

# ATTI DELLA SOCIETÀ TOSCANA DI SCIENZE NATURALI

MEMORIE • SERIE A • VOLUME CXXVIII • ANNO 2021



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### FIRST REPORT OF *CLADOCORA ARBUSCULA* IN EARLY PLEISTOCENE DEPOSITS (WESTERN UMBRIA, ITALY) AND ITS RELATIONSHIPS WITH THE DISTRIBUTION OF *CLADOCORA CAESPITOSA*

**Abstract** - A. BALDANZA, R. BIZZARRI, F. FAMIANI, L. FARALLI, *First* report of Cladocora arbuscula in Early Pleistocene deposits (Western Umbria, Italy) and its relationships with the distribution of Cladocora caespitosa.

Corals ascribed to the species Cladocora caespitosa (Linnaeus, 1767) and secondarily to sister taxa are widespread in the present-day Mediterranean Sea. Although C. caespitosa was documented from Pliocene onward, it was commonly correlated to the Tyrrhenian (Marine Isotopic Stage 5, MIS5), particularly in the Italian fossil record. In many cases, the presence of C. caespitosa alone was considered a datum event marking the Pleistocene. In early Pleistocene deposits of Western Umbria, central Italy, several Cladocora horizons were recognized. The first known record of Cladocora arbuscula (Le Sueur, 1820) in early Pleistocene clay to sand deposits is presented here, and this also represents the first fossil datum of the species from the whole Mediterranean area. Inside deposits related to rocky coast environment, the two species coexisted. The paleoecology seems to be different for the two species, as C. caespitosa colonies develop in the shoreface and/or the beachface, while C. arbuscula prefers the distal and less energetic "transition to offshore" environment. Nevertheless, their occurrence records the same depositional phases during the evolution of the rocky coast. Like C. caespitosa, C. arbuscula probably formed small patchreefs during transgressive and high-stand system-tracts.

Key words - coral bioconstructions, *Cladocora caespitosa, Cladocora arbuscula*, deltaic and rocky coasts, early Pleistocene, Umbria, Italy

**Riassunto** - A. BALDANZA, R. BIZZARRI, F. FAMIANI, L. FARALLI, *Prima* segnalazione di Cladocora arbuscula in depositi del Pleistocene inferiore (Umbria occidentale) e relazione con la distribuzione di Cladocora caespitosa.

La presenza diffusa di coralli appartenenti al genere Cladocora nel Mediterraneo è documentata a partire dal Pliocene. Nella documentazione fossile italiana, la presenza di Cladocora caespitosa (Linnaeus, 1767) è comunemente associata al Tirreniano e in particolare allo stage isotopico MIS5, tuttavia la specie è documentata anche in depositi del Pleistocene inferiore e medio. All'interno di depositi del Pleistocene inferiore nell'Umbria occidentale (Italia centrale), sono stati riconosciuti diversi orizzonti a Cladocora. Presentiamo la prima segnalazione di Cladocora arbuscula (Le Sueur, 1820) in depositi argilloso-sabbiosi del Pleistocene inferiore; questo ritrovamento costituisce anche il primo rinvenimento fossile della specie nell'area mediterranea. All'interno di depositi prossimi ad ambienti costieri rocciosi, le due specie C. caespitosa e C. arbuscula coesistevano. La ecologia e paleoecologia appare differente per le due specie: C. caespitosa si sviluppa in un contesto di shoreface-beachface, mentre C. arbuscula preferisce ambienti a minore energia nella transizione all'offshore. Tuttavia, la loro presenza ha registrato le stesse fasi deposizionali durante l'evoluzione della costa rocciosa. Oltre a *C. caespitosa*, si sono infatti sviluppati piccoli patch reefs di *C. arbuscula* durante fasi trasgressive e/o di stazionamento alto del livello marino.

Parole chiave - biocostruzioni a coralli, *Cladocora caespitosa, Cladocora arbuscula*, coste deltizie e rocciose, Pleistocene inferiore , Umbria, Italia

#### INTRODUCTION

The Scleractinian *Cladocora caespitosa* (Linnaeus, 1767) is the main native colonial zooxantellate coral living today in the Mediterranean. It belongs to the family Faviidae (Zibrowius, 1980), and colonized the Mediterranean Sea at least since the late Pliocene-early Pleistocene (Aguirre & Jiménez, 1998; Dornbos & Wilson, 1999). At present, the species colonises rocky and sandy bottoms from the sea surface down to 40 m depth (Peirano *et al.*, 2004), although it becomes rarer below 30 m (Kružić *et al.*, 2008). To grow, it usually needs firmground such as bedrock, isolated rocks, gravels and/or shell beds. Moreover, in the Mediterranean Sea *C. caespitosa* is one of the major benthic carbonate producers (Montagna *et al.*, 2007; Peirano *et al.*, 2001, 2004, 2009).

On the other hand, in the same basin the congeneric species *Cladocora arbuscula* (Le Sueur, 1820) seems subordinate, being reported as living only in the protected marine area of Porto Cesareo (Fanelli *et al.*, 2000) and in the Gulf of Gabes (El Kateb *et al.*, 2016; OBIS database, 2021). This species has never been documented in the fossil Mediterranean record.

*Cladocora arbuscula* (also named "Tube Coral" due to its tubular branches) is currently widespread in the Gulf of Mexico, Florida and Caribbean islands including the Bahamas archipelago. Minor occurrences are also reported from the southwestern coasts of Africa and South America, and the Galapagos Islands (OBIS database, 2021). Most records come from non deltaic coasts, where *C. arbuscula* proliferates between 1 and 25 m depth, in bottoms covered by vegetation,

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in shallow and protected lagoon environments, in soft substrates, and in the back reef, or at the base of the reef (Aronson & Precht, 2001; Baron-Szabo, 2005). It is found mainly in turbid waters, in high rates sedimentation settings, and is very tolerant to fluctuations in temperature and salinity. When they are attached to the hard substrate, colonies of C. arbuscula form small compact tufts, densely branched, with a length that varies from 2.5 to 15 cm; or, if it grows on a soft substrate, it can create free and delicate colonies that break when they are disturbed by currents. The short and tubular branches have evident longitudinal ribs, a diameter of the branch never exceeding 4 mm, and decreasing slightly near branch tips with single corallites having delicate and thin septa ribs alternating in two orders, and irregular light brown or dark brown teeth and translucent tentacles (Aronson & Precht, 2001).

In Western Umbria - Southeastern Tuscany, the presence of *Cladocora* colonies, ascribed to *C. caespitosa*, within early Pleistocene deposits was already documented (Ambrosetti *et al.*, 1987; Baldanza *et al.*, 2017; Bizzarri, 2010; Bizzarri & Baldanza, 2020; Checconi *et al.*, 2007; Jacobacci *et al.*, 1967, 1969, 1970; Monaco *et al.*, 2011) (Fig. 1).

On spring 2013, a geological survey was led on in the Civitella del Lago area (Umbria, central Italy) by SGA (Studio Geologi Associati), and a 30 m borehole was trigged near the Civitella del Lago cemetery (Figs 2 and 3). C. arbuscula specimens were recovered in the lowermost samples (Bizzarri & Baldanza, 2020) and here further analysed to shed light on the distribution of Cladocora horizons in early Pleistocene marine deposits of western Umbria and refine stratigraphic and paleoenvironmental inferences. Following this discovery, a review of past and present-day distribution of Cladocora in the Mediterranean area is also provided. Furthermore, the co-occurrence of these two species C. arbuscula and C. caespitosa, rarely documented together both in present-day and fossil record, is discussed.

#### GEOLOGICAL SETTINGS

The study area (Fig. 1), positioned in present-day western Umbria (central Italy), belongs to the Late Miocene-Holocene South Valdichiana extensional basin. Pliocene-Holocene marine to continental deposits, with volcanoclastic episodes, filled-up the basin bounded east- and westwards by Mesozoic-Cenozoic reliefs (Bizzarri & Baldanza, 2020, and references therein). Early Pleistocene marine deposits mainly belong to the "Chiani-Tevere Cycle" (Bizzarri & Baldanza, 2020), and span from Gelasian to late Calabrian (CNPL4 *pro parte* - CNPL9 *pro parte*  Nannofossil zones of Backman *et al.*, 2012, as partly discussed in Bizzarri & Baldanza, 2020; *Globorotalia inflata p.p.-Globigerina cariacoensis p.p.* zones *sensu* Iaccarino *et al.*, 2007). Deposits record a wide facies heteropy, both along and across the paleoshoreline. Nonetheless, three main paleoenvironments were recognized, related to braided-delta system, gravel beach system, and rocky coasts (Bizzarri & Baldanza, 2020).

#### MATERIALS AND METHODS

Eleven Cladocora-bearing sites were studied (Fig. 1), with emphasis on the analysis of coral horizons and their position in the stratigraphic sections. The sections of Civitella borehole, Poggio Carnevale, Salviano (transition-to-offshore paleoenvironment), Scoppieto, Cerreto, Montecchio, Pian di Giuncheto (rocky coast paleoenvironment), Monteleone d'Orvieto, Fosso Aiuole, S. Faustino, Fossatello-Cottano (fan-delta coast paleoenvironment) were considered. The occurrence of corals has been directly documented in most sections but not in two sites for which only literature data are available. The description of each of the other sites is focused on the coral horizons; when available, sedimentological, micro- and macropaleontological data are also summarized. The Civitella borehole samples containing Cladocora-rich layers (Fig. 3) were preliminarily analyzed under X-ray to investigate the original position of the corallites within the sediment.

Moreover, the isolated and washed corallites were radiographed to identify any possible difference in the calcification during growth.

About 200 g of sediment from each sample of the Civitella borehole was processed for micropaleontological analyses. The sediment was washed with a solution of hydrogen peroxide (5% vol.) and water, then sieved through a 63 µm mesh to obtain a washed residue, that was completely observed under a stereomicroscope (Nissho optical, TZ240) for quantitative and semi-quantitative analyses.

## FOSSIL *CLADOCORA ARBUSCULA* FROM THE CIVITELLA BOREHOLE

In the 29 m deep Civitella borehole (Figs 1 and 2), deposits are silty clay in the lowermost 15 m, grading upwards to sandy silt and sand. Two horizons, between -24.75 and -23.75 m, and -17.90 and -16.60 m, respectively (Fig. 2), mark an increase in the fine sand fraction, with sand percentages varying from 17 to 55%. In association with the uppermost one, small colonies of *Cladocora arbuscula* occur.



Figure 1. Simplified geological map of the study area, and locations of sites yielding *Cladocora caespitosa* mounds (modified after Bizzarri & Baldanza, 2020, and Bizzarri *et al.*, 2015).

#### Skeleton morphology

The cored interval from -17.73 to -16.68 m contains *Cladocora* colonies developed on soft substrate (Fig. 3). The corallites are about 1.5-3 cm in length and 3-5 mm in diameter (Figs 4A and 4F-H). In this 1 meter thick interval, colonies were concentrated in 3 major horizons and estimated as constituted by over 300-400 corallites.

The radiographs (taken with the maximum power of the X rays) showed a predominantly vertical arrangement with some sub-horizontal corallites.

The analysis showed a particularity about the morphology of the corallites and the growth of secondary branches (Figs 4A and C). New branches form angles of 90° to the main axis, a feature never observed in the species *C. caespitosa*, in which branches are long and rarely branching growing subparallel to each other after the new branches diverge at an acute angle to the main axis and soon bend upwards. Instead, the particularly wide branching angle is comparable with current examples of *C. arbuscula* (Figs 4B and D). Furthermore, the diameter of corallites, sometimes exceeding 1 mm, is larger in respect to that of *C. caespitosa* and the number of septa (32-34) is lower than 38-42, a feature typical of *C. caespitosa*. All these characters support attributing the specimens of Civitella borehole to *C. arbuscula* rather than to *C. caespitosa*.



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Figure 2. Civitella borehole sedimentological/stratigraphic log (lithological and stratigraphic data are after Bizzarri & Baldanza, 2020). The uppermost 2m of soil cover were not considered in drawing. Ecological intervals, benthos/plankton percentages, and frequencies of most relevant benthic foraminifers are also shown.



Figure 3. Civitella borehole: sediment coring (interval from -15.00 to -20.00 m) and details of the three studied samples. Sediments containing *Cladocora arbuscula* (from -18.00 to -16.65 m) are highlighted by their yellow colour in respect to the under- and overlaying grey clays.

#### Rate of growth and presumed corallites life span

The rectilinear continuous growth of corallites in Cladocora facilitates the measurement of the annual growth rate, following the methodology of Peirano et al. (2009) applied to fossil corallites of *Cladocora*. The method is based on the identification of high density bands (HD), produced during winter and appearing white in x-radiograph negatives, and of low density bands (LD), produced during the summer, black in x-radiograph negatives. Each couple of HD and LD designates annual deposition of CaCO<sub>3</sub>. The two fossil samples of C. caespitosa, analyzed by Peirano et al. (2009) and collected in a fossil bank located on a raised marine terrace 12 m above mean sea-level (Mar Piccolo di Taranto, Apulia, Southern Italy) showed a clear alternating banding pattern as seen in recent corallites of the same species (Peirano *et al.*, 2004). In that case, the distance between high-density peaks allowed the estimation of a mean annual growth rate of 2 to 4.1 mm year<sup>-1</sup>.

The analysis of the x-radiographs of our corallites of *C. arbuscula* showed alternating banding patterns (Figs 4H and 5) including almost five or six couples in corallites of 3 cm in length (Figs 5A-C). This implies mean annual growth rate of 5 mm year<sup>-1</sup>. This value is comparable with the mean annual growth rate of 4.1 mm year<sup>-1</sup> inferred from the fossil corallites of *C. caespitosa* (Peirano *et al.*, 2009).

#### Paleoecological and paleoenvironmental inferences

The benthic foraminifers and the rare planktonic foraminifers recognized in the washing residues of the Civitella borehole samples allowed the identification of some paleoenvironmental and paleoecological variations. The composition of the assemblages and the variations in abundance of the most relevant taxa (expressed in percentages), are reported in Figure 2, with *Ammonia* and *Elphidium* species considered together in genus groups.

The life habit of benthic foraminifers, the ecological parameters, such as sea-bottom oxygenation and temperature, sea grass cover and nutrients availability were extrapolated according to the ecological data provided by Murray (1991, 2006), and the ecological characters of planktonic foraminifers were deduced according to data of Hemleben *et al.* (1989).

Assemblages consist of both epifaunal and infaunal taxa. Among the epifaunal taxa have been identified Hyalinea balthica, Asterigerinata planorbis, Elphidium crispum (keeled), Cancris auriculus, Heterolepa floridana, Planulina ariminensis, Quinqueloculina seminula, Rosalina bradyi, Cibicidoides lobatulus, Cassidulina carinata, and Cibicides refulgens.

The infaunal taxa are represented by the species Pullenia bulloides, Marginulinopsis costata, Ammonia spp. (mainly Ammonia beccarii), Bulimina marginata, Elphidium advenum (unkeeled), Melonis pompilioides, Siphotextularia concava, Uvigerina mediterra-



Figure 4. Corallites of *C. arbuscula* (A, C, E-H) extracted from the Civitella core and compared with extant representatives (B, D).

nea, Fursenkoina complanata, Nonion depressulum, Gvroidina altiformis and Valvulineria bradvana. The benthic taxa that prefer cold-water temperature as Lenticulina, Heterolepa, Martinottiella, Gyroidina, Melonis, and Hyalinea are always present in the assemblages. The species that prefer to feed bacteria and algae, such as Q. seminula, S. concava, A. beccarii, B. marginata, N. depressulum, and the detritivores such as Epistominella, F. complanata (phytodetritus feeders), Globocassidulina oblonga, Oridorsalis umbonatus, C. carinata (organic matter flows), C. lobatulus (phytodetritus feeders in sea-grass habitat) have been recorded frequently. The taxa Cassidulina, Uvigerina, Bulimina, Bolivina tolerating oxygen deficiency (and especially the last three ones) were found only in few samples.

The variation in abundance, the presence/absence and the first occurrences of particular species allowed the identification of six ecological intervals which follow one another from the bottom (-29.50 m) to the top (-1.70 m) of the core.

- Ecological Interval 1: (from -29.50 to -25.50 m). The assemblages show abundance of species of Ammonia and Elphidium groups, and Florilus boueanum. The epifaunal and shallow infaunal taxa are dominant while the deep infaunal ones are subordinate. This is the only interval where representatives of planktonic foraminifers (Orbulina universa, Globigerina bulloides, Globigerina cariacoensis, Globigerinoides ruber, Globigerinoides sacculifer and Turborotalita quinqueloba) were found. The co-occurrence of planktonic species that live in the intermediate water (between -50 m and -100 m), as G. bulloides and O. universa, and of species with symbionts that live in shallower water, as G. ruber and G. sacculifer (Hemleben et al., 1989) indicates the existence of a structured water column in an infralittoral environment with a maximum depth of about 100 m.
- Ecological Interval 1a: (-27.50 m). Within the Ecological interval 1, the sample (27.50) showed a marked decrease of the shallow infaunal Ammonia group, the disappearance of infaunal taxa such as *F. complanata* and *F. boueanum*, the first occurrence of the northern guest *H. balthica* and an increase of species that prefer cold temperature, such as *C. carinata, Gyroidina alticarinata*, and species of the genera Uvigerina, Cibicides and Cibicidoides. Genera tolerant to oxygen depletion, as the infaunal Uvigerina and Bulimina and the epifaunal Cassidulina reached here their highest frequencies. This assemblage indicates a decrease in water temperature and in oxygen content at bottom.



Figure 5. X-radiograph negatives of *C. arbuscula* corallites (A-C) and details of light bands (LB) and dark bands (DB); (D) numbered septa of one single corallite. The white arrows indicate the correspondence between the LB and the thickenings on the corallite external surface.

- Ecological Interval 2: (from -25.50 to -23.50 m). In this interval the fine sand fraction increases. The *Elphidium* group dominates the assemblages; the epiphytic *C. lobatulus* first occurs, accompanied by the clinging species *E. crispum* and *E. macellum*, indicating a diffuse sea grass (*Posidonia oceanica*) cover. The infaunal taxa *Fursenkoina*, *Florilus* and *Bolivina* were absent.
- Ecological interval 3: (from -23.50 to -18.50 m). The infaunal taxa *F. complanata*, *F. boueanum*, *Bolivina*, *Cassidulina* and the epifaunal *Elphidium* group and *Astrononion*, increase. The epifaunal species *Q. seminula* first occurs and the *Ammonia* group reappears. The bottom was oxygenated, enriched in nutrients and covered by sea grasses, as indicated by the occurrence of infaunal taxa, *Cassidulina* species, and phytal and phytodetritus feeders (*Quinqueloculina* and *Cibicidoides*), respectively.



Figure 6. Palaeoenvironmental reconstruction during highstand/transgressive phase for rocky coasts (A) and fan-delta coasts (B). Numbers refer to sections of Figure 1.

- Ecological interval 4: (from -18.50 to -16.68 m). This interval contains the *C. arbuscula* levels (from -17.73 to -16.73 m), showing a dramatic decrease of both infauna and epifauna, with assemblages only composed of the *Elphidium* group and *Q. seminula*. An increase in sand fraction, like in the ecological interval 2, characterizes this interval. In both intervals, this increase testifies for minor regressive phases in the evolution of the rocky coast. The development of *C. arbuscula* (which currently develops between 5 and 30 meters depth) points to a shallowing.
- Ecological interval 5: (from -16.68 to -8.50 m). After the reduction in benthic foraminifers specimens and species in the ecological interval 4, in the interval 5 the benthos enriches again in shallow infaunal taxa (*Ammonia* group and *F. boueanum*), while the *Elphidium* group markedly fluctuates with a tendency to decrease.
- Ecological interval 6: (from -8.50 to -1.70 m). This last interval is characterized by a marked lithological change: clay decreases whereas silt and fine sand increase. The assemblages become strongly impoverished and only abraded specimens of *Ammonia* and *Elphidium* occur. The decrease of benthic foraminifers indicates that paleoenvironmental conditions became unfavourable for their development.

From the base to the top of the Civitella borehole, the benthic foraminifers evidenced a trend of progressive

deterioration of the sea bottom conditions with temperature decrease and periods of altered oxygenation. In the uppermost part, the nutrient flow undergoes an increase in relation to the arrival of river supplies highlighted by the increase of silt and fine sand.

## OCCURRENCE OF *CLADOCORA* HORIZONS IN OFFSHORE DEPOSITS

Besides the Civitella core section, other few sites of the area, related to an offshore/transition to offshore environment, and partially influenced by the processes acting on the neighbouring rocky paleocoast, returned fossil specimens of *C. caespitosa*. On the other hand, *C. arbuscula* has only been found so far in two sites (Civitella and Poggio Carnevale, Fig. 1).

The Poggio Carnevale site (Fig. 1) is a clayey hill less than 1 km north from the Civitella well. Outcrop conditions do not allow a complete geological and stratigraphic description. Nonetheless, small outcrops permit to recognize deposits as offshore silty clay, including two or three coral horizons. Corals are attributable to both *C. arbuscula* and *C. caespitosa*, and corals occur in life's position, at least locally. In another case (Salviano, Fig. 1), few undeterminable fragments were collected in silty sand deposits of the transition to offshore, according to Jacobacci *et al.* (1970).

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## DISTRIBUTION OF *CLADOCORA* COLONIES ON ROCKY COAST DEPOSITS

#### The Civitella del Lago area

Coastal marine deposits, dated to early Pleistocene (CNPL8a nannofossil subzone, according to Bizzarri & Baldanza, 2020) and related to rocky coast evolution, were described in the area (Bizzarri, 2010). Sediments ranged from very coarse gravel (boulders to blocks), to rounded pebbles and cobbles, to sands, silty clays and clays, and facies associations related to cliff talus, beachface, upper and lower shoreface were identified (Figs 6A and 7).

In cliff talus-beachface deposits (Scoppieto and Montecchio sections, Fig. 7), small *Cladocora* colonies, up to 20-30 cm both in height and width, directly grow above imbricate cobbles and pebbles. Smaller, isolated colonies (few centimetres in diameter) occur in shoreface deposits (Cerreto section, Figs 1 and 7), where corals developed on large cobbles and/or colonized shell lags. In both situations, the *Cladocora* bioconstructions are hosted by medium locally weakly cemented sands.

#### Pian di Giuncheto

Alongside the Rapolano-Mt. Cetona ridge (Fig. 1), the occurrence of Pliocene biocalcarenites is widely documented (Calcare Organogeno Auct.: Jacobacci et al., 1967, 1970; Passerini, 1965). In the Pian di Giuncheto site, these deposits are exposed in a vertical cliff, about 300 m long and 40 m high, directly overlying the Jurassic Calcare Massiccio Fm, forming a carbonate wedge thinning toward W-NW, and showing a roughly decimeter- to meter-scale bedding (Checconi et al., 2007). Deposits are described as alternations of bioturbated bioclastic calcarenites and laminated sandstones, grading upward into bioturbated calcarenites with coralline algas, bryozoans and Amphistegina spp., with broken shell accumulations (coquinas) and erosional surfaces (Checconi et al., 2007). They are usually considered Pliocene in age, mainly due to the occurrence of Globorotalia aemiliana in interspersed finer layers. The Pian di Giuncheto calcarenites were interpreted as deposited in a coralline algal-dominated, warm-temperate carbonate ramp (Checconi et al., 2007).

The analysis of calcareous nannofossils, in new recently collected samples along the section, reveals a significantly younger age for these deposits, attributable to the early Pleistocene (lowermost CNPL8 Zone: Bizzarri & Baldanza, 2020).

Small colonies of *C. caespitosa* locally occur. The colonies, about 1 m<sup>2</sup>-sized, are spread within the carbonates, and seem to lie directly on the hard substrates of the Mesozoic basement at the most proximal part of the transect (Checconi *et al.*, 2007), marking a transgressive phase.

#### CLADOCORA HORIZONS ON FAN-DELTA COASTAL DEPOSITS

In most of the basin, roughly organized fluvial systems fed the coastal area, building small fan-deltas (Bizzarri & Baldanza, 2020). Deposits formed in wave-dominated nearshore environment show a smooth seaward morphology (Fig. 6B: Baldanza *et al.*, 2014; Bizzarri & Baldanza, 2020).

#### Fosso Aiuole

The 35 m thick Fosso Aiuole section (Figs 1 and 8) was described alongside the Aiuole stream (Bizzarri *et al.*, 2015). Marine deposits unconformably lie on the pre-Pliocene substratum (Macigno Fm *Auctorum*), and gently dip northeastward. The lower part of the section (about 15 m thick) is made of boulder-sized, matrix-supported channelled conglomerates, intermingled with tabular beds of fine to coarse pebbles and coarse to very coarse sand/granules. Conglomerates mainly consist of sub-angular, poorly sorted sandstone clasts; few limestone cobbles are present, commonly showing *Lithophaga* borings. Pebbles and cobbles are commonly imbricate.

Sediments were interpreted as debris flow deposits, partially reworked in the nearshore marine environment (beachface), and a shallow water fan-delta was inferred (Bizzarri & Baldanza, 2020). In the upper part of the section (about 18 m), massive sand deposits dominated, with an almost regular interposition of tabular, plane-parallel laminated layers of granules and/ or very fine pebbles in the first meters. This interval seemingly formed in a high energy, wave-dominated marine paleoenvironment, possibly the foreshore, and shows a deepening upward trend toward shoreface conditions (Bizzarri & Baldanza, 2020).

The malacofauna associated to conglomerates is very poor, badly preserved and usually reworked, mainly made of *Spondylus* cf. *S. crassicosta*, *Glycymeris glycymeris*, *Natica* sp., and fragments belonging to *Laevicardium* cf. *L. crassum*. Nonetheless, fairly well-preserved shells occur in the sandy deposits of the lower section. They belong to *Cypraecassis testiculus*, *Cypraea porcellus*, *Persististrombus* cf. *P. coronatus*, *Conus* sp., *Glycymeris insubrica*, and *S. crassicosta*, all species well suited to coarse sand/gravel sediments and high-energy proximal marine bottoms. In the upper section, specimens of *Gigantopecten (Chlamys) latissima* and *Pinna nobilis* are commonly found in life position.

The *Cladocora* horizon occurs at the transition between the lower and the upper part of the section. Corals directly grow on a 1m thick matrix-supported conglomerate consisting of medium-sized boulders (up to 1 m in diameter). The gravel beds are directly colonised by *C. caespitosa* immersed in a 60-70 cm thick, laterally continuous, sandy bed. Colonies, about 25 cm large and 50 cm high, are well-developed and branched (Fig. 8). Corals are buried by a very fine sand-silty sand deposit, which is totally barren in microfossils (benthic foraminifers).

#### S. Faustino

The ~30 m thick section of S. Faustino showed the same sedimentological features and organization described in the intermediate and upper parts of the Fosso Aiuole section, including the occurrence of a *C. caespitosa* horizon. In a well-exposed cut (Fig. 8), *C. caespitosa* colonies, up to 30 cm high and 20 cm wide, occur in life position on sandstone boulders, and are buried by very fine sand-silty sand deposits. In its uppermost part, *Persististrombus* cf. *P. coronatus* is widely reported (Bizzarri & Baldanza, 2020).

#### Fossatello-Cottano

The ~100 m thick composite sedimentological-stratigraphic Fossatello-Cottano section (Figs 1 and 8) was reconstructed between about 290 m and 390 m a.s.l. and a detailed sedimentological and stratigraphic description can be found in Monaco et al. (2011). The whole section points to a shallow water coastal marine paleoenvironment, with little river supply. Deposits are represented by: 1) fan delta front/beachface gravels and sands in the lowermost part (about 55 m), 2) lower shoreface to transition to offshore fine sand to silty sands (about 50 m) in the intermediate section, and 3) upper shoreface sands in the about 15 m top part, with a main transgressive-regressive trend. Calcareous nannofossils and planktonic foraminifers allowed the attribution of the upper part of the section to the base of the Calabrian (CNPL8 Zone: Backman et al., 2012; Globorotalia inflata - Globigerina cariacoensis foraminifer zones: Iaccarino et al., 2007). A Gelasian-Calabrian age for the lower portion was inferred (Monaco et al., 2011).

A *C. caespitosa* horizon occurs at about 345 m a.s.l. and nearly 10 m above a *Teredolites*-bored trunk (Monaco *et al.*, 2011), within deposits attributed to the lower shoreface. Deposits are fine to very fine sands and silty sands, locally cemented, mainly in correspondence to fossil horizons, including the *Cladocora* one. Sand looks massive and lacks sedimentary structures; yet, irregularly disposed shell beds occur, with prevailing oligotypic bivalve associations, which were alternatively interpreted (Monaco *et al.*, 2011) as winnowed beds (tempestites) and/or as shell pavements (c- and b-cases of Kidwell, 1991).

The malacofauna was dominated by well preserved valves of *Chamelea gallina*, *Spisula subtruncata*, *Tellina nitida*, *P. coronatus*, and *Nassarius pygmaeus* (SFBC *sensu* Pérès & Picard, 1964), and suggested a paleodepth < 30-40 m. The *C. caespitosa* colonies (Figs 1 and 8) were found in life position, inside weakly to hardly cemented fine sand deposits. They grew-up from a large

pectinids shell lag and reached about 50 cm in height and 30 cm in diameter.

#### Monteleone d'Orvieto

Near Monteleone d'Orvieto (Fig. 1), inside 25 m thick sand and clay deposits that unconformably lay on a conglomerate layer formed in beachface/delta front settings, Ambrosetti *et al.* (1987) reported the occurrence of at least one horizon of *C. caespitosa*. The abundant *C. caespitosa* remains were collected inside 1 m thick sandy clay bed intermingled to clay.

Benthic foraminifers dominated the microfauna, while the poor malacofauna mainly consisted of *Chlamys* sp., *Amusium cristatum* and *Terebratula ampulla*. No data are available about the original layout of the corals, although they were probably growing on oyster and/ or pectinids shell beds (Baldanza, pers. observation). Unfortunately, the original outcrop described in Ambrosetti *et al.* (1987) no longer exists, and other accessible sand and clay deposits in the area lack coral documentation. Reasonably, *Cladocora*-bearing deposits record a transgressive phase and a shallow water shoreface-transition to offshore environment.

#### DISCUSSION

The distribution of *Cladocora* species in the study area lead Bizzarri & Baldanza (2020) to express some paleoecological, stratigraphic and sedimentological considerations and general assessments on the role they play in the present-day and past Mediterranean Sea.

#### Paleoecological inferences for C. arbuscula

If compared with other species of *Cladocora*, the present-day and past distribution of C. arbuscula is restricted to specific environmental conditions. Its rareness, in both present and fossil record, indicates a low adaptability and a very restricted ecological niche. Extant representatives prefer environmental conditions such as vegetation cover, shallow and protected bottoms, soft substrates (also carbonate), turbid water with high sedimentation rate and a depth range from 1 to 25 m (Aronson & Precht, 2001; Baron-Szabo, 2005), all in agreement with evidences found in this case study. In study samples, C. arbuscula occurs in assemblages including the north guest epifaunal foraminifer H. balth*ica*, and further species preferring cold temperatures, in vegetate bottoms consisting of clay with subordinate fine sands and pulsing nutrient flows. Thus, vegetated sea floor, cold and nutrient rich waters with a supposed reduced salinity due to marine/frewhwater mixing (Bizzarri, 2010) or to distant river influx (Bizzari & Baldanza, 2020) probably represent the ideal paleoecological conditions for the development of C. arbuscula colonies.



Figure 7. Sedimentological and stratigraphic sections representative of rocky coasts, redrawn and modified after Bizzarri (2010).



Figure 8. Sedimentological and stratigraphic sections representative of fan-delta coasts, redrawn and modified after Bizzarri & Baldanza (2020) and Monaco *et al.* (2011).

## Past and present distribution of Cladocora in the Mediterranean area

The areal distribution of main *Cladocora*-bearing sites in the Pliocene-Pleistocene sediments of the Mediterranean area is shown in Figure 9A. Throughout the Mediterranean, large fossil *Cladocora* formations were found as old as the ?Piacenzian-Gelasian and up to the Holocene, when this coral formed very large buildsup both in the eastern and western Mediterranean Sea (Aguirre & Jimenez, 1998; Bernasconi *et al.*, 1997; Chefaoui *et al.*, 2017; Coletti *et al.*, 2018; Dornbos & Wilson, 1999; Kružić & Benković, 2008; Ozalp & Alparslan, 2011; Peirano *et al.*, 1998, 2004, 2009).

Because *C. caespitosa* is common in the Mediterranean (Fig. 9B), and due to its ability to form large-sized build-ups (Chefaoui *et al.*, 2017; Kružić & Benković, 2008) even comparable to those of tropical reefs, this species has widely been studied (Aguirre & Jimènez, 1998; Coletti *et al.*, 2018; Peirano *et al.*, 1998; Zibrowius, 1980).

Several environmental factors have been suggested to control the present-day and past distribution of *C. caespitosa*, including environmental energy, water depth, soft or hard bottom and a possible relation with temperature (Bernasconi *et al.*, 1997; El Kateb *et al.*, 2016; Kersting & Linares, 2012; Kružić & Benković, 2008; Kružić *et al.*, 2012; Peirano & Kružić, 2004; Peirano *et al.*, 2004, 2009; Rodolfo-Metalpa *et al.*, 2006, 2008; Schiller, 1993; Zibrowius, 1980).

Recently, Coletti *et al.* (2018), in an overview of Quaternary build-ups along the Adriatic and Ionian coasts, indicated that *C. caespitosa* general distribution was mainly controlled by temperature, with most of the occurrences dating back to the middle-late Pleistocene warm periods (late Ionian and Tarantian), of interglacial stages. Coletti *et al.*, 2018 (and the references therein) also evidence that excessive warm temperature is not favourable for *Cladocora* to grow, while these species can better tolerate cooler conditions (Fig. 9B).

Beside Western Umbria deposits, two other cases of *C. caespitosa* build-ups are well documented from the early Pleistocene (Calabrian) deposits: S. Polo d'Enza (Emilia Romagna; Borghi, 2019) and the Crati basin (northern part of the Calabrian Arc; Bernasconi *et al.*, 1997). In all these cases, there are clear evidence that the build-ups developed under temperate to cool water conditions. This case study integrates the limited data available on the distribution of *Cladocora* in the early Pleistocene, confirming that at least in this period *Cladocora* was adapted to cooler conditions.

Large build-ups of *Cladocora* are restricted to embayments and gulfs well-protected against storm waves, and wave energy probably played a more decisive role (Coletti *et al.*, 2018). Thus, the development of *Cladocora*, in cooler conditions, has been probably favoured by the peculiar coastal morphologies (bays, inlets, shorefaces influenced by river mouth) which mitigated the thermal conditions of the seabed.

Notwithstanding the quantity of records, information is still lacunose for both present and past distribution of *Cladocora* in the Mediterranean. Few information is available from the Northern African coasts and raised beach deposits. Moreover, the occurrence of *Cladocora* corals throughout the early Pleistocene deposits of Italy is probably underestimated and not very detailed. Several geological records only report a generic presence of this coral inside sandy deposits, rather than refer the datum to specific sites or sections, thus hindering detailed stratigraphic and paleoenvironmental studies.

## *Stratigraphic, sedimentological and paleoenvironmental implications for Cladocora horizons*

According to Bizzarri & Baldanza (2020), the presence of *Cladocora* species (mainly *C. caespitosa*) in western Umbria early Pleistocene deposits in different stratigraphic positions could be regarded as a local rather than regional marker event.

Although it was considered diagnostic for the detection of Pleistocene deposits (Ambrosetti *et al.*, 1987), in the fossil record the occurrence of *C. caespitosa* alone is not strictly time-dependent, and it holds a too wide stratigraphic distribution, not limited to Pleistocene (Fig. 9A; Bizzarri & Baldanza, 2020).

However, *Cladocora* is relevant from a paleoecological point of view and some environmental preferences shared by the two species allow to consider them together:

- both *C. caespitosa* and *C. arbuscula* prefer shallow depths, mostly between 2 and 30 m (Aguirre & Jimenez, 1998), although *C. arbuscula* probably thrived further offshore, at least in the study area;
- both species tolerate relatively temperate to cool waters (sea surface temperature15-20°C: OBIS Database, 2021 )
- in the study area, *Cladocora* horizons occur on both rocky coasts and river-fed gravel beaches (Bizzarri & Baldanza, 2020), whilst they are not reported from deltaic coasts, except for the Monteleone area (Ambrosetti *et al.*, 1987; Bizzarri & Baldanza, 2020), marginally influenced by the Città della Pieve deltaic system (Bizzarri & Baldanza, 2009, 2020).

The finding of colonies of *C. arbuscula* (Lesueur, 1820), in sandy/clayey marine sediments of southwestern Umbria (Central Italy), represents the first evidence that this living species inhabited the Mediterranean Sea, at least during the early Pleistocene. In the present-day Mediterranean, living colonies are only reported from Porto Cesareo and the Gulf of Gabes (Fig. 9B, El Kateb *et al.* 2016; Fanelli *et al.*, 2000; OBIS database, 2021).



Figure 9. A) Map of sites documenting the occurrence of fossil *Cladocora* and B) present-day distribution of *Cladocora* in the Mediterranean area. Surface isotherms of February (averaged from 1906-1995 data) are also reported (modified after Bianchi, 2007). Data source from Aguirre and Jimenez (1998), Annoscia (1963), Chefaoui *et al.* (2017), Coletti *et al.* (2018), De Santis *et al.* (2010), D'Orefice *et al.* (2012), Drinia *et al.* (2010), Ozalp & Alparslan (2011), Peirano *et al.* (1998, 2004, 2009), Roberts *et al.* (2009), Zazo *et al.* (2003).

More generally, the occurrence of *Cladocora* build-ups in the study area is dated to the Calabrian (CNPL8 Zone), and marks minor oscillations on the sea level (transgressive phases). Even when compared to other case studies in the Mediterranean area (Aguirre & Jimenez, 1998; Baldanza *et al.*, 2017; Coletti *et al.*, 2018; Dornbos & Wilson, 1999), and regardless of paleoenvironmental context, *Cladocora* horizons can only be related to shoreface and/or the beachface environments, during sea level transgression/highstand (Bizzarri & Baldanza, 2020).

Similarly, the role of temperature in the paleodistribution of *Cladocora* needs to be discussed. First, the "Tyrrhenian stage" was overused in the past decades, and Tyrrhenian attribution usually pointed to "warm" guests vs. "cold" ones (e.g. Raffi, 1986). However, not all deposits traditionally attributed to the Tyrrhenian stage has really that age, and the equation Tyrrhenian = MIS5e does not always work. Moreover, the Mediterranean area is affected by a marked asymmetry in available data (Fig. 9), with wide areas of the northern African coasts not or poorly surveyed (Martin *et al.*, 2014).

Cladocora distribution seems not particularly sensitive to water temperature. Broadening the conclusions of Coletti et al. (2018), it is probably more correct to say that *Cladocora* prefers cool water, but that in the presence of further more relevant factors, such as bathymetry and availability of nutrients, it can tolerate medium-high water temperatures, up to a limit that is not easy to determine if not in laboratory tests or local observation (Kružić & Benković, 2008; Kružić et al., 2012; Peirano & Kružić, 2004; Peirano et al., 2009; Rodolfo-Metalpa et al., 2006). Like temperature, water energy affects the growth rate of corallites and the possibility to develop large bioconstructions, before they are broken by main storm events seemibly forcing a preference of *Cladocora* for more protected areas. Nonetheless, in the case study colonies developed indifferently in high and low energy zones, as well as along rocky and fan-delta coasts (Bizzarri, 2010; Bizzarri & Baldanza, 2020). A firmground seafloor in the optimal bathymetric range, and high input of nutrients are probably crucial. Large amount of nutrients may be associated to river discharge, and to high sedimentation of fines. Within certain limits (i.e. the polyps' ability to free themselves from granules), *Cladocora* may tolerate high water turbidity by silt/ clay, and high sedimentation rate. Consequently, the occurrence of local small rivers can be more favorable than large river deltas, as supported by both present and past absence of *Cladocora* records from large river mouths (Fig. 9A, B).

However, the geological surveys (Fig. 6) suggest that *Cladocora* distribution is restricted to transgressive

and incipient highstand sea-level phases (TST - early HST). Furthermore, present-day situation in the Mediterranean derives from the abrupt sea-level rise, started at the end of the LGM and with its apex at about 6000y BP, and can be still described as a highstand phase. Sea-level rise and incipient highstand cause the coastal systems starvation and the establishment of inherited coastal morphologies, so influencing the profile and bathymetry of the sea floor and the sedimentation rate (particularly of fine sediments), promoting conditions favorable to the development of *Cladocora* colonies. When the sedimentation rate becomes too high and fine fractions dominate sediments, *Cladocora* colonies cannot keep up and only more or less broken specimens are found (Fig. 8).

#### CONCLUSIONS

From Late Pliocene to Recent, Cladocora species are commonly distributed in the Mediterranean, with C. caespitosa being among the most important bioconstructors. Although the (paleo)ecological distribution of the genus is connected to numerous parameters, its presence in the geological record seems to indicate a preference for cool waters and a good tolerance for a fairly wide range of temperatures, together with an association to transgressive/highstand sea level phases. Presently, such relation with sea-level variations, and the preference for cool waters, are probably the most solid geological and paleoecological data deriving from past *Cladocora* distribution. If compared with present-day situation, the presence of Cladocora in the Mediterranean geological record is probably underestimated, and a revision of surveys is needed. At least from the early Pleistocene (Calabrian) onwards, both C. caespitosa and C. arbuscula occurred in the Mediterranean area, with the former always being dominant. Moreover, the presence of both C. caespitosa and C. arbuscula associated to rocky coasts and to offshore/transition to offshore settings in the study area allow proposing a similar geological meaning for the two species. Although this datum is extremely localized, this work suggests revise the geological record of *Cladocora* in the Italian and more generally in the Mediterranean area, in order to prove the possible occurrence of the still unreported C. arbuscula.

#### Acknowledgements

We are indebted with M.A. Rosso and D. Violanti for their punctual review and the precious suggestions in improving the manuscript.

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(ms. pres. 4 agosto 2021; ult. bozze 22 novembre 2021)