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PALEOENVIRONMENTAL RECONSTRUCTION ON LATE CALABRIAN STAGE SEDIMENTS FROM THE BELICE VALLEY (SOUTHWESTERN SICILY - ITALY) BASED ON OSTRACODA.

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ABSTRACT: The Middle Pleistocene Transition is the most recent re-organization of the climate system, happened between 1.2 and 0.7 Ma. Marine sediments outcropping in Sicily have been a relevant source of information on the paleoclimatic and paleoenvironmental evolution of the Mediterranean Sea, over this time window. Among others, previous studies in Sicily identified and described the very cold phase and the marked sea level fall associated with the top MIS 22, which is lithologically expressed by a calcarenite bed colonized by the *Arctica islandica* northern guest.

Here we investigate ostracod assemblages from marine sediments in the southwestern Sicily. Sediments, ascribed to the late Calabrian Stage, have in-depth been studied by foraminifera, coccolith and pteropod specialists. Our results support previous micropaleontological-based paleoenvironmental reconstructions, but also include original elements that better define the paleobathymetric and bottom condition evolution. By grouping infralittoral, circalittoral and bathyal taxa, ostracods describe a significant sea level fall up to the *A. islandica* calcarenite bed and then a rise to circalittoral and bathyal environments during the interglacial MIS 21. The abundance increases of ostracod taxa able to survive in low-oxygen environments and a significant diversity loss point to the establishment of water column stratification and seafloor dysoxia, in the lower part of MIS 21. Finally, *Bythocythere turgida* is the only northern guest found in our samples, associated with *A. islandica* specimens. However, during the interglacial period we note subtle but significant percentage variations in ostracod groups that may have been driven by productivity changes, rather than real sea level variations. These changes may be associated to Atlantic Meridional Overturning Circulation weakening phases and to millennial-scale cold spells that punctuated MIS 21.

Keywords: Marine ostracods, Palaeoecology, Pleistocene, Mediterranean.

1. INTRODUCTION

Ostracods are small aquatic crustaceans equipped with low-magnesium calcite bivalved shells. Ostracods are commonly preserved in Neogene and Quaternary sediments. Though their adoption as paleoenvironmental proxies is largely overlooked, ostracods have an excellent potential, in marine environments, in comparison to other microfossil groups, mostly for paleobathymetry and bottom water conditions reconstruction (Holmes & Chivas, 2002).

The Middle Pleistocene Transition (1.2-0.7 Ma) is a significant re-organization of the climate system, in terms of glacial/interglacial cycles duration, CO2 levels drop, sea surface temperature cooling in the oceans, Atlantic Ocean circulation and monsoon activity weakening (Lisiecki & Raymo, 2005; Clark et al., 2006; Martinez-Garcia et al., 2011). Sedimentary sequences of this time interval outcrop in western Sicily and led to a former proposal of the chronostratigraphic subdivision of the Early Pleistocene in three substages (Ruggieri & Sprovieri, 1984; Ruggieri et al., 1984). In the last substage, the so-called Sicilian substage, it was identified a biocalcarenite bed, including specimens of the northern guest bivalve *Arctica islandica*, deposited during the global cooling of Marine Isotopic Stage (MIS) 22 (Di Stefano & Rio, 1981; Buccheri, 1984). Though the chronostratigraphy of the Early and Middle Pleistocene has been issued following different criteria (Gibbard et al., 2010; Head et al., 2021; Suganuma et al., 2021), the western Sicily is still a valuable setting to investigate paleoclimatic and paleoenvironmental modifications over this Quaternary time window.

Here, we investigate the ostracod assemblages from Casa Parrino section, that outcrops in the Belice valley (southwestern Sicily). The sedimentary sequence starts with the *A. islandica* calcarenite bed and is over thirty meters thick, possibly covering the development of an almost complete glacial/interglacial cycle (Di Stefano et al., 1991). The investigation benefits from the comparison with different micropaleontological groups, calcareous nannofossils, planktonic and benthic foraminifera and pteropods carried out in previous studies on the same sediments (Buccheri, 1985; Di Stefano et al., 1991) and from the comparison with Casa Catarinicchia section (Sprovieri & Cusenza, 1972), which is only a few hundreds of metres far (Fig. 1A). Significantly, the first report on ostracods from the the Belice Valley area was by Ruggieri (1977), who provided a list of "northern guests" from the Casa Catarinicchia section. Faranda &

Gliozzi (2011) reviewed the "northern guest" species described in Sicily sedimentary sections, including the studies on the Belice Valley area.

The study is aimed at the reconstruction of the evolution of the depositional and environmental setting over the late Calabrian Stage sedimentary sequence.

2. STUDY AREA

The Sicily fold and thrust belt is a segment of the Apennine-Maghrebian orogen, developed for the African and European collision (Catalano et al., 2000; Gasparo Morticelli et al., 2015). The Casa Parrino section is located in the southwestern sector of Sciacca-Sicani Mountains, where Pleistocene deposits outcrop (Fig. 1a) (Di Stefano et al., 2015a).

The Pliocene-Calabrian interval in Sicily documents two sedimentary cycles (Ruggeri and Sprovieri, 1984; Ruggeri et al., 1984). The first one, from the Zanclean to the Calabrian (the former Emilian substage) is represented by a regressive succession starting with "Trubi" followed by grey-blue sandy clays that are progressively silt- and sand-enriched and include sapropels and calcarenite turbidite layers, as in Monte Narbone and Monte San Nicola. In marginal areas, since the MPl 4 planktonic foraminifera Mediterranean biozone (Cita, 1975; Sprovieri, 1993; Lirer et al., 2019), in the upper part of the Zanclean Stage, there is a significant calcarenite turbiditic supply (the Belice Valley Formazione Marnoso-Arenacea), as described by Ruggieri and Torre (1973). The second sedimentary cycle is transgressive and covers the upper part of the Calabrian Stage (the former Emilian and Sicilian substages). This cycle in the western Sicily is represented by neritic to epibathyal sediments (Ruggieri et al., 1979; Di Stefano et al., 1991). Sediments outcropping in the "Casa Parrino" section belong to the upper part of the second sedimentary cycle.

Looking at the paleoceanographic and paleoclimatological framework, the Casa Parrino section is a former marginal area of the Sicily Channel. The Sicily Channel is a key area for the Mediterranean oceanographic circulation, being the sill that divides the basin in the western and eastern subbasins and that reallocates heat and salt through the surface and intermediate layers of the thermohaline circulation (Malanotte-Rizzoli et al., 2014; Incarbona & Sprovieri, 2020). The high sensitivity of the Sicily Channel to late Quaternary climate changes is well-established (e.g. Sprovieri et al., 2003; 2006; Sprovieri et al., 2012; Incarbona et al., 2008, 2010; 2013; 2016; 2019) and represents a key reference area for Mediterranean paleoenvironmental changes. The Sicily Channel is significantly affected by sea surface temperature (SST) variations in the North Atlantic Ocean that drive different atmospheric patterns (e.g. North Atlantic Oscillation) and the arrival of moisture and storm track penetration (Josey et al., 2011; Incarbona et al., 2016; 2019), as well under the indirect influence of North Africa Monsoon activity that leads to different physico-chemical properties in the intermediate water (Incarbona et al., 2011; 2016; Incarbona & Sprovieri; 2020).

3. CASA PARRINO SECTION

The Casa Parrino locality is located close to the Belice River mouth (Fig.1a) and belongs to a repeatedly faulted monoclinal with a slight (5-6°) southward dip (Sprovieri & Cusenza, 1972; Buccheri, 1985, Di Stefano et al., 1991). The section is 50 m thick but only the first 32 m were sampled. The short description below follows Di Stefano et al. (1991) and is shown in Figure 1b by a lithological log. The sequence starts with 1.25 m of grey clayey marls (sample 1-7), passing into sands and topped off with a 0.90 cm thick layer of greyish biocalcarenites (samples 8-11) where specimens of A. islandica occur. Ditrupa arietina is common to abundant in samples 3-6. The calcarenite bed is especially enriched of marine invertebrate shells that, in the middle part, seem to be reworked by storm waves in a 15 cm-thick rippled-layer.

The rest of the section consists of grey clays (sample 12 -41), up to the top where a yellow sand layer occurs. Grey clays are poor in macro-invertebrate elements and include a few sand interbedded layers (Fig. 1b). The entire sequence is cut off by the erosional phase which gave origin to the Great Upper Terrace (the so-called Grande Terrazzo Superiore), visible in a large portion of western Sicily (Ruggieri & Unti, 1974). Sediments of the Great Upper Terrace are fossil-barren conglomerates and rounded coarse sands. Presently, the Casa Parrino succession is only in part visible because, during the 90's, the richly fossiliferous calcarenitic levels have been object of several sampling that have nearly demolished the level itself; the part, survived at the sampling, is now almost completely covered by an illegal dump that has completely scarred the area. Only the grey clay overlying the calcarenitic bed survived to human activity and can actually be seen.

4. BIOSTRATIGRAPHIC AND CHRONOSTRATIGRAPHIC FRAMEWORK

The Casa Parrino section is ascribed to the calcareous nannofossil MNN 19f Zone (Rio et al., 1990) on the basis of the occurrence of *Gephyrocapsa omega* and *Pseudoemiliana lacunosa* specimens (Di Stefano et al., 1991). On the basis of the occurrence of *Globorotalia truncatulinoides excelsa* (Di Stefano et al., 1991) and the common occurrence of *Neogloboquadrina pachyderma* sinistral coiling, sediments are also referred to the planktonic foraminifera *Globorotalia truncatulinoides excelsa* biozone (Cita, 1975; Sprovieri, 1993). The identification of the planktonic foraminifera biozone in the Lirer et al. (2019) could not be applied, because of the fine quantitative approach used in the scheme (*Neogloboquadrina pachyderma* sinistral coiling Last Regular Occurrence and Paracme End) for discerning between MPle1c and MPle2a.

The biostratigraphic Zones identified by calcareous nannofossils and planktonic foraminifera is compatible with the late Calabrian Stage (Rio et al., 1990; Sprovieri, 1993; Lirer et al., 2019). Since the *A. islandica* limestone in the lowermost part of the Casa Parrino section is correlated with that identified at Cava Puleo (Di Stefano and Rio, 1981; Buccheri, 1984), the investigated sedimentary section is ascribed to the uppermost part of MIS

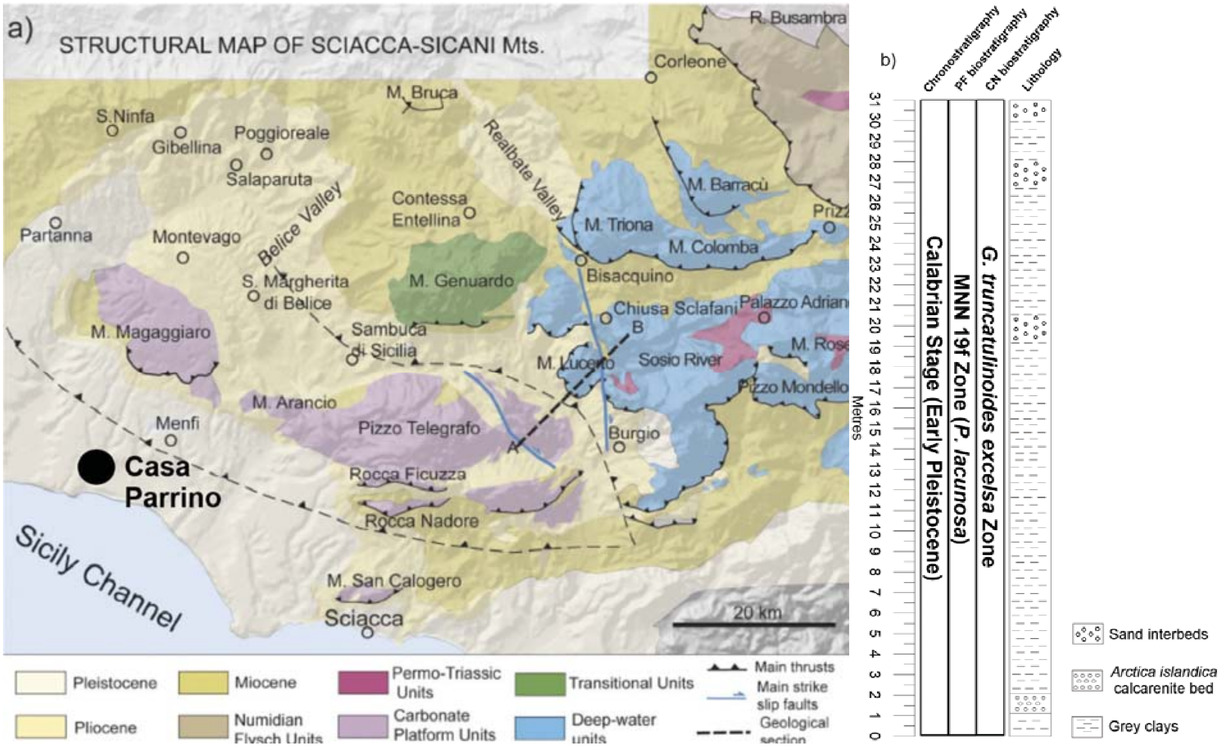

Fig. 1 - Location of the study area and stratigraphic log of the investigated section. a: Location of the Casa Parrino section and structural map of the southwestern Sicily (modified from Di Stefano et al., 2015a). b): simplified lithostratigraphic log of the Casa Parrino section. Chronostratigraphic, planktonic foraminifera and nannofossil biostratigraphic information are also provided.

22 and to part of MIS 21 (Buccheri, 1985; Di Stefano et al., 1991). The biostratigraphic and chronostratigraphic framework is summarized in Figure 1b.

5. METHODS

The present study considered the same 41 samples used by Buccheri, 1985 and Di Stefano et al. (1991) for the study of nannofossils and benthic and planktonic foraminifera. The samples were taken at about 20 cm intervals in the lower part of the sequence until the limestone block (the lowermost 2.1 m) and about at one meter in the remnant part of the succession.

Samples were washed using a 63 µm mesh sieve and were oven-dried at 40 °C.

The identification of species was carried out on the basis of shape and size of the valves, surface ornamentation, types of marginal pore canals, and internal features including the hinge, muscle imprints, inner lamella and vestibule, by a stereoscopic microscope. Transmitted light microscopy was also used to observe characteristics not discernible with a stereoscopic microscope, such as marginal pore canals. Taxa identification follows modern literature reviews and/or single holotypes original description (e.g. Moore, 1961; van Morkhoven, 1962; Mueller, 1894; 1912, Ruggieri, 1976 a,b, 1992; Schornikov, 1966; Ciampo, 1972, 1976; Sissingh, 1972; Bonaduce et al., 1976, 1999; Colalongo & Pasini, 1980; Athersuch et al., 1989; Abate et al.,1993; D'Arpa & Ruggieri, 2004; Aiello et al., 1993,1996a, b, 2000; Barra & Bonaduce, 2000).

All adult and juvenile ostracods were picked for reconstructing relative abundance and diversity curves, when at least 50 specimens were found in the sample. Twelve samples (14, 15, 17, 20, 21, 22, 23, 28, 29, 38, 39 and 41) were ruled out because of the insufficient number of specimens (Supplementary material). Juvenile valves are ruled out when they are not occurring with adult specimens. A few specimens of the freshwater *Cypria* spp. (Bunbury, 2012), occurring up to the calcarenite bed top, were ruled out as allochtonous.

The Shannon-Wiener diversity H-index was assessed by:

$$H = -\sum[(p_i) * \log(p_i)]$$

where $p_i = n/N$, and where n is the number of individuals of a given species and N is the total number of individuals of the assemblage.

Infralittoral taxa abundance is calculated by the sum of *Aurila* spp., *Cimbaurila latisolea*, *Callistocythere flavidofusca*, *Callistocythere pallida*, Carinocythereis *carinata*, *Citherella circumpunctata*, *Citherella vulgata*, *Pontocythere rubra*, *Leptocythere* spp. and *Loxoconchidea minima*. Circalittoral taxa abundance is calculated by the sum of *Semicytherura* spp., *Sagmatocythere* spp., *Loxoconcha* spp., *Eucitherura* spp., *Hemicytherura* spp., *Bosquetina dentata*, *Cytheropteron* spp., *Callistocythere adriatica*, *Callistocythere crispata*, *Callistocythere littoralis*, *Callistocythere rastrifera*, *Callistocythere ephemera*, *Costa edwardsii* and *Cytheridea neapolitana*. Bathyal taxa abundance is calculated by the sum of *Henryhowella sarsii*, *Krithe* spp., *Buntonia sublatissima*, *Pterygocythereis jonesii* and *Bairdia conformis*. Taxa cited as a genus include just species found in the study and listed in Supplementary material. The attribution of bathymetric environments (infralittoral, circalittoral and bathyal) follows relevant literature (Yassini, 1969; Uffenorde, 1972; Bonaduce & Pugliese, 1975; Bonaduce et al., 1976, 1977, 1983, 1988, 1999; Athersuch et al., 1989; Barra et al., 1998; Montenegro et al., 1998; Didiè and Bauch, 2000; Didiè, 2001; Faranda et al., 2007; Frezza & Di Bella, 2015; Maiorano et al., 2008; Sciuto & Rosso, 2002, 2008; Aiello et al., 2015, 2018, 2020, 2021). The infaunal/epifaunal ratio follows Maiorano et al. (2008) and Aiello et al. (2015) and is formulated by the number of *Krithe* spp. / (*H. sarsii* + *Cytheropteron* spp.) specimens.

6. RESULTS

The ostracofauna is generally well preserved and 108 species belonging to 42 genera were identified (Supplementary material). Selected species are illustrated in Plates I and II. The highest diversity is recorded in the lowermost part of the section and gradually decreases up to 15 m depth, where a constant value around 1 is observed (Fig. 2).

Callistocythere ephemera (<38.4%, dominant just at 7 m depth), *C. edwardsii* (<53.8%) and *H. sarsii* (<78.9%) are the dominant species from 7 m depth up to the top of the section (Fig. 2). In the lower part of the section (< 7 m depth), many species contribute to the assemblage without a clear dominance role, except *H. sarsii* which is again the dominant species in basal samples (Fig. 2). *Bairdia conformis*, *Eucytherura patercoli*, *Krithe compressa*, *Semicytherura acuticostata* and *Urocythereis* sp. are common and show percentage value peaks over 10% in the first 2.1 m depth of the section (Figs. 3-4). *Aurila convexa*, *Aurila nana*, *Aurila punctata*, *Cytherella circumpunctata*, *C. vulgata*, *C. neapolitana*, *Leptocythere multipunctata* and *Loxoconcha ovulata* are common and show percentage value peaks over 10% between 2.1 and 7 m depth (Figs. 2, 4). A unique peak of *Bythocythere turgida* occurs within the *A. islandica* calcarenite bed (Fig. 2).

7. DISCUSSION

7.1. Bathymetric evolution

In the following, we show the bathymetric evolution in the Casa Parrino section, based on the environmental preference of ostracod taxa, grouped in infralittoral, circalittoral and bathyal assemblages (see Section 5 and references therein) (Fig. 5A).

Ostracod taxa identified at the studied section are benthic organisms and respond to different factors, among others the kind of substrate, organic matter and oxygen availability on the sea floor. As observed for benthic foraminifera, they do not provide reliable paleodepth estimates, since bathymetric ranges for single species changes in different areas, especially due to different organic matter fluxes (De Rijk et al., 1999, 2000; van der Zwaan et al., 1990, 1999; Jorissen et al., 2007). However, independently from a numerical bathymetric range, they still retain information on the original bottom environment, especially when assemblages, and not single taxa, are taken into account in the reconstruction.

Basal marl samples (0.0-1.2 m depth) show the occurrence of bathyal taxa that disappear within the *A. islandica* calcarenite bed (1.2-2.1 m depth), where an increasing number of infralittoral taxa specimens is recorded (Fig. 5A). Circalittoral taxa specimens occur in both marl and sandy samples, though they clearly decrease in relative abundance in the calcarenite bed (Fig. 5A). Thus, ostracod groups abundance changes indicate a pronounced sea level fall, in agreement with relative sea level fluctuations (Fig. 5C) that led to a drastic fall down to about -100 m depth at the top of MIS 22 (Rohling et al., 2014). The significant sea level fall described between basal marls and the calcarenite bed is also in agreement with the benthic foraminifera bathymetric reconstruction that suggests the rapid change from the epibathyal (100-150 m depth) to infralittoral environment (no more than 40 m depth) (Di Stefano et al., 1991).

From the *A. islandica* calcarenite bed top (2.1 m depth), infralittoral taxa show an abundance decline up to 9.0 m depth, where they permanently cease to be a significant component of ostracod assemblages and are replaced by an abundant number of circalittoral specimens (Fig. 5A). This bathymetric deepening is likely related to the gradual oxygen isotopic lightening during the MIS 22-21 Termination X (Lisiecki and Raymo, 2005; Hodell et al., 2015) (Fig. 5D) and the rapid sea level rise (Fig. 5C). The establishment of the climatic optimum, marked by permanent light oxygen isotopic values in the MIS 21g plateau (Lisiecki and Raymo, 2005; Hughes and Gibbard, 2018), as well a permanent sea level like to the modern one (Fig. 5C), may be indicated by the bathyal-circalittoral taxa abundance reversal at 11.0 m depth, which extends as far as the top of the Casa Parrino section (Fig. 5A). This reversal implies the deepening to an epibathyal environment, in agreement with a 100-120 water depth by benthic foraminifera estimates (Di Stefano et al., 1991).

7.2. Bottom water oxygen

In figure 5C, the abundance percentages of ostracod taxa (*C. neapolitana* and the genus *Loxoconcha*), able to survive in low-oxygen environments (Barbieri et al., 2019; Salvi et al., 2020), and the infaunal/epifaunal ratio (Maiorano et al., 2008; Aiello et al., 2015) are shown. The only significant interval when oxygen deficiency species and the infaunal/epifaunal ratio significantly increase is recorded during Termination X and the earliest MIS 21 (see Section 7.1), while the most significant diversity loss (Fig. 2) and the lowest number of specimens, even < 50 (Supplementary material), is also observed. We argue that bottom water dysoxia may be developed in the Sicily Channel at the passage between MIS 22 and MIS 21, in response to water column stratification. Increased summer insolation may have prevented water column convection, as observed during the two last interglacial phases, by planktonic foraminifera and

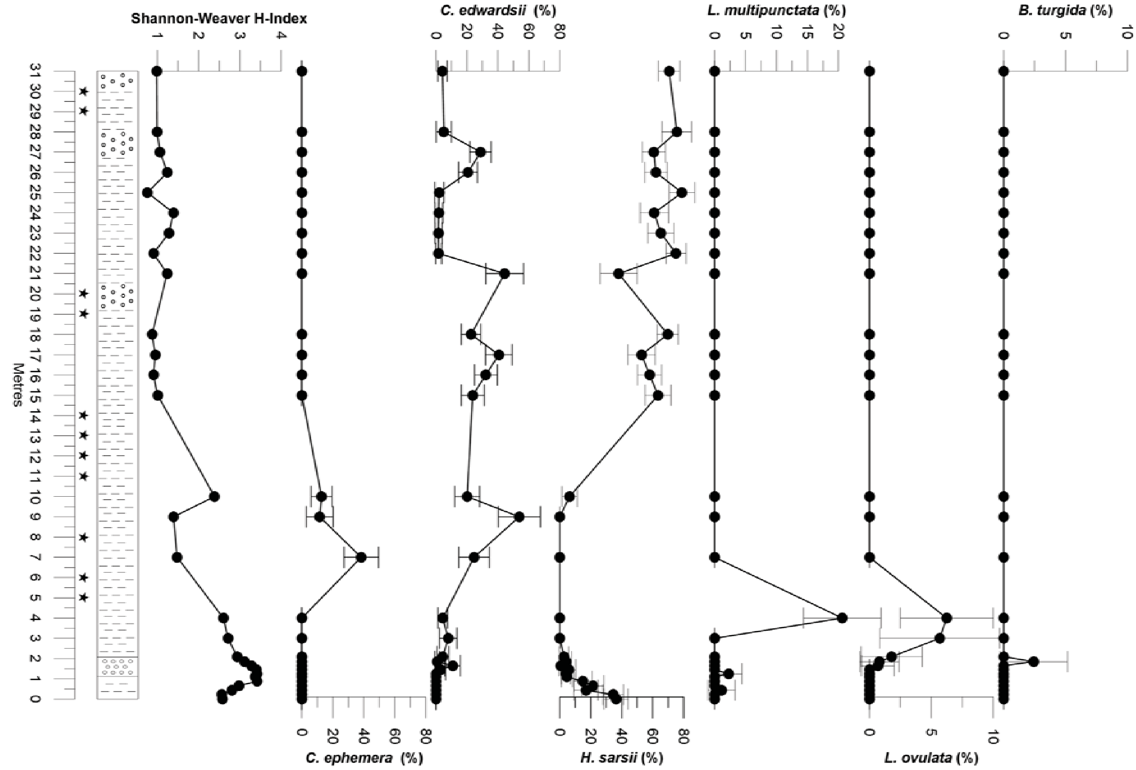

Fig. 2 - Distribution pattern of selected ostracod taxa, expressed in percentage values, and their diversity. The simplified lithostratigraphic log is also shown. Asterisks mark samples with < 50 ostracod specimens.

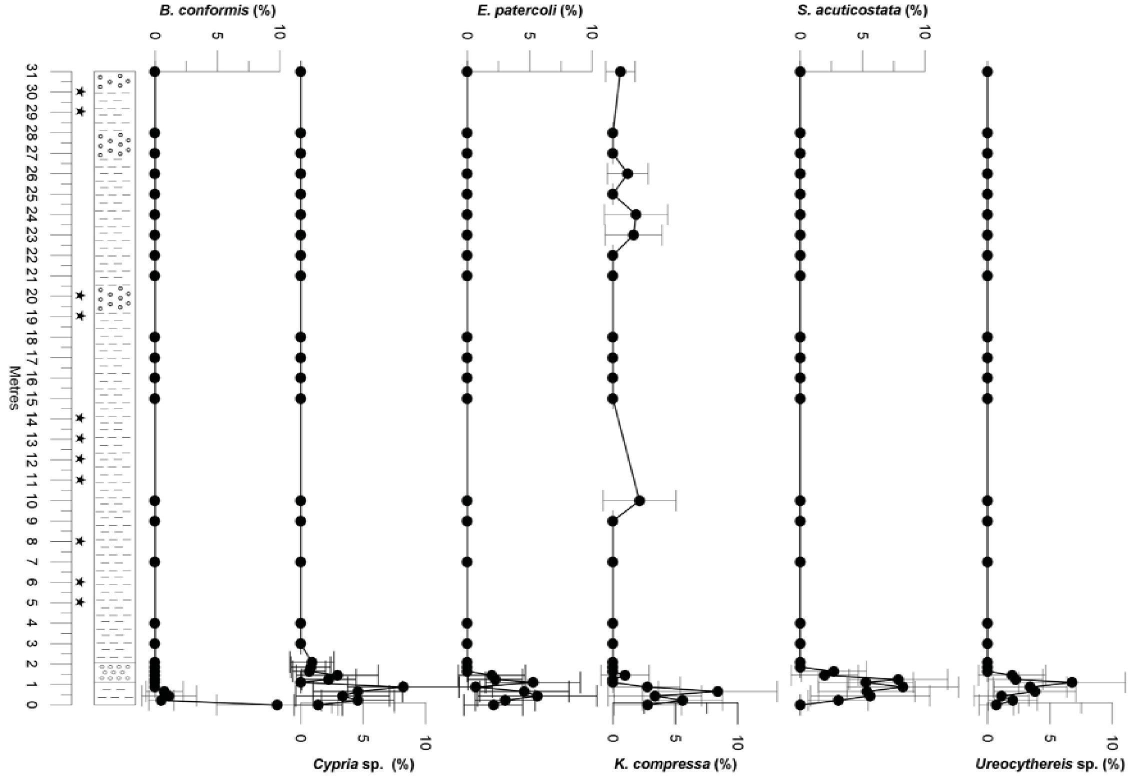

Fig. 3 - Distribution pattern of selected ostracod taxa, expressed in percentage values. The simplified lithostratigraphic log is also shown. Asterisks mark samples with < 50 ostracod specimens.

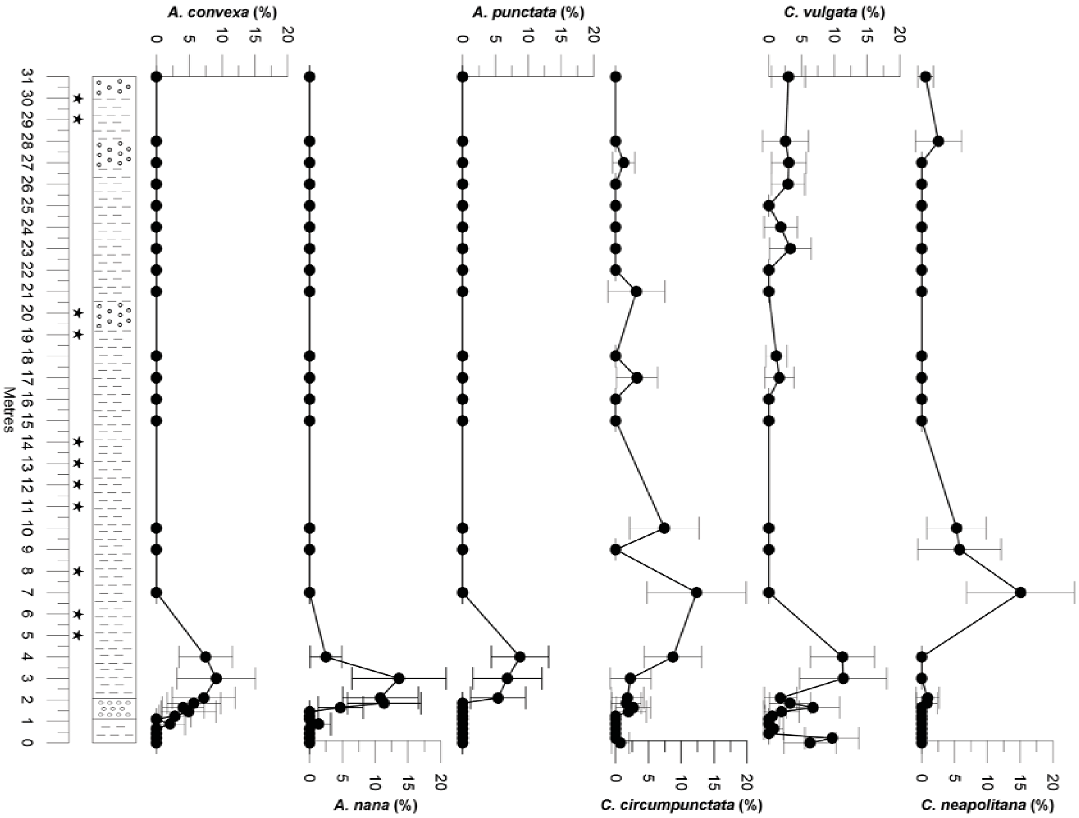

Fig. 4 - Distribution pattern of selected ostracod taxa, expressed in percentage values. The simplified lithostratigraphic log is also shown. Asterisks mark samples with < 50 ostracod specimens.

nannofossil assemblages (e.g. increased abundance of *Globigerinoides ruber* and *Florisphaera profunda*) and by the difference between oxygen isotopic values of benthic and planktonic foraminifera species (Sprovieri et al., 2003, 2006; Incarbona et al., 2008, 2011, 2013; Sprovieri et al., 2012; Incarbona & Sprovieri, 2020). The same phenomenon, dealing with summer water column stratification down to the lower photic zone, is evident across the whole central-western Mediterranean Sea for the Holocene and the last interglacial (Flores et al., 1997; Sbaffi et al., 2001; Perez-Folgado et al., 2004; Incarbona et al., 2008; Ausin et al., 2015; Di Stefano et al., 2015b; Bazzicalupo et al., 2018, 2020). The sea bottom oxygen deficiency at the Case Parrino section, above the calcarenite bed, is further confirmed by the occurrence of pyrite, diverity loss in benthic foraminifera assemblages and the occurrence of low-oxygen tolerant taxa (Globobulimina spp.) (Di Stefano et al., 1991).

It is noteworthy that a sapropel layer deposited on the eastern Mediterranean seafloor, as shown by Ocean Drilling Program 967 Site Ba/Al and PC2 (Fig. 5F-G), respectively proxies for enhanced productivity and North Africa River runoff (Grant et al., 2017), around ~ 864 ka. Though there is no sign of laminites in the Case Parrino section, as well in the Sicily Channel Middle Pleistocene sediments (Emeis et al., 1996), it is well-established that the eastern Mediterranean carbon-enriched layer deposition led to Mediterranean thermohaline circulation perturbation and and had a large-scale impact (Sprovieri et al., 2003; Incarbona et al., 2011; Incarbona & Sprovieri, 2020). In particular, the thermohaline circulation would significantly have weakened across the Sicily Strait, where oxygen-depleted water masses of the surface-intermediate cells would be exchanged between the sub-basins (Rohling, 1991; Myers et al., 1998; Incarbona & Sprovieri, 2020). Thus, the weakened Mediterranean circulation may have further sea bottom oxygen deficiency, observed in ostracod and benthic foraminifera assemblages, at least during the earliest MIS 21.

7.3. Paleoclimatic inferences

Several ostracod species are known to be Quaternary northern guest in the Mediterranean Sea (Faranda & Gliozzi, 2011). In the Casa Parrino section, just one of these taxa, *B. turgida* (Ruggieri, 1976a; Faranda and Gliozzi 2011, Sciuto, 2016), exhibit an abundance spike in coincidence of the *A. islandica* calcarenite bed (Fig. 2), where the intense climatic cooling is also marked by the subarctic species *Limacina retroversa* increase in the Pteropod assemblage (Buccheri, 1985).

Apparently, no other sign of climatic oscillation may be gathered from ostracod taxa in the studied section. However, four episodes of distinct changes exist in the distribution pattern of bathyal and circalittoral taxa (black arrows and question marks in Fig. 5A) between 17 and 27 m depth. Looking at the Atlantic Meridional Overturning Circulation (AMOC) from the Log Ca/Ti record by Hodell et al. (2015) in the Iberian Margin, there are four

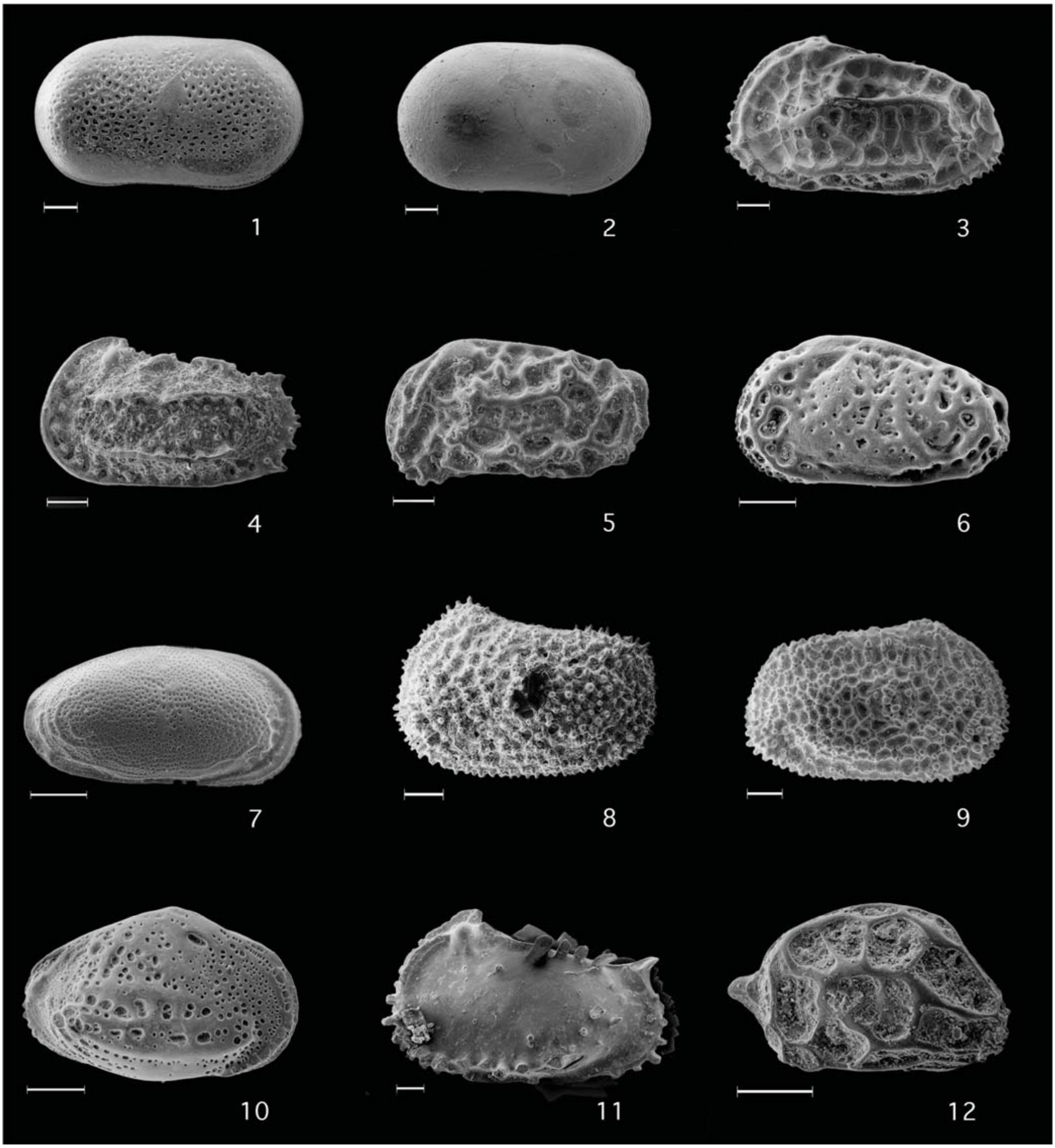

Plate Ia: 1) *Cytherella scutulum*, LV, lateral external view; 2) *Cytherella vulgata*, RV, lateral external view; 3) *Costa edwardsii*, LV, lateral external view; 4) *Carinocyhtereis carinata*, LV, lateral external view; 5) *Callistocythere adriatica*, LV, lateral external view; 6) *Callistocythere (Rastrocythere) ephemera*, LV, lateral external view; 7) *Leptocythere multipunctata*, RV, lateral external view; 8) *Henryhowella sarsii*, LV, lateral external view; 9) *Henryhowella sarsii*, RV, lateral external view; 10) *Buntonia sublatissima*, RV, lateral external view; 11) *Pterygocythereis jonesii*, LV, lateral external view; 12) *Hemicytherura videns*, LV, lateral external view. The scale bar is 100 µm.

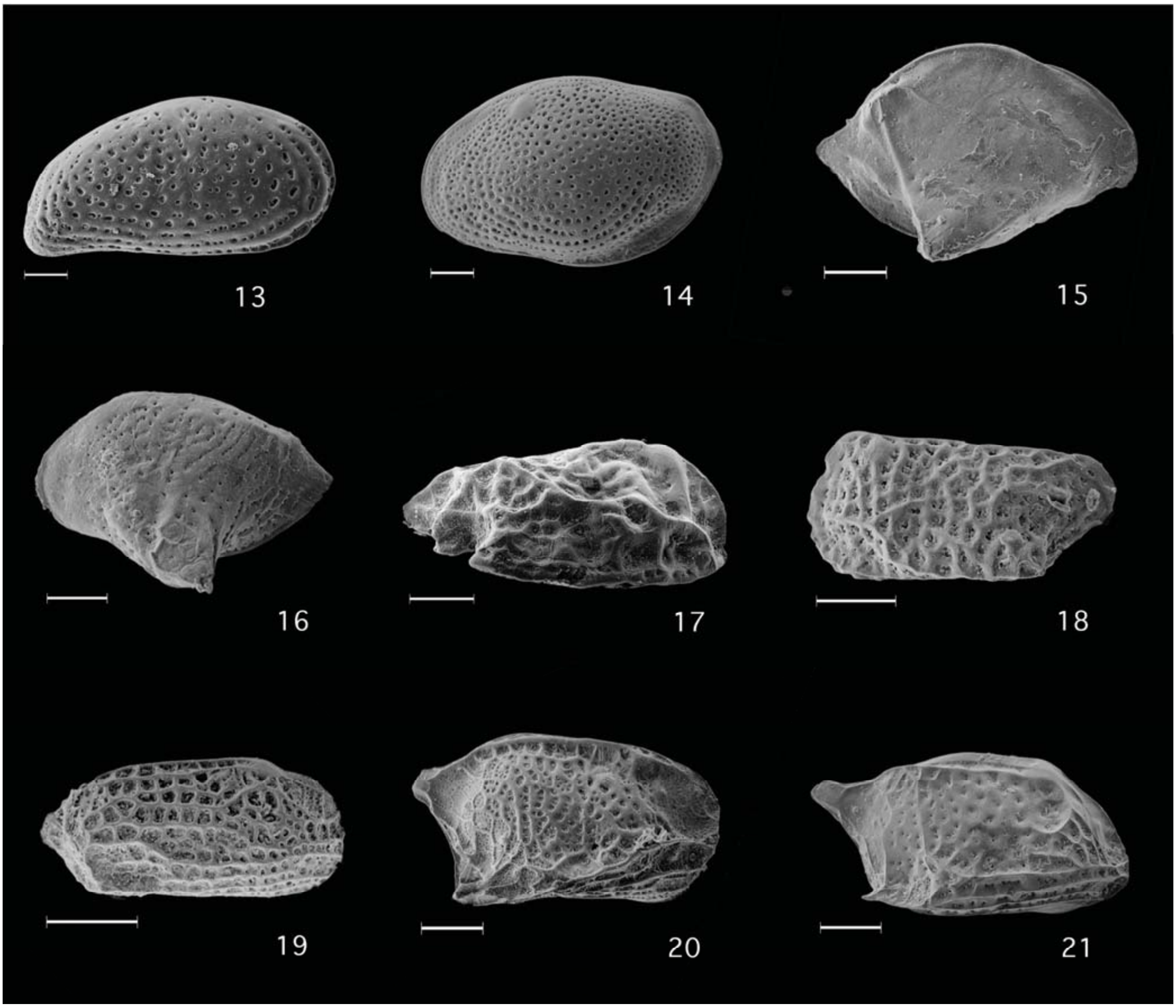

Plate Ib: 13) *Cytheridea neapolitana*, RV, lateral external view; 14) *Loxoconcha cfr. gibberosa*, LV, lateral external view; 15) *Cytheropteon sulcatum*, RV, lateral external view; 16) *Cytheropteron cfr. monoceros*, LV, lateral external view; 17) *Paracytheridea triquetra*, RV, lateral external view; 18) *Eucytherura patercoli*, LV, lateral external view; 19) *Semicytherura rara*, RV, lateral external view; 20) *Semicytherura alifera*, RV, lateral external view; 21) *Semicytherura frenzeli*, RV, lateral external view. The scale bar is 100 µm.

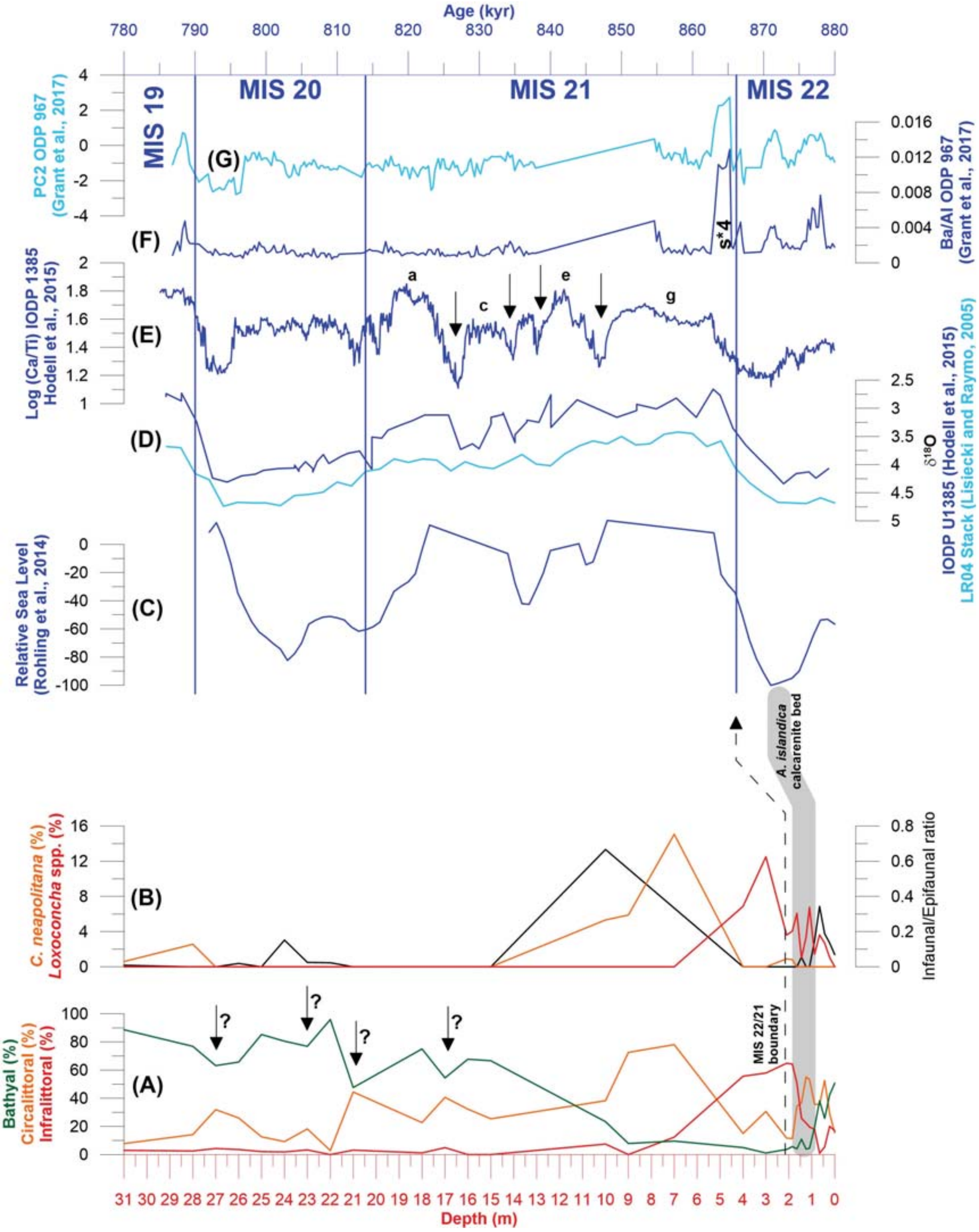

Fig. 5 - Distribution pattern of selected ostracod taxa, groups and ratio (plotted versus depth) in comparison with global, Mediterranean Sea and Atlantic Ocean paleoenvironmental and paleoclimatic proxy data (plotted versus age, kiloyears ago, following their own original age model). A: infralittoral (red line), circalittoral (orange line) and bathyal (green line) ostracod groups. The four black arrows and question marks indicate the possible MIS 21 cold spells. B: deficiency oxygen stress ostracod taxa (red and orange lines) and the infaunal/epifaunal ratio, *Krithe* spp. / (*H. sarsii* + *Cytheropteron* spp.) specimens, following Maiorano et al. (2008) and Aiello et al. (2015) (black line). C: relative sea level variations, expressed in m compared to today (0 m) (Rohling et al., 2014). D: benthic foraminifera d18O from the Iberian Margin (Hodell et al., 2015) (blue line) and the LR04 stack (Lisiecki and Raymo, 2005) (light blue line). E: very high-resolution log (Ca/Ti) record in the Iberian Margin (Hodell et al., 2015), proxy for the AMOC circulation. a-g show MIS 21 substages. Black arrows show the four episodes of AMOC slowdown/shutdown within MIS 21. F: Ba/Al ratio at ODP 967 Site (Grant et al., 2017), whose peaks indicate enhanced productivity in the eastern Mediterranean Sea during sapropel layer deposition. S*4 is the name for the sapropel layer identified in the earliest MIS 21 (Grant et al., 2017). G: Principal Component (PC) 2 for elemental proxies at ODP 967 Site (Grant et al., 2017), whose peaks indicate enhanced North Africa River runoff.

episodes of slowdown during MIS 21. It is well-established as AMOC slowdown/shutdown episodes led to millennial-scale climatic instability even during interglacials (Martrat et al., 2004, 2007, 2014; Tzedakis et al., 2018) and produced pronounced cooling even in the Mediterranean Sea (Manabe & Stouffer, 1997; Vellinga and Wood, 2002; Sprovieri et al., 2006).

Coupling millennial-scale cold spells to relative sea level drops, as they would be indicated by increased relative abundance of circalittoral ostracods versus bathyal ones, is not a straightforward issue. In the last glacial period, sea level variations during Dansgaard-Oeschger variability could be affected by rapid cycles of accumulation/melt in the Antarctica ice sheet, whose millennial-scale climatic variations are in anti-phase (Siddall et al., 2003; Rohling et al., 2004). Thus, we are not sure that bathymetric fluctuations indicated by ostracod groups, since the middle part of the Casa Parrino section, are truly related to sea level fall, though the sea level indeed felt down to ~ -50 m between 850 and 835 ka (Fig. 5C). As introduced in Section 7.1, benthic organisms may migrate through different bathymetry following food supply fluxes. In the modern eastern Mediterranean Sea, where oligotrophic conditions persist, many benthic foraminifera species tend to occupy a shallower position. Thus, we argue that the apparent bathymetric fluctuations shown by ostracod groups may be driven by productivity changes, rather than real sea level variations. Increased circalittoral taxa percentages may be due to decreased productivity during cold spells, as observed in Sicily Channel calcareous plankton assemblages (Incarbona et al., 2013). If true, the link between ostracod bathymetric fluctuations and AMOC variations, may provide tie-points for sedimentation rate estimates at Casa Parrino, that would range between 45.9 and 51.7 cm/kyr, in line with other Middle Pleistocene southern Italy outcrops of a relatively shallow environment (Maiorano et al., 2008; Capraro et al., 2011).

Planktonic foraminifera assemblages indicate the occurrence of an episode of climate deterioration at 23 m depth, coinciding with the penultimate episode of ostracod circalittoral taxa increase (Fig. 5A), and a general cooling trend for the upper part of the studied section (Di Stefano et al., 1991). Ostracod assemblages do not show a similar cooling, as well as that a new glacial cycle has been established in the uppermost part of the record, perhaps indicating that the top of the section is still deposited during the interglacial MIS 21.

8. CONCLUSION

Ostracod assemblages in 41 samples from the Casa Parrino section were investigated, aimed at reconstructing paleoenvironmental conditions, over the late Calabrian Stage (calcareous nannofossil MNN 19f Zone, Di Stefano et al., 1991). A total of 108 species and 42 genera were identified. The highest diversity is recorded in the lowermost part of the section and gradually decreases up to 15 m depth. *Callistocythere ephemera*, *C. edwardsii* and *H. sarsii* are the dominant species except for the lower part of the section where many species contribute to the assemblage without a clear dominance role (Figs. 2-3).

The bathymetric evolution was carried out grouping infralittoral, circalittoral and bathyal taxa. We show a marked sea level drop in the lower part of the section, up to the top of the *A. islandica* calcarenite bed (2.1 m depth). Then, infralittoral taxa cease to be a significant component of ostracod assemblages at 9.0 m depth, replaced by an abundant number of circalittoral specimens (Fig. 5A). The bathyal-circalittoral taxa abundance reversal at 11.0 m depth, which extends as far as the top of the Casa Parrino section (Fig. 5A), marks the deepening to an epibathyal environment, in agreement with water depth estimates by benthic foraminifera (Di Stefano et al., 1991). This paleobathymetric sketch is compatible with eustatic sea level changes, depicted for the upper part of MIS 22 and MIS 21 (Rohling et al., 2014) (Fig. 5C).

The significant occurrence of *C. neapolitana* and the genus *Loxoconcha* specimens, high values in the infaunal/epifaunal ratio (Maiorano et al., 2008; Aiello et al., 2015) (Fig. 5B) and the decreased diversity suggest the development of bottom water dysoxia at the passage between MIS 22 and MIS 21, in response to water column stratification. Bottom oxygen deficiency may have been worsened by the thermohaline circulation weakening of the surface-intermediate cells during the deposition of a sapropel layer in the eastern Mediterranean Sea in the earliest MIS 21 (Grant et al., 2017) (Fig. 5F-G).

Bythocythere turgida is the only Quaternary northern guest that was identified in the Casa Parrino section, in coincidence of the *A. islandica* calcarenite bed (Fig. 2), where the intense climatic cooling is also marked by the subarctic species *Limacina retroversa* increase in the Pteropod assemblage (Buccheri, 1985). However, we note four episodes of increased relative abundance of circalittoral ostracods versus bathyal ones (Fig. 5A) that may reflect different organic matter pulses. These subtle productivity change events may be occurred during cold spells, driven by AMOC weakening (Fig. 5E), like for late Quaternary interglacial and glacial cycles (Martrat et al., 2004, 2007; Incarbona et al., 2013; Tzedakis et al., 2018).

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