INTRODUCTION

Mississippian rocks are well exposed in the northwestern part of the Moscow Basin. During the first half of the 20th 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 (Brus, 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 (Steshievian 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 (Stuckenberg, 1904; Karaeva, 1935; Sokolov, 1939a; Dobrolyubova, 1938b), 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 contains a rich foraminiferal assemblage, with the remarkable occurrence of *Brenchkleina rugosa* (Brazhnikova, 1964) and the narrow form of *Eostaffellina paraprotrata* (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. protvaensis* Gishman, 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.
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 multisepetata 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. gorskii (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).
Fig. 2 - (color online) Stratigraphic section at Uglovka quarry (based on Savitsky et al., 2007). The arrows show the location of the samples.
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

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.
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 (Rodriguez 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

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Fig. 4 - (color online) Palaeogeographical distribution of corals recorded in the Zarech’e 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. huangjiangense 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-Continent, 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, Dibuophylum 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, Dibuophylum bipartitum, Actinocyathus floriformis, A. borealis* and *A. crassiconus*. The assemblage in the Zarech’e quarry is composed of *Syringopora reticulata, Dibuophylum 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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