor the dimensions fit with that species. The only species that has comparable dimensions and number of septa is *A. bronni* (Milne-Edwards & Haime, 1851) which has a more complex axial structure, with more radial lamellae and axial tabellae. In addition, none of the cited species fit with the age. The only species registered in the Moscow Basin in the Protvian are *Actinocyathus crassiconus*, *A. gorskyi* (Dobrolyubova, 1958), *A. floriformis*, *A. borealis* (Dobrolyubova, 1958) and *A. ornatus* (Dobrolyubova, 1958) (Hecker, 1997). None of them has similar features to the studied specimens. *A. ornatus* has a similar axial structure, but bears long septa, a smaller size and has fewer septa. Consequently, we leave these specimens in open nomenclature as *Actinocyathus* sp. because the material is not well preserved to erect a new species. But it means that the variety of species in the Serpukhovian from Moscow basin could be higher than known to date.

One single specimen of fasciculate petalaxid coral has been recorded in the Uglovka quarry (Fig. 3h). The sample was collected by E. Poty during a field trip of the X International Symposium on Fossil Cnidaria and Porifera and it was kindly given to one of us (SR). The genus

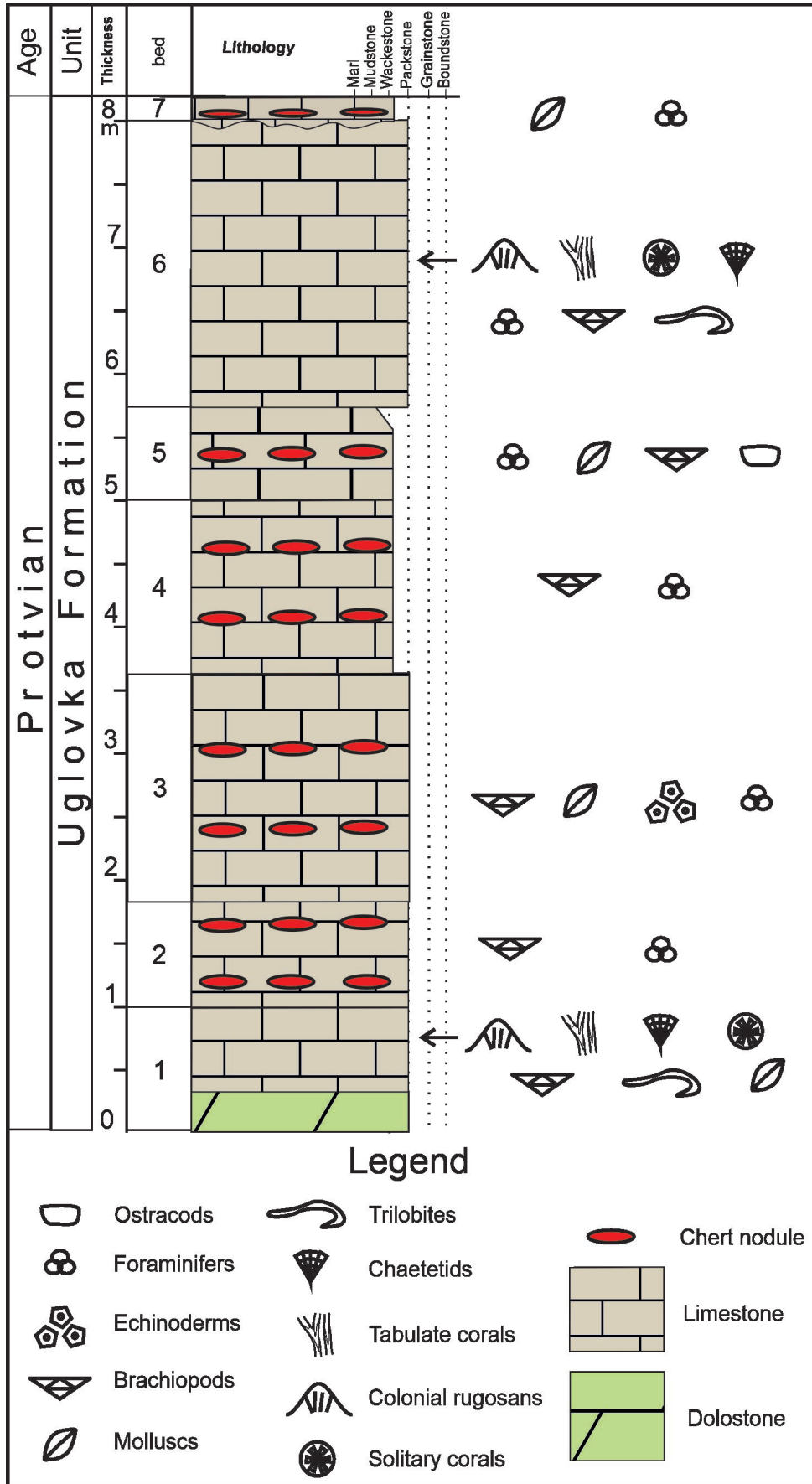


Fig. 2 - (color online) Stratigraphic section at Uglovka quarry (based on Savitsky et al., 2007). The arrows show the location of the samples.

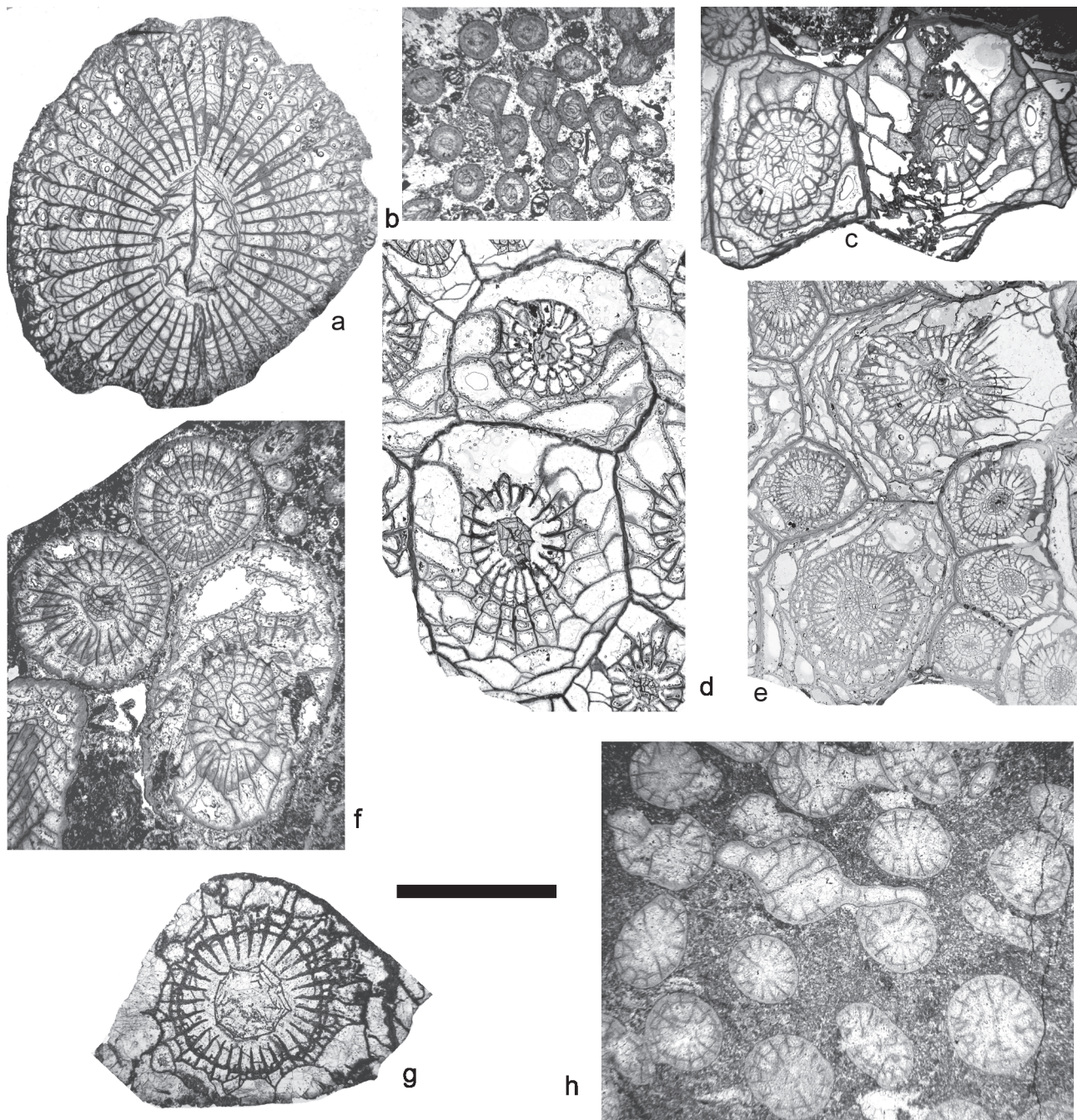


Fig. 3 - Corals recorded in the Zarech'e and Uglovka quarries. a) *Dibunophyllum bipartitum*, specimen UGL2-32B. b) *Syringopora reticulata*, specimen UGL2-29. c) *Actinocyathus floriformis*, specimen ZAR-5. d) *Actinocyathus borealis*, specimen ZAR-10. e) *Actinocyathus crassiconus*, specimen ZAR-7. f) *Lonsdaleia multiseptata*, specimen UGL2-28. g) *Actinocyathus* sp., specimen UGL2-10. h) *Schoenophyllum* sp., specimen UGL2-27. Scale bar is equal to 10 mm.

*Schoenophyllum* Simpson has been mostly recorded in the uppermost Viséan and Serpukhovian from North America (Bamber et al., 2017). Rodríguez & Bamber (2010) expanded its distribution to the East European Platform when synonymising it with the genus *Paralithostrotion*, which is regarded as a guide fossil for the Serpukhovian in the East European Platform and Urals (Hecker, 2001). Another similar genus, *Tschernowiphyllum* Dobrolyubova was also discussed as being very close to *Schoenophyllum*, but clearly different by the presence of a double elongation of the counter and cardinal septa (Bamber et al., 2017).

The specimen from the Uglovka quarry shows several features typical of *Schoenophyllum*, such as fasciculate colonies, thin septa, scarce and irregular dissepiments, complete concave tabulae, irregular axial structure linked to the cardinal septum and lateral increase with unusual offsetting. However, it differs from species of *Paralithostrotion* recorded in the Eastern European Platform (*P. sarmentosa* [Lonsdale, 1845], *P. jermolaevi* Gorsky, 1938 and *P. talkaense* Rakshin, 1965). It shows low development of the axial structure, which is absent in many cases. Some corallites show elongation of the

counter septum as well as that of the cardinal septum, showing intermediate features between *Schoenophyllum* and *Tschernowiphyllum*. It could prove the hypothesis of Rakshin that both should be put in synonymy or more simply, that both are closely related and the specimen from Uglovka is a transitional form. As the specimen from Uglovka does not allow to assign it to any known species, and because it is a single fragment of a colony, we leave it in open nomenclature.

## DISCUSSION

The assemblage from the Zarech'e quarry is dominated by colonial corals and chaetetids. All the identified species have been previously recorded in the Serpukhovian. The depositional environment was a littoral or sublittoral carbonate platform, which coincides with the main environmental requirements of *Actinocyathus crassiconus* (Hecker, 1997).

*Dibunophyllum bipartitum* is one of the most broadly distributed rugose coral in the upper Viséan and Serpukhovian. It has been widely recorded in the whole Palaeotethys from Japan in the east (Minato & Kato, 1974) to the British Isles and North Africa in the west (Semenoff-Tian-Chansky, 1985; Jones & Somerville, 1996). It has been regarded as a marker of the upper Asbian to Arnsbergian and equivalent regional substages in China (Wang, 1989), in the Urals (Sayutina, 1973), in the Moscow Basin (Altmark, 1978), in Poland (Fedorowski, 1968; Khoa, 1977), in Belgium (Poty, 1994), in Britain (Mitchell, 1989), in France (Perret & Semenoff-Tian-Chansky, 1971), in Spain (Rodríguez et al., 2016) and in North Africa (Aretz, 2011; Said et al., 2013). It has not been recorded outside the Palaeotethys so far in North

America or Australia (Fig. 4). However, this species has been also reported in Bashkirian rocks from Arctic Canada (Fedorowski et al., 2012) and Tindouf Basin in North Africa (Rodríguez et al., 2013), where it survived the coral extinctions that occurred during the Serpukhovian. Its maximum geographical expansion took place at the top of the Viséan. So, its occurrence in the Serpukhovian coincides with the declining of the species.

*Syringopora reticulata* is very common in the Tournaisian-lower Viséan from central and western Palaeotethys (Carruthers, 1910; Gorsky, 1935; Dobrolyubova et al., 1966; Chudinova, 1986; Ogar, 2003), but it has been also cited in the upper Viséan-Serpukhovian from Russia (Sokolov, 1950) and Japan (Minato, 1975) (Fig. 4).

*Actinocyathus floriformis* is widely distributed in the western and central Palaeotethys. It has been described in the British Isles (McCoy, 1849; Smith, 1916; Hill, 1940; Mitchell, 1989), in Belgium (Poty, 1981), in France (Poty & Hecker, 2003), in Morocco (Rodríguez et al., 2013), in Poland (Khoa, 1977), in the Moscow Basin (Dobrolyubova, 1958; Hecker, 1997), in the Urals and Novya Zemlya (Gorsky, 1938, 1948). It has been also doubtfully mentioned in China (Yü et al., 1983). It appeared in Western Europe in the late Viséan, migrated to eastern basins also in the late Viséan and evolved to several species in the East European Platform during the latest Viséan and Serpukhovian (Hecker, 1997; Poty & Hecker, 2003). It reached its maximum expansion during the Serpukhovian, when it migrated north-east (Urals, Novya Zemlya) and south-west (North Africa) (Fig. 4). It has been recorded previously in the surroundings of the Uglovka town (Dobrolyubova, 1958).

*Actinocyathus borealis* is a result of the evolution of *A. floriformis* during the Serpukhovian and it is located only

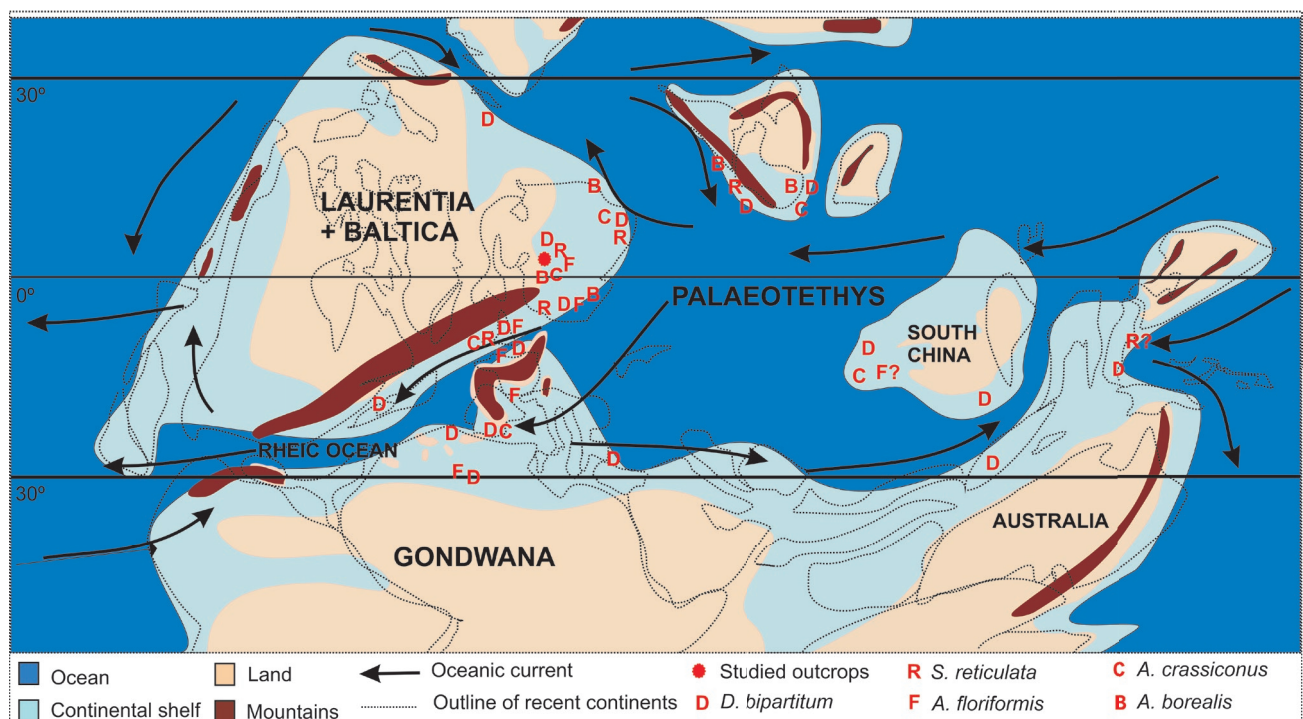


Fig. 4 - (color online) Palaeogeographical distribution of corals recorded in the Zarech'e quarry.

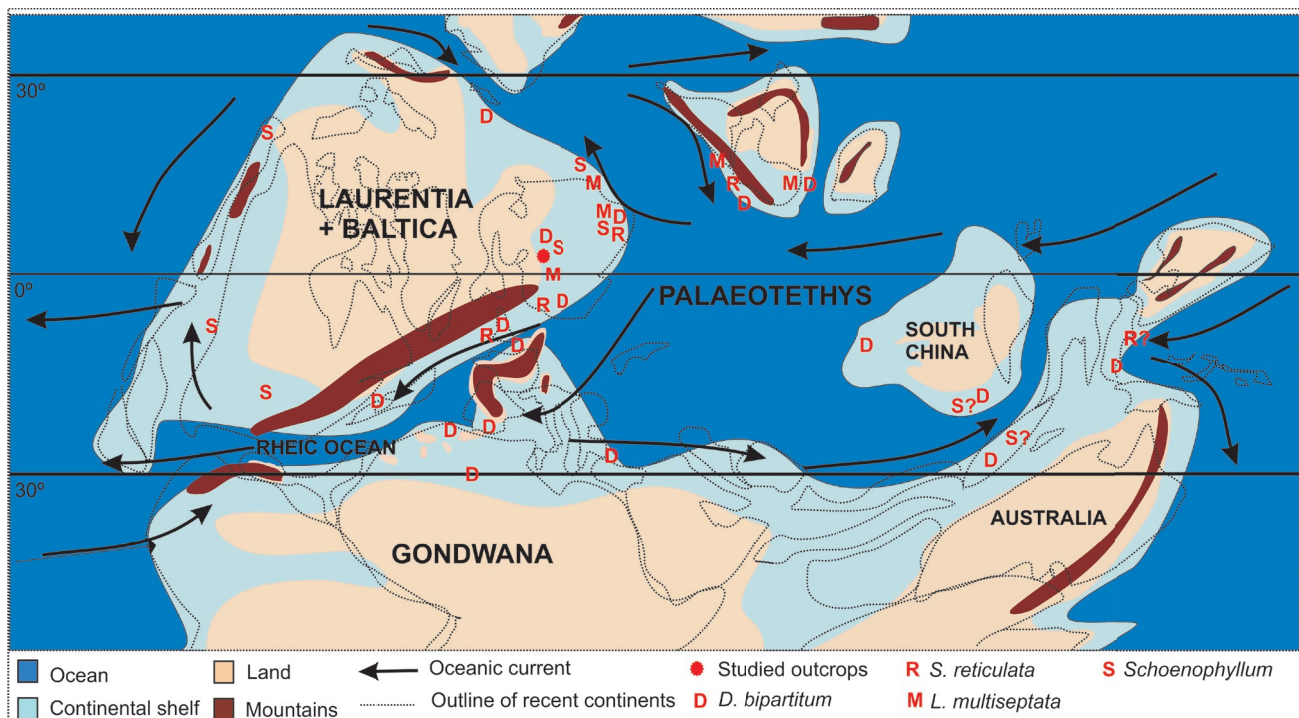


Fig. 5 - (color online) Palaeogeographical distribution of corals recorded in the Uglovka quarry.

in the north-central Palaeotethys, being common in the region of the Msta River (Dobrolyubova, 1958; Savitsky et al., 2007). It reached its maximum abundance during the Steshevian substage.

*Actinocyathus crassiconus* appeared in the western Palaeotethys during the late Viséan (British Isles; Smith, 1916; Poty & Hecker, 2003) and migrated to the east into the Eastern European Platform, where it evolved to form several closely related species (Hecker, 1997, 2010; Poty & Hecker, 2003) and persisted up to the Protvian substage. It has been also cited in south Spain (Herbig, 1986), Belgium (Conil et al., 1991), Tataria (Altmark, 1975) and China (Fan, 1978).

The palaeogeographical distribution of the species recorded in Zarech'e indicates that the assemblage is typical from the western and central Palaeotethys, and some of the species could also reach the eastern and southern Palaeotethys migrating along the margins of that ocean (Fig. 4).

The assemblage in the Uglovka quarry is dominated by chaetetids and colonial lonsdaleiinae, but solitary corals and tabulates are also common. As the distribution of *Dibunophyllum bipartitum* and *Syringopora reticulata* has been discussed in the Zarech'e assemblage, it is not developed here.

*Lonsdaleia multiseptata* has been recorded only in the East European Basin (Dobrolyubova, 1958). It has been previously cited in the vicinity of the Uglovka town (Dobrolyubova, 1958).

Several specimens belong to a species previously not described. It is not formally introduced here because of the incompleteness of the recorded specimens.

The genus *Schoenophyllum* has been documented in the Viséan and Serpukhovian from North America (Bamber et al., 2017) and in the Serpukhovian from central

Palaeotethys (Gorsky, 1938; Rakshin, 1965). Several species have been described in the Pennsylvanian from China (*Paralithostrotion huanglongense* Yu, 1991; *P. huanjiangense* Xu in Jia et al., 1977; *P. jiangsuense* Yu, 1980; *P. minor* Fan, 1978). All those species show most typical features of the genus, but none of the checked figures show its typical offsetting. It leaves in doubt if the Chinese species belong to another closely related petalaxid. *P. ceriodium* Xu, in Jia et al., 1977 is cerioid and it is not a true *Paralithostrotion*.

The assemblage from Uglovka quarry reveals that at least two species have not been previously described, indicating a certain degree of endemism in the Protvian of the Eastern European Basin. In addition, it confirms that in spite of many years of studies on corals from that region, the variety of species in the Serpukhovian from the Eastern European Basin could be higher than known to date, as pointed out by Hecker (2010), who described two new species of *Actinocyathus* from the southern Moscow Basin.

The palaeogeographical distribution of the species recorded in Uglovka indicates a higher degree of endemism than in the Zarech'e quarry. However, the presence of a petalaxid close to the genus *Schoenophyllum* indicates a palaeogeographic connection with North America. *Schoenophyllum* is recorded in the upper Viséan and Serpukhovian from Mid-Centroid, Western Interior and the Rockies (Bamber et al., 2017) and also in the Eastern European Basin (Fig. 5). The migration route should be along the north of Laurentia, because that genus is not recorded in the western and southern Palaeotethys. But the presence of *Schoenophyllum* in lower beds in other areas of the Eastern European Basin (Gorsky, 1938; Rakshin, 1965) indicates that such a migration occurred earlier during the Serpukhovian. The occurrences in

eastern Palaeotethys are doubtful (see above), but the communication along the northern and southern coast of the Palaeotethys is proved by the presence of other species (*Syringopora reticulata*, *Dibunophyllum bipartitum*, etc.).

## CONCLUSIONS

The study of the coral assemblages from two quarries in the surroundings of the Uglovka village (northwestern Moscow Basin) yielded two different assemblages. The assemblage in the Zarech'e quarry is composed of *Syringopora reticulata*, *Dibunophyllum bipartitum*, *Actinocyathus floriformis*, *A. borealis* and *A. crassiconus*. The assemblage in the Zarech'e quarry is composed of *Syringopora reticulata*, *Dibunophyllum bipartitum*, *Actinocyathus* sp., *Lonsdaleia multiseptata* and *Schoenophyllum* sp.

The age of the rocks at the Zarech'e and the Uglovka quarry is Serpukhovian.

The assemblages from both quarries indicate that the degree of endemism increased during the Serpukhovian in the Eastern European Basin. During the sedimentation of the rocks recorded in the Zarech'e quarry there was clear communication with western, southern and eastern Palaeotethys. Later, the increase in endemism indicates that communication was reduced, but still active.

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## REFERENCES

- Altmark M.S. (1975). Ecological features and living conditions of corals in the early Carboniferous basin of Tataria. *Transactions of the Institute of Geology and Geophysics, Academy of Sciences USSR (Siberian Branch)*, 2: 37-47, 124-129, 180-194. [in Russian]
- Altmark M.S. (1978). The significance of corals in the correlation of sections from the Lower Carboniferous. *The Stratigraphy and Paleontology of the Eastern Part of the Russian Platform*. Kazan University Publishers, Kazan: 113-118. [in Russian]
- Aretz M. (2011). Corals from the Carboniferous of the central Sahara (Algeria): the collection "Marie Legrand-Blain". *Geodiversitas*, 33: 581-624.
- Bamber E.W., Rodríguez S., Richards B.C. & Mamet B.L. (2017). Uppermost Viséan and Serpukhovian (Mississippian) rugose corals and biostratigraphy, Canadian Cordillera. *Palaeontographica Canadiana*, 36: 1-169.
- Brazhnikova N.E. (1964). On the study of *Eosigmoilina* from the Lower Carboniferous of the Greater Donets Basin. *In Material on the Upper Palaeozoic Fauna of the Donets Basin. Akademiya Nauk Ukrainskoi SSR, Trudy Instituta Geologicheskikh Nauk, Seriya Stratigrafii i Paleologii*, 48: 3-15. [in Russian]
- Bruns E.P. (1935). The lithology of the sandy-clay unit of C<sub>1</sub><sup>hm</sup> of Borovichi district. *Izvestia Leningrad geologo-gidrogeodezich tresta*, 2-3: 52-64. [in Russian]
- Carruthers R.G. (1910). On the evolution of *Zaphrentis delanouei* in Lower Carboniferous times. *Quarterly Journal of the Geological Society of London*, 66: 523-538.
- Chudinova I.I. (1986). The composition, system and phylogeny of fossil corals. Order Syringoporida. *Trudy Paleontologicheskii Institut*, 216: 1-204. [in Russian]
- Conil R., Groessens E., Laloux M., Poty E. & Tourneur F. (1991). Carboniferous guide foraminifera, corals and conodonts in the Franco-Belgian and Campine basins. Their potential for widespread correlation. *Courier Forschungsinstitut Senckenberg*, 130: 15-30.
- Coronado I. & Rodríguez S. (2014). Carboniferous auloporids from the Iberian Peninsula: palaeoecology, diversity, and spatio-temporal distribution. *Journal of Iberian Geology*, 40: 61-85.
- Dobrolyubova T.A. (1958). Lower Carboniferous colonial tetracorals of the Russian platform. *Trudy Paleontologicheskogo Instituta, Akademiya Nauk SSSR*, 70: 1-224. [in Russian]
- Dobrolyubova T.A., Kabakov N.V. & Sayutina T.A. (1966). Lower Carboniferous corals from the Kuznetsk Basin. *Trudy Paleontologicheskii Instituta*, 3: 1-276. [in Russian]
- Fan Y.N. (1978). Subclass Rugosa. *In Atlas of fossils of Southwest China, Chengdu Institute of Geology and Mineral Resources, Sichuan Volume, Part II, Carboniferous to Mesozoic: 149-210, 620-631. [in Chinese]*
- Fedorowski J. (1968). Upper Viséan Tetracoralla from some borings in the Lublin Coal measures (Poland). *Acta Palaeontologica Polonica*, 13: 203-217.
- Fedorowski J. (1981). Carboniferous corals: distribution and sequence. *Acta Palaeontologica Polonica*, 26: 87-160.
- Fedorowski J., Bamber E.W. & Baranova D.V. (2012). An unusual occurrence of Bashkirian (Pennsylvanian) rugose corals from the Sverdrup Basin, arctic Canada. *Journal of Paleontology*, 86: 979-995.
- Forsh N.N. (1935). New data on the structure of the Okian deposits of the Borovichi and Tikhivian districts and significance of this issue for problem for C1. *Izvestia of Leningrad Geologo-gidrogeodezich. tresta*, 2-3: 18-33. [in Russian]
- Ganelina R.A. (1951). Eostaffells and Millerells of the Viséan and Namurian of the western part of the Moscow basin. *Sbornik statei*: 179-210. [in Russian]
- Ganelina R.A. (1956). Foraminifers of the Viséan deposits of the northwestern regions of the Moscow Basin. *Trudy VNGRI, Nova Seriya*, 98: 61-183.
- Gibshman N.B. (2019). Morphological evolution and detailed biostratigraphy of *Eostaffellina* Reitlinger, 1963 (Foraminifera) in the Serpukhovian stage of the Moscow Basin. *In Bogdanova T.N., Brugrova E.M., Vuks V.Ya., Gabrilova V.A., Evdokimova I.O., Ivanov A.O., Kossovaya O.L., Modzalevskaya T.L., Oshurkova M.V., Popov E.V., Raevskaya E.G., Sapelko T.V., Suyarkova A.A., Tesakov A.A., Titov V.V., Tomacheva T.Yu. & Yanina T.A. (eds), Morphologic evolution and stratigraphical problems; Season LXV Palaeontological Society, St. Petersburg 2019. All-Russian Geological Survey Institute, St. Petersburg: 39-41. [in Russian]*
- Goldfuss A. (1826). *Petrefacta Germaniae*, Arnz & Co. Düsseldorf, 1: 1-76.
- Gorsky I.I. (1935). Some Coelenterata from the Carboniferous beds of Novaya Zemlya. *Trudy Arktiki Instituta*, 28: 1-128. [in Russian]
- Gorsky I.I. (1938). Carboniferous corals of Novaya Zemlya. *In Nalivkin D.V. (ed.), Paleontology of the Soviet Arctic. Vsesoyuznyi Arkticheskii Institut, Souz Sovetskykh Socialisticheskikh Respublik*, 93: 7-221. [in Russian]
- Gorsky I.I. (1948). Stratigraphic significance of rugose corals on the example from the upper Paleozoic coral fauna from Urals. *Vsesoiuznyi nauchno-issled geologicheskii institute. Materialy paleontologii i stratigrafia*, 5: 104-119. [in Russian]
- Hecker M. (2001). Lower Carboniferous (Dinantian and Serpukhovian) rugose coral zonation of the East European Platform and Urals, and correlation with Western Europe. *Bulletin Tohoku University Museum*, 1: 298-310.
- Hecker R.F. (1938a). The organization of the palaeogeological study of the lower Carboniferous deposits of the Leningrad district.

- Materialy po regional'noi i prikladnoi geologii Lenoblasti i Karelskoi Avtonomnaya Sovetskaya Socialisticheskaya Respublika*, 2: 3-15. [in Russian]
- Hecker R.F. (1938b). Section of the "unit of alternation (a)" Oka Formation of the Lower Carboniferous along the Msta River. *Materialy po regional'noi i prikladnoi geologii Lenoblasti i Karelskoi Avtonomnaya Sovetskaya Socialisticheskaya Respublika*, 2: 15-22. [in Russian]
- Herbig H.-G. (1986). Rugosa und Heterocorallia aus Oberviseé-Geröllen der Marbella-Formation (Betsche Kordillere, Südspanien). *Paläontologische Zeitschrift*, 60: 189-225.
- Hill D. (1938-41). A monograph on the Carboniferous rugose corals of Scotland. 213 pp. Palaeontographical Society, London.
- Jia H., Xu S., Kuang G., Zhang B., Zuo Z. & Wu J. (1977). Class Anthozoa. In *Paleontological atlas of the central South China Region (2)*. Hubei Provincial Geological Science Research Institute: 109-270, 675-742, 763-789. [in Chinese]
- Jones G.L. & Somerville I.D. (1996). Irish Dinantian biostratigraphy: practical application. In Strogon P., Somerville I.D. & Jones G.L. (eds), *Recent Advances in Lower Carboniferous Geology. Geological Society of London, Special Publication*, 107: 371-385.
- Karaeva M.V. (1935). Significance of the coral fauna for the stratigraphy of the Lower Carboniferous of the Leningrad District. *Leningradskiy geologo-gidrogeodezicheskyy Trest*, 2-3: 36-38. [in Russian]
- Khoa N.D. (1977). Carboniferous Rugosa and Heterocorallia from boreholes in the Lublin region (Poland). *Acta Palaeontologica Polonica*, 22: 301-404.
- Lonsdale W. (1845). Description of some Palaeozoic Corals of Russia. In Murchison R.I., de Verneuil E. & von Keyserling A., *The Geology of Russia in Europe and the Ural Mountains*: 591-634.
- Martin W. (1809). Petrificata derbiensia, or Figures and Descriptions of Petrifications collected in Derbyshire. D. Lyon (Wigan): 1-102.
- McCoy F. (1849). On some new genera and species of Palaeozoic corals and Foraminifera. *Annals and Magazine of Natural History, Series 2*, 3: 1-20, 119-136.
- Mikhailov A.V. (1939). About Palaeozoic Ammodiscidae. Lower Carboniferous deposits of the northwestern part of the Moscow Basin. *Sbornik Leningradskogo Geologicheskogo Upravleniya*, 3: 47-62. [in Russian]
- Milne-Edwards H. & Haime J. (1851). Monograph de Polypiers fossiles des terrains palaeozoïques, précédée d'un tableau général de la classification des polypes. *Archives Muséum Histoire Naturelles Paris*, V: 1-502.
- Minato M. (1975). Japanese Palaeozoic corals. *Journal of the Geological Society of Japan*, 81: 103-126.
- Minato M. & Kato M. (1974). Upper Carboniferous corals from the Nagaiwa series, Southern Kitakami Mountains, NE Japan. *Journal of the Faculty of Science Hokkaido University. Series IV. Geology and Mineralogy*, 16: 43-119. [in Japanese]
- Mitchell M. (1989). Biostratigraphy of Viséan (Dinantian) rugose coral faunas from Britain. *Proceedings of the Yorkshire Geological Society*, 47: 233-247.
- Ogar V. (2003). Corals (rugosa and tabulata) at the Tournaisian-Viséan boundary of median Tien Shan. *Berichte der Institut von Geologie und Paläontologie der Universität Graz*, 7: 76.
- Perret M.-F. & Semenoff-Tian-Chansky P. (1971). Coralliaires des calcaires carbonifères d'Ardengost (Hautes-Pyrénées). *Bulletin de la Société d'Histoire naturelle de Toulouse*, 107: 567-594.
- Poty E. (1981). Recherches sur les Tétracoralliaires et les Hétérocoralliaires du Viséan de la Belgique. *Mededelingen Rijks Geologische Dienst*, 35: 1-161.
- Poty E. & Hecker M.R. (2003). Parallel evolution in European rugose corals of the genus *Lonsdaleia* McCoy, 1849 (Lower Carboniferous). *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique. Sciences de la Terre*, 73: 109-135.
- Poty P. (1994). Nouvelles précisions sur les corrélations stratigraphiques du Dinantien du Boulonnais et de la Belgique: application de la biozonation corallienne. *Comptes Rendus de l'Académie des Sciences*, 319: 467-473.
- Pozner V.M. (1951). Ostracodes of the Lower Carboniferous of the western part of the Moscow basin. *Sbornik statei*: 5-108. [in Russian]
- Rakshin P.P. (1965). New Viséan rugose corals from west slopes of Urals. *Paleontologicheskii Zhurnal*, 1: 54-59. [in Russian]
- Rausser-Chernousova D.M. (1948). Some new species of foraminifers from Lower Carboniferous deposits of the Moscow Basin. *Akademiya Nauk Souza Sovetskikh Socialisticheskikh Respublik, Trudy Instituta Geologicheskikh Nauk, Geologicheskaya Seriya (No. 19)*, 62: 227-238. [in Russian]
- Reitlinger E.A. (1963). Paleontological criteria for establishing the boundaries of the Lower Carboniferous Division (based on foraminiferal fauna). *Akademiya Nauk SSSR, Voprosy Mikropaleontologii*, 7: 22-56. [in Russian]
- Rodriguez S. & Bamber E.W. (2010). Unusual offsetting in Serpukhovian (Lower Carboniferous) representatives of the rugose coral genus *Schoenophyllum* Simpson, 1900. *Palaeoworld*, 19: 401-409.
- Rodríguez S., Somerville I., Cózar P., Coronado I. & Said I. (2016). Inventory and analysis of the distribution of Viséan corals from the Guadiato Area (Córdoba, SW Spain). *Spanish Journal of Paleontology*, 31: 181-220.
- Rodríguez S., Somerville I., Said I. & Cózar P. (2013). An Upper Viséan (Asbian-Brigantian) and Serpukhovian coral succession at Djebel Ouarkiz (northern Tindouf Basin, southern Morocco). *Rivista Italiana di Paleontologia e Stratigrafia*, 119: 3-18.
- Said I., Somerville I.D., Rodríguez S. & Cózar P. (2013). Mississippian coral assemblages from the Khenifra area, Central Morocco: Biostratigraphy, biofacies, palaeoecology and palaeobiogeography. *Gondwana Research*, 13: 367-379.
- Savitsky Y.V., Kossovaya O.L. & Vevel Y.A. (2007). Lower Carboniferous of the northwestern part of the Moscow Syncline. Guidebook of pre-conference field trip, X International Congress on Fossil Cnidaria and Porifera. 96 pp. All-Russian Geological Survey Institute, Publishing House, St. Petersburg.
- Savitsky Y.V., Kossovaya O.L., Vevel Y.A. & Evdokimova I.O. (eds) (2015). Lower Carboniferous of the St. Petersburg region (northwest Russia). A field Guidebook of XVIII International Congress on the Carboniferous and Permian. 77 pp. All-Russian Geological Survey Institute, Publishing House, St. Petersburg.
- Sayutina T.A. (1973). Lower Carboniferous corals of the northern Urals; Suborder Acrophyllina. *Akademiya Nauk SSSR, Trudy Paleontologicheskogo Institut*, 140: 1-168. [in Russian]
- Semenoff-Tian-Chansky P. (1985). Corals. In Wagner R.H., Winkler-Prins C.F. & Granados L.F. (eds), *The Carboniferous of the World, II, Australia, Indian subcontinent, South Africa, South America and North Africa*. International Union of Geological Sciences Publication, 20: 374-381, 431-435.
- Shlykova T.I. (1951). Foraminifers of the Viséan and Namurian stages of the Lower Carboniferous of the western part of the Moscow basin. *Sbornik statei*: 109-178. [in Russian]
- Simpson G.B. (1900). Preliminary descriptions of new genera of Paleozoic rugose corals. *Bulletin of the New York State Museum*, 39: 199-222.
- Smith S. (1916). *Aulina rotiformis*, gen. et sp. nov., *Phillipsastraea hennahi* (Lonsdale) and *Orionastraea* gen. nov. *Quarterly Journal of the Geological Society of London*, 72: 280-307.
- Sokolov B.S. (1939a). Significance of Rugosa and tabulate corals in the stratigraphy of the C1 of the Moscow basin. *Doklady Akademii Nauk Souza Sovetskikh Socialisticheskikh Respublik*: 2. [In Russian]
- Sokolov B.S. (1939b). Stratigraphical significance and types of Chaetetidae of the Carboniferous in the USSR. *Doklady Akademii Nauk Souza Sovetskikh Socialisticheskikh Respublik*: 4. [in Russian]
- Sokolov B.S. (1940). Sandy-clay deposits of the Lower Carboniferous of the Moscow basin. *Sovetskaya Geologia*, 5-6: 145-152. [in Russian]

- Sokolov B.S. (1941). Stratigraphical scheme of the northern part of the Moscow basin. *Izvestia Akademii Nauk Souza Sovetskikh Socialisticheskikh Respublik, Seriya Geologicheskaya*: 13-22. [in Russian]
- Sokolov B.S. (1944). New data on stratigraphy and palaeogeography of the north of the Moscow basin (Ljubytno district). *Uchenye Zapisky Leningradskogo Universita, Seriya Geologicheskaya*, 70: 112-136. [in Russian]
- Sokolov B.S. (1950). Carboniferous Chaetetidae of southeastern Ukraine and contiguous regions. *Trudy VNIGRI*, 27: 3-144. [in Russian]
- Stuckenberga A. (1904). Anthozoan and bryozoan of the lower Carboniferous from Central Russia. *Trudy Geologicheskogo Komiteta*, 14: 1-128. [in Russian]
- Vostokova B.A. (1955). Lower Carboniferous gastropods "Rovnoe Limestone". *Voprosy palaeontologii*, 2: 70-81. [in Russian]
- Wang Z.G. (1989). On lithostrotionelloid corals. *Acta Paleontologica Sinica*, 28: 522-545. [in Chinese]
- Yanishevsky M.E. (1936). The brief report about the work of 1935 year. *Uchenye Zapisky Leningradskogo Universiteta, seriya geologo- pochvovedennykh u- geograficheskikh nauk*, 3: 80-95. [in Russian]
- Yanishevsky M.E. (1937). Carboniferous deposits. *Articles to the geological map of the south part of the Leningrad District*: 64-83.
- Yanishevsky M.E. (1954). Brachiopod fauna of the Lower Carboniferous of the Leningrad District. *Isdatelstvo Leningradskogo Gosudarstvennogo Universiteta*: 1-46. [in Russian]
- Yu C.C., Lin Y.D., Shi Y., Huang Z.X. & Yu X.G. (1983). Carboniferous and Permian corals. 391 pp. Jilin People's Publishing House, Jilin, China. [in Chinese]
- Yu X. (1980). Upper Carboniferous Chuanshanian tetracorals of Southern Jiangsu. *Professional Papers of the Chinese Academy of Geological Sciences. Stratigraphy and Paleontology*, 9: 48-88. [in Chinese]
- Yu X. (1991). New genus and species of Carboniferous tetracorals from Jiangsu and Anhui. *Acta Palaeontologica Sinica*, 30: 420-444. [in Chinese]

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