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ORIGINAL PAPER

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Shallow-buried Pleistocene *Madrepora*-dominated coral mounds on a muddy continental slope, Tuscan Archipelago, NE Tyrrhenian Sea

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Abstract Subfossil azoxanthellate deep-sea coral mounds occur at 355–410 m on the continental slope of the NE Tyrrhenian Sea between Gorgona and Capraia islands, Tuscan Archipelago. These low-relief patch reefs are at present buried by a thin muddy drape. Their age is latest Pleistocene. The colonial scleractinian *Madrepora oculata* is the major frame builder, in association with the solitary coral *Desmophyllum dianthus* and the colonial coral *Lophelia pertusa*. These NE Tyrrhenian *Madrepora*-dominated coral mounds represent one of the few known Mediterranean examples of deep-coral colonization of a muddy, low-gradient continental slope.

Keywords Deep coral mound · Mediterranean Sea · Pleistocene · *Madrepora*

Introduction

Submerged deep-sea coral bioconstructions and related sedimentary deposits are widespread in the Mediterranean basin (Taviani et al. 2004, 2005). The Tyrrhenian Sea with an area of ca 247,000 km^2, depths exceeding 3,000 m, and irregular submarine topography, offers many chances to successful suitable habitats and environmental conditions for scleractinian growth in the deep-sea. In fact, deep-water corals, especially *Lophelia pertusa*, *Madrepora oculata* , *Dendrophyllia cornigera* and *Desmophyllum dianthus* (syn. *D. cristagalli)* have been recorded at various localities, even if many such records refer to non-living or clearly subfossil occurrences (e.g., Segre 1959; Segre and Stocchino 1969; Selli 1970; Sartori 1980; Zibrowius 1980; Rocchini 1983; Bonfitto et al. 1994; Terreni and Voliani 1995). Most Mediterranean occurrences of azooxanthellate deep-water corals relate to sediment-starved situations characterized by rocky bedrock such as seamount/bank flanks and edges, canyon heads and walls, steep cliffs etc. Records of deep-coral mounds developed on firm sedimentary substrata are considerably scarcer. Forest and Cals (1977) first recorded dead and living *Madrepora oculata* from 450 m off the islands of Gorgona and Capraia, Tuscan Archipelago. Scientific information by ecologists belonging to ARPAT environmental agency (*Agenzia regionale per la protezione ambientale della Toscana*) confirms the presence of deep-sea corals in this area and the disturbance caused by coral framework to commercial fishing operations (F. Serena 1999, personal communication). Furthermore, there is anecdotal information from commercial fishermen and amateur malacologists on the potential existence of unspecified living “white corals” (sensu Pérès and Picard 1964) in this area.

In the context of the systematic exploration of the Mediterranean Sea conducted by the CNR of Bologna since 1995 to identify, image and sample deep coral settings, a sector of the NE Tyrrhenian Sea was targeted to search for such mounds. A geo-biological survey of the NE Tyrrhenian Sea (cruise LM-99 *Lophelia* -Millenium) was then conducted in winter 1999–2000 aboard RV *Urania* (Taviani and Remia 2001; Remia et al. 2004). Another survey of this same area was conducted in winter 2003–2004 (cruise CORTI of RV *Urania*) but only some preliminary data are included in the present article.

Shallow-buried low-relief deep-coral mounds were identified along the muddy continental slope between Gorgona and Capraia islands, Tuscan Archipelago and are discussed here (Fig. 1).

Material and methods

Positioning during Cruises LM-99 and CORTI was provided by GPS navigational system installed on RV *Urania*. High-resolution seismic imaging was achieved using Chirp-Sonar (frequency 2–7 kHz), integrated by DESO-25 (frequency 12 kHz), echo-sounding. Sampling was undertaken by using a large-volume (65 l) modified Van Veen grab, epibenthic and heavy-chained dredges. Successful sampling stations, dredging tracks and related profiles are reported in Fig. 2 and Table 1.

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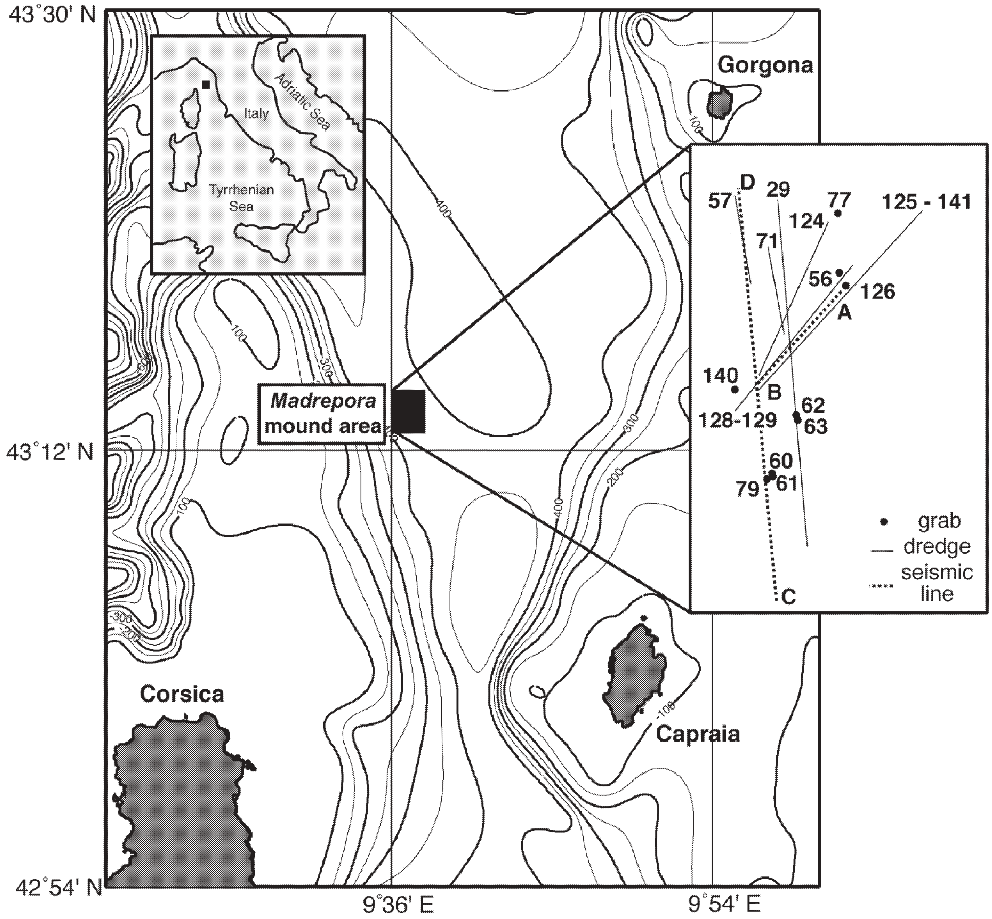

Fig. 1 Location map of the coral mound area in the Tuscan Archipelago discussed here with sampling stations and selected seismic tracks. Bathymetry is from IBCM (International Bathymetric Chart of the Mediterranean)

Results

Coral mounds punctuate a virtually flat muddy bottom on the upper slope between 355 and 410 m offshore Gorgona and Capraia islands at c. 43°13 N and 09°36 E (Fig. 1). These mounds display a patchy distribution and are acoustically detectable. For instance, the mounds are visible on both chirp-sonar profiles and DESO-25 (frequency 12 kHz) acoustic images (Fig. 2). As seen on Chirp line C–D (Figs. 1, 2) the coral buildups occur as discrete mounds many tens of meters wide and up to 3–4 m in height. Direct sampling (grab and epibenthic dredge) provided evidence that these coral mounds are at present buried only by a thin veneer of soft mud and are at places still exposed. Large-volume grab samples have consistently documented that corals still embedded in mud are well preserved and white, while those exposed on the sea bottom are deeply bioeroded, Mn-Fe patinated and exploited by a number of dwellers (zoozoans *sensu* Taylor and Wilson 2002).

As demonstrated by sampling transects, not much coral rubble is present around any single coral mound. The coral assemblages show the absolute dominance of fresh-looking *Madrepora oculata* branches (Fig. 3c), and *Desmophyllum dianthus* (Fig. 3a, b) with the corallites still retaining their original lustre. Subfossil branches belonging to *Lophelia pertusa* are less common (Fig. 3d). The largest single piece of dredged *Madrepora* colony attains a size of 26 cm (Fig. 3c). Early diagenetic limestones (wackestones, packstones and framestones) encasing biostromal coral rubble are occasionally recovered from this area.

Diversity and taphonomy

Ecological work on living *Lophelia* mounds in the Eastern Atlantic Ocean has clearly demonstrated that such environments promote a significant increase of biodiversity with respect to the surrounding sea bottom (e.g., Jensen and Frederiksen 1992; Freiwald 1998, 2002; Freiwald et al. 2004). However, only a few faunal elements seem strictly related to such deep-coral buildups and, among them, only a handful of taxa actually settle on living parts of the coral reefs while the number of exploiters of coral substrata substantially increases on dead portions of these coral mounds suggesting complicated patterns of taphonomic turnovers (Freiwald 1998; Freiwald and Wilson 1998).

Taphonomically, these Tyrrhenian coral mounds (Figs. 4, 5) share many analogies with E Atlantic counterparts. Most corals appear encrusted by subfossil valves

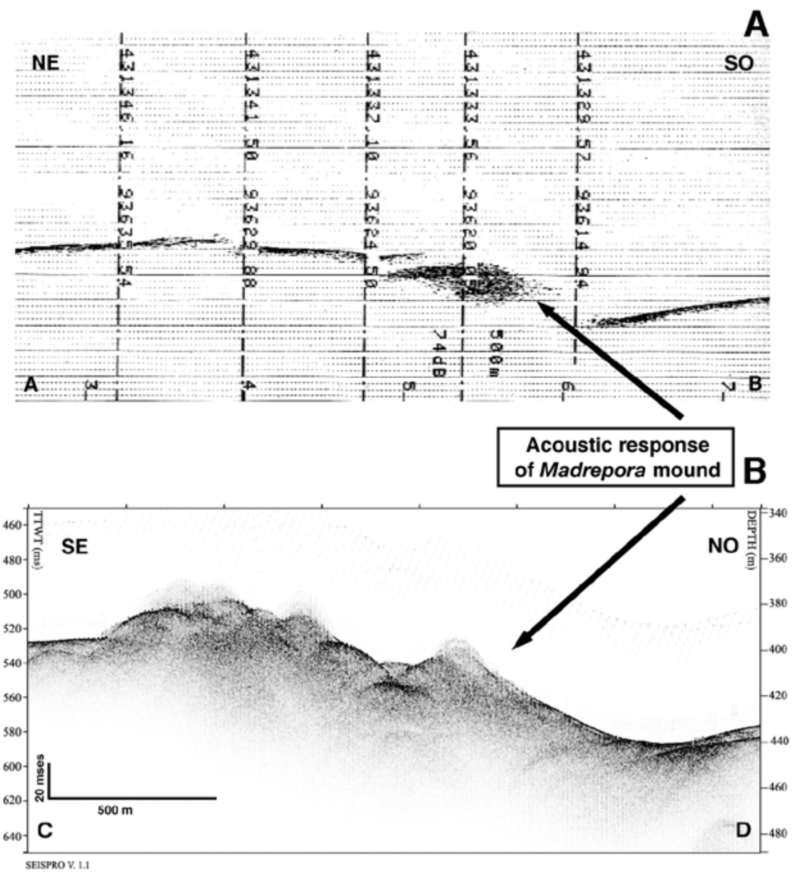

Fig. 2 Seismic profiles across the coral mound area reported in Fig. 1; **A** Line A-B DESO-25 (12 kHz); **B** Line C-D chirp-sonar. TWTT (ms) is two-way travel time. Depth (m) is calculated with sound speed (1,500 m/s)

Table 1 Location, sampling gear and depth of LM-99 and CORTI stations that provided deep-water corals

Station	Lat. N	Long. E	Device	Depth (m)
LM 99–124	43°13.52	9°36.26	Dredge	411
	43°13.94	9°36.52		377
LM99–125	43°13.55	9°36.32	Dredge	390
	43°13.99	9°36.93		374
LM99–126	43°13.76	9°36.58	Grab	375
LM99–128	43°13.42	9°36.17	Dredge	425
	43°13.82	9°36.61		376
LM99–129	43°13.46	9°36.23	Dredge	432
	43°13.81	9°36.61		376
LM99–140	43°13.48	9°36.17	Grab	434
LM99-141	43°13.48	9°36.26	Dredge	406
	43°13.97	9°36.87		377
CORTI-29	43°14.00	9°36.33	Dredge	399
	43°13.05	9°36.44		385
CORTI-56	43°13.80	9°36.56	Grab	390
CORTI-57	43°13.77	9°36.23	Dredge	406
	43°14.01	9°36.17		447
CORTI-60	43°13.19	9°36.30	Grab	384
CORTI-61	43°13.18	9°36.31	Grab	384
CORTI-62	43°13.28	9°36.38	Grab	353
CORTI-63	43°13.28	9°36.40	Grab	354
CORTI-71	43°13.50	9°36.32	Dredge	390
	43°13.68	9°36.26		370
CORTI-77	43°13.98	9°36.41	Grab	372
CORTI-79	43°13.16	9°36.41	Grab	374

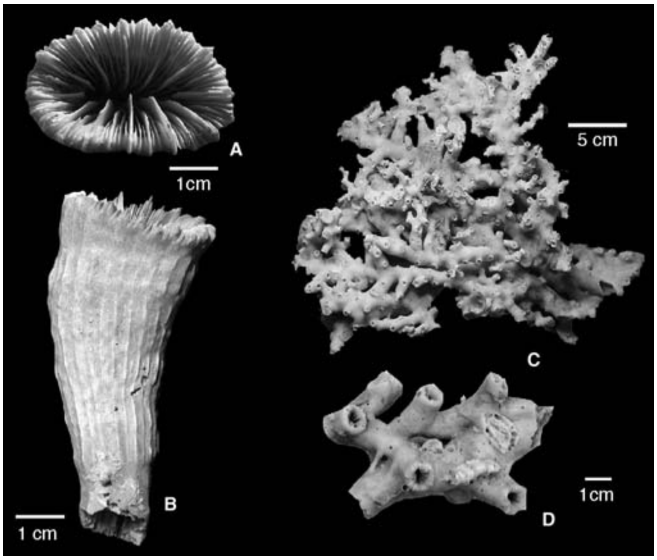

Fig. 3 Dominant species from the coral mound area: **a,b** *Desmophyllum dianthus* (Esper 1794), large *well*-preserved specimen under study for trace and minor element geochemistry; **c** *well*-preserved *Madrepora oculata* Linnaeus, 1758, largest piece of coral framework dredged; **d** *Lophelia pertusa* Linnaeus, 1758, fragment of coral colony; all from st. LM99–124

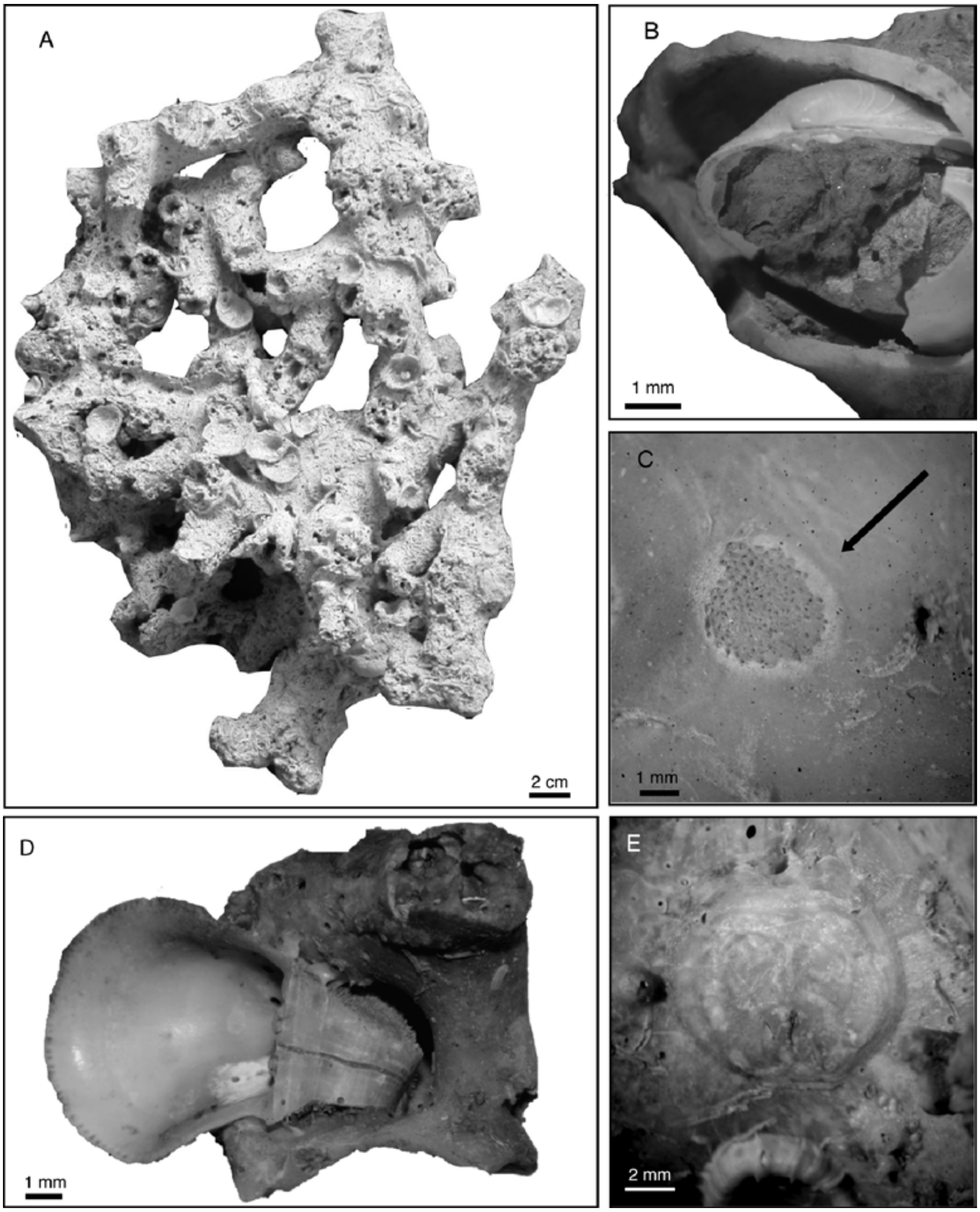

Fig. 4 Taphonomic aspects; **A** highly encrusted and endolithic-bioeroded *Madrepora* colony, st. LM99–124; **B** the bivalve *Coralliophaga lithophagella* (Lamarck 1819) nestling inside an *Eunice* tube-gall in *Lophelia*, st. LM99–124; **C** pitted scar of a benthic foraminifer (*arrow*), st. LM99–124; **D** valve of *Spondylus gussonii* with an extraordinarily developed hinge cemented to an *Eunice*-related tube-gall, st. CORTI-29; **E** scar related to the brachiopod *Neocrania* sp. and fouling serpulids and bryozoans, st. LM99–124

of *Spondylus gussonii*, serpulid polychaete tubes and bryozoan colonies. Various living organisms were also observed on degraded and patinated corals and coral framestones including hydroids, sponges, bivalves (e.g., *Asperarca nodulosa*), polychaetes (e.g., *Metavermilia multicristata),* brachiopods (e.g., *Neocrania* sp., *Terebratulina retusa*), etc. (Fig. 6). Extra-calcification as a response to parchment tubes of the commensal polychaete *Eunice* is common on both *Madrepora* and *Lophelia* (Fig. 5). Pitted scars possibly attributable to parasitic epibiont foraminifers have been observed on some *Lophelia* branches. Other scars found on *Madrepora* and *Lophelia* related to cemented brachiopods (*Neocrania* sp.).

A collection of skeletal invertebrates was obtained through sampling of *Madrepora*-mounds, including 10 Scleractinia (Table 2). Such an invertebrate assemblage does not necessarily represent the actual biodiversity of the original deep-coral mound.

Sampling on and around the mounds provided many skeletal taxa, most of which are indicative of soft clay coral-free bottom. Among macrobenthic invertebrates, Mollusca are by far the most diverse taxonomic group with 140 species (44 bivalves, 88 Gastropoda, 3 Polyplacophora and 5 Scaphopoda that will be treated in a separate paper), followed by Cnidaria (Scleractinia, Octocorallia), Annelida (Serpulidae: *Protula* sp., *Serpula* spp., *Metavermilia multicristata*, *Semivermilia* spp., *Filogranula* spp., *Placostegus tridentatus*, *Vermiliopsis* cf. *infundibulum*, *Ditrupa arietina;* Spirorbidae: *Janua* sp., cf. *Pileolaria* sp.), Brachiopoda *(Neocrania* sp., *Megerlia truncata*, *Gryphus vitreus*, *Terebratulina retusa*, *Platidia anomioides*, *P. davidsoni*), Crustacea Decapoda (e.g. *Ebala*), Echinoidea (e.g. *Cidaris* sp.). Microbenthos

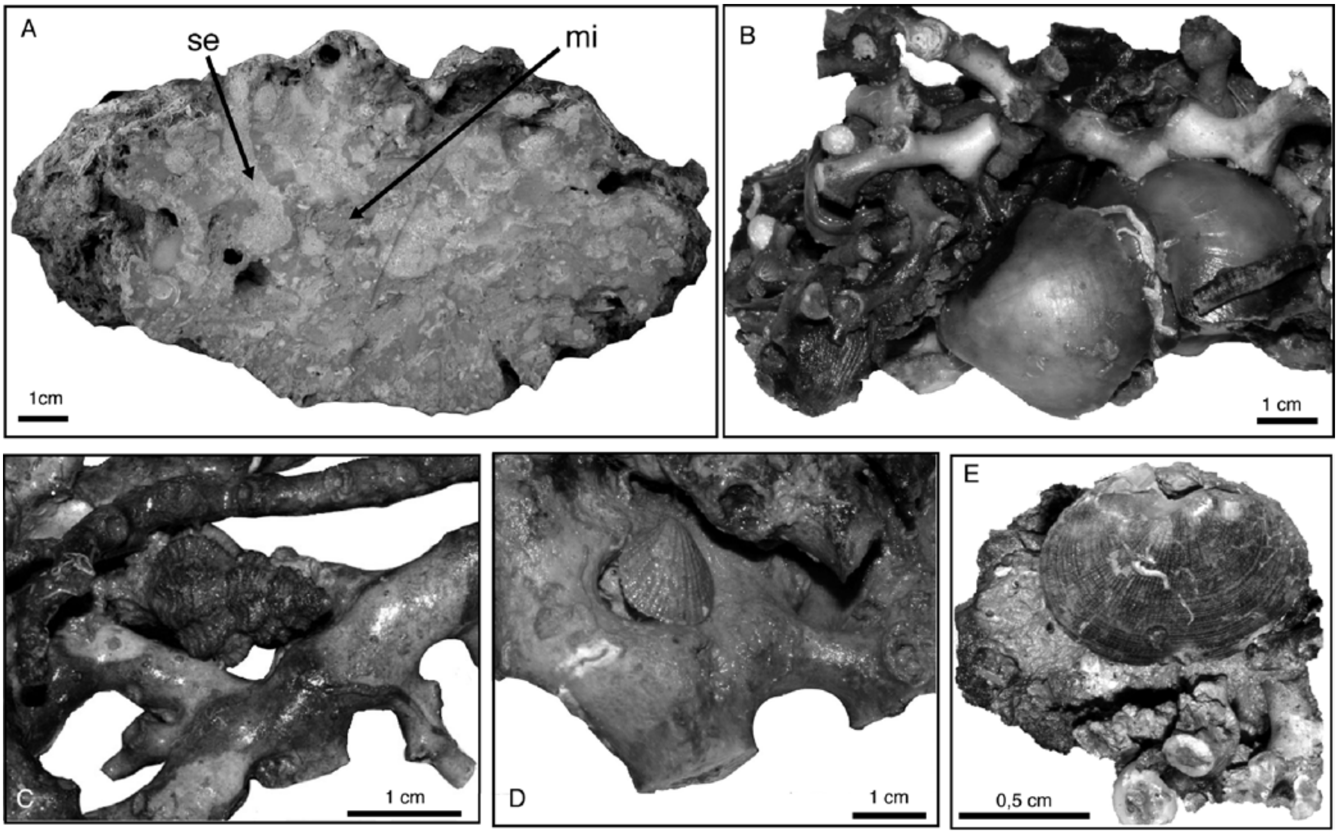

Fig. 5 Taphonomic aspects; **A** coral wackestone, (mi) early diagenetic micritic cement and (se) pockets of still unlithified muddy sediment (sample recovered off Gorgona Island by the trawler *Franci*); **B** loosely cemented coral packstone encasing articulated brachiopod shells belonging to *Gryphus vitreus* (Born 1778), st. CORTI-29; **C** *Madrepora* coral colony with an in situ cemented shell of the predatory gastropod *Coralliophila squamosa* (Bivona 1838), st. CORTI-57; **D** *Madrepora* coral packstone encasing a shell of the limpet *Emarginula* sp., st. CORTI-29; **E** loosely cemented coral framestone encasing an articulated brachiopod shell belonging to *Megerlia truncata* (Linnaeus 1767), st. CORTI-57

is dominated by Foraminifera (e.g. *Ammonia* aff. *beccarii*, *Elphidium* spp., *Bigenerina nodosaria*, *Textularia* sp., *Brizalina* sp., *Sigmoilina* spp., *Cornuspira involvens*, *Lenticulina* sp., *Dentalina* spp., *Pyrgo* spp., *Quinqueloculina* sp., *Bulimina inflata*, *B. marginata*, *Cassidulina* spp., *Planulina ariminensis*, *Paromalina coronata*, *Stilostomella* spp, *Cibicides lobulatus*, *Cibicidoides* sp., *Lagenodosaria scalaris*, *Praeglobobulimina pupoides*, *Hyalinea balthica*, *Saracenaria italica*, *Uvigerina mediterranea*, *U. peregrina*, *U. proboscidea* and agglutinated species) and Ostracoda (e.g., *Bythocypris* sp., *Polycope* sp., *Paracytherois* sp., *Henryhowella* sp. and *Argilloecia acuminata*).

Age

One specimen of *Desmophyllum dianthus* from station LM99–124 provided an U/Th age of 11.1±0.1 ka (Research School of Earth Sciences, Australian National University, Canberra, Australia). Associated fauna includes, amongst others, abundant glacial-Pleistocene subfossil valves of the scallop *Pseudamussium septemradiatum* (e.g., Malatesta and Zarlenga 1986). Further U/Th and AMS–^{14}C dating of corals is in progress, but there is little doubt that such mounds thrived during the last glacial epoch.

Impact by commercial trawling

Deep-sea trawling operations are routinely conducted in this sector of the Tyrrhenian Sea. Unlike the Atlantic Ocean (e.g., Hall-Spencer et al. 2002; Freiwald et al. 2004), Mediterranean deep-coral banks are not a target for and therefore are not deliberately impacted by any commercial fishing. On the contrary, they represent a type of bottom that trawlers try carefully to avoid in order not to damage their nets. Fishing-boat echo-sounders are capable of indicating the likely presence of coral mounds. The experience gained by the accidental entangling of nets with coral colonies has greatly reduced such accidents among commercial fishermen (A. Voliani 2003, personal communication). Notwithstanding such observations, deep-coral rubble is almost ubiquitous in any trawling catch from this area because of the patchy presence of shallow-buried corals and the perpetual re-collection of corals discarded by previous trawling activity.

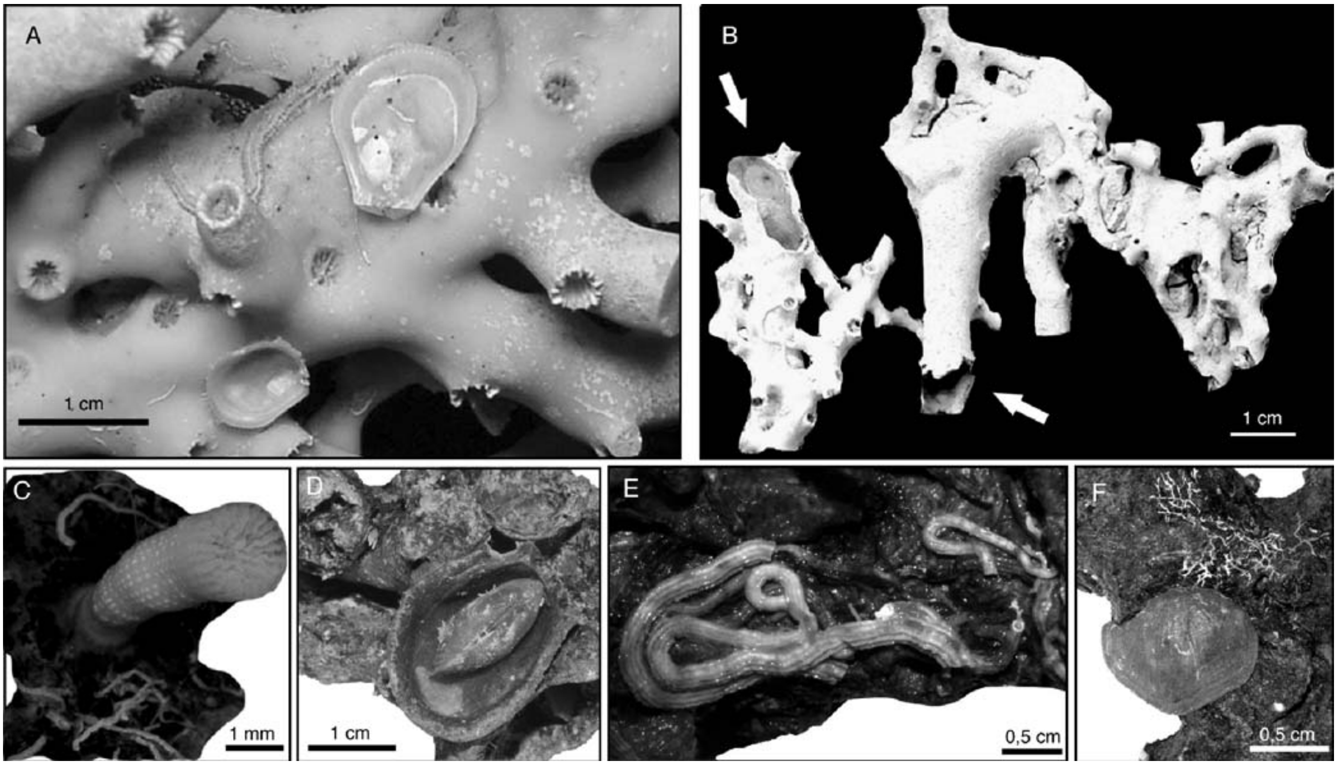

Fig. 6 Associated calcareous invertebrates; **A** attached valves belonging to the bivalve *Spondylus gussonii* Costa, 1829, st. LM99–124; **B** tube galls and parchment tubes of the commensal polychaete *Eunice* (st. LM99–124); **C** fresh solitary coral *Stenocyathus vermiformis* (Pourtalès 1868) attached to a highly degraded and patinated coral substrate, st. CORTI-56; **D** a living specimen of the bivalve *Asperarca nodulosa* (Müller 1776) byssated on a subfossil valve of *S. gussonii*, st. CORTI-29; **E** living specimen of the serpulid polychaete *Metavermilia multicristata* (Philippi 1844), one of the commonest members of the attached epifauna, st. CORTI-56; f: *Neocrania* sp. (Müller 1776) attached to a highly degraded and patinated coral substrate, st. CORTI-57

Table 2 Scleractinian corals identified from the *Madrepora* mounds surveyed during cruise LM99

Scleractinia	LM99 Station						
	124	125	126	128	129	140	141
Caryophyllia calveri	X	X	X	X		X	X
Caryophyllia smithii				X			
Balanophyllia thalassae				X			
Ceratotrochus magnaghii	X	X	X	X			
Dendrophyllia cornigera	X			X			X
Desmophyllum dianthus	X	X					X
Javania cailleti		X					X
Madrepora oculata	X	X	X	X	X	X	X
Lophelia pertusa	X	X				X	X
Stenocyathus vermiformis	X	X	X	X			

Discussion

While most known submarine deep coral buildups in the Mediterranean basin colonized sediment-starved rugged topographic highs (seamounts, banks, canyons, steep overhangs etc.), these Tyrrhenian mounds represent an example of corals developed on firm sedimentary units contributing to a gently dipping continental slope. The coral mounds under scrutiny may be categorized as patch reefs in the sense proposed by Wilson (1979) and Freiwald (2002). Similar bio-constructions are not uncommon in the modern oceans (e.g., Moore and Bullis 1960; Allen and Wells 1962; Stetson et al. 1962; Squires 1965; Mullins et al. 1981; Newton et al. 1987) and in the fossil record (e.g., Squires 1964). In the Mediterranean basin, the healthy *Lophelia* -reef reported from the Ionian Sea are another example of successful colonization of a prevalently non-rocky substratum on a gently sloping margin (Taviani et al. 2004).

It appears that deep coral growth along this sector of the Tyrrhenian slope was severely reduced at the end of the Pleistocene, c. 11 ka ago. The postglacial basinal decline of deep-sea corals in the Mediterranean Sea has been noticed long ago (Taviani and Colantoni 1984;

Delibrias and Taviani 1985). We observe that these Tyrrhenian mounds were rapidly buried by a thin veneer of mud and we tentatively suggest that this silting event is possibly a response to sediment availability due to an Early Holocene climatically-forced strengthening of continental runoff. Planktonic foraminifer assemblages recovered from the mud draping the coral mounds contain *Globigerinoides ruber* (pink), *G. sacculifer* , *G. trilobus*, *Globigerina precalida*, *G. predigitata* and are indicative of warm water (possibly the Holocene Climatic Optimum), together with fresh-temperate forms such as *Globorotalia truncatulinoides*, *G. inflata*, *Neogloboquadrina pachyderma*, *Globigerina quinqueloba*, *G. bulloides* (A. Borsetti 2003, personal communication). Coexistence of such forms may be taken as an indication that mud-burial of the coral mounds started at the very end of the Pleistocene but that its peak took place between 6,000–9,000 years ago.

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