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Carboniferous buildups in the Donets Basin (Ukraine)

Victor V. OGAR

Kyiv Taras Shevchenko National University, 90, Vasylkivska str., Kyiv, Ukraine, 03022; ogar_victor@ukr.net

ABSTRACT. The Carboniferous (Mississippian and Pennsylvanian) of the Donets Basin contains bioherms and biostromes in several stratigraphic levels. The study of buildups of this region and their comparison with other areas allows to suggest that the composition of reef-building organisms changed during the Carboniferous. Up to the late Viséan, they were formed on a shallow water carbonate platform, whereas younger bioconstructions are restricted to distinctive limestone horizons of cyclothems. Viséan shallow-marine bioconstructions are represented by *Siphonodendron*-biostromes which are typical for the Late Viséan of many areas of the Paleothetys. In the unstable conditions of the paralic basin with frequent environmental changes bioconstructions formed during transgressive phases. The late Serpukhovian buildups were complex coral-chaetetid biostromes and bioherms. In Bashkirian times appeared chaetetid and coral-chaetetid biostromes as well as algal bioherms. In the early Moscovian coral and coral-chaetetid biostromes were the most common. During the middle Moscovian dominated bioherms probably of microbial origin, and at the end of Moscovian time chaetetid biostromes were typical. At the earliest Gzhelian time algae-sponge bioherms appeared in the Donets Basin.

KEY WORDS: Mississippian, Pennsylvanian, bioconstructions, coral biostrome, chaetetid biostrome, bioherm, Donets Basin.

1. Introduction

The Donets Basin together with the Dnieper-Donets Depression is part of the Don-Dnieper Downwarp. The Carboniferous bioconstructions of the Donets Basin can be used as outcrop analogous for oil and gas fields in the subsurface of the Dnieper-Donets Depression. There such structures are only known in greater depths, and their studies are based mainly on seismological and geophysical data, since only very limited core material is available.

Only fragmentary data on Carboniferous bioconstructions of the Donets Basin were obtained. Except the detailed study of Poljakova (1986) on Upper Serpukhovian coral bioherms, information is limited to briefly described and mentioned horizons rich in bioconstructors as corals (Fomichev, 1953), chaetetids (Vassiljuk, 1959) and palaeoaplysins (Vassiljuk, 1974).

It is the aim of this paper to summarize all available data of bioconstructions based on the previous studies and personal observations (Fig. 1). During field works a focus was laid on the spatial distribution of rugose and tabulate corals, chaetetids, and "stromatoporoid"-like fossils in order to determine their role as a reef builders. The comparisons of studied buildups with those described in other areas of the world can help to identify the most common patterns in their evolution during the Carboniferous period.

2. Geological setting and stratigraphy

The Donets Basin is part of a Paleozoic fold belt near the southern part of the East–European Platform between the Ukrainian Shield and the Voronezh Massif (Fig. 2). The Carboniferous deposits are dislocated here in folds with north-western direction of axes and complicated by faults of the same direction. The Golovna Anticline occupies the central position in the structure of the Donets Basin. In the northern part of the Donets Basin younger sediments cover the "Zone of Small Folds". It forms a transition zone between the Folded Donets Basin and the southern slope of the Voronezh Massif and is widely known as the Northern Outskirts of the Donets Basin.

The study area is located within the Donetsk and Lugansk regions of Ukraine (Fig. 1). Carboniferous deposits of

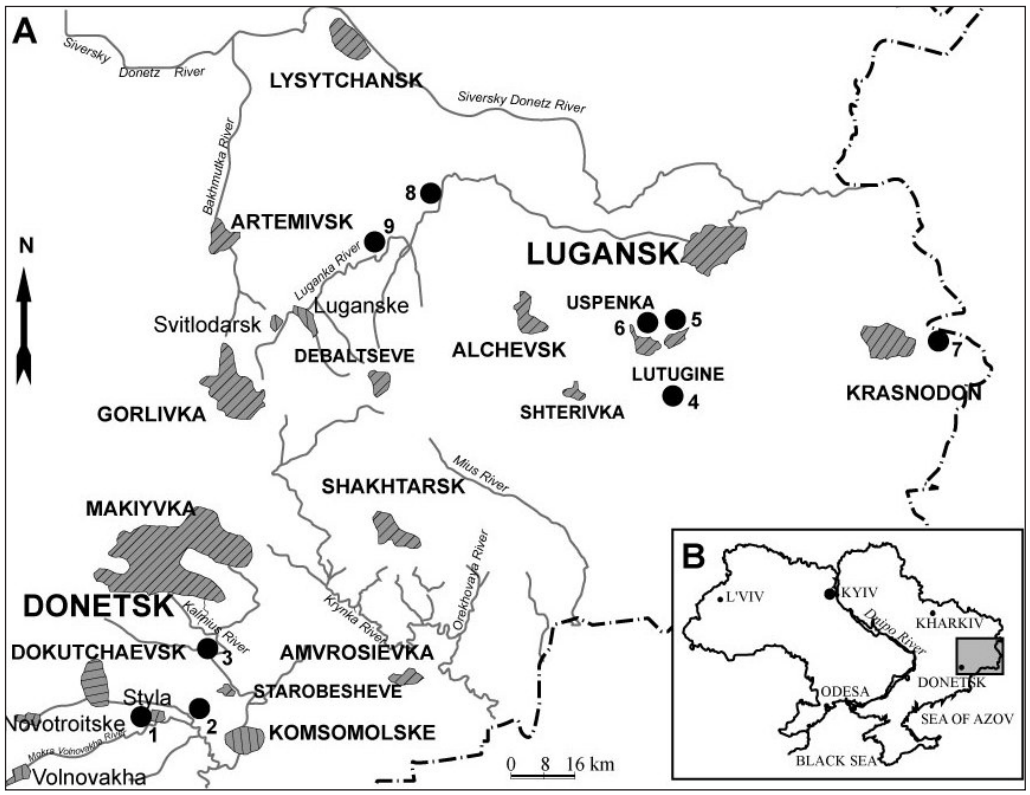

Figure 1. Location map of studied sections. 1: Mokra Volnovakha River near the village Styla, 2: Kypucha Krynytsa village, 3: Starobesheve village, 4: Volnukhino village, 5: Karahuz ravine, 6: Pashenna ravine, 7: Izvarine railway station, 8: Golubovka railway station, 9: Kalynove village.

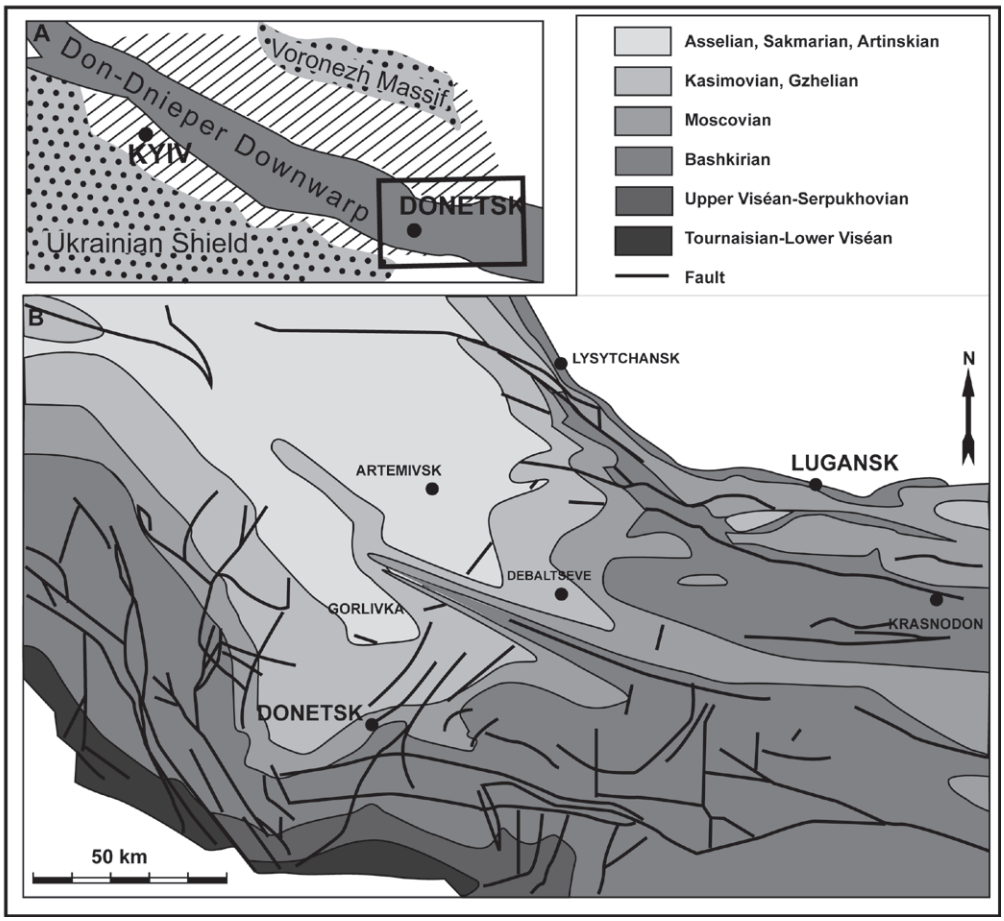

Figure 2. A: Sketch of the Don-Dnieper Downwarp B: Geological map of the Donets Basin (modified after Aizenverg et al., 1975).

Global Stratigraphic Scale				Regional Stratigraphic Scale					
System	Subsystem	Series	Stage	Series	Regional Stage	Regional Substage (Horison)	Zone	Suite	Limestone
CARBONIFEROUS	MISSISSIPPIAN	LOWER	TOURNAISIAN	Lower Carboniferous	Lower Buzinivian	Bazaliivian	$C_1^1 b^l$	Mokrovolnovakha Siries C_1^1(A)	Bazaliivka
						Karakubian	$C_1^1 b^u$		Karakuba
					Upper Buzinivian	Volnovakhian	$C_1^1 c$		Volnovakha
						Karpovkian	$C_1^1 d$		Karpivka
						Dokuchaevskian	$C_1^v a$		
		MIDDLE	VISEAN		Olenivkian	Glybokian	$C_1^v b$-d		Skelyuvatka
						Sukhian			
						Stylian	$C_1^v e$		Styla
						Donetsian	$C_1^v f$		Donetsk
		UPPER	SERPUKHOVIAN		Efremovian	Mezhevian	$C_1^v g$	Mezha C_1^2(B)	B_1
						Samarian	$C_1^s a$	Samara C_1^3(C)	C_1
						Prokhorovian	C_1^s b-c		C_5
					Starobeshevian	Novolyubivkian	$C_1^s d$	Kalmiuska C_1^4(D)	D_1^{sl}
						Zapaltyubian	C_1^s e-f		D_3
						Voznesenskian	$C_1^s g$		D_5^{su}
	PENNSYLVANIAN	LOWER	BASHKIRIAN		Olmezivkian	Feninian	$C_2^b a$	Amvrosiivka C_2^0(E)	E_1
					Mandrykinian	Manuilivian			E_8
						Blagodatnian		Mandrykinka C_2^1 (F)	F_1
					Kayalian	Zujevian	C_2^b b-c	Mospinska C_2^2 (G)	G_1
						Makijivkian	$C_2^b d$	Smolyanynovka C_2^3 (H)	H_4
						Krasnodonian	$C_2^b e$	Bilokalytvenka C_2^4 (I)	I_2
		MIDDLE	MOSCOVIAN	Middle Carboniferous	Lozovian	Kamenkian	$C_2^m a$	Kamenka C_2^5 (K)	K_3
						Marjivkian	C_2^m b-d	Almazna C_2^6 (L)	L_1
						Sabivkian			M_1
					Lomovatkian	Sanzharivkian	$C_2^m e$	Gorlivka C_2^7(M)	M_8
		UPPER	KASIMOVIAN	Upper Carboniferous	Toretzian	Kartanashkian		Isaivka C_3^1 (N)	N_5-N_5^1
						Svitlanovkian		Avilovka C_3^2 (O)	O_4^1
					Kalynovian	Kluchovian			O_5
						Troizkian		Araukaritova C_3^3 (P)	P_3
			GZHELIAN		Myronovkian	Luganskian			P_8^g
						Vyskrivskian			Q_1
								Kartamysh (Q)	Q_7

Figure 3. General stratigraphic chart of the Carboniferous of the Donets Basin (after Mening et al., 2006; Poletaev et al., 2011).

the Donets Basin have been studied since the 18th century. The early history of their study was described by Novick et al. (1960). Since then, a very detailed stratigraphic subdivision was achieved (Lissitzin, 1925, 1929; Aizenverg et al., 1963; Rotai, 1975). Foraminifers are the main biostratigraphic tools and have been used to define horizons, but detailed biostratigraphic charts for other group of fossils exist also (Poletaev et al., 2011).

According to the lithological differences, the Carboniferous of the Donets Basin is divided into two parts. The lower part, Mokrovolnovakha Series, is predominantly composed of limestone, which formed on a carbonate platform during the Tournaisian and most of the Viséan. The series is well exposed in the Southern Donets Basin and has a thickness of 500 m. Carboniferous carbonate strata unconformably overlies the Devonian carbonate deposits. The latter had been considered as being Carboniferous in age (C_1^ta), but detailed biostratigraphic studies showed their Late Devonian age. The Uppermost Devonian and Lower Carboniferous limestones are mined by numerous quarries for flux material used in steel industry.

A much larger thickness is found in the upper part of the Carboniferous deposits. Cyclothems accumulated to a total thickness of 7-10 km in a paralic basin from the end of the Viséan to the top of the Carboniferous. These deposits are exposed in the central and northern parts of the Donets Basin and often contain industrial coal seams. The Fig. 3 shows a general stratigraphic chart of the Carboniferous of the Donets Basin. Stratigraphic correlations of the Carboniferous of the Donets Basin to neighbouring regions have been established, but remain partly controversial (Mening et al., 2006).

3. Stratigraphic distribution and structure of the buildups

3.1. Lower Viséan

Corals become abundant in the Upper Tournaisian strata. The Volnovakha Suite (Zone C_1^tc) contains a number of large solitary rugose corals *Cyathoclisia* and *Keyserlingophyllum* as well as numerous tabulate corals *Syringopora, Roemeripora, Michelinia,*

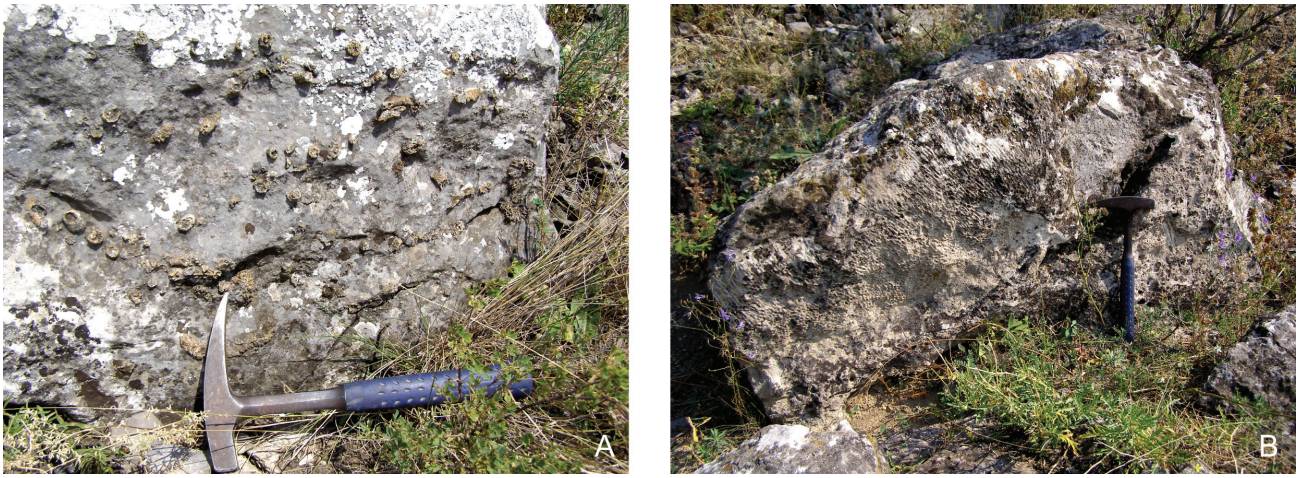

Figure 4. Viséan coral-rich limestones. A: The Lower Viséan coral rudstones. The base of the Skelyuvatka Suite (C_1^vb). B: The Upper Viséan coral biostrome is composed of fasciculate colonies of *Siphonodendron junceum* (Fleming). Middle part of the Donetsk Suite (C_1^vf).

and *Volnovakhipora*. Corals are found in bioclastic limestones. There are some features of transportation and they do not form significant accumulations.

The role of corals in carbonate sedimentation increases markedly with the appearance of colonial rugose corals as *Siphonodendron*, *Dorlodotia* and *Eolithostrotionella* in the lower part of the Viséan. This is clearly seen in the outcrop "Pigeons Rock" on the left bank of the Styla reservoir (Mokra Volnovakha River). Here at the bottom of the Skelyuvatka Suite (Olenivskian Regional Stage, Zone C_1^vb) fragments of *Siphonodendron affine* var. *tanaicum* Vassiljuk, and *Syringopora* form a coral-rich bed (Vassiljuk, 1960). Its thickness is 0.3-0.5 m (Fig. 4A). Coral debris is cemented by bioclastic material and forms coral rudstones.

In the western extension of the Donets Basin and Dnieper-Donets Depression a Tournaisian-Viséan reef complex is described (Lukin & Vakarchuk, 1999). The authors stressed that corals did not play a significant role in the structure of this complex. But its reef nature, in our opinion, has not been studied in enough detail.

3.2. Upper Viséan

The first real bioconstructions are found in Upper Viséan deposits. These simplest buildups occur in the middle part of the Donetsk Suite (Zone C_1^vf, Efremovian Regional Stage) in the outskirts of Styla and Kypucha Krynica villages.

These bioconstructions are composed of large fasciculate colonies of *Siphonodendron junceum* (Fleming), each of which has a height of 15 cm to 40 cm and in some cases up to 80 cm. Colonies grow one by one, touching or placing at a distance of 10-30 cm, both vertically and horizontally forming coral biostromes. The length of these constructions is 2-3 m and a height of 80 cm (Fig. 4B, Pl. 1A).

The biostromes are intercalated between coarse-grained bioclastic limestone beds and argillaceous limestone with inclusions of black chert of irregular shape. The limestone includes the debris of *Dibunophyllum*, clusters of gigantoproductid brachiopods, and flat chaetetid colonies (*Chaetetipora* and *Caetetiporella*).

3.3. Upper Serpukhovian

The Upper Serpukhovian buildups (the Starobeshevian Regional Stage, the Kalmiuska Suite, C_1^4 (D) are more complex in composition and structure than the Upper Viséan. They are exposed around the Starobesheve village on the banks of Kalmius River and studied in detail by Poljakova (1986), who related them to shore reefs. These coral-rich structures were observed by the author in two outcrops.

The first outcrop is located on the left bank of the Kalmius River near the former village Novolyubivka. Here two thick limestone levels of the group D_1^5 (Novolyubivkian Horizon) are separated by a 10 m thick shale interval containing plant remains. Several interbedded thin layers of yellow clay limestone contain numerous fragments of small solitary rugose corals, brachiopods, bryozoans, and crinoids (Poletaev et al., 2011).

The lower limestone level is 11.2 m thick. It is a dark-brown bioclastic limestone, with abundant remnants of various macrofauna and biolithites. Corals are abundant in bafflestones and framestones. They form separate lenses (coral bioherms) with a thickness of about 0.7 m, composed of large colonies of rugose corals *Lithostrotion, Siphonodendron* and *Aulina.* Among colonial rugose corals the fasciculate *S. asiatica* are predominant. They form the framework that can accommodate solitary rugose corals mainly *Dibunophyllum*, as well as calcareous algae, bryozoans, foraminifers, brachiopods, gastropods, bivalves, and the debris of other organisms. The upper limestone level is 9.2 m thick. The light-gray micritic clotty massive limestone contains many stromatolites, and thus is probably microbial in origin. Fauna is rare in this limestone.

The second outcrop is located on the right bank of the Kalmius River in the outskirts of the Starobesheve village. On the eastern slope of the Zapal-Tube mountain the coral-chaetetid limestone D_5 (the Zapaltyubian Horizon) is exposed. The chaetetids *Chaetetiporella* and *Chaetetes* (*Boswellia*) and "stromatoporoid"-like fossils *Kyklopora* are presented along with colonial and solitary rock-forming rugose corals. Often there are also calcareous algae, bryozoans, brachiopods and remains of other organisms. Colonies of rugose corals, "stromatoporoid"-like fossils and chaetetids form several layers (Fig. 5). The lower layer is composed of flat colonies of *Kyklopora* and *Chaetetiporella* (bindstone). At the top of the bed, they are replaced by spherical colonies of *Chaetetes*, *Actinocyathus*, *Lonsdaleia*, *Siphonodendron*, *Lithostrotion* (Pl. 1B) and *Aulina* (Pl. 1C) forming bafflestones and framestones. The thickness of the buildup is 1.75 m, the visible length reaches 12 m.

Limestones D_1^5 and D_5 are much persistent in the area. But near the former village Novolyubivka (D_1^5) and on the eastern slope of the Zapal-Tube Mountain (D_5) they reach their maximum thickness, which also indirectly indicates to their reef origin. Drilling results show that the thickness of some Serpukhovian limestones can reach several tens of meters, but reef genesis of these thickening limestones has not been studied and is only supposed.

3.4. Bashkirian

The Bashkirian is characterized by the arrival of a new coral community, and among corals, the typical reef builders of the Serpukhovian have become extinct.

On the right bank of Kalmius River in the limestone D_5^9 (the lowermost of the Bashkirian; the upper part of the Kalmiuska Suite; Voznesenskian Horizon), are exposed many nodules of *Chaetetes (Boswellia)* with sizes up to 1 m and placed among bioclastic limestones. They belong to chaetetid sponge biostromes. Up-section, in the Amvrosiivka Suite (limestone E_1, E_2; Feninian Horizon), *Chaetetes* (*Boswellia*) *boswelli* Heritsch and *Multithecopora sokolovi* Vassiljuk form biostromes. Large

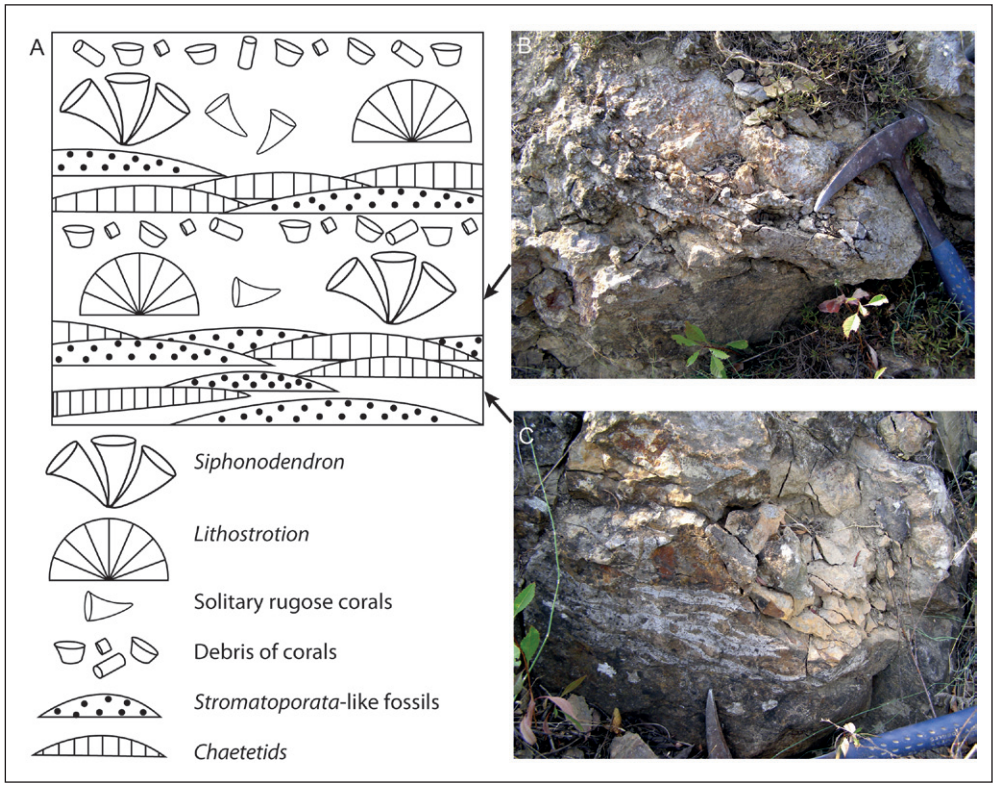

Figure 5. The Upper Serpukhovian coral bioherms near Starobesheve village, Limestone D_5. A: Sketch of the bioherm. B: *Siphonodendron rossicum* (Stuckenberg) colony (upper layer). C: Chaetetids *Chaetetiporella* and "stromatoporoid"-like fossils *Kyklopora* (lower layer).

Figure 6. Pennsylvanian bioherms. A, D: Moscovian microbial? bioherm, Pashenna section, limestone L_7. A: General view, D: tubes of *Tubulus*. B, C, E: Moscovian microbial? bioherm, Golubivka railway station, limestone L_6. B: General view. C: crinoidal limestone. E: fragment of stromatolite. F: Moscovian microbial? bioherm, Karahuz section, limestone L_7, tube of *Tubulus*. G: Gzhelian algal-sponge bioherm, "Stone Gate" outcrop near the village Kalinove, limestone O_6^1.

colonies of ?*Lytvophyllum dobrolyubovae* Vassiljuk with widths and heights of both 50 cm (Vassiljuk, 1960) occur dispersed in the biostrome. They do not form any significant clusters and thus did not contribute to biostrome formation.

In a quarry near the Volnukhino village lenticular structures crop out in the limestone F_1 (Mandrykinka Suite, C_2^1 (F); Blagodatnian Horizon). The quarry exposes two parts of this limestone. The lower, thicker part is composed of bluish-gray massive possibly phylloid algae dominated bafflestone (Pl. 2A). This part is covered by a 1.5-2 m thick layer of dark-gray bioclastic and clayish limestone with numerous red algae, which according to D. Vachard (pers. com.) possibly belong to *Archaeolithophyllum lamellosum* Wray, 1964 (Pl. 2B), fragments of crinoids, brachiopods, bryozoans, bivalves and solitary rugose corals. Limestone F_1 is evenly distributed in this area, due to its persistence distinctly manifested in the landscape. Usually, it is only few meters thick, but near the Volnukhino village its thickness reaches 10-12 m (Aizenverg et al., 1975*;* Poletaev et al., 2011).

3.5. Moscovian

Probably microbial-mediated lenticular structures (bioherms) are particularly well developed in the middle part of the Moscovian in the northern part of the Donets Basin (Ogar, 2007). These bioherms are associated with limestone L_6 and L_7 (Lozovian Regional Stage, Almazna Suite C_2^6 (L). Microbial origin of these buildups is very probable, but not completely proven.

In the Pashenna section, located in the northern outskirts of Chelyuskinets, limestone L_7 is exposed near the mine in an old quarry (Fig. 6A). Light-gray massive limestone is overlain by a crinoidal layer with thickness 30 cm. The limestones include in some cases chaetetid colonies and massive colonies of the rugose corals *Ivanovia*. The thickness of the bioherm exceeds 3 m and its length reaches several tens of meters.

The largest buildup is the Holubivka bioherm. It is located in the northern part of Kirov (opposite to the railway station Holubivka) on the right bank of the Luganka River near the heap of coal mine No.100 (Fig. 6B). The bioherm is associated with the limestone L_6. It has the shape of a lens and 200×300 m as viewed from the top. The central part of this bioherm is almost mined by the quarry. Only a marginal part is preserved and the thickness exceeds 3 m. The bioherm is composed of light-gray thick-layered and massive wackestone-packstone. Macrofauna is rare and represented by brachiopods, chaetetids, solitary rugose corals (*Yuanophylloides*), and massive colonial corals (*Petalaxis*). Stromatolites are frequently found (Fig. 6E).

The upper part of the bioherm is composed of light-brown crinoidal rudstone (encrinite) with a thickness of 30 cm (Fig. 6C). The diameter of the largest crinoid fragments reaches 1.5 cm. Debris of chaetetids and solitary rugose corals are commonly found in these crinoidal limestones.

A smaller bioherm is found in the Karahuz section. It is located at a distance of about 2 km to the east of the Pashenna section and it also occurs in limestone L_7. The limestone lens reaches a thickness of 6 m and a length of 12-15 m. The central part of the bioherm (core) is composed of massive light-gray limestone with poorly preserved texture. The microphotograph (Pl. 2C) illustrates recrystallized probably primary microbial origin mudstone with scattered foraminifers and dark round tubes. The upper part of the buildup consists of crinoidal limestones, which contain the solitary rugose corals *Axolithophyllum*, *Yuanophylloides* and *Monophyllum*, the tabulate corals *Cladochonus* and bryozoans. A crinoidal layer is distributed locally and thinned along strike. Towards the marginal parts the thickness of the limestone L_7 is reduced to 2.5-3 m.

A characteristic feature of the Moscovian bioherms is the presence of cylindrical tubes (Figs 6D, F; Pl. 2C). Their diameter varies from 0.6 to 4 mm and maximum length is 3 cm. Most tubes are straight; curved tubes connected with straight ones are only occasionally observed. They can form clusters in which the tubes may be in contact to each other, but do not intersect, and are located within a distance of 5 mm. Most of these tubes are oriented perpendicular to the surface layers. Thus the characteristic feature of limestone texture is the presence of cylindrical channels, which are probably the traces of unknown borrowing organisms possibly worms for which the name *Tubulus* was proposed (Ogar, 2007). Similar structures are described in the Pennsylvanian of the South China, where they regarded as probably worm tubes (Zhang et al., 2010).

Coral and chaetetid limestones are very common in the lower part of the Moscovian; the top of the Kamenka Suite, C_2^5(K), limestone K_8, and in the middle part of the Almazna Suite,C_2^6(L), limestone L_5. They have been studied in outcrops on the Karahuz, Pashenna sections and near the railway station Izvaryne. These bioconstructions are considered to be coral and coral-chaetetid biostromes because there are no significant changes in the thickness of these limestones along strike.

Limestone K_8 is composed mainly of colonies of the fasciculate rugose coral *Donophyllum* (Pl. 1E) and chaetetids. Individual *Donophyllum* colonies have significant size - up to 30 cm in height and up to 1 m in diameter. Limestone L_5 comprises massive colonies of the rugose coral *Petalaxis* (Pl. 1D) and chaetetids. They are mentioned by Fomichev (1953), who indicates that in the section near the railway station Maryivka, limestone L_5 has a thickness of 10 m and contains *Petalaxis maccoyanum*. Dimensions of the colonies reach 0,75-1 m in diameter (Fomichev, 1953). The biostromes have an even surface. Their central part (core) is composed of coral boundstone including calcareous algae, crinoids, brachiopods, foraminifers. Along their strike they are replaced by packstone-wackestone with foraminifers and calcareous algae.

To the top of the Moscovian deposits of the Donets Basin (the Isaivka Suite, C_3^1(N), limestones N_2 and N_3) chaetetids form biostromes. Vassiljuk (1959) named them chaetetid beds. In the biostrome in the outskirts of the Kalynove key-section *Chaetetes mosquensis* Stuckenberg (Pl. 1F) reaches 30-40 cm in height and 1.2 m in width.

3.6. Gzhelian

The Gzhelian buildup is located in the northern part of the left bank of Lugan River, near the village Kalinove (Avilovka Suite, C_3^2(O). In the "Stone Gate" outcrop a bioherm has a lenticular shape with a maximum thickness of 5.2 m that decreases along the strike to 0.7-1.0 m (Aizenverg et al., 1975). It is confined to limestone O_6^1. Vassiljuk (1974) considered that it consists of *Palaeoaplysina*.

According to our data this buildup is an algal-sponge bioherm. It is composed primarily of phylloid algae (Pl. 3H). D. Vachard (pers. com.) identified also primitive forms of *Tubiphytes* and perhaps cyanobacteria (Pl. 2D, E, H). Some parts of the bioherm also consist of aggregates of spicules of siliceous sponges (Pl. 2F). Spicules are in some cases scattered in the dark mass of primitive *Tubiphytes*, probably trapped in the growth process (Pl. 2D). Often there are also bryozoans, and foraminifera. Sponge spicules dominant limestone is similar to those described from the Late Viséan of NE Morocco (Aretz & Herbig, 2008).

The solitary rugose corals *Amplexus* and *Sestrophyllum* are rare in this limestone. Along the strike these limestone are replaced by dark-grey clayey limestone with different macrofauna. In the quarry on the eastern outskirts of Luganske (section Buchkov Yar) a coral rudstone bed about 30 cm thick is observed in the same limestone O_6^1. It consists of large debris of solitary rugose corals *Bothrophyllum* and *Arctophyllum*. It seems that these coral accumulations were deeper than algal-spicule bioherms.

4. Interpretation

Reef structures have not been found in the Tournaisian deposits. Perhaps favourable conditions for their formation may occur on the western extension of the Donets Basin and in the Dnieper-Donets Depression. In the Donets Basin first bioconstructions appeared only in the Viséan with the emergence of a wide variety of colonial rugose corals. Moreover, the maximum development of buildups is during the Late Viséan and Late Serpukhovian. At late Viséan time formed coral biostromes, at late Serpukhovian occured coral and coral-chaetetid biostromes and bioherms. The abundance of remains of various organisms occurring in association with reef builders, the rock textures and the encasing deposits show that buildups are formed under favourable

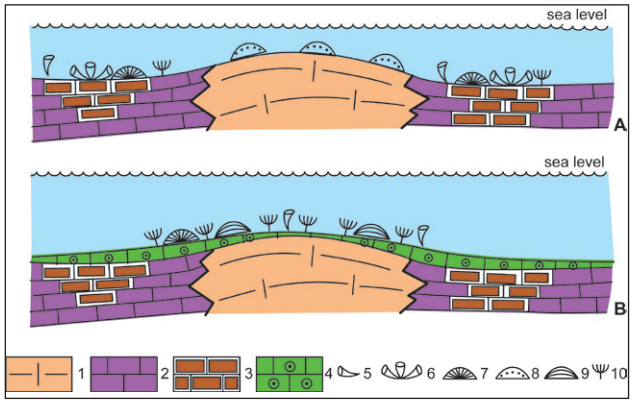

Figure 7. Model for the development of the shallow water shelf with microbial buildup: to deepen (A) and after the deepening of the basin (B). Limestones: 1: microbial, 2: bioclastic, 3: coral-chaetetid boundstone, 4: crinoidal rudstone. Fauna and Flora: 5: solitary rugose corals, 6: colonial rugose corals, 7: chaetetid sponge, 8: microbial organisms, 9: stromatolites, 10: crinoids.

conditions of the shallow water shelf. The coral buildups do not reach a significant thickness due to reduced accommodation space of a slowly sinking shelf. But, it is possible that they could achieve considerable thickness, if such bioconstructions are located on the border of the shelf edges and deeper basins (Aretz & Chevalier, 2007). Then the steady subsidence of the shelf edge could be compensated by the growth of colonial organisms. Such areas may be found in the deep parts of the Donets Basin and Dnieper-Donets Depression.

So, only the Upper Viséan *Siphonodendron* biostromes are interbedded into limestone facies. Carbonate sedimentation during this period occurred in a shallow-water shelf environment with slow sea-level fluctuation.

The most parts of the studied bioconstructions are located in the Donets Basin coal-bearing rocks of the Upper Serpukhovian and Pennsylvanian. They are also predominantly shallow-water biostromes and bioherms. But due to periodic interruption of carbonate sedimentation in the cyclothems, the bioconstructions did not reach important heights.

During Pennsylvanian times calcareous algae and probably microbial organisms played an important role in the formation of buildups. In Bashkirian times coral and coral-chaetetid biostromes as well as algal bioherms formed. But chaetetid sponges were involved as reef builders only since late Viséan up to the end of the Moscovian. During Moscovian time along with the coral and coral-chaetetid biostromes were common bioherms, a probably microbial origin is still not enough studied. An algal-sponge origin can be postulated for Gzhelian bioherms in the Donets Basin.

The studied Pennsylvanian bioconstructions of the Donets Basin formed in shallow water. Locally the interaction of a variety of bioconstructors (algae, probably microbial communities, algal-sponge associations) resulted in the appearance of mounds resistant to the destruction by waves. Ecospace between the mounds was populated by a variety of benthic organisms, among which were especially numerous brachiopods, bryozoans, crinoids as well as colonial and solitary rugose corals and chaetetid sponge forming underwater thickets. But even during a small increase in the deepening of the basin growth of builders was stopped, and crinoid thickets on the mounds developed.

The simplified hypothetical model for the development of the Moscovian shallow shelf with microbial buildup (limestones L_{6-7}) is shown in Figure 7. Further deepening of the basin led to a complete stop of carbonate sedimentation and burial of the carbonate rocks by clayey sediments. As a result, at different stratigraphic levels buildups are covered by clayey or crinoidal facies. Along strike the buildups facies are replaced by bioclastic limestones or in some cases coral rudstones or coral and chaetetid sponge biostromes.

5. Comparison with other areas

Similarly to the Donets Basin, Carboniferous buildups occur at various stratigraphic levels in other regions (see recent reviews of Wahlman (2002), Kuznetsov & Antoshkina (2006) and Aretz &Vachard (2007).

Tournaisian-Lower Viséan reefs were found in the Dnieper-Donets Depression by seismic surveys and drilling (Lukin & Vakarchuk, 1999; Machulina, 1996). But the nature of this carbonate structures has not been investigated in details yet. Most wells cut through predominantly bioclastic Tournaisian-Viséan rocks.

Most common are Upper Viséan buildups. In addition to the Donets Basin, they occur in similar stratigraphic levels of the Lvov-Volyn basin (Shul'ga & Ogar, 2009), are known in Western Europe, Urals, Japan and many other places of the world (Aretz, 2002a, 2002b; Aretz & Chevalier, 2007; Aretz & Webb, 2007; Aretz & Herbig, 2003a, 2003b, 2008; Kuznezov & Antoshkina, 2006; Somerville et al., 2003). Similar to coral biostromes of the Donets Basin these formations are also known in Western Europe - Belgium, north-west of Ireland, Spain and other countries, as well as in North Africa where framework are formed by *Siphonodendron* colonies (Aretz, 2001, 2002; Aretz & Herbig, 2008; Somerville et al., 2009; Aretz et al., 2010). Most similar to the Donetsk ones are biostromes described in Belgium from the Royseux area (Aretz, 2001, 2002). They are built mainly by the colonial rugose corals *Siphonodendron* and *Lithostrotion.*

The Late Serpukhovian-Early Bashkirian buildups are known on the Northern Outskirts of the Donets Basin (Lukin et al., 1979), the Caspian depression (Kuznezov, 1998; Konyukhov et al., 2006) and in the Urals (Kulagina et al., 2009). Contemporaneous reefal facies was discovered in wells in the northern outskirts of the Donets Basin (Lukin et al., 1979), but they were not studied in detail.

The same situation can be applied to the Caspian Basin and the Urals, where the bioherm facies composed barrier reef mounds (Kuznezov, 1998; Konyukhov et al., 2006). Serpukhovian-Early Bashkirian bioherm facies of the Southern Urals are documented in details (Kulagina et al., 2009). These are mainly small algal bioherms, which have dimensions of 10-15 m and height of 3-5 m.

Coral biostromes and bioherms are known from the Upper Moscovian deposits of the Moscow Basin. Massive colonies of the massive corals *Ivanovia* and chaetetids form small bioherms in the middle part of the Podolskian Horizon (Makhlina et al., 2001). Algal bioherms are described in the Podolskian Horizon of the western part of the Moscow Basin (Ilhovsky, 1975). Their thickness is 1-5 m. Persistent along strike coral-chaetetid beds (biostrome), comprising chaetetids colonies and massive rugosan *Petalaxis* and *Ivanovia,* are distinguished at the base of the Myachkovian Horizon (Makchlina et al., 2001).

In Western Europe Pennsylvanian bioconstructions are described in the Cantabrian Mountains (northern Spain). Here various bioconstructions built by calcareous algae, chaetetids, rugose and tabulate corals, and bryozoans are documented (Minwegen, 2001; Samankassou, 2001). Very similar to the Bashkirian algae bioherms of the Donets Basin (limestone F_1) were described as *Donezella* buildups from the San Emiliano Formation of Cantabrian Mountains (Samankassou, 2001).

The chaetetid buildups at the top of the Moscovian Stage, were studied in south-eastern Kansas (Marmaton Group) (West & Clark, 1984), Central Texas and New Mexico (Late Atokan) (Sutherland, 1984) and Mexico (Almazán-Vázquez et al., 2007).

In the central parts of the Caspian basin synchronous deposits are made of thin (a few tens of meters) deep clay-carbonate rocks of the uncompensated basin, among which are the individual reef tracts that have arisen within the various paleoshallow sites in the Caspian Sea (Kuznezov, 1998). In the eastern part of the depression are found microbial-algal "carbonate mounds" similar to Donetsk ones which are believed to have emerged in parts of the paleoshelf edge (Konyukhov et al., 2006).

The most studied Upper Carboniferous reefs are located in the Uralian Foredeep. They can be traced along the eastern

margin of the East European Platform in the area of its junction with the Uralian Foredeep (Shcherbakov & Shcherbakova, 1986; Vennin, 1997). Most of them were discovered by wells, but some are exposed to the surface and carefully studied. Among them are Voskresenka Reef, Plakunsky Reef, and Ust-Koyvynskian bioherms. Along with calcareous algae and bryozoans, palaeoaplysins also played a significant role in the construction of these buildings. Unlike the Upper Carboniferous buildups of the Donets Basin, these are typical reefs. One of them, Voskresenka Reef is exposed in the form of elongated hill of about 80 m in height, with length of 2.0 km and width of 200 m. Its frame is constructed mainly bryozoans and calcareous algae (Alexandrov & Einor, 1984).

Upper Carboniferous-Lower Permian buildups very similar to the Gzhelian bioherms of the Donets Basin are described from Carnic Alps, where they are composed of phylloid algal and calcisponge-*Shamovella* boundstone (Samankassou, 2003). The large Pennsylvanian (Gzhelian) coral reef described recently in Guizhou (South China, Zhang et al., 2010) is so far rather unique and nothing comparable has been found in the Donets Basin.

6. Conclusions

Coral, coral-chaetetid, chaetetid biostromes and coral-sponge, calcareous algae, calcareous algae-sponge and probably microbial bioherms can be identified in the Donets Basin. Carbonate bioconstructions as well as coral and chaetetid sponge rudstones occur in the Donets Basin during Carboniferous time only in specific stratigraphic levels. They are confined to the Lower Viséan (probably), upper parts of the Viséan, Upper Serpukhovian, Lower Bashkirian, Upper Moscovian and Gzhelian sediments (Fig. 8). However, the composition of the bioconstructors in the Donets Basin has changed over time. The coral biostromes appeared in late Viséan. Coral, chaetetid sponge and "stromatoporoid"-like fossils formed biostromes and bioherms during the late Serpukhovian. At Bashkirian time along with coral, coral-chaetetid and chaetetid biostromes, developed also algae bioherms. Coral and coral-chaetetid biostromes were also common at Moscovian time, but along with them were also the bioconstructions formed probably by microbial communities. At the end of Moscovian time in the Donets Basin extend the chaetetid biostromes. At the similar stratigraphic levels they were studied in many areas of the world. At Gzhelian time in the Donets Basin appeared algae-sponge bioherms.

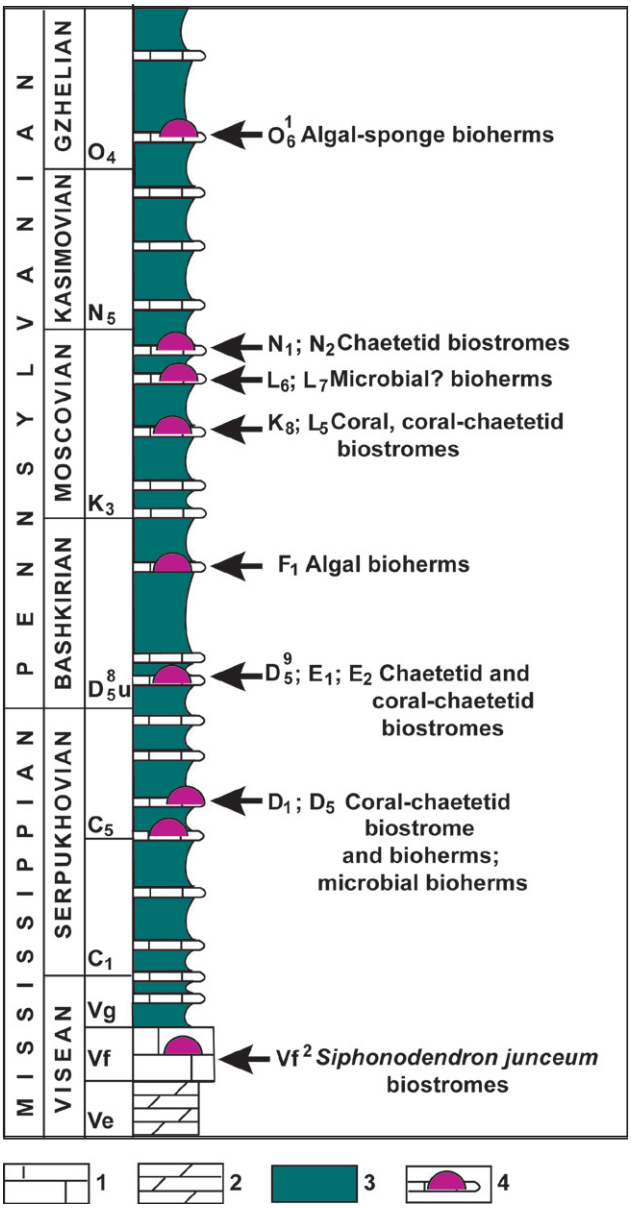

Figure 8. Distribution of the Carboniferous buildups in the Donets Basin. Legend: 1: limestone, 2: marl, 3: alternation of sandstones, siltstone, shale and coals, 4: limestone with buildups.

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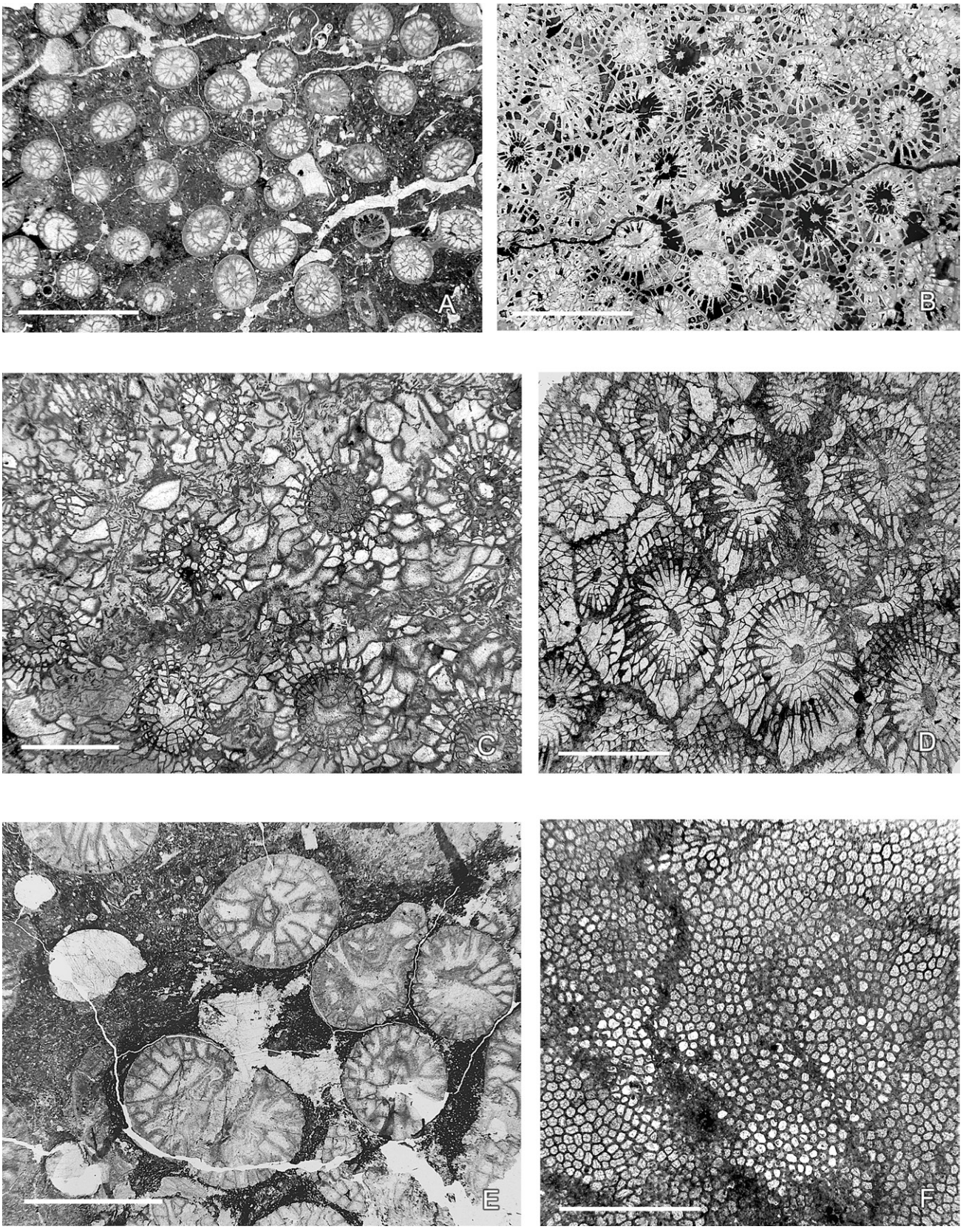

Plate 1. Typical Carboniferous coral and sponge boundstones of the Donets Basin (scale: 5 mm). A: *Siphonodendron junceum* (Fleming) (coral bafflestone, village Kypucha Krynytsa, Donetsk Suite (C_1^vf). B: *Lithostrotion maccoyanum* (Edwards & Haime), coral framestone, village Starobesheve, Kalmiuska Suite, limestone D_5. C: *Aulina parasenex* Vassiljuk; coral framestone, village Starobesheve, Kalmiuska Suite, limestone D_5. D: *Petalaxis donbassicus* (Fomichev), coral framestone, railway station Izvarine, Almazna Suite, limestone L_5. E: *Donophyllum intermedium* Fomichev, coral bafflestone, Karaguz section, Almazna Suite, limestone L_5. F: *Chaetetes mosquensis* Stuckenberg, chaetetid-sponge framestone, village Kalynove, Isaivka Suite, limestone N_3.

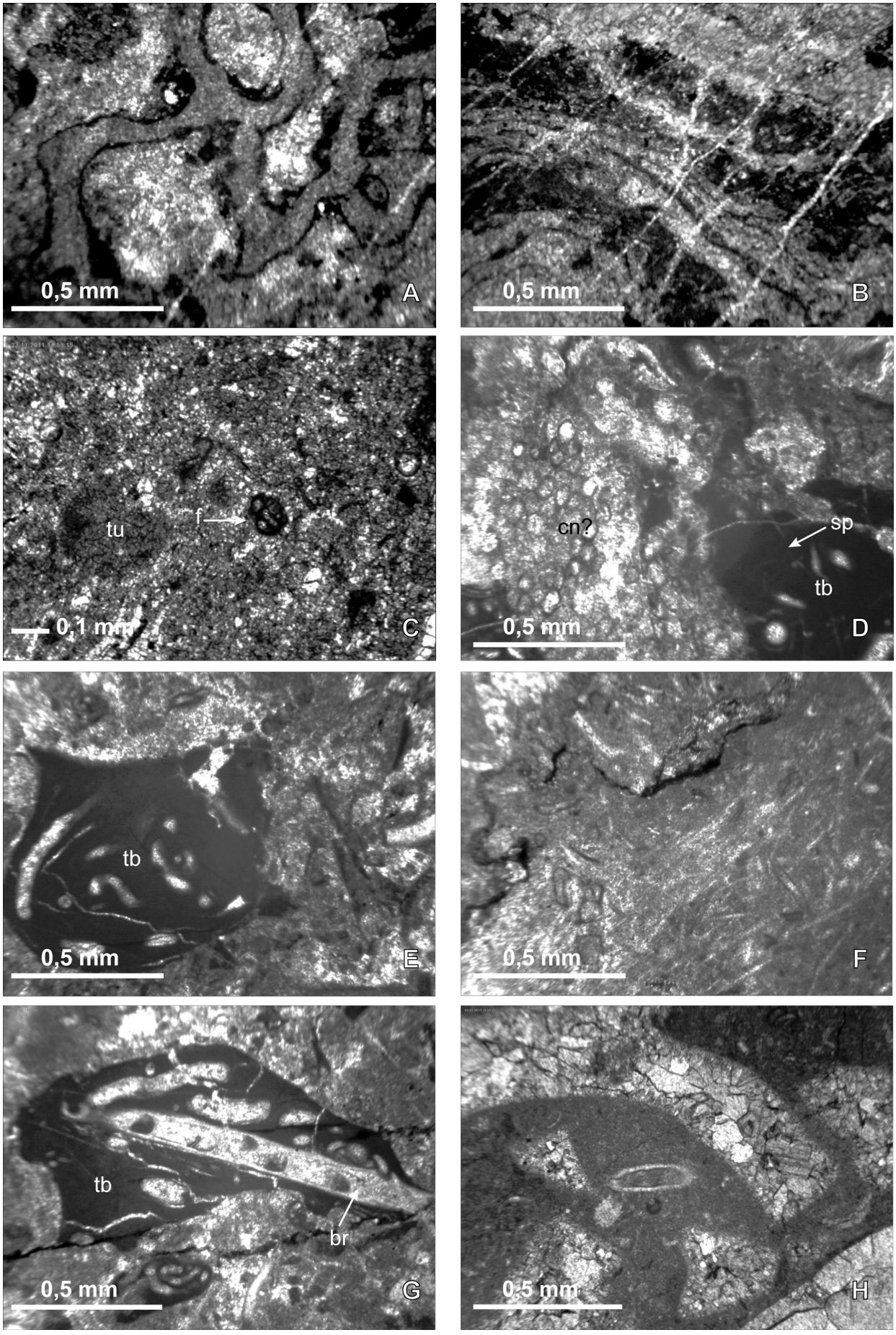

Plate 2. Microfacies of the Pennsylvanian limestones of the Donets Basin. A: Algae bafflestone, composed of possibly phylloid algae or "*Contortiporidium*" Maslov, 1973, limestone F_1, village Volnukhino, Mandrykinska Suite. B: Algae boundstone consisting probably *Archaeolithophyllum lamellosum* Wray, 1964 village Volnukhino, Mandrykinska Suite. C: Recrystallized probably primary microbial limestone with scattered in it foraminifers (f), dark round tube (tu), Karahuz section, limestone L_7. D-H: Algae-sponge bioherm, "Stone Gate" outcrop near the village Kalinove, limestone O_6^1. D, E, G: Algae boundstone consisting of cyanobacteria (cn?) or red algae, primitive *Tubiphytes* (tb) with inclusions of sponge spicules (sp) and bryozoans (br). F: Sponge spicule packstone. H: Probably phylloid algae boundstone.