

Size variations in the genus *Gephyrocapsa* during the Early Pleistocene in the eastern Mediterranean

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ABSTRACT

The genus *Gephyrocapsa*, belonging to coccolithophores, has often been used in biostratigraphic and paleoceanographic studies of the late Cenozoic. This taxon exhibits a gradual increase in size during the Early Pleistocene which has been ascribed to evolutive and/or environmental processes and has been used for biostratigraphic purposes.

Here we show both biometric and relative abundance data of specimens of this genus between about 2.0 and 0.9 Ma, from sediments of the Ionian Sea (eastern Mediterranean). Measurements on the long axis of placoliths highlight a gradual size increase between the upper part of MNN 19a and the top of MNN 19d biozones. On the basis of the comparison with paleoenvironmental proxy data acquired on the same site, we rule out the influence of climate and oceanographic phenomena due to glacial/interglacial oscillations, on *Gephyrocapsa* spp. size variations. However, we argue that the climate/environmental forcing may have acted by longer-scale phenomena, for instance the growth of ice sheets and the subsequent sea surface cooling in the oceans. Finally, we suggest that the First Common Occurrence of *Gephyrocapsa* >4.5 μm and the First Occurrence of *Gephyrocapsa* >5.0 μm may approximate the Last Occurrence of *Calcidiscus macintyreii* in studies dealing with terrigenous sediments affected by severe reworking.

KEY WORDS: *Gephyrocapsa* spp., Biometry, Early Pleistocene, Ionian Sea.

INTRODUCTION

Following the original definition of KAMPTNER (1943), all placoliths with a bridge across the central area can be referred to the genus *Gephyrocapsa*. The first appearance of this genus occurred about 3.5 Ma and can be ascribed to the NN15 Zone (MARTINI, 1971) in the lower Pliocene (PIRINI-RADDRIZZANI & VALLERI, 1977; SAMTLEBEN, 1980; RIO, 1982).

Living and fossil specimens have been grouped in different morphotypes and species on the basis of variations in placolith size, placolith bridge angle and shape, the central collar, roundness and the central area width (fig. 1) (PUJOS-LAMY, 1976; BRÉHÉRET, 1978; SAMTLEBEN, 1980; BOLLMANN, 1997). Especially important for biostratigraphic purposes is the coccolith size (e.g. GARTNER, 1977; RAFFI & RIO, 1979; MATSUOKA & OKADA, 1990; RAFFI *et alii*, 1993) that in the Mediterranean bioprovince allowed the detailed subdivision of the Early Pleistocene,

from about 1.6 Ma to about 0.9 Ma by three biohorizons (RIO *et alii*, 1990). After the first occurrence of specimens of *Gephyrocapsa oceanica* s.l. $\geq 4 \mu\text{m}$ at about 1.6 Ma, there is a general increase in size of the coccoliths which culminates with the first occurrence of large *Gephyrocapsa* >5.5 μm at about 1.3 Ma. The *Gephyrocapsa* spp. population is radically modified at about 1.1 Ma, with the disappearance of all the specimens $\geq 4 \mu\text{m}$ and is again diversified after about 0.9 Ma with a new radiation of *Gephyrocapsa* spp. $\geq 4 \mu\text{m}$, including specimens with a bridge parallel to the short axis (BUKRY, 1973; RIO, 1982; RIO *et alii*, 1990). The origin of Pleistocene variations in the *Gephyrocapsa* size variations remains poorly known, although these variations have been interpreted as the result of evolutionary and/or environmental process by different authors (PUJOS-LAMY, 1976; BRÉHÉRET, 1978; SAMTLEBEN, 1980; RIO, 1982; GARD, 1988; MATSUOKA & OKADA, 1990; RAFFI *et alii*, 1993).

We have measured biometric relationships of *gephyrocapsid* specimens and determined the relative abundance of different species in sediments retrieved from Ocean Drilling Program (ODP) Site 964 (Ionian Sea, eastern Mediterranean Sea) during the Early Pleistocene (between about 2.0-0.9 Ma), at a sample resolution of about 20 kyr. Results are compared to paleoenvironmental/paleoceanographic proxy data in order to test how *Gephyrocapsa* spp. modifications were affected by changes in the marine environment.

MATERIAL AND METHODS

ODP Site 964 (36°15.62'N, 17°45.025', 3650 m water depth) is located at the foot of the Calabrian Ridge near the Ionian Abyssal Plain (fig. 2). All holes of Site 964 are characterized by locally discontinuous and tectonically attenuated sedimentary sequences (EMEIS *et alii*, 1996). The sediment consists of brownish to greenish clayey nannofossil ooze and nannofossil clay. Numerous ash layers, ashy turbidites, discrete beds of tuffs and normally graded turbidites have been recognized. Volcanic glass fragments are intercalated throughout (EMEIS *et alii*, 1996; LOURENS, 2004). Erosional gaps at the base of turbidites and high-angle extensional faults have been observed and the construction of the magnetostratigraphic record was hindered by overprints that could not be removed (EMEIS *et alii*, 1996). A total of 59 sapropel layers are present in the composite section of Site 964 (SAKAMOTO *et alii*, 1998) and they were compared with the Plio-Pleistocene sections outcropping in south-

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ern Italy (SPROVIERI *et alii*, 1998; DI STEFANO & INCARBONA, 2008).

In the present study, the portion between 63.14 and 32.94 revised meter composite depth (rmcd) has been selected and it represents the interval between the Gelasian Stage (MNN 18 Zone) and the Calabrian Stage (MNN 19f Zone) (SPROVIERI *et alii*, 1998). The lithology consists of brownish to greenish clayey nannofossil ooze and nannofossil clay and includes a thick turbidite layer between 52.98 and 49.46 rmcd.

Three different analyses were carried out by observation with a polarized microscope at about 1000 × magnification, in rippled smear slides prepared following standard procedures (BOWN & YOUNG, 1998). AxioCam Cci camera and software Axiovision 4.7 were used for length measurements of the long axis of 50 specimens of *Gephyrocapsa* spp. >3 μm in 45 samples. Following the biometric subdivision of RIO (1982) and RIO *et alii* (1990), small *Gephyrocapsa* includes specimens <4 μm, medium *Gephyrocapsa* includes specimens between 4 and 5.5 μm, large *Gephyrocapsa* includes specimens >5.5 μm. A different criterion was applied to describe the genus *Gephyrocapsa* in terms of species, evaluated *versus* 300 specimens of this taxon in 42 samples. Following INCARBONA *et alii* (2009) the species concept used are: very small *Gephyrocapsa* for specimens <3 μm; *Gephyrocapsa muelleriae* for specimens >3 μm with a low bridge angle; *Gephyrocapsa caribbeanica* for specimens >3 μm with an almost closed central area; *Gephyrocapsa oceanica* and *Gephyrocapsa omega* (or *Gephyrocapsa* sp. 3 sensu RIO, 1982) specimens were not distinguished one each other. They include specimens >3 μm with a high bridge angle. A total of 83 samples were analysed to determine the relative abundance of *Florisphaera profunda* *versus* 100 coccolithophore specimens (CASTRADORI, 1993; SPROVIERI *et alii*, 2003).

The instrumental uncertainty due to the Axiovision 4.7 software is of 0.005 μm (1 pixel) and is therefore negligible. A further error in measurements may be given by the tilt of placoliths. However, the error would become significant (>5%) if the tilt of placolith is ≥20°, which is rather unlikely and would prevent the correct identification at the species level.

STUDY AREA

Three water masses exist in the Ionian Sea. Modified Atlantic Waters occupy the upper 100-200 m of the water column. They enter from the northern part of the Sicily Strait, transported by the Atlantic Ionian Stream that meanders into the Ionian Sea and feeds the Mid-Mediterranean Jet (POEM GROUP, 1992; PINARDI & MASETTI, 2000). Levantine Intermediate Waters (LIW), located between 150-200 and 600 m, formed in February-March as a process of surface cooling on water masses that underwent a severe salt enrichment in the area between Rhodes and Cyprus (OVCHINNIKOV, 1984; POEM GROUP, 1992). Bottom waters, whose origin is due to the sinking of surface cooling and the mixing with LIW, form in the northern part of the basin, in the Adriatic and Aegean Sea (POEM GROUP, 1992).

The trophic resources of the eastern Mediterranean Sea are among the poorest in the world's oceans, and this deficit is especially pronounced with respect to phosphorous (KROM *et alii*, 2010). Productivity estimates in the

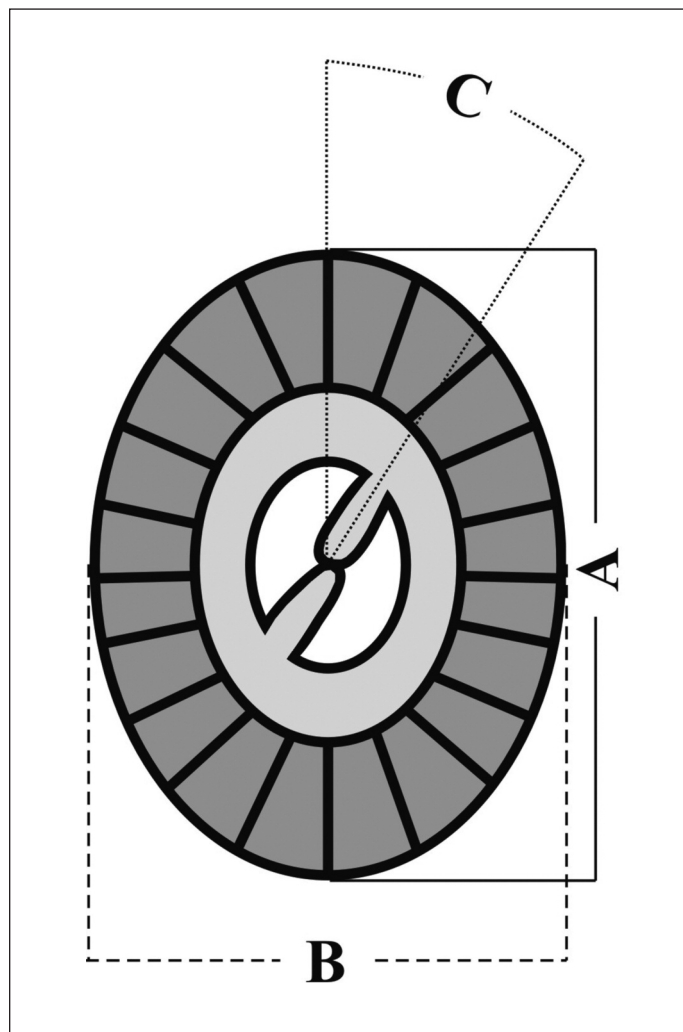


Fig. 1 - Cartoon showing some of the measurements that can be carried out on placoliths of the genus *Gephyrocapsa*: A) Long axis length; B) Short axis length; C) Bridge angle.

Ionian Sea range between about 105 and 130 gC × m⁻² × yr⁻¹ and demonstrate that it is one of the most oligotrophic subbasins in the Mediterranean Sea (ANTOINE *et alii*, 1995; D'ORTENZIO *et alii*, 2003; BOSCH *et alii*, 2004). In particular, Site 964 is located in an area characterized by low biomass during late spring-summer and higher biomass up to the maxima in late fall-winter (D'ORTENZIO & RIBERA D'ALCALÀ, 2009).

RESULTS

Calcareous nannofossil assemblages are well diversified and preserved. However, in four samples, at 56.48, 41.77, 40.36 and 37.84 rmcd, severe dissolution processes led to the complete disappearance of *Gephyrocapsa* spp. specimens (fig. 3).

Gephyrocapsa spp. assemblages are dominated by very small specimens (<3 μm), with relative abundance values between 70% and 100%, apart from values of 40% in the uppermost sample (fig. 3). At distinct intervals, there is a significant contribution of *G. muelleriae*, *G. caribbeanica*,

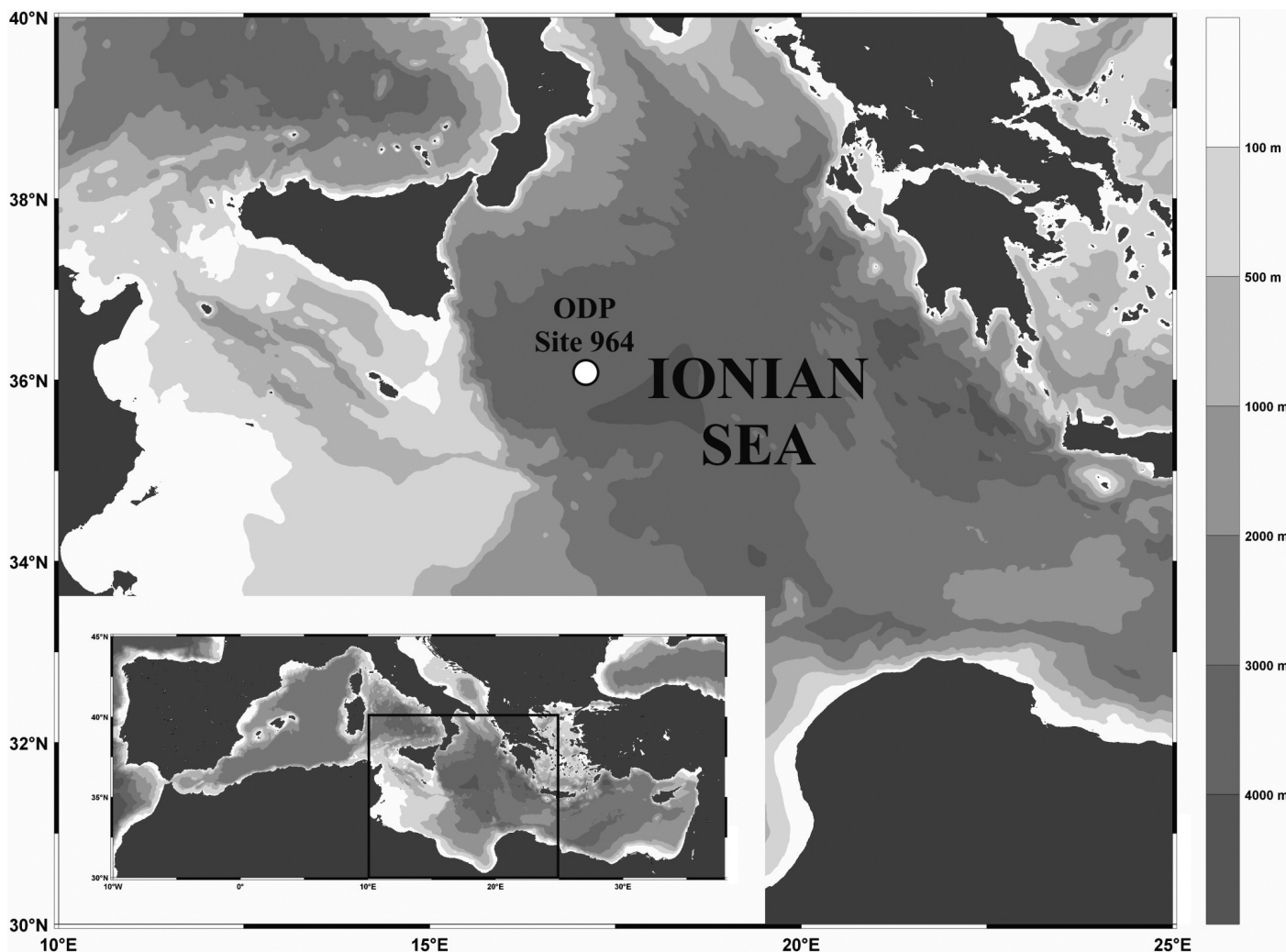


Fig. 2 - Bathymetric map of the Ionian Sea and location of the ODP Site 964. Inset below, the map of the Mediterranean basin.

G. oceanica and *G. omega*. *Gephyrocapsa muelleriae* shows a few positive peaks, up to about 16%, in the lower part of the record. *G. oceanica* and *G. caribbeanica* increase in abundance, with values up to respectively 10% and 25% respectively, mainly during Zones MNN 19c and MNN 19d. After the re-entrance of medium sized *gephyrocapsids*, *G. oceanica* is rather sparse. *Gephyrocapsa omega*, however, is the only species that successfully competes with very small *Gephyrocapsa* (fig. 3).

Coccolith size measurements on specimens $>3 \mu\text{m}$ of the genus *Gephyrocapsa* show a rather gradual increasing trend from the base of the studied interval. After an interval with only specimens of *Gephyrocapsa* $<4 \mu\text{m}$ (MNN 19e), there is a new radiation of medium sized *Gephyrocapsa* (fig. 4).

The First Occurrence (FO) of *Gephyrocapsa* $\geq 4 \mu\text{m}$ at 58.62 rmcd is composed of specimens of *G. caribbeanica* and is not therefore able to mark the base of MNN 19b, which is defined by the FO of *Gephyrocapsa oceanica* sensu lato $>4 \mu\text{m}$ (R10 *et alii*, 1990). The first occurrence of specimens of *Gephyrocapsa* $>5.5 \mu\text{m}$ was observed at 49.1 rmcd and a few specimens of *Gephyrocapsa* $\geq 4 \mu\text{m}$ immediately above this horizon were considered as reworked. Finally, the re-entrance of medium-sized specimens occurred at 33.94 rmcd (fig. 3).

Florisphaera profunda shows wide abundance fluctuations between about 3% and 60%. Positive peaks are usually associated to odd (interglacial) Marine Isotopic Stages (MIS) or to sapropel layers, for instance at 56.92, 56.42 and 55.82 rmcd. The lowest percentage values are recorded in coincidence of even (glacial) MIS (fig. 4). However the comparison is not always unambiguous and shows low abundance values for instance in coincidence of MIS 41, 45 and 65.

DISCUSSION

BIOSTRATIGRAPHIC IMPLICATIONS

Biostratigraphic boundaries MNN 19a/MNN 19b, MNN 19c/MNN 19d, MNN 19d/MNN 19e and MNN 19e/MNN 19f, marked by *Gephyrocapsa* spp. horizons, are constantly shifted above, with respect to SPROVIERI *et alii* (1998). These displacements, between 0.3 and 0.9 metres, can readily be explained by different methodologies, such as sampling strategy and the number of counted specimens, that may have affected the accuracy of the determinations of the biohorizons.

The First Common Occurrence (FCO) of *Gephyrocapsa* $>4.5 \mu\text{m}$ and the FO of *Gephyrocapsa* $>5.0 \mu\text{m}$ fall very close

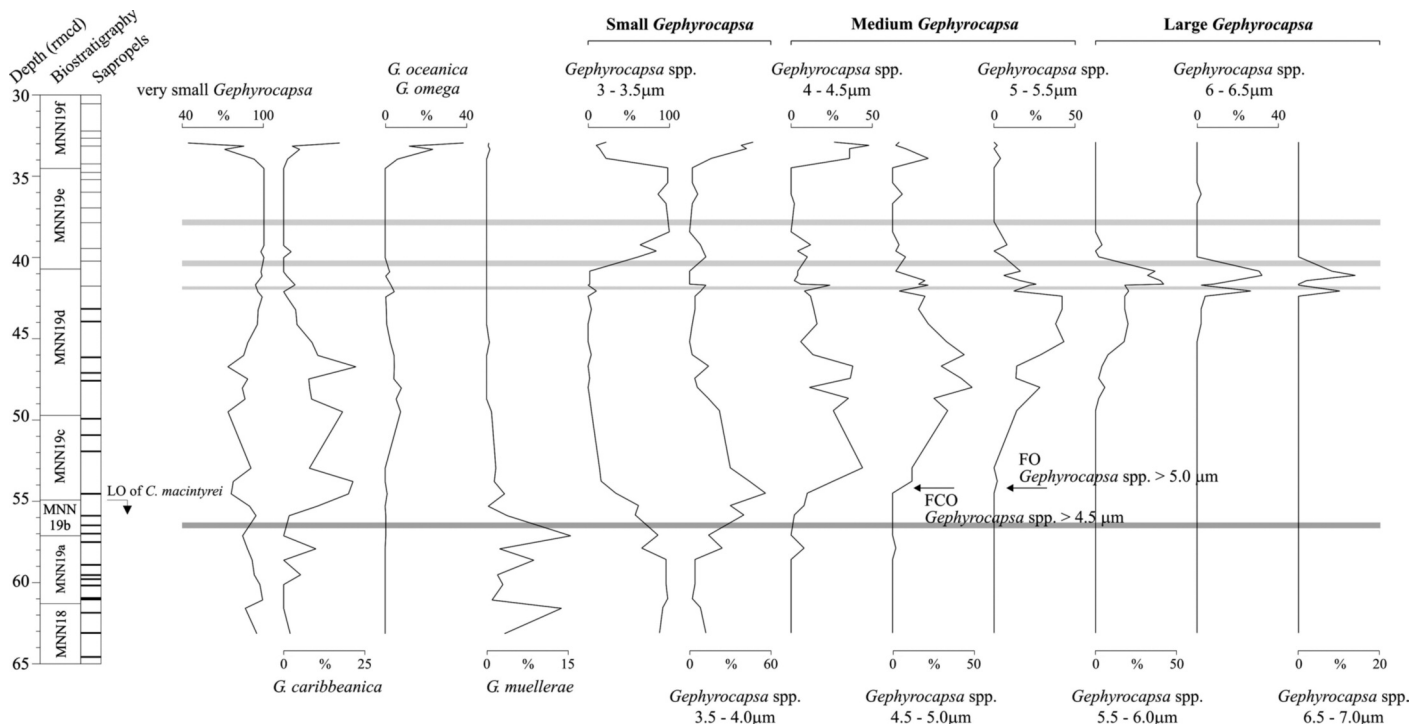


Fig. 3 - Downcore variations of biometric and compositional data of the genus *Gephyrocapsa* collected at the ODP Site 964 during the Early Pleistocene, plotted versus depth in mcd. From the left, the biostratigraphic framework, following SPROVIERI *et alii* (1998); Sapropel layers' setting (EMEIS *et alii*, 2000b); Relative abundance of the taxonomic units, very small *Gephyrocapsa*, *G. caribbeanica*, *G. oceanica*, *G. omega* and *G. muellerae* identified in the study; Biometric data collected on the long axis of placoliths, grouped every 0.5 μm . Taxonomic units used by RIO *et alii* (1990) for biostratigraphic purposes, small *Gephyrocapsa*, medium *Gephyrocapsa* and large *Gephyrocapsa* are also indicated. Black arrows mark biohorizons that may reinforce the LO of *C. macintyreii* in terrigenous sections. Light grey bands show sample where severe dissolution processes led to the disappearance of most of *Gephyrocapsa* spp. specimens.

to the LO of *C. macintyreii* that defines the base of the MNN 19c Zone (fig. 3). It is well-established that the LO of *C. macintyreii* is time-transgressive when low-latitude Atlantic and Pacific sites are compared with middle-latitude Atlantic sites, occurring 43 kyr earlier in Atlantic middle-latitude sites (RAFFI *et alii*, 1993, 2006; RAFFI, 2002). A similar discrepancy is observed in the Mediterranean Sea, where this biohorizon seems to disappear from the sedimentary record within the MIS 59/58 transition in the eastern Mediterranean Sea (RAFFI, 2002; RAFFI *et alii*, 2006) and in the upper part of MIS 56 in the western Mediterranean Sea (DE KAENEL *et alii*, 1999). In the composite ODP Site 964 record from the Ionian Sea, the LO of *C. macintyreii* occurs within MIS 56 (SPROVIERI *et alii*, 1998), similar to its disappearance horizon in the western Mediterranean Sea. The gap between the FCO of *Gephyrocapsa* >4.5 μm and the FO of *Gephyrocapsa* >5.0, identified within MIS 55 (figs. 3-4), is less than the duration of a full glacial/interglacial cycle. The FCO of *Gephyrocapsa* >4.5 μm and the FO of *Gephyrocapsa* >5.0 μm may thus approximate the detection of the LO of *C. macintyreii* in terrigenous sediments where reworking masks this signal. This problem is especially important in terrigenous land sections of southern Italy and Sicily, where most of Pliocene-Pleistocene Global Stratigraphic Sections and Points and historical reference sections outcrop (CITA *et alii*, 2006, 2008).

ENVIRONMENTAL INFLUENCE ON GRADUAL SIZE INCREASE

Measurements on the long axis of the genus *Gephyrocapsa* highlight a clear gradual size increase in minima,

average and maxima values, from the upper part of MNN 19a to the top of MNN 19d Zones (fig. 4). The mean value of these ≥ 3.0 μm placoliths increases from 3.0-3.5 μm to about 6.0 μm

Several paleoclimatic/paleoenvironmental studies have been carried out on the sediments of the ODP Site 964 and of the Ionian Sea (NEGRI *et alii*, 1999; EMEIS *et alii*, 2000a; NEGRI & GIUNTA, 2001; GERAGA *et alii*, 2008; INCARBONA *et alii*, 2011; MAIORANO *et alii*, 2013). We show $\delta^{18}\text{O}$ data collected on shells of the planktonic foraminifera species *Globigerina bulloides* (fig. 4) representing global ice volume fluctuations and local sea surface temperature (SST) and salinity variations (SPROVIERI *et alii*, 1998). We also show abundance fluctuations of *F. profunda* (fig. 4), a proxy for primary productivity levels (CASTRADORI, 1993; INCARBONA *et alii*, 2008, 2011). The oxygen isotope and *F. profunda* records demonstrate that environmental conditions, such as SST/salinity and nutrient dynamics, oscillated with glacial/interglacial changes. Given the relatively steady size increase in *Gephyrocapsa* spp. specimens, we suggest that variable conditions in the photic zone environments induced by glacial/interglacial oscillations did not have any obvious effect on the size evolution of *gephyrocapsids*. However, we note that the time interval between 2.0 and 1.2 Ma is characterized by a linear trend towards heavier oxygen isotopic values, due to the growth of ice sheets (LISIECKI & RAYMO, 2005). Also suspect is the timing of the disappearance of specimens of *Gephyrocapsa* spp. >4.0 μm at the base of biozone MNN 19e. It coincides with the Middle Pleistocene Transition (MPT), the most recent re-

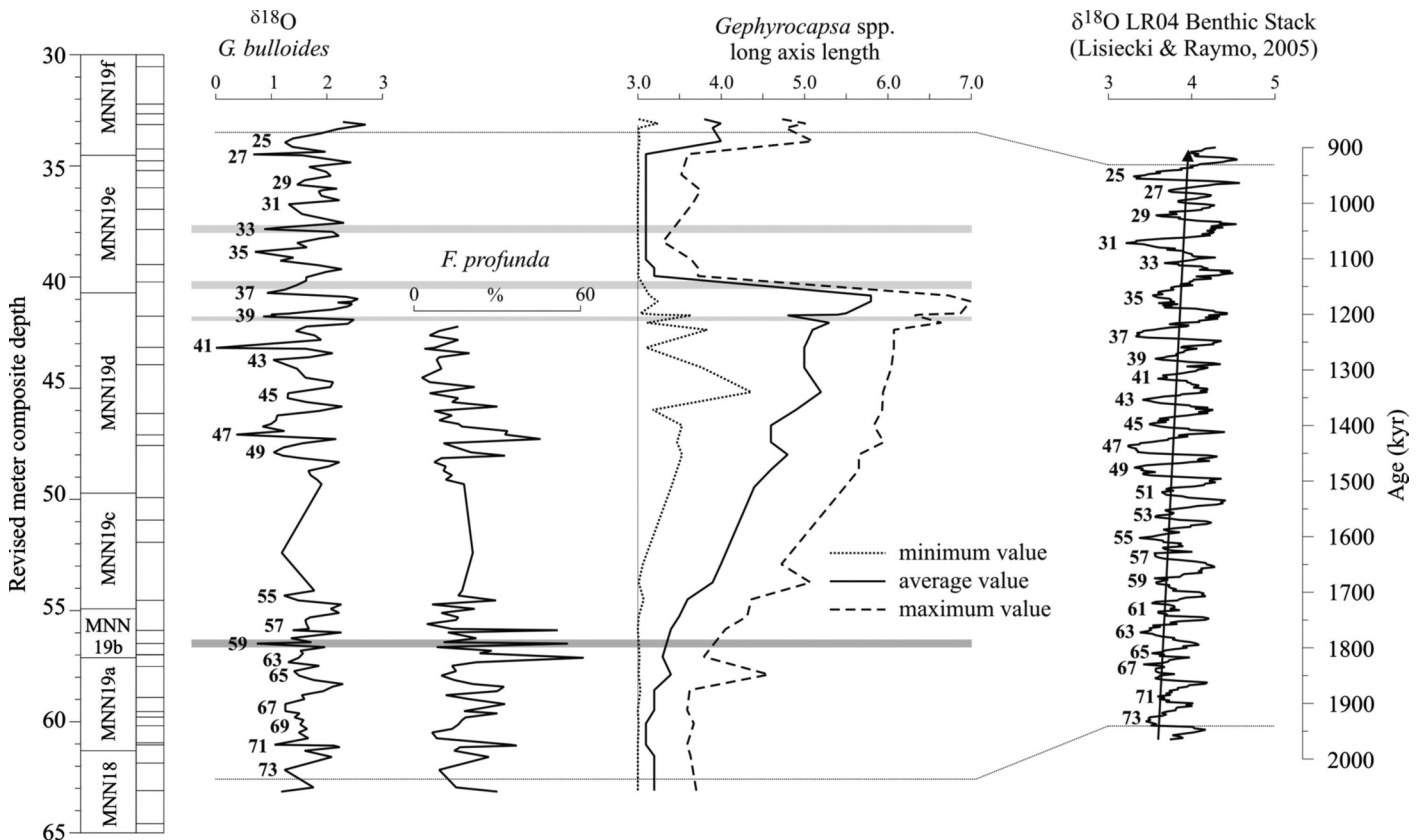


Fig. 4 - Comparison of biometric data of the genus *Gephyrocapsa* and environmental proxy data at the ODP Site 964 during the Early Pleistocene, plotted versus depth in rmcd. From the left, the biostratigraphic framework, following SPROVIERI *et alii* (1998); Sapropel layers' setting (EMEIS *et alii*, 2000b); Oxygen isotope values collected on the shells of *G. bulloides* (SPROVIERI *et alii*, 1998); Downcore variations of *F. profunda*; Minima, medium and maxima values in the long axis of placoliths of *Gephyrocapsa* spp. specimens; Oxygen isotope values of the LR04 Benthic Stack (LISIECKI & RAYMO, 2005) and their linear trend (black arrow). Light grey bands show sample where severe dissolution processes led to the disappearance of most of *Gephyrocapsa* spp. specimens. Dotted lines indicate the correlation between MIS of ODP 964 and the LR04 Benthic Stack.

organization of the global climate system that involved, among others, changes in the amplitude of glacial/interglacial cycles, an increase in ice sheets volume, SST cooling in the oceans, variations in the Atlantic Meridional Overturning Circulation, a significant drop in CO₂ atmospheric levels (RUDDIMANN *et alii*, 1989; HODELL *et alii*, 2003; LISIECKI & RAYMO, 2005; CLARK *et alii*, 2006).

We suggest that the influence of the climate and of the environment on size variations of the genus *Gephyrocapsa*, if any, would have acted on time scales that were longer than glacial/interglacial cycles. For instance the linear trend in ice sheet growth, may have had a global impact on the marine realm and are therefore compatible with the report of the increasing size of *Gephyrocapsa* placoliths from all oceans.

CONCLUSION

Biometric and compositional data of *Gephyrocapsa* spp. were collected with a resolution of about 20 kyr in early Pleistocene sediments of the ODP Site 964 (Ionian Sea, eastern Mediterranean).

We discuss the influence of the environmental/climatic forcing on the size increasing trend of placoliths of this genus and conclude that only long-scale phenomena, such as the trend observed in the growth of ice sheets and

the subsequent SST cooling in oceans, may have had a role in *Gephyrocapsa* spp. size variations. Finally, we point out that the FCO of *Gephyrocapsa* >4.5 μm and the FO of *Gephyrocapsa* >5.0 μm occur close to the LO of *C. macintyreii*. As the LO of *C. macintyreii*, that defines the base of the Zone MNN 19c in Mediterranean biostratigraphic schemes (RIO *et alii*, 1990), is difficult to determine in terrigenous land sections having much reworking, these two biohorizons may be used in biostratigraphic studies.

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