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Charlie Morelle Angue Minto'o, Maria-Angela Bassetti, Samuel Toucanne, Gwenael Jouet. Distribution of ostracod and benthic foraminiferal assemblages during the last 550kyr in the East-Corsica basin, western Mediterranean Sea: A paleo-environmental reconstruction. *Revue de Micropaléontologie*, 2016, 59 (2), pp.Pages 83-96. 10.1016/j.revmic.2016.01.002 . hal-01336508

HAL Id: hal-01336508

<https://univ-perp.hal.science/hal-01336508>

Submitted on 25 Oct 2023

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La distribution des assemblages d'ostracodes et de foraminifères benthiques le long des derniers 550 ka dans le bassin Est-Corse, Méditerranée occidentale : une reconstitution paléo-environnementale

Distribution of ostracod and benthic foraminiferal assemblages during the last 550kyr in the East-Corsica basin, western Mediterranean Sea: A paleo-environmental reconstruction

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Abstract :

The study of Quaternary sediments covering the last 550 kyr from the borehole GDEC-4-2, East-Corsica basin, was performed through the study of benthic meiofaunal assemblages (ostracoda and benthic foraminifera) whose distribution responds to climate changes, and glacial–interglacial variability in particular. The interglacial ostracod group is mainly composed of the *Argilloecia acuminata*, *Cytheropteron alatum*, *Henryhowella* sp., *Polycope* sp. and *Cytherella* sp., which indicate an enhanced surface productivity and possibly high bottom water temperature during these warm intervals. Benthic foraminifera, such as *Hoeglundina elegans*, *Sigmoilopsis schlumbergeri*, *Bigenerina nodosaria* and *Hyalinea balthica* are predominant during interglacial periods and also show an increasing surface productivity associated to warm intervals. Increase in surface productivity would contribute to an enhanced export of organic matter to sea floor at the GDEC-4-2 site during interglacial periods. The bottom temperature drop coupled with the important sedimentary inputs (associated to a significant quantity of refractory organic matter) during glacial periods was highlighted by the predominance of ostracoda, such as *Paradoxostoma* sp., *Cytheropteron testudo*, *Bathocythere vanstraateni*, *Macrocypris* sp., *Echinocythereis echinata* and benthic foraminifera as *Bolivina spathulata*, *Bulimina costata*, and *Bulimina marginata*. The distribution of some benthic foraminifera species describing a turnover system allowed the characterization of the last three climate cycles (MIS 8–9, MIS 6–7, MIS 1–5) probably

marked by changes of bottom water paleoceanographic conditions in terms of temperature, salinity, bottom current intensity and surface productivity. The cyclic variations of the allochthonous group recorded over the last 550 kyr suggest a major role played by the eustatic factor, with the latter possibly favouring down slope transport. The distribution of this group allowed thus establishing a link between shelf-basin sediment transfer and climate, with enhanced shelf-basin sediment transfer during glacial low stands.

Keywords : East-Corsica, Ostracoda, Benthic foraminifera, Allochthonous group

Résumé :

L'étude des sédiments du Quaternaire provenant du forage GDEC-4-2 couvrant les derniers 550 ka, dans le bassin Est-Corse, a été faite grâce à la distribution des assemblages de méiofaunes benthiques (les ostracodes et les foraminifères benthiques) dont la distribution répond aux changements climatiques, et particulièrement, à la variabilité glaciaire–interglaciaire. Le groupe interglaciaire des ostracodes est principalement composé de *Argilloecia acuminata*, *Cytheropteron alatum*, *Henryhowella* sp. *Polycope* sp. et *Cytherella* sp. qui indiquent une amélioration de la productivité de surface et probablement des températures élevées au fond pendant ces intervalles chauds. Les foraminifères benthiques, tels que *Hoeglundina elegans*, *Sigmoilopsis schlumbergeri*, *Bigenerina nodosaria* et *Hyalinea balthica* prédominent pendant les périodes interglaciaires et montrent également une augmentation de la productivité de surface associée à ces intervalles chauds. L'augmentation de la productivité de surface a pu contribuer à une amélioration, pendant les interglaciaires, de l'apport de la matière organique au fond au niveau du site du forage GDEC-4-2. La chute de la température du fond combinée à un apport sédimentaire important (associée à une bonne quantité de matière organique réfractaire) pendant les périodes glaciaires a été mise en évidence par la prédominance des ostracodes, tels que *Paradoxostoma* sp., *Cytheropteron testudo*, *Bathocythere vanstraateni*, *Macrocypris* sp., *Echinocythereis echinata* et des foraminifères benthiques comme *Bolivina spathulata*, *Bulimina costata*, et *Bulimina marginata*. La distribution de certains foraminifères benthiques, décrivant un système de *turnover*, a permis la caractérisation des trois derniers cycles climatiques (MIS 8–9, MIS 6–7, MIS 1–5) probablement marqués par des changements des conditions paléocéanographiques des eaux profondes en termes de : température, salinité, intensité du courant au fond et productivité de surface. Les variations cycliques du groupe allochtone, enregistrées pendant les 550 000 dernières années, suggèrent le rôle major joué par les facteurs eustatiques pouvant favoriser le transport de la pente vers le bassin profond. La distribution de ce group a donc permis d'établir un lien entre le transfert sédimentaire plateau continental-bassin profond et le climat avec un renforcement du transfert durant les bas niveaux marins.

Mots-clés : Est-Corse ; Ostracode ; Foraminifère benthique ; Groupe allochtone

1. Introduction

Ostracoda and benthic foraminifera are found in most marine environments and are among the most important components of modern and ancient benthic communities. They constitute an important tool for paleo-climatic-environmental-oceanographic reconstructions because of their high sensitivity to environmental conditions (e.g. Barut et al., 2015; Casier et al., 2015; Trabelsi et al., 2015). As a result, these benthic microfossils are largely studied over the world (e.g. Zhao and Whatley, 1997; Wollenburg and Mackensen, 1998; Redois and

Debenay, 1999; Zhou and Zhao, 1999; Fontanier et al., 2002; Triantaphyllou et al., 2005; Schumacher et al., 2007; Pascual et al., 2008; Hess and Jorissen, 2009; Nachite et al., 2010; Drinia and Anastasakis, 2012; Munef et al., 2012; Martínez-García et al., 2013; among others).

Studies on variation and distribution of benthic foraminifera and ostracod assemblages East-Corsica basin, western Mediterranean, are very rare. A recent study focusing on both the modern and ancient benthic foraminifera and ostracoda in this area, allowed generating data about the general bathymetric distribution of those in this area (Angue Minto'o et al., 2013). These data are used for interpreting the distribution of benthic microfossils in the 125-m long GDEC-4-2 sedimentary record that covered the last 550 kyr and represents the first long and continuous sedimentary record in the East-Corsica basin (Angue Minto'o, 2014; Toucanne et al., 2015). We use these benthic microfossils as a tool to 1) establish the relationship between climatic variations, sea level changes and sedimentary transfer; 2) characterize bottom physical and chemical conditions associated to glacial-interglacial periods.

2. Study area

The East-Corsica margin, located in the northern part of the Tyrrhenian Sea (Western Mediterranean), is characterized by a narrow continental shelf with a shelf break situated around 110-120 m (Gervais, 2002; Gervais et al., 2004). This continental shelf is followed by a steep continental slope incised by numerous meandering canyons (Gervais, 2002). The latter open out into a deep basin which is characterized by a depression named Corsican Trough. The Corsican Trough is narrow (10-30 km) and shallow (400 to ca. 900 m) and is bordered by the Pianosa Ridge on its eastern flank (Fig. 1). The sedimentary transport into the East-Corsica basin is mainly driven by the Golo River (main river of the East-Corsican margin) (Calvès et al., 2012).

The oceanographic structure of the East-Corsica basin includes a surface layer of Modified Atlantic Water (MAW, down to 200 m water depth) principally constituted by North Atlantic central water drawn into the Mediterranean Sea through the Gibraltar Strait and an intermediate layer of Levantine Intermediate Water below (LIW, down to 600-1.000 m water depth) mainly formed in the Levantine basin (Eastern Mediterranean) (Gasparini et al., 2005; Astraldi and Gasparini, 2013). The LIW enters into the Western Mediterranean Sea through the strait of Sicily. In the northern part of the Tyrrhenian Sea (and in the Corsica Trough especially), a strong seasonal variability of this water mass is noted with a maximal flow observed during winter and early spring (Astraldi and Gasparini, 1992; Vignudelli et al., 2000).

3. Materials and method

The present work is based on the study of 291 samples collected in the borehole GDEC-4-2 drilled at a water depth of 492 m in the East-Corsica margin. Samples were washed and sieved (63 μm) before performing micropaleontological analyses on the sedimentary fraction $> 150 \mu\text{m}$. Taxonomy of benthic foraminifera was based on Ausseil-Badie (1978); Jorissen, (1987), Sgarrella and Moncharmont Zei (1993), Abu-Zied, (2001), Fontanier (2003), Aiello et al. (2006), Milker et al. (2009), Frezza, and Carboni, (2009), Mojtahid et al. (2009, 2010). Data on ostracoda systematics are taken from Müller (1894), Bonaduce et al. (1975); Peypouquet, and Nachite (1984), Didié and Bauch, (2001) Aiello et al. (2006), Triantaphyllou et al (2005). Ostracoda and benthic foraminifera stocks were grouped on the basis of their bathymetric and climatologic distribution (Lutze and Coulbourn, 1984; Peypouquet and Nachite, 1984; Jorissen, 1987; Babinot and El Khanchoufi, 2000; El Hmaidi et al., 2002; Frezza and Carboni, 2009; Milker et al., 2009; Mojtahid et al., 2009; El Hmaidi et al., 2010; Zaïbi et al., 2011; Angue Minto'o et al., 2013).

The extension of the continental shelf on the East-Corsica margin is defined by the position of the shelf break around 110-120 m depth (Gervais, 2002; Gervais et al., 2004). Two main bathymetric species groups are thus considered. The shallow water species consisting of all species that are known to live in a bathymetric range from 0 to 120 m (Infralittoral to Circalittoral environments). The presence of this species group at a water depth >500 m is considered having been displaced and constitute the allochthonous group in this study. The bathyal species group composed of species living at water depth greater than 120 m, constitute the autochthonous group.

Oxygen stable isotope measurements were performed on specimens of planktonic foraminifera species *Globigerina bulloides* and *Globigerinoides ruber* (white) from the 250-315 μm size fraction, *Neogloboquadrina pachyderma* (dextral) from the 200-250 μm size fraction, and on the epifaunal benthic foraminifera *Cibicides wuellerstorfi*, *Cibicidoides pachyderma* and *Cibicidoides kullenbergi* found in the >150 μm size fraction (Toucanne et al., 2015).

The chronology for GDEC-4-2 was developed by aligning the planktonic $\delta^{18}\text{O}$ (influenced by local hydrography and global ice volume changes) and both the weight percent CaCO_3 and XRF-log(Ca/Ti) records (influenced by carbonate productivity and detrital sedimentation) to the NGRIP ice core isotopes from Greenland for the last 60 ka (GICC05 chronology; Rasmussen et al., 2006; Svensson et al., 2008) and to the synthetic Greenland ($\text{GL}_T\text{-syn}$) record of Barker et al. (2011) from 60 to ~550 ka (Toucanne et al., 2015). The synchronization of GDEC-4-2 with the synthetic Greenland record reveals that the 125.7 m long marine sedimentary archive encompasses the last 547 kyr with a mean sedimentation rate of 23 cm kyr^{-1} . It corresponds to the highest resolution continuous marine sedimentary archive of the last five climatic cycles in the Mediterranean Sea obtained to date (Toucanne et al., 2015).

4. Results

4.1. Ostracod groups

A total of 62 ostracoda *taxa* have been identified. 25 species and genera are considered as part of allochthonous group and the autochthonous group is composed of 37 *taxa* (Table 1). The ostracoda autochthonous species is subdivided into three sub-groups: 1) group with species showing a discontinuous distribution; 2) ostracod species with continuous distribution and 3) group with species whose distribution is synchronous with climatic periods.

4.1.1. Autochthonous ostracod group

4.1.1.1. Ostracod species with discontinuous distribution

The following ostracoda are autochthonous and show a discontinuous distribution along the borehole GDEC-4-2: *Buntonia sublatissima* Neviani, 1906, *Bythocypris* sp., *Bythocythere turgida* Sars, 1866, *Bythocythere* sp., *Krithe compressa* Ruggieri, 1952, *Pterygocythereis jonesii* Baird, 1850, *Pterygocythereis* sp., *Krithe pernoides* Bornemann, 1855, *Pedicythere polita* Colalongo and Pasini, 1980, *Pedicythere tessellata* Bonaduce, Ciampo and Masoli, 1976, *Cytheropteron rotundatum* Mueller, 1894, *Monoceratina mediterranea* Sissingh, 1972 and *Cluthia* sp. (Table 1).

4.1.1.2. Ostracod species with continuous distribution

The following ostracoda are part of group with a continuous distribution: *Bairdia* sp., *Pseudocythere caudata* Sars, 1866, *Parakrithe* sp., *Phlyctocythere* sp. and *Xestoleberis* sp. (Table 1). These ostracoda *taxa* are frequent along borehole.

4.1.1.3. Ostracoda correlated with climate periods

Interglacial ostracod group

This group consist of *Argilloecia acuminata* Mueller, 1894, *Cytheropteron alatum* Sars, 1866, *Henryhowella* sp., *Rectobuntonia inflata* Colalongo and Pasini, 1980, *Cytherella* sp., *Carinocythereis carinata* Roemer, 1838, *Krithe keyi* Breman, 1978, *Polycope* sp., *Bosquetina dentata* Mueller, 1894; show higher relative abundance during interglacial intervals (Table 1, Fig. 2). In this interglacial group, the most abundant taxa are *A. acuminata* (55%), *C. alatum* (50 %), *Polycope* sp. (50 %), *Henryhowella* sp. (45 %), *Cytherella* sp. (25%). The genus *Polycope* is rare along borehole except during Marine Isotopic Stage (MIS) 5 (130-71 kyr BP) and MIS 1 (14 kyr to present).

Glacial ostracod group

The following ostracoda present a distribution that seems to correlate with glacial intervals: *Cytheropteron hadriaticum* Bonaduce, Ciampo & Masoli, 1976, *Paradoxostoma* sp., *Cytheropteron monoceros* Bonaduce, Ciampo & Masoli, 1976, *Cytheropteron zinzulusae* Bonaduce, Ciampo & Masoli, 1976, *Macrocypris* sp., *Echinocythereis echinata* Sars, 1866, *Bathycythere vanstraateni* Sissingh, 1971 and *Cytheropteron testudo* Sars, 1869, *Bythoceratina reticulata* Bonaduce, Ciampo and Masoli, 1976, (Table 1, Fig. 2). The dominant *taxa* in this ostracod glacial group are: *Paradoxostoma* sp., *Macrocypris* sp., *E. echinata* and *B. vanstraateni*, *C. testudo*.

4.1.2. Allochthonous ostracod group

Among the 62 ostracoda *taxa* identified in this study, 25 species and genera are considered allochthonous (Table 1, Fig. 2). The individual relative abundance of allochthonous varies from 1.5 to 50% (Table 1). The allochthonous elements yielding

percentages higher than 10% are the following: *Semicytherura* spp., *Aurila* sp., *Loxoconcha* sp., *Hemicytherura videns* Mueller, 1894, *Pseudocytherura calcarata* Seguenza, 1880, *Urocythereis favosa* Roemer, 1838, *Leptocythere* sp., *Sagmatocythere* sp., *Callistocythere littoralis* Mueller, 1894, *Paracypris* sp., *Costa* sp., *Heterocythereis* sp. (Table 1).

4.2. Benthic foraminifera groups

A total of 84 benthic foraminifera species have been identified. Among those, 21 species are considered as allochthonous (Table 2) and they are not taken into account in this study, because do not allow a clear interpretation of the paleo-environmental conditions. Autochthonous benthic foraminifera species are represented by 63 species and are grouped into three groups: 1) group including species showing a discontinuous distribution; 2) group composed of species with continuous distribution and 3) group including species whose distribution is correlated with climate oscillations.

4.2. 1. Autochthonous benthic foraminifera groups

4.2. 1.1. Benthic foraminifera species with discontinuous distribution

A discontinuous distribution is observed for the 16 following benthic foraminifera species *Gyroidina umbonata* Silvestri, 1898, *Lagena hexagona* Williamson, 1848, *Lagena sulcata* Walker and Jacob, 1798, *Bolivina alata* Seguenza, 1862, *Bolivina* sp., *Lagenosolenia sigmoidella* Cushman, 1933, *Lagena hispida* Reuss, 1858, *Uvigerina bifurcata* d'Orbigny, 1839, *Fissurina* sp., *Lagena* sp., *Lagena striata* d'Orbigny, 1839, *Neoeponides schreibersii* d'Orbigny, 1846, *Fissurina apiculata* Reuss, 1851, *Bulimina elongata* d'Orbigny, 1826. (Table 2).

4.2. 1.2. Benthic foraminifera species with continuous distribution

Several benthic foraminifera species (21) show a continuous distribution in this study (Table 2): *Cassidulina carinata* Silvestri, 1896, *Fissurina cucullata* Silvestri, 1902, *Uvigerina mediterranea* Hofker, 1932, *Planulina ariminensis* d'Orbigny, 1826, *Cibicides* sp., *Melonis barleeanus* Williamson, 1858, *Cycloforina contorta* d'Orbigny, 1839, *Cyclogyra* sp., *Trifarina angulosa* Williamson, 1858, *Cassidulina minuta* Nørvang, 1945, *Pullenia* sp., *Bulimina elegans* d'Orbigny, 1826, *Bulimina aculeata* d'Orbigny, 1826, *Cibicides pachyderma* Rzehak, 1886, *Triloculina* sp., *Uvigerina peregrina* Cushman, 1923, *Chilostomella* sp., *Pyrgo* sp..

However species such as *C. minuta*, *C. contorta*, *F. cucullata*, *Cyclogyra* sp., *Pyrgo* sp., and *Pullenia* sp., are poorly represented along the borehole with relative abundances less than 5%. The most abundant species are *M. barleeanus* (45%), *U. mediterranea* (36%), *T. angulosa* (36%) and *C. pachyderma* (29%) (Table 2).

4.2. 1.3. Benthic foraminifera correlated with climate periods

Interglacial Benthic foraminifera group

Several benthic foraminifera show a distribution which can be correlated to interglacials interval (Table 2, Fig. 2): *Hoeglundina elegans* d'Orbigny, 1878, *Lenticulina* sp., *Neolenticulina* sp., *Sigmoilopsis schlumbergeri* Silvestri, 1904, *Robulus* sp., *Bigenerina nodosaria* d'Orbigny, 1826, *Siphonina reticulata* Czjzek, 1884, *Spiroloculina* sp., *Gyroidina altiformis* Stewart and Stewart, 1930, *Bolivina dilatata* Reuss, 1850, *Rectuvigerina phlegeri* Le Calvez, 1958, *Nonionella turgida* Williamson, 1858, *Uvigerina auberiana* d'Orbigny, 1839, *Amphicoryna scalaris* Batsch, 1791, *Rectobolivina zitteli* Karrer, 1878, *Hyalinea balthica* Schröter, 1783 and *Pseudoclavulina crustata* Cushman, 1936. However, the dominant species in this group are: *H. elegans* (16%), *S. schlumbergeri* (20%), *Bigenerina*

nodosaria (20%) and *H. balthica* (55%, Table 2). This latter is especially abundant during the MIS 5, while *H. elegans*, *S. schlumbergeri*, *B.nodosaria* are present during MIS 11, MIS 9, MIS 7 and MIS 1.

Glacial Benthic foraminifera group

The following benthic foraminifera present a distribution that can be related to glacial conditions (Table 2, Fig. 2): *Bolivina spathulata* Williamson, 1858, *Bulimina costata* d'Orbigny, 1852, *Gyroidina orbicularis* d'Orbigny, 1826, and *Bulimina marginata* d'Orbigny, 1826, *Pyrgo elongata* d'Orbigny, 1826, *Pyrgo murrhina* Schwager, 1866, *Cibicides wuellerstorfi* Schwager, 1866, , *Fissurina apiculata* Reuss, 1851, *Eggerella bradyi* Cushman, 1911, *Suggrunda eckisi* Natland, 1950, *Spirosigmoilina tenuis* Czjzek, 1848, *Globobulimina affinis* d'Orbigny, 1839, *Valvulineria bradyana* Fornasini, 1900, *Cassidulinoides bradyi* Norman, 1881. The dominant species in this group are *B. spathulata*, *B. costata*, and *B. marginata*.

Benthic foraminifera: turnover across climatic cycles

Looking in details, the distribution of some glacial/interglacial benthic foraminifera show a turnover system following climate cycles (Fig. 3). The time period from 530 to 420 kyr (MIS 13 and MIS 12) is characterized by the occurrence of *B. spathulata*, *B. costata*, *G. orbicularis* and *B. marginata*. Although they have a continuous distribution, highest relative abundances of these species are recorded during this interval (Fig. 3).

The interglacial-glacial coupled MIS 11-MIS 10 and MIS 9-MIS 8 are characterized by abundant *S. schlumbergeri*, *Spiroloculina* sp., *B. nodosaria*, *S. reticulata* and (Fig. 3). The observed feature is a relatively high abundance during the interglacial and strong (abrupt) decrease during the glacials (Fig. 3). A similar, but less marked trend is observed for the MIS

7-MIS 6 intervals (Fig. 3). Here, two species are dominant: *S. schlumbergeri* and *B. nodosaria* (Fig. 4).

Benthic foraminifer species such as *G. altiformis*, *S. tenuis*, *S. eckisi* and *B. dilatata* occur during the time interval from 330 to 240 kyr (that includes MIS 9 and MIS 8) where their higher relative abundances are observed (Fig. 3). *G. altiformis* and *S. tenuis* are the most abundant during the interglacial MIS 9, whereas *S. eckisi* peaks are observed during MIS 8 (Fig. 5). *Bolivina dilatata* occurs only during the MIS 9 (Fig. 5). This group disappears at the end of MIS 8 and it is replaced by group composed of *R. phlegeri*, *G. affinis*, *V. bradyana*, *C. bradyi*, *B. albatrossi*, *N. turgida* and *U. auberiana* during the interval time from 240 to 130 kyr (MIS 7 and MIS 6, Fig. 3). *U. auberiana* peaks during the MIS 7 and it is absent from glacial interval. While *C. bradyi*, *V. bradyana* and *B. albatrossi* are more abundant during the MIS 6 (191-130 kyr BP), *N. turgida*, *R. phlegeri* and *G. affinis* are found during MIS 7 and MIS 6 (Fig. 6). *A. scalaris*, *R. zitteli*, *H. balthica*, *P. crustata* are species characterizing the period from 130 kyr to present (from MIS 5 to MIS 1, Fig. 3). In this group, *H. balthica* is the most abundant species with its higher relative abundance recorded during the MIS 5 (Fig. 7). *P. crustata* appears more abundant during the MIS 1. *R. zitteli* and *A. scalaris* are found during the MIS 5 and the MIS 1 and they strongly decrease during MIS 4 (71-57 kyr BP), MIS 3 and MIS 2 (Fig. 7).

5. Discussion

5.1. Ostracoda assemblages over the last 550kyr in the East-Corsica basin: downslope transport and physic-chemical bottom conditions

An important number of allochthonous ostracod species is found at the GDEC-4-2 site. There are 25 allochthonous ostracod species among the 62 ostracod species identified. In this group, the most abundant species with higher than 10% (*Semicytherura* spp., *Aurila* sp.,

Loxoconcha sp., *H. videns*, *P. calcarata*, *Leptocythere* sp., *U. favosa*, *Sagmatocythere* sp., *Paracypris* sp., *Costa* sp., *C. littoralis*, *Bairdia* sp., *Heterocythereis* sp. and *B. turgida*, Table 1) are found all along the borehole GDEC-4-2.

It is known that ostracoda can be displaced by post-mortem transport more easily than benthic foraminifers (Passlow, 1994). This may be caused by their light, bowl-shaped valves, giving them potential as indicators of transport process more than many other microfossil groups (Zhou and Zhao, 1999). Littoral species can thus be transported as deep as the bathyal waters as shown by several studies (Hao and Ruan, 1987; Drapala, 1993; Sciuto 2014).

The distribution of allochthonous cumulative abundance species plot (Fig. 2) shows that allochthonous ostracoda are more abundant during glacial periods and gradually decrease at the end of the cold stage, as shown by the positive correlation with the $\delta^{18}\text{O}$ curves (Fig. 2, Toucanne et al., 2015). This result suggests that the shelf-basin sediment transfer is enhanced during the glacial lowstands (in agreement with the former conclusions of Calvès et al., 2012 and Toucanne et al., 2015). The allochthonous group is constituted by ostracoda shelf species that are considered as affected by reworking processes at the GDEC-4-2 site. Thus, the variations of the allochthonous during climate oscillations (Fig. 2) suggest the major control of eustatic factors in slope sedimentation. During sea level lowstands, gravity-induced mechanisms (i.e. turbidity currents, debris flows) or high energy hydrodynamic processes (i.e. storms, inducing sediment flows at the shelf edge) may increase sediment transport to deeper parts of the continental margins mainly through submarine canyons (Shanmugam et al., 1985 ; Sciuto, 2014). During high sea level the sediment supply might be reduced because sediment is mostly trapped in the inner part of continental shelf, in the delta and prodelta settings, except for the periods with abundant rainfall on land (Toucanne et al., 2015). Submarine canyons are considered as preferential conduits for shelf-slope sediment transport than the adjacent open slope areas (Durrieu de Madron, 1994). However, several studies provided

information about contemporary sediment-transport processes acting within canyons and sediment resuspension events that is transported to the open slope (Puig et al., 2003, 2004). Sediments along the slope are subsequently shaped by bottom current flowing parallel to bathymetric contours that begins the formation of contourites (Stow and Lovell, 1979; Stow et al., 2002). Thus, a major role is certainly played by the variable intensity of intermediate currents in the sediment lateral transport in the open slope areas. In western Mediterranean Sea, it has been demonstrated that an intensification of Western Mediterranean Deep Water (WMDW) and Levantine Intermediate Water (LIW) circulation during cold climatic phases (Cacho et al., 2000; Sierro et al., 2005; Cacho et al., 2006; Toucanne et al., 2012) at Milankovitch to millennial sub-orbital time-scale. On East-Corsica margin, the intensity of downslope and along slope transport is inferred on the basis of the occurrence of allochthonous ostracoda, which suggest that the sea level variations strongly controlled the downslope transport at the glacial-interglacial time scale (Miramontes et al., in press). During glacial stages (positive correlation with $\delta^{18}\text{O}$ values in Fig. 2), high abundances of allochthonous specimens are observed. High sediment supply is expected to be transferred from the shelf to the canyons and slopes during low sea level because of the sediment sources proximity (river mouths) to the shelf edge. Ostracoda from the shelf are thus easily transported in the detritic fraction and found abundant during glacial lowstands.

The abundances of interglacial ostracoda species are negatively correlated to $\delta^{18}\text{O}$ plots (Fig. 2). In the interglacial group, the most significant contribution comes from *Argilloecia acuminata*, *Cytheropteron alatum*, *Henryhowella* sp. *Polycope* sp. and *Cytherella* sp.. The genera *Argilloecia* and *Cytheropteron* have been effectively observed to be influenced by warm water masses (Cronin et al., 2002; Iwatani et al., 2014) either because sensitive to bottom water temperature changes or to food availability, which is related to

surface productivity (Alvarez Zarikian et al., 2009) whereas *C. alatum* and *Henryhowella* are known to be species preferring oligotrophic conditions (Di Donato et al. 2009). The ecological requirements for *Henryhowella* are still controversial: it is often found dominant in the bathyal zone off West Africa in well oxygenated waters (Dingle et al., 1990) but there is actually no obvious relationship between the abundance of *Henryhowella* and the oxygen content, according to Bonaduce et al. (1998) who studied the distribution of *Henryhowella* in the Gulf of Naples (Tyrrhenian Sea). Thus, *Henryhowella* is here considered as belonging to the interglacial group but with giving no specific indications for paleoenvironmental conditions. The genus *Cytherella* is considered as opportunistic filter-feeders species (Russo et al., 2012). It is thought to belong to ostracoda species resistant to large decreases in water oxygenation levels because they feed by filtration, ventilate large volumes of water to obtain their food and thus achieve a maximum and optimal state of oxygenation.

At GDEC-4-2 site, the interglacial intervals (e.g., MIS5a, MI7c, 7e) were generally marked by an increase of Golo river discharges due to the increase in the precipitation over the Corsica. Consequently, the runoff increase possibly led to the higher flux of continental detritus (i.e., sediment and organic matter) to the bottom (Toucanne et al., 2015). The increase of interglacial ostracod group during interglacial periods can be linked to organic matter quality arriving at the bottom coupled with higher sea temperature that would favour an enhanced surface productivity. The distribution of these taxa can also be related to high bottom water temperature, as suggested by the perfect correlation with $\delta^{18}\text{O}$ plots (Fig. 2). However, we do not have data from modern ostracoda to confirm this hypothesis and identifying which species are more sensitive to temperature change.

The glacial ostracoda species are not well represented along the borehole GDEC-4-2. Their cumulative plot shows an important accumulation at the end of MIS 12, during the MIS

8 and MIS 2 (Fig. 2). The dominant taxa being: *Paradoxostoma* sp., *C. testudo*; *B. vanstraateni*, *Macrocypris* sp., and *E. echinata*.

C. testudo ostracod species is well known as a “cold guest” of the Mediterranean Plio-Pleistocene (Bonaduce and Sprovieri, 1984; Ciampo, 2004). It has been used to identify the input of “cold” Atlantic waters in the Mediterranean Sea during some cold Quaternary climatic events together with other “Northern guest” ostracod species which include some *Paradoxostoma* species such as *Paradoxostoma abbreviatum*, *Paradoxostoma ensiforme*, *Paradoxostoma tenuissimum* (see references in Faranda and Gliozzi, 2011). Martínez-García et al. (2015) used the presence of *C. testudo* together with *Acanthocythereis dunelmensis* and *Trachyleberis* sp. to evidence the occasional input of cold bottom waters coming from the circumpolar area of the North Atlantic Ocean into the Basque shelf during late Quaternary. The study of core MD99-2348 (Gulf of Lions, NW Mediterranean) shows that *C. testudo* is part of glacial group (Bassetti et al., 2010). In Alboran Sea, the *E. echinata*-*B. vanstraateni*-*Macrocypris* sp. group is known as a deep and cold environment association (Babinot and El Khanchoufi, 2000). *E. echinata* is considered as probably an indicator of well-ventilated bottom water and sufficient food supply (Alvarez Zarikian et al., 2009; Bassetti et al., 2010). In the borehole GDEC-4-2, the glacial ostracoda taxa show high abundance in the upper part of MIS 12, during the MIS 8 and MIS 2. The MIS 12 appears as marked by strong cold conditions with a climate that was colder than more recent glacial intervals (Healey and Thunell, 2004). The MIS 8 is known as a relatively weak glacial in terms of global ice volume whereas MIS 2 is on average a very intense glacial phase (Lisiecki and Raymo, 2005; Lang and Wolff, 2011). The increase of *Paradoxostoma*, *C. testudo*, *B. vanstraateni*, *Macrocypris* sp., *E. echinata* abundances observed in the GDEC-4-2 borehole during these cold climate intervals (MIS 12, MIS 8 and MIS 2) is interpreted as related to temperature drop, but coupled with the trophic level of hosting waters. As discussed above, the glacial intervals correspond

to the periods with the highest sediment flux carried by the Golo River that means nutrients enriched waters. In this context, however, it is not possible to disentangle the impact of temperature from the nutrient supply in the distribution of the observed glacial ostracoda.

5.2. Ostracoda distribution: Mediterranean Sea vs Atlantic Ocean

The distribution of ostracoda in the Mediterranean seems to not be uniform with respect to the Atlantic during glacial-interglacial transitions. *Polycope* sp. and *E. echinata* distribution are here compared in the attempt to correlate their distribution to water masses properties, which are related to climate conditions.

The genus *Polycope* is often associated to fine-grained, organic-rich sediment, possibly linked to interglacial high productivity both in the Mediterranean and Arctic Ocean (Breman, 1975; Bonaduce et al., 1975; Cronin et al, 1994). Benson et al. (1983) consider *Polycope* sp. associated with diminished vertical mixing because of its tolerance to oxygen deficient conditions, as found in the Newfoundland slope (eastern coast of Canada) in fine-grained sediment and low bottom current velocities.

In the borehole GDEC-4-2 the genus *Polycope* is very abundant (50% of the total ostracoda fauna) during MIS 5 and MIS 1 (Table 1), as previously observed in the core MD01-2472 by Angue Minto'o et al. (2015) where up to 70 % of the total ostracoda consists of *Polycope* sp. during MIS 1. This suggests low current velocities and lower bottom water oxygenation during the current interglacial. In the North Atlantic, *Polycope* sp. abundance reaches the maximum during the glacial periods (Didié and Bauch, 2000; Alvarez Zarikian et al., 2009). Considering that *Polycope* sp. is not a temperature marker, its inverse distribution between Atlantic and Mediterranean Ocean would explain by a reverse bottom paleoceanographic conditions. During cold intervals, Atlantic Meridional Overturning Circulation (AMOC) is highly reduced in North Atlantic (Labeyrie et al., 1995; McCave et

al., 1995; Cortijo et al., 1997; Vidal et al., 1997; Healey and Thunell, 2004; Stanford et al., 2011), while an higher bottom current velocity is observed in the Mediterranean Sea during cold climatic intervals (Cacho et al., 2000; Sierro et al., 2005; Cacho et al., 2006; Toucanne et al., 2012).

E. echinata is part of glacial ostracod group (Fig. 2). Bassetti et al. (2010) observed in the Gulf of Lions () the same pattern, where *E. echinata* is particularly abundant during cold stadials (Heinrich events). In the subpolar regions and North Atlantic, *E. echinata* has been associated with interglacial group (Alvarez Zarikian et al., 2009; Cronin et al., 1999; Didié and Bauch, 2000). *E. echinata* is considered as probably an indicator of well-ventilated bottom water and sufficient food supply (Bassetti et al., 2010). As *Polycope*, the reverse distribution shown by *E. echinata* between Mediterranean Sea and Atlantic Ocean can be linked to trophic level and dissolved oxygen content related to thermohaline circulation (Marchitto et al., 1998).

5.3 Benthic foraminifera species distribution over the last 550 kyr in the East-Corsica basin: bottom trophic conditions

Autochthonous benthic foraminifera are grouped into three main groups. 1) species with continuous distribution composed of 23 species where the most abundant are *M. barleeanus* (45%), *U. mediterranea* (36%), *T. angulosa* (36%) and *C. pachyderma* (29%, Table 2). 2) group of 16 species that show a discontinuous distribution (Table 2). 3) group of 24 benthic foraminifera species whose distribution allows a characterization glacial/interglacial periods. The first two groups do not allow a clear interpretation of the paleo-environmental conditions of the last 550 kyr. As a result, discussion is focus on the third group.

The interglacial benthic foraminifera group (Fig. 2) is marked by the predominance of *H. elegans*, *S. schlumbergeri*, *B. nodosaria* (MIS 11, MIS 9, MIS 7, and MIS 1) and *H. balthica* (MIS 5). *H. elegans* is often observed in meso-oligotrophic sediments, at elevated water depth (Mojtahid et al., 2010; Duros et al., 2011, Dessandier et al., 2015) but with variable quantity of organic fluxes (Altenbach et al., 1999). Its dominance at deep environment (up to 2000 m) suggests that it tolerates low quality organic matter, often found in well-oxygenated sediments (e.g. Mojtahid et al., 2010). More recently, Dessandier et al. (2015) shown that *H. elegans* is part of deeper environments that correlate to fairly abundant but low quality organic matter. In the Adriatic Sea, *S. schlumbergeri* is known to positively correlate with the percentage of organic matter, while it shows a negative correlation with the coarseness of the substrate and percentage of calcium carbonate (Jorissen, 1987). *B. nodosaria* was observed as having an opportunistic behaviour in the outer shelf of the Bay of Biscay when it grows after a phytoplankton bloom (Duchemin et al., 2008). This species is also observed in the upper slope of the Gulf of Lions and in the Bay of Biscay suggesting its dependence to marine phytodetritus (Fontanier et al., 2008). High oxygen and labile organic matter are necessary for feeding *H. balthica* (Fontanier et al., 2002, 2008) which is abundant particularly during MIS 5. At the borehole GDEC-4-2 site, the abundance increase of *H. elegans*, *S. schlumbergeri*, *B. nodosaria* during the interglacials (MIS 11, MIS 9, MIS 7, and MIS 1) and *H. balthica* during the MIS 5 can be linked to important supply of organic matter. It might be related to increasing surface productivity, allowing an enhanced export of organic matter to sea floor at the GDEC-4-2 site.

The glacial benthic foraminifera group (Fig. 2) is characterised by the predominance of *B. spathulata*, *B. costata*, and *B. marginata* with higher abundance especially observed during MIS 12 and MIS 6 (and on lesser extent MIS 10 and MIS 2). These species known as

opportunistic taxa (Gooday, 1988), can be indicative of organic matter abundance, even of low quality (pytodetritus and detrital organic flux). Their abundance in the glacial intervals can possibly link to an enhanced flux of continental detritus (i.e., sediment and organic matter) via runoff at the GDEC-4-2 site. In fact, glacial intervals (sea level lowstand periods) are characterized by the proximity of river mouths conducting to an important sediment flux transfer to the seafloor (e.g. Bonneau et al., 2014; Lombo Tombo et al., 2015 for the Western Mediterranean). The abundance of opportunistic benthic foraminifera during the MIS 12, MIS 10, MIS 6 and MIS 2 could be explained by the direct connection between the Golo River and Golo canyon heads leading to important sedimentary inputs associated to well quantity of refractory organic matter.

5.4. Benthic foraminifera turnover system: the last three climate cycles bottom conditions

Based on the distribution of benthic foraminifera in both glacial/interglacial group, the last three climatic cycles (MIS 8-9, MIS 6-7, MIS 1-5, Fig. 3) can be characterised in a relatively good detail. The MIS 8-9 interval is marked by the occurrence of *G. altiformis*, *S.tenuis*, *S. eckisi* *B. dilatata* (especially abundant during the MIS 9, Fig. 3). During the MIS 6-7 interval, these taxa are replaced by *R. phlegeri*, *G. affinis*, *V. bradyana*, *C. bradyi*, *B. albatrossi*, *N. turgida* and *U. auberiana* (Figs. 3 and Fig. 6). The last climatic cycle is characterised by the occurrence of *A. scalaris*, *R. zitteli*, *H. balthica* and *P. crostata* (Figs. 3 and 7).

The $\delta^{18}\text{O}$ plots (Fig. 3) show that during MIS 9 stable oceanic condition in term of temperature and salinity at the bottom may have prevailed, causing long-term water stratification. The occurrence of *B. dilatata*, tolerating relatively high bottom water salinity (Figs. 3 and 5), (Van der Zwaan, 1982; Jorissen et al., 1992) or *G. altiformis* (Figs. 3 and 5),

tolerating slightly suboxic conditions (Kaiho, 1999), is an indication of reduced vertical mixing.

Later on, during MIS 7 and MIS 6, bottom and surface water temperatures (and salinities?) change “quickly” ($\delta^{18}\text{O}$ plots in Fig.3 show high amplitude of values variation on a short-term time scale). We think that the presence of *V. bradyana*, *R. phlegeri* and *G. affinis* might be significant in this group (Figs. 3 and 6). *R. phlegeri* is known to inhabit shallow water settings in the Mediterranean Sea, in organic-rich sediment (Jorissen, 1987; Frezza and Carboni, 2009). Similarly, *V. bradyana* and *G. affinis* are considered as opportunistic species living in organic-matter rich bottoms, including low-quality organic detritus (Fontanier et al. 2002). *V. bradyana* is also observed to prefer silt sized sediments (Frezza and Carboni, 2009) and has been described in low oxygen sediments from the center of the Adriatic Sea mud belt (Jorissen, 1987; Van der Zwaan and Jorissen, 1991). We suppose that this distribution can be strongly related to mechanisms of sediments dispersion (downslope transport and lateral advection) and linked to changing intensity in bottom currents during climate oscillations.

High oxygen and labile organic matter are correlated with the occurrence of *H. balthica* and *A. scalaris* (Fontanier et al., 2002, 2008) that are abundant particularly during MIS 5 (Fig. 7). In the Corsica Trough (northwestern Tyrrhenian Sea), *P. crustata*, was especially found during the MIS 1 (Holocene) where bottom conditions was characterized by oligo-mesotrophic trophic level and low-energy bottom conditions (Angue Minto’o et al., 2015). *P. crustata* presents the same distribution in this study (Fig. 7). During the last climate cycle (MIS 5-MIS 1), several factors (climate/sea level) interplay for determining the characteristic of the bottom water conditions (Angue Minto’o, 2014). However, we think that changes in surface productivity probably associated to changes in the bottom current could have play an important role in the occurrence of *A. scalaris*, *R. zitteli*, *H. balthica* and *P. crustata* during the last climate cycle.

6 Conclusion

In this study, both ostracoda and benthic foraminifera abundances show glacial-interglacial swings. Although, ostracod-foraminiferal differences in relationships between environmental drivers and trophic change can be observed in the borehole GDEC-4-2. The use of both benthic microfossils is very useful because this allows complementarity in interpretation of different environmental parameters.

Interglacial periods are characterized by the increase of ostracoda group mainly composed of the *A. acuminata*, *C. alatum*, *Henryhowella* sp. *Polycope* sp. and *Cytherella* sp. indicating an enhanced surface productivity and possibly high bottom water temperature during these warm periods. Benthic foraminifera representing interglacial intervals are *H. elegans*, *S. schlumbergeri*, *B. nodosaria* and *H. balthica*. They also show an increasing surface productivity which allowed an enhanced export of organic matter to sea floor at the GDEC-4-2 site during these interglacial periods. The abundance increase of ostracoda as *Paradoxostoma* sp., *C. testudo*, *B. vanstraateni*, *Macrocypris* sp., *E. echinata* during glacial intervals (MIS 12, MIS 8 and MIS 2) at GDEC-4-2 borehole site, is interpreted as related to bottom temperature drop, but coupled with the trophic level of hosting waters. Higher abundance show by benthic foraminifera as *B. spathulata*, *B. costata*, and *B. marginata* (especially during MIS 12, MIS 10, MIS 6 and MIS 2) indicate that this trophic level is characterized by important sedimentary input associated to high quantity of refractory organic matter. Glacial periods are characterized by an enhanced of the shelf-basin sediment transfer. High abundances of allochthonous ostracoda during these intervals are observed on the basis of cumulative abundance of (post-mortem) species.

The last three climate cycles (MIS 8-9, MIS 6-7, MIS 1-5) show a turnover system for benthic foraminifera specific groups. Ostracoda as *Polycope* sp. and *E. echinata* show a

reverse distribution between Mediterranean and the Atlantic oceans during glacial-interglacial oscillations. This can be linked to the opposite paleoceanographic conditions between the two areas during climatic oscillations.

Acknowledgments

The authors also thank the crew and scientific team (G. Calvès, G. Dan-Unterseh, L. Droz, I. Jégou, G. Lericolais, E. Marchès, T. Marsset) of the GOLODRILL cruise (R/V 'Bavenit' - FUGRO) for the recovery of the GDEC-4-2 borehole. This study has been realized in the frame of the "GOLO PROGRAM", a research consortium between IFREMER, TOTAL, EXXONMOBIL and FUGRO. The authors are very grateful to IFREMER technical staff for sampling and samples treatment and to the two anonymous reviewers who provide helpful review of the manuscript.

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Figures captions

Figure 1:

Bathymetry of northern part of East-Corsica margin and location of studied borehole GDEC-4-2 drilled at water depth of 492 m. The dash lines indicate the Levantine Intermediate Water (LIW) path.

Figure 2:

Distribution along borehole GDEC-4-2 of $\delta^{18}\text{O}$ curves, cumulative abundance of interglacial ostracod group, allochthonous ostracod group, glacial ostracod group, and of interglacial - glacial benthic foraminifera groups. Oxygen stable isotope measurements were performed on *Globigerinoides ruber*, *Neogloboquadrina pachyderma* and *Globigerina bulloides* (for planktonic foraminifer) and on *Cibicides wuellerstorfi*, *Cibicidoides pachyderma* and *Cibicidoides kullenbergi* (for benthic foraminifera plot, Toucanne et al., 2015).

Figure 3:

Distribution of benthic foraminifer groups describing a turnover system along the GDEC-4 borehole and allowed the characterization of climate cycles. And $\delta^{18}\text{O}$ curves whose

measurements were performed on *Globigerinoides ruber*, *Neogloboquadrina pachyderma* and *Globigerina bulloides* (for planktonic foraminifer) and on *Cibicides wuellerstorfi*, *Cibicidoides pachyderma* and *Cibicidoides kullenbergi* (for benthic foraminifera plot, Toucanne et al., 2015).

Figure 4:

Distribution of benthic foraminifera group whose highest relative abundances are recorded during the climate cycle including the MIS 11-MIS 10, the MIS 9-MIS 8 and the MIS 7-MIS 6. The two dominant species in this group are: *S. schlumbergeri* and *B. nodosaria* with percentages up to 20%.

Figure 5:

Distribution of benthic foraminifera group whose highest relative abundances are recorded during the climatic cycle including the MIS 9 and the MIS 8.

Figure 6:

Distribution of benthic foraminifera group whose highest relative abundances are recorded during the climatic cycle including the MIS 7 and the MIS 6.

Figure 7:

Distribution of benthic foraminifera group whose highest relative abundances are recorded during the last climatic cycle.

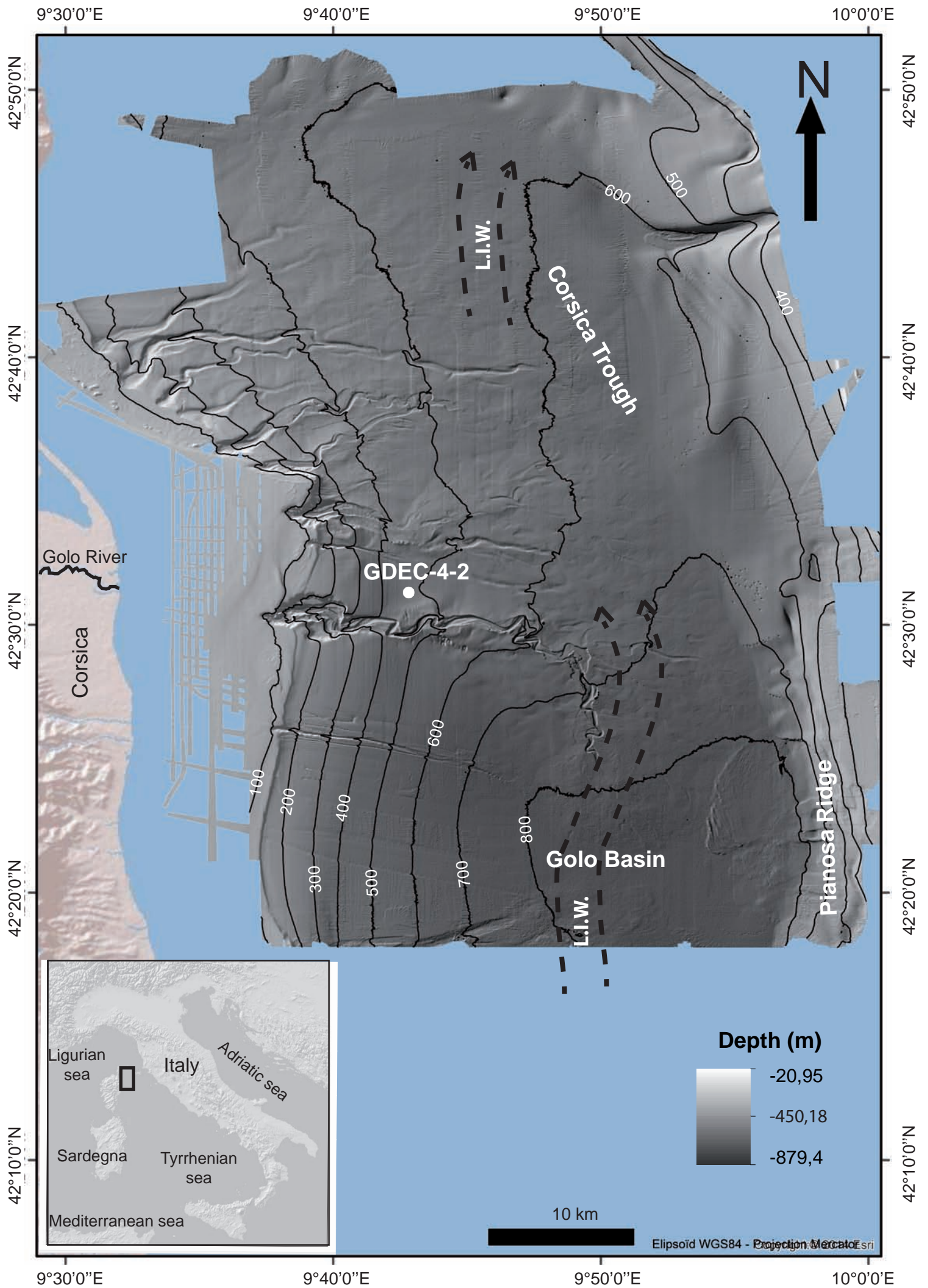
Tables captions

Table 1:

Table of actual counts of all ostracoda taxa identified in the 291 analysed samples collected in the borehole GDEC-4-2.

Table 2:

Table of actual counts of all benthic foraminifera taxa identified in the 291 analysed samples collected in the borehole GDEC-4-2.



9°30'0"E

9°40'0"E

9°50'0"E

10°0'0"E

42°50'0"N

42°50'0"N

42°40'0"N

42°40'0"N

42°30'0"N

42°30'0"N

42°20'0"N

42°20'0"N

42°10'0"N

42°10'0"N

9°30'0"E

9°40'0"E

9°50'0"E

10°0'0"E



Golo River

Corsica

GDEC-4-2

L.I.W.

Corsica Trough

Golo Basin

L.I.W.

Pianosa Ridge

Depth (m)



10 km

Elipsoido WGS84 - Projection Mercator Esri

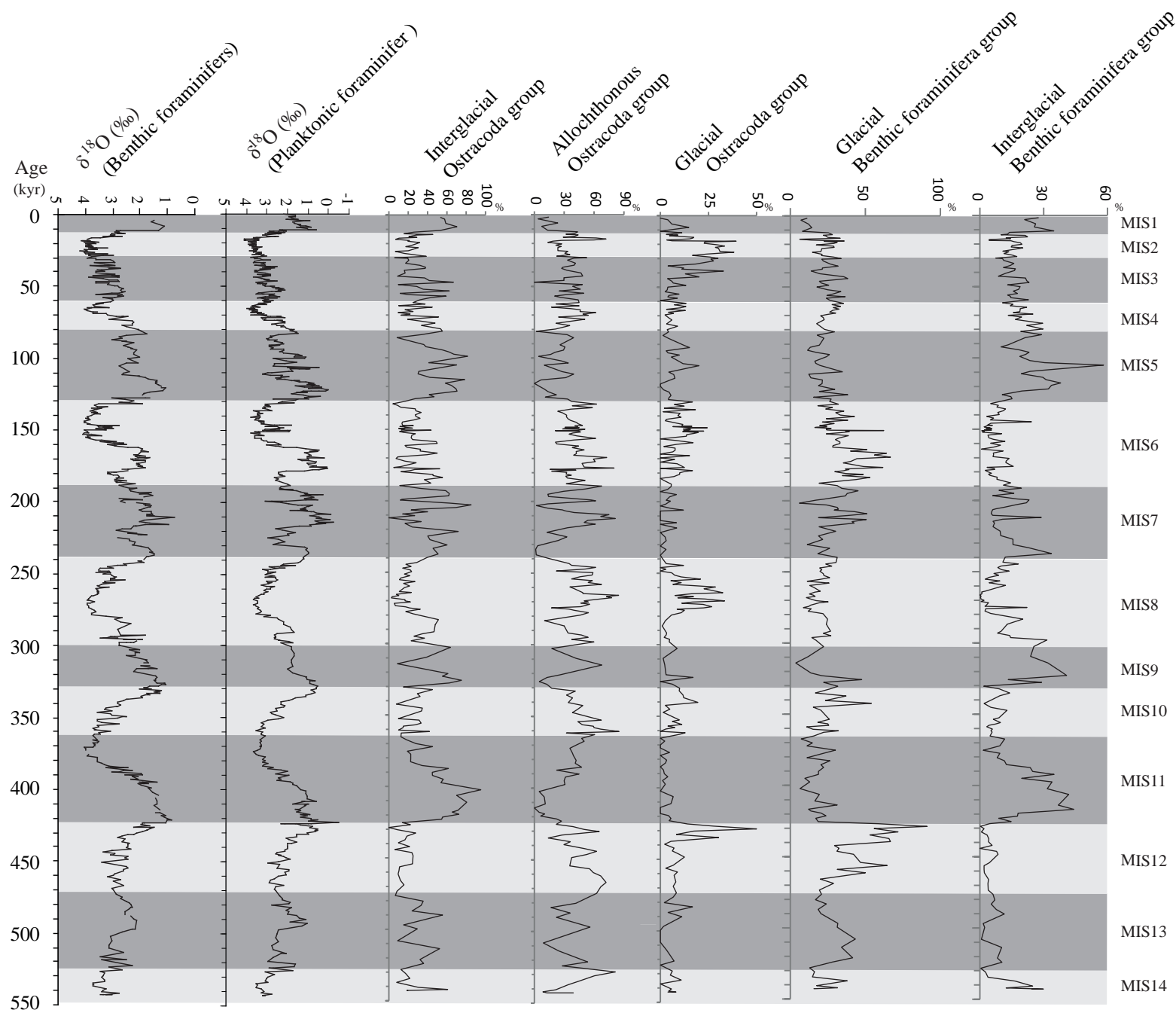


Fig. 2 Angue Minto'o et al.

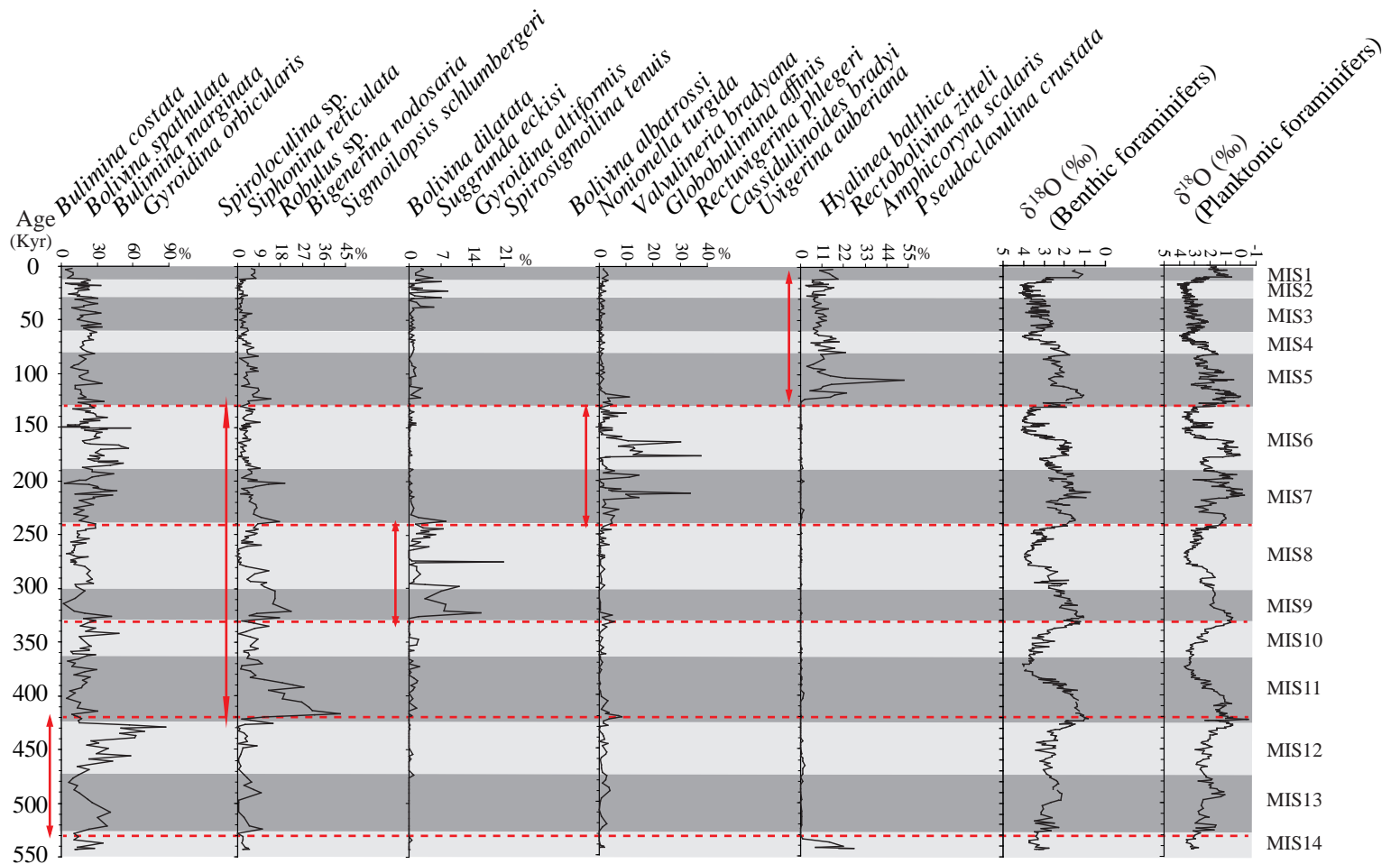


Fig. 3 Angue Minto'o et al.

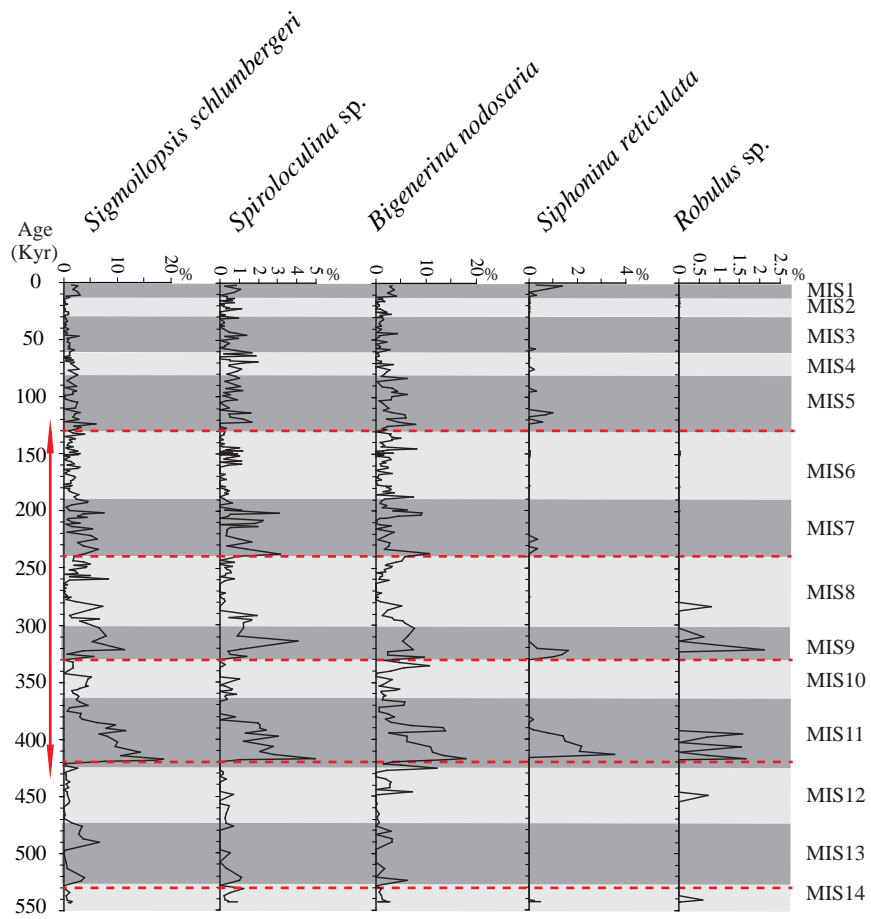


Fig. 4 Angue Minto'o et al.

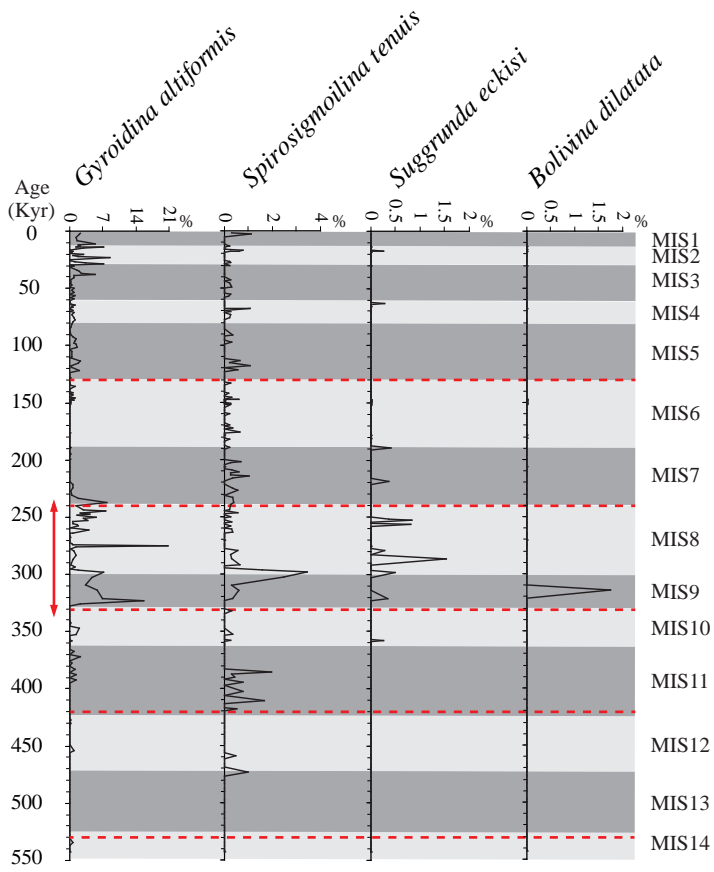


Fig. 5 Angue Minto'o et al.

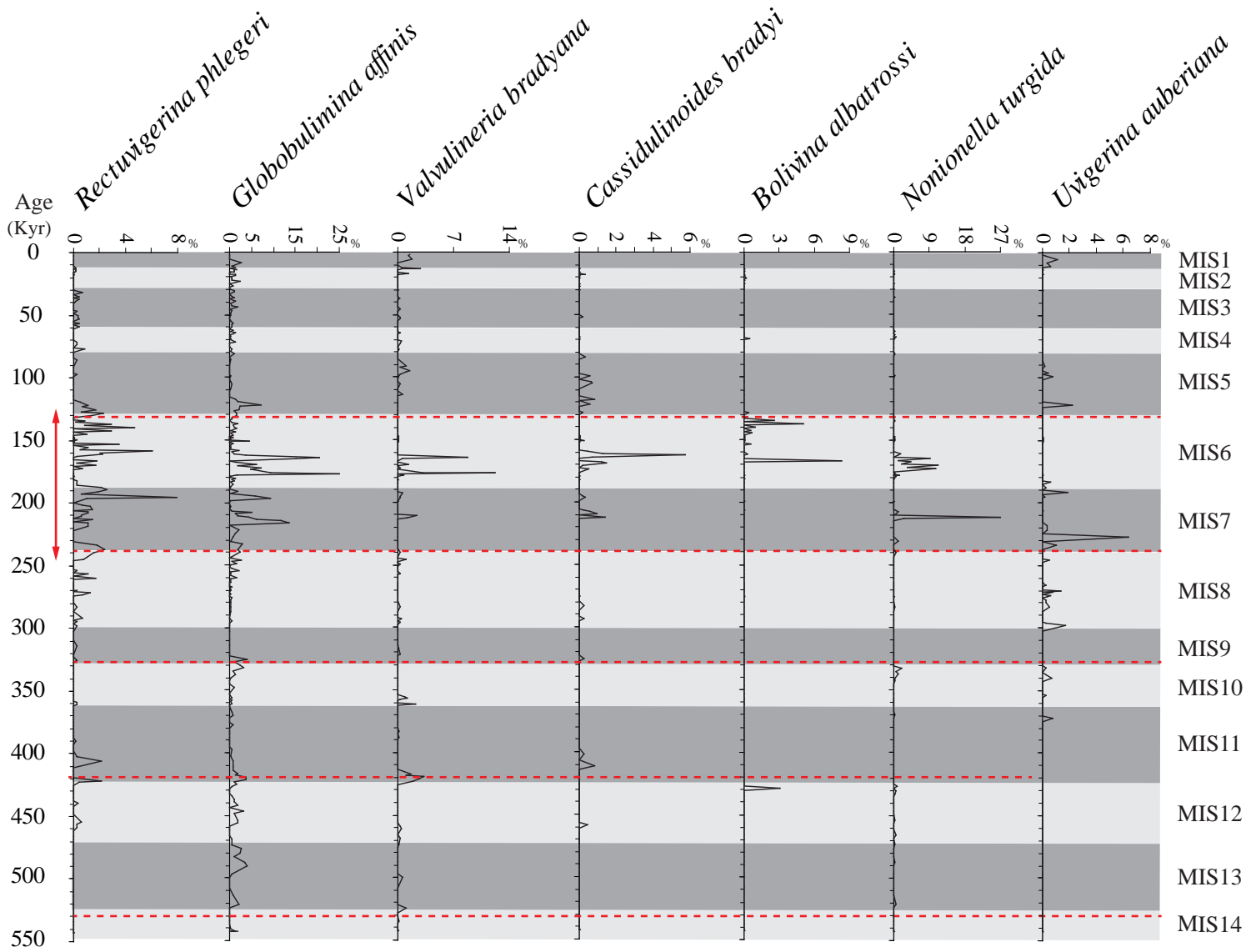


Fig. 6 Angue Minto'o et al.

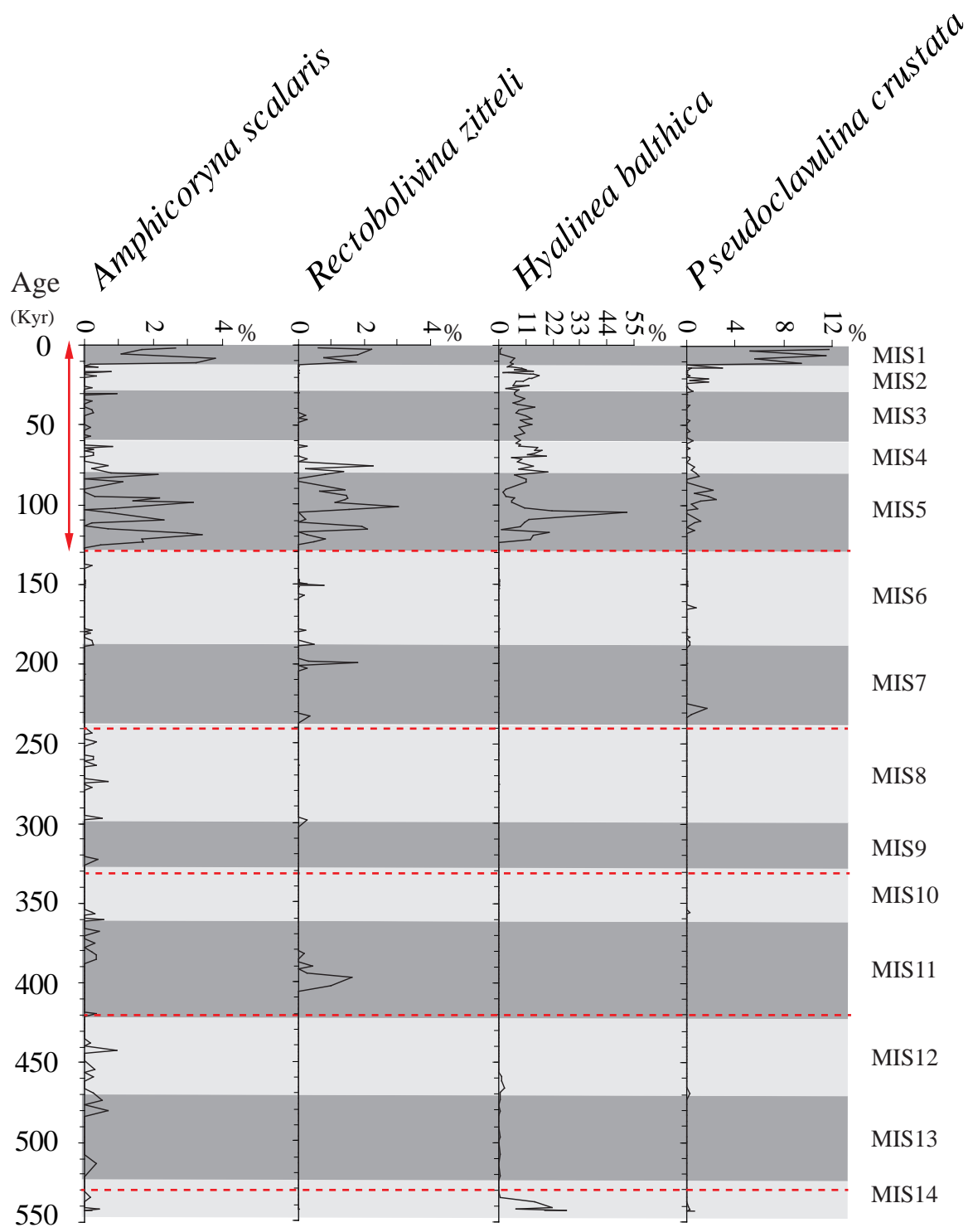


Fig. 7 Angue Minto'o et al.