

# LATE BADENIAN ZOOXANTHELLATE CORALS OF THE MEDOBORY HILLS (WESTERN UKRAINE) AND THEIR ENVIRONMENTAL SIGNIFICANCE

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Górka, M., 2018. Late Badenian zooxanthellate corals of the Medobory Hills (western Ukraine) and their environmental significance. *Annales Societatis Geologorum Poloniae*, 88: 243–256.

**Abstract:** Zooxanthellate corals in the Badenian (Langhian to lower Serravallian) of western Ukraine occur in different lithofacies, but are most abundant in the upper Badenian coralgall reefs of the Ternopil Beds. The coral assemblage consists of five genera, with two predominant (*Tarbellastraea* and *Porites*) and three strongly subordinate (*Favia*, *Heliastrea*, *Siderastrea*). The present study is the first record of *Heliastrea defrancei* in the Fore-Carpathian Basin. The taxonomic composition of the corals indicates that their development occurred in conditions of some ecological stress, most probably connected with climate (location at the northern limit of coral distribution) and sedimentary environment (possible influx of terrigenous material). The coral assemblage shows similarities to numerous fossil reefs of Miocene age from the Paratethyan and Mediterranean realms.

**Key words:** Corals, scleractinians, palaeoenvironment, Badenian (Middle Miocene), Ukraine.

Manuscript received 28 March 2018, accepted 5 October 2018

## INTRODUCTION

The occurrence of corals in the late Badenian of the Medobory Hills was recorded as early as in the 19<sup>th</sup> century. Among the first reports on corals were those of Barbot de Marny, who investigated the area in 1865 (Barbot de Marny, 1867; see also Eroseeff, 1867), followed by Michalski (1895), Teisseyre (1895), and Siemiradzki (1909). All these reports were just scant remarks, in which corals were listed among other fossils. The first complete monographic report was presented by Dembińska-Rózkowska (1932), who described Miocene corals from pre-WWII Poland. The north-western part of the Medobory Hills, comprising about half of this hilly ridge, then was located within the Polish borders. From the Polish part of the Medobory Hills, Dembińska-Rózkowska (1932) reported nine taxa, including three new species: *Favia friedbergi*, *Siderastrea felixi*, and *Siderastrea lomnickii*. The number of taxa later was reduced considerably after they were synonymised with a few widely distributed species (Roniewicz and Stolarski, 1991; Chaix and Saint Martin, 2008). After Dembińska-Rózkowska's paper, only limited notes on the corals of Medobory were given by Davidashvili (1937), Korolyuk (1952), and Kudrin (1966). At the beginning of the 21<sup>st</sup> century, a few papers were published, in which brief remarks also were presented on the coral assemblage of the Medobory Hills

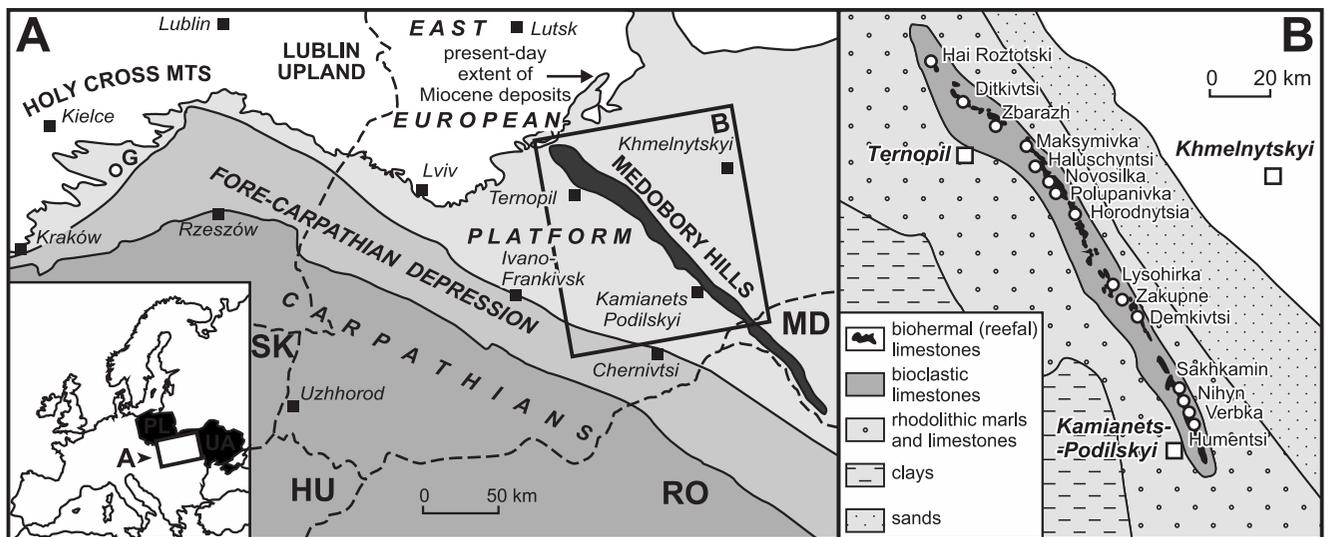
(Jasionowski *et al.*, 2005, 2006; Radwański *et al.*, 2006; Górka *et al.*, 2012; Górka in Wysocka *et al.*, 2016).

The aim of this paper is to present and depict the most recent state of recognition of the late Badenian corals from the Medobory Hills, including the systematic position and geographical distribution of the corals, supported by some palaeoecological remarks.

## THE AGE AND LITHOLOGY OF THE CORAL-BEARING FACIES

Isolated parts of colonies may be found occasionally in different Miocene deposits in western Ukraine (Dembińska-Rózkowska, 1932). The specimens are often fragmented and/or abraded (Dembińska-Rózkowska, 1932), as they were most probably eroded from their original locations and transported in turbulent hydrodynamic conditions, together with other skeletal elements (see also Wysocka *et al.*, 2012).

The only lithofacies, in which corals are abundant and are important rock-builders, is limited to the Medobory Hills (Fig. 1), a distinct range of hummocks composed of resistant biohermal limestones of Miocene age (Górka *et al.*, 2012). This hilly ridge stretches from the northern sur-



**Fig. 1.** Location of coral-bearing sites studied in the Medobory Hills in western Ukraine. **A.** Location within Europe, in relation to Poland/Ukraine border. G – the site of Grobie in Poland, where an early Badenian coral-reef was recorded. **B.** Detailed map, showing the location of sites and extent of lithofacies in the Medobory Hills and their vicinity during the late Badenian (after Korolyuk, 1952; Kudrin, 1966; Górka *et al.*, 2012; changed).

roundings of Ternopil to Kamianets Podilskyi (e.g., Górka *et al.*, 2012) and its continuation extends even further south to the Moldovan-Romanian border (see Yanakevich, 1977; Pisera, 1996; Jasionowski *et al.*, 2005, 2006; Radwański *et al.*, 2011). It is an extensive fossil barrier reef (Korolyuk, 1952; Jasionowski *et al.*, 2005; Górka *et al.*, 2012), the central part of which is composed of the Ternopil Beds of upper Badenian (i.e., lower Serravallian) age (Fig. 2). Within this lithostratigraphic unit, two lithological varieties were distinguished in the Medobory Hills (Górka *et al.*, 2012), namely bioclastic limestones and biohermal (reefal) coralline boundstones, in which coralline algae are supplemented by rock-building corals and oysters (Jasionowski *et al.*, 2005, 2006; Studencka and Jasionowski, 2011). The younger early Sarmatian microbialite-serpulite reefs overlie the Ternopil Beds (Korolyuk, 1952; Jasionowski *et al.*, 2005, 2006; Górka *et al.*, 2012; Wysocka *et al.*, 2016).

The distribution of corals within the biohermal Ternopil Beds is very uneven. Large parts of this lithofacies, exposed in numerous quarries, are devoid of corals. Where corals are present, the assemblage is dominated by two species: *Tarbellastraea reussiana* and *Porites vindobonorum prima*. Representatives of both these taxa co-occur in many places, although monospecific occurrences also are common, more often those formed by *P. vindobonorum prima*. Even where corals are concentrated, their frequency only rarely exceeds that of coralline algae (see also Dembińska-Rózkowska, 1932, p. 109), thus the term “coral reef” should not be used (or used only to emphasize the presence of corals, see Górka in Wysocka *et al.*, 2016) in descriptions of the Medobory Hills.

The concentrations of corals, regardless of their taxonomic composition, are relatively small, when compared to the overall dimensions of reefal structures. The thickness of such coral-enriched zones is usually less than 3 m and their lateral dimensions vary from a few to 15 m.

The lower boundaries of these enriched zones in the Ternopil Beds are either horizontal or sloping, most probably reflecting the position of the sea bottom that was colonised by corals during late Badenian deposition (see also Riegl and Piller, 2000). The geometry and size of coral concentrations in the Medobory Hills are also comparable to those described by Saint Martin *et al.* (2007) from the Badenian of Romania.

## SYSTEMATIC ACCOUNT

In this account, the taxa described are presented in their full taxonomic positions. Quite recently, new concepts of scleractinian taxonomy have been proposed (Budd *et al.*, 2012; Huang *et al.*, 2014, 2016), but they do not include some extinct genera present in the assemblage studied here. Because of this, the systematic data in the present study to a large extent follow those applied by Chaix and Saint Martin (2008).

The taxa recognised here are common in the Miocene deposits of the Central Paratethys (e.g., Reuss, 1871; Dembińska-Rózkowska, 1932; Kojumdgieva, 1960; Roniewicz and Stolarski, 1991; Stolarski, 1996) or the Mediterranean realm (e.g., Chaix and Saint Martin, 2008) and they were in the past the subjects of numerous and very detailed descriptions. Accordingly, the descriptions of most taxa are intentionally brief in the present paper.

The collected coral material presented here is housed in the Museum of the Faculty of Geology of the University of Warsaw; under the collection numbers MWGUW ZI/81.

Order Scleractinia Bourne, 1900  
 Family Faviidae Gregory, 1900  
 Subfamily Faviinae Gregory, 1900  
 Genus *Favia* Milne-Edwards, 1857

**Remarks:** Recent investigations have shown that extant Indo-Pacific representatives of the genus *Favia* should be assigned to the genus *Dipsastraea* de Blainville, 1830 of the family Mussidae Ortmann, 1890 (see Budd *et al.*, 2012; Huang *et al.*, 2014). Thus, it is very probable that fossil representatives of the genus *Favia* from Paratethyan realm also may be assigned to the genus *Dipsastraea*. At present, this matter needs further study.

Representatives of the genus *Favia* seem to be the rarest elements of the coral assemblage from the Medobory Hills. Their fossils were not found during recent studies, but they were reported by Dembińska-Rózkowska (1932) as single specimens from just a few sites. The collected material permitted the recognition of two different taxa (see Dembińska-Rózkowska, 1932, pp. 129–130): *Favia friedbergi* n. sp. and *Favia corollaris* Reuss, 1871 (cited erroneously as *F. corollaris*). Unfortunately, as the material described by Dembińska-Rózkowska came from various (both state-owned and private) collections and the repositories of the mentioned specimens were not indicated, it was impossible to examine these specimens nowadays.

*Favia corollaris* Reuss, 1871

\* 1871 *Favia corollaris* n. sp. – Reuss, pp. 238–239, pl. 9, fig. 2, pl. 18, fig. 4.

1932 *Favia corollaris* Reuss – Dembińska-Rózkowska, p. 130, pl. 2, fig. 9.

**Remarks:** The species *Favia corollaris* seems to be extremely rare in the Ternopil Beds. Two specimens of this species were reported by Dembińska-Rózkowska (1932) from one site in Medobory Hills and another one in their close proximity (respectively: Zbarazh and Skala). Unfortunately, the present location of the mentioned specimens was not determined and it was impossible to study them nowadays. Also, intensive fieldworks during the preparation of this study did not reveal any new occurrences nor specimens of *Favia corollaris* in the Ternopil Beds. *Favia corollaris* was also reported from the Miocene of Hungary (Reuss, 1871) and western France (Cahuzac and Chaix, 1993).

The description of the species presented by Dembińska-Rózkowska (1932) gives the most significant features. The colonies are flat, the calices are round or slightly oval, 7–8.5 mm of diameter, close to each other. The number of septa is 36–40. The costae are wide and rounded, often covered by calcareous deposits.

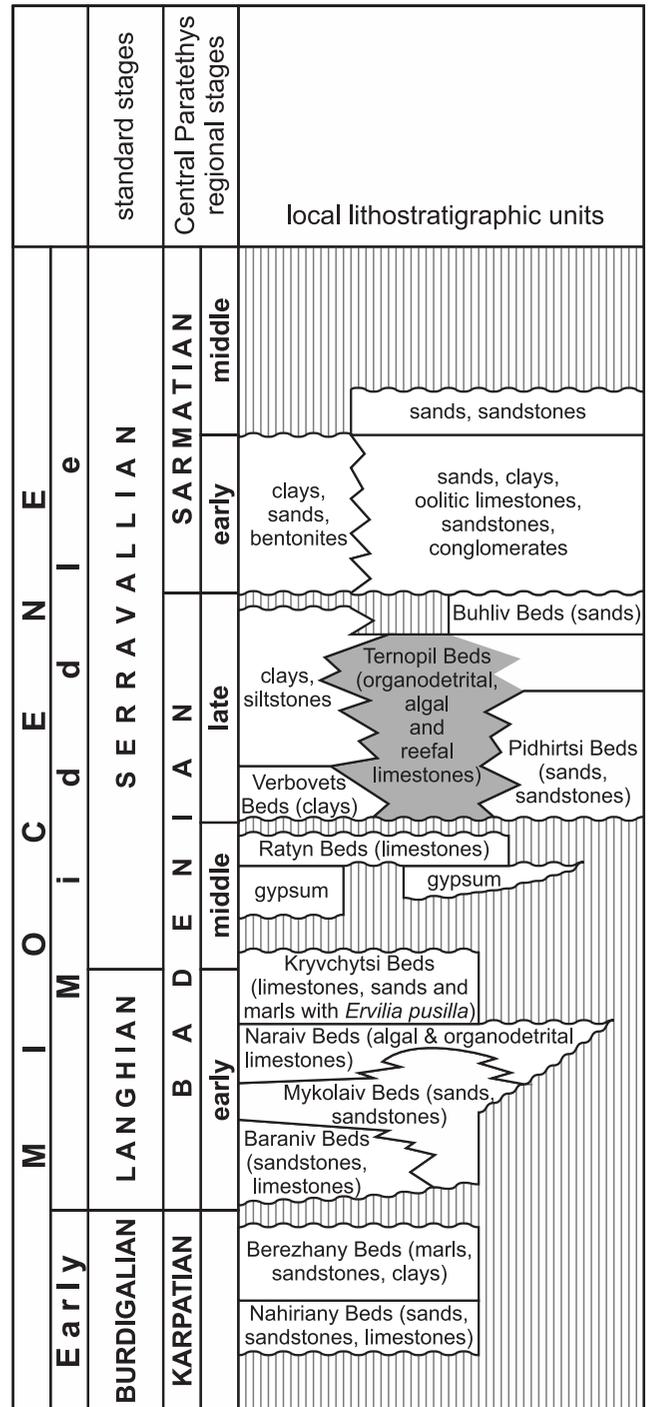
*Favia friedbergi* Dembińska-Rózkowska, 1932

\* 1932 *Favia Friedbergi* n. sp. – Dembińska-Rózkowska, pp. 129–130, pl. 3, fig. 1.

**Remarks:** The species *Favia friedbergi* is known exclusively from the Ternopil Beds of western Ukraine and seems to be very rare there. Three isolated specimens were reported by Dembińska-Rózkowska (1932) from three different sites along the Medobory Hills: Mount Bohit, Zbarazh and Chystopady near Hai Roztotski. Again, the repository of

the specimens was not determined and they were not re-examined. No specimens of *Favia friedbergi* were also found during the preparation of this study despite of numerous attempts.

The main diagnostic features of *Favia friedbergi* (after Dembińska-Rózkowska, 1932) are as follows: the colony is round and calices are distributed irregularly. Their diameters vary from 3 to 14 mm and the distance between them may reach up to 10 mm. Calices are round or slightly oval



**Fig. 2.** Position of the upper Badenian coral-bearing deposits of Ternopil Beds studied in western Ukraine within the regional and standard zonation schemes (compiled from: Andreyeva-Grigovich *et al.*, 1997; Górká *et al.*, 2012; Radwański *et al.*, 2014).

and the number of septa varies from 26 to 86, depending on the size and shape of calice.

Closer examination of the illustrated material showed that the exceptional calice of the largest size (e.g., its longer axis) and with the most numerous septa was in fact in the stage of extratentacular budding (see Dembińska-Rózkowska, 1932, pl. 3, fig. 1).

Genus *Tarbellastraea* Alloiteau, 1952

*Tarbellastraea reussiana*

(Milne-Edwards and Haime, 1850)

Fig. 3

- \* 1850 *Astrea Reussiana* n. sp. – Milne-Edwards and Haime, p. 110.
- 1871 *Heliastrea Reussana* Milne-Edwards and Haime – Reuss, p. 240, pl. 9, fig. 2, pl. 18, fig. 4.
- 1871 *Heliastrea conoidea* n. sp. – Reuss, pp. 240–241, pl. 10, fig. 3.
- 1932 *Orbicella Reussiana* Milne-Edwards and Haime – Dembińska-Rózkowska, p. 124, pl. 2, fig. 2.
- 1932 *Orbicella Reussiana* Milne-Edwards and Haime var. *minor* Felix – Dembińska-Rózkowska, p. 125.
- 1932 *Orbicella conoidea* Reuss – Dembińska-Rózkowska, p. 125, pl. 2, fig. 3.
- 1932 *Orbicella plana* Michelin – Dembińska-Rózkowska, pp. 125–126, pl. 2, fig. 4.
- 1937 *Orbicella reussiana* Milne-Edwards and Haime – Davidashvili, pp. 549–551, pl. 2, figs 1–2.
- 1952 *Orbicella reussiana* Milne-Edwards and Haime – Kopek, pp. 72–74, pl. 12, figs 1–2, pl. 13, figs 1, 3.
- 1954 *Orbicella reussiana* (Milne-Edwards and Haime) – Kopek, p. 9, pl. 1, figs 9–12.
- 1960 *Heliastrea reussiana* (Milne-Edwards and Haime) – Kojumdgieva, pp. 16–17, pl. 3, figs 3–4.
- 1960 *Heliastrea reussiana* var. *minor* Felix – Kojumdgieva, p. 17, pl. 4, fig. 1.
- 1963 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Kühn, p. 104–105, pl. 1, figs 4–6
- 1977 *Orbicella reussiana* Milne-Edwards and Haime – Yanakevich, p. 83, pl. 1, fig. 7.
- 1990 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Oosterbaan, p. 9, pl. 1, fig. 3.
- 1991 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Roniewicz and Stolarski, pp. 73–74, pl. 2, figs 1–3.
- 1996 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Budd *et al.*, pp. 551–552, pl. 4, figs 5–6, pl. 5, figs 1–12.
- 1996 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Stolarski, p. 630, pl. 176, fig. 2.
- 2005 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Chaix and Cahuzac, pl. 1, fig. 1.

- 2006 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Radwański *et al.*, p. 94, fig. 7a.
- 2008 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Chaix and Saint Martin, pp. 189–190, fig. 2e.
- 2008 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Rus and Popa, p. 327, pl. 2, fig. 4.
- 2016 *Tarbellastraea reussiana* (Milne-Edwards and Haime) – Górka in Wysocka *et al.*, p. 366, fig. 7a–c.

**Material:** Ternopil Beds (late Badenian): Demkivtsi: 1 natural imprint (MWGUW ZI/81/025); Ditkivtsi: 1 natural imprint (MWGUW ZI/81/043); Haluschyntsi: 13 fragments and natural imprints (MWGUW ZI/81/039–040); Hument-si: 2 large fragments (MWGUW ZI/81/006–007); Komariv: 1 natural imprint (MWGUW ZI/81/044); Maksymivka: 15 fragments and natural imprints (MWGUW ZI/81/001, 045–049); Nihyn: 2 fragments (MWGUW ZI/81/009); Novosilka: 5 fragments and natural imprints (MWGUW ZI/81/036, 038); Polupanivka: 4 fragments (MWGUW ZI/81/032–035); Sakhkamin: 20 fragments and natural imprints (MWGUW ZI/81/012–016, 019–020); Zakupne: 5 natural imprints (MWGUW ZI/81/027–028, 030). Also documented from Staryi Zbarazh.

**Description:** Colonies are massive, branching or fan-shaped. Corallites are plocoid and circular or ovoid in outline and with diameters 1.0–3.5 mm. Spaces between corallites vary from 0.5 to 3.3 mm. There are 20–24 septa of three cycles; septa of the two first cycles reach the columella. In some cases, the columella is absent. The coenosteum is adorned with numerous costae.

**Remarks:** *Tarbellastraea reussiana* is distributed widely in the Miocene deposits of almost the entire Paratethyan and Mediterranean realms. Its ubiquitous records appeared since the establishment of the species (see below). Simultaneously, numerous new species of *Tarbellastraea* were established and/or re-assigned (e.g., Budd *et al.*, 1996), or referred to it (e.g., Dembińska-Rózkowska, 1932). These new species/subspecies or varieties often sooner or later were synonymised with *Tarbellastraea reussiana* (e.g., Roniewicz and Stolarski, 1991; Budd *et al.*, 1996; Chaix and Saint Martin, 2008). Thus, it becomes obvious that within the genus *Tarbellastraea* further taxonomic changes are still possible and the present specific composition of this genus has some degree of uncertainty.

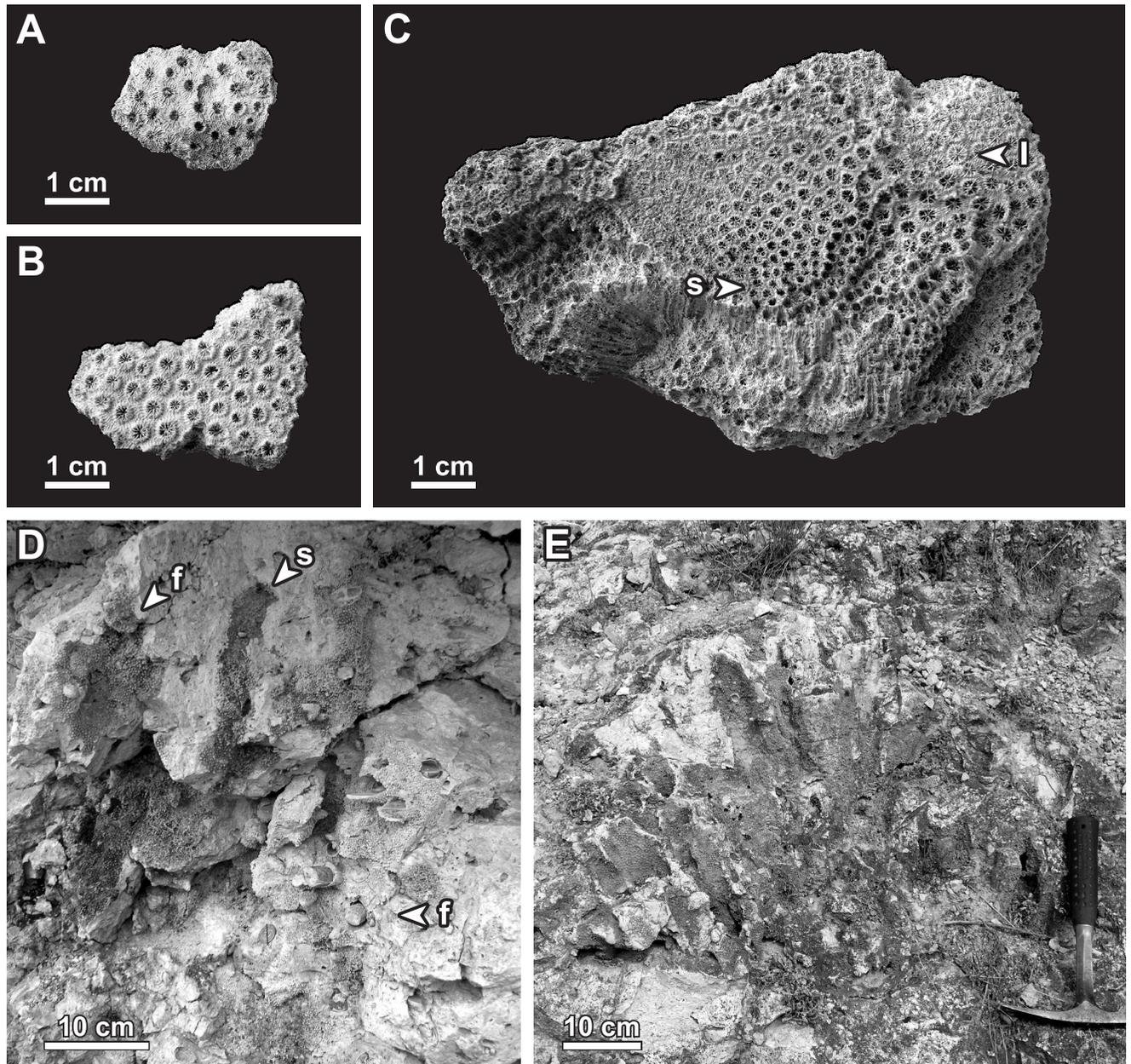
The material of the genus *Tarbellastraea*, collected in the Ternopil Beds of western Ukraine, shows distinct similarity to the specimens described by Dembińska-Rózkowska (1932), who distinguishes four different taxa within that genus; they later were assigned by Roniewicz and Stolarski (1991) to one species *T. reussiana*. The minor differences, such as smaller calices, that could be observed in some specimens (see Fig. 3A, B) fit in the spectrum of intraspecific variability of that species (see descriptions in Dembińska-Rózkowska, 1932; Roniewicz and Stolarski, 1991; Stolarski, 1996). This conclusion is confirmed by the presence of specimens, in which the calice diameter changes significantly within a distance of centimetres (Fig. 3C);

this feature shows clearly that the diameter of calyces is a parameter of lesser diagnostic importance (see also Dembińska-Rózkowska, 1932, p. 124). Considering all these circumstances, all representatives of genus *Tarbellastraea* from Ternopil Beds are counted here among species *Tarbellastraea reussiana*.

Setting aside taxonomic concerns, it must be stated that the colonies of *Tarbellastraea reussiana* are of the most diversified shapes and sizes within the entire coral assemblage of the Ternopil Beds. The thinnest colonies are platy, encrusting forms, similar in appearance to those described by Dembińska-Rózkowska (1932) as *Orbicella plana* Miche-

lin. The thickness of colonies reaches about 1–2 cm, and the lateral dimensions reach up to 20 cm.

More diversified shapes of colonies are branching forms, built of numerous vertical sticks (Fig. 3D, E). The size of such bushy colonies may reach as much as tens of centimetres (see also Radwański *et al.*, 2006, fig. 7a; Górka *et al.*, 2012, fig. 12e; Górka in Wysocka *et al.*, 2016, fig. 7b); the diameter of a single branch (“stick”) varies from 1.5 up to 4 cm. The length (height) of a single branch may exceed 30 cm. The diameters of calices often are distinctly larger than those from colonies of other shapes. This morphological form is most concordant with material referred to by



**Fig. 3.** *Tarbellastraea reussiana* (Milne-Edwards & Haime) from the upper Badenian Ternopil Beds of western Ukraine. **A.** Fragment of colony with small calices and wide inter-calice spaces, top view (specimen no. MWGUW ZI/81/019 from Sakhkamin). **B.** Fragment of colony with wide calices and small inter-calice spaces, top view (specimen no. MWGUW ZI/81/020 from Sakhkamin). **C.** Fragment of colony with calices differing in size, top view (specimen no. MWGUW ZI/81/007 from Humentsi). **D.** Natural imprint of colony made up of flat branches (“f”) passing upwards into vertical (“s”) sticks (field photo from Demkivtsi). **E.** Natural imprint of bush-shaped colony made up of large sticks (field photo from Demkivtsi).

Dembińska-Rózkowska (1932) as *Orbicella conoidea* Reuss (see also Oosterbaan, 1990). The larger diameter of calices probably may be explained by the rapid increase in “stick” diameter (and its outer surface), caused by the growth of corallites. If this “swelling” is not compensated by the development of new corallites, it must lead to an increase in corallites diameter and/or the spaces between them.

Other morphological forms that are in part similar to the branching ones are those constructed by vertical, fan-like branches. Such colonies often bear additional folds and there are also subordinate branches, giving them an overall resemblance to the deformed antlers of a moose (Fig. 3D). Very similar colonies were described as “flat branches or blades” by Bossio *et al.* (1996). The entire shape of colonies is quite complex and thus not easy to reconstruct, as it is usually embedded in a boundstone matrix and only empty moulds and/or the imprints of colonies may be observed in two-dimensional sections.

The last morphological variety of *Tarbellastraea reussiana* takes the form of massive colonies (Górka *et al.*, 2012, fig. 12D). Dome-shaped colonies are rare; the shapes are very differentiated and often irregular. This feature most probably reflects numerous syn-depositional factors, among them competition with other rock-forming organisms, such as coralligenous algae. The largest of the massive colonies usually can reach up to 50 cm in height and almost 100 cm in width.

Colonies of *Tarbellastraea reussiana* from the Ternopil Beds often bear the traces of boring bivalves (Fig. 3D; Radwański *et al.*, 2006, fig. 7a).

**Distribution:** *Tarbellastraea reussiana* is common in Badenian of almost the entire Central Paratethys. It was recorded in Austria (Reuss, 1847), Bulgaria (Kojumdgieva, 1960), Croatia (Sremac *et al.*, 2015), Hungary (Kopek, 1954), Moldova (Yanakevich, 1977), Poland (Dembińska-Rózkowska, 1932; Roniewicz and Stolarski, 1991), Romania (Rus and Popa, 2008), Slovakia (Kopek, 1952), and Ukraine (Dembińska-Rózkowska, 1932; Davidashvili, 1937; Radwański *et al.*, 2006).

In the Mediterranean realm, this species is common (see details in Chaix and Saint Martin, 2008); it is also present in the Miocene of western France (Cahuzac and Chaix, 1993; Chaix and Cahuzac, 2005).

Family Montastraeidae Yabe and Sugiyama, 1941

Genus *Heliastrea* Milne-Edwards, 1857

*Heliastrea defrancei* Milne-Edwards and Haime, 1850

Fig. 4

- \* 1850 *Astrea Defranciai* n. sp. – Milne-Edwards and Haime, pp. 106–107.
- 1871 *Heliastrea Defrancei* (Milne-Edwards and Haime) – Reuss, pp. 239–240, pl. 9, fig. 3, pl. 10, fig. 1.
- 1954 *Orbicella defrancei* (Milne-Edwards and Haime) – Kopek, pp. 10–11, pl. 2, figs 4–6.
- 1960 *Heliastrea defrancei* (Milne-Edwards and Haime) – Kojumdgieva, p. 16, pl. 3, figs 1–2.

2008 *Montastraea tchihatcheffi* (Chevalier) – Rus and Popa, p. 327, pl. 2, fig. 2.

2016 ?*Montastrea* sp. – Górka in Wysocka *et al.*, p. 366, fig. 8d.

**Material:** Ternopil Beds (late Badenian): D itkivtsi: 1 natural imprint (MWGUW ZI/81/041); Maksymivka: 3 fragments (MWGUW ZI/81/050); Novosilka: 1 natural imprint (MWGUW ZI/81/038); Sakhkamin: 4 natural imprints (MWGUW ZI/81/021–024); Staryi Zbarazh: 1 fragment (MWGUW ZI/81/005). Also documented from: Demkivtsi, Hai Roztotski, Zakupne.

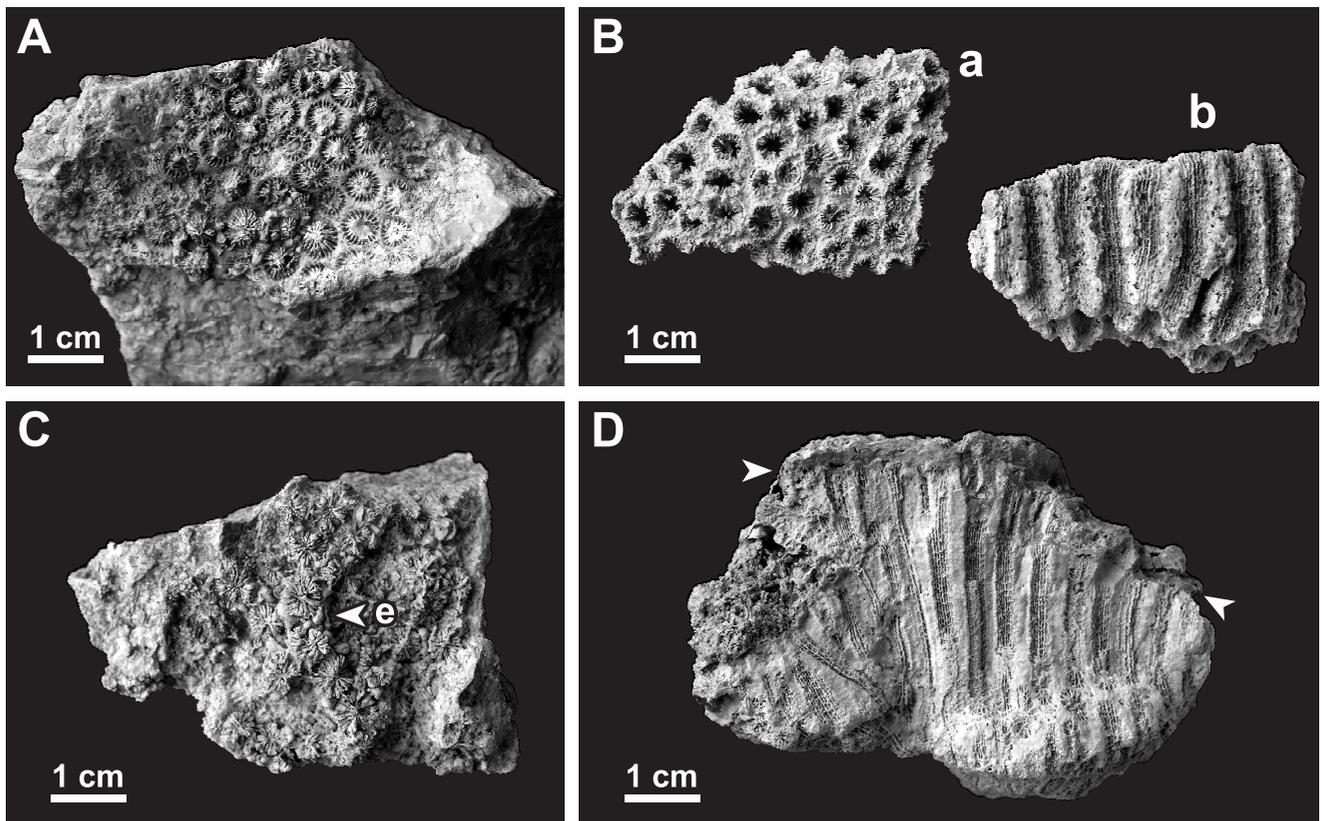
**Description:** The colonies are massive, plocoid corallites are circular and with diameters of 4.0–5.2 mm and distances between them of about 1.0–1.5 mm. The number of septa varies from 26 to 30. The original coenosteum surface was not observed, owing to the poor state of preservation.

**Remarks:** *Heliastrea defrancei* from the lithofacies discussed may be characterised by relatively a small diameter of calices and thus it shows a great resemblance to specimens described by Kopek (1954) from Hungary. Specimens of this species are relatively scarce within the Ternopil Beds, but its occurrences indicate that it is present along the entire length of the Medobory Hills. Recorded specimens previously were described as *Montastrea* sp. (Radwański *et al.*, 2006; Górka *et al.*, 2012, fig. 12c; Górka in Wysocka *et al.*, 2016, fig. 8d). This distinct similarity between *H. defrancei* and the genus *Montastrea* de Blainville, 1830 was emphasised when the species was renamed by Chevalier (1961) as *H. tchihatcheffi* and later assigned to the genus *Montastraea* as *M. tchihatcheffi* (e.g., Rus and Popa, 2008).

However, as this assignment was not confirmed as yet, the taxon is here still described as *H. defrancei*. Moreover, as the taxonomic relations between *Heliastrea* and *Montastrea* remain unsolved (Chaix and Cahuzac, 2005; Chaix and Saint Martin, 2008), this seems to be the most acceptable, though probably temporary solution.

Specimens of *H. defrancei* in most cases occur as natural imprints of the colony’s upper surface (Fig. 4A–C) and only rarely is the colony preserved (i.e., not dissolved, but neomorphised; Fig. 4B–D). Imprints show numerous traces of boring clionid sponges, preserved as natural moulds (“*Entobia* balls”; see Radwański *et al.*, 2011). The high density of such traces on the upper surfaces of colonies (Fig. 4C) clearly shows that the borings developed after the death of the coral. In addition to the traces of boring sponges, those of boring bivalves (*Gastrochaenolites* isp.) also were found.

**Distribution:** Representatives of *Heliastrea defrancei* were found in the Miocene of Central Paratethys in present-day Austria, Czech Republic, and Hungary (Reuss, 1847; Kopek, 1954); it is also present in the Badenian of Bulgaria (Kojumdgieva, 1960) and Romania (Rus and Popa, 2008). In the Mediterranean realm, this species was found in Italy and Turkey (see Milne-Edwards and Haime, 1849; Kühn, 1926); it was also recorded in the Miocene of Aquitaine (Bordeaux, see Milne-Edwards and Haime, 1849).



**Fig. 4.** *Heliastraea defrancei* (Milne-Edwards & Haime) from the upper Badenian Ternopil Beds of western Ukraine. **A.** Natural imprint of the upper surface of a colony (specimen no. MWGUW ZI/81/024 from Sakhkamin). **B.** Fragment of a well-preserved colony, a – top view, b – side view (specimen no. MWGUW ZI/81/005 from Saryi Zbarazh). **C.** Natural imprint of the upper surface of colony, “e” – “*Entobia* balls” – moulds of borings of clionid sponges (specimen no. MWGUW ZI/81/021 from Sakhkamin). **D.** Fragment of a colony with encrustations of coralline-algae, resulting in temporal halt in coral development (specimen no. MWGUW ZI/81/050a from Maksymivka).

Family Siderastreae Vaughan and Wells, 1943

Genus *Siderastrea* de Blainville, 1830

*Siderastrea italica* (Defrance, 1826)

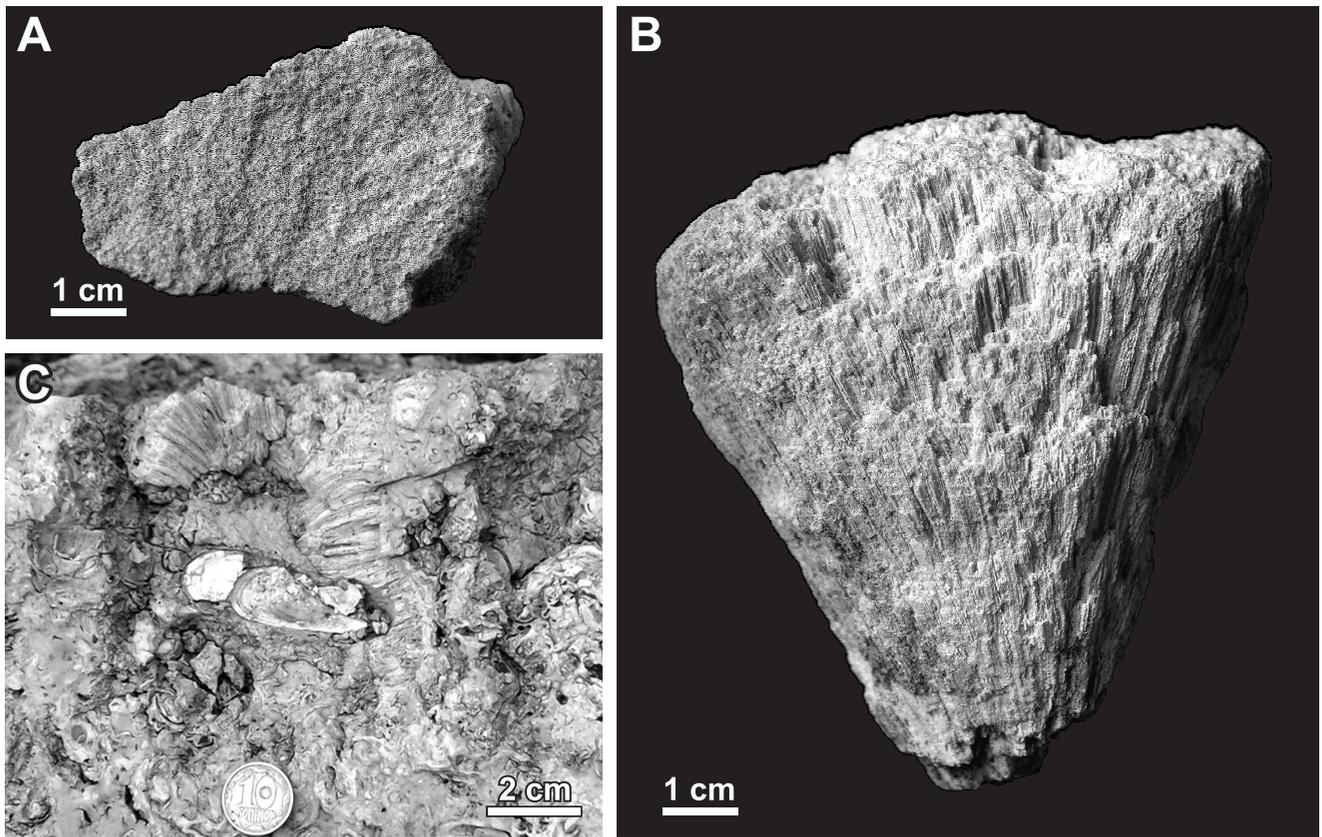
Fig. 5

- \* 1826 *Astrea italica* n. sp. – Defrance, pp. 382–383.
- 1932 *Siderastraea italica* (Defrance) – Dembińska-Rózkowska, p. 133, pl. 4, fig. 1.
- 1937 *Siderastraea* cf. *italica* (Defrance) – Davidashvili, pp. 551–553, fig. 2, pl. 2, figs 3–4.
- 1991 *Siderastraea italica* (Defrance) – Roniewicz and Stolarski, pp. 76–77, pl. 4, fig. 1.
- 1996 *Siderastraea italica* (Defrance) – Stolarski, p. 632, pl. 175, fig. 1.
- 2005 *Siderastraea miocenica italica* (Defrance) – Chaix and Cahuzac, pl. 3, fig. 2.
- 2008 *Siderastraea miocenica italica* (Defrance) – Chaix and Saint Martin, pp. 196–197, fig. 4d.
- 2016 *Siderastraea* cf. *italica* (Defrance) – Górka in Wysocka *et al.*, p. 366, fig. 7d.

**Material:** Ternopil Beds (late Badenian): Humentsi: 1 large fragment (MWGUW ZI/81/004); Maksymivka: 1 large fragment (MWGUW ZI/81/002); Zakupne: 3 fragments (MWGUW ZI/81/029). Also documented from: Demkivtsi.

**Description:** Relatively large, massive, cerioidal colonies. The calices are polygonal with diameters ranging from 3.6 to 4.6 mm. There are usually 31–34 septa (but up to 44 in the largest corallites). First-cycle septa are fused with a distinct columella.

**Remarks:** The features of the material agree with descriptions presented by Dembińska-Rózkowska (1932) and Roniewicz and Stolarski (1991). The presence of *Siderastraea italica* in the Ternopil Beds previously was recorded by Dembińska-Rózkowska (1932) and Davidashvili (1937). Dembińska-Rózkowska described from the Medobory Hills two new species: *S. felixi* and *S. lomnickii* (Dembińska-Rózkowska, 1932). According to Davidashvili (1937), these two species may be just ecological varieties of *S. italica*. Chevalier (1961) also suggested that *S. lomnickii* should be synonymised with *S. italica* (see Roniewicz and Stolarski, 1991). To the contrary, Chevalier (1962) and later Chaix and Saint Martin (2008) retained *S. felixi* as a separate species.



**Fig. 5.** *Siderastraea italica* (Defrance) from the upper Badenian Ternopil Beds of western Ukraine. **A.** Fragment of a well-preserved, massive colony, top view (specimen no. MWGUW ZI/81/029a from Zakupne). **B.** Fragment of a large, massive colony, side view (specimen No. MWGUW ZI/81/002 from Maksymivka). **C.** Fragment of a large colony with boring and shell of *Lithophaga* sp. (specimen no. MWGUW ZI/81/004 from Humentsi, field photograph).

However, it must be emphasized that the remains of *Siderastraea italica* are quite uncommon among corals of the lithofacies investigated. Its presence was recorded at four localities, where fragments of large, massive colonies were found (Fig. 5A, B). Their maximum recorded size was about 15 cm (Górka *et al.*, 2012, fig. 12f; Górka in Wysocka *et al.*, 2016, fig. 7d). Unlike other recorded taxa, no imprints or traces of dissolved *S. italica* colonies were found. The collected material bears the traces of bioerosion, large bivalve borings that may be attributed to *Lithophaga* sp. (see Fig. 5C).

**Distribution:** *Siderastraea italica* was found in the Badenian of Central Paratethys in Austria (Reuss, 1847), Poland (Roniewicz and Stolarski, 1991), Romania (Rus and Popa, 2008), and Ukraine (Dembińska-Rózkowska, 1932; Davidashvili, 1937). In the Mediterranean realm, this species was found in Turkey (Kühn, 1926) and Algeria (Chaix and Saint Martin, 2008); it was also present in the Miocene of Aquitaine (Chaix and Cahuzac, 2005).

Family Poritidae Gray, 1842

Genus *Porites* Link, 1807

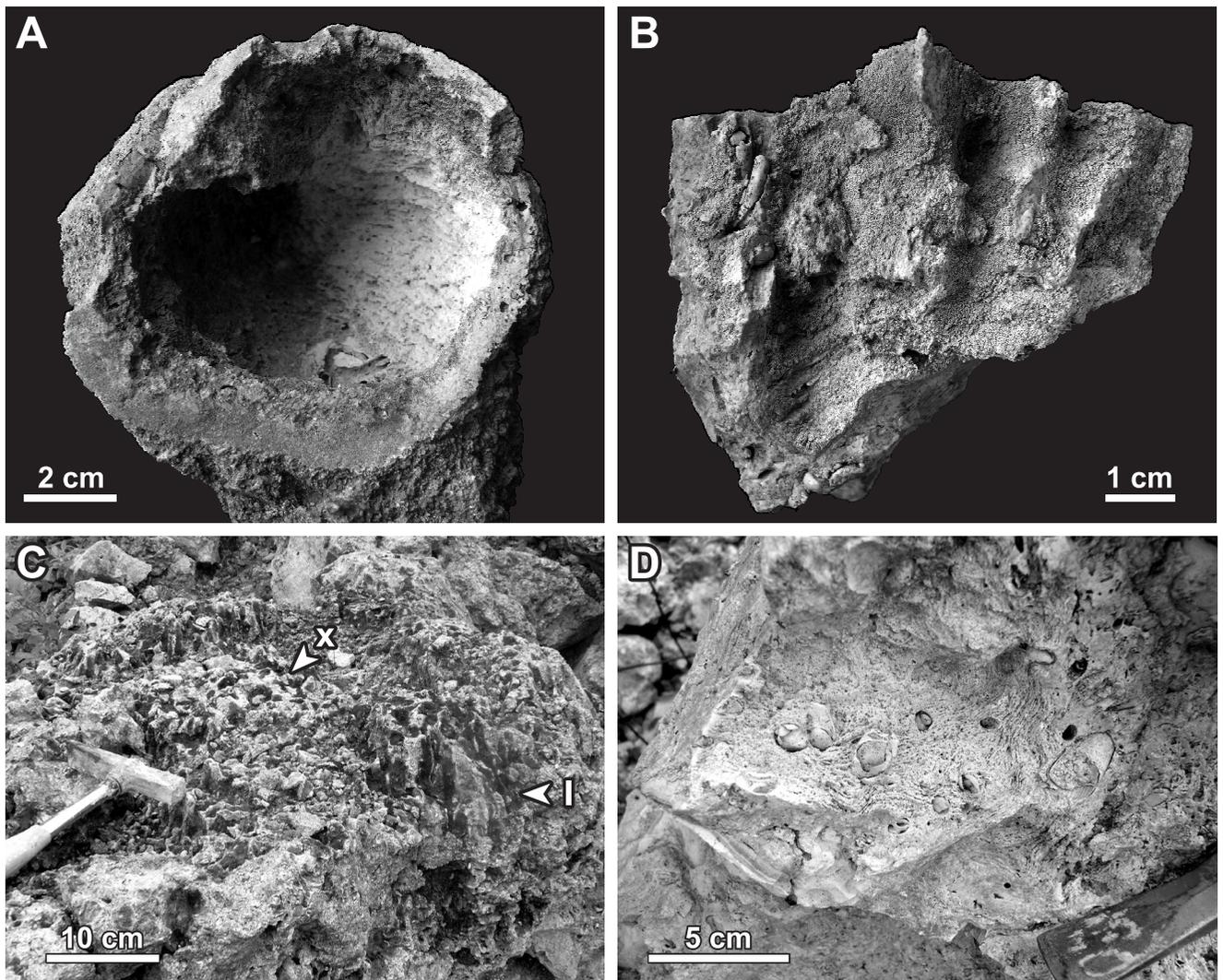
*Porites vindobonarum prima* Kühn in Felix, 1927

Fig. 6

\* 1927 *Porites vindobonarum prima* n. sp. – Kühn in Felix, p. 473.

- 1932 *Porites vindobonarum prima* Kühn in Felix – Dembińska-Rózkowska, pp. 154–156, pl. 6, fig. 10.  
 1960 *Porites vindobonarum prima* Kühn in Felix – Kojumdgieva, p. 24, pl. 7, figs 3–4.  
 1991 *Porites vindobonarum prima* Kühn in Felix – Roniewicz and Stolarski, pp. 77–78, pl. 4, fig. 3.  
 1996 *Porites vindobonarum prima* Kühn in Felix – Stolarski, p. 632, pl. 176, fig. 3.  
 2006 *Porites vindobonarum prima* (Kühn in Felix) – Radwański *et al.*, p. 94, pl. 1, fig. 1.  
 2008 *Porites vindobonarum prima* Kühn in Felix – Rus and Popa, p. 331, pl. 4, fig. 3.  
 2016 *Porites vindobonarum prima* Kühn in Felix – Górka in Wysocka *et al.*, p. 366, fig. 8a–c.

**Material:** Ternopil Beds (late Badenian): Demkivtsi: 1 fragment (MWGUW ZI/81/026); Ditkivtsi: 1 large fragment (MWGUW ZI/81/042); Humentsi: 1 large fragment (MWGUW ZI/81/008); Maksymivka: 2 fragments (MWGUW ZI/81/051–052); Nihyn: 1 large colony, partially dissolved (MWGUW ZI/81/010); Novosilka: 1 fragment (MWGUW ZI/81/037); Polupanivka: 1 fragment (MWGUW ZI/81/035); Sakhkamin: 7 fragments and natural imprints (MWGUW ZI/81/003, 011, 017–018); Zakupne: 1 fragment (MWGUW ZI/81/031).



**Fig. 6.** *Porites vindobonarum prima* Kühn in Felix from the upper Badenian Ternopil Beds of western Ukraine. **A.** Spheroidal colony, partially neomorphised, internal part completely dissolved (specimen no. MWGUW ZI/81/010 from Nihyn). **B.** Natural imprint of a branching “organ pipe” colony, side view (specimen no. MWGUW ZI/81/018 from Sakhkamin). **C.** Large branching “organ pipe” colony, “x” – cross-sections, “l” – longitudinal sections (field photograph from Sakhkamin). **D.** Partially neomorphised massive colony with numerous borings of bivalves, mainly *Lithophaga* sp. (field photograph from Zakupne).

**Description:** Colony form differs from lamellar/encrusting to massive; there are also branching forms. Corallites of small diameter (1.0–1.5 mm) are divided by thin polygonal walls. Septa are visible, but owing to the high degree of diagenesis (dissolution and/or neomorphism), the details of them are usually indistinct.

**Remarks:** Recorded specimens of *Porites vindobonarum prima* are similar to specimens described from the present-day Ukraine by Dembińska-Rózkowska (1932) and from Poland by Roniewicz and Stolarski (1991) and Stolarski (1996). This species is quite common in the Ternopil Beds; its frequency is similar to that of *Tarbellastraea reussiana*. Also, as in the latter species, colonies of *P. vindobonarum prima* appear in a variety of shapes and sizes. Colonies are either neomorphised and/or dissolved, so that only imprints of their outer surfaces are visible. In many cases, additional material (shell grit, lime mud) was amassed in the voids after dissolved corals.

Two morphological forms are the most common: massive, often spheroidal colonies (Fig. 6A; Radwański *et al.*, 2006, pl. 1, fig. 1; Górka *et al.*, 2012, fig. 12a; Górka in Wysocka *et al.*, 2016, fig. 8a) and thin, encrusting ones. The latter may be as thin as a few mm and usually are overgrown by coralline-algal thalli. With an increase in thickness, these colonies may become massive. The largest massive colonies may reach 30 cm in size.

The most spectacular forms are less frequent branching, stick-like colonies. They were most abundant in Sakhkamin (Fig. 6C; Górka *et al.*, 2012, fig. 12b; Górka in Wysocka *et al.*, 2016, fig. 8b). The diameter of the sticks varies from 1.5 cm up to 3 cm and their height may reach 20 cm. The distance between sticks varies from about 2 to 6 cm (Fig. 6B).

The moulds of borings, attributable to bivalves *Jouanetta* sp. and *Lithophaga* sp., are relatively common in the colonies of *P. vindobonarum prima* (Fig. 6D; e.g., Radwański *et al.*, 2006, pl. 1, fig. 2).

**Distribution:** *Porites vindobonarium prima* was found in the Badenian of Central Paratethys in Austria (Felix, 1927), Bulgaria (Kojumdgieva, 1960), Poland (Roniewicz and Stolarski, 1991), Romania (Rus and Popa, 2008), and Ukraine (Dembińska-Rózkowska, 1932; Radwański *et al.*, 2006; Górka *et al.*, 2012; Górka in Wysocka *et al.*, 2016).

## PALAEOENVIRONMENT

The development of coral faunas in the Central Paratethys was possible, owing to the climatic optimum that appeared during the span of the Badenian (Itoigawa, 1989; Müller, 1996; Böhme, 2003; see also Bosellini and Perrin, 2008). As a result, the distribution limits of numerous organic groups typical of warm-water-to-tropical areas shifted northward. Rich and diversified faunas appeared in the Fore-Carpathian Basin, comprising the northernmost part of the Central Paratethys, and numerous fossil assemblages are common in both the lower Badenian and the upper Badenian deposits (e.g., Davidashvili, 1937; Kudrin, 1966; Yanakevich, 1977; Bałuk and Radwański, 1977, 1979, 1984; Wysocka *et al.*, 2012.). The decline in faunal diversity between these two stratigraphic levels marks the mid-Badenian episode of a cool climate (Radwański *et al.*, 2014). The re-establishment of warm-climatic conditions after this cooler episode is clearly marked by the development of the late Badenian coral fauna in western Ukraine, Moldova and NE Romania.

Unlike other faunistic assemblages (Davidashvili, 1937; Yanakevich, 1977; Radwański *et al.*, 2006, 2014), the late Badenian coral fauna has a relatively low diversity, comprising of only 5 genera, in which the representatives of two (*Tarbellastraea* and *Porites*) predominate. This is clearly an effect of different ecological factors that even could have been superimposed during the development of the corals. The Medobory Hills are located at a high palaeolatitude, which puts the study area at the northernmost limit of coral distribution (see Wiedl *et al.*, 2013). Moreover, the Fore-Carpathian Basin during the late Badenian was a long and relatively narrow bay, surrounded by large landmasses, including the Carpathian orogenic belt (Oszczypko, 1997; Popov *et al.*, 2004; Harzhauser and Piller, 2007; Kováč *et al.*, 2007; Wysocka *et al.*, 2016), which provided a large input of fine terrigenous material that was deposited in central parts of Fore-Carpathian Basin and in close proximity to Medobory (Fig. 1B). Suspended fine-grained material strongly affected the coral assemblages and changed their taxonomic composition. This led to the disappearance of numerous taxa, but more resistant genera, such as *Porites* (see Müller, 1984; McCall *et al.*, 1994; Esteban, 1996; Drinia *et al.*, 2010), survived and dominated the coral assemblage, as is shown by monospecific occurrences of *P. vindobonarium prima* in particular zones of the Ternopil Beds. Such impoverished coral faunas, almost exclusively composed of these two genera (*Tarbellastraea* and *Porites*) and only locally accompanied by another taxa, are common in the Badenian of the Paratethys (Müller, 1984; Friebe, 1991, 1993; Riegl and Piller, 2000; Górka, 2002; Saint Martin *et al.*, 2007; Perrin and Bosellini, 2012; Wiedl *et al.*, 2013). In the Mediterranean realm, such assemblages developed in various

time spans: in the Burdigalian (Early Miocene) of Corsica (Galloni *et al.*, 2001) and in the Langhian (Middle Miocene) of Catalonia (Müller, 1993, Esteban *et al.*, 1996). The peak of their occurrences in the Mediterranean was in the Tortonian to Messinian (Late Miocene) at numerous localities within the entire Mediterranean. Their occurrences range from NW Africa (Saint Martin, 1996; Saint Martin and Cornée, 1996) through Spain (Calvet *et al.*, 1996; Esteban *et al.*, 1996; Pomar *et al.*, 1996), the Central Mediterranean (Grasso and Pedley, 1988; Bossio *et al.*, 1996; Pedley, 1996a,b; Bosellini *et al.*, 2001), to Greece (Drinia *et al.*, 2010; Pomoni *et al.*, 2013) and Turkey (Kühn, 1926; Hayward *et al.*, 1996). Some of the coral assemblages described from Miocene reefs of the Egyptian shore of the Red Sea and the Gulf of Suez (Purser *et al.*, 1996; Perrin *et al.*, 1998) also show significant resemblances to the coral fauna from the Medobory Hills.

In the Mediterranean area, there are numerous examples where a distinct zonation of coral shapes was recorded and this was attributed to variable hydrodynamic conditions during the growth of the coral reefs (Grasso and Pedley, 1988; Esteban *et al.*, 1996). Such zonation was also reported from the coral fauna of the Makran Range, Iran (McCall *et al.*, 1994). Surprisingly, despite of the high differentiation of shapes, a similar distinct zonation was not observed in the Ukrainian counterparts. The most probable reason was the relatively small thickness of coral accumulations in the Ternopil Beds, not allowing fully developed zonation within the coral concentrations.

The significant difference between the corals in the Medobory Hills and their occurrences in other regions are the overall ecological-depositional settings. While most of the Miocene coral build-ups in the Paratethyan and Mediterranean realms are readily distinguishable coral-carpet (e.g., Riegl and Piller, 2000), fringing reefs or patch-reefs (e.g., Grasso and Pedley, 1988), the situation in the Medobory Hills is different. The Ternopil Beds lack coral-dominated biostromes and/or bioherms; corals are subordinate to the main rock-building organisms, i.e. coralline algae. Another striking difference between the coral occurrences in the Medobory Hills and those of other areas is well marked by the lithology of accompanying deposits. The vast majority of reefs in the Paratethys and Mediterranean developed within clastic (organodetrital, bioclastic, and/or siliciclastic) successions of various thicknesses (e.g., Grasso and Pedley, 1988; Friebe, 1991, 1993; Hayward *et al.*, 1996). In contrast, the rock-forming corals of the Ternopil Beds occur in a large system of coralgal bioherms, forming a fossil barrier reef with a total length approaching 300 km (Górka *et al.*, 2012), i.e., within huge carbonate organogenic build-ups, rather than in environments dominated by clastic sedimentation.

## CONCLUSIONS

The coral assemblage from the late Badenian coralgal reefs of western Ukraine was dominated by two species (*Tarbellastraea reussiana* and *Porites vindobonarium prima*) and included four scarce taxa (*Favia friedbergi*, *Favia corollaris*, *Heliastrea defrancei*, *Siderastraea italica*). This

composition of zooxanthellate corals was very common in the Miocene in different types of coral build-up from the Paratethyan and Mediterranean realms.

The low taxonomic diversity of the corals reflects their development in conditions of ecological stress, either climatic (near the northern limit of coral distribution) or sedimentary (from the input of terrigenous material) in origin. However, the exact cause of such impoverishment in species is not evident and it is certainly more complex. Reports on other groups of organisms, such as bivalves (Studencka and Jasionowski, 2011), echinoids (Radwański *et al.*, 2014), and decapods (Górka *et al.*, 2012) confirm their high taxonomic diversity. This incongruity surely needs further studies. Such studies and more fieldwork also should help to reveal more details about representatives of the genus *Favia* in the Ternopil Beds.

The late Badenian corals in the Medobory Hills originated in a carbonate sedimentary environment, dominated by large coralgal bioherms and thus differing distinctly from the clastic environments in the Paratethys and Mediterranean realms, where build-ups of zooxanthellate corals developed.

### Acknowledgements

I wish to thank the late Andrzej Radwański and Anna Wysocka (both in the Faculty of Geology, University of Warsaw) for their interest and support in collecting fossil material in Ukraine. I also want to thank all my friends and colleagues, with whom I spent time during the fieldwork in Ukraine. Thus, very sincere thanks are offered to Marek Jasionowski and Tadeusz M. Peryt (both Geological Survey of Poland, Warsaw), Andriy V. Poberezhskyy and Oksana O. Stupka (both Institute of Geology and Geochemistry of Combustible Minerals, National Academy of Sciences of Ukraine, Lviv), Barbara Studencka (Museum of the Earth, Polish Academy of Sciences, Warsaw), Danuta Peryt (Institute of Paleobiology, Polish Academy of Sciences, Warsaw). Special thanks are expressed to Grzegorz Sujka, who kindly made available his collection of corals from Saryi Zbarazh, and to Olexander Stalennuy (Ternopil), who provided access to his collection of corals from Maksymivka. All of the helpful remarks of Ann F. Budd (Department of Earth and Environmental Sciences, University of Iowa, Iowa City), Tadeusz M. Peryt (Polish Geological Institute, Warsaw) and of an anonymous reviewer, who kindly commented on the manuscript, are deeply appreciated. The fieldwork was supported in part by Grant N 307 113635 of 2008–2011.

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