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# Late Albian-Cenomanian planktonic foraminiferal biostratigraphy, taxonomy and paleoceanographic inferences

Ph.D. Thesis

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# Abstract

The mid-Cretaceous period (about 120 Ma to 80 Ma) was characterized by unusually warm climate, low thermal gradient between latitudes and by a series of Oceanic Anoxic Events (OAEs) promoting deposition of black shales (e.g. Bréhéret, 1988; Gale et al., 1996; Coccioni, 2001; Bornemann et al., 2005; Gambacorta et al., 2014, among others). During the late Albian-Cenomanian (~105-93 Ma), a major radiation of planktonic foraminifera did occur for the first time in their evolutionary history and was marked by the appearance of novel morphologies (biserial taxa and single-keeled trochospiral taxa with supplementary apertures) and by the development of new and more complex wall textures (macroperforate, muricate and costellate) on planispiral and trochospiral taxa that lasted until the end of the Cretaceous (González-Donoso et al., 2008; Lipson-Benitah, 2008; Georgescu and Huber, 2006, 2009; Huber and Leckie, 2011). However, the often imprecise usage of the key taxonomic criteria for species identification (morphology vs. wall texture) and/or broad species concept used for the identification of some upper Albian-Cenomanian species have lead to uncertainties in the planktonic foraminiferal biozonation.

This study is aimed 1) to review the upper Albian-Cenomanian planktonic foraminiferal species in order to clarify the key taxonomic features of some often misidentified species (e.g., *Th. reicheli, R. cushmani, R. montsalvensis*); 2) to refine the planktonic foraminiferal biozonation according to the revised taxonomy; 3) to describe the planktonic foraminiferal preferred trophic regime in the upper Albian-Cenomanian interval through the observation and comparison of relative abundances and diversity of species with inferred similar depth ecology; and 4) to clarify the planktonic foraminiferal response to the upper Albian Oceanic Anoxic Event 1d (OAE1d) (Erbacher and Thurow, 1997) and to the Mid Cenomanian Event (MCE) (Ernst et al., 1983).

The upper Albian-Cenomanian samples analyzed were selected from different sedimentary basins:

1) the Umbria-Marche Basin (Monte Petrano and Le Brecce sections) and 2) the Mazagan Plateau (Deep Sea Drilling Program - DSDP Leg 79, Sites 547A and 545).

All the studied sections include the Albian/Cenomanian boundary and the OAE1d (Leckie, 1984; Nederbragt et al., 2001; Gambacorta et al., 2014, 2015, 2016).

In addition, the Monte Petrano section also records the MCE (Coccioni and Galeotti, 2003; Gambacorta et al., 2014, 2015, 2016).

Samples from the Umbria-Marche Basin were processed using a technique with acetic acid, while those from the Mazagan Plateau were prepared with the standard methodology. A scanning electron microscope (SEM) was used to document the species and to observe the wall texture at higher magnification. Finally, quantitative analysis were performed for the Monte Petrano and Site 547A to document variations in abundance of species and genera respect to the total planktonic foraminifera, and, consequently, to evaluate the evolutionary trends and the changes in the assemblages composition.

Five Biozones and one Subzone (Robaszynski and Caron, 1995) were identified, specifically from base to top: *Pseudothalmanninella ticinensis* Zone*, Thalmanninella appenninica* Zone*, Planomalina buxtorfi* Subzone*, Thalmanninella globotruncanoides* Zone, *Thalmanninella reicheli* Zone and *Rotalipora cushmani* Zone.

Moreover, the LO (lowest occurrence) of *Th. appenninica,* the LO of *P. buxtorfi,* the LO of *P. libyca,* the LO of *Th. brotzeni,* the LO of *Th. globotruncanoides,* the LO of *Th. greenhornensis,* and the LO of *R. cushmani* are identified to be potentially useful bioevents for regional and global correlations by comparing the results from this study with data reported from the literature (Mont Risou section, Vocontian Basin: Gale et al., 1996; Kennedy et al., 2004; Petrizzo et al., 2015; and Blake Nose ODP Site 1050C, northwestern Atlantic: Petrizzo and Huber, 2006a; Petrizzo et al., 2008; Ando et al., 2010; Petrizzo et al., 2015).

*Thalmanninella reicheli* that in the current planktonic foraminiferal biozonation (Robaszynski and Caron, 1995) defines the base of the nominal Zone, resulted to be a problematic marker, as it is a rare taxon and/or displays a scattered stratigraphic distribution. Therefore, the lowest occurrences of *Th. greenhornensis* and of *Whiteinella* sp. are proposed to be potentially useful bioevents to approximate the base of the *Th. reicheli* Zone in the absence of the zonal marker.

The lowest occurrence of *Th. globotruncanoides*, primary criterion for the definition of the Albian/Cenomanian boundary (Kennedy et al., 2004), falls close to the interval of maximum values of the $\delta^{13}$C in all the studied sections and at Site 1050C (Blake Nose, northern west Atlantic Ocean). On the contrary, in the Mont Risou section, (stratotype section for the Cenomanian GSSP), *Th. globotruncanoides* first appears below the interval of higher $\delta^{13}$C values (Gale et al., 1996). Although the observed discrepancies may rely on different causes (e.g., sampling resolution, diagenesis) new integrated stratigraphy studies of the stratotype section are certainly needed to verify the reproducibility of the primary and secondary criteria for the definition of the base of the Cenomanian Stage in localities from different paleogeographic areas.

According to the composition of the planktonic foraminiferal assemblages, both sedimentary sections record a late Albian time interval characterized by a dominant oligo-mesotrophic regime with a rather stable column water stratification, sometimes disrupted by perturbations possibly related to the late Albian OAE1d. In fact, as confirmed also at Blake Nose (Wilson and Norris, 2001; Petrizzo et al., 2008), in the stratigraphic interval inferred to be coincident with the OAE1d, the extinction of the warmest planktonic foraminiferal genera (*Biticinella, Paracostellagerina* and *Ticinella*) is documented, indicating a reduced thermal gradient of the water column. The low abundance and diversity of warmer taxa (*Protoheterohelix*) and the increase in abundance and diversity of colder taxa (*Praeglobotruncana,* rotaliporids, *Muricohedbergella*), suggest a mesotrophic to meso-eutrophic regime with a low temperature gradient in the stratigraphic interval comprised between the OAE1d and the MCE.

The variation in the composition of the planktonic foraminiferal assemblages across the MCE at Monte Petrano reveals a remarkable decrease in relative abundance of warm taxa (*Whiteinella*), which might be associated to a minimum of temperature in agreement with the data reported in the Anglo-Paris Basin (Voigt et al., 2004; Wilmsen et al., 2007), where the MCE is correlated to a cold event, the so-called *primus* Event (LO of the belemnite *Praeactinocamax primus*).

# Chapter 1

# Introduction

The Cretaceous Period is characterized by a gradual increase of the temperature, occasionally interrupted by short and widespread climatic instabilities (i.e., Oceanic Anoxic Event in the Aptian, Albian and Cenomanian). This temperature increment reached its apex in the Turonian then the temperature gradually started to decrease till the end of the Cretaceous (e.g. Clarke & Jenkyns, 1999; Huber et al., 2002; Cramer et al., 2009; Friedrich et al., 2012). The greenhouse period was interrupted by some short but intense events of cooling (Santonian and Campanian) and heating (Maastrichtian) (Jenkyns et al., 1994; Clarke and Jenkyns, 1999; Huber et al., 2002; Friedrich et al., 2012, among many others).

The evolution of Cretaceous planktonic foraminifera is characterized by speciation and extinction events (e.g., Caron and Homewood, 1983; Hart, 1999; Premoli Silva and Sliter, 1999), and high rates of species and genera turnover are documented in time intervals associated to environmental perturbations. According to previous studies planktonic foraminifera are sensitive to oceanic chemical and physical changes including atmospheric $CO_2$ variations and this could be particularly evident near OAEs, where planktonic foraminifera might have developed anomalous morphologies and/or novel shell texture and might have underwent increase/decrease rates in diversification (e.g., Hart, 1999; Premoli Silva and Sliter, 1999; Leckie et al., 2002).

Particularly, during the Late Albian-Cenomanian (~105-93 Ma) planktonic foraminifera experienced, for the first time in their evolutionary history, a major radiation with the appearance of biserial taxa and of single-keeled trochospiral taxa with supplementary apertures on the umbilical side, informally called rotaliporids (Brotzen, 1942; Sigal, 1948; Wonders, 1978; Caron, 1985; Gonzalez-Donoso et al., 2007; Lipson-Benitah, 2008). At the same time, planispiral and trochospiral taxa developed new and more complex wall textures (macroperforate, muricate and costellate) that persisted until the end of the Cretaceous (e.g. Caron, 1985 and references herein; Huber and Leckie, 2011).

In this thesis, four upper Albian-Cenomanian stratigraphic sections, belonging to different sedimentary basins and showing high diversity and abundance of the planktonic foraminifera, are studied:

- the Monte Petrano and Le Brecce sections from the Umbria-Marche Basin;
- DSDP Sites 547A and 545 from the Mazagan Plateau.

All the studied sections record:

- the Albian/Cenomanian boundary, defined at Mont Risou section (Vocontian Basin) based on the lowest occurrence of the single keeled planktonic foraminifera *Thalmanninella globotruncanoides* (Kennedy et al., 2004);
- the Oceanic Anoxic Event 1d (OAE1d) (Erbacher and Thurow, 1997)

In addiction at Monte Petrano is also recorded the Mid Cenomanian Event (MCE) (Ernst et al., 1983)

The following detailed analyses have been carried out and presented in this thesis:

1) taxonomic analysis (Chapter 5)

A detailed taxonomic analysis aimed to review the upper Albian-Cenomanian planktonic foraminiferal species is performed. Specifically, particular attention is given to the analysis of the validity of some bioevents in order to improve the planktonic foraminiferal biozonations (Premoli Silva and Sliter, 1995; Robaszynski and Caron, 1995), as follows:

- *Thalmanninella reicheli,* bioevent for the base of the nominal Zone. It has been confused for a long time with other species, such as *Thalmanninella deeckei.* Criteria for its identification are here evaluated.

- *Rotalipora cushmani,* bioevent for the base and the top of the nominal Zone. It has been often misidentified and confused with its ancestor species *Rotalipora montsalvensis.* In this study, the main features for the distinction of the two species are highlighted and described.

- *Thalmanninella globotruncanoides,* primary criterion for the definition of the Albian/Cenomanian boundary (Kennedy et al., 2004), has often been confused with *Thalmanninella brotzeni.* Transitional morphotypes between the two species are here observed and the main features for the distinction between *Thalmanninella brotzeni* and

*Thalmanninella globotruncanoides* are identified in agreement with the description and illustration of the type materials (Petrizzo et al., 2015).

- The relationship between *Ticinella raynaudi aperta* and species belonging to the *Thalmanninella* genus is documented at Monte Petrano and at Mazagan Plateau. The inferred phyletic lineage is reinforced by the identification of several transitional taxa between species.

2) biostratigraphic analysis (Chapter 4)

The commonly applied low latitude planktonic foraminiferal biozonation (Premoli Silva and Sliter, 1995; Robaszynski and Caron, 1995) is here refined according to the revised taxonomy. Specifically:

- the reliability of the lowest occurrence of *Thalmanninella reicheli* as bioevent is discussed. Moreover, alternative bioevents possibly useful to approximate the base of *Thalmanninella reicheli* Zone, in the absence of the nominal taxon, are identified.

- results from the studied sections are compared to data from the available literature from different sedimentary basins, namely the Blake Nose Plateau in the northwestern Atlantic Ocean (Watkins et al., 2005; Petrizzo and Huber, 2006a; Petrizzo et al., 2008; Petrizzo et al., 2015), and the Mont Risou section in the Vocontian Basin (Gale et al., 1996; Kennedy et al., 2004 and Petrizzo et al., 2015). Reliable bioevents for regional and global correlation are identified.

- the biostratigraphic and carbon isotope data across the Albian-Cenomanian boundary interval are discussed in order to document the sequence of the bio- and chemostratigraphic events and to test the reliability of the correlation among locations from different paleogeographic area.

- The stratigraphic interval inferred to register the Oceanic Anoxic Event 1d is discussed in all the studied sections.

3) quantitative analysis (Chapter 6)

   Variations in species and genera relative abundances respect to the total planktonic foraminifera, and to changes in the number of species inferred to possess similar life strategies (upper and lower mixed layer and thermocline dwellers), are compared in order to describe the trophic regime in the upper Albian-Cenomanian interval. Relative abundance data are obtained for the Monte Petrano and the Mazagan Plateau Site 547A.

   Particular attention is given to the stratigraphic intervals that register the upper Albian Oceanic Anoxic Event 1d and the Mid Cenomanian Event (Chapter 2) in order to evaluate the response of planktonic foraminifera during the late Albian-Cenomanian environmental perturbations.

# Chapter 2

# The Oceanic Anoxic Event 1d and the Mid-Cenomanian Event: state of the art

The mid-Cretaceous period (about 120 Ma to 80 Ma) is characterized by unusually warm climate, low thermal gradient between latitudes and by a series of Oceanic Anoxic Events (OAEs) promoting deposition of black shales and high biological turnover (e.g. Leckie et al., 2002). The high temperature is widely considered as caused by elevated levels of atmospheric greenhouse gases such as $CO_2$ (i.e., Barron and Washington, 1985; Arthur et al., 1985; Ernst and Buchan, 1997; Embry and Osadetz, 1998; Neal et al., 1997; Saunders et al., 1997; Storey et al., 1997; Kerr et al., 1997; Peate, 1997; Eldholm and Coffin, 2000; Coffin et al., 2002; Jenkyns, 2010; Hasegawa et al., 2012, among others). Specifically, at Blake Nose, based on isotopic analysis on benthic foraminifera, temperature of 14-17°C are suggested for the bathyal zone, while the sea surface water temperature is reported to exceed 30°C in the Late Albian (Norris and Wilson, 1998; Petrizzo et al., 2008). Moreover, Friedrich et al. (2012), based on stable isotope and Mg/Ca of planktonic foraminifera (Wilson et al., 2002; Bice et al., 2006; Bornemann et al., 2008) and the $TEX_{86}$ proxy (Forster et al., 2007), suggest that the maximum warming is reached between the middle Cenomanian and the lower Turonian, when the tropical sea surface temperature are >35°C and data from the benthic foraminifera indicate about 20°C in the southern high latitudes and in the Pacific Ocean.

During the late Albian time interval, the rising sea level and the global warming resulted in a pronounced increase in the degree of calcification of the planktonic foraminiferal shells, with the development of more complex morphologies and the increase in diversity and in size (Caron and Homewood, 1983; Leckie, 1989; Hart, 1999; Premoli Silva and Sliter, 1999). In fact, single keeled taxa and globigerinoid forms with muricae and costellae appear for the first time in the evolutionary history of planktonic foraminifera.

In addition, the late Albian to late Cenomanian interval is characterized by two major geochemical anomalies corresponding to positive excursions of the stable carbon isotope profile: the Oceanic Anoxic Event 1d (OAE1d) and the Mid-Cenomanian Event (MCE).

## 2.1 The Oceanic Anoxic Event 1d

The Oceanic Anoxic Event 1d was first introduced by Erbacher and Thurow (1997) in Le Brecce section near Piobbico (Umbria-Marche Basin) to identify a rhythmically bedded black shale sequence associated to a positive carbon isotope shift falling within the upper Albian *Planomalina buxtorfi* Subzone of the *Thalmanninella appenninica* Zone. The OAE1d is interpreted to be widespread as it was subsequently recognized in south east France (Vocontian Basin, Mont Risou and Col de Palluel: Gale et al., 1996; Bornemann et al., 2005), in the northeastern Atlantic Ocean (DSDP Leg 79, Site 547 Mazagan Plateau: Nederbragt et al., 2001), and in the northwestern Atlantic Ocean (ODP Leg 171B, Sites 1052 and 1050 Blake Nose: Wilson and Norris, 2001; Petrizzo et al., 2008).

In the Vocontian Basin the lithological expression of the Oceanic Anoxic Event 1d was called Niveau Breistroffer (Bréhéret, 1988; Gale et al., 1996) that consists in a horizon of about 10 meters, including beds of laminated black shale layers alternated with dark gray bioturbated marls. The carbon isotope record reveals a 0.5‰ positive shift followed by fluctuating values increasing up to 0.3‰ about 14 m above the highest occurrence of *Planomalina buxtorfi* and 22 m above the top of the Breistroffer (Gale et al., 1996). Afterwards, more detailed studies on the same section by Bornemann et al. (2005) allowed the definition of the 6.28 m thick "main Niveau Breistroffer" including 4 black shale levels. The bulk carbonate stable isotope record, obtained by Bornemann et al. (2005), shows fluctuating $\delta^{13}C$ values from 1 to 1.5‰ across the main Niveau Breistroffer with the highest values associated with black shales. A 1.3‰ $\delta^{13}C$ positive shift is identified from the top of the main Breistroffer to 12 m below the highest occurrence of *Planomalina buxtorfi.*

At Mazagan Plateau (DSDP Site 547) Nederbragt et al. (2001) documented a long term $\delta^{13}C$ 1.5‰ positive shift that extends from just below the lowest occurrence of *Planomalina buxtorfi* to just above the lowest occurrence of *Thalmanninella globotruncanoides*, the foraminiferal species marker of the Albian/Cenomanian boundary (Kennedy et al., 2004).

At Blake Nose Plateau (ODP Leg 171B) the upper Albian stratigraphic interval is characterized by common black shales. Specifically, at Site 1052E Wilson and Norris (2001) defined the OAE1d as starting from the beginning of the major black shale occurrence within the *Thalmanninella appenninica* Zone and ending at the $\delta^{13}C$ highest values near the Albian/Cenomanian boundary, that correlate with the $\delta^{13}C$ values in the Vocontian Basin (Gale et al., 1996; Bornemann et al., 2005) and with data from DSDP Site 547A (Nederbragt et al., 2001). On the basis of a cyclostratigraphic age model, Wilson and Norris (2001) calculated that the OAE1d interval has a duration of about 280 k.y. Otherwise, Petrizzo and Huber (2006a), on the basis of a revised biostratigraphy and an age model based on calcareous nannofossil and planktonic foraminifera, observed that the OAE1d interval, as defined by Wilson and Norris (2001), lasted about 500 k.y. Afterwards, Petrizzo et al. (2008) observed the somewhat equivocal correlation among sections of the interval assigned to OAE1d because of the strong fluctuations of the $\delta^{13}C$ values in the earlier phase, and defined the OAE1d as the interval between the starting point of the $\delta^{13}C$ excursion and the maximum $\delta^{13}C$ value.

In the Umbria-Marche Basin the rhythmically bedded black shale, known as Pialli level, of late Albian age, is regarded to be the lithological expression of the OAE1d. The Pialli level was first described by Coccioni (2001), in the lower part of the Scaglia Bianca Formation in the Monte Petrano section, as a distinctive regional marker of about 4 m-thick, composed by 5 black marl levels with a TOC content higher than 2‰ intercalated to cherty limestones and radiolarian layers.

At Monte Petrano and Le Brecce sections, Gambacorta et al. (2015) defined the OAE1d interval between the starting point of the $\delta^{13}C$ excursion and the point where the anomaly definitely ended (maximum $\delta^{13}C$ value), in agreement with the definition by Petrizzo et al. (2008).

According to the literature, the OAE1d has been interpreted related to different paleoceanographic conditions:

1) at Blake Nose both the planktonic-benthic $\delta^{18}O$ gradient and the isotopic range among planktonic foraminifera increase with rising sea level and sea surface water temperature, indicating that the water column becomes well stratified by the early late Albian interval. Afterwards, during the late Albian OAE1d, a collapse of the ocean stratification does occur as shown by the reduced range of $\delta^{18}O$ among surface and thermocline planktonic species during a period of increased wind-driven deep winter mixing and reduced summer stratification, promoting higher productivity (Wilson and Norris, 2001). Therefore, the OAE1d is interpreted relating anoxia to increased surface ocean productivity, possibly initiated by monsoon overturning and leading to a thickening of the oxygen minimum zone in the water column.

   Petrizzo et al. (2008) confirm the OAE1d as a global event, but they observe that black shale deposition at Blake Nose could be also controlled by the local oceanographic setting or depositional pattern. This observation is confirmed by the occurrence of common black shales in the sediments below the stratigraphic interval where the carbon isotope shift is recorded. Moreover, in correspondence of the beginning of the black shale deposition no changes in the water column stratification or in biodiversity are observed according to the planktonic foraminiferal data, so that the authors considered the process driving the global carbon isotope anomaly still unknown.

2) in the Vocontian Basin, on the basis of planktonic foraminifera, calcareous nannofossil, palynomorph and carbon isotope data (Bornemann et al., 2005), the formation of the late Albian black shales resulted as a consequence of great monsoonal activity leading to high humidity and wind stress. These conditions are inferred to cause a decrease in low latitude deep water formation and an increase in surface water stratification. Specifically, a nutrient index based on calcareous nannofossil and on the abundances of hedbergellids planktonic foraminifera indicate short-term changes in the surface water productivity. Therefore, during the formation of black shale, productivity is reduced, while during the deposition of marlstone it is increased. Moreover, calcareous nannofossil temperature index and carbon isotope data indicate warmer surface waters in correspondence of the black shales. Bornemann et al. (2005) also highlight that during the OAE1d a greater abundance of deep dweller rotaliporids is observed, indicating more stratified water conditions.

## 2.2 The Mid Cenomanian Event

The Mid-Cenomanian Event (MCE) was first introduced by Ernst et al. (1983) and later by Meyer (1990) to describe a nodular limestone layer in the Cenomanian of NW Germany (Friedrich et al., 2009). Moreover, Paul et al. (1994) identified a small carbon isotope excursion slightly above the nodular layer, with a double peak and a maximum excursion of 1‰ in two sedimentary basins in northwest Europe (the Anglo – Paris Basin and the Cleveland Basin, U.K.). The authors suggest that this carbon isotope excursion was likely caused by variations in the isotopic composition of Cenomanian sea water due to enhanced rate of burial of organic matter.

The first peak is the MCE Ia and corresponds to an increase of about +0.5‰ in $\delta^{13}C$. After a short interval of minor values, a second peak named MCE Ib is described and reaches values slightly higher than MCE Ia. Mitchell et al. (1996) also described a negative shift of about -0.3‰, the so-called MCE II above MCE I.

The $\delta^{13}C$ excursion associated to the MCE has been observed in both the Boreal (Jenkyns et al., 1994; Paul et al., 1994; Mitchell et al., 1996; Jarvis et al., 2001; 2006; Voigt et al., 2004;) and Tethyan Realms (Jenkyns et al., 1994; Erbacher et al., 1996; Stroll and Schrag, 2000; Voigt et al., 2004; Gambacorta et al., 2015), in the Atlantic Ocean (Huber et al., 2002; Ando et al., 2009), and in shelf environments in the western of Morocco (Gertsch et al., 2010).

The MCE is not characterized by the deposition of black shales (Jenkins et al., 1994), but it is often associated to lithological changes (Jenkyns et al., 1994; Coccioni and Galeotti, 2003). Moreover, several changes in the marine biota (planktonic and benthic foraminifera, radiolaria, dinoflagellates, bivalves, ammonites and belemnites) can be related to the MCE (e.g. Paul et al., 1994; Erbacher et al.,1996; Erbacher and Thurow, 1997; Coccioni and Galeotti, 2001, 2003; Wilmsen et al., 2007; Friedrich et al., 2009; Giraud et al., 2013).

According to the literature, the MCE has been interpreted as related to different paleoclimatic conditions:

1) The hypothesis of the development of short-lived ice sheet (at least in Antarctica) during the interval associated to the MCE, is supported by Stroll and Schrag (2000) (Umbria-Marche Basin and Santa Ines Section, Spain) and by Miller et al. (2003; 2005) (northern western Atlantic Ocean and Russian platform). The Authors, based on the evidence from the sequence stratigraphy analyses, document a high amplitude sea level falls related to bulk carbonate and $\delta^{18}O$ benthic foraminiferal shifts.

   Moreover, the MCE is suggested to be related to the *primus* Event, an important interbasinal marker horizon, defined by the lowest occurrence of the belemnite *Praeactinocamax primus* and supposed to coincide with a minimum of temperature (Voigt et al., 2004; Wilmsen et al., 2007). This cooling event is also visible in the dataset by Friedrich et al. (2012). According to the Friedrich et al. (2012) dataset, the lowest values of the oxygen isotope data measured on benthic foraminiferal shells from sites drilled in the Atlantic and Pacific Oceans and at low and southern high latitudes, occur in the mid Cenomanian just below the interval of highest temperature known as the mid-Cretaceous thermal maximum.

2) According to Coccioni and Galeotti (2003) (Umbria-Marche Basin), after a lower Cenomanian interval characterized by rather stable environment, the MCE would represents a no returning point in the process of increasing atmospheric $CO_2$ and climatic-oceanographic changes within the warming-cycle. This interpretation is based on the combination of data such as the

planktonic and benthic foraminiferal and radiolaria assemblages, carbon isotope data, and Sr/Ca ratio. The interval between the MCE and the OAE2 consists in a cyclical deposition of carbon-rich layers that lasted about 2 Myr and culminate with the deposition of the Bonarelli Level. The authors also highlight that, during this interval, opportunistic planktonic foraminifera gradually increase respect to the specialized taxa that disappear in correspondence of the Bonarelli Level. In addiction, a decline in diversity and abundance of benthic foraminifera indicate the turning to a dysaerobic sea floor. Moreover, after the loss of species at the MCE, radiolaria show a gradual decreasing towards the OAE2 (Erbacher et al., 1996).

On the contrary, according to Gambacorta et al. (2016), facies analysis from sections belonging to the Umbria-Marche Basin, suggest that the period between the MCE and OAE2 is characterized by circulation at the sea floor and re-oxygenation.

Moriya et al. (2007), highlighting the absence of planktonic/benthic covariation in oxygen isotope data from Demerara Rise (equatorial Atlantic Ocean), and claim that no short-lived ice sheet occurred in the mid-Cenomanian. In addition, Ando et al. (2009) support this hypothesis through stable isotope and Sr/Ca data from the Blake Nose Plateau (northern western Atlantic Ocean). They infer that the planktonic foraminiferal $\delta^{18}O$ is constant or even shows more negative values across the MCE. In addition, a positive shift of the benthic oxygen isotope signal during MCE I and a reduction of the planktonic-benthic $\delta^{18}O$ difference are observed. The authors advance two possible motivations to explain the reduced stratification of the ocean water: 1) upwelling or downwelling, and 2) the ingression of saline waters characterized by high $\delta^{18}O$ as inferred at Demerara Rise (Moriya et al., 2007).

# Chapter 3

# Materials and methods

## 3.1 Localities

To perform this study, I have analyzed 172 samples from two localities belonging to different paleoceanographic and paleogeographic settings (Fig. 3.1):

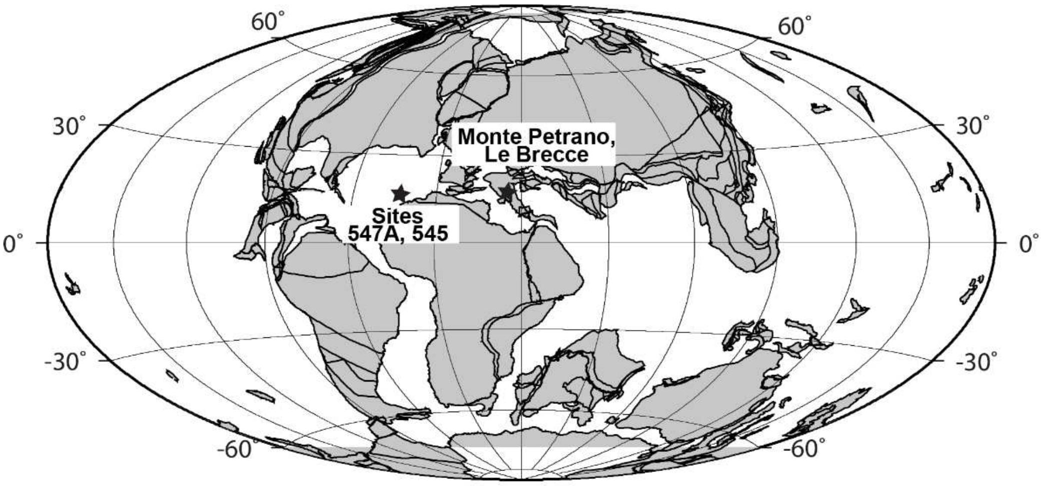


**Fig. 3.1** Paleogeographic reconstruction for the upper Albian-Cenomanian. The location of the studied section are reported. After Hay et al., (1999).

1) **Umbria-Marche Basin** (Fig. 3.2)
    a) Monte Petrano section (61 washed residues and 30 thin sections)
    b) Le Brecce section (22 washed residues)

2) **Mazagan Plateau** (Fig. 3.3)
    a) Site 547A (64 washed residues)
    b) Site 545 (25 washed residues)

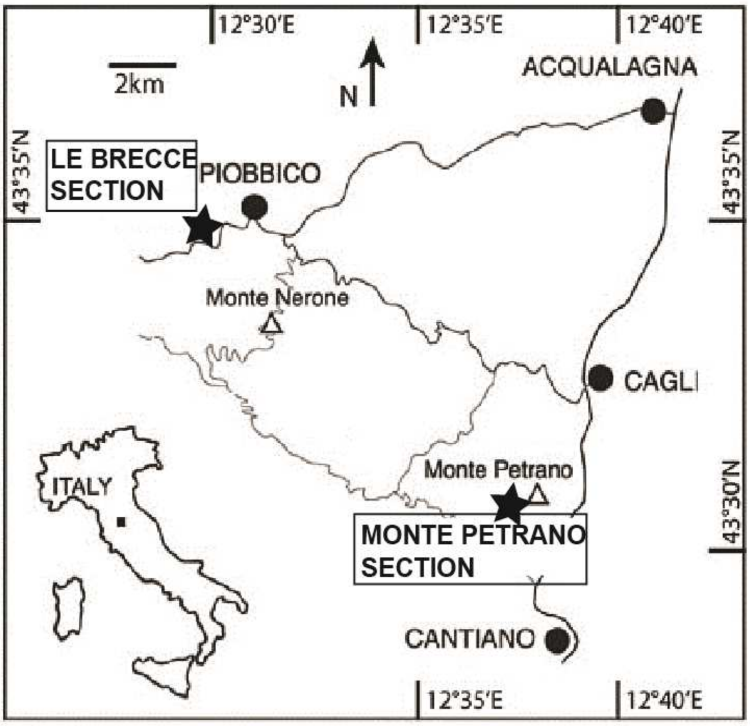


**Fig. 3.2** Location of the Monte Petrano and Le Brecce sections in the Umbria-Marche Apennine, Italy.

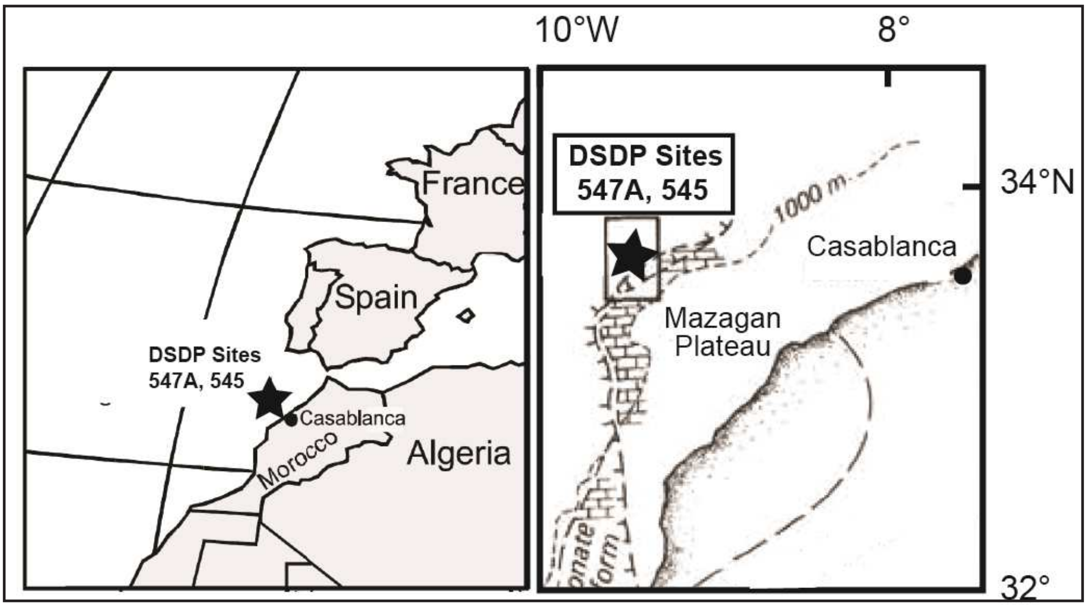


**Fig. 3.3** Location of DSDP Sites 547A and 545 in the offshore of Morocco, south-eastern North Atlantic.

## 3.2 Lithostratigraphy

### 3.2.1 Umbria-Marche Basin: Monte Petrano and Le Brecce

The Umbria–Marche Basin is characterized by a pelagic sedimentary sequence of Jurassic to Oligocene age. Specifically, in the Cretaceous pelagic limestones are mostly composed by calcareous nannofossil and planktonic foraminifera, cherts and marlstones deposited on a highly irregular sea floor with characteristic seamount-and-basin morphology (Channell et al., 1979; Lavecchia and Pialli, 1989; Parisi, 1989; Marchegiani et al., 1999; Hu et al., 2006).

The Monte Petrano and the Le Brecce sections are both located in the Umbria-Marche Apennine, on the southwestern side of Monte Petrano, near the town of Cagli (Schwarzacher, 1994; Erbacher et al., 1996; Giorgioni et al., 2012; Gambacorta et al., 2015) and on the west respect to the town of Piobbico, respectively (Fig 3.2).

An upper Albian to Cenomanian sedimentary succession has been studied at Monte Petrano section (65 meters-thick) and at Le Brecce section (20 meters-thick) (Fig. 3.4), both covering a continuous stratigraphic record (Gambacorta et al., 2015). The sedimentary succession entirely belongs to the Scaglia Bianca Formation and consists of whitish pelagic limestones resulting from lithification of nannofossil-foraminiferal oozes with chert bands, radiolarian and shale layers (Arthur and Premoli Silva, 1982; Parisi, 1989; Coccioni and Galeotti, 2003; Gambacorta et al., 2014). The Monte Petrano and the Le Brecce sections record the upper Albian OAE 1d (Erbacher and Thurow, 1997) and its lithological expression (Pialli level) that consists of 6 and 5 levels of black shales, respectively (Coccioni, 2001). Furthermore, the Monte Petrano section records the Mid Cenomanian Event and the top of the studied section is marked by the Bonarelli level, a ~1 meter-thick interval, consisting of black shales, grey claystones and radiolarian-rich sands (Gambacorta et al., 2014, 2015), corresponding to the Cenomanian-Turonian boundary interval.

### 3.2.2 Mazagan Plateau: Leg 79 Sites 547A and 545

DSDP Site 547A and 545 (Figs. 3.3 and 3.4) were both drilled in 1981 in the southern-east North Atlantic, offshore of Morocco.

Site 547A (33°46.84'N; 09°20.98'W) was drilled to 744.5 m with a core recovery of about 49% and covers the stratigraphic interval from the late Albian to the Plio-Pleistocene. The upper Albian-Cenomanian stratigraphic interval, recorded from core 73R to 39R with a total thickness of 350 m, is characterized by a moderate to good recovery except for the intervals from core 67R to 64R, from 54R to 52R, from 49R to 45R and from 41R to 39R, and it is included in the lithological Unit V. The dominant lithology of Unit V is composed by dark greenish grey nannofossil claystone and calcareous claystone. The stratigraphic interval from core 39R to 42R (upper 37 m) is characterized by swelling claystone, from core 43R to 56R (128 m) it is composed by a mixture of wavy and swelling claystone and from core 56R to 73R (lower 185 m) it is dominated by wavy claystone. Moreover, in the lower part of the Unit, intervals of planar laminated dark claystone to mudstone, containing shell fragments and more quartz silt than the dominant lithology, does occur (Hinz, Winterer et al., 1984; Nederbragt et al., 2001). The other minor lithology is a pebbly claystone to mudstone and mudstone conglomerate, particularly frequent in the lower part of the Unit.

Site 545 (33°39.86'N; 09°21.88'W) was drilled to 701 m with a recovery of about 51% and covers the stratigraphic interval from late Aptian to early Pleistocene. The upper Albian-Cenomanian stratigraphic interval is recorded in the about 114 m-thick interval from core 40R to 28R, it is characterized by poor slightly increasing downward recovery and is included in the lithological Subunit IIIA. The dominant lithology of Subunit IIIA is grayish olive green nannofossil claystones. A minor lithology is represented by grayish green, greenish gray, and yellow green laminated claystone rich in nannofossil; below 312.5 m grayish olive green colors still predominate in the nannofossil rich claystones and reflect a downward increase in calcium carbonate of the sediment. In the lower part of the studied interval, two levels of claystone conglomerate composed of flat pebbles have been observed.

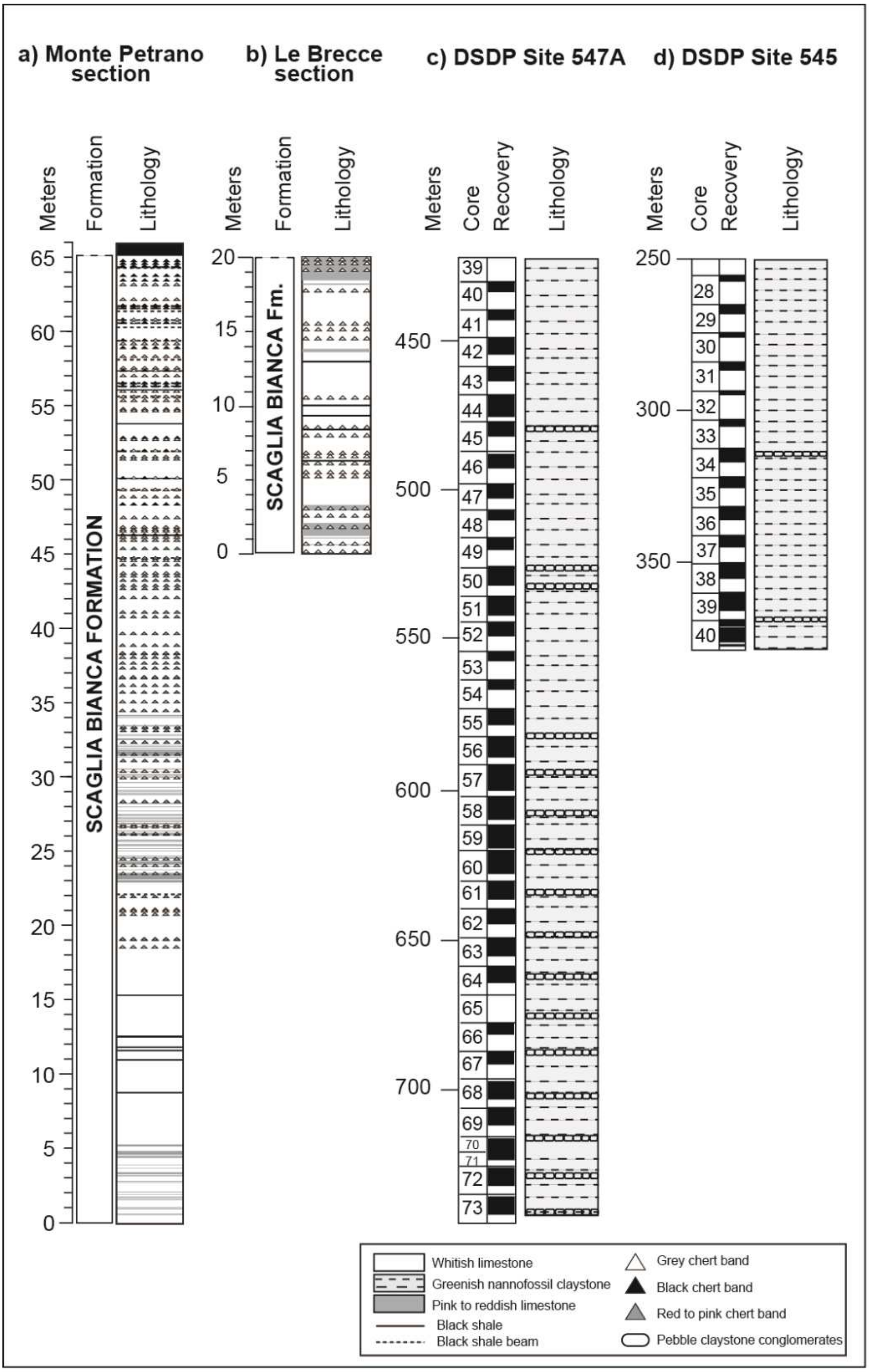


**Fig. 3.4** Stratigraphic logs of the studied section: a) Monte Petrano section; b) Le Brecce section; c) DSDP Site 547A (Mazagan Plateau); d) DSDP Site 545 (Mazagan Plateau); Logs of Monte Petrano and Le Brecce are by Gambacorta et al. (2015), while those of Mazagan Plateau are by Leckie (1984).

## 3.3 Sample processing

The upper Albian-Cenomanian Monte Petrano section was sampled for planktonic foraminiferal analyses from the base of the Scaglia Bianca Formation to the base of the Bonarelli Level with a sampling resolution from 50 cm to 1 m. The sampling resolution used for the upper Albian Le Brecce section was between 0.2 and 1.6 meters.

The compactness of the lithology prevented to apply the standard procedure to obtain washed residues for performing the micropaleontological analysis. Therefore, 61 rock samples from the Monte Petrano section and 22 rock samples from the Le Brecce section were processed using a solution of acetic acid at 80%. Rock samples were first broken into small fragments and then covered by the solution for hours, depending from the lithology. This experimental method modified after Lirer (2000), although time-consuming because it requires frequent monitoring, allowed obtaining 4 size-fractions (>355 μm, between 355 μm and 250 μm, between 250 μm and 125 μm and between 125 μm and 38 μm), all of good quality and suitable for performing planktonic foraminiferal analyses.

On the contrary, samples from the Mazagan Plateau have been processed following the standard procedure with hydrogen peroxide and all the available samples have been studied.

## 3.4 Taxonomic and biostratigraphic analyses

The methods of the taxonomic analysis are reported in Chapter 5. Isolated specimens from the washed residues and specimens in thin sections were photographed at the Scanning Electron Microscope (SEM) and by using a camera Q imaging micropublisher 5.0 RTV at 10x magnifications, respectively, and are illustrated in Plates 1 to 25 (Plates section).

Biostratigraphic analyses were carried out for all the residues on fraction larger than 125 μm. Afterwards, 30 rock samples from Monte Petrano, sampled at a resolution of 2-3 meters, were studied in thin section in order to compare biostratigraphic results obtained from the washed residues.

Range charts and results of quantitative analysis are reported in the Appendix section (Table 1-9).

## 3.5 Quantitative analysis

Quantitative analyses on 56 washed residue from the Monte Petrano section and on 31 samples from Mazagan Plateau DSDP Site 547A were performed on the size-fraction comprised between 125 μm and 355 μm using the same aliquot of residue for each sample when possible and excluding those residues characterized by very poor preservation of planktonic foraminifera. Where residues were small, all the specimens and grains were counted. The experimental technique used to process the lithified samples from the Umbria-Marche Basin sections, although very successful, sometimes caused fragmentation of specimens. Moreover, particularly in the Monte Petrano section, some samples are characterized by great abundance of calcitic agglomerates that may influence the quantitative analysis. To minimize the error the agglomerates have been counted and their relative abundances has been compared with the total abundance of foraminifera in each sample. Subsequently, relative abundances of all planktonic foraminiferal genera have been calculated and results from the two localities have been compared for paleoceanographic reconstructions.

# Chapter 4

# Biostratigraphy

## 4.1 Introduction

Planktonic foraminifera are one of the most important tools in biostratigraphy, as they are characterized by high evolutionary rate and widespread distribution across latitudes, allowing the correlation of sedimentary succession deposited in different paleogeographic and paleoceanographic settings. Thereafter, the Cretaceous is currently subdivided in 38 planktonic foraminiferal biozones according to the Geological Time Scale (Gradstein et al., 2012).

In this study, biostratigraphic analysis is performed taking into account distinctive features to distinguish genera and species assigned to each genus. The degree of variability of specimens falling within the species concept applied in this study is carefully examined in the dedicated chapter (Chapter 5).

The planktonic foraminiferal biozonation applied in this study is described in Paragraph 4.2. The detailed biostratigraphic analysis of two upper Albian-Cenomanian sections belonging to the Umbria-Marche Basin (Monte Petrano and Le Brecce sections) and from the cores drilled at the Mazagan Plateau Leg 79 (Sites 547A and 545) is presented in Paragraph 4.3 and 4.4, while range charts (Table 1-5) and the illustrations of the species (Plate 1-25) are reported in the Appendix section and in the Plates section, respectively. Afterwards, the sequence of bioevents observed in the above mentioned sections is compared to data from the literature, particularly from the Blake Nose Plateau ODP Site 1050C and from the Mont Risou stratotype section for the Cenomanian GSSP in order to verify the reliability of the detected bioevents for regional to global correlations (Paragraph 4.5 and 4.6). Finally, remarks on the definitions and on the correlation of the Albian/Cenomanian boundary and of the Oceanic Anoxic Event 1d across the analyzed localities are reported in Paragraph 4.7.

## 4.2 Biozonal schemes

Biostratigraphy consists in the subdivision of the stratigraphic sedimentary succession in biozones, defined as stratigraphic intervals between two bioevents. Bioevents are lowest and highest occurrences of biomarker species in a stratigraphic section, allowing to constrain zonal boundaries. In the upper Albian-Cenomanian time interval, two kinds of planktonic foraminiferal Zone are described:

1) Partial Range Zone (PRZ) defined as a stratigraphic interval (body of strata) constrained between the highest occurrence (HO) or, preferably, the lowest occurrence (LO) of two different species. The name of the Zone is usually given from the species that marks the base.
2) Total Range Zone (TRZ) defined as a stratigraphic interval constrained between the lowest occurrence (LO) and the highest occurrence (HO) of the nominal species.

Over the years, several Cretaceous biozonation based on planktonic foraminifera have been proposed, among others: Moullade (1966) defined Zone and Subzone for the Lower Cretaceous in the Vocontian Basin, Sigal (1977) developed a Cretaceous zonation for the Mediterrean area and Sliter (1989) provided biozones for the low-middle latitude assemblages using thin sections. The mentioned biozonations were further developed and improved by Premoli Silva and Sliter (1995) and recently updated by Coccioni and Premoli Silva (2015) based on the Bottaccione section and by Robaszynski and Caron (1995) by studying the Kaalat Senan section (Fig. 4.1) and incorporated in the Geological Time Scale (Gradstein et al., 2004; 2012).

The biozonations by Robaszynski and Caron (1995) and Premoli Silva and Sliter (1995) are very similar except for the Cenomanian interval where a different definition of the *Thalmanninella reicheli* and *Rotalipora cushmani* Zones is applied. At the Bottaccione section, the *Th. reicheli* Zone is defined as a Total Range Zone (TRZ) of the nominal taxon, while the *R. cushmani* Zone is defined as a Partial Range Zone (PRZ) between the HO (Highest Occurrence) of *Th. reicheli* and the HO of *R. cushmani*. On the contrary, at Kaalat Senan the *Th. reicheli* Zone is defined as a PRZ between LO (Lowest Occurrence) of *Th. reicheli* and LO *R. cushmani* and the *R. cushmani* Zone is a TRZ (Fig. 4.1). Because of the rarity of *Th. reicheli* and the uncertainty in the identification of its highest occurrence in the studied sections the biozonation by Robaszynski and Caron (1995) is applied.

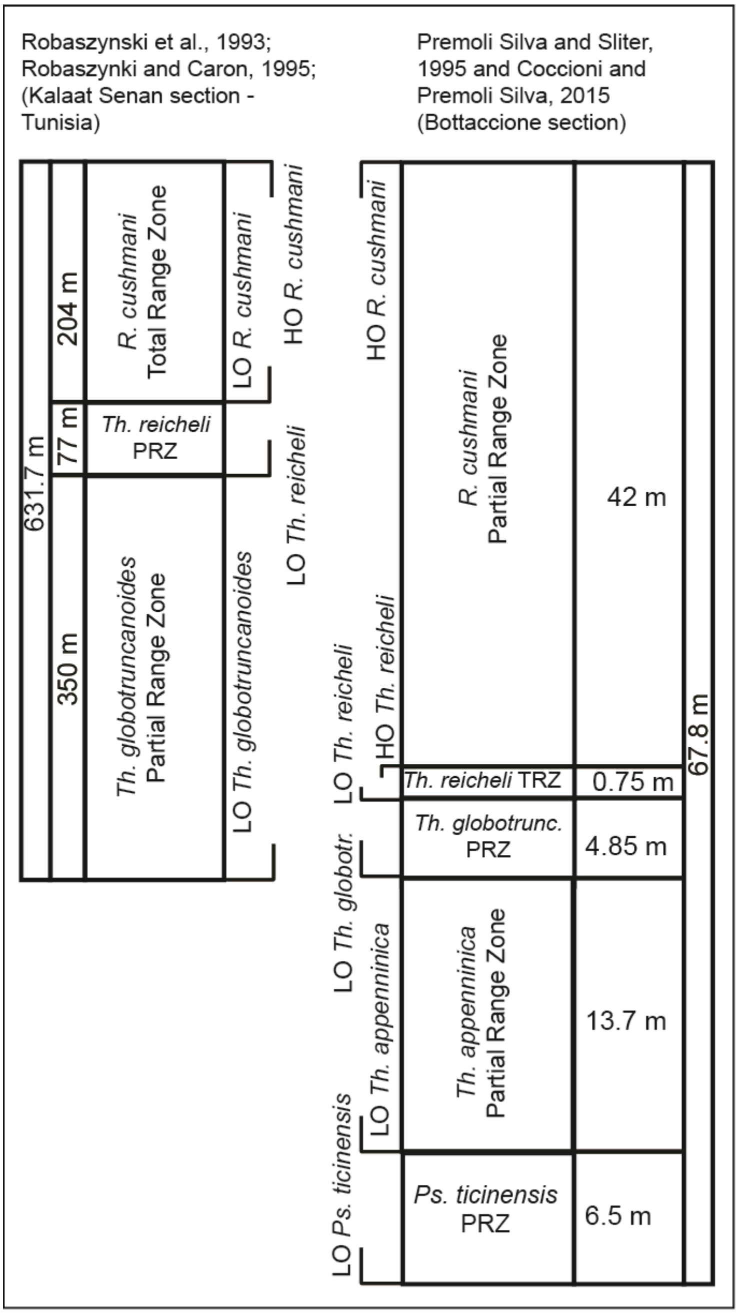


**Fig. 4.1** Comparison between the Late Cretaceous biozonations by Premoli Silva and Sliter (1995) and Robaszynski and Caron (1995) showing the marker events for the definition of the biozones and the corresponding thickness of the body of strata assigned to the zones. Information about thickness of the biozones in the Kaalat Senan section are from Robaszynski et al. (1993), while those of the Bottaccione section are according to Premoli Silva and Sliter (1995) and Coccioni and Premoli Silva (2015).

Consequently, in the studied sections, five biozones and one subzone are identified according to the definition by Robaszynski and Caron (1995), from base to top:

1. *Pseudothalmanninella ticinensis* (Plate 12, figs. 3-7) Partial Range Zone defined as the stratigraphic interval between the LO of *Ps. ticinensis* and the LO of *Th. appenninica*. The base is not detected because the studied sections already contain *Ps. ticinensis*.

2. *Thalmanninella appenninica* (Plate 14, figs. 8-9; Plate 15, figs. 1-4) Partial Range Zone defined as the stratigraphic interval between the LO of *Th. appenninica* and the LO of *Th. globotruncanoides.*

2.1. *Planomalina buxtorfi* (Plate 19, figs. 9-10; Plate 20, figs. 1-3) Total Range Subzone defined as the stratigraphic interval between the LO and the HO of *P. buxtorfi.*

3. *Thalmanninella globotruncanoides* (Plate 16, figs. 7; Plate 17, figs. 1-4) Partial Range Zone defined as the stratigraphic interval between the LO of *Th. globotruncanoides* and the LO of *Th. reicheli*.

4. *Thalmanninella reicheli* (Plate 18, figs. 6-9) Partial Range Zone defined as the stratigraphic interval between the LO of *Th. reicheli* and the LO of *R. cushmani.*

5. *Rotalipora cushmani* (Plate 22, figs. 9; Plate 23, figs. 2-4) Total Range Zone defined as the stratigraphic interval between the LO and the HO of *R. cushmani.*

Specifically, this study focuses on the stratigraphic interval from the top of the *Pseudothalmanninella ticinensis* Zone to the top of the *Rotalipora cushmani* Zone. The high evolution rate of planktonic foraminifera, in this time interval, is highlighted by the appearance and diversification of the following genera, in stratigraphic order: *Biticinella, Pseudothalmanninella*, *Thalmanninella*, *Praeglobotruncana*, *Muricohedbergella, Planomalina*, *Paracostellagerina*, *Whiteinella, Rotalipora*, *Dicarinella* and the disappearance of three genera, *Biticinella*, *Planomalina* and *Ticinella*.

## 4.3 Umbria-Marche Basin: Monte Petrano and Le Brecce sections

### 4.3.1 Bioevents

Biostratigraphic results for the Monte Petrano and the Le Brecce sections are illustrated in Figure 4.2. In both sections, four primary planktonic foraminiferal bioevents are recognized, from the oldest to the youngest:

1) the lowest occurrence (LO) of *Th. appenninica* (Monte Petrano, meter 3; Le Brecce, meter 1.4);
2) the LO of *P. buxtorfi* (Monte Petrano, meter 4; Le Brecce, meter 2.4);
3) the highest occurrence (HO) of *P. buxtorfi* (Monte Petrano, meter 13; Le Brecce, meter 9.6);
4) the LO of *Th. globotruncanoides* (Monte Petrano, meter 20.5; Le Brecce, meter 15).

In the Cenomanian interval at Monte Petrano section are also recorded, from base to top, the LO of *Th. reicheli* (meter 35) and the LO of *R. cushmani* (meter 50).

In addition secondary bioevents are observed in both sections, from base to top: 1) HO of *B. breggiensis* at the base of the *P. buxtorfi* Subzone and 2) the HO of *Ps. subticinensis* coincident with the LO of *P. buxtorfi* at Monte Petrano, on the contrary at Le Brecce it coincides with LO of *P. libyca.* Moreover, at Monte Petrano the HOs of *P. libyca* and of *Ps. ticinensis* and the LO of *Th. brotzeni* are recorded above the extinction of *P. buxtorfi* in the upper part of the *Th. appenninica* Zone. In both sections the genus *Ticinella* disappears in the lower part of the *Th. globotruncanoides* Zone. In the Monte Petrano section the LOs of *Th. greenhornensis*, *Th. deeckei* and *Th. gandolfii* are recorded at the base, mid and upper part of the *Th. reicheli* Zone, respectively. The HO of *Th. appenninica* falls in the upper part of the *Th. reicheli* Zone and the HO of *Th. gandolfii* within the *R. cushmani* Zone.

## 4.3.2 Biozonation

According to the events reported above, five Zones and one Subzone are identified, from base to top (Fig. 4.2). Observations on the composition of the assemblages and on the relative abundances of taxa within each zone are based on the quantitative analysis (Chapter 6) performed on samples from the Monte Petrano section in the large-size fraction (between 355 μm and 250 μm) and small-size fraction (between 250 μm and 125 μm), and on the qualitative analyses in the > 38 μm size fraction (between 125 μm and 38 μm):

### *Pseudothalmanninella ticinensis* Partial Range Zone

<u>Remarks</u>: the base of the Zone is not recorded because *Ps. ticinensis* is already present in the lowermost sample analyzed. In the studied sections, the nominal taxon is quite common.

The large-size fraction is dominated by *B. breggiensis, T. raynaudi digitalis* and *T. raynaudi aperta,* while *Muricohedbergella* (*M. astrepta, M. simplicissima* and *M. praelibyca*) and *T. primula* are the most abundant species in the small-size fraction. *Praeglobotruncana* first appears in the upper part of the Zone.

<u>Stratigraphic distribution</u>: Monte Petrano, meter 0 to meter 3 (3 meters-thick); Le Brecce, meter 0 to meter 1.4 (1.4 meters-thick).

### *Thalmanninella appenninica* Partial Range Zone

Remarks: The original description by Sigal (1948) considered *Th. brotzeni* and *Th. globotruncanoides* as synonyms, but, as following study have observed that they are two different species (Caron and Premoli Silva, 2007; Petrizzo et al., 2015), we use *Th. globotruncanoides* as marker taxon which appearance marks the top of the Zone (see Chapter 5 for more details on the species concept of *Th. globotruncanoides*), whereas the appearance of *Th. brotzeni is* stratigraphically lower in the studied section.

In the large-size fraction, the rotaliporids, including *Th. appenninica*, increase in abundance till the upper part of the Zone and they are the most common planktonic foraminifera together with *Planomalina* and *Muricohedbergella*. In the small-size fraction, *Praeglobotruncana* is even more abundant toward the top of the Zone and it is the most common genus together with *Planomalina* and *Muricohedbergella. Biticinella* and *Paracostellagerina* show a short stratigraphic record, in fact *Biticinella* disappears in the lowermost *Th. appenninica* Zone and *Paracostellagerina* appears in the middle part of the Zone.

Stratigraphic distribution: Monte Petrano, meter 3 to meter 20.5 (17.5 meters-thick); Le Brecce 1.4 to 15 (13.6 meters-thick).

### *Planomalina buxtorfi* Total Range Subzone

Remarks: *Planomalina buxtorfi* commonly occurs in the assemblage with rotaliporids, *Muricohedbergella* and *Praeglobotruncana* in both size fractions. On the contrary, *Ticinella* is quite rare in the entire stratigraphic interval. *Paracostellagerina libyca* appears in the lower part of the *P. buxtorfi* Subzone and disappears in the upper part of the *Th. appenninica* Zone while *B. breggiensis* disappears at the base of the Zone.

Stratigraphic distribution: Monte Petrano, meter 4 to meter 13 (9 meters-thick); Le Brecce, meter 2.4 to meter 9.6 (7.2 meters-thick).

### *Thalmanninella globotruncanoides* Partial Range Zone

Remarks: the marker species is frequent in the entire stratigraphic interval. In the large-size fraction rotaliporids are the most abundant group and reach their maximum abundance in the middle of the Zone where also the number of specimens of *Praeglobotruncana* increases. The small-size fraction is dominated by *Muricohedbergella* and in the upper part of the Zone by *Praeglobotruncana.*

Planispirals are generally more common than in the remaining part of the section. The genus *Ticinella* disappears in the lower part of the Zone.

Stratigraphic distribution: Monte Petrano, meter 20.5 to meter 35 (14.5 meters-thick); Le Brecce, 15 m to 19.97 (top of the section; 4.97 meters-thick).

### *Thalmanninella reicheli* Partial Range Zone

Remarks: *Thalmanninella reicheli* is very rare and shows a scattered stratigraphic record. Rotaliporids dominate the large-size fraction (*Th. globotruncanoides, Th. greenhornensis* and *R. montsalvensis)* together with *Praeglobotruncana* in the lower part of the Zone. Considering the small-size fraction, rotaliporids are the most abundant group and *Praeglobotruncana* become very common in the upper part of the Zone. *Thalmanninella greenhornensis* and species belonging to the genus *Whiteinella* appear together and near the base of the Zone, respectively.

Stratigraphic distribution: Monte Petrano, meter 35 to meter 50 (15 meters-thick).

### *Rotalipora cushmani* Total Range Zone

Remarks: Rotaliporids, specifically the zonal marker species and *Th. greenhornensis* are the most frequent taxa in the large-size fraction, followed by *Praeglobotruncana.* The small-size fraction is dominated by *Praeglobotruncana*.

The appearance of *Dicarinella* in the middle part of the Zone is correlated to a decrease in abundance of *Praeglobotruncana* in both size fractions.

According to the literature, in the Umbria-Marche Basin a major hiatus across the Cenomanian/Turonian boundary occurs, so that the HO of *R. cushmani* is not recorded (e.g., Borsetti, 1962; Premoli Silva and Sliter, 1995). Nevertheless, other authors observe the last occurrence of *R. cushmani* below the Bonarelli level (Coccioni and Luciani, 2005; Coccioni and Premoli Silva, 2015), specifically Coccioni et al. (2016) recognize it about 15 cm below the lithological expression of the OAE2. In this study, at Monte Petrano, the highest occurrence of *R. cushmani* is not recorded as the species occurs in the last sample examined.

Stratigraphic distribution: meter 50 to meter 65 (top of the studied section; 15 meters-thick).

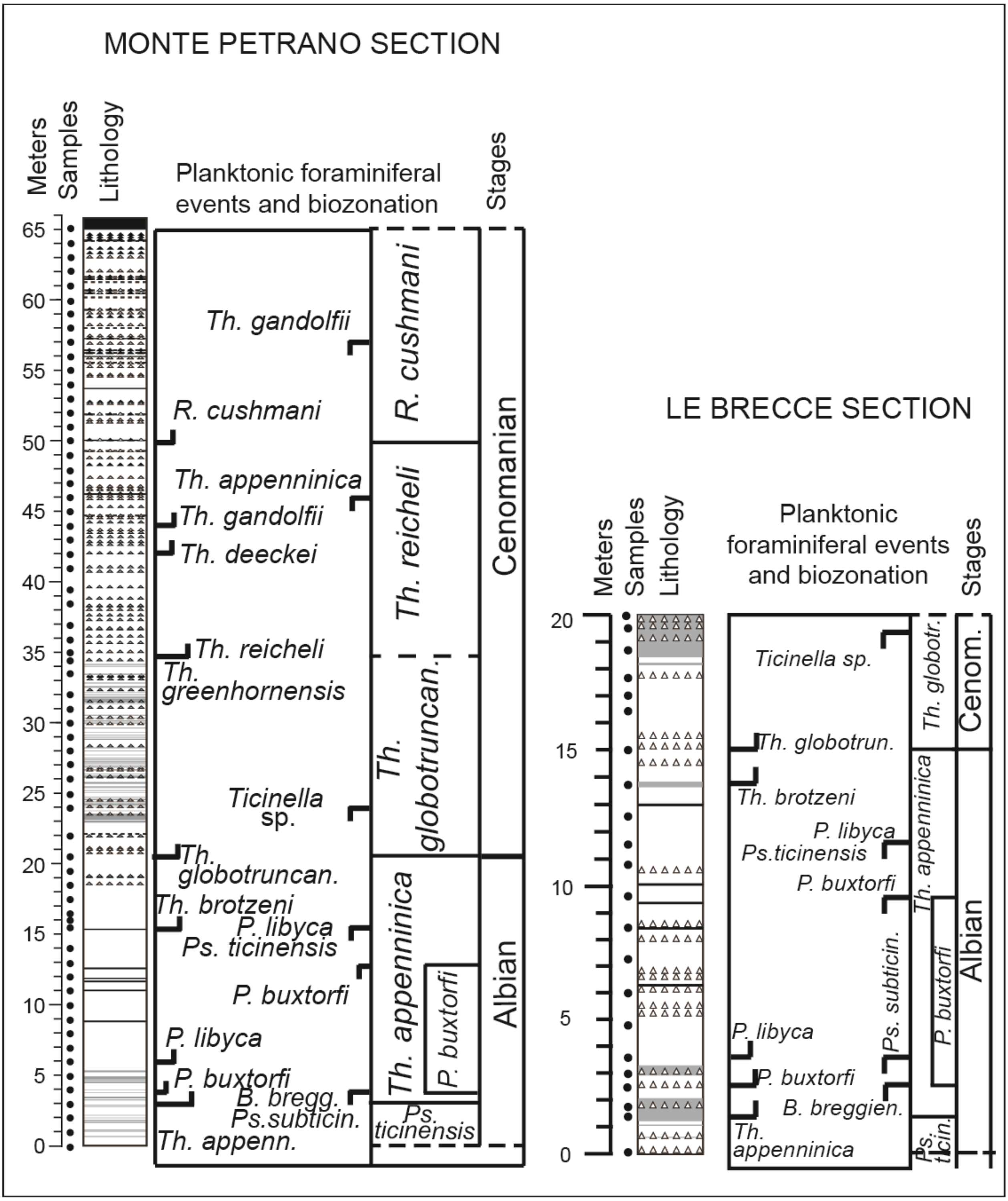


**Fig. 4.2** Monte Petrano and Le Brecce sections planktonic foraminiferal biostratigraphy. The base of the *Th. reicheli* Zone is dashed because the nominal species is very rare and shows scattered occurrences throughout the stratigraphic interval. Lithological logs are from Gambacorta et al. (2014).

## 4.4 Mazagan Plateau Sites 547A and 545

### 4.4.1 Bioevents

Biostratigraphic results for the Mazagan Plateau DSDP Leg 79 Sites 547A and 545 are illustrated in Figure 4.3. In both sites, four primary planktonic foraminiferal bioevents are recognized, from the oldest to the youngest:

1) the lowest occurrence (LO) of *Th. appenninica* (Site 547A-69R-1, 50-52 cm; Site 545-38R-3, 90-92 cm),
2) the LO of *P. buxtorfi,* coinciding with LO of *Th. appenninica* in Site 545 (Site 547A-66R-2, 67-69 cm; Site 545-38R-3, 90-92 cm),
3) the highest occurrence (HO) of *P. buxtorfi* (Site 547A-63R-3, 49.5-52 cm; Site 545-37R-3, 50-53 cm),
4) the LO of *Th. globotruncanoides* (Site 547A-61R-1, 48-50 cm; Site 545-34R-1, 123-125 cm).

Furthermore, the LO of *R. cushmani* is recorded at Site 547A in Sample 40R-1 30.5-33.
Several secondary bioevents are observed in both sections, from base to top:
the HO of *B. breggiensis* at Site 545 falls in the upper *Ps. ticinensis* Zone, while at Site 547A it is recorded in the middle part of the *P. buxtorfi* Subzone together with the HO of *Ps. subticinensis* and the LO of *P. libyca*. On the contrary, at Site 545 the HO of *Ps. subticinensis* coincides with the appearance of *Th. appenninica* and *P. buxtorfi* and the LO of *P. libyca* falls in the middle of the *P. buxtorfi* Zone. At Site 545 the LO of *Ticinella* sp., the LO of *Th. gandolfii* and the HO of *P. libyca,* all occur in the upper part of the *Th. appenninica* Zone, otherwise at Site 547A the sequence of bioevents is reversed and both LO of *Th. gandolfii* and HO of *Ticinella* sp. are observed in the lower *Th. globotruncanoides* Zone. In both sites, the appearance of *Th. greenhornensis* and *Th. deeckei* occur in the *Th. reicheli* Zone.

### 4.4.2 Biozonation

According to the sequence of events reported above, four Zones and one Subzone are identified, from base to top:

### *Pseudothalmanninella ticinensis* Partial Range Zone

<u>Remarks</u>: the base of the Zone is not recorded because *Ps. ticinensis* is already present in the lowermost sample analyzed. In the studied sections, the nominal taxon is frequent in the large-size fraction and quite common in the small-size fraction.

The small-size fraction is dominated by *T. primula* and *T. madecassiana,* by *Muricohedbergella* specifically *M. simplicissima* and *M. praelibyca* and by common *Globigerinelloides* (*G. bentonensis* and *G. pulchellus*). *Ticinella* (*T. primula* and *T. madecassiana*) is also among the most abundant taxa in the large-size fraction together with *Ps. ticinensis* and *Ps. tehamaensis.* In the upper part of the Zone of Site 545 the disappearance of the *Biticinella* genus occurs.

<u>Stratigraphic distribution</u>: Samples from DSDP Site 547A-73R-CC, 23-25 cm to 547A-69R-1, 50-52 cm (30.36 meters-thick); Samples from DSDP Site 545-40R-6, 57-60 cm to 545-38R-3, 90-92 cm (22.99 meters-thick).

### *Thalmanninella appenninica* Partial Range Zone

<u>Remarks</u>: In both size fractions the *Th. appenninica* shows high fluctuations in abundance from common to rare and the assemblage is dominated by *T. primula, M. simplicissima* and *G. bentonensis;* in the large-size fraction, *Ps. ticinensis* and *Ps. tehamaensis* also show noteworthy abundances but in the middle and upper part of the Zone, respectively, they are not present. In both Sites the LOs of the genera *Paracostellagerina* and *Planomalina* are observed and, in addition, in Site 545 the disappearance of *Ticinella* are recorded in the upper part of the Zone.

<u>Stratigraphic distribution</u>: Samples from DSDP Site 547A-69R-1, 50-52 cm to 547A-61R-1, 48-50 cm (76.02 meters-thick); Samples from DSDP Site 545-38R-3, 90-92 cm to 545-34R-1, 123-125 cm (40.55 meters-thick).

### *Planomalina buxtorfi* Total Range Subzone

<u>Remarks</u>: the nominal taxon is quite rare in both sections. Its ancestor species *P. praebuxtorfi* disappears in the upper part of the Subzone. The assemblage in both size fractions is dominated by *T. primula, M. simplicissima* and *M. praelibyca,* while *G. bentonensis* is more abundant in the small-size fraction. At Site 547A the highest occurrence of the *Biticinella* genus is recorded.

<u>Stratigraphic distribution</u>: Samples from DSDP Site 547A-66R-2, 67-69 cm to 547A-63R-3, 49.5-52 cm (27.18 meters-thick); Samples from DSDP Site 545-38R-3, 90-92 cm to 545-37R-3, 50-53 cm (10.08 meters-thick).

### *Thalmanninella globotruncanoides* Partial Range Zone

Remarks: the base of the Zone is defined by the LO of *Th. globotruncanoides* which is quite rare in the small size-fraction, while it increases in abundance and size in the upper part of the Zone. The assemblage of the large size-fraction is dominated by *Thalmanninella*, particularly *Th. globotruncanoides,* and by *P. delrioensis,* while the small size-fraction is dominated by *M. simplicissima*, *P. delrioensis* and by *Thalmanninella,* specifically *Th. brotzeni,* and *G. bentonensis.*
Stratigraphic distribution: Samples from DSDP Site 547A-61R-1, 48-50 cm to 547A-47R-CC, 15-16.5 cm (128.83 meters-thick); Samples from DSDP Site 545-34R-1, 123-125 cm to 545-32R-1, 34-37 cm (19.89 meters-thick).

### *Thalmanninella reicheli* Partial Range Zone

Remarks: the marker species *Th. reicheli* is not observed. The base of the Zone is approximated with the LO of *Th. greenhornensis* that at Monte Petrano coincides with the LO of *Th. reicheli.*
The assemblage of the large size-fraction is dominated by *Thalmanninella*, particularly *Th. globotruncanoides* and to a lesser extent by *P. delrioensis.* On the contrary, the small size-fraction is dominated by *M. simplicissima*, *P. delrioensis*, *Thalmanninella,* particularly *Th. brotzeni,* and *G. bentonensis.*
Stratigraphic distribution: Samples from DSDP Site 547A-47R-CC, 15-16.5 cm to 547A-40R-1, 30.5-33 cm (70.5 meters-thick); Samples from DSDP Site 545-32R-1, 34-37 cm to 545-28R-1, 10-12 cm (top of the section) (30.24 meters-thick).

### *Rotalipora cushmani Total Range Zone*

Remarks: the base of the Zone is detected at the top of Site 547A.
Stratigraphic distribution: it is observed only in DSDP Site 547A-40R-1, 30.5-33 cm.

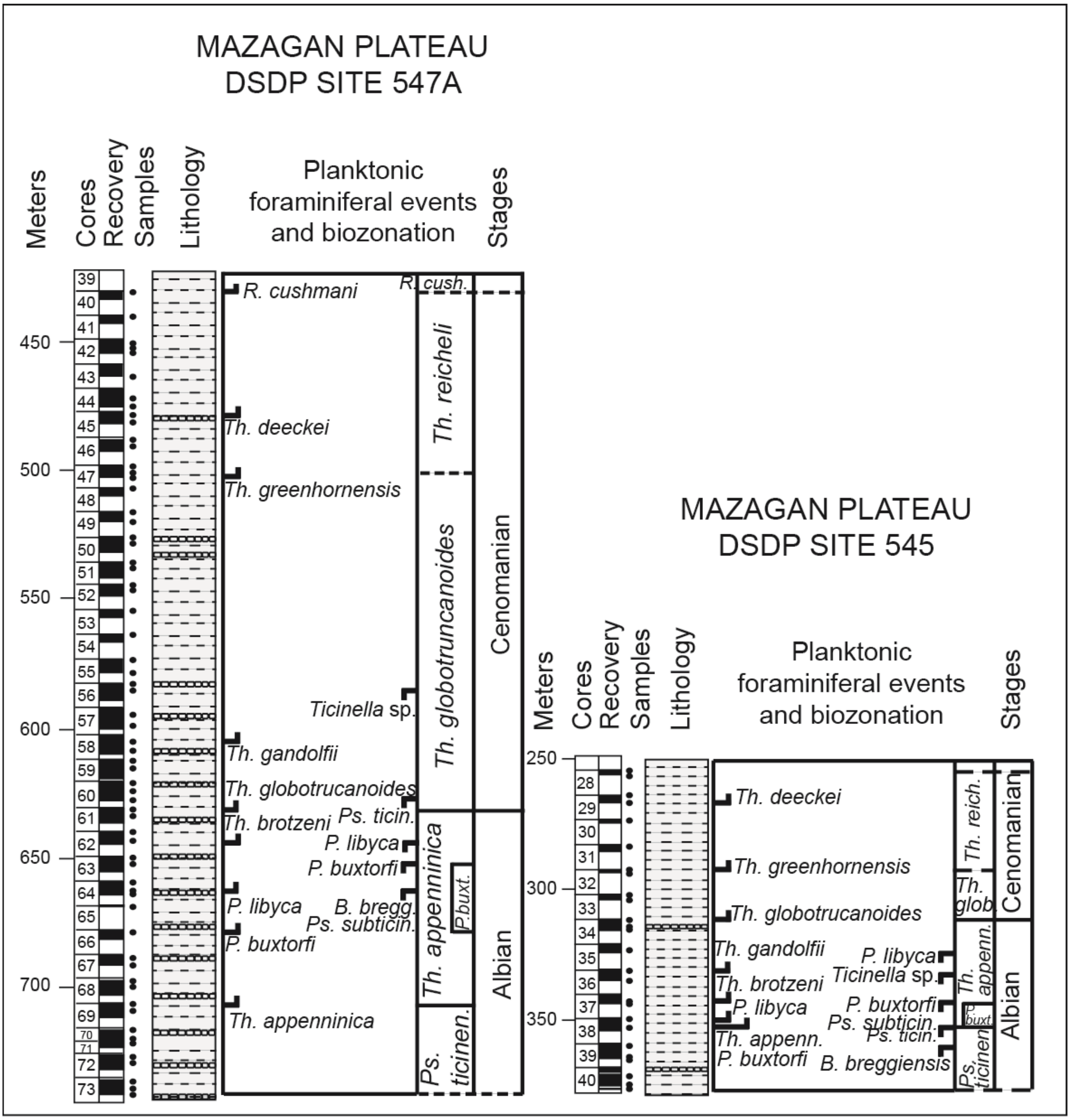


**Fig. 4.3** Mazagan Plateau Sites 547A and 545 sections planktonic foraminiferal biostratigraphy. The base of the *Th. reicheli* Zone is dashed because the marker species is absent and the base of the Zone is defined on the LO of *Th. greenhornensis* according to Monte Petrano data. Lithological logs are according to the sedimentological descriptions in Hinz, Winterer et al. (1981).

## 4.5 Identification of reliable bioevents for correlation

The comparison of the planktonic foraminiferal bioevents (Figure 4.4) recorded in the studied sections with those available at DSDP Leg 171B Site 1050C (Petrizzo and Huber, 2006a; Petrizzo et al., 2008) and Mont Risou (Kennedy et al., 2004: Petrizzo et al., 2015) is performed to evaluate the reliability of the bioevents for correlation. To be reliable a bioevent has to be well recognizable, with continuous stratigraphic record, and it has to occur in the same stratigraphic position in all sections. Bioevents are discussed from base to top:

- the LO of *Th. appenninica* is recorded in all the examined sections. *Th. appenninica* always appears close to the appearance of *Th. balernaensis*. Specifically, at Monte Petrano, at Site 1050C and at Site 547A, *Th. balernaensis* appears just below *Th. appenninica* in agreement with the data from the Col de Palluel section (Vocontian Basin; Gale et al., 2011) and those reported from the Carmel region in Israel (Lipson-Benitah et al., 1997). At Le Brecce, at Site 545, at Blake Nose Site 1052E (Petrizzo and Huber, 2006a) and at Bottaccione (Premoli Silva and Sliter, 1995) the first appearance of *Th. balernaensis* and *Th. appenninica* are considered to be synchronous. In this study, the LO of *Th. appenninica* is considered the lowest reliable event, because it is easily recognizable, abundant and characterized by continuous stratigraphic record (Figs. 4.5 and 4.6).

- the HO of *Ps. subticinensis* is recognized in all sections, but it is not considered a reliable bioevent because it occurs at different stratigraphic positions. Specifically, in the Umbria-Marche Basin, at Monte Petrano it is observed together with the HO of *B. breggiensis* and LO of *P. buxtorfi* (base of the *P. buxtorfi* Subzone) and at Le Brecce it coincides with the LO of *P. libyca* (lower *P. buxtorfi* Subzone). Moreover, at Mazagan Plateau Site 547A it coincides with the HO of *B. breggiensis* and it falls between LO of *P. buxtorfi* and of *P. libyca* (lower *P. buxtorfi* Subzone), while at Site 545 it occurs at the same level of the LO of *Ps. ticinensis* (base of *Th. appenninica* Zone and *P. buxtorfi* Subzone). According to Kennedy et al. (2004), at Mont Risou, the HO of *Ps. subticinensis* is recorded below the HO of *P. buxtorfi.* At Site 1050C it is observed in the upper *Ps. ticinensis* Zone (Petrizzo and Huber, 2006a). Furthermore, these discrepancies are supported by the observation that the extinction of *Ps. subticinensis* is quite difficult to identify because of the morphological similarities with its descendant species *Th. ticinensis.*

- the HO of *B. breggiensis* is considered as a not reliable bioevent, even if it is easily recognizable, because it occurs at different stratigraphic positions in the studied sections. At Monte Petrano and at Le Brecce it coincides with the LO of *P. buxtorfi*, while at Site 547A its appearance is observed in between the LO of *P. buxtorfi* and LO of *P. libyca* and, on the other hand, at Site 545 it is anticipated and falls within the *Ps. ticinensis* Zone. The scarce reliability of this bioevent is also confirmed by the data from Site 1050C (Petrizzo and Huber, 2006a) where the disappearance of *B. breggiensis* is recorded above the LO of *P. libyca* and together with the LO of *Th. brotzeni.*

- the LO of *P. buxtorfi* is an easily detectable event and, thus, regarded as reliable, because the species has a very distinctive morphology and its first appearance is observed between the LO of *Th. appenninica* and the LO of *P. libyca* in all the studied sections. Moreover, the abundance of *P. buxtorfi* in correspondence of its first appearance is observed to be very high at Monte Petrano (Fig. 4.5), while it is common at Mazagan Plateau (Fig. 4.6). The reliability of this bioevent is also confirmed by Gale et al. (2011) in the Col de Palluel section (Vocontian Basin).

- the HO of *Ps. ticinensis* is resulted to be a not reliable bioevent among the studied sections. Specifically in the Umbria-Marche Basin and at Mont Risou, it occurs in the upper *Th. appenninica* Zone. At Monte Petrano and at Le Brecce sections it coincides with the HO of *P. libyca* and with the LO of *Th. brotzeni,* while at Mont Risou, it falls between the LO of *Th. brotzeni* and *Th. globotruncanoides,* above the HO of *P. buxtorfi.* Moreover, at Mazagan Plateau at Sites 547A and 545, it is observed in the lowermost *Th. globotruncanoides* and at the base of the *Th. appenninica* Zone, respectively. At Site 545 it coincides with the HO of *Ps. subticinensis.* In addition, at Site 1050C the disappearance of *Ps. ticinensis* is reported corresponding to the HOs of *B. breggiensis* and of *Ticinella* sp. in the upper part of the *Th. appenninica* Zone (middle part of the *P. buxtorfi* Subzone). For these reasons, the HO of *Ps. ticinensis* is not considered a useful bioevent for global correlation.

- the LO of *P. libyca* is recognized in all the studied sections. It is always comprised between the LO of *P. buxtorfi* and the LO of *Th. brotzeni*, as shown by Premoli Silva and Sliter (1995) at the Bottaccione section. Although *P. libyca* is not a very abundant species, it shows continuous stratigraphic distribution and its first occurrence is well recognizable (Figs. 4.5 and 4.6) and consequently, in this study it is regarded as a valid bioevent.

- The position of the HO of *P. buxtorfi* in the Umbria-Marche Basin and at Mazagan Plateau is always constrained between the LO of *P. libyca* and the LO of *Th. brotzeni,* and significantly precedes the LO of *Th. globotruncanoides*. Nevertheless, it is not assumed as reliable bioevent because at Site 1050C it occurs above the LO of *Th. brotzeni,* very close to the top of the *Th. appenninica* Zone. Moreover, Robaszynski et al. (2008) in the Kaalat Senan area reported the HO of *P. buxtorfi* above the LO of *Th. globotruncanoides*. In any case, the same authors regarded *Th. brotzeni* and *Th. globotruncanoides* as synonyms, and in the absence of illustration of the species, it is not clear which species was used to define the base of *Th. globotruncanoides* Zone. Ultimately, the disappearance of *P. buxtorfi* cannot be regarded as useful bioevent for global correlation.

- the HO of *P. libyca* is observed below the LO of *Th. brotzeni* at Monte Petrano, Le Brecce, at Site 547A and at Mont Risou, while at Site 545 and at Site 1050C it occurs above the appearance of *Th. brotzeni.* According to Coccioni and Premoli Silva (2015), *P. libyca* is recorded in the assemblages of the Bottaccione section till the *R. cushmani* Zone. Because of the different stratigraphic positions of the event and of the difficulty in the identification of certain specimens with less developed costellae, it cannot be included among the reliable events.

- the LO of *Th. brotzeni* is always detected below the LO of *Th. globotruncanoides* in all the studied sections as well as in the Bottaccione section (Coccioni and Premoli Silva, 2015) and in the Carmel region (northern Israel, Lipson-Benitah et al., 1997). Consequently, also considering the *Th. brotzeni's* continuous stratigraphic record and its generally high abundances (Figs. 4.5 and 4.6), its appearance is regarded as reliable.

- the LO of *Th. globotruncanoides* is easily detected and the species is characterized by high abundances and continuous stratigraphic record (Figs. 4.5 and 4.6) in all the studied successions. The first appearance of *Th. globotruncanoides* is always comprised between the LO of *Th. brotzeni* and the LO of *Th. greenhornensis,* in agreement with the data by Lipson-Benitah et al. (1997) from Israel, and, thus, it is considered a reliable bioevent.

- the HO of *Ticinella* sp. is not easy to detect because poor preservation and especially shell recrystallization can widely alter the wall texture of small specimens. Moreover, *Ticinella* species disappear at different stratigraphic positions. Specifically, at Monte Petrano, Le Brecce and Site 547A it is observed between the LO of *Th. globotruncanoides* and the LO of *Th. greenhornensis*. On the contrary at Site 545 and at Site 1050C it is recorded below the LO of *Th. globotruncanoides*. For these reasons, it should not be considered a reliable bioevent.

- the LO of *Th. greenhornensis* is observed at Monte Petrano and at Site 547A between the LO of *Th. globotruncanoides* and the LO of *R. cushmani* according with the sequence of bioevents reported by Lipson-Benitah et al (1997). At Mazagan Plateau, *Th. greenhornensis* is not a common species, but its LO is considered a possible reliable bioevent because it is synchronous among sections (Figs. 4.5 and 4.6).

- the LO of *Th. reicheli* is problematic because *Th. reicheli* is a rare species and characterized by a very scattered stratigraphic range. Nevertheless, its first occurrence at Monte Petrano and at the Bottaccione sections (Coccioni and Premoli Silva, 2015) is recorded between the LO of *Th. globotruncanoides* and the LO of *R. cushmani*. In both sites of the Mazagan Plateau, *Th. reicheli* is not recorded. At Monte Petrano, the LO of *Th. greenhornensis* coincides with the base of the *Th. reicheli* Zone and, thus the former events may be used as secondary bioevent to approximate the base of the Zone in the Mazagan Plateau sites, even if additional insights are needed to verify the reliability of the LO of *Th. greenhornensis* as bioevents for global correlation. *Whiteinella* sp. appears close to the base of the *Th. reicheli* Zone in all the studied sections except at Site 547A where it occurs below *Th. greenhornensis*. Further studies are needed to evaluate the reliability of the appearance level of the *Whiteinella* genus which, however, seems to be a promising bioevent for correlation.

- the LO of *Th. deeckei* in the Monte Petrano section and at Sites 547A and 545 is constrained between the LO of *Th. greenhornensis* and the LO of *R. cushmani*. According to Lipson-Benitah et al. (1997), it occurs together with *Th. greenhornensis*. However, because *Th. deeckei* is rare in Sites 547A and 545 and absent in the other examined sections, its validity as reliable bioevent for global correlation cannot be verified.

- the LO of *Th. gandolfii* is observed in all sections except for Le Brecce. It is regarded as diachrounous, in fact at Monte Petrano it appears in the upper half of the *Th. reicheli* Zone, between the LO of *Th. deeckei* and the LO of *R. cushmani.* At Site 547A it is observed in the lower *Th. globotruncanoides* Zone, between the LO of *Th. globotruncanoides* and the LO of *Th. greenhornensis,* and at Site 545 it is detected in the upper part of the *Th. appenninica* Zone, between the LO of *Th. brotzeni* and the LO of *Th. globotruncanoides.* Moreover, at Mont Risou it occurs with the LO of *Th. brotzeni* and at Site 1050C it is recorded with the LO of *Th. globotruncanoides.* The appearance of *Th. gandolfii* below the LO of *Th. brotzeni*, reinforces the observation that it should not be considered a reliable event.

- the LO of *R. cushmani* Zone is identified at the Monte Petrano section having high abundances and at Site 547A above the LO of *Th. reicheli.*

After comparison and evaluation of the succession of bioevents recorded in the stratigraphic sections studied in this study with data reported from the literature, specifically from the Mont Risou section (Kennedy et al., 2004) and Blake Nose ODP Site 1050C (Petrizzo and Huber, 2006a), the best sequence of bioevents useful for regional to global correlation is, from base to top:
the LO of *Th. appenninica,* the LO of *P. buxtorfi,* the LO of *P. libyca,* the LO of *Th. brotzeni,* LO of *Th. globotruncanoides,* the LO of *Th. greenhornensis,* LO of *R. cushmani*. The relative abundances of the reliable bioevents at the Monte Petrano section and at Site 547A are presented in Figure 4.5 and 4.6, respectively.

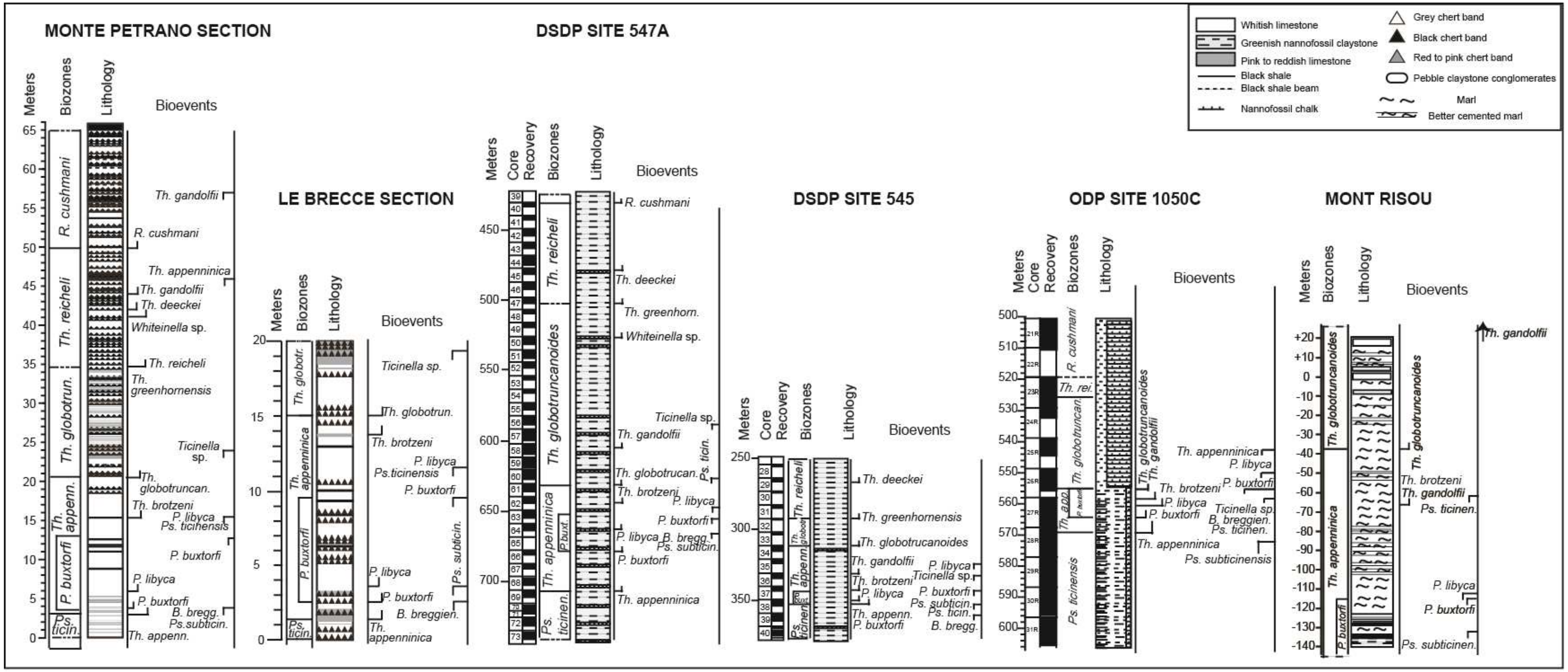


**Fig. 4.4** Comparison of the bioevents recorded in the studied sections with data reported from the Blake Nose ODP Site 1050C and Mont Risou. Biostratigraphy of the Umbria-Marche Basin and Mazagan Plateau according to this study. The base of the *Th. reicheli* Zone is dashed in all the studied sections: at the Mazagan Plateau because of the absence of the nominal taxon (the base of the Zone is placed at the LO of Th. greenhornensis in agreement with the data from the Monte Petrano section), while at Monte Petrano because the marker species is rare and with a scattered distribution. Lithology and biostratigraphic data of Site 1050C are from Petrizzo and Huber (2006a), and Petrizzo et al. (2008, 2015). Biostratigraphy of the Mont Risou is from Kennedy et al. (2004) and Petrizzo et al. (2015), while lithology is according to Kennedy et al. (2004).

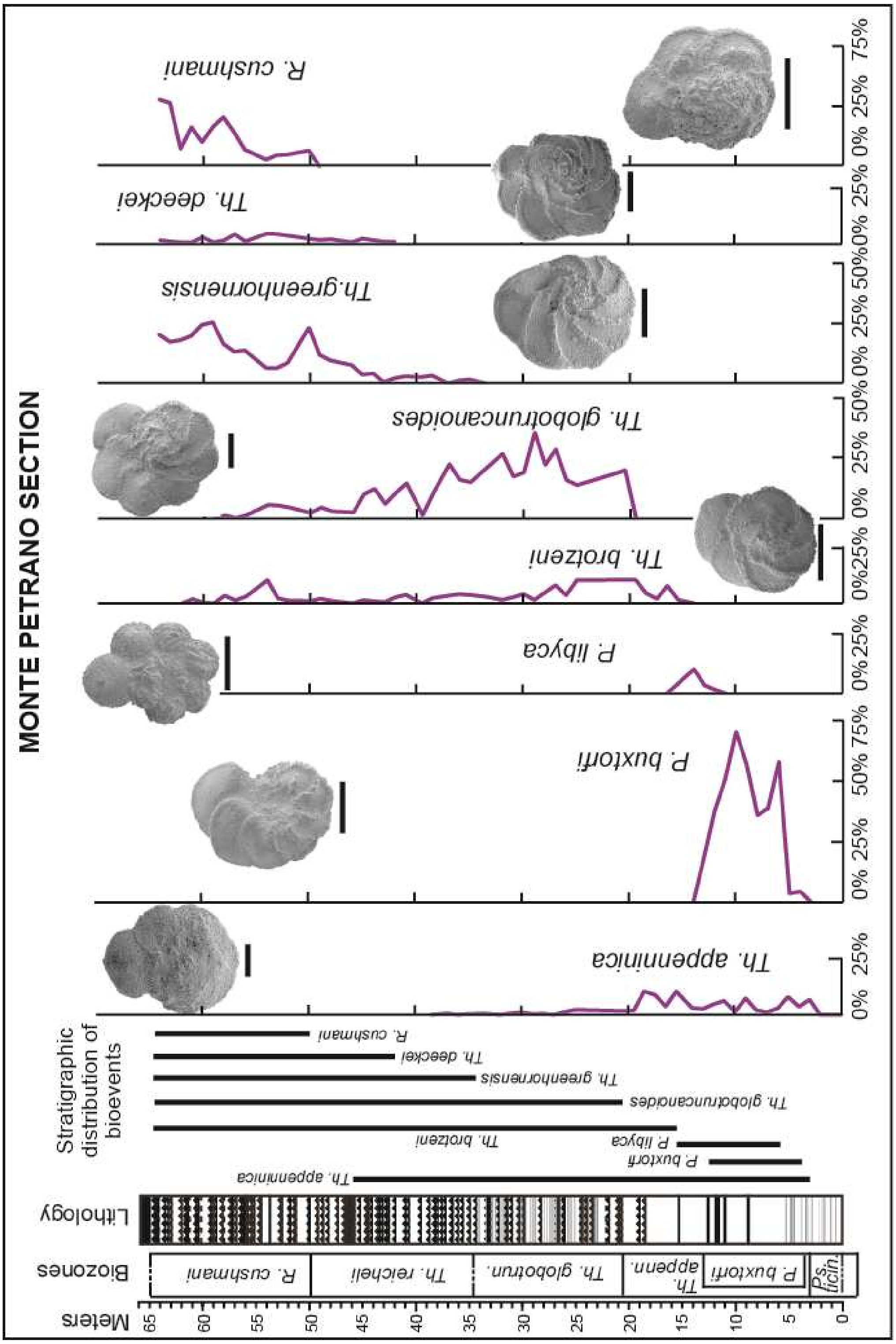


**Fig. 4.5** Stratigraphic distribution and relative abundances respect to the total planktonic foraminifera counted of reliable bioevents from the Monte Petrano section. (*Th. appenninica*, MP4; *P. buxtorfi* MP13; *P. libyca* MP14*; Th. brotzeni*, MP19.5; *Th. globotruncanoides*, MP35; *Th. greenhornensis* MP57; *Th. deeckei*, MP45; *Th. cushmani*, MP65. Scale bar 200 µm). The base of the *Th. reicheli* Zone is dashed because the nominal species is very rare and shows scattered occurrences throughout the stratigraphic interval. Lithological log is from Gambacorta et al. (2015).

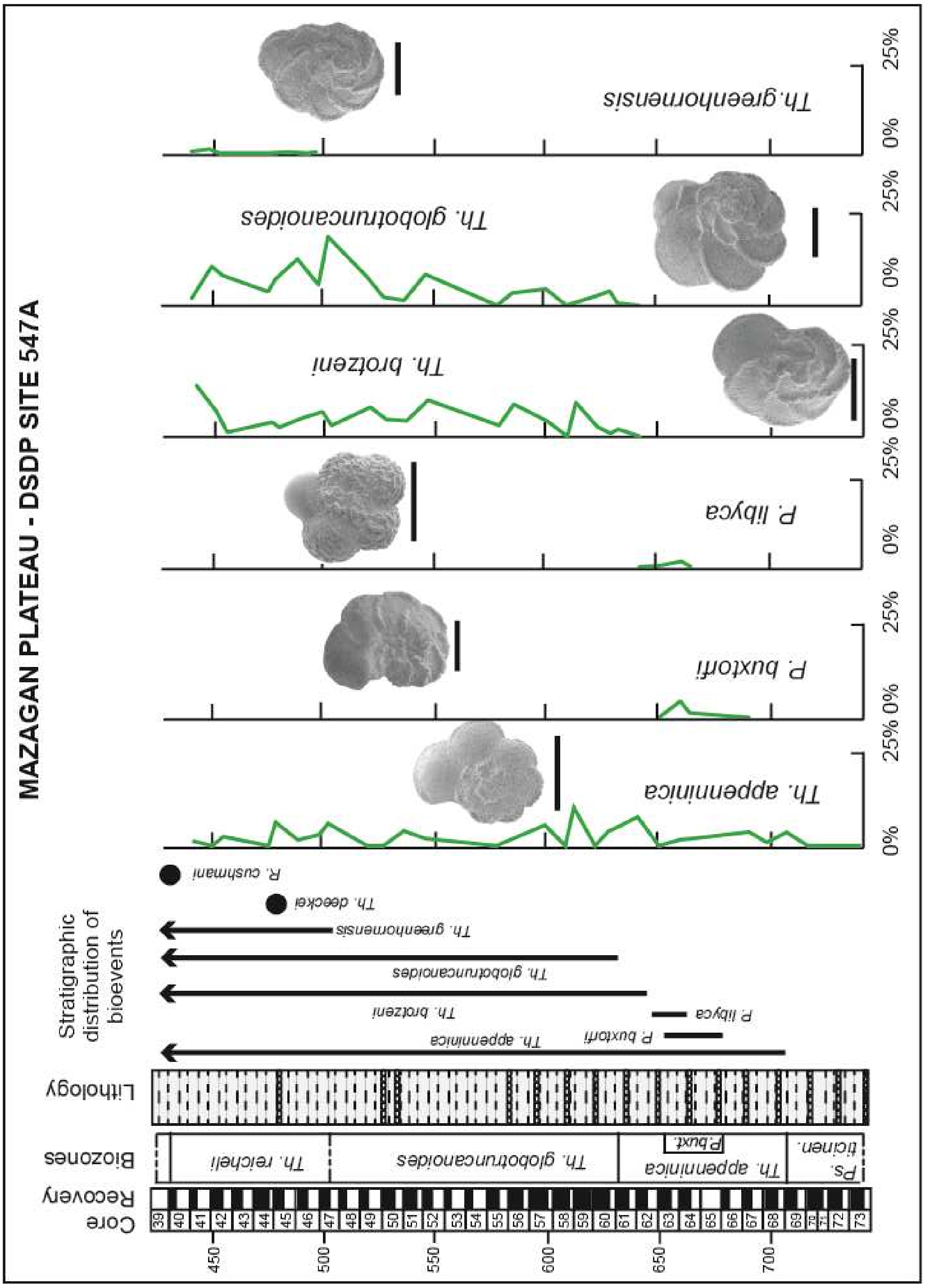


**Fig. 4.6** Stratigraphic distribution and relative abundances respect to the total planktonic foraminifera counted of reliable bioevents from Site 547A. (*Th. appenninica,* 547A 65R/1 36.5-38 cm; *P. buxtorfi* 547A 64R/3 51-53 cm; *P. libyca* 547A 64R/3 51-53 cm; *Th. brotzeni,* 547A 60R/3 49.5-51.5 cm; *Th. globotruncanoides,* 547A 60R/5 50-52 cm; *Th.* cf. *greenhornensis* 547A 47R/3 52.5-54.5 cm. Scale bar 200 µm ). *Thalmanninella deeckei* relative abundances is not plotted because it is too low, while *R. cushmani* is observed only in the last sample analyzed. However, they are observed to be synchronous among sections. The base of the *Th. reicheli* Zone is dashed because the marker species is absent and the base of the Zone is defined on the LO of *Th. greenhornensis* according to Monte Petrano data. Lithological logs are according to the sedimentological descriptions in Hinz, Winterer et al. (1981).

## 4.6 Regional and global correlation

Depth vs. depth graphic correlation is performed to compare the thickness of the sediments between the reliable bioevents previously selected. The Mont Risou section is excluded because it records only two events (*Th. brotzeni* and *Th. globotruncanoides*), while the Mazagan Plateau DSDP Site 545 is not considered as the common abundance of glauconite in the washed residues suggests the presence of frequent hiatus in the sedimentary succession. In order to minimize the different sampling resolution among sections, planktonic foraminifera lowest and highest occurrences in the sections are calculated as the average thickness/depth between the sample in which the bioevents are recorded and the sample just below or just above (Fig. 4.7 and Tab. 4.1).

The preferred line of correlation is drawn through bioevents that are deemed to be the most reliable and consequently the best-fit regression line is plotted. Moreover, the equation of the best-fit regression line and the coefficient $R^2$, varying from 0 to 1, are reported. Specifically, $R^2$ is higher when bioevents are closer to the best-fit regression line.

**Monte Petrano vs. Le Brecce (Fig. 4.7a)**

The correlation between the Monte Petrano and Le Brecce shows high values of the best-fit regression line ($R^2$=0.96). The preferred line of correlation highlights that the LO of *Th. appenninica* and the LO of *P. libyca* show a good correlation between the two sections, while the LO of *P. buxtorfi* seems to be delayed at Le Brecce, probably because of the small size of specimens in the lowermost samples that were not correctly isolated from the sediment preventing the species identification.

**Monte Petrano vs. Site 547A (Fig. 4.7b)**

The best-fit regression line ($R^2$=0.97) suggests a good correlation between the two sections. The preferred line of correlation highlights a change in sedimentation in correspondence of the LO of *P. libyca* and of the LO of *Th. globotruncanoides* at Site 547A.

**Monte Petrano vs. Site 1050C (Fig. 4.7c)**

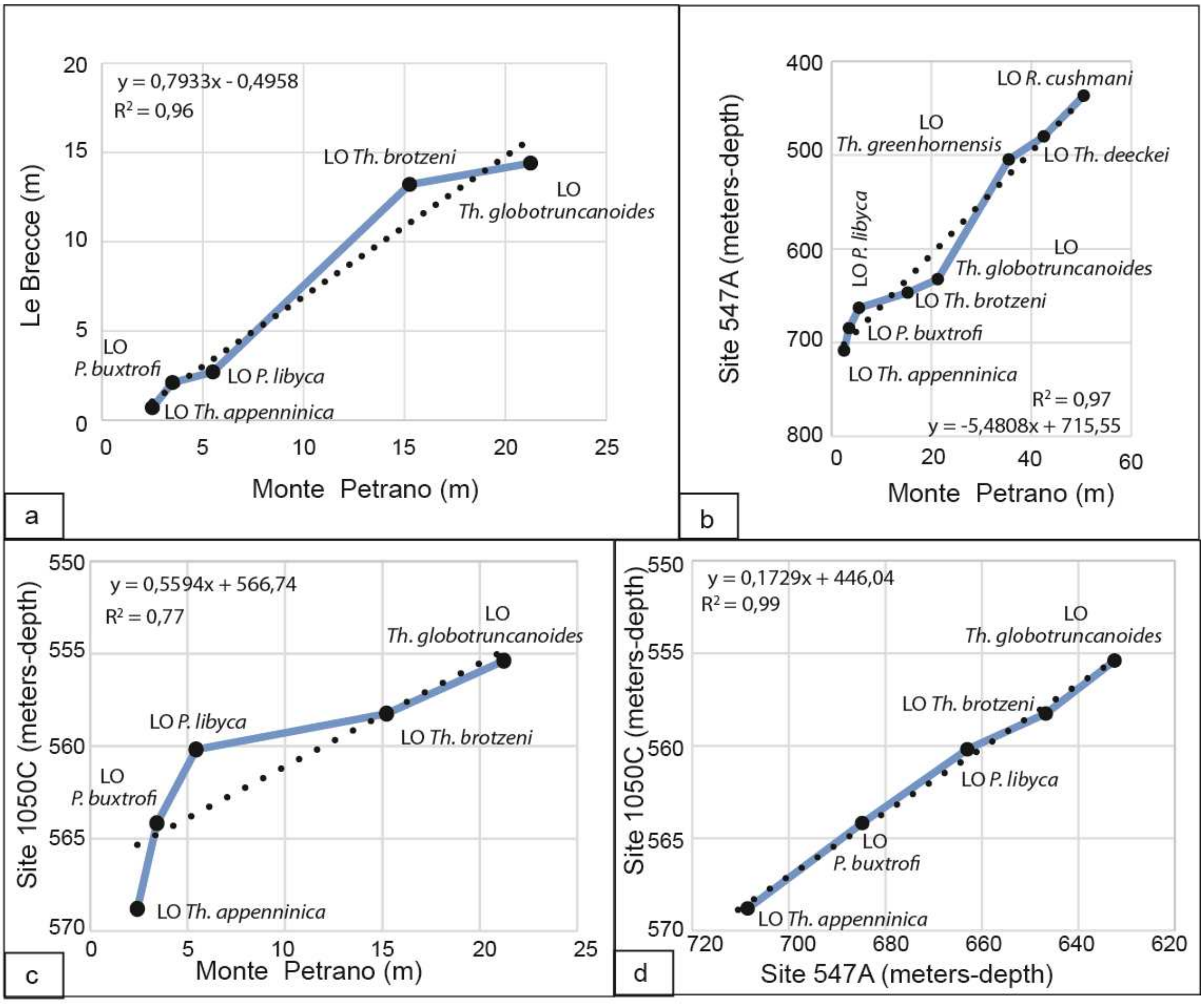
Bioevents show a moderate correlation as highlighted by the coefficient $R^2$=0.77. The preferred line of correlation highlights a change in sedimentation in correspondence of the LOs of *P. buxtorfi* and of *P. libyca.*

### Site 547A vs. Site 1050C (Fig. 4.7d)

The two sites are located on the opposite sides of the southern Atlantic Ocean and the bioevents occurrences perfectly correlate between the two sections, as demonstrate by the high coefficient of the regression line ($R^2$=0.99); consequently, the preferred line of correlation is indeed well comparable to the best-fit regression line.

| Site | Event | Sample | Zone | Stage | Bottom Depth (m) | Top Depth (m) | Mid Depth (m) |
|---|---|---|---|---|---|---|---|
| MONTE PETRANO SECTION | LO *R. cushmani* | MP 50 | *R. cushmani* Zone | Cenomanian | 50,00 | 51,00 | 50,50 |
| | LO *Th. deeckei* | MP 42 | *Th. reicheli* Zone | Cenomanian | 43,00 | 42,00 | 42,50 |
| | LO *Th. greenhornensis* | MP 35 | *Th. reicheli* Zone | Cenomanian | 36,00 | 35,00 | 35,50 |
| | LO *Th. globotruncanoides* | MP 20.5 | *Th. globotruncanoides* Zone | Cenomanian | 22,00 | 20,50 | 21,25 |
| | LO *Th. brotzeni* | MP 15.5 | *Th. appenninica* Zone | Albian | 15,00 | 15,50 | 15,25 |
| | LO *Th. libyca* | MP 6 | *Th. appenninica* Zone | Albian | 5,00 | 6,00 | 5,50 |
| | LO *Th. buxtorfi* | MP 4 | *Th. appenninica* Zone | Albian | 3,00 | 4,00 | 3,50 |
| | LO *Th. appenninica* | MP 3 | *Th. appenninica* Zone | Albian | 2,00 | 3,00 | 2,50 |
| LE BRECCE SECTION | LO *Th. globotruncanoides* | B 15 | *Th. globotruncanoides* Zone | Cenomanian | 13,80 | 15,00 | 14,40 |
| | LO *Th. brotzeni* | B 13.80 | *Th. appenninica* Zone | Albian | 12,60 | 13,80 | 13,20 |
| | LO *Th. libyca* | B 3 | *Th. appenninica* Zone | Albian | 2,40 | 3,00 | 2,70 |
| | LO *Th. buxtorfi* | B 2.40 | *Th. appenninica* Zone | Albian | 1,80 | 2,40 | 2,10 |
| | LO *Th. appenninica* | B 1.40 | *Th. appenninica* Zone | Albian | 0,01 | 1,40 | 0,70 |
| LEG 79 SITE 547A | LO *R. cushmani* | 40R-1, 30.5-33 cm | *R. cushmani* Zone | Cenomanian | 441,51 | 431,80 | 436,66 |
| | LO *Th. deeckei* | 45R-1, 17-19 cm | *Th. globotruncanoides* Zone | Cenomanian | 481,56 | 478,67 | 480,12 |
| | LO *Th. greenhornensis* | 47R-CC, 15-16.5 cm | *Th. globotruncanoides* Zone | Cenomanian | 507,48 | 502,15 | 504,82 |
| | LO *Th. globotruncanoides* | 61R-1, 48-50 cm | *Th. globotruncanoides* Zone | Cenomanian | 634,00 | 630,98 | 632,49 |
| | LO *Th. brotzeni* | 62R-3, 48-50 cm | *Th. appenninica* Zone | Albian | 649,98 | 643,48 | 646,73 |
| | LO *Th. libyca* | 64R-3, 51-53 cm | *Th. appenninica* Zone | Albian | 663,78 | 662,19 | 662,99 |
| | LO *Th. buxtorfi* | 66R-2, 67-69 cm | *Th. appenninica* Zone | Albian | 689,39 | 680,17 | 684,78 |
| | LO *Th. appenninica* | 69R-1, 50-52 cm | *Th. appenninica* Zone | Albian | 710,00 | 707,00 | 708,50 |
| LEG 79 SITE545 | LO *Th. deeckei* | 29R-CC, 4-7 cm | *Th. globotruncanoides* Zone | Cenomanian | 274,75 | 267,00 | 270,88 |
| | LO *Th. greenhornensis* | 32R-1, 25-28.5 cm | *Th. globotruncanoides* Zone | Cenomanian | 294,19 | 293,84 | 294,02 |
| | LO *Th. globotruncanoides* | 34R-1, 123-125 cm | *Th. globotruncanoides* Zone | Cenomanian | 315,80 | 313,73 | 314,77 |
| | LO *Th. brotzeni* | 37R-3, 50-53 cm | *Th. appenninica* Zone | Albian | 344,23 | 344,20 | 344,22 |
| | LO *Th. libyca* | 38R-1, 89-91 cm | *Th. appenninica* Zone | Albian | 354,28 | 351,39 | 352,84 |
| | LO *Th. buxtorfi* | 38R-3, 90-92 cm | *Th. appenninica* Zone | Albian | 360,96 | 354,28 | 357,62 |
| | LO *Th. appenninica* | 38R-3, 90-92 cm | *Th. appenninica* Zone | Albian | 360,96 | 354,28 | 357,62 |
| ODP SITE 1050C | LO *Th. globotruncanoides* | 26R-5,83-86 cm | *Th. globotruncanoides* Zone | Cenomanian | 555,57 | 555,23 | 555,40 |
| | LO *Th. brotzeni* | 27R-1, 10-12 cm | *Th. appenninica* Zone | Albian | 558,42 | 558,10 | 558,26 |
| | LO *Th. libyca* | 27R-2, 54-56 cm | *Th. appenninica* Zone | Albian | 560,35 | 560,04 | 560,20 |
| | LO *Th. buxtorfi* | 27R- 5, 4.5-6.5 cm | *Th. appenninica* Zone | Albian | 564,32 | 564,05 | 564,19 |
| | LO *Th. appenninica* | 28R-1, 70-73 cm | *Th. appenninica* Zone | Albian | 569,71 | 568,30 | 569,01 |
| MONT RISOU SECTION | LO *Th. globotruncanoides* | -36 | *Th. globotruncanoides* Zone | Cenomanian | -36,00 | -38,00 | -37,00 |
| | LO *Th. brotzeni* | -64 | *Th. appenninica* Zone | Albian | -64,00 | -68,00 | -66,00 |

**Tab. 4.1** Planktonic foraminiferal bioevents identified at Monte Petrano and Le Brecce sections, Mazagan Plateau Sites 547A and 545, Blake Nose Site 1050C and Mont Risou. Sample, biozone and Stage, and bottom, mid and top depth of occurrence are reported.



**Figs. 4.7** Graphic correlation of reliable bioevents between sections: a) Monte Petrano and Le Brecce section (Umbria-Marche Basin); b) Monte Petrano and Site 547A (Mazagan Plateau); c) Monte Petrano and Site 1050C (Blake Nose); d) Site 547A (Mazagan Plateau) and Site 1050C (Blake Nose). The equations of the best-fit regression line and the coefficient $R^2$ are reported in each graphic. Blue line = preferred line of correlation; dotted line = best-fit regression line.

## 4.7 Identification of the Albian/Cenomanian boundary and of the OAE1d

The Albian/Cenomanian boundary is defined at Mont Risou section (Vocontian Basin) (Fig. 4.8) and the primary criterion for the definition of the base of the Cenomanian GSSP is the lowest occurrence of the single keeled planktonic foraminifera *Th. globotruncanoides,* 36 meters below the top of the Marnes Bleues (Kennedy et al., 2004). Among the secondary criteria, the lowest occurrence of the single keeled taxa *Ps. tehamaensis* was recommended to be useful (Kennedy et al., 2004), but subsequently its distribution is reported to be diachronous by comparing the Vocontian Basin and the northwestern Atlantic Ocean records (Petrizzo et al., 2015). The highest occurrence of *Ps. ticinensis* occurs at meter -60 and the lowest occurrence of the nannofossil *Calculites anfractus* occur 4 meters below the Albian/Cenomanian boundary (Kennedy et al., 2004). Moreover, the Albian-Cenomanian boundary interval is marked by an extended plateau of high $\delta^{13}C$ values followed by a negative peak of the carbon isotope curve where the LO of *Th. globotruncanoides* is recorded (Kennedy et al., 2004).

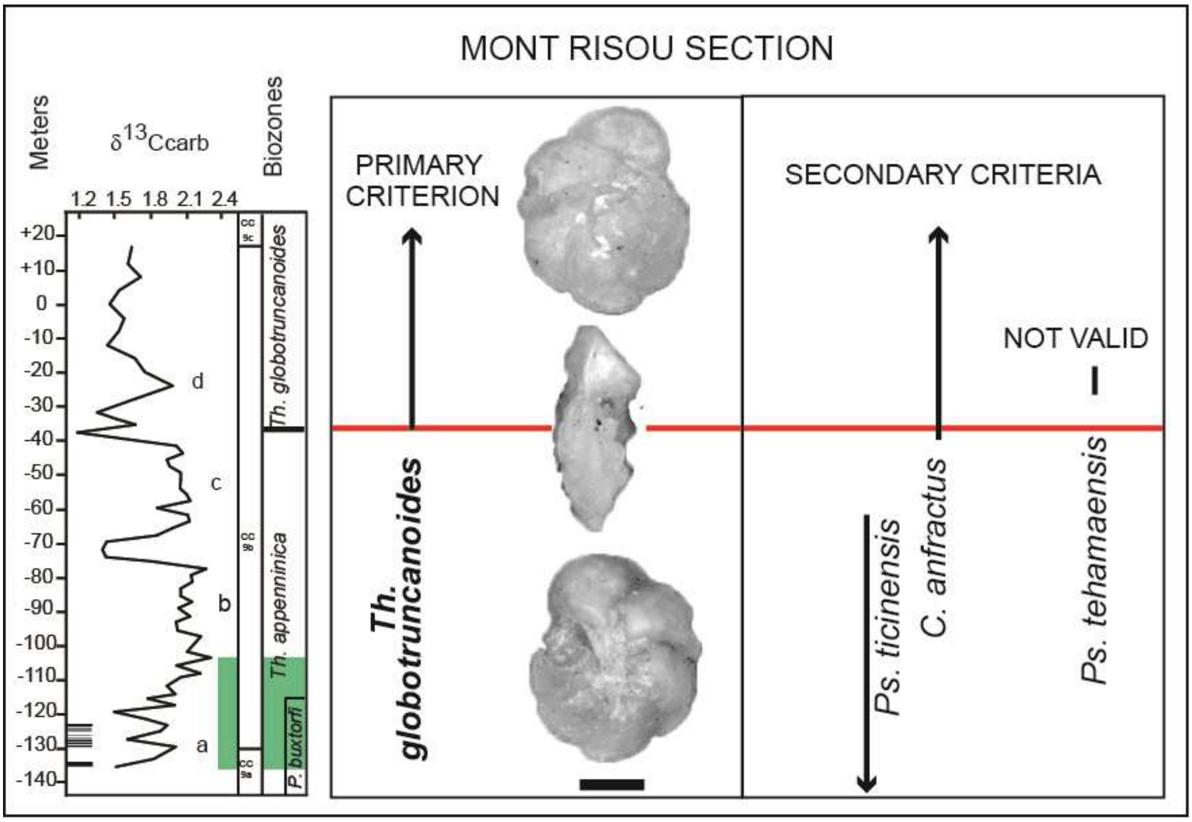


**Fig. 4.8** Primary criterion (*Th. globotruncanoides* holotype; scale bar =100 µm) and three secondary bioevents (*Ps. ticinensis*; *C. anfractus*; *Ps. tehamaensis*) used for the definition of the Albian/Cenomanian boundary in the stratotype section Mont Risou. *Pseudothalmanninella tehamaensis* is considered not reliable according to Petrizzo et al. (2015). Carbon isotope curve and peaks are by Gale et al. (1996), planktonic foraminiferal biozonation is according to Gale et al. (1996), Kennedy et al. (2004) and Petrizzo et al. (2015), calcareous nannofossil biozonation is according to Kennedy et al. (2004).

At Mont Risou, the carbon isotope curve shows a complex trend with a maximum value of 2.3‰ at -104 m, in which 4 peaks can be distinguished, from a to d, not corresponding to lithological changes. Specifically peak b indicates the highest values, gradually decreasing through c and d (Gale et al., 1996). In Figure 4.9 the Albian/Cenomanian boundary reported in all the sections is placed at the LO of *Th. globotruncanoides*; the biozones of the Monte Petrano and Le Brecce sections and of the Mazagan Plateau Site 547A are integrated with the calcareous nannofossil zonation and chemostratigraphic datum by Russo (2013), Gambacorta et al. (2015) and Nederbragt et al. (2001), respectively. These sections are compared with the Mont Risou section (Gale et al., 1996; Kennedy et al., 2004) and the Blake Nose Site 1050C (Watkins et al., 2005; Petrizzo and Huber, 2006a; Petrizzo et al., 2008; Petrizzo et al., 2015) (Figure 4.9). Results show that the Albian/Cenomanian boundary falls within the calcareous nannofossil Zone NC10a or CC9 in the Umbria – Marche Basin, while it can be correlate to the upper, the middle and the lower parts of the CC9b Zone at Site 547A, Mont Risou and Site 1050C, respectively.

For the Monte Petrano and Le Brecce sections the four (a to d) peaks recognized by Gambacorta et al. (2015), following Gale et al. (1996) and Kennedy et al. (2004), are reported while the carbon isotope peaks a to c at the Mazagan Plateau and Blake Nose Site 1050C are recognized using the same approach (Fig. 4.9).

Consequently, from base to top:

1) peak a is identified in the Umbria-Marche Basin and at Site 547A in between the top of the *P. buxtorfi* Subzone and the upper *Th. appenninica Zone.* On the contrary, in the Mont Risou section and at Site 1050C, it can be correlated to the middle part of the *P. buxtorfi* Subzone.
2) peak b corresponds to the maximum $\delta^{13}C$ values. At Monte Petrano, at Mazagan Plateau and at Blake Nose it consists in a gradual increment of the carbon isotope value culminating in a maximum value, while at Le Brecce and at Mont Risou peak b is expressed by a plateau of highest values. At Monte Petrano and at Site 547A, peak b falls just below and above the LO of *Th. globotruncanoides,* respectively, while at Site 1050C the maximum value is exactly in correspondence of the LO of *Th. globotruncanoides*. At Mont Risou peak b can be correlated to an interval in the upper part of the *Th. appenninica* Zone*,* while at Le Brecce it coincides to an interval between the upper *Th. appenninica* Zone and the lowermost *Th. globotruncanoides* Zone.
3) peak c falls in the lowermost part of the *Th. globotruncanoides* Zone in all sections, except at Mont Risou where it can be correlated with the upper *Th. appenninica* Zone.
4) peak d, is certainly identified in the Mont Risou section (Gale et al., 1996; Kennedy et al., 2004) and at Monte Petrano (Gambacorta et al., 2015) in the lower and middle part of the *Th. globotruncanoides* Zone, respectively.

The stratigraphic position of the LO of *Th. globotruncanoides* and peak b, are perfectly comparable in all the illustrated sections, except for the Mont Risou where the isotopic positive plateau anomaly falls below the Albian/Cenomanian boundary as defined by the primary criterion (Gale et al., 1996; Kennedy et al., 2004). Therefore, sections from different paleogeographic and paleoceanographic area are successfully comparable, even if the stratotype section slightly differs because the LO of *Th. globotruncanoides* stratigraphically coincides to the negative carbon isotope anomaly between peak c and d.

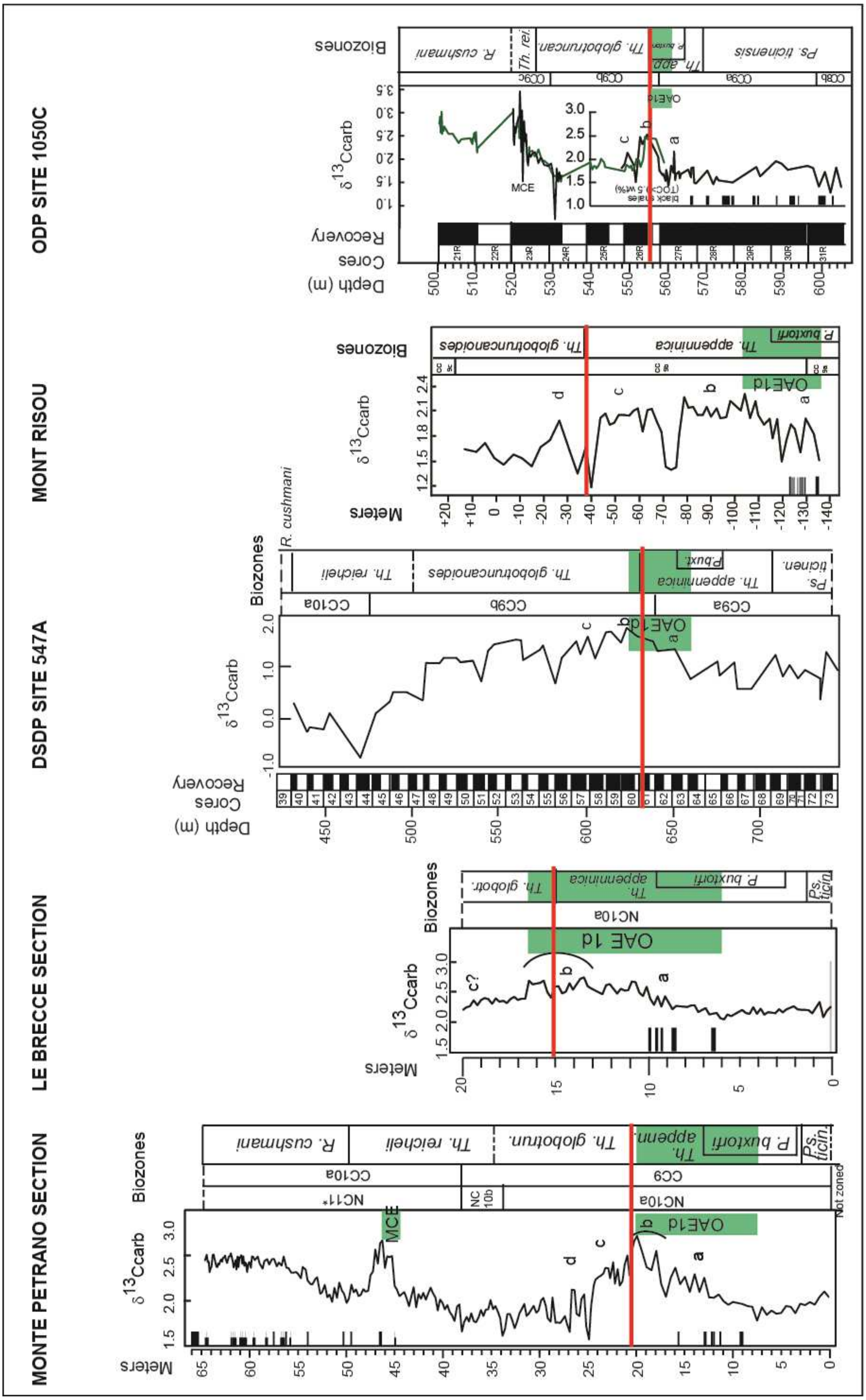
The correlation between biostratigraphic and chemostratigraphic criteria used for the definition of the Albian/Cenomanian boundary*,* is also confirmed in the Bottaccione section (Sprovieri et al., 2013; Coccioni and Premoli Silva, 2015) and in the Permanent Quarry (California; Robinson et al., 2008), where the LO of *Th. globotruncanoides* falls just above the maximum carbon isotope value.

Consequently, the successful correlation among the Umbria-Marche Basin, Mazagan Plateau and Blake Nose, shows a correspondence between biostratigraphic and chemostratigraphic criteria for the definition of the Albian/Cenomanian boundary (Kennedy et al., 2004) and, thus, confirms the reliability of the LO of *Th. globotruncanoides* as boundary bioevent.

OAE1d is identified as the interval between the starting point of the $\delta^{13}C$ excursion and the point where the anomaly definitely ended (maximum $\delta^{13}C$ value), in agreement with the definition by Petrizzo et al. (2008) and Gambacorta et al. (2015) as explained in Chapter 2. The comparison among the studied sections highlight that the beginning of the OAE1d is always correlated to the middle part of the *P. buxtorfi* Subzone. On the contrary, the end of the event falls in different biozones; specifically, at Monte Petrano and at Mont Risou it is observed in the uppermost *Th. appenninica* Zone, while at Le Brecce and at Site 547A, it is correlated to the lowermost *Th. globotruncanoides* Zone and at Site 1050C it perfectly coincides to the Albian/Cenomanian boundary (Fig. 4.9).

**Fig. 4.9** Integrated stratigraphy and comparison between the Monte Petrano and Le Brecce sections (Umbria-Marche Basin), Site 547A (Mazagan Plateau), Mont Risou (Vocontian Basin) and Site 1050C (Blake Nose). Umbria-Marche Basin: planktonic foraminiferal biostratigraphy according to this study (the base of the *Th. reicheli* Zone is dashed because the marker species is rare and with a discontinuous distribution), calcareous nannofossil biozonation and chemostratigraphy from Gambacorta et al. (2015). Mazagan Plateau: planktonic foraminiferal biostratigraphy according to this study (the base of the *Th. reicheli* Zone is dashed because the marker species is absent and the LO of *Th. greenhornensis* is used to approximate the base of the Zone, according to the Monte Petrano data), calcareous nannofossil biozonation and chemostratigraphy from Nederbragt et al. (2001). Mont Risou section, planktonic foraminiferal biostratigraphy from Gale et al. (1996), Kennedy et al. (2004) and Petrizzo et al. (2015), calcareous nannofossil biozonation from Kennedy et al. (2004) and chemostratigraphy from Gale et al. (1996). Carbon isotope data from the Umbria-Marche Basin, Mazagan Plateau and Mont Risou section are obtained from bulk carbonate. Blake Nose (ODP Site 1050C): planktonic foraminiferal biostratigraphy is from Petrizzo and Huber (2006a), and Petrizzo et al., 2015; calcareous nannofossil biozonation are from Watkins et al. (2005). Carbon isotope curve of the upper Albian-lower Cenomanian interval is from Petrizzo et al. (2008), while the Cenomanian interval is from Ando et al. (2010); black curve = data obtained by single planktonic foraminifera specimens, green curve = data derived by coccoliths. Red lines indicate the Albian/Cenomanian boundary as defined by

Kennedy et al. (2004). Green bands highlight the OAE1d according to the definition by Petrizzo et al. (2008) and Gambacorta et al. (2015).



# Chapter 5

# Systematic taxonomy and phylogeny

## 5.1 Introduction

The classification of Cretaceous planktonic foraminifera, according to Loeblich and Tappan (1988), is based on the hierarchical order assigned to selected morphological features. Consequently, species were assigned to the following Superfamilies: Rotaliporacea Sigal, 1958 and Planomalinacea Bolii, Loeblich and Tappan, 1957 and to Families Rotaliporidae Sigal, 1958, Globigerinelloididae Longoria, 1974, Hedbergellidae Loeblich and Tappan, 1961, Schackoinidae Pokorný, 1958, Heterohelicidae Cushman, 1927, Planomalinidae Bolli, Loeblich and Tappan, 1957, Globotruncanidae Brotzen, 1942.

Genera and species have been identified according to holotypes and paratypes reported on the Chronos Portal (on line taxonomic Dictionary updated by the Mesozoic Planktonic Foraminifera Working Group, http://www.chronos.org/) and Ellis and Messina Catalogues (Micropaleontology Press, http://www.micropress.org). Moreover, several publications have been used for taxonomic identification (e.g. Petrizzo and Huber, 2006a, 2006b; Caron and Spezzaferri, 2006a, 2006b; Ando and Huber, 2007; González-Donoso et al., 2007; Desmares et al., 2008; Lipson-Benitah, 2008; Robaszynski et al., 2008; Huber and Leckie, 2011; Petrizzo et al., 2015).

All the trochospiral single keeled taxa with umbilical-extraumbilical primary aperture and umbilical or sutural secondary apertures that first appeared in the middle-late Albian, were included in the family Rotaliporidae by Sigal (1958) with the identification of two subfamilies: the keeled Rotaliporinae Sigal, 1956b and the unkeeled Ticinellinae Longoria, 1974. Under the subfamily Rotaliporinae six genera were identified including *Rotalipora* Brotzen, 1942, *Thalmanninella* Sigal, 1948 and *Pseudothalmanninella* Wonders, 1978. González-Donoso et al. (2007) revised this subdivision and recognized as distinct genera only the above mentioned genera by designation of their polyphyletic lineages:

- *Ticinella praeticinensis* – ***Pseudothalmanninella*** *subticinensis* – *Pseudothalmanninella ticinensis* – *Pseudothalmanninella tehamaensis*.
- *Ticinella raynaudi* – ***Thalmanninella*** *praebalernaensis* – *Thalmanninella balernaensis* – *Thalmanninella appenninica* – *Thalmanninella brotzeni* – *Thalmanninella globotruncanoides.*
- unclear ancestor – ***Rotalipora*** *montsalvensis* – *Rotalipora praemontsalvensis* – *Rotalipora cushmani.* According to Gonzalez-Donoso et al. (2007), *Praeglobotruncana* or a hedbergellid species seemed to be the more probable ancestors of the *Rotalipora* lineage.

Lipson-Benitah (2008) subsequently erected from the polyphyletic *Thalmanninella* the new genus *Parathalmanninella* and, she supposed that the two genera derived from two different ancestors: *Ps. tehamaensis* and *T. raynaudi,* respectively. Consequently, Lipson-Benitah (2008) included in the genus *Parathalmanninella* the species *praebalernaensis, balernaensis, appenninica, gandolfi* and *micheli.* However, in the present study the *Parathalmanninella* genus is not considered as valid because no intermediate specimens between *ps. tehamaensis* and the species *brotzeni* were identified to support the phyletic lineage, as previously pointed out by Petrizzo et al. (2015). In addition, the data presented in this thesis and the finding of transitional morphotypes allow to document the phyletic lineage from *T. raynaudi aperta* – *Th. appenninica* – *Th. brotzeni* – *Th. globotruncanoides* to *Th. greenhornensis* (see Paragraph 5.3).

Planispiral species are included in the genus *Globigerinelloides* even if they are all characterized by macroperforate wall texture unlike the Aptian planispiral taxa. Because the type species is an Aptian species and Aptian planispiral taxa all disappear at the Aptian/Albian boundary (Petrizzo et al., 2012; Kennedy et al., 2014), the Albian-Maastrichtian planispirals are not evolutionary related to the Aptian planispirals. However, for the time being the genus *Globigerinelloides* is retained to include all the planispiral forms without keel pending further studies. Moreover, in the Albian-Cenomanian time interval the *Globigerinelloides* genus is very problematic as it shows a large range of forms included under the same species name. Specifically, the species *G. bentonensis* shows a large variability and includes all planispiral specimens more or less inflated with globular chambers and smooth wall texture. Specimens very similar to *G. alvarezi*, but with less abundant chambers are recorded at Mazagan Plateau Site 547A (see *G*. cf. *alvarezi* in Plate 6, figs. 5-6). *Globigerinelloides pulchellus* is a very distinctive planispiral species, primarily recognizable thanks to the pustulose wall, whose stratigraphic distribution is usually restricted to the upper Albian. Anyhow, some planispiral specimens really close to *G. pulchellus* are observed in the upper Cenomanian of the Monte Petrano and Mazagan Plateau Site 547A, as shown in Plate 6 (figs. 7-8); further studies are needed to verify the possible continuity of the stratigraphic distribution of *G. pulchellus* from the late Albian to the late Cenomanian interval.

All the globigeriniform taxa possessing supplementary apertures on the umbilical side and with a typical thick wall texture are included the *Ticinella* genus.

Specimens with very low trochospiral to planispiral test, macroperforate and smooth wall texture characterized by hollow pores surrounded by a thick wall and possessing strongly inflated globular chambers belongs to the genus *Biticinella.*

The *Planomalina* genus includes all planispiral taxa with mostly to fully raised sutures and partially to entirely keeled.

Taxa characterized by low to medium trochospiral test, aligned pustules at least at the beginning of the last whorl, pinched to keeled lateral profile, depressed to raised and straight to curved spiral sutures, and straight and depressed umbilical sutures, belong to genus *Praeglobotruncana.* Specifically, *Praeglobotruncana delrioensis* and *P. stephani* show a large variability and, from the late Albian to the late Cenomanian interval, specimens provided with a single alignment of pustules, a single weakly developed keel, and a double alignment are observed. In the late Albian of the Monte Petrano section are also observed specimens really close to the Turonian *P. oraviensis,* reported in the range chart as *P.* cf. *oraviensis.*

All low to high trochospire specimens characterized by pustulose to muricate wall texture, globular chambers and straight depressed sutures on both sides are included in the *Muricohedbergella* genus. It is worth noting that in the literature the species *simplicissima* is assigned to the genus *Clavihedbergella* Banner and Blow (1959), nevertheless, in this study it is included in the genus "*Muricohedbergella"* even if it is characterized by a less pustulose wall texture respect to the other species belonging to that genus.

The *Paracostellagerina* genus is very similar to *Muricohedbergella* but it differs in having strongly aligned pustules giving rise to costellae, particularly at the beginning of the last whorl.

The *Schackoina* genus is characterized by very low trochospiral test with smooth to finely perforate wall texture, stellate outline and elongate chambers passing from subspherical to fingerlike.

The *Whiteinella* genus includes all trochospiral taxa with coarsely pustulose wall texture, globular and inflated chambers, pinched to rounded lateral view and straight depressed umbilical and spiral sutures.

All double keeled trochospiral taxa biconvex to planoconvex with pinched to keeled edge view, curved raised spiral sutures and depressed straight umbilical sutures are included in *Dicarinella* genus. Nevertheless, the species *D. algeriana* can also be regarded as a transitional form between *Praeglobotruncana* and *Dicarinella,* or possibly similar to the *P. stephani* forms with double alignment of pustules observed in the Monte Petrano section.

## 5.2 Description of genera and species

Genera are discussed according to their stratigraphic order of appearance in the geological record, while species are listed according to their phyletic relationships when information are available, except for the species *Mi.* cf. *rischi* that is discussed at the end of the section. Phyletic relationships of *Thalmanninella* are discussed in Paragraph 5.3. Species are illustrated in Plates 1 to 25 in the Plates section.

Supergroup RHIZARIA Cavalier-Smith, 2002
Class FORAMINIFERA d'Orbigny, 1826
Order GLOBIGERININA Delage and Hérouard, 1896
Superfamily ROTALIPORACEA Sigal, 1958
Family ROTALIPORIDAE Sigal, 1958
Subfamily TICINELLINAE Longoria,1974

Genus ***Ticinella*** Reichel, 1950
Type species: *Anomalina roberti* Gandolfi, 1942

***Ticinella madecassiana*** Sigal, 1966
Plate 1, figs. 1-6

*Ticinella madecassiana* Sigal, 1966, p. 197, pl. 3, figs. 7ab-10ab (upper Albian, Diego-Suarez well, north of Mount Raynaud, Madagascar).

*Ticinella madecassiana* Sigal, 1966, Leckie, 1984, p. 600, pl. 6, figs. 7-12 (upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

*Ticinella madecassiana* Sigal, 1966, Petrizzo and Huber, 2006a, p. 180, pl. 2, figs. 1a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

*Ticinella madecassiana* Sigal, 1966, Huber and Leckie, 2011, pl. 21, figs. 3-4 (Albian, Western North Atlantic Ocean, Blake Nose, DSDP Site 392A).

Wall texture: macroperforate and smooth, thick wall.

Test morphology: low trochospiral test, 5-6 subglobular chambers that become reniform in the last whorl and gradually increase in size, on the umbilical side the last chamber is often very inflated and partially covers the previous one. Rounded peripheral margin, sutures depressed and straight on both sides, umbilicus sometimes covered by a lip in correspondence of the umbilical-extraumbilical primary aperture, umbilical supplementary apertures.

Distinguishing features: it differs from *T. primula* in having fewer chambers reniform in shape instead of globular, and by possessing a narrower umbilicus and all the supplementary apertures are umbilical.

Remarks: *Ticinella madecassiana* is a distinctive species characterized by a continuous stratigraphic record in all the studied sections but it is definitely more abundant at the Mazagan plateau than in the Umbria-Marche Basin.

Phyletic relationships: according to Huber and Leckie (2011), *T. madecassiana* is the intermediate species in the phyletic lineage from *Mi. rischi to T. primula.* This hypothesis is supported by the observation of transitional morphotypes between *M. rischi* and *T. madecassiana* characterized by the lack of supplementary apertures, larger dimension and density of pores than in *T. rischi*, and by the development of "ticinellid" wall texture characterized by being thicker. However, in the studied sections *T. madecassiana* is abundant and very distinctive but no transitional forms deriving from *Mi. rischi* are detected.

Stratigraphic distribution: in the Umbria-Marche Basin and at Mazagan Plateau Site 547A it is observed from the base of the section to the lower part of *Th. globotruncanoides* Zone, while at Site 545 its disappearance is recorded in the upper part of the *Th. appenninica* Zone.

### ***Ticinella primula*** Luterbacher, 1963

Plate 1, figs. 7-9; Plate 2, figs 1-4

*Ticinella primula* Luterbacher, in Renz et al., 1963, p. 1085, fig. 4 (upper Albian, western Switzerland).

*Ticinella primula* Luterbacher, 1963, Leckie, 1984, p. 600, pl. 6, figs. 1-6 (upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

*Ticinella primula* Luterbacher, 1963, Petrizzo and Huber, 2006a, p. 180, pl. 2, figs. 2a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

*Ticinella primula* Luterbacher, 1963, Huber and Leckie, 2011, pl. 21, figs. 6-8 (Albian, Western North Atlantic Ocean, Blake Nose Escarpment, DSDP Site 392A, ODP Site 1050C).

Wall texture: macroperforate and smooth, thick wall.

Test morphology: low trochospiral test, 6-8 globular chambers gradually increasing in size, rounded to oblate peripheral margin, sutures depressed and straight on both sides, wide umbilicus sometimes partially covered by a large lip in correspondence of the umbilical-extraumbilical primary aperture, umbilical to sutural rimmed supplementary apertures.

Distinguishing features: It differs from *Mi. rischi* in having macroperforate wall texture instead of being micro to finely perforate and by having supplementary apertures. It can be distinguished from *T. madecassiana* in having all chambers globular instead of reniform. It differs from *M. praelibyca* because of the different wall texture and the presence of secondary supplementary apertures.

Remarks: *Ticinella primula* is abundant and it shows a continuous stratigraphic record in all the studied section.

Phyletic relationships: according to Moullade et al. (2002), *Mi. rischi* gave rise to *T. primula* with the acquisition of supplementary apertures. Afterwards, Huber and Leckie (2011) agreed that the two species are phylogenetic linked, but they also suggested that *T. madecassiana* is an intermediate species in this evolutionary lineage based on stratophenetic observations. According to Moullade (1966) and Lipson-Benitah and Almogi-Labin (2000) *T. primula* is the ancestor of *Th. appenninica.* Data from the studied sections support the interpretation that *Th. appenninica* evolved from *T. raynaudi aperta*, as several transitional specimens between the two species are identified (see Paragraph 5.3 and Plate 14, figs. 6-7).

Stratigraphic distribution: in the Umbria-Marche Basin and at Mazagan Plateau Site 547A *T. primula* is observed from the base of the studied section to the lower part of the *Th. globotruncanoides* Zone, while at Site 545 its last occurrence is in the middle part of the *Th. appenninica* Zone.

### ***Ticinella raynaudi*** Sigal, 1966

Plate 2, figs. 5-9; Plate 3, figs. 1-2

*Ticinella raynaudi* Sigal, 1966, p. 200-201, pl. 6, figs. 1ab-3ab (upper Albian, Diego-Suarez well, north of Mount Raynaud, Madagascar).

Wall texture: macroperforate and smooth wall.

Test morphology: low trochospiral test, 5-6 elongate chambers, rounded peripheral margin, depressed and straight sutures on both sides, umbilical-extraumbilical primary aperture, umbilical supplementary apertures.

Distinguishing features: it can be distinguished from the other species of *Ticinella* genus in having more elongate and triangular chambers. The two subspecies described by Sigal, 1966 *T. raynaudi aperta* and *T. raynaudi digitalis* are observed in all the studied sections. Specifically, *T. raynaudi aperta* is characterized by the elongation of the last chamber, whereas *T. raynaudi digitalis* has all the chamber radially elongated.

Remarks: In the Umbria-Marche Basin it is quite rare and characterized by a scattered stratigraphic record, while at Mazagan Plateau *T. raynaudi* is more abundant, it shows a more continuous distribution in the geological record and it is generally larger in size than in the Mazagan Plateau assemblage.
Phyletic relationships: In this study, the two subspecies are interpreted to be the ancestors of *Th. appenninica* and *Th. evoluta* as transitional specimens from *T. raynaudi aperta* to *Th. appenninica* (see Paragraph 5.3 and Plate 14, figs. 6, 7) and from *T. raynaudi digitalis* to *Th. evoluta* (Plate 13, figs. 8, 9) have been observed, particularly at Monte Petrano and at Mazagan Plateau Site 547A.
Stratigraphic distribution: In all the studied sections *T. raynaudi* has been observed from the base to the upper *Th. appenninica* Zone.

### ***Ticinella roberti*** (Gandolfi, 1942)

Plate 3, figs. 3-6

*Anomalina roberti* Gandolfi, 1942, pp. 100, 134, 150, pl. 2, figs. 2a-c (Aptian or Albian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).
*Ticinella roberti* var. *bejaouaensis* Gandolfi, 1942, Sigal, 1966, pp. 207-208, pl. 5, figs. 5-9 (lower Albian, Diégo-Suarez well, north of Mount Raynaud, Madagascar).
*Ticinella roberti* s.l. Gandolfi, 1942, Leckie, 1984, p. 600, 601, pl. 5, figs. 1-4 (upper Albian, Mazagan Plateau, DSDP Site 545 and Site 547A, eastern North Atlantic).
*Ticinella roberti* Gandolfi, 1942, Lipson-Benitah and Almogi-Labin, 2000, p. 20, pl. 5, figs. 1,2,4 (Albian, Yam ST and Yam 2 borehole, near Tel Aviv, Israel).

Wall texture: macroperforate, very thick and pustulose in the first chambers of the last whorl.
Test morphology: medium trochospiral test, 7-9 inflated chambers trapezoidal on the spiral side and more triangular on the umbilical side, rounded peripheral margin, suture depressed and straight on both sides, umbilicus partially covered by a large lip in correspondence of the umbilical-extraumbilical primary aperture and by the last chamber, umbilical rimmed supplementary apertures.
Distinguishing features: it differs from specimens of *Muricohedbergella* in possessing a diverse wall texture. Among *Ticinella* species, it differs from *T. primula* in having chambers more abundant and inflated and a higher trochospire and from *T. moulladei* because it is characterized by a lower trochospiral test, less inflated chambers and a flatter lateral view.
Remarks: *Ticinella roberti* is a quite rare species, observed only in the Mazagan Plateau. It is not easy to identify because it can be confused with other rare taxa such as *T. moulladei* or with small specimens of *M. astrepta*.

Stratigraphic distribution: at Mazagan Plateau it occurs from the base of the studied section till the lower part of the *Th. globotruncanoides* Zone.

### ***Ticinella moulladei*** Premoli Silva et al., 2009

Plate 3, figs. 7-9

*Ticinella moulladei* Premoli Silva et al., 2009, p. 136, pl. 3 figs. 1 (upper Albian, Diego-Suarez well, north of Mount Raynaud, Madagascar).

Wall texture: coarsely pustulose in the inner spire and in the early chambers that appeared as reticulated; it becomes smoother at the end of the last whorl.

Test morphology: low trochospiral test, 8-9 globular chambers slowly increasing in size, rounded peripheral margin, sutures depressed and straight on both sides, umbilicus wide and shallow, umbilical-extraumbilical primary aperture, umbilical supplementary apertures.

Distinguishing features: It differs from *T. primula* by having more numerous chambers, a larger umbilical area and a more ornamented wall texture. It can be distinguished by *T. roberti* by having a very low trochospire and less inflated chambers.

Remarks: *Ticinella moulladei* is observed only at Mazagan Plateau as rare and is characterized by low abundance and discontinuous stratigraphic record.

Stratigraphic distribution: it is recorded from the base of the section to the upper *Th. appenninica* Zone at Site 547A, while at Site 545 is has been found only in one sample in *Ps. ticinensis* Zone.

### Superfamily PLANOMALINACEA Bolii, Loeblich and Tappan, 1957

### Family GLOBIGERINELLOIDIDAE Longoria, 1974

### Subfamily GLOBIGERINELLOIDINAE Longoria, 1974

### Genus ***Globigerinelloides*** Cushman and ten Dam, 1948

Type species: *Globigerinelloides algeriana,* Cushman and ten Dam, 1948

### ***Globigerinelloides bentonensis*** (Morrow, 1934)

Plate 4, figs. 1-7

*Anomalina bentonensis* Morrow, 1934, p. 201, pl. 30, figs. 4a-b (Cenomanian, Hartland member of Greenhorn Limestone of Kansas).

*Planomalina caseyi* Bolli, Loeblich and Tappan, 1957, p. 24, pl. 1, figs. 4-5 (Albian, Gault Clay at Arlesey, England).

*Globigerinelloides bentonensis* (Morrow), Leckie, 1984, p. 593, pl. 10, fig. 9-11 (Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

Wall texture: macroperforate and smooth.

Test morphology: planispiral involute test, rounded to oblate profile, 7-9 inflated chambers and rapidly increasing in size, rounded peripheral margin, depressed and straight sutures and equatorial aperture.

Distinguishing features: it differs from *G. ultramicrus* in being smooth instead of pustulose, larger in size and by having more inflated and rapidly growing chambers. It can be distinguished by *G. alvarezi* because it shows inflated chambers instead of more flat and globular chambers rather than trapezoidal.

*Remarks: Globigerinelloides bentonensis* is a very common species that has been observed in all the studied sections. It shows a large species specific variability including specimens characterized by more or less inflated chambers and rounded to oblate profile. According to Petrizzo and Huber (2006a) *G. bentonensis* is considered the senior synonym of *G. caseyi* (Loeblich and Tappan, 1957) because their type material is regarded to be identical (Leckie, 1984).

Phyletic relationships: for several years, *G. bentonensis* has been regarded as the *Planomalina* ancestor species (Moullade, 1966; Leckie, 1984; Moullade et al., 2002). According to Petrizzo and Huber (2006), the specimens of *G. bentonensis* illustrated by Moullade et al. (2002) is pustulose at the beginning of the last whorl and it is more similar to *G. pulchellus.* This observation is here confirmed, consequently, having *G. bentone*nsis a macroperforate wall texture very different from that of *Planomalina,* it is not considering as the ancestor of the *Planomalina* phyletic lineage.

Stratigraphic distribution: it occurs from the base of the sections. *G. bentonensis* is present in all the studied interval at Mazagan Plateau, while its last occurrence is observed in the middle of the *Th. appenninica* Zone in the Umbria-Marche Basin.

### ***Globigerinelloides pulchellus*** (Todd and Low, 1964)

Plate 4, figs. 8-9; Plate 5, figs. 1-4

*Planomalina pulchella* Todd and Low, 1964, p.409, pl. 1, figs. 9a-b (Cenomanian?, Puerto Rico Trench).

*Globigerinelloides pulchellus* Petrizzo and Huber, 2006b, p. 236, pl. 1, figs. 4-7 (Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

*Planohedbergella bentonensis* (Morrow, 1934), Moullade et al., 2002, p. 141-142, pl. 5, figs. F-M (late Albian, Western North Atlantic Ocean, Blake Nose Escarpment, DSDP Site 392A, ODP Site 1050C).

Wall texture: macroperforate with pustules at the beginning of the last whorl, becoming smooth in the last chambers.

Test morphology: planispiral involute test, rounded to subrounded profile, 7-9 slightly inflated chambers gradually increasing in size, depressed and radial to curving backward sutures, equatorial aperture.

Distinguishing features: it differs from *G. bentonensis* by having the beginning of the last whorl ornamented by coarse muricae. It can be distinguished by *P. praebuxtorfi* because of the lack of the keel on the earlier chambers, the more rounded peripheral margin and by having all the sutures depressed. The main difference with its ancestor *M. wondersi* is coiling mode that is planispiral in *G. pulchellus* and very low trochospiral in *M. wondersi*.

Remarks: it is not an abundant taxon observed in all the studied sections except for Site 545 but it is quite easy to detect because the other upper Albian *Globigerinelloides* possess smooth wall texture instead of pustulose.

Phyletic relationships: in the Monte Petrano section and in the Mazagan Plateau Site 547A, transitional specimens between *G. pulchellus* and *P. praebuxtorfi* are observed (Plate 5, figs. 5-7). *Globigerinelloides pulchellus* differs from the other upper Albian *Globigerinelloides* in having pustulose wall texture instead of smooth and it is the ancestor of the *Planomalina* genus (Petrizzo and Huber, 2006b); for these reasons it should be moved back into the *Planomalina* genus.

Stratigraphic range: at Monte Petrano it occurs from the base of the section (*Ps. ticinensis* Zone) to the middle of the *P. buxtorfi* Subzone. At Le Brecce it appears at the base of the *Th. appenninica* Zone to the lower part of the *P. buxtorfi* Subzone. At Mazagan Plateau Site 547A from the base of the section to the lower part of the *Th. appenninica* Zone.

### ***Globigerinelloides ultramicrus*** (Subbotina, 1949)

Plate 5, figs. 8-10

*Globigerinella ultramicra* Subbotina, 1949, p. 33, pl. 2, figs, 17-18 (Cenomanian, Kapustnaya Gorge, southern slope of Caucasus, Russia).

*Globigerinelloides ultramicrus* Subbotina, 1949, Leckie, 1984, p. 598, pl. 11, figs. 10-11 (late Cenomanian, Mazagan Plateau, eastern North Atlantic, DSDP Site 547A).

Wall texture: macroperforate, finely pustulose at the beginning of the last whorl, becoming smooth in the last chambers.

Test morphology: planispiral involute test, rounded profile, 7-8 slightly inflated chambers very slowly increasing in size, depressed and radial sutures and equatorial aperture.

Distinguishing features: it differs from *G. bentonensis* by having finely pustulose wall texture, chambers less inflated and very slowly increasing in size. It can be distinguished by *G. pulchellus* in having a faster growing rate, a more rounded profile, a wider umbilicus and straight sutures.

Remarks: it is a rare and discontinuous taxon and not easy to detect because it can be confused with small specimens of *G. bentonensis.* It is recorded in all the studied section except for the Mazagan Plateau Site 545. Specimens resembling *G. ultramicrus* are identified as cf. *ultramicrus* (Pl. 5, fig. 9). Further studies are needed to verify the taxonomic status of these specimens.

Stratigraphic range: at Monte Petrano it is observed till the upper part of *Th. globotruncanoides* Zone, while at Le Brecce only in the *Ps. ticinensis* Zone. At Mazagan Plateau Site 547A it is present from the *Ps. ticinensis* Zone to the top of the section.

### ***Globigerinelloides alvarezi*** (Eternod Olvera, 1959)

Plate 6, figs. 1-4

*Planomalina alvarezi* Eternod Olvera, 1959, p. 91-92, pl. 4, figs. 5-7 (Campanian – Maastrichtian, well Bustos, Tumaulipas, Mexico).

Wall texture: macroperforate and smooth.

Test morphology: planispiral involute test, oblate profile, 7-8 slightly inflated and globular chambers gradually increasing in size and becoming more reniform at the end of the last whorl, rounded peripheral margin, wide and shallow umbilicus, depressed and straight sutures and equatorial aperture. Specimens resembling *G. alvarezi* are identified as cf. *alvarezi* (Pl. 6, figs 5, 6). Further studies are needed to verify the taxonomic status of these specimens.

Distinguishing features: it differs from *G. ultramicrus* by having less inflated chambers globular to reniform in shape. It can be distinguished from *G. ultramicrus* because it has smooth wall texture, an oblate profile and chambers increase faster in size.

Remarks: *Globigerinelloides alvarezi* is recorded only at Mazagan Plateau as rare and with a scattered resolution but it is quite easy to identify because of the typical reniform shape of the last chambers.

Stratigraphic distribution: at Mazagan Plateau it is observed throughout all the studied interval.

### Superfamily ROTALIPORACEA Sigal, 1958

### Family ROTALIPORIDAE Sigal, 1958

### Subfamily TICINELLINAE Longoria, 1974

### Genus ***Biticinella*** Sigal, 1956a

Type species: *Anomalina breggiensis,* Gandolfi, 1942

### ***Biticinella subbreggiensis*** Sigal, 1966

Plate 7, figs 1-3

*Biticinella breggiensis* Gandolfi, 1942, Luterbacher and Premoli Silva, 1962, p. 288-289, pl. 23, figs. 2 (upper Albian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).

*Ticinella* (*Biticinella*) spectrum-*breggiense* Sigal, 1966, p. 193, pl. 1 figs. 1-7, pl. 2 figs. 2 (upper Albian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland; Mount Raynaud, Madagascar).

*Biticinella subbreggiensis* Sigal, 1966, Gale et al., 2011, p. 106, pl. 46, figs. G-L (upper Albian, Col de Palluel).

Wall texture: macroperforate and smooth with hollow pores surrounded by a thick wall.

Test morphology: very low trochospiral to pseudoplanispiral, subcircular outline, 7-8 inflated and trapezoidal chambers, sutures depressed and straight on both sides, umbilicus wide and deep, umbilical to extraumbilical primary aperture characterized by a lip.

Distinguishing features: it differs from specimens of *Ticinella* in having more inflated chambers and a trochospiral becoming pseudoplanispiral test. It can be distinguished from *Globigerinelloides* in having a trochospiral stage.

Remarks: it is observed only in the Umbria-Marche Basin as a very rare species, but at Monte Petrano it shows a continuous stratigraphic record. *Biticinella subbreggiensis* is a distinctive species because of its particular wall texture and it is easily distinguished by its descendant *B. breggiensis* because of its trochospiral coiling mode. Sigal (1996) in the *Ticinella* spectrum–*breggiense* (Gandolfi, 1942) clearly distinguished and described two morphologies: *Ticinella* (*Ticinella*) spectrum *breggiense* and Ticinella (*Biticinella*) *sub-breggiensis,* corresponding to *Biticinella breggiensis* and *Biticinella subbreggiensis,* respectively.

Phyletic relationship: Lipson-Benitah and Almogi-Labin (2001) included *B. subbreggiensis* in *B. breggiensis* and considered it as a descendant of *T. primula* and a transitional species from trochospiral to planispiral morphologies. However, the process started with *Ticinella* and continued with the appearance of *Biticinella* failed and the phyletic lineage interrupted.

Stratigraphic distribution: at Monte Petrano from the upper *Ps. ticinensis* Zone to the base of the *P. buxtorfi* Subzone, while at Le Brecce it is recorded in only one sample at the top of the *Ps. ticinensis* Zone.

### ***Biticinella breggiensis*** (Gandolfi, 1942)

Plate 7, figs. 4-9

*Anomalina breggiensis,* Gandolfi, 1942, p. 102, pl. 3, figs. 6 (Albian-lower Cenomanian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).

*Biticinella breggiensis* Gandolfi, 1942, Lipson-Benitah and Almogi-Labin, 2001, p. 237-239, pl. 1, figs. 1-4 and pl. 2, figs. 1-3 (upper Albian, Yam S.T. Bore hole, offshore Israel; Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1052E; Bottaccione section, Gubbio, central Italy).

*Biticinella breggiensis* Gandolfi, 1942, Leckie, 1984, p. 600, pl. 8, figs. 1-2 (late Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547B).

*Biticinella breggiensis* Gandolfi, 1942, Petrizzo and Huber, 2006a, p. 183, pl. 3, figs. 1 (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate and smooth with hollow pores surrounded by a thick wall.

Test morphology: (pseudo)planispiral involute test, subcircular outline, almost symmetrical in edge view, 8-9 inflated and trapezoidal chamber, sutures depressed and straight on both sides, umbilicus wide and deep, primary aperture umbilical extending to the spiral side and characterized by a lip, secondary aperture very small and covered by a flap on both sides.

Distinguishing features: it differs from specimens of *Ticinella* in being planispiral and in having secondary apertures on both sides. It can be distinguished by *Globigerinelloides* in having thicker wall texture similar to that of *Ticinella* genus, and characterized by secondary apertures on both sides. It differs from its ancestor *B. subbreggiensis* in being pseudoplanispiral instead of low trochospiral.

Remarks: *B. breggiensis* is not a very common taxon, it has a continuous stratigraphic distribution and it is a very distinctive species because of the typical wall texture. Moreover, in the Umbria-Marche Basin it usually shows larger size that at the Mazagan Plateau.

Phyletic relationship: *B. breggiensis* is the end member of the *Biticinella* lineage and records the evolution from low trochospiral to pseudoplanispiral taxa (Lipson-Benitah and Almogi-Labin, 2001).

Stratigraphic distribution: In the Umbria-Marche Basin its last occurrence is in the lower part of the *Th. appenninica* Zone. At Mazagan Site 547A it is observed from the base of the studied interval to the middle part of the *Th. appenninica* Zone, while at Site 545 its last occurrence is at the top of the *Ps. ticinensis Zone.*

### Superfamily ROTALIPORACEA Sigal, 1958
### Family HEDBERGELLIDAE Loeblich and Tappan, 1961

### Genus ***Muricohedbergella*** Huber and Leckie, 2011
Type species: *Muricohedbergella delrioensis* (Carsey, 1926)

### ***Muricohedbergella delrioensis*** (Carsey, 1926)
Plate 8, figs 1-6

*Globigerina cretacea* var. *del rioensis* Carsey, 1926, p. 43-44 (lower Cenomanian, Del Rio Clay, Grayson Formation, Austin, TX).

*Hedbergella delrioensis* Carsey 1926, Longoria, 1974, p. 54, pl. 10, figs. 1-3 (neotype, Del Rio Clay, Grayson Formation, Austin, TX ).

*Hedbergella delrioensis* Carsey 1926, Masters, 1976, p. 328, pl. 3, fig. 2 (neotype, Del Rio Clay, Grayson Formation, Austin, TX ).

Wall texture: macroperforate with irregularly distributed pustules more developed at the beginning of the last whorl.

Test morphology: low trochospiral test, biconvex, 4-5 globular chambers in the last whorl rapidly increasing in size, last chamber slightly offset towards the umbilical side, rounded peripheral margin, sutures straight and depressed on both sides, umbilicus small and partially covered by the last chamber, primary aperture umbilical to extraumbilical.

Distinguishing features: It differs from *M. simplicissima* in having a more pustulose wall texture and globular inflated chambers instead of elongated.

Remarks: *Muricohedbergella delrioensis* has been misidentified for long time because it was erected by Carsey (1926), but he went wrong in the illustration and in the designation of the repository of the type species (Pessagno, 1976). Consequently, Plummer (1931) reported *M. delrioensis* as missing.

Two neotype were erected first by Longoria (1974) and then by Masters (1976) and both were deposited at the Smithsonian Museum of Natural History. The neotype erected by Longoria had the priority

(Masters, 1977) and was chosen as valid neotype, but according to Petrizzo and Huber (2006a) it has been lost and only the invalid neotype of Masters remained stored in the repository.

The two neotypes mainly differs for the elevation of the trochospire that is a slightly higher in the specimens by Longoria that is characterized by an elevated internal spire instead of flat. Specimens resembling the two neotypes are observed in all the studied sections except at Mazagan Plateau Site 545, and the specimens close to the neotype by Longoria (1974) are always more abundant and show a more continuous stratigraphic record.

Stratigraphic distribution: in the Umbria-Marche Basin *Mu. delrioensis* is observed from the base of the *Th. appenninica* Zone to the mid part of the *R. cushmani* Zone. At Mazagan Site 547A it occurs between the upper *Ps. ticinensis* and the upper part of the *Th. globotruncanoides* Zone.

### ***Muricohedbergella planispira*** (Tappan, 1940)

Plate 8, figs 7-9

*Globigerina planispira* Tappan, 1960, p. 12, pl. 19, fig.12 (Cenomanian, Grayson Formation, Denton County, TX).

*Hedbergella planispira* Tappan, 1960, Leckie, 1984, p. 599, pl. 9, figs. 6-7 (upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

*Hedbergella planispira* Tappan, 1960, Petrizzo and Huber, 2006a, p. 185, pl. 7, figs. 2a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

*Muricohedbergella planispira* Tappan, 1940, Huber and Leckie, 2011, p. 84, pl. 17, figs. 7a-b and 8a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1052E).

Wall texture: macroperforate with irregularly distributed pustules especially at the beginning of the last whorl.

Test morphology: very low trochospiral test, biconvex, 6-8 globular chambers in the last whorl slowly increasing in size, rounded peripheral margin, all sutures are straight and depressed, umbilicus wide and shallow, primary aperture umbilical to extraumbilical and bordered by a lip.

Distinguishing features: It differs from *M. praelibyca* in having a lower trochospire, a circular outline, less inflated and more abundant chambers and a wider umbilicus. It can be distinguished from *M. wondersi* in having more globular chambers and more spread pustules.

Remarks: *Muricohedbergella planispira* is observed in all the studied sections except for Le Brecce and it shows a very scattered stratigraphic record particularly at Monte Petrano and at Site 547A. It is not a distinctive species and it can be confused with small specimens of *M. praelibyca.*

Stratigraphic distribution: at Monte Petrano it is rare and with a discontinuous stratigraphic record from the lower portion of the *Th. appenninica* Zone to the lower *R. cushmani* Zone. At Mazagan Site 547A it is observed from the base of the section to the upper part of the *Th. appenninica* Zone, while at Site 545 it is present only in two samples in the *Ps. ticinensis* Zone.

### ***"Muricohedbergella" simplicissima*** (Magné and Sigal, 1954)

Plate 9, figs. 1-6

*Hastigerinella simplicissima* Magné and Sigal, 1954 p. 487, pl. 14, figs. 11 (lower Cenomanian, Rhazouane, Tunisia).

Wall texture: macroperforate and finely pustulose.

Test morphology: very low trochospiral test, 4-4½ inflated and elongated chambers slowly increasing in size, rounded to pinched peripheral margin, sutures are straight and depressed on both sides, umbilicus narrow and shallow, primary aperture from umbilical-extraumbilical bordered by a thin lip.

Distinguishing feature: it differs from *Muricohedbergella* in having a less pustulose wall texture for this reason its generic assignment is placed with quote pending further studies. It can be confused with specimens of *M. delrioensis* with less inflated chambers, but it differs by showing a finely pustulate wall texture and a lower trochospire.

Remarks: it is a very abundant species especially in the Umbria-Marche Basin showing a continuous stratigraphic record. It is very recognizable because of its typical morphology with 4-4½ cross-shaped chambers.

Stratigraphic distribution: *M. simplicissima* is always present in all the stratigraphic studied section.

### ***Muricohedbergella wondersi*** (Randriasolo and Anglada, 1989)

Plate 9, figs. 7-8

*Hedbergella wondersi* Randriasolo and Anglada, 1989, p. 806, pl. 1, figs. 1-3 (upper Albian, Antsiranana, northern Madagascar).

*Hedbergella wondersi* Randriasolo and Anglada, 1989, Petrizzo and Huber, 2006a, p. 185, pl.1, figs. 4 (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate wall texture characterized by muricae on the first chambers of the last whorl.

Test morphology: low trochospiral test, 7-9 inflated and trapezoidal chambers slowly increasing in size, rounded peripheral margin, sutures are straight and depressed on both sides, umbilicus shallow, primary aperture from umbilical-extraumbilical to slightly equatorial.

Distinguishing features: it differs from *M. planispira* in having more developed pustules at the beginning of the outer whorl and less globular chambers. It can be distinguished from *G. pulchellus* in having a trochospiral test.

Remarks: it is rare and generally small specimens are observed in all the studied sections except for the Mazagan Plateau Site 545, however, it is easy to distinguish from the other *Muricohedbergella* because of its very low trochospiral test.

Phyletic relationship: according to Petrizzo and Huber (2006b), it is considered the ancestor of the *Planomalina* phyletic lineages (*M. wondersi – G. pulchellus – P. praebuxtorfi – P. buxtorfi*). Transitional specimens between *M. wondersi* and *G. pulchellus* characterized by having trochospiral test, pustules concentrated at the beginning of the last whorl and slightly curve suture are observed.

Stratigraphic distribution: in the Umbria-Marche Basin it has a short stratigraphic record ranging from the upper *Ps. ticinensis* Zone to the lower *Th. appenninica* Zone at Monte Petrano and at the base of the section in the *Ps. ticinensis* Zone at Le Brecce. At Mazagan Plateau Site 547A it is present from the base of the section to the middle part of the *Th. appenninica* Zone.

### ***Muricohedbergella astrepta*** (Petrizzo and Huber, 2006a)

Plate 10, figs. 1-4

*Hedbergella astrepta* Petrizzo and Huber, 2006a, p. 182 pl. 6, figs. 1a-c and 4a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

*Hedbergella almadenensis* (Cushman and Todd), Bellier and Moullade, 2002, p. 20, pl.1, figs. 16-18 (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate wall texture characterized by pustules irregularly scattered on test surface more abundant at the beginning of the outer whorl.

Test morphology: low to medium trochospiral test, biconvex, 7-8 globular chambers in the last whorl slowly increasing in size, rounded peripheral margin, all sutures are straight and depressed, umbilicus narrow, deep and often partially covered by the last chamber, primary aperture umbilical to extraumbilical.

Distinguishing features: it differs from the other species belonging to the *Muricohedbergella* genus in having more inflated chambers especially on the umbilical side and more depressed sutures on both sides. Moreover, *M. praelibyca* has less chambers and a lower trochospiral test than *M. astrepta*.

*Muricohedbergella astrepta* can be distinguished by *T. roberti* in having a different wall texture and by lacking the supplementary apertures.

Remarks: *Muricohedbergella astrepta* is a common species, characterized by a discontinuous stratigraphic record in all the studied sections. It is not difficult to recognize even if it can be confused with poorly preserved *T. roberti.*

Stratigraphic distribution: at Monte Petrano it is observed from the base of the section (*Ps. ticinensis* Zone) to the upper part of the *Th. reicheli* Zone. At Le Brecce it is always present. At Mazagan Sites 545 and 547A is present from the lower *Th. appenninica* to the upper part of the *Th. globotruncanoides.*

### ***Muricohedbergella praelibyca*** (Petrizzo and Huber, 2006a)

Plate 10, figs. 5-9

*Hedbergella praelibyca* Petrizzo and Huber, 2006a, p. 185, pl. 5, figs. 1a-c to 5a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate wall texture characterized by irregularly scattered pustules sometimes becoming aligned.

Test morphology: test low trochospiral, biconvex, 5-6 globular chambers in the last whorl gradually increasing in size, rounded peripheral margin and lobate outline, sutures are straight and depressed on both sides, umbilicus narrow and deep, primary aperture umbilical to extraumbilical with a lip.

Distinguishing features: it differs from *P. libyca* in lacking costellae. It can be distinguished by *M. astrepta* in having less chambers in the last whorl. *Muricohedbergella praelibyca* resembles *W. aprica* but it has a wall texture with a more irregularly scattered pustules and a narrower umbilicus.

Phyletic relationship: according to Georgescu and Huber (2006), *M. praelibyca* is regarded as the ancestor of *P. libyca* by the developing of costellae from aligned pustules.

Remarks: it is a common species present in all the studied sections and characterized by a continuous stratigraphic record.

Stratigraphic distribution: at Monte Petrano it is observed from the base of the section (*Ps. ticinensis* Zone) to the lower part of the *R. cushmani* Zone. At Le Brecce and at Mazagan Plateau it is always present.

### ***Muricohedbergella blakensis*** (Petrizzo and Huber, 2006a)

Plate 11, figs 1-5

*Hedbergella blakensis* Petrizzo and Huber, 2006a, p. 182, pl. 4, figs. 5a-c, 6a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1052E).

Wall texture: macroperforate wall texture with muricae irregularly distributed and more developed on the inner whorls and on the first chambers of the last whorl.

Description: medium trochospiral test, biconvex, 5-7 inflated and slightly elongate chambers triangular in the umbilical side and petaloid on the spiral side gradually increasing in size, pinched peripheral margin, straight and depressed sutures on both sides, umbilicus moderately narrow, umbilical to extraumbilical primary aperture bordered by a lip.

Distinguishing features: it differs from *P. delrioensis* in lacking alignment of pustules that are more abundant and randomly distributed on the shell, in having a more lobate outline and the end of the last whorl pinched; moreover, the inner whorl is more prominent, probably because of the concentration of pustules. It can be distinguished from *M. simplicissima* by the greater number of chambers that increase more gradually in size and in having a strongly muricate wall texture instead of smooth to finely pustulose.

Remarks: in all the studied section *Muricohedbergella blakensis* is a rare species and specimens with 5, 6 and 7 chambers have been observed.

Phyletic relationship: according to Petrizzo and Huber (2006a), *M. blakensis* is supposed to be the descendant of *M. simplicissima* by increasing the number of chambers and by becoming less lobate and the ancestor of *P. delrioensis.* In this study, evidences of this phylogenetic relationship are not detected.

Stratigraphic distribution: in the Umbria-Marche Basin, it appears in the lower *Th. appenninica* Zone and its last occurrence is observed at the base of the *R. cushmani* Zone. At the Mazagan Plateau Site 547A, it is recorded from the middle *Th. appenninica* Zone to the top of the section, while at Site 545 it is present in only one sample in the middle *Th. appenninica* Zone.

### Superfamily PLANOMALINACEA Bolli, Loeblich and Tappan, 1957

### Family ROTALIPORIDAE Sigal, 1958

### Subfamily ROTALIPORINAE Sigal, 1958

### Genus ***Pseudothalmanninella*** Wonders, 1978

Type species: *Globotruncana ticinensis* Gandolfi 1942

### ***Pseudothalmanninella subticinensis*** (Gandolfi, 1957)

Plate 11, figs. 6-9 and Plate 12, figs. 1-2

*Globotruncana ticinensis* subsp. *subticinensis* Gandolfi, 1957, p. 59, pl. 8, figs. 1 (upper Albian or lowermost Cenomanian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).

*Rotalipora subticinensis* Gandolfi, 1957, Robaszynski and Caron et al. 1979, p.110. pl. 19. figs. 1-2 (upper Albian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).

*Rotalipora subticinensis* Gandolfi, 1957, Leckie, 1984, p. 601-602, pl. 13, figs. 5-7 (upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547B).

Wall texture: macroperforate and smooth with pustules along the spiral sutures that appear raised.

Test morphology: low to medium trochospiral test, equally biconvex profile and circular outline, 7-8 compressed to inflated chambers triangular on the umbilical side and globular to trapezoidal on the spiral side, single keel present only at the beginning of the last whorl, raised to depressed and slightly curved sutures on the spiral side and depressed and straight on the umbilical side, umbilicus narrow and deep, primary aperture umbilical to extraumbilical, umbilical supplementary apertures bordered by a flap.

Distinguishing features: it differs from *Ps. ticinensis* and *Ps. tehamaensis* in having the last chambers rounded to pinched instead of keeled and spiral sutures raised to depressed.

Remarks: *Pseudothalmanninella subticinensis* is quite a rare species but it has a continuous stratigraphic record and it is easy to recognize because it is the only non-keeled *Pseudothalmanninella*. In the Umbria-Marche Basin and at Mazagan Plateau Site 545 it shows a continuous stratigraphic record, while at Site 547A it shows a scattered stratigraphic distribution.

Phyletic relationships: according to Gonzalez-Donoso et al. (2007), in this study *Ps. subticinensis* is considered the ancestor of *Ps. ticinensis.*

Stratigraphy distribution: in the Umbria-Marche Basin and at Mazagan Plateau Site 545 its last occurrence is observed in the lowermost part of the *Th. appenninica* Zone, while at Site 547A its last occurrence is in the middle part of the *Th. appenninica* Zone.

### ***Pseudothalmanninella ticinensis*** (Gandolfi, 1942)

Plate 12, figs. 3-7

*Globotruncana ticinensis* Gandolfi, 1942, p. 113-135, pl. 2, figs. 3 (upper Albian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).

*Rotalipora ticinensis* Gandolfi, 1942, Robaszynski and Caron et al. 1979, p. 114, pl. 20, figs. 1-2 (upper Albian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland; Spain).

*Rotalipora ticinensis* Gandolfi, 1942, Leckie, 1984, p. 602, pl. 13, figs, 1-3 (upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

Wall texture: macroperforate and smooth with pustules along the spiral sutures that appear raised.
Test morphology: low to medium trochospiral test, equally biconvex edge view and circular outline, 7-8 rather chambers triangular on the umbilical side, inflated at the end of the last whorl and trapezoidal on the spiral side, single keel, raised and slightly curved sutures on the spiral side and depressed or slightly raised and straight on the umbilical side, umbilicus narrow and deep, primary aperture umbilical to extraumbilical, umbilical supplementary apertures bordered by a flap.
Distinguishing features: it differs from *Ps. subticinensis* in being completely keeled, in having less inflated chambers on both sides and all spiral suture raised.
Remarks: *Pseudothalmanninella ticinensis* is abundant and it has rather continuous stratigraphic record in all the studied sections.
Phyletic relationship: it derives from *Ps. subticinensis* (Sigal 1966, 1969; Wonders, 1978; Gonzalez-Donoso et al., 2007) by the acquisition of the keel on the last chambers.
Stratigraphic distribution: at Monte Petrano its last occurrence falls in the middle of *Th. globotruncanoides.* At Le Brecce and at Mazagan Plateau Site 545 it disappears in the upper part of the *Th. appenninica* Zone, while at Site 547A its last occurrence is in the lower *Th. globotruncanoides* Zone.

### ***Pseudothalmanninella tehamaensis*** (Marianos and Zingula, 1966)

Plate 12, figs, 8-9 and Plate 13, figs. 1-3

*Rotalipora tehamaensis* Marianos and Zingula, 1966, p.399, pl. 38, figs. 4 (upper Albian, Dry Creek, Beegum Basin, Chickabally Member, Sacramento Valley, California).
*Pseudothalmanninella tehamaensis* Marianos and Zingula, 1966, Petrizzo et al., 2015, p. 528-530, pl. 5, figs. d-r (Albian, Tehama County, California; lower Cenomanian, Mont Risou, Hautes Alpes, France; upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate and smooth with pustules along the spiral sutures that appear raised.
Test morphology: low to medium trochospiral test, equally biconvex edge view and circular outline, 7-8 chambers triangular on the umbilical side, crescentic to trapezoidal on the spiral side and very angular on the edge side, single keel, raised and almost straight to curved sutures on the spiral side and depressed and straight on the umbilical side, umbilicus narrow and deep surrounded by a periumbilical ridge, primary aperture umbilical to extraumbilical, umbilical supplementary apertures bordered by a flap.

Distinguishing features: it differs from *Ps. ticinensis* in having flat chambers in the umbilical side and by being very angular in edge view and in possessing a very marked periumbilical ridge. It can be distinguished by *Th. brotzeni* because it has more chambers and more angular umbilical view with a more prominent periumbilical ridge.

Remarks: at Monte Petrano and at Mazagan Plateau Site 545 *Ps. tehamaensis* has a discontinuous stratigraphic record and it is quite rare. On the contrary, at Le Brecce it has a continuous stratigraphic record and at Mazagan Plateau Site 547A, where it is common, it is characterized by a continuous distribution till the middle part of *Th. appenninica* Zone, but scattered specimens have been founded till the upper *Th. globotruncanoides* Zone. *Pseudothalmanninella tehamaensis* is not a distinctive taxon because it can be confused with *Ps. ticinensis.* Nowadays, its LO is one of the secondary criteria for the definition of the Albian/Cenomanian boundary, but according to Petrizzo et al. (2015) it is diachronous and consequently it can not be considered a reliable marker and it should not be used anymore for placing the Albian/Cenomanian boundary. Data resulted from this study confirm its scarce reliability as a bioevent for correlation among different depositional basins.

Phyletic lineages: several authors (i.e. Wonders, 1978; González-Donoso et al., 2007; Lipson-Benitah, 2008) considered *Ps. tehamaensis* the descendant of *Ps. ticinensis*. On the contrary, in this study, considering its variability in abundance and its diachrounous and discontinuous stratigraphic record, I considered it as a phenotype of *Ps. ticinensis*.

Stratigraphic distribution: at Monte Petrano it is observed between the lower part of *Th. appenninica* Zone and the lower part of *Th. reicheli.* At Le Brecce it disappears in the lower part of *Th. appenninica* Zone. At Mazagan Plateau Site 545 it is present only in two sample at the base of *Th. appenninica* Zone and at the lower part of the *Th. globotruncanoides* Zone, while in Site 547A it is observed till the upper *Th. globotruncanoides* Zone.

Superfamily PLANOMALINACEA Bolli, Loeblich and Tappan, 1957
Family ROTALIPORIDAE Sigal, 1958
Subfamily ROTALIPORINAE Sigal, 1958

Genus ***Thalmanninella*** Sigal, 1948
Type species: *Thalmanninella brotzeni* Sigal, 1948

### ***Thalmanninella evoluta*** (Sigal, 1969)

Plate 13, figs. 4-7

*Rotalipora praebalenaensis* forma *evoluta* Sigal 1969, p. 637-638, pl. 1 figs. 10-12 (upper Albian, the Diego-Suarez well, north of Mount Raynaud, Madagascar).

*Rotalipora evoluta* Sigal 1969, Petrizzo and Huber, 2006a, p. 181, pl. 2, figs. 6a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate and finely pustulose on the inner spire and at the beginning of the last whorl.

Test morphology: low trochospiral test, equally biconvex edge view and very lobate outline, 5-7 petaloid chambers, single keel present only at the beginning of the last whorl, last one or two chambers pinched, primary aperture umbilical-extraumbilical, raised and curved sutures on the spiral side and depressed and straight on the umbilical side, supplementary apertures at the base of the sutures.

Distinguishing features: it differs from *Th. appenninica* and *Th. balernaensis* in having the last chambers unkeeled, a more lobate outline, non-overlapping chambers and a narrower and shallower umbilicus.

Remarks: it is present in all the studied sections; specifically, at Mazagan it is very rare, while in the Umbria-Marche Basin it shows a less scattered and longer stratigraphic record. *Thalmanninella evoluta* is not a distinctive species and can be easily confused with specimens of *Th. balernaensis* with few chambers.

Phyletic relationships: in this study, is recognized the phyletic lineage from *T. raynaudi digitalis, Th. evoluta* to *Th. balernaensis.* Rare transitional specimens between *T. raynaudi digitalis* and *Th. evoluta* (see Paragraph 5.3), characterized by pinched margin and depressed spiral sutures (Plate 13, figs. 8-9) are observed. When spiral sutures become raised and the beginning of the last whorl is keeled a specimen can be called *Th. evoluta.*

Stratigraphic distribution: in the Umbria-Marche Basin it is observed from the upper *Ps. ticinensis* Zone to the lower *Th. globotruncanoides* Zone. On the contrary, at Mazagan Site 547A between the upper *Ps. ticinensis* Zone and the middle part of the *Th. appenninica* Zone and at Site 545 it is observed in the lower half of the *Th. appenninica* Zone.

### ***Thalmanninella balernaensis*** (Gandolfi, 1957)

Plate 14, figs. 1-5

*Globotruncana appenninica* Renz 1936, var. alpha Gandolfi 1942, p. 118-119, text fig. 40 (lower Cenomanian, Breggia River, Switzerland).

*Rotalipora appenninica balernaensis* Gandolfi 1957, p. 60, pl. 8, figs. 3a-c (lower Cenomanian, Breggia River, Switzerland).

*Rotalipora balernaensis* Gandolfi 1957, Petrizzo and Huber 2006a, p. 181, pl. 3, figs. 5a-c.

Wall texture: macroperforate and smooth.

Test morphology: trochospiral test, planoconvex edge view and circular outline, 8-9 lobate chambers slowly increasing in size, angular peripheral margin except for the last chamber that is slightly inflated, single keel, raised and curved sutures on the spiral side and depressed and straight on the umbilical side, primary aperture umbilical-extraumbilical, narrow and deep umbilicus, umbilical supplementary apertures.

Distinguishing features: it differs from *Th. appenninica* in having a more circular outline and chambers that increase gradually in size. It can be distinguished from *Th. evoluta* in being completely keeled and in having a less lobate outline

Phyletic relationships: In this study it is considered the possible end member of the phyletic lineage starting from *T. raynaudi digitalis* (see Paragraph 5.3).

Remarks: in the Umbria-Marche Basin it is a usually a large and abundant species and it shows a continuous stratigraphic record, while at Mazagan it is rare, smaller and characterized by a more scattered stratigraphic record.

Stratigraphic distribution: In all the studied sections, it first occurs in the lowermost part of the *Th. appenninica* Zone, except at the Monte Petrano where it appears in the upper *Ps. ticinensis* Zone. Its last occurrence is observed in the lower *Th. globotruncanoides* Zone at Monte Petrano, in the upper part of the *Th. appenninica* Zone in Site 545 and in the middle *Th. globotruncanoides* Zone in Site 547A, while at Le Brecce it is present till the top of the section.

### ***Thalmanninella appenninica*** (Renz, 1936)

Plate 14, figs. 8-9 and Plate 15, figs. 1-4

*Globotruncana appenninica* Renz, 1936, p. 14, fig.2 (lower Cenomanian?, Bottaccione section, Gubbio, central Italy).

*Rotalipora appenninica appenninica* (Renz), Luterbacher and Premoli Silva, 1962, p. 266-268, pl. 19, figs.1 (upper Albian, Bottaccione section, Gubbio, central Italy).

*Rotalipora appenninica* (Renz, 1936), Robaszynski and Caron et al., 1979, p. 60, pl.4, figs.1a-c (topotype) (upper Albian, Bottaccione section, Gubbio, central Italy).

*Rotalipora appenninica* (Renz, 1936), Petrizzo and Huber, 2006a, p. 181, pl. 3, figs. 7 (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1052E).

Wall texture: macroperforate and smooth to finely pustulose at the beginning of the last whorl.

Test morphology: low trochospiral test, planoconvex edge view and subcircular outline, 6-7 chambers rapidly increasing in size lobate on the spiral side and triangular on the umbilical side, angular peripheral margin except for the last chamber that is slightly inflated, single keel, raised and curved sutures on the spiral side and depressed and straight on the umbilical side becoming slightly curved at the end of the last whorl, primary aperture umbilical-extraumbilical, slightly narrow umbilicus without peripheral ridge, umbilical supplementary apertures.

Distinguishing features: it differs from *Th. balernaensis* in having a more elongate outline and chambers less abundant and rapidly increasing in size.

Remarks: *Thalmanninella appenninica* is a problematic species as it has been revised several times (Luterbacher and Premoli Silva, 1962; Sigal, 1969; Wonders, 1978; Robaszynski et al., 1979) especially because Renz (1936) erected it from a thin section. This led to confusion in the definition of *Th. appenninica* and in the distinction from other rotaliporids. One of these is *Th. balernaensis* that has been considered as its synonym for a long time (Wonders, 1978; Robaszynski, Caron, and al., 1979). In this study, the concept of Luterbacher and Premoli Silva (1962) is followed and I refer to the topotype illustrated in Robaszynski and Caron et al. (1979) by the European Working Group of Planktonic Foraminifera, so that the first occurrence of *Thalmanninella appenninica* is easily identified in all the studied sections.

Phyletic relationships: according to González-Donoso et al. (2007), *Th. appenninica* is the ancestor of *Th. globotruncanoides,* considered as synonym of *Th. brotzeni;* moreover, *Th. appenninica* is thought to derive from *Th. balernaensis.* In this study, I consider *Th. appenninica* descending from *T. raynaudi aperta* and giving rise to *Th. brotzeni*. This phyletic relationship is supported by the finding of transitional specimens in between *T. raynaudi aperta* and *Th. appenninica* (Plate 14, figs. 6-7) and in between *Th. appenninica* and *Th. brotzeni* (Plate 15, figs. 10 and Plate 16, figs 1-2) (see Paragraph 5.3).

Stratigraphic range: the first occurrence of *Th. appenninica* is the bioevent used to define the base of the nominal Zone and its disappearance occurs in the upper *Th. reicheli* Zone at Monte Petrano, while at Le Brecce and at Mazagan Plateau its last occurrence is not recorded.

### ***Thalmanninella gandolfii*** (Luterbacher and Premoli Silva, 1962)

Plate 15, figs. 5-8

*Globotruncana appenninica* var. *typica* Gandolfi, 1942, p. 116-123, text-fig. 43 (2, 3); pl. 2, figs. 6; pl. 4, figs. 13, 14; pl. 9, figs. 6; pl. 12, figs. 4-6; pl. 14, figs. 3, 4.

*Rotalipora appenninica gandolfii* Luterbacher and Premoli Silva, 1962, p. 267 pl. 19, figs. 3 (Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).

*Rotalipora appenninica gandolfii* Luterbacher and Premoli Silva, 1962, Leckie, 1984, p. 601, pl. 15, figs. 5-12 (late Albian-Cenomanian, upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Sites 545 and 547A).
*Rotalipora gandolfii* Luterbacher and Premoli Silva, 1962, Petrizzo and Huber, 2006a, p. 183, pl. 3, figs. 2 (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1052E).

Wall texture: macroperforate and smooth.

Test morphology: low trochospiral test, plano-convex to slightly biconvex, subcircular and lobate outline, 6-7 petaloid chambers that are inflated in the final part of the whorl on the umbilical side, single keel, raised and curved suture on the spiral side, while on the umbilical side sutures are depressed to slightly raised at the beginning of the whorl then they become straight to barely curved, wide umbilicus bordered by an umbilical ridge, umbilical to extra-umbilical primary aperture, umbilical supplementary apertures.

Distinguishing features: it can be distinguished from *Th. globotruncanoides* showing slightly curved umbilical sutures, supplementary apertures in umbilical position and more inflated chambers on the umbilical side. It differs by *Th. deeckei* in having a more planoconvex test, less abundant and more petaloid chambers, a wider umbilicus and less curved umbilical sutures.

Remarks: in all the studied sections, *Thalmanninella gandolfi* is not really abundant, it is characterized by scattered record and small specimens can be often confused with *Th. deeckei.*

*Thalmanninella gandolfii* was erected by Luterbacher and Premoli Silva (1962) that elevated to the rank of species forms belonging to *Globotruncana appenninica* var. *typica* recognized by Gandolfi (1942) (=*Globotruncana apenninica apenninica* Gandolfi 1957) and distinguished in having the last chambers very large and inflated that goes gradually towards the umbilicus.

Stratigraphic distribution: at Monte Petrano *Th. gandolfii* is observed from the lowest *Th. reicheli* Zone to the middle of *R. cushmani* Zone, while at Le Brecce it appears just below the top of the section, in the *Th. globotruncanoides* Zone. At Mazagan Site 545 its first occurrence is in the upper part of the *Th. appenninica* Zone and at Site 547A in the lower *Th. globotruncanoides* Zone.

### ***Thalmanninella brotzeni*** Sigal, 1948

Plate 15, figs. 9 and Plate 16, figs. 3-6

*Thalmanninella brotzeni* Sigal, 1948, p.102, pl. 1, figs. 5 (middle Cenomanian, Sidi Aïssa, Algeria).
*Rotalipora brotzeni* (Sigal, 1948), Robaszynski and Caron et al., 1979, p. 68, pl. 6, figs. 1a-c and 2 a-c (Arnayon, Southern West France).

*Thalmanninella brotzeni* Sigal, 1948, Ando and Huber, 2007, pl. A1, figs. 1 (metatype USNM P3930).
*Thalmanninella brotzeni* Sigal, 1948, Caron and Premoli Silvia, 2007, pl. 1 figs. 1 (middle Cenomanian, topotype from Sidi Aïssa, Algeria).
*Thalmanninella brotzeni* Sigal, 1948, Petrizzo et al., 2015, p. 5, pl. 4, figs. g-i (upper Albian, Mont Risou, Hautes Alpes, France).

Wall texture: macroperforate and smooth.
Test morphology: low to moderate trochospiral test, equally biconvex and subcircular outline passing form compact to slightly lobate, in edge view acute peripheral margin, 6-8 crescentic to more petaloid chambers at the end of the last whorl, the last chamber sometimes is very inflated on the umbilical side, single keeled, raised and curved sutures on the spiral side and raised to depressed and curved backwards on the umbilical side, umbilicus rather small, deep and bordered by a marked umbilical ridge, primary aperture umbilical to extraumbilical, supplementary umbilical apertures bordered by thin lips.
Distinguishing features: it differs from *Th. globotruncanoides* by being generally smaller, by having a biconvex profile, a less lobate outline, more crescentic chambers, more evident umbilical ridge and supplementary apertures only in umbilical position. It can be distinguished by *Th. greenhornensis* in having less chambers, raised and less curved umbilical suture, umbilical to sutural secondary apertures bordered by marked rims.
Remarks: In the studied section *Th. brotzeni* is quite common and easy to identify and it has a continuous stratigraphic record. It has long been considered the junior synonym of *Th. globotruncanoides* (Wonders, 1978, 1980; Robaszynski and Caron, 1995; Gale et al., 1996; González-Donoso et al., 2007; Ando and Huber, 2007; Lipson-Benitah, 2008; Robaszynski et al., 2008) till Caron and Premoli Silva (2007) identified differences between them and started to considerate *Th. brotzeni* and *Th. globotruncanoides* as two distinct species.
Phyletic relationships: in this study, *Th. brotzeni* is considered the descendant of *Th. appenninica* (see Paragraph 5.3) according to the presence of transitional specimens between the two species, particularly in the Umbria-Marche Basin (Plate 15, figs. 10 and Plate 16, figs 1-2).
Stratigraphic distribution: Its first appearance falls in the upper *Th. appenninica* Zone and its last occurrence in the Umbria-Marche Basin falls at the base of the *R. cushmani*, while at Mazagan Plateau is present till the top of the studied sections.

### ***Thalmanninella globotruncanoides*** (Sigal, 1948)

Plate 16, figs. 7 and Plate 17, figs. 1-4

*Thalmanninella globotruncanoides* Sigal, 1948, p. 100, pl. 1, figs. 4 (middle Cenomanian, Sidi Aïssa, Algeria).

*Thalmanninella globotruncanoides* Sigal, 1948, Ando and Huber, 2007, pl. 3, figs. 3 (topotype USNM 479719).

*Thalmanninella globotruncanoides* Sigal, 1948, Caron and Premoli Silvia, 2007, pl. 1 figs. 2 (middle Cenomanian, topotype from Sidi Aïssa, Algeria).

*Thalmanninella globotruncanoides* Sigal, 1948, Petrizzo et al., 2015, p. 7, pl. 4, figs. a-f and v-x (lower Cenomanian, Mont Risou, Hautes Alpes, France; Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate and smooth.

Test morphology: low trochospiral test, umbilico-convex, inner spire plane to slightly elevated, lobate outline, 6-7 slightly crescentic to petaloid chambers that are flat to more inflated at the end of the last whorl, single keel, raised and curved sutures on the spiral side and raised to partially depressed and curved with distinctive “fish-hook” shape on the umbilical side, umbilicus rather large and shallow, umbilical to extraumbilical primary aperture, umbilical secondary aperture becoming sutural in the last chambers.

Distinguishing features: it differs from *Th. brotzeni* in having a planoconvex profile, a more lobate outline, more petaloid chambers, a less marked umbilical ridge and supplementary apertures migrating out of the umbilical area becoming sutural. It can be distinguished by *Th. greenhornensis* in having less and more petaloid chambers, partially depressed sutures on the umbilical side, less pronounced umbilical ridge and supplementary apertures not bordered by rims.

Remarks: *Thalmanninella globotruncanoides* is abundant and easy to identify and it has a continuous stratigraphic record. Its first occurrence is the bioevent used for the base of the nominal Zone and the primary criterion for the definition of the Albian/Cenomanian boundary and, for this reason, in this study a very strict species concept is applied. Ando and Huber (2007) described *Th. globotruncanoides* as characterized by completely raised umbilical sutures and proposed that it gave rise to *Th. greenhornensis* by the acquisition of depressed umbilical sutures. In this study, *Th. globotruncanoides* is also considered the ancestor of *Th. greenhornensis*, but its umbilical sutures are described as mostly depressed to almost completely raised following the features of the phyletic lineage. *Thalmanninella globotruncanoides* and

*Th. brotzeni* were considered synonyms until Caron and Premoli Silva (2007) described them as distinct species (see also *Th. brotzeni*).

Phyletic lineages: According to González-Donoso et al. (2007) and Lipson-Benitah (2008), in this study, *Th. globotruncanoides* is regarded as the descendant of *Th. brotzeni* as several transitional taxa are observed in all the studied sections (Plate 16, figs. 8-10) and the ancestor of *Th. greenhornensis* (see Paragraph 5.3).

Stratigraphic distribution: at Monte Petrano it disappears in the middle part of the *Th. cushmani* Zone, while at Mazagan Plateau is present till the top of the sections.

### ***Thalmanninella greenhornensis*** (Morrow, 1934)

Plate 17, figs. 8-9 and Plate 18, figs. 1-2

*Globorotalia greenhornensis* Morrow, 1934, p. 199, pl. 31, figs. 1 (Upper Cretaceous, Colorado group, Greenhorn Formation, Hartland shale member).

*Rotalipora greenhornensis* Morrow, 1934, Desmares et al., 2008, p. 97, pl. 2, figs. 1 (Western Interior Basin, Las Animas section, Colorado).

*Rotalipora greenhornensis* Morrow, 1934, Ando and Huber, 2007, pl. 4, figs. 3-4 (Cenomanian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C; Western Pacific Mountains, DSDP Site 463).

Wall texture: macroperforate and smooth wall texture.

Test morphology: low trochospiral test, planoconvex to biconvex, outline subcircular and usually non lobate, angular outline in edge view, 8-9 strongly crescentic chambers, single keeled, raised and curved sutures on the spiral side and curved and mostly raised on the umbilical side, deep umbilicus surrounded by a marked periumbilical ridge, umbilical to extraumbilical primary aperture, umbilical secondary apertures migrating till the base of the suture characterized by thick rims.

Distinguishing features: it differs from *Th. globotruncanoides* in having more crescentic chambers, more raised sutures on the umbilical side. It can be distinguished by *Th. deeckei* in having more crescentic chambers, an angular periphery in edge view, umbilical sutures more curved and supplementary apertures evident and surrounded by rims.

Remarks: *Thalmanninella greenhornensis* is abundant and has a continuous stratigraphic distribution in the Monte Petrano section, while at Mazagan Plateau it is rare and characterized by a scattered record. Ando and Huber (2007) photographed and described in detail the holotype of *Th. greenhornensis* and enunciated the main morphological keys for its identification and distinction form its ancestor *Th. globotruncanoides* (see also *Th. globotruncanoides*). They observed that, probably because of the poor preservation on the holotype, the *Th. greenhornensis* concept is unclear and has a very large variability. Afterward, even if the holotype clearly shows depressed umbilical sutures except for the first one on the last whorl, the general concept of *Th. greenhornensis* is a taxon with strongly raised umbilical sutures. Thus, according to the authors, partially raised umbilical sutures, umbilically positioned supplementary apertures and closely spaced periumbilical ridge are taken as the diagnostic features of *Th. greenhornensis,* so that it can be easily distinguished by its ancestor *Th. globotruncanoides* that, on the contrary, is characterized by fully raised umbilical sutures. They suggested that the transition from the ancestor to the descendant occurs by the loss of almost one raised suture. According to Ando and Huber (2007) other morphological features, considered for long time as diagnostic for the identification of *Th. greenhornensis,* such as crescentic numerous chambers and smooth and circular peripheral outline, on the contrary can be applied to evolved forms of *Th. globotruncanoides.* Desmares et al (2008), illustrated *Th. greenhornensis* as a single keeled form characterized by angular lateral view, curved sutures raised on the spiral side and mostly raised on the umbilical side, with pronounced periumbilical ridge and umbilical supplementary apertures. In this study, the species concept by Desmares et al. (2008) is followed according to the species features above mentioned.

Phyletic relationship: according to González-Donoso et al. (2007) and Lipson-Benitah (2008), *Th. greenhornensis* is regarded as the descendant of *Th. globotruncanoides*. In this study, transitional specimens between the two species are not found. Specimens of evolved *Th. globotruncanoides* characterized by thicker and more angular edge view, umbilical suture more raised and slightly rimmed umbilical sutures, are observed in the Monte Petrano section and at Mazagan Plateau Site 547A. Even if these specimens possess intermediate features between *Th. globotruncanoides* and *Th. greenhornensis,* they cannot be regarded as transitional morphotypes because they first occur above the LO of *Th. greenhornensis* (Plate 17, figs. 5-7). Moreover, Desmares et al. (2008) described the transition from *Th. greenhornensis* to its descendant *Anaticinella multiloculata* by the gradual loss of keel and of umbilical and spiral raised curved sutures passing to straight and depressed. In the studied sections, transitional specimens to *A. multiloculata* are not observed.

Stratigraphic distribution: at Monte Petrano it appears at the base of the *Th. reicheli* Zone and it is present till the top of the section. At Mazagan Plateau its first occurrence falls in the lower *Th. globotruncanoides* Zone.

### ***Thalmanninella deeckei*** (Franke, 1925)

Plate 18, figs. 3-5

*Rotalia deeckei* Franke, 1925, p. 88-90, pl. 8, figs. 7 (Cenomanian, Jordanshutte auf Wollin, Pommern, Germany).

*Rotalipora deeckei* Franke, 1925, Robaszynski et al., 1979, p. 80, pl. 9, figs. 1-2 and pl. 10, figs. 1-2 (La Batie-Cremezin, south-east France; Pakistan).

Wall texture: macroperforate and smooth.

Test morphology: low trochospiral test, umbilico-convex, outline subcircular and slightly lobate, subangular edge view, 6-7 crescentic to petaloid chambers on the spiral side and trapezoidal on the umbilical side, single keeled, raised and curved sutures on the spiral side and curved and partially raised on the umbilical side, deep umbilicus surrounded by a periumbilical ridge, umbilical to extraumbilical primary aperture, umbilical supplementary aperture sometimes bordered by rims.

Distinguishing features: It differs from *Th. gandolfi* in being umbilico-convex, in having more abundant and crescentic chambers and a less marked periumbilical ridge. It can be distinguished by *Th. reicheli* in having more crescentic chambers and partially raised and curved umbilical sutures.

Remarks: *Thalmanninella deeckei* is a rare species characterized by an almost continuous stratigraphic record at Monte Petrano and by a scattered stratigraphic distribution at Mazagan Plateau. It is easily confused with *Th. reicheli* because they have a very similar morphology, but they can be distinguished according to the above listed differences.

Stratigraphic distribution: at Monte Petrano its first appearance falls in the middle of *Th. reicheli* Zone and it is present till the top of the section. At Mazagan Plateau Site 547A its first occurrence is recorded in the middle *Th. globotruncanoides* Zone, while at Site 545 *Th. deeckei* is observed in only one sample in the *Th. globotruncanoides* Zone.

### ***Thalmanninella reicheli*** (Mornod, 1950)

Plate 18, figs. 6-9

*Globotruncana reicheli* Mornod, 1950, p. 583, figs. 5(4) (upper Cenomanian, Ruisseau des Covayes, southern east slope of the Montsalvens chain, north of Cerniat, Préalpes fribourgeoises, Switzerland).

*Thalmanninella reicheli* Mornod, 1950, Caron and Spezzaferri, 2006, p. 375-378, pl. 1, figs. 3 (neotype).

Wall texture: macroperforate and smooth.

Test morphology: low trochospiral test, planoconvex, lobate and subcircular outline, subangular edge view, 6-7 chambers petaloid on the spiral side and trapezoidal to subtriangular and slightly inflated on the umbilical side, single keel, raised and curve sutures on the spiral side and depressed and straight on the umbilical side, umbilicus quite wide and deep, umbilical to extraumbilical primary aperture, umbilical secondary apertures becoming sutural in the last chambers.

Distinguishing features: It differs from *Th. deeckei* in being planoconvex, in having less chambers and straight and depressed umbilical sutures. It can be distinguished by *Th. gandolfi* in showing straight and depressed umbilical sutures and umbilical to sutural umbilical supplementary sutures.

Remarks: *Thalmanninella reicheli* is a rare species that is observed at Monte Petrano with a very scattered stratigraphic distribution. The holotype is missing and the neotype has been described and illustrated by Caron and Spezzaferri (2006a).

Stratigraphic distribution: the first appearance of *Thalmanninella reicheli* is used as the bioevent for the base of the nominal Zone, while its last occurrence is observed in the upper part of the *Th. reicheli* Zone.

### Superfamily PLANOMALINACEA Bolli, Loeblich and Tappan, 1957
### Family SCHACKOINIDAE Pokorný, 1958

### Genus ***Schackoina*** Thalmann, 1932
Type species: *Siderolina cenomana* Schacko, 1897

### ***Schackoina leckiei*** Bellier, Moullade and Tronchetti, 2003
Plate 19, figs. 2

*Schackoina leckiei* Bellier, Moullade and Tronchetti, 2003, p. 137, pl. 1, figs 1-13 (holotype under the name of *Clavihedbergella moremani in* Leckie, 1984, p. 611, pl. 8, figs. 12) (upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

Wall texture: finely perforate and smooth to finely pustulose.

Test morphology: pseudoplanispiral test, 5 elongate chambers gradually increasing in size and in the elongation of chambers passing from subspherical to fingerlike, stellate outline and hourglass edge view, sutures depressed on both sides, narrow and shallow umbilicus, equatorial primary aperture with a thin lip.

Distinguishing features: it differs form *S. cenomana* in having more abundant and elongated chambers. It can be distinguished by *S. bicornis* in having more elongated and non-bifurcated chambers.

Remarks: it is a very rare species observed only at Mazagan Plateau Site 547A and indeed, it has been observed in two samples.

Stratigraphic distribution: it is observed in the *Ps. ticinensis* Zone (base of the section) and in the lower *Th. appenninica* Zone.

### ***Schackoina cenomana*** (Schacko, 1897)

*Siderolina cenomana* Schacko, 1897, p. 166, pl. 4, figs. 3-5 (Cenomanian, type locality not given).

*Schackoina cenomana* Schacko, 1897, Leckie, 1984, p. 598, pl. 9, figs. 5, 9 (Cenomanian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

Wall texture: finely perforate and slightly pustulose.

Test morphology: pseudoplanispiral test, 4 elongate chambers gradually increasing in size, stellate outline and hourglass edge view, sutures depressed on both sides, narrow and shallow umbilicus, equatorial primary aperture with a thin lip.

Distinguishing features: the *Schackoina* genus is very distinctive because of the typical stellate morphology. It differs from *S. bicornis* in having the last chamber non-bifurcated.

Remarks: it is a very rare species observed at Monte Petrano and at Mazagan Plateau Site 545 and characterized by a very scattered stratigraphic record.

Stratigraphic distribution: at Monte Petrano from upper *Th. appenninica* to lower *Th. reicheli*. At Mazagan Site 545, it is observed from the upper *Ps. ticinensis* Zone till the top of the section.

### ***Schackoina bicornis*** Reichel, 1948

Plate 19, figs. 1

*Schackoina cenomana bicornis* Reichel, 1948, p. 400, figs, 4, 6-10 (Cenomanian, Gorge of the Breggia River, Canton Ticino, southeastern Switzerland).

*Schackoina bicornis* Reichel, 1948, Leckie, 1984, p. 598, pl. 9, figs. 10-11 (Cenomanian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

Wall texture: finely perforate and smooth to finely pustulose.

Test morphology: pseudoplanispiral test, 4 slightly inflated and elongate chambers gradually increasing in size, the last chambers bifurcates in two equally oblique parts in a plane perpendicular to the equatorial view, stellate outline and hourglass edge view, sutures depressed on both sides, narrow and a shallow umbilicus, equatorial primary aperture whit thin lip.

Distinguishing feature: it differs from species belonging to the *Schackoina* genus in having the last chamber doubled. Moreover, it can be distinguished from *S. leckiei* in having less abundant and elongate chambers.

Remarks: it is a very rare, but distinctive species observed in only one sample at Mazagan Plateau Site 545.

Stratigraphic distribution: at Monte Petrano, it is observed in the *Th. reicheli* Zone.

Superfamily HETEROHELICACEA Cushman, 1927

Family HETEROHELICIDAE Cushman, 1927

Subfamily HETEROHELICINAE Cushman, 1927

Genus ***Protoheterohelix*** Georgescu and Huber, 2009

Type species: *Guembelina washitensis* Tappan, 1940

***Protoheterohelix washitensis*** (Tappan, 1940)

Plate 19, figs 3

*Protoheterohelix washitensis* Tappan, 1940, p. 115, pl. 19, figs. 1 (Lower Cretaceous, Grayson Formation, Austin, TX).

*Protoheterohelix washitensis* Tappan, 1940, Georgescu and Huber, 2009, p. pl. 1, figs. 2-14 (upper Albian- lower Cenomanian, Del Rio Clay, Grayson Formation, Austin, TX; Blake Nose Escarpment, Western North Atlantic Ocean, ODP Sites 1050C and 1052E).

Wall texture: finely perforate and smooth.

Test morphology: twisted biserial test, 10-12 globular to reniform chambers gradually increasing in size, the first chamber should correspond to a generally large proloculus, sutures depressed and straight on both sides, primary aperture at the base of the last chamber.

Distinguishing feature: *Protoheterohelix washitensis* differs from its supposed ancestor *P. obscura* in having generally a more elongate test, more abundant chambers that are globular rather than reniform.

Remarks: it is a rare species characterized by scattered stratigraphic record that is observed in all the studied sections except for le Brecce.

Stratigraphic distribution: At Monte Petrano, it is observed in the middle and upper part of the *R. cushmani* Zone. At Mazagan Site 545 it is present from the base to the upper *Th. appenninica* Zone, while in Site 547A it is observed only in one sample in the upper *Th. globotruncanoides* Zone.

Superfamily PLANOMALINECEA Bolli, Loeblich and Tappan, 1957

Family PLANOMALINIDAE Bolli, Loeblich and Tappan, 1957

Genus ***Planomalina*** Loeblich and Tappan, 1946

Type species: *Planomalina apsidostroba* Loeblich and Tappan, 1946

= *Planulina buxtorfi* Gandolfi, 1942

***Planomalina praebuxtorfi*** Wonders, 1975

Plate 19, figs. 4-8

*Planomalina praebuxtorfi* Wonders, 1975, p. 90, pl. 1, figs. 1 (upper Albian, El Burrueco, southern Spain).

*Planomalina praebuxtorfi* Wonders, Leckie 1984, p. 613, p. 110, figs. 1-2 (upper Albian, Mazagan Plateau, Eastern North Atlantic, DSDP Site 547A).

Wall texture: macroperforate and smooth.

Test morphology: planispiral involute test, 9-11 crescentic chambers, suture curved, the great abundance of aligned muricae gives rise to raised suture and to a keel at the beginning of the last whorl while last chambers are pinched, equatorial aperture.

Distinguishing features: it differs from *G. pulchellus* in having raised sutures and a keel at the beginning of the last whorl. It can be distinguished by *P. buxtorfi* because the last chambers are more rounded and with depressed sutures.

Remarks: it is not a common species and in the Umbria-Marche Basin and at Site 547A it has continuous stratigraphic record, while at Site 545 it is observed in only one sample.

Phyletic relationship: according to Petrizzo and Huber (2006b), it is considered the descendant of *G. pulchellus* and the ancestor of *P. buxtorfi* in the phyletic lineage from *M. wondersi* to *P. buxtorfi*. Moreover, transitional taxa between *G. pulchellus* and *P. praebuxtorfi* and between *P. praebuxtorfi* and *P. buxtorfi* is observed in the Monte Petrano section and at the Mazagan Plateau Site 547A.

Stratigraphic distribution: at Monte Petrano and at Le Brecce it spans from the base of the *Th. appenninica* Zone to the upper part of the *P. buxtorfi* Subzone. At Mazagan Plateau Site 547A it appears at the base of the *Th. appenninica* Zone till the middle part of the same Zone, while at Site 545 it is present at the base of the *Th. appenninica* Zone.

### ***Planomalina buxtorfi*** (Gandolfi, 1942)

Plate 19, figs, 9-10 and Plate 20, figs. 1-3

*Planulina buxtorfi* Gandolfi, 1942, p.103, pl. 3, figs 7 (lower Cenomanian, Breggia River near Chiasso, Canton Ticino, Switzerland).

Wall texture: macroperforate and smooth.

Description: planispiral involute test, 9-11 crescentic chambers, completely raised and strongly curved backward sutures, pronounced keel, equatorial aperture.

Distinguishing features: It differs from its ancestor *P. praebuxtorfi* in having a complete keel and all the sutures raised.

Remarks: it is an abundant and very distinctive taxon particularly in the Umbria-Marche Basin.

Phyletic relationship: it is considered the last member of the phyletic lineage from *M. wondersi – G. pulchellus – P. praebuxtorfi* to *P. buxtorfi* (Petrizzo and Huber, 2006b).

Stratigraphic distribution: its stratigraphic range defines the *P. buxtorfi* Subzone, included in the *Th. appenninica* Zone.

## Superfamily ROTALIPORACEA Sigal, 1958

## Family HEDBERGELLIDAE Loeblich and Tappan, 1961

## Subfamily ROTUNDININAE Bellier and Salaj, 1977

### Genus **Praeglobotruncana** Bermudez, 1952

Type species: *Globorotalia delrioensis* Plummer, 1931

### ***Praeglobotruncana delrioensis*** (Plummer, 1931)

Plate 20, figs. 4-9

*Globorotalia delrioensis* Plummer, 1931, p. 199, pl. 13, figs. 2 (lower Cretaceous, Del Rio Formation, on right bank of Shoal Creek, Austin, Travis Country, TX).

*Praeglobotruncana delrioensis* Plummer, 1931, Robaszynski and Caron et al., 1979, p. 29 pl. 43, figs. 1-2 (topotype, Grayson Formation).

*Praeglobotruncana delrioensis* Plummer, 1931, Petrizzo and Huber, 2006a, p. 182, pl. 4, figs. 2a-c (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1052E).

Wall texture: macroperforate and characterized by aligned pustules, particularly on the first chambers of the last whorl; chambers surface is pustulose.

Test morphology: low trochospiral test, biconvex profile and lobate outline, 5-6 slightly inflated petaloid chambers gradually increasing in size as added, imperforate peripheral margin rounded to pinched characterized by aligned pustules more common in the first chambers, in evolved specimens the concentration of pustules can result in a keel at the beginning of the last whorl, straight and depressed sutures on the umbilical side while on the spiral side sutures are slightly curved and depressed or raised and marked by pustules at the beginning of the last whorl, umbilicus narrow and deep, umbilical to extraumbilical primary aperture.

Distinguishing features: it can be distinguished from *M. blakensis* in having an imperforate margin marked by the concentration of aligned pustules. It differs from *P. stephani* by having a lower trochospire and a more lobate outline.

Remarks: *Praeglobotruncana delrioensis* is an abundant species in all the studied sections characterized by a continuous stratigraphic record. According to the original description by Plummer (1931), *P. delrioensis* is a single keeled taxon with thin lateral profile and all spiral sutures are curved and raised. Specimens similar to the holotype are observed only in the Monte Petrano section as very rare and consequently the species concept has been enlarged (Robaszynski, Caron at al. 1979, Petrizzo and Huber, 2006a). In the Cenomanian, together with *P. delrioensis* characterized by a single alignment, specimens with two alignments of pustules are observed (Plate 20, figs. 7). Moreover, *P. delrioensis* gradually developed raised spiral sutures and the increasing of the concentration of pustules gives rise to a keel.

Stratigraphic distribution: at Monte Petrano its stratigraphic range spans from the uppermost *Ps. ticinensis* Zone to the top of the section; both *P. delrioensis* with two alignments of pustules and keeled specimens is observed from the base of the *Th. reicheli* Zone. At Le Brecce and at Mazagan Plateau Site 545 its first occurrence is at the base of the *Th. appenninica* Zone, while at Site 547A *P. delrioensis* appears in the middle part of the same Zone.

### ***Praeglobotruncana stephani*** (Gandolfi, 1942)

Plate 21, figs. 1-5

*Globotruncana stephani* Gandolfi, 1942, p. 130, pl. 3, figs. 4 (Cenomanian, Gorge of the Breggia River, near Chiasso, southeastern Switzerland).

*Praeglobotruncana stephani* (Gandolfi), Robaszynski, Caron et al., 1979, p. 47, pl. 48, figs. 1 (topotype, Breggia, southeastern Switzerland).

*Praeglobotruncana stephani* (Gandolfi), Petrizzo and Huber, 2006a, p. 182, pl. 4, figs. 4 (upper Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1052E).

Wall texture: macroperforate and characterized by aligned pustules, particularly on the first chambers of the last whorl; chambers are pustulose.

Description: medium trochospiral test, spiroconvex profile and slightly lobate profile, the internal whorl covers more than a half of the diameter on the spiral side, 6-7 slightly inflated petaloid chambers slowly increasing in size, imperforate pinched peripheral margin characterized by aligned pustules more common in the first chambers and the concentration of pustules can bring to a keel at the beginning of the last whorl; primary aperture umbilical to extraumbilical; straight and depressed sutures on the umbilical side while on the spiral side sutures are slightly curve and depressed or raised and marked by pustules at the beginning of the last whorl, narrow umbilicus.

Distinguishing features: It differs from *P. delrioensis* in having higher throcospire, a less lobate outline and a long spire resulting in more chambers in the internal whorl. Moreover, it shows a lower trochospire if compared to *P. gibba.*

Remarks: *Praeglobotruncana stephani* is an abundant species in all the studied sections characterized by an almost continuous stratigraphic record. It can be confused with *P. delrioensis* because of their similar morphology. In the Cenomanian, as for *P. delrioensis,* specimens with two alignments of pustules are observed. Meanwhile, raised spiral suture developed and the increasing of the concentration of pustules gives rise to a keel.

Stratigraphic distribution: at Monte Petrano its stratigraphic distribution spans from the lower part of the *Th. appenninica* to the top of the section; both *P. stephani* with two alignments of pustules and keeled specimens are observed from the base of the *Th. reicheli* Zone. At Le Brecce and at Mazagan Plateau Site 547A the first occurrence of *P. stephani* is observed at about the middle of the *Th. appenninica* Zone. On the contrary, at Site 545 *P. stephani* appears in the upper *Ps. ticinensis* Zone.

### ***Praeglobotruncana gibba*** Klaus, 1960

Plate 21, figs. 6-9

*Praeglobotruncana stephani* (Gandolfi) var. *gibba,* Klaus 1960, pp. 209, 304-305, pl. 16-17, fig. 6a-c (Cenomanian, Gorge of the Breggia River, near Chiasso, southeastern Switzerland).

*Praeglobotruncana gibba* (Klaus), Robaszynski, Caron et al., 1979, p. 30, pl. 44, figs. 1a-c (Cenomanian, Gorge of the Breggia River, near Chiasso, southeastern Switzerland).

Wall texture: macroperforate and characterized by pustules particularly concentrated on the spiral sutures.

Test morphology: high trochospiral test, slightly lobate and circular outline, 5-6 triangular to trapezoidal slightly inflated chamber on the umbilical side and petaloid chambers on the spiral side, imperforate pinched margin, sutures straight and depressed on the umbilical side and curved and depressed or raised on the spiral side, concentration of aligned pustules along the spiral sutures, umbilicus narrow and deep, umbilical to extraumbilical primary aperture.

Remarks: it is a rare species observed in all the studied section characterized by a discontinuous stratigraphic range and clearly distinguishable by other species belonging to the *Praeglobotruncana* genus because of the peculiar high trochospire.

Distinguishing features: *Praeglobotruncana gibba* differs from other *Praeglobotruncana* in having a more convex spiral side and spiral sutures always raised.

Stratigraphic distribution: at Monte Petrano it appears in the middle of the *Th. appenninica* Zone but it has not a continuous record till the middle part of the *Th. reicheli* Zone. At Site 547A it is observed from the top of the *Th. appenninica* Zone to the middle part of the *Th. globotruncanoides* Zone and at le Brecce and at Mazagan Plateau Site 545 it is recorded in only one sample in the *Th. globotruncanoides* Zone.

### Superfamily ROTALIPORACEA Sigal, 1958
### Family HEDBERGELLIDAE Loeblich and Tappan, 1961
### Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961

### Genus ***Paracostellagerina*** Georgescu and Huber, 2006

Type species: *Hedbergella libyca* Barr, 1972

### ***Paracostellagerina libyca*** (Barr, 1972)

Plate 22, figs. 1-5

*Hedbergella libyca* Barr, 1972, p. 14, pl. 10, figs. 5 (lower Cenomanian, Cyrenaica province, Libya).

*Costellagerina libyca* Barr, 1972, Petrizzo and Huber, 2006a, p. 186, pl. 5, figs. 6 (Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

*Paracostellagerina libyca* Barr, 1972, Georgescu and Huber, 2006, p. 370-372, pl. 1, figs. 4-6 (Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1050C).

Wall texture: macroperforate characterized by distinctive costellae derived from aligned pustules

Test morphology: low trochospiral test, 5-7 globular chambers gradually increasing in size, rounded peripheral margin and lobate outline, sutures straight and depressed on both sides, umbilicus narrow and deep, primary aperture umbilical to extraumbilical with a lip.

Distinguishing features: it differs from *Muricohedbergella* in having costellae.

Phyletic relationship: according to Georgescu and Huber (2006), *P. libyca* derived from *M. praelibyca* by the increasing of aligned pustules becoming costellae.

Remarks: it is a distinctive taxon with a continuous stratigraphic range, observed in all the studied section, particularly abundant at the Mazagan Plateau 545.

Stratigraphic distribution: in all the studied sections the first occurrence of *P. libyca* falls in the *P. buxtorfi* Subzone, while its disappearance is observed in the upper part of the *Th. appenninica* Zone.

### Superfamily PLANOMALINACEA Bolli, Loeblich and Tappan, 1957
### Family ROTALIPORIDAE Sigal, 1958
### Subfamily ROTALIPORINAE Sigal, 1958

### Genus ***Rotalipora*** Brotzen, 1942
Type species: *Rotalipora turonica* Brotzen, 1942

### ***Rotalipora montsalvensis*** (Mornod, 1950)
Plate 22, figs. 6-8

*Globotruncana montsalvensis* Mornod, 1950, p. 584, figs. 4(1) (upper Cenomanian, Ruisseau des Covayes, southern east slope of the Montsalvens chain, north of Cerniat, Préalpes fribourgeoises, Switzerland).

*Rotalipora montsalvensis* Mornod, 1950, Caron and Spezzaferri, 2006a, p. 378, pl. 2, figs. 3.

Wall texture: macroperforate and smooth.

Test morphology: low trochospiral test, biconvex, lobate profile and subcircular outline, 5-6 slightly inflated chambers petaloid on the spiral side and subtriangular on the umbilical side, pinched or single keeled, sutures are depressed and curve on the spiral side and depressed and straight on the umbilical side, umbilicus wide and shallow, umbilical to extraumbilical primary aperture, sutural secondary aperture bordered by rims.

Distinguishing features: It differs from *R. cushmani* in having all spiral sutures depressed, slightly inflated chambers and a less angular edge view.

Remarks: *Rotalipora montsalvensis* is a common species with a continuous stratigraphic record that is observed in the Monte Petrano section. At Mazagan Plateau Site 547A it is observed only in one sample in the upper part of the *Th. globotruncanoides* Zone.

Phyletic relationship: data from the Monte Petrano section support the interpretation that *R. montsalvensis* is the ancestor species of *R. cushmani* according to Gonzalez-Donoso et al. (2007), as transitional specimens between the two species are observed (Plate 22, figs. 10 and Plate 23, figs. 1).

Stratigraphic distribution: at Monte Petrano its stratigraphic record coincides with the *Th. reicheli* Zone, while at Mazagan Plateau Site 547A few specimens are observed in one sample in the upper part of the *Th. globotruncanoides.*

### ***Rotalipora cushmani*** (Morrow, 1934)

Plate 22, figs. 9 and Plate 23, figs. 2-4

*Globorotalia cushmani* Morrow, 1934, p. 199, pl. 31, figs. 4 (upper Cretaceous, Hodgeman County, Kansas, U.S.A.).

*Rotalipora cushmani* Mornod, 1934, Robaszynski and Caron, 1979, p. 74, pl. 7, figs. 1 and pl. 8, figs. 1-2 (upper Cretaceous, Hodgeman County, Kansas, U.S.A.; région de Rocroi, north of France).

Wall texture: macroperforate and smooth.

Test morphology: low to medium trochospiral test, biconvex, very lobate profile and subcircular outline, angular edge view, 5-6 chambers petaloid on the spiral side and subtriangular on the umbilical side, each chamber on the umbilical side is characterized by a pyramid-like structure formed by the concentration of pustules, strongly pronounced single keel, sutures are raised and curve on the spiral side and depressed and straight on the umbilical side, umbilicus wide and shallow, umbilical to extraumbilical primary aperture, sutural secondary aperture bordered by rims.

Distinguishing features: It differs from *R. montsalvensis* in having raised spiral sutures, a more pronounced keel and the typical pyramid-like structure on the umbilical side.

Remarks: *Rotalipora cushmani* is observed at Monte Petrano where it is quite abundant and it shows a continuous stratigraphic record. At Mazagan Plateau Site 547A only one specimens has been observed. Moreover, particularly at Monte Petrano, several transitional specimens with its ancestor species *R. montsalvensis* are recorded.

Phyletic relationship: transitional specimens observed in the Monte Petrano section and at Mazagan Plateau Site 547A support the interpretation that *R. cushmani* derives from *R. montsalvensis* (Plate 22, figs. 10 and Plate 23, figs. 1).

Stratigraphic distribution: its stratigraphic record defines the *R. cushmani* Zone according to Robaszynski and Caron (1995).

Superfamily ROTALIPORACEA Sigal, 1958
Family HEDBERGELLIDAE Loeblich and Tappan, 1961
Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961

Genus ***Whiteinella*** Pessagno, 1967
Type species: *Whiteinella archeocretacea* Pessagno, 1967

***Whiteinella aumalensis*** (Sigal, 1952)
Plate 23, figs. 5-8

*Globigerina aumalensis* Sigal, 1952, p. 28, figs. 29 (middle Cenomanian, probably Aumale, southeast of Algiers, northern Algeria).

*Praeglobotruncana aumalensis* Sigal, 1952, Robaszynski and Caron et al., 1979, p. 28, pl. 42, figs. 1 (Loeffre-Lewarde, north of France).

Wall texture: macroperforate and pustulose.

Test morphology: middle trochospiral test, spiroconvex, gently lobate profile and subcircular outline, 6-7 chambers petaloid on the spiral side and trapezoidal on the umbilical side, pinched margin, sutures depressed and slightly curve on the spiral side and depressed and straight on the umbilical side, umbilicus quite wide and deep, umbilical to extraumbilical primary aperture.

Distinguishing features: It differs from *Praeglobotruncana* in having more uniform pustules, no alignment in lateral view and larger umbilicus. Moreover, it can be distinguished by *P. delrioensis* in having a higher trochospire and by *P. stephani* because it has depressed spiral sutures. It differs from *W. aprica* in having a pinched peripheral margin.

Remarks: it is a quite abundant species with continuous stratigraphic record that is observed only at Monte Petrano. *Whiteinella aumalensis* is not a distinctive species and it shows a wall texture less pustulose respect to other specimens of *Whiteinella*. Moreover, it is easily misidentified with *P. stephani*

because of its pinched outline. For this reason, in this study, the appearance of the *Whiteinella* genus is referred to the first occurrence of non-pinched species.
Stratigraphic distribution: it appears in the middle of *Th. reicheli* Zone till the top of the Monte Petrano section.

### ***Whiteinella baltica*** Douglas and Rankin, 1969

*Whiteinella baltica* Douglas and Rankin, 1969, p. 193, pl. 9, figs A-C (lower Santonian, east of Bavnodde Pynt, Bornholm, Denmark).
*Whiteinella baltica* Douglas and Rankin, 1969, Robaszynski and Caron et al., 1979, p. 174, pl. 25, figs. 1-5 and pl. 36, figs. 1-2 (east of Bavnodde Pynt, Bornholm, Denmark; Poland).
*Whiteinella baltica* Douglas and Rankin, 1969, Leckie, 1985, p. 144, pl. 2, figs 4,5, 8, 11 (upper Cenomanian, Rock Canyon Anticline, Pueblo, Colorado).

Wall texture: macroperforate and coarsely pustulose.
Test morphology: low trochospiral test, equally biconvex, strongly lobate profile, 4 moderately inflated globular chambers, rounded peripheral margin, strongly depressed and straight sutures on both sides, umbilicus shallow partially covered by a lip, umbilical to extraumbilical primary aperture.
Distinguishing features: it differs from *W. aprica, W. brittonensis, W. paradubia* in having less chambers and a lower trochospire. It can be distinguished by *W. inornata* in having a rounded peripheral margin.
Remarks: it is a rare species and is observed only in the Monte Petrano. It is easily distinguishable from the others species belonging to the *Whiteinella* genus, but it can be confused with small *M. delrioensis* because they shows the same number of chambers in the last whorl especially when the difference in wall texture are not visible because of poor preservation.
Stratigraphic distribution: it appears in the upper of *Th. reicheli* Zone till the top of the Monte Petrano section.

### ***Whiteinella aprica*** (Loeblich and Tappan, 1961)

Plate 24, figs. 1-4

*Ticinella aprica* Loeblich and Tappan, 1961, p. 292, pl. 4, figs. 16 (Cenomanian, U.S. Highway 80, west of Dallas, Texas).
*Whiteinella aprica* Loeblich and Tappan, 1961, Leckie, 1985, p. 144, pl. 1, figs. 1-4 (upper Cenomanian?, Rock Canyon Anticline, Pueblo, Colorado).

Wall texture: macroperforate and coarsely pustulose.

Test morphology: low trochospiral test, equally biconvex, strongly lobate profile, 5-7 moderately inflated globular chambers, rounded peripheral margin, strongly depressed and straight sutures on both sides, umbilicus wide and shallow, umbilical to extraumbilical primary aperture.

Distinguishing features: it differs from *W. brittonensis and W. paradubia* in having a lower trochospire and from *W. aumalensis* in having rounded peripheral margin.

Remarks: at Monte Petrano it is a common species with a quite continuous stratigraphic record while at Mazagan Plateau Site 547A it is not common and characterized by a scattered record.

Stratigraphic distribution: it appears in the upper of *Th. reicheli* Zone till the top of the Monte Petrano section and in the middle part of the *Th. globotruncanoides* at Site 547A.

### ***Whiteinella brittonensis*** (Loeblich and Tappan, 1961)

Plate 24, figs. 5-6

*Hedbergella brittonensis* Loeblich and Tappan, 1961, p. 274, pl. 4, figs., 1 (Cenomanian, Eagle Ford Group, west of Cedar Hills, Dallas County, Texas).

*Whiteinella brittonensis* Loeblich and Tappan, 1961, Robaszynski and Caron et al., 1979, p. 180, pl. 38, figs. 1-2 (Loeffre-Lewarde, north of France).

Wall texture: macroperforate and coarsely pustulose.

Test morphology: moderate to high trochospiral test, spiroconvex, gently lobate profile and subcircular outline, 6 inflated globular chambers, rounded peripheral margin, depressed and straight sutures on both sides, umbilicus narrow and deep, umbilical to extraumbilical primary aperture.

Distinguishing features: it differs from *W. aprica* and *W. paradubia* in having a higher and lower trochospire, respectively. It can be distinguished by *W. aumalensis* because it shows a rounded peripheral margin.

Remarks: it is a not common species and is observed only in the Monte Petrano section.

Stratigraphic distribution: it appears in the middle of *Th. reicheli* Zone till the top of the Monte Petrano section.

### ***Whiteinella paradubia*** (Sigal, 1952)

Plate 24. figs. 7-8

*Globigerina paradubia* Sigal, 1952, p. 28, figs. 28 (Cenomanian, probably northern Algeria).

*Whiteinella paradubia* Sigal, 1952, Robaszynski and Caron et al., 1979, p. 184, pl. 39, figs. 1-2 (upper Cretaceous, Hodgeman County, Kansas, U.S.A.).

*Whiteinella brittonensis/paradubia* Sigal, 1952, Leckie, 1985, p. 144, pl. 1, figs. 13-16 (upper Cenomanian-lower Turonian?, Rock Canyon Anticline, Pueblo, Colorado).

Wall texture: macroperforate and coarsely pustulose.

Test morphology: high trochospiral test, spiroconvex, gently lobate profile and subcircular outline, 6-7 inflated globular chambers, rounded peripheral margin, depressed and straight sutures on both sides, umbilicus narrow and deep, wide and shallow umbilicus, umbilical to extraumbilical primary aperture.

Distinguishing features: it shows the highest trochospire among species belonging to the *Whiteinella* genus. Moreover, it can be distinguished from *W. brittonensis* in having a wider and shallower umbilicus.

Remarks: it is a quite rare species with a discontinuous stratigraphic record that is observed only in the Monte Petrano.

Stratigraphic distribution: it appears in the middle of *Th. reicheli* Zone till the top of the Monte Petrano section.

### ***Whiteinella archeocretacea*** Pessagno, 1967

*Whiteinella archeocretacea* Pessagno, 1967, p. 298-299, pl. 51, figs. 22-24 (Turonian, Eagle Ford Group, west of Cedar Hills, Dallas County, Texas).

*Whiteinella archeocretacea* Pessagno, 1967, Robaszynski and Caron et al., 1979, p. 167, pl. 33, figs. 1 (Eagle Ford Group, west of Cedar Hills, Dallas County, Texas).

Wall texture: macroperforate and coarsely pustulose.

Test morphology: low trochospiral test, equally biconvex, lobate outline and subcircular outline, 4-4½ slightly inflated and petaloid chambers, rounded peripheral margin and thin edge view, depressed and straight sutures on both sides, umbilicus narrow and deep, umbilical to extraumbilical primary aperture.

Distinguishing features: it differs from *W. inornata* in having rounded peripheral margin and thinner edge view. It can be distinguished by *W. baltica* in having thinner edge view.

Remarks: it is a very rare species and is observed only at Monte Petrano.

Stratigraphic distribution: it occurs in the upper part of *Th. reicheli* Zone till the top of the Monte Petrano section.

### ***Whiteinella inornata*** (Bolli, 1957)

*Globotruncana inornata* Bolli, 1957, p. 57, pl. 13, figs. 5 (Coniacian, Trinidad Petroleum Development well Moruga 15, Trinidad).

*Praeglobotruncana inornata* Bolli, 1957, p. 143, pl. 2, figs. 6-7 (upper Cenomanian, Rock Canyon Anticline, Pueblo, Colorado).

Wall texture: macroperforate and pustulose.
Test morphology: low trochospiral test, equally biconvex, lobate outline and subcircular outline, subangular edge view, 4-4 ½ slightly inflated and petaloid chambers, pinched margin, sutures depressed and straight on both sides, umbilicus wide and shallow, umbilical to extraumbilical primary aperture.
Distinguishing features: It differs from *W. baltica* in having a pinched margin, a less pustulose wall texture and in being more angular in lateral view. It can be distinguished from *W. aumalensis* in having less chambers and a lower trochospire.
Remarks: it is a quite rare species that is observed only at Monte Petrano.
Stratigraphic distribution: it occurs in the lower part of *Th. reicheli* Zone till the top of the Monte Petrano section.

### Superfamily GLOBOTRUNCANANCEA Brotzen, 1942
### Family GLOBOTRUNCANIDAE Brotzen, 1942
### Subfamily HELVETOGLOBOTRUNCANINAE Lamolda, 1976

### Genus ***Dicarinella*** Porthault, 1970
Type species; *Globotruncana indica* Jacob and Sastry, 1950

### ***Dicarinella algeriana*** Caron, 1966
Plate 25, figs. 1-2

*Praeglobotruncana algeriana* Caron, 1966, p. 74-75, pl. 16, figs. 8 (lower Turonian, Sidi Aïssa, Algeria).
*Dicarinella algeriana* Caron, 1966, Robaszynski and Caron et al., 1979, p. 60, pl. 50, figs. 2 (lower Turonian, Sidi Aïssa, Algeria).

Wall texture: macroperforate and finely pustulose.
Test morphology: medium trochospiral test, biconvex to spiroconvex edge profile and slightly lobate profile and circular outline, 5-7 petaloid to semicircular chambers slowly increasing in size and generally flat on the spiral side and trapezoidal and slightly inflated on the umbilical side, 2 alignments of pustules

particularly visible at the beginning of the last whorl and divided by an imperforate band, sutures curved and raised on the spiral side and straight and depressed on the umbilical side, umbilicus wide and shallow, umbilical to extra-umbilical primary aperture.

Distinguishing features: it differs from the other species belonging to the genus *Dicarinella* in having a more pustulose wall texture and in lacking the two keels. It differs from *P. stephani* in showing a wider umbilicus and two well defined alignments of pustules divided by an imperforate band.

Remarks: it is observed only at the Monte Petrano section where it is quite common and it shows a continuous stratigraphic record. It can be easily confused with evolved *P. stephani* with two weakly developed alignments of pustules also because it has a similar wall texture.

Phyletic lineages: because it shows common features of *Praeglobotruncana* and *Dicarinella* indeed it has been considered a transitional taxon between the two genera.

Stratigraphic distribution: at Monte Petrano it appears in the lower part of the *R. cushmani* Zone and it is present till the to the top of the section.

### ***Dicarinella imbricata*** (Mornod, 1950)

Plate 25, figs. 3-4

*Globotruncana imbricata* Mornod, 1950, p. 589, pl. 15, figs. 5(3) (Turonian, Ruisseau des Covayes, southern east slope of the Montsalvens chain, north of Cerniat, Préalpes fribourgeoises, Switzerland).

*Dicarinella imbricata* Mornod, 1950, Robaszynski et al., 1979, p. 92, pl. 58, figs 1-2 (Ruisseau des Covayes, southern east slope of the Montsalvens chain, north of Cerniat, Préalpes fribourgeoises, Switzerland; Bellone well, northern France).

*Dicarinella imbricata* Mornod, 1950, Caron and Spezzaferri, 2006b, p. 299, pl. 1, figs. 2, 4, 5.

Wall texture: macroperforate and smooth to finely pustulose.

Test morphology: low trochospiral test, biconvex profile and lobate outline, 5-6 chambers subtriangular on the umbilical side and petaloid on the spiral side, double keel, the keel band appears to be discontinuous from a chamber to the next producing an imbricate sequence, straight and depressed sutures on the umbilical side and slightly curve and raised on the spiral side, umbilicus quite wide and deep, umbilical primary aperture.

Distinguishing features: the imbricated effect of the chambers is a very characteristic feature of *D. imbricata.* Moreover, it differs from *P. stephani* in being double keeled, in showing a lower trochospire and in having umbilical primary aperture.

Remarks: it is an abundant species showing a continuous stratigraphic record in the Monte Petrano section.

Phyletic relationship: in this study it is considered the ancestor of *D. hagni.*

Stratigraphic distribution: it appears in the middle of the *R. cushmani* Zone of the Monte Petrano section.

### ***Dicarinella hagni*** (Scheibnerova, 1962)

Plate 25, figs. 5-7

*Praeglobotruncana hagni* Scheibnerova, 1962, p. 225-226, figs. 6 (middle Turonian, Horné Srnie, west Carpathians, Czechoslovakia).

*Dicarinella hagni* Scheibnerova, 1962, Robaszynski and Caron et al., 1979, p. 58, pl. 56, figs. 1-2 (Loeffre-Lewarde, North of France and Angola).

*Dicarinella hagni* Scheibnerova, 1962, Hasegawa, 1999, p. 184-186, pl. 7, figs. 5 (middle Turonian, Takinosawa Formation, Hokkaido, Japan).

Wall texture: macroperforate and smooth to finely pustulose.

Test morphology: low trochospiral test, biconvex to planoconvex profile, slightly lobate profile and circular outline, 5-7 chambers slowly increasing in size, petaloid and flat on the spiral side and trapezoidal and weakly inflated on the umbilical side, double keel separated by an imperforate band and sometimes disappearing in the last chambers, sutures curved and strongly raised on the spiral side and straight and depressed on the umbilical side, umbilicus wide and shallow, umbilical to extra-umbilical primary aperture.

Distinguishing features: It differs from *D. imbricata* in lacking the imbrication of chambers, in showing more raised suture on the spiral side and in often having the two keels closer one to the other. It is quite similar to *D. elata* but it they can be distinguished in having less inflated chambers on the umbilical side. It differs from *D. roddai* in having more chambers, nearer keels, and in lacking the typical *D. roddai* box-shaped edge view.

Remarks: it has been observed only at Monte Petrano where it is quite rare but characterized by a continuous stratigraphic record.

According to Douglas (1969) and Robaszynski and Caron et al. (1979), it shows strong morphological similarities with *D. roddai* and they considered them as synonyms. On the contrary, in this study they are clearly distinguished.

Phyletic relationship: In this study *D. hagni* is regarded as the descendant of *D. imbricata* by the decreasing distance of the two keels and by the developing of more raised spiral sutures.

Stratigraphic distribution: it appears in the middle part of the *R. cushmani* Zone till the top of the section.

### ***Dicarinella takayanagii*** Hasegawa, 1999

Plate 25, figs. 8

*Dicarinella takayanagi* Hasegawa, 1999, p. 186, pl. 8, figs. 1-4 (uppermost Cenomanian, lower part of the Takinosawa Formation, Hokkaido, Japan).

*Dicarinella takayanagi* Hasegawa, 1999, Falzoni et al., 2016b, p. 81, pl. 10, figs. 6-8 (upper Cenomanian-Turonian, Clot Chavalier, Vocontian Basin, southern-east France).

Wall texture: macroperforate and finely pustulose.

Test morphology: very low trochospiral test, equally biconvex to slightly planoconvex, slightly lobate profile and oval outline, 4-4½ cross-shaped chambers gradually increasing in size flat and crescentic to semicircular on the spiral side and slightly inflated and triangular on the umbilical side, two alignments of pustules or two weakly developed keels divided by a peripheral band, sutures curved and raised on the spiral side and straight and depressed on the umbilical side, umbilicus shallow and narrow, umbilical to extra-umbilical primary aperture with a large lip.

Distinguishing features: It differs from the other species belonging to the *Dicarinella* genus in having 4 crossed-shaped chambers, weakly developed keels and a wide peripheral band.

Remarks: it is rarely observed only at Monte Petrano.

Stratigraphic distribution: at Monte Petrano, the first occurrence of *D. takayanagii* is in the upper part of the *R. cushmani* Zone.

### ***Dicarinella roddai*** (Marianos and Zingula, 1966)

*Globotruncana roddai* Marianos and Zingula, 1966, p. 340,pl. 39, figs. 5 (Turonian, Dry Creek, Beegum Basin, Sacramento Valley, California).

*Dicarinella roddai* Marianos and Zingula, 1966, Hasegawa, 1999, p. 186, pl. 7, figs. 1-2 (uppermost Cenomanian and lower Turonian, lower to middle part of the Takinosawa Formation, Hokkaido, Japan).

*Praeglobotruncana shirakinensis* Hasegawa, 1999, p.181, pl. 5, figs. 8 (upper Cenomanian, Takinosawa Formation, Hokkaido, Japan).

*Dicarinella roddai* Marianos and Zingula, 1966, Falzoni et al., 2016b, p. 81, pl. 10, figs. 2 (upper Cenomanian, Clot Chavalier, Vocontian Basin, southern-east France).

Wall texture: macroperforate and weakly pustulose.

Test morphology: low trochospiral test, equally biconvex and characterized by the typical box-shaped edge view, slightly lobate profile and circular outline, 4-5 chambers slowly increasing in size semicircular to slightly crescentic and weakly imbricated on the spiral side and trapezoidal and moderately inflated, two alignments of pustules to well developed keels at least at the beginning of the final whorl divided by an imperforate band, sutures curved and raised on the spiral side and straight and depressed on the umbilical side even if at the beginning of the last whorl they can be curved and weakly raised, umbilicus narrow and deep, umbilical to extra-umbilical primary aperture.

Distinguishing feature: It differs from *D. hagni* in having slightly inflated semi-circular to crescentic chambers on the spiral side, a less developed double-keeled peripheral margin, a more circular outline and a typical box-shaped in edge view.

Remarks: *Dicarinella roddai* is a rare species with a discontinuous record that is observed only in the Monte Petrano section. It has been longer considered a synonym of *D. hagni* but they can be easily distinguished considering the morphological featured listed above.

Stratigraphic distribution: at Monte Petrano it is recorded in only two samples in the middle part of the *R. cushmani* Zone.

### ***Dicarinella canaliculata*** (Reuss, 1854)

*Rosalina canaliculata* Reuss, 1854, p. 70, pl. 26, figs. 4 (upper Cretaceous, Gosau valley, Ostalpen near Salzburg, Austria).

*Dicarinella canaliculata* Reuss, 1854, Robaszynski and Caron et al., 1979, p. 67, pl. 53, figs. 1-3 (Santonian, Autriche, northerwest France; Bellone well, northern France).

*Dicarinella canaliculata* Reuss, 1854, Falzoni et al., 2016b, p. 75, pl. 5, figs. 2 (Cenomanian/Turonian boundary, Clot Chavalier, Vocontian Basin, southern-east France).

Wall texture: macroperforate and finely pustulose.

Test morphology: low trochospiral test, biconvex to slightly spiroconvex and characterized by a very angular edge view, slightly lobate profile and circular to subcircular outline, 5-6 petaloid chambers slowly increasing in size on the spiral side and trapezoidal on the umbilical side and flat to slightly inflated in both views, two keels strongly developed and divided by a large peripheral imperforated band, sutures curved and raised on the spiral side and straight and depressed on the umbilical side, umbilicus narrow and shallow, umbilical to extra-umbilical primary aperture.

Distinguished features: It differs from all the observed *Dicarinella* in having two strongly marked keels and a very large imperforate peripheral band giving it the typical strongly angular edge view.

Remarks: it is a rare species that is observed in only one sample of the Monte Petrano section.

Stratigraphic distribution: at Monte Petrano it is observed in the upper part of the *R. cushmani* Zone.

### ***Microhedbergella* cf. *rischi*** (Moullade, 1974)

Plate 25, figs. 9

*Hedbergella rischi* Moullade, 1974, p. 1816.

*Hedbergella rischi* Moullade, 1974, Bellier and Moullade, 2002, p. 16-18, pl. 1, figs. 1-6 (lower Albian, Blake Nose Escarpment, Western North Atlantic Ocean, ODP Site 1049A).

Wall texture: smooth and macroperforate.

Test morphology: very low trochospiral test, 5-5 ½ inflated and globular chambers gradually increasing in size, rounded to oblate peripheral margin, sutures depressed and straight on both sides, wide and shallow umbilicus, primary aperture extraumbilical reaching the spiral side and bordered by a lip and one small umbilical supplementary aperture.

Distinguishing feature: it differs from *T. primula* in having less chambers, a lower trochospire and an extraumbilical primary aperture that reaches the spiral side. Moreover, it can be distinguished from *T. madecassiana* in having more globular chambers. It differs from *Mi. rischi* in being macroperforate and a “Ticinella-like” wall texture and in having a lower trochospire.

Remarks: it is a very rare species with a scattered stratigraphic record observed at Monte Petrano and at Mazagan Plateau Site 547A. Huber and Leckie (2011) distinguished the genus *Microhedbergella* on the base of the microperforate wall texture. However, the specimens observed in this study are characterized by a morphology very close to *Mi. rischi,* but they possess a different wall texture that is more comparable to that of *Ticinella*.

Stratigraphic distribution: it is observed from the base of the sections to the upper part of the *Th. appenninica* Zone.

## 5.3 *Thalmanninella* lineage

*Ticinella raynaudi* was first described by Sigal (1966) and two subspecies were distinguished, *T. raynaudi digitalis* and *T. raynaudi aperta,* based on the radial elongation of the chambers that, specifically, characterizes the end of the whorl in *T. raynaudi aperta* and the entire last whorl in *T. raynaudi digitalis.* According to the observations of the assemblages of the Monte Petrano section (Figure 5.1) and of Mazagan Plateau Site 547A (Figure 5.2), the two subspecies of *T. raynaudi* are identified and they are regarded as ancestor of two distinct phyletic lineages. Consequently, the ancestor-descendant relationship of the *Thalmanninella* lineage from *Ticinella raynaudi aperta, Th. appenninica,* *Th. brotzeni, Th. globotruncanoides to Th. greenhornensis* is reconstructed. On the other hand, the relationship from *T. raynaudi digitalis, Th. evoluta* to *Th. balernaensis* needs further observations.

The classification of each species is based on the shape of the chambers (petaloid to crescentic chambers), on the peripheral margin (non-keeled to keeled forms), on the umbilical and spiral sutures (depressed to raised) and on the wall textures (smooth to slightly pustulose). The main features of each taxon mentioned here are summarized in Table 5.1.

According to the literature, *Ticinella raynaudi aperta* first appears in lower Albian sediments and it is distinguished by its smooth wall texture and by its globular chambers, except for the last one that is elongated in the coiling direction (Plate 2, figs 4, 6 and Plate 3, figs, 2). In this study, it is observed in both sections.

At Site 547A, few specimens characterized by having ticinellids wall texture, depressed sutures on both sides, last chamber elongate and strongly pinched margin are recognized from the upper *Ps. ticinensis* Zone to the lower *Th. appenninica* Zone. These taxa always co-occur with *T. raynaudi aperta* and, in their last occurrence, with *Th. appenninica* and they are identified as transitional morphologies from *T. raynaudi aperta* to *Th. appenninica* (Plate 14, figs. 6-7).

*Ticinella raynaudi aperta*, gives rise to *Thalmanninella appenninica* (Plate 14, figs. 8-9 and Plate 15, figs. 1-4) by the development of the keel, of sutures raised and curved on the spiral side and partially raised straight to slightly curved on the umbilical side. Moreover, the wall texture develops from smooth to slightly pustulose on the first chambers of the last whorl.

The evolution from *Th. appenninica* to *Th. brotzeni* (Plate 15, figs. 9 and Plate 16, figs. 3-6) in the upper part of *Th. appenninica* Zone is characterized by the development of a biconvex profile, more angular profile, crescentic chambers and curved umbilical sutures. Several transitional taxa between *Th. appenninica* and *Th. brotzeni* are observed (Plate 15, fig. 10, Plate 16, figs. 1-2) both in the Monte Petrano and in Site 547A from the upper part of the *Th. appenninica* Zone and stratigraphically above the last occurrence of *P. buxtorfi*.

Above the appearance of *Th. brotzeni,* rare transitional specimens to *Th. globotruncanoides* are recognized in both sections (Plate 16, figs. 8-10). At Monte Petrano they are recorded from the upper *Th. appenninica* Zone till the upper *Th. reicheli* Zone, while at Mazagan Plateau they are present from the base of the *Th. globotruncanoides* Zone till the top of the section. These specimens are characterized by subcircular outline test and crescentic to petaloid chambers. On the umbilical side they possess curved and depressed sutures, except for the beginning of the last whorl where they are raised, and by umbilical to sutural supplementary apertures.

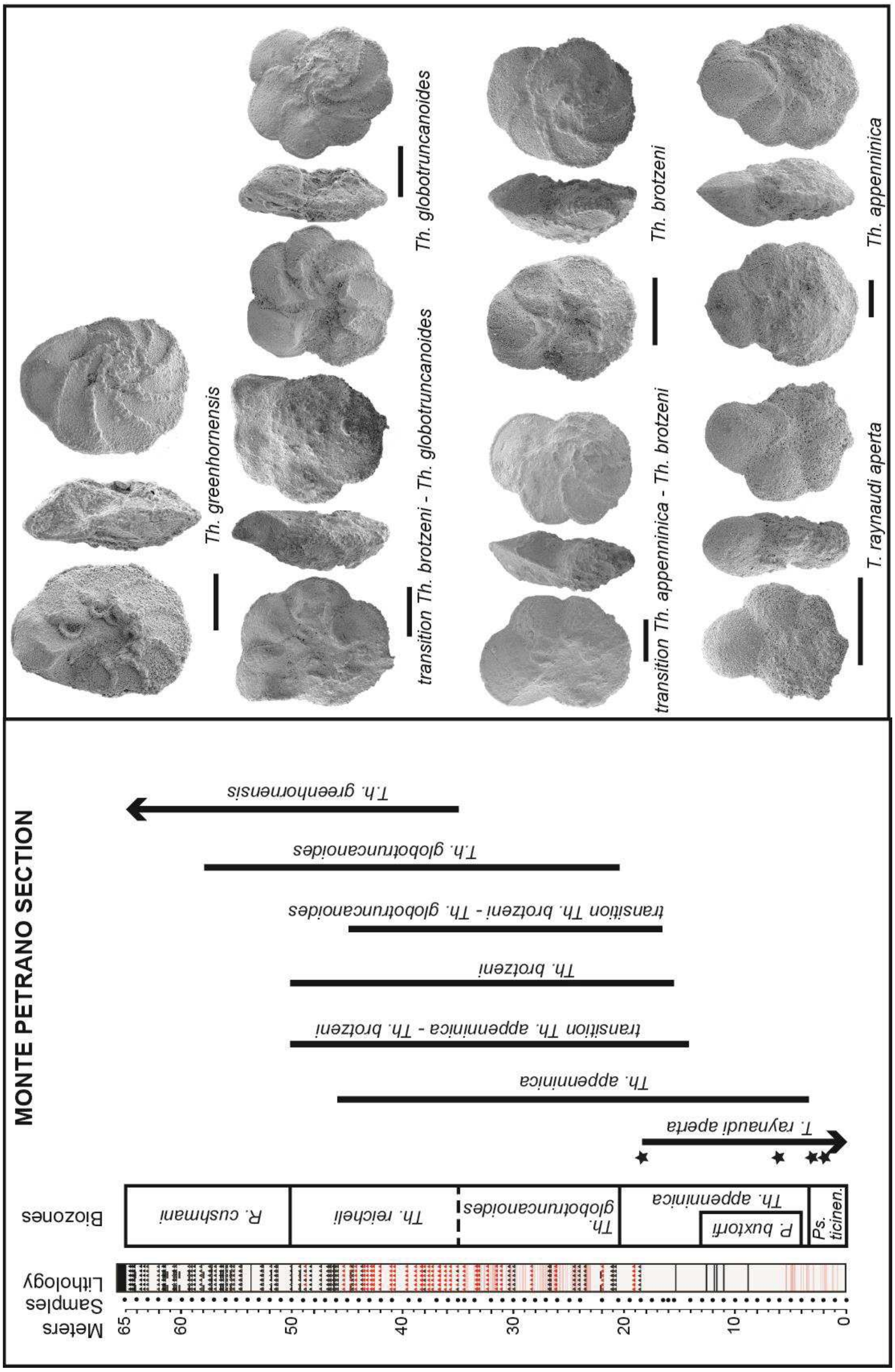


**Fig. 5.1** Stratigraphic range of the species observed at Monte Petrano belonging to the *Thalmanninella* phyletic lineage. *Th. greenhornensis,* Sample MP57; *Th. globotruncanoides*, Sample MP35; trans. *Th. brotzeni – Th. globotruncanoides*, Sample MP15.5; *Th. brotzeni*, Sample MP19.5; trans. *Th. appenninica – Th. brotzeni*, Sample MP20.5; *Th. appenninica*, Sample MP4; *T. raynaudi aperta,* Sample MP2; scale bar = 200µm. Markers are used when a taxon is quite rare and with a discontinuous stratigraphic range, to indicate the presence of the species. The base of the *Th. reicheli* Zone is dashed because the LO of the nominal species is considered a problematic bioevent.

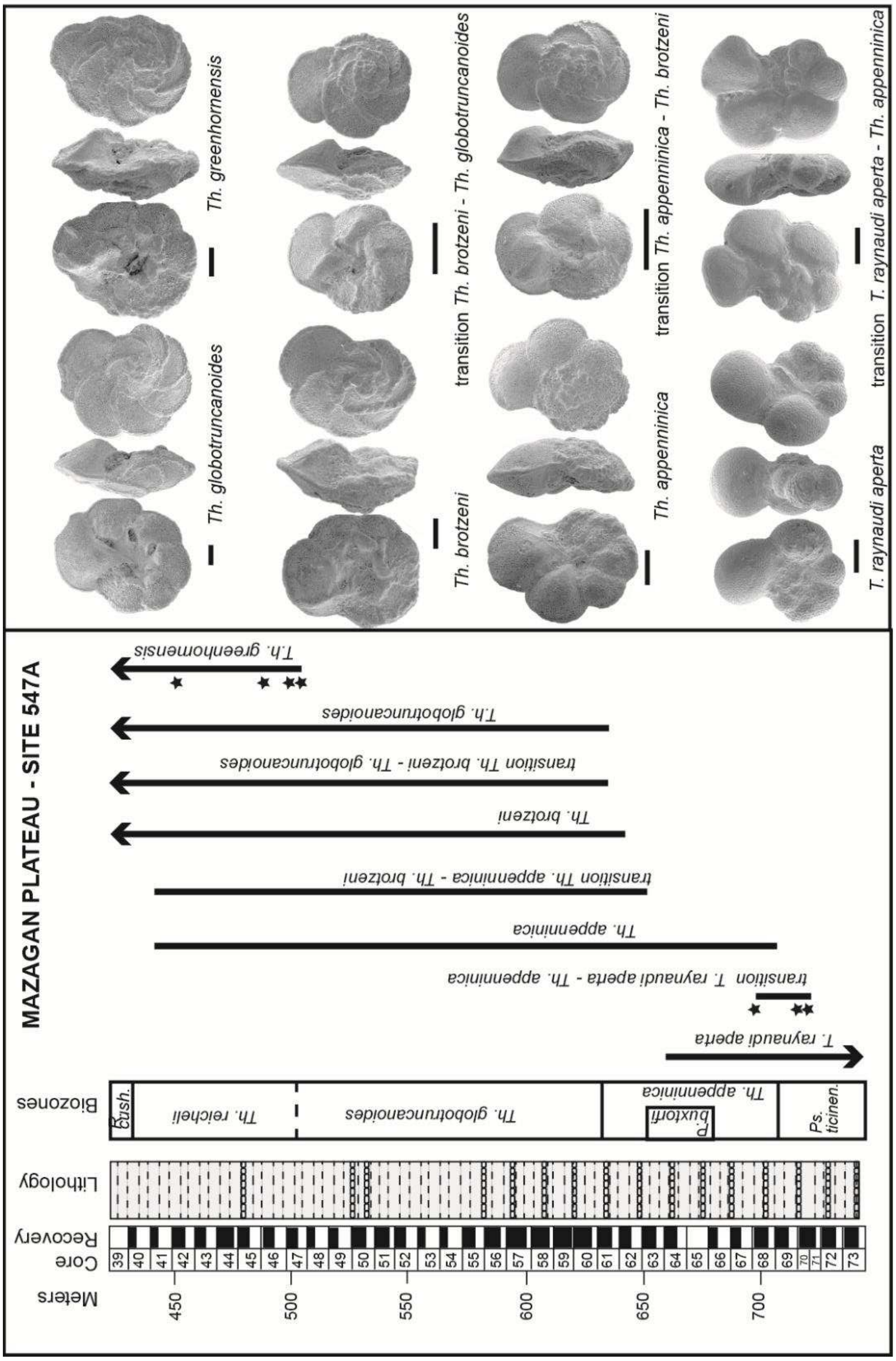


**Fig. 5.2** Stratigraphic range of the species observed at Mazagan Plateau Site 547A belonging to the *Thalmanninella* phyletic lineage. *Th. greenhornensis* 547A-47R-3, 52.5-54.5 cm; *Th. globotruncanoides* 547A-46R-3, 60-62 cm; transition *Th. brotzeni-Th. globotruncanoides* 547A-53R-1, 50-51.5 cm; *Th. brotzeni* 547A-60R-3, 49.5-51.5 cm; transition *Th. appenninica-Th. brotzeni* 547A-53R-1, 50-51.5 cm; *Th. appenninica* 547A-65R-1, 36.5-38 cm; *T. raynaudi aperta-Th. appenninica* 547A-68R-2 93-95 cm; *T. raynaudi aperta,* Sample 547A-73R-3, 53-54.5 cm; scale bar = 100µm. Markers are used when a taxon is quite rare and with a discontinuous stratigraphic range, to indicate the presence of the species. The base of the *Th. reicheli* Zone is dashed because the marker species is not observed at Site 57A and to approximate the base of the Zone is used to LO of *Th. greenhornensis.*

*Thalmanninella brotzeni* gives rise to *Th. globotruncanoides* (Plate 16, figs. 7 and Plate 17, figs. 1-4) by the development of planoconvex profile, petaloid chambers, “fish-hook” shaped umbilical sutures and sutural supplementary apertures on the last chambers.

The transition from *Th. globotruncanoides* to *Th. greenhornensis* corresponds to the increase in the numbers of chambers and to the development of raised umbilical sutures. Nevertheless, no clear transitional forms between the two species are distinguished. *Thalmanninella greenhornensis* (Plate 17, figs. 8-9 and Plate 18, figs. 1-2) appears at the Monte Petrano section at the base of the *Th. reicheli* Zone and at Site 547A. The last member of the phyletic lineage can be distinguished by its ancestor in having more numerous and crescentic chambers, a more angular edge view with a marked periumbilical margin and umbilical supplementary apertures surrounded by rims.

The Monte Petrano and the Mazagan Plateau section are quite comparable in term of observed species and taxa distribution. Specifically, the members of the described phyletic lineage are observed in both sections except for the transition from *T. raynaudi* to *Th. appenninica* that is observed only at Site 547A. However, this taxon is very rare and characterized by a short and scattered stratigraphic record and maybe the different sampling resolution between the two sections could have affected its finding in the Monte Petrano section.

| SPECIES | MODE OF COILING | EDGE VIEW | WALL TEXTURE | PERIPHERAL MARGIN | SUTURES | SECONDARY APERTURES | SHAPE OF THE CHAMBERS |
|---|---|---|---|---|---|---|---|
| ***Ticinella raynaudi aperta*** | low trochospiral | equally biconvex | macroperforate and smooth | rounded | straight an depressed on both side | umbilical | elongated, particularly the last one, inflated on both sides |
| **transition *T. raynaudi aperta - Th. appenninica*** | low trochospiral | equally biconvex | macroperforate and smooth | pinched | spiral side: straight to curved and depressed;<br>umbilical side: straight and depressed | one small suture at the base of the suture of the last chamber | elongated and slightly inflated |
| ***Thalmanninella appenninica*** | low trochospiral | planoconvex | macroperforate and smooth to finely pustulose at the beginning of the last whorl | keeled | spiral side: curved and raised<br>umbilical side: straight to slightly curved and depressed; raised at the beginning on the last whorl | one small suture at the base of the suture of the last chamber | spiral side: lobate and elongate;<br>umbilical side: subtriangular and slightly inflated at the end of the last whorl |
| **transition *Th. appenninica - Th. brotzeni*** | low to medium trochospiral | planoconvex to biconvex | macroperforate and smooth to finely pustulose at the beginning of the last whorl | keeled, slightly angular | spiral side: curved and raised;<br>umbilical side: curved and partially raised | umbilical | spiral side: lobate to crescentic;<br>umbilical side: subtriangular and flat; periumbilical ridge |
| ***Thalmanninella brotzeni*** | medium thocospiral | biconvex | macroperforate and smooth to finely pustulose at the beginning of the last whorl | keeled, angular | spiral side: curved and raised;<br>umbilical side: curved and partially raised | umbilical | spiral side: crescentic;<br>umbilical side: subtriangular and flat; strongly formed periumbilical ridge |
| **transition *Th. brotzeni - Th. globotruncanoides*** | low to medium trochospiral | planoconvex to biconvex | macroperforate and smooth to finely pustulose at the beginning of the last whorl | keeled, angular | spiral side: curved and raised;<br>umbilical side: curved and partially raised | umbilical to sutural | spiral side: crescentic to petaloid;<br>umbilical side: subtriangular and flat; strongly formed periumbilical ridge |
| ***Thalmanninella globotruncanides*** | low trochospiral | planoconvex | macroperforate and smooth to finely pustulose at the beginning of the last whorl | keeled, fairly angular | spiral side: curved and raised;<br>umbilical side: curved and partially raised | umbilical to sutural | spiral side: petaloid;<br>umbilical side: subtriangular and flat to slightly inflated; strongly formed periumbilical ridge |
| ***Thalmanninella greenhornensis*** | low to medium trochospiral | planoconvex to biconvex | smooth to finely pustulose at the beginning of the last whorl | keeled, angular | spiral side: curved and raised;<br>umbilical side: curved and almost fully raised | umbilical surrounded by rims | spiral side: crescentic;<br>umbilical side: subtriangular and flat to slightly inflated; strongly formed periumbilical ridge |

**Tab. 5.1** Morphologic characters of the species discussed in this paragraph.

# Chapter 6

# Paleoceanography

## 6.1 Paleoenvironmental conditions of the Umbria-Marche Basin and of the Mazagan Plateau

The studied sections belong to different paleogeographic and paleoceanographic settings. Specifically, during the late Albian-Cenomanian time interval the Umbria-Marche Basin was located in the western Tethys, on the continental crust of the Adria microplate and the Scaglia Bianca Formation deposited above the calcite compensation depth (CCD), in the deep bathyal realm at about 1500-2000 meters (Arthur and Premoli Silva, 1982).

As suggested by Gambacorta et al. (2016), the succession of the Monte Petrano section was deposited in a narrow or proximal part of the Umbria-Marche Basin (see also Turgeon and Brumsack, 2006) and the presence of a sill, dividing it from the rest of the basin, probably promoted water stratification (Fig. 6.1). According to Tiraboschi (2009), the deposition of the Scaglia Bianca (limestones, marls and cherty limestone) can be related to a dry climate with more active circulation water and higher evaporation rate. On the contrary, the accumulation of organic matter and the deposition of black shales are related to warm and moist conditions with an increasing runoff and precipitations leading to the decrease of salinity and to the formation of a superficial pycnocline. This oceanographic condition associated to weak water circulation can lead to anoxic condition on the sea floor. The Pialli level, lithological expression of the OAE1d, is composed by alternation of black shales and limestone and it would be deposited during period of intermittent water stratification, disrupted by the increasing of water currents (Gambacorta et al., 2016).

Moreover, according to Gambacorta et al. (2016), phases of enhanced sea floor circulation between the MCE and the OAE2 are demonstrated by the results of facies analysis, indicating that tractive bottom currents repeatedly re-oxygenated the Umbria-Marche Basin sea floor and lead to alternating phases of meso-eutrophic regime and of more oligotrophic regime.

During the late Albian-Cenomanian time interval, the Mazagan Plateau was located in the northern Atlantic Ocean, only connected with other oceans through narrow pathways. According to benthic foraminiferal data, Nederbragt et al. (2001), inferred a middle bathyal paleodepth of about 500-1500 meters for the deposition of the mid-Cretaceous succession of Site 547A, consisting of terrigenous clays and subordinate pelagic biogenic sediments. The suggested paleodepth is definitely shallower respect that of 1500-2500 meters indicated by Leckie (1987) and the deposition occurred above the foraminiferal lysocline.

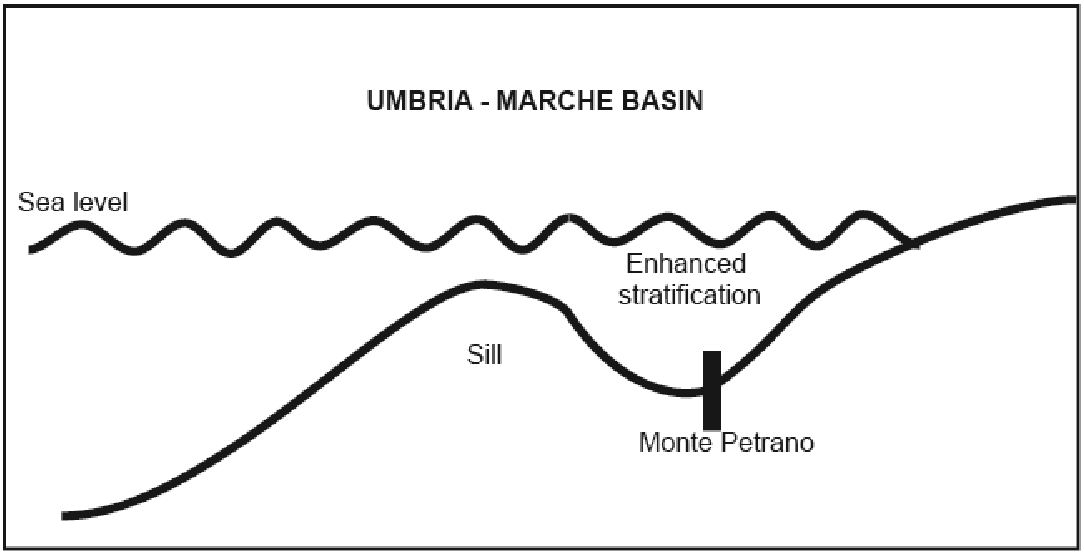


**Fig. 6.1** Location of the Monte Petrano section during deposition in the upper Albian – Cenomanian interval (modified after Turgeon and Brumsack, 2006).

During the mid-Cretaceous the northwestern offshore of Morocco is influenced by upwelling regime and associate fertile shallow waters, particularly occurring in the outer Mazagan Plateau and upper Mazagan Escarpment, adjacent to Site 545 (Leckie, 1984; Leckie, 1987; Nederbragt et al., 2001) (Fig. 6.2). According to Leckie (1984), in the latest Aptian to early Albian, at Site 545 an intensified Oxygen Minimum Zone (OMZ) occurred as a consequence of a dominant upwelling regime, causing the disappearance of several planktonic taxa and favoring the diversification of species with simple morphologies. Moreover, a slower average accumulation rate characterized the upper Albian to middle Cenomanian of Site 545 (Cores 40 through 28). At Site 545 the upwelling regime may have reached its maximum intensity during the middle Albian when thin black shale levels deposited. Although Site 547A is only 15 km far-away from Site 545, there is no evidence of this upwelling event in the middle Albian (Leckie, 1984; Leckie, 1987). At the beginning of the late Albian the upwelling regime suddenly ended after a minor hiatus as reflected by the lower abundance of siliceous skeletons from the lower part of Core 40, by the increase in planktonic foraminiferal diversity, including keeled taxa, by the increase in foraminiferal preservation, and by the return to a normal bathyal planktonic/benthic ratio.

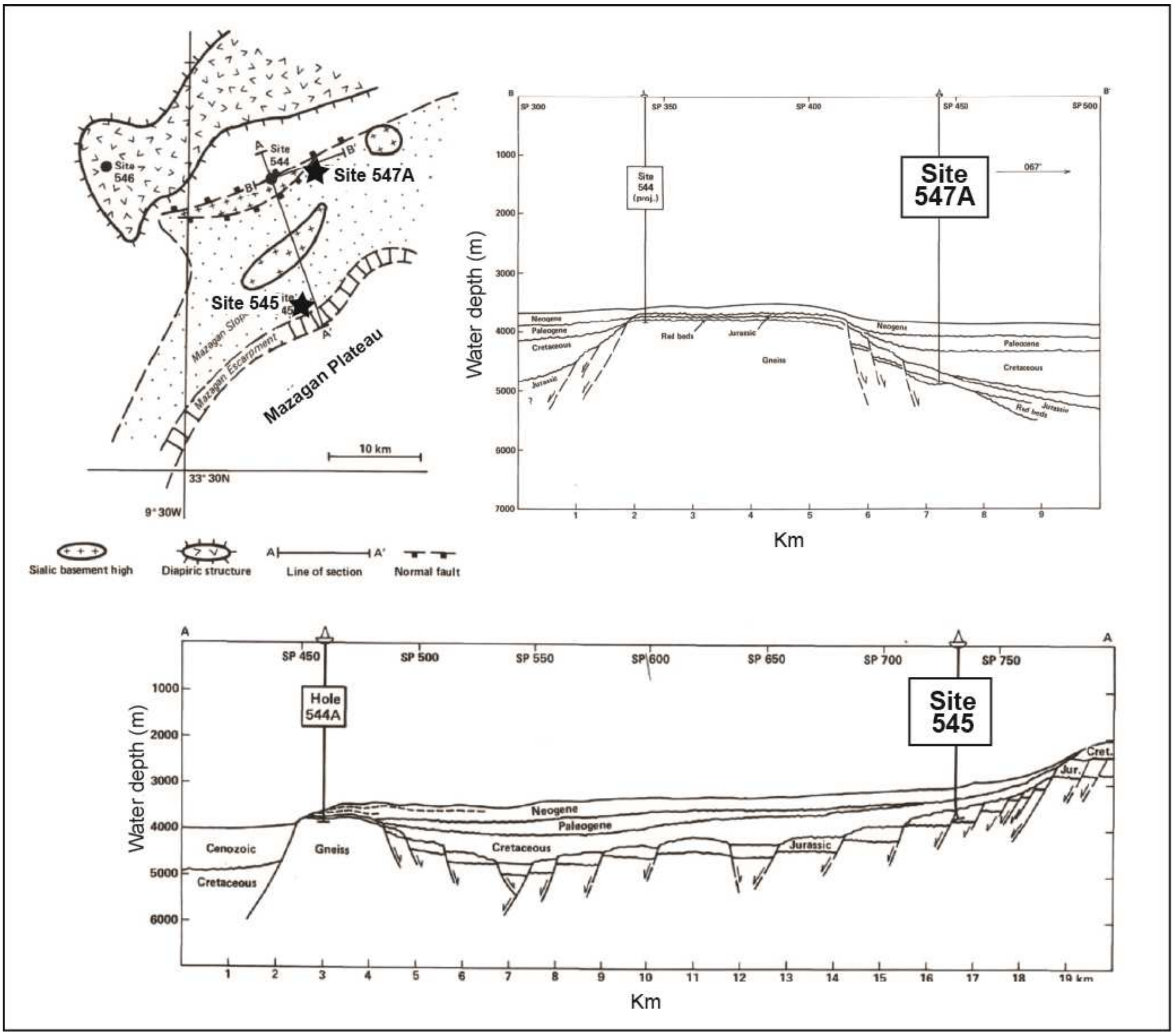


**Fig. 6.2** Present days position of Sites 547A and 545 at Mazagan Plateau (modified after Leckie, 1984).

## 6.2 Introduction to planktonic foraminiferal ecology and paleoecology

Planktonic foraminifera live stratified within the water column that is subdivided in an upper and warmer portion, named mixed layer, and a colder and deeper thermocline (e.g. Hemleben et al., 1989). Tropical regions, where the water column is well stratified because of a defined temperature gradient, are characterized by a stable and deeper thermocline and by a thick mixed layer. In this environment characterized by lower productivity (oligotrophy), the larger abundance of niches is available for planktonic foraminifera to occupy and, consequently, diversification of planktonic foraminifera is higher. On the contrary, towards the higher latitudes and in region characterized by upwelling regime, the thermocline is even shallower and the mixed layer is thinner. These areas are characterized by a less stratified water column as intense mixing between shallow and deep waters takes place with the ascent of cold and nutrient enriched waters (eutrophy), promoting the primary productivity. In this environment, less niches are available for planktonic foraminifera compared to the tropical area.

Therefore, habitat diversity is inversely related to the amount of nutrients; specifically, an unstable and eutrophic water column, typical of high latitudes or regions characterized by upwelling regime, runoff, or seasonal blooms, allows low diversification of the ecological niches in the water column and consequently a low planktonic foraminiferal diversity. On the contrary, more stable and oligotrophic environment, typical of low latitudes, provides a wide range of ecological niches and, thus, promotes the specialization of planktonic foraminiferal taxa (Hallock, 1987).

Based on the shape of the shell, modern planktonic foraminifera may be divided into two main groups: the globular spinose forms with larger pores (globigerinoid) and the flattened, smoother, discoidal and without spines taxa (globorotaliid). It has been observed that the globigerinoid forms, such as the *Globigerina* and *Globigerinoides* genera, tend to be shallower dwelling, while the globorotaliid forms, as *Globorotalia,* preferentially inhabit deeper waters. In fact, the heavier, smoother and more flattened taxa sink more rapidly in the water column and, consequently, they are considered adapted to maintain buoyancy in colder and denser water. On the contrary, in warmer waters the shell needs to be less dense and with spines to promote buoyancy and resist sinking (Furbish and Arnold, 1997). Moreover, some shallower planktonic foraminifera are found in association to symbiotic algae, known as symbionts, with a density that can exceed 5000 algal cells/foraminifera (Spero and Parker, 1985). The association of symbionts with spinose foraminifera is characterized by a diurnal patter of movement; specifically the host deploys its symbionts outside the test along the spines during the day and withdraw them into the cytoplasm within the shell at night. This cycle seems on one hand, to allow the maximum exposure of the symbionts to light during the day and, on the other hand, to protect them from micrograzer and to give an enhanced exposure to host metabolites. Laboratory experiments demonstrated that the symbiotic association can influence the shell growth and the longevity of individuals (Spero and Lea, 1993). In terms of life strategies, the shallower globigerinoid taxa are interpreted as opportunist (r-strategist), while the deeper globorotaliid dwellers are considered as specialized taxa (k-strategy).

The observations on the modern assemblages have been used to interpret the paleoecology of the Cretaceous planktonic foraminifera. According to Caron and Homewood (1983), Premoli Silva and

Sliter (1999), Hart (1999), two main life strategies were adopted by the Cretaceous planktonic foraminifera depending on the environmental/paleoceanographic conditions:

a) opportunistic species (r-strategists): they are typical of unstable conditions, eutrophic waters, and are characterized by simple and globular morphologies and are smaller in size, because of their shorter reproduction cycle and faster reproduction rate (Hallock, 1985; Caron and Homewood, 1983). They are cosmopolites and more tolerant to variation in the chemical-physical conditions of the ocean. Examples of opportunist taxa are *Hedbergella* and *Heterohelix.*
b) specialist species (k-strategists): they are typical of stable conditions, oligotrophic water, and are characterized by complex and larger in size morphologies, because of their longer reproduction cycle and slower reproduction rate. They inhabit restricted ecological niches, as they are less tolerant to variation of the biotic and abiotic parameters of the water column (Caron and Homewood, 1983; Hallock et al., 1991). Keeled taxa, including *Rotalipora,* are specialized dwellers.

Comprised between these two main life strategies, there are all the planktonic foraminifera adapted to mesotrophic conditions between the r-strategy and k-strategy mode of life, and characterized by having intermediate morphological features (Premoli Silva and Sliter, 1999; Petrizzo, 2002). Taxa characterized by the alignment of pustules, such as *Praeglobotruncana,* are included in this category.

In summary, a stable and well-stratified water column, typical of low latitudes, generally corresponds to oligotrophic regimes where a high habitat partitioning is provided and, consequently, planktonic foraminiferal diversity is high and specialized taxa (k-strategy) are able to slowly reproduce. On the other hand, unstable conditions, typical of high latitudes or upwelling regime, correspond to meso-eutrophic environments, where less ecological niches are available and opportunist species (r-strategist) quickly proliferate, but planktonic foraminiferal diversity is lower respect to more stable conditions.

## 6.3 Introduction to isotope geochemistry of planktonic foraminifera

The study of oxygen and carbon isotope composition recorded in the shell of planktonic foraminifera can return information about paleohabitat and paleotemperature allowing inferences on the life strategies adopted by extinct taxa.

Oxygen isotope analysis is based on the ratio between the heaviest and the lightest isotopes, $^{18}$O and $^{16}$O, respectively. Because of different weight of the isotopes, a fractionation in the sea water does occur and $\delta^{18}$O is calculated through the following equation:

$$\delta^{18}O = [(^{18}O/^{16}O)_{sample}/ (^{18}O/^{16}O)_{standard} - 1] * 1000;$$

Specifically, $\delta^{18}O$ values, measured on planktonic foraminiferal shell, vary depending on temperature of calcification as more $^{16}O$ respect to $^{18}O$ is incorporated during calcification at higher temperature. Consequently, the deep-dwelling species that inhabit colder and enriched in $^{16}O$ waters, record a less negative $\delta^{18}O$, while the shallow-dwelling species, living in warmer waters, register a more negative $\delta^{18}O$. Moreover, salinity during calcification influences oxygen ratio because high evaporation rate led to the preferential evaporation of the lightest isotope $^{16}O$ and correspond to lower $\delta^{18}O$ values. Finally, in case of diagenetic alteration $\delta^{18}O$ values tend to more negative values. Anyhow, early recrystallization in shallow burial environments may cause the opposite effect.

The carbon isotope signature is more problematic to interpret and $\delta^{13}C$ is calculated through the following equation:

$$\delta^{13}C = [(^{13}C/^{12}C)_{sample}/ (^{13}C/^{12}C)_{standard} - 1] * 1000;$$

The standard for isotopic analysis on biologic carbonated, known as PDB (Pee Dee Belemnite) is the calcium carbonate of the Cretaceous *Belemnitella americana* from the Pee Dee Formation, North Carolina. For the calibration of every isotopic measurement, a piece of the standard belemnite is needed, so that it is now consumed. In any case, NBS-19 is commonly used as secondary standards to define the VPDB (Vienna Pee Dee Belemnite) scale but, since the difference of isotopic values with PDB is given by the National Institute of Standards and Technology (NIST) in Gaithersberg, Maryland, U.S.A., (NIST, 1992), results of $\delta^{13}C$ and $\delta^{18}O$ always refers to the primary standard.

The main source of carbon for planktonic foraminifera to precipitate their shell consists in dissolved $CO_2$ from the surrounding water, but many other secondary factors, such as vital effect, geological burial and reintroduction of organic matter to the ocean-atmosphere system, can influence the $\delta^{13}C$. The carbon isotope ratio tends to decrease through the upper water column because photosynthesis preferentially removes the lightest isotope $^{12}C$, and consequently waters in the shallower euphotic zone are characterized by heavier $\delta^{13}C$ respect to the deeper waters.

One of the main vital effect is caused by the presence of symbionts around the foraminifera, as their activity may increase the $\delta^{13}C$ of dissolved $CO_2$ close to the specimens by the preferential consumption of light carbon isotope. Consequently, as demonstrate by laboratory experiments (Spero and Williams, 1988), cultured foraminifera grown in illuminated conditions with active symbionts tend to have a more positive $\delta^{13}C$ respect to the same species grown in the dark. Moreover, Spero and Lea (1993) performed experiments on the planktonic foraminifera *Globigerinoides sacculifer* in order to determine the effect of symbiont photosynthesis on the carbon and oxygen composition of the shell; stable isotope analyses of each chamber, calcified under controlled temperature and light levels, demonstrate that $\delta^{13}C$ increase with increasing light, as effect of symbiont photosynthesis. In addition, the $\delta^{18}O$ of chambers are not affected by ontogeny but decrease with increasing light levels, presumably due to symbiont activity; oxygen stable isotope analyses show that chambers are enriched in $^{18}O$ respect to what would be expected by kinetic fractionation models, probably because of the secretion of a gametogenic calcite layer on the surface of the shell at the end of the life cycle.

Another vital effect is related to respiration, as some carbon may derive from isotopically light expelled respiratory $CO_2$. If the vital effect causes a large variation in the $\delta^{13}C$, it can lead to the misinterpretation of the planktonic foraminiferal habitat. Finally, also food consumption and water chemistry can influence the $\delta^{13}C$ recorded in the shell.

All these factors can vary during the lifespan of an individual, and thus, the interpretation of the carbon isotope is very complex. In addition, diagenesis can alter the carbon isotope signal even if the $\delta^{13}C$ composition of planktonic foraminifera is usually less susceptible to alteration respect to $\delta^{18}O$. Ultimately, observation on modern foraminifera shows that carbon isotopes are less reliable as paleodepth indicator if compared to oxygen isotopes.

According to Spero and Williams (1989), large variation of the oxygen and carbon isotope signals in the shell of planktonic foraminifera mainly depends on habitat depth and seasonality. Specifically, laboratory simulations on *O. universa* were carried out on individuals from different depth habitats to estimate seasonal temperature for the upper and lower euphotic water column, combining $\delta^{13}C$ and $\delta^{18}O$ values. Carbon and oxygen isotopes were used to hypothesize their variations in an *O. universa* fossil assemblage in areas with stable thermocline, seasonal thermocline and turbid mixed layer linked to upwelling regime. The model for the interpretation of planktonic foraminifera from an open ocean site is afterwards reassessed by Pearson et al. (1993) (Fig. 6.3). A J-shape curve in a carbon vs. oxygen diagram lead to the identification of three main groups of fauna. Specifically, the mixed layer dwellers characterized in having the heaviest carbon ratio and show large variability in the $\delta^{18}O$ because they are more influenced by the seasonal thermocline, the thermocline dwellers with middle isotopic ratios, and the subthermocline dwellers with lightest carbon and heaviest oxygen ratios.

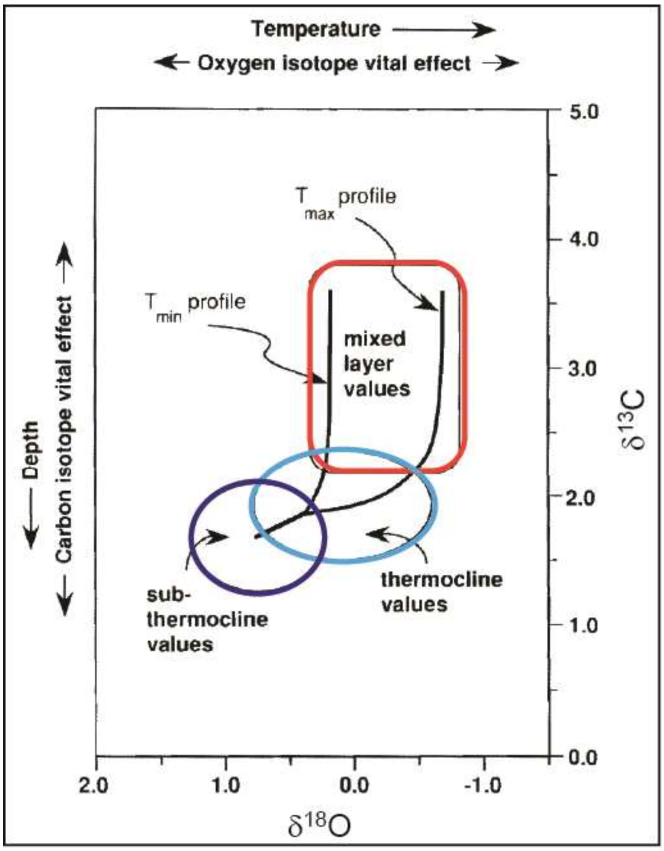


**Fig. 6.3** J-shaped model used for the interpretation of the paleoecology of planktonic foraminifera from an open ocean site with stable thermocline (modified after Pearson et al., 1993).

## 6.4 Overview of the paleoecology of Albian-Cenomanian planktonic foraminifera

Reliable measurements of carbon and oxygen isotope values for paleoceanographic reconstruction require that the shells have to be composed by primary calcite, as diagenesis can alter the original isotopic signal. In this study, planktonic foraminifera observed in the assemblages are all recrystallized and infilled with calcite, therefore, it was not possible to measure the original isotopic signature at the time of calcification of the shells. Nevertheless, according to the literature, the interpretation of the paleoecological preferences of the single species, and the inferences on species' preferred habitats (upper mixed layer, lower mixed layer or thermocline) are used to interpret the quantitative data collected on the assemblages from the Monte Petrano and the Mazagan Plateau Site 547A (see Paragraph 6.8).

Over the years, the mid-Cretaceous flattened keeled planktonic foraminifera have been associated to deep habitats, while globular and muricate and/or pustulose taxa have been related to shallower environments as explained in the previous paragraph (i.e. Caron and Homewood, 1983; Leckie, 1987; Hart, 1999; Petrizzo, 2002).

The available interpretation from the literature in term of paleohabitat of the upper Albian-Cenomanian species, are listed in Table 6.1 and here explained from the shallower to the deeper taxa together with comments regarding life strategy and nutrients requirements according to Caron and Homewood (1983), Premoli Silva and Sliter (1999), and Hart (1999).

*Ticinella primula,* and *P. libyca* are regarded shallow dwellers as they exhibit relatively high variability in $\delta^{18}O$ and $\delta^{13}C$ among samples and show the lowest $\delta^{18}O$ and highest $\delta^{13}C$ of the taxa analyzed (Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010). The same paleodepth interpretation is given for *T. raynaudi* by Norris and Wilson (1998). According to Petrizzo et al. (2008), *B. breggiensis* shows relatively high variability among samples but has slightly higher $\delta^{18}O$ values and slightly lower $\delta^{13}C$ values than *T. primula*, suggesting that *B. breggiensis* lived near the seasonal thermocline and/or slightly earlier or later in the year than *T. primula.* In any case, the species is also interpreted by Wilson and Norris (2001) as a surface dwellers; the authors also highlight that *B. breggiensis* is the only species analyzed to display significant size related changes in $\delta^{18}O$ decrease with increasing shell size, suggesting that individuals migrate towards shallower waters during their growth.

*Whiteinella* was described by Hart (1999), based on its shape, as a genus typically living in the upper part of the water column; afterwards, according to Huber et al. (1999), Bornemann and Norris (2007) and Falzoni et al. (2016a), *Whiteinella* is confirmed to be a shallow dweller taxon from the Cenomanian to the Coniacian. Moreover, Bornemann and Norris (2007), as a result of a correlation between isotope values and the size of specimens, highlight that *W. baltica* does not change its depth habitat during its life cycle. Finally, data from high latitudes (Falkland Plateau) suggest that in the Turonian – Coniacian interval, *W. baltica* lived at intermediate depth, yielding isotopic values between the deepest and shallowest planktonic species (Huber et al., 2011).

Among the Albian-Cenomanian biserial taxa, only *H. moremani* is studied in term of paleodepth and life strategy. Nederbragt et al. (1998) described it as a surface water dweller in the circum-north Atlantic, with the shell depleted in $\delta^{13}C$ because of the vital effect related to its opportunistic strategy.

In summary, *Ticinella, Biticinella, Paracostellagerina* and the biserials planktonic foraminifera are considered as opportunist taxa and *Whiteinella* as having an intermediate strategy but more oriented towards an opportunistic behavior; however the above mentioned genera are all described as adapted to meso-eutrophic regimes.

According to the isotopic data from the Blake Nose Plateau (Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010), *P. praebuxtorfi* and *P. buxtorfi* are interpreted as lower mixed layer dwellers. Therefore, *Planomalina* is reported as an intermediate r/k strategist more specialized, living in oligo-mesotrophic conditions.

In the upper Albian-lower Cenomanian the *Praeglobotruncana* genus, including *P. delrioensis* and *P. stephani,* is interpreted as a lower mixed layer taxa by Petrizzo et al. (2008). It has also been interpreted by Norris and Wilson (1998) as relatively deeper water dweller, living together with rotaliporids and *Muricohedbergella,* if compared to *Planomalina*, *Ticinella and Biticinella*. Furthermore, according to Ando et al. (2009; 2010; 2015), the deep dweller *P. stephani* experienced a rapid upward migration at the Albian/Cenomanian boundary to occupy shallower ecological niches. Finally, *Praeglobotruncana* is interpreted as intermediate taxon more specialized and preferring oligo-mesotrophic habitats.

According to Petrizzo et al. (2008), the planispirals *G. bentonensis* and *G. pulchellus* inhabit the lower part of the mixed layer and the genus *Globigerinelloides* is considered opportunistic and more adapted to meso-eutrophic conditions.

Different interpretations of the genus *Muricohedbergella* are reported in the literature. Specifically, Hart (1999), interpret *Muricohedbergella* as a shallow dweller based on morphological criteria, later supported by isotope data (Price and Hart, 2002). According to Petrizzo et al. (2008), *M. planispira* and *M. praelibyca* are considered thermocline dwellers, while *M. simplicissima* is suggested to live slightly below the seasonal thermocline, possibly near the permanent thermocline. On the contrary, according to Ando et al. (2010), *M. simplicissima* is considered one of the deepest dweller taxon. Moreover, Coxall et al. (2007) suggest that forms with digitate chambers, as *M. simplicissima* and the genus *Schackoina,* are typical of dysoxic conditions. The authors claim that the primary function of digitate and clavate chambers is to increase the effective shell size and the food gathering efficiency for survival in environment with low nutrients, close to the Oxygen Minimum Zone. Moreover, the species *M. delrioensis,* is documented to live below the seasonal thermocline, together with *M. simplicissima* (Petrizzo et al., 2008), while Price et al. (1998) suggest that it would inhabit the mixed layer having lighter $\delta^{18}O$ and heavier $\delta^{13}C$ respect to the deeper rotaliporids. On the contrary, Norris et al. (2002) showed that *M. delrioensis* yielded the most negative $\delta^{18}O$ value and the most positive $\delta^{13}C$ that can possibly indicate a shallow habitat. In addition, Ando et al. (2010) documented a migration of *M. delrioensis* from the mixed layer to the thermocline during the Albian/Cenomanian boundary. Therefore, the depth ecology of the *Muricohedbergella* genus is still unclear as the most common species show a wide range of ecological preferences, for this reason the muricohedbergellids as a group are here regarded as opportunistic species more adapted to meso-eutrophic regimes.

The rotaliporids are generally related to deeper water environments (Caron and Homewood, 1983; Hart, 1999; Wilson and Norris, 2001; Price and Hart, 2002). Specifically, *Ps. ticinensis*, *Th. appenninica, Th. brotzeni, Th. montsalvensis* and *Th. reicheli* are considered thermocline dwellers (Norris and Wilson, 1998; Price et al., 1998; Petrizzo et al., 2008; Ando et al., 2010). According to Ando et al. (2010), *Th. appenninica*, *Th. gandolfii* and *Th. globotruncanoides* show isotopic trends suggesting a vertical migration across the Albian/Cenomanian boundary, shifting from the thermocline to shallower waters. *Dicarinella* is regarded by Caron and Homewood (1983), Hart (1999) and Falzoni et al. (2016a) as deeper dweller. Specifically, Falzoni et al. (2016a) distinguished two different morphologies related to diverse paleodepths: the umbilico-convex species occurring in the uppermost Cenomanian to Santonian assemblages are inferred to be thermocline dwellers, while the Turonian-Santonian plano-convex species are supposed to live in the shallower waters. Finally, in this study and according to the data from the literature rotaliporids (*Pseudothalmanninella, Thalmanninella, and Rotalipora*) and *Dicarinella* are considered k-strategist, preferentially living in oligo-mesotrophic conditions.

**Tab. 6.1** Available interpretations from the literature in term of paleohabitat of the upper Albian-Cenomanian species. Authors and studied localities are, as follow:
Ando et al. (2009), Blake Nose DSDP Site 1050, early to middle Cenomanian; Ando et al. (2010), Blake Nose DSDP Site 1050, late Albian-early Cenomanian; Ando et al. (2015), TDP Site 24, late Albian-early Cenomanian; Bornemann and Norris (2007), Demerara Rise ODP Leg 207, late Cenomanian-Coniacian; Falzoni et al. (2016a), Exmouth Plateau ODP Site 762C, late Cenomanian-Maastrichtian; Huber et al. (1999), Blake Nose DSDP Site 1050, late Cenomanian-Turonian; Huber et al. (2011), Falkland Plateau DSDP Site 511, late Cenomanian-Turonian; Nederbragt et al. (1998), circum north Atlantic sections, late Albian-middle Turonian; Norris and Wilson, 1998, Blake Nose DSDP Site 1052, late Albian-early Cenomanian; Norris et al. (2002), Demerara Rise DSDP Site 144, late Cenomanian; Petrizzo et al. (2008), Blake Nose DSDP Sites 1050 and 1052, late Albian-early Cenomanian; Price et al. (1998), Shatsky Rise DSDP Site Site 305 and Hawaiian Ridge DSDP Site 3015, late Albian- early Cenomanian and middle-late Cenomanian; Price and Hart (2002), Hawaiian Ridge DSDP Site 463, early Albian-Cenomanian; Wilson and Norris (2001), Blake Nose DSDP Site 1052, Albian-early Cenomanian.

| GENERA | SPECIES | HABITAT | STRATEGY | REQUIREMENTS | | AUTHORS |
|---|---|---|---|---|---|---|
| | | | | OXYGEN | TROPHIC | |
| TICINELLA | *T. primula* | upper mixed layer | r-strategist | | meso-eutrophic | Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010; |
| | *T. raynaudi* | upper mixed layer | | | | Norris and Wilson, 1998; |
| PARACOSTELLAGERINA | *P. libyca* | upper mixed layer | r-strategist | | meso-eutrophic | Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010; |
| BITICINELLA | *B. breggiensis* | upper mixed layer | r-strategist | | meso-eutrophic | Norris and Wilson, 1998; Wilson and Norris 2001; Petrizzo et al., 2008; |
| BISERIALS | *H. moremani* | upper mixed layer | r-strategist | | meso-eutrophic | Nederbragt et al., 1998; |
| WHITEINELLA | *Whiteinella* sp. | upper mixed layer | r/k intermediate more r-selected | | meso-eutrophic | Hart,1999; Huber et al., 1999; Falzoni et al., 2016a; |
| | *W. baltica* | lower mixed layer | | | | Huber et al., 2011; |
| | | upper mixed layer | | | | Bornemann and Norris, 2007; |
| GLOBIGERINELLOIDES | *M. pulchellus* | lower mixed layers | r-strategist | | meso-eutrophic | Petrizzo et al., 2008; |
| | *M. bentonensis* | lower mixed layers | | | | Petrizzo et al., 2008; |
| PLANOMALINA | *P. buxtorfi* | lower mixed layers | r/k intermediate more k-selected | | oligo-mesotrophic | Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010; |
| | | mixed layer | | | | Norris and Wilson, 1998: |
| | *P. praebuxtorfi* | lower mixed layers | | | | Petrizzo et al., 2008; |
| PRAEGLOBOTRUNCANA | *P.delrioensis* | lower mixed layers | r/k intermediate more k-selected | | oligo-mesotrophic | Petrizzo et al., 2008; |
| | | deep waters | | | | Norris and Wilson, 1998; |
| | *P. stephani* | lower mixed layers | | | | Petrizzo et al., 2008; |
| | | (Upper Albian) - thermocline; (Cenomanian) - upper mixed layer | | | | Ando et al., 2009; Ando et al., 2010; Ando et al., 2015; |
| | *P. gibba* | deep waters | | | | Hart , 1999; |
| MURICOHDBERGELLA | *M. simplicissima* | thermocline | r-strategist | dysoxia | meso-eutrophic | Petrizzo et al., 2008, Ando et al., 2010; Coxall et al., 2007; |
| | *Muricohedbergella sp.* | shallow waters | | | | Hart, 1999; Price and Hart, 2002; |
| | *M. planispira* | thermocline | | | | Petrizzo et al., 2008; |
| | *M. praelibyca* | thermocline | | | | Petrizzo et al., 2008; |
| | *M. delrioensis* | thermocline | | | | Petrizzo et al., 2008; Norris and Wilson, 1998; |
| | | (Albian/Cenomanian) - mixed layer ; (Cenomanian) -thermocline | | | | Ando et al., 2010 |
| | | Cenomanian - upper mixed layer | | | | Norris et al., 2002 |
| | | mixed layer | | | | Price at al., 1998 |
| ROTALIPORIDS | *rotaliporids* | thermocline | k-strategist | | oligotrophic | Hart, 1999; Wilson and Norris, 2001; Price and Hart, 2002; Petrizzo et al., 2008; |
| | *Th. globotruncanoides* | Albian/Cenomanian - upper thermocline; Cenomanian upper mixed layer | | | | Ando et al., 2009 ;Ando et al., 2010; Ando et al., 2015; |
| | *Th. appenninica* | Albian/Cenomanian - upper thermocline; Cenomanian upper mixed layer | | | | Ando et al., 2010; Norris and Wilson, 1998; |
| | | deep waters | | | | Norris and Wilson, 1998; Price et al., 1998; |
| | *Th. gandolfii* | Albian/Cenomanian - upper thermocline; Cenomanian upper mixed layer | | | | Ando et al., 2010; |
| | *R. montsalvensis* | thermocline | | | | Ando et al., 2010; |
| | *Th. reicheli* | thermocline | | | | Ando et al., 2010; |
| | *Ps. ticinensis* | thermocline | | | | Ando et al., 2010; Norris and Wilson, 1998; Petrizzo et al., 2008 |
| | *Th. brotzeni* | deep waters | | | | Norris and Wilson, 1998; |
| DICARINELLA | *Dicarinella algeriana* | upper mixed layer | k-strategist | | oligotrophic | Huber et al., 1999; |
| | *Dicarinella hagni* | lower mixed layer | | | | Huber et al., 1999; |
| | *Dicarinella* sp. (bioconvex species) | thermocline | | | | Falzoni et al., 2016a; |
| | *Dicarinella* sp. (umbilico-convex species) | upper mixed layer | | | | Falzoni et al., 2016a; |
| SCHACKOINA | *Schackoina* sp. | thermocline | r-strategist | dysoxia | meso-eutrophic | Coxall et al., 2007; |

## 6.5 Description of the composition of the planktonic foraminiferal assemblages

### 6.5.1 Results of the quantitative analysis for the Monte Petrano section

Planktonic foraminifera are common to abundant in the Monte Petrano section, while secondary components are benthic foraminifera, radiolaria, quartz fragment and black lithics depending on the sample. Anyhow, calcitic agglomerates are always present because of the difficulty in disaggregating the rock samples (see Chapter 3). Relative abundances of genera respect to the total planktonic foraminifera in each sample are calculated in order to minimize the influence of agglomerates on the results. Consequently, as disaggregated clasts and indeterminate specimens are counted, quantitative results are reliable and not affected by the processing technique.

Quantitative data collected for the Monte Petrano section are reported in Table 6-7 in the Appendix section and illustrated in Fig. 6.4, where the percent of planktonic foraminifera counted in the small (between 250 µm and 125 µm) and large (between 355 µm and 250µm) size fractions is presented and species diversity is plotted. Relative abundance of total planktonic foraminifera ranges from 4% and 91% and is always more abundant when compared to the total benthic values; the latter group show maximum values of about 13% only in the lower *P. buxtorfi* Subzone.

Rotaliporids, including the genera *Pseudothalmanninella*, *Thalmanninella* and *Rotalipora*, represent the most abundant group in the studied stratigraphic interval except for the interval containing *P. buxtorfi* where the planomalinids show the highest percentage values.

Other abundant genera are *Praeglobotruncana* and *Muricohedbergella,* varying from 1% to 63% and from 1% to 67%, respectively. *Planomalina* and *Dicarinella* are abundant as they constitute the 4-71% and the 2-33% of the total planktonic foraminifera, and they are characterized by restricted stratigraphic record, while *Biticinella* constitute the 4-33% of the assemblages with higher values at the base of the section. *Ticinella*, *Paracostellagerina*, *Whiteinella* and *Globigerinelloides* are less common and all together never exceed the 23% of the total assemblages.

The rotaliporids group shows high fluctuations in abundance ranging from 7% and 75% with an average of 43%. In the *P. buxtorfi* Subzone the higher abundance of *P. buxtorfi* (71%) corresponds to the lowest abundance of rotaliporids. In the upper *Th. appenninica* Zone, above the extinction of the genus *Planomalina*, rotaliporids reach the maximum values recorded in the studied section. From the upper part of the *Th. appenninica* Zone to the top of the stratigraphic section, rotaliporids are the most abundant group although their relative abundance slightly decreases from 75% to 50%. In general, species included in the rotaliporids group are always more abundant in the large-size fraction, except for the interval between the base on the studied section to the lower part of the *Th. appenninica* Zone; *Praeglobotruncana* is characterized by variation in relative abundance between 0% and 63%. Its trend can be divided in two intervals of highest relative abundance separated by lower values: in the first interval (from the middle of the *Th. appenninica* Zone to the lower part of the *Th. globotruncanoides* Zone) small specimens dominate; the second interval (from the lower part of the *Th. globotruncanoides* Zone to the top of the studied interval) is characterized by both high values of the small and large sized specimens.

The genus *Muricohedbergella*, characterized by a relative abundance between 1% and 67%, follows an opposite trend compared to *Praeglobotruncana* with higher values in the lower part of the section gradually decreasing towards the top. Specimens assigned to the genus *Muricohedbergella* are more abundant in the small-size fraction, except in the interval from the base of the section to the upper *Th. appenninica* Zone*,* where they are common also in the large-size fraction.

*Biticinella* shows values between 4% and 33% with an average of 18% and it follows a decreasing trend until its disappearance in the *Th. appenninica* Zone.

*Whiteinella* that shows its lowest occurrence in the lower part of the *Th. reicheli* Zone ranges from 1% to 21% with an average of 7% and it is equally abundant in both size fractions.

*Dicarinella* that shows its lowest occurrence in the middle part of the *R. cushmani* Zone is characterized by a relative abundance between 2% and 33% with an average of 18% and in the large-size fraction it progressively increases in number of specimens to the top of the section.

The *Ticinella* genus, mostly composed by small specimens*,* shows values from 0% and 20% and progressively decrease upward section till its disapperance within the *Th. globotruncanoides* Zone.

Small specimens of *Globigerinelloides* show steady values along the section in between 1% to 12%. Finally, *Paracostellagerina* is observed also in the large-size fraction when it reaches the maximum values in relative abundance of 2% before its extinction in the uppermost *Th. appenninica* Zone.

The species diversity ranges from 10 to 27 along the studied section and 4 main intervals are distinguished; the first one is between the base of the section and the lowermost part of the *Th. globotruncanoides* Zone where a decrease from 23 to 12 species is observed. The overlying interval is between the lower *Th. globotruncanoides* Zone and the upper part of *Th. reicheli* Zone and consists in a general increasing trend of the species diversity characterized by large oscillations in the values with a minimum of 10 and reaching the maximum value of 27 species for the entire section. The third distinguished interval, from the upper *Th. reicheli* Zone to the base of the *R. cushmani* Zone, is charaterized by an abrupt decrease in values reached in the lower *R. cushmani* Zone with 11 species. The latter part shows an increasing trend till the top of the section with a maximum of 20 species.

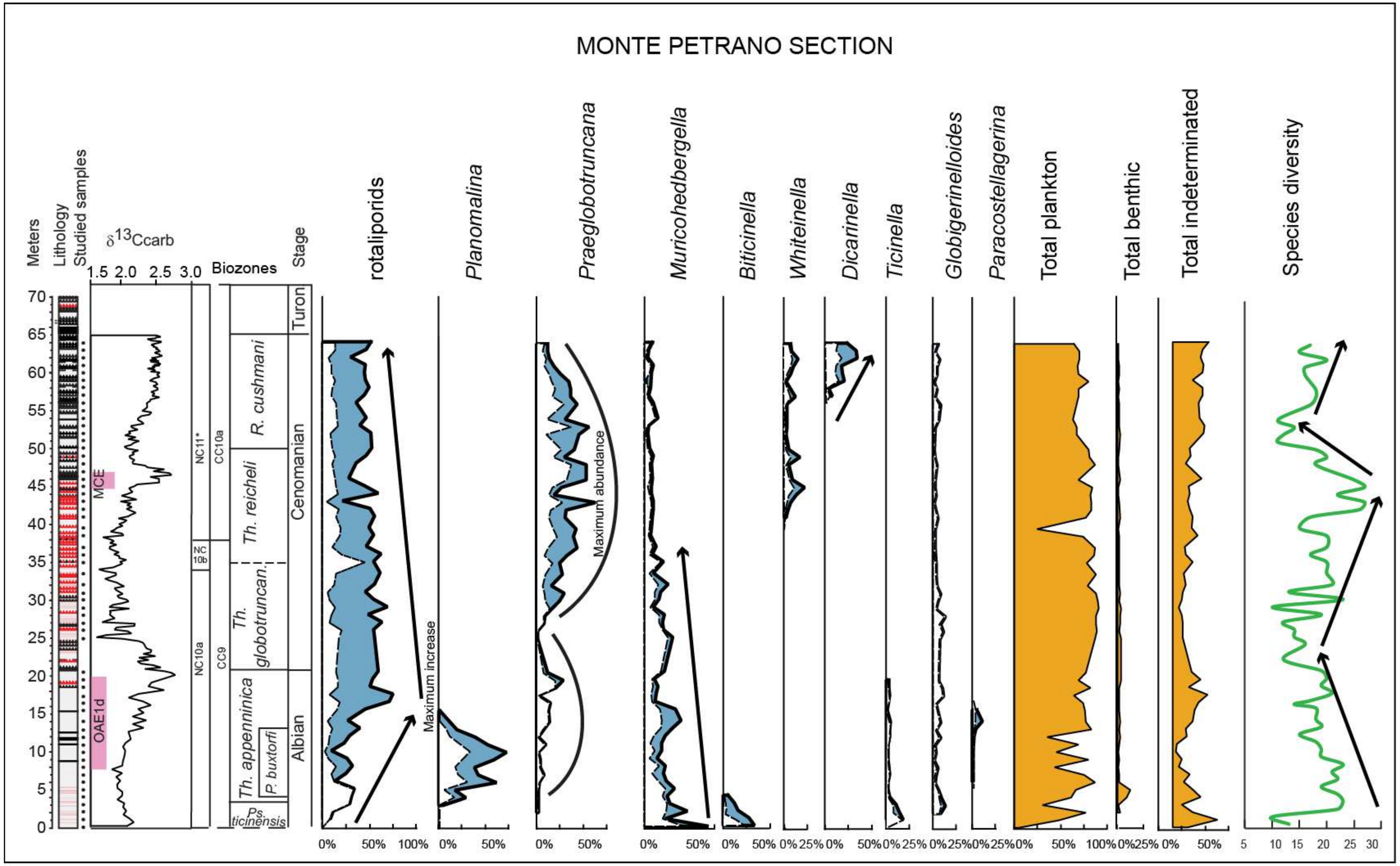


**Fig. 6.4** Quantitative analysis for the Monte Petrano section. Lithology, zonation based of calcareous nannofossil and chemostratigraphy are from Gambacorta et al. (2015). In light blue are illustrated the relative abundances of genera respect to the total planktonic foraminifera counted, while the overlapped white areas represent the small size fraction (between 125 μm and 250 μm) contribution respect to the total planktonic foraminifera. In orange are represented the relative abundance of planktonic and benthic foraminifera on the total counted, Green curve represents the total species diversity. The base of the *Th. reicheli* Zone is dashed because the LO of the marker species is considered a problematic bioevents.

## 6.5.2 Results of the quantitative analysis for Site 547A

The main components of the Mazagan Plateau DSDP Site 547A are planktonic foraminifera, even if dark lithics, quartz, glauconite and benthic foraminifera are present in almost all the stratigraphic intervals.

Quantitative data collected for Site 547A are reported in Table 8-9 in the Appendix section and species diversity are shown in Fig. 6.5. Abundance of total plankton, spanning from 2% to 71%, is always higher respect to the benthic percentages, showing a maximum of 25%. The most abundant genus is *Muricohedbergella,* except in the intervals where the genera *Ticinella* and *Praeglobotruncana* reach their maximum abundances. Moreover, other frequent taxa are rotaliporids, including *Pseudothalmanninella, Thalmanninella* and *Rotalipora, Praeglobotruncana* and *Globigerinelloides. Muricohedbergella* shows abundances ranging from 13% to 69% with an average of 39%. Between the upper *Ps. ticinensis* Zone and the lower *Th. appenninica* Zone*,* low values of *Muricohedbergella* correspond to higher abundances of *Ticinella,* while till the lower *Th. globotruncanoides* Zone values are almost stable (below 50%). Just above, a gradually increasing trend from an interval characterized by an average of 26% to the top of the *Th. globotruncanoides* Zone is observed, reaching the maximum value of the entire section of 69%, whereupon abundances tend to decrease. Rotaliporids show fluctuation in abundances with values comprised between 3% and 47% and an average of 18%. Relative abundances slightly increase till the lowest occurrence of *Th. appenninica*, and then gradually diminish, reaching the lowest values in the upper *Th. appenninica* Zone, corresponding to high values of *Ticinella*. The overlying interval is characterized by high fluctuation in abundances and by a general rise in abundance, reaching the maximum value of the entire section in the upper part of the *Th. globotruncanoides* Zone*.* In this interval, fluctuations of rotaliporids seem to be complementary to that of *Praeglobotruncana*, specifically lower values of the single keeled taxa correspond to the interval of maximum abundances of *Praeglobotruncana* and, on the contrary, maximum values of rotaliporids can be correlated to the lowest values of *Praeglobotruncana,* in the lower and upper *Th. globotruncanoides* Zone, respectively.

*Ticinella* shows the highest values of 68% at the base of the section and the values tend to gradually decrease till its extinction, except for a sample in the upper *Th. appenninica,* that records low abundance of single keeled forms.

The steady increase of abundance of the *Praeglobotruncana* genus starts from its appearance, corresponding to the decrease of *Ticinella* and culminates with abundance values of 59% in the middle part of *Th. globotruncanoides* Zone. In the overlying interval, values decrease, reaching the 0% (Sample 547A, 47R-CC, 15-16.5 cm) and start to rise in the upper part of the section. The relative abundance of

*Globigerinelloides* shows two intervals of slightly higher values, corresponding to the decrease of *Ticinella* and to the decrease of *Praeglobotruncana,* respectively.

The other groups are in suborder and characterized by a restricted or scattered stratigraphic distribution. Specifically, *Planomalina* shows values ranging from 1% to 6% and *Whiteinella* from 4% to 9%; *Protoheterohelix* has a discontinuous record and very low abundances from 1% to 3% and *Biticinella* and *Paracostellagerina* from 1% to 2%.

The species diversity is comprised between 5 and 26. Specifically, from the base of the section to the top of the *P. buxtorfi* Subzone, it is characterized by high values with deep oscillations especially in the upper *Ps. ticinensis* Zone. The number of species slightly decreases with several fluctuations till the top of the section. Values quickly increase to 18 species in the upper part of the Th. *globotruncanoides* Zone and oscillate between 8 and 22 till the top of the section with maximum values at the base and in the upper part of the *Th. reicheli* Zone.

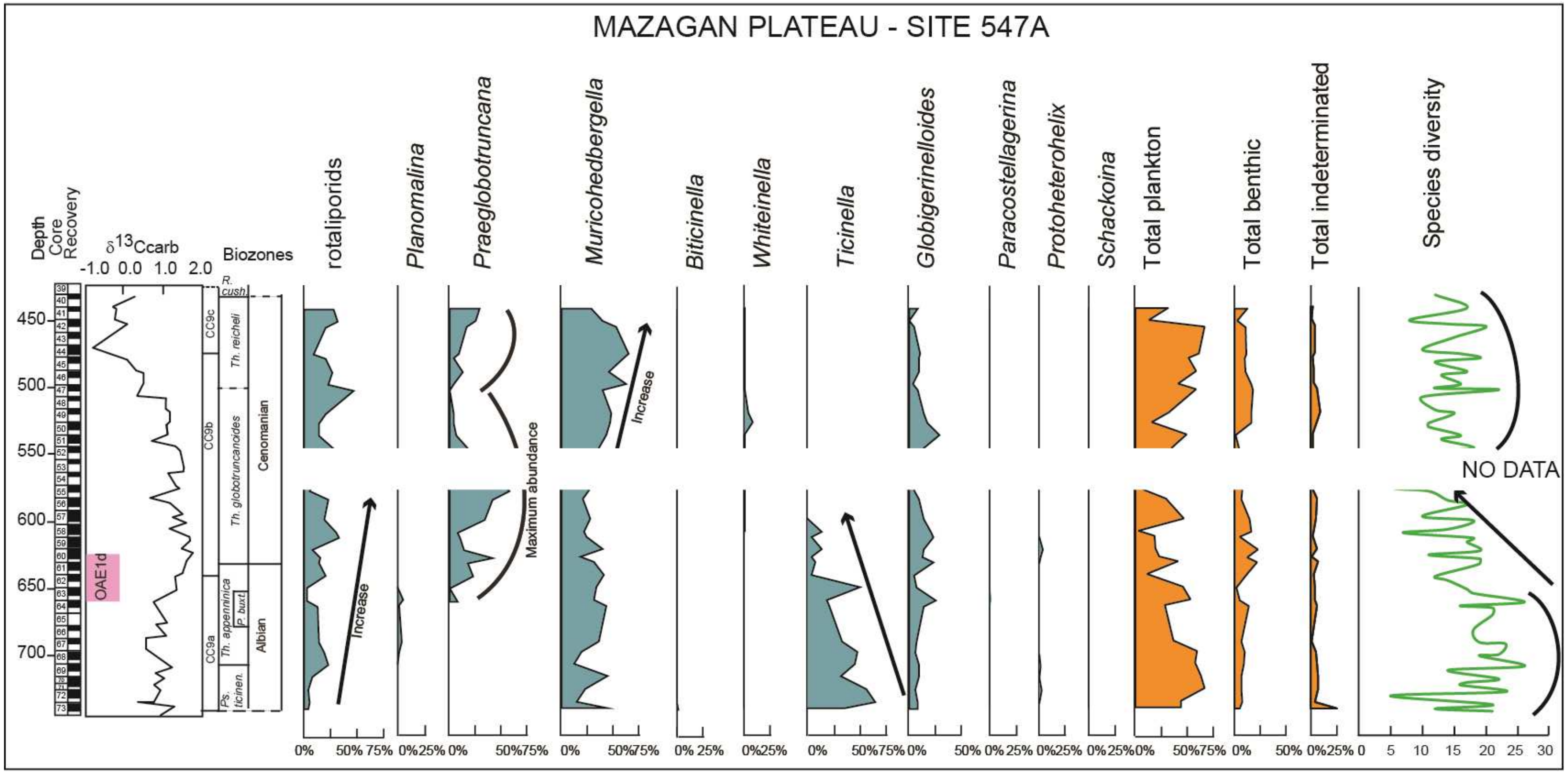


**Fig. 6.5** Quantitative analysis for the DSDP Site 547A. Lithological log is according to the sedimentological descriptions in Hinz, Winterer et al. (1981), while zonation based of calcareous nannofossil and chemostratigraphy are from Nederbragt et al. (2001). In light blue are illustrated the relative abundances of genera respect to the total planktonic foraminifera counted, while in orange are represented the relative abundance of planktonic and benthic foraminifera on the total counted. Green curve represents the total species diversity. White band indicates an interval where quantitative analysis were not performed. The base of the *Th. reicheli* Zone is dashed because the marker species is absent at Site 547A and the LO of *Th. greenhornensis* is used to approximate the base of the Zone.

## 6.6 Comparison of the planktonic foraminiferal assemblages between Monte Petrano and Site 547A

Comparing quantitative analysis collected for the Monte Petrano and DSDP Site 547A, several differences are observed:

1) the most abundant taxa are the single keeled group at Monte Petrano and the *Muricohedbergella* at DSDP Site 547A;

2) *Planomalina, Biticinella, Whiteinella* and *Paracostellagerina* are generally more rare at Mazagan Plateau, while *Globigerinelloides* and *Ticinella* resulted to be less common at Monte Petrano;

3) benthic foraminifera are definitely more abundant at Mazagan Plateau respect to the Umbria – Marche Basin;

4) some species within the rotaliporids, namely *Th. gandolfii, Th. greenhornensis, Th. deeckei* and *R. montsalvensis* are very rare at Site 547A, while they are quite abundant at Monte Petrano;

5) at Mazagan Plateau specimens assigned to the genera *Biticinella, Paracostellagerina, Whiteinella* and the rotaliporids are generally smaller and less common while specimens of *Ticinella* and *Globigerinelloides* are larger and more common respect to the Umbria-Marche Basin.

The comparison between species diversities highlights that in both sections the interval from the upper Albian to about the middle *Th. globotruncanoides* Zone shows quite stable or slightly decreasing values till a minimum diversification in the middle-upper part of the Zone. In the overlying interval at both sections the species diversities slightly increase. On the other hand, three main differences are observed:

1) the variability between maximum and minimum number of species at Site 547A is wider respect to Monte Petrano;

2) at the Mazagan Plateau fluctuations in diversity are recorded along the entire sections, while at Monte Petrano remarkable oscillations are observed only in the upper *Th. globotruncanoides* Zone;

3) maximum diversities values are recorded in the *Th. reicheli* Zone at Monte Petrano, while the interval of maximum diversification at Site 547A is observed in the upper Albian.

## 6.7 Planktonic foraminifera depth habitats and variation in abundance

According to the available literature (see Paragraph 6.4), genera are associated to the upper and lower mixed layer and to the thermocline as summarized in Figure 6.6. Specifically, *Ticinella* (Norris and Wilson, 1998; Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010)*, Biticinella* (Norris and

Wilson, 1998; Wilson and Norris, 2001; Petrizzo et al., 2008), *Paracostellagerina* (Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010), *Whiteinella* (Hart, 1999; Huber et al., 1999; Bornemann and Norris, 2007; Huber et al., 2011; Falzoni et al., 2016a), and *Protoheterohelix* (Nederbragt et al., 1998) are inferred as upper mixed layer dwellers and considered opportunistic taxa. Among the genera inhabiting the lower mixed layers, *Planomalina* (Norris and Wilson, 1998; Wilson and Norris, 2001; Petrizzo et al., 2008; Ando et al., 2010;) and *Praeglobotruncana* (Hart, 1999; Norris and Wilson, 1998; Price and Hart, 2002; Petrizzo et al., 2008; Ando et al., 2009, 2010, 2015) are considered as intermediate strategist more specialized, while *Globigerinelloides* (Petrizzo et al., 2008)*,* and *M. simplicissima* (that is considered shallower respect to the others *Muricohedbergella* based on its different wall texture: Petrizzo et al., 2008) are included in the intermediate more r-strategist taxa. Finally, rotaliporids (Hart, 1999; Wilson and Norris, 2001; Price and Hart, 2002; Norris and Wilson, 1998; Price et al., 1998; Petrizzo et al, 2008; Ando et al., 2010, 2015) and *Dicarinella* (Huber et al., 1999; Falzoni et al., 2016a) are considered as thermocline k-strategist dwellers. *Schackoina* (Coccioni and Luciani, 2005; Coxall et al., 2007) and *Muricohedbergella* (Price et al., 1998; Norris and Norris, 1998; Hart, 1999; Norris et al., 2002; Price and Hart, 2002; Petrizzo et al., 2008; Ando et al., 2009, 2010, 2015) are generally considered thermocline r-strategist dwellers. Moreover, the genus *Muricohedbergella* is here considered as a cold opportunist taxon that can live in a wide range of depth habitats (see discussion Paragraph 6.4).

Relative abundances of each of the upper mixed layer, lower mixed layer and thermocline dwellers are presented below and illustrated in Figure 6.7 and 6.8 for the Monte Petrano section and for the Mazagan Plateau Site 547A, respectively. The P/B ratio and the number of species inferred to have inhabited the upper mixed layer, lower mixed layer and the thermocline are also plotted for completeness but they will be discussed in Paragraph 6.8.

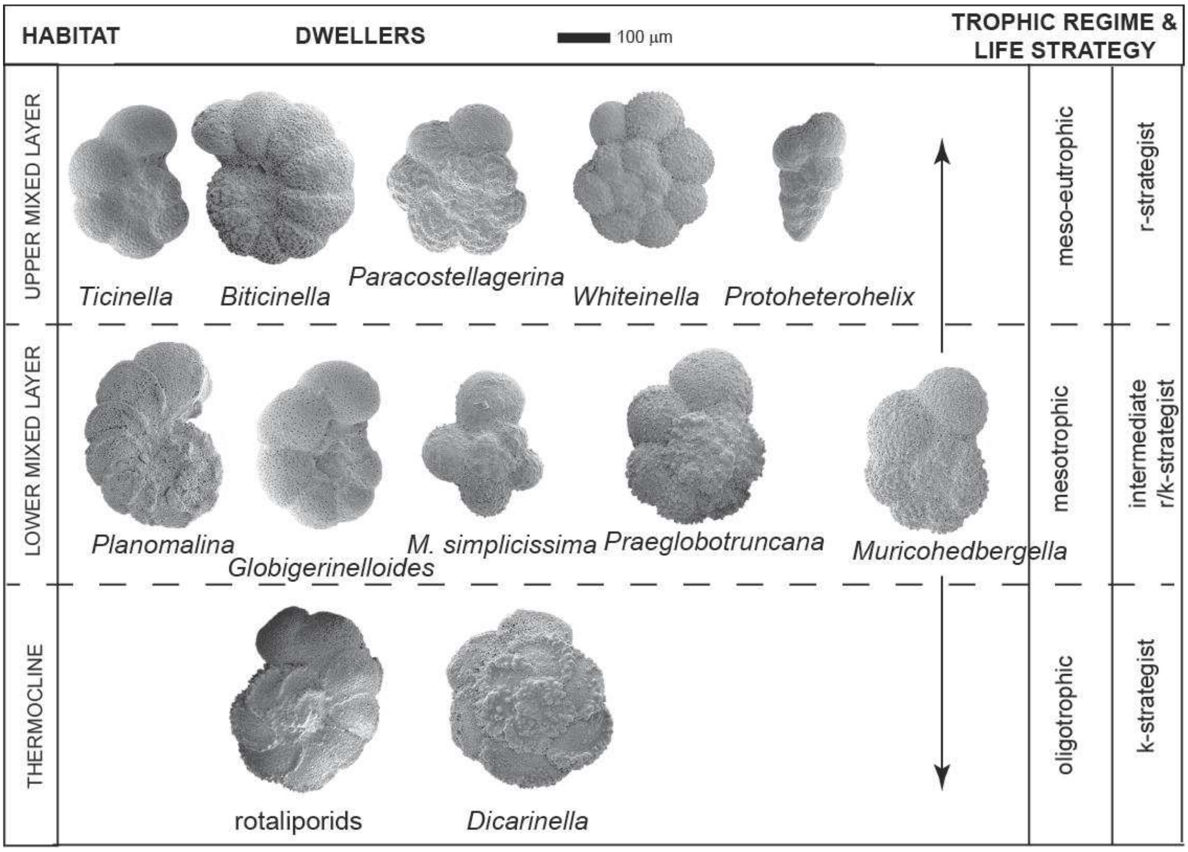


**Fig. 6.6** Genera distribution in the water column and general information on their life strategy and preferred trophic regimes as considered in this study. SEM images: *T. primula*, Sample 547A 73R-3, 53-54.5 cm; *B. breggiensis*, Sample B0.01*; P. libyca*, Sample 545 38R-1, 89-91 cm; *W. aprica*, Sample MP44; *P. washitensis*, Sample 547A 47R-3, 52.5-54.5 cm; *P. buxtorfi*, Sample B6; *G. bentonensis*, Sample 547A 45R-3, 16-18 cm; *M. simplicissima*, Sample MP6; P. delrioensis, Sample MP42; *M. praelibyca*, Sample MP0; *Th. balernaensis*, Sample MP13; *D. hagni*, Sample MP59. Scale bar 100 µm.

In general, the two studied successions show comparable changes in the composition of the assemblages. Specifically, the lower part of the studied interval is dominated by the shallower dwellers *Ticinella* at Site 547A and the *Biticinella* at Monte Petrano. Surface dweller taxa are gradually replaced by species living in deeper habitats: initially by the lower mixed layer dwellers *Planomalina* at Monte Petrano and *Praeglobotruncana* at Site 547A, and later by the thermocline inhabitants such as rotaliporids at Monte Petrano and *Muricohedbergella* at Site 547A. Moreover, in the Umbria-Marche Basin, the upper part of the stratigraphic section is characterized by an increase in the lower mixed layer dwellers *Praeglobotruncana,* respect to the thermocline inhabitants, in fact *Muricohedbergella* is characterized by a quite low abundance and rotaliporids show a gradually decreasing trend even though they are still very abundant.

The variations in abundance of the upper and lower mixed layer and of the thermocline dwellers are described below from base to top.

*Mixed layer dwellers.* The relative abundances of taxa in both sections highlight that in the upper *Ps. ticinensis* Zone, species inhabiting the upper mixed layer reach a maximum of 47% at Monte Petrano (*Biticinella* and *Ticinella*) and of 70% (*Ticinella*) at Site 547A. In the upper *P. buxtorfi* Subzone, lower mixed layers dwellers seems to dominate the water column, as they reach peak abundances of 79% at Monte Petrano (mostly *Planomalina*) and of 42% (mostly *Globigerinelloides*) at Mazagan Plateau. A second peak of abundance is shown in both sections in the uppermost *Th. appenninica* Zone at Monte Petrano and in the lowermost *Th. globotruncanoides* Zone at Site 547A.

Coincident with the decreasing phase between the above mentioned positive peaks of the lower mixed layer dwellers, increasing values are shown by the shallower dwelling taxa, that are higher at Mazagan Plateau, where they dominate the mixed layer population.

In the uppermost *Th. appenninica* Zone at Monte Petrano and in the lower *Th. globotruncanoides* Zone at Site 547A, shallower taxa start to fluctuate till the top of the sections. Very low values of lower mixed layer dwellers are observed in both sections in the upper part of *Th. appenninica* Zone, then they gradually start to increase, reaching a maximum of 66% in the middle part of *Th. reicheli* Zone at Monte Petrano, and of 65% in the middle *Th. globotruncanoides* Zone at Mazagan Plateau. In both sections this increase in abundance is related to the interval of maximum values of *Praeglobotruncana*. At Site 547A, *Praeglobotruncana* decrease and reach minimum values of 10% close to the appearance of *Th. greenhornensis,* used to approximate the base of the *Th. reicheli* Zone. In the overlying stratigraphic interval, it increases till the top of the studied stratigraphic interval, reaching the 40% of abundance. In the lower *Th. reicheli* Zone of the Monte Petrano section, an increase in abundance of shallower taxa related to the appearance of *Whiteinella* is observed and it is characterized by fluctuating values till the top of the section.

*Thermocline dwellers.* The thermocline dwellers curve show different trends in the two sections. Specifically, at Monte Petrano thermocline taxa have a specular trend if compared to the lower mixed layer dwellers, whereas shallower taxa are a minor component of the assemblage. Thermocline dwellers (mostly rotaliporids) reach a maximum abundance of 83% in the upper *Th. appenninica* Zone, whereupon they slightly decrease till a minimum of 24% in the middle of the *Th. reicheli* Zone. In the overlying stratigraphic interval, abundances of the deepest dwellers fluctuate and slightly increase till the appearance of *Dicarinella* in the lower *R. cushmani* Zone. Then the thermocline inhabitants (mostly rotaliporids and *Dicarinella*) increase till the top of the section, reaching abundance of 78%. On the contrary, at Mazagan Plateau, the thermocline dwellers, mostly dominated by *Muricohedbergella*, fluctuate and slightly increase in abundance in the lower *Th. globotruncanoides* Zone. In the overlying stratigraphic interval they increase more quickly till the appearance of *Th. greenhornensis*, where they reach the 89% in correspondence of minimum values of the mixed layer taxa. The uppermost part of the section is characterized by a decrease of the deeper dwellers reaching the 60% in abundance.

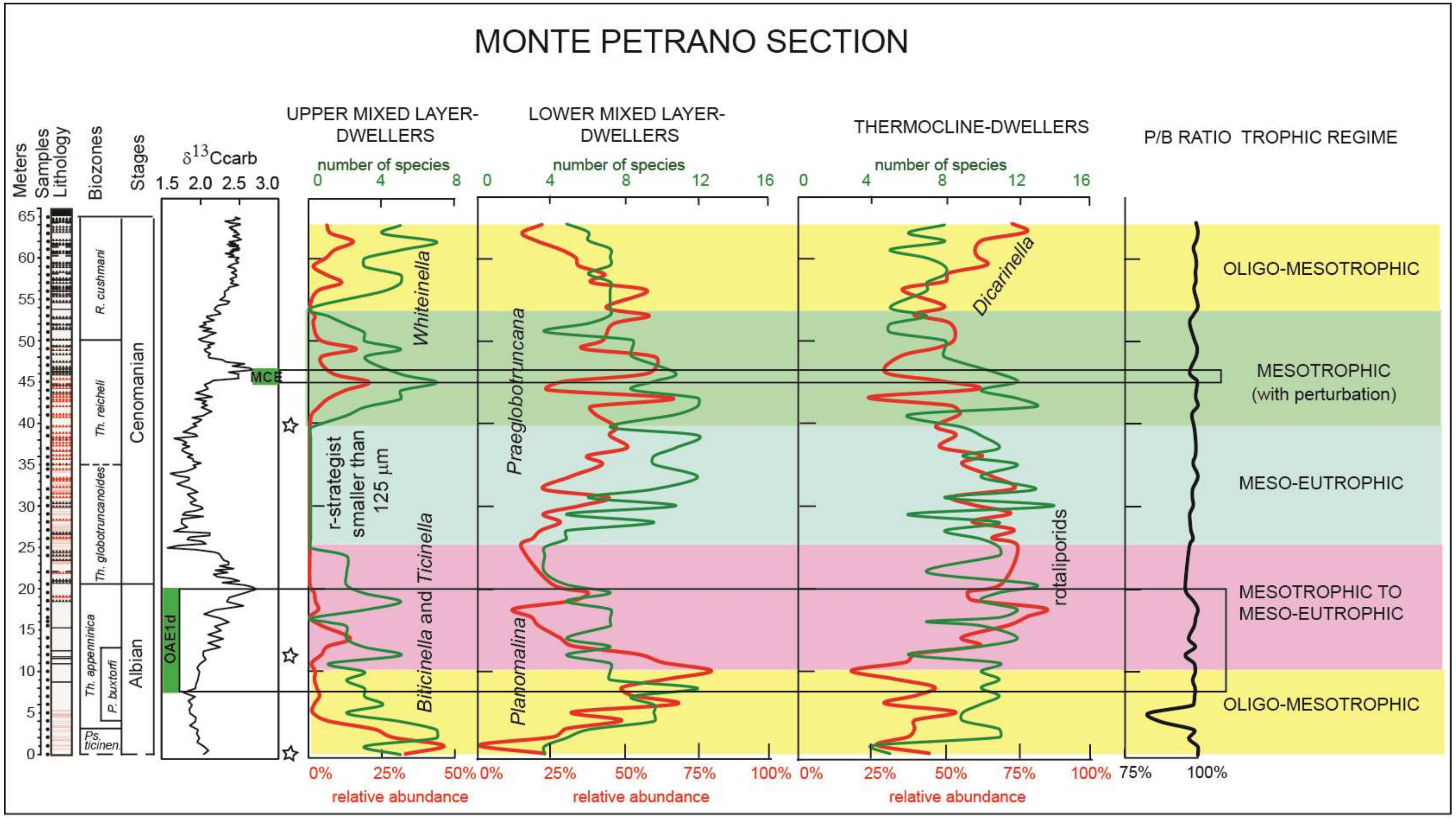


**Fig. 6.7** Relative abundances of each of the upper mixed layer, lower mixed layer and thermocline dwellers respect to the total planktonic foramInifera (red curves), number of species (green curves), plankton/benthic ratio (black curve) and information about the trophic regime for the Monte Petrano section. Genera that most influence the abundance and/or the species diversity are reported close to the related interval. Colored bands indicate phases of different trophic regimes, while black rectangles highlight the variation of the assemblages during the OAE1d and the MCE. Lithology and chemostratigraphy are from Gambacorta et al. (2015). Stars indicate samples characterized by high abundance of radiolaria. The base of the *Th. reicheli* Zone is dashed because the LO of the marker species is considered a problematic bioevents.

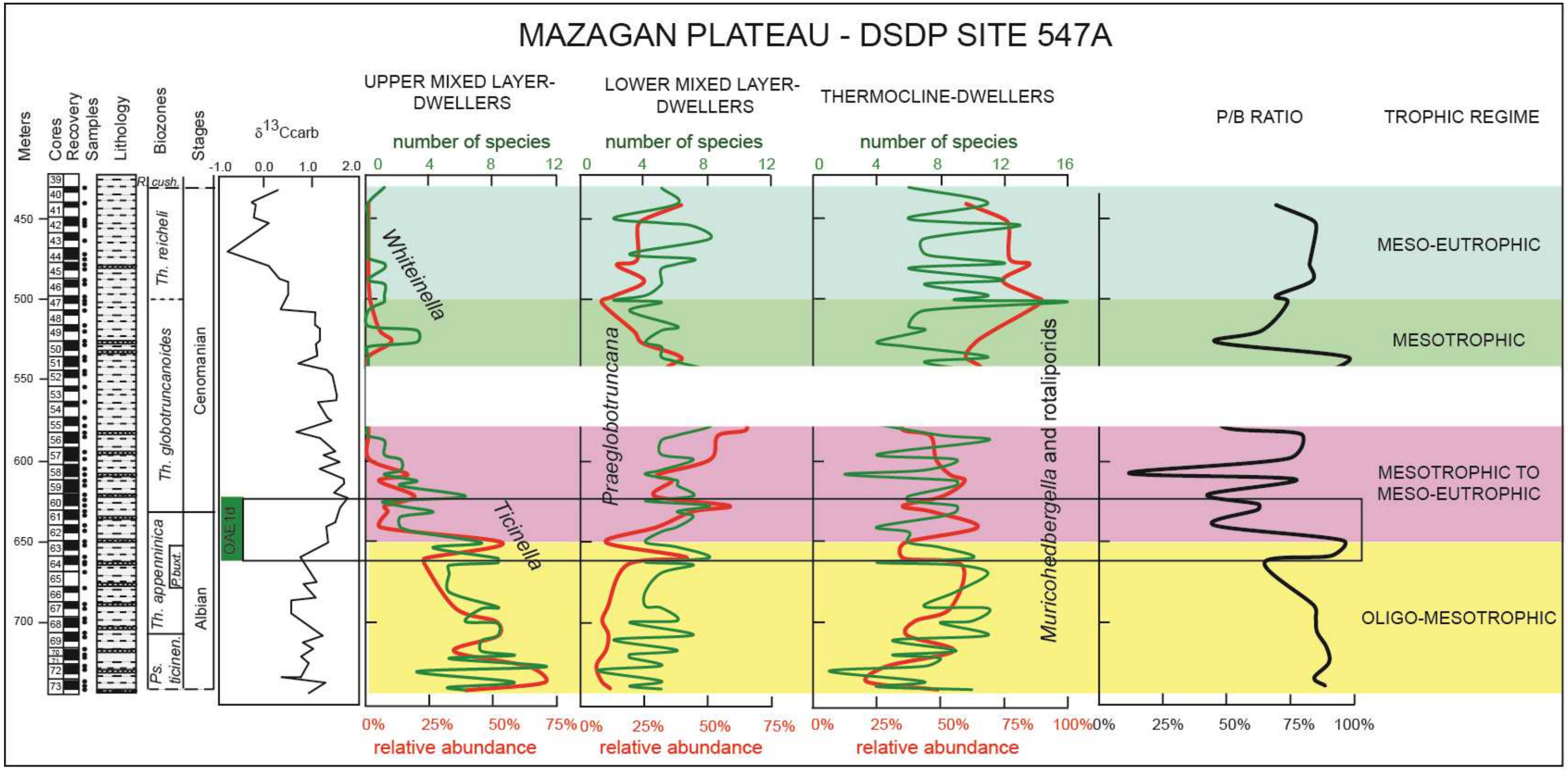


**Fig. 6.8** Relative abundances of each of the upper mixed layer, lower mixed layer and thermocline dwellers respect to the total planktonic foraminifera (red curves), number of species (green curves), plankton/benthic ratio (black curve) and information about the trophic regime for Site 547A. Genera that most influence the abundance and/or the species diversity are reported close to the related interval. Colored bands indicate phases of different trophic regimes, while black rectangles highlight the variation of the assemblages during the OAE1d. White band indicates an interval where quantitative analysis were not performed. Lithology is interpreted according to the sedimentological descriptions in Hinz, Winterer et al. (1981), while chemostratigraphy is from Nederbragt et al (2001). The base of the *Th. reicheli* Zone is dashed because the marker species is absent at Site 547A and the LO of *Th. greenhornensis* is used to approximate the base of the Zone.

## 6.8 Paleoceanographic interpretation based on planktonic foraminiferal abundances, diversity and depth habitats

Paleoceanographic interpretation is given according to the variations in diversity and relative abundances of taxa with similar depth habitats (upper mixed layer, lower mixed layer and thermocline dwellers) as described in Paragraph 6.7.

### 6.8.1 Monte Petrano (Fig. 6.4 and Fig. 6.7)

The foraminiferal assemblages at Monte Petrano are dominated by planktonic foraminifera throughout the stratigraphic interval and benthic foraminifera are always quite rare, as shown by the P/B ratio, which, however, is plotted in Fig. 6.7 for completeness.
Intervals characterized by a dominant trophic regime are described below.

#### 1) Oligo-mesotrophic regime

From the base of the section to the upper *P. buxtorfi* Subzone, the water column is dominated by lower mixed layer taxa, mostly *Planomalina* and to a lesser extent in abundance *Praeglobotruncana* and *Globigerinelloides,* and thermocline dwellers, specifically rotaliporids and *Muricohedbergella,* followed by the shallower taxa *Biticinella, Ticinella* and *Paracostellagerina*. In any case, the interval of high abundance of the lower mixed layer dwellers is due to a maximum value and to the increasing abundance of the intermediate more k-strategists *Planomalina* and *Praeglobotruncana*, that occur together with the increase in abundance and diversity of the deeper specialist rotaliporids, while the shallower waters are inhabited by r-strategist taxa such as *Biticinella, Ticinella, Paracostellagerina* and *Globigerinelloides.*
In the upper part of the interval (middle *P. buxtorfi* Subzone), corresponding to the beginning of the OAE1d (as defined by the carbon isotope record), an abrupt decrease in the number of warm species (*Ticinella*) is observed. However, the diversification of the assemblages in terms of preferred depth habitats along the water column suggests the presence of a rather defined thermal gradient, and of a stable and thick thermocline layer.

#### 2) **Mesotrophic to Meso-eutrophic regime**

The interval between the upper *P. buxtorfi* Subzone and the lower *Th. globotruncanoides* Zone is characterized by specular marked fluctuation in diversity of the shallower dwellers (*Ticinella*) respect to the cold taxon rotaliporids that abruptly increase in abundance. Meanwhile, the decrease in abundance of the intermediate more specialized taxa, mostly *Planomalina* (that disappears in the lower part of the interval) and *Praeglobotruncana* is observed. At the top of the interval the extinction of the warm *Ticinella* does occur, coinciding with the lower abundance and diversity of the intermediate more k-strategist *Praeglobotruncana* and to the highest abundance of the cold dwellers (*Muricohedbergella* and rotaliporids).

The marked oscillations of taxa with similar depth habitats suggest the presence of perturbations, possibly related to the OAE1d, that periodically cause the reduction/variation of the thermal gradient in the upper water column. This condition leads to the extinction of the warm dwellers *Paracostellagerina* and *Ticinella* and to the increase in abundance of taxa more adapted to colder environments.

### 3) Meso-eutrophic regime

From the lower *Th. globotruncanoides* Zone to the lower *Th. reicheli* Zone, the intermediate taxa (*Praeglobotruncana*) increase in abundance and in the number of species, while the deeper rotaliporids decrease. Moreover, the population of the cold r-strategist *Muricohedbergella* is mostly constituted by small specimens (between 125 µm and 250 µm) and its decrease in abundance can be interpreted as a decrease in size (under 125 µm that has not been counted but qualitatively observed in the small-size fractions), likely caused by a faster reproduction rate corresponding to an interval of a dominant meso-eutrophic regime. Accordingly, the k-strategist rotaliporids, more adapted to oligo-mesotrophic environment, decrease and the intermediate *Praeglobotruncana* reaches its maximum abundance at the top of the interval. Moreover, because of the absence of warm taxa, indicating a reduced gradient of temperature and a weak stratification in the upper column water, *Praeglobotruncana* can occupy the entire mixed layer.

### 4) Mesotrophic regime (with perturbation)

The interval between the lower *Th. reicheli* Zone and the lower *R. cushmani* Zone is characterized by marked fluctuations in the abundances of taxa. The lower mixed layer dwellers trend is opposite respect to that of the shallower and thermocline taxa. Specifically, the number of lower mixed layer and thermocline dweller species is decreasing, while shallower taxa are more diversified because of the appearance of the opportunist *Whiteinella* in the lower part of the *Th. reicheli* Zone, that may indicate the beginning of the restoration of a more defined thermal gradient. The opposite trend between specialized rotaliporids coupled with opportunist *Whiteinella* and the intermediate *Praeglobotruncana* can be possibly explained by competition during phases of instabilities alternated to intervals of defined stratification. When *Whiteinella* occurs, *Praeglobotruncana,* that dominates the mixed layer habitats, probably migrate in deeper water to occupy the niches inhabited by the rotaliporids. The hypothesis of migration and of the transition to a more specialized life strategy and, thus, to a longer life cycle is reinforced by the observation that, in this interval, a larger number of keeled *Praeglobotruncana* is observed. Consequently, *Praeglobotruncana* is in competition with both the shallowest and the deepest taxa and gradually decrease in abundance.

The shallow and opportunist *Whiteinella* reaches its maximum in term of species diversity and abundance in the upper part of the *Th. reicheli* Zone then it decreases. The beginning of the decreasing trend of *Whiteinella* can be correlated to an increase of *Praeglobotruncana,* and to a decrease of rotaliporids and might correspond to the MCE event (as identified by the carbon isotope record). Consequently, the MCE could be interpreted as a short event of cooling in the upper water column, in which *Praeglobotruncana,* more adapted to cold temperature, increases in abundance, occupying also the part of the mixed layer previously inhabited by the warmer dweller *Whiteinella.* Nevertheless, the decrease of the k-strategist rotaliporids can be explained by attributing different ecological preferences (depth habitats) to each species. Moreover, evidence of an upward migration in the lower Cenomanian of *Th. appenninica, Th. gandolfii* and *Th. globotruncanoides* are also reported by Ando et al. (2010) (see Paragraph 6.4).

**5) Oligo-mesotrophic regime**

The interval between the lower *R. cushmani* Zone and the top of the section is characterized by the increase in abundance and diversification of the shallow *Whiteinella* and of the deeper k-strategist *Dicarinella,* indicating a separation of the ecological niche available for the planktonic foraminifera to occupy that likely corresponds to an increase of the thermal gradient and a more stratified water column and/or the thickening of the thermocline in a more a oligo-mesotrophic regime.

### 6.8.2 Mazagan Plateau (Fig. 6.5 and Fig. 6.8)

The foraminiferal assemblages at Mazagan Plateau are generally dominated by planktonic foraminifera. However, benthic foraminifera shows very fluctuating abundances particularly from the middle *P. buxtorfi* Subzone to the base of the *Th. reicheli* Zone, and common radiolaria are observed in the entire section. The P/B ratio is plotted in Fig. 6.8.

Intervals characterized by a dominant trophic regime are described below:

### 1) Oligo-mesotrophic regime

From the base of the section to the top of the *P. buxtorfi* Subzone, the water column is dominated by opportunistic dwellers, mostly including the deeper *Muricohedbergella* and the shallower *Ticinella*, which is the only abundant warm taxon observed in the assemblages. Specialized taxa are represented by rotaliporids and by the intermediate more k-strategist *Planomalina* and *Praeglobotruncana.* However, the quite diversified assemblages suggest a moderately defined thermal gradient and the presence of a stable thermocline in a more oligo-mesotrophic regime.

### 2) Mesotrophic to Meso-eutrophic regime

From the top of the *P. buxtorfi* Subzone to the lower *Th. globotruncanoides* Zone the decline of the warm dwellers (*Ticinella*) is characterized by phases of fluctuations in abundances and diversities. Particularly, marked oscillations are observed in the stratigraphic interval corresponding to the OAE1d, when phases of lower abundance of *Ticinella* coincide with the increase of the colder *Praeglobotruncana* and rotaliporids. Thereafter, *Ticinella* is gradually substituted by intermediate strategists such as the more opportunistic *Globigerinelloides* and the more specialized *Praeglobotruncana,* till its extinction in the lower *Th. globotruncanoides* Zone. Moreover, this interval is characterized by marked fluctuation of the P/B ratio, with phases of increase in the benthic abundance. This interval is suggested to be characterized by a mesotrophic to eutrophic regime, in which the decrease of the thermal gradient of the water column leads to the reduction of the available niches, and, thus, to the diminution and the extinction of the warmest dwellers *Ticinella.* Consequently, *Praeglobotruncana,* that is more adapted to colder environments, can increase in both abundance and diversity and occupy the larger part of the mixed layer.

### 3) Mesotrophic regime

Despite the lack of data in the middle part of the *Th. globotruncanoides* Zone, in the upper part of the Zone the shallower warm dweller *Whiteinella* first occurs and diversifies. This phase corresponds to a decrease of colder species, of the intermediate more specialized dweller *Praeglobotruncana* and of the k-strategist rotaliporids. However, *Whiteinella* is not abundant and colder dwellers continue to prevail in the column water. The increase of the available ecological niches and the occurrence of warmer taxa, suggests that a stable stratification of the water column seems to re-establish in a more mesotrophic environment.

**4) Meso-eutrophic regime**

In the upper part of the section, the assemblages are dominated by cold dwellers, specifically the r-strategist *Muricohedbergella* and the intermediate inhabitant *Praeglobotruncana*. On the contrary, the warm *Whiteinella* and the k-strategist rotaliporids decrease in abundance and in diversity, indicating a reduced thermal gradient and a meso-eutrophic environment.

## 6.9 Planktonic foraminiferal response to the OAE1d and the Mid Cenomanian Event

Paleoceanographic observations about the response of the planktonic foraminiferal assemblages to the OAE1d and MCE (see Paragraph 6.8) are compared with the available literature on these topics as reported in Chapter 2.

Specifically, results from this study for the stratigraphic interval inferred to correspond to the OAE1d, are similar to that from the Blake Nose (NW Atlantic) (Wilson and Norris, 2001; Petrizzo et al., 2008). The Authors suggest that the variation of the planktonic foraminiferal assemblages would correspond to an interval of reduced thermal gradient probably caused by increased wind-driven mixing coincident with the OAE1d. Moreover, as for the Monte Petrano and Site 574A, the extinction of the warm *Ticinella* may be related to a dominant regime of high productivity. At Blake Nose, the interpretation of enhanced productivity is also supported by the calcareous nannofossil data (Watkins et al., 2005), which suggest that across the interval of reduced vertical gradient, taxa more related to mesotrophic regimes increase in maximum abundance, while oligotrophic taxa decrease. Ultimately, in the stratigraphic interval inferred to correspond to the OAE1d in the Umbria-Marche Basin and at Mazagan Plateau, the planktonic foraminiferal assemblages suggest phases of reduced thermal gradient in the upper water column, leading to the decrease of the available ecological niches for planktonic foraminifera to occupy and to the extinction of the warmest dwellers (*Paracostellagerina* and *Ticinella*).

Results of this study related to the stratigraphic interval inferred to include the MCE in the Umbria-Marche Basin, are comparable to the data from the Anglo-Paris Basin (Voigt et al., 2004; Wilmsen et al., 2007). In fact the authors correlate the MCE with the *primus* Event that is associated to a minimum of temperature. Moreover, a short interval of cooling before the mid-Cretaceous thermal maximum is also observed by Friedrich et al. (2012) on the basis of carbon and oxygen benthic foraminiferal data from sites in the Atlantic and Pacific Oceans and in the southern high latitudes.

In this study, the planktonic foraminiferal assemblages across the MCE is characterized by an abrupt decrease of warm *Whiteinella* taxa that occurs at their maximum diversification and abundance and might indicate a sudden reduction of the temperature gradient in the upper water column.

# Chapter 7

# Conclusions

## 7.1 Biostratigraphy

This study provides a detailed biostratigraphic analysis of the upper Albian-Cenomanian planktonic foraminiferal assemblages from the Umbria-Marche Basin and the Mazagan Plateau. The most important results are highlighted, as follows:

1) five Biozones and one Subzone are recognized according to the biozonation by Robaszynski and Caron (1995); specifically, from base to top: *Ps. ticinensis* Zone*, Th. appenninica* Zone*, P. buxtorfi* Subzone*, Th. globotruncanoides* Zone, *Th. reicheli* Zone and *R. cushmani* Zone;

2) the detailed taxonomic and biostratigraphic analyses and the comparison of the sequence of bioevents with data reported from the literature (Mont Risou section, Vocontian Basin: Gale et al., 1996; Kennedy et al., 2004; Petrizzo et al., 2015; and Blake Nose ODP Site 1050C, northwestern Atlantic: Petrizzo and Huber, 2006a; Petrizzo et al., 2008; Petrizzo et al., 2015), allow to identify the best sequence of bioevents useful for regional to global correlations. Specifically, from base to top: the LO of *Th. appenninica,* the LO of *P. buxtorfi,* the LO of *P. libyca,* the LO of *Th. brotzeni,* the LO of *Th. globotruncanoides,* the LO of *Th. greenhornensis,* and the LO of *R. cushmani*;

3) the best regional correlation is that between the Mazagan Plateau and the Blake Nose, where the sequence of bioevents perfectly correlates, as expected since the two sites were located on the opposite sides of the opening northern Atlantic Ocean;

4) the LO of *Th. reicheli* resulted to be a problematic bioevent, as the species is rare and shows a scattered stratigraphic distribution. However, in the Umbria-Marche Basin it is still used for the definition of the base of the nominal Zone pending the identification of more reliable events for correlating localities outside the Umbria-Marche Basin. At Mazagan Plateau the species *Th. reicheli* is not recorded and secondary bioevents (the LOs of *Th. greenhornensis* and of the genus *Whiteinella*) are here proposed to approximate the base of *Th. reicheli* Zone. The secondary bioevents are considered to be promising for correlation, even if additional insights from other tropical to subtropical localities are needed to verify their reliability at global scale;

5) the LO of *Th. globotruncanoides*, bioevent for the definition of the Albian/Cenomanian boundary is well constrained by the carbon isotope data. In fact, the LO of *Th. globotruncanoides* falls very close to the positive carbon isotope value (peak b) registered in sections located at different paleogeographic and paleoceanographic areas (Monte Petrano section, Umbria-Marche Basin: Gambacorta et al., 2015; DSDP Site 547A, Mazagan Plateau, southern-east North Atlantic: Nederbragt et al., 2001; ODP Site 1050C, Blake Nose Plateau, northern-west Atlantic: Petrizzo et al., 2008; Petrizzo et al., 2015; Mont Risou section, Vocontian Basin: Gale et al., 1996; Kennedy et al., 2004; Petrizzo et al., 2015). However, the stratotype section at Mont Risou represents an exception because the carbon isotope positive plateau anomaly is recorded below the LO of *Th. globotruncanoides*. The reason can be due to a scarce reliability of the carbon isotope data from the Risou section, as sediments may be altered by diagenesis. New studies using a higher sampling resolution are needed to implement the chemostratigraphic record in the stratotype section;

6) the correlation of the OAE1d, defined as the interval between the starting point of the $\delta^{13}C$ excursion and the point where the anomaly definitely ended (maximum $\delta^{13}C$ value), among sections highlights that the beginning of the environmental perturbation always falls in the middle part of the *P. buxtorfi* Subzone. On the contrary, the end of the event falls at different biostratigraphic positions; specifically, at Monte Petrano and at Mont Risou the end of the event is observed in the uppermost *Th. appenninica* Zone, while at Le Brecce and at Site 547A, it is correlated to the lowermost *Th. globotruncanoides* Zone, and at Site 1050C it perfectly coincides with the Albian/Cenomanian boundary.

## 7.2 Taxonomy

The review of the upper Albian-Cenomanian planktonic foraminiferal species is carried out through a detailed taxonomic analysis. The abundance and relatively good preservation of planktonic foraminifera has simplified the identification of the key morphological features and of the wall texture. The most important results are, as follows:

1) *Thalmanninella reicheli* can be misidentified with *Thalmanninella deeckei*; therefore, the criterion used in this study to separate the two species is based on the umbilical sutures that are all straight and depressed in *Th. reicheli,* whereas they are raised and slightly curved at the beginning of the last whorl in *Th. deeckei*;

2) a strict species concept of *R. cushmani* is needed as it is the marker for the definition of the base of the nominal Zone (Robaszynski and Caron, 1995) and several transitional specimens between *R. cushmani* and its ancestor, *R. montsalvensis,* are observed. Therefore, the identification of *R. cushmani* is based on strict morphological features: raised sutures on the spiral side and chambers characterized by pyramid-like structures sometimes emphasized by pustules on the umbilical side;

3) *Thalmanninella globotruncanoides* is the marker for the definition of the base of the nominal Zone and it is the primary criterion for the definition of the base of the Cenomanian Stage. Several transitional specimens between *Th. brotzeni* and *Th. globotruncanoides* are observed*,* therefore the two species have been distinguished by strict morphological differences: in *Th. brotzeni* the umbilical sutures are slightly curved while in *Th. globotruncanoides* they have a hook-like shape, and the supplementary apertures are umbilical in *Th. brotzeni* and sutural in *Th. globotruncanoides*;

4) *Ticinella raynaudi aperta* and *T. raynaudi digitalis* are interpreted to be the ancestors of *Th. appenninica* and *Th. evoluta,* respectively, as transitional specimens from *T. raynaudi aperta* to *Th. appenninica* and from *T. raynaudi digitalis* to *Th. evoluta* have been observed, particularly at Monte Petrano and at Mazagan Plateau Site 547A. The ancestor-descendant relationship of the *Thalmanninella* lineage from *T. raynaudi aperta – Th. appenninica – Th. brotzeni – Th. globotruncanoides* to *Th. greenhornensis* has been documented through identification of

transitional taxa between the species*,* whereas the relationship among *T. raynaudi digitalis, Th. evoluta* to *Th. balernaensis* needs further observations.

## 7.3 Paleoceanography

The comparison between variations in relative abundances and in number of species inferred to possess similar life strategies allows to achieve the following conclusions:

1) the Monte Petrano section and Site 547A show similar variation in the composition of the planktonic foraminiferal assemblages. Consequently, in both sections, the late Albian time interval seems to be characterized by a dominant oligo-mesotrophic regime with a quite stable column water stratification and a defined thermocline, sometimes disrupted by short perturbations. On the contrary, during the Cenomanian a mesotrophic to meso-eutrophic regime is inferred according to the composition of the planktonic foraminifera population;

2) planktonic foraminifera at Site 547A records a generally more mesotrophic regime respect to that registered in the Umbria-Marche section as testified by the presence of radiolaria and by the higher abundance of cold opportunist planktonic foraminifera (*Muricohedbergella*);

3) the planktonic foraminiferal response to the OAE1d observed at Monte Petrano and Site 547A is comparable to that of Blake Nose (Wilson and Norris, 2001; Petrizzo et al., 2008).
Specifically, the OAE1d is associated to the extinction of the warmest planktonic foraminiferal taxa (*Biticinella, Paracostellagerina* and *Ticinella*) and, thus, indicate a phase of decreasing thermal gradient in the upper water column;

4) the features of the planktonic foraminiferal assemblages in the stratigraphic interval comprised between the OAE1d and the MCE (the latter not identified at Mazagan Plateau), suggest the presence of a disrupted stratification of the water column. Specifically, this interval is characterized by the absence of warm dwellers and by increasing abundances and diversity of colder taxa (*Praeglobotruncana*, rotaliporids and *Muricohedbergella*), indicating a low temperature gradient of the upper column water.

5) the planktonic foraminiferal response to the MCE observed at Monte Petrano is comparable to data from the Anglo-Paris Basin (Voigt et al., 2004; Wilmsen et al., 2007). Specifically, the abrupt decrease of warm taxa (*Whiteinella*) at Monte Petrano and the *primus* Event (LO of the belemnite *Praeactinocamax primus*) in the Anglo-Paris Basin both suggest that the MCE could be associated to a minimum of temperature (cold event).

## 7.4 Final remarks and future perspectives

This thesis leads to the clarification of the species concept for the identification of some markers species (*Thalmanninella reicheli* and *Rotalipora cushmani*) that have been often misidentified and to the refinement of the planktonic foraminiferal biozonation.

Moreover, this study allows the identifications of reliable bioevents and the improvement of regional to global correlations based on planktonic foraminifera. Finally, the interpretation of the planktonic foraminiferal response to the upper Albian-Cenomanian ocean perturbations (OAE 1d and MCE) is performed.

Further researches would deepen and broaden the topics developed in this thesis. Therefore, the future perspectives are, as follow:

1) Taxonomy
    - to revise the taxonomy and the stratigraphic distribution of the Albian-Cenomanian planispiral species currently included in the *Globigerinelloides* genus;
    - to document the phyletic lineage *Ticinella raynaudi aperta* – *Thalmanninella evoluta* – *Th. balernaensis* by studying at higher sampling resolution selected stratigraphic intervals;

2) Biostratigraphy
    - to perform new biostratigraphic analysis on sections belonging to different sedimentary basins and latitudes in order to verify the reproducibility of the bioevents identified in this study;
    - to verify the regional to global correlation of the lowest occurrences of *Th. greenhornensis* and of *Whiteinella* spp. and their suitability to approximate/substitute the base of the *Th. reicheli* Zone;

- to perform new integrated stratigraphic studies of the Mont Risou stratotype section for the base of the Cenomanian Stage to especially implement the calibration between bio- and chemostratigraphic data;

3) Paleoceanography

- to identify upper Albian-Cenomanian sections deposited at low to middle paleolatitudes and containing planktonic foraminiferal shells not affected by diagenesis in order to perform species-specific isotope analysis. Particularly, rotaliporids and praeglobotruncanids need additional investigation to clarify their depth habitats and their ability/modality to vertically migrate within the water column. In general, further information on the planktonic foraminiferal paleoecology are required to better understand their response to the late Albian-Cenomanian paleoenvironmental perturbations. .

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# PLATES

**Plate 1**

1A-C, *T. madecassiana* Sample ODP 171, Leg 1050C-27R-3, 79–82 cm (Petrizzo and Huber, 2006). 2A-C, *T. madecassiana,* Sample MP0, *Ps. ticinensis* Zone. 3A-C, *T. madecassiana,* Sample MP4, *Th. appenninica* Zone; 3D, *T. madecassiana*, MP16, *Th. appenninica* Zone. 4A-C, *T. madecassiana,* Sample MP6, *Ps. appenninica* Zone. 5A-D*, T. madecassiana,* Sample DSDP Leg 79, 547A-73R-3, 53-54.5 cm, *Ps. ticinensis* Zone; 5D, scale bar 20 µm. 6A-D, *T. madecassiana,* Sample DSDP Leg 79, 545-39R-1, 96-98 cm, *Ps. ticinensis* Zone; 6D, scale bar 20 µm. 7A-C, *T. primula* holotype, western Switzerland, catalogue number: 20533. 8A-C, *T. primula,* MP0, *Ps. ticinensis* Zone. 9A-C, *T. primula,* Sample B3, *Th. appenninica* Zone. Scale bar 100 µm except when specified.

# Plate 1

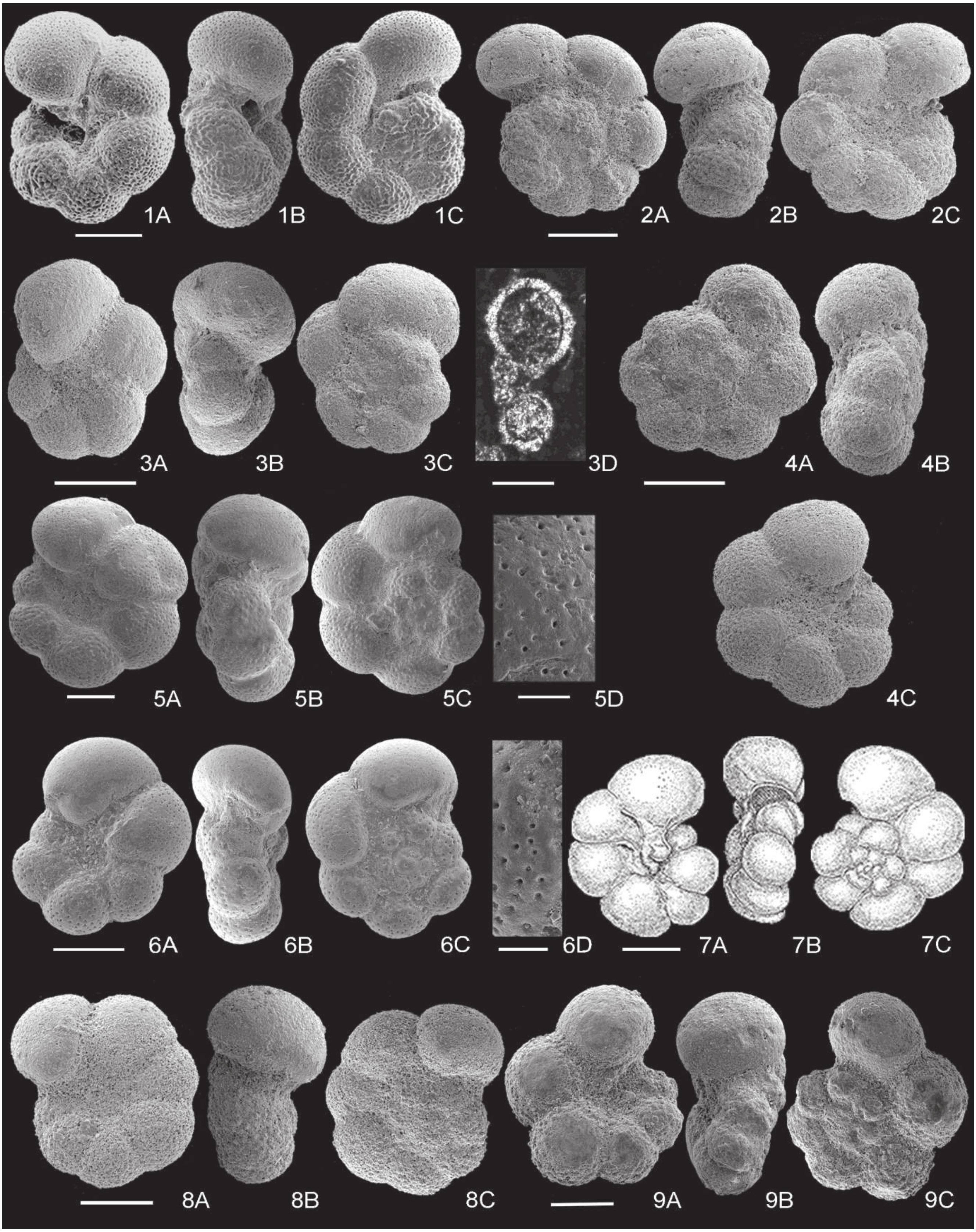
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**Plate 2**

1A-D, *T. primula*, Sample DSDP Leg 79, 547A-73R-3, 53-54 cm; 1D, scale bar 20 µm. 5, *Ps. ticinensis* Zone. 2A-D, *T. primula*, Sample DSDP Leg 79, 547A-71R-1, 50.5-52 cm, *Ps. ticinensis* Zone; 2D, scale bar 20 µm. 3A-C, *T. primula,* Sample DSDP Leg 79, 547A-69R-3, 50-52 cm, *Ps. ticinensis* Zone. 4A-C, *T. primula*, Sample DSDP Leg 79, 545-39R-5, 23-25 cm, *Ps. ticinensis* Zone. 5A-C, *T. raynaudi aperta* holotype, Diego-Suarez well, Madagascar, catalogue number: case 21. 6A-C, *T. raynaudi digitalis* holotype, Diego-Suarez well, Madagascar, catalogue number: case 11. 7A-C, *T. raynaudi aperta,* Sample MP2, *Ps. ticinensis* Zone. 8A-C, *T. raynaudi digitalis,* Sample MP2, *Ps. ticinensis* Zone. 9A-C, *T. raynaudi digitalis,* Sample B0.01, *Ps. ticinensis* Zone. Scale bar 100 µm except when specified.

# Plate 2

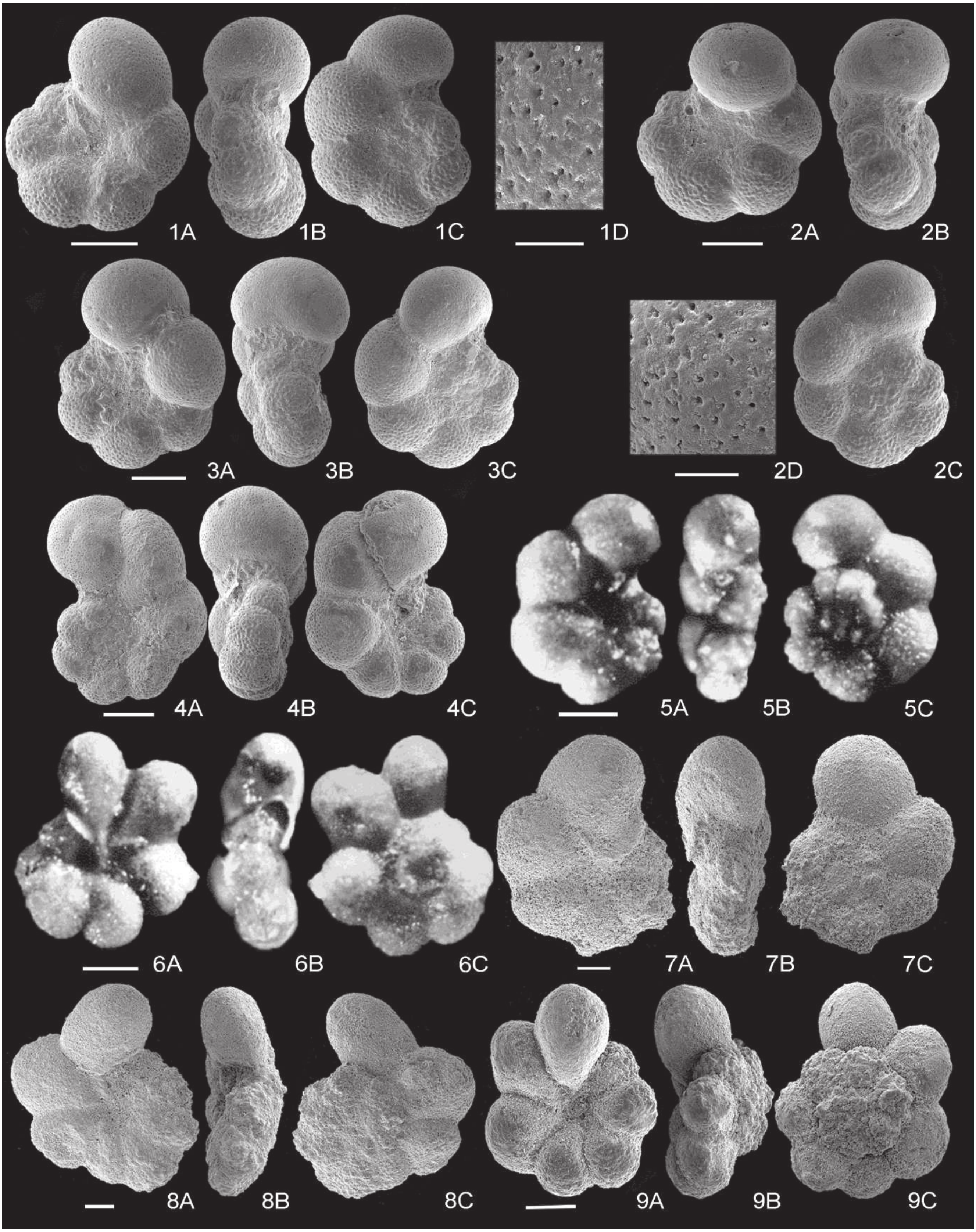
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**Plate 3**

1A-D, *T. raynaudi digitalis,* Sample DSDP Leg 79, 547A-73R-3, 53-54.5 cm, *Ps. ticinensis* Zone; 1D, scale bar 20 µm. 2A-C *T. raynaudi aperta,* Sample DSDP Leg 79, 545-39R-1, 96-98 cm, *Ps. ticinensis* Zone. 3A-C, *T. roberti,* Yam S. T borehole (Lipson-Benitah and Almogi-Labin, 2000). 4A-D, *T. roberti,* Sample DSDP Leg 79, 547A-71R-1, 50.5-52, *Ps. ticinensis* Zone; 4D, scale bar 20 µm. 5A-C, *T. roberti*, Sample DSDP Leg 79-547A-67R-2, 39-41 cm, *Th. appenninica* Zone. 6A-D, *T. roberti,* Sample DSDP Leg 79, 545-39-5, 23-25 cm, *Ps. ticinensis* Zone; 6D, scale bar 20 µm. 7A-C, *T. moulladei* holotype, Diego-Suarez well, Madagascar, catalogue number: case 9. 8A-C, *T. moulladei,* Sample DSDP Leg 79, 547A-69R-3, 50-52 cm, *Ps. ticinensis* Zone. 9A-C, *T. moulladei,* Sample DSDP Leg 79, 545-39R-5, 23-25, *Ps. ticinensis* Zone. Scale bar 100 µm except when specified.

# Plate 3

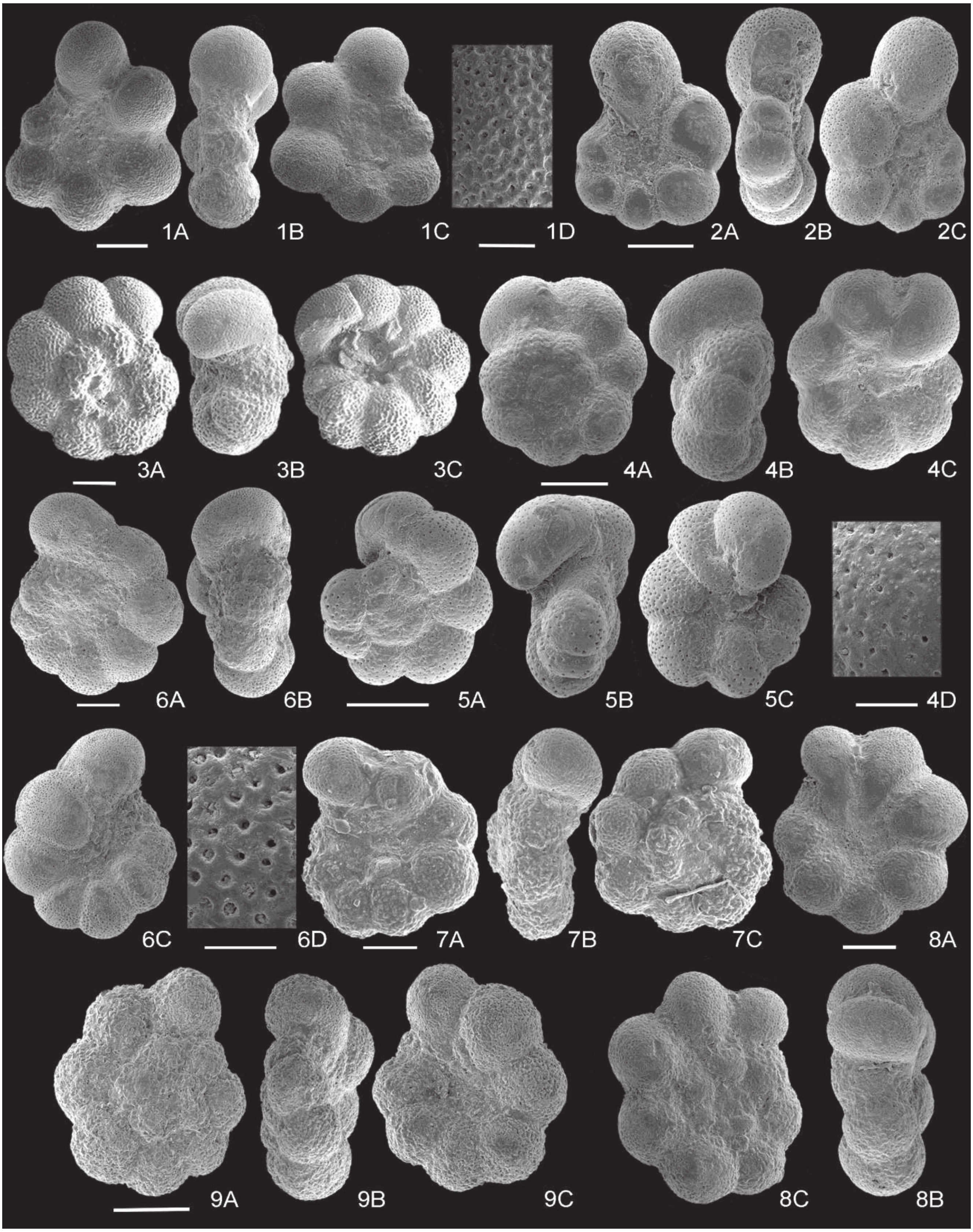
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**Plate 4**

1A-C, *G. bentonensis* holotype, Hartland member of Greenhorn Limestone of Kansas, catalogue repository: 75381. 2A-C, *G. bentonensis*, Sample MP8, *Th. appenninica* Zone. 3A-C, *G. bentonensis,* Sample MP24, *Th. appenninica* Zone. 3D, *G. bentonensis*, Sample MP40, *Th. appenninica* Zone. 4A-C, *G. bentonensis*, Sample B0.01, *Ps. ticinensis* Zone. 5A-C, *G. bentonensis*, Sample DSDP Leg 79, 547A-61R-3, 50-52 cm, *Th. globotruncanoides* Zone. 6A-D, *G. bentonensis,* Sample DSDP Leg 79, 547A-45R-3, 16-18 cm, *Th. globotruncanoides* Zone; 6D, scale bar 20 µm. 7A-C, *G. bentonensis,* Sample DSDP Leg 79, 545-34R-1, 123-125 cm, *Th. globotruncanoides* Zone. 8A-C, *G. pulchellus* holotype, Puerto Rico Trench, catalogue number: 641522. 9A-C, *G. pulchellus,* Sample MP0, *Ps. ticinensis* Zone. Scale bar 100 µm except when specified.

# Plate 4

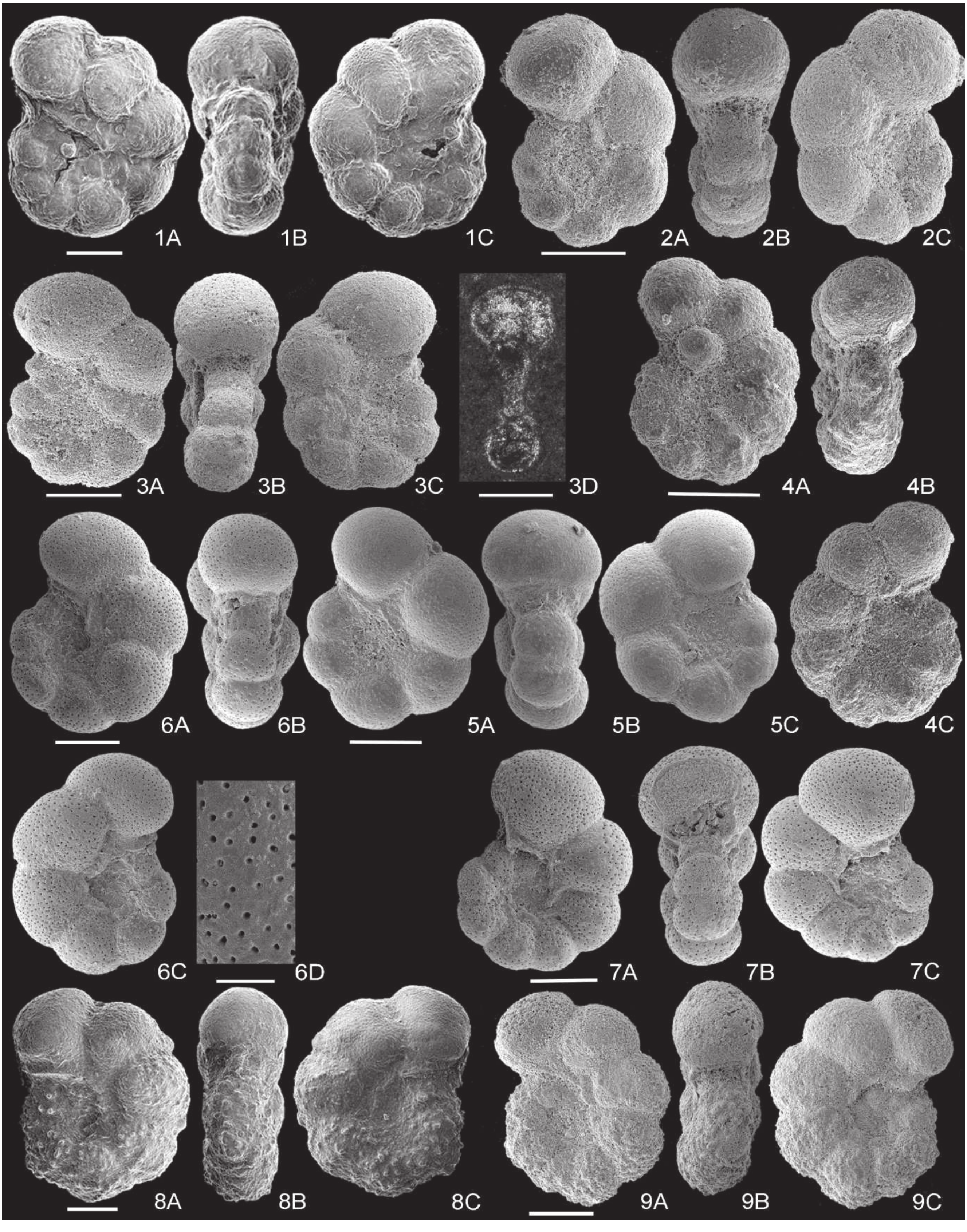
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**Plate 5**

1A-C, *G. pulchellus,* Sample MP2, *Th. appenninica* Zone. 2A-C, *G. pulchellus,* Sample B1.8, *Th. appenninica* Zone. 3A-C, *G. pulchellus,* Sample DSDP Leg 79, 547A-73R-3, 53-54.5 cm, *Ps. ticinensis* Zone. 4A-C, *G. pulchellus,* Sample DSDP Leg 79, 547A-71R-1, 50.5-52 cm, *Ps. ticinensis* Zone. 5A-C, transition *G. pulchellus – P. praebuxtorfi,* Sample B1.8, *Th. appenninica* Zone. 6A-C, transition *G. pulchellus – P. praebuxtorfi,* Sample DSDP Leg 79, 547A- 68R-2, 93-95 cm, *Th. appenninica* Zone. 7A-C, transition *G. pulchellus – P. praebuxtorfi,* Sample DSDP Leg 79, 545-38R-3, 90-92 cm, *Th. appenninica* Zone. 8A-B, *G. ultramicrus* holotype, Kapustnaya Gorge, Russia, catalogue number: 1590. 9A-C, *G.* cf. *ultramicrus,* MP18.5, *Th. appenninica* Zone. 10A-B, *G. ultramicrus,* MP18.5, *Th. appenninica* Zone. Scale bar 100 µm.

# Plate 5

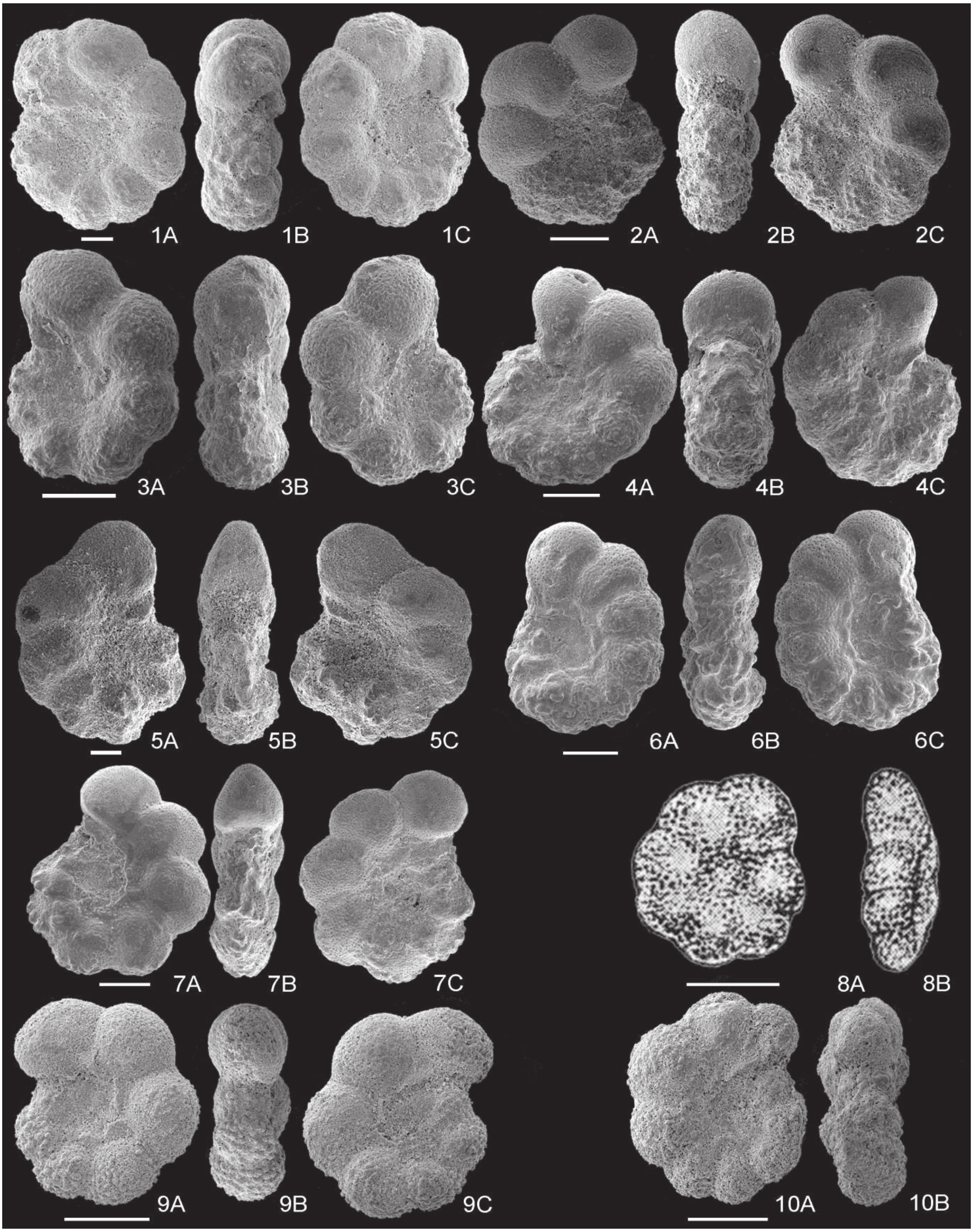
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**Plate 6**

1A-C, *G. alvarezi* holotype, Kapustnaya Gorge, Russia, catalogue number: k-49. 2A-C, *G. alvarezi,* Sample MP17.5, *Th. appenninica* Zone. 3A-C, *G. alvarezi,* Sample DSDP Leg 79, 547A-64R-3, 51-53 cm, *Th. appenninica* Zone. 4A-C, *G. alvarezi,* Sample DSDP Leg 79, 545-37R-3, 50-53 cm, *Th. appenninica* Zone. 5A-D, *G.* cf. *alvarezi,* Sample DSDP Leg 79, 547A-44R-3, 51-53 cm, *Th. globotruncanoides* Zone; 5D, scale bar 20 µm. 6A-D, *G.* cf. *alvarezi,* Sample DSDP Leg 79, 547A-43R-CC, 0-15.5 cm, *Th. globotruncanoides* Zone; 6D, scale bar 20 µm. 7A-D, *G.* cf. *pulchellus,* Sample DSDP Leg 79, 547A-43R-CC, 0-15.5 cm, *Th. globotruncanoides* Zone; 7D, scale bar 20 µm. 8A-C, *G.* cf. *pulchellus,* Sample DSDP Leg 79, 547A-44R-3, 51-53 cm, *Th. globotruncanoides* Zone. 9A-C, *G.* cf. *bollii,* Sample DSDP Leg 79, 547A-43R-CC, 0-15.5 cm, *Th. globotruncanoides* Zone. Scale bar 100 µm except when specified.

# Plate 6

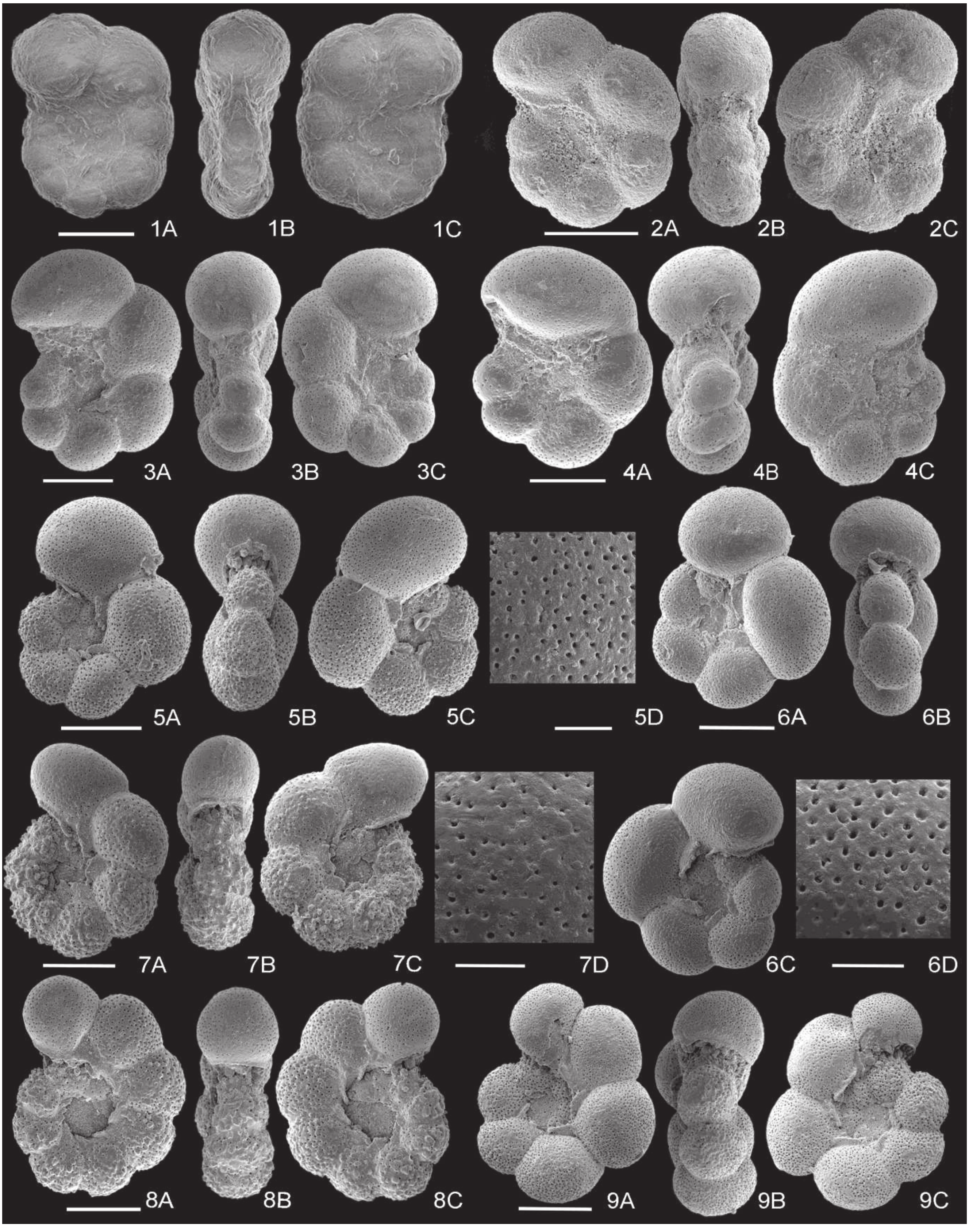
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**Plate 7**

1A-C, *B. subbreggiensis,* Sample MP2*, Ps. ticinensis* Zone. 2A-C, *B. subbreggiensis,* Sample MP6, *Th. appenninica* Zone. 2D, *B. subbreggiensis,* Sample MP2, *Ps. ticinensis* Zone. 3A-C, *B. subbreggiensis,* Sample B0.01, *Ps. ticinensis* Zone. 4A-C, *B. breggiensis,* Yam S. T. borehole (Lipson-Benitah and Almogi-Labin, 2000). 5A-C, *B. breggiensis,* Sample MP4, *Th. appenninica* Zone. 5D, *B. breggiensis,* Sample MP2. 6A-C, *B. breggiensis,* Sample B0.01, *Ps. ticinensis* Zone. 7A-C, *B. breggiensis,* Sample B1.8, *Th. appenninica* Zone. 8A-C, *B. breggiensis,* Sample DSDP Leg 79, 547A-73R-3, 53-54.5 cm, *Ps. ticinensis* Zone. 9A-C, *B. breggiensis,* Sample DSDP Leg 79, 545-39R-1, 96-98 cm, *Ps. ticinensis* Zone. Scale bar 100 μm.

# Plate 7

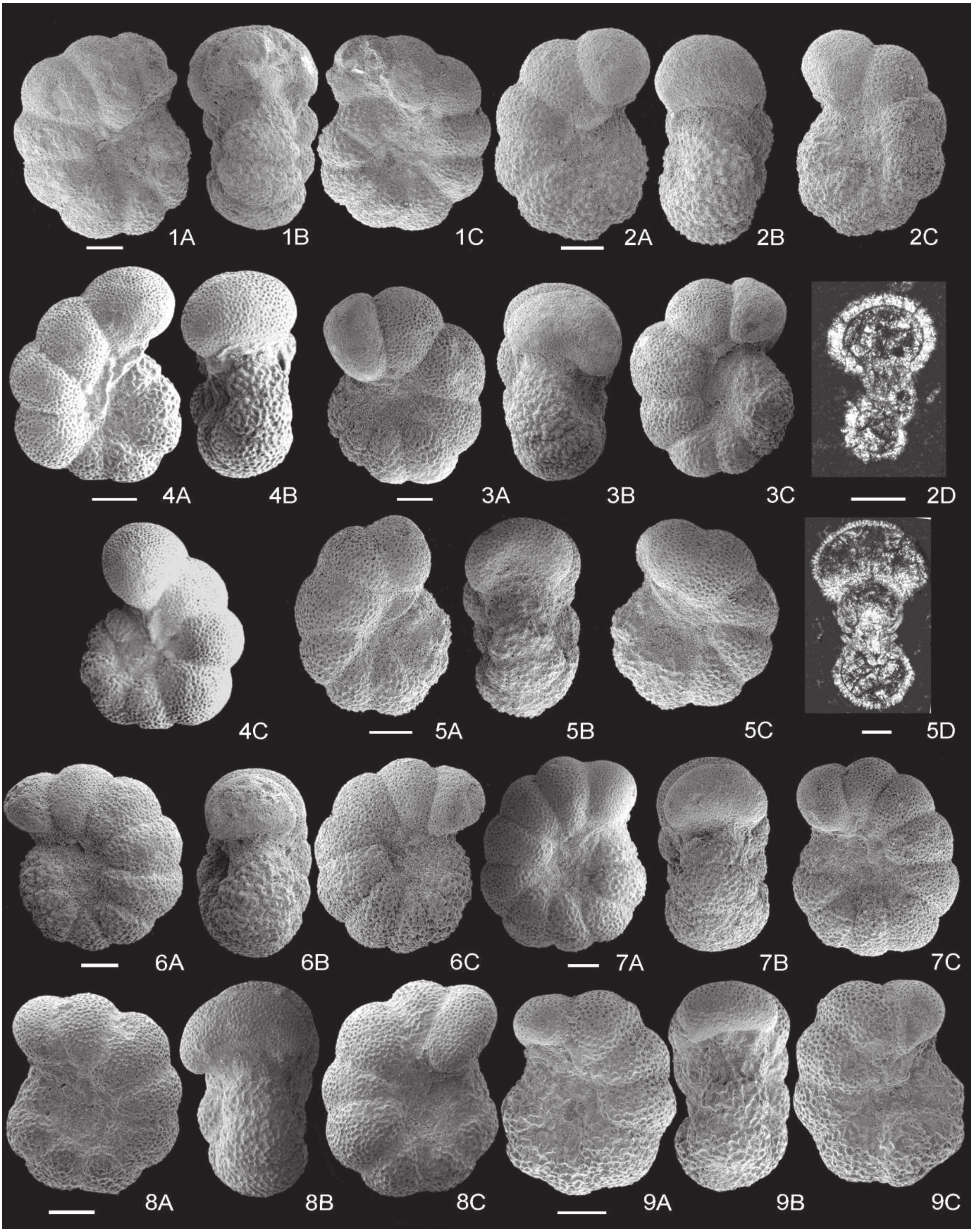
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**Plate 8**

1A-C, *M. delrioensis Master*'s neotype, Grayson Formation, Texas. 2A-C, *M. delrioensis Longoria,* Sample ODP 171, Leg 1052E-41R-1, 119-120 cm (Petrizzo and Huber, 2006a), *Th. appenninica* Zone. 3A-C, *M. delrioensis*, Sample MP0, *Ps. ticinensis* Zone. 4A-C, *M. delrioensis*, Sample MP4, *Th. appenninica* Zone. 5A-D, *M. delrioensis,* Sample DSDP Leg 79, 547A-63R-3, 49.5-52 cm, *Th. appenninica* Zone; 5D, scale bar 20 µm. 6A-C, *M. delrioensis,* Sample DSDP Leg 79, 547A-50R-3, 80-82 cm, *Th. globotruncanoides* Zone. 7A-C, *M. planispira* holotype, Grayson Formation, Texas, catalogue number: 25113. 8A-C, *M. planispira,* MP18.5, *Th. appenninica* Zone. 9A-C, *M. planispira,* Sample DSDP Leg 79, 547A-65-1, 36.5-38 cm, *Th. appenninica* Zone. Scale bar 100 µm except when specified.

# Plate 8

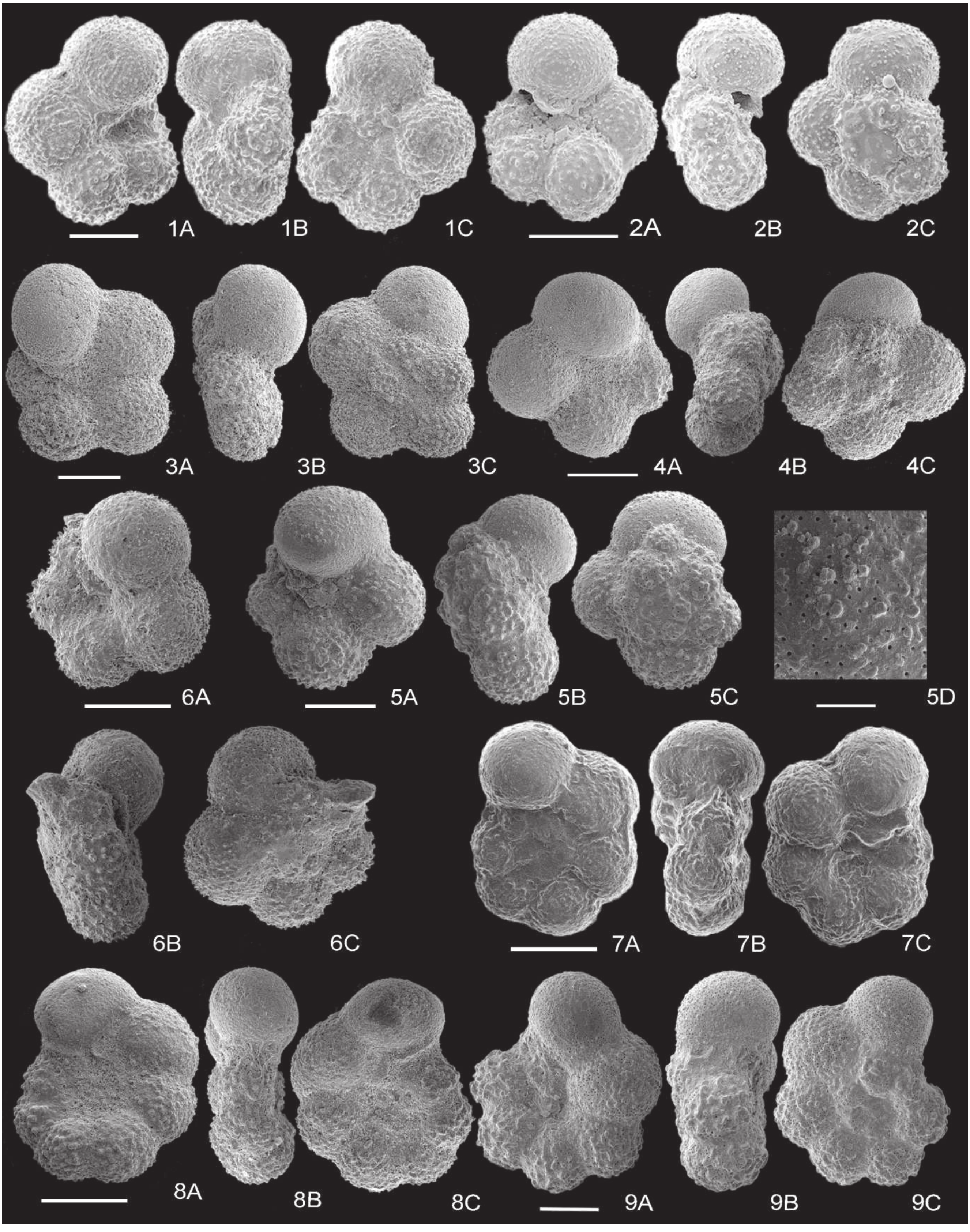
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**Plate 9**

1A-C, *M. simplicissima,* holotype, Rhazouane, Tunisia, catalogue number: F6 0880. 2A-C, *M. simplicissima,* Sample MP6, *Th. appenninica* Zone. 2D, *M. simplicissima,* Sample MP30, *Th. globotruncanoides* Zone. 3A-C, *M. simplicissima,* Sample B3, *Th. globotruncanoides* Zone. 4A-C, *M. simplicissima,* Sample DSDP Leg 79, 547A-63R-3, 49.5-52 cm, *Th. appenninica* Zone. 5A-C, *M. simplicissima,* Sample DSDP Leg 79, 547A-53R-1, 50-51.5 cm, *Th. globotruncanoides* Zone. 6A-C, *M. simplicissima,* Sample DSDP Leg 79, 545-38R-7, 89-91 cm, *Th. appenninica* Zone. 7A-C, *M. wondersi* holotype, Antsiranana, northern Madagascar. 8A-C, *M. wondersi,* MP2, *Ps. ticinensis* Zone. Scale bar 100 µm.

# Plate 9

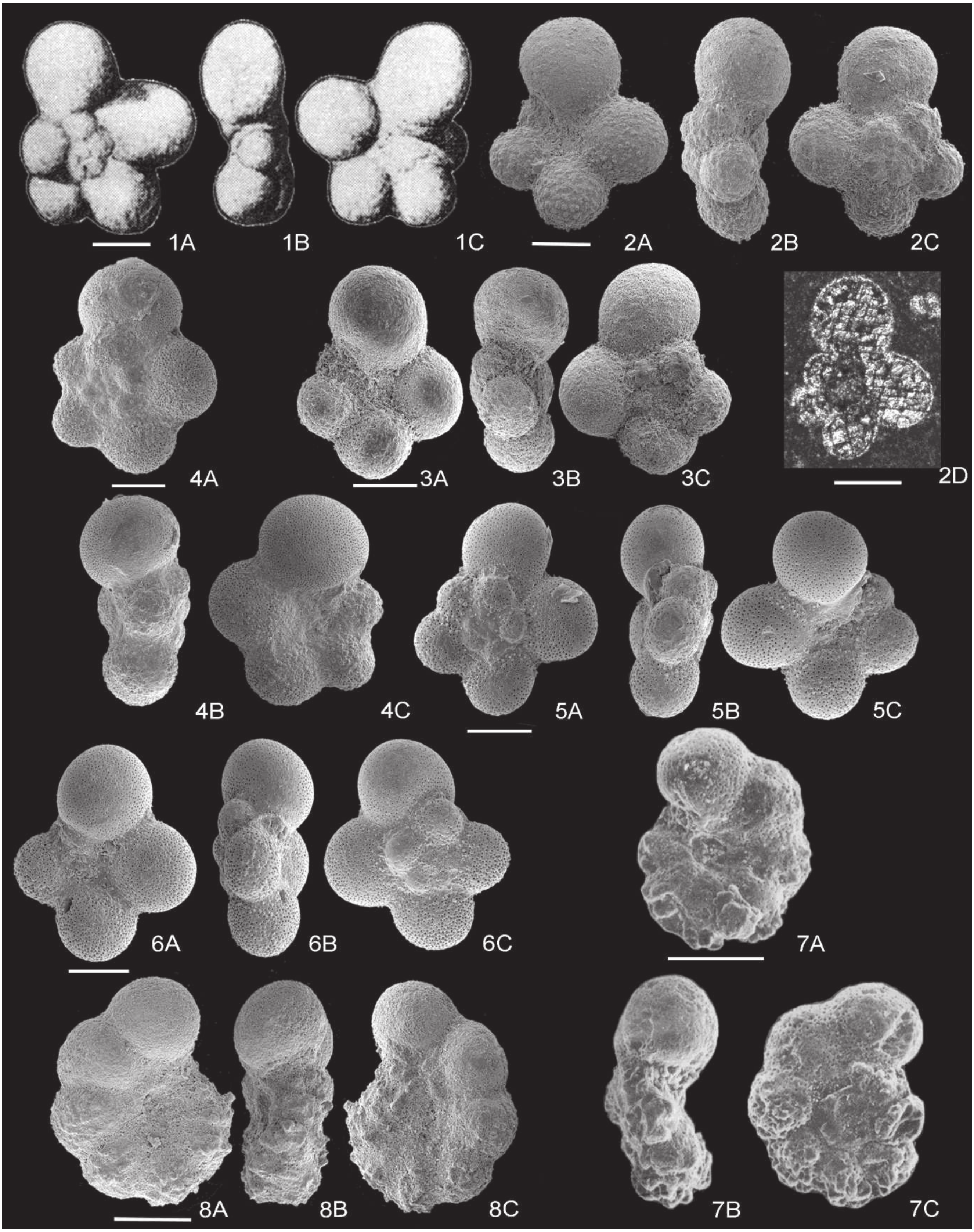
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**Plate 10**

1A-C, *M. astrepta* holotype, Blake Nose, western North Atlantic, catalogue number: 527794. 2A-C, *M. astrepta,* Sample MP2, *Ps. ticinensis* Zone. 3A-C, *M. astrepta*, Sample B3, *Th. appenninica* Zone. 4A-C, *M. astrepta,* Sample DSDP Leg 79, 545-36R-1, 145-150 cm, *Th. appenninica* Zone. 5A-C, *M. praelibyca* holotype, Blake Nose, western North Atlantic, catalogue number: 527791. 6A-C, *M. praelibyca,* Sample MP0, *Ps. ticinensis* Zone. 7A-C, *M. praelibyca,* Sample B3, *Th. appenninica* Zone. 8A-C, *M. praelibyca,* Sample DSDP Leg 79, 547A-65R-1, 36.5-38 cm, *Th. appenninica* Zone. 9A-C, *M. praelibyca,* Sample DSDP Leg 79, 545-34R-CC, 1-4 cm, *Th. appenninica* Zone. Scale bar 100 µm.

# Plate 10

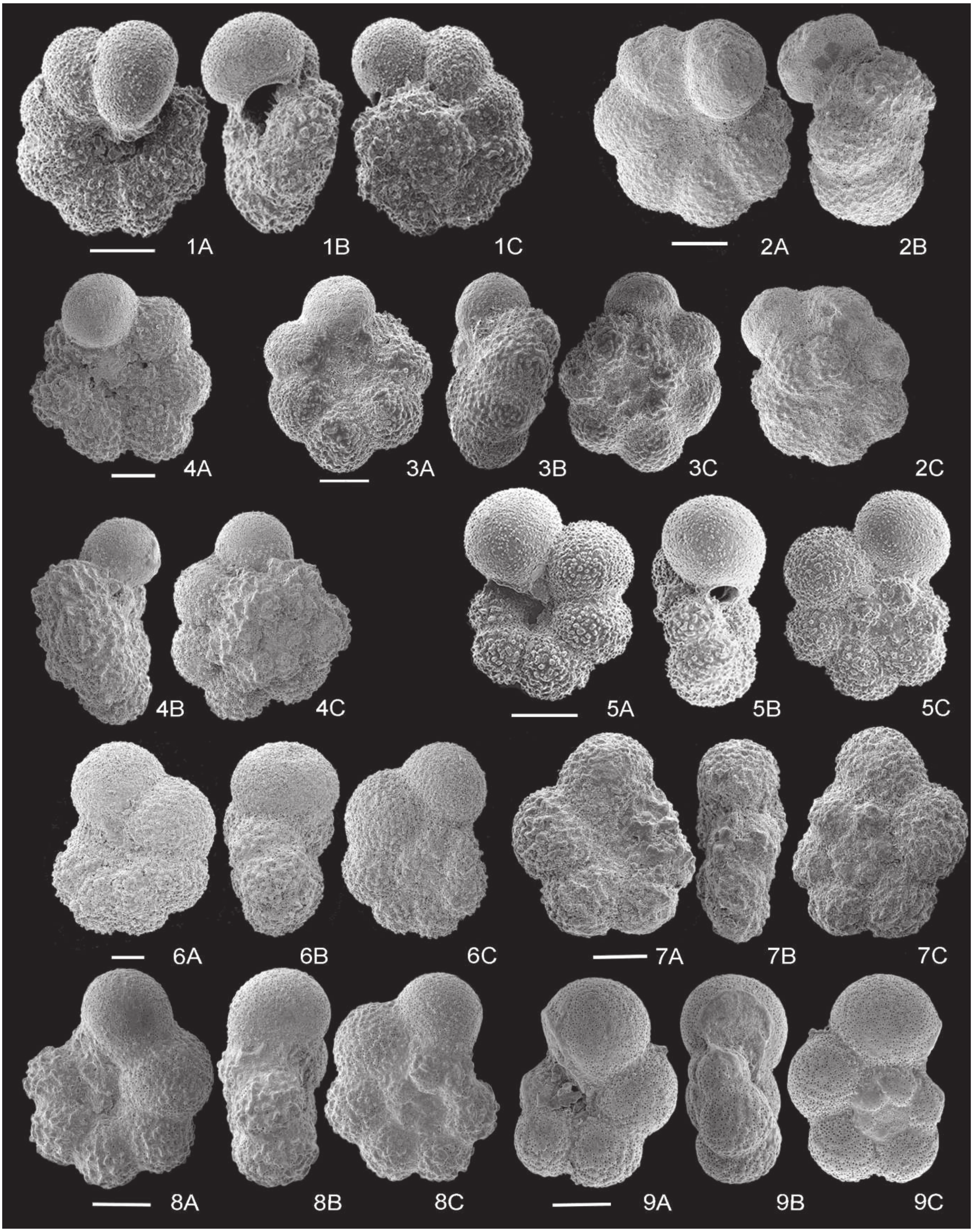
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**Plate 11**

1A-C, *M. blakensis* holotype, Blake Nose, western North Atlantic, catalogue number: 527788. 2A-C, *M. blakensis,* Sample MP12, *Th. appenninica* Zone. 3A-C, *M. blakensis,* Sample MP13, *Th. appenninica* Zone. 4A-C, *M. blakensis,* Sample DSDP Leg 79, 547A-64R-3, 51-53 cm, *Th. appenninica* Zone. 5A-C, *M. blakensis,* Sample DSDP Leg 79, 545-37R-3, 50-53 cm, *Th. appenninica* Zone. 6A-C, *Ps. subticinensis* holotype, Gorge of the Breggia River, southeastern Switzerland. 7A-D, *Ps. subticinensis,* Sample MP4, *Th. appenninica* Zone. 8A-D, *Ps. subticinensis,* Sample B0.01, *Ps. ticinensis* Zone. 9A-C, *Ps. subticinensis*, Sample B3.6, *Ps. ticinensis* Zone. Scale bar 100 µm.

# Plate 11

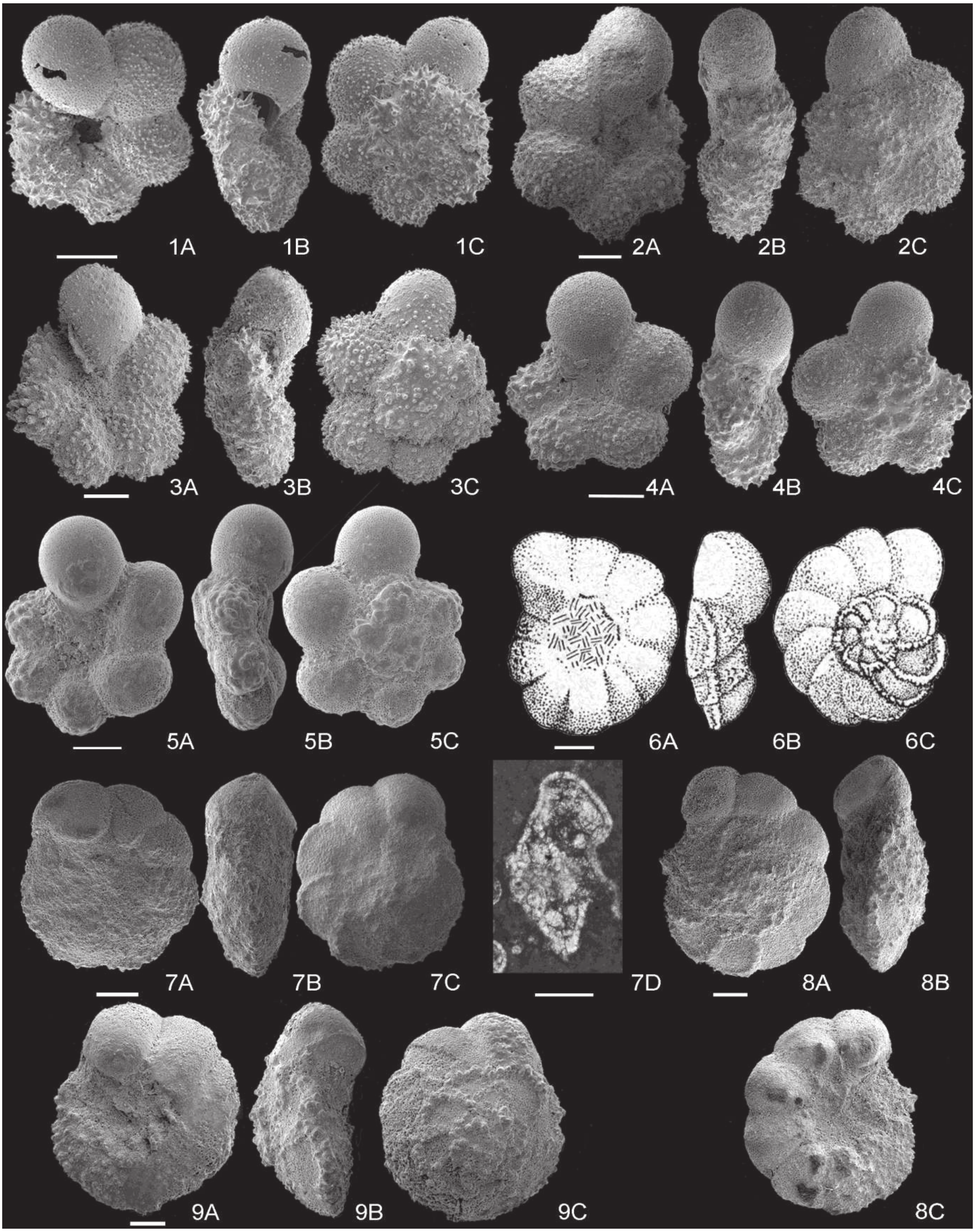
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**Plate 12**

1A-C, *Ps. subticinensis,* Sample DSDP Leg 79, 547A-65R-1, 36.5-38 cm, *Th. appenninica* Zone. 2A-C, *Ps. subticinensis,* Sample DSDP Leg 79, 545-40R-5, 8-10 cm, *Ps. ticinensis* Zone. 3A-C, *Ps. ticinensis* holotype, Gorge of the Breggia River, southeastern Switzerland, catalogue number: C25554. 4A-D, *Ps. ticinensis,* Sample MP6, *Th. appenninica* Zone. 5A-C, *P. ticinensis,* Sample B0.01, *Ps. ticinensis* Zone. 6A-C, *Ps. ticinensis,* Sample DSDP Leg 79, 547A-65R-1, 36.5-38 cm, *Th. appenninica* Zone. 7A-C, *Ps. ticinensis,* Sample DSDP Leg 79, 545-38-3, 90-92 cm, *Th. appenninica* Zone. 8A-C, *Ps. tehamaensis* holotype, Beegum Basin, Sacramento Valley, California, catalogue number: 641551. 9A-C, *Ps. tehamaensis,* Sample MP4, *Th. appenninica* Zone. Scale bar 200 µm.

# Plate 12

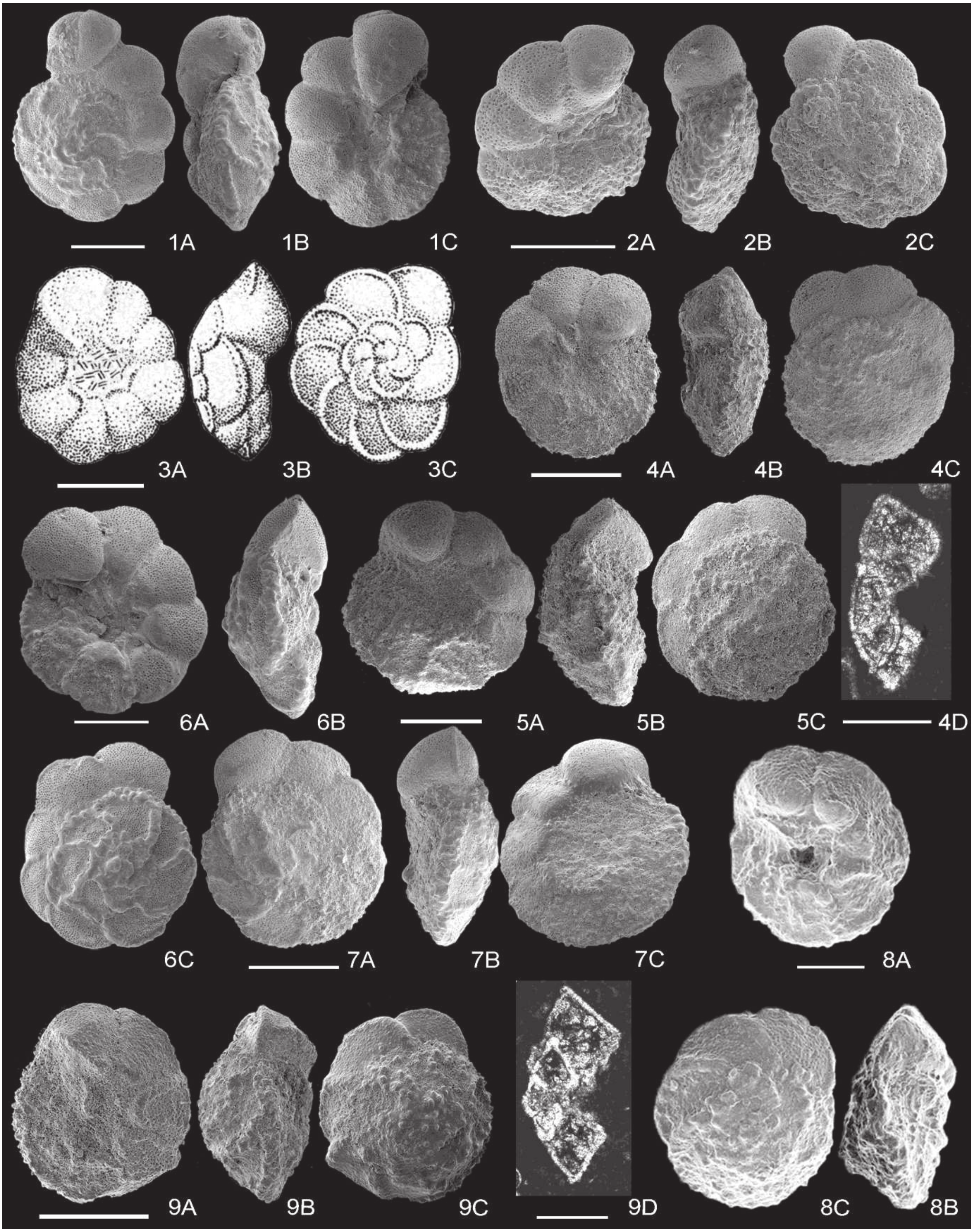
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**Plate 13**

1A-C, *Ps. tehamaensis,* Sample B3.6, *Th. appenninica* Zone. 2A-C, *Ps. tehamaensis,* Sample DSDP Leg 79, 547A-65R-1, 36.5-38 cm, *Th. appenninica* Zone. 3A-C, *Ps. tehamaensis,* Sample DSDP Leg 79, 547A-47R-3, 52.5-54.5 cm, *Th. globotruncanoides* Zone. 4A-C, *Th. evoluta* holotype, Diego-Suarez well, Madagascar, catalogue number: 1969. 5A-C, *Th. evoluta,* Sample MP2, *Ps. ticinensis* Zone. 6A-C, *Th. evoluta,* Sample B1.8, *Th. appenninica* Zone. 7A-C, *Th. evoluta,* Sample DSDP Leg 79, 547A-51R-3, 50-52 cm, *Th. globotruncanoides.* 8A-C, transition *T. raynaudi digitalis-Th. evoluta,* Sample DSDP Leg 79, 545-38-3, 90-92 cm, *Th. appenninica* Zone. 9A-C, transition *T. raynaudi digitalis-Th. evoluta,* Sample DSDP Leg 79, 547A-68-2, 93-95 cm, *Th. appenninica* Zone. Scale bar 200 µm.

# Plate 13

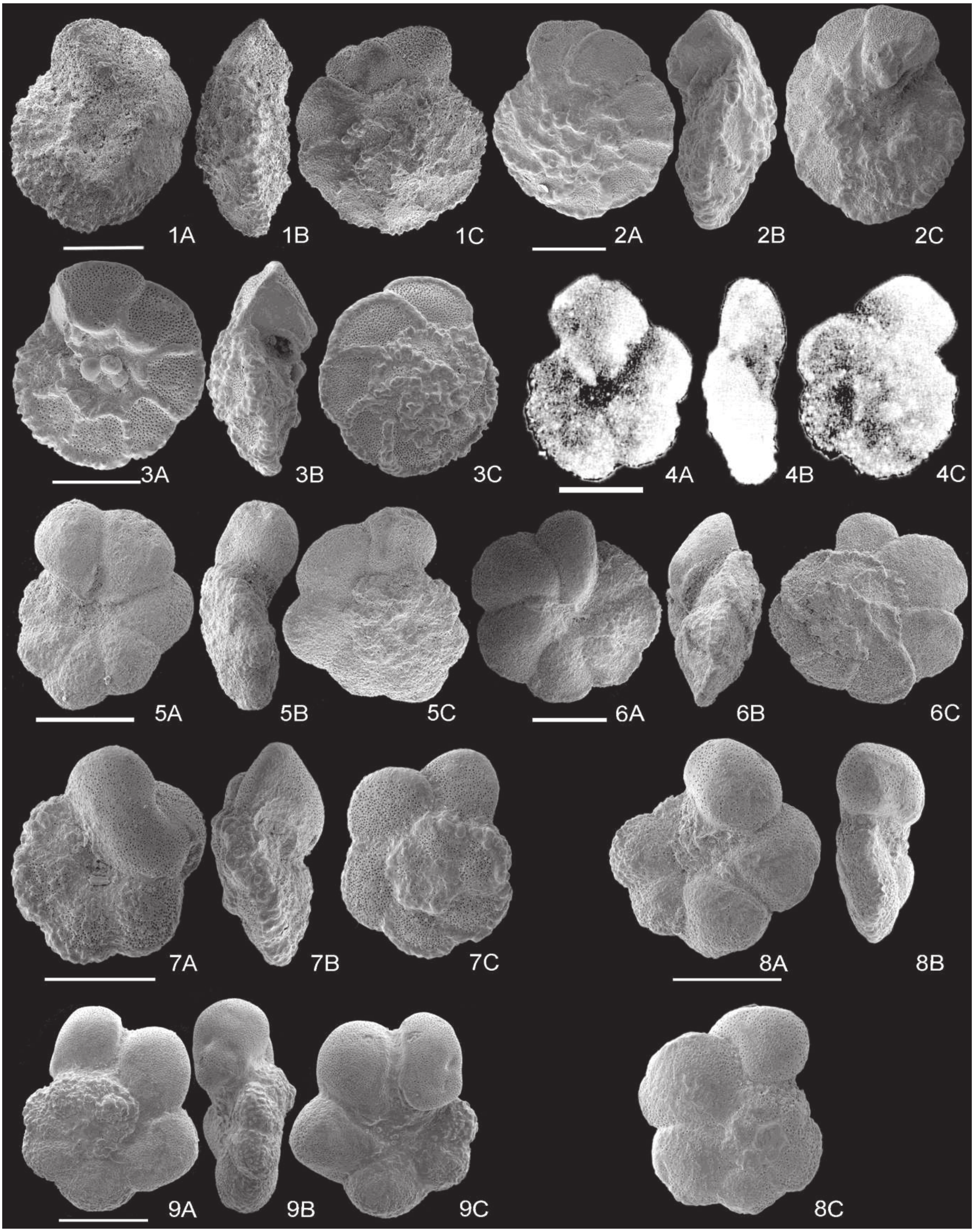
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**Plate 14**

1A-C, *Th. balernaensis*, Sample MP4, *Th. appenninica* Zone. 2A-C, *Th. balernaensis*, Sample MP13, *Th. appenninica* Zone. 2D, *Th. balernaensis*, Sample MP2, *Ps. ticinensis* Zone. 3A-C, *Th. balernaensis*, Sample B6, *Th. appenninica* Zone. 4A-C, *Th. balernaensis,* Sample DSDP Leg 79, 547A-61R-3, 50-52 cm, *Th. appenninica* Zone. 5A-C, *Th. balernaensis,* Sample DSDP Leg 79, 545-35R-2, 69-74 cm, *Th. appenninica* Zone. 6A-D, transition *T. raynaudi aperta – Th. appenninica,* Sample DSDP Leg 79, 547A-68R-2, 93-95 cm, *Th. appenninica* Zone, scale bar 100 µm; 6D, scale bar 20 µm. 7A-C, transition *Ticinella – Th. appenninica,* Sample DSDP Leg 79, 545-39R-1, 96-98 cm, *Ps. ticinensis* Zone, scale bar 100 µm. 8A-C, *Th. appenninica,* Sample ODP 171, Leg 1052E-43R-3, 143-145 cm (Petrizzo and Huber, 2006a), scale bar 100 µm. 9A-C, *Th. appenninica,* Sample MP4, *Th. appenninica* Zone. 9D, *Th. appenninica,* Sample MP28, *Th. globotruncanoides* Zone. Scale bar 200 µm except where otherwise stated.

# Plate 14

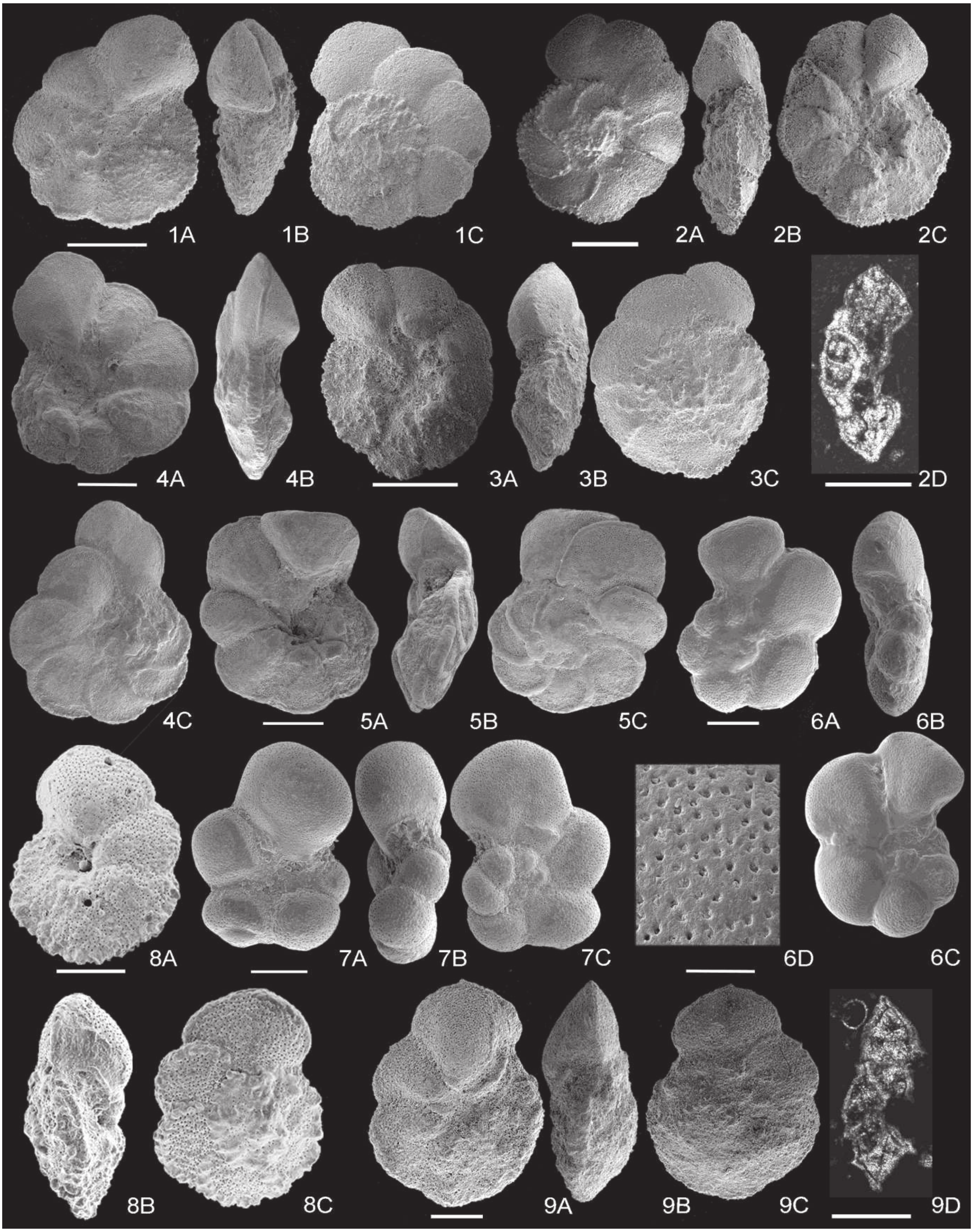
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**Plate 15**

1A-C, *Th. appenninica,* Sample B1.8, *Th. appenninica* Zone. 2A-C, *Th. appenninica,* Sample DSDP Leg 79, 547A-68R-2, 93-95 cm, *Th. appenninica* Zone, scale bar 100 µm. 3A-C, *Th. appenninica,* Sample DSDP Leg 79, 547A-65R-1, 36.5-38 cm, *Th. appenninica* Zone. 4A-C, *Th. appenninica,* Sample DSDP Leg 79, 545-38R-3, 90-92 cm, *Th. appenninica* Zone. 5A-C, *Th. gandolfii* holotype, Gorge of the Breggia River, southeastern Switzerland, catalogue number: C25557. 6A-C, *Th. gandolfii,* Sample MP36, *Th. reicheli* Zone. 7A-C, *Th. gandolfii,* Sample DSDP Leg 79, 547A-58R-3, 52-54 cm, *Th. globotruncanoides* Zone, scale bar 100 µm. 8A-C, *Th. gandolfii,* Sample DSDP Leg 79, 545-36R-1, 145-150 cm, *Th. appenninica* Zone. 9A-C, *Th. brotzeni* holotype, Sidi Aïssa, Algeria, scale bar 100 µm, catalogue number, F6 0843. 10A-C, transition *Th. appenninica-Th. brotzeni,* Sample MP20.5, *Th. globotruncanoides* Zone. Scale bar 200 µm except where otherwise stated.

# Plate 15

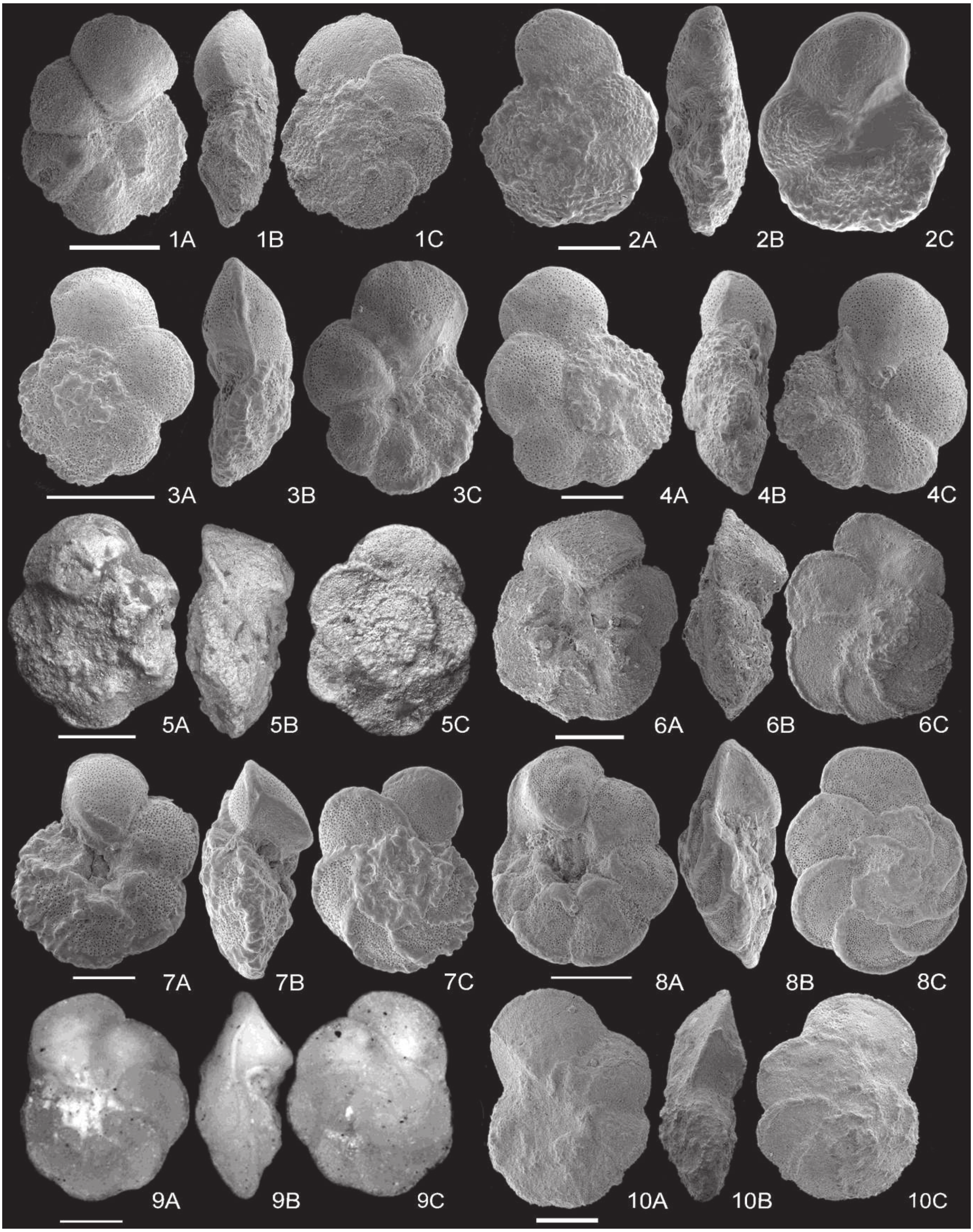
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**Plate 16**

1A-C, transition *Th. appenninica-Th. brotzeni,* Sample B18.8, *Th. appenninica* Zone. 2A-C, transition *Th. appenninica-Th. brotzeni,* Sample DSDP Leg 79, 545-36R-CC, 10-13 cm, *Th. appenninica* Zone. 3A-C, *Th. brotzeni,* Sample MP19.5, *Th. appenninica* Zone. 4A-C, *Th. brotzeni,* Sample B18.8, *Th. globotruncanoides* Zone. 5A-C, *Th. brotzeni,* Sample DSDP Leg 79, 547A-60R-3, 49.5-51.5 cm, *Th. globotruncanoides* Zone. 6A-C, *Th. brotzeni,* Sample DSDP Leg 79, 545-30R-1, 25-28.5 cm, *Th. reicheli* Zone. 7A-C, *Th. globotruncanoides* holotype, Sidi Aïssa, Algeria, scale bar 100 µm, catalogue number, F6 0840. 8A-C, transition *Th. brotzeni-Th. globotruncanoides,* Sample MP15.5, *Th. appenninica* Zone. 9A-C, transition *Th. brotzeni-Th. globotruncanoides,* Sample B16.4, *Th. globotruncanoides* Zone. 10A-C, transition *Th. brotzeni-Th. globotruncanoides,* Sample DSDP Leg 79, 545-34R-3, 61.5-64 cm, *Th. appenninica* Zone. Scale bar 200 µm except where otherwise stated.

# Plate 16

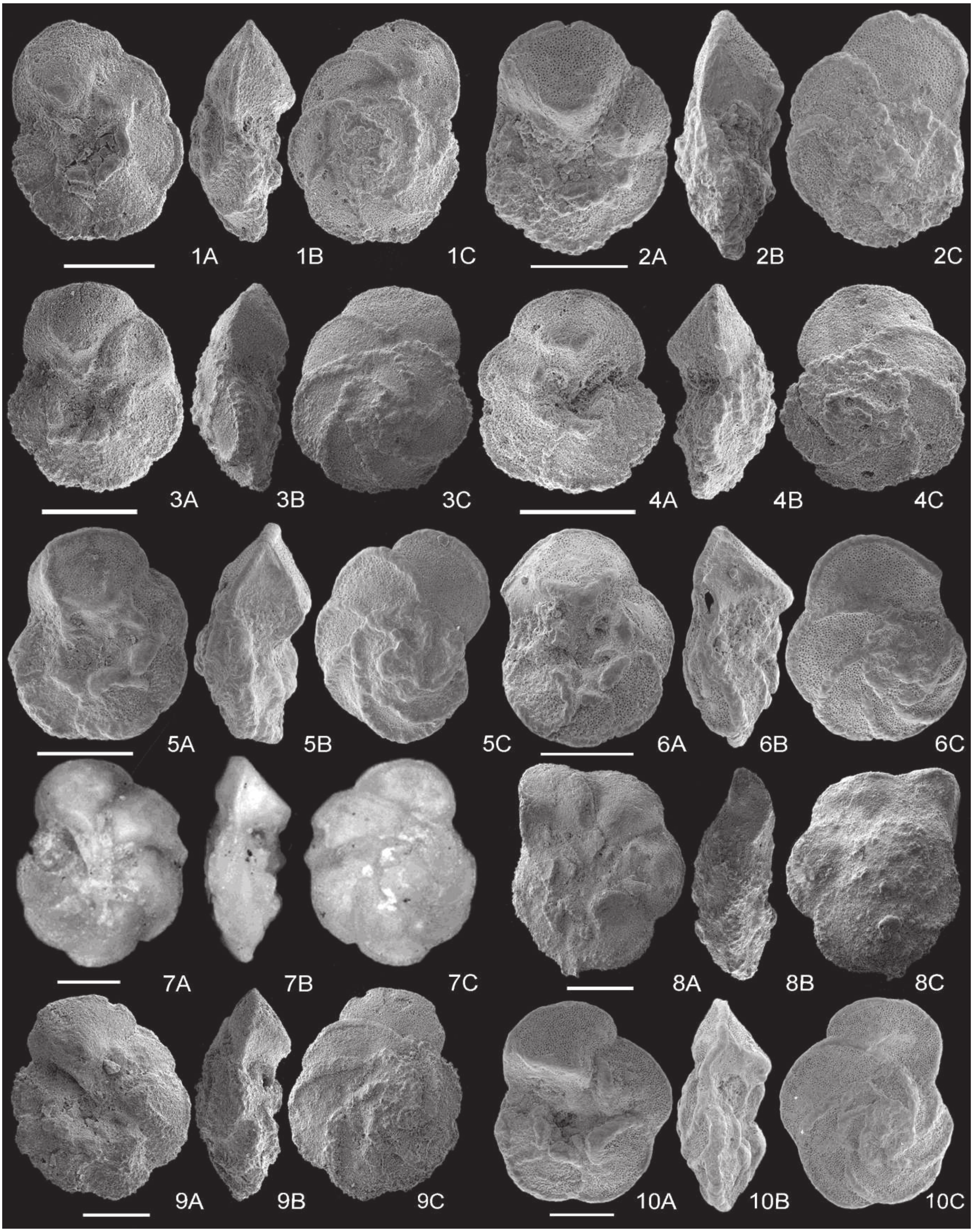
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**Plate 17**

1A-C, *Th. globotruncanoides,* Sample MP35, *Th. reicheli* Zone. 1D, *Th. globotruncanoides,* Sample MP20.5, *Th. globotruncanoides* Zone. 2A-C, *Th. globotruncanoides,* Sample B16.4, *Th. globotruncanoides* Zone. 3A-C, *Th. globotruncanoides,* Sample DSDP Leg 79, 547A-60R-5, 50-52 cm, *Th. globotruncanoides* Zone. 4A-C, *Th. globotruncanoides,* Sample DSDP Leg 79, 545-30R-1, 25-28.5 cm, *Th. reicheli* Zone. 5A-C, intermediate morphology *Th. globotruncanoides-Th. greenhornensis,* Sample MP49, *Th. reicheli* Zone. 6A-C, intermediate morphology *Th. globotruncanoides-Th. greenhornensis,* Sample MP50, *R. cushmani* Zone. 7A-C, intermediate morphology *Th. globotruncanoides-Th. greenhornensis,* Sample DSDP Leg 79, 547A-48R-1, 47.5-49.5 cm, *Th. globotruncanoides* Zone. 8A-C, *Th. greenhornensis,* Sample MP57, *R. cushmani* Zone. 8D, *Th. greenhornensis,* Sample MP44, *Th. reicheli* Zone. 9A-C, *Th. greenhornensis,* Sample MP60, *R. cushmani* Zone. Scale bar 200 µm.

# Plate 17

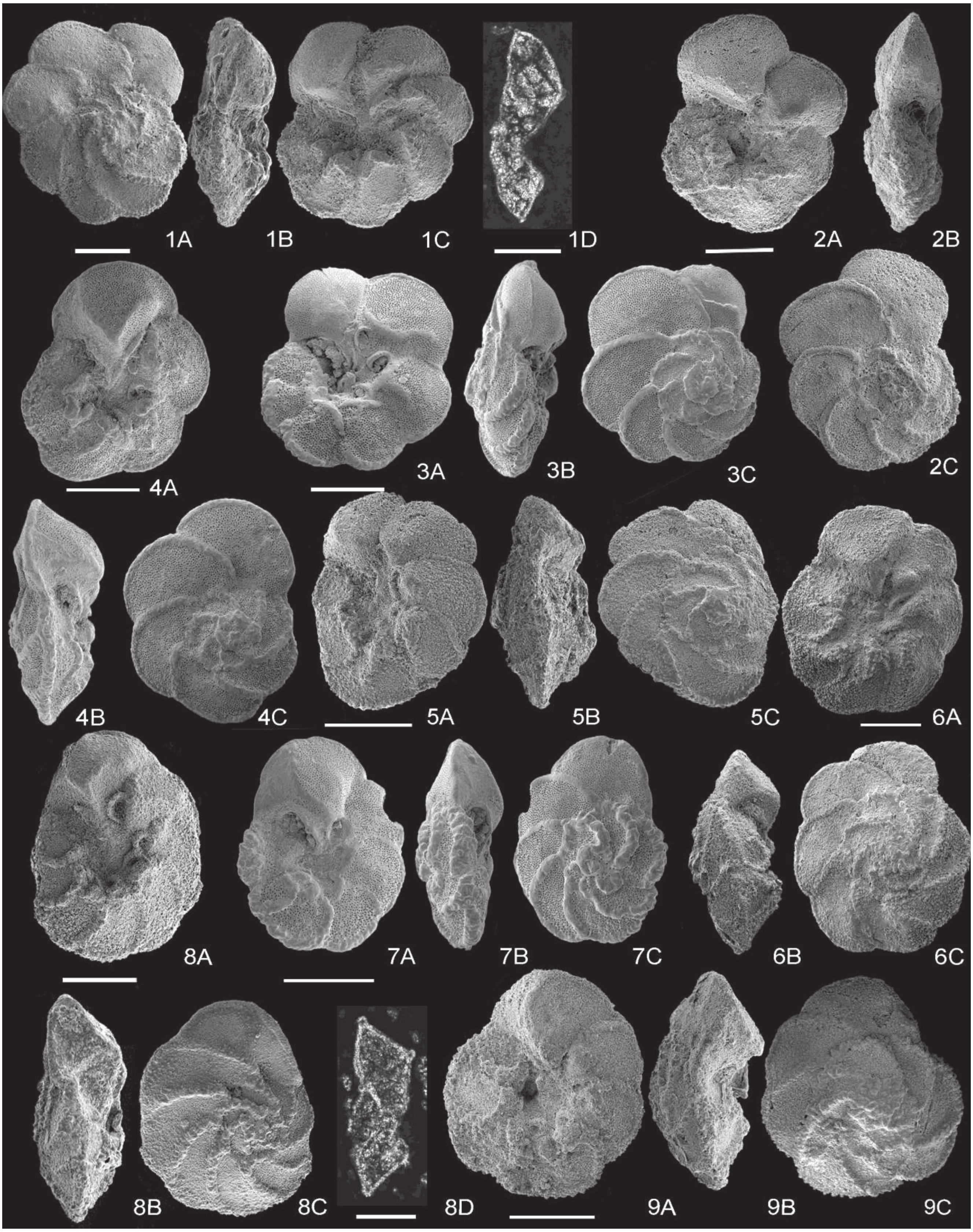
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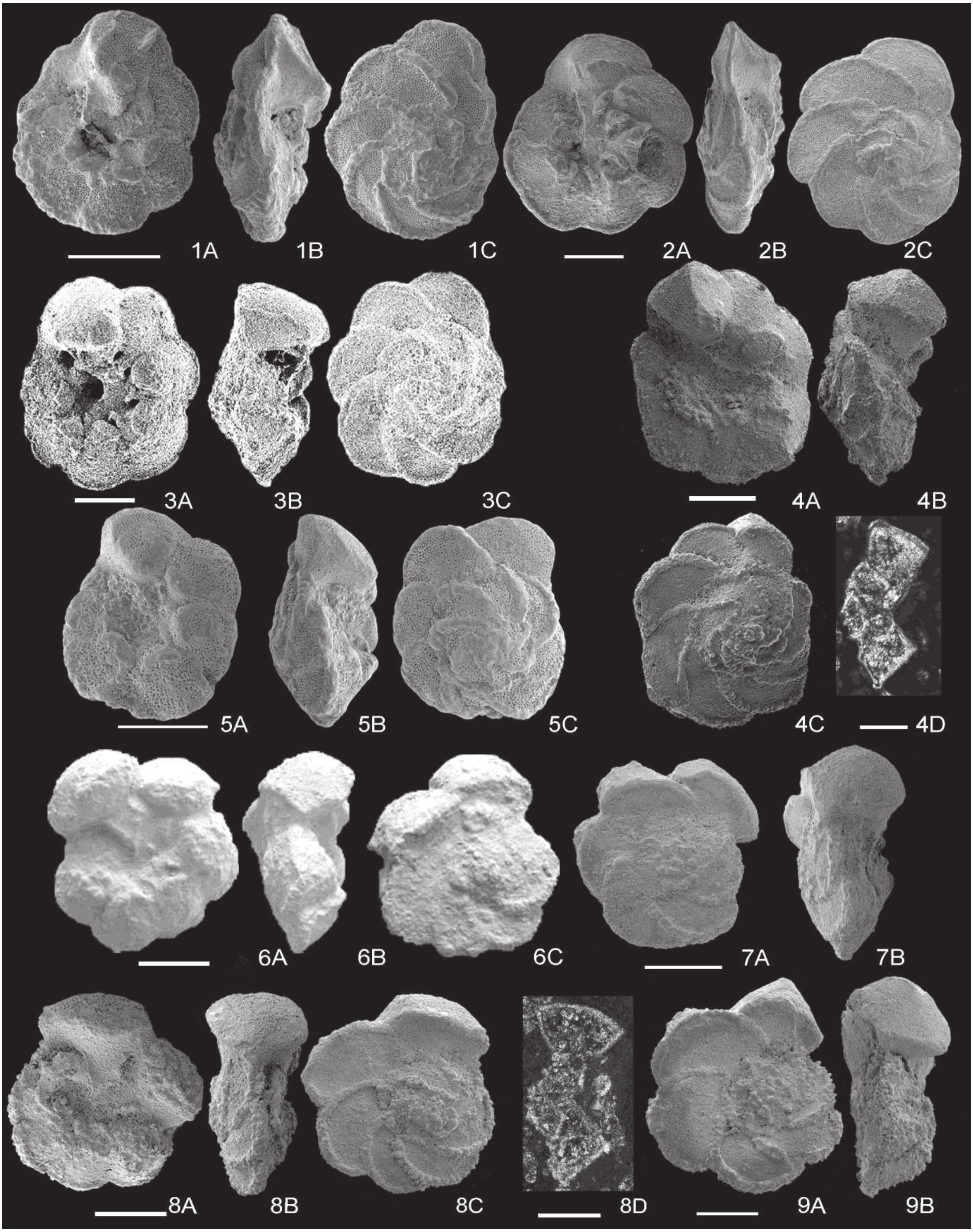
**Plate 18**

1A-C, *Th.* cf. *greenhornensis,* Sample DSDP Leg 79, 547A-47R-3, 52.5-54.5 cm, *Th. globotruncanoides* Zone. 2A-C, *Th.* cf. *greenhornensis,* Sample DSDP Leg 79, 545, 29-1, 18-22 cm, *Th. reicheli* Zone. 3A-C, *Th. deeckei,* Sample ODP 171, Leg 1050C-21R-1, 135-136 cm (Ando and Huber, 2007), *R. cushmani* Zone. 4A-C, *Th. deeckei,* Sample MP45, *Th. reicheli* Zone. 4D, *Th. deeckei,* Sample MP64, *R. cushmani* Zone. 5A-C, *Th. deeckei,* Sample DSDP Leg 79, 545-36R-1, 145-150 cm. 6A-C, *Th. reicheli* holotype, Ruisseau des Covayes, Switzerland, catalogue number: C39013. 7A-B, *Th. reicheli,* Sample MP35, *Th. reicheli* Zone. 8A-C, *Th. reicheli,* Sample MP44, *Th. reicheli* Zone. 8D, *Th. reicheli,* Sample MP46, *Th. reicheli* Zone. 9A-B, *Th. reicheli,* Sample MP45, *Th. reicheli* Zone. Scale bar 200 µm.

# Plate 18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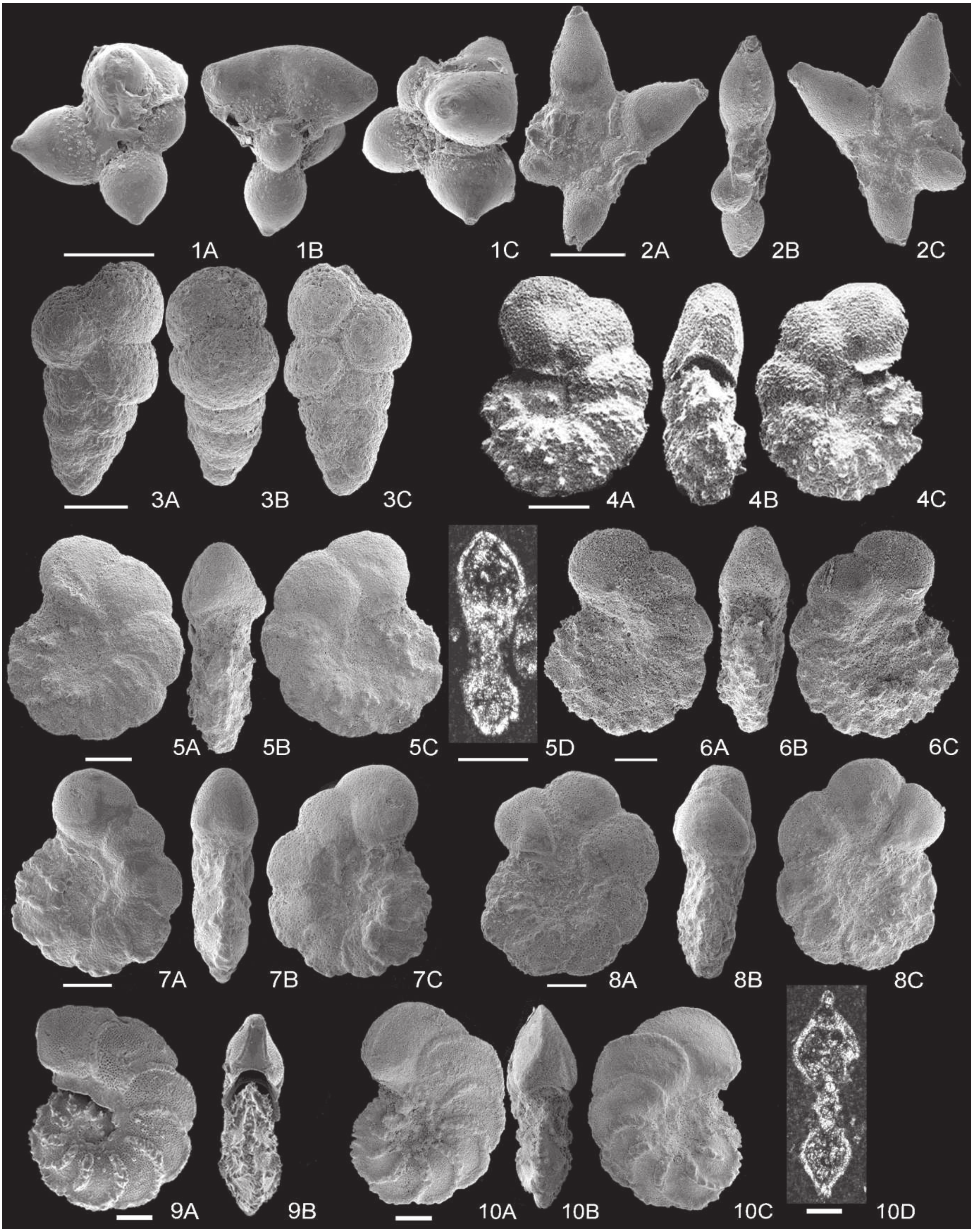
5C
4C
4D
6A
6B
6C
7A
7B
8A
8B
8C
8D
9A
9B

**Plate 19**

1A-C, *S. bicornis,* Sample DSDP Leg 79, 547A-44R-3, 51-53 cm, *Th. globotruncanoides* Zone. 2A-C, *S. leckiei,* Sample DSDP Leg 79, 545-39R-1, 96-98 cm, *Ps. ticinensis.* 3A-C, *P. washitensis,* Sample DSDP Leg 79, 547A-47R-3, 52.5-54.5 cm, *Th. globotruncanoides* Zone. 4A-C, *P. praebuxtorfi* holotype, El Burrueco, southern Spain, catalogue number: T222. 5A-D, *P. praebuxtorfi,* Sample MP4, *Th. appenninica* Zone. 6A-C, *P. praebuxtorfi,* Sample B1.8, *Th. appenninica* Zone. 7A-C, *P. praebuxtorfi,* Sample DSDP Leg 79, 547A-67R-2, 39-41 cm, *Th. appenninica* Zone. 8A-C, *P. praebuxtorfi,* Sample DSDP Leg 79, 545-38R-3, 90-92 cm, *Th. appenninica* Zone. 9A-B, *P. buxtorfi,* Sample ODP 171, Leg 1052E-40R-1, 127-130 cm (Petrizzo and Huber, 2006a). 10A-C, *P. buxtorfi,* Sample MP13, *Th. appenninica* Zone. 10D, *P. buxtorfi,* Sample MP10, *Th. appenninica* Zone. Scale bar 100 µm.

# Plate 19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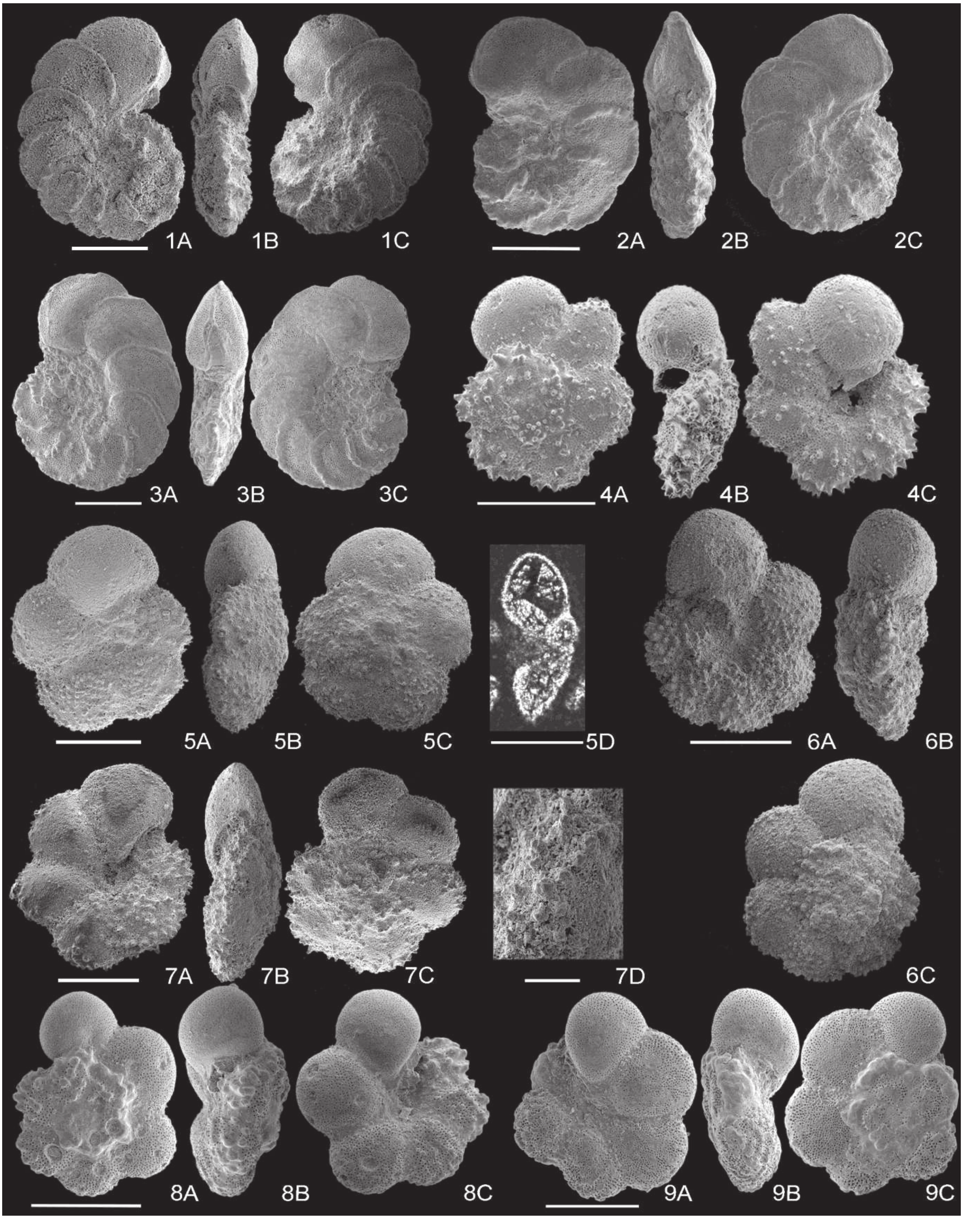
7C
8A
8B
8C
9A
9B
10A
10B
10C
10D

**Plate 20**

1A-C, *P. buxtorfi,* Sample B6, *Th. appenninica* Zone. 2A-C, *P. buxtorfi,* Sample DSDP Leg 79, 547A-64R-3, 51-53 cm, *Th. appenninica* Zone. 3A-C, *P. buxtorfi,* Sample DSDP Leg 79, 545-37R-3, 50-53 cm, *Th. appenninica* Zone. 4A-C, *P. delrioensis,* Sample ODP 171, Leg 1052E-42R-3, 64-66 cm (Petrizzo and Huber, 2006a). 5A-C, *P. delrioensis,* Sample MP19.5, *Th. appenninica* Zone. 5D, *P. delrioensis,* Sample MP14, *Th. appenninica* Zone. 6A-C, *P. delrioensis,* Sample MP42, *Th. reicheli* Zone. 7A-D, *P. delrioensis* with double alignment, Sample B9.6. 7D, scale bar 50 µm, *Th. appenninica* Zone. 8A-C, *P. delrioensis,* Sample DSDP Leg 79, 547A-58R-3, 52-54 cm, *Th. globotruncanoides* Zone. 9A-C, *P. delrioensis,* Sample DSDP Leg 79, 545-38R-1, 89-91 cm, *Th. appenninica* Zone. Scale bar 100 µm except where otherwise stated.

# Plate 20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6A
6B
7A
7B
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7D
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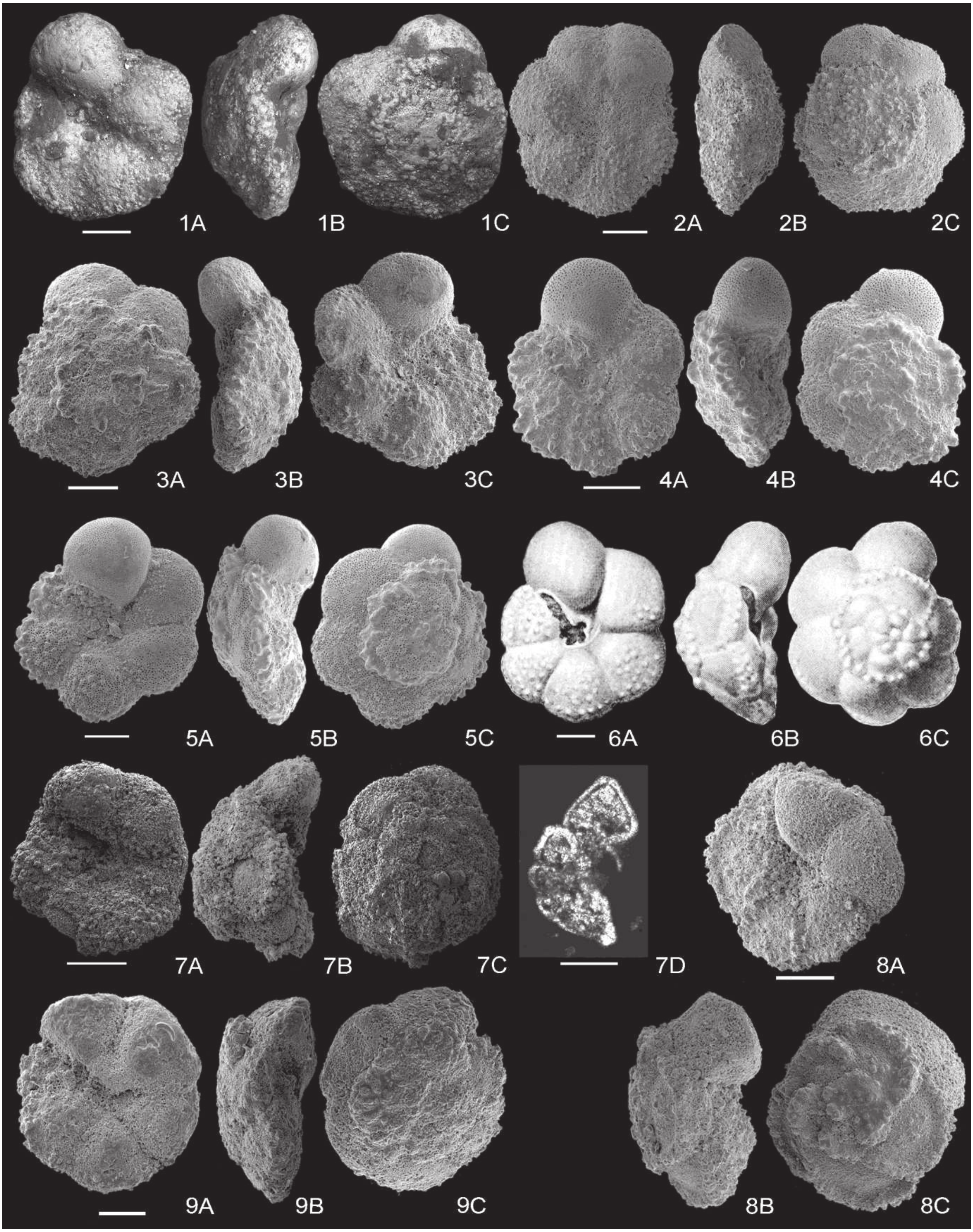
8A
8B
8C
9A
9B
9C

**Plate 21**

1A-C, *P. stephani* holotype, Gorge of the Breggia River, southeastern Switzerland. 2A-C, *P. stephani,* Sample MP35, *Th. reicheli* Zone. 3A-C, *P. stephani,* Sample B9.6, *Th. appenninica* Zone. 4A-C, *P. stephani,* Sample DSDP Leg 79, 547A-62R-3, 48-50 cm, *Th. appenninica* Zone. 5A-C, *P. stephani,* Sample DSDP Leg 79, 545-34R-CC, 1-4 cm, *Th. appenninica* Zone. 6A-C, *P. gibba* holotype, Gorge of the Breggia River, southeastern Switzerland. 7A-C, *P. gibba,* Sample MP50, *R. cushmani* Zone. 7D, *P. gibba,* Sample MP64, *R. cushmani* Zone. 8A-C, *P. gibba,* Sample MP60, *R. cushmani* Zone. 9A-C, *P. gibba,* Sample B16.4, *Th. globotruncanoides* Zone. Scale bar 100 µm.

# Plate 21


1A
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6C
7A
7B
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7D
8A
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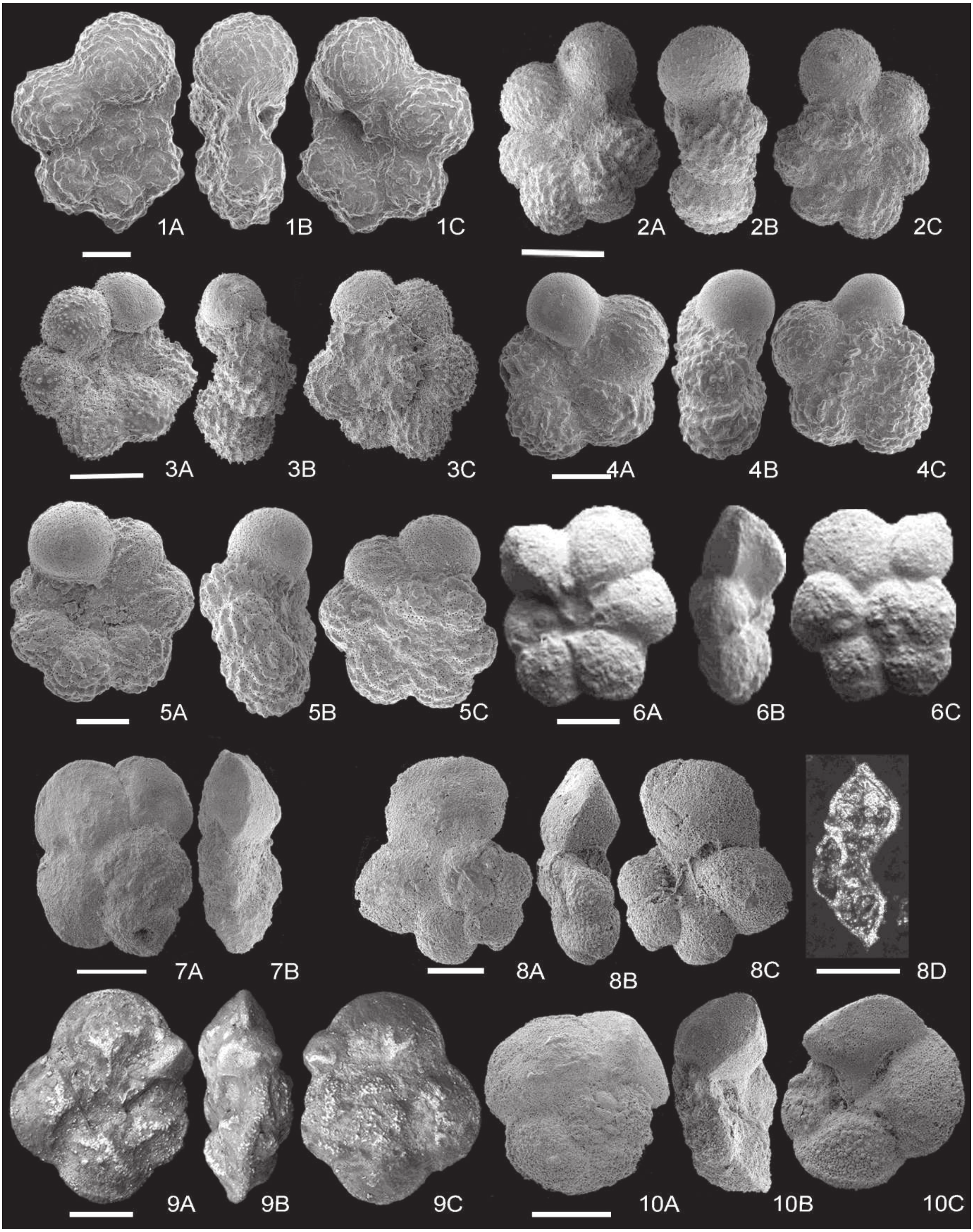
9B
9C
8B
8C

**Plate 22**

1A-C, *P. libyca* holotype, Cyrenaica province, Libya, scale bar 100 µm, catalogue number: 169703. 2A-C, *P. libyca,* Sample MP14, *Th. appenninica* Zone, scale bar 200 µm. 3A-C, *P. libyca,* Sample B11.4, *Th. appenninica* Zone, scale bar 200 µm. 4A-C, *P. libyca,* Sample DSDP Leg 79, 547A-64R-3, 51-53 cm, *Th. appenninica* Zone, scale bar 100 µm. 5A-C, *P. libyca,* Sample DSDP Leg 79, 545-38R-1, 89-91 cm, *Th. appenninica* Zone, scale bar 100 µm. 6A-C, *R. montsalvensis* holotype, Ruisseau des Covayes, Switzerland, scale bar 200 µm, catalogue number: C39014. 7A-B, *R. montsalvensis,* Sample MP38.5, *Th. reicheli* Zone, scale bar 200 µm. 8A-C, *R. montsalvensis,* Sample MP46, *Th. reicheli* Zone, scale bar 100 µm. 8D, *R. montsalvensis,* Sample MP36, *Th. reicheli* Zone, scale bar 200 µm. 9A-C, *R. cushmani* holotype, Hodgeman County, Kansas, scale bar 200 µm, catalogue number: 75377. 10A-C, transition *R. montsalvensis-R. cushmani*, Sample MP46, *Th. reicheli* Zone, scale bar 200 µm.

# Plate 22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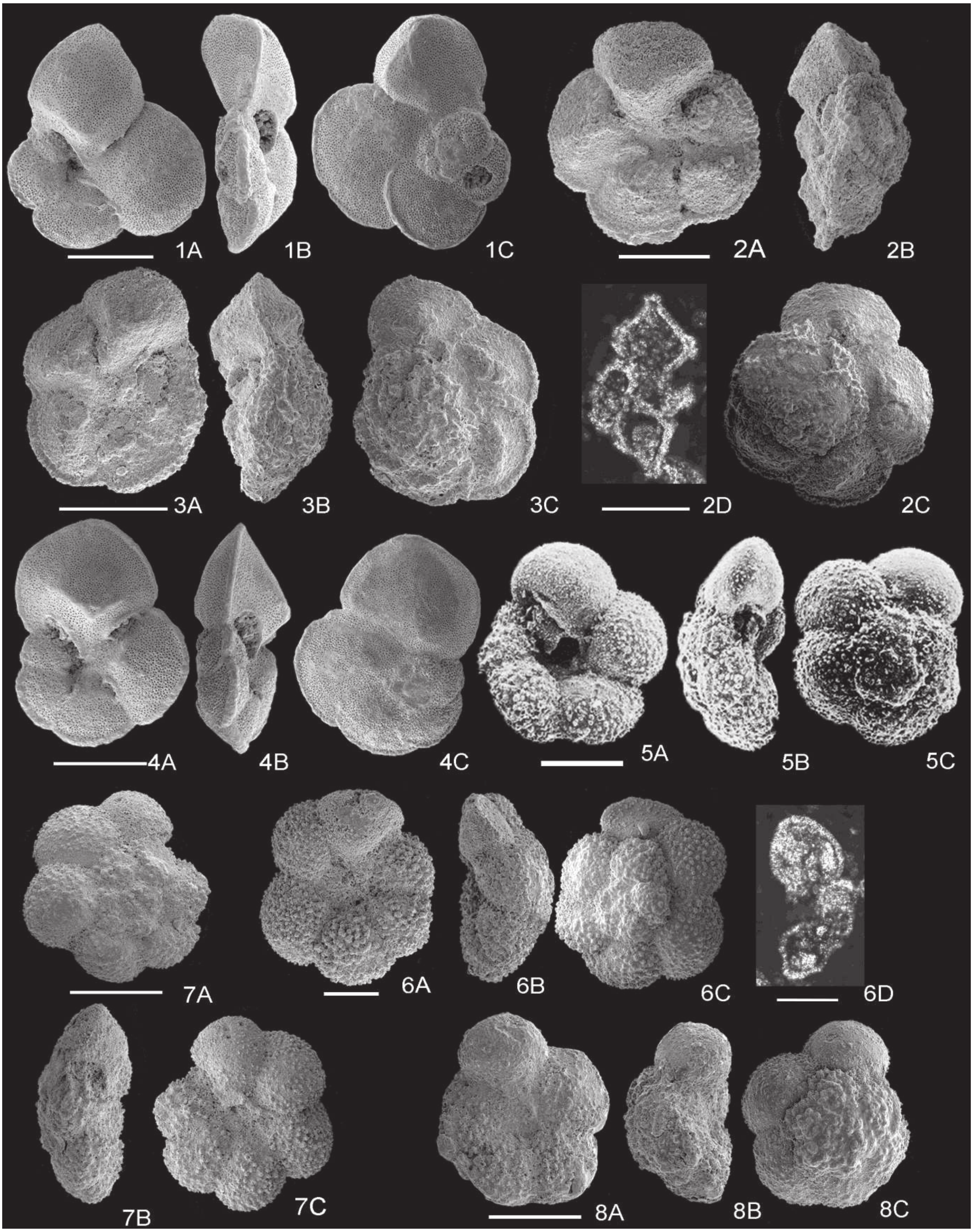
8B
8C
8D
9A
9B
9C
10A
10B
10C

**Plate 23**

1A-C, transition *R. montsalvensis-R. cushmani,* Sample DSDP Leg 79, 547A-42R-3, 40.5-42 cm, *Th. globotruncanoides* Zone. 2A-C, *R. cushmani,* Sample MP59, *R. cushmani* Zone. 2D, *R. cushmani,* Sample MP64, *R. cushmani* Zone. 3A-C, *R. cushmani,* Sample MP65, *R. cushmani* Zone. 4A-C, *R. cushmani,* Sample DSDP Leg 79, 547A-40R-1, 30.5-33 cm, *R. cushmani* Zone. 5A-C, *W. aumalensis,* Loeffre-Lewarde, north of France (Robaszynski and Caron, 1979). 6A-C, *W. aumalensis,* Sample MP44, *Th. reicheli* Zone. 6D, *Whiteinella* sp., Sample 55MP, *R. cushmani* Zone. 7A-C, *W. aumalensis,* Sample MP45, *Th. reicheli* Zone. 8A-C, *W. aumalensis,* Sample MP64, *R. cushmani* Zone. Scale bar 200 µm.

# Plate 23


1A
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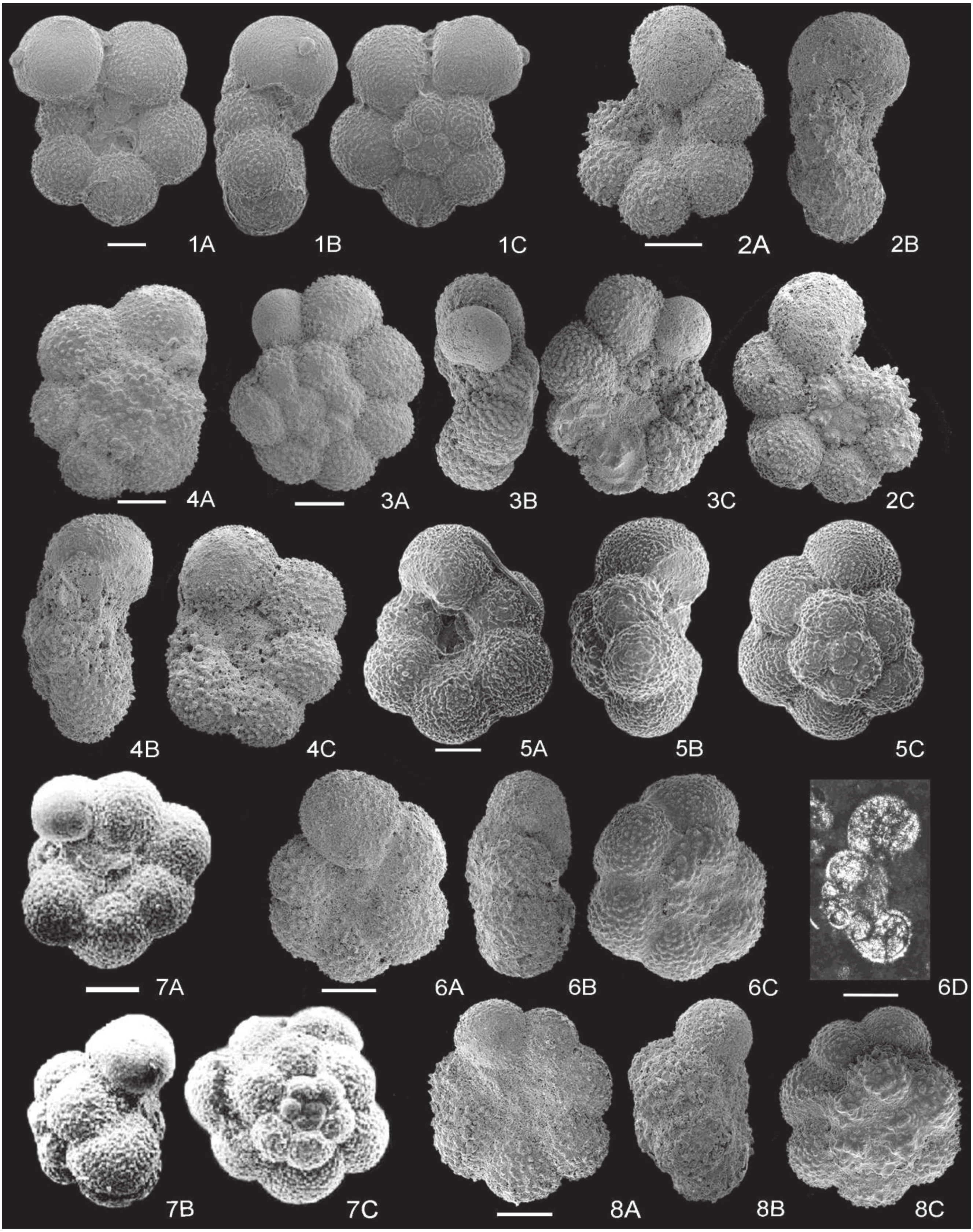
5C
7A
6A
6B
6C
6D
7B
7C
8A
8B
8C

**Plate 24**

1A-C, *W. aprica* holotype, U.S. Highway 80, Texas, catalogue number: 371451. 2A-C, *W.* cf. *aprica,* Sample MP42, *Th. reicheli* Zone. 3A-C, *W. aprica,* Sample MP44, *Th. reicheli* Zone. 4A-C, *W. aprica,* Sample MP44, *Th. reicheli* Zone. 5A-C, *W. brittonensis* holotype, Eagle Ford Group, Dallas County, Texas, catalogue number: 371438. 6A-C, *W. brittonensis,* Sample MP45, *Th. reicheli* Zone. 6D, *W. brittonensis,* Sample MP58, *R. cushmani* Zone. 7A-C, *W. paradubia,* Hodgeman County, Kansas (Robaszynski and Caron, 1979). 8A-C, *W. paradubia,* Sample MP45, *Th. reicheli* Zone. Scale bar 100 µm.

# Plate 24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6B
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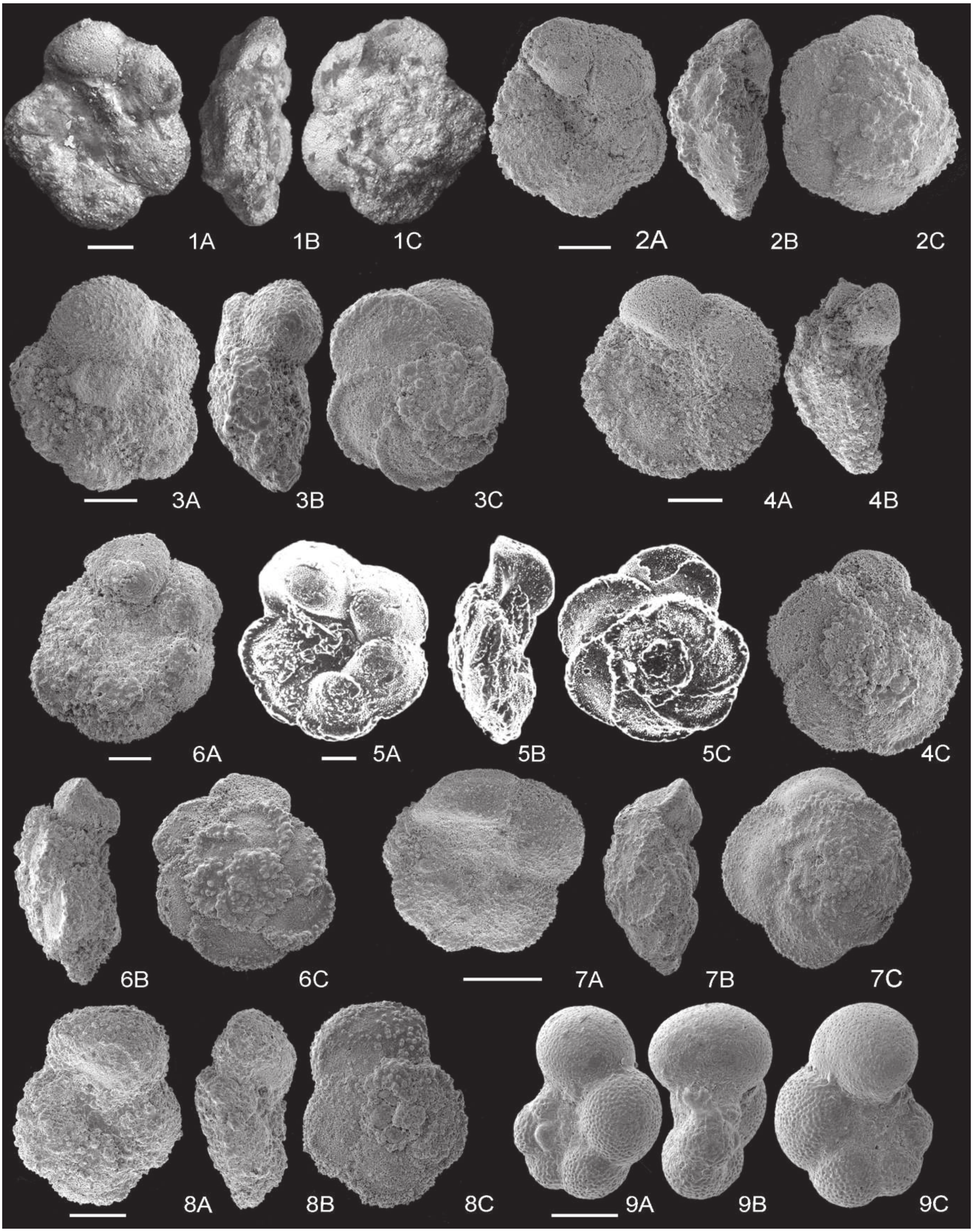
7C
8A
8B
8C

**Plate 25**

1A-C, *D. algeriana* holotype, Sidi Aïssa, Algeria. 2A-C, *D. algeriana*, Sample MP59, *R. cushmani* Zone. 3A-C, *D. imbricata,* Sample MP58, *R. cushmani* Zone. 4A-C, *D. imbricata,* Sample MP59, *R. cushmani* Zone. 5A-C, *D. hagni,* Sidi Aïssa, Algeria (Robaszynski and Caron et al., 1979). 6A-C, *D. hagni,* Sample MP59, *R. cushmani* Zone. 7A-C, *D. hagni,* Sample MP64, *R. cushmani* Zone. 8A-C, *D. takayanagi,* Sample MP59, *R. cushmani* Zone, scale bar 200 µm. 9A-C, *Mi.* cf. *rischi,* Sample DSDP Leg 79, 547A-71R-1, 50.5-52, *Ps. ticinensis* Zone. Scale bar 100 µm except where otherwise stated.

# Plate 25


1A
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9C

# APPENDIX

|0|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15.5|16|16.5|17.5|18.5|19.5|20.5|22|24|25|26|27|28|29|30|31|32|33.5|35|36|37|38.5|39.5|41|42|43|44|45|46|48|49|50|51|52|53|54|56|57|58|59|60|61|62|63|64|METERS|
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|ALBIAN||||||||||||||||||||||CENOMANIAN|||||||||||||||||||||||||||||||||||||||AGE|
|*Ps. tic.*|||*Th. appenninica*||||||||||||||||||*Th. globotruncanoides*||||||||||||*Th. reicheli*|||||||||||||*R. cushmani*||||||||||||||PLANKTONIC FORAMINIFERAL ZONE|
|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X|X|X|X|X|X|X|X|planispiral|
|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X||X||X|X|X|X|X|X|||X|||X|||||||||||*M. praelybica*|
|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X||||X||||X||X||||||||||||||||||*M. astrepta*|
|X|||||X||||X|X|X||||||||||||X|||||X||X|X||||||||||||||||||||||||||||||||*M. delrioensis* Masters|
|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X|X|*M. simplicissima*|
|X||X|X||||||||||||||||||||||||||||||||||||||||||||||||||||||||trans. *M. wondersi* - *G. pulchellus*|
|X||X|X|X||X|X|X||X||X|X|||||X|X|||X?|X|||||||||||||||||||||||||||||||||||||||*T. madecassiana*|
|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X|X|X||||||||||||||||||||||||||||||||||||||*T. primula*|
|X|X|X|X|X|||||||||||||||||||||||||||||||||||||||||||||||||||||||*B. breggiensis*|
|X|X|X|X|X|X|X|X|X|X||X||X?|X|X|X|X||||||X|X|||X|||||||||||||||||||||||||||||||||*Ps. ticinensis*|
|X||X|X|||||||||X||||||X?|||||||||||||||||||||||||||||||||||||||||*T. raynaudi digitalis*|
|X|X|X|X|X|X|X||X||||||||||||||||||||||||||||||||||||||||||||||||||||*G. pulchellus*|
|X||X|X|X|X|||||||X|||||X|X|||||||||||||||||||||||||||||||||||||||||*Mi.* cf. *rischi*|
||X|X|X|X|||||||||||||||||||||||||||||||||||||||||||||||||||||||*B. subbreggiensis*|
||X|X|X||||||||||||||||||||||||||||||||||||||||||||||||||||||||*M. wondersi*|
|||X|X|||X||||||||||||X||||||||||||||||||||||||||||||||||||||||*T. raynaudi aperta*|
|||X|X|X|X|X|X|X|X|X|X|X|X|X|X|||X|X|X|X||||X||||||||X||||||||||||||||||||||||||*Th. evoluta*|
|||X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|*P. delrioensis*|
|||X|X|X||||||||||||||||||||||||||||||||||||||||||||||||||||||||*Ps. subticinensis*|
|||X|X|X||X|X|X|X|X|X||X|X||||X||||||X||X||||X|X||||||||||||||X|||||||||||||||||*Ps. tehamaensis*|
|||X|||||||||||||||||X||||||||X||||||||||||||||||||||||||||||*Schackoina* sp.|
|||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|||||||||||||||||||||||||||||||||||*Th. balernaensis*|
|||X|||||||||||||||||||||||||||||||||||||||||||||||||||||||||*M. blakensis* (ancestral)|
||||X|||||X|||||||X|X|X|X|||||X||X||X||X||X|X||X||X||||X||X|||||||||||||||||||*Globigerinelloides* **sp.1**|
||||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X|X|X|X|X|X|X|X|X|||||X|||||||||||||||||*Th. appenninica*|
||||X|X|X|X|X|X|X|X|X||X||X||X|X||X|X|X|X|X|X||X|X|X|X|X|X|X||X|X|||X|X||||||||||||||||||||*M. delrioensis* (Longoria)|
||||X|X|X|X|X|X|X|X|||||||||||||||||||||||||||||||||||||||||||||||||||*P. praebuxtorfi*|
|||||X|X|X|X|X|X|X|X|X|X||||||||||||||||||||||||||||||||||||||||||||||*P. buxtorfi*|
|||||X|X|X|X|X|X|X|X||X|X|X||X|X|X|X|X|X||||X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|X|X|X|X|X|X|X|X|X||*P. stephani*|
|||||X||||X||||||X|X||||||||||X||X||X|X||||||X|||||||||||||||||||||*Globigerinelloides* sp.2|
||||||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X||X|X|X||X||X||X||X||X|X|X|X|X|||||||||||||||||*M. blakensis* (5 chambers)|
||||||X|||||||||||||||||||||X||X||X||X||X|||||||X|||||||||||||||||*P. delrioensis* holotype|
|||||||X|X|X|X|X||X|X|X|X|||||||||||||||||||||||||||||||||||||||||||||*P. libyca*|
|||||||X|X|X|X|X|X||X|X|X||||X||X||X|||X|X||X||X||||||||||X|X|||X|X|X||||||||||||||*M. blakensis* (6 chambers)|
|||||||X||||||X?|||||||||||||||||||||X||X||X|X|X|X|X||X||X?|X|||||||X||X|||||||*P.* cf. *oraviensis*|
||||||||X||||||X|||X?|X||||X|||||X|||X|X||||||||X||||||||||X|||||||||||*M. planispira*|
||||||||X|||||||||||||||||||X|||||X|||||||||||||||||||||||||||||||*G. ultramicrus*|
|||||||||X||||||||X|X|X||||||||X|||X||X||X||X|X|||X||X|||||||||||||||||||*Globigerinelloides* sp.3|
|||||||||||||||X|||||||X|||||||||X|||X|X|||||X|X|X|X|X|X|X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|*P. gibba*|
|||||||||||||||X|||||X|||||||||||||||||||||||||||||||||||||||||*M. blakensis* (7 chambers)|
|||||||||||||||X||X|X|||X|X|X|X|X|X||X||X||X|X|X||X|X||X|X|X||X|X|||||||||||||||||||trans. *Th. appenninica* - *Th. brotzeni*|
||||||||||||||||X|X|X|X|X||||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|X|||||||||||||||||*Th. brotzeni*|
||||||||||||||||||X||X||||||||||X||X|X|X|X|X|X|||||X||||||||||||||||||||trans. *Th. brotzeni* - *Th. globotruncanoides*|
|||||||||||||||||||X||X|X||||||||||||X|||X||||||||||||||||||||||||*S. cenomana*|
|||||||||||||||||||X?|||||||||||X||||||||||||||||||||||||||||||*S. bicornis*|
|||||||||||||||||||||X|X|||||||||||X?||||||||X?|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X|||X|X|*Th. deeckei*|
|||||||||||||||||||||X|X||||||||||||||||||||X|X|X|X|X|X|X|X|X|X||X|||X||X|X|X|X|X|X|*W. aumalensis*|
|||||||||||||||||||||X?||||||||||||||||||||X|X|X|X|X|X|X||X|||X|||X|X|X|X||X|*W. inornata*|
|||||||||||||||||||||X|||||||||||||||X||X|X|X|X|X|||X|X|X|X|||||||X||X|||*P. delrioensis* (double alignment)|
||||||||||||||||||||||X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X||X||||||*Th. globotruncanoides*|
||||||||||||||||||||||||||||X|||||X|X||X|X||X|X|X|||||||||||||||||||cf. *Biticinella*|
|||||||||||||||||||||||||||||||||||X|X|X|X|X|X|X|X|X|X|X|X|X|||||||||||||||*R. montsalvensis*|
|||||||||||||||||||||||||||||||||||X|X|||X?||X?||X|X||X|||||||||||||||||||*Th. reicheli*|
|||||||||||||||||||||||||||||||||||X|X||X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|X|*Th. greenhornensis*|
||||||||||||||||||||||||||||||||||||X|X|X||X|X|X|||X|X|X|X|X|X|||||||||||||trans. *R. montsalvensis* - *R. cushmani*|
||||||||||||||||||||||||||||||||||||X|||X||X||X|X||X|||||X|X|X|X||||||||*Th. gandolfii*|
||||||||||||||||||||||||||||||||||||X|X|X||X|X|X|X|X|X|X||X|X||X|||X|X|||||*P. stephani* (double alignment)|
||||||||||||||||||||||||||||||||||||||||X|X|X|X|X|X|X|X|X||X||X|X|X|X||X|X|X|X|*W. aprica*|
|||||||||||||||||||||||||||||||||||||||||X|X|X|X||X|X|X|||||X|X||X|X|X|X||*W. brittonensis*|
|||||||||||||||||||||||||||||||||||||||||X||X|X|||||||||X|||||X|||*W. paradubia*|
||||||||||||||||||||||||||||||||||||||||||X|X|||X||||||X|X|||X|X|X|X|*W. baltica*|
|||||||||||||||||||||||||||||||||||||||||||X||||||X|||X||||||||||*W. archeocretacea*|
||||||||||||||||||||||||||||||||||||||||||||||X|||||||||||||||||interm. *Th. globotruncanoides* - *Th. greenhornensis*|
|||||||||||||||||||||||||||||||||||||||||||||||X|X|X|X|X|X|X|X|X|X|X|X|X|X|*R. cushmani*|
||||||||||||||||||||||||||||||||||||||||||||||||||||X||X||||||||*D. roddai*|
||||||||||||||||||||||||||||||||||||||||||||||||||||X|X|X|X|X|X|X|X|X|*D. algeriana*|
||||||||||||||||||||||||||||||||||||||||||||||||||||X||X||||X|||*P. washitensis*|
|||||||||||||||||||||||||||||||||||||||||||||||||||||X|X|X|X|X|X|X|X|*D. imbricata*|
||||||||||||||||||||||||||||||||||||||||||||||||||||||X||||||X|*W. bornholmensis*|
|||||||||||||||||||||||||||||||||||||||||||||||||||||X|X|X|||X|X|X|*D. hagni*|
|||||||||||||||||||||||||||||||||||||||||||||||||||||||X|X|X|X||X|*D. takayanagi*|
|||||||||||||||||||||||||||||||||||||||||||||||||||||||X||||||*D. canaliculata*|
|||||||||||||||||||||||||||||||||||||||||||||||||||||||X|X||X||X|*P. gibba* (double alignment)|
||||||||||||||||||||||||||||||||||||||||||||||||||||||||||?|||trans. *Th. greenhornensis* - *A. multiloculata*|

**Table 1** Monte Petrano section. Stratigraphic distribution of planktonic foraminiferal species based on washed residues.

| METERS | AGE | PLANKTONIC FORAMINIFERAL ZONE | radiolaria | *Biticinella* sp. | *Th.* cf. *appenninica* | *P. praebuxtorfi* | *Ps. ticinensis* | *Ps. tehamaensis* | *P. buxtorfi* | *Murichedbergella* sp. | *Globigerinelloides* sp. | *Ticinella* sp. | *Praeglobotruncana* sp. | *M. simplicissima* | *P. libyca* | *Th. balernaensis* | *Th.* cf. *brotzeni* | *P. stephani* | *Th. globotruncanoides* | *M. astrepta* | rotaliporids | *P. gibba* | *R. montsalvensis* | *Th. greenhornensis* | *Th. reicheli* | *Th. deeckei/Th. gandolfii* | *Th. reicheli/Th. deeckei* | trans. *R. montsalvensis*-*R. cushmani* | *Th. cushmani* | *Whiteinella* sp. | *Dicarinella* sp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64 | CENOMANIAN | *R. cushmani* |  |  |  |  |  |  |  |  |  |  | × | × |  |  |  |  |  |  |  |  |  |  |  |  | × |  | × |  | × |
| 61 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  |  |  |  |  |  |  | × | × | × |
| 58 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  |  | × |  |  |  |  | × | × | × |
| 55 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  |  |  | × | × |  |
| 52 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  |  |  | × |  |  |
| 49 |  |  |  |  |  |  |  |  |  |  |  |  | × |  |  |  |  |  |  |  |  |  |  |  | × |  |  | × |  |  |  |
| 46 |  | *Th. reicheli* |  |  | × |  |  |  |  |  |  |  | × |  |  |  |  |  |  |  |  | × | × | × |  |  | × |  |  |  |  |
| 44 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × | × |  |  | × |  |  |  |  |
| 42 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  | × |  | × | × |  |  |  |  |  |
| 40 |  |  |  |  |  |  |  |  |  |  | × |  | × |  |  |  |  |  |  |  |  |  |  | × | × |  |  |  |  |  |  |
| 38 |  | *Th. globotruncanoides* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  | × | × | × | × |  |  |  |  |  |  |  |
| 36 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × | × | × |  |  |  |  |  |  |  |  |
| 34 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 32 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  |  |  | × |  |  |  |  |  |  |  |  |  |  |
| 30 |  |  |  |  |  |  |  |  |  |  |  |  | × | × |  |  |  |  |  |  | × |  |  |  |  |  |  |  |  |  |  |
| 28 |  |  |  |  | × |  | × |  |  | × |  |  |  |  |  |  |  |  |  |  | × |  |  |  |  |  |  |  |  |  |  |
| 26 |  |  |  |  |  |  |  |  |  | × |  |  |  |  |  |  | × |  |  |  | × |  |  |  |  |  |  |  |  |  |  |
| 24 |  |  |  |  |  |  |  |  |  | × |  | × |  |  |  |  | × |  |  | × | × |  |  |  |  |  |  |  |  |  |  |
| 22 |  |  | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 20 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | × |  | × |  |  |  |  |  |  |  |  |  |  |  |  |
| 18 | ALBIAN | *Th. appenninica* |  |  | × |  |  |  |  |  |  |  | × |  |  |  | × | × |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 16 |  |  |  |  | × |  |  |  |  | × |  | × |  |  |  |  | × | × |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 |  |  |  |  |  |  |  |  |  |  |  |  | × |  |  | × | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 12 |  |  | × |  | × |  |  |  |  | × |  |  |  | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 |  |  |  |  | × |  |  |  | × | × | × | × |  |  | ? |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8 |  |  |  |  | × |  | × |  |  | × |  |  | × | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 |  |  |  |  | × |  | × |  | × | × | × | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 |  |  |  |  | × | × | × | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  | *Ps. ticinen.* |  | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0 |  |  | × |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Table 2** Monte Petrano section. Stratigraphic distribution of planktonic foraminiferal species based of thin sections. Planktonic foraminiferal zonation reported in this table may differs to that inferred by the observation of the washed residues because of the different sampling resolution.

**Table 3** Le Brecce section. Stratigraphic distribution of planktonic foraminiferal species.

| 0.01 | 1.4 | 1.8 | 2.4 | 3 | 3.6 | 4.8 | 6 | 7.2 | 8.4 | 9.6 | 10.8 | 11.4 | 12.5 | 13.8 | 15 | 16.4 | 17 | 17.6 | 18.8 | 19.4 | 19.97 | **METERS** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ALBIAN** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | **CENOMANIAN** |  |  |  |  |  |  | **AGE** |
| ***Ps. ticinen*** | ***Th. appenninica*** |  |  |  |  |  |  |  |  |  |  |  |  |  | ***Th .globotrunc.*** |  |  |  |  |  |  | **PLANKTONIC FORAMINIFERAL ZONE** |
| x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *B subbreggiensis* |
| x | x | x | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *B. breggiensis* |
| x |  | x |  | x |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *M. bentonensis* |
| x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *M. ultramicrus* |
| x |  | x |  | x | x | x | x | x |  | x | x |  | x | x |  | x | x |  | x | x |  | *Macroglobigerinelloides* sp. |
| x | x | x |  |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *Ps. subticinensis* |
| x | x | x | x | x | x |  |  |  |  |  | x | x |  |  |  |  |  |  |  |  |  | *Ps. ticinensis* |
| x | x | x | x | x | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *Ps. tehamaensis* |
| x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *M. wondersi* |
| x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | *M. simplicissima* |
| x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | *M. praelybica* |
| x |  | x |  | x | x |  |  | x | x | x | x | x | x | x |  |  |  | x |  |  | x | *M. astrepta* |
|  | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *T. rischi* |
| x |  | x | x | x |  | x | x |  | x | x | x |  | x |  |  |  |  |  |  | x |  | *T. madecassiana* |
| x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *T. raynaudi digitalis* |
| x |  |  |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *T. raynaudi aperta* |
|  | x | x | x | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | M. *pulchellus* |
|  | x | x | x | x | x |  |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  | *P. praebuxtorfi* |
|  |  | x | x | x | x | x |  | x | x |  |  |  |  |  |  |  |  |  |  |  |  | trans. *P. praebuxtorfi - P. buxtorfi* |
|  |  |  | x | x | x | x | x | x | x | x |  |  |  |  |  |  |  |  |  |  |  | *P. buxtorfi* |
|  | x | x |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | trans M. *pulchellus - P. praebuxtorfi* |
|  | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | *Th. appenninica* |
|  | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |  |  | x | x | x | *Th. balernaensis* |
|  | x | x | x | x |  |  |  |  |  | x |  |  |  |  | x |  | x |  |  | x |  | *Th. evoluta* |
|  | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |  | x | x |  | *T. primula* |
|  | x |  |  | x |  | x |  | x | x | x | x | x | x | x | x | x | x | x | x |  |  | *P. delrioensis* |
|  |  | x | x | x | x |  |  |  | x |  | x | x |  | x | x |  | x | x | x |  | x | *M. delrioensis Longoria* |
|  |  |  |  | x | x |  |  | x | x |  |  |  | x | x | x |  |  |  |  | x |  | *M. blakensis 6 chambers* |
|  |  |  |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | trans. *T. raynaudi - Th. appenninica/balernaensis* |
|  |  |  |  |  | x | x | x | x | x | x | x | x | x |  |  |  |  |  |  |  |  | *P. libyca* |
|  |  |  |  |  | x | x | x | x |  | x |  | x | x | x | x |  | x |  |  |  |  | *M. blakensis 5 chambers* |
|  |  |  |  |  |  | x | x | x | x | x | x | x | x | x | x | x | x | x | x |  |  | *P. stephani* |
|  |  |  |  |  |  |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  | x | *M. delrioensis Masters* |
|  |  |  |  |  |  |  | x |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *M. blakensis* 7 chambers |
|  |  |  |  |  |  |  |  |  | x |  |  |  |  |  |  |  |  |  |  |  |  | trans. T. *raynaudi - Th. appenninica* |
|  |  |  |  |  |  |  |  |  |  | x |  |  |  |  |  |  |  |  |  |  |  | *P. delrioensis* double alignmennt |
|  |  |  |  |  |  |  |  |  |  | x | x |  |  |  | x | x |  | x |  |  |  | trans. Th. *appenninica - Th. brotzeni* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | x | x? | x | x | x | x | x | x | *Th. brotzeni* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x | x |  | x |  |  |  | trans. Th. *brotzeni - Th. globotrunc.* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x | x |  | x | x | x | x | *Th. globotruncanoides* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x |  |  |  |  | x | trans. *Th. globotrun. - Th. greenhorn.* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x | x | cf. Th. *gandolfii* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x |  |  |  |  |  | *Th. gibba* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x |  |  |  |  |  | *Th. stephani* double alignment |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x | cf. *Th. greenhornensis* |
| x |  | x |  | x | x | x | x | x | x | x | x | x |  | x | x | x | x |  | x |  | x | benthos |

| SITE | CORE | SECTION | INTERVAL DEPTH (cm) | DEPTH (m) | AGE | PLANKTONIC FORAMINIFERAL ZONE | *Muricohedbergella* sp. | *M. praelibyca* | *M. wondersi* | *Pseudothalmanninella* sp. | *Ps. subticinensis* | *Ps. ticinensis* | *Ps. tehamaensis* | *Thalmaninnella* sp. | *Ticinella* sp. | *T. madecassiana* | *T. primula* | *T. raynaudi digitalis* | *T. raynaudi aperta* | *M. astrepta* | *M. simplicissima* | *M. planispira* | *G. pulchellus* | *G. bentonensis* | *G. alvarezi* | *Globigerinelloides* sp. | *B. breggiensis* | *S. leckiei* | *cf. Mi. rischi* | *M. delrioensis* (Longoria) | *M. delrioensis* (Masters) | *T. moulladei* | *T. roberti* | *G. ultramicrus* | trans. *T. raynaudi aperta - Th. appenninica* | *P. washitensis* | *Th. balernaensis* | trans. *T. raynaudi digitalis - Th. evoluta* | *Th. evoluta* | *Th. appenninica* | *P. praebuxtorfi* | trans. *G. pulchellus - P. praebuxtorfi* | trans. *P. praebuxtorfi- P. buxtorfi* | *P. buxtorfi* | *M. blakensis* (5 chambers) | *M. blakensis* (6 chambers) | *P. libyca* | *P. delrioensis* | *P. stephani* | trans. *Th. appenninica - Th. brotzeni* | *Th. brotzeni* | *Praeglobotruncana* sp. | *P. gibba* | *Th. globotruncanoides* | trans. *Th. brotzeni - Th. globotruncanides* | *Th. gandolfi* | *P. delrioensis* (double alignment) | trans. *Th. globotruncanoides - Th. greenhornensis* | *Whiteinella* sp. | *W. aprica* | *Th. greenhornensis* | *M. blakensis* (7 chambers) | *Th. deeckei* | *S. biconis* | *R. montsalvensis* | trans. *R. montsalvensis - R. cushmani* | *R. cushmani* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 547A | 40 | 1 | 30.5-33 | 431.8 | CENOMANIAN | *R. cush.* | X | | | | | | | | | | | | | | X | | | X | | | | | | | | | | X | | X | | | | | | | | | | | | X | X | | X | | | X | X | | | | | | | | | | | X | X |
| 547A | 41 | 1 | 100.5-102.5 | 441.51 | | *Th. reicheli* | X | X | | | | | | X | | | | | | | X | X | | X | | X | | | | | | | | | | | | | | X | | | | | X | | X | X | X | X | X | | X | X | | | | | | X | | | | | | |
| 547A | 42 | 2 | 40-42 | 450.4 | | | X | X | | | | | | X | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | X | | | | | | | X | | | X | | | | | | |
| 547A | 42 | 3 | 40.5-42 | 453.4 | | | X | | | | | | | | | | | | | | X | | | X | | | | | | | | | | X | | | | | | X | | | | | X | | X | X | | X | | | X | | X | | X | | | | | | | X | X | |
| 547A | 42 | CC | 4-6 | 455.34 | | | X | X | | | | | | X | | | | | | | X | X | | X | | X | | | | X | | | | X | | | | | | X | | | | | X | X | | X | X | X | X | X | | X | X | | | X | | | | | | | | | |
| 547A | 43 | CC | 0-15.5 | 463.32 | | | | | | | | | | | | | | | | | X | | ? | X | ? | X | | | | | | | | X | | | | | | X | | | | | X | | X | X | X | X | | | X | | X | | X | | | | | | | | | |
| 547A | 44 | 3 | 51-53 | 472.51 | | | | | | | | | | | | | | | | | X | | | | | X | | X | | | | | | | | | | | | X | | | | | X | | X | | | X | | | X | | X | | | | | | | | X | | | |
| 547A | 44 | 5 | 47-49 | 475.47 | | | X | X | | | | | | X | | | | | | | X | X | | X | | X | | | | X | | | | X | | | | | | | | | | | X | | X | X | | X | X | | X | | X | | | | | | | | | | | |
| 547A | 45 | 1 | 17-19 | 478.67 | | | X | X | | | | | | X | | | | | | X | X | X | | X | | X | | | | X | | | | X | | | | | | X | | | | | | X | | X | X | | X | | | X | | | | X | | | | | X | | | | |
| 547A | 45 | 3 | 16-18 | 481.56 | | | X | | | | | | | | | | | | | | X | | | X | X | | | | | X | | | | X | | X | | | | X | | | | | | X | | X | | | X | | | X | | | | | | | | | | | | | |
| 547A | 46 | 1 | 60-62 | 488.6 | | | X | X | | | | | | X | | | | | | X | X | X | | X | | X | | | | X | | | | X | | | | | | X | | | | | | | | X | | X | X | | | X | | | | X | | | X | | | | | | |
| 547A | 46 | 3 | 60-62 | 491.27 | | | | | | | | | X | | | | | | | | X | | | X | | X | | | | | | | | X | | X | | | | X | | | | | | X | | X | | X | X | | | X | | X | | | | | | | | | | | |
| 547A | 47 | 1 | 52.5-54.5 | 498.02 | | | X | X | | | | | X | X | | | | | | X | X | X | | X | | X | | | | | | | | | | | | | | X | | | | | | X | | X | | | X | | | X | | | | | | X | | X | | | | | |
| 547A | 47 | 3 | 52.5-54.5 | 501.02 | | | X | | | | | | | | | | | | | | X | | | | | | | | | X | | | | | | X | | | | X | | | | | X | X | | X | | | X | | | X | | | | X | | | X | | | | | | |
| 547A | 47 | CC | 15-16.5 | 502.15 | | | X | X | | | | | X | X | | | | | | X | X | X | | X | X | X | | | | | | | | | | X | | | | X | | | | | X | X | | X | | X | X | | | X | X | X | | X | | | X | | | | | | |
| 547A | 48 | 1 | 47.5-49.5 | 507.48 | | *Th. globotruncanoides* | X | | | | | | | | | | | | | | X | | | X | | | | | | | X | | | X | | | | | | X | | | | | | | | | | X | | | X | X | | | X | | | | | | | | | |
| 547A | 49 | 1 | 48-50 | 516.98 | | | | ? | | | | | | | | | | | | | X | | | X | X | X | | | | | | | | X | | | | | | | | | | | | | | X | | X | X | | | X | X | | | X | | | | | | | | | |
| 547A | 49 | CC | 11-13 | 519.61 | | | X | X | | | | | | X | | | | | | | X | X | | X | | X | | | | | | | | | | X | | | | | | | | | | | | X | X | | X | | | X | | | | X | X | X | | | | | | | |
| 547A | 50 | 1 | 83-85.5 | 526.83 | | | X | | | | | | | X | | | | | | | X | | | X | | X | | | | | | | | | | X | | | | | | | | | | | | X | | | X | | | X | | | | | X | X | | | | | | | |
| 547A | 50 | 3 | 80-82 | 529.68 | | | X | | | | | | | | | | | | | | X | | | X | | X | | | | X | | | | | | | | | X | X | | | | | | | | X | X | | X | | | X | | | | | | | | | | | | | |
| 547A | 51 | 1 | 48-50 | 535.98 | | | X | X | | | | | | X | | | | | | X | X | X | | X | | X | | | | | | | | | | | X | | | X | | | | | | X | | X | X | X | X | | | X | | | | | | | | | | | | | |
| 547A | 51 | 3 | 50-52 | 539 | | | | X | | | | | | | | | | | | | X | ? | | X | | X | | | | | | | | X | | | | | X | X | | | | | | | | X | X | X | X | | | | X | | | | | | | | | | | | |
| 547A | 52 | 1 | 52-54 | 545.52 | | | X | X | | | | | | X | | | | | | | X | X | | X | X | X | | | | | | | | X | | | | | | X | | | | | | | | X | X | X | X | X | | X | X | | | X | | | | | | | | | |
| 547A | 52 | 3 | 47.5-50.5 | 548.7 | | | X | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | X | | | | | | | | X | X | X | X | | | X | | | | | | | | | | | | | |
| 547A | 53 | 1 | 50-51.5 | 555 | | | X | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | X | X | | | | X | | | | | | | | | | | | |
| 547A | 54 | 1 | 82-83.5 | 564.82 | | | | X | | | | | | | | | | | | | X | | | X | | | | | | X | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 55 | 1 | 104-106 | 574.54 | | | X | | | | | | | | | | | | | | X | | | | | | | | | | X | | | | | | | | | | | | | | | | | X | | X | | | | | | | | | | | | | | | | | |
| 547A | 55 | CC | 7-8 | 577.32 | | | X | | | | | | | X | | | | | | | X | | | | X | X | | | | | | | | | | | | | | | | | | | | | | X | X | | X | X | X | | | | X | | | | | | | | | | |
| 547A | 56 | 1 | 106-107.5 | 584.06 | | | X | X | | | | | | X | | | | | | | X | | X | X | | X | | | | | | | | | | | | | | X | | | | | | | | X | X | X | X | | | X | X | | | | | | | | | | | | |
| 547A | 56 | 3 | 132-134 | 587.32 | | | X | X | | | | | | | | | X | | | X | X | | | X | | | | | | X | X | | | | | | X | | | X | | | | | | | | X | X | X | X | | X | X | | X | | | | | | | | | | | |
| 547A | 57 | 3 | 50-52 | 596 | | | | | | | | | | | | ? | | | | | X | | | | ? | X | | | | | | | | | | | | | | X | | | | | | X | | X | X | X | X | | | | | | | | | | | | | | | | |
| 547A | 57 | 5 | 49-51 | 598.99 | | | X | X | | | | | | X | X | | | | | | X | | | X | X | X | | | | | | | | X | | X | | | | X | | | | | X | X | | X | X | X | X | | | X | | | | | | | | | | | | | |
| 547A | 58 | 3 | 52-54 | 605.52 | | | | X | | | | | | | | X | X | | | | | | | X | X | | | | | | | | | X | | | | | | X | | | | | | X | | X | X | X | X | | | | X | X | | | | | | | | | | | |
| 547A | 58 | 5 | 51-53 | 608.18 | | | X | | | | | | | X | X | | | | | | X | | | X | X | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | |
| 547A | 59 | 1 | 47-48.5 | 611.97 | | | X | X | | | | | X | X | X | X | X | | | | X | | | X | | X | | | | | | | | X | | | X | | | X | | | | | | | | X | X | X | X | | | X | | | | | | | | | | | | | |
| 547A | 59 | 3 | 49-51 | 614.99 | | | | X | | | | | | | | X | X | | | | X | X | | X | X | | | | | | X | | | X | | | X | | | X | | | | | X | X | | X | X | X | X | | | | | | | | | | | | | | | | |
| 547A | 60 | 1 | 48.5-50.5 | 621.48 | | | X | | | | | | | X | X | X | X | | | | X | | | X | X | X | | | | | | X | X | X | | X | | | | | | | | | X | X | | X | | | X | X | | X | | | | | | | | | | | | | |
| 547A | 60 | 3 | 49.5-51.5 | 624.49 | | | | X | | | | | | | | | X | | | | X | | | X | X | | | | | X | | | | | | | X | | | | | | | | | X | | X | | X | X | | | | | | | | | | | | | | | | |
| 547A | 60 | 5 | 50-52 | 627.4 | | | X | X | | X | | X | | X | X | | X | | | | X | | | X | X | X | | | | | | | | X | | | | | | X | | | | | | | | X | X | X | X | X | | X | | | | | | | | | | | | | |
| 547A | 61 | 1 | 48-50 | 630.98 | | | X | X | | | | | | X | X | X | X | | | | X | | | X | | X | | | | X | | | | X | | X | | | | X | | | | | | | | X | X | X | X | | | X | X | | | | | | | | | | | | |
| 547A | 61 | 3 | 50-52 | 634 | ALBIAN | *Th. appenninica* | X | X | | | | | | | | X | X | | | | X | | | X | X | | | | | X | | | | X | | | X | | | X | | | | | X | | | X | X | X | X | | X | | | | | | | | | | | | | | |
| 547A | 62 | 1 | 50-52 | 640.5 | | | X | X | | | | | | X | X | | X | | | | X | | | X | | X | | | | | | | | | | | | | | X | | | | | | | | X | X | | | X | | | | | | | | | | | | | | | |
| 547A | 62 | 3 | 48-50 | 643.48 | | | | X | | | | | | | | | X | | | | X | | | X | X | | | | | X | | X | | | | | | | | X | | | | | X | | X | X | X | X | X | | | | | | | | | | | | | | | | |
| 547A | 63 | 1 | 48-49.5 | 649.98 | | | X | X | | | | X | X | | X | X | X | X | | X | X | X | X | X | | X | | | | | | X | X | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | |
| 547A | 63 | 3 | 49.5-52 | 652.99 | | | | X | | | | | | | | X | X | | | X | X | | | X | X | | | | | X | X | X | | | | | | | | X | | | | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | |
| 547A | 64 | 1 | 49-52 | 659.49 | | | X | X | X | | | | X | X | X | X | X | | X | | X | X | | X | | X | | | | X | | X | X | X | | X | | | | X | X | | | X | X | X | X | X | X | | | | | | | | | | | | | | | | | |
| 547A | 64 | 3 | 51-53 | 662.19 | | | | X | | | X | | X | | | X | | X | X | | | | | X | X | | X | | X | | | X | X | | | | X | | | | | | X | X | | | X | | | | | | | | | | | | | | | | | | | | |
| 547A | 64 | CC | 5.5-7.5 | 663.78 | | | X | X | | X | | X | X | X | X | X | X | | X | | X | X | | X | X | X | | | | X | | | | X | | | | X | | X | X | | | X | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 65 | 1 | 36.5-38 | 668.86 | | | | X | | X | X | X | X | | | X | X | | | X | X | X | | | | X | | | X | | X | X | | | | | X | X | X | X | X | | X | X | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 66 | 2 | 67-69 | 680.17 | | | X | X | | | | X | X | | | X | X | X | | | X | | | | | X | | | | | X | X | | | | | X | X | | X | | | X | X | X | X | | | | | | | | | | | | | | | | | | | | | |
| 547A | 67 | 2 | 39-41 | 689.39 | | | | X | | | | X | X | | | X | X | | X | | X | | X | | | | X | | X | | X | X | X | | | | X | X | X | X | X | | X | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 67 | CC | 7-9 | 690.38 | | | X | X | | | | X | X | X | X | X | X | X | X | X | X | | X | X | | X | | | | X | X | X | X | | | | X | | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 68 | 1 | 123-125 | 698.23 | | | X | X | | X | | X | X | X | X | X | X | X | | | X | X | X | X | | X | | | | X | | | X | X | | X | | | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 68 | 2 | 93-95 | 699.43 | | | | X | X | | | X | X | | | X | X | X | X | | X | | X | | | | | X | X | X | X | | X | | X | | | X | | X | | X | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 69 | 1 | 50-52 | 707 | | | X | X | | | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | | | X | | | X | X | | X | X | | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 69 | 3 | 50-52 | 710 | | *Ps. ticinensis* | X | X | | | | X | X | | | X | X | X | X | | X | | X | | | | X | | X | | | X | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 70 | 1 | 49.5-51.5 | 716.49 | | | X | X | | | | X | X | X | X | X | X | X | | X | X | | X | X | X | X | X | | | X | | X | X | X | | | X | | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 70 | 3 | 50.5-53 | 719.05 | | | | X | | | | | X | | | X | X | X | X | | X | | X | | | X | X | | X | X | X | | X | | X | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 71 | 1 | 50.5-52 | 721.01 | | | | X | X | | | X | X | | | X | X | X | X | X | X | | X | | | X | X | | | X | X | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 72 | 1 | 47-49 | 725.97 | | | X | X | | | | X | X | | X | X | X | X | X | X | X | | X | X | | X | X | | X | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 72 | 3 | 48-50 | 728.98 | | | | | | | | | X | | | | X | X | | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 73 | 1 | 48-50 | 735.48 | | | X | X | X | | | X | X | | X | X | X | X | X | | X | | X | X | | X | X | | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 73 | 3 | 53-54.5 | 738.53 | | | | X | X | | | X | X | | | X | X | X | X | | X | | X | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 547A | 73 | CC | 23-25 | 740.36 | | | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**Table 4** Mazagan Plateau DSDP Site 547A. Stratigraphic distribution of planktonic foraminiferal species.

| **SITE** | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 | 545 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CORE** | 28 | 28 | 28 | 29 | 29 | 30 | 31 | 32 | 32 | 33 | 33 | 34 | 34 | 34 | 35 | 36 | 36 | 37 | 37 | 38 | 38 | 39 | 39 | 40 | 40 |
| **SECTION** | 1 | 1 | CC | 1 | CC | 1 | 1 | 1 | CC | 1 | CC | 1 | 3 | CC | 2 | 1 | CC | 3 | CC | 1 | 3 | 1 | 5 | 5 | 6 |
| **INTERVAL DEPTH (cm)** | 10-12 | 47-49 | 10-12 | 18-22 | 4-7 | 25-28.5 | 25-27 | 34-37 | 4-8 | 99-103 | 7-9 | 123-125 | 61.5-64 | 1-4 | 69-74 | 145-150 | 10-13 | 50-53 | 2.5-5 | 89-91 | 90-92 | 96-98 | 23-25 | 8-10 | 57-60 |
| **DEPTH (m)** | 255.60 | 255.97 | 256.42 | 265.18 | 267.00 | 274.75 | 284.25 | 293.84 | 294.19 | 303.99 | 30.422 | 313.73 | 315.80 | 316.16 | 324.19 | 332.95 | 335.62 | 344.20 | 344.23 | 351.39 | 354.28 | 360.96 | 366.23 | 375.28 | 377.27 |
| **AGE** | **CENOMANIAN** | | | | | | | | | | | | **ALBIAN** | | | | | | | | | | | | |
| **PLANKTONIC FORAMINIFERAL ZONE** | ***Th. reicheli*** | | | | | | | | ***Th. glob.*** | | | | ***Th. appenninica*** | | | | | | | | | ***Ps. ticiner*** | | | |
| *M. simplicissima* | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | | × | × | × | × | × | × |
| *Ps. ticinensis* | | | | | | | | | | | | | | | | | | | | | × | × | × | | × |
| *B. breggiensis* | | | | | | | | | | | | | | | | | | | | | | × | × | × | |
| *T. madecassiana* | | | | | | | | | | | | | | | | × | × | × | | | × | × | × | × | |
| *M. planispira* | | | | | | | | | | | | | | | | | | | | | | | × | × | |
| *T. primula* | | | | | | | | | | | | | | | | | × | × | × | × | × | × | × | × | |
| *T. raynaudi aperta* | | | | | | | | | | | | | | | | | | | | | × | × | | × | |
| *T. raynaudi digitalis* | | | | | | | | | | | | | | | | | | | | | | × | | × | |
| *P. stephani* | | | | × | | × | × | | × | × | × | × | × | × | × | × | × | | × | | | | | × | |
| *Ps. subticinensis* | | | | | | | | | | | | | | | | | | | | | × | × | × | × | |
| *G. bentonensis* | × | × | × | | × | × | × | × | × | × | × | × | × | × | × | × | | × | × | × | × | | × | | |
| *T. moulladei* | | | | | | | | | | | | | | | | | | | | | | | × | | |
| *T. roberti* | | | | | | | | | | | | | | | | | | | | | | | × | | |
| *S. cenomana* | | × | | | | | | | | | × | | | | | | | | | | | × | | | |
| trans. *raynaudi aperta-appenninica* | | | | | | | | | | | | | | | | | | | | | | × | | | |
| trans. *raynaudi digitalis-evoluta* | | | | | | | | | | | | | | | | | | | | | × | × | | | |
| *Th. appenninica* | | × | × | | × | | | | × | | × | | | | × | × | × | × | × | × | × | | | | |
| *Th. balernaensis* | | | | | | | | | | | | | | × | × | × | × | | | × | × | | | | |
| *P. buxtorfi* | | | | | | | | | | | | | | | | | | × | × | × | × | | | | |
| *Th. evoluta* | | | | | | | | | | | | | | | | | | × | | | × | | | | |
| *M. praelibyca* | × | | | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | | | | |
| *P. praebuxtorfi* | | | | | | | | | | | | | | | | | | | | | × | | | | |
| trans. *G. pulchellus - P. praebuxtorfi* | | | | | | | | | | | | | | | | | | | | | × | | | | |
| *Ps. tehamaensis* | | | | | | | × | | | | | | | | | | | | | | × | | | | |
| *M. astrepta* | | | | × | | × | | × | | | × | | × | × | × | × | | | | × | | | | | |
| *P. delrioensis* | × | × | × | × | × | × | × | | × | × | × | × | × | × | × | × | × | | × | × | | | | | |
| *P. libyca* | | | | | | | | | | | | | | | × | × | × | × | | × | | | | | |
| *G. alvarezi* | | × | | | | | × | | | | | | | | | × | | × | | | | | | | |
| *M. blakensis* 6 chambers | | | | | | | | | | | | | | | | | | × | | | | | | | |
| *Th. brotzeni* | | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | | | | | | | |
| trans. *Th. appenn- Th. brotzeni* | | | | | | | | | | | × | | | | | | × | | | | | | | | |
| *Th. deeckei* | | | | | × | | | | | | | | | | | | | | | | | | | | |
| *Th. gandolfii* | × | × | × | | | × | | × | × | | | × | | × | × | × | | | | | | | | | |
| trans. *brotzeni - globotruncanoides* | | | × | | | | | | | | | | × | | | | | | | | | | | | |
| *Th. globotruncanoides* | × | × | | × | | × | × | × | × | × | ? | × | | | | | | | | | | | | | |
| intermediate *globotruncanoides*_ *greenhornensis* | | | | | | | × | | | | | × | | | | | | | | | | | | | |
| *Th. greenhornensis* | × | × | × | × | × | × | × | × | | | | | | | | | | | | | | | | | |
| *P. gibba* | | | | × | | | | | | | | | | | | | | | | | | | | | |
| *S. bicornis* | | | × | | | | | | | | | | | | | | | | | | | | | | |

**Table 5** Mazagan Plateau DSDP Site 545. Stratigraphic distribution of planktonic foraminiferal species.

| METERS | AGE | PLANKTONIC FORAMINIFERAL ZONE | agglomerates | benthic | indeterminated | quartz | radiolaria | black lithics | *Muricohedbergella* sp. | *M. delrioensis* (Longoria) | *M. wondersi* | *M. praelibyca* | *M. astrepta* | *M. simplicissima* | *M. blakensis* (7 chambers) | *M. blakensis* (6 chambers) | *M. blakensis* (5 chambers) | *Globigerinelloides* sp. | *G. pulchellus* | *G. bentonensis* | *Biticinella* sp. | *B. subbreggiensis* | *B. breggiensis* | cf. *Biticinella* | *Ticinella* sp. | *T. raynaudi digitalis* | *T. raynaudi aperta* | *T. primula* | *T. madecassiana* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64 | CENOMANIAN | *R. cushmani* | 98 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 63 | | | 51 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 62 | | | 117 | 1 | | | | 8 | | | | | | | | | | | | | | | | | | | | | |
| 61 | | | 50 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 60 | | | 17 | | 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 59 | | | 1 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 58 | | | 8 | 2 | 1 | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| 57 | | | 28 | 1 | 3 | | | 3 | | | | | | | | | | | | | | | | | | | | | |
| 56 | | | 149 | | | 6 | | 1 | | | | | | | | | | 2 | | | | | | | | | | | |
| 54 | | | 164 | | 1 | 14 | | 11 | | | | | | | | | | | | | | | | 1 | | | | | |
| 53 | | | 100 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 52 | | | 26 | 2 | 1 | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| 50 | | | 13 | 3 | 2 | 5 | | | | | | | | | | 1 | | | | | | | | | | | | | |
| 49 | | *Th. reicheli* | 30 | 1 | | | 1 | | | | | | | | | 1 | | | | | | | | | | | | | |
| 48 | | | 107 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 46 | | | 10 | 3 | | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| 45 | | | 68 | | 1 | | | | | | | 5 | 2 | | | | | | | | | | | | | | | | |
| 44 | | | 3 | 2 | 1 | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| 43 | | | 14 | 2 | 1 | 2 | 1 | | | | | 1 | | | | | | | | | | | | | | | | | |
| 42 | | | 60 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 41 | | | 45 | 5 | 1 | 4 | | | | | | | | | | | | | | | | | | | | | | | |
| 39.5 | | | 202 | 1 | 2 | 10 | 54 | | | | | | | | | | | | | | | | | | | | | | |
| 38.5 | | | 127 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 37 | | | 86 | 3 | | | | | | | | 2 | | 3 | | | | | | | | | | | | | | | |
| 36 | | | 113 | 2 | | | | | | | | | | 2 | | | | | | | | | | | | | | | |
| 35 | | | 40 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 33.5 | | *Th. globotruncanoides* | 156 | 2 | | 3 | | | | | | | 5 | | | | | | | | | | | | | | | | |
| 32 | | | 126 | 8 | 7 | 23 | | | 8 | | | 12 | 10 | 3 | | 2 | | | | | | | | | | | | | |
| 31 | | | 87 | 8 | 1 | | | | 5 | 2 | | 10 | 3 | | | | | | | | | | | | | | | | |
| 30 | | | 134 | 6 | 3 | | | | 3 | | | | | 2 | | 2 | | | | | | | | | | | | | |
| 29 | | | 121 | 10 | | | | | 3 | | | | | | | | | | | | | | | | | | | | |
| 28 | | | 201 | 10 | 2 | | | | 5 | | | 2 | | | | | 2 | | | | | | | | | | | | |
| 27 | | | 133 | 12 | 3 | | | | 3 | | | | | 5 | | | | 2 | | | | | | | | | | | |
| 26 | | | 94 | 3 | | | 1 | | | | | | | | | | | | | | | | | | | | | | |
| 25 | | | 261 | 4 | | | | | 2 | | | 2 | | 1 | | | 1 | | | | | | | | | | | | |
| 20.5 | | | 98 | 13 | 9 | | 1 | | | | | | | 1 | | 1 | | | | | | | | | | | | | |
| 19.5 | ALBIAN | *Th. appenninica* | 34 | 9 | 6 | 1 | | | 1 | | | | | | | | | | | | | | | | 1 | | | | |
| 18.5 | | | 185 | 1 | 5 | | | | | | | 1 | | 1 | 2 | 4 | 1 | | | | | | | | | | | | |
| 17.5 | | | 277 | 1 | 5 | | | | 1 | | | | 1 | 1 | | | | | | | | | | | | | | | |
| 16.5 | | | 257 | 1 | 10 | | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | | |
| 15.5 | | | 164 | 3 | 15 | 1 | | | 4 | | | 9 | 16 | 1 | | 1 | 1 | | | | | | | | | | | | |
| 14 | | | 4 | 8 | 7 | 4 | | | 4 | | | 13 | 16 | 5 | 1 | 8 | 4 | | | | | | | | | | | 1 | 0 |
| 13 | | | 4 | 8 | 4 | 10 | | | 2 | 1 | | 7 | 11 | 2 | | 8 | 8 | | | | | | | | | | | | |
| 12 | | | 133 | 5 | 14 | 4 | 100 | | 1 | | | 6 | 1 | 3 | | | 4 | | | 1 | | | | | | | | | |
| 11 | | | 2 | 3 | 2 | 113 | | | 1 | 1 | | 16 | 13 | 4 | | 1 | 2 | | | 1 | | | | | | | | | |
| 10 | | | 32 | 3 | 3 | 193 | | | 2 | | | 2 | 2 | 4 | | 4 | 1 | | | | | | | | | | | | |
| 9 | | | 4 | 8 | 4 | 31 | | 1 | 1 | 1 | | 4 | 11 | 3 | | 1 | 1 | | | | | | | | | | | | |
| 8 | | | 108 | 1 | 2 | 126 | 1 | | 1 | | | 2 | 2 | | | 1 | | | | 1 | | | | | | | | | |
| 7 | | | 285 | 2 | 6 | 15 | | | 3 | | | 2 | 10 | 1 | | 3 | 2 | | | 1 | | | | | | | | | |
| 6 | | | 99 | 5 | 4 | | | | | | | 2 | 15 | | | 1 | 1 | | | 1 | | | | | | | | | |
| 5 | | | 254 | 14 | 3 | | | | 1 | | | 1 | 3 | 1 | | | | | | | | | | | | | | | |
| 4 | | | 176 | 23 | 16 | 4 | | | | 1 | | 1 | 2 | 1 | | | | | 2 | | 3 | 1 | 2 | | | | | | |
| 3 | | | 210 | 2 | 4 | 103 | | | | | | | 1 | | | | | | 3 | | 4 | | 3 | | | | | 1 | 2 |
| 2 | | *Ps. ticinen.* | 23 | 7 | 13 | 1 | 1 | | 5 | | 1 | 11 | 31 | 14 | | | | | 4 | 2 | 14 | 1 | 28 | | 1 | 8 | 8 | 2 | |
| 1 | | | 433 | | 1 | | | 1 | | | | | | | | | | | | | 1 | | 1 | | | | | | |
| 0 | | | 355 | 2 | 1 | 23 | 46 | | | | | | 1 | 1 | | | | | | | | | 1 | | | | | | |

| METERS | rotaliporids | *Pseudothalmanninella* sp. | *Ps. subticinensis* | *Ps. ticinensis* | *Ps. tehamaensis* | *Thalmanninella* sp. | *Th. balernaensis* | *Th. evoluta* | *Th. appenninica* | trans. *Th. appenninica* - *Th. brotzeni* | *Th. brotzeni* | trans. *Th. brotzeni* - *Th. globotruncanoides* | *Th. globotruncanoides* | *Th.* cf. *greenhornensis* | trans. *Th. greenhornensis* - *A. multiloculata* | *Th. gandolfii* | *Th. deeckei* | *Th. greenhornensis* | *Th. reicheli* | *Rotalipora* sp. | *R. montsalvensis* | trans. *R. montsalvensis* - *R. cushmani* | *R. cushmani* | *Planomalina* sp. | *P. praebuxtorfi* | *P. buxtorfi* | *P. libyca* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64 | | | | | | 4 | | | | | | | | 1 | | | 3 | 47 | | | | | 73 | | | | |
| 63 | | | | | | 2 | | | | | | | | | | | 1 | 42 | | | | | 50 | | | | |
| 62 | | | | | | 7 | | | | | | | | | 2 | | | 42 | | | | | 14 | | | | |
| 61 | | | | | | 10 | | | | | 6 | | | | | | | 58 | | | | | 45 | | | | |
| 60 | | | | | | 13 | | | | | | | | | | | 8 | 80 | | | | | 32 | | | | |
| 59 | | | | | | 9 | | | | | | | | | | | | 78 | | | | | 47 | | | | |
| 58 | | | | | | 10 | | | | | 5 | | 4 | | | | 3 | 55 | | | | | 62 | | | | |
| 57 | 1 | | | | | 12 | | | | | 3 | | | | | 9 | 10 | 35 | | 2 | | | 41 | | | | |
| 56 | 1 | | | | | 11 | | | | | 3 | | 2 | | | 1 | 1 | 17 | | 1 | | | 12 | | | | |
| 54 | 2 | | | | | 14 | | | | | 5 | | 12 | | | 1 | 7 | 14 | | 2 | | 2 | 6 | | | | |
| 53 | 2 | | | | | 13 | | | | | 2 | | 8 | | | 4 | 8 | 13 | | | | 4 | 11 | | | | |
| 52 | 4 | | | | | 42 | | | | | 3 | | 11 | | | | 7 | 17 | | 7 | | 4 | 12 | | | | |
| 50 | 5 | | | | | 32 | | | | | 3 | | 9 | | | | 5 | 71 | | 12 | | 7 | 24 | | | | |
| 49 | | | | | | 53 | | | | | 5 | | 18 | | | | 4 | 35 | 1 | 2 | | 15 | | | | | |
| 48 | 3 | | | | | 35 | | | | | | | 11 | | | 2 | 5 | 28 | | 2 | 3 | 7 | | | | | |
| 46 | | | | | | 12 | | | | | | | 4 | | | | | 11 | | | 2 | 1 | | | | | |
| 45 | 5 | | | | | 39 | | | | | 3 | | 33 | | | 2 | 6 | 7 | 4 | 2 | 16 | | | | | | |
| 44 | 6 | | | | | 78 | | | | | 1 | | 47 | | | 1 | 3 | 15 | 2 | | 32 | | | | | | |
| 43 | 12 | | | | | 16 | | | | | | | 23 | | | | 1 | 2 | | | 6 | 2 | | | | | |
| 42 | 24 | | | | | 23 | | | | | 5 | | 39 | | | | 1 | 6 | | 6 | 8 | 15 | | | | | |
| 41 | 32 | | | | | 34 | | | | | 7 | | 45 | | | | | 10 | | 3 | 5 | 7 | | | | | |
| 39.5 | 1 | | | | | 12 | | | | | | | 1 | | | | | 2 | | 4 | 1 | | | | | | |
| 38.5 | 15 | | | | | 18 | | | | | 2 | | 19 | | | | | 6 | | 4 | 10 | 3 | | | | | |
| 37 | 10 | | | | | 40 | | | | | 8 | | 107 | | | | | | | 7 | 7 | 3 | | | | | |
| 36 | 18 | | | | | 47 | | | | | 3 | | 40 | | | | | 3 | 3 | | 8 | 7 | | | | | |
| 35 | | | | | | 5 | | | | | 1 | | 15 | | | | | 1 | | | 1 | | | | | | |
| 33.5 | 3 | | | | | 75 | | | 2 | | 7 | | 57 | | | | | | | | | | | | | | |
| 32 | 18 | 2 | | | | 48 | | | | | 3 | | 113 | | | | | | | | | | | | | | |
| 31 | | 3 | | | | 95 | | | 3 | | 10 | | 83 | | | | | | | | | | | | | | |
| 30 | | | | | | 107 | | | 5 | | 10 | | 83 | | | | | | | | | | | | | | |
| 29 | 2 | | | | | 128 | | | 2 | | 3 | | 185 | | | | | | | | | | | | | | |
| 28 | 13 | 2 | | | | 32 | | | 2 | | 8 | | 67 | | | | | | | | | | | | | | |
| 27 | | 5 | | | 2 | 87 | 2 | | | | 18 | | 118 | | | | | | | | | | | | | | |
| 26 | | | | | | 41 | 1 | 2 | 2 | | 9 | | 32 | | | | | | | | | | | | | | |
| 25 | | | | | | 46 | 5 | | 4 | | 18 | | 38 | | | | | | | | | | | | | | |
| 20.5 | 1 | 1 | | | | 68 | 2 | 1 | 4 | | 14 | | 62 | | | | 1 | | | | | | | | | | |
| 19.5 | 5 | | | | | 72 | 4 | 1 | 4 | | 17 | | | | | | 1 | | | | | | | | | | |
| 18.5 | 0 | | | | | 57 | 7 | 1 | 30 | 1 | 6 | 4 | | | | | | | | | 1 | | | | | | |
| 17.5 | 6 | | | | 1 | 25 | 1 | 2 | 5 | 1 | 1 | 1 | | | | | | | | | | | | | | | |
| 16.5 | 2 | | | | | 44 | 2 | | 4 | 3 | 8 | 11 | | | | | | | | | | | | | | | |
| 15.5 | 11 | | | | | 16 | 22 | 2 | 17 | 2 | | | | | | | | | | | | | | | | | 6 |
| 14 | 8 | | | 1 | 1 | 11 | 28 | 1 | 8 | | | | | | | | | | | | | | | | | | 23 |
| 13 | 8 | 1 | | 5 | | 18 | 69 | 4 | 10 | | | | | | | | | | | | | | | | | 46 | 10 |
| 12 | 1 | | | | | 4 | 17 | 1 | 6 | 1 | | | | | | | | | | | | | | | | 38 | 2 |
| 11 | 3 | 1 | | 2 | 1 | 6 | 30 | 4 | 17 | | | | | | | | | | | | | | | | | 113 | |
| 10 | 7 | 1 | | | | 1 | 5 | | 4 | | | | | | | | | | | | | | | | | 112 | |
| 9 | 4 | | | 1 | | 8 | 34 | 5 | 23 | | | | | | | | | | | | | | | | | 128 | 1 |
| 8 | 2 | 4 | | 11 | 2 | 1 | 4 | 2 | 4 | | | | | | | | | | | | | | | | | 34 | |
| 7 | 6 | 3 | | 14 | 3 | 1 | 3 | 2 | 2 | | | | | | | | | | | | | | | 3 | 1 | 44 | 1 |
| 6 | | | | 31 | 1 | 4 | 11 | 4 | 5 | | | | | | | | | | | | | | | 1 | 5 | 100 | 1 |
| 5 | 3 | | | 21 | | 1 | 8 | 3 | 1 | | | | | | | | | | | | | | | 1 | 7 | 1 | |
| 4 | 3 | 1 | | 29 | | 3 | 7 | 5 | 2 | | | | | | | | | | | | | | | 1 | 20 | | |
| 3 | | 4 | 1 | 7 | 2 | | 3 | 2 | 1 | | | | | | | | | | | | | | | | 3 | | |
| 2 | | 15 | | 46 | 26 | | 9 | 4 | | | | | | | | | | | | | | | | | | | |
| 1 | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| METERS | *Praeglobotruncana* sp. | *P. delrioensis* | *P. delrioensis* (double alignment) | *P. stephani* | *P. stephani* (double alignment) | *P. oraviensis* | *P. gibba* | *P. gibba* (double alignments) | *P. hilalensis* | *Whiteinella* sp. | *W. inornata* | *W. aumalensis* | *W. brittonensis* | *W. aprica* | *W. paradubia* | *W. baltica* | *D. algeriana* | *Dicarinella* sp. | *D. imbricata* | *D. elata* | *D. hagni* | *D. roddai* | *D. takayanagi* | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64 | 1 | | | | | | 5 | | 1 | | | 1 | | 1 | | | 2 | 4 | 24 | | | | | |
| 63 | 5 | | | 1 | | | 3 | | | | | 1 | | | | | 6 | 13 | 41 | | 5 | | | |
| 62 | 2 | | | 1 | | | 2 | 1 | 2 | 2 | 1 | 3 | 5 | | 1 | 1 | | 9 | 35 | 1 | | | 1 | |
| 61 | 10 | | 1 | | | | 6 | | 11 | | | 1 | 3 | | | 2 | 6 | 6 | 10 | | | | | |
| 60 | 8 | 1 | | 5 | 1 | | 10 | 6 | 3 | 4 | 1 | 3 | 1 | | | | 11 | 5 | 18 | | | | 3 | |
| 59 | 20 | 2 | | 10 | | | 16 | | 15 | | | | | 1 | | | 9 | 5 | 14 | | 2 | | | |
| 58 | 18 | | | 11 | | | 19 | | 4 | 2 | | | 1 | 3 | | | 6 | 3 | | | 1 | 1 | | |
| 57 | 19 | 5 | | 15 | | 2 | 7 | | 11 | 2 | | 3 | 2 | 6 | 1 | | 2 | | 5 | 1 | | | | |
| 56 | 8 | 1 | | 5 | 1 | | 7 | | 8 | | | | | | | | 1 | | | | | | | |
| 54 | 12 | 2 | | 18 | | 2 | 5 | | 3 | | | | | | | | | | | | | | | |
| 53 | 20 | 1 | | 21 | 1 | | 9 | | | | | | | | | | | | | | | | | |
| 52 | 17 | 6 | | 39 | 3 | | 20 | | | | | | | 1 | | | | | | | | | | |
| 50 | 3 | 3 | | 27 | 1 | | 16 | | | 3 | | 3 | 1 | 2 | | | | | | | | | | |
| 49 | 13 | 9 | | 11 | | | 11 | | | 5 | | 20 | 1 | 12 | | | | | | | | | | |
| 48 | 14 | 5 | 1 | 23 | 2 | | 14 | | | 1 | | 7 | | | | | | | | | | | | |
| 46 | 3 | 7 | | 30 | 1 | | | | | | | 1 | | 3 | | | | | | | | | | small residue |
| 45 | 9 | 4 | | 15 | 6 | | 3 | | | 9 | | 2 | 7 | 13 | 4 | 2 | | | | | | | | |
| 44 | 18 | | | 1 | 2 | | 2 | | | 4 | | 7 | 4 | 15 | | 1 | | | | | | | | |
| 43 | 29 | 4 | 10 | 20 | 64 | | 4 | | | 3 | | 4 | 1 | 5 | 1 | | | | | | | | | |
| 42 | 32 | 8 | 1 | 14 | 6 | | 1 | | | 1 | 3 | 5 | | | | | | | | | | | | |
| 41 | 4 | 14 | 1 | 38 | 2 | | 3 | | | | | | | | | | | | | | | | | |
| 39.5 | 4 | 6 | 1 | 10 | | | | | | | | | | | | | | | | | | | | |
| 38.5 | | 14 | 1 | 24 | | | | | | | | | | | | | | | | | | | | |
| 37 | | 72 | 2 | 78 | 5 | | | | | | | | | | | | | | | | | | | |
| 36 | | 37 | | 32 | 5 | | | | | | | | | | | | | | | | | | | |
| 35 | | 11 | | 7 | | | | | | | | | | | | | | | | | | | | small residue |
| 33.5 | | 20 | | 33 | | | 2 | | | | | | | | | | | | | | | | | |
| 32 | | 32 | | 8 | | | | | | | | | | | | | | | | | | | | |
| 31 | | 75 | | 28 | | 2 | | | | | | | | | | | | | | | | | | |
| 30 | | 55 | | 8 | | | 2 | | | | | | | | | | | | | | | | | |
| 29 | | 12 | | 2 | | | | | | | | | | | | | | | | | | | | |
| 28 | | 2 | | | | | | | | | | | | | | | | | | | | | | |
| 27 | | 3 | | | | | | | | | | | | | | | | | | | | | | |
| 26 | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20.5 | | | | 12 | 1 | | | | | | | | | | | | | | | | | | | |
| 19.5 | | | 2 | 16 | 2 | | 1 | | | | | | | | | | | | | | | | | |
| 18.5 | | | | 1 | | | | | | | | | | | | | | | | | | | | |
| 17.5 | | | | | | | | | | | | | | | | | | | | | | | | |
| 16.5 | | | | 1 | | | | | | | | | | | | | | | | | | | | |
| 15.5 | | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | | | | 2 | | | | | | | | | | | | | | | | | | | | |
| 13 | | | | 1 | | | 2 | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | | | | 1 | | | | | | | | | | | | | | | | | | | | |
| 10 | | | | 1 | | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | | | | | | | | | | | | | | | | | | | | | | | | |

**Table 6**. Monte Petrano section. Quantitative analysis on size fraction comprised between 355 µm and 250 µm.

| METERS | AGE | PLANKTONIC FORAMINIFERAL ZONE | agglomerates | benthic | indeterminated | quartz | radiolaria | red litics | globigeriniformis | *P. washitensis* | *Mi.* cf. *rischi* | *Muricohedbergella* sp. | *M. delrioensis* (Longoria) | *M. delrioensis* (Masters) | *M. wondersi* | *M. praelibyca* | *M. astrepta* | *M. simplicissima* | *M. blakensis* (6 chambers) | *M. blakensis* (5 chambers) | trans. *M. wondersi* - *G. pulchellus* | *M. planispira* | planispirals | *G. pulchellus* | cf. *Biticinella* | *Ticinella* sp. | *T. raynaudi digitalis* | *T. raynaudi aperta* | *T. primula* | *T. madecassiana* | rotaliporids | *Pseudothalmanninella* sp. | *Ps. ticinensis* | *Ps. tehamaensis* | *Thalmanninella* sp. | *Th. evoluta* | *Th. balernaensis* | *Th. appenninica* | *Th. brotzeni* | *Th. globotruncanoides* | *Th. greenhornensis* | *Th. gandolfii* | *Th. deeckei* | *Rotalipora* sp. | *R. montsalvensis* | trans. *R. montsalvensis* - *R. cushmani* | *R. cushmani* | *Planomalina* sp. | *P. praebuxtorfi* | *P. buxtorfi* | *P. libyca* | *Praeglobotruncana* sp. | *P. delrioensis* | *P. delrioensis* (double alignment) | *P. stephani* | P. stephani (double alignment) | *P. gibba* | *P. gibba* (double alignment) | *P. hilalensis* | *P. inermis* | *Whiteinella* sp. | *W. inornata* | *W. aumalensis* | *W. aprica* | *W. brittonensis* | *W. baltica* | *W. archeocretacea* | *W. paradubia* | *W. bornholmensis* | *Dicarinella* sp. | *D. algeriana* | *D. imbricata* | *D. elata* | *D. roddai* | *D. canaliculata* | *D. hagni* | *D. takayanagi* | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64 | CENOMANIAN | *R. cushmani* | 36 | 2 | | | | | | | | | | | | | | 21 | | | | | 15 | | | | | | | | 2 | | | | | | | | | | 22 | | | | | | 21 | | | | | 14 | 2 | | | | 7 | 2 | | | 5 | 1 | 8 | 2 | | 1 | | | 1 | 15 | 2 | 28 | | | | 1 | 1 | |
| 63 | | | 21 | | | | | | 1 | | | | | | | | | 5 | | | | | 4 | | | | | | | | | | | | 4 | | | | | 8 | | | | | 26 | | | | | 8 | | | | | 8 | | | | 6 | | 8 | 3 | 1 | 2 | | | | 9 | 2 | 23 | | | | | | |
| 62 | | | 84 | | | | | | 5 | 4 | | | | | | | | 4 | | | | | 15 | | | | | | | | | | | | 2 | | | | | 7 | | | | | 6 | | | | | 7 | | | 3 | | 13 | | 2 | | 6 | 1 | 3 | 8 | 3 | 4 | | | | 9 | 2 | 35 | | | | | 1 | |
| 61 | | | 65 | 2 | | | | | 11 | | | | | | | | | 22 | | | | | 10 | | | | | | | | | | | | 12 | | | | | 8 | | | | | 9 | | | | | 11 | | | 1 | | 7 | | 1 | | 8 | 4 | 4 | 3 | 2 | 2 | | | | 9 | 6 | 25 | 1 | | | | 1 | |
| 60 | | | 2 | 3 | | | | | 2 | | | | | | | | | 17 | | | | | 13 | | | | | | | | | | | | 11 | | | | 1 | | 12 | | | | | 6 | | | | | 11 | | | 4 | 2 | 9 | 4 | 3 | | 2 | 1 | 9 | | | | | | | 7 | 16 | 27 | | | | | 3 | |
| 59 | | | | | | | | | 2 | | | | | | | | | | | | | | 1 | | | | | | | | | | | | 5 | | | | | | 26 | | | | | 20 | | | | | 21 | 3 | 1 | 7 | 1 | 17 | 1 | 4 | | 2 | 1 | 1 | | | | | | | 17 | 11 | 34 | | | 2 | 1 | 2 | |
| 58 | | | 6 | 1 | | | | | 2 | | | 1 | | | | | | 15 | | | | | 9 | | | | | | | | | | | | 13 | | | | 7 | | 4 | | | | | 11 | | | | | 23 | 7 | | 17 | | 9 | | 4 | 2 | 3 | | | 8 | 1 | 1 | | | 1 | 1 | 8 | 1 | | 1 | | | | |
| 57 | | | 2 | 1 | | | | | 2 | | | | | | | | | 5 | | | | | 3 | | | | | | | | | | | | 15 | | | | 1 | | 7 | | 1 | | | | 4 | | | | | 25 | 7 | | 10 | | 5 | | 6 | | 7 | | 2 | 8 | 3 | 1 | | | | 4 | | 1 | 2 | 5 | | | | |
| 56 | | | 104 | 3 | | 12 | | | 11 | 1 | | 1 | | | | | | 16 | | | | | 15 | | | | | | | | | | | | 8 | | | | 4 | 1 | 15 | | | | | 4 | | | | | 33 | 14 | | 17 | | 1 | | 4 | | 1 | 1 | | 2 | | | 1 | | | | | | | | | | | |
| 54 | | | 162 | | | 6 | 1 | | 14 | | | 9 | | | | | | 17 | | | | | 11 | | | | | | | | | | | | 15 | | | | 17 | | | | 1 | | | | | | | | 8 | 1 | | 11 | | 2 | | 2 | | | | | | | | | | | | | | | | | | | |
| 53 | | | 3 | 5 | 1 | 2 | | | 3 | | | | | | | 1 | | 3 | | | | 1 | 2 | | | | | | | | 5 | | | | 14 | | | | 4 | 7 | 5 | 1 | 2 | 3 | | 1 | 2 | | | | | 24 | 16 | | 54 | | 13 | | | | 2 | | 3 | | | | | | | | | | | | | | | |
| 52 | | | 10 | 5 | 1 | 2 | | | 4 | | | | | | | | | 2 | | | | | | | | | | | | | | | | | 15 | | | | | | 4 | | | 1 | | | | | | | | 11 | 4 | | 9 | | 1 | | | | 1 | | | | | | 1 | | | | | | | | | | | small residue |
| 50 | | | 11 | 3 | | 3 | | | 3 | | | 2 | | | | | | 7 | | | 2 | | 2 | | | | | | | | 3 | | | | 7 | | | | 1 | | 22 | | 1 | 2 | | 2 | 2 | | | | | 26 | 7 | 2 | 64 | 2 | 9 | | | | 4 | | 1 | 2 | | | | | | | | | | | | | | |
| 49 | | *Th. reicheli* | 18 | | | | | | 5 | | | 4 | | | | | | 21 | | 2 | | | 4 | | | | | | | | | | | | 33 | | | | 3 | | 13 | | | 1 | 1 | | | | | | 30 | 8 | | 25 | 1 | 9 | | | | 3 | 1 | 17 | 4 | | 2 | | | | | | | | | | | | |
| 48 | | | 45 | 1 | | | | | 5 | | | | | | | | | 17 | | 1 | | | 10 | | | | | | | | | | | | 23 | | | | 4 | | 9 | | | | 1 | 1 | | | | | 39 | 26 | | 71 | 2 | 8 | | | | 1 | | 5 | 1 | | | | | | | | | | | | | | |
| 46 | | | 34 | 5 | 1 | | | | 10 | | | 3 | | | | 1 | | 8 | | | | | 2 | | | | | | | | | | | | 18 | | | | | 1 | 5 | | | 1 | 2 | | | | | | 11 | 11 | | 46 | | 1 | | | | 3 | 1 | 4 | 4 | 1 | | | | | | | | | | | | | |
| 45 | | | 11 | 1 | | | | | 11 | | | 4 | | 1 | | 2 | | 6 | | | | | 2 | | | | | | | | 6 | | | | 23 | | | | 2 | 5 | 7 | 1 | | 5 | 3 | | | | | | 29 | 7 | | 25 | 2 | 1 | | | | 7 | 1 | 10 | 15 | 4 | 2 | 2 | 1 | | | | | | | | | | |
| 44 | | | 6 | 2 | | | | | 13 | | | 1 | | | | 3 | | 15 | | 3 | | | 8 | | | | | | | | 7 | | | | 34 | | | | 3 | 6 | 3 | | 1 | | 14 | | | | | | 37 | 4 | | 11 | 2 | 2 | | | | 6 | 1 | 5 | 8 | 1 | 2 | | | | | | | | | | | | |
| 43 | | | 16 | 1 | 1 | 1 | 2 | | 14 | | | 7 | | | | 6 | | 12 | | 2 | | | 1 | | | | | | | | 1 | | | | 12 | | | | 2 | 1 | | | | | 2 | | | | | | 43 | 2 | 13 | 7 | 46 | 1 | | | | 3 | 1 | 4 | 2 | 2 | | | | | | | | | | | | | |
| 42 | | | 24 | | 1 | | | | 25 | | | 3 | | | | 1 | | 21 | 1 | | | 1 | 6 | | | | | | | | 20 | | | | 21 | | | | 5 | 1 | 2 | | | 5 | 7 | 2 | | | | | 40 | 3 | 2 | 8 | 1 | 1 | | | | 2 | | 1 | | | | | | | | | | | | | | | |
| 41 | | | 47 | 3 | | 1 | 1 | | 11 | | | 1 | | | | | | 19 | | | | | 15 | | 1 | | | | | | 16 | | | | 12 | | | | 6 | 5 | | | | 2 | 4 | 2 | | | | | 5 | 25 | | 16 | | | | | | | | 1 | 1 | | | | | | | | | | | | | | |
| 39.5 | | | 124 | 1 | | 78 | 36 | | 1 | | | | | | | | | 4 | | | | | 1 | | | | | | | | 5 | | | | 5 | | | | | | | | | 1 | 3 | 1 | | | | | 2 | 3 | | 9 | | | | | | | | | | | | | | | | | | | | | | | |
| 38.5 | | | 135 | 1 | | | | | 2 | | | | | | | | | 8 | | | | | 3 | | 2 | | | | | | 12 | | | | 14 | | | | 3 | 4 | 1 | | | 2 | 3 | 1 | | | | | 11 | 14 | | 22 | | | | | | | | | | | | | | | | | | | | | | | |
| 37 | | | 78 | | | | | | 4 | | | 6 | | | | 6 | | 32 | | | | | 4 | | 3 | | | | | | 6 | | | | 22 | | | 3 | 9 | 8 | | | | | 4 | | | | | | 3 | 33 | | 26 | 1 | | | | | | | | | | | | | | | | | | | | | | |
| 36 | | | 181 | 1 | | | | | 2 | | | 2 | | | | | | 14 | | | | | | | | | | | | | 8 | | | | 33 | | | | 9 | 9 | | | | | 1 | | | | | | | 10 | 2 | 12 | | | | | | | | | | | | | | | | | | | | | | | |
| 35 | | | 48 | 3 | | 1 | | | 3 | | | 1 | | | | 3 | | 41 | | | | | 4 | | 3 | | | | | | 16 | | | | 43 | | | 1 | 8 | 22 | 3 | | | | 18 | | | | | | 4 | 22 | | 15 | | | | | | | | | | | | | | | | | | | | | | | |
| 33.5 | | *Th. globotruncanoides* | 160 | 1 | | 1 | | | 10 | | | 5 | 2 | | | 2 | 1 | 5 | | | | | 6 | | | | | | | | 2 | 1 | | | 31 | | | | 2 | 7 | | | | | | | | | | | 2 | 13 | | 14 | | | | | | | | | | | | | | | | | | | | | | | |
| 32 | | | 79 | 2 | | 12 | | | 20 | | | 16 | 3 | 1 | | 22 | 6 | 15 | 1 | | | | 12 | | | | | | | | 1 | | | | 47 | | | | 3 | 3 | | | | | | | | | | | 5 | 15 | | 5 | | | | | | | | | | | | | | | | | | | | | | | |
| 31 | | | 119 | 1 | | | | | 17 | | | 8 | 1 | | | | 1 | 37 | | | | 9 | 35 | | | | | | | | 11 | | | | 9 | | | | 3 | 2 | | | | | | | | | | | 3 | 28 | | 9 | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | | | 94 | 3 | 2 | | | | 25 | | | 13 | | | | 7 | | 28 | | 1 | | 1 | 17 | | | | | | | | 15 | | | | 8 | | | | 8 | | | | | | | | | | | | 3 | 36 | | 2 | | | | | | | | | | | | | | | | | | | | | | | |
| 29 | | | 38 | 6 | | | | | 33 | | | 10 | | | | 5 | 1 | 18 | | | | | 14 | | | | | | | | 4 | | | | 47 | | | | 5 | 18 | | | | | | | | | | | 6 | 69 | | 5 | | | | | | | | | | | | | | | | | | | | | | | |
| 28 | | | 145 | | | 1 | | | 41 | | | 13 | | | | 11 | 1 | 26 | | | | | 36 | | | | | | | | 13 | 2 | | | 4 | | | | 6 | 2 | | | | | | | | | | | | 22 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 27 | | | 120 | | 1 | | | | 21 | | 2 | 19 | | | | 17 | 1 | 24 | | | | 2 | 26 | | | | | | | | 11 | 1 | | | 3 | | | | 15 | 1 | | | | | | | | | | | 1 | 23 | | 4 | | | | | | | | | | | | | | | | | | | | | | | |
| 26 | | | 122 | 1 | | | | | 40 | | 1 | 13 | | | | 12 | | 20 | | 1 | | | 25 | | | | | | | | 31 | 1 | | | 9 | | | 1 | | 8 | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | | | 227 | 5 | 2 | 1 | | | 32 | | | 18 | 2 | | | 29 | 1 | 25 | | 2 | | | 16 | | | | | | | | | | | | 32 | | 1 | 3 | 12 | 2 | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20.5 | | | 129 | 3 | 6 | | | | 19 | | | 12 | | | | 5 | 7 | 29 | 1 | 1 | | 8 | 17 | | | 0 | | | | | 1 | | | | 17 | | | 2 | 20 | 5 | | | | | | | | | | | 1 | 16 | | 6 | | | | | | | | | | | | | | | | | | | | | | | |
| 19.5 | ALBIAN | *Th. appenninica* | 32 | 3 | 11 | | | | 10 | | | 1 | | | | 7 | 2 | 11 | | 1 | | | 15 | | | 2 | | | 2 | | 1 | | | | 28 | 1 | 1 | 2 | 11 | | | | | | | | | | | | 2 | 47 | | 7 | | 1 | | | | | | | | | | | | | | | | | | | | | |
| 18.5 | | | 62 | 4 | 4 | | 1 | | 21 | | 1 | 4 | | | | 12 | 4 | 8 | | | | | 28 | | | 2 | | | 2 | 1 | 14 | | | | 26 | | 1 | 2 | 8 | | | | | | | | | | | | 2 | 56 | | 5 | | | | | | | | | | | | | | | | | | | | | | | |
| 17.5 | | | 311 | | | | | | | | 1 | 3 | | | | 1 | 1 | | | | | | 6 | | | 1 | | | 1 | 1 | | | | | 2 | | | 0 | 3 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16.5 | | | 242 | | | | | | 6 | | | 2 | | | | 3 | 1 | 2 | | 2 | | | 2 | | | 0 | | | | | 17 | 1 | | | 4 | | | 2 | 2 | | | | | | | | | | | | 1 | 17 | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 15.5 | | | 157 | | 10 | | | | 9 | | | 11 | 1 | | | 10 | 8 | 8 | 2 | 1 | | | 10 | | | 0 | | | 1 | | 7 | | 1 | | 15 | | 3 | 7 | 4 | | | | | | | | | | 1 | 4 | 2 | 25 | | 2 | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | | | 96 | 2 | 5 | 1 | | | 8 | | | 17 | | | | 4 | 2 | 15 | 2 | 5 | | 6 | 19 | | | 2 | | | 8 | | 3 | | | 1 | 8 | | 1 | 1 | | | | | | | | | | | | 5 | 1 | 30 | | 4 | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | | | 59 | 1 | 5 | 5 | | | 1 | | | 18 | | | | 14 | 2 | 19 | 8 | 14 | | | 8 | | | 3 | | | 7 | 1 | 16 | 1 | 1 | 2 | 4 | | 15 | 1 | | | | | | | | | | | 29 | 4 | | 20 | | 4 | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | | | 130 | 2 | 4 | 2 | 92 | 1 | 2 | | | 1 | | | | 3 | 1 | 8 | | 1 | | | 9 | | | 1 | | | 2 | | 1 | 1 | | | 5 | | 2 | 1 | | | | | | | | | | | 15 | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | | | 113 | 2 | 3 | 34 | | | 1 | | | 5 | | | | 9 | 2 | 3 | 3 | 1 | | | 2 | | | 0 | | | 2 | | | | | | 5 | | 11 | 7 | | | | | | | | | | | 84 | | 2 | 25 | | 8 | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | | | 48 | 2 | 1 | 153 | | | 3 | | | 5 | | | | 7 | 2 | 13 | 1 | 3 | | | 5 | | | 0 | | | 4 | | 1 | | | | 2 | | 2 | 1 | | | | | | | | | | 1 | 98 | 1 | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | | | 118 | 1 | 2 | 20 | | | 8 | | | 1 | | | | 4 | 2 | 12 | 1 | | | | 1 | | | 1 | | | 4 | | 1 | 1 | | | 7 | | 11 | 6 | | | | | | | | | 1 | 1 | 98 | | | 11 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | | | 187 | 1 | 3 | 71 | 1 | | 4 | | | 5 | | | | 5 | 3 | 8 | 4 | 4 | | | 4 | 1 | | 2 | | | 1 | 1 | 6 | 6 | 1 | 2 | 2 | 1 | 4 | 0 | | | | | | | | | 1 | 1 | 28 | | | 4 | | 2 | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | 166 | 1 | 2 | 4 | 1 | | 10 | | | 5 | 1 | | | 4 | 2 | 4 | 1 | 2 | | 1 | 3 | | | 2 | | | 2 | 2 | 8 | 1 | 2 | 1 | 3 | | 5 | 1 | | | | | | | | | | 1 | 44 | | | 16 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | 69 | 2 | 2 | 1 | | 1 | 5 | | | 11 | | | | 11 | 8 | 13 | 5 | 4 | | | 2 | | | 0 | | | 3 | 1 | 5 | 4 | 2 | 9 | 2 | 3 | 13 | 5 | | | | | | | | | 2 | 1 | 101 | 1 | | 8 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | 238 | 2 | 4 | | | | 11 | | | 2 | | | | 5 | 2 | 7 | | 2 | | | 4 | | | 0 | | | | 1 | 2 | 5 | 2 | | 4 | 1 | 7 | 5 | | | | | | | | | | 2 | 2 | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | 177 | 3 | 2 | 3 | | | 9 | | 1 | 5 | | | | 4 | 4 | 21 | | | | | 6 | 5 | 2 | 1 | | | 2 | 1 | 12 | 5 | 2 | 4 | 10 | 4 | 11 | 4 | | | | | | | | | 7 | 13 | 7 | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | 190 | | 1 | 55 | 2 | | 7 | | 1 | | 1 | | 1 | 4 | 2 | 11 | | | 1 | | 3 | 4 | 2 | 2 | | | 3 | 1 | | 6 | 2 | 1 | 1 | 4 | 5 | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | *Ps. ticinen.* | 6 | 4 | 11 | 1 | | | 25 | | 2 | 5 | | | 4 | 13 | 16 | 38 | | | 1 | | 11 | 6 | 3 | 8 | 2 | 1 | 10 | 2 | 3 | 4 | 7 | 2 | 1 | 10 | 1 | | | | | | | | | | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | | | 325 | | 1 | 1 | | | 2 | | | 1 | | | 1 | 1 | | | | | | | | | 1 | 1 | | | 1 | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | | | 298 | | | | 37 | | | | | | | | | 2 | | 1 | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**Table 7** Monte Petrano section. Quantitative analysis on size fraction comprised between 250 µm and 125 µm.

|SITE|CORE|SECTION|INTERVAL DEPTH (cm)|DEPTH (m)|AGE|PLANKTONIC FORAMINIFERAL ZONE|agglomerates|benthic|indetermined|indetermined fragment|indetermined planktonic|indetermined benthos|planktonic fragment|radiolaria|ostracods|dark lithic|quartz|glauconite|*Protoheterohelix* sp.|*P. obscura*|*P. washitensis*|*Mi.* cf. *rischi*|*Muricohedbergella* sp.|*M. delrioensis* (Longoria)|*M. delrioensis* (Masters)|*M. wondersi*|*M. praelibyca*|*M. astrepta*|*M. simplicissima*|*M. blakensis* (5 chambers)|*M. blakensis* (6 chambers)|*blakensis* (7 chambers)|*M. planispira*|*Globigerinelloides* sp.|*G. pulchellus*|*G. bentonensis*|*G. ultramicrus*|*G. alvarezi*|*B. breggiensis*|*Ticinella* sp.|*T. raynaudi digitalis*|*T. raynaudi aperta*|*T. madecassiana*|*T. primula*|*T. moulladei*|*T. roberti*|trans. *T. raynaudi digitalis* - *Th. appenninica*|*Pseudothalmanniniella* sp.|*Ps. subticinensis*|*Ps. ticinensis*|*P. tehamaensis*|*Thalmanninella* sp.|*Th. evoluta*|*Th. balernaensis*|*Th. appenninica*|trans. Th. *appenninica* - *Th. brotzeni*|*Th. brotzeni*|*globotruncanoides*|*Th. globotruncanoides*|intermediate Th. *globotrucanoides* - *Th. greenhornensis*|*Th. greenhornensis*|*Th. gandolfii*|*Th. deeckei*|*P. praebuxtorfi*|*P. buxtorfi*|*P. libyca*|*Praeglobotruncana* sp.|*P. delrioensis*|*P. stephani*|*P. gibba*|*W. aprica*|*W. aumalensis*|*Shackoina* sp.|COMMENTS|
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|547A|41|1|100.5-102.5|441.51|CENOMANIAN|*Th. reicheli*|10|26|||1||1|||47|24|||||||4||||||6|||||2||1|||||||||||||||||9|||1|1|13||2|||||||||15|2|||||small residue|
|547A|42|2|40-42|450.40||||4||||||||28|122||||||||||||||||||||||||||||||||||||||||||2|||||2||8|1||||||||||||||small residue|
|547A|42|CC|4-6|455.34|||1|22|1|3||||2||9|7|||||||2||||2||4|1|1||||||||||||||||||||||||||9|||3|1|2|1|16|1||||||||3|3|||||small residue|
|547A|44|5|47-49|475.47|||5|37|||||||2|16|2|||||||2||||2||6|||||||3|1||||||||||||||||||3|||||4||9|||1||||||||||||||small residue|
|547A|45|1|17-19|478.67|||21|48|2|3|||1|||99|2|||||||5||||4||26||1||1|||5|1||||||||||||||||||10|||13||3||19|1|||1|||||4||||||
|547A|46|1|60-62|488.60|||5|9||1||||||36||1|||||3||||||7|||||||3||||||||||||||||||||8|||1||2||30|1|1|||||||||||||small residue|
|547A|47|1|52.5-54.5|498.02|||14|36|2|3|||1|||21|37|||||||11||||3|1|1||1|1||||2|||||||||||||||||1|5|||5||5||12|||||||||2||||||small residue|
|547A|47|CC|15-16.5|502.15|||42|31|1|2|5||1|1||10|2|3|2||||6||||1|1|8|||||1||1||1|||||||||||1|||1|15|||10|2|1||37|1|1|1||||||||||||small residue|
|547A|49|CC|11-13|519.61|*Th. globotruncanoides*||12|18|1|||||||47|1|||||||2||||||||||||1||1||||||||||||||||||3|||||2||5|1|||||||||1|1||1|1||small residue|
|547A|50|1|83-85.5|526.83|||4|7||||||||22|30||||||||||||||||||||||||||||||||||||||||||||||||||||1||||||||||||||||small residue|
|547A|51|1|48-50|535.98|||5|1||||||||30|51||||||1||||||||1||1|||9|||||||||||||||||4||1|5||1||3|||||||||3|4||||small residue|
|547A|52|1|52-54|545.52||||11||||||||50|159|3|||||2||||1||2|||||||||1||||||||||||||||6|||5|1|5|1|22|1||||||||1|6|1||||||
|547A|55|CC|7-8|577.32|||9|7||||||||84|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||3|||1||||small residue|
|547A|56|1|106-107.5|584.06|||2|7|||||2|3||106|9||||||||||||1|||||||||||||||||||||||||||7||||2|4||4|||||||||12|7|||||small residue|
|547A|57|5|49-51|598.99|||19|37|1|1||||||35|14||||||3||||||2|||||||4|||||||||||||||||||5|||8|1|2||11|||||||||12|10|||||small residue|
|547A|58|5|51-53|608.18|||11|30||1||||||89|33|1||||||||||||||||||||||||||||||||||||||||||||2|||||||||||||||||||||||||small residue|
|547A|59|1|47-48.5|611.97|||1|14|||2|||||78|172||||||2||||||||||||1||3|||||||||||||||||1|6||1|11|2|3||1|||||||||1||||||
|547A|60|1|48.5-50.5|621.48|||8|9||1|||3|||24|2||3|||||||||||||1||||||||||||||||||||||||||||1|||||||1|||||||||1||||||small residue|
|547A|60|5|50-52|627.40|||34|26|2|1|||1|||19|98||3|||||||||||1|||||||||||||||||||||||||||1||2|||4||||5|||||||1|6|3|||||small residue|
|547A|61|1|48-50|630.98|||4|33||2||||1||9||1|||||||||||1|||||||||||||||||||1||||||||||3|||4|||||||||||||||5|1|||||small residue|
|547A|62|1|50-52|640.50|ALBIAN|*Th. appenninica*|24|30|||1|1|1|1||41|143|2|||||1||||||1|||||||1||||||||||||||||||3|||1|||||||||||||2|1|||||small residue|
|547A|63|1|48-49.5|649.98|||11|2||||||||29|52||||||1||||||2||||||||||||||1|||2|1||||||2||||||||||||||||||||||||||small residue|
|547A|64|1|49-52|659.49|||59|8||3|7||2|2||99|2|1|1||||13|6||3|11||29|4|2|||4||37|4|||6|||5|17|1||||||1|1|||3||||||||||2|7|5||9|9||||||
|547A|64|CC|5.5-7.5|663.78|||20|34||8|2|1|2|1||133|2|||||||||||2||1|||||1||1||1||3|||1||||||3|7|1|||||1|||||||||||||||||small residue|
|547A|67|CC|7-9|690.38|||147|19||2||||||151|||||||7|1|||1|5|6|||||2||2||||5||1|4|4|||||||10|6|5|1|1|4|||||||||4||||||||||
|547A|68|1|123-125|698.23|||37|44||8|1||||||27||40|||1||3|1||||1|1||||1|1|1|4||||4|||9|15||||2||23|21|1|4||1|||||||||2||||||||||small residue|
|547A|69|1|50-52|707.000|*Ps. ticinensis*||112|41||11|6||1|1||63|||3|1|4||1|1|||2||13|||||2|5|12|||3|4||1|13|32||1|||3|34|24|1|1|2|6|||||||||||||||||||||
|547A|70|1|49.5-51.5|716.49|||16|19||||||||33|3||||||5|2|||5|2|5||||||1|||1|3|8|||10|15||2|||||6|9|1|1|3|||||||||||||||||||small residue|
|547A|72|1|47-49|725.97|||30|21||2|1||1|3||31|||10|||1|2|2|1||7|6||||||2|1|4|||3|4|2|2|21|54|1|1|2|||8|6|||||||||||||||||||||||small residue|
|547A|73|1|48-50|735.48|||40|24||2||||||108||||||2||||1|||||||||2|2|1|||1||3||3|11|1||||||7|3|||||||||||||||||||||||small residue|
|547A|73|CC|23-25|740.36|||21|10||70|1||1|1||40|24|2|||||8||||6||8||||2|3|1|5||1|1|3|1||1|3||||1||5|1|1|||||||||||||||||||||1|small residue|

**Table 8** Mazagan Plateau DSDP Site 547A. Quantitative analysis on size fraction comprised between 355 µm and 250 µm.

| SITE | CORE | SECTION | INTERVAL DEPTH (cm) | DEPTH (m) | AGE | PLANKTONIC FORAMINIFERAL ZONE | agglomerates | benthic | indetermined fragments | indetermined planktonic | indetermined | planktonic fragment | radiolaria | quartz | dark lithic | glauconite | ostracod | *P. washitensis* | Mi. cf. *rischi* | *Muricohedbergella* sp. | *M. delrioensis* (Longoria) | *M. delrioensis* (Masters) | *M. wondersi* | *M. praelibyca* | *M. astrepta* | *M. simplicissima* | *M. blakensis* (6 chambers) | *M. blakensis* (5 chambers) | *M. planispira* | *Globigerinelloides sp.* | *G. pulchellus* | *G. bentonensis* | *G. ultramicrus* | *G. alvarezi* | *B. breggiensis* | *Ticinella* sp. | *T. raynaudi digitalis* | *T. raynaudi aperta* | *T. primula* | *T. madecassiana* | *T. moulladei* | *T. roberti* | trans. *T. raynaudi aperta - Th. appenninica* | *Pseudothalmanninella* sp. | *Ps. ticinensis* | *Ps. tehamaensis* | *Thalmaninnella* sp. | *Th. evoluta* | *Th. balernaensis* | *Th. appenninica* | trans. *Th. appenninica - Th. brotzeni* | *Th. brotzeni* | trans. Th. brotzeni - *Th. globotruncanoides* | *Th. globotruncanoides* | *Th. greenhornensis* | *Th. gandofii* | *P. praebuxtorfi* | *P. buxtorfi* | *P. libyca* | *Praeglobotruncana* sp. | *P. delrioensis* | *P. delrioensis* (double alignment) | *P. stephani* | *Whiteinella* sp. | *W. aprica* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 547A | 41 | 1 | 100.5-102.5 | 441.51 | CENOMANIAN | *Th. reicheli* | 21 | 41 | 1 | 2 |  | 5 |  | 38 | 112 |  |  |  |  | 14 |  |  |  | 4 |  | 18 | 1 |  | 1 | 7 |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6 |  |  | 1 | 1 | 8 | 1 | 1 | 1 |  |  |  |  | 2 | 23 |  | 4 |  |  |
| 547A | 42 | 2 | 40-42 | 450.40 |  |  |  | 11 | 2 | 1 |  | 2 | 1 | 199 | 100 | 2 |  |  |  | 13 |  |  |  | 6 |  | 12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 7 |  |  |  |  | 3 |  |  | 1 |  |  |  |  |  | 19 |  |  |  |  |
| 547A | 42 | CC | 4-6 | 455.34 |  |  | 7 | 26 | 6 | 4 |  | 2 |  | 3 | 20 |  |  |  |  | 40 | 1 |  |  | 21 |  | 82 | 1 |  | 1 | 1 |  | 12 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  | 12 |  |  | 4 | 1 | 1 |  | 7 |  |  |  |  |  | 3 | 30 |  | 8 |  |  |
| 547A | 44 | 5 | 47-49 | 475.47 |  |  | 8 | 17 | 12 | 2 |  | 2 |  |  | 40 |  | 1 |  |  | 58 | 2 |  |  | 50 |  | 55 |  | 1 | 5 | 6 |  | 20 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  | 6 |  | 1 |  |  |  |  |  | 1 | 19 |  | 4 |  |  |
| 547A | 45 | 1 | 17-19 | 478.67 |  |  | 24 | 13 | 2 | 2 |  |  |  |  | 54 |  |  |  |  | 31 | 1 |  |  | 28 | 2 | 87 |  |  | 1 | 1 |  | 23 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  | 6 |  | 4 |  | 2 |  |  |  |  |  |  | 6 |  | 1 |  |  |
| 547A | 46 | 1 | 60-62 | 488.60 |  |  | 11 | 40 |  | 9 |  | 2 |  | 7 | 35 |  |  |  |  | 32 | 1 |  |  | 37 | 6 | 33 |  |  | 4 | 1 |  | 21 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  | 6 |  |  | 3 | 2 | 10 |  | 2 |  |  |  |  |  |  | 33 |  |  |  |  |
| 547A | 47 | 1 | 52.5-54.5 | 498.02 |  |  | 9 | 64 | 5 | 4 | 1 | 1 |  | 44 | 55 | 1 |  |  |  | 26 |  |  |  | 20 |  | 76 | 4 |  | 9 | 3 |  | 6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 11 |  |  | 2 |  | 10 |  | 1 |  |  |  |  |  |  | 9 |  |  |  | 1 |
| 547A | 47 | CC | 15-16.5 | 502.15 |  |  | 45 | 65 | 8 | 4 |  | 5 | 1 |  | 15 | 1 |  | 1 |  | 24 |  |  |  | 35 | 3 | 34 | 2 | 2 | 1 | 4 |  | 17 |  |  |  |  |  |  |  |  |  |  |  | 1 |  | 1 | 23 |  |  | 7 | 2 | 7 | 1 | 15 |  | 1 |  |  |  |  | 1 |  |  |  |  |
| 547A | 49 | CC | 11-13 | 519.61 |  | *Th. globotruncanoides* | 53 | 47 | 10 | 11 | 3 | 6 | 2 | 3 | 66 | 2 |  | 4 |  | 23 |  |  |  | 7 |  | 25 |  |  | 2 |  |  | 16 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  | 7 |  | 4 |  |  |  |  |  |  | 3 |  |  | 1 | 2 |
| 547A | 50 | 1 | 83-85.5 | 526.83 |  |  | 65 | 44 | 3 | 11 |  | 2 |  | 56 | 39 | 1 |  | 1 |  | 12 |  |  |  |  |  | 10 |  |  |  | 2 |  | 7 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  | 2 |  |  |  |  |  |  |  |  | 2 |  |  | 2 | 2 |
| 547A | 51 | 1 | 48-50 | 535.98 |  |  | 13 | 5 |  | 8 |  | 2 |  | 30 | 61 |  |  |  |  | 35 |  |  |  | 24 | 1 | 36 |  |  |  | 9 |  | 52 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 |  |  | 4 | 1 | 8 |  |  |  |  |  |  |  |  | 7 |  | 2 |  |  |
| 547A | 52 | 1 | 52-54 | 545.52 |  |  | 6 | 19 | 1 | 9 |  | 5 |  | 95 | 38 | 9 |  |  |  | 46 |  |  |  | 20 |  | 23 |  |  | 2 | 5 |  | 30 |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  | 2 | 20 | 1 |  |  |  |  |  |  |  | 35 |  | 3 |  |  |
| 547A | 55 | CC | 7-8 | 577.32 |  |  | 41 | 30 | 6 |  | 3 | 1 | 3 |  | 238 |  |  |  |  | 5 |  |  |  |  |  | 5 |  |  |  | 1 |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 1 |  |  |  |  |  |  |  | 9 | 3 | 4 |  |  |  |
| 547A | 56 | 1 | 106-107.5 | 584.06 |  |  | 7 | 38 | 10 | 14 | 2 | 3 | 2 | 3 | 174 |  |  |  |  | 22 |  |  |  | 4 |  | 11 |  |  |  | 3 | 1 | 15 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6 |  |  | 3 |  | 11 | 1 | 2 |  |  |  |  |  |  | 44 |  | 12 |  |  |
| 547A | 57 | 5 | 49-51 | 598.99 |  |  | 6 | 46 | 5 | 9 | 2 | 5 | 1 | 21 | 53 | 2 |  | 1 |  | 25 |  |  |  | 10 |  | 28 | 2 | 2 |  | 3 |  | 28 | 2 | 1 |  | 1 |  |  |  |  |  |  |  |  |  |  | 4 |  |  | 6 |  | 8 |  |  |  |  |  |  |  |  | 34 |  | 29 |  |  |
| 547A | 58 | 5 | 51-53 | 608.18 |  |  | 45 | 65 | 7 |  | 4 | 3 |  | 72 | 151 | 1 |  |  |  | 2 |  |  |  |  |  | 1 |  |  |  |  |  | 2 |  | 1 |  | 2 |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |
| 547A | 59 | 1 | 47-48.5 | 611.97 |  |  | 20 | 22 |  | 4 | 1 | 3 |  | 141 | 57 |  |  |  |  | 11 |  |  |  | 2 |  | 16 |  |  |  | 8 |  | 18 | 1 |  |  | 1 |  |  | 2 | 2 |  |  |  |  |  |  | 1 |  | 2 | 2 | 2 | 8 |  |  |  |  |  |  |  |  | 9 |  | 3 |  |  |
| 547A | 60 | 1 | 48.5-50.5 | 621.48 |  |  | 53 | 94 | 6 | 4 | 2 | 6 | 3 | 6 | 127 | 1 |  | 1 |  | 5 |  |  |  |  |  | 26 | 1 |  |  | 4 |  | 3 | 1 | 4 |  | 2 |  |  | 5 | 2 | 1 | 1 |  |  |  |  | 1 |  |  |  |  | 2 |  | 1 |  |  |  |  |  | 2 | 8 |  |  |  |  |
| 547A | 60 | 5 | 50-52 | 627.40 |  |  | 49 | 49 | 2 |  |  | 1 | 1 | 119 | 61 | 1 |  |  |  | 4 |  |  |  | 1 |  | 18 |  |  |  | 1 |  | 15 | 2 | 1 |  | 2 |  |  | 3 |  |  |  |  | 1 |  |  | 4 |  |  | 1 | 1 | 1 |  |  |  |  |  |  |  |  | 25 |  | 19 |  |  |
| 547A | 61 | 1 | 48-50 | 630.98 |  |  | 28 | 63 | 9 | 8 | 1 | 6 | 3 | 3 | 51 | 3 |  | 2 |  | 11 | 3 |  |  | 2 |  | 35 |  |  |  | 8 |  | 28 | 5 |  |  | 2 |  |  | 7 | 2 |  |  |  |  |  |  | 5 |  |  | 4 | 2 | 3 |  | 1 |  |  |  |  |  |  | 14 |  | 9 |  |  |
| 547A | 62 | 1 | 50-52 | 640.50 | ALBIAN | *Th. appenninica* | 39 | 45 | 1 | 4 | 2 | 6 | 1 | 92 | 84 | 1 |  |  |  | 5 |  |  |  | 1 |  | 19 |  |  |  | 1 |  | 2 |  |  |  | 2 |  |  | 1 |  |  |  |  |  |  |  | 5 |  |  | 4 |  |  |  |  |  |  |  |  |  | 1 | 7 |  | 4 |  |  |
| 547A | 63 | 1 | 48-49.5 | 649.98 |  |  | 27 | 7 | 1 | 13 |  | 2 | 1 | 25 | 59 | 2 |  |  |  | 12 |  |  |  | 10 | 2 | 37 |  |  | 5 | 6 | 2 | 8 |  |  |  | 22 | 2 |  | 62 | 5 | 2 | 3 |  |  | 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |
| 547A | 64 | 1 | 49-52 | 659.49 |  |  | 50 | 27 | 4 | 9 |  | 3 | 1 | 9 | 85 |  |  |  |  | 12 | 1 |  |  | 19 |  | 14 | 4 |  | 1 | 5 |  | 53 | 1 |  |  | 11 |  | 1 | 26 | 4 | 1 | 2 |  |  |  |  | 3 |  |  | 3 |  |  |  |  |  |  | 1 | 10 | 1 |  | 9 |  | 1 |  |  |
| 547A | 64 | CC | 5.5-7.5 | 663.78 |  |  | 29 | 50 | 9 | 5 |  | 3 |  | 2 | 99 |  |  |  |  | 19 | 2 |  |  | 18 |  | 28 |  |  | 2 | 7 |  | 13 | 2 |  |  | 7 |  | 2 | 10 | 8 |  |  | 4 | 2 | 2 |  | 2 |  |  | 3 |  |  |  |  |  |  | 1 | 2 |  |  |  |  |  |  |  |
| 547A | 67 | CC | 7-9 | 690.38 |  |  | 53 | 20 |  | 2 |  | 1 |  |  | 116 | 1 |  |  |  | 13 | 8 | 1 |  | 11 | 2 | 25 |  |  |  | 5 | 2 | 5 |  |  |  | 10 | 1 |  | 28 | 16 | 2 | 1 |  |  | 1 |  |  |  |  | 4 |  |  |  |  |  |  | 4 |  |  |  |  |  |  |  |  |
| 547A | 68 | 1 | 123-125 | 698.23 |  |  | 4 | 15 | 3 | 5 |  | 8 |  |  | 13 | 14 |  |  |  | 8 | 3 |  |  | 6 |  | 48 |  |  |  | 2 |  | 14 | 1 |  |  | 17 | 4 |  | 107 | 10 |  | 2 |  |  | 6 | 1 |  | 2 |  | 2 |  |  |  |  |  |  | 6 |  |  |  |  |  |  |  |  |
| 547A | 69 | 1 | 50-52 | 707.000 |  | *Ps. ticinensis* | 60 | 27 | 3 | 7 |  | 9 | 2 |  | 61 |  |  |  |  | 4 | 3 |  |  | 1 | 2 | 27 |  |  |  | 1 | 2 | 17 | 3 | 2 |  | 20 | 1 | 3 | 93 | 26 |  | 1 |  |  | 3 | 1 | 6 | 4 | 1 | 9 |  |  |  |  |  |  | 4 |  |  |  |  |  |  |  |  |
| 547A | 70 | 1 | 49.5-51.5 | 716.49 |  |  | 26 | 17 | 4 | 15 |  | 10 |  |  | 34 |  |  |  |  | 23 | 9 |  |  | 12 | 6 | 71 |  |  |  | 5 | 5 | 14 | 3 | 4 |  | 5 | 3 |  | 46 | 4 | 4 | 1 |  |  | 1 | 3 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 547A | 72 | 1 | 47-49 | 725.97 |  |  | 19 | 19 | 4 | 17 | 1 | 11 |  |  | 24 |  |  |  | 1 | 7 |  | 8 |  | 14 | 2 | 43 |  |  |  | 4 | 3 | 10 | 3 |  | 2 | 23 | 2 | 2 | 70 | 24 | 5 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 547A | 73 | 1 | 48-50 | 735.48 |  |  | 27 | 16 | 1 | 8 |  | 7 |  |  | 68 |  |  |  |  | 6 | 4 | 1 |  | 3 |  | 19 |  |  |  | 3 | 3 | 7 | 2 |  | 2 | 22 | 10 | 3 | 63 | 25 | 1 | 4 |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 547A | 73 | CC | 23-25 | 740.36 |  |  | 13 | 19 | 32 | 11 |  | 6 |  | 5 | 26 | 5 |  |  |  | 22 |  |  | 1 | 25 | 1 | 30 |  |  | 3 | 6 | 3 | 4 |  | 1 | 3 | 12 | 4 | 1 | 48 | 11 |  |  |  | 1 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Table 9** Mazagan Plateau DSDP Site 547A. Quantitative analysis on size fraction comprised between 250 µm and 125.

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